Planning Humanoid Multi-Contact Dynamic Motion using Optimization Techniques

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with

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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

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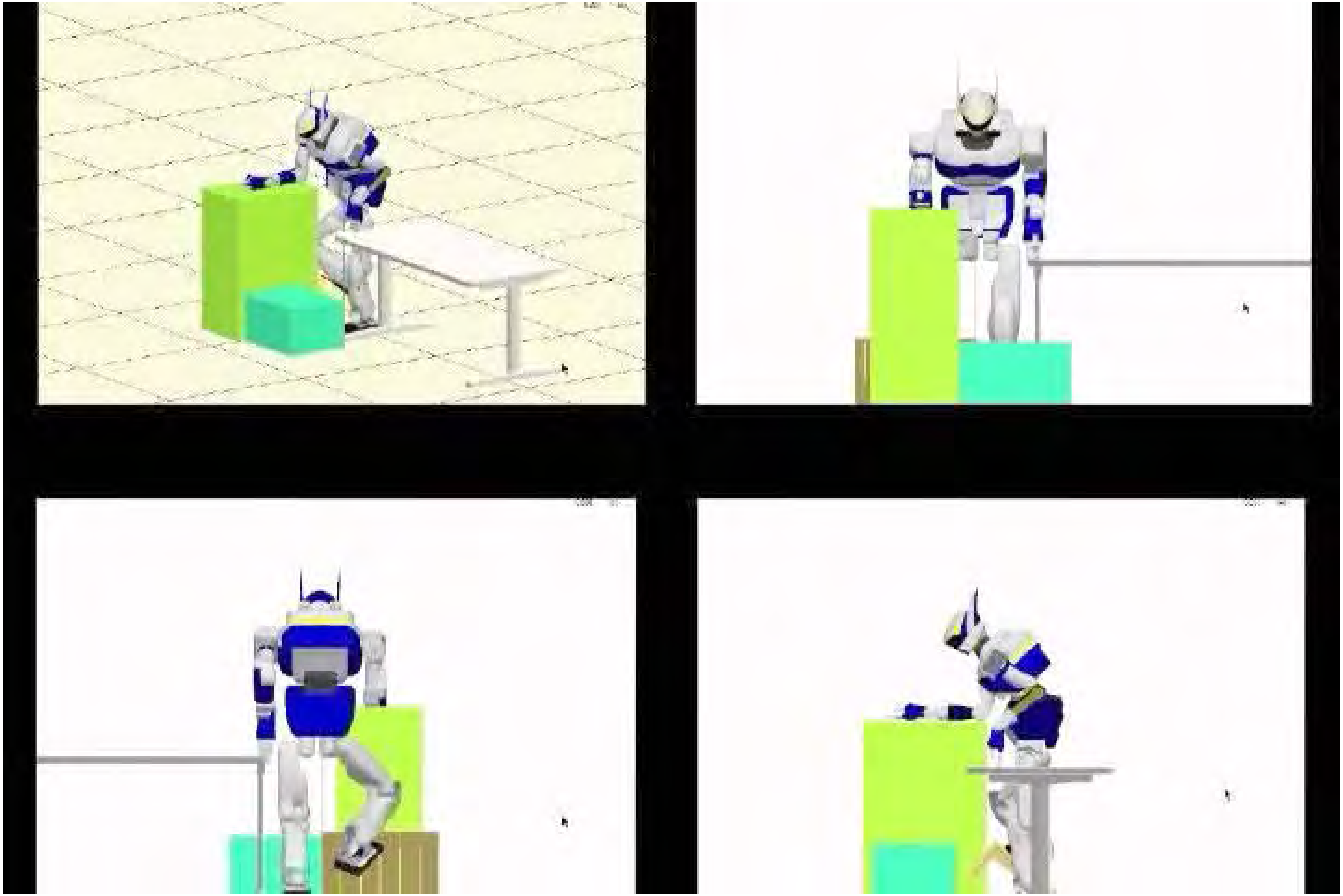
Example

