Autonomous Robot Dancing Driven by Beats and Emotions of Music

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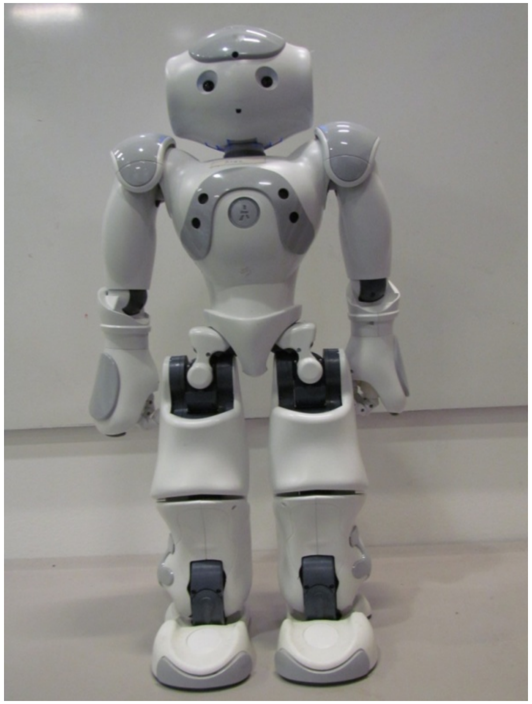


