Analyse, Modélisation et Simulation du Mouvement Humain

Analysis, Modeling and Simulation of Human Movements

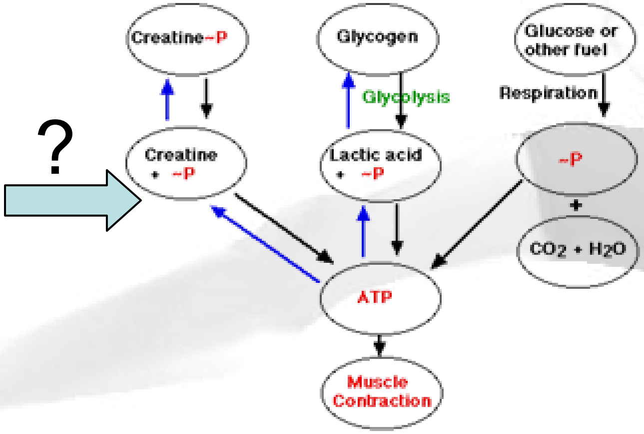
Franck MULTON

Université Rennes 2 – IRISA/Bunraku

Actuellement en délégation INRIA

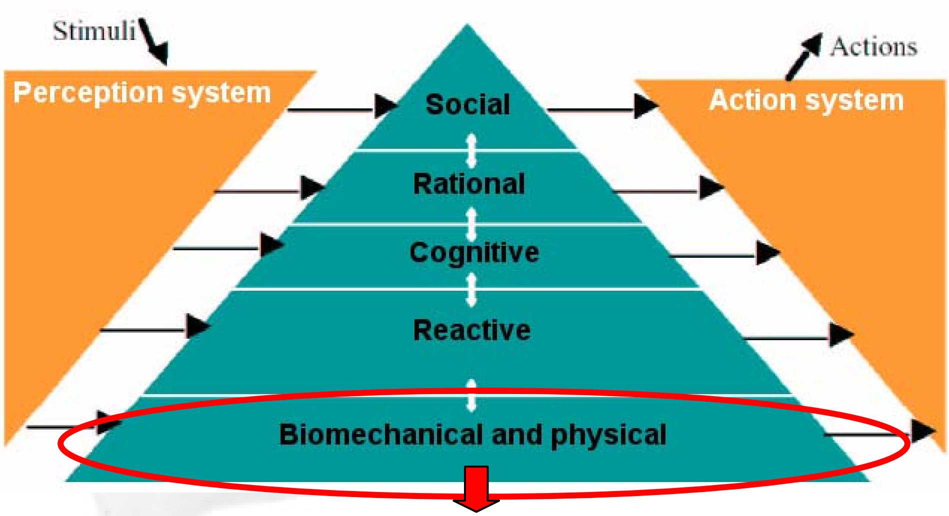
Introduction

- Human motion → sociological (i.e. health care) and economical (i.e. sports) issue
- Human motion = f(biomechanics, physiology, psychology…)



Introduction

- Decomposition in several independent layers of control *[Newel90]*
- How to isolate phenomena?

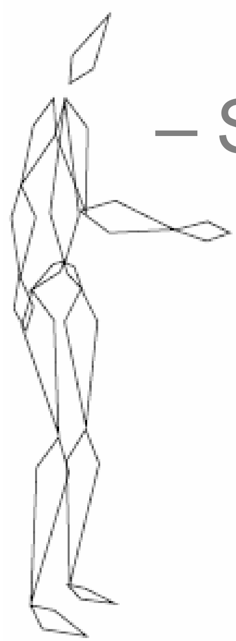


Adapted from *[Newel90, Donikian04]*

Preamble

- Complexity of the motion control system
  - >200 bones and muscles *[Gray18]*
  - Several natural sensors *[Berthoz03]*
  - Various laws (mechanics, physiology…)

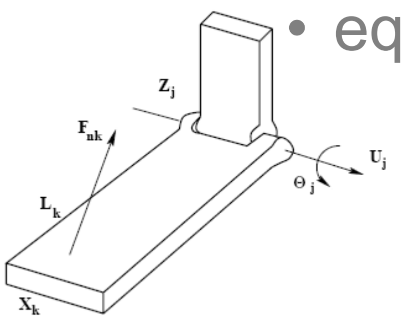
    ➔ simplifications!
  - Skeleton = articulated rigid bodies *[H-ANIM, ISB02]*



Preamble

- Complexity of the motion control system
  - >200 bones and muscles *[Gray18]*
  - Several natural sensors *[Berthoz03]*
  - Various laws (mechanics, physiology…)

    ➔ simplifications!
  - Skeleton = articulated rigid bodies
  - Muscles
    - equivalent rotational actuators *[Zajac90]*



Preamble

- Complexity of the motion control system
  - >200 bones and muscles *[Gray18]*
  - Several natural sensors *[Berthoz03]*
  - Various laws (mechanics, physiology…)

    ➔ simplifications!
  - Skeleton = articulated rigid bodies
  - Muscles
    - equivalent muscles in rotation *[Zajac90]*
    - Musculoskeletal models *[Delp90, Nakamura05]*

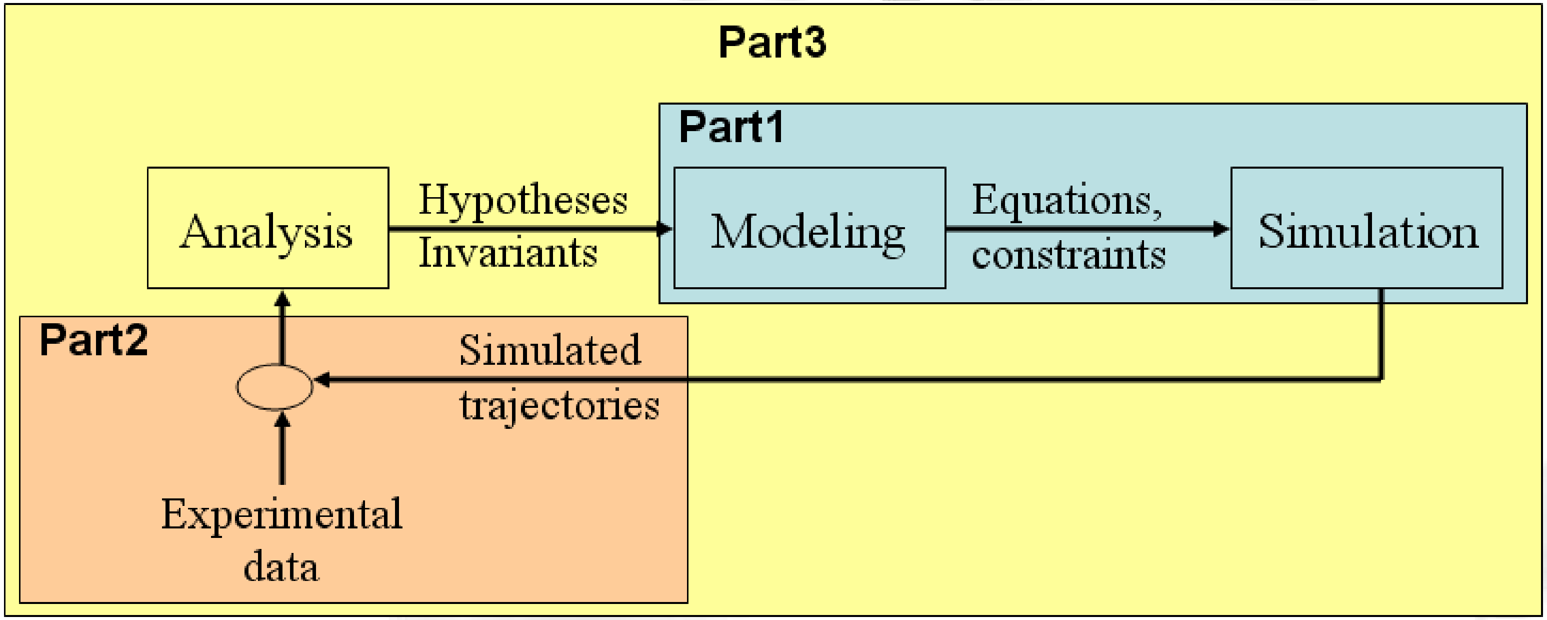
Preamble (2)

- Several scientific domains are involved
- Experimental Research (ER) vs. simulation
  - ER ➔ simulation: early in computer animation *[Zeltzer82]* and humanoid robotics
    - Mainly used to mimic natural motions *[Alexander83]➔[Boulic90]*
  - Simulation ➔ ER *[Delp90, Yeadon90]*
    - Mainly to understand the link between various phenomena

