

Motion control and prediction of virtual characters

Dr. Nicolas Pronost

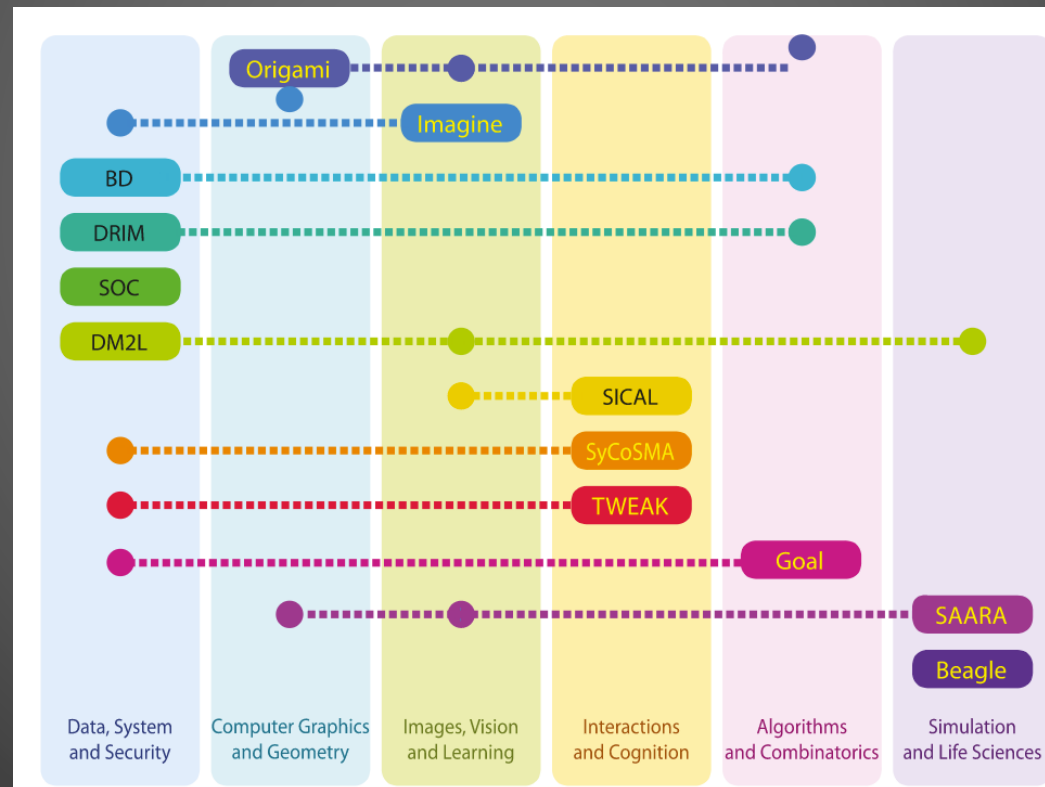
*Université Claude Bernard Lyon 1
UMR CNRS 5205 - LIRIS
France*

nicolas.pronost@univ-lyon1.fr - <http://liris.cnrs.fr/nicolas.pronost/>

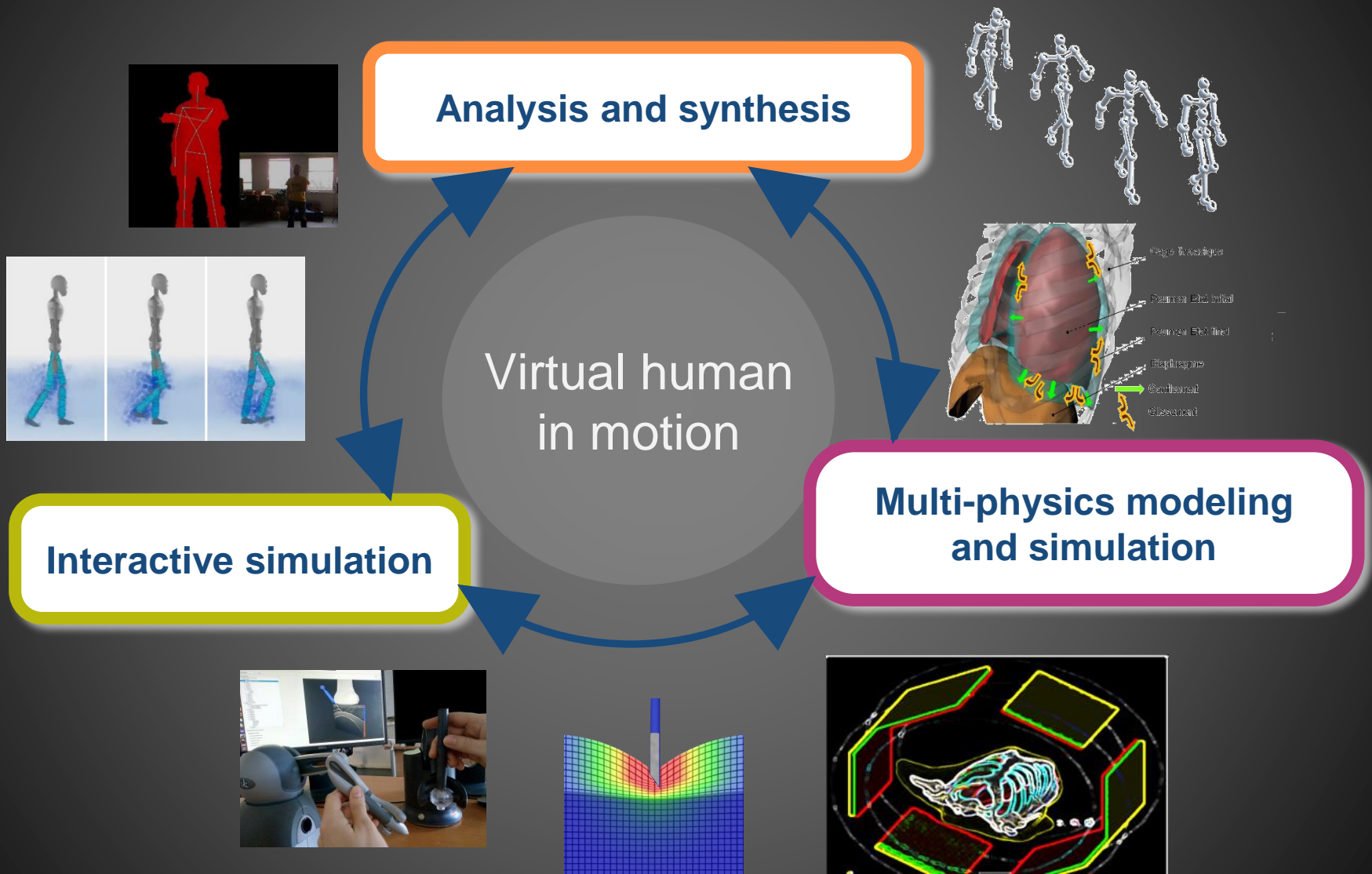
Introduction

LIRIS laboratory - <https://liris.cnrs.fr/en>

- 330 members
- 12 research groups structured in 6 areas

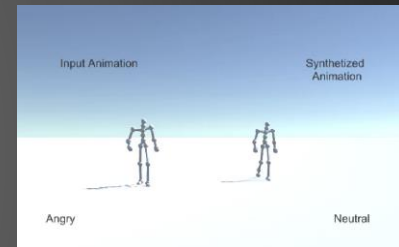
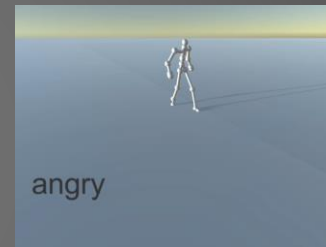
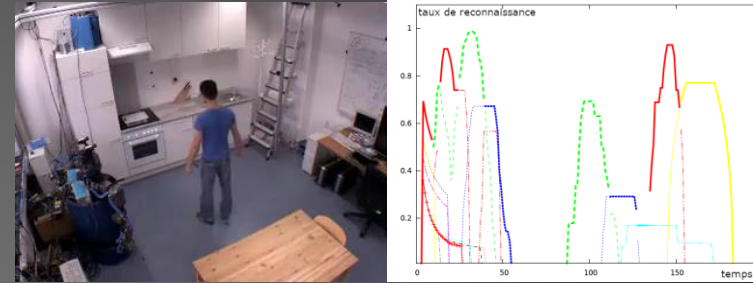


