ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Institute for
Dynamic Systems and Control
IDSC

A Platform for Dance Performances with Multiple Quadrocopters

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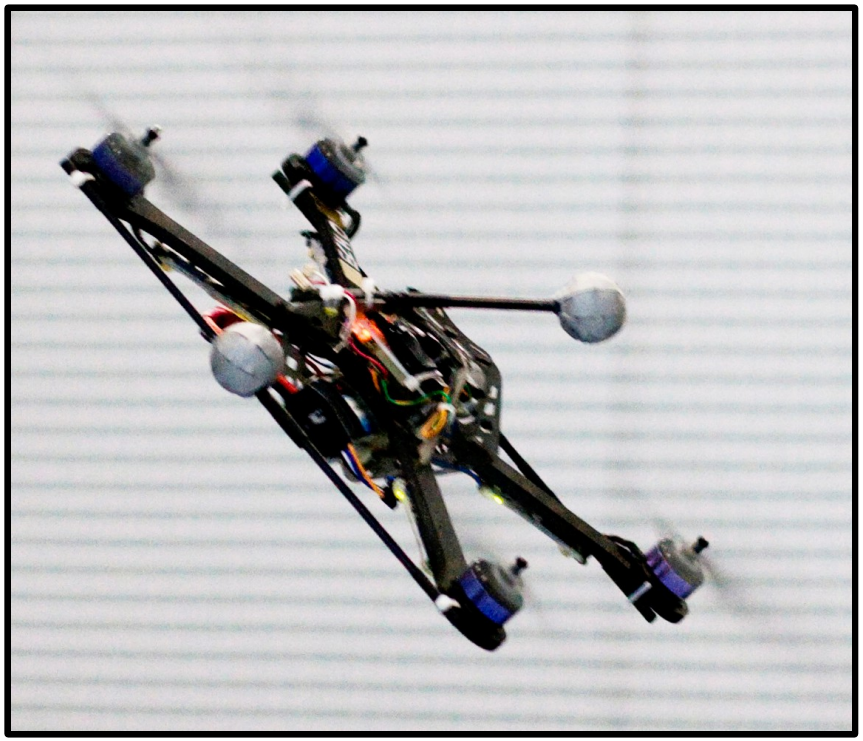
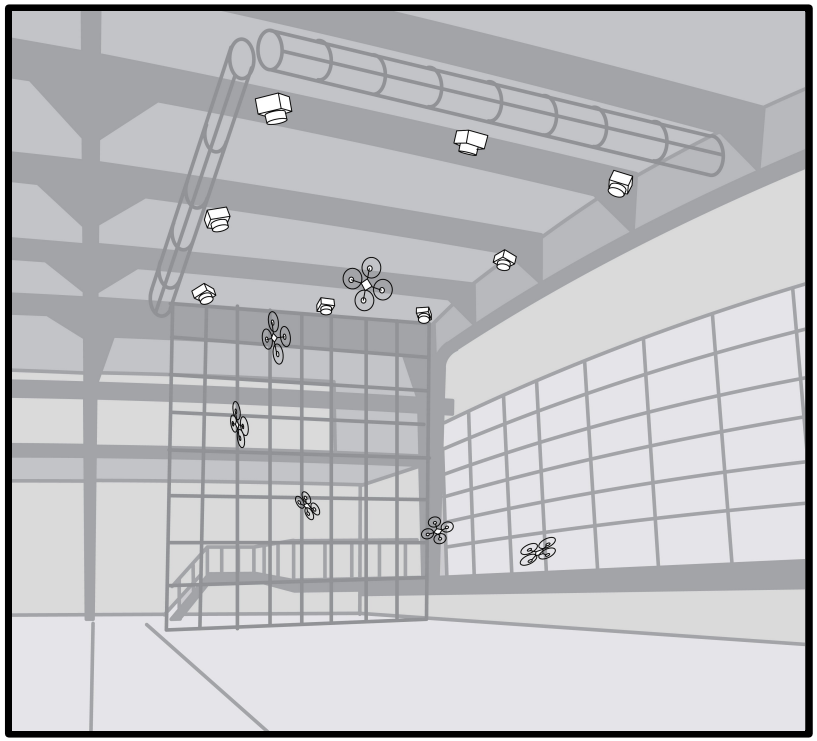
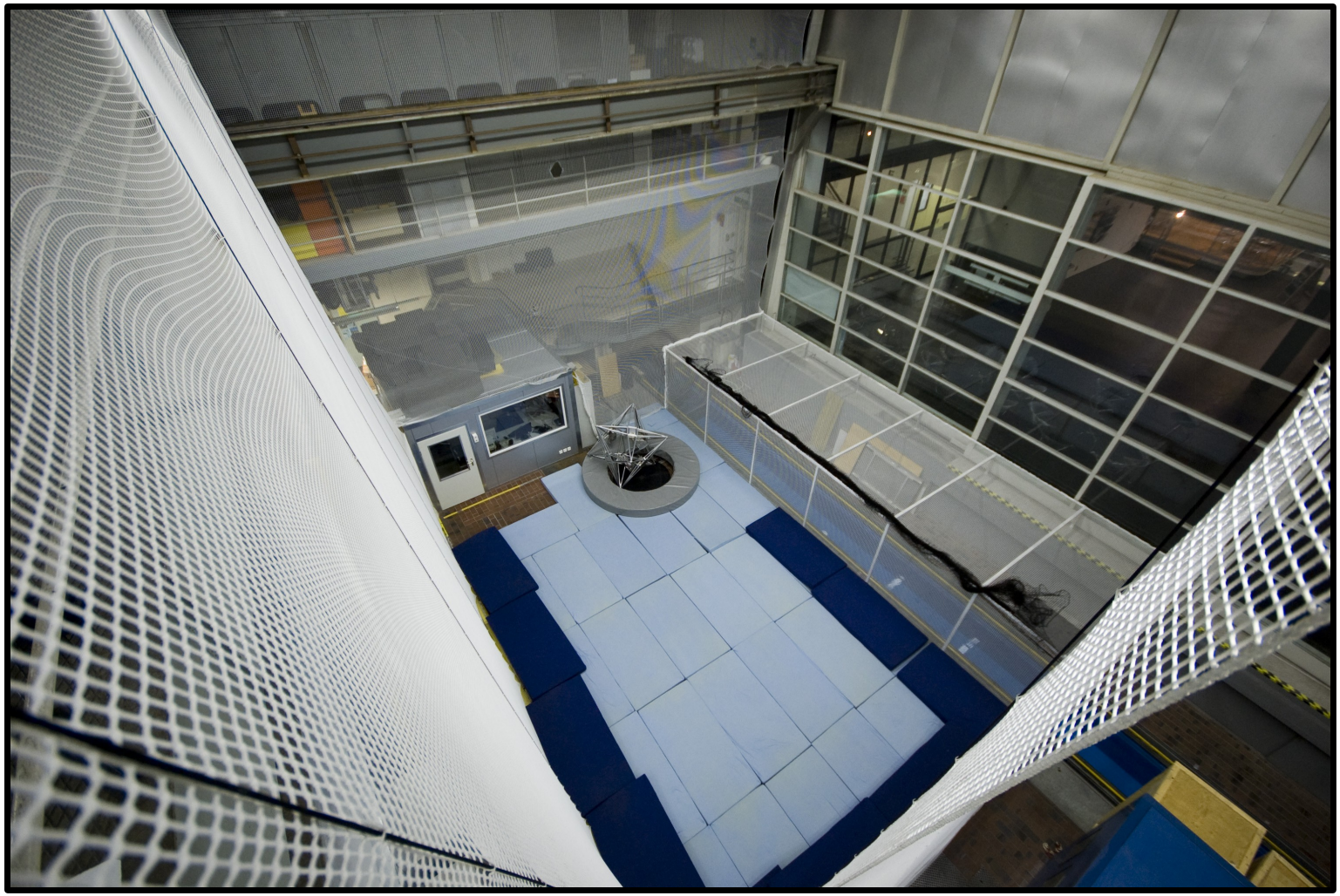
Vision

