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# Planning Humanoid Multi-Contact Dynamic Motion using Optimization Techniques

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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

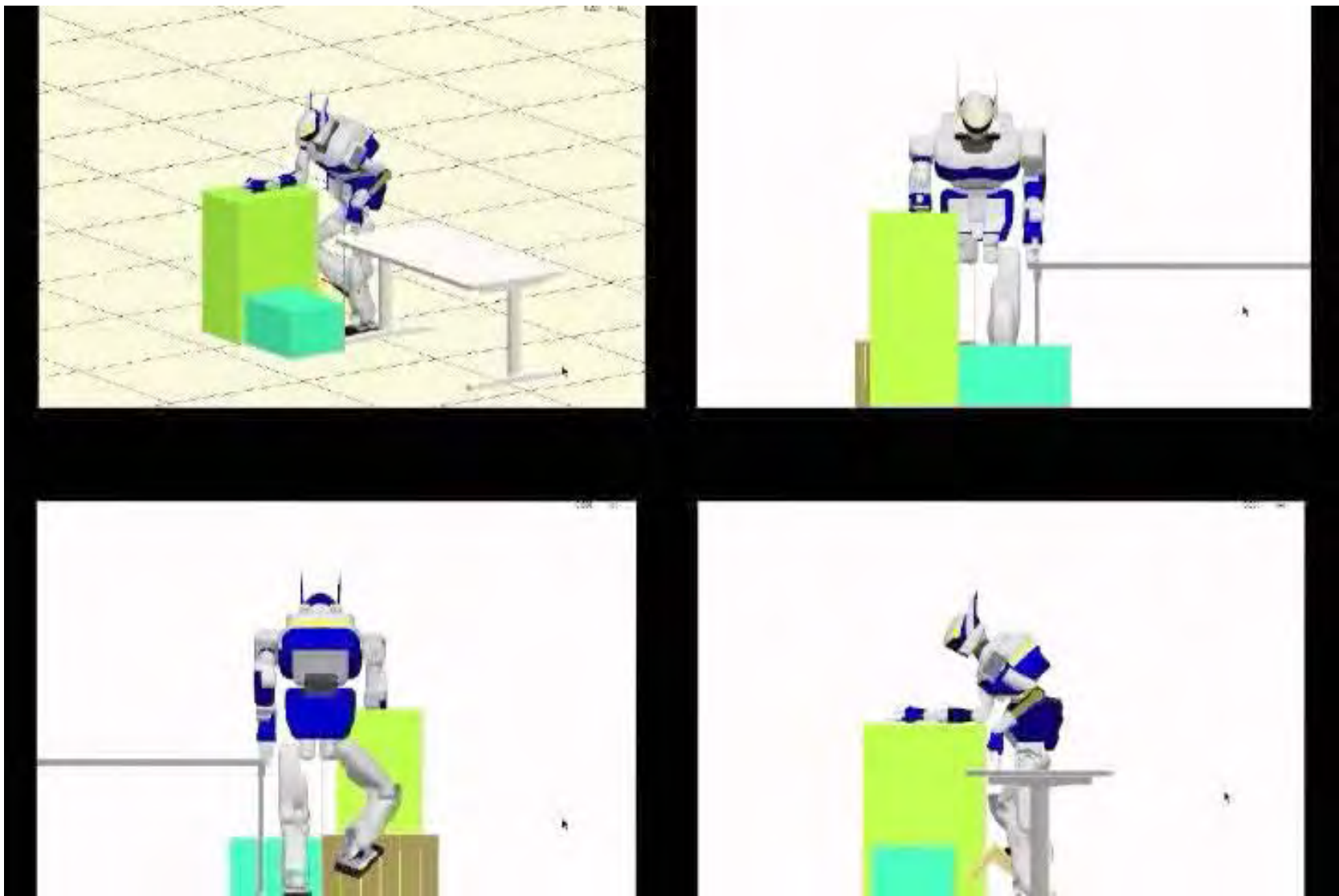
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# Example



