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Planning Humanoid Multi-Contact Dynamic Motion using Optimization Techniques

Abderrahmane KHEDDAR

with

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がんばって、日本

私達は、あなたと共にいます

Summary

- Contact support planner
 - Problem
 - Main components
 - Experiments on HRP-2

- Unifying locomotion and manipulation
 - Main extensions
 - Simulations

- Dynamic motion generation between stances
 - Whole-body dynamic optimization
 - Experiments on HRP-2

Summary

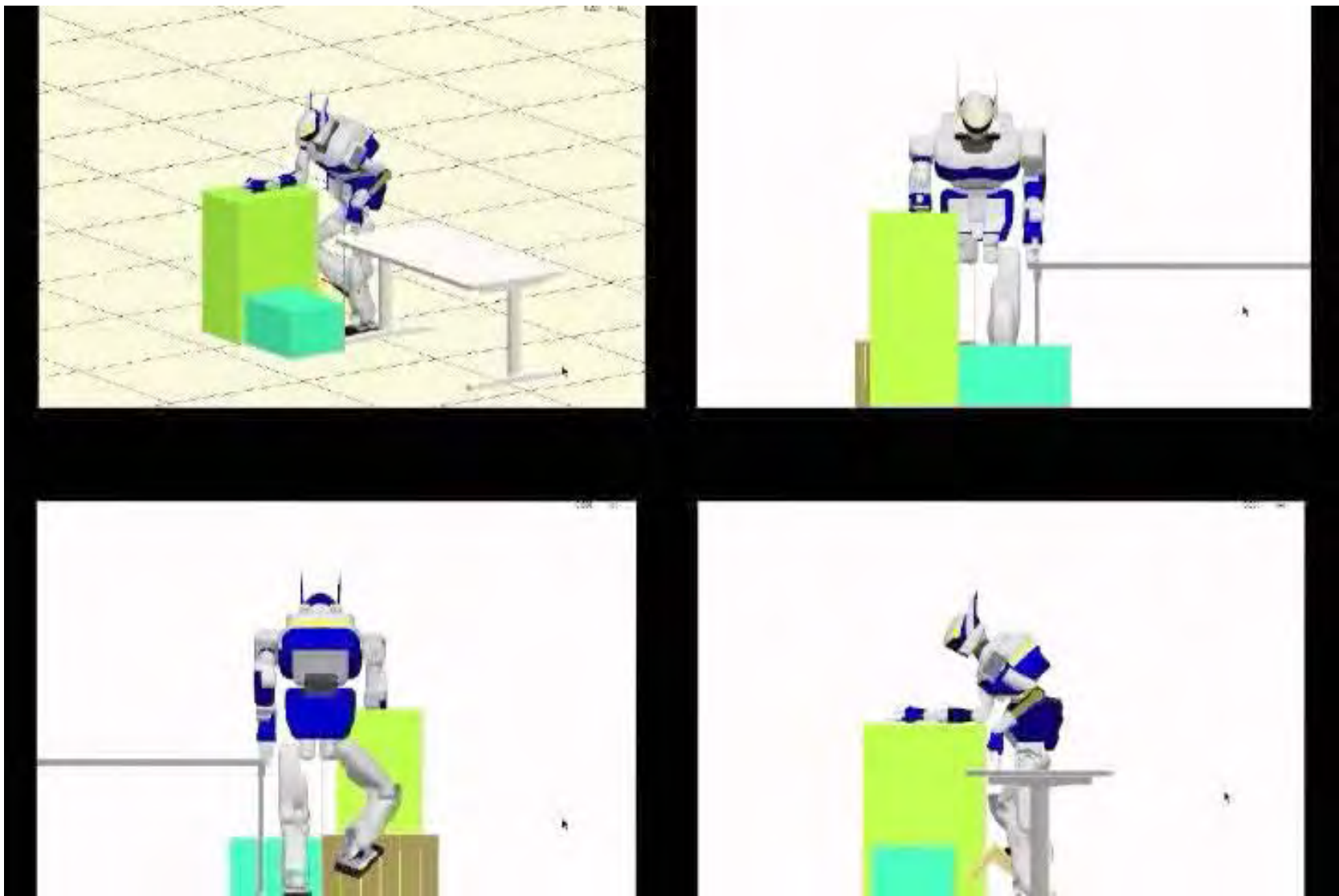
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Example



