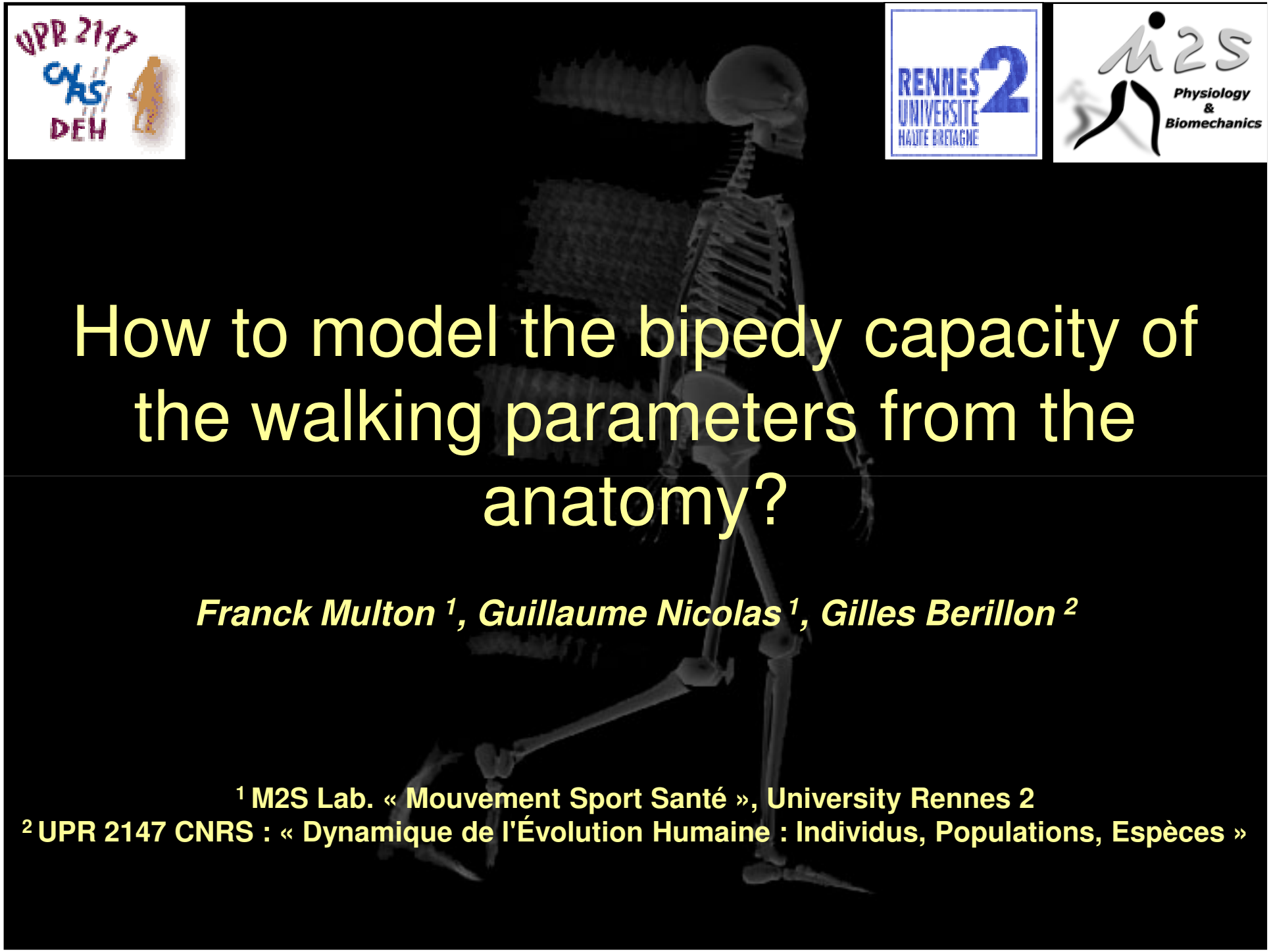
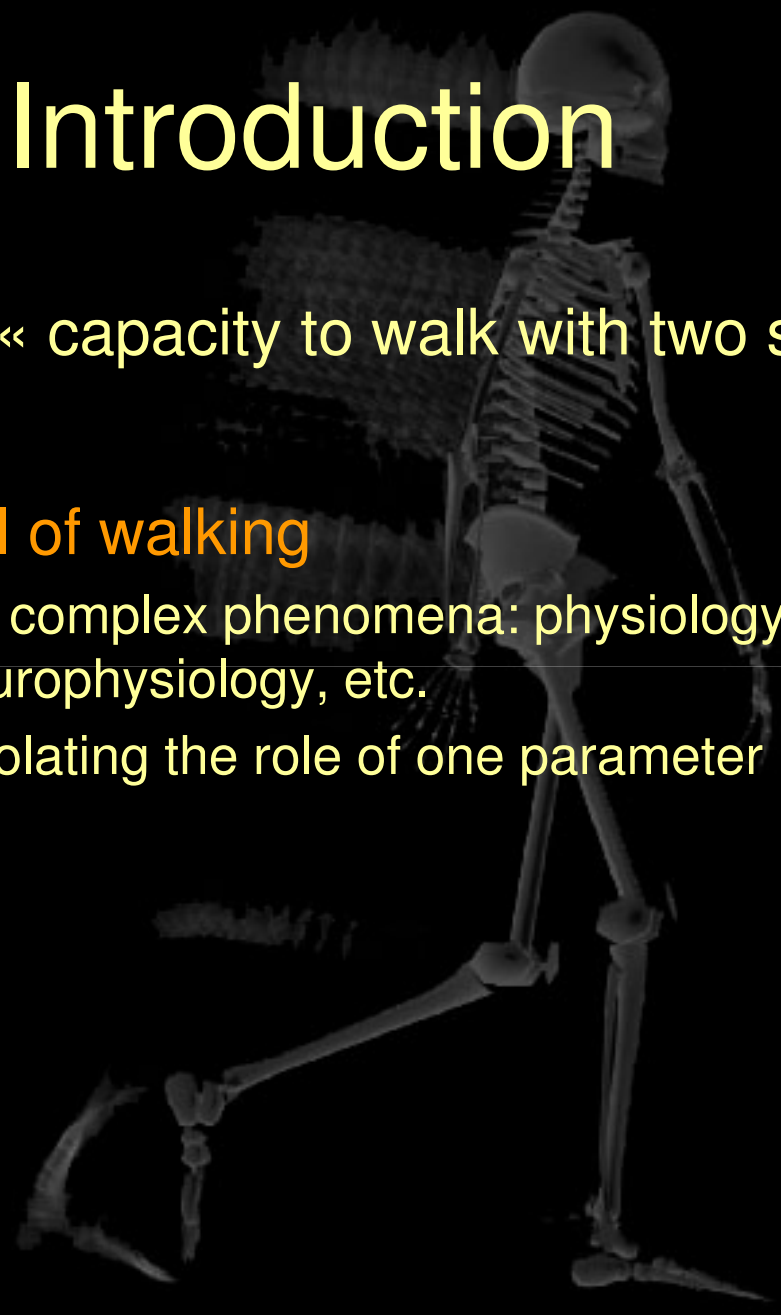