SAARA research group



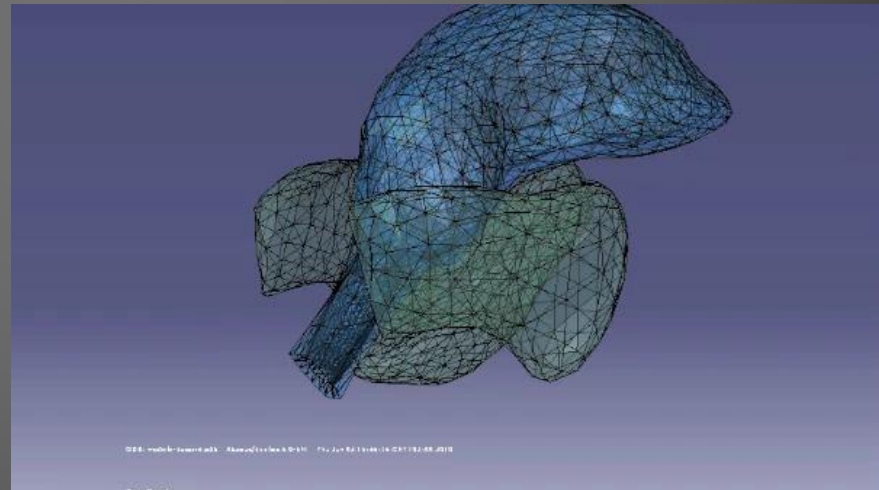
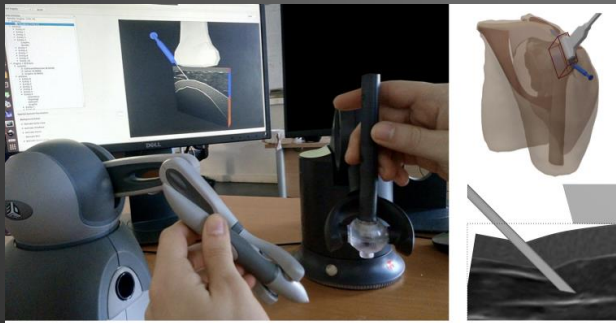
Analysis and synthesis

- Online recognition of complex activities from video
- Style and expression recognition and synthesis
- Recognition of facial expressions
 - Child and micro-expression



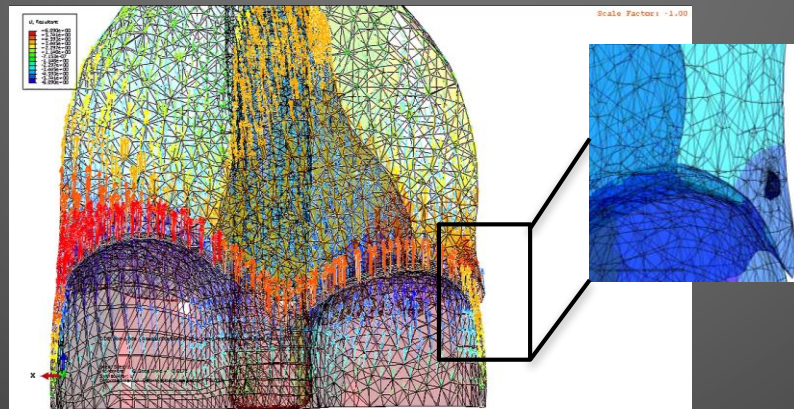
Interactive simulation

- Motion control for stable, robust, reactive and bio-inspired human motions
 - Today's topic !
- Simulators to learn or train medical gestures



Multi-physics modeling and simulation

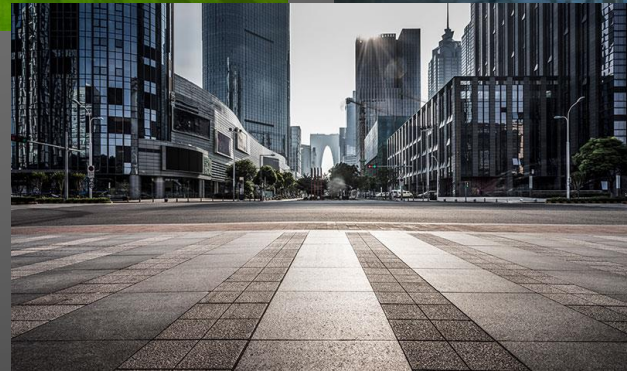
- Real-time tracking of a tumor from external data
 - To optimize the radiotherapeutic treatment
 - Use a physiological and biomechanical patient-specific model of the respiratory system



Context and fundamentals

Humans and virtual humans

- We are humans among others
- We desire to populate virtual worlds with humans



Many questions arise

- How should they look like?
 - Photorealistic, symbolic representation, cartoon style...
- What should they do?
 - Body movement, emotion and facial expression, hair, cloth, ability to get injured or sick, age...
- How should real humans interact with them?
 - Direct control, autonomous, virtual and augmented reality, multi-sensory input and feedback...
- ...

Physics based, interactive animation

- Physics based animation is useful to simulate passive phenomenon
 - Fluids, clothes, soft-bodies, ragdolls
- State-of-the-art methods allow to actively control complex systems such as virtual characters
 - Improvements in robustness, visual quality and usability

Physics based, interactive animation

- In 1996, we could have that in interactive time (control only) ...
- ... we now have that in real-time (control + rendering)



Hodgins et al. 1996



Lee et al. 2018

Physics based, interactive animation

- The motion is the result of a process
- Benefits
 - The possibility to generate motions without data set
 - Objects and characters interact in a physically realistic way
- Main issue : more difficult to control than pure kinematics
 - Need forces and torques
 - No direct global control
 - Require components to manage balance, etc.

Actuators

- Joint torques (fake motors at joints)

Actuators



Actuators

- Joint torques (fake motors at joints)
- External forces (puppetry like technique)

Actuators



Actuators

- Joint torques (fake motors at joints)
- External forces (puppetry like technique)
- Virtual forces (emulation of external forces by torques)

Actuators



Actuators

- Joint torques (fake motors at joints)
- External forces (puppetry like technique)
- Virtual forces (emulation of external forces by torques)
- Muscle forces (movement from contraction forces)

Actuators



Actuators

- Joint torques (fake motors at joints)
- External forces (puppetry like technique)
- Virtual forces (emulation of external forces by torques)
- Muscle forces (movement from contraction forces)
- *Muscle fibers, contractile elements activated by the brain ... up to the source of motion! Where do we stop?*

Motion control

Motion controller design

- Joint space motion control
 - tracks kinematics targets through local feedback
- Optimization based motion control
 - finds optimal actuator values through optimization
- Stimulus-response network control
 - genetically evolves controllers connecting sensors to actuators

