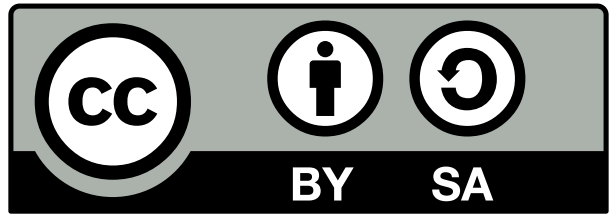

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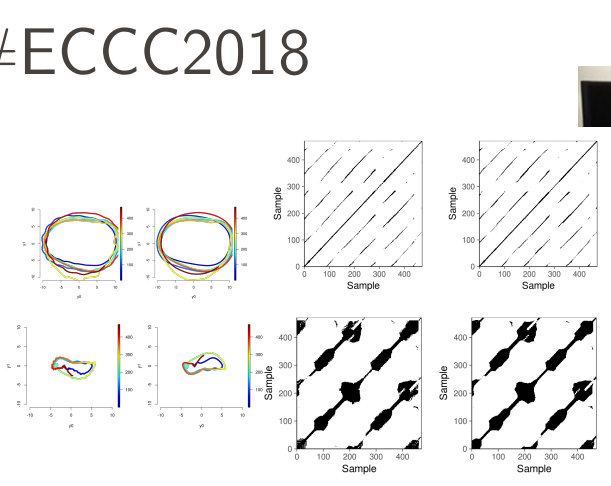
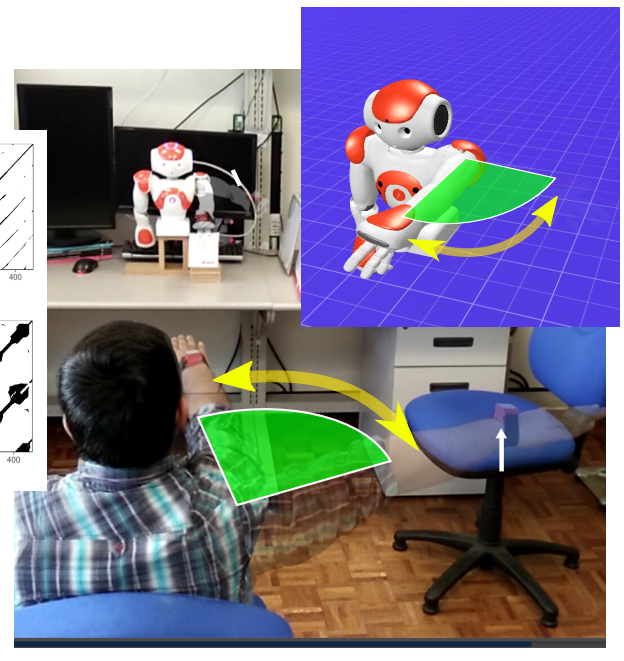
15th EXPERIMENTAL CHAOS & COMPLEXITY CONFERENCE

