Haptic Interaction in Human-Human and Human-Robot Dyads

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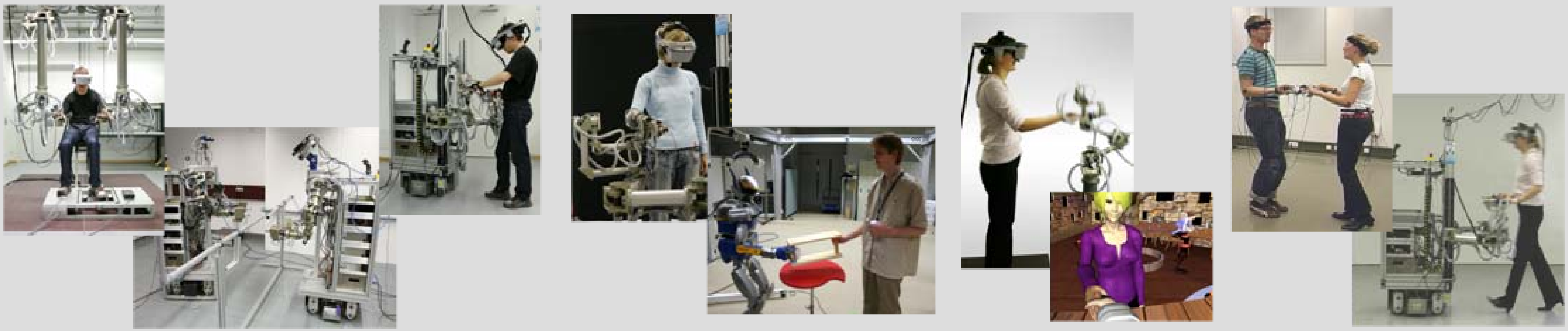
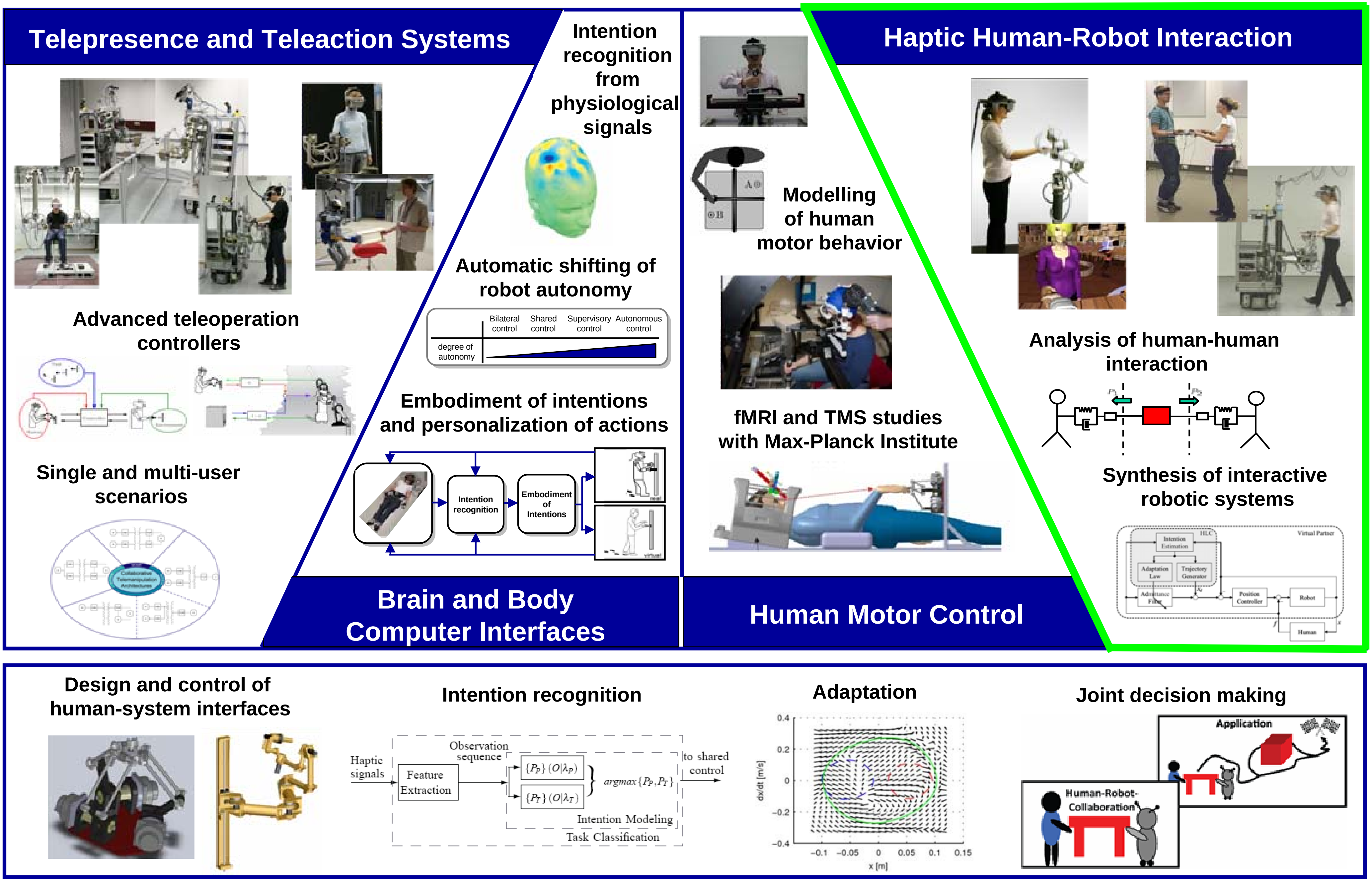


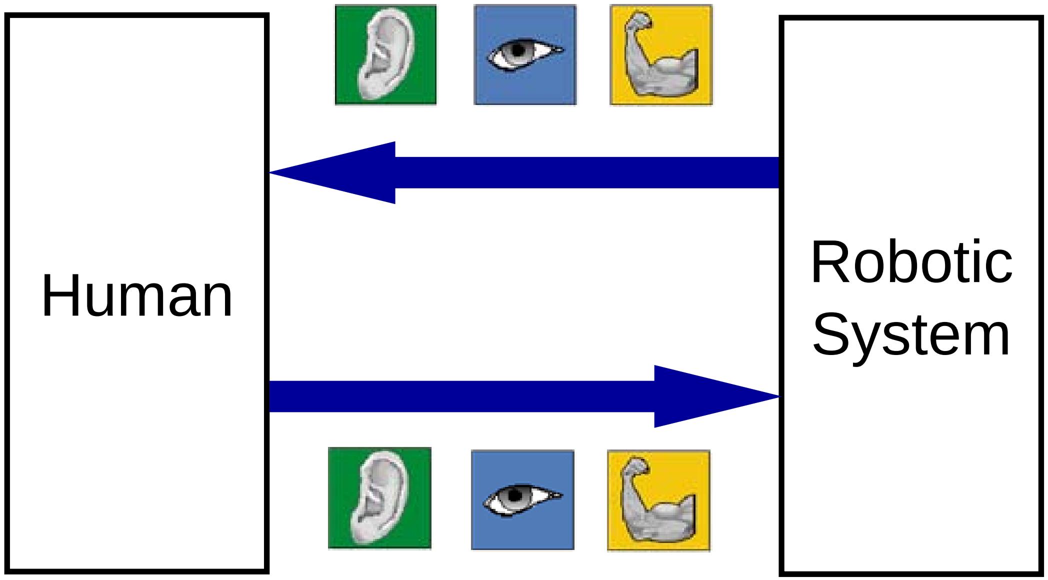
Towards Human-Centred Robotic Systems

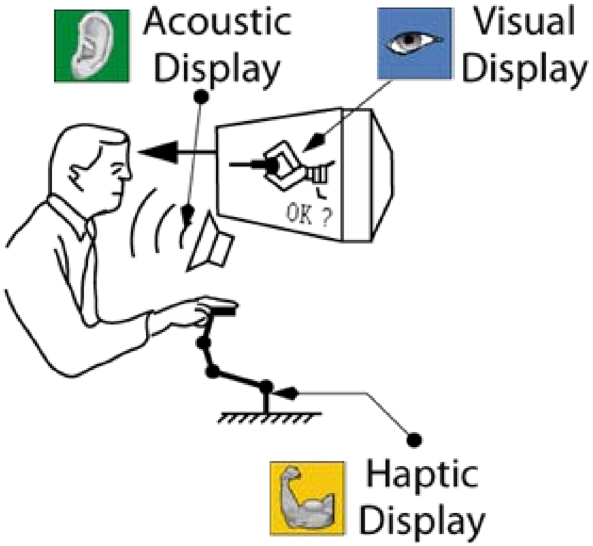
Human-Centred Robotic Systems

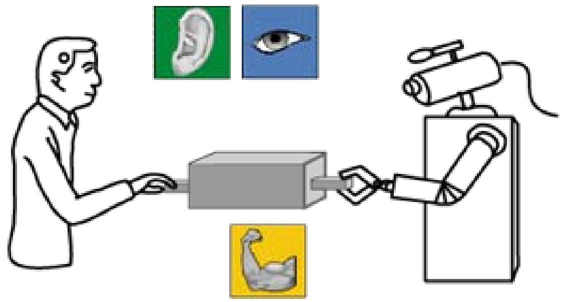


Haptics and other Modalities

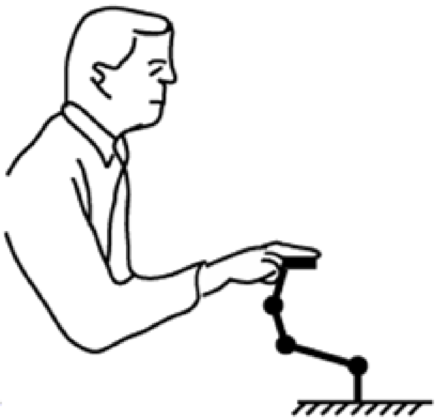
Haptics refers to the sense of touch





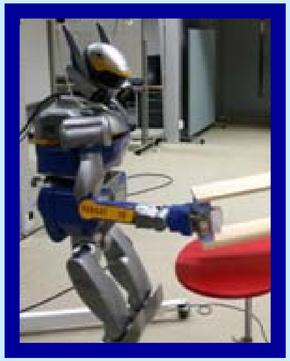


Haptic Interaction



Interaction with passive systems:

virtual



real

Interaction with active systems:

virtual

real

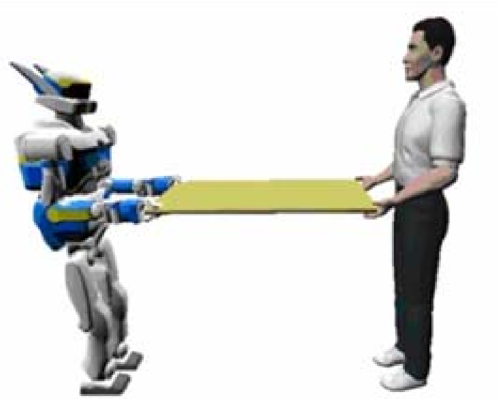
Interaction Types

- Direct human-robot interaction

[Buss et al., 2009]