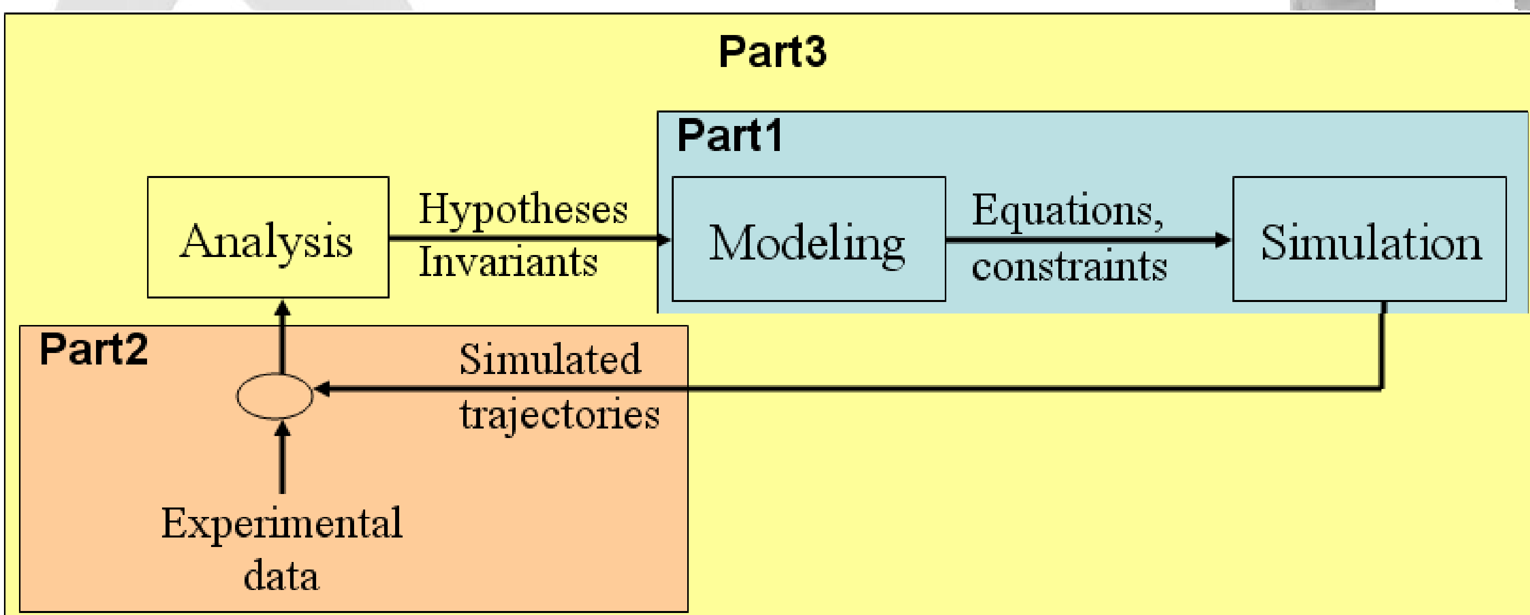
Analysis Simulation

Proposal

- To an analysis/synthesis workflow



Part1: Simulation for human motion understanding



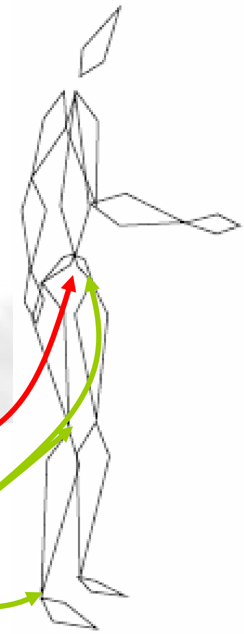
Problem

- To propose a method:
  - For generating natural and controllable motions
  - For testing hypotheses from experimental sciences
  - Compatible with interactive applications
- Common assumption:
  - Rigid bodies with rotational actuators

➔ State = $\theta(t) = \{P(t), \Theta(t), \{q_i(t)\}_{i=1\ldots n}\}$

(P(t),Θ(t))=position and orientation of the root

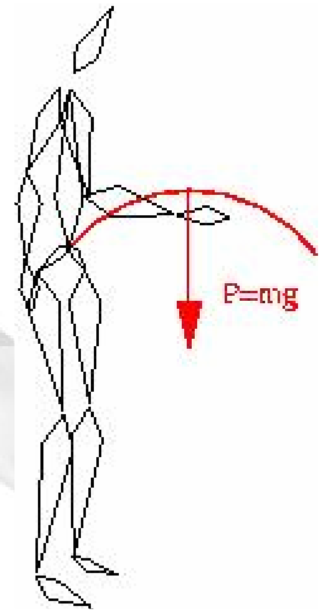
{qi(t)}=joint angles



Problem (2)

- Control= application of constraints
  - Kinematic: constraints in the Cartesian frame

    i.e. Inverse Kinematics $f(\{q_i\})=X \rightarrow \{q_i\}=f^{-1}(X)$
  - Kinetic: taking masses into account
  - Dynamic: forces, torques, inertia…
  - “Style”: remaining constraints
    - Psychological state: sad, nervous…
    - Social status: macho walking style…
    - Other…



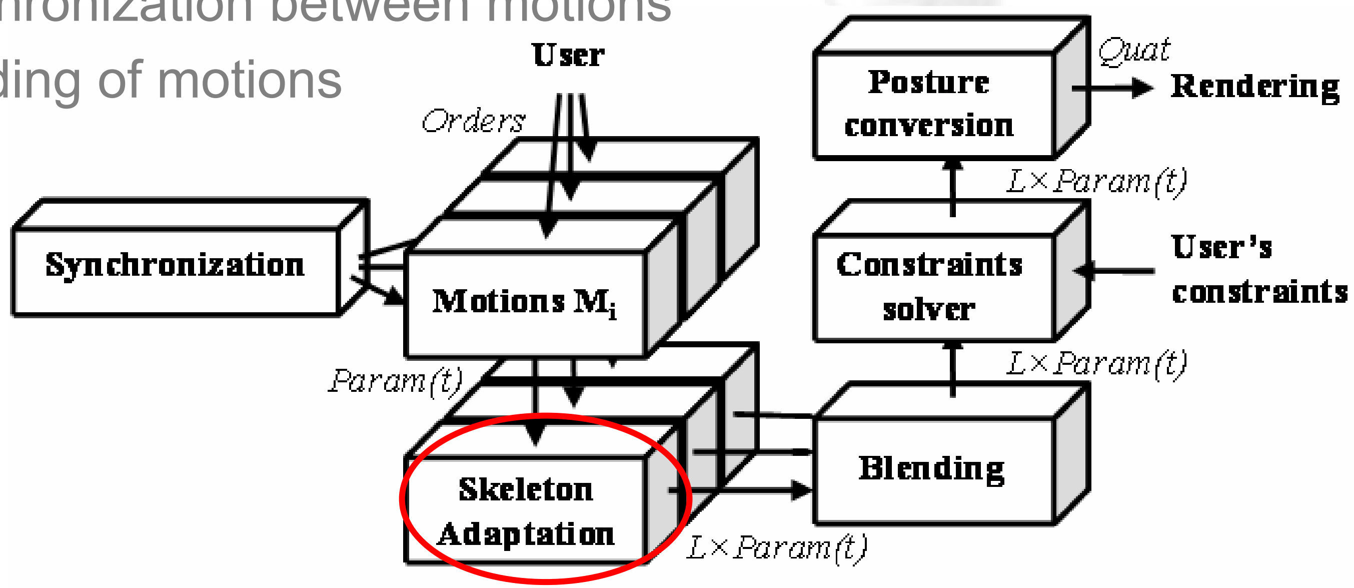
➔ 2 families: using or not motion capture data

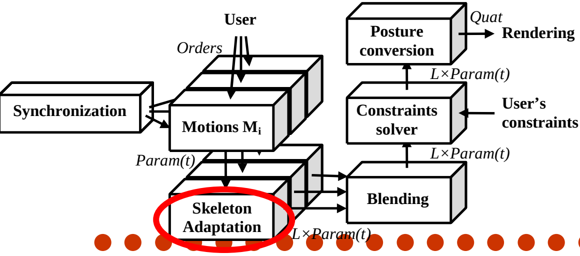
Classification of simulation methods

	Without captured data	With captured data
Kinematic constraints	Kinematic models *[Zeltzer82, Girard85, Boulic90, Sun01]*	Motion graphs *[Kovar02, Lee02]* Blending *[Boulic97, Ashraf01, Kovar03]* Displacement maps *[Gleicher97, Shin01, LeCallennec04]*
	Planning *[Arechavaleta04, Esteves06]*	
Dynamic constraints	Dynamic models *[Yeadon90, Hodgins95, Brogan98, Yang04]*	Motion adaptation + dynamics *[Zordan99, Pollard00, Yamane03, Zordan05, Arikan05, Komura05]*
Style	Procedural approaches *[Rose98, Chi00]*	Statistical analysis *[Glardon04, Hsu05, Liu05]* Navigation into a database *[Grochow04]*