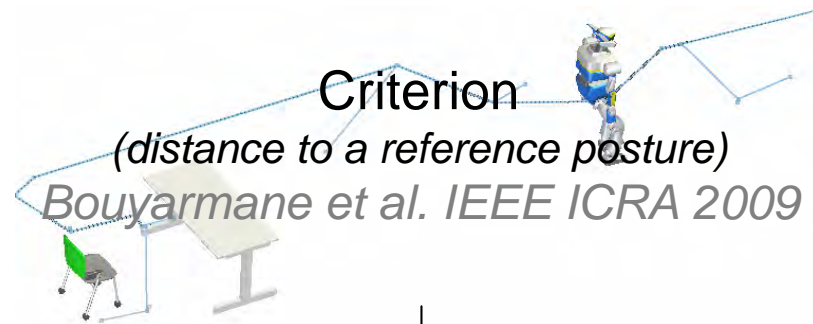
Escande, Kheddar, Miossec IEEE/RSJ IROS 2006

Cumbersome environments



Contact Planning for Acyclic Motion with Tasks Constraints

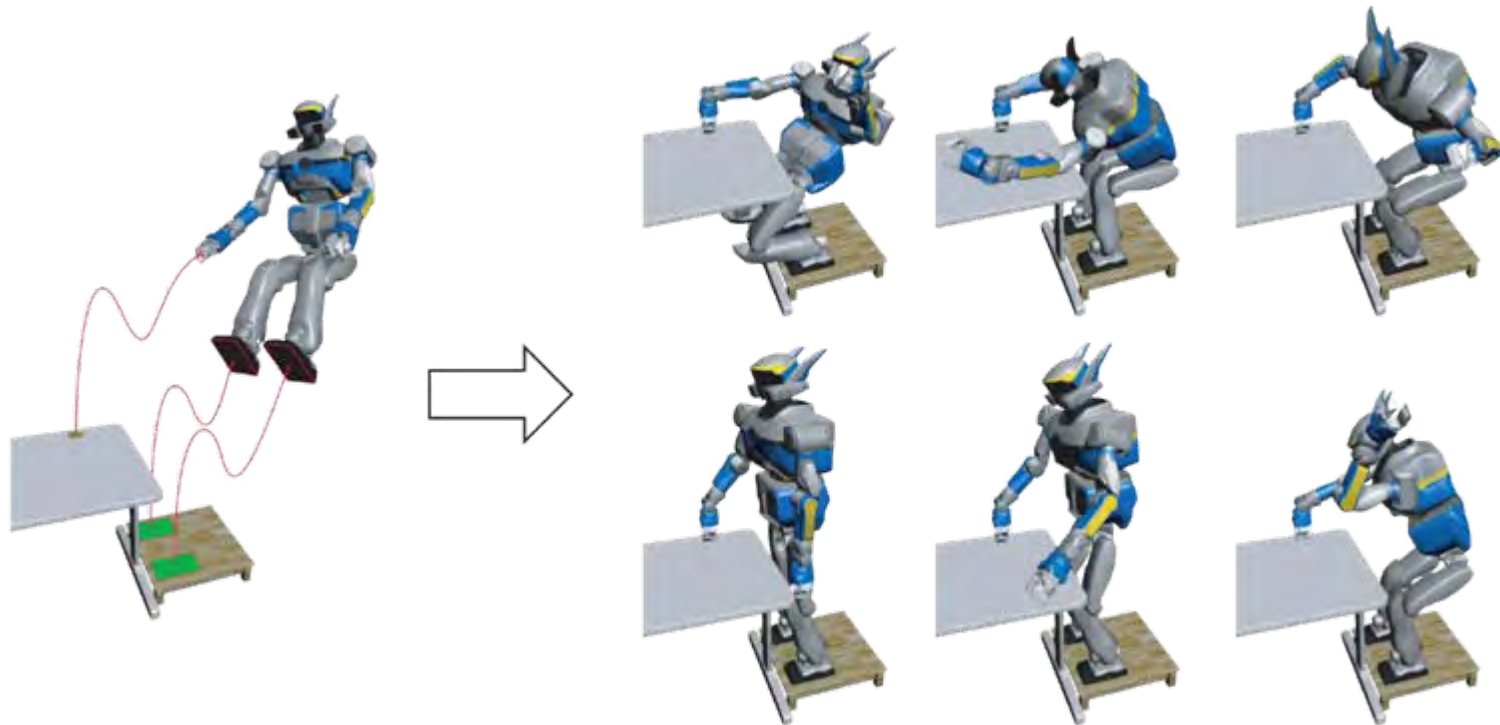
Posture generator: concept



Collision free stable
robot configuration
respecting the contacts
and the joint limitations