[Honda]

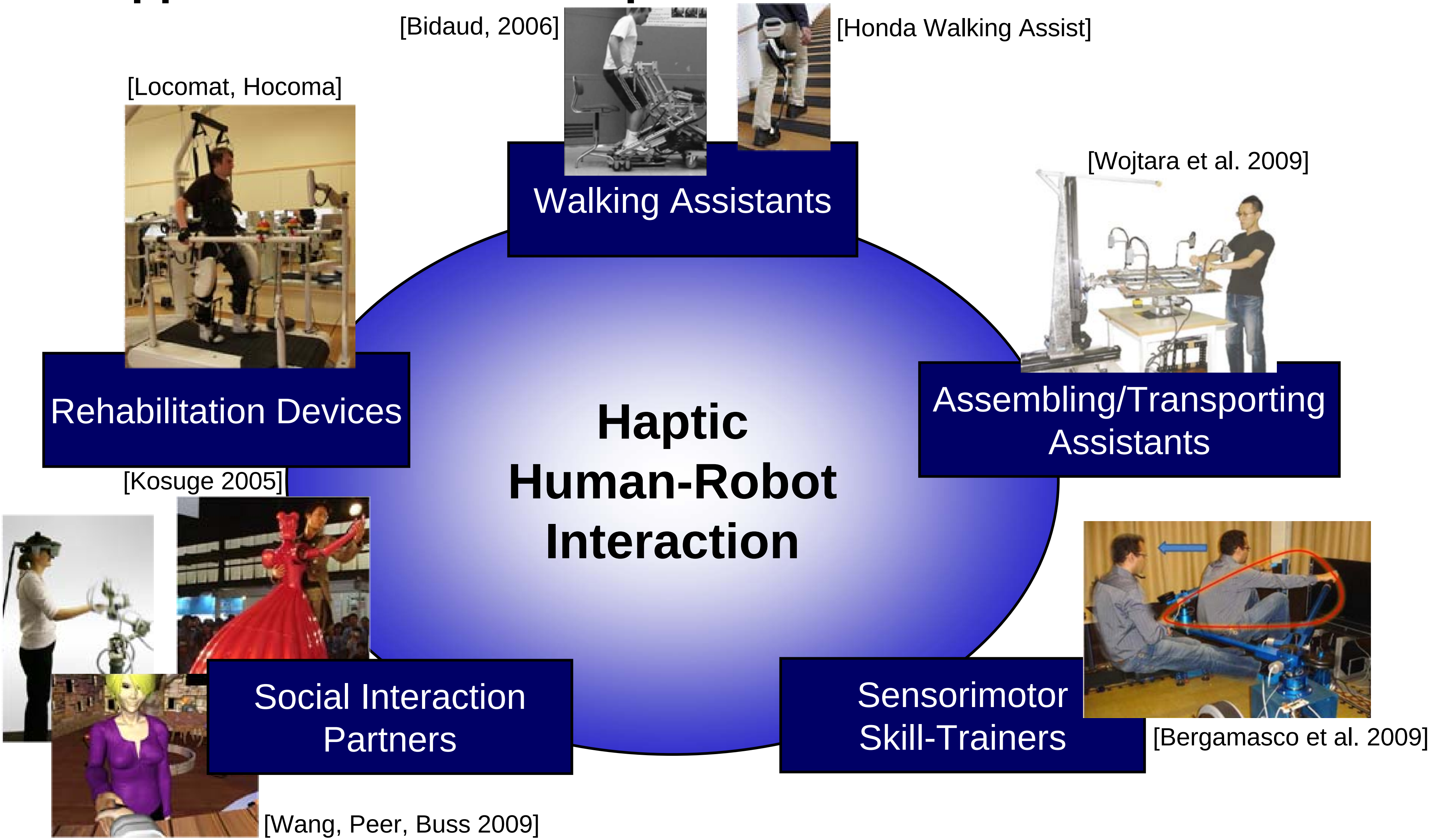
- Human-robot interaction mediated by an object



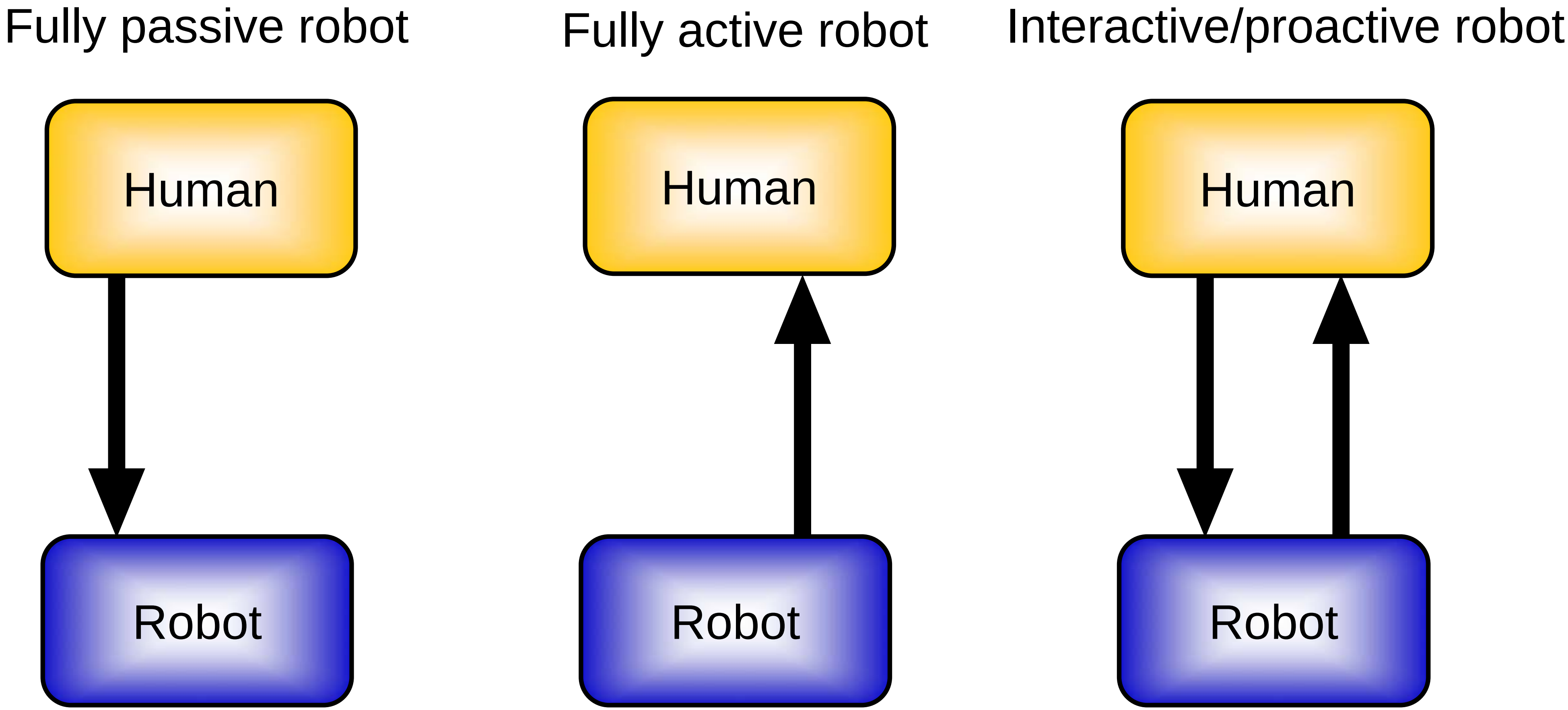
[AIST/JRL]

[Wojtara et al. 2009]

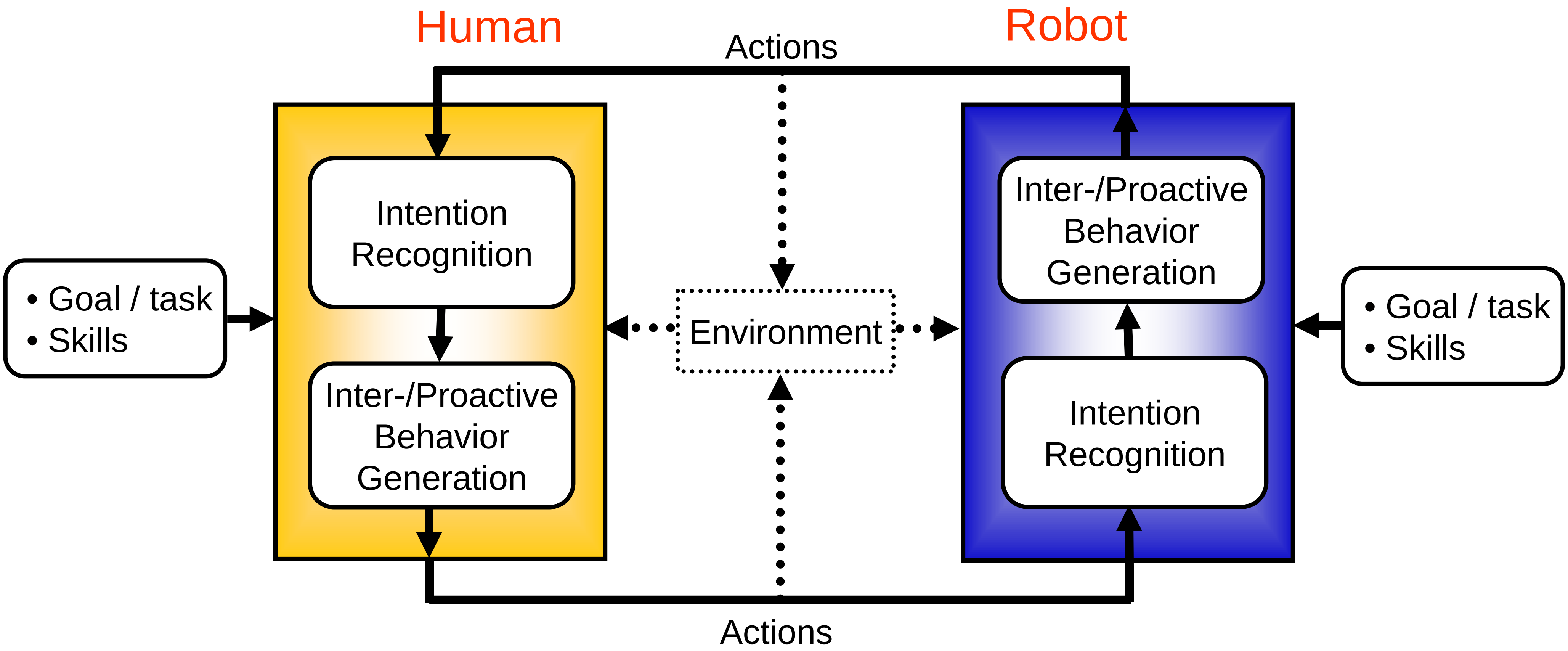
Application Fields of Haptic Human-Robot Interaction



