Learning and Generalization of Motor Skills by Learning from Demonstration

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ICRA, 2009

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Outline

- Motivation
- Background
- Methodology
- Experiments and results
- Conclusion

Motivation

Complex movements are composed of sets of *primitive* action

- executed in *sequence* and / or in *parallel*

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DMPs are mathematical formalization of these *primitives*.

- each DMP is a nonlinear dynamical system

Motivation

Goal:

- represent complex motor actions
- flexibly adjusted
- without manual parameter tuning

Idea: take a dynamical system with well specified, stable behaviour and <u>add another term</u> that makes it follow some desired path / trajectory.

Background

DMP for motion control originates from Stefan Schaal's lab (USC).

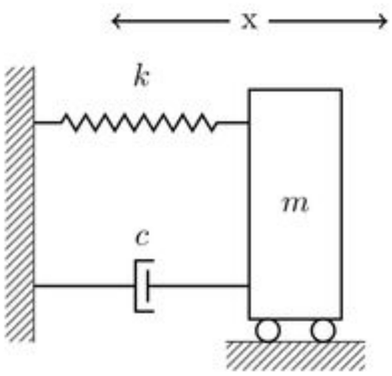
- *Stefan Schaal, Dynamic Movement Primitives–A Framework for Motor Control in Humans and Humanoid Robotics, 2002*

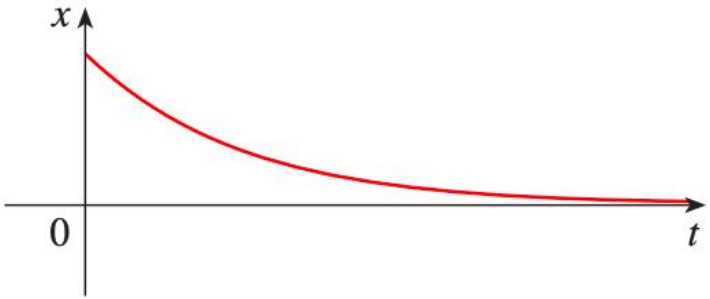
- *[Ref 5] A. J. Ijspeert, J. Nakanishi, and S. Schaal, "Movement Imitation with Nonlinear Dynamical Systems in Humanoid Robots," in Proceedings of the IEEE International Conference on Robotics and Automation, 2002.*

Background

Linear Spring systems with damping

$$m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = 0$$





Background: DMP

Transformation system:

$$\begin{aligned} \tau\dot{v} &= K(g-x) - Dv + (g-x_0)\,f \\ \tau\dot{x} &= v \ , \end{aligned}$$

x : position, v: velocity, K: spring constant, D: damping term, τ: temporal scaling factor

Additional nonlinear system used to define the forcing function, f.

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Additional nonlinear system used to define the forcing function, f.

$$f(s) = \frac{\sum_i w_i \psi_i(s) s}{\sum_i \psi_i(s)} \qquad \psi_i(s) = \exp(-h_i(s-c_i)^2)$$

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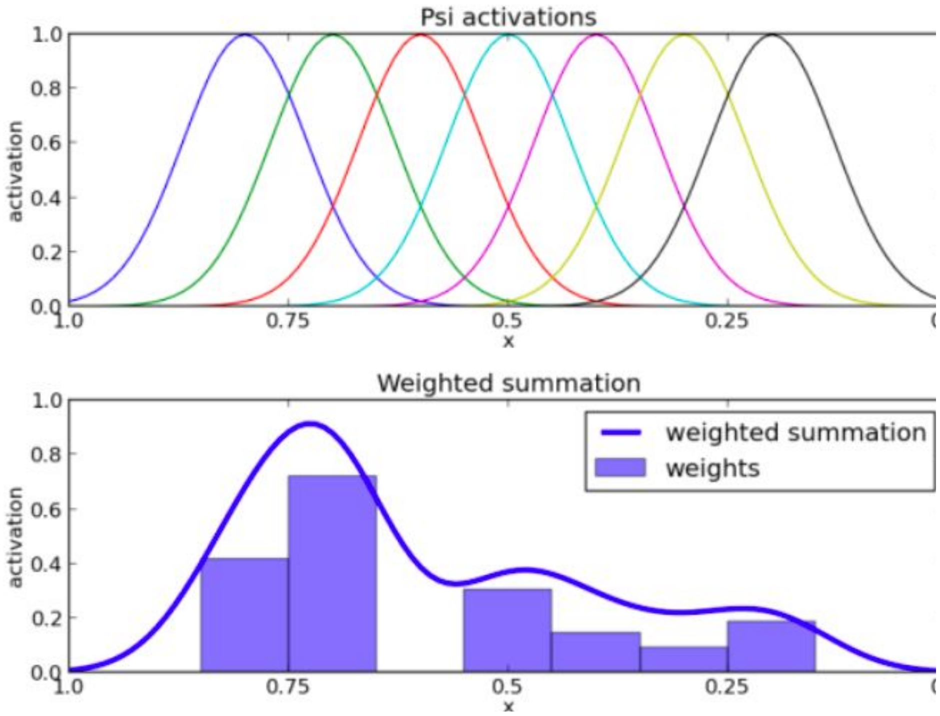