How to model the bipedy capacity of the walking parameters from the anatomy?

Franck Multon [1], Guillaume Nicolas [1], Gilles Berillon [2]

[1] M2S Lab. « Mouvement Sport Santé », University Rennes 2
[2] UPR 2147 CNRS : « Dynamique de l'Évolution Humaine : Individus, Populations, Espèces »

Introduction



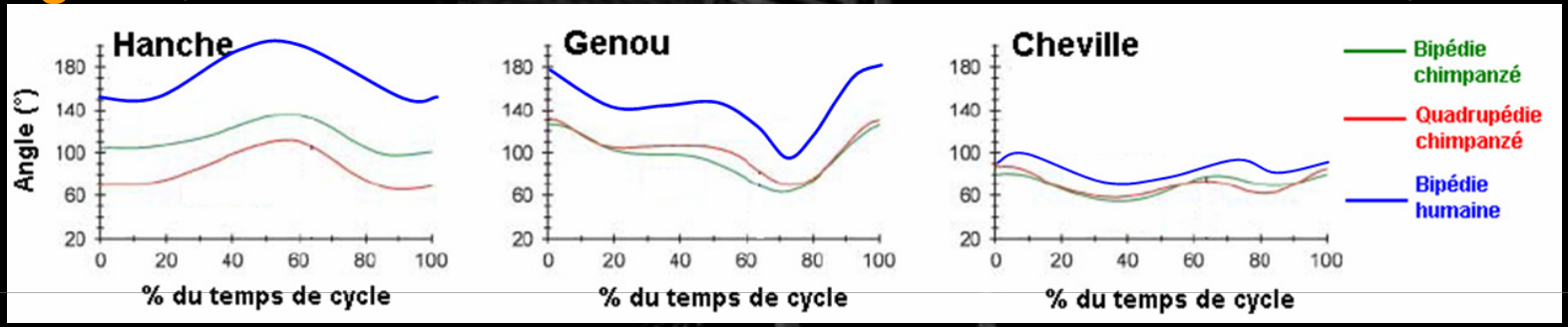
- Bipedalism = « capacity to walk with two supports »

- Motion control of walking
  - Coupled and complex phenomena: physiology, biomechanics, anatomy, neurophysiology, etc.
  - Problem = Isolating the role of one parameter

Differences between species

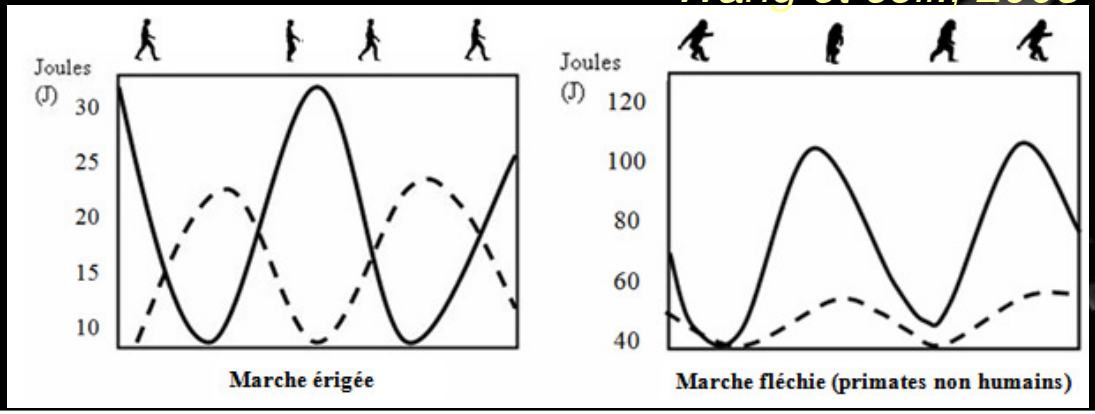
- Joint angles (Whittle, 1991; D'Août et coll., 2004; Hirasaki et coll., 2004)