Interactive / Proactive Robot vs. Fully Passive/Active Robot



Haptic Human-Robot Interaction



State of the Art

Human intention recognition:

- recognition of human intention to accelerate/decelerate by analyzing energy [Tsumigawa:2001] and force derivative [Duchaine:2007]
- recognition of task phase from motion/force data using production rules, NN, HMM [e.g. Kosuge:2007; Stefanov, Peer, Buss: 2009, 2010]

Fully passive robots:

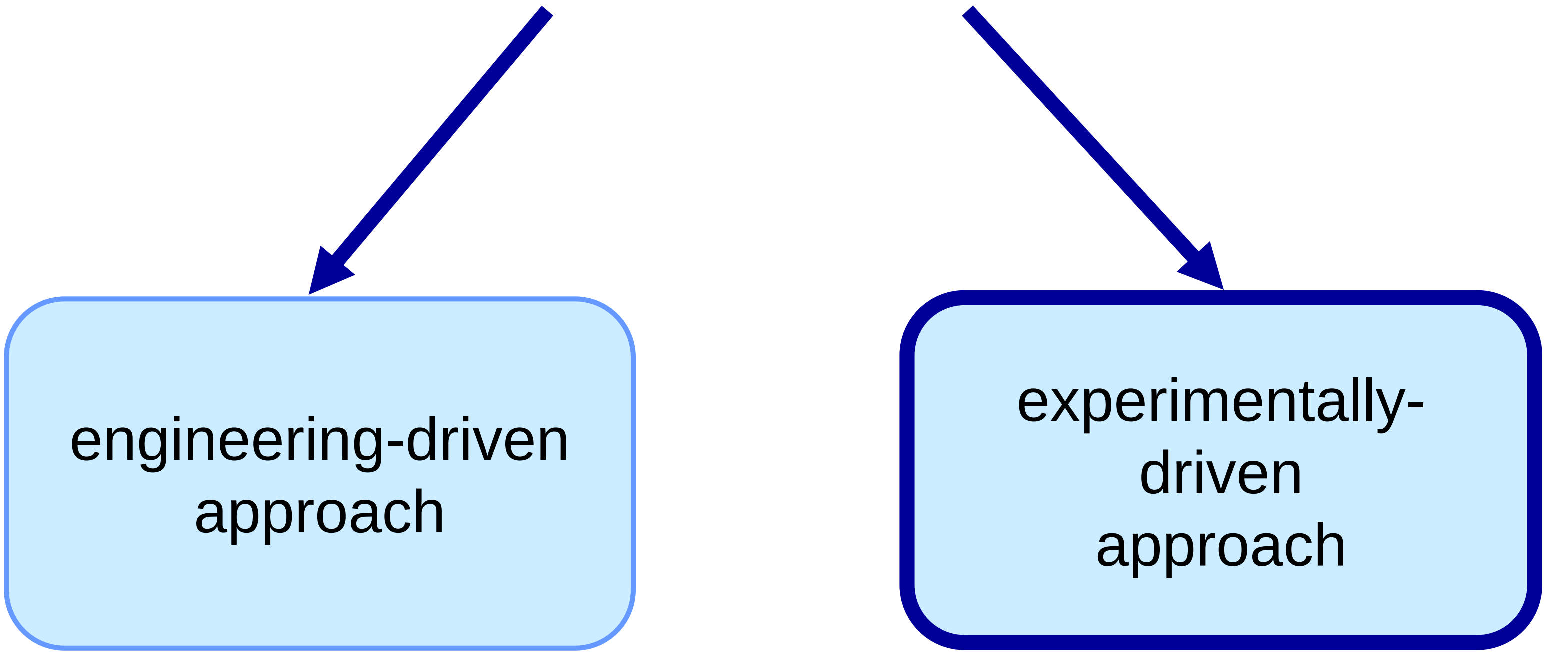
- Robots with constant impedance parameters [Kosuge:2000]
- Robots with human-like pre-recorded impedance characteristics [Rahman:1999]
- Robots with varying impedance parameters depending on human intention [Tsumigawa:2001, Duchaine:2007], human arm stiffness [Tsumigawa:2002], optimality functions [Ikeura:2002]
- Robots implementing virtual constraints [Arai:2000]

Interactive/proactive robot behavior generation:

- Robots implementing minimum jerk model [Maeda:2001,Corteville:2007]
- Robots implementing role sharing strategies: accelerator/decelerator [Reed:2007], active/passive [Wang, Peer, Buss:2009, Evrard:2009], weight and DOF seperation [Wojtara:2009]

Synthesis of Robot Behavior: Two Approaches

Synthesis of robot behavior



- performance-driven
- based on pre-knowledge or optimality criteria

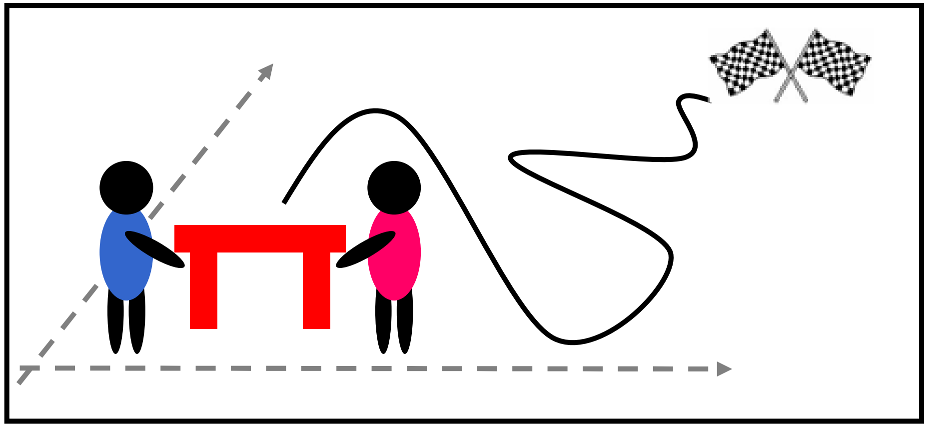
- human-centered
- based on experimental data

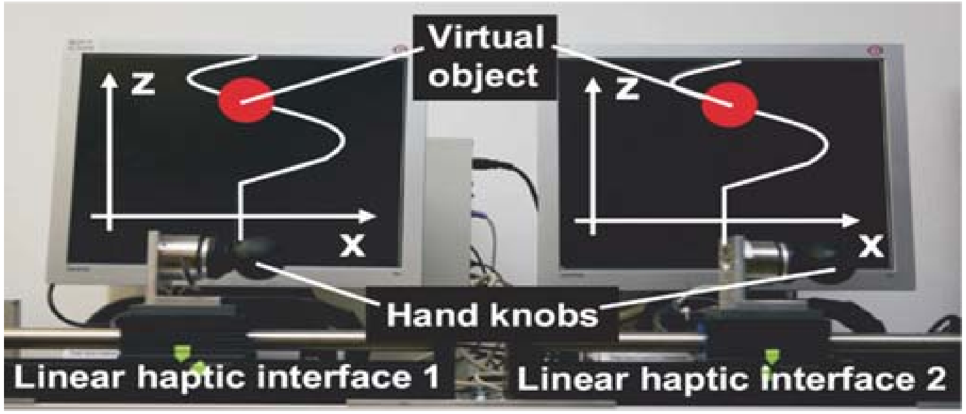
Experimental Paradigm to Investigate Haptic Collaboration

Research Questions:

- What influence has haptics on human-human collaboration?
- Do partners take over strategies?
- How do people adapt to each other?