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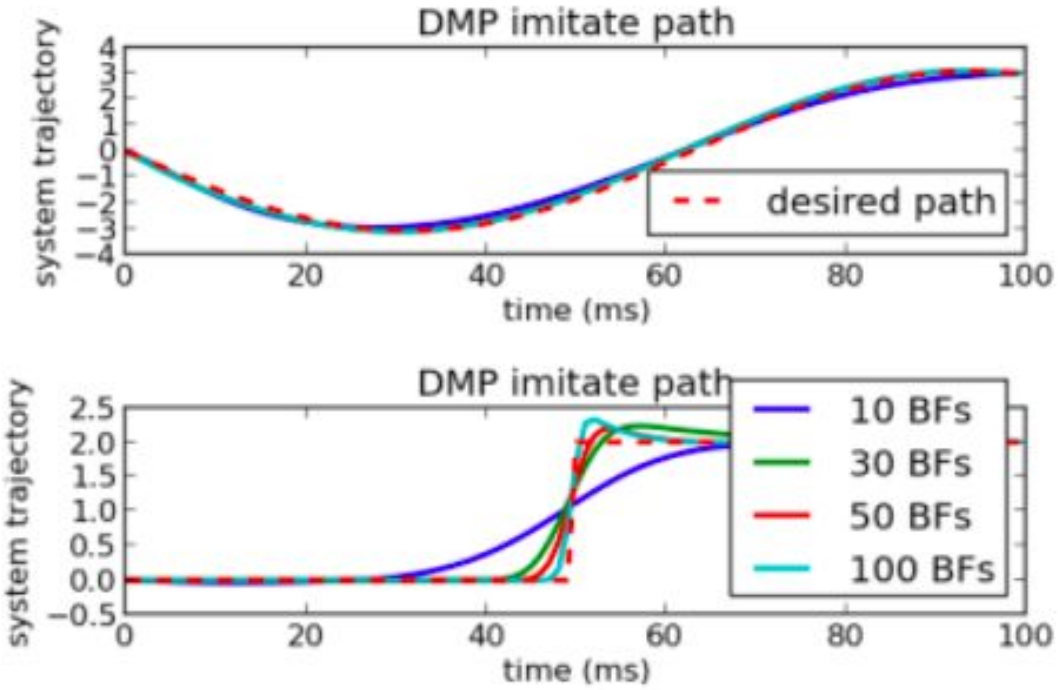

Background: DMP

Introduced system is called the *canonical system*: $\tau \dot{s} = -\alpha\, s$

To learn a movement from demonstration

1. Movement x(t) is recorder and its derivatives are computed.

2. s(t) is computed from the canonical system.