(D'Août 2004)

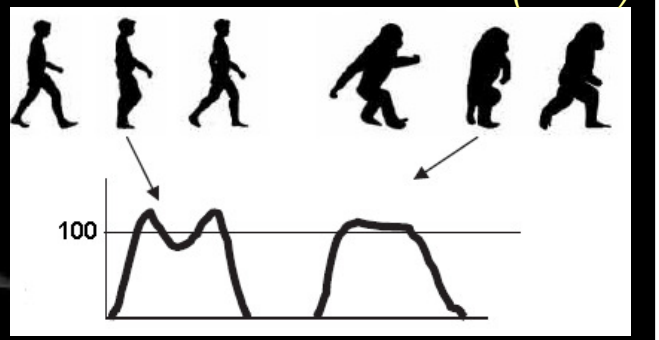


- Ground reaction force (Kimura et coll., 1977, 1990; Alexander, 1991; Li et coll., 1996; Schmitt, 2003)
- Mechanical Energies (*Cavagna et Kaneko, 1977 ; Wang et coll., 2003*)

Wang et coll., 2003



Schmitt (2003)



Main principles of bipedal locomotion

- Energy expenditure minimization (Zarrugh et coll., 1974; Alexander, 1991, 1992, 1997, 2004; Bejan et Marden, 2006)

Sockol et coll. (2007)

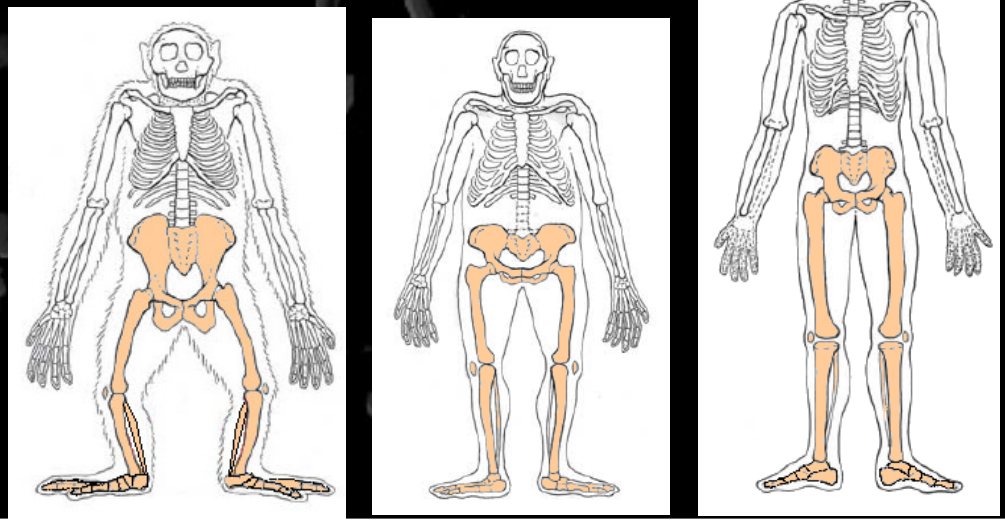
  - Kinetic energy (gesticulation) (Williams, 1985 ; Mansour et coll., 1982 Beaupied, 2003) :

  - Internal work(Burdett et coll., 1983 ; Winter, 1990 ; Minetti et coll., 1994 ; Unnithan et coll., 1999) :

Main principles of bipedal locomotion

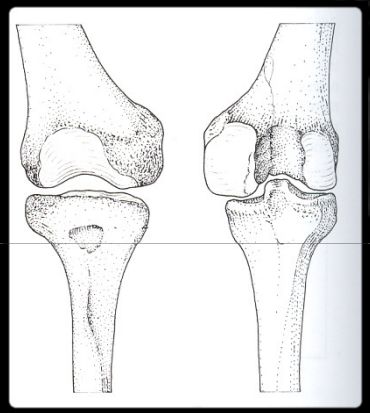
- Minimum Jerk (Flash et Hogan, 1985; Todorov, 2004)
- Many other specific knowledge…

➔ How to use it for determining a range of possible motions knowing anatomical data?

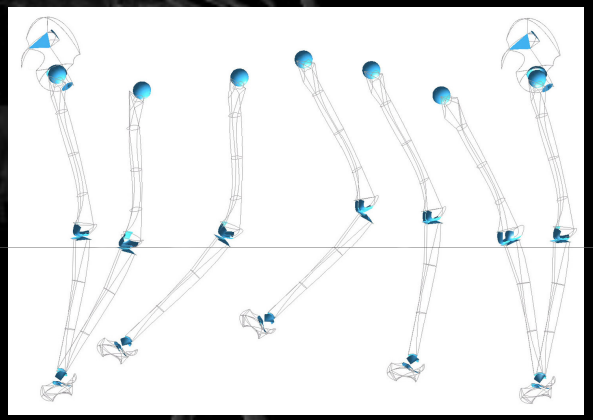


Classical approaches

- Comparative approach: shape ⇔ function



Tardieu (1983)



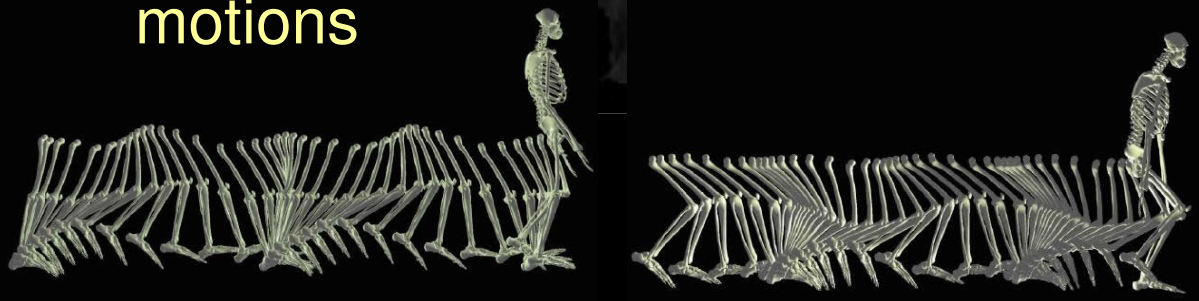
➔Focused on a unique part of the skeleton

≠ global system

➔ SIMULATION!