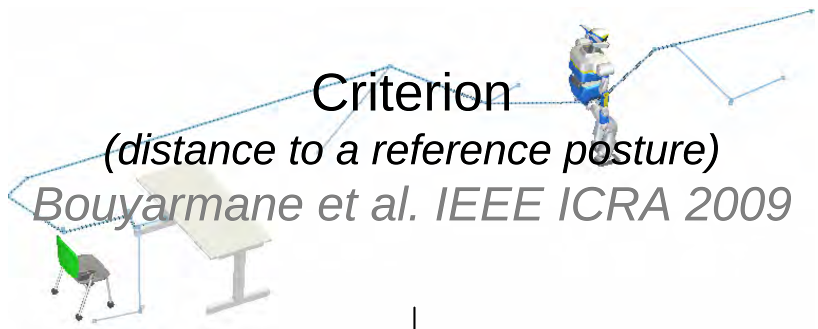
Escande, Kheddar, Miossec IEEE/RSJ IROS 2006

Cumbersome environments



Escande, Kheddar, Miossec IEEE/RSJ IROS 2009 (video session)

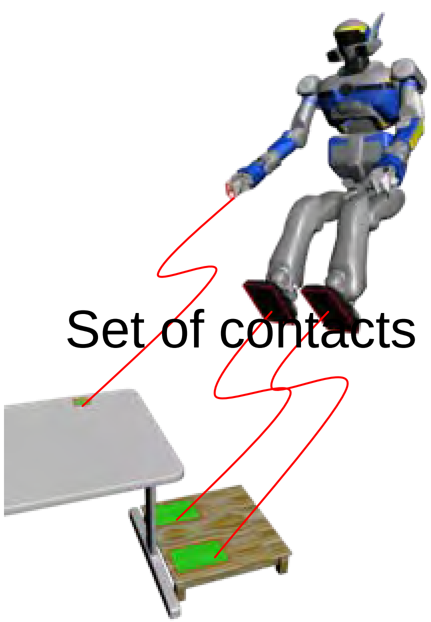
Posture generator: concept



Criterion

(distance to a reference posture)