Quantifying the Inherent Chaos of Human Movement Variability

@ecc15madrid2018 #ECCC2018

Madrid, Spain, 4-7 June 2018





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OVERVIEW

1. Movement Variability
2. RSS
3. Recurrence Quantification
4. Experiment
5. Results
6. Conclusions and Future Work

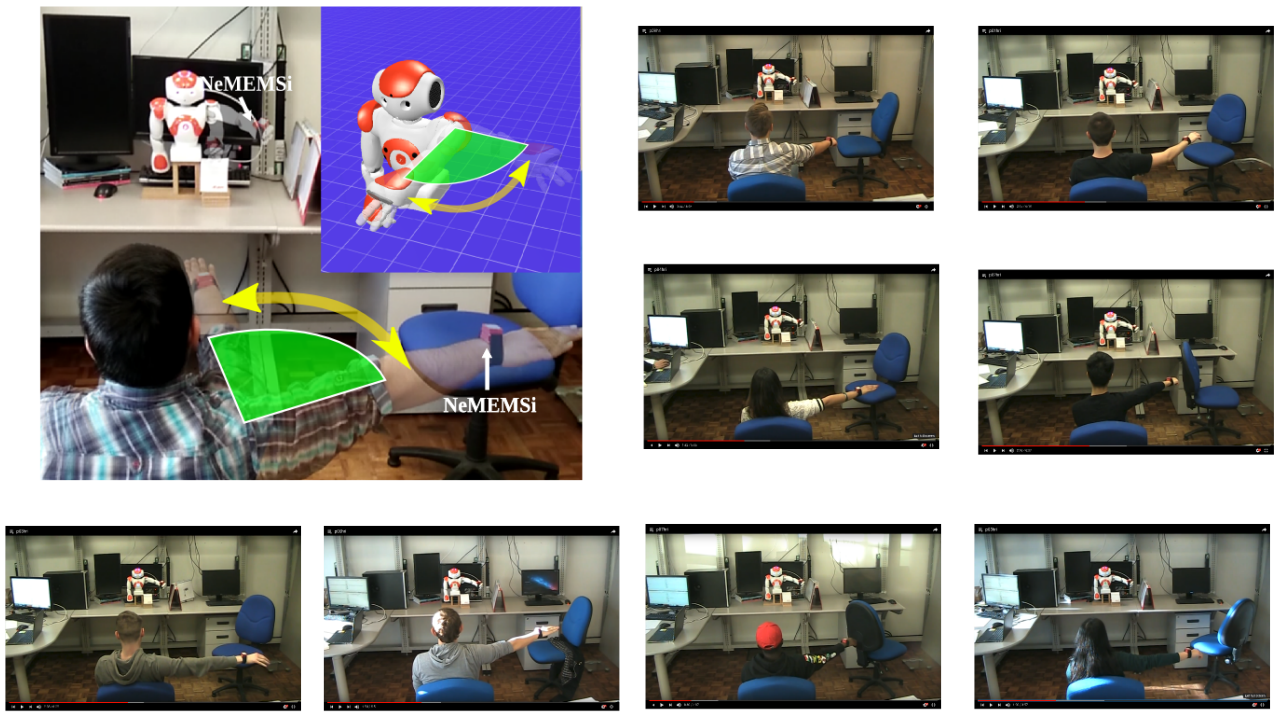
MOVEMENT VARIABILITY

WHAT IS MOVEMENT VARIABILY?

MOVEMENT VARIABILITY is defined as the variations that occur in motor performance across multiple repetitions of a task and such behaviour is an inherent feature within and between each person's movement.

[Stergiou, N. and Decker, L. M., 2011 in **Human Movement Science**]

MV IN THE CONTEXT OF HUMAN-ROBOT INTERACTION



Work in progress (Xochicale et al. 2018)

Figure 1: MV within and between each person's movement.

RSS

RECONSTRUCTED STATE SPACE (RSS) THEOREM

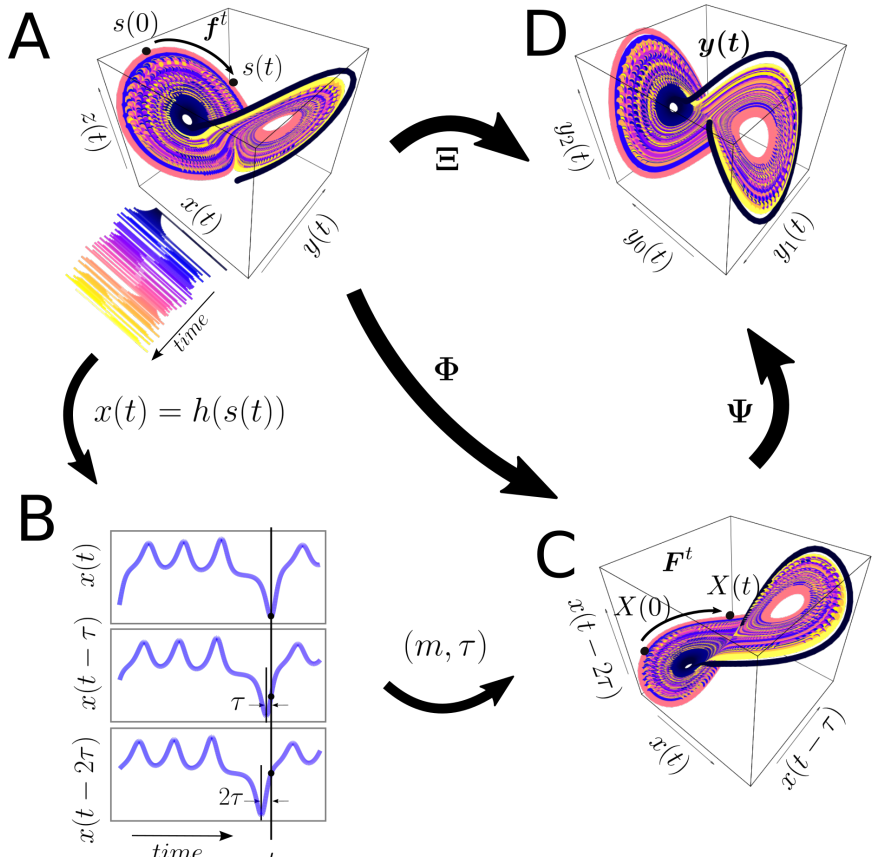


Figure adapted from (Casdagli et al. 1991, Uzal et al. 2011)