Experimental paradigm: Shared path following

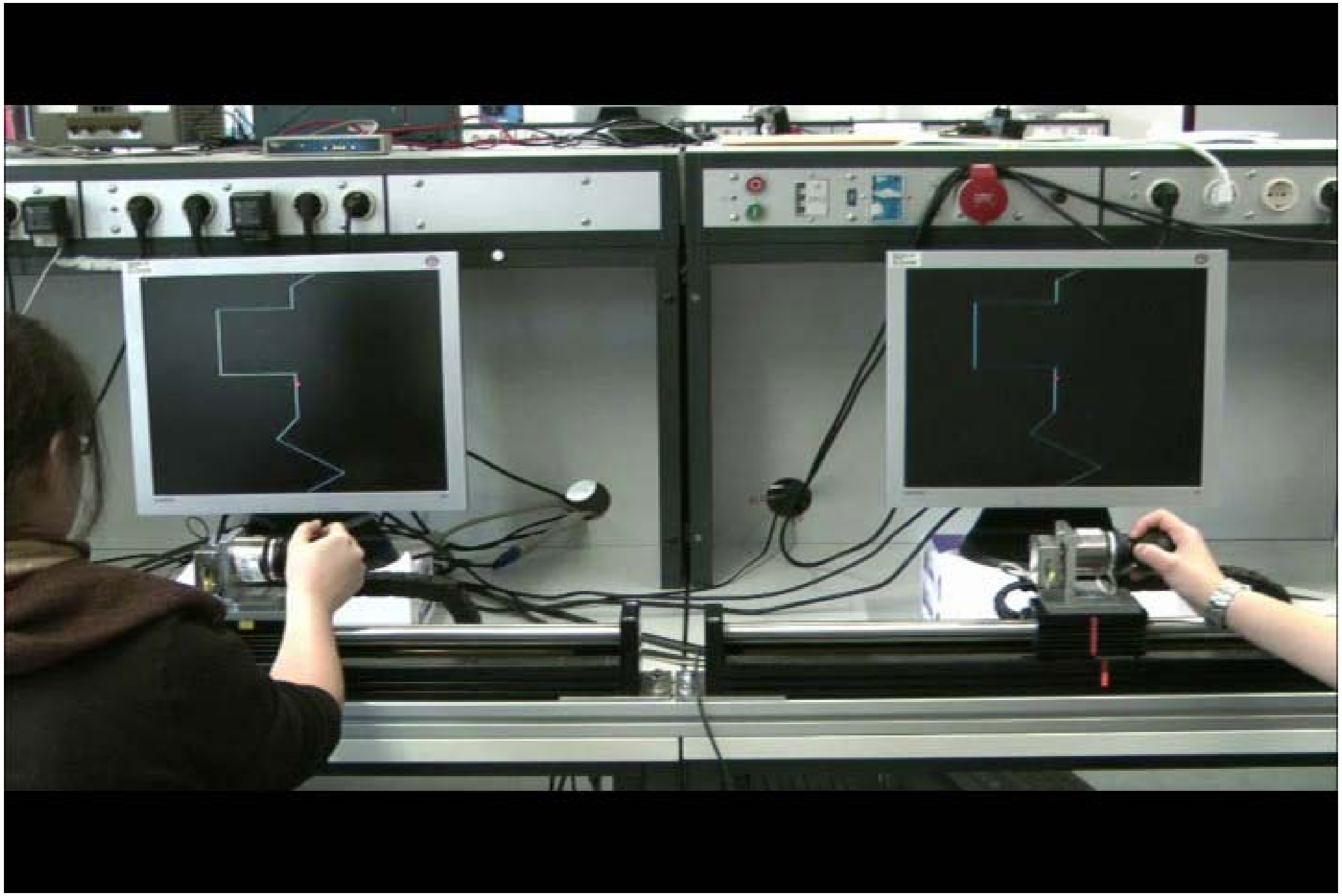




Investigated conditions:

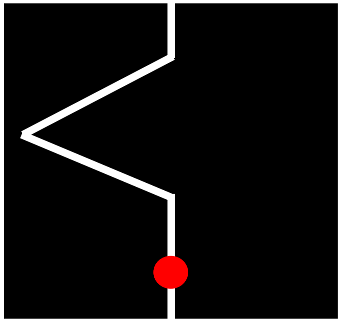
- Individual and dyadic condition
- With and without haptic feedback

Haptic Human-Human Collaboration



Levels of Haptic Collaboration

low-level of haptic collaboration

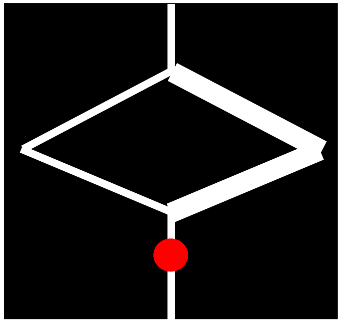


- 1DoF Pursuit Tracking Task
- Goal: stay on the track
- Action plan: follow the track

→ **Control / adaptation / strategies**

Application: joint carrying / placing

high-level of haptic collaboration

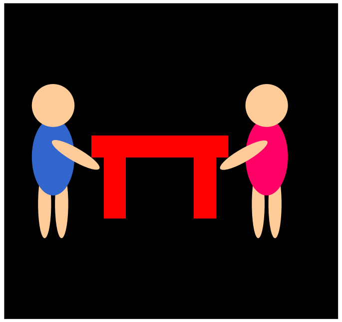


- 1DoF Pursuit Tracking Task
- Goal: stay on the track
- Action plan: follow one of the tracks

→ **Decision making**

Application: obstacle avoidance

haptic collaboration in daily activities



- More DoF
- Different tasks

→ **Generalization**

Dominance in Haptic Interaction

[Groten/Feth/Peer/Buss, Ro-Man 2009]

Dominance measure for haptic interaction:

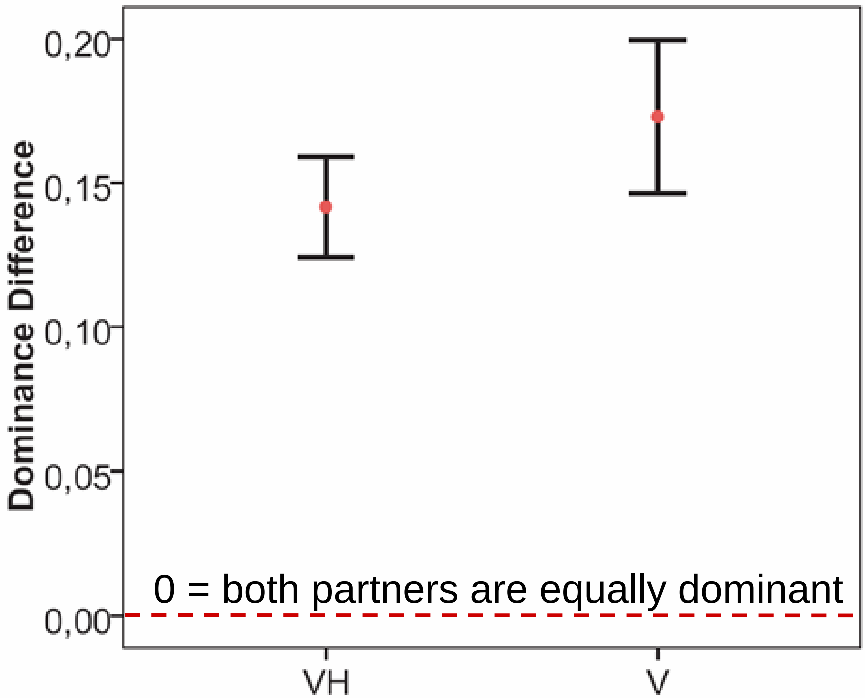
Individual

$$D_{12,i} = \frac{f^E_{1,i}}{f_{sum,i}}$$

Dyadic

$$\bar{D}_{diff} = |\bar{D}_{12} - \bar{D}_{21}|$$

- Time independent dominance: [.39, .61]
- One partner always domineers
- In both feedback conditions



Results:

Analysis of behavioral consistency

- Consistency **across partners** for V = 49% and VH = 64%
- 32% in V and 24% in VH depend on **interaction**

→ Adaptation

- Dyadic reciprocity: V= -.36; VH= -.52

→ Dominance differences between partners varies in sub-trials

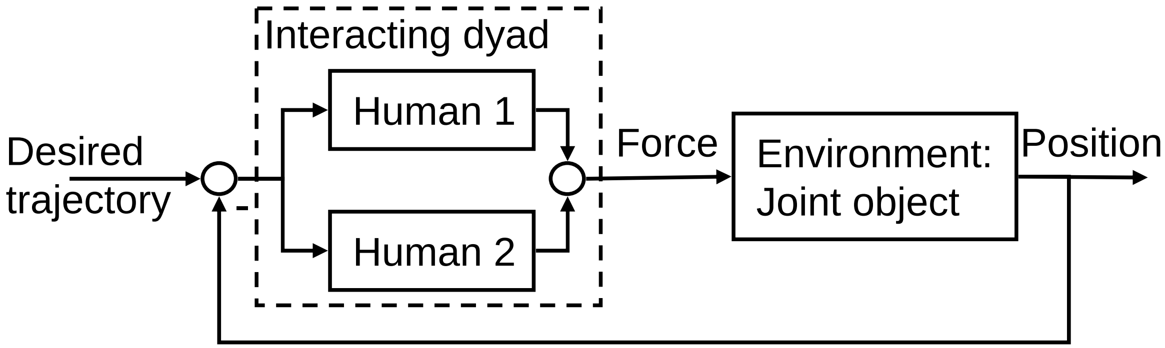
Control-theoretic Model of Haptic Human-Human Interaction

[Feth/Groten/Peer/Buss, Ro-Man 2009]

Crossover model of single human‘s behavior [McRuer/Jex, 1967]:

$$G_h(s) = \underbrace{\frac{e^{-\tau s}}{(1-T_p s)}}_{\text{Perception/action loop}} \underbrace{[K(1+T_z s)]}_{\text{Human control action}}$$

→ Extension to interacting dyad:



Results:

- Single operator
- Interacting dyad
  → Mutual adaptation
- Individual within interacting dyad
  → Future work