*Escande, Kheddar, Miossec IEEE/RSJ IROS 2006*

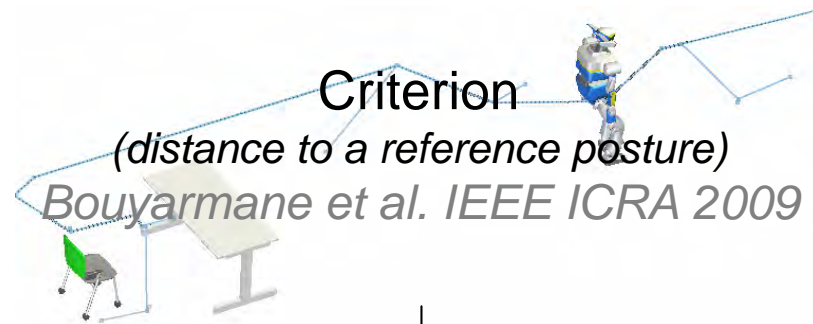
# Cumbersome environments



# Contact Planning for Acyclic Motion with Tasks Constraints



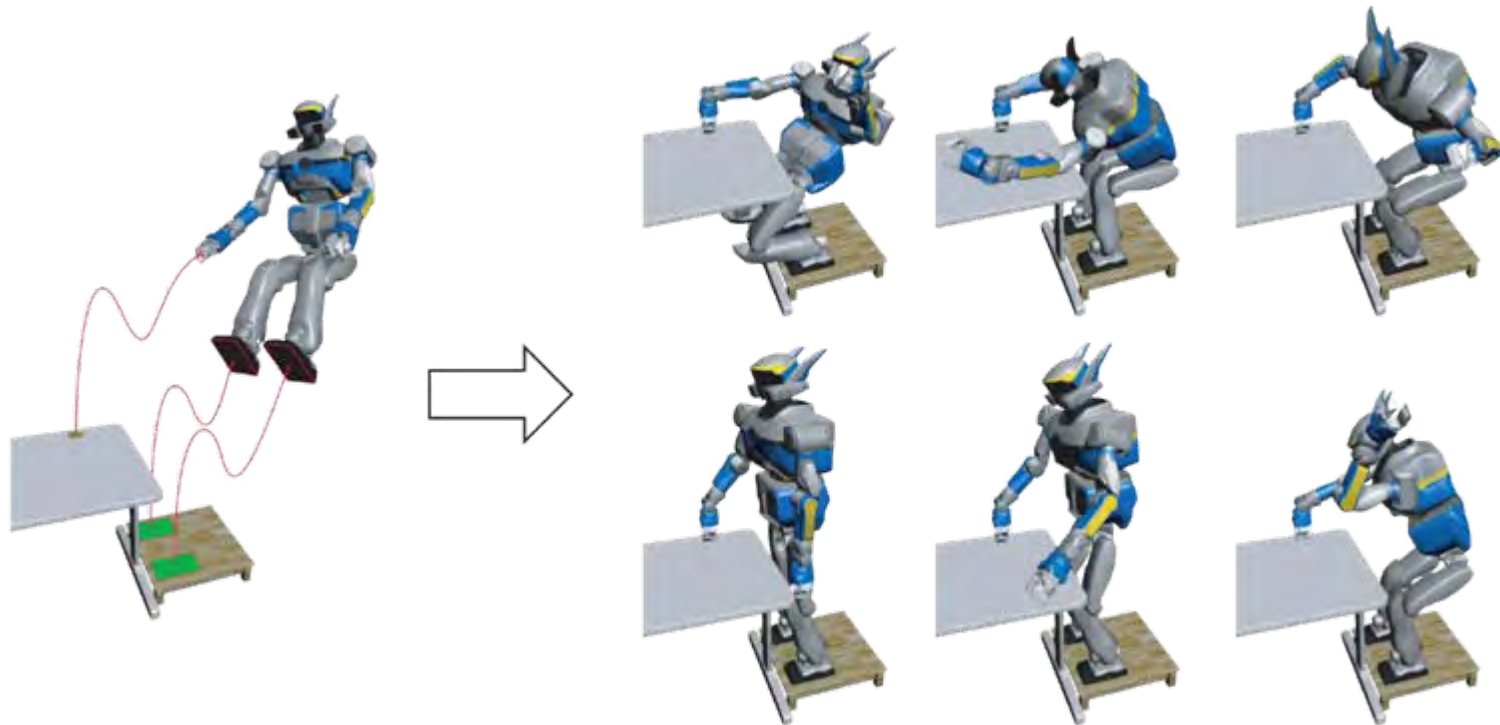
# Posture generator: concept



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



# Posture Generator: criterion

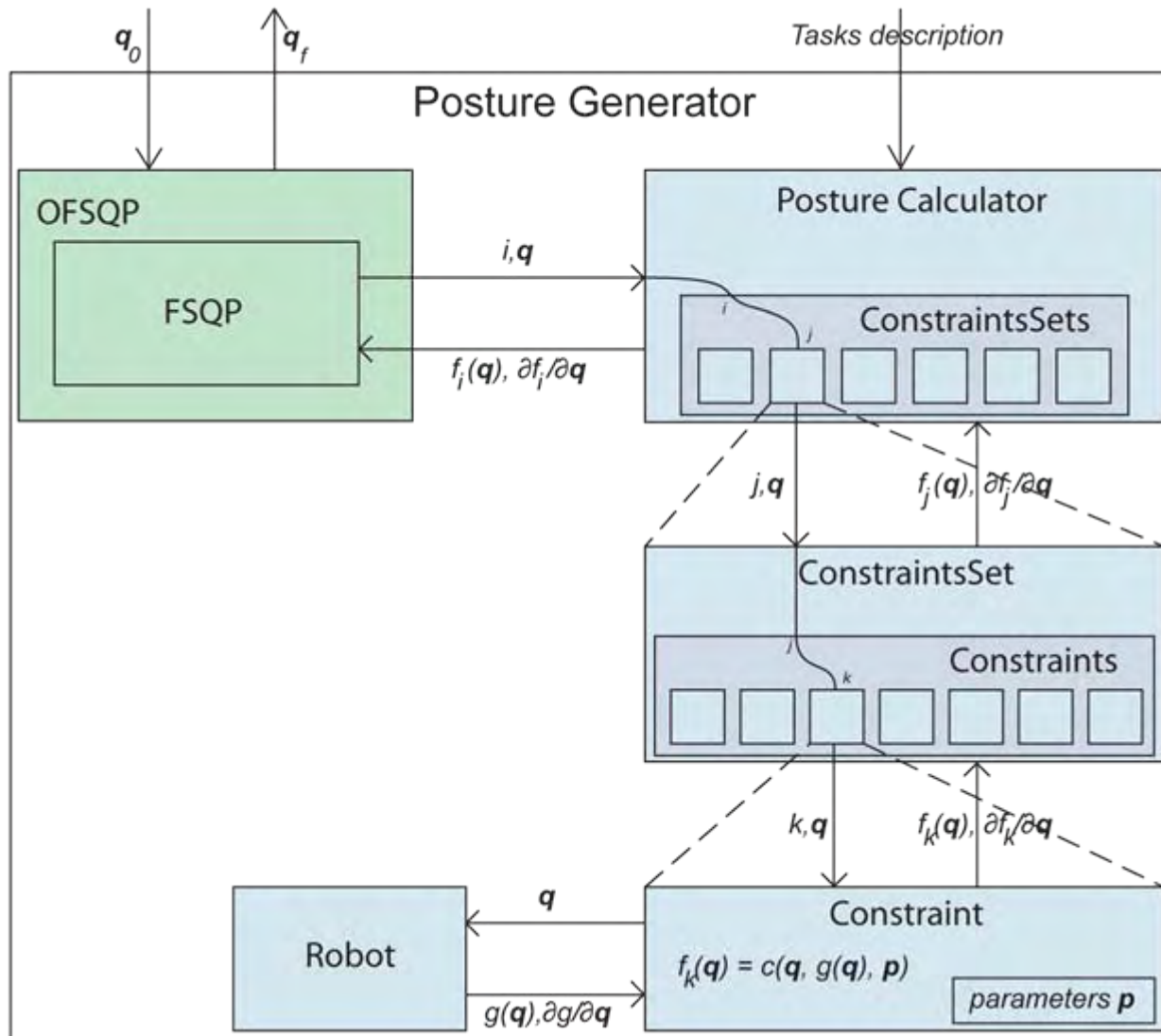


If  $\mathcal{Q}$  is non empty it usually contains an infinity of points  
 —→ use of a minimization criterion

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

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

# PG implementation



# Tasks in PG

$$\begin{array}{l} g_i(\mathbf{q}) = 0 \quad \forall T_i \\ h_i(\mathbf{q}) \leq 0 \quad \forall T_i \end{array}$$
 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
- ...