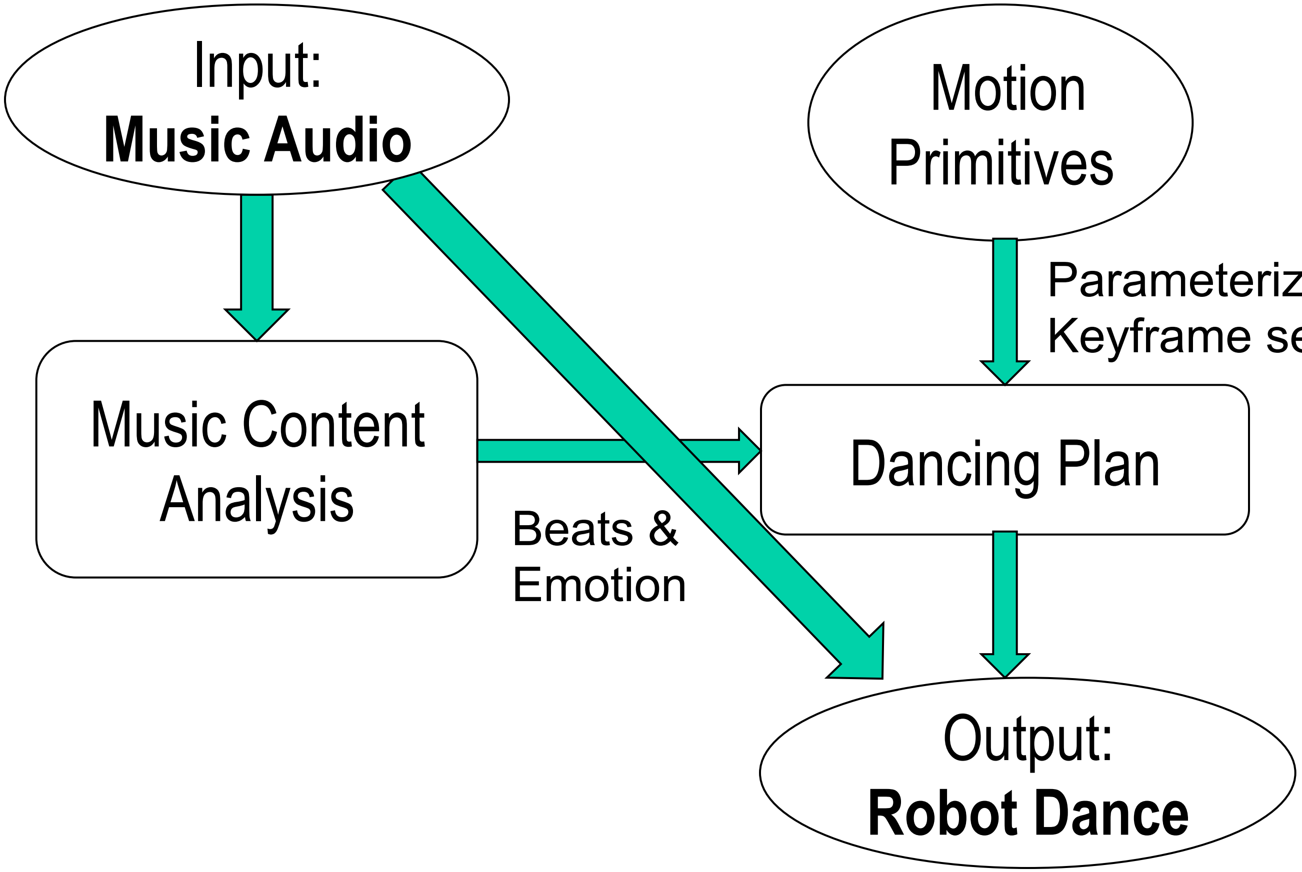
Introduction: Goal

- Context: Many robot dances are preprogrammed
- Idea: How about automating the task?
- Our goal:

Given a piece of music, we want to automatically generate a robot dance

The dance should be interesting, safe, reflecting the emotion, and synchronized to the beats of music.

Introduction: General approach



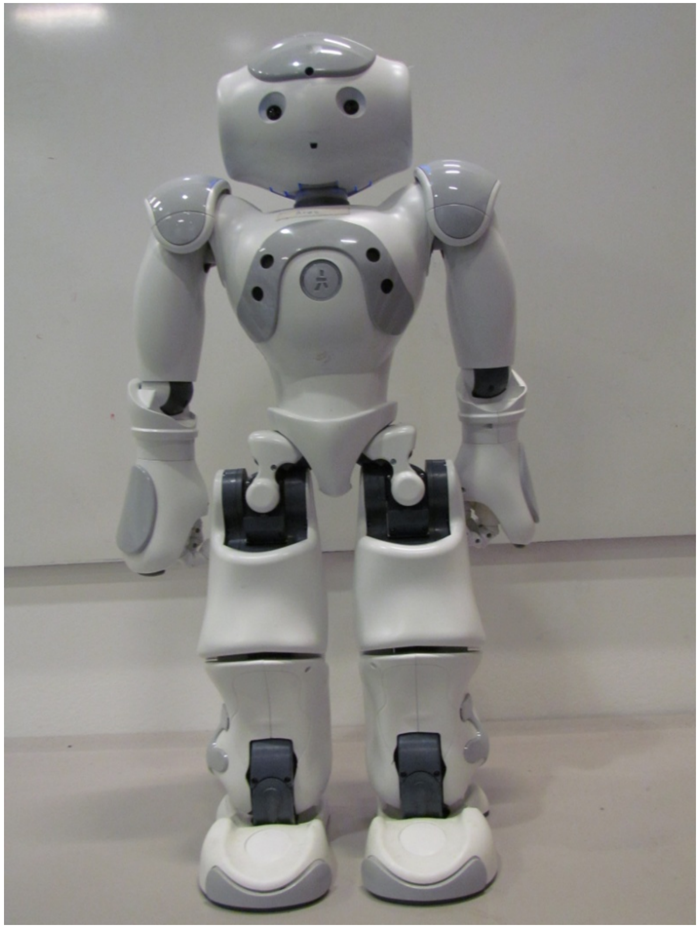
Notice: the dancing plan is created offline, and then executed and synchronized with music audio

Outline

- Introduction
- Motion primitives
- Music content analysis
- Dancing plan
- Execution
- Demo
- Conclusion

Motion primitives (MPs)

- Robot we use
  - NAO
  - Stand-alone autonomous robot
  - 21 joints
- Four catalogs: Head, Left Arm, Right Arm, Legs
- For each catalog, we build its own MPs library



