

## From human interaction...



## ...to human-robot interaction!

### Movement synchronization...

- ... is a naturally emerging phenomenon between humans.
- ... is hardly avoidable [3,4].
- ... is related to human social interaction by increasing rapport [5].
- ... might improve joint task performance by enhancing perceptual sensitivity between interaction partners [8].

### Challenges for transfer to HRI

1. Precision during goal-directed actions (→ necessary in pick-and-place tasks)
2. Mismatched capabilities
3. Moving in close proximity (→ danger of colliding with objects/ each other)

### Applied in HRI, movement synchronization...

- ... enables robot learning by imitation/ through social feedback [8].
- ... enables turn-taking among humans and robots [9].
- ... may increase predictability [7] and thus safety during interaction.
- ... may increase rapport and social acceptance.
- ... improve joint task performance.

### Work packages for HHI

1. Exploring the underlying dynamics of the reaching actions (and grasping)
2. Does movement synchronization emerge in goal-directed tasks?
3. Does movement synchronization emerge under mismatch/ disturbance?



### Work packages for HRI

1. Develop an implementable model of human movement synchronization
2. Does synchronization emerge during HRI under similar constraints as between humans? → test validity of the proposed model

## A Paradigm

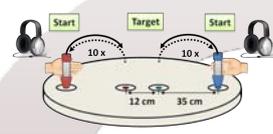
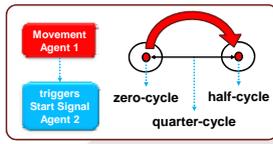
### ...to explore human movement synchronization

#### Setup:

- Table with individual start and target position
- 2 Agents with a pen in right endeffector
- Headphones for acoustical start and stop signals
- 3 Start delays to avoid trivial synchronization
- PTI Phoenix Motion Tracker (sampling rate: 200 Hz)

#### Instructions

1. Place pen in start position
2. Start signal (auditory via headphone for the human)
3. Lift pen and tap in the target position
4. Move back and tap start position  
→ To be continued until stop signal



## A model...

### ...of human movement synchronization

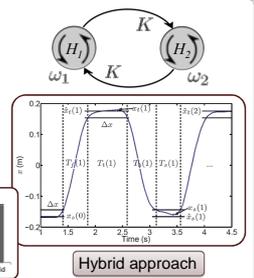
- 2 Coupled oscillators (inspired by the Kuramoto model)
- Extended to enable both in-phase and anti-phase synchronization [11]

#### Phase signal is derived with different methods

- State-space: Phase angle of normalized state
- Spectral approach: Hilbert Transform
- Hybrid approach:
  - 2 Movement Segments: inverted minimum-jerk
  - 2 Dwell Segments: linear phase progress

#### Model parameters

- coupling strength  $K$
- frequency detuning  $\Delta\omega$



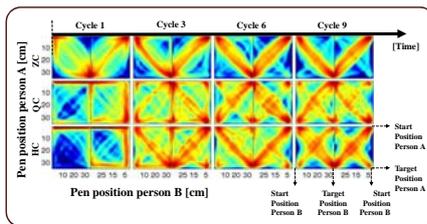
## Human Movement Synchronization...

### ... in goal-directed tasks ?

#### Experiment 1: 10 dyads [11,16]

Do humans synchronize in goal-directed tasks?

- Simultaneous start: in-phase
- Delayed start:
  - People need more time to synchronize
  - In-phase and anti-phase relation
- Information of forwards movement is used to predict the other's behavior
- Dwell times are adjusted by resting in start or target area



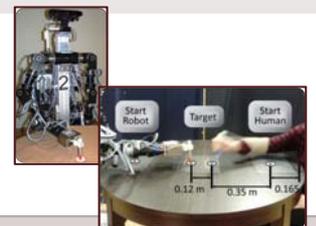
## Human-Robot Movement Synchronization...

### ... with a non-adaptive robot?

#### Experiment 4: 8 participants/ anthropomorphic robot [14]

Do people synchronize their hand movements to a non-adaptive robot in the same way they synchronize to a human?

- Movement synchronization does not emerge as in HHI
- might require bidirectionality [15]

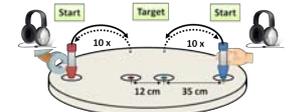


### ... with an adaptive robot?

#### Experiment 5: 8 participants and anthropomorphic robot [14] (ongoing work)

Do people synchronize their hand movements to an adaptive robot?

- Exploration of different coupling strengths.
  - How adaptive should the robot be
  - To be accepted by the human ?
  - While still successfully enabling movement synchronization?

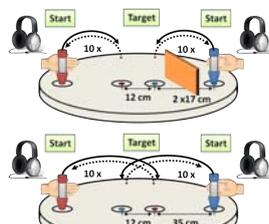


### ... during mismatch and complications

#### Experiment 2: 20 dyads (ongoing work)

Do humans synchronize in goal-directed tasks if their trajectories differ?

- Synchronization emerges even if movement trajectories differ
- Due to the perceptual mismatch, establishing synchronization seems to be more complex



#### Experiment 3: (in preparation)

Do people synchronize with each other if they risk colliding?

## Movement synchronization...

- ... is naturally emerging also during goal-directed tasks
- ... is a very stable phenomenon of human interaction

- ... is a promising way to lead HRI towards
  - improved social acceptance
  - Improved safety
  - Improved joint task performance

## References

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