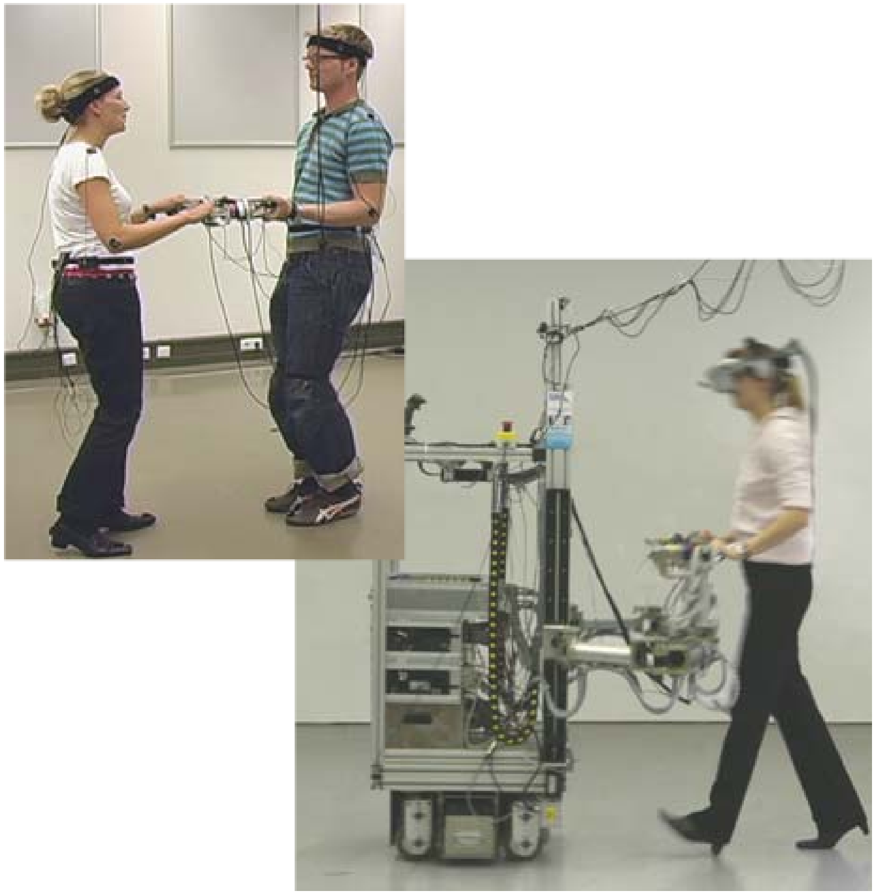
Lessons Learned

- Haptic feedback leads to higher predictability of behavior (consistency analysis)
- With haptic feedback the communication between partners is supported (performance in decision making)
- Control architectures for haptic collaboration should provide unequal dominance values for the involved partners (dominance analysis)
- Humans mutually adapt to each other → adaptation capabilities of technical partner required

Two Prototypical Scenarios

Human-robot handshaking

Human-robot dancing

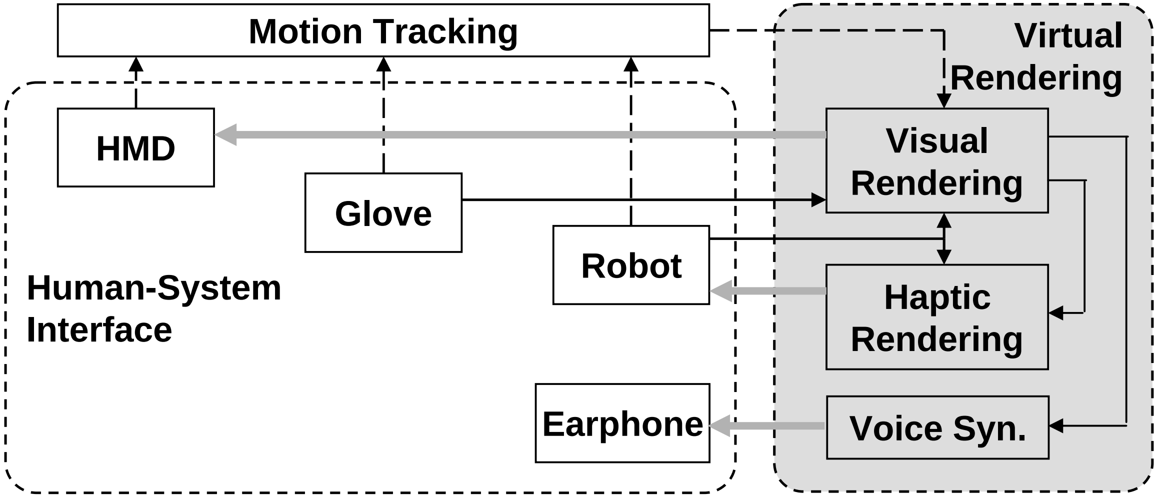


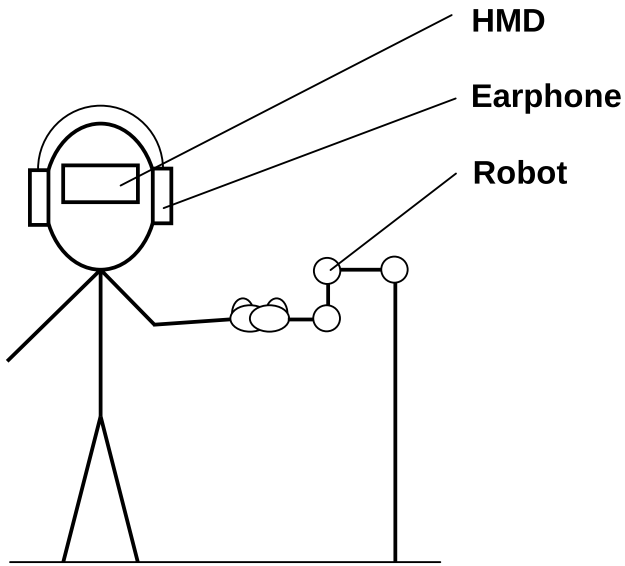
Human-Robot Handshaking

Overall goal:

- Replace one human in handshaking with a robot
- Multi-modality: haptics, vision, audio
- Recreate handshake arm dynamics
- Provide the human participant with a realistic handshaking experience

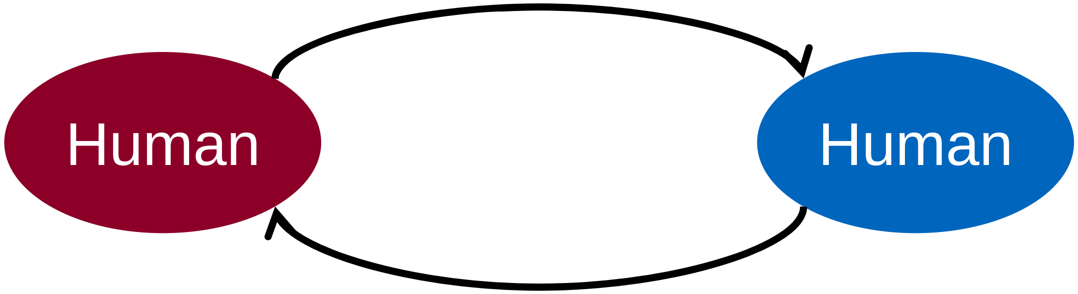
[Wang, Lu, Peer, Buss, EH2010]



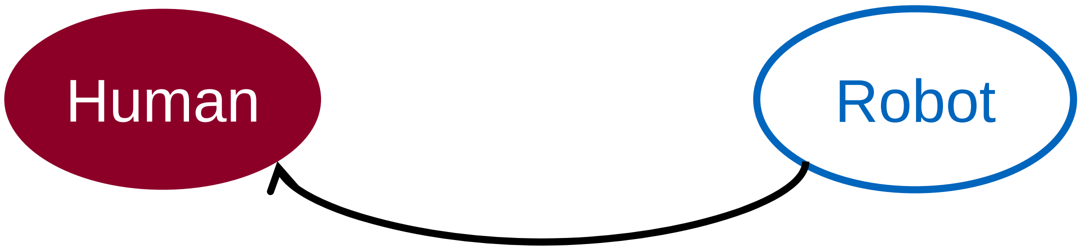


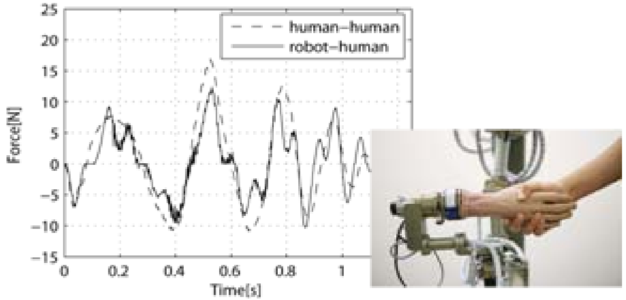
Our Approach: Record – Replay – Recreate

