Human-Robot Collaborative Dance

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16-662: Robot autonomy
Final project presentation

April 27, 2016

Motivation

- Work on artistic applications of robotics is sparse
  - Robot painting [1]
  - Robot theater [2]
  - Robot dance [3]
- Focused on **non-collaborative** / **non-interactive** settings
- Human-Robot Interaction often considers non-verbal modalities as secondary
  - We use motion and physical contact as primary interaction modalities

[1] Tresset P., and Oliver D. "Artistically skilled embodied agents." (2014)
[3] Zeglin, G., et al. "HERB's Sure Thing: A rapid drama system for rehearsing and performing live robot theater." Advanced Robotics and its Social Impacts (ARSO), 2014 IEEE Workshop on. IEEE, 2014.
[2] Shinozaki K., Akitsugu I., and Ryohei N. "Concept and construction of a robot dance system." International Workshop and Conference on Photonics and Nanotechnology 2007.

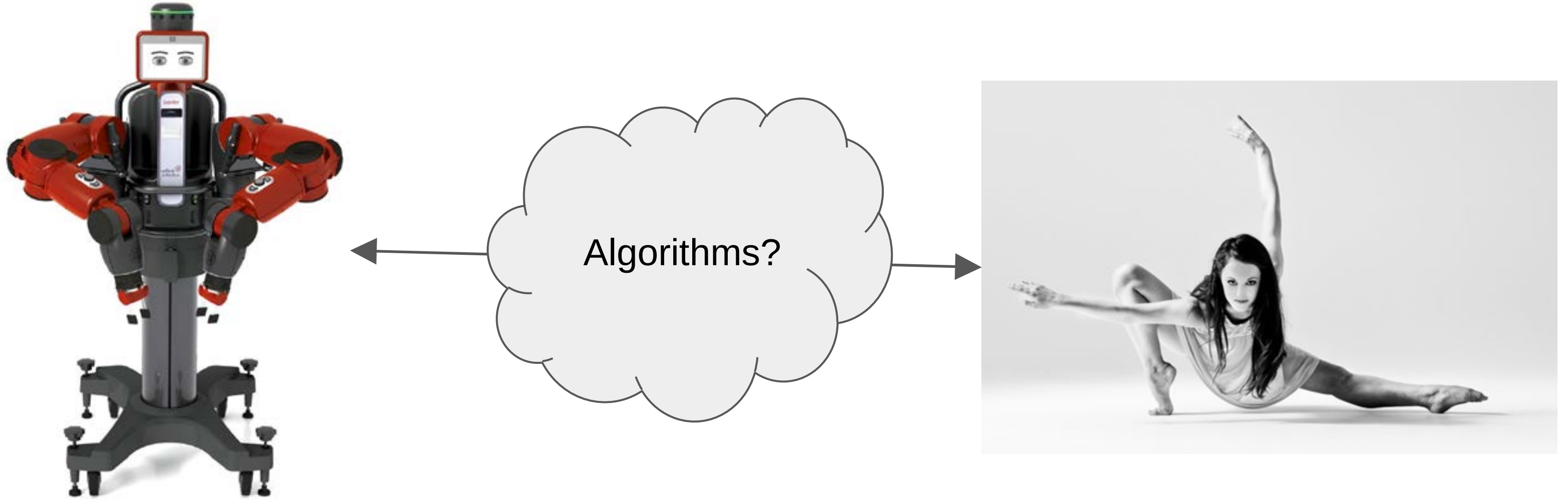
Motivation

- No work on using physical HRI for artistic purposes
    - We use two modalities:
        - Motion
        - Physical contact (inspired by *contact improvisation*)
- Planning around humans is an unsolved problem
- Safety concerns
- Physical Human-Robot Interaction