Bouyarmane et al. IEEE ICRA 2009

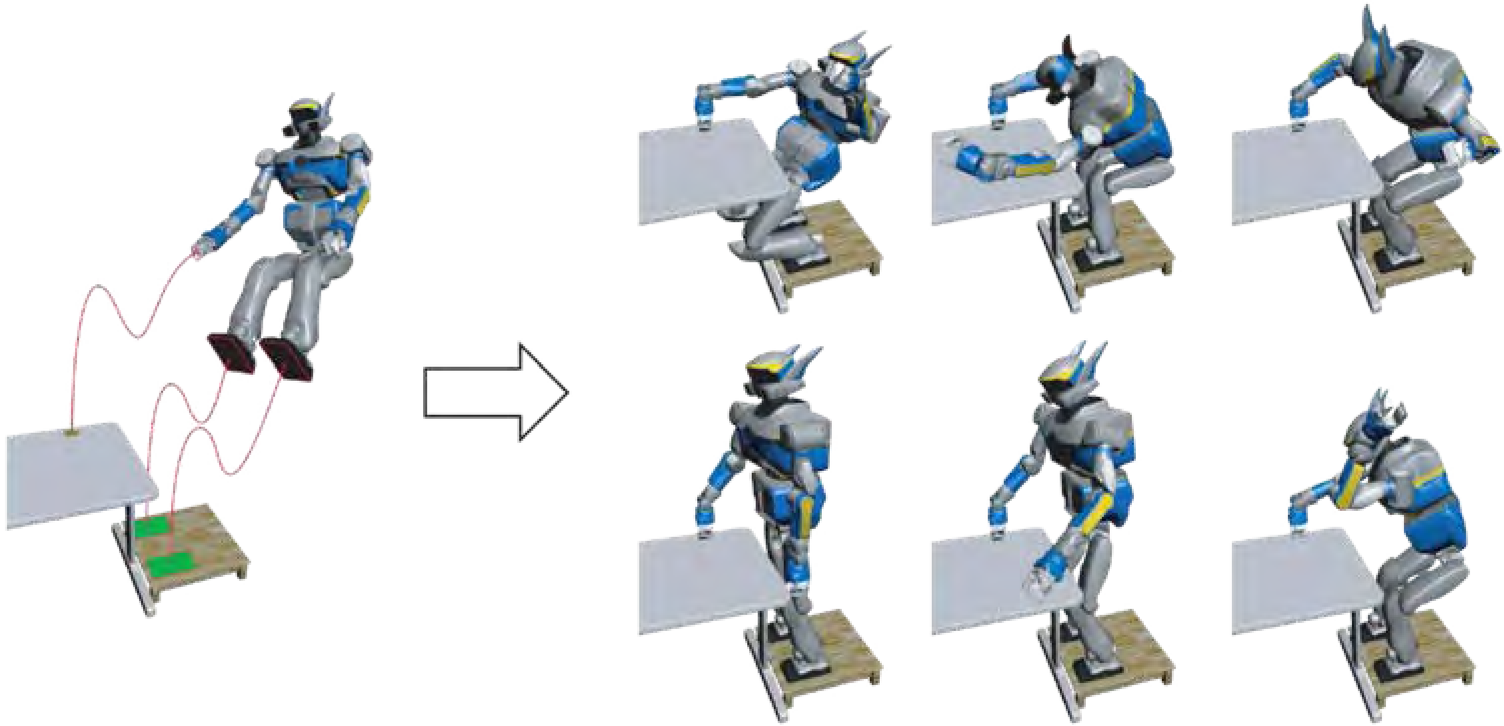


Set of contacts

PG

Collisi e stable
robot co guration
res the contacts
an t limitations

Posture Generator: criterion



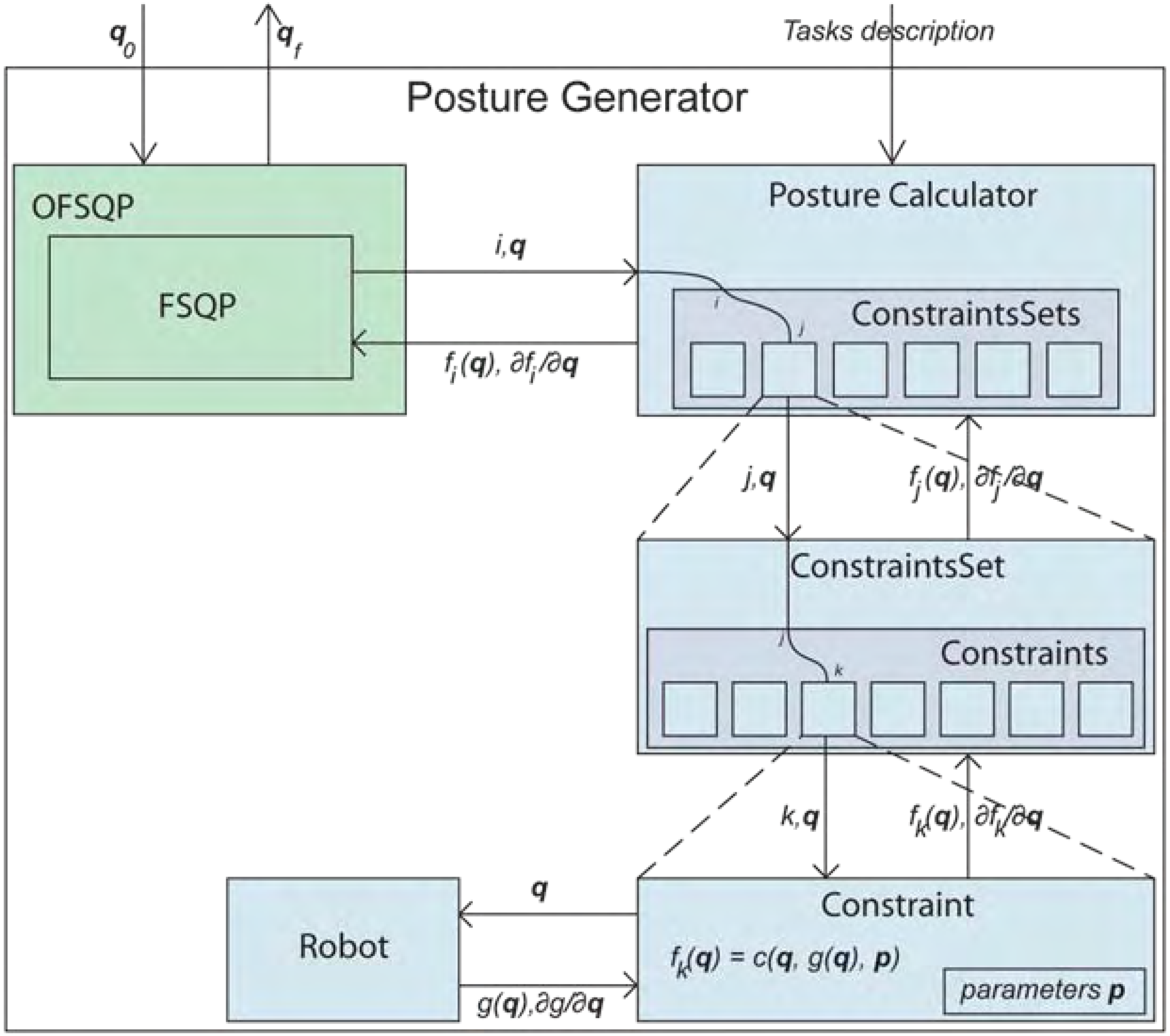
If $\mathcal{Q}$ is non empty it usually contains an infinity of points