- Dance performances featuring multiple quadrocopters at the Flight Machine Arena, ETH Zurich





The Flight Machine Arena



Dancing Performance with Two Vehicles

Pirates of the Caribbean

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Dancing performances

- Current status
  - Beat time information from music
  - Manual composition of the choreography
- Goal
  - Multiscale analysis of any piece of music
  - Automatic composition of a choreography that reflects the music's character

Dancing quadrocopter
an introduction

- Our work focused on:
  - design
  - control
  - and synchronization of the rythmic quadrocopter motion

- Major challenges include:
  - Motion Design
  - Motion Control
  - Motion Synchronization

Major challenges

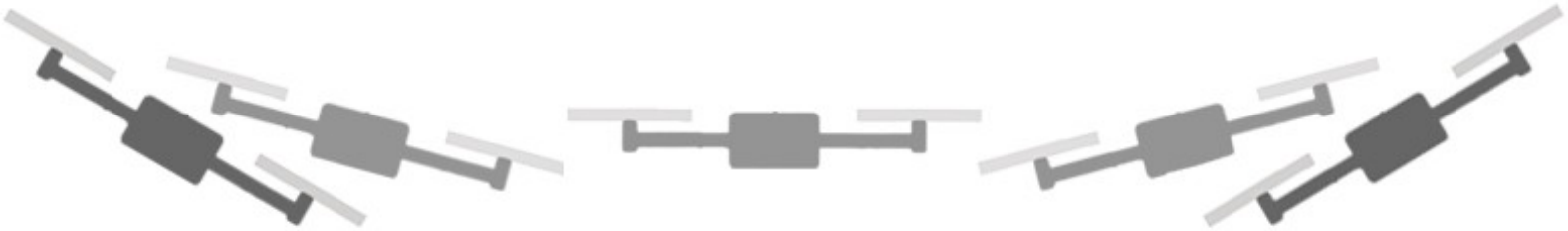
some issues

- Motion Design
  - Translate music into suitable motion patterns
  - Cannot just replicate human movements
  - Motion has to meet vehicles' constraints
- Motion Control
  - Quadrocopters are unstable and highly nonlinear systems
  - Following precise path needs sophisticated controller
- Motion Synchronization
  - Motion must be timed to the music beat

Motion design

moving with the beat

- Design a periodic motion
- Choose the period to match the music beat (or multiple of it)
- Example
  - A side-to-side motion



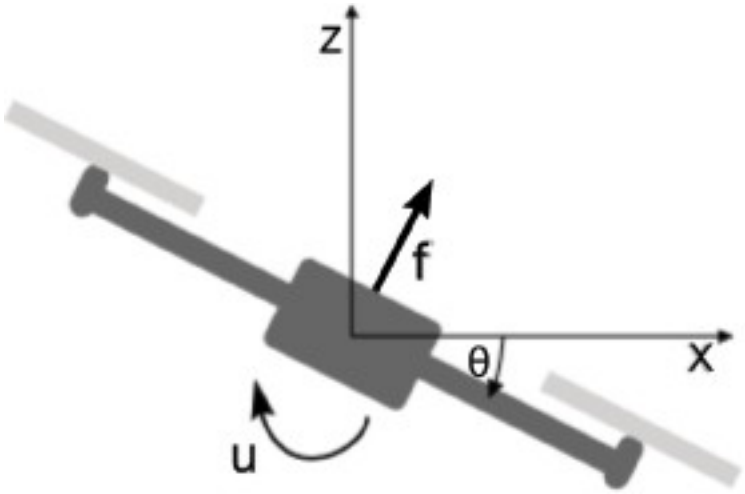
$$x_d(t) = A_d \cos(\omega_d t)$$

Motion control

based on a first principles model

- Start with 2D model

$$\ddot{z}(t) = f(t)\cos\theta(t) - g$$
$$\ddot{x}(t) = f(t)\sin\theta(t)$$
$$\dot{\theta}(t) = u(t),$$