Motion primitives: properties

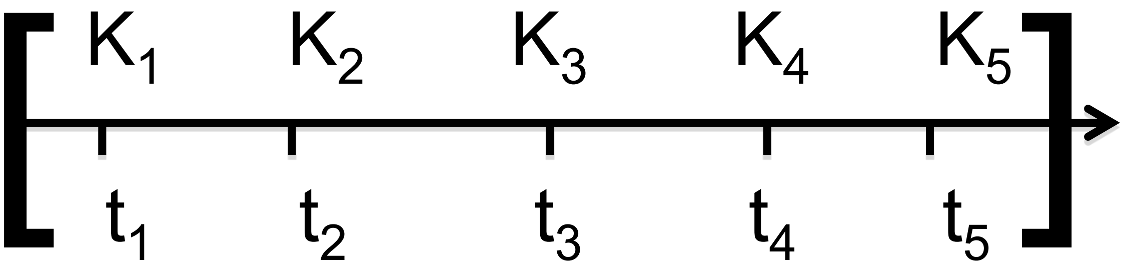
- Large variety of combinations
- Allow speed change
- Safe to execute
- Convey emotions

Motion primitives: Variety

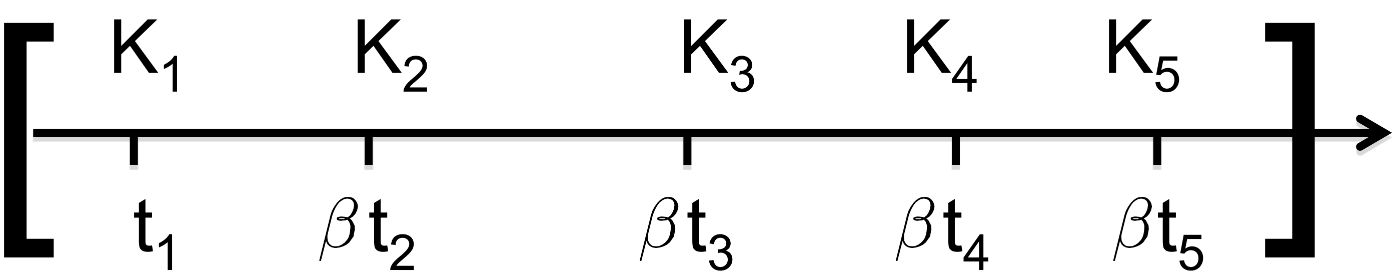
- In order to maximize variety of the combination of Motion Primitives:
- Design the library for four catalogs *independently*
  - Head: 8, Left Arm: 9, Right Arm: 9, Legs: 26
- Execute the four catalogs *simultaneously*
- Though we only designed 52 MPs in total, there are thousands of possible combinations at each time while execution.

Motion primitives: Parameterization

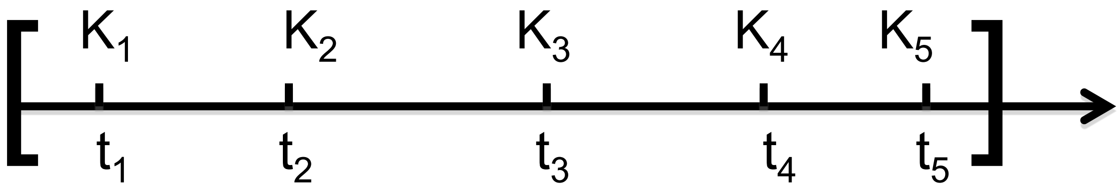
- Motion primitive = sequence of keyframes



- In order to allow speed change:
- A single stretching parameter β
- If t_1 =0, the parameterized motion primitive is