Motion controller design

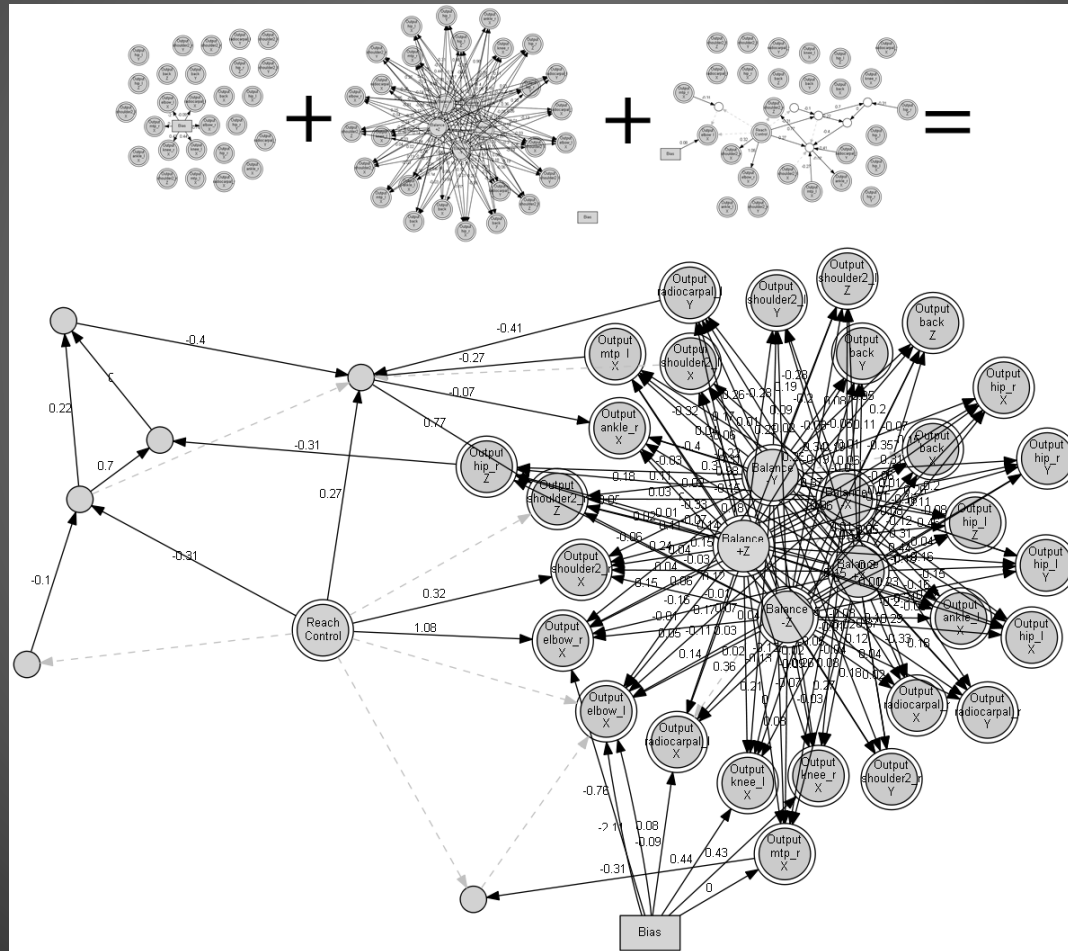
	Joint space	Optimization	Genetic
Maturity	++	++	-
Quality of results	-	++	+
Genericity	+	--	+
Control	++	-	-
Animation time	++	-	+
Interactivity	+	--	+

Genetic approach to motion control

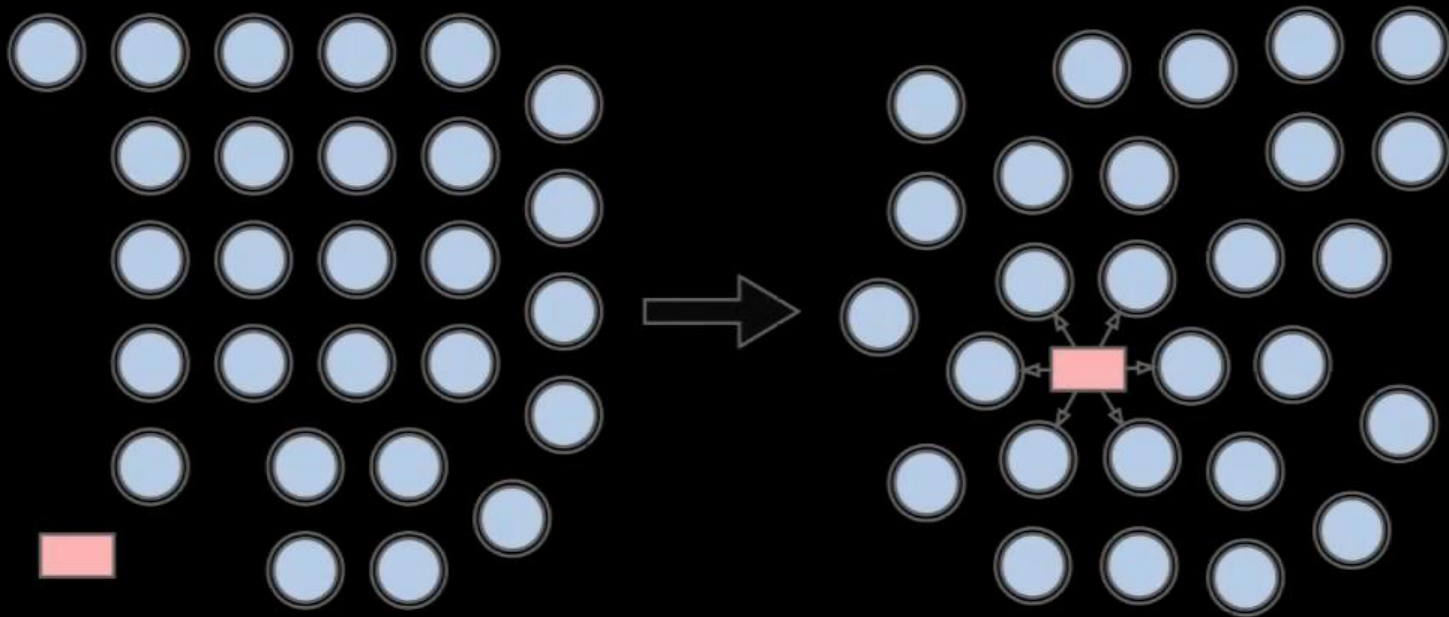
- Artificial neural network (ANN) created through evolutionary algorithm
- Hierarchical and modular design
 - step-by-step evolution from lower-level simple objectives (e.g. individual DOF manipulation such as posing)
 - to high-level functionalities (e.g. coordinated DOFs such as walking and running)