Record

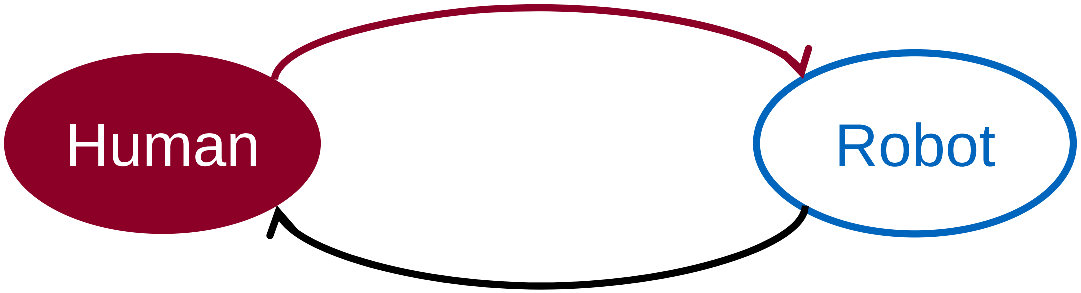


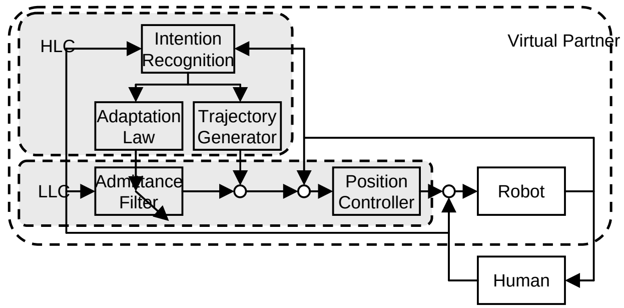
Replay





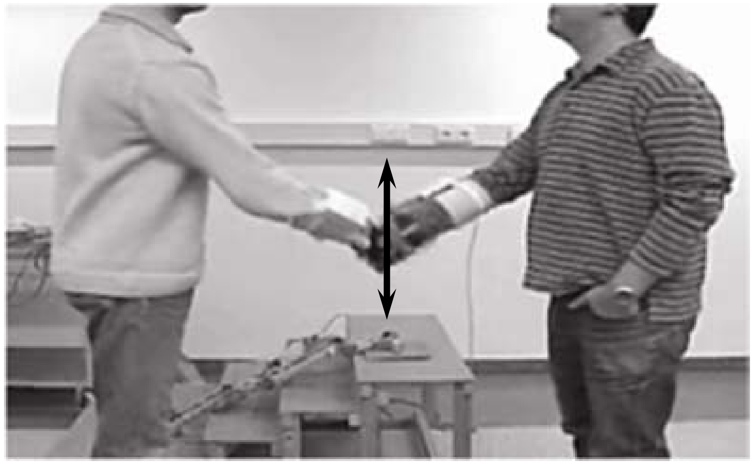
Recreate

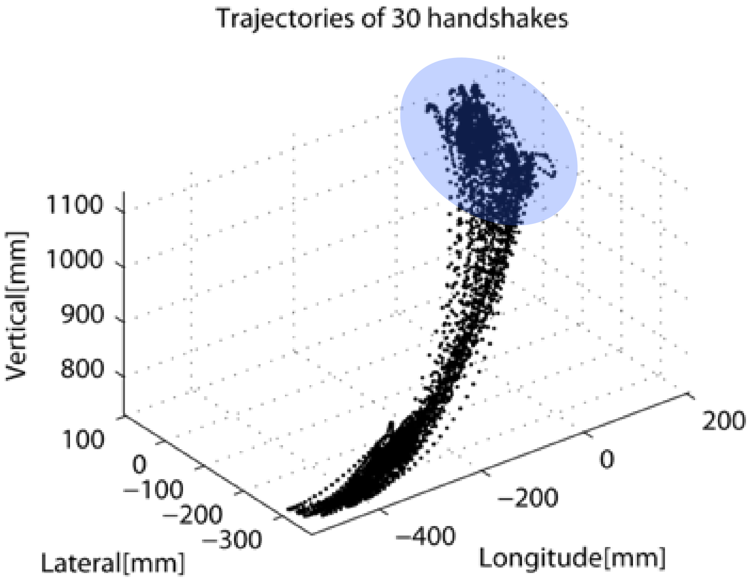




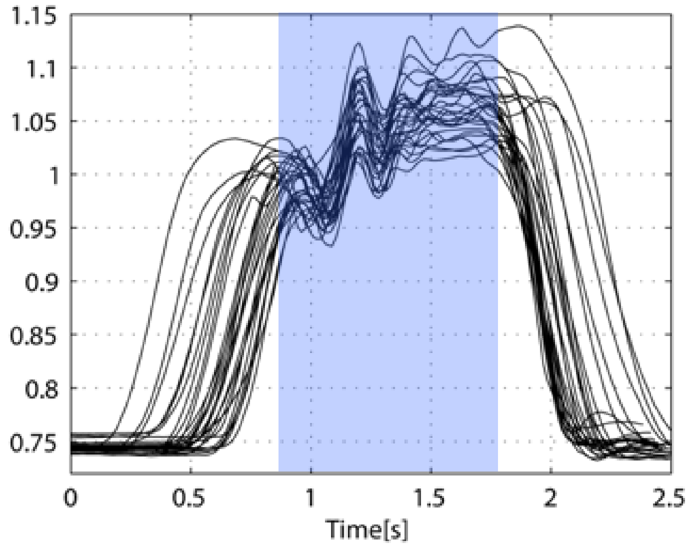
Recording Handshakes

- 900 human-human handshakes
- similarity and variance
- 3 stages: approach, **shake**, release





3-D motion trajectories of 30 handshakes



Vertical-time motion trajectories of 30 handshakes

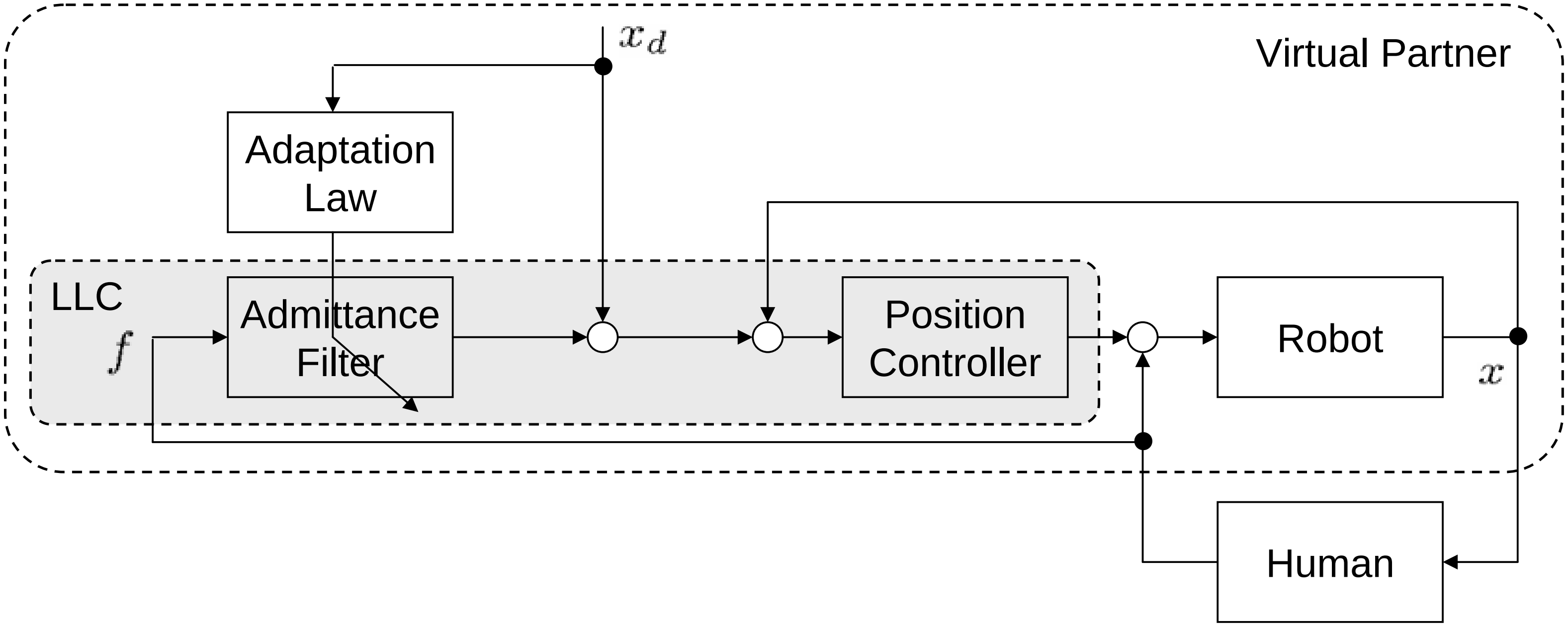
Replaying Handshakes

[Wang, Peer, Buss, WHC2009]

Replay strategy:

- Replay of pre-recorded trajectories x_d
- Admittance filter to provide compliance, parameters adjustable with respect to the reference trajectory

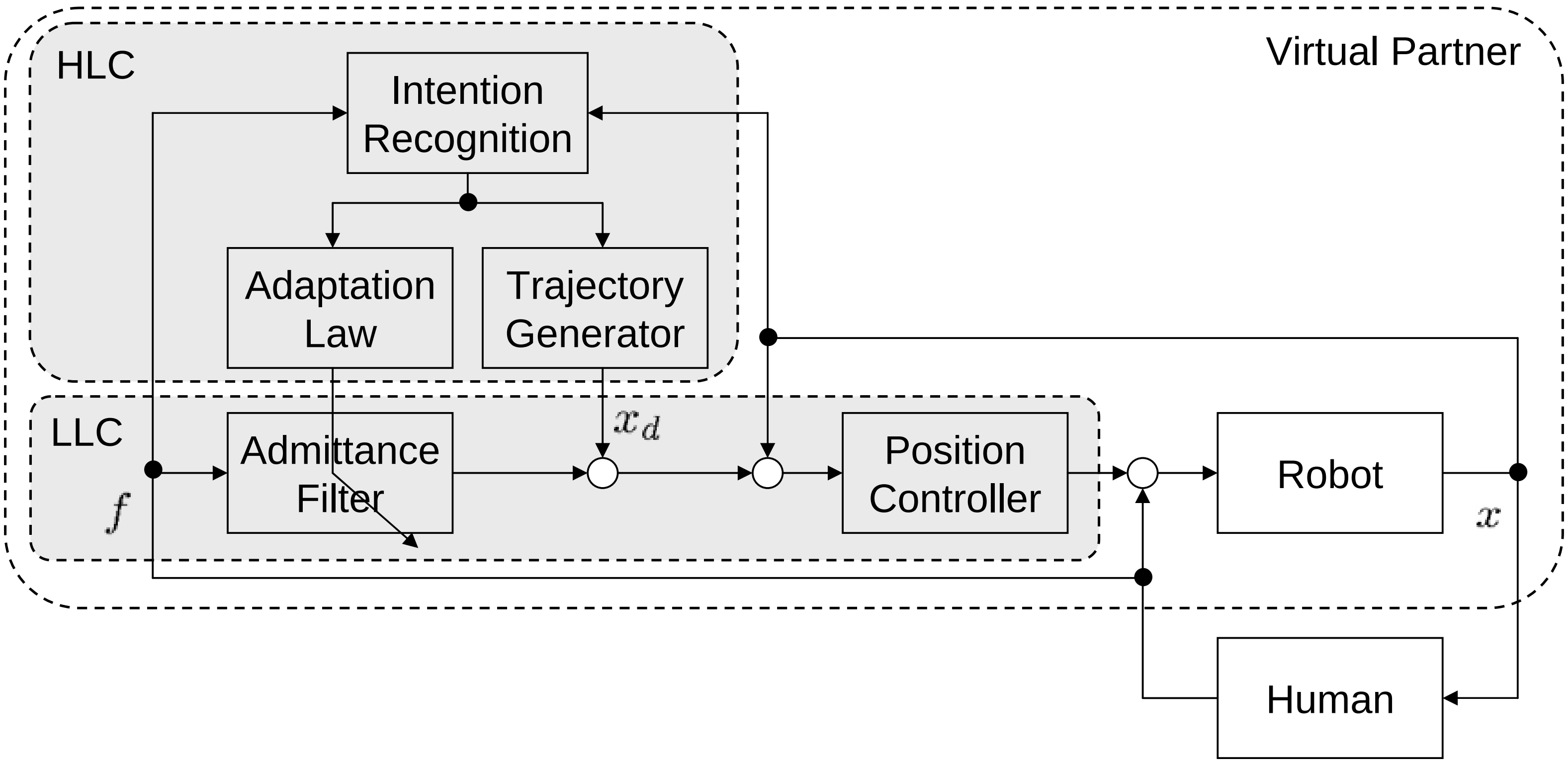
$$f(t) = M(t)\ddot{x}(t) + B(t)\dot{x}(t) + K(x_d)(x_d(t) - x_0)$$
$$K(x_d) = K_0 + \lambda(x_d(t) - x_0)$$