Motion primitives: Safety

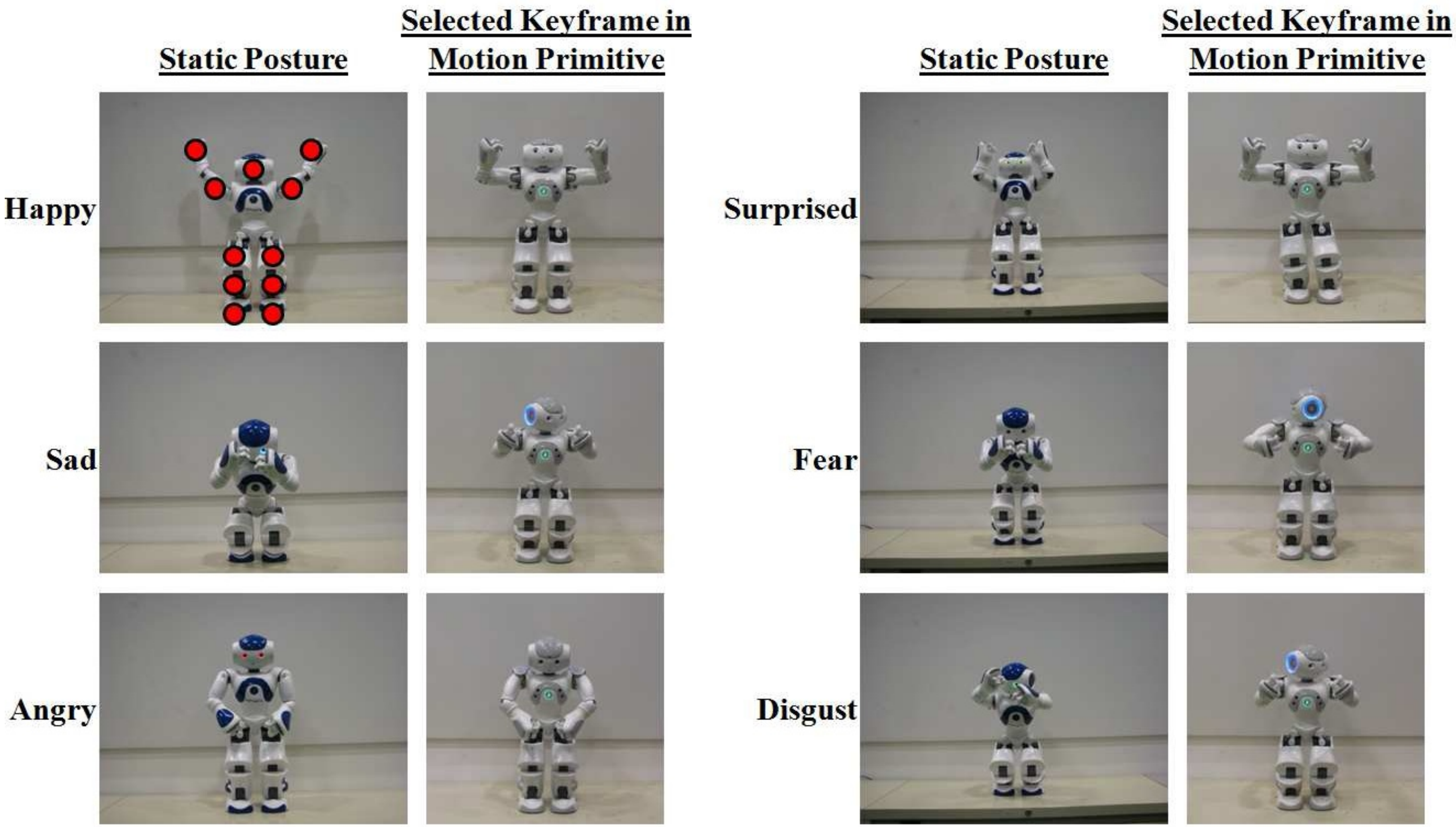


- In order to make sure MPs are safe execute:
- Define Minimum Interpolation Time (MIT) between keyframes and force execution time larger than MIT
- Case 1: Within a MP:
  - MIT is designed as difference between two contiguous time stamps, so that β is no less than 1
- Case 2: Between two MPs :
  - MIT is from the last keyframe of current MP to the first keyframe of next MP: $dist_M(M_n, M_{n+1})$

Motion primitives: Emotion Label

- In order to get conveyed emotions:
- Automatically label the emotion of MPs based on a pre-labeled keyframe library
- For each keyframe
- …find nearest static pose in our pre-labled library, return their emotions
- Use a weighted sum of emotions to estimate emotion of the motion primitive