Genetic approach to motion control

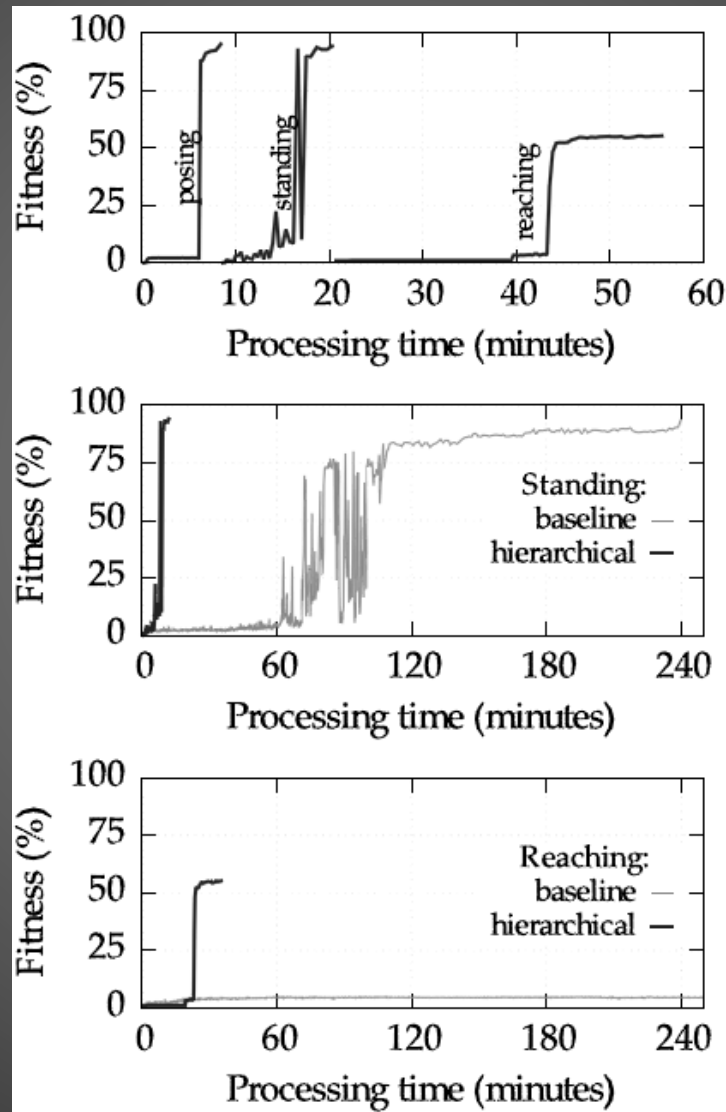
- posing + standing + reaching



Evolution of "posing" control module.



Genetic approach to motion control



Joint space motion control

- Simple data-driven control for simulated bipeds
 - No pre-processing of reference motion
 - No inverse dynamics
 - No online optimization feedback

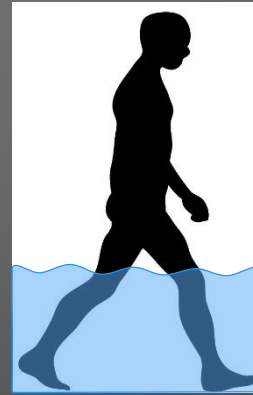
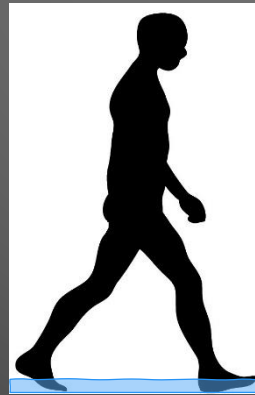
Data-driven control for bipeds

- Tracking of individual DOFs by PD controllers
- Jacobian Transpose Control for balance
 - Manages COM position and velocity, trunk orientation and angular momentum
 - Applies virtual forces and torques on lower limbs
- Offline optimization for specific motions and characters
 - PD gains and weights of balance tasks
 - According to pose error, stance state error, foot sliding and total torque
 - Optimization based on Covariance Matrix Adaptation



Gait control for immersed bipeds

- Objective to develop a fast and interactive method to control human gait for immersed bipeds
- Create a physical controller to produce plausible gait patterns involving the interactions between the virtual character and the fluid



Gait control for immersed bipeds

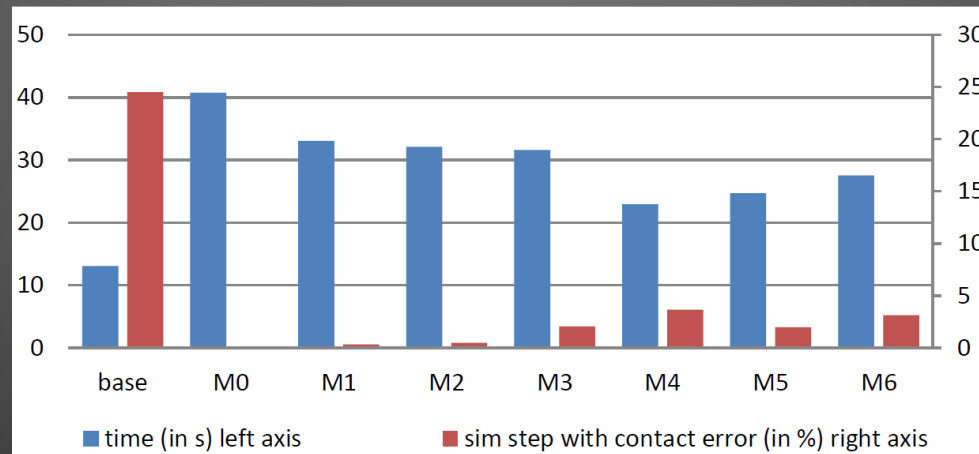
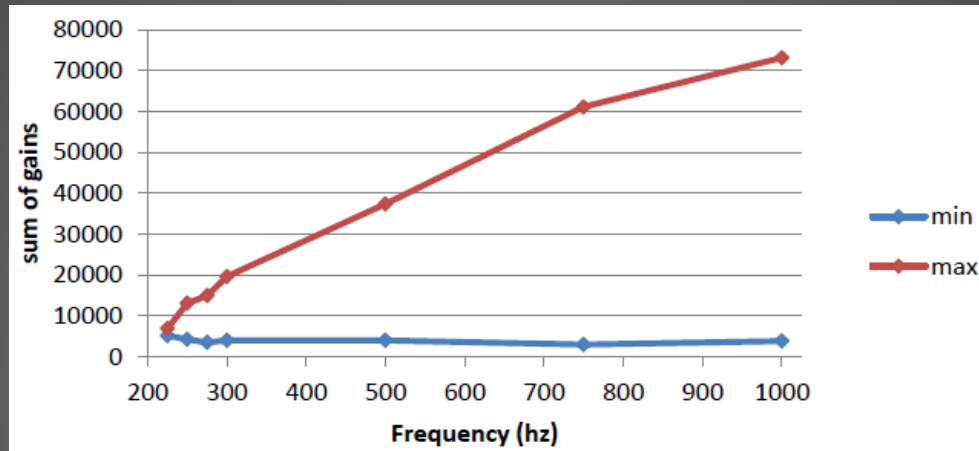
- Simple hydrodynamics
 - fluid drag and buoyancy force
- Offline optimization of the target gait pattern
 - consumed energy, liquid drag, angular acceleration
- Real-time gait pattern adaptation
 - motion combiner
- Precise velocity tracking
 - learning strategy and inverted pendulum model
- Real-time control of one character immersed in up to 1 meter of liquid walking at up to 1 m/s