$\longrightarrow$ use of a minimization criterion

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

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

PG implementation



Tasks in PG

$$\boxed{\begin{array}{ll} g_i(\mathbf{q}) = 0 & \forall\, T_i \\ h_i(\mathbf{q}) \leq 0 & \forall\, T_i \end{array}}$$

can be used in a more general way

to express ***tasks*** not related to planning

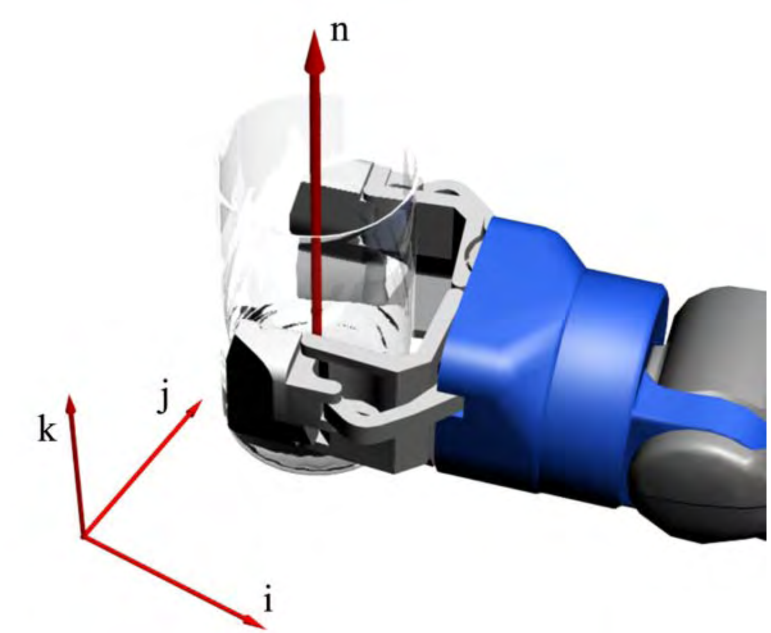
- Orientation of a body
- looking at a target (including a new contact)
- keeping visual features in the field of view
- …

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

Example of task

- Carrying a glass vertically

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



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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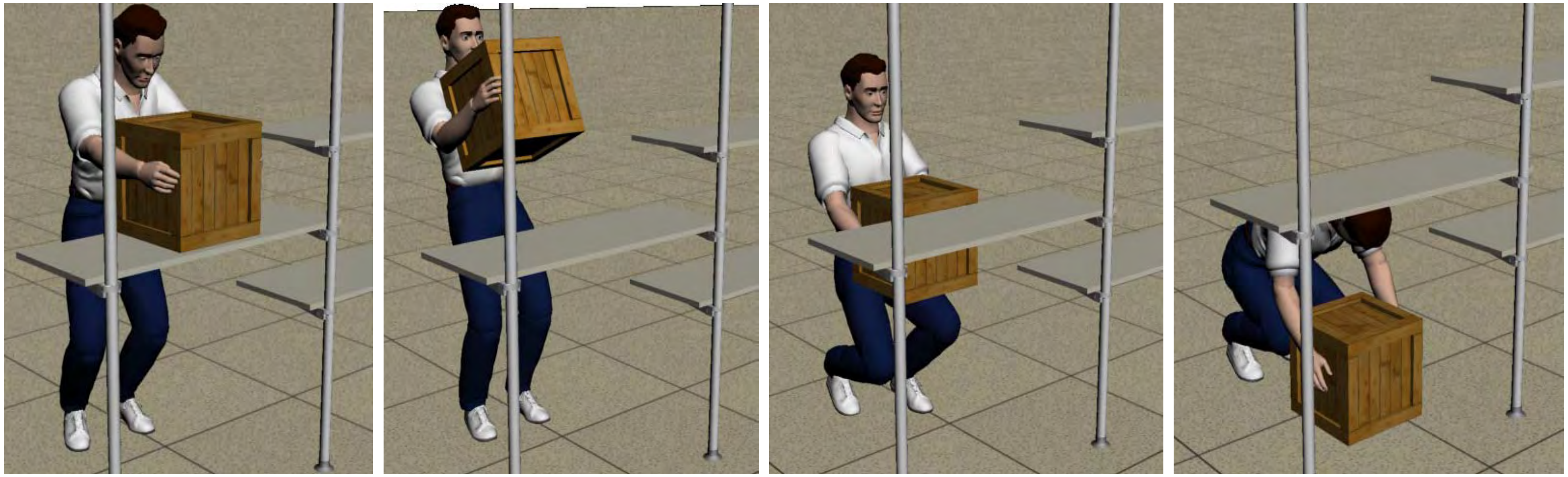
- Extension of contact planning toward merging manipulation and locomotion