3. $$f_{\text{target}}(s) = \frac{-K(g-x) + Dv + \tau \dot{v}}{g - x_0}$$

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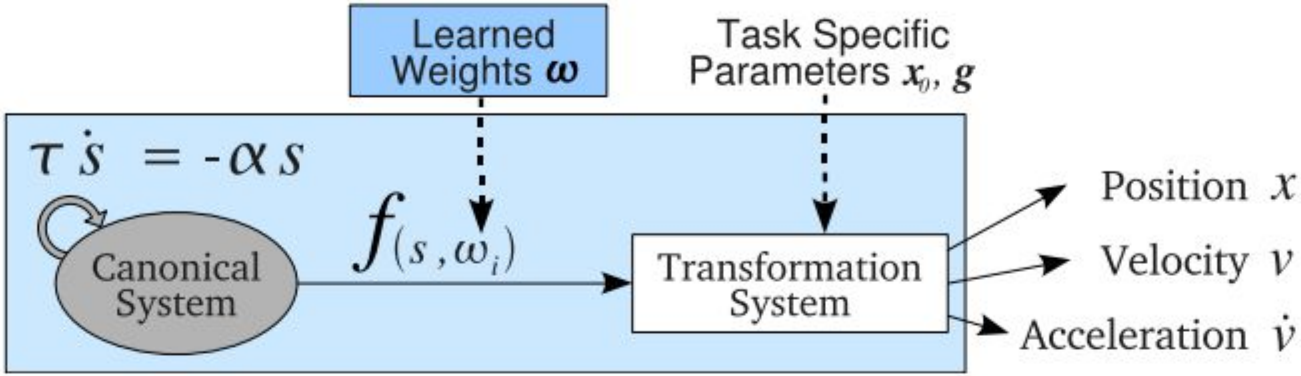
$$f(s) = \frac{\sum_i w_i \psi_i(s) s}{\sum_i \psi_i(s)}$$

Finding weights w_i is an optimization problem, which can be solved with linear regression.

Minimize $$J = \sum_s \left(f_{\text{target}}(s) - f(s)\right)^2$$

Background: DMP



Drawbacks of original DMP

1. If the start and goal position of a movement are same, then the system will remain at start position as $(g - x_0) = 0$.

2. If $(g - x_0)$ is close to zero, then scaling it with f might lead to huge accelerations for a small change in g.

3. If $(g_{new} - x_0)$ changes its sign compared to $(g_{original} - x_0)$, then the DMP formulation will be unsuitable for adapting to new goal positions. (mirror issue)

Methodology

$$\begin{aligned} \tau\dot{v} &= K(g-x) - Dv - K(g-x_0)s + Kf(s) \\ \tau\dot{x} &= v \ , \end{aligned}$$

Non linear function is not multiplied by (g - x_0).

K(g - x_0)s is required to avoid jumps.

$$f_{\text{target}}(s) = \frac{\tau\,\dot{v} + D\,v}{K} - (g-x) + (g-x_0)\,s$$

Obstacle avoidance

$$\tau\dot{\mathbf{v}} = \mathbf{K}(\mathbf{g}-\mathbf{x})-\mathbf{D}\mathbf{v}-\mathbf{K}(\mathbf{g}-\mathbf{x}_0)\,s+\mathbf{K}\mathbf{f}(s)+\mathbf{p}(\mathbf{x},\mathbf{v})$$

$$\mathbf{p}(\mathbf{x},\mathbf{v}) = \gamma\,\mathbf{R}\,\mathbf{v}\,\varphi\exp(-\beta\,\varphi)$$

B. R. Fajen and W. H. Warren, “Behavioral dynamics of steering, obstacle avoidance, and route selection,” Journal of Experimental Psychology: Human Perception and Performance.