Our proposal: MKM

- Blending & adaptation of captured motions
  - Originality = designed for interactive animation + test of hypotheses
    - Definition of a morphology-independent representation of motion
    - Kinematic constraints solver
    - Synchronization between motions
    - Blending of motions

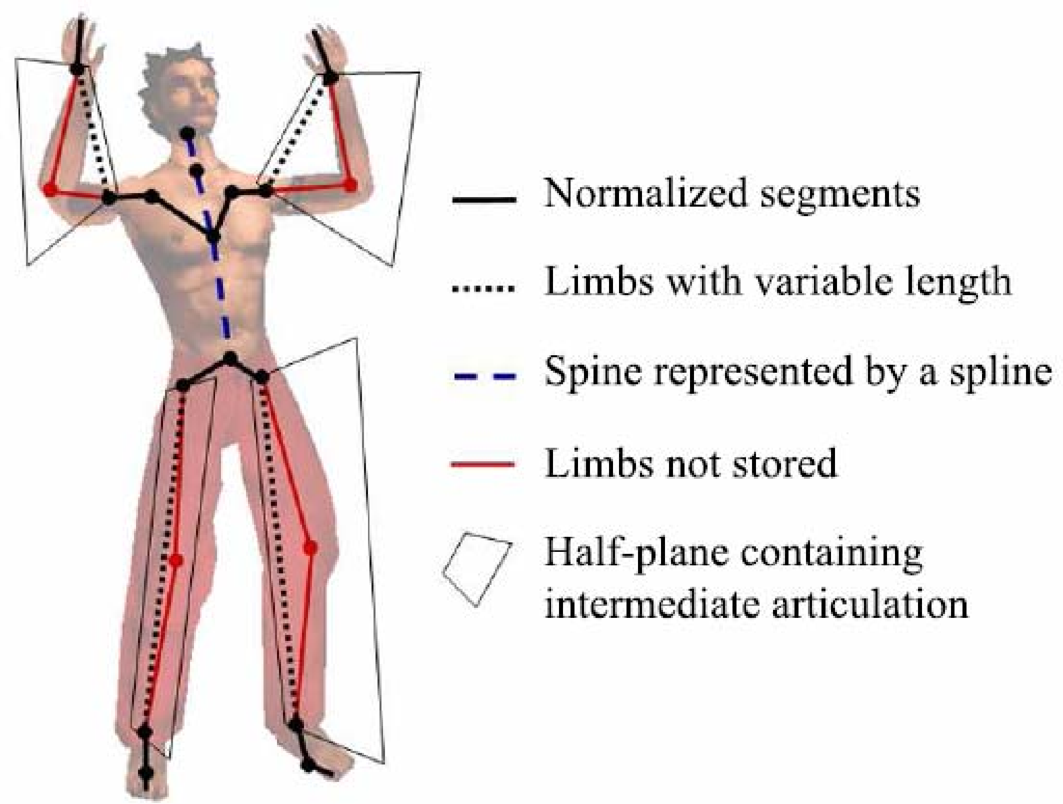


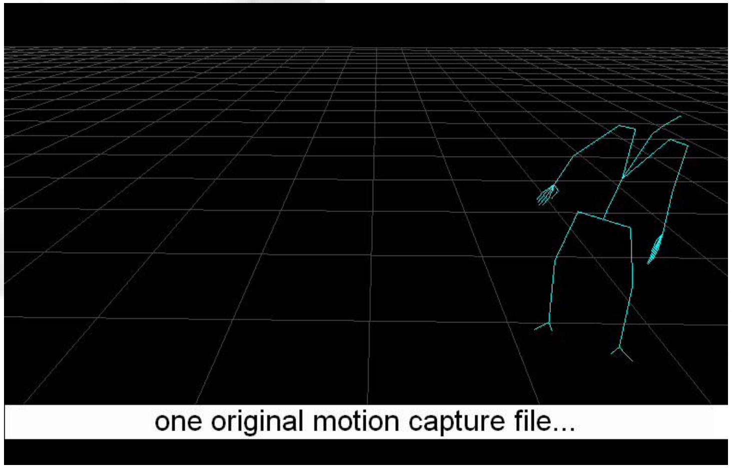


Representation of motion

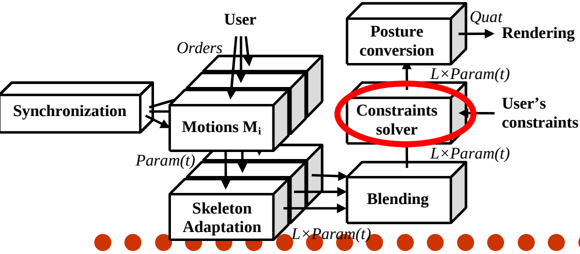
- Retargeting motion to another character

➔ *Morphology-independent representation to avoid using Inverse Kinematics*





[Menardais03PhD, Kulpa05EG]



Kinematic constraint solver

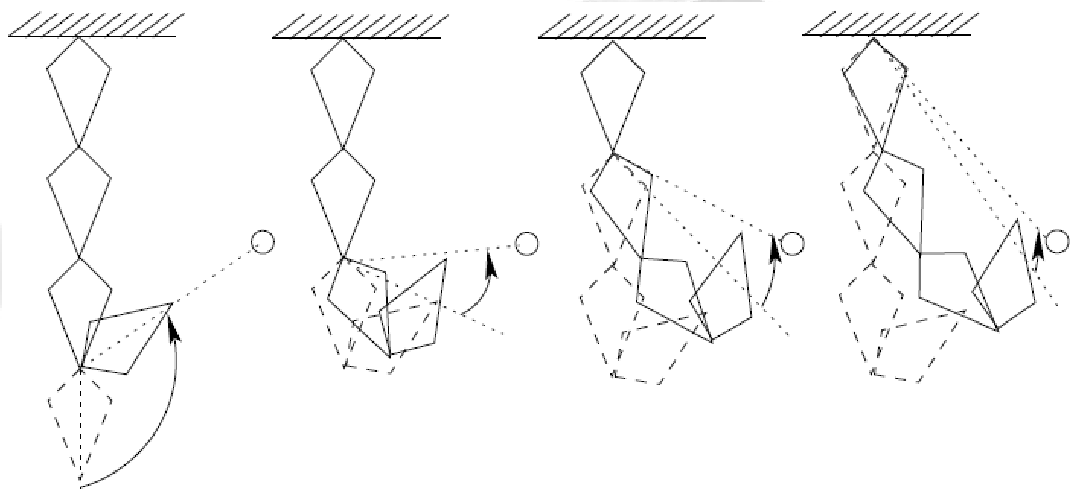
- Problem: $f(\{q_i\})=X$ ➔ $\{q_i\}=f^{-1}(X)$ *Inverse kinematics*
- Classical approaches
  - Local linearization of f with Jacobian *[Baerlocher04]*

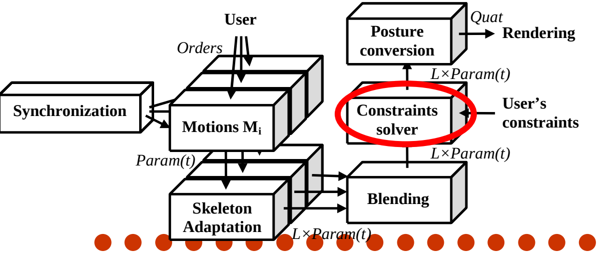
$$\Delta\theta = J^{+}\Delta X + (I - J^{+}J)z$$