Figure 2: Reconstructed State Space

[Takens F. 1981 in **Dynamical Systems and Turbulence**]

THE METHOD OF UNIFORM TIME-DELAY EMBEDDING (UTDE)

For a given discrete time series $x(n) = [x(1), x(2), \ldots, x(N)]$, a reconstructed state space matrix is defined as

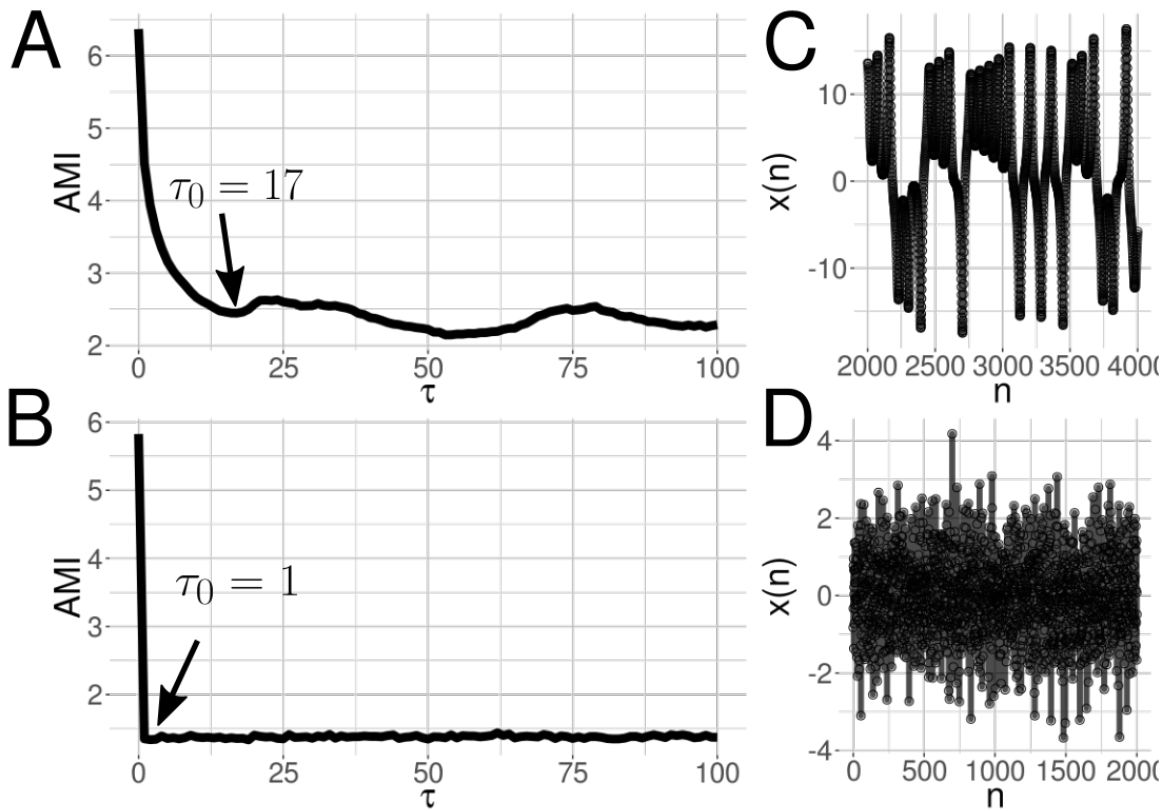
$$\mathbf{X}_{\tau}^{m} = \begin{pmatrix} \tilde{x}(n) \\ \tilde{x}(n-\tau) \\ \vdots \\ \tilde{x}(n-(m-1)\tau) \end{pmatrix}^{T}$$

where m is the **embedding dimension** and τ is the **embedding delay**.

Dimensions of $\mathbf{X}_{\tau}^{m}$ are $(m,(N-(m-1)\tau))$ and sample length for $\tilde{x}(n-i\tau)$, where $0 \leq i \leq (m-1)$, is $N-(m-1)\tau$.

[Takens F. 1981 in **Dynamical Systems and Turbulence**]