Real-time gait control for partially immersed bipeds

Low frequency simulation

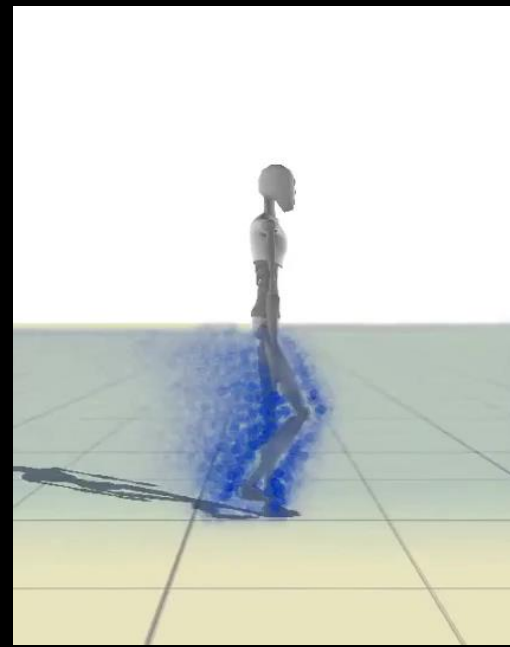
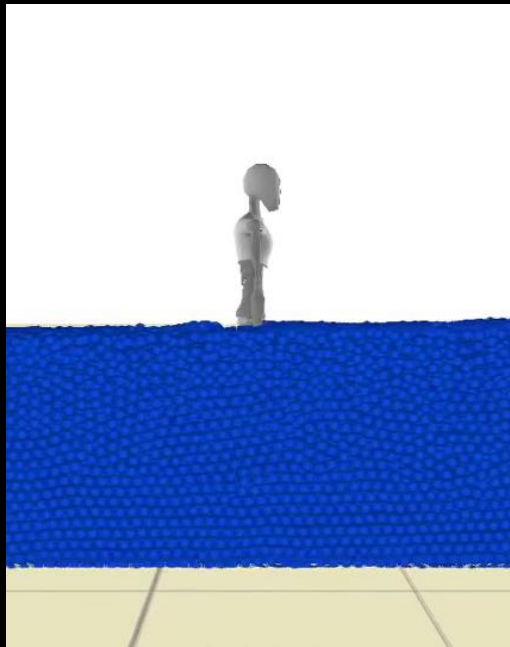
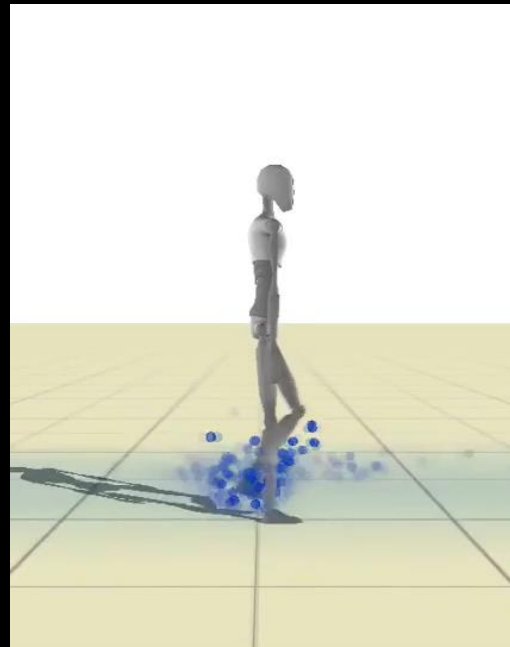
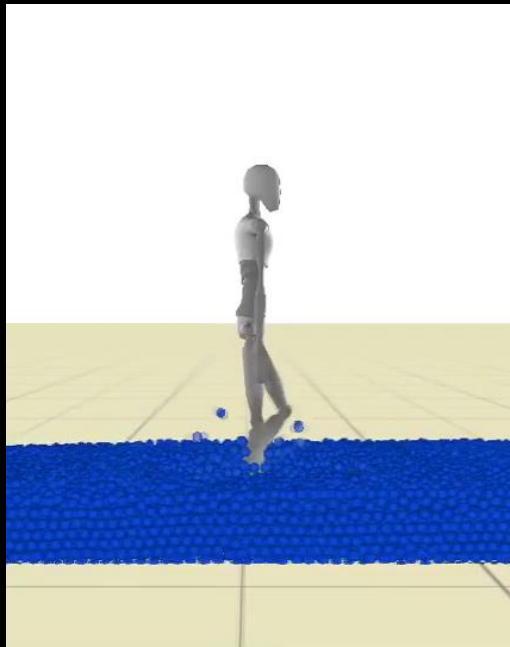
- Simple hydrodynamics does not include dual interactions
- Require actual fluid simulation that takes (a lot of) computation time
- Save some using simple and low frequency motion control
 - Frequency dependent PD gains
 - Contact (ground/feet) stabilization using online optimization on a reduced model

Low frequency simulation



Simulation window for DFSPH

- Fast initialization of new fluid at rest
- Possibility to use any boundary shape
- Use open boundary to prevent reflections



Fluid simulation on GPU

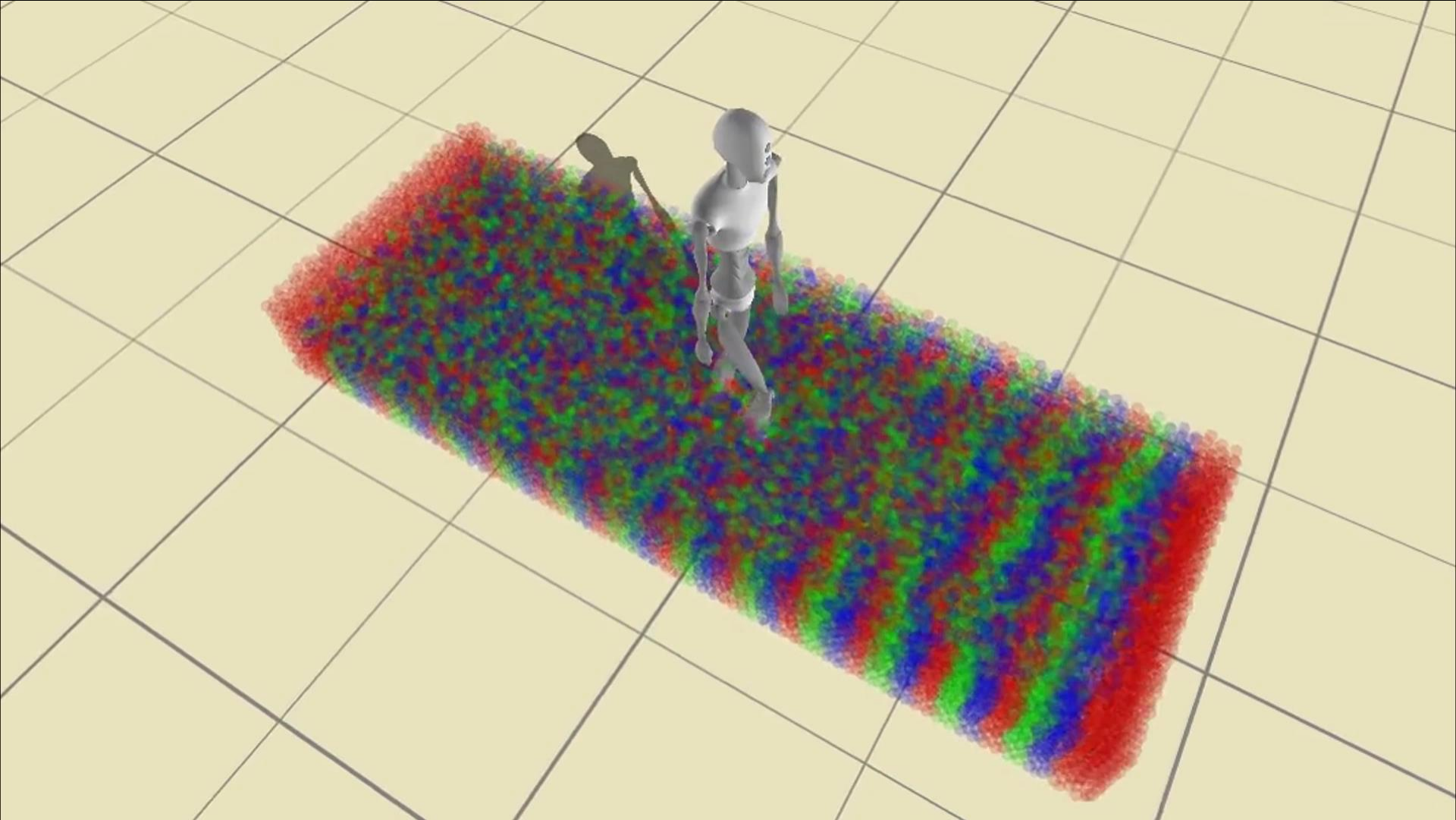
- GPU implementation of the DFSPH
- Implementation of several CPU optimizations and study of their impacts
 - Neighborhood indexing
 - Reference table for the kernel function
 - Warmstart