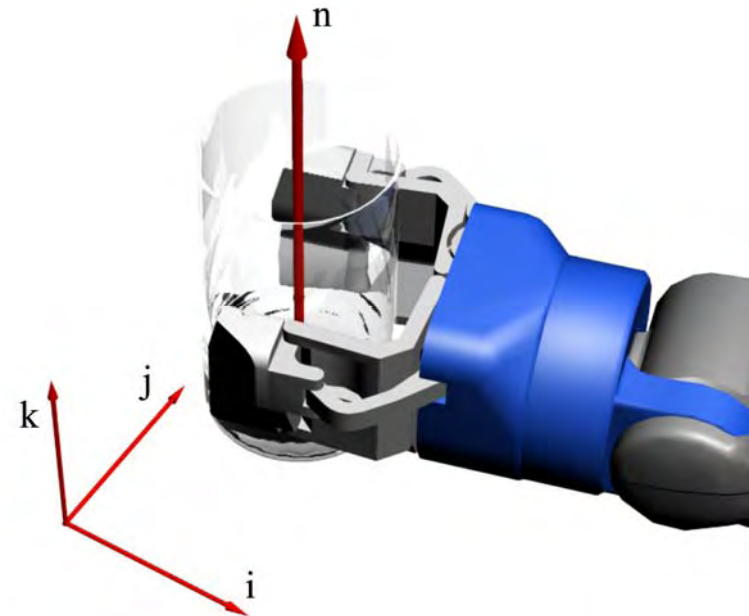
It amounts to restraint  $\mathcal{Q}$  to *smaller* sub-manifolds