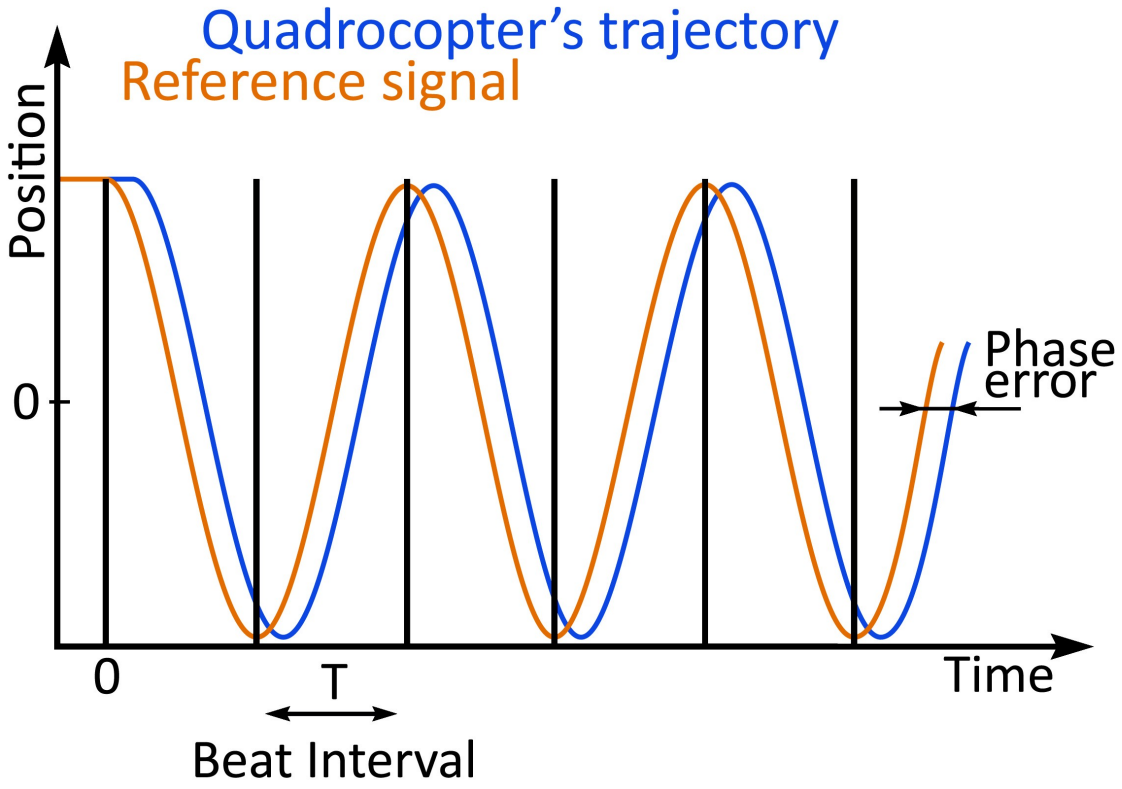
- Input-output linearization leads to

$$\ddot{x}(t) = g\,\theta(t) \quad \Leftrightarrow \quad \dddot{x}(t) = g\,u(t)$$

Motion synchronization

motion has to be timed to music

- Phase error between reference trajectory and actual quadrocopter's trajectory



**The synchronization problem

Phase error detection

- Phase Comparator
  - ω_d : Desired frequency
  - φ_t : Phase error

$$\eta_1(t) = \frac{1}{T_d} \int_{t-T_d}^{t} x(t) \cos(\omega_d t)\ dt = \frac{A}{2} \cos\varphi_t$$