Wedge drop experiment

Left : closed boundary // Right : open boundary

boundary: box 1x5x10 (123000 particles)

fluid: 1m (91200 particles)



Pathological motion prediction

Anatomical virtual humans

- Not common in computer animation even though relates better to real motions
 - are computationally expensive
 - require accurate and specific modeling and tracking
 - have a high dimensional parameter space
- Recent trends in research
 - Speed-up execution by making assumptions and simplifications
 - Offline optimization of
 - the controller including modeling and tracking
 - the actuator values

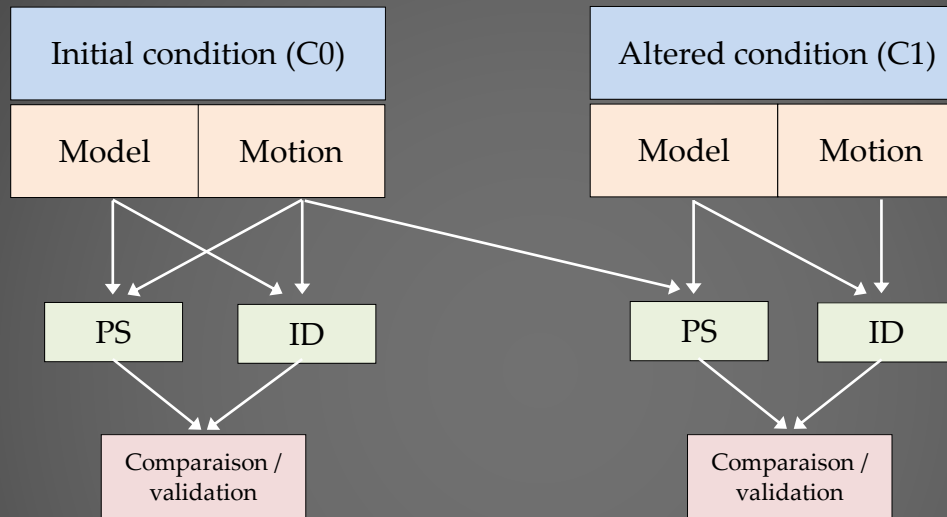


Laclé, Pronost - CAVW 2015

Simulation of pathological gait

- Goals
 - Estimation of the internal condition of a patient
 - Prediction of motion after natural evolution, disease/disorder, therapy or surgery
- Challenges
 - Patient-specific modeling of pathologies
 - Design of a predictive simulator
 - Controllability and stability
- Projects
 - Gait for RoM reduction and drop foot pathology
 - Accessibility tasks for weakened (elderly) people

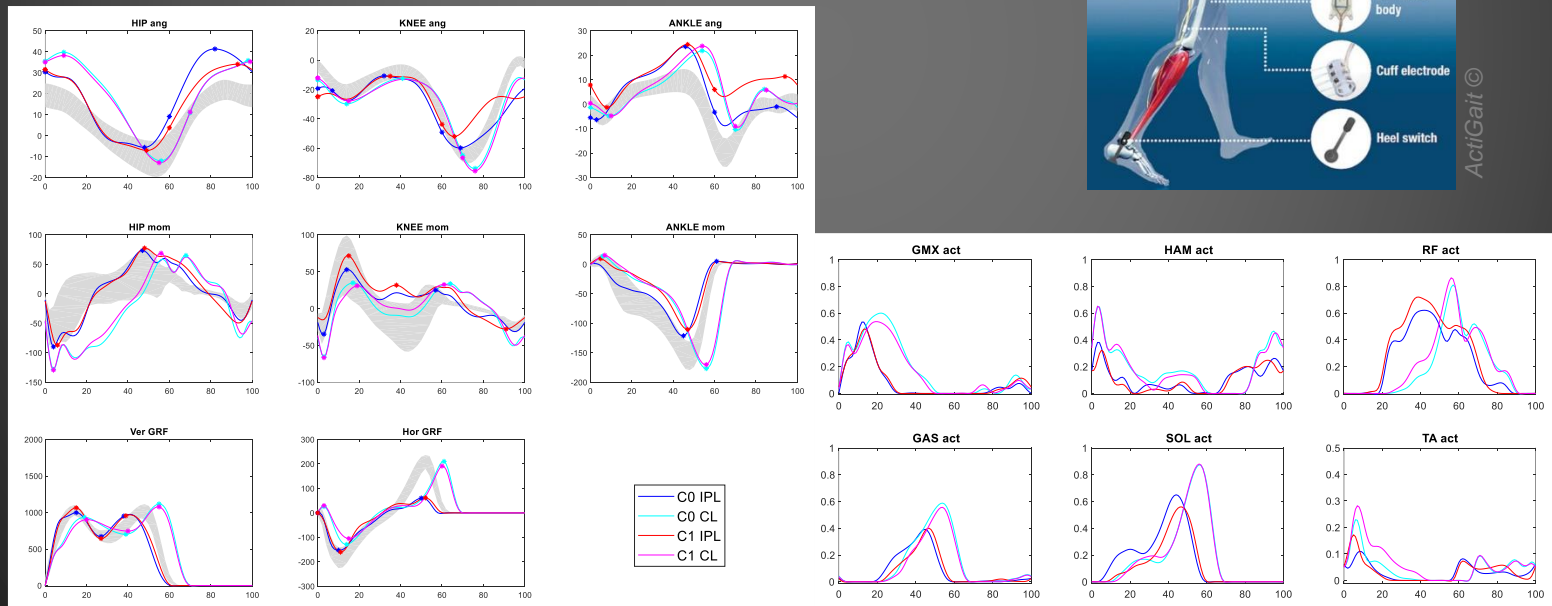
The OMEGA project



- RoM reduction : C0=without knee brace, C1=with
- Drop foot pathology : C0=initial, C1=electrical stimulator

Drop foot pathology

- Weakness of the anterior leg muscles preventing ankle dorsiflexion
- Usually observed after a stroke