➔ Time consuming

  - Iterative algo. *[Shin01]*; Ex.: CCD *[Lander98]*

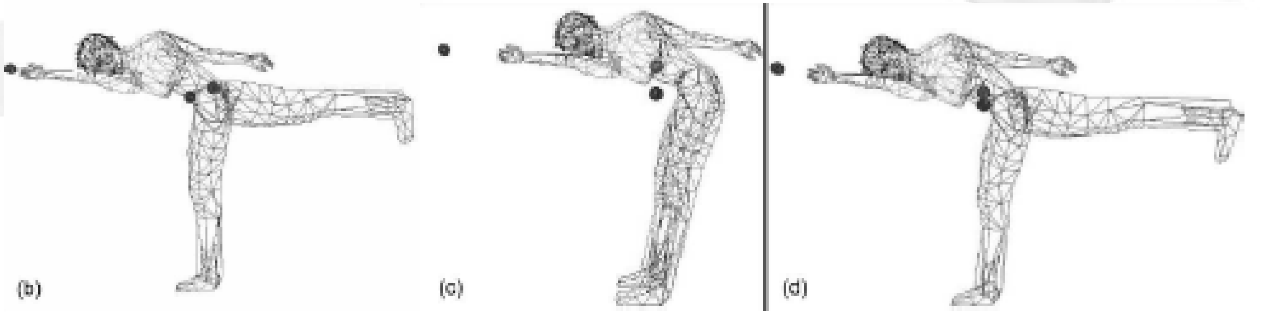
➔ Lot of iterations & unrealistic poses

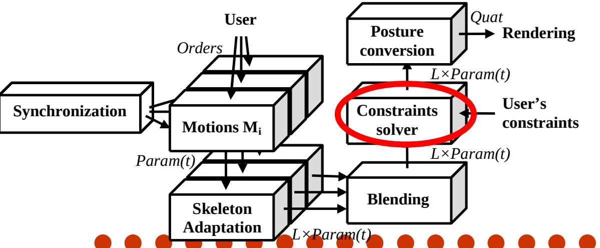




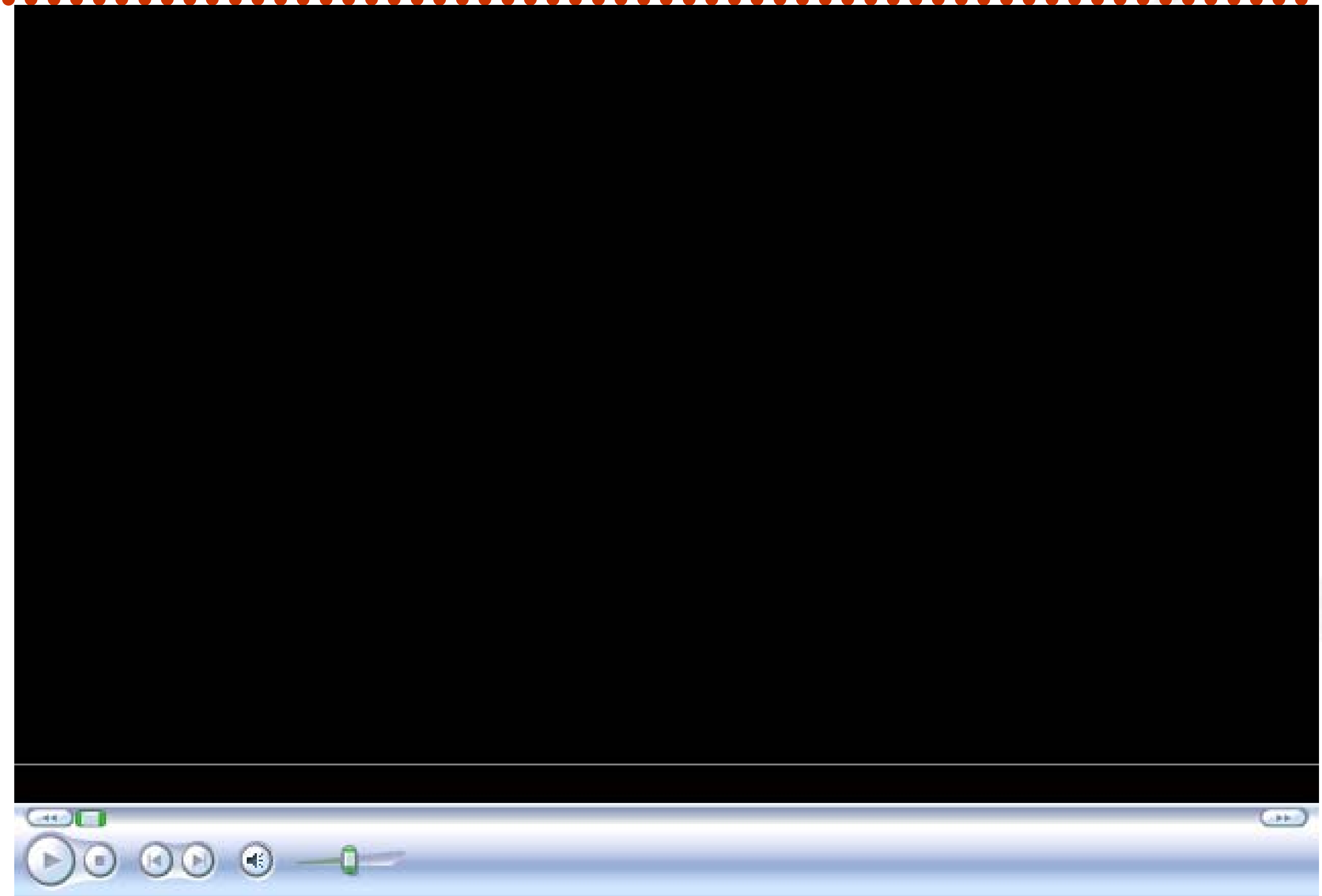
Kinematic constraint solver

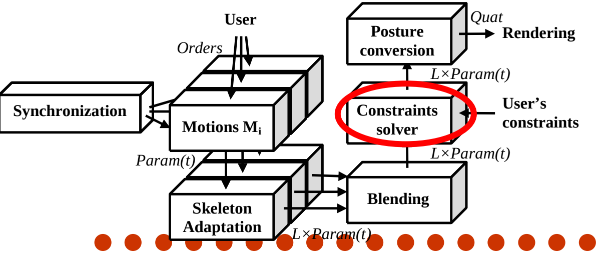
- Skeleton viewed as a hierarchy of groups
  - Analytical solution (like IKAN *[Tolani00]*)
  - Iterative algorithm (like CCD)
- Iterative process ➔ order for the groups?
  - Hypothesis=energy minimization *[Alexander04]*
    - Distal groups with less mass first; also the groups with larger range of motions
  - But other hypotheses could be tested such as specific segmental sequences *[Fradet04SportsSciences]*




User
Orders
Posture conversion
Quat
Rendering
L×Param(t)
Synchronization
Motions M_i
Constraints solver
User's constraints
Param(t)
L×Param(t)
Skeleton Adaptation
Blending
L×Param(t)