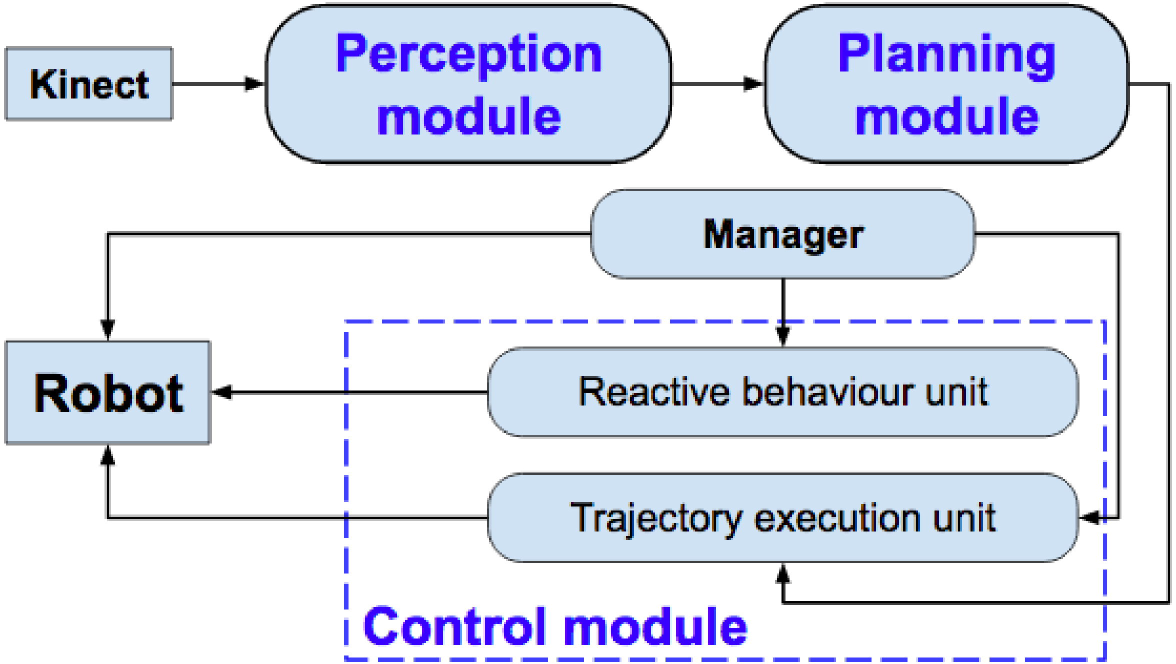
Contact improvisation, a dance technique in which dancers mainly interact through physical contact

Problem Statement

*“How can a robot interact with a dancer through **motion** and **physical contact** in a way that is both **safe** and **creatively valuable**?”*



System Architecture



Control

Torque Control (PD controller) with torque saturation → safe and compliant

$$\tau = k_p * (\theta_d - \theta) + k_d * (\dot{\theta}_d - \dot{\theta})$$

$where,$

$\tau \rightarrow torque\ applied\ to\ joint$

$k_p \rightarrow\ Stiffness\ Factor$

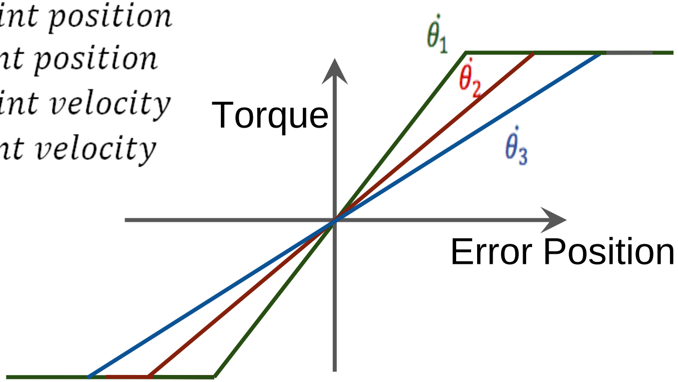
$k_d \rightarrow Damping\ Factor$

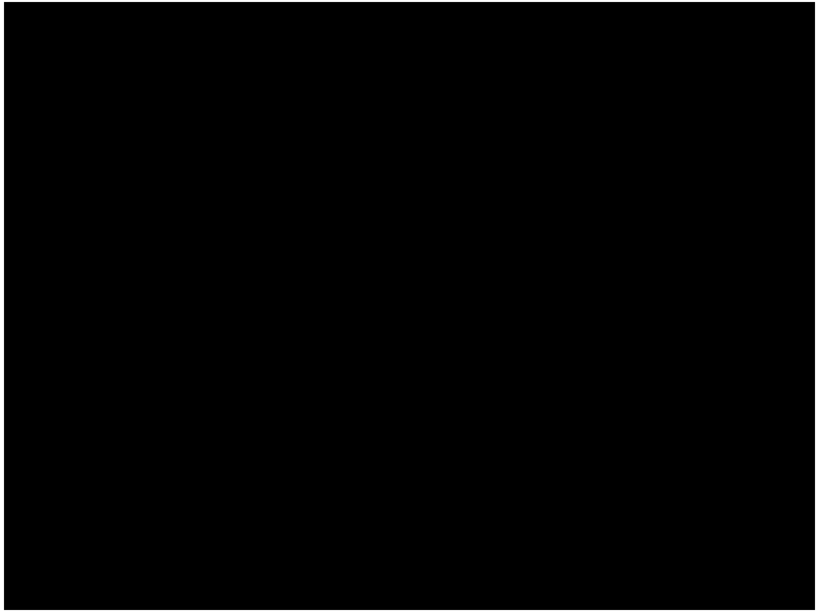
$\theta_d \rightarrow desired\ joint\ position$