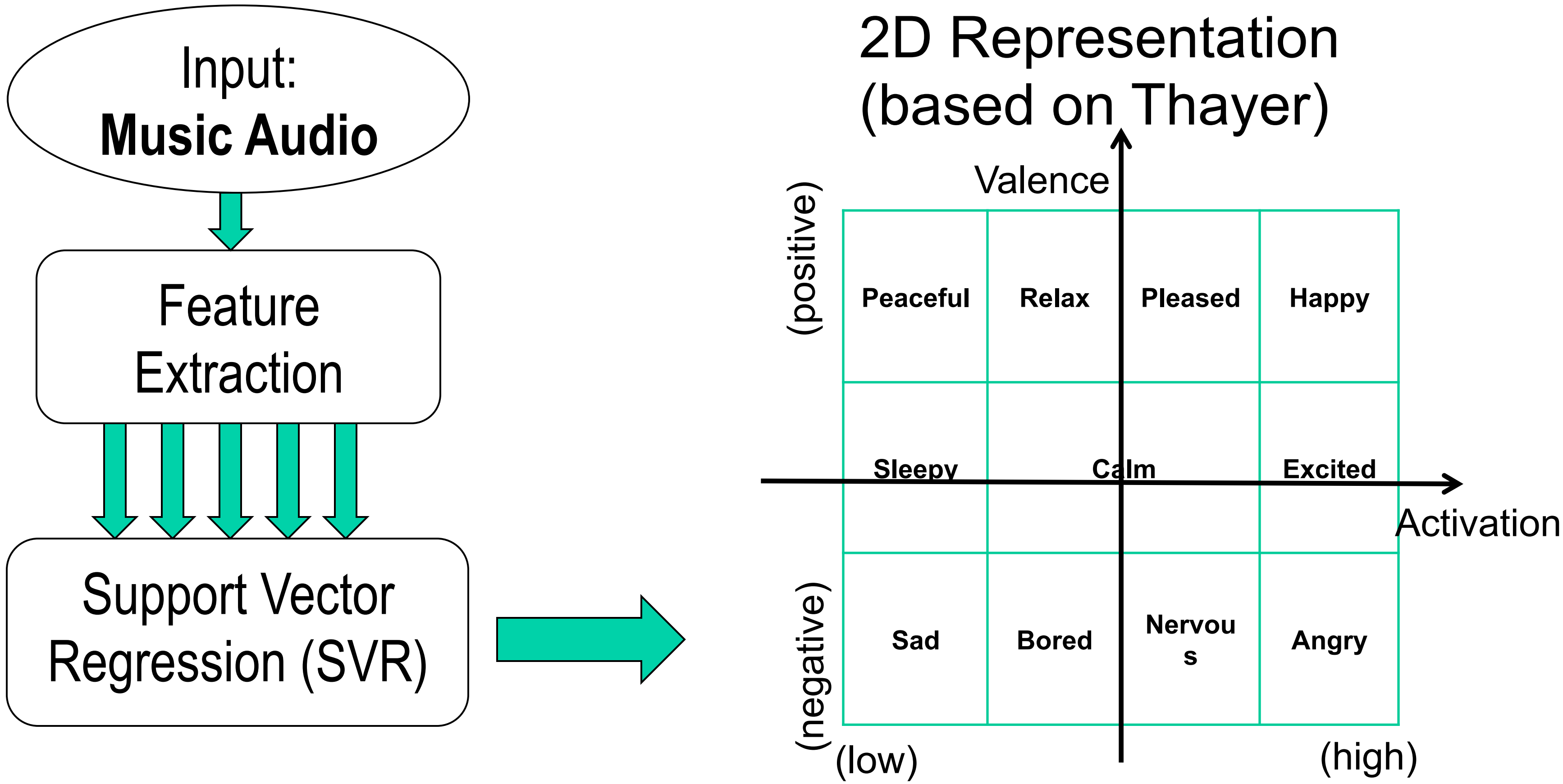
Example: Static Postures Vs. MPs



Music Content Analysis

- We want to extract emotion and beat times from music, to use as cues for the robot dance.
- MPs should convey the emotions of music
- MPs should be synchronized with the beat of music

Music Content Analysis: Emotion



Byeong-jun Han, et al. (2009) SMERS: Music Emotion Recognition by using SVR

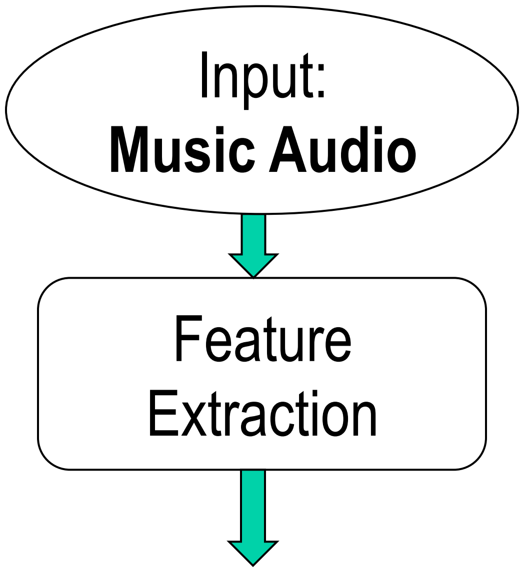
One more step: use a 30-seond sliding window to compute the trajectory of music emotion