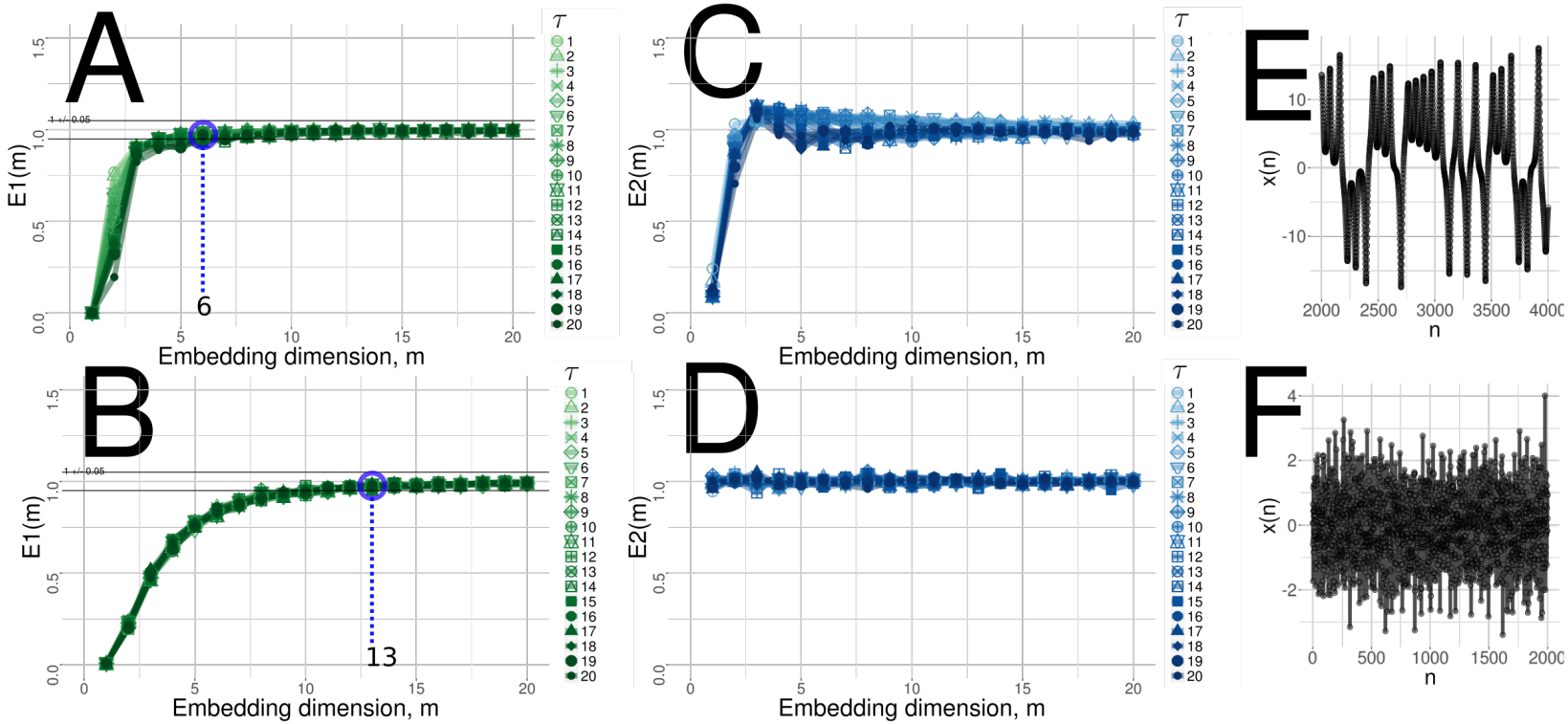
AVERAGE MUTUAL INFORMATION (AMI)



Work in progress (Xochicale et al. 2018)

Figure 3: (A, B) AMI values for (C) chaotic and (D) noise time series.

FALSE NEAREST NEIGHBOURS (FNN)



Work in progress (Xochicale 2018)

Figure 4: (A,B) $E_1(m)$ and (C, D) $E_2(m)$ values for (E) chaotic and (F) random time series

[Cao L. 1997 in **Physica D**]

RECURRENCE QUANTIFICATION

RECURRENCE PLOTS

$\mathbf{R}^m_{i,j}(\epsilon)$ is two dimensional plot of $N \times N$ square matrix defined by

$$\mathbf{R}^m_{i,j}(\epsilon) = \Theta(\epsilon_i - ||X(i) - X(j)||), \quad X(i) \in \mathbb{R}^m, \quad i, j = 1, \ldots, N \tag{1}$$

where N is the number of cosidered states of $X(i)$, ϵ is a theshold distance, $||\dot{|}||$ a norm, and $\Theta(\dot{})$ is the Heaviside function.