Recreating an Inter-/Proactive Handshake Partner

[Wang, Peer, Buss, ICM2009; WHC2009]

- Implementation of additional **high-level controller**
  → Trajectory generation / impedance adaptation based on human intentions

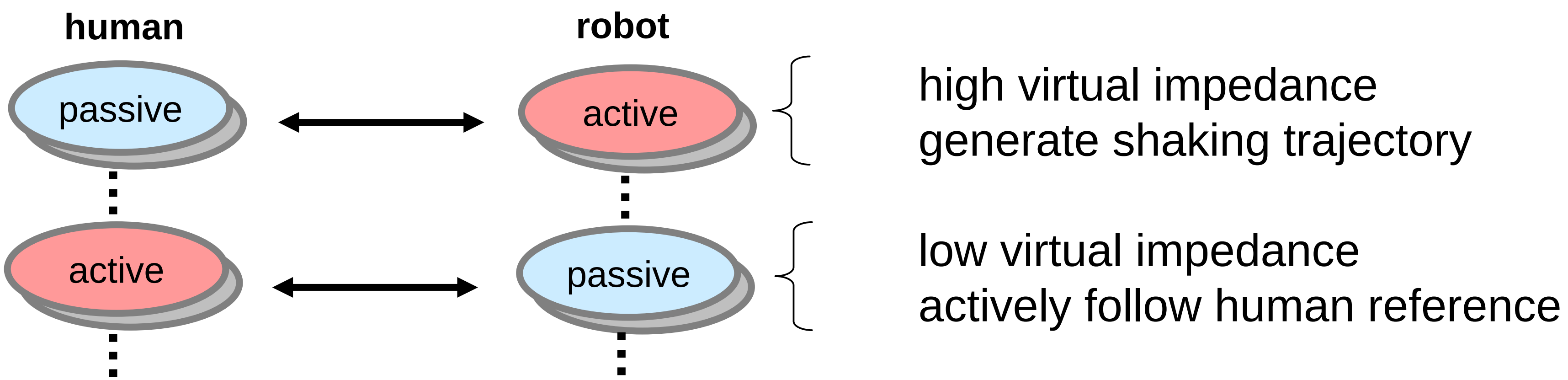


Recreation Strategy

- Partners can select between **two different strategies** when performing a handshake:

  1. „active“ → take over the lead and decide on the joint trajectory
  2. „passive“ → follow as best as possible the lead of the partner

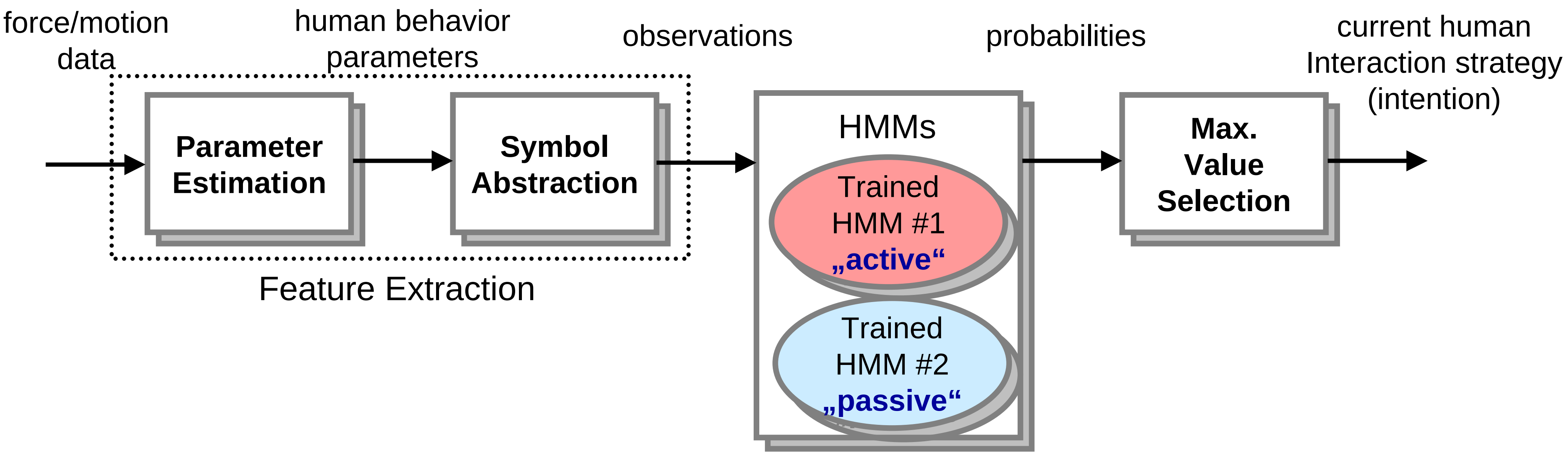
- Interacting partners take over **opposite roles**



- **Timely combination of both strategies** allows to create arbitrary types of handshakes

Intention Recognition Module

- Classifier based on Hidden Markov Models (HMMs)
- Two trained **HMMs "Active" and "Passive"**
- Symbolized human behavior parameters as HMM observations
- Select the HMM with maximum likelihood to determine the current human interaction strategy (intention)



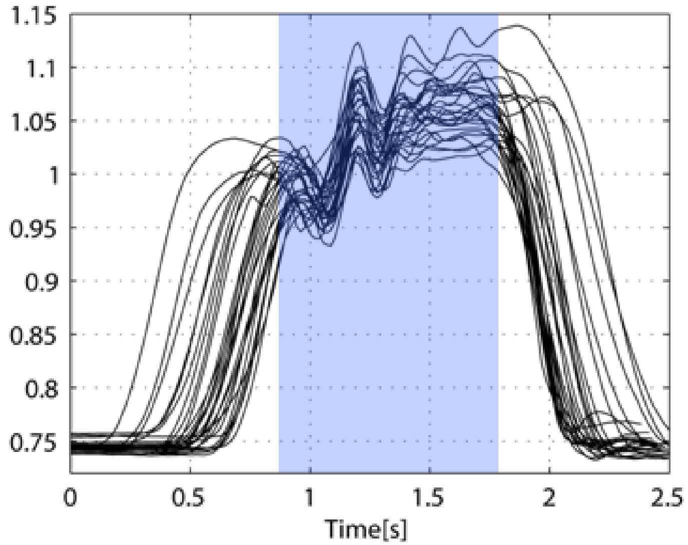
Trajectory Generator and Adaptation Law: Passive Human

Trajectory Generator:

- Damped sinusoidal function for typical handshake
- Parametrization according to results obtained in human experiments

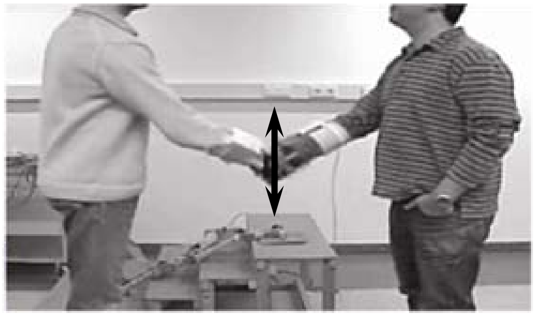
Position	Min	Max	Mean
Duration/s	0.712	1.816	1.01
Amplitude/m	-	0.161	0.098

Vertical-time motion trajectories of 30 handshakes



Adaptation Law :

- no adaptation



Trajectory Generator and Adaptation Law: Active Human

Trajectory Generator:

- Trajectory defined by turning points A and E, and segment lengths D

Adaptation Law (minimization of interaction force):

- Online adaptation of trajectory to human partner depending on interaction force f

$$A_{n+1} = dir \cdot \beta_1(\beta_2 + f_t)(1 - \sin \frac{\pi t}{2D_n}) + x_t$$

$$E_{n+1} = -dir \cdot \beta_1(\beta_2 + f_t) \sin(\frac{\pi}{2}(\frac{t}{D_n} + 3)) + x_t$$

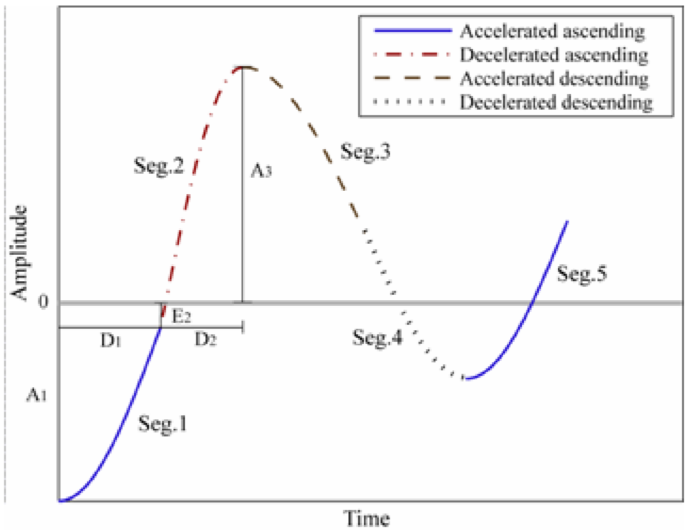
D_{n+1} starts if force changes direction