A/V value of emotions on the 2-D plane

Emotion	Activation	Valence
Happy	1	1
Sad	-1	-1
Angry	1	-1
Surprised	1	0
Fear	0.5	-1
Disgust	-0.5	-0.5

- Metric of emotion similarity: $dist_E(E(M), e)$
  - The Euclidian distance on the 2-D plane
  - $E(M)$: emotion of the motion primitive *M*
  - e : emotion of the music

Music Content Analysis: Beat



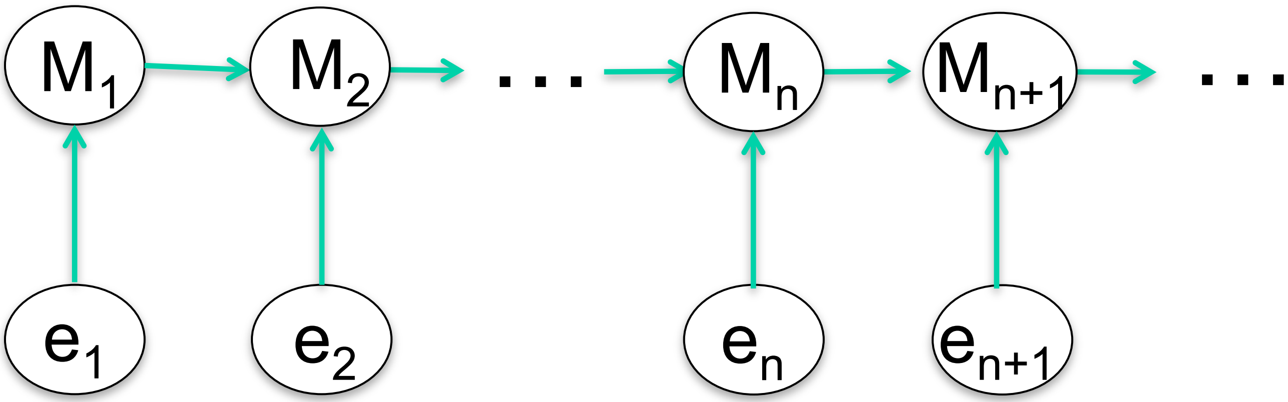
Periodicity estimation using autocorrelation

Search for roughly equally spaced peaks using DP

Dan Ellis (2007), Beat Tracking by Dynamic Programming

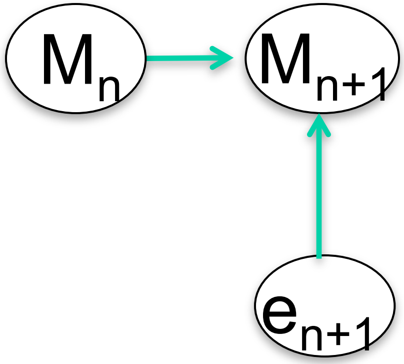
Dancing Plan

- We have got music information and MPs
- Combine them to generate a sequence of MPs
- Nondeterministic, Smooth, Emotional, Synchronized
- Solution: Sampling from a stochastic process



- A generative model, sequentially generating MPs by drawing samples from $p(M_{n+1} \mid M_n, e_{n+1})$