[Eckmann et al. 1987 in **Europhysics Letters**]

RECURRENCE PLOTS

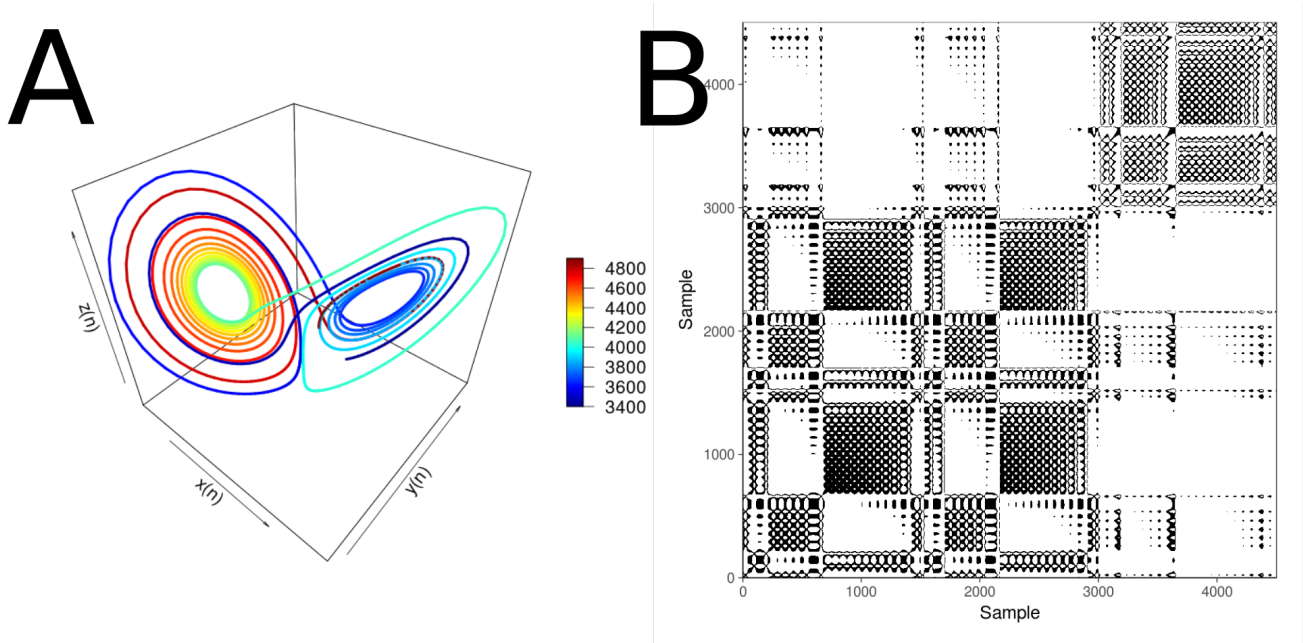


Figure is adapted from (Marwan et al. 2007).

Figure 5: (A) State space for Lorenz systems, and (B) Recurrence plots with no embeddings and $\epsilon = 5$

[Eckmann et al. 1987 in **Europhysics Letters**]

RECURRENCE PLOT PATTERNS

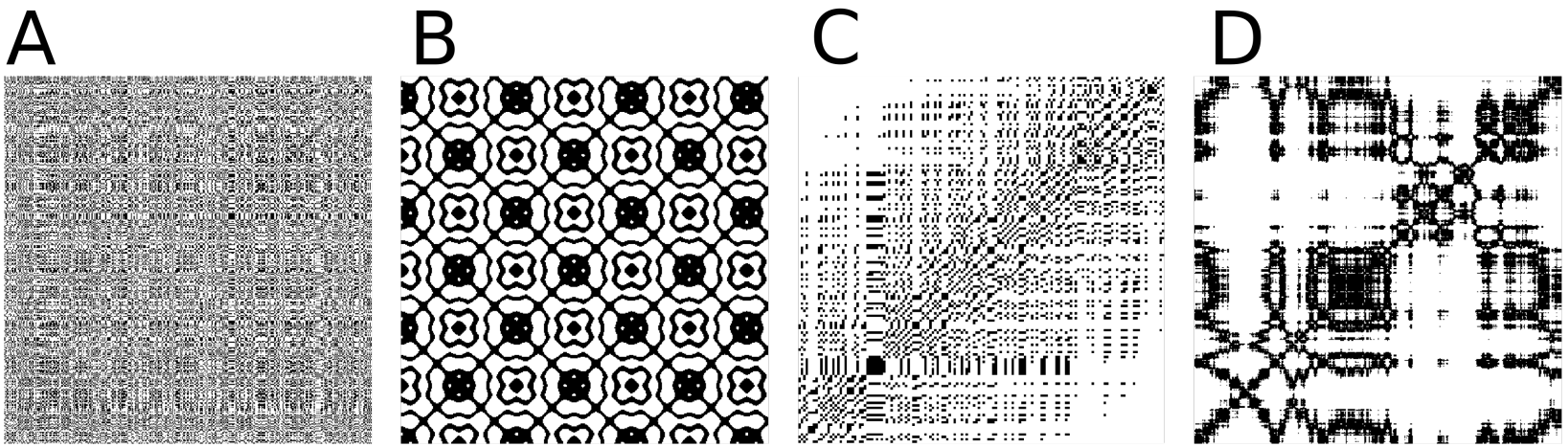


Figure is adapted from (Marwan et al. 2007)

Figure 6: Recurrence plots for (A) uniformly distributed noise, (B) super-positionet harmonic oscillation, (C) drift logistic map with a linear increase term, and (D) disrupted brownian motion.