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…t_f]
  - Criteria to minimize f(q(t),u(t))
  - Constraints to satisfy c(q(t),u(t))</=0. t in [0…t_f]
  - Problem to solve

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

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

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: $c(q(t_i)) \leq 0$ i $\in$ [0…N]
  - System control *u*(*t*) computed with inverse dynamic model
  - Problem to solve

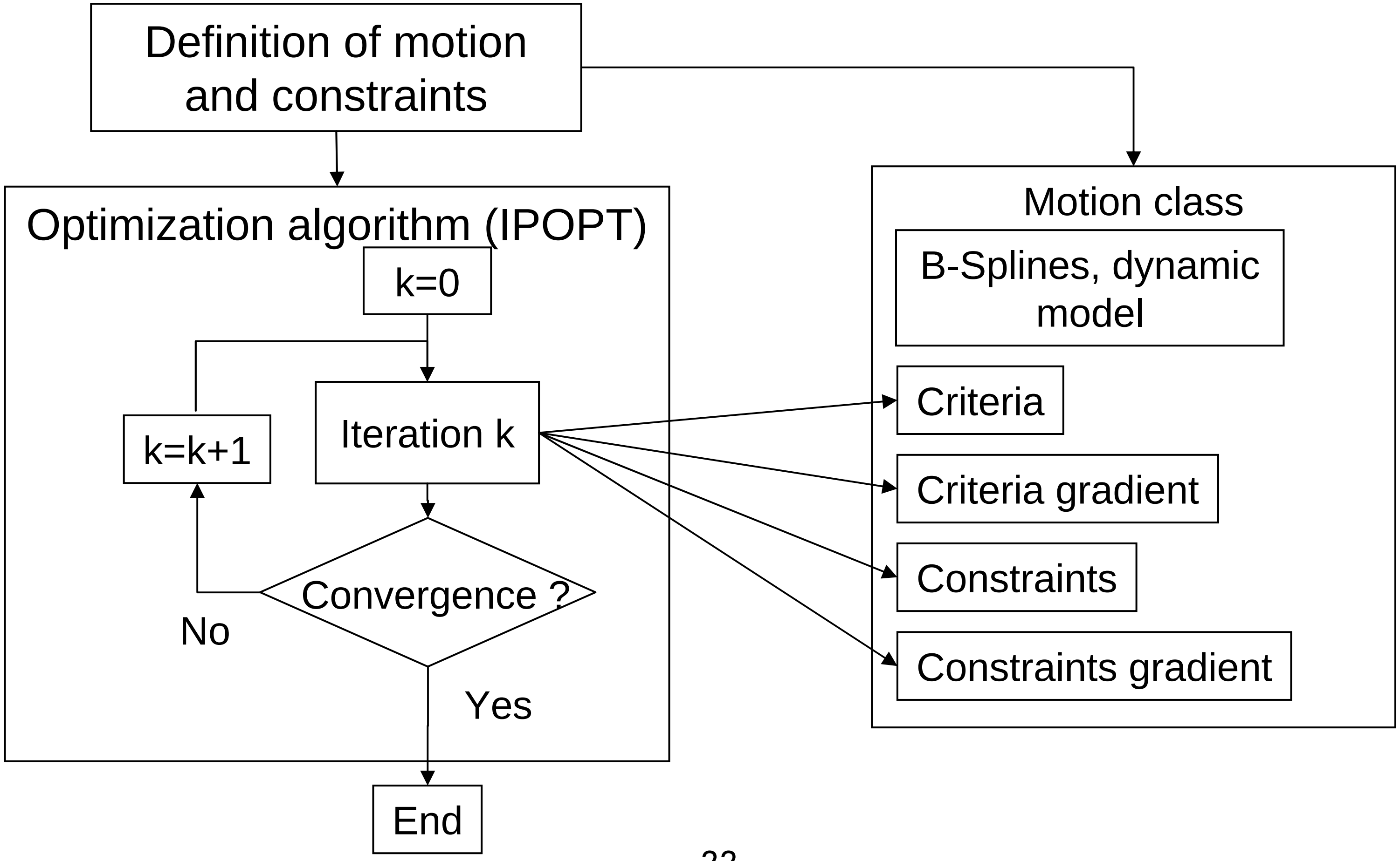
$$\min_{p} f\left(q(p,t), u\left(q(p,t)\right)\right)$$