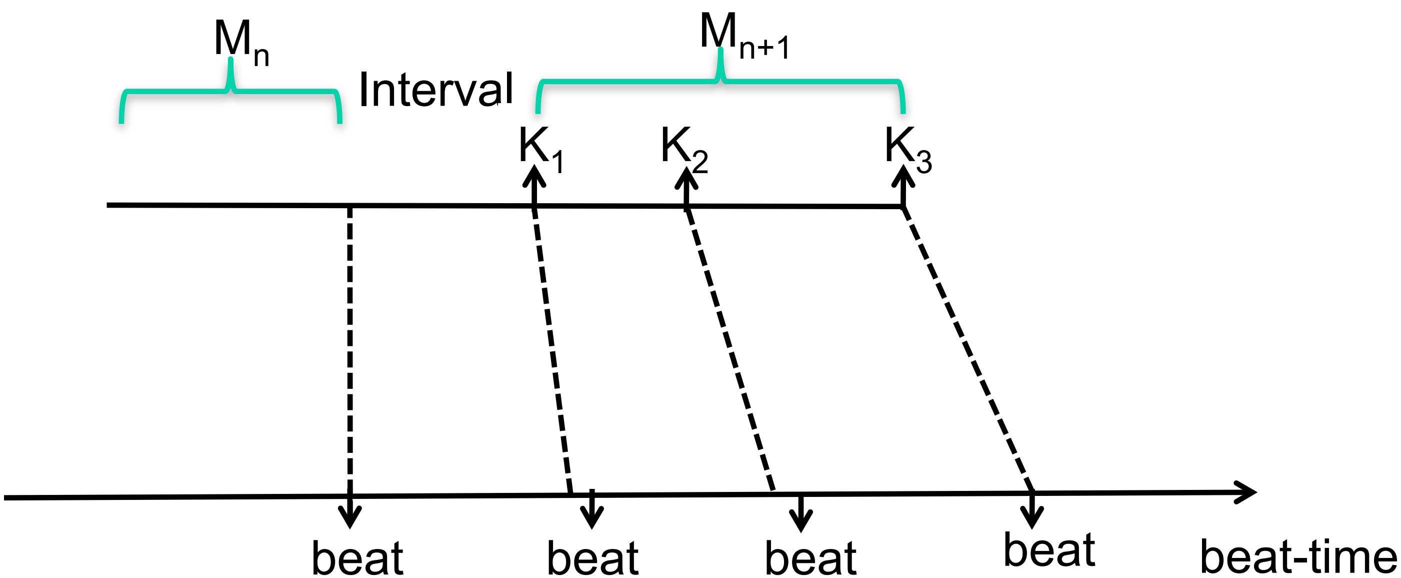
Dancing Plan: To define $p(M_{n+1} \mid M_n, e_{n+1})$



- Nondeterministic
- Smooth:
  - Continuity from one motion primitive to the next
  - Continuity Factor : $CF = \frac{1}{\sqrt{2\pi\sigma_M^2}} \exp\{-\frac{dist_M^2(M_n, M_{n+1})}{2\sigma_M^2}\}$
- Emotional:
  - Considering the music, MPs should reflect the emotion of music.
  - Emotion Factor : $EF = \frac{1}{\sqrt{2\pi\sigma_E^2}} \exp\{-\frac{dist_E^2(E(M_n), e_n)}{2\sigma_E^2}\}$
- Definition: $p(M_{n+1} \mid M_n, e_{n+1}) = CF \cdot EF \cdot N$
- Synchronized: stretch selected MP, making its last keyframe end on a beat time