[Marwan et al. 2007 in **Physics Reports**]

RECURRENCE QUANTIFICATION ANALYSIS

REC the percent of recurrence enumerates the black dots in the RP excluding the line of identity.

DET the percent of determinism if the fraction of recurrence points that form diagonal lines. *(interpreted as the predictibility where, for example, periodic signals show longer diagonal lines than chaotic ones.)*

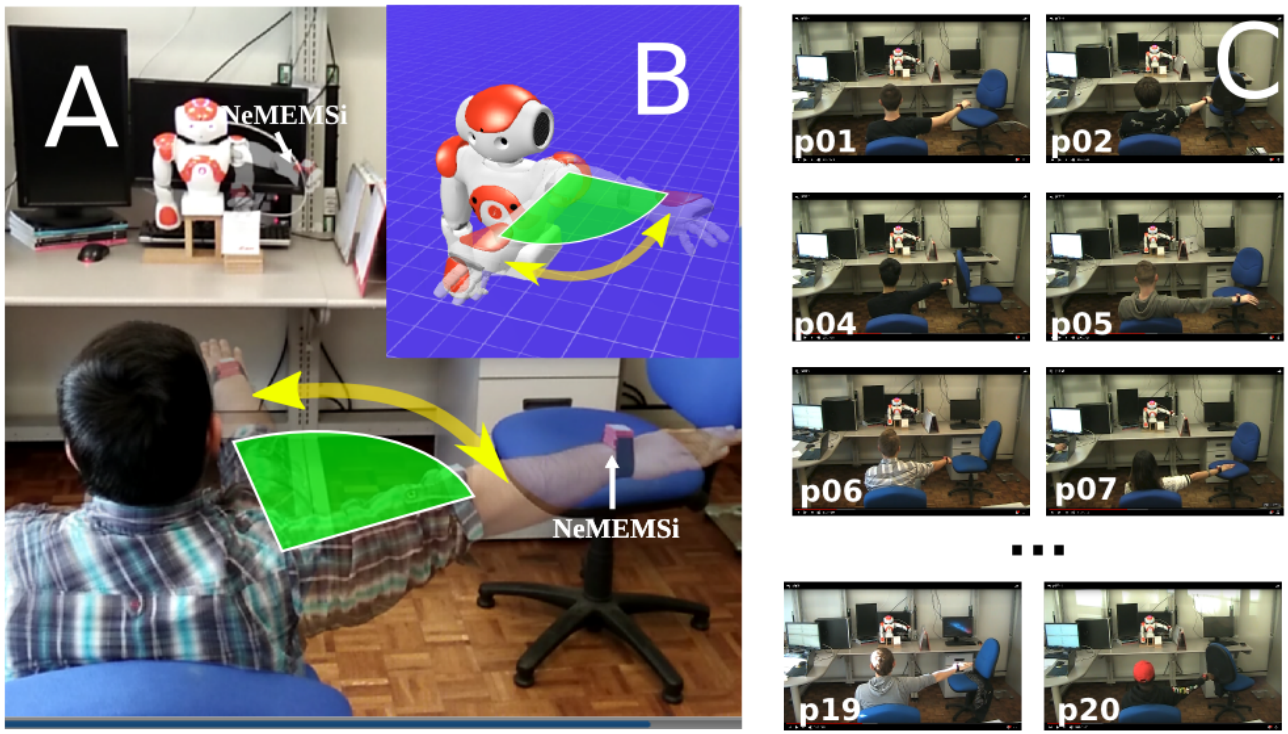
RATIO is the radio of DET to REC. *(useful to discover dynamic transitions)*.

LAM computes the recurrence points in the vertical lines *(analogous to DET)*.

[Marwan et al. 2007 in **Physics Reports**]