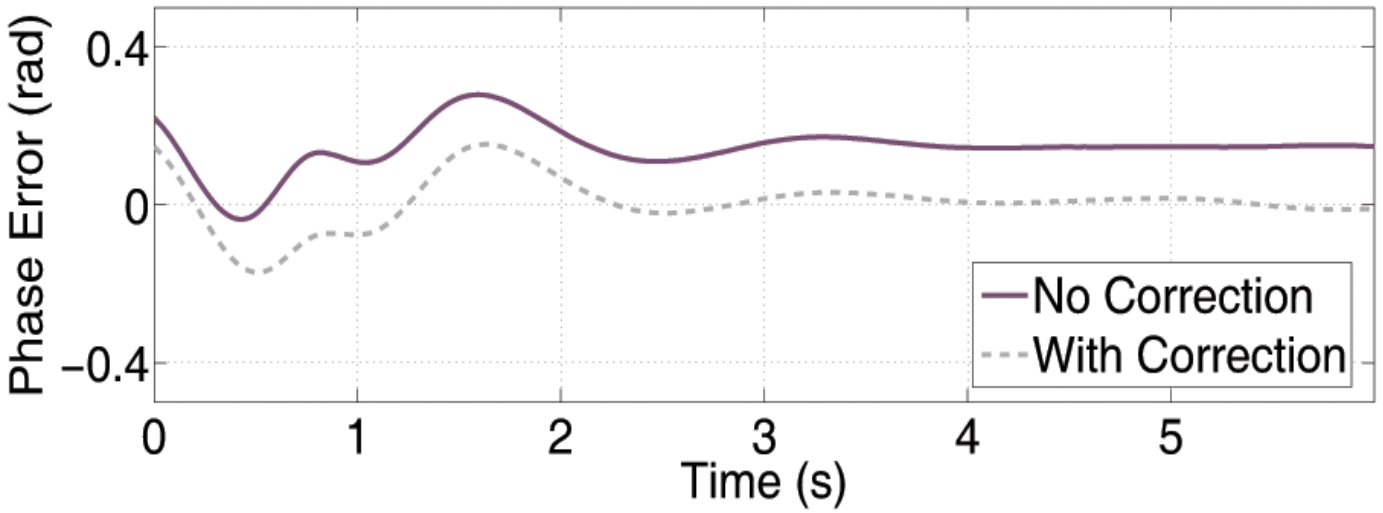
$$\eta_2(t) = \frac{1}{T_d} \int_{t-T_d}^{t} x(t) \sin(\omega_d t)\ dt = -\frac{A}{2} \sin\varphi_t,$$

$$\varphi_t = -\arctan\left(\frac{\eta_2(t)}{\eta_1(t)}\right)$$

The synchronization problem

Phase error correction

- Compensate for the constant phase error with an integral term



A. Schöllig, F. Augugliaro, S. Lupashin, and R. D'Andrea, "Synchronizing the motion of a quadrocopter to music," in *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*, 2010, pp. 3355–3360

The synchronization problem

Further results

- Define periodic motion primitives as Fourier Series

$$s_d(t) = a_0 + \sum_{k=1}^{N} a_k \cos(k\,\Omega t) + b_k \sin(k\,\Omega t)$$

- A framework to establish feasibility has been developed

Angela Schöllig, Markus Hehn, Sergei Lupashin, Raffaello D'Andrea
Feasible Periodic Motion Primitives for Choreographed Quadrocopter Flight
American Control Conference (ACC), 2011, submitted.