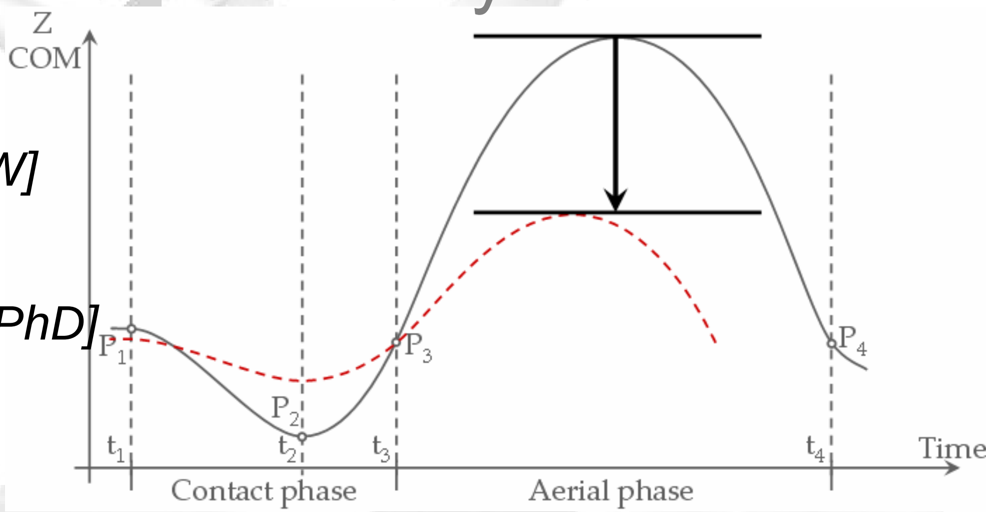
Video

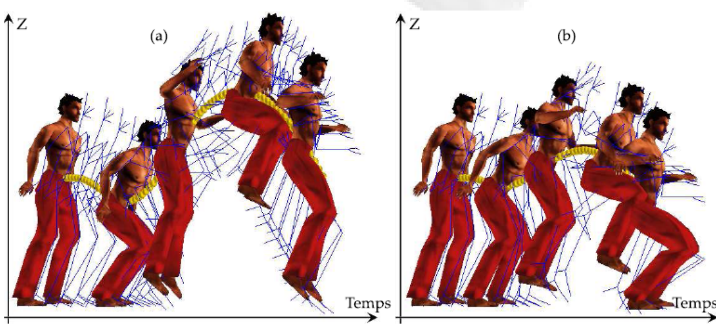




Dynamic constraints

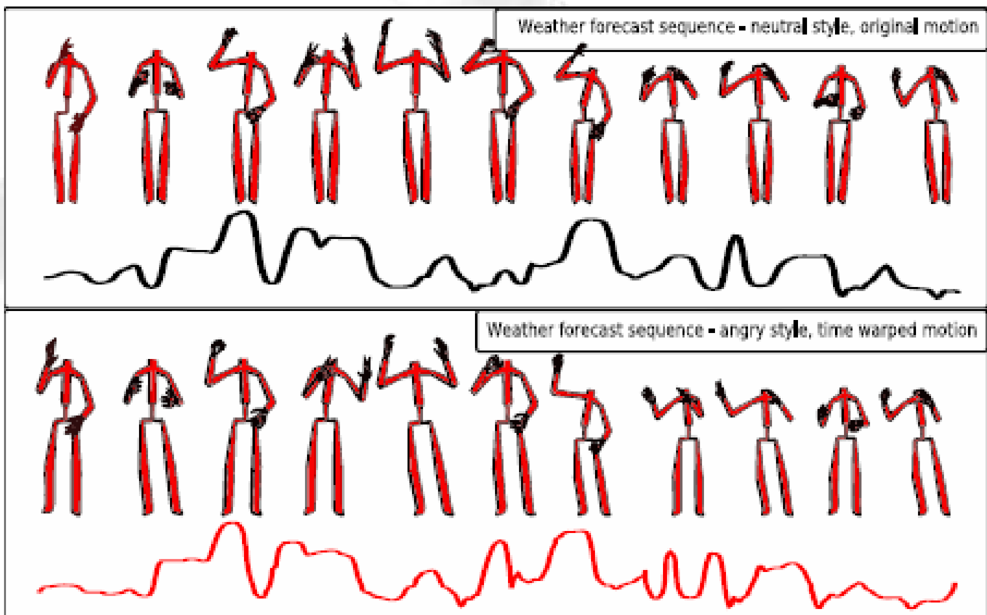
- Problem: verifying mechanical laws of motion *[Safonova05]*
- Proposal: preliminary work on COM's system
  - Ident. masses *[Durocher05GW]*
  - Optimization of P2 *[Kulpa05PhD]*
    - Verifying gravity
    - Verifying constraints
    - Preserving the shape of the initial motion
  - Inverse kinetics for posture retrieval





Dealing with style

- Problem: applying a style to a motion
- Context: analysis/synthesis of sign language (coll. with VALORIA/UBS)
- Proposal: time-alignment and identification of a warp path using DTW *[Heloir06CASA]*

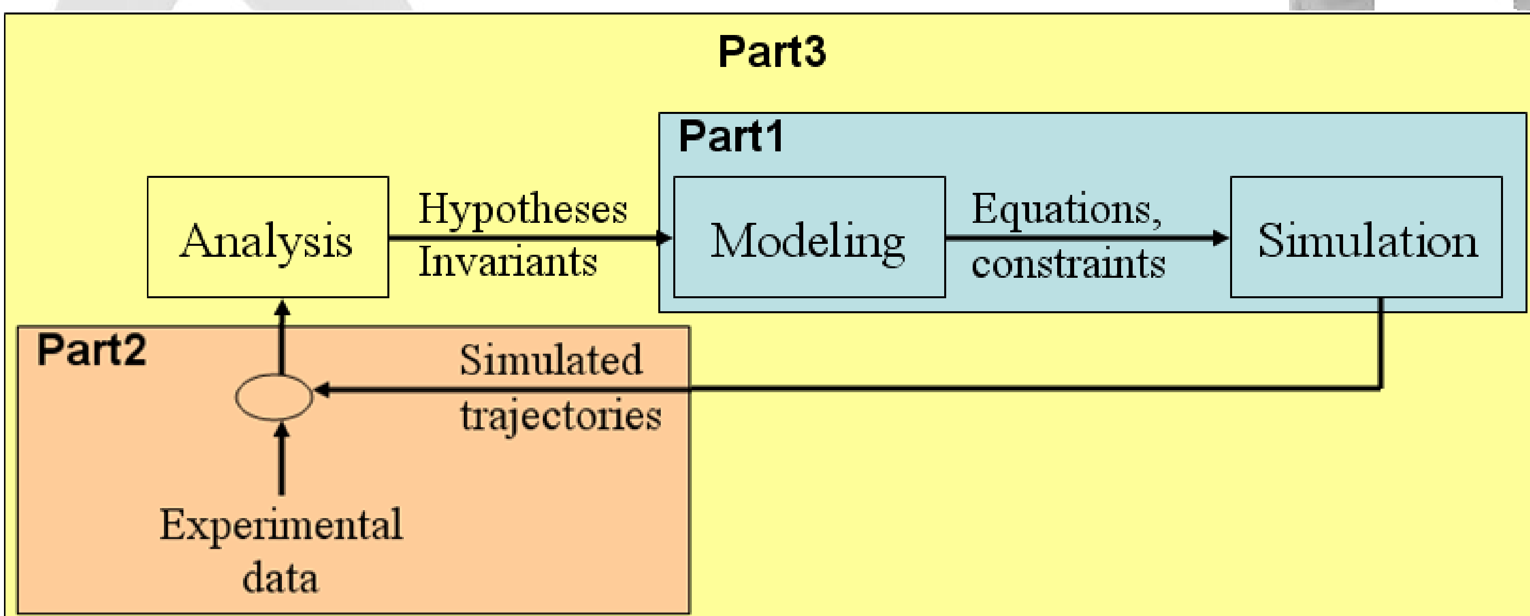


Alexis Héloir
SIGNE project (coll. with VALORIA)

Discussion

- Fast algorithms for adapting motion capture data
  - Assumption: adapting locally a motion preserves its naturalness properties (to be verified…)
- Several encoded hypotheses
  - Order for constraints solving
  - Dealing with constraints
- Perspectives
  - Dealing with dynamics
  - Testing with real biomechanical protocols
  - Validation!

Part2: VR for validation



Problem

- Simulation ➔ angular trajectories + animations
- Experimental data ➔ angular trajectories

➔ How to compare?

– Multidimensional data

– Root Mean Square, correlations ➔ average values ≠ small details

Problem (2)

➔How to validate?

– Involving subjects to evaluate the animations *[Hodgins97, Bodenheimer99, Reitsma03]*

– But sensible to subjective feelings

➔ How the motion is perceived?

- Many different factors such as the device on which it is displayed, the quality of the rendering *[Hodgins97]*, the experience of the subject *[Psotka95]*…

– Close to the “Presence” evaluation in VR

- “sensation of being there” *[Slater93]*
- Evaluated through questionnaires *[Witmer98, Slater98]* or task evaluation *[Slater95]*

Proposal

- Validation of an animation with subjects
  - Evaluation of a task in relation with the animation
    - Interaction in VR
    - Comparison of the behavior in real vs. virtual situations

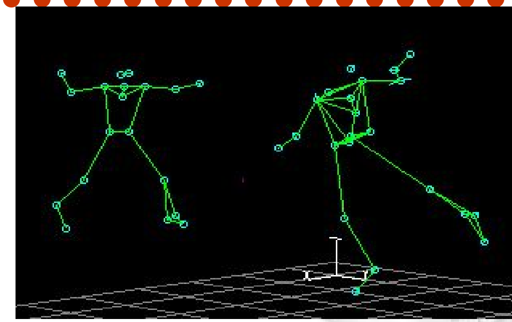
➔ study-case: interaction between a goalkeeper and opponents

Study case

- Interaction between a real goalkeeper and simulated opponents in handball
  - Goalkeepers take information on the opponents motions for ANTICIPATION *[Cottin89, Derrider85]*
  - Generally studied thanks to eye-tracking *[Derrider85,Williams98, Savelsbergh02]*, film analysis *[Abernethy90]*

Workflow

Experiment in real world



Real thrower's motion

Goalkeeper's Motion (in real)

Biomechanical analyses + MKM

Comparison

Presence *Validation*

Synthetic thrower's motion

Goalkeeper's Motion (in VR)

Experiment in VR

Results

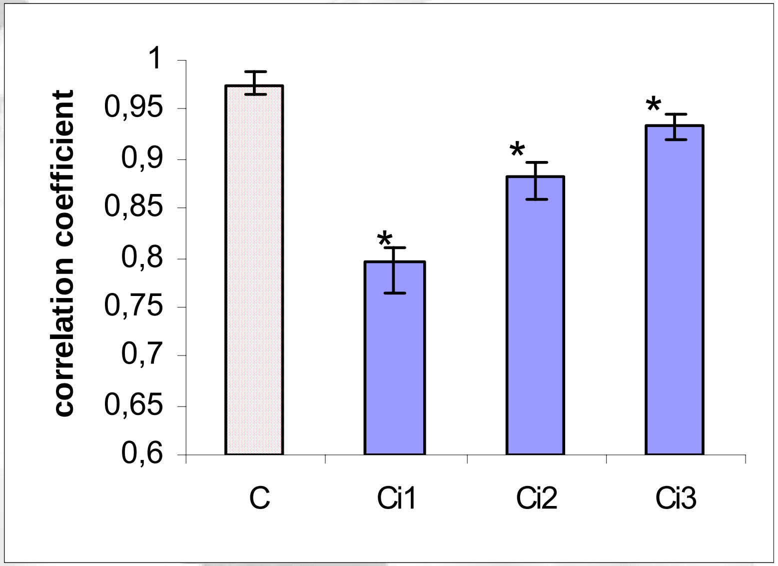
- Correlation in real world: ≈0.8 (hard to evaluate)
- Correlation in VR: ≈0.98
- 3 small modifications