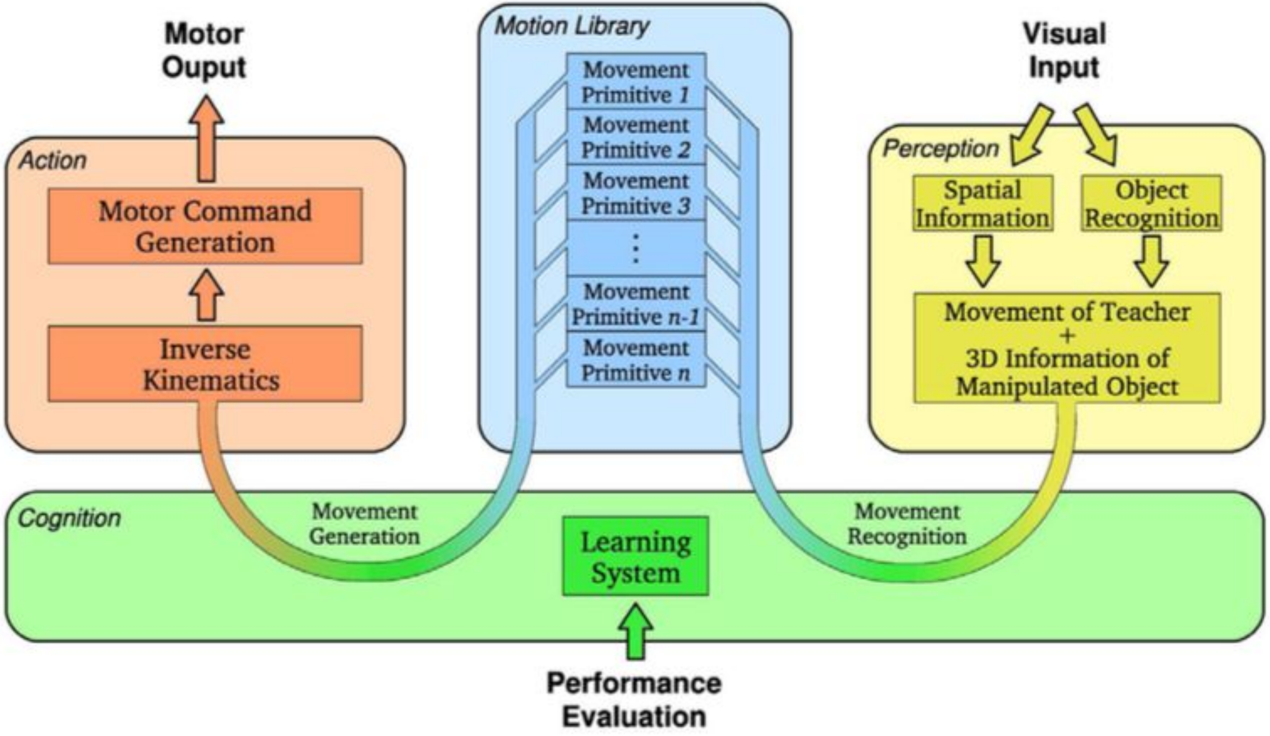
Building Library of movements

Motion library generation:

Learning DMPs requires users to demonstrate only characteristic movements.

Movement reproduction requires only choosing a primitive, and setting its task specific parameters.

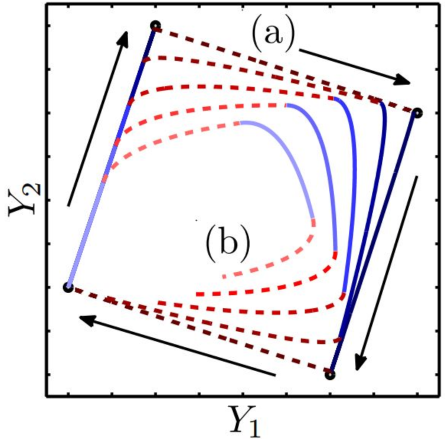
Building Library of movements



Combining movement primitives

To generate more complex movements.

- Sequence of DMPs
- Starting execution next DMP before previous DMP has finished.
- Velocity and starting position adjusted accordingly



$$\mathbf{v}_{\text{pred}} \longrightarrow \mathbf{v}_{\text{succ}} \text{ and } \mathbf{x}_{\text{pred}} \longrightarrow \mathbf{x}_{\text{succ}}$$