# 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*

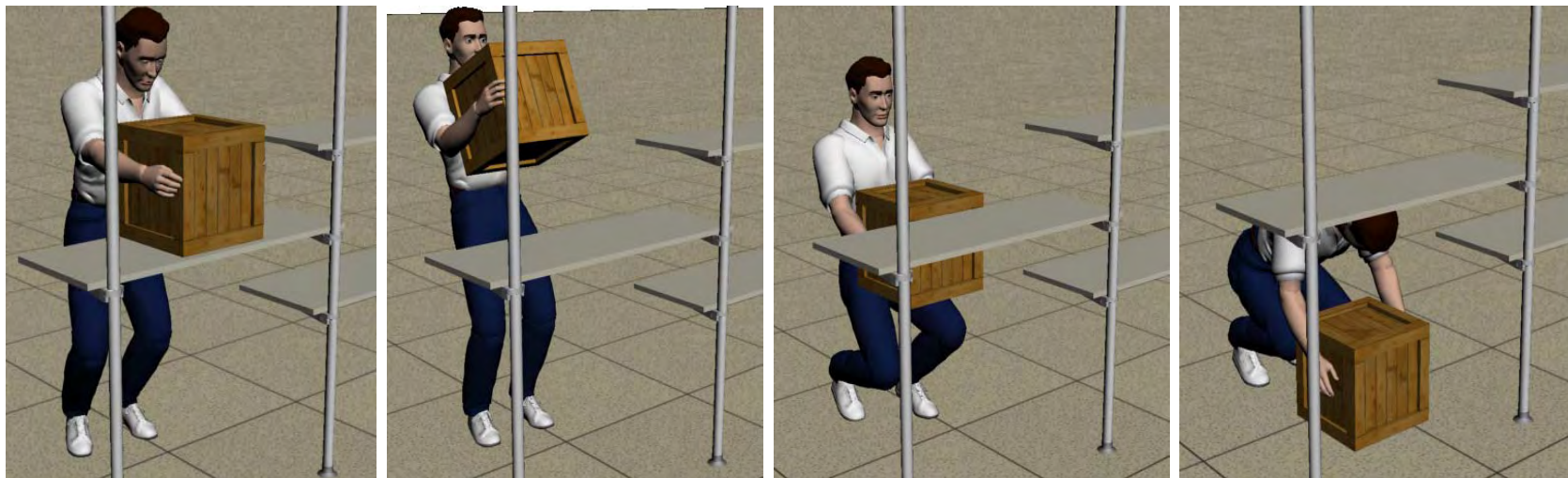
# Interactive PG



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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**

# Summary

- Contact support planner
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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

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

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

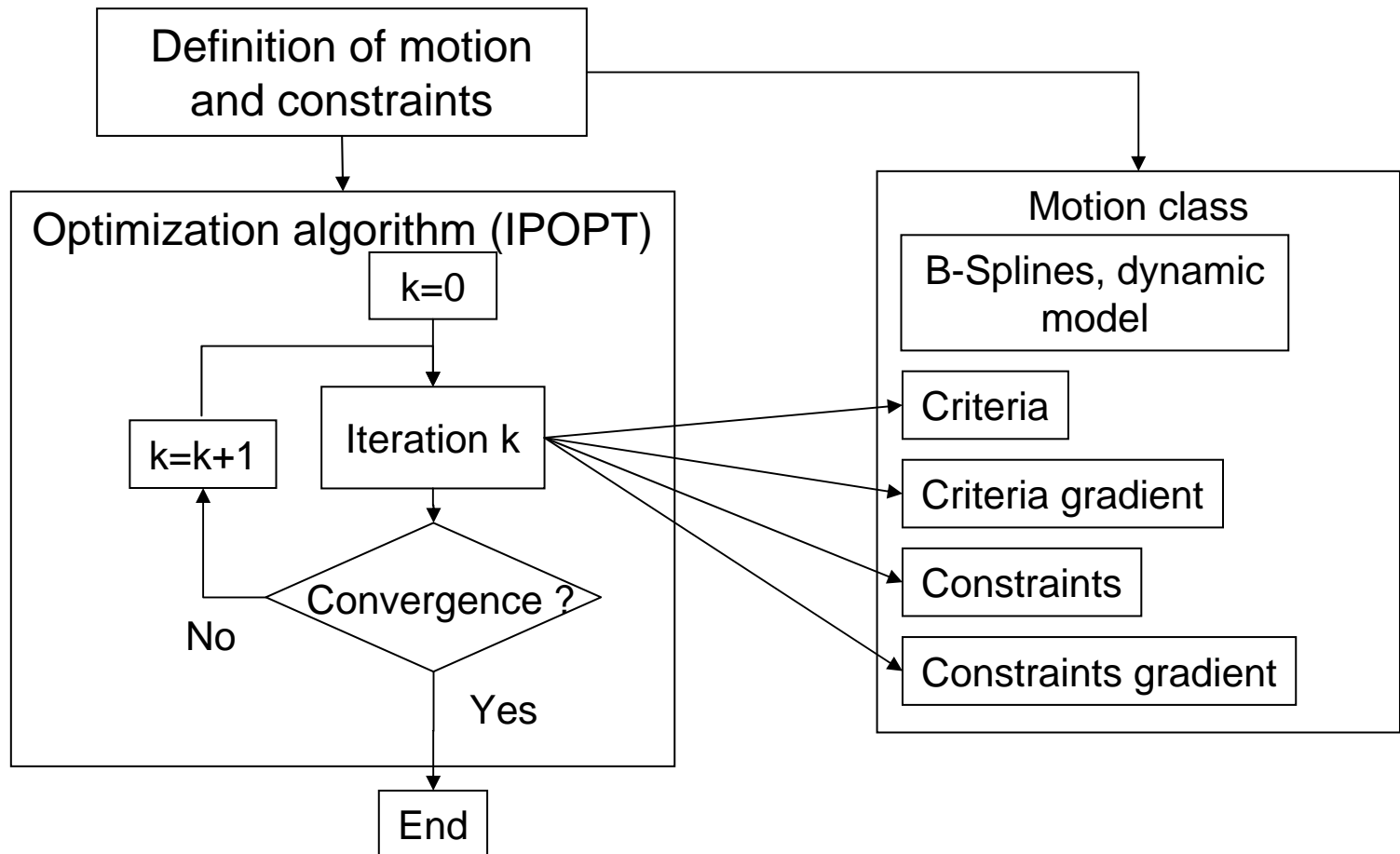
# How to solve optimization pb?