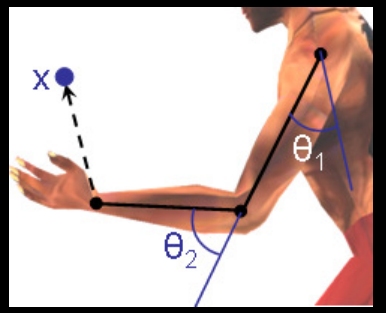
Simulation based on kinematic models

- Direct kinematics
  - Requires a complete knowledge of the joint angles
  - Anatomy not directly taken into account ➔ unrealistic motions



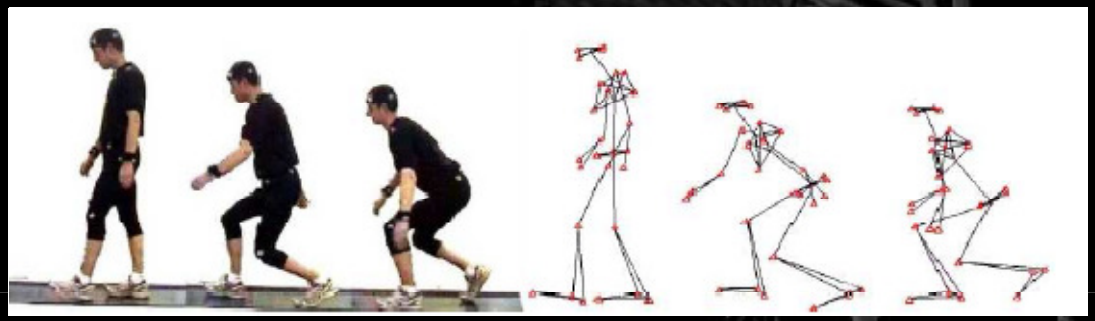
Crompton et coll. (1998)

- Inverse kinematics *(Boulic et coll. 1992)*
  - Cartesian constraints ➔ adaptation
  - Anatomy in the kinematic chain function



Simulation based on kinematic models

- Interpolation in a set of motion clips

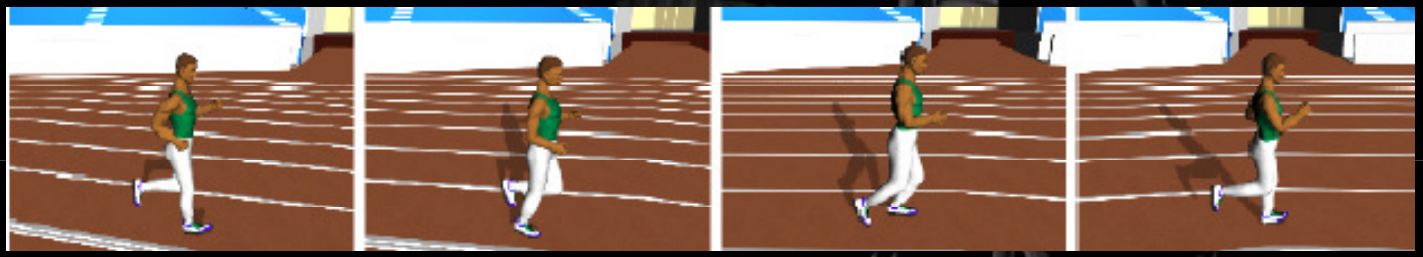


Pronost et coll. (2006)

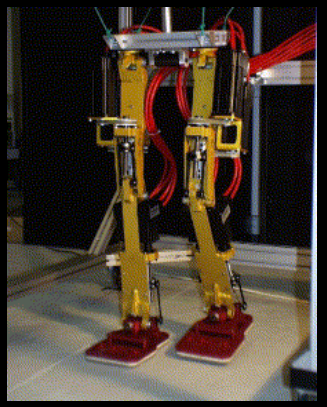
  - Interpolation based on anatomical properties
  - Extrapolation!?
  - Physically-invalid motions (Safonova et Hodgins, 2006; Pronost et coll., 2007)

Dynamic models

- Mechanical model
  - Bones vs. musculoskeletal modeling
  - Controller (Gorce, 1999; Hodgins, 1995)



Hodgins (1995)

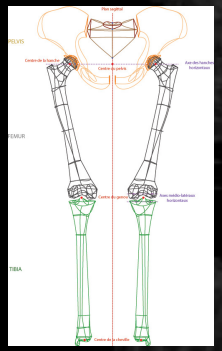


Gorce (2001)

  - Based on known trajectories
  - Unnatural motions
  - Muscles activations with optimal control (Sellers et coll., 2004)

Delp (1990)

Overview



Numerical models

Hypotheses: footprints, joint limits, rotation axes…

Original feet's traj.

Computation of the feet's traj.