$$c\left(q(p,t_i), u\left(q(p,t_i)\right)\right) \leq 0 \quad i \in [1 \ldots N]$$

  - Resolution with a nonlinear optimization algorithm

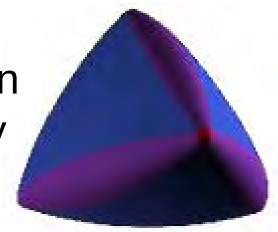
Implementation on HRP-2

- General architecture of the program



Optimal Motion Generation

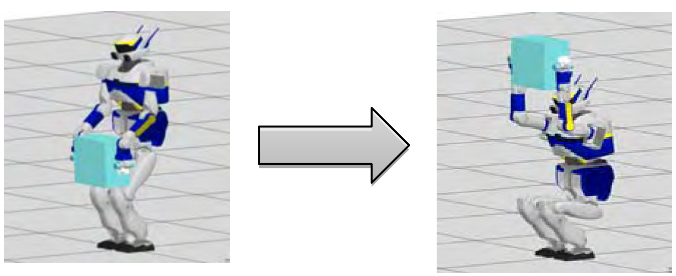
- Optimal motion problematic
  - Minimization of any criteria
    - Energy consumption
    - Time, jerk, etc.
  - Constraints
    - Actuators' torque, max speeds, Joint limits…
    - Collision and Auto-collision
    - Unilateral contact, stability
- Output
  - High performance desired motion with constraint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

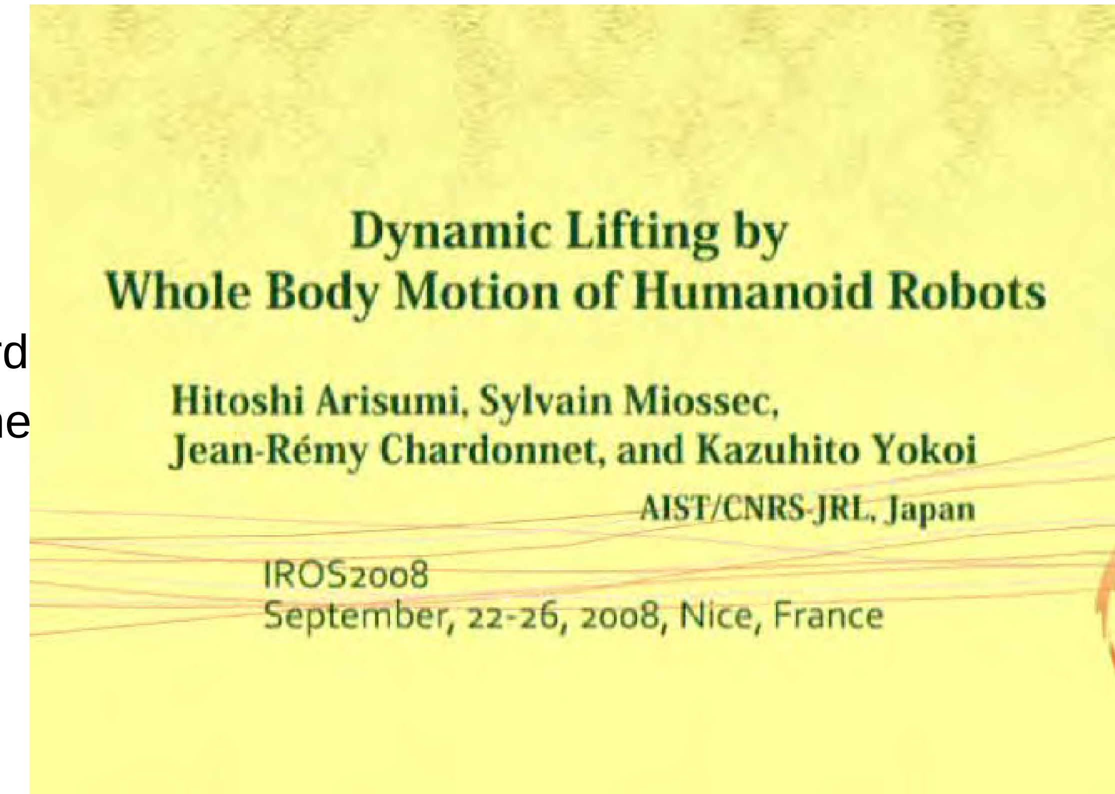


Miossec, Yokoi, Kheddar, *Development of software for motion optimization of robots- Application to the kick motion of the HRP-2 robot*, **IEEE ROBIO**, 2006