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

$$c(q(p,t_i), u(q(p,t_i))) \leq 0 \quad i \in [1...N]$$
  - 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

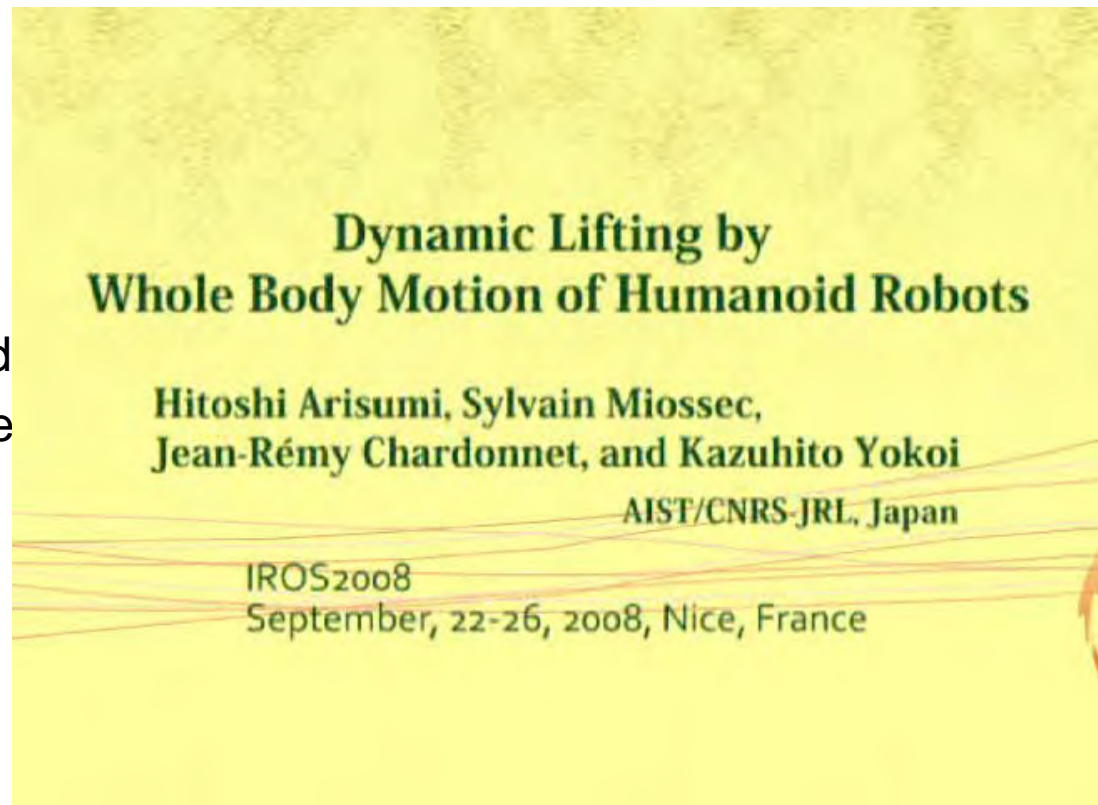
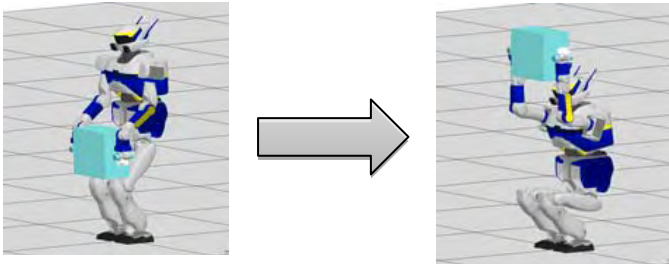