Posture Generator: criterion

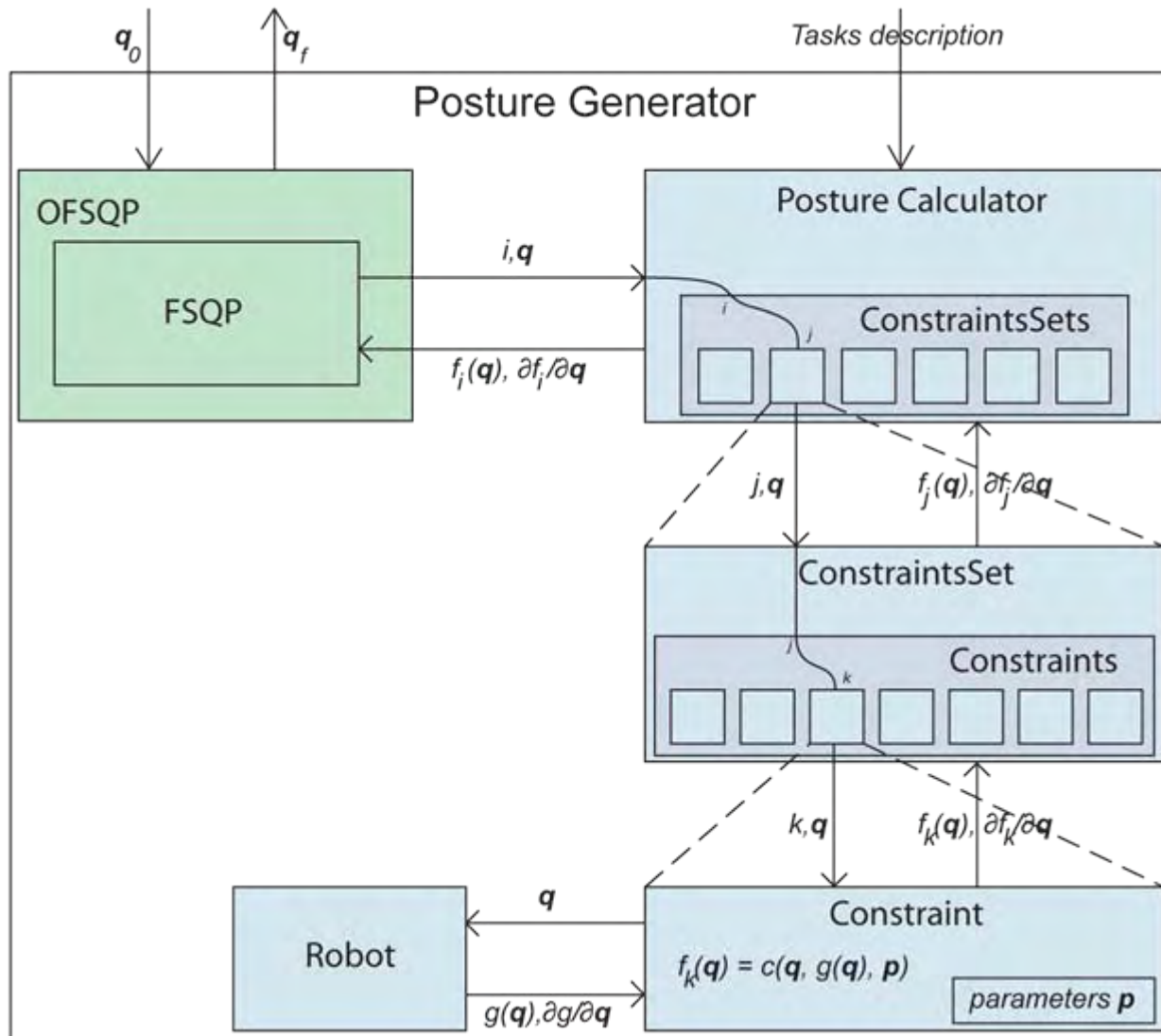


If \mathcal{Q} is non empty it usually contains an infinity of points
 —→ use of a minimization criterion

$$\min_{\mathbf{q}} \text{obj}(\mathbf{q})$$

$$\mathbf{q} \in \mathcal{Q}$$

PG implementation



Tasks in PG

$$\begin{matrix} g_i(\mathbf{q}) = 0 & \forall T_i \\ h_i(\mathbf{q}) \leq 0 & \forall T_i \end{matrix}$$
 can be used in a more general way

to express **tasks** not related to planning

- Orientation of a body
- looking at a target (including a new contact)
- keeping visual features in the field of view
- ...