Feet's trajectories

Direct kinematic model

Criteria

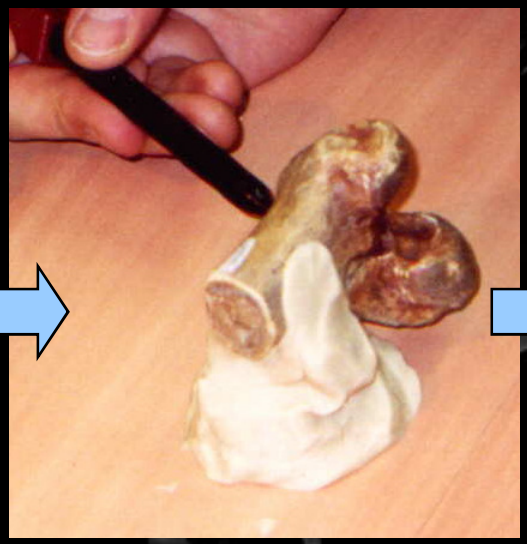
Inverse kinematics algorithm

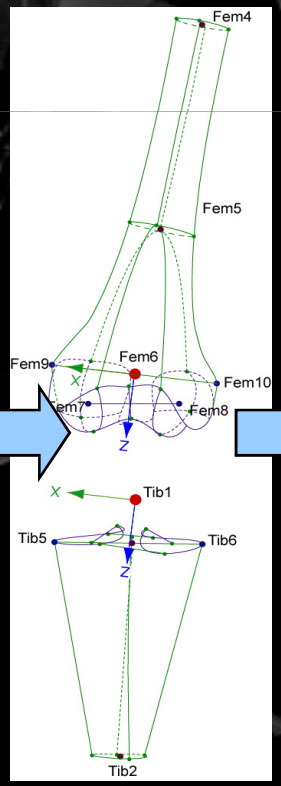
Simulated motion

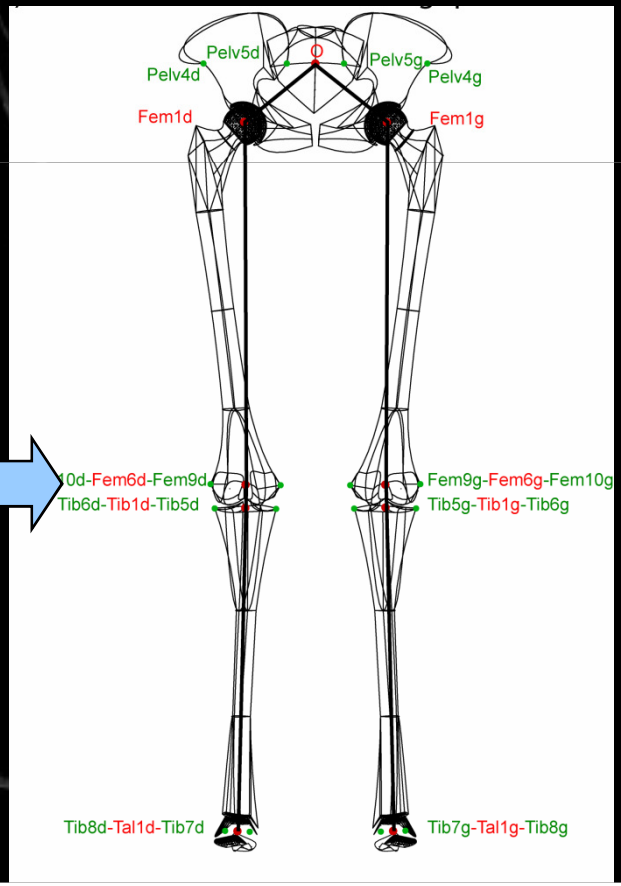
Numerical model

- Digitalization of bones and 3D complete model (Berillon et coll., 2005)
  - "Lucy" A.L. 288-1 (National Museum of Ethiopia, Addis Abeba)

Microscribe 3D-X







Inverse kinematics

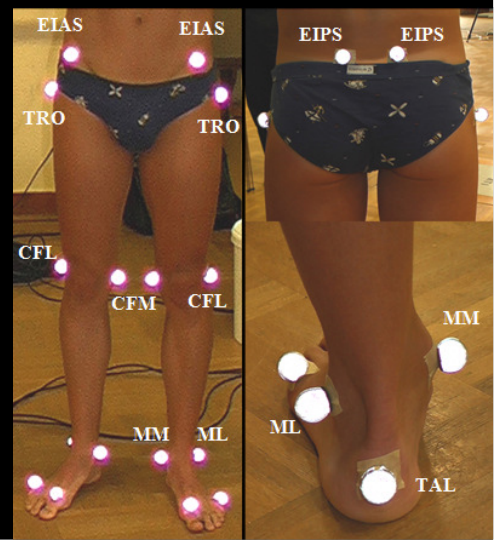
- 11 DOFs for 6 constraints ➔ 5 DOFs solution space