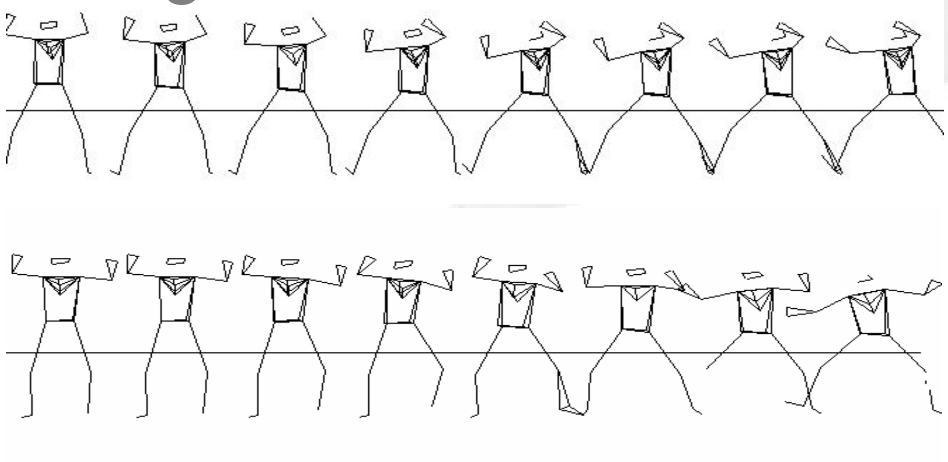
  C1: Height of the hand

  C2: Orientation of the trunk

  C3: Ball release delay

➔ Significant influence





Bideau03Presence, Bideau04NSL
Bideau04PhD

Video

Conclusion

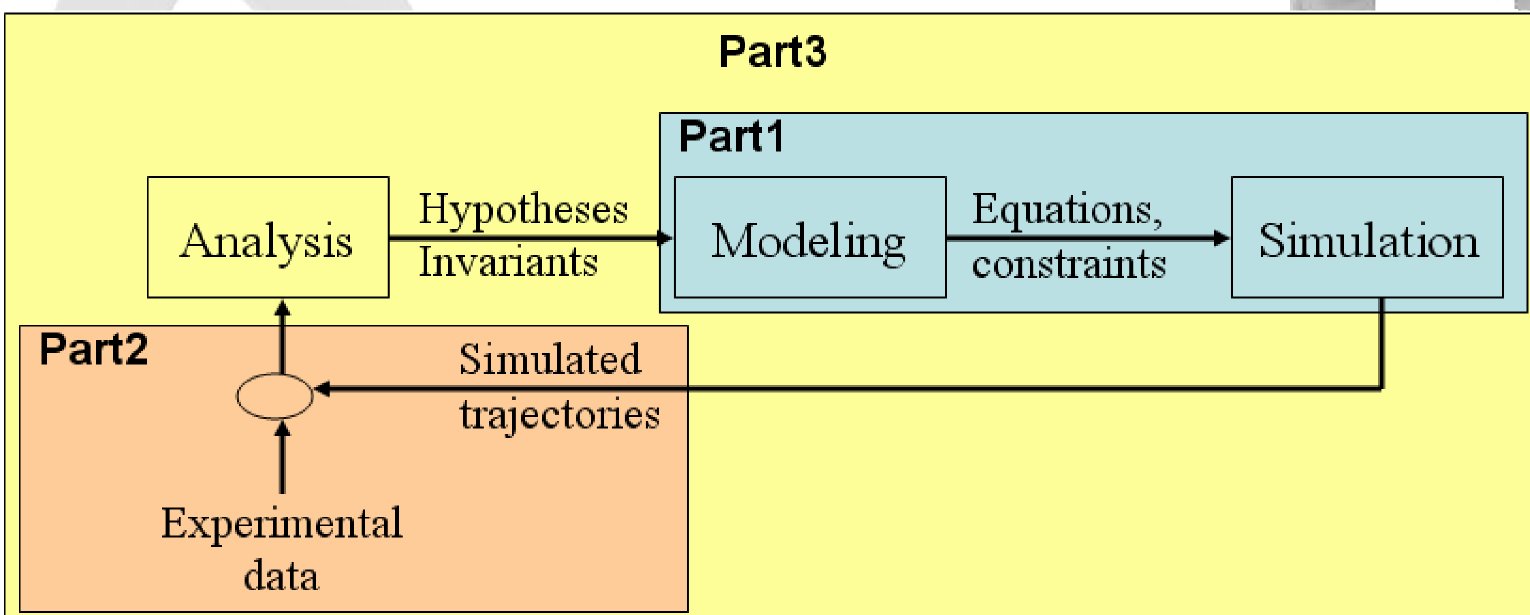
- Proposal of an original workflow to evaluate simulated motions
  – Evaluation of a task involving "natural" interaction with simulated entities

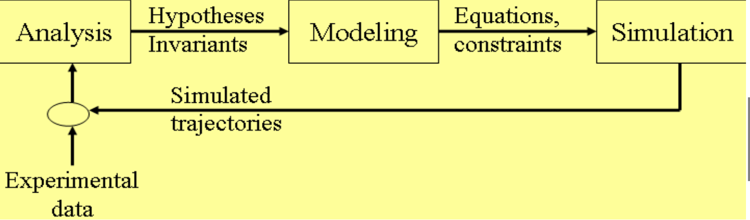
  ➔*Beyond subjectivity of questionnaires*

  – But do we really evaluate realism?

Ongoing project with neuroscientists

Part3: Generation of plausible bipedal locomotion



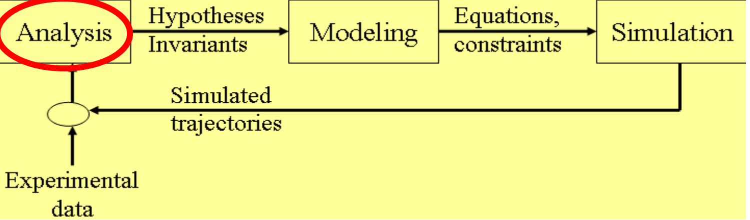


Problem

- Motion capture on a skeleton may not be adapted for another one
  - Not only geometric/kinematic ≠ "motion retargetting" *[Gleicher98, Crompton98, Kramer00,Wang03, Nagano05]:* Human ➔? Chimpanzee
  - Interpolation in a database *[Pronost06]* (extrapolation?)
  - Musculoskeletal models: too complex *[Sellers05]*
  - Plausible locomotion for fossils?

➔ Design of a method that does not use knowledge on kinematics

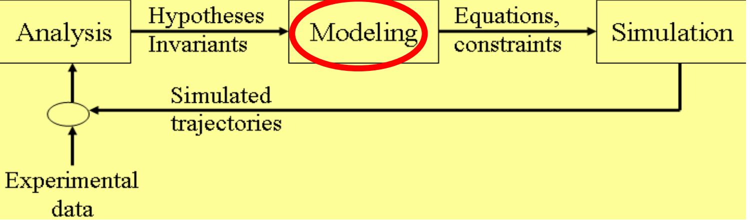
Coll. G. Berillon, UPR2147CNRS



What is plausible?

- Plausible
  - Adapted to joint limits, joint config… ➔hypotheses
  - Taking general laws into account ➔hypotheses
    - Minimum Jerk *[Flash85]*
    - Minimum metabolic energy *[Alexander97, Alexander04]*
    - Coordination in limb kinematics *[Lacquaniti94]* ➔ link to energy expenditure *[Bianchi98]*
    - Phases in mechanical energies (opposition in walking vs in phase in running) *[Cavagna77, Alexander83]*
    - Head stabilization *[Pozzo90]*
    - …

  ➔ which ones are necessary? Combinations?