$\theta \rightarrow current\ joint\ position$

$\dot{\theta}_d \rightarrow desired\ joint\ velocity$

$\dot{\theta} \rightarrow current\ joint\ velocity$



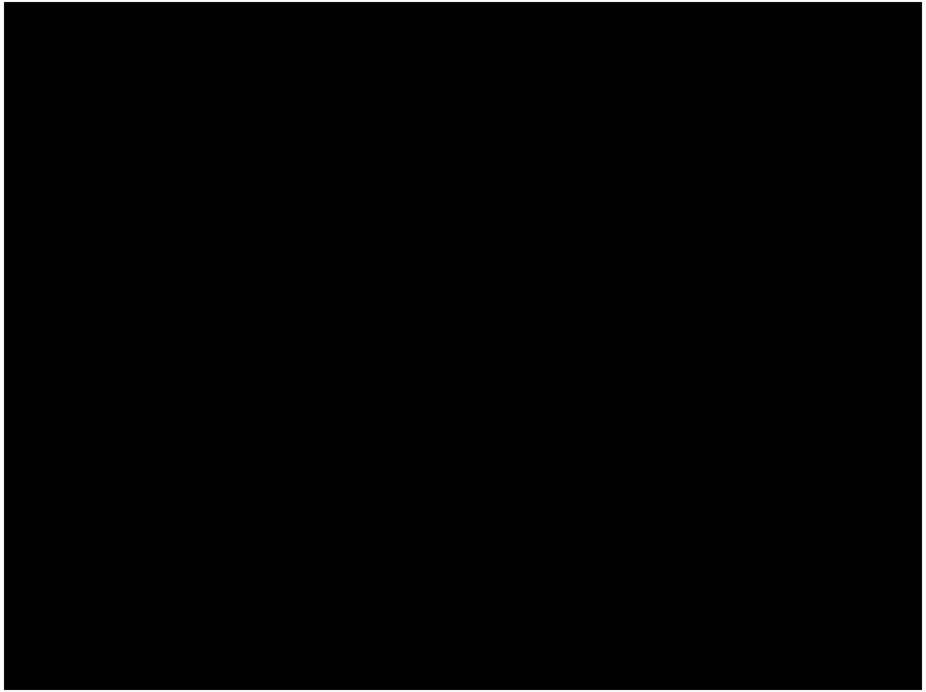


Control

Reactive Behavior – First

- Get normal between the collision link and dancers

- Move the end effector in the direction of the normal using velocity PD control



$$\dot{\theta} = (J(\theta)^T J(\theta))^{-1} J(\theta)^T \dot{x}\, \hat{n}$$

where,

$\dot{\theta} \rightarrow$ *joint velocities*

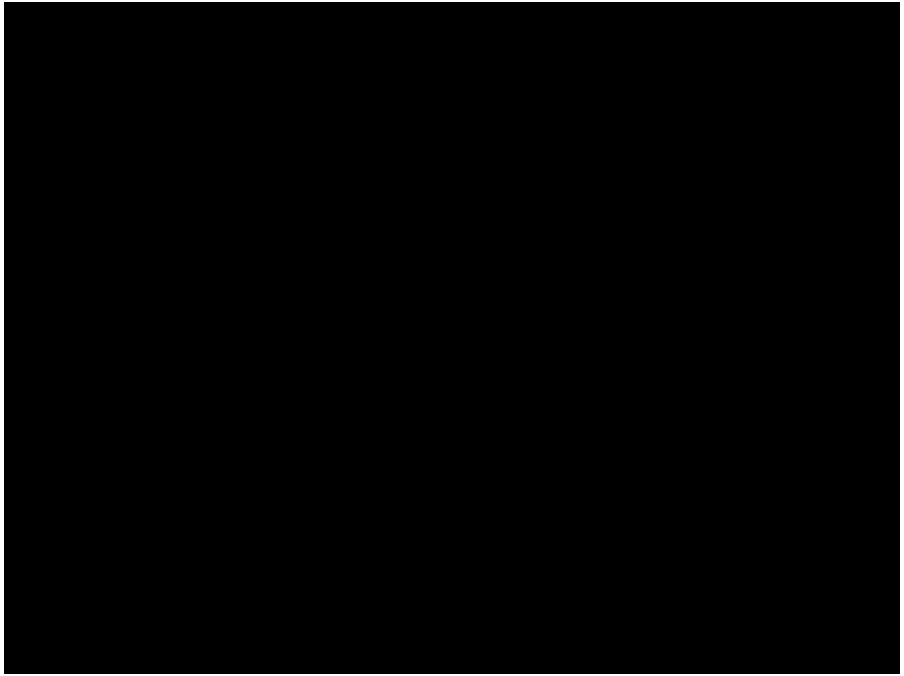
$J(\theta) \rightarrow$ *updated jacobian based on joint positions*

$\dot{x} \rightarrow$ *default end effector velocities for reactive behavior*

$\hat{n} \rightarrow$ *normal pointing away from the centroid of the point cloud and the collision link*