EXPERIMENT

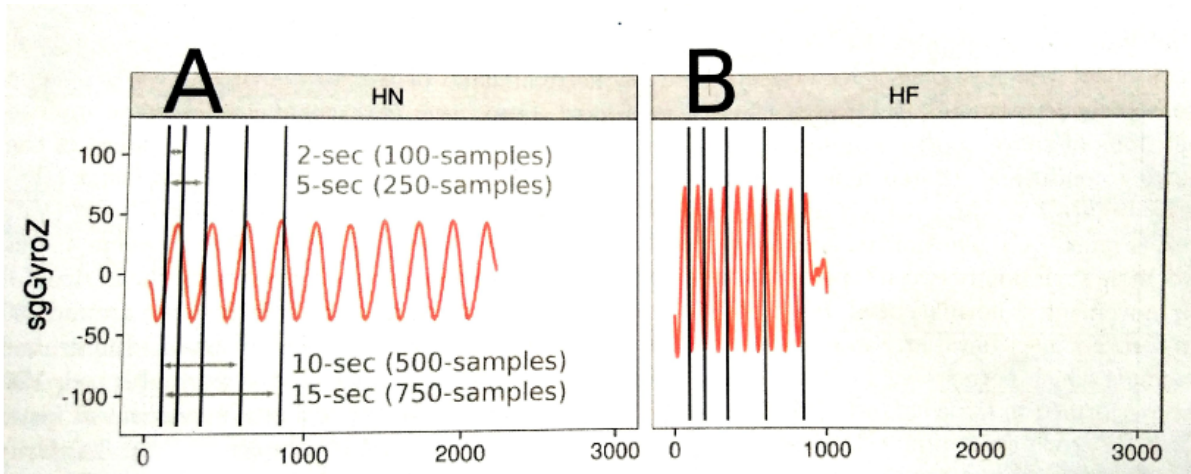
HUMAN-HUMANOID IMITATION ACTIVITIES



Work in progress (Xochicale et al. 2018)

Figure 7: (A) Front-to-Front Human-Humanoid Imitation of Horizontal Movements, (B) NAO, humanoid robot, and (C) 20 rigth-handed healthy participants (age: mean=19.8, SD=1.39).

HORIZONTAL ARM MOVEMENTS

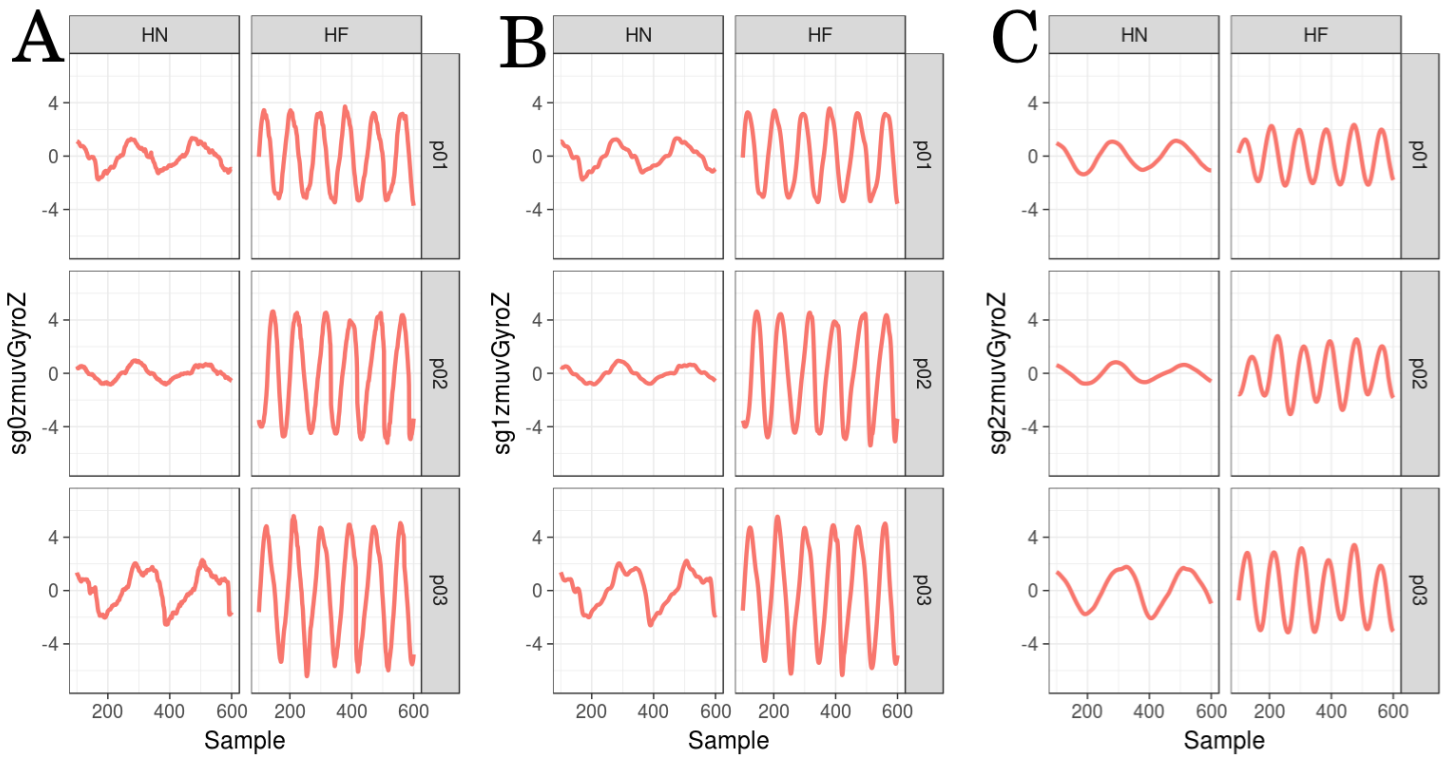


Work in progress (Xochicale et al. 2018)

Figure 8: Arm Movements for two speed conditions: Horizontal Normal (HN) and Horizontal Faster (HF) with different window lengths.