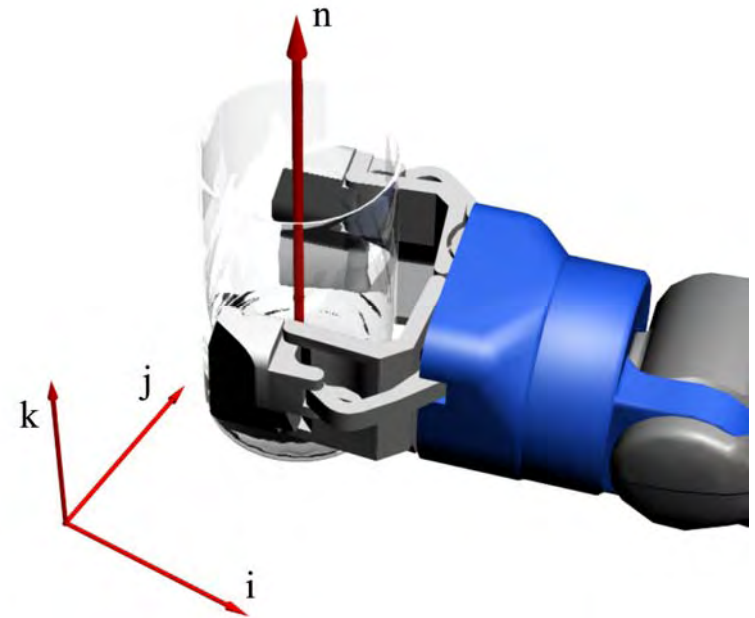
It amounts to restraint \mathcal{Q} to *smaller* sub-manifolds

Example of task

- Carrying a glass vertically

$$\mathcal{T}_{\text{glass}} = \begin{cases} \mathbf{n}(\mathbf{q}) \cdot \mathbf{i} = 0 \\ \mathbf{n}(\mathbf{q}) \cdot \mathbf{j} = 0 \\ -\mathbf{n}(\mathbf{q}) \cdot \mathbf{k} < 0 \end{cases}$$

Idea: having n collinear to k with the same direction



Escande, Kheddar, Miossec, Garsault, ISER, 2008

Escande, Kheddar, IEEE/RSJ IROS 2009

Escande, Kheddar, Chapter 6 in Humanoid Motion Planning, K. Harada, E. Yoshida and K. Yokoi (Eds), Springer, STAR series, pp. 161–180, 2010

Interactive PG



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- Extension of contact planning toward merging manipulation and locomotion



Generalized PG

- Unifies manipulation and locomotion
 - No distinctions
- Unifies objects, robots, agents
 - Only goals are specified
- Functional extensions
 - Bilateral contacts (e.g. grasps)
 - **Deformable bodies**

Bouyarmane, Kheddar, IEEE/RSJ Humanoids, 2010

Bouyarmane, Kheddar, Multi-contact stances planning for multiple agents, IEEE ICRA, 2011 **Session ThA212.3 Room 5H 10:35-10:50**

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Motion generation

- Main ideas
 - MPC on simplified models
 - All variants of Kajita et al.'s PG
 - Operational task-based prioritized control
 - E.g. *Sentis, Park, Khatib, IEEE TRO 2010*
 - E.g. Saab et al. **Session ThA211.5 Room 5F 11:05-11:20**
 - Closed-loop QP-based control
 - Computer Graphics communities (all variants)
 - Whole-dynamic optimization
 - **This talk**
 - Possibly others
 - E.g. learning techniques, etc.

Why motion optimization

- Benefits
 - Minimization of a criteria
 - Same method whatever the motion
 - Easy inclusion of all constraints (actuator limitations, joint limits, stability, collision)
 - Necessary for high performance motions, highly constrained motions
- Drawbacks
 - Off-line (solution: motions database)
 - Does not solve control problem (possibility : stochastic optimization)

Motion optimization problem

- System model

$$u = A(q)\ddot{q} + H(q, \dot{q}) - J(q)^T F_c$$

- General problem

- Look for a motion $q(t)$ or control $u(t)$ t in $[0 \dots t_f]$
- Criteria to minimize $f(q(t), u(t))$
- Constraints to satisfy $c(q(t), u(t)) \leq 0$, t in $[0 \dots t_f]$
- Problem to solve

$$\min_{q(t) \text{ or } u(t)} f(q(t), u(t))$$

$$c(q(t), u(t)) \leq 0$$

How to solve optimization pb?