Dancing Plan: Review

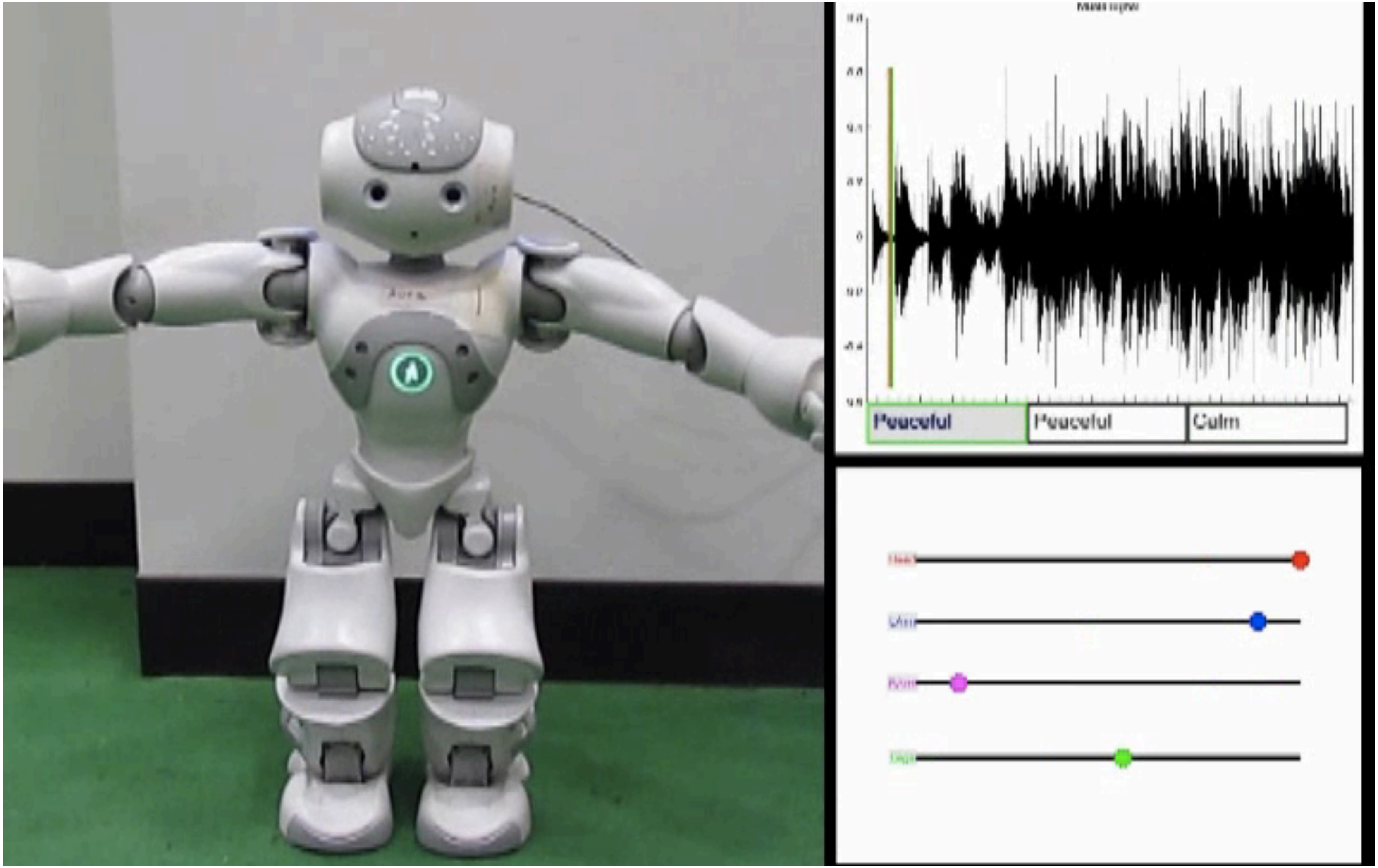
- For each catalog, we iteratively:
  - Get the detected emotion at the end of current motion primitive, e_{n+1}
  - Draw a new motion primitive, M_{n+1} , from the generative distribution $p(M_{n+1} | M_n, e_{n+1})$
  - Stretch M_{n+1} to end on nearest future beat time



Execution

- Even if the planned timing is perfect, there are latency and other execution time errors
- Solution: Real time synchronization algorithm to overcome time drifting
- At each step while execution, iteratively:
  - Check the timing and then re-schedule next step

Video Demo



Conclusion and acknowledgements

- Conclusion
  - An approach to automate robot dancing, based on matching parameterized MPs to music features
  - Nondeterministic, Smooth, Emotional, and Synchronized with music
  - A complete demonstration with a NAO humanoid robot with multiple pieces of music.
  - The scheme generalizes to other robots

- Acknowledgements
  - Byeong-jun Han
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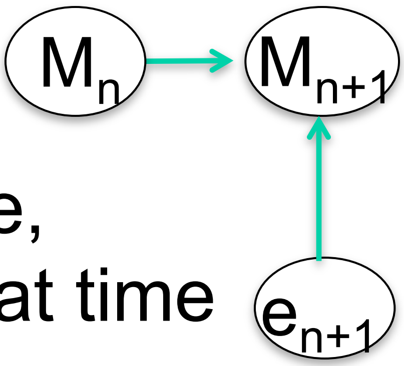
Synchronized with music beats



- Just stretch the selected motion primitive, making its last keyframe ending on a beat time
- Make sure:
  - Interval is no less than $dist_M(M_n, M_{n+1})$
  - β is no less than 1