$\dot{q} = J^{+}\dot{x} + (I - J^{+}J)\dot{q}_0$

Primary task

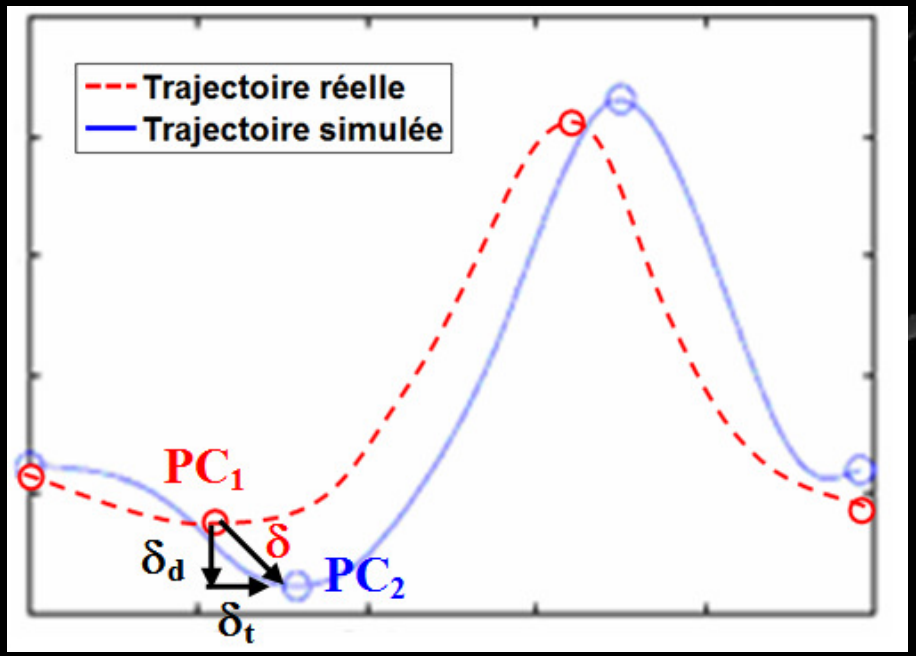
Secondary tasks

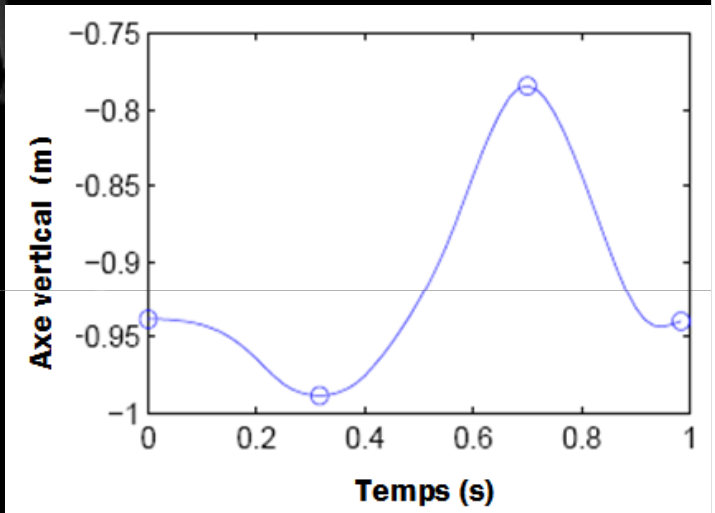
- Secondary tasks
  - Main principles of bipedal locomotion (min. energy)
  - Anatomical constraints (joints limits, natural rest posture hypothesis)
- Validation on 10 human subjects
  - Motion capture with Vicon-MX
  - Average RMS error < 0.05rad for joint angles
  - Relative errors < 9%

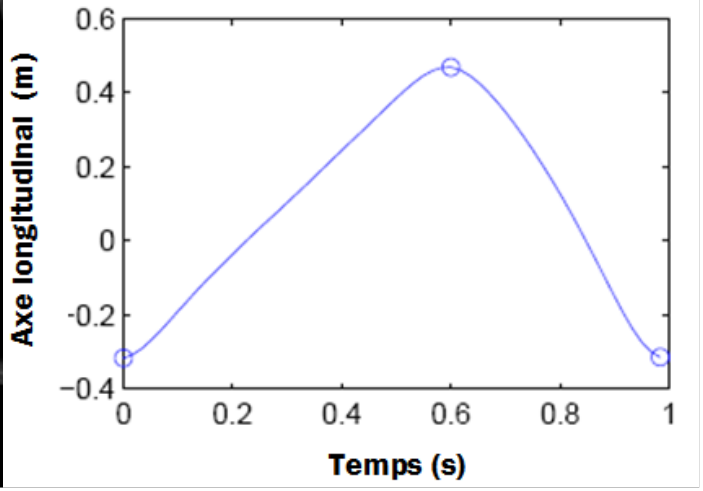


Searching for the correct traj. of the feet

- Parametric curve with 7 control points (splines)
  - ➔Decreasing the seach space
- Motion warping

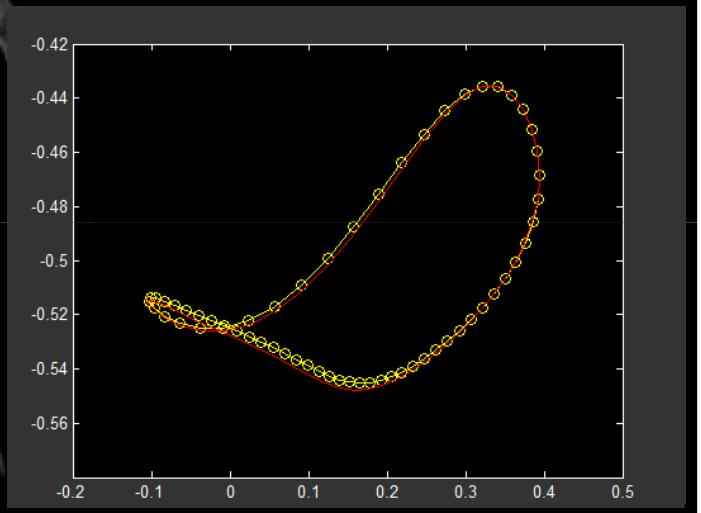






Minimization functions

- Internal work minimization (Alexander, 2003; Burdett et coll., 1983)
- Minimum Jerk (Flash, 1985)