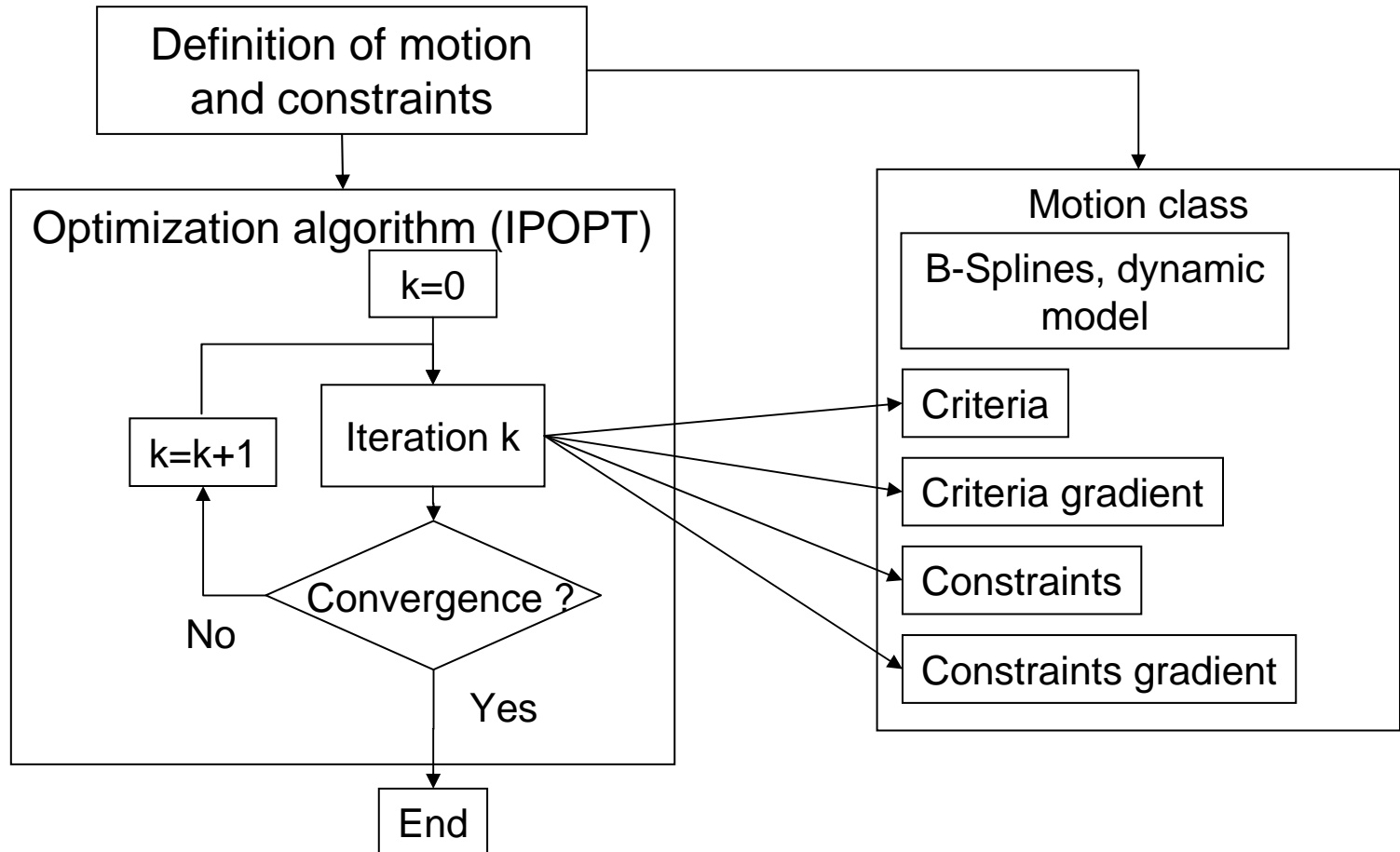
- Solving method (*first implementations*)
 - Discretization
 - Of parameters $q(t) = q(p,t)$ (ex.: B-Splines)
 - Of constraints at times t_i : $c(q(t_i)) \leq 0 \quad i \in [0 \dots N]$
 - System control $u(t)$ computed with inverse dynamic model
 - Problem to solve

$$\min_p f(q(p,t), u(q(p,t)))$$

$$c(q(p,t_i), u(q(p,t_i))) \leq 0 \quad i \in [1 \dots N]$$
 - Resolution with a nonlinear optimization algorithm