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 ICRA**07
Arisumi et al., **IEEE/RSJ IROS**08

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

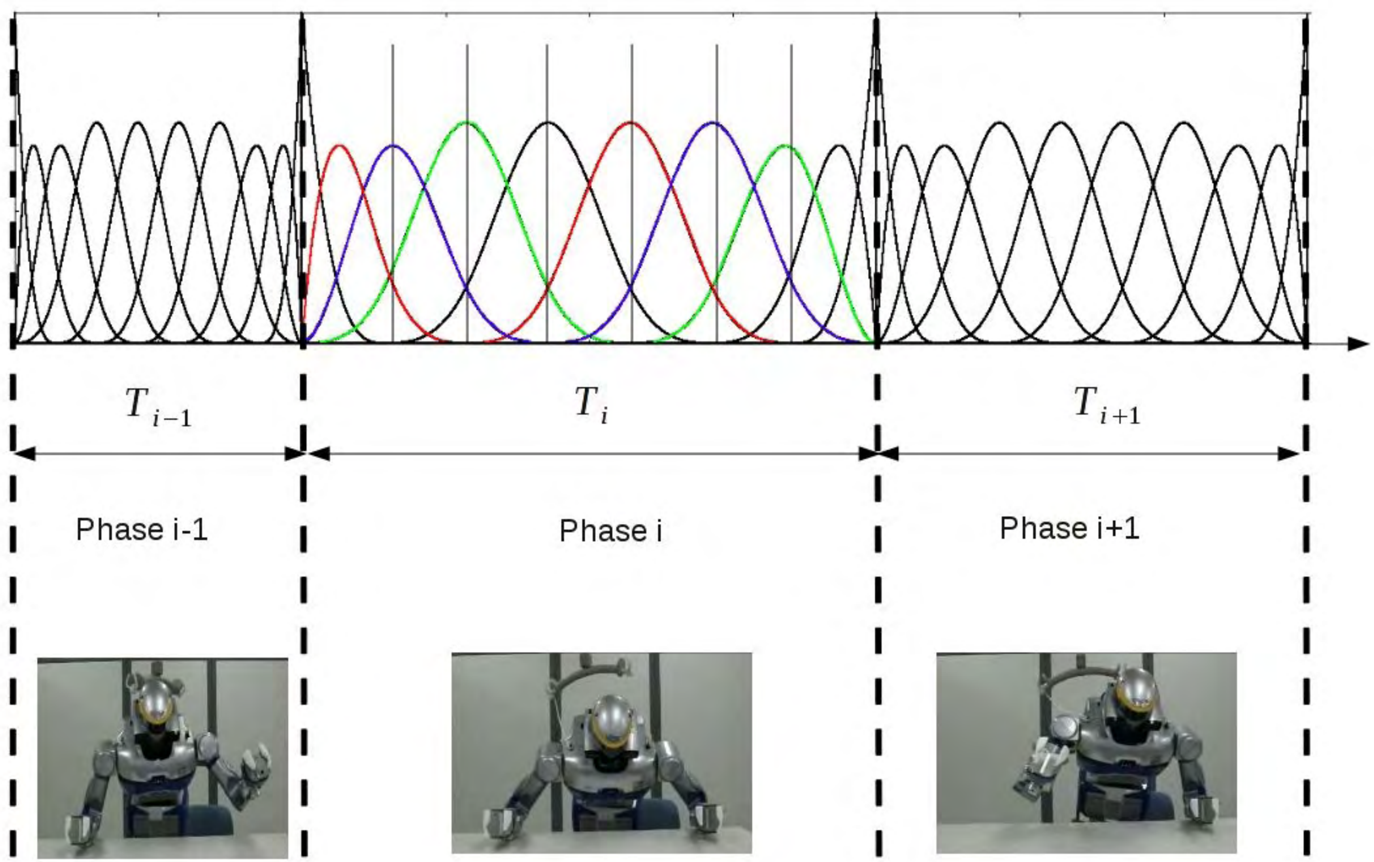
Multi-contact optimization

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

Contact sets → **Optimization** → Dynamic motion