Experiments and results

- SARCOS slave arm
    - 7DOF arm and 3 DOF end effector

Tasks

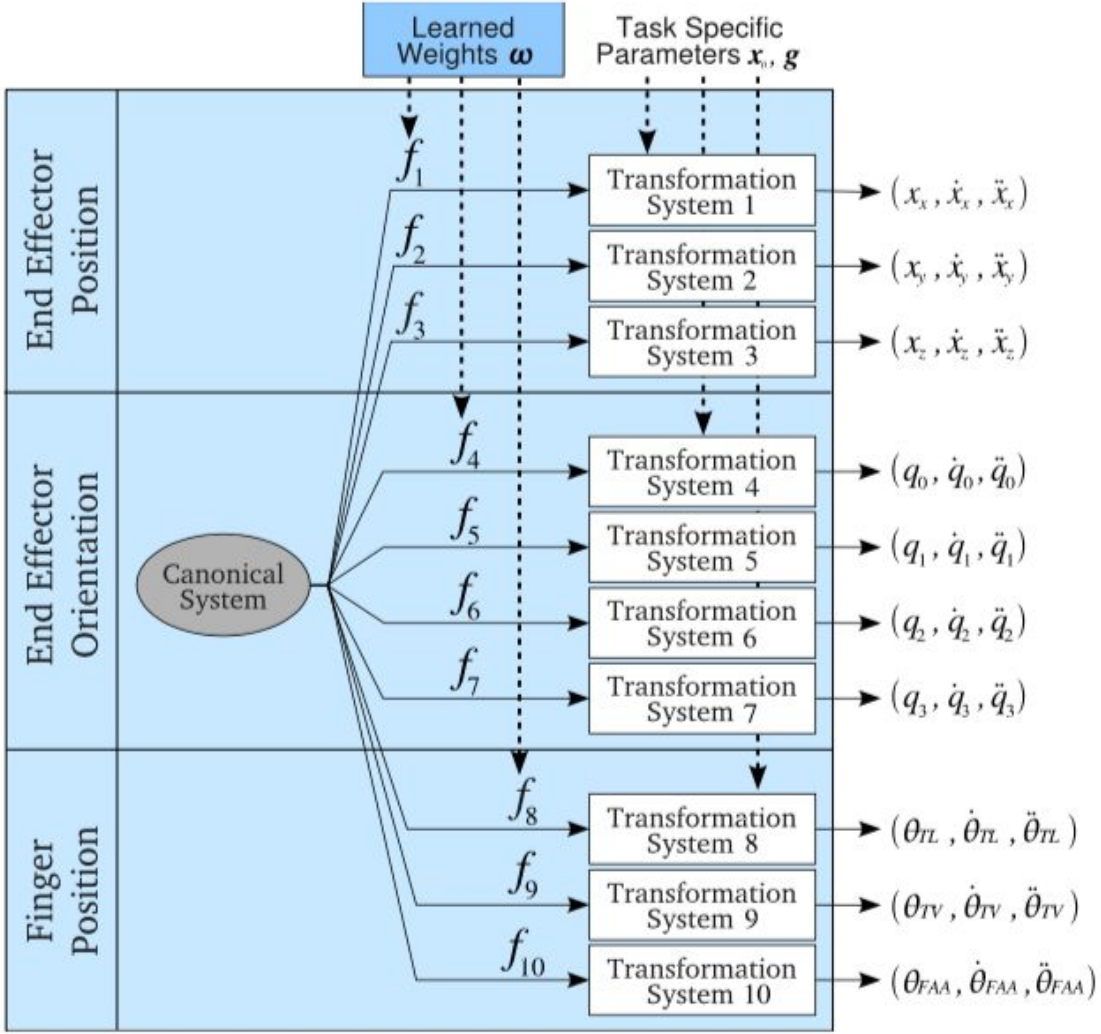
- Water pouring
- Grasping cup and placing