Implementation on HRP-2

- General architecture of the program



Optimal Motion Generation

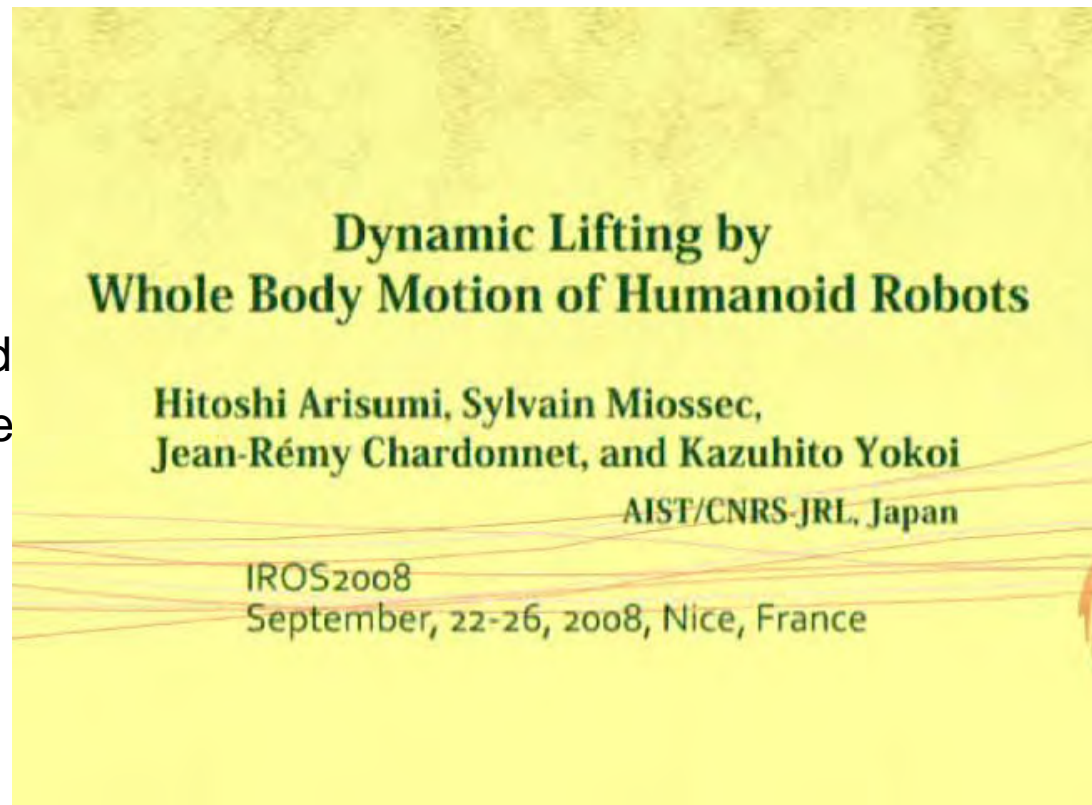
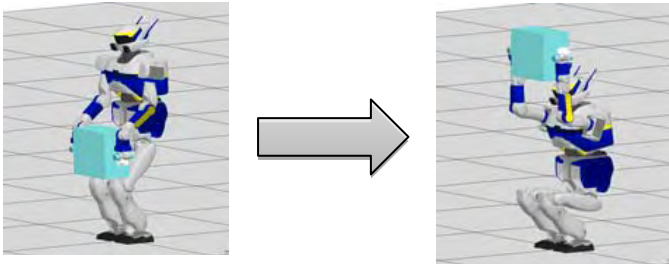
- Optimal motion problematic
 - Minimization of any criteria
 - Energy consumption
 - Time, jerk, etc.
 - Constraints
 - Actuators' torque, max speeds, Joint limits...
 - Collision and Auto-collision
 - Unilateral contact, stability
- Output
 - High performance desired motion with constraint satisfaction
- Tool
 - Development of a software framework
 - A unified constraint definition



Miossec, Yokoi, Kheddar, *Development of software for motion optimization of robots- Application to the kick motion of the HRP-2 robot, IEEE ROBOTICS AND AUTOMATION*, 2006

Extreme tasks

- Dynamic transition from one feasible posture to another under joint torque limitation
- Combining two different motions
 - accelerating an object upward
 - sliding the body into under the object



Arisumi, Chardonnet, Kheddar, Yokoi, **IEEE ICRA07**

Arisumi et al., **IEEE/RSJ IROS08**

Problem

■ Theoretical

- Difficult to find a compromise between the number of trajectory control points (optimization variables) and sampling time
- Difficult to keep a uniformed sampling when the final time is an optimization variable
- No guarantee of constraints satisfaction between time samples
 - Optimization using interval analysis (*Lengagne et al.*)
 - Guarantee of constraint satisfaction
 - Computationally heavy