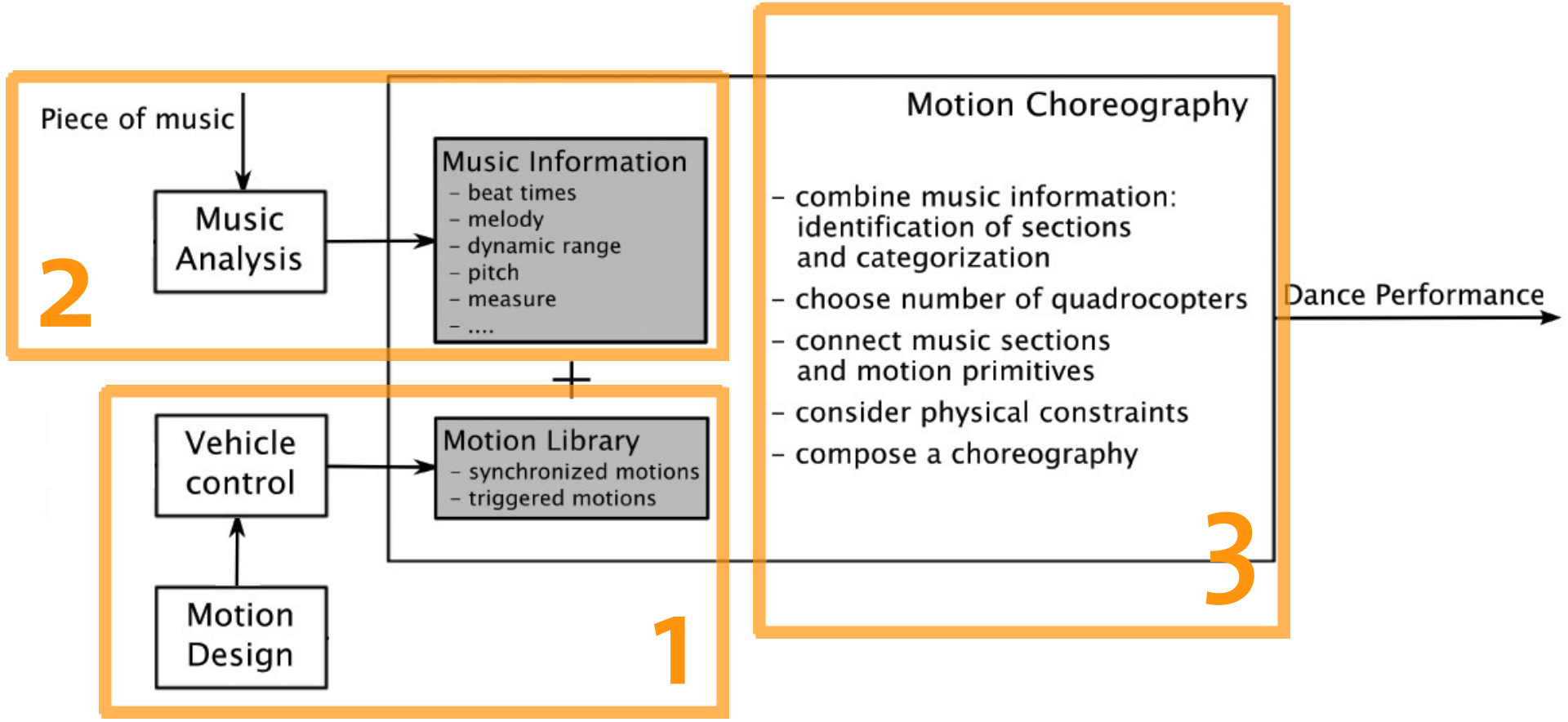
Towards a dance performance
a motion library

- Synchronized Motion
  - Must be precisely synchronized to the beat (or multiple of it)
  - e.g: Side-to-side motion
- Triggered Motion
  - Not strictly linked to the rhythm of the music
  - Used as transition between two synchronized motions or to reflect a particular music section (e.g. intro, transitions)
  - Aggressive trajectories like flips, eights, circles,...

Library

Towards a dance performance

the concept



Music analysis

emulating human perception

- Beat times can be readily extracted, but human comprehension of music is not limited to rhythm
- Dancing movements are also a reaction to the emotions transmitted by the music
- Can a mathematical analysis of music emulate human perception?

Music analysis

extracting useful features from music

- Technical Features
  - Beat times
  - Dynamic Range
  - Pitch
  - Measure
  - ...
- Human-related Features
  - Emotions
  - Mood
  - ...