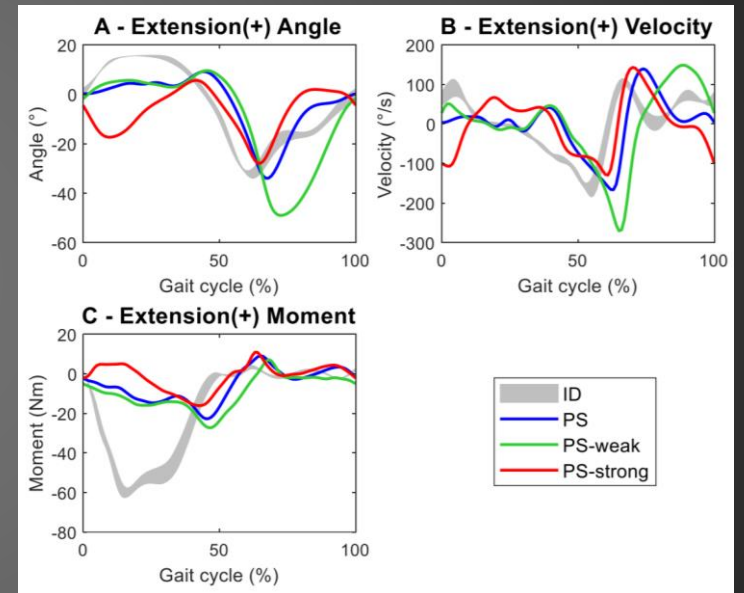
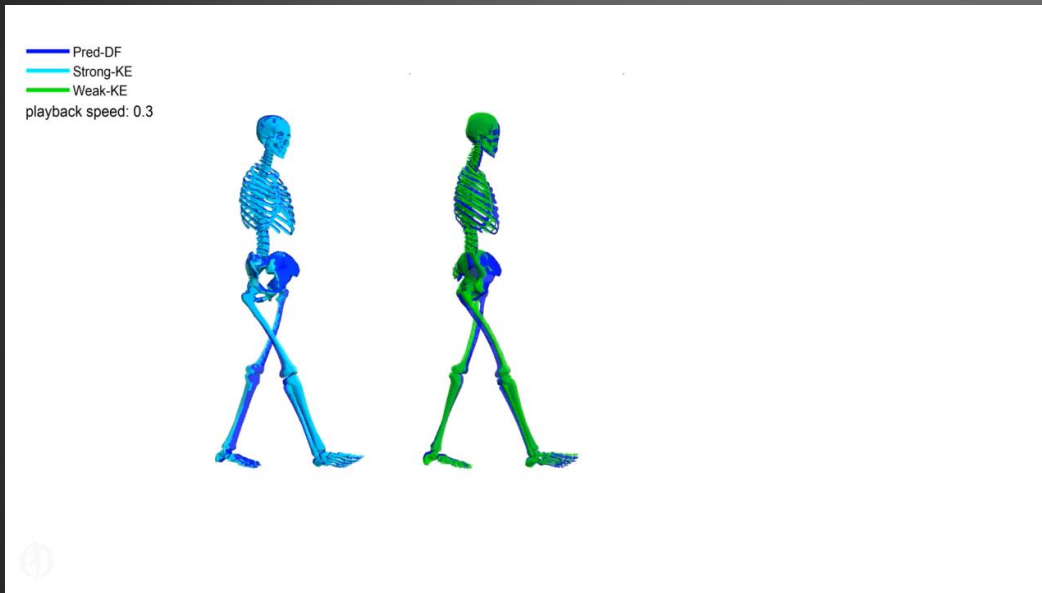
Optimal control

- Using the framework from [Falisse et al., 2019]
- Fitness function

$$J_{Track} = \int_{t_i}^{t_f} \sum \left(W_{T1}(q - q_R)^2 + W_{T2}(Mj - Mj_R)^2 + W_{T3}(Fr - Fr_R)^2 + W_{T4}(Mr - Mr_R)^2 + W_{T5}a^2 + W_{T6}(\ddot{q}^2 + \dot{a}^2 + F\dot{m}^2) \right) dt, \quad (1)$$

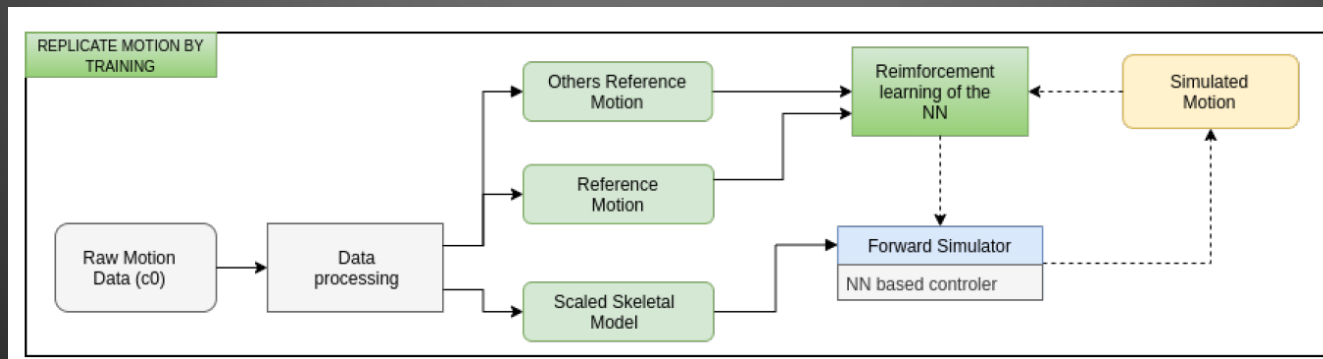
- Most outcomes as expected
 - Slower with brace, limited range of motion, decreased hip flexion, ankle joint moments and anterior-posterior GRF
 - Faster with FES, larger ankle dorsoflexion
- Realistic muscle activation patterns and their abnormalities

Optimal control



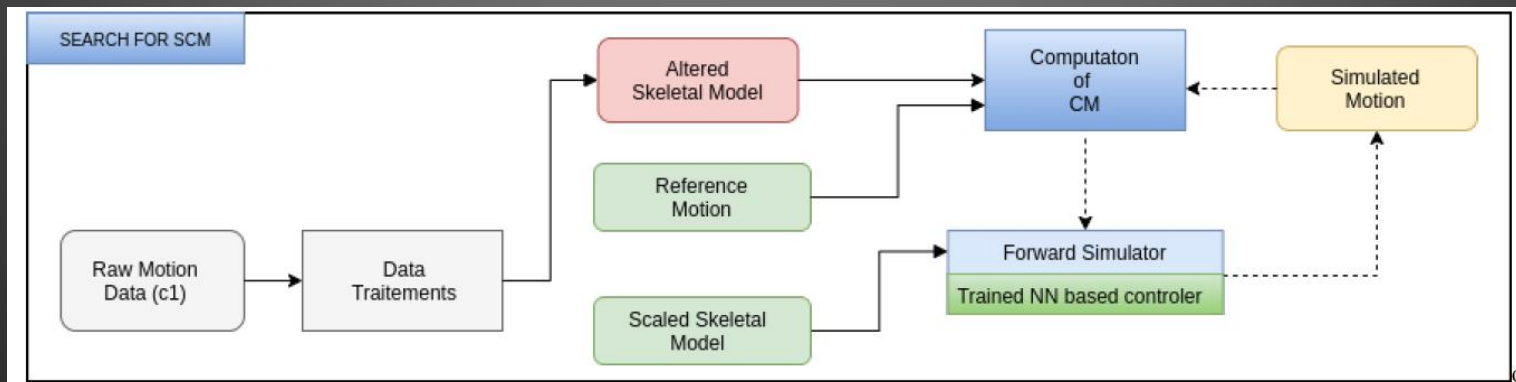
Neural-network motion prediction

- Training of a NN to replicate a motion (C0)
- Outputs angular offsets to the reference motion fed to DoF based PD controllers
- Sufficient robustness to produce variations of the reference motion ($C0 \pm \Delta$)
- Stabilizing Control Motions (SCM) are target motions producing stable motions (predictions)