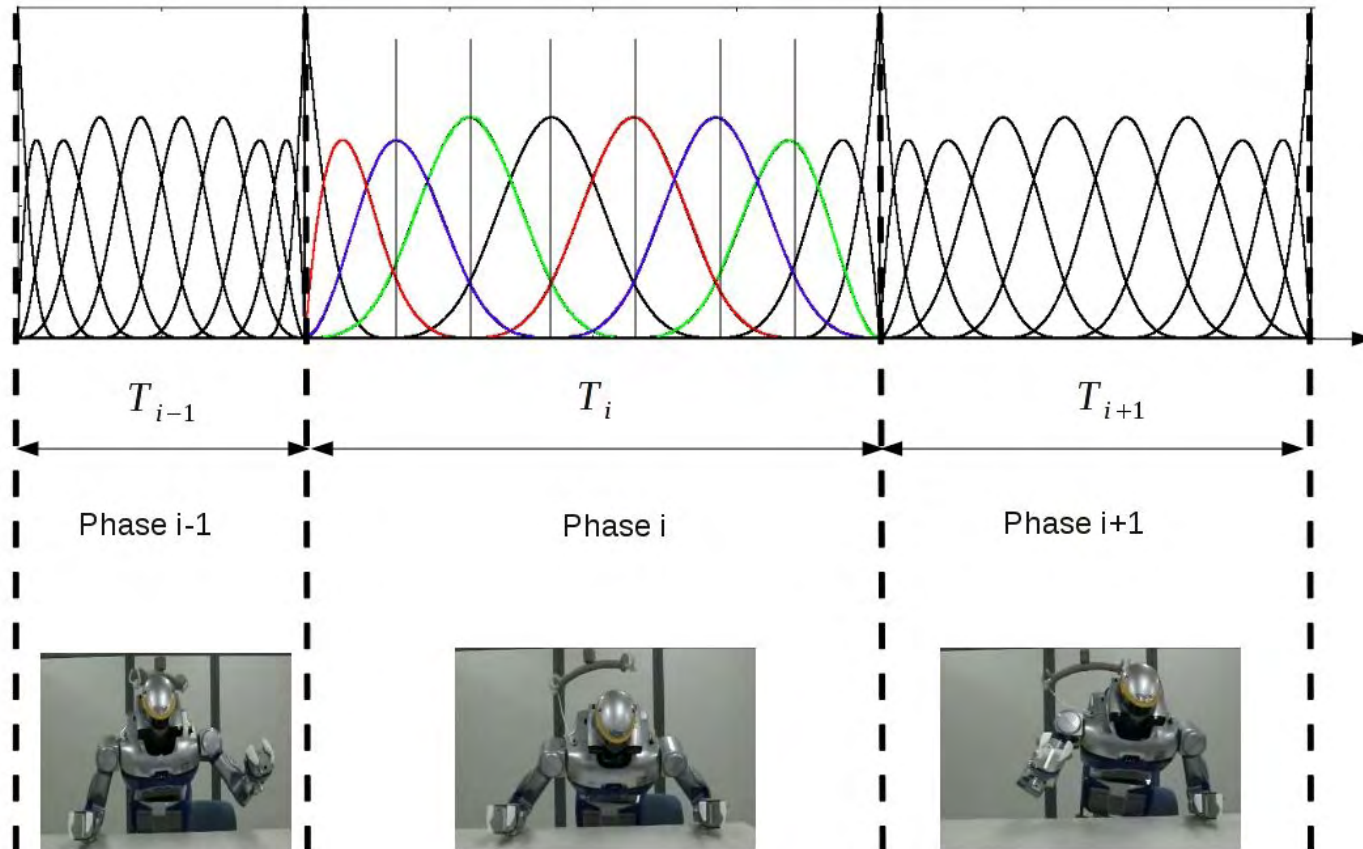
Multi-contact optimization

- Whole-body model (incl. dynamics)
- Motion local planning
- Play trajectories in pseudo-closed-loop



- ... if the solutions fits within critical time
 - Use in closed-loop scheme

Latest approach



Lengagne, Mathieu, Kheddar, Yoshida, **HUMANOIDS**, 2010
 Lengagne, Mathieu, Kheddar, Yoshida, **IROS**, 2010

Video: HRP-2

CNRS-AIST JRL (Joint Robotics Laboratory), UMI3218,CRT

Generation of Dynamic Multi-Contact Motions (Kicking, stepping, sitting and walking motions)