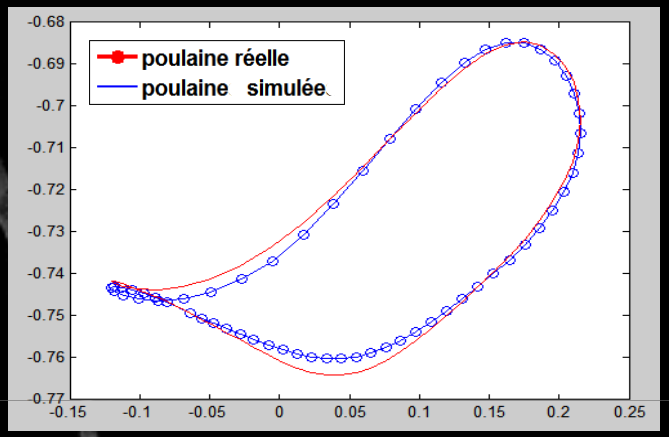


➔ Optimization loop including IK

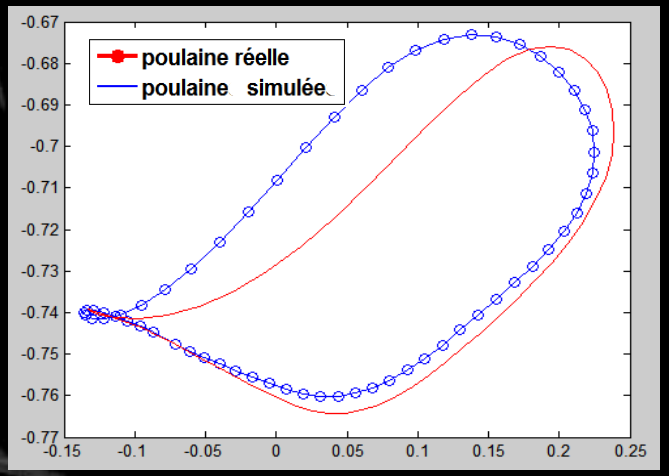
➔ Application to 10 human subjects, 1 Pan troglodites, 1 Homo sapiens (Museo Antropologia, Universidade de Coimbra, Coimbra, Portugal) , A.L. 288-1

Results in humans

- Two cases
  - 8 subjects: almost identical

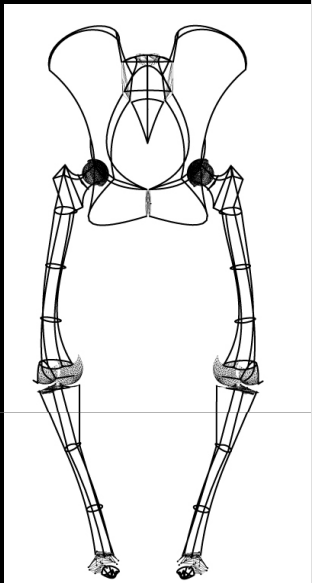


  - 2 subjects: incorrect results



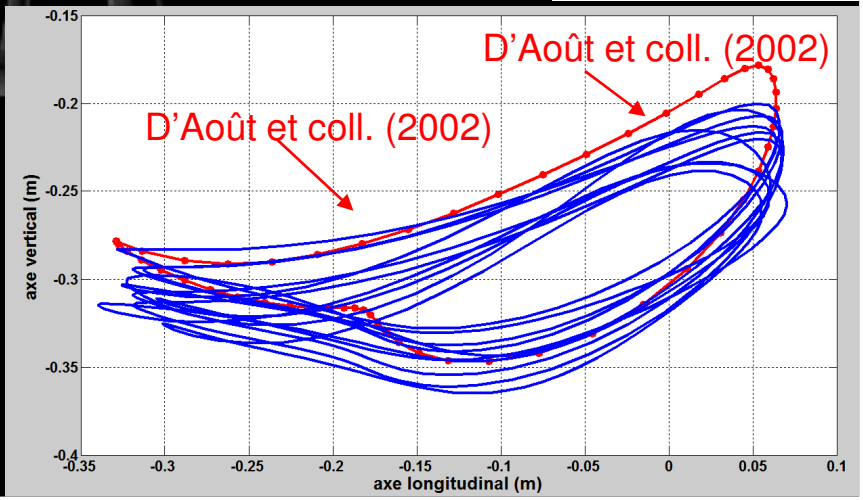
Results in Pan troglodytes

- Original trajectory of the feet = human
- Pan troglodytes (Hamann Todd Collection, Cleveland Museum of Natural History, Cleveland, USA)
- Inputs:
  - Step length L=0.4m (Aerts et coll., 2000)
  - Anthropometric data (Schoonaert et coll., 2007)
  - Joint limits experimentally evaluated



Pan troglodytes

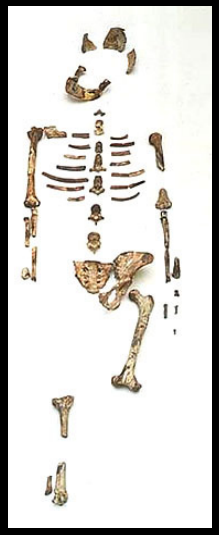
- Different shape than humans
- Similar to D'Août et coll. (2002)
- $WF_{int\ moy}$ > 28% / human!