D_n … segment length, initialized with 250ms

β_1, β_2 … tunable parameters

f_t, x_t … currently measured interaction force and position

dir … direction of motion

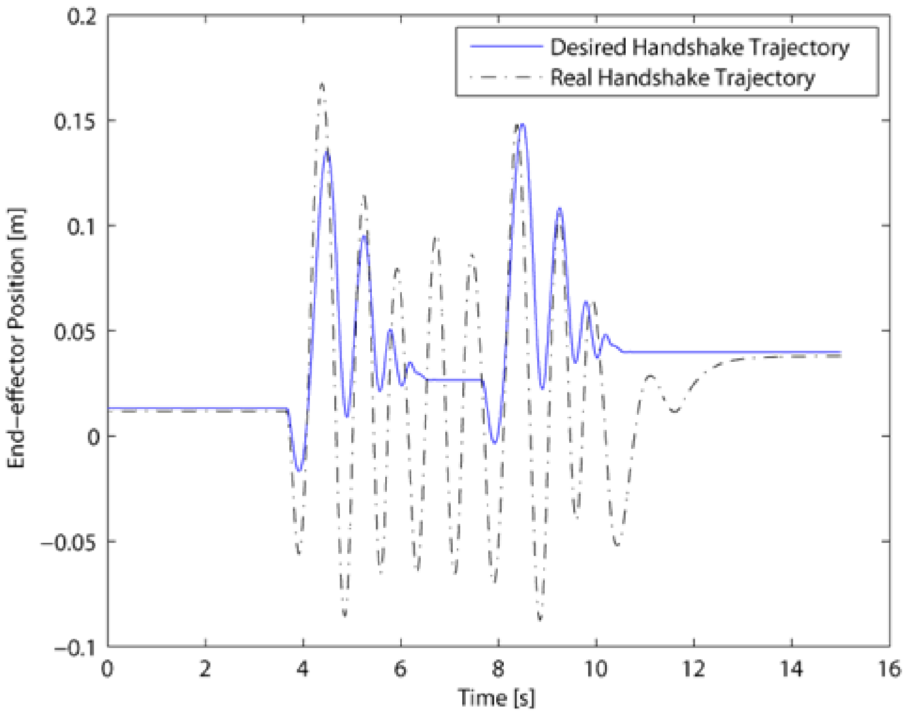


- Interpolation using 5th order polynomial connecting current and desired positions

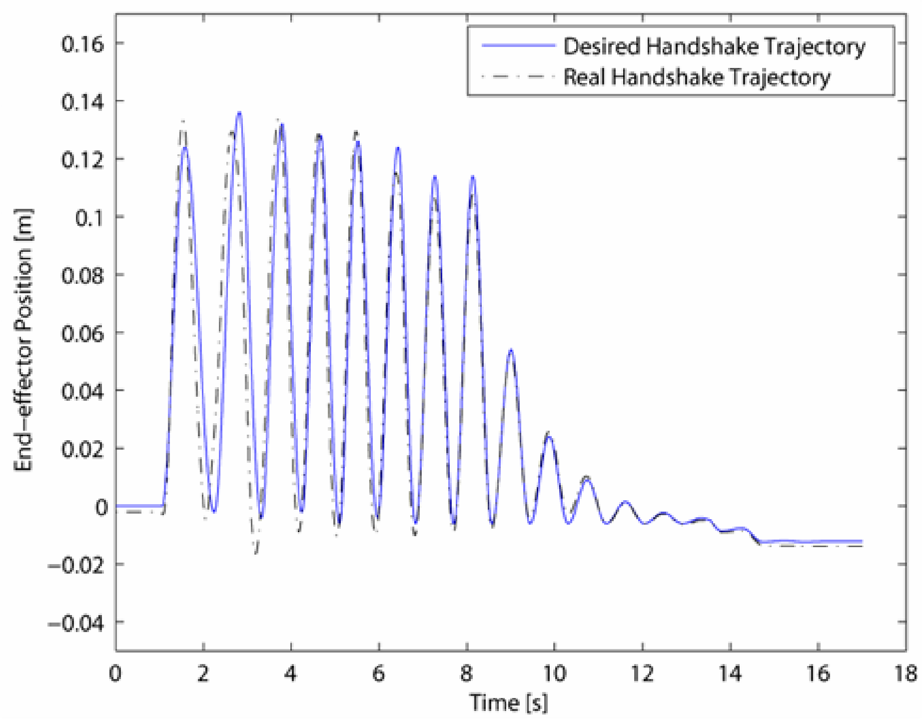
Experimental Comparison: Replay vs. Interactive Controller

- Human is "active" and tries to lead the robot
- High level controller synchronizes with human trajectory

Compliance controller used for replay



Interactive controller used for recreation

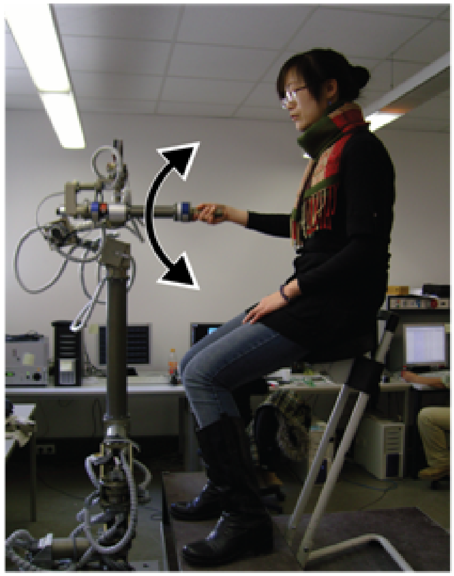


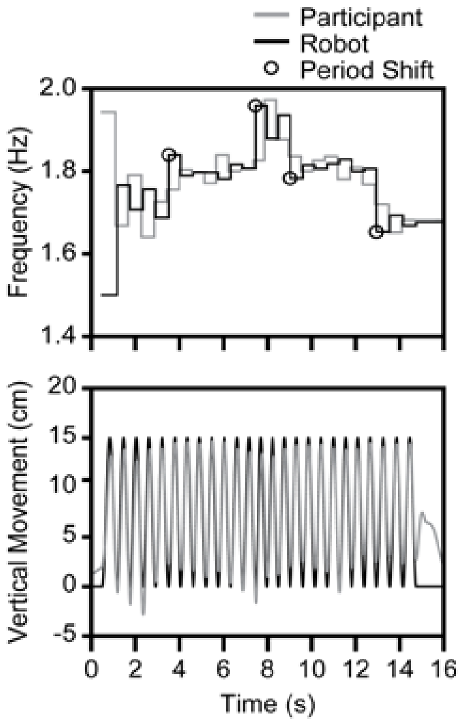
Mutual Frequency Adaptation in Rhythmic Motor Tasks

collaboration with Prof. Alan Wing from University of Birmingham

Research question:

Is evolution of movement in cooperative haptic manipulation tasks governed by error-based learning?

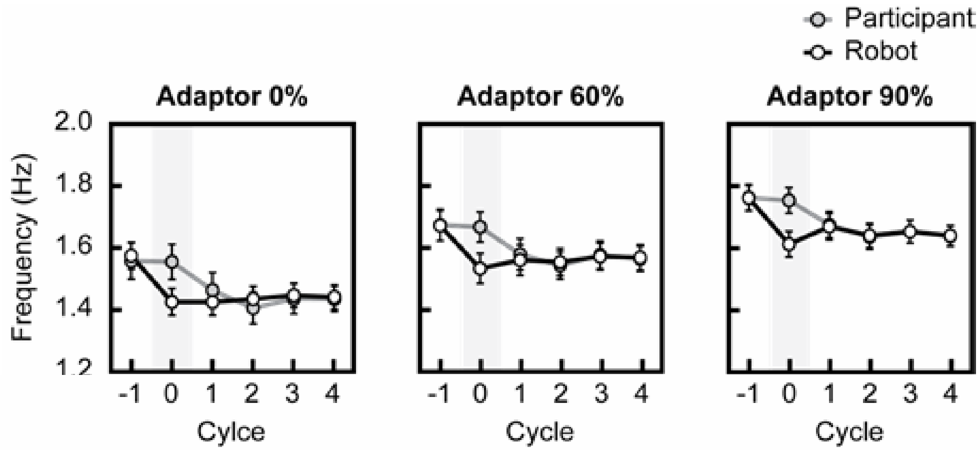




Results:

- large parts of corrections occur within the period shift cycle
- cooperative behaviour is very sensitive to partner behavior

→ adaptation rate is flexibly adjusted to optimise net adaptation gain at cooperative level



Implemented adaptation law:

$$F_{n+1}^{R} = F_{n}^{R} + \alpha(F_{n}^{P} - F_{n}^{R})$$

Video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RECORD A HANDSHAKE

Evaluation Study: Virtual Cocktail Bar Scenario

[Giannopoulos/Wang/Peer/Buss/Slater, Brain Research Bulletin, submitted]

Participants:
35 (29 male, 6 female)

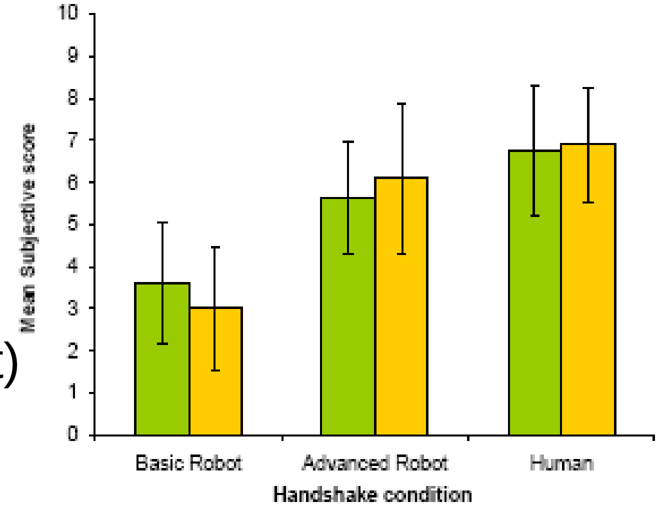
Haptic conditions:
- Basic robot
- Advanced robot
- Human

Audio conditions:
- Stereo sound
- Binaural sound

2nd study: Visual condition

Dependent variable:
Presence feeling: plausibility, (place illusion)
Quesionnaire: (robot-like) 1 ... 5 ...10 (human-like)

Results:
- mean(human) > mean(advanced robot) > mean(basic robot)
- substantial confusion between advanced robot and human-operated handshakes (similar effect sizes)



Video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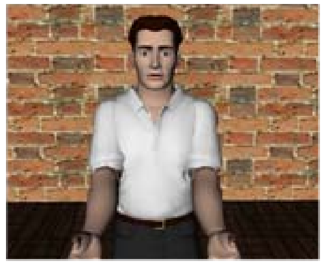
RECORD A DANCING COUPLE

Summary and Conclusion

- Implementation of a haptic robot interaction partner is challenging as humans expect a partner showing **human-like interaction capabilities** in terms of **interactivity, proactivity, adaptivity**
- Thus, implementation of haptic interaction partners requires algorithms for
  - Human intention estimation
  - Interactive path planning
  - Adaptation of robot behavior
- **Synthesis of robot behavior** can follow different approaches
  - Engineering-driven or experimentally-driven approach
- **Human-human experiments** can inform implementation of haptic interaction partners





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