Sébastien Lengagne
Abderrahmane Kheddar
Eiichi Yoshida



Reported by the **NEW SCIENTIST** and
REUTERS Press Agency

Other videos: HRP-2

CNRS-AIST JRL (Joint Robotics Laboratory), UMI3218,CRT

Improving Optimization Performances For Multi-Contact Motion Generations

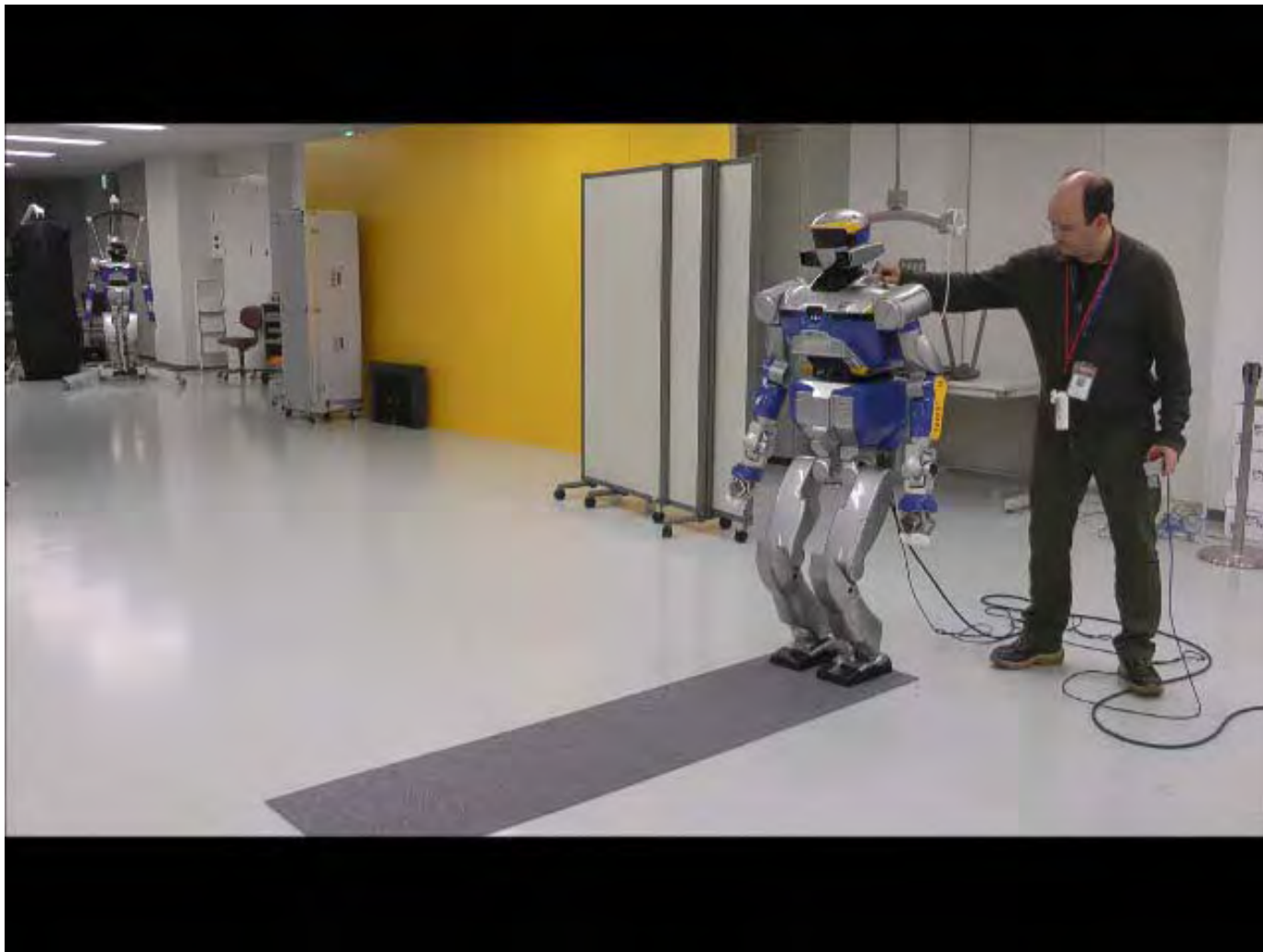
- 1- putting away motion
- 2-throwing motion
- 3- walking on a platform motion
- 4- effects of the choc absorber



Sébastien Lengagne
Abderrahmane Kheddar
Eiichi Yoshida



HRP-2 as a physical manikin



What else?

- Impact
- Multi-contact stabilizer
- Collision avoidance
- **Faster solvers**
- Flexibility of the ankle



Conclusion

- Some further extensions
 - Complex deformable environments
 - Sliding contacts
 - Taking support on movable objects (difficult)
 - Taking into account uncertainties (very difficult)
 - Haptic cover (close the loop)