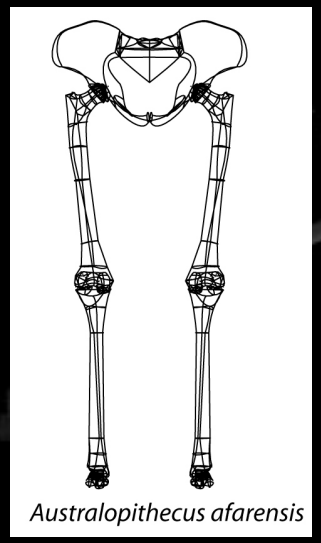


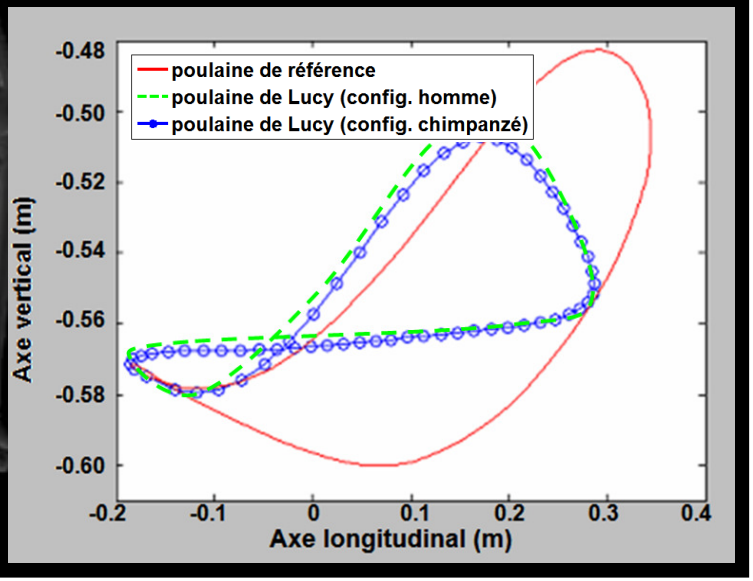
Results in *Australopithecus afarensis* (« Lucy », A.L. 288-1)

- Step length = 46cm Laetoli (Leakey et Hay, 1979 ; Leakey et Harris, 1987)
- Anthopometric tables = humans & chimpanzee
- Original traj. of the feet = human

➔ $WF_{int,\ Laetoli} \cong 30$ J/Kg/min ≅ human



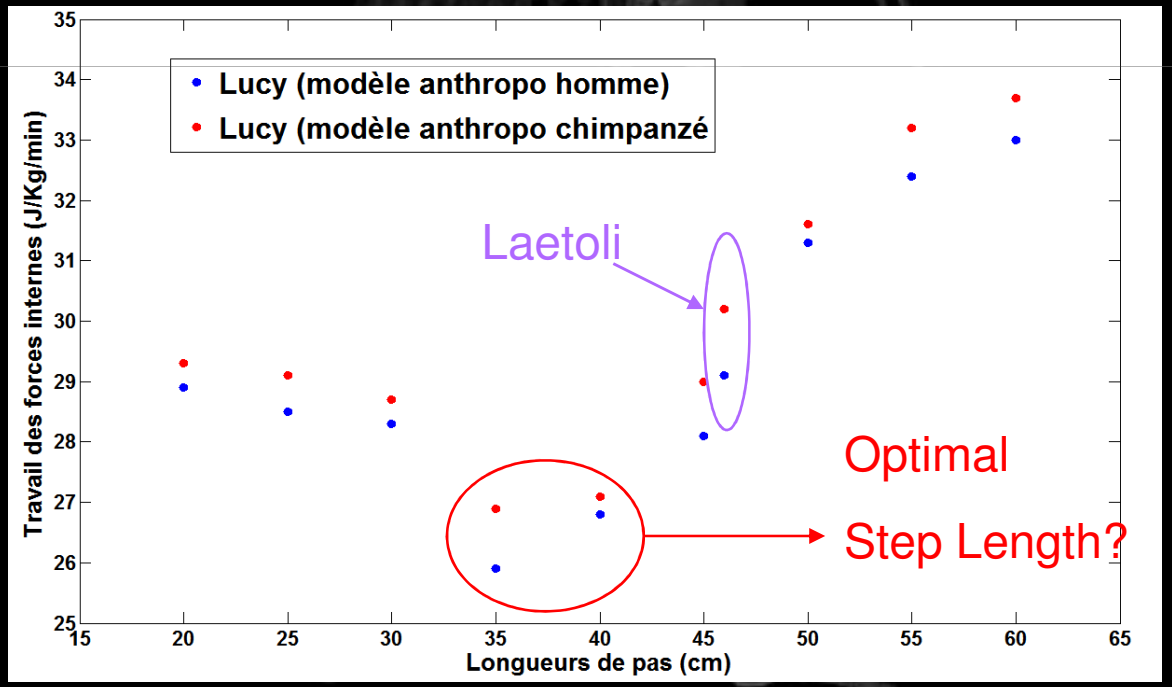




Changes in step length

- Biomechanics: speed and step length naturally selected to decrease energy expenditure (Minetti et coll., 1995)

➔ WF_{int} mini for $L_{pas} \cong$ 35 to 40cm < 15% for Laetoli



Visualisation

Conclusion

- Promising results even for simplified models
  - Lower-part of the body
  - Simplified joints
  - No feet, just the ankle

- Software platform for testing hypotheses
  - In anthropology ➔ modifying the anatomical data
  - In human movement sciences ➔ main principles of human motion control

Perspectives

- Feet!
- Validation on a wider set of species



- Taking dynamics into account
  - Dynamic Stability (Hof, 2008)
  - Joint torques (Kang et Freeman, 1993)
  - Muscles (Delp, 1990)

Questions?