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

Latest approach

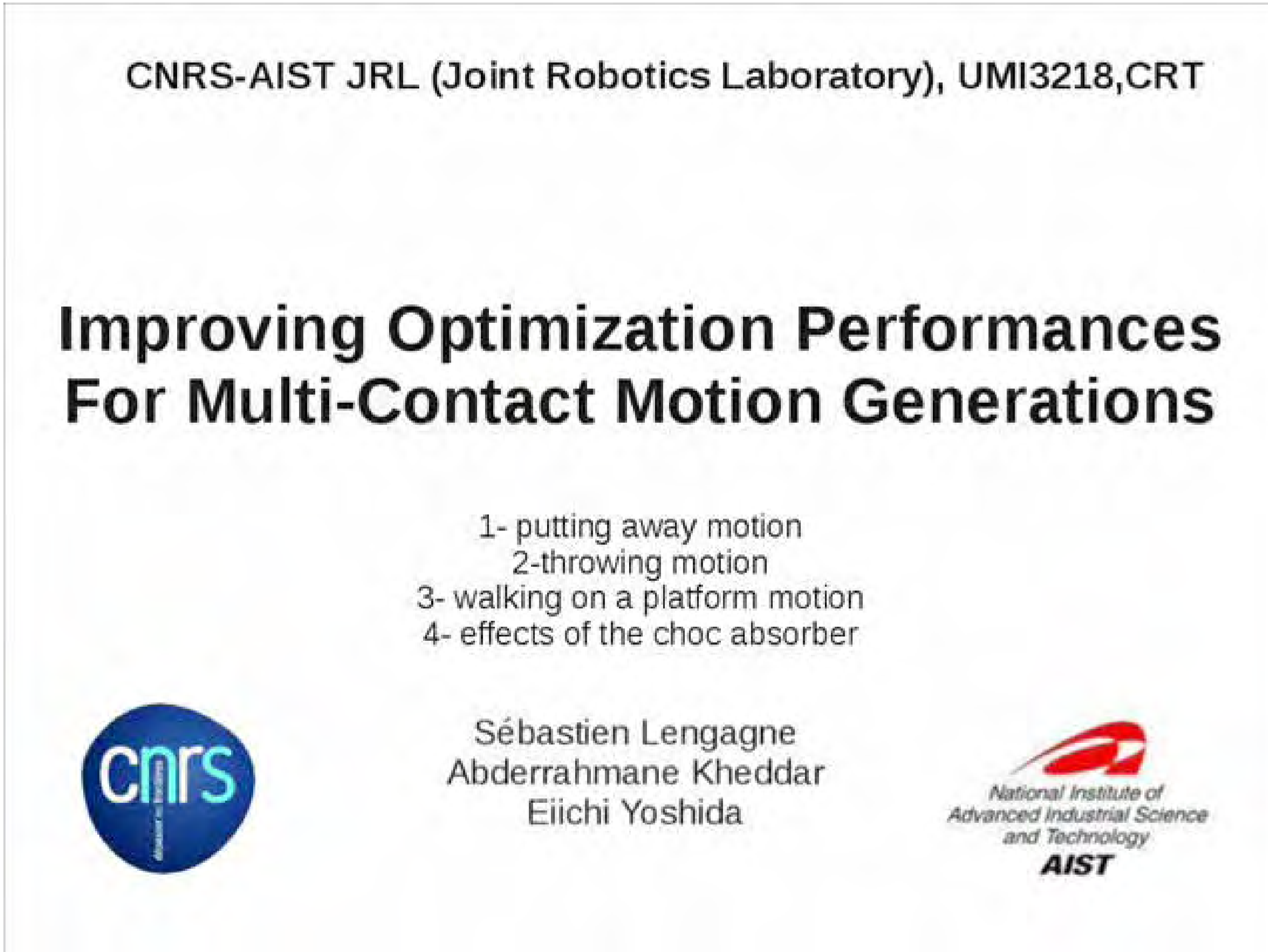


*Lengagne, Mathieu, Kheddar, Yoshida, **HUMANOIDS**, 2010*
*Lengagne, Mathieu, Kheddar, Yoshida, **IROS**, 2010*

Video: HRP-2

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

Other videos: HRP-2



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)