Vocabulary

To describe music sequences

Music analysis

a basic description of music

Section: 2
BPM: 100
Adjectives: Fast, Funny

Section: refrain
BPM: 100
Adjectives: Fast, Happy

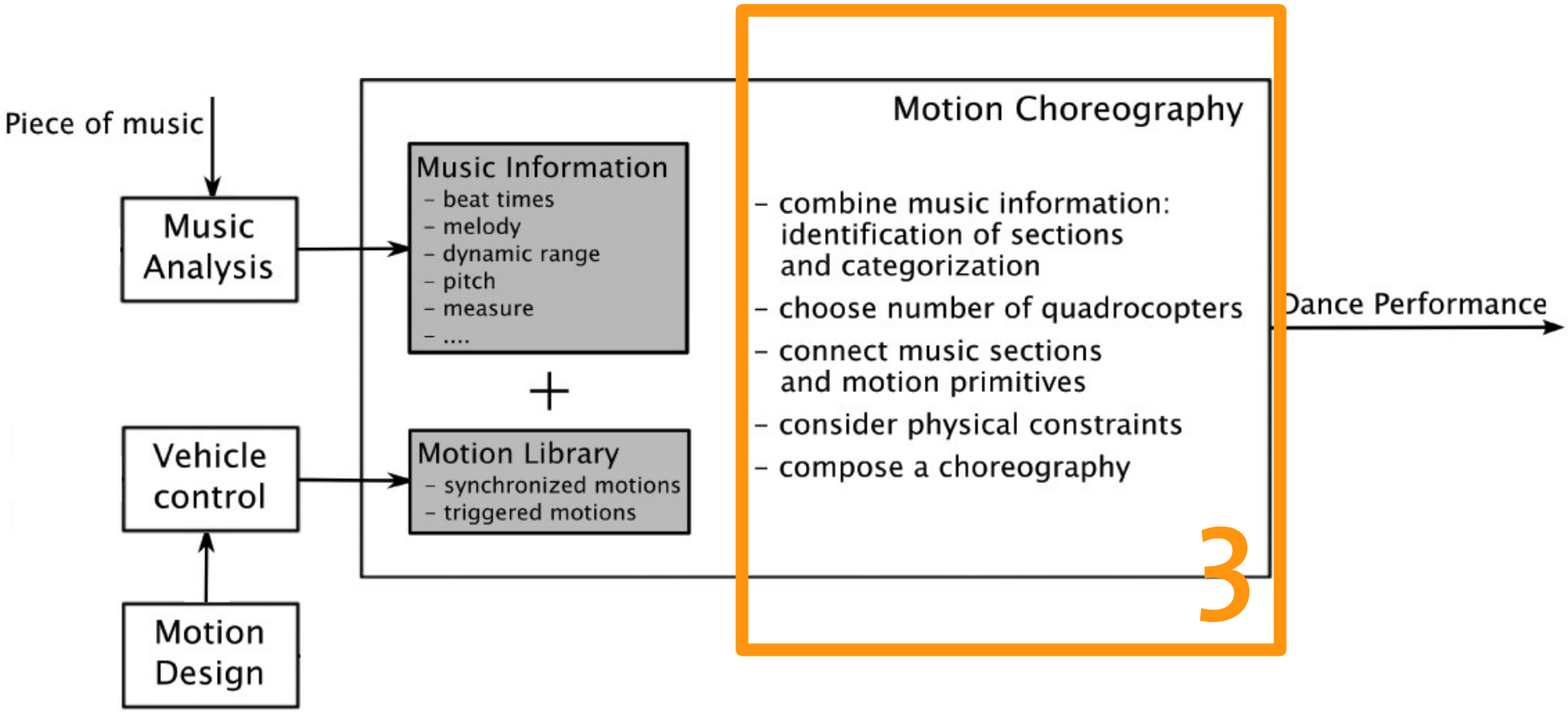
Section: refrain
BPM: 100
Adjectives: Fast, Happy

Section: 1
BPM: 80
Adjectives: Slow, Sad, Intense

1. **Average BPM**: 100 BPM
2. **Genre**: 80's
3. **Mood**: Party

Towards a dance performance

the concept



Motion choreography

combine music analysis with the motion library

- Humans just need some artistic skills to create a nice choreography

- How can be *beauty* evaluated by a machine?

**Motion choreography

choreographer's parameters for human dance

- Space
  - how the dancer moves through the area
  - characterized by the path of a movement, its size, level, and shape
- Time
  - rhythm, tempo, duration, and phrasing of movements
  - e.g. quick-quick, slow or stop movements
- Energy
  - Relates to the quality of the movement (e.g. ballet vs. tap dance)
  - Soft and smooth, or sharp and energic
- Structure
  - organization of movement sequences into larger concepts
  - combination and variation of movements using recurring elements, contrast, and repetition

Motion choreography

how to compose a pretty dance performance?

- Characterize motion primitives with respect to
  - Time
  - Space
  - Energy
  - Structure
- Combine them with music information in a *meaningful* way
- Creativity and aesthetic judgment is required to achieve artistic quality