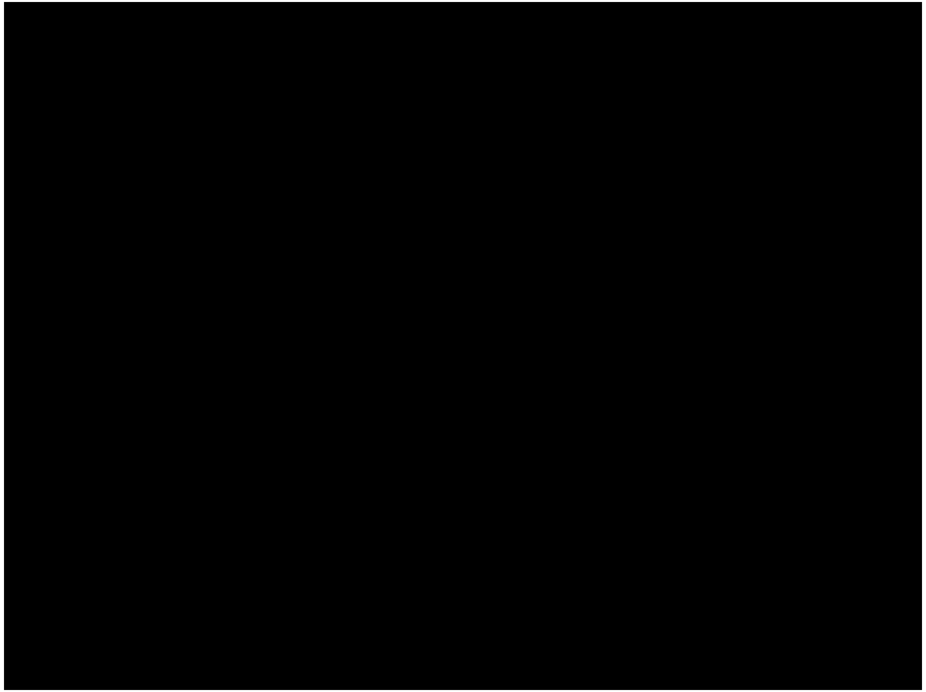
Control

Reactive Behavior to High Velocity - Second



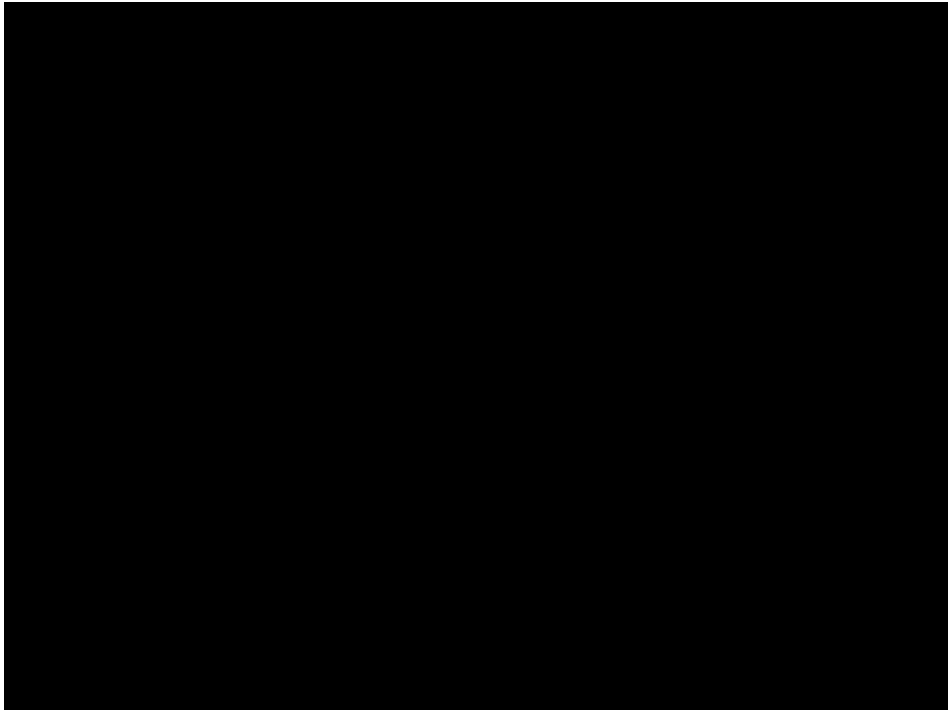
Perception

We use depth data from a head mounted Kinect



Perception