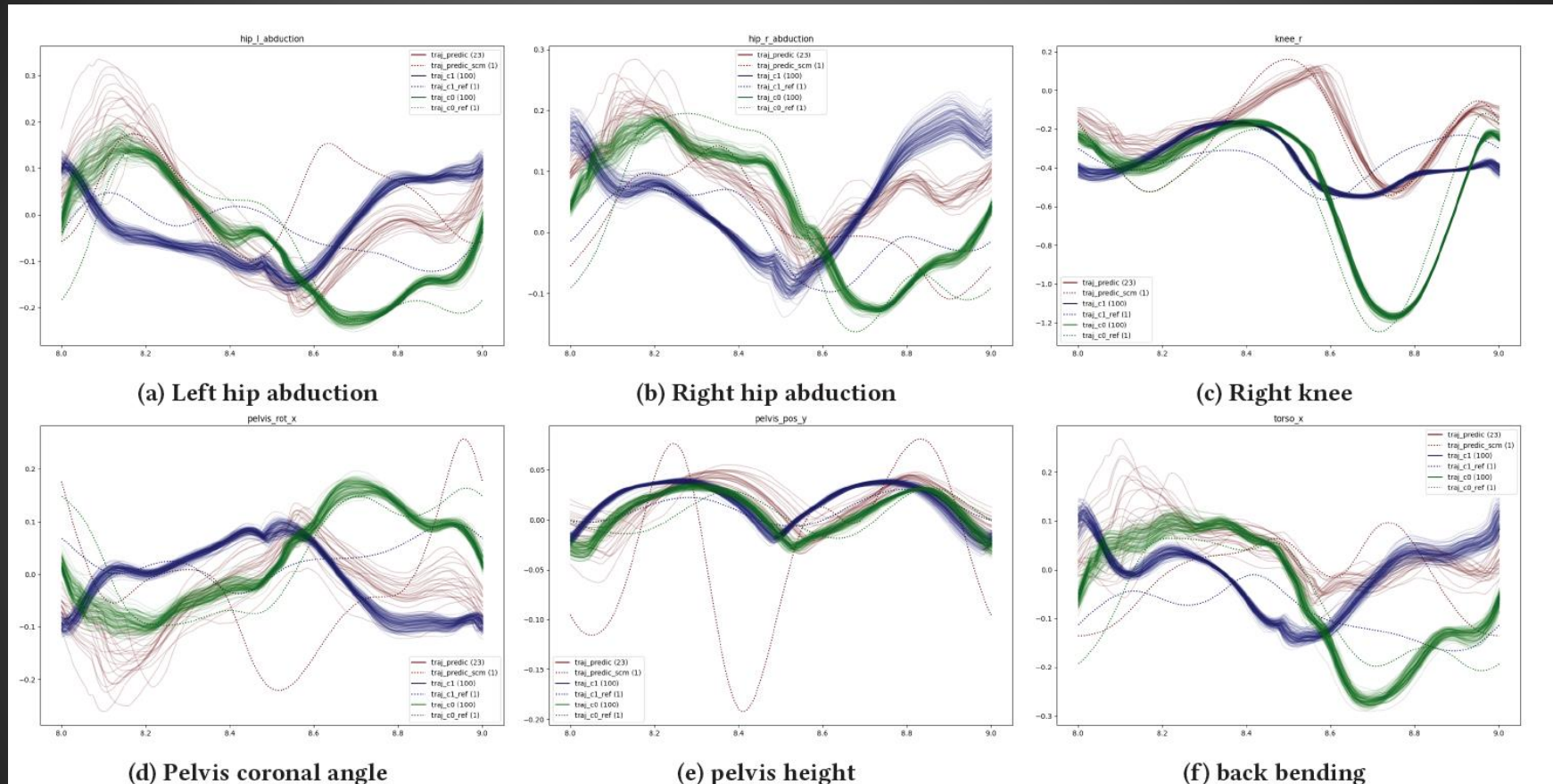


Neural-network motion prediction

- We search SCM by optimization
- Search space is reduced by
 - Representing the motion using parametric curves with a small number of control points
 - Selecting the most relevant trajectories, depending on the pathology



Neural-network motion prediction



RoM reduction

Solid green = simulated C0

Solid blue = simulated C1

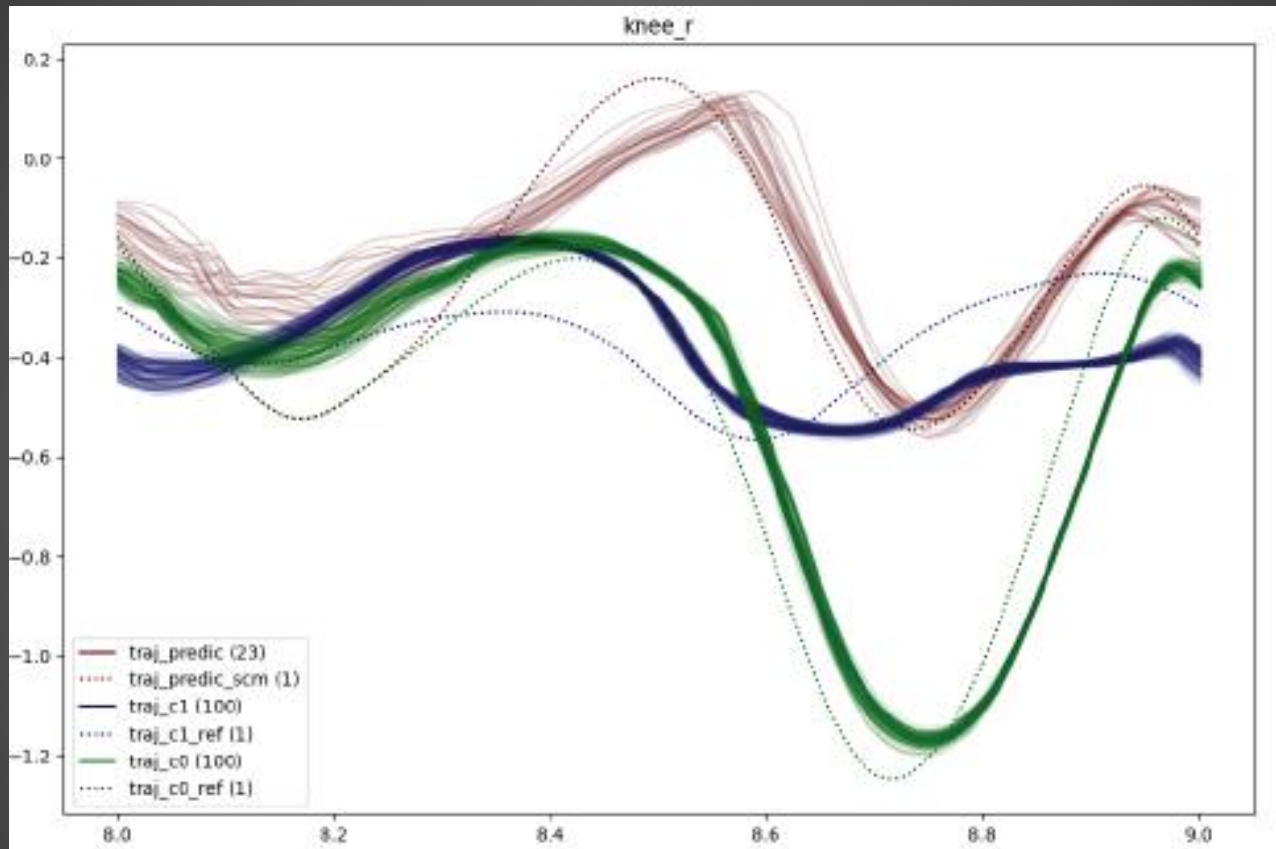
Solid red = predicted C1

Dotted green = reference C0

Dotted blue = reference C1

Dotted red = SCM

Neural-network motion prediction



RoM reduction

Solid green = simulated C0

Solid blue = simulated C1

Solid red = predicted C1

Dotted green = reference C0

Dotted blue = reference C1

Dotted red = SCM

Motion control for accessibility

- Use common motion controller (i.e. joint space control with offline optimization) to simulate less commonly studied motions
 - Get it a train/bus/car with gap, get on/off treadmill
 - Challenging for weakened people
- We are currently creating the data set

To conclude

- The gap between offline and online motion control will remain
 - The real-time constraint for interactive applications limits the possibilities
- The future of control and prediction
 - Depends on application: specific/generic, interactive, actuators, ...
 - Active physics, anatomical modeling, deep learning, multi-scale simulation, ...

Thank you for your attention

Many thanks to Thomas Geijtenbeek, Mart Hagenaars, Francis Laclé, Arjan Egges, Frank van der Stappen, Samuel Carensac, Thomas Bonis, Vincent Gibeaux, Saida Bouakaz, Raphaël Dumas, Gilmar F. Santos, and Christof Hurschler

Webpage : <http://liris.cnrs.fr/nicolas.pronost/>

Email : nicolas.pronost@univ-lyon1.fr