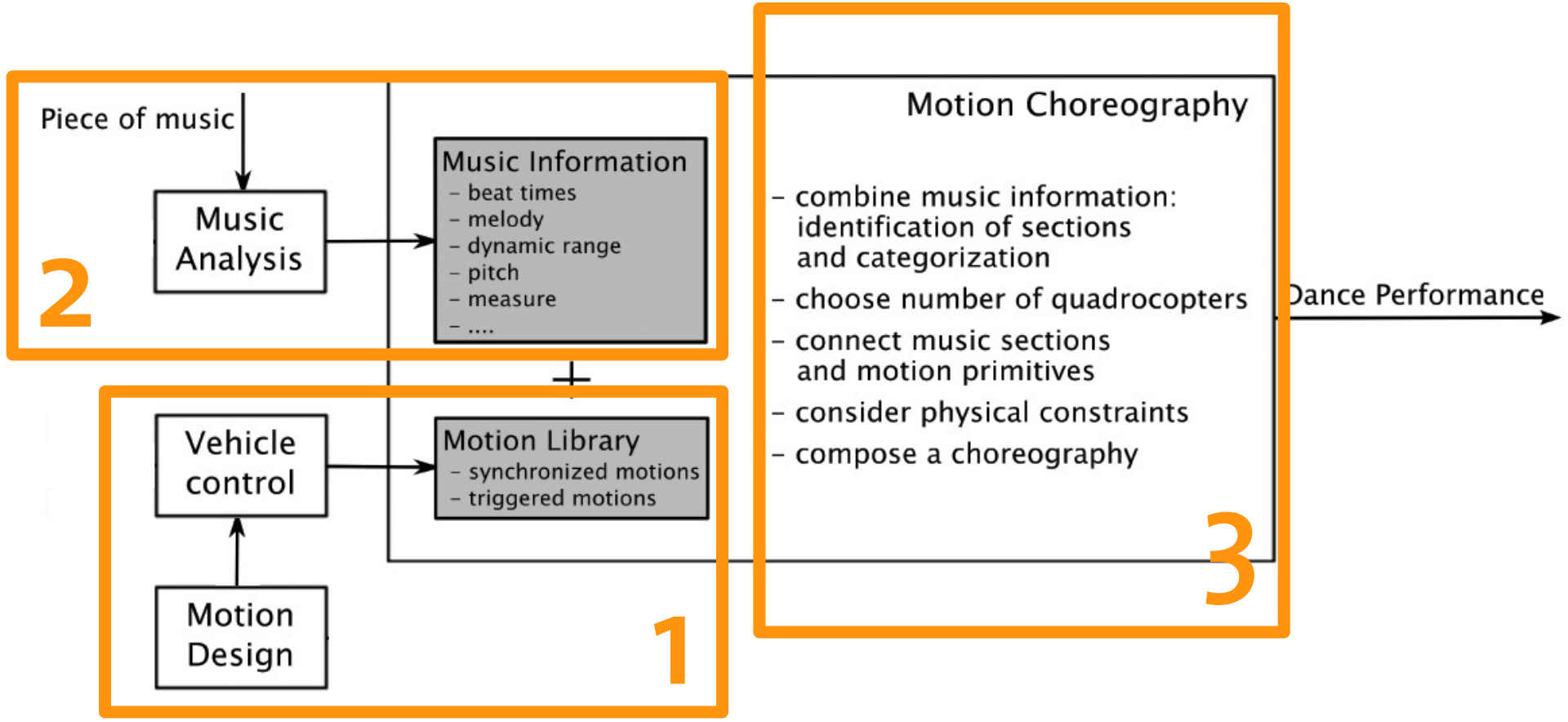
Supervised learning

What is *nice*?

Human rating will guide the process

Towards a dance performance

the concept



Current status

Dance performances

- Motion library
  - Basic side-to-side motion
  - Theoretical results and software/hardware framework for readily evaluating the feasibility of a movement
  - Currently expanding the library with other synchronized and triggered motions
- Music analysis
  - Currently using a beat extractor tool (rhythm)
  - Exploring music analysis methods
- Motion choreography
  - Brainstorming
  - Project starting in the group in February 2011

Current status

where we are

- Dance performances
  - 2 quadrocopters dance: Pirates of the Caribbean
  - 3 quadrocopters dance: Rise Up

Long Video Here (~2 minutes)

Recap

- Goal
  - A system able to process any kind of music and compose a choreography for it in a reasonable time (minutes).
- What we have
  - A reliable platform consisting of various quadrocopters and an expanding motion library
- What we need
  - A collaboration with experts from the MIR Community
  - Know-how, ideas
  - A tool which can provide a description of a music piece

Contacts

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- www.idsc.ethz.ch >> Research D'Andrea >> Music in motion