We keep track of the dancer’s centroid



Planning

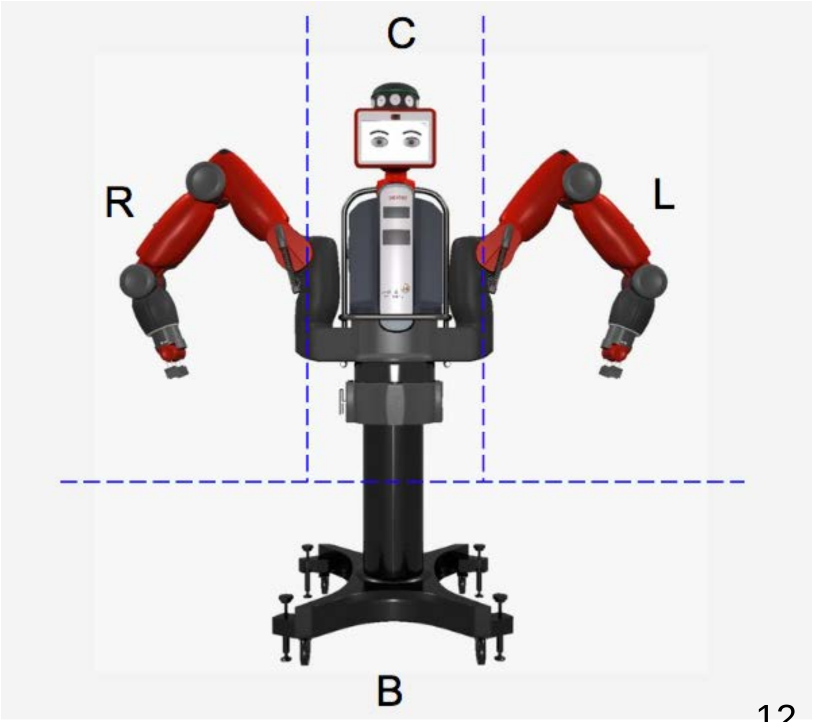
- Originally attempted traditional motion planning and collision checking in MoveIt
- Limitations: perceptual, expressivity and natural appearance.