https://www.youtube.com/watch?v=LuFlWNIcdfM

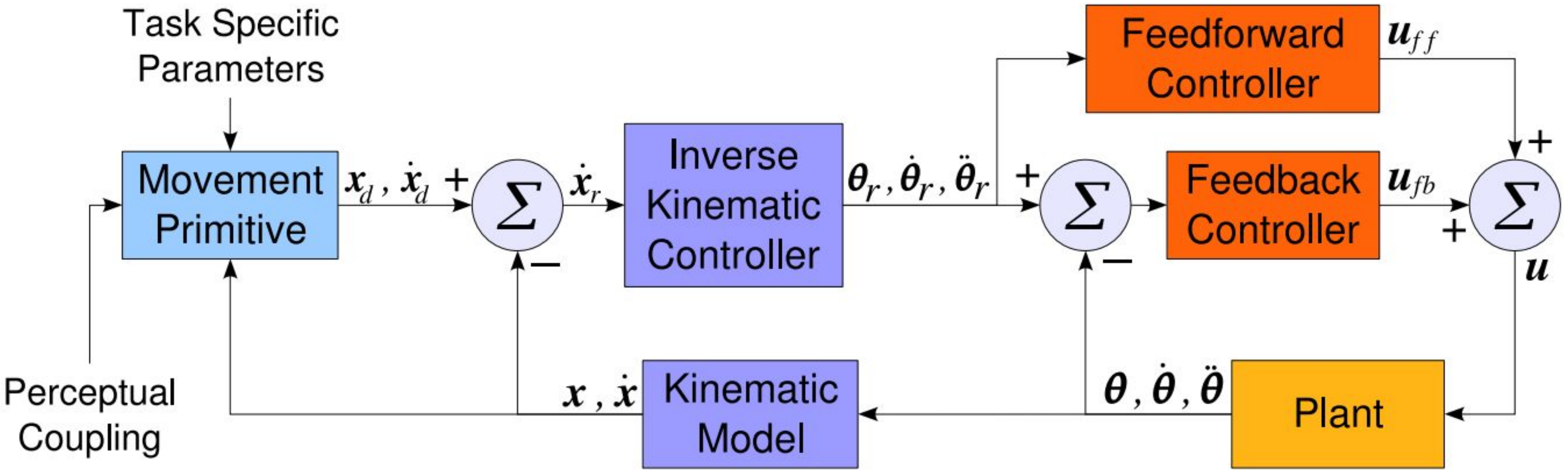
https://www.youtube.com/watch?v=QIA9nFaU1cc

Experiments

- For each demonstrated movement a DMP was learnt and added to the motion library.



DMP control diagram



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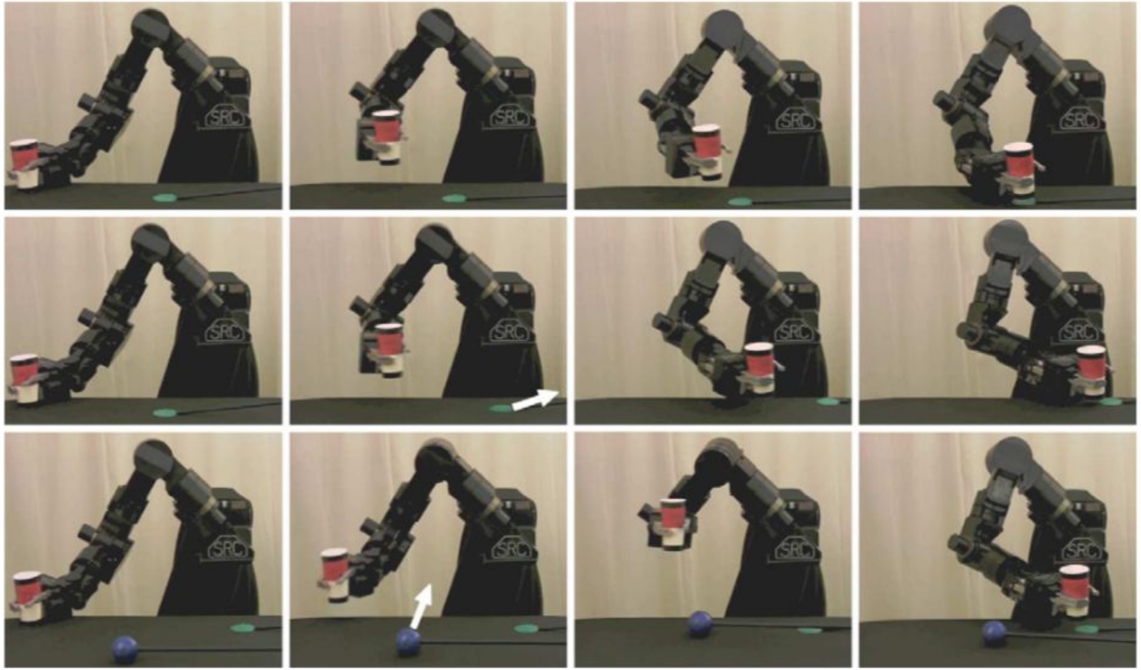

Conclusion

Pros:

- Online
- robust to perturbations (obstacle avoidance)
- Flexibility in defining trajectory
- scaled and translated arbitrarily

Cons

- an inverse kinematics
- Sequencing
- (Object shape/orientation/affordance not considered??)

Thank you