Miossec, Yokoi, Kheddar, *Development of software for motion optimization of robots- Application to the kick motion of the HRP-2 robot, IEEE ROBOTICS AND AUTOMATION, 2006*



# 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

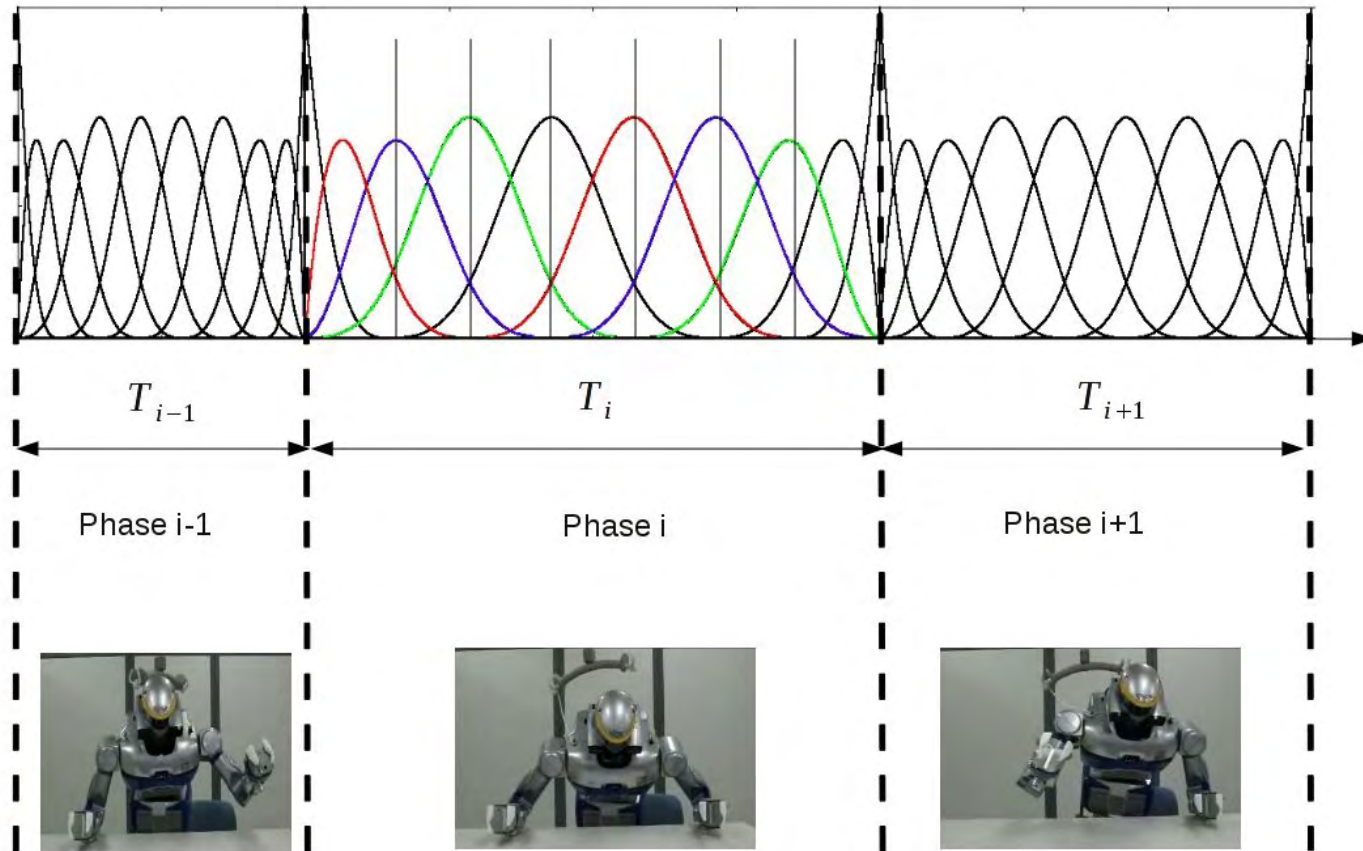
# Multi-contact optimization

- 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)