Planning

Trajectories were recorded kinesthetically

Made a database of *motion primitives* avoiding each quadrant

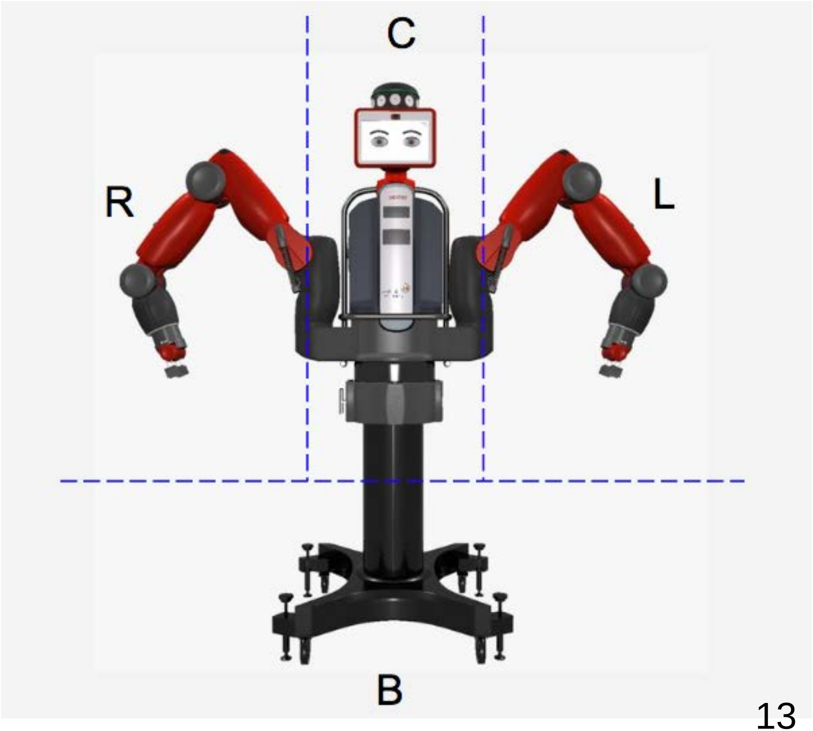
Right quadrant	Center quadrant	Left quadrant	Bottom quadrant
$\zeta_{1,R}$	$\zeta_{1,C}$	$\zeta_{1,L}$	$\zeta_{1,B}$
$\zeta_{2,R}$	$\zeta_{2,C}$	$\zeta_{2,L}$	$\zeta_{2,B}$
$\zeta_{3,R}$	$\zeta_{3,C}$	$\zeta_{3,L}$	$\zeta_{3,B}$
…	…	…	…
$\zeta_{k,R}$	$\zeta_{l,C}$	$\zeta_{m,L}$	$\zeta_{n,B}$



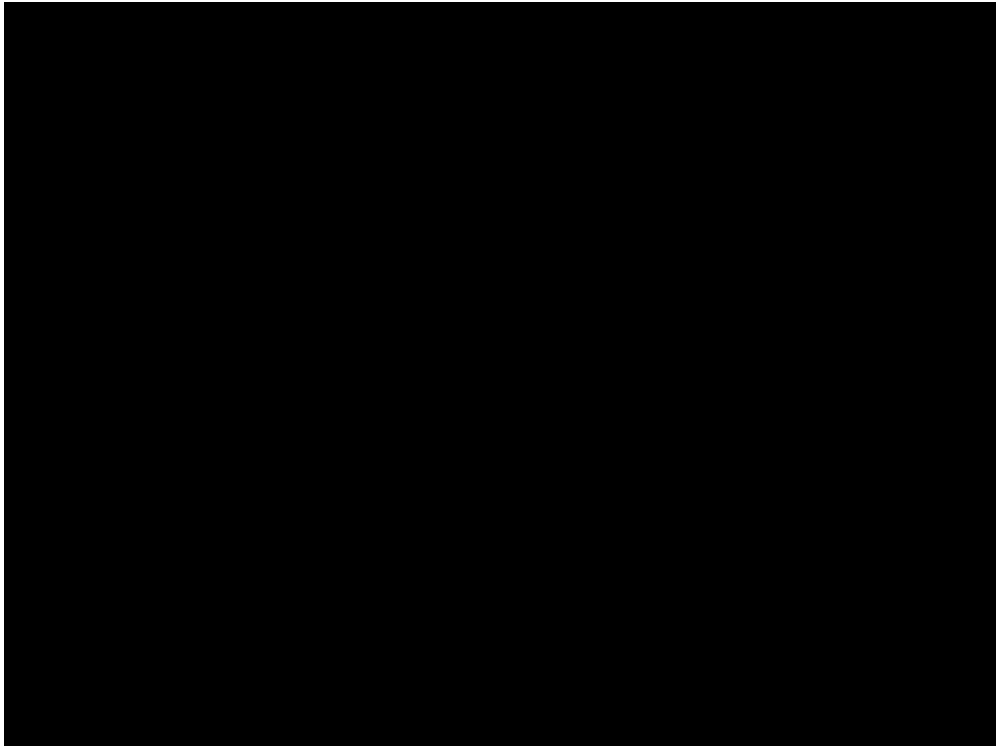
Quadrant-Based Planning

The robot algorithm alternates between two phases:

1) Planning phase:
    a) Identify quadrant of dancer
    b) Choose random motion primitive in corresponding quadrant
2) Execution phase:
    a) Execute pre-recorded motion primitive
    b) Move to neutral position if high velocity is detected
    c) Delay to let dancer change quadrants



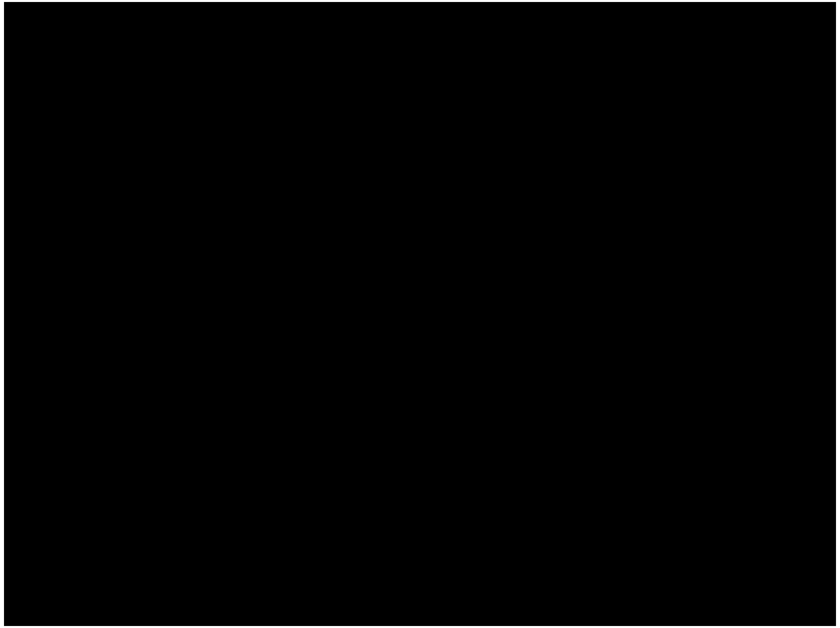
Quadrant-Based Planning



Introducing Labels

We extend our planning scheme to account for labels, e.g., slow mellow, fast playful.

$(\zeta_{1,R}, l_{i1,R})$	$(\zeta_{1,C}, l_{i1,C})$	$(\zeta_{1,L}, l_{i1,L})$	$(\zeta_{1,B}, l_{i1,B})$
$(\zeta_{2,R}, l_{i2,R})$	$(\zeta_{2,C}, l_{i2,C})$	$(\zeta_{2,L}, l_{i2,L})$	$(\zeta_{2,B}, l_{i2,B})$
$(\zeta_{3,R}, l_{i3,R})$	$(\zeta_{3,C}, l_{i3,R})$	$(\zeta_{3,L}, l_{i3,L})$	$(\zeta_{3,B}, l_{i3,B})$
...	...	...	...
$(\zeta_{k,R}, l_{ik,R})$	$(\zeta_{l,C}, l_{il,C})$	$(\zeta_{m,L}, l_{im,L})$	$(\zeta_{n,B}, l_{in,B})$
Right quadrant	Center quadrant	Left quadrant	Bottom quadrant



Evaluation: Methodology

- Recruited 2 dancers from the School of Drama (1 male, 1 female) and one observer
- Each dancer interacted with the Baxter in the following 2 conditions:
    - C1: Baseline (compliant control with no trajectory following)
    - C2: Our approach (Quadrant-based planning + trajectory following)
- Observer answered survey after each condition for one of the sessions
- Survey: Godspeed questionnaire by Bartneck et al. [1]
    - Questionnaire was answered after each condition

[1] Bartneck, C., Croft, E., Kulic, D. & Zoghbi, S. (2009). Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. International Journal of Social Robotics, 1(1) 71-81.