Simulation of energy expenditure

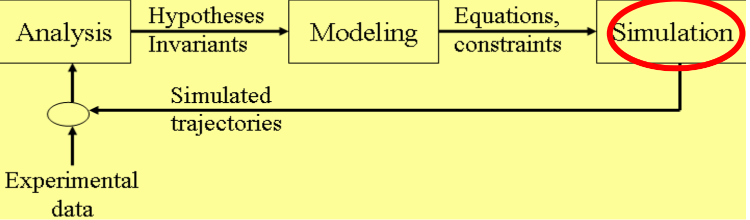
- Metabolism vs. mechanics
  - 2D Musculoskeletal models ➔ relations with energy expenditure *[Ma91, Alexander97]*
  - Internal work calculated indirectly *[Winter79, Pierrynowski 80]*

$$\overline{W^1_{int}} = \sum_{k=1}^{m} \Delta \left[\sum_{i=1}^{n} \left| 0.5 \left(m_i \dot{x}_i^{\,2} + I_i \dot{\theta}_i^{\,2} \right) \right| + \left| -m_i g h_i \right| \right]$$

$$\overline{W^2_{int}} = \sum_{k=1}^{m} \Delta \left[\sum_{i=1}^{n} \left| 0.5 \left(m_i \dot{x}_i^{\,2} + I_i \dot{\theta}_i^{\,2} \right) - m_i g h_i \right| \right]$$

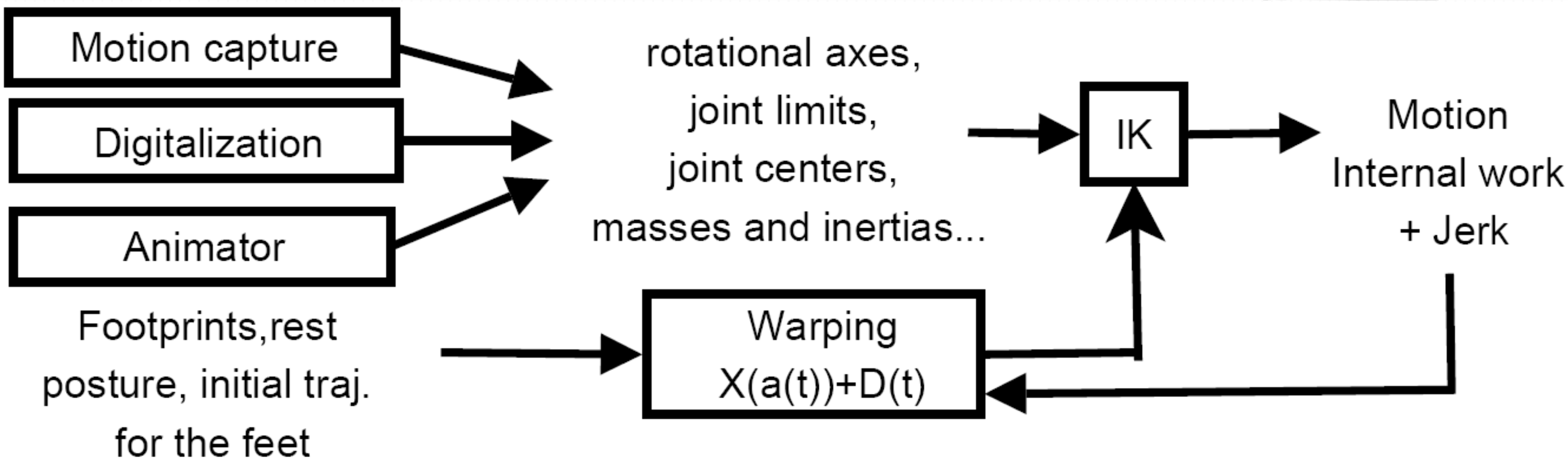
[Burdett83] ➔ $$\overline{W^3_{int}} = \sum_{k=1}^{m} \left| \Delta \left[\sum_{i=1}^{n} 0.5 \left(m_i \dot{x}_i^{\,2} + I_i \dot{\theta}_i^{\,2} \right) - m_i g h_i \right] \right|$$

Appl. human portable engine & coll. Satie *[Beaupied03HMS, Beaupied03T]*

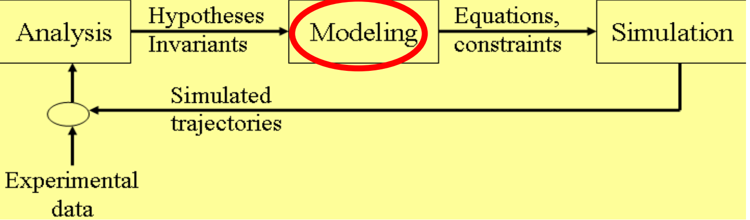


Proposal

- Process
  - Input: Anatomical data + pal. hypotheses
  - Output: Angular traj.
  - Assumption: min Jerk & $\overline{W_{int}^3}$ $min_\theta \frac{1}{t_f - t_0} \sum_{t=t_0}^{t_f} |W_{int}(\theta, t)| + \left(\frac{d^3\theta(t)}{dt^3}\right)^2$
  - Philosophy: two sub-problems *[Esteves06]*

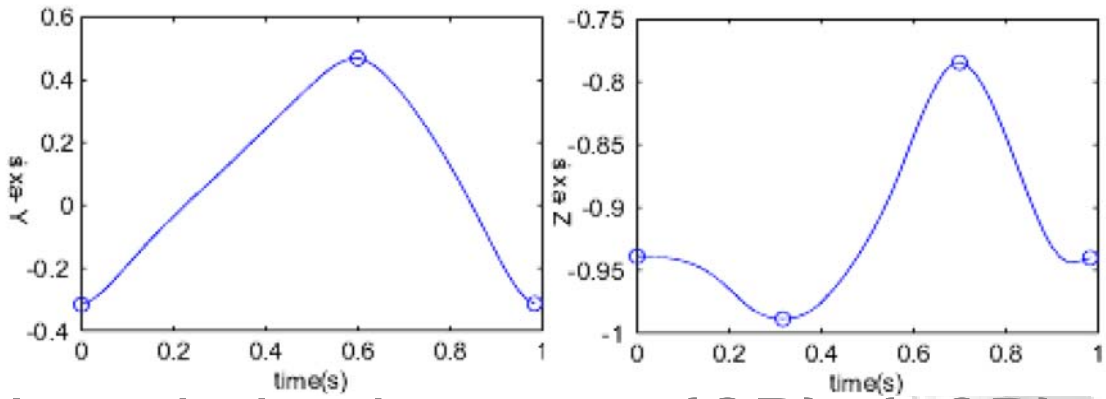


[Nicolas04CASA, Nicolas06JOB]



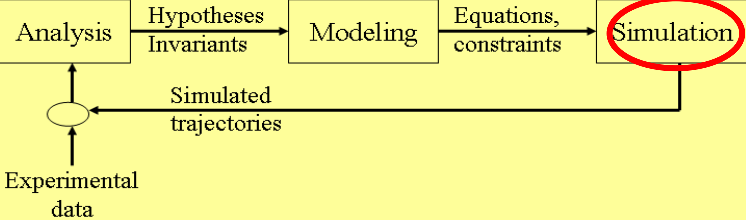
Optimization of feet trajectories

- Traj. modeled with control points {CP}
  - Intrinsically linked to the motion not the specie



- For each optimization step: {CP}+{δCP}
- Constraint: verifying the footprints

$$h(CP, t_{rFS}) = (-X_l(CP, t_{rFS}) + X_r(CP, t_{rFS}))$$



Optimization process

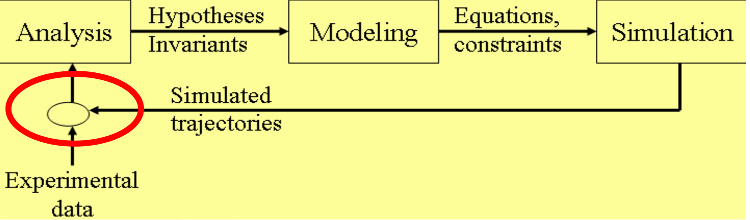
- Non-linear problem
  - ΔFootprints=h(CP)
  - Locally linearized

$$J(CP, t_{rFS}) = \begin{pmatrix} \frac{\partial h_x}{\partial CP_1} & \cdots & \frac{\partial h_x}{\partial CP_n} \\ \frac{\partial h_y}{\partial CP_1} & \cdots & \frac{\partial h_y}{\partial CP_n} \\ \frac{\partial h_z}{\partial CP_1} & \cdots & \frac{\partial h_z}{\partial CP_n} \end{pmatrix}$$

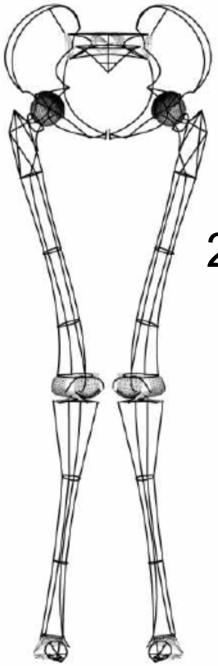
  - Constraint = $\Delta F = (F_r - F_l)_{new} - (F_r - F_l)_{old}$
  - Inversion of the problem:

$$\Delta(CP, t_{rFS}) = J(CP, t_{rFS})^{+} \Delta F + P_F(J)\delta_{CP}$$

Imposed by the optimization process

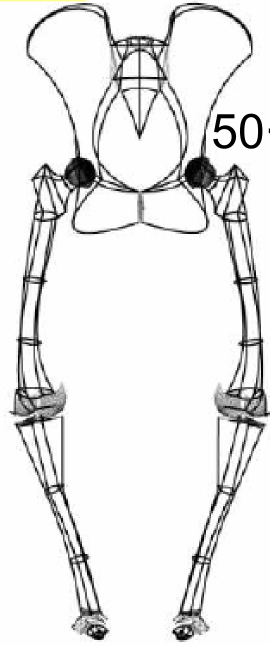


51→19J.Kg^{-1}.min^{-1}



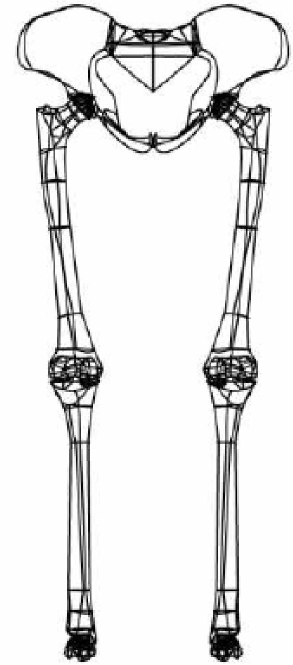
22→20J.Kg^{-1}.min^{-1}

Homo sapiens

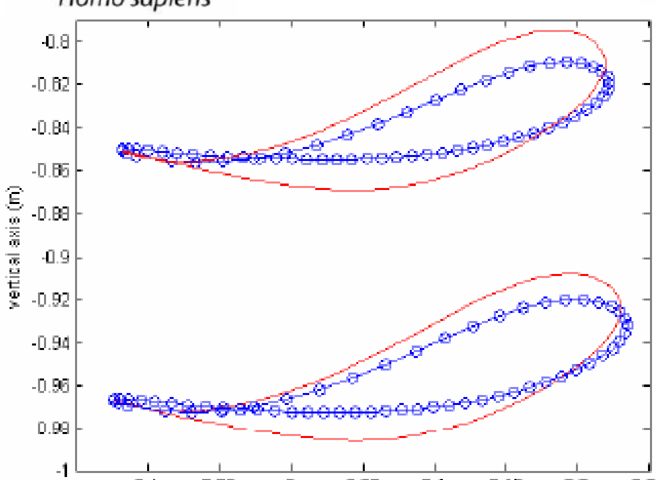


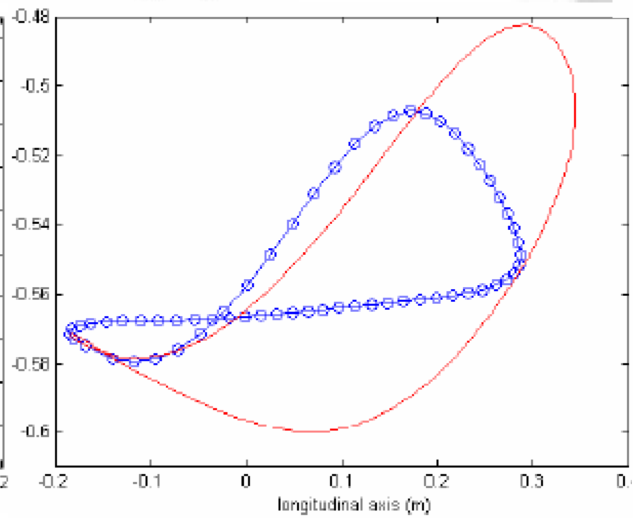
50→30J.Kg^{-1}.min^{-1}

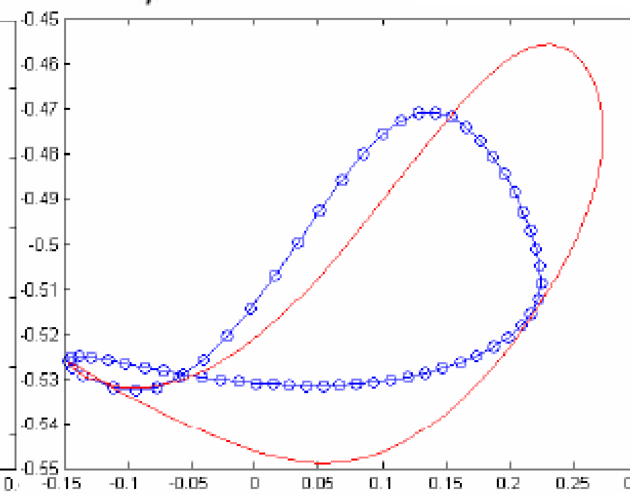
Pan troglodytes

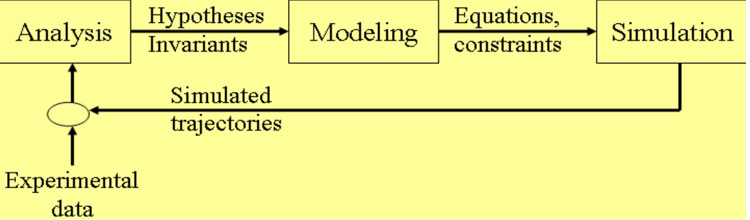


Australopithecus afarensis

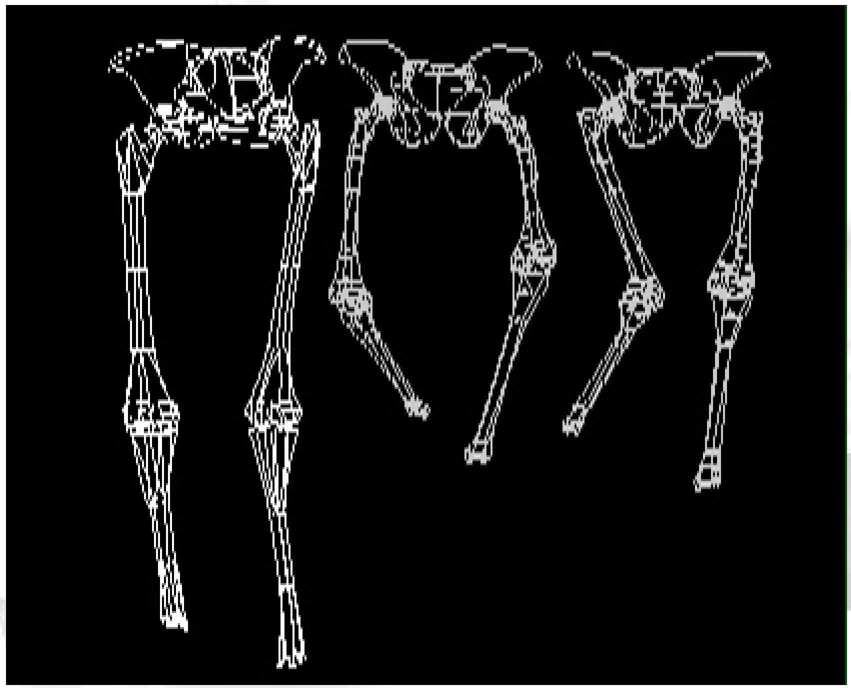







Analysis
Hypotheses
Invariants
Modeling
Equations,
constraints
Simulation
Simulated
trajectories
Experimental
data

Videos



Conclusion

- Main contribution:
  - No kinematic knowledge
  - Problem divided into 2 sub-problems
  - Test of general laws

- Preliminary work ➔ perspectives
  - Testing on a wider set of primates (ongoing project)
  - Experimenting new hypotheses
  - Actual link between metabolic and mechanical energy?

Conclusion

Contributions

- Analysis/synthesis approach
- Multidisciplinary work
  - Publications in various domains, many collaborations & projects
    - Computer graphics (6 journals, 12 confs), biomechanics (3 journals), sports sciences (1 journal), neurosciences (1 journal), humanoid robotics (1 conf), paleoanthropology (1 journal), VR (2 journals, 2 confs)…
  - PhD & Master theses in biomechanics (5 PhD/3 defended) and computer graphics (3 PhD/2 defended)

Applications

- Patent for human motion simulation software (MKM)
  - Tested in industry (Dassault Systems, EADS & video games companies) *PRIAMM HVTR, RIAM AVA Motion*
  - Used for behavioral animation *[Paris06, Badawi06]*
- Model-based motion capture systems
  - *RIAM SEMOCAP, RNTL “Mouvement”, RNTL Perf-RV2*
- Handicap (sign language, physical therapy)
  - *“SIGN” project, CNRS ROBEA HuGeX project*
- Sports (training, performance evaluation & understanding)
  - *Funds from the Ministry of Sports, Federations and regional direction of sports and youngness*

Perspectives

- Middle-term
  - Dynamics (low-cost)
  - Style operators identification
  - Real use in experimental research
- Long-term
  - Design of a convenient metrics for motions
  - Multi-layers controller
    - Coherence between layers?
    - Hierarchical simulation

Contributors

- Master students:
  - S. Canneçu,L. Fradet, N. Fusco, J. Hénaff
- PhD students:
  - H. Beaupied, S. Ménardais, B. Bideau, C. Durocher, R. Kulpa, H. Gain, G. Nicolas, A. Héloir
- And many engineers…

Questions?

What I didn’t address in the oral presentation:

- motion synchronization & blending
- models of constraints
- motion compression
- BSP customization
- IK for natural bipedal locomotion
- simulation LOD
- energy analysis of human locomotion
- application to handicap
- energy extraction from natural motion
- model-based motion capture system
- gymnastic motions analyses
- …