Evaluation: Results

Anthropomorphism

Please rate your impression of the robot on these scales:

Fake	1	2	3	4	5	Natural
Machinelike	1	2	3	4	5	Humanlike
Unconscious	1	2	3	4	5	Conscious
Artificial	1	2	3	4	5	Lifelike
Moving rigidly	1	2	3	4	5	Moving elegantly

Subject 1: +0.6 Subject 2: -1.4 Observer: +0.6

Animacy

Please rate your impression of the robot on these scales:

Dead	1	2	3	4	5	Alive
Stagnant	1	2	3	4	5	Lively
Mechanical	1	2	3	4	5	Organic
Artificial	1	2	3	4	5	Lifelike
Inert	1	2	3	4	5	Interactive
Apathetic	1	2	3	4	5	Responsive

Subject 1: +1.17 Subject 2: -0.5 Observer: +0.5

Evaluation: Results

Likeability

Please rate your impression of the robot on these scales:

Dislike	1	2	3	4	5	Like
Unfriendly	1	2	3	4	5	Friendly
Unkind	1	2	3	4	5	Kind
Unpleasant	1	2	3	4	5	Pleasant
Awful	1	2	3	4	5	Nice

Subject 1: +1.0 Subject 2: 0 Observer: -0.4

Perceived Intelligence

Please rate your impression of the robot on these scales:

Incompetent	1	2	3	4	5	Competent
Ignorant	1	2	3	4	5	Knowledgeable
Irresponsible	1	2	3	4	5	Responsible
Unintellegent	1	2	3	4	5	Intelligent
Foolish	1	2	3	4	5	Sensible

Subject 1: +0.8 Subject 2: 0 Observer: +0.8

Perceived Safety

Please rate how you felt on these scales:

Anxious	1	2	3	4	5	Relaxed
Agitated	1	2	3	4	5	Calm
Quiescent	1	2	3	4	5	Surprised

Subject 1: +1.33 Subject 2: -0.33 Observer: -0.33

Evaluation: Results

- Subject 1 reported increased: **perceived safety** (+1.33), **animacy** (+1.17), **likeability** (+1), **perceived intelligence**, and **anthropomorphism** (+0.6) when using our system compared to baseline.

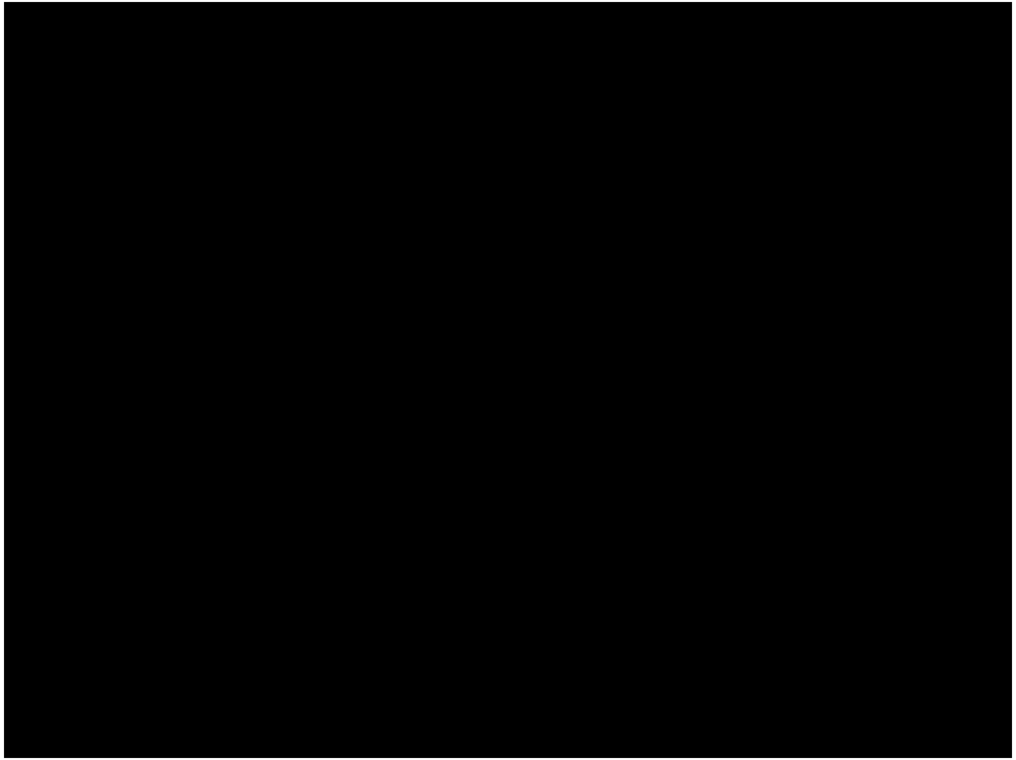
- Subject 2 results were noisy

- Observer showed similar pattern as subject 1

- Perceived safety increased with number of trials with the robot for both subjects.

Final Output

Playful motion primitives (Kate) and slow motion primitives (Carson)



Thank you

Questions?