RESULTS

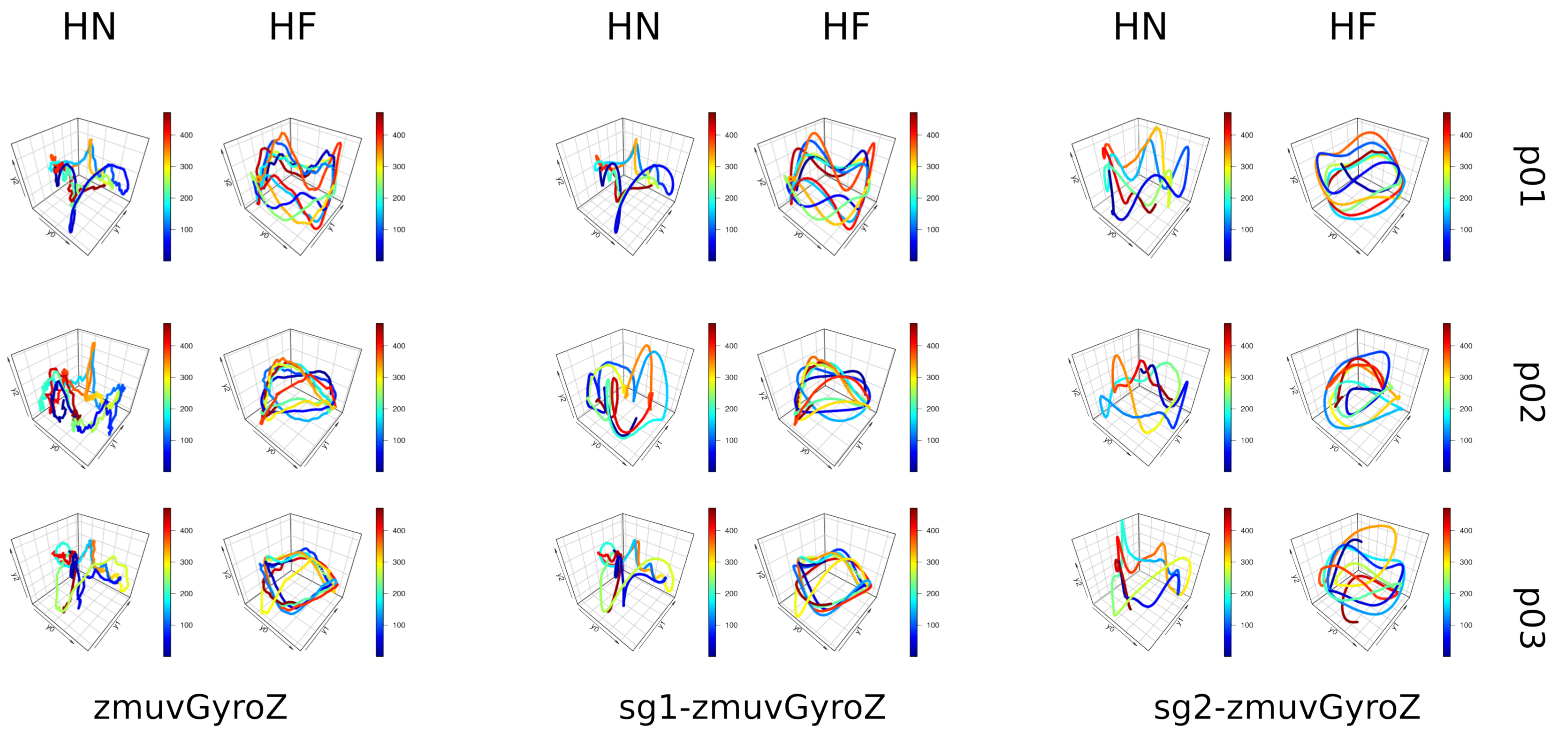
FROM RAW TO SMOOTHED TIME SERIES



Work in progress (Xochicale et al. 2018)

Figure 9: (A) Normalised, (B) sgolay(p=5,n=25), and (C) sgolay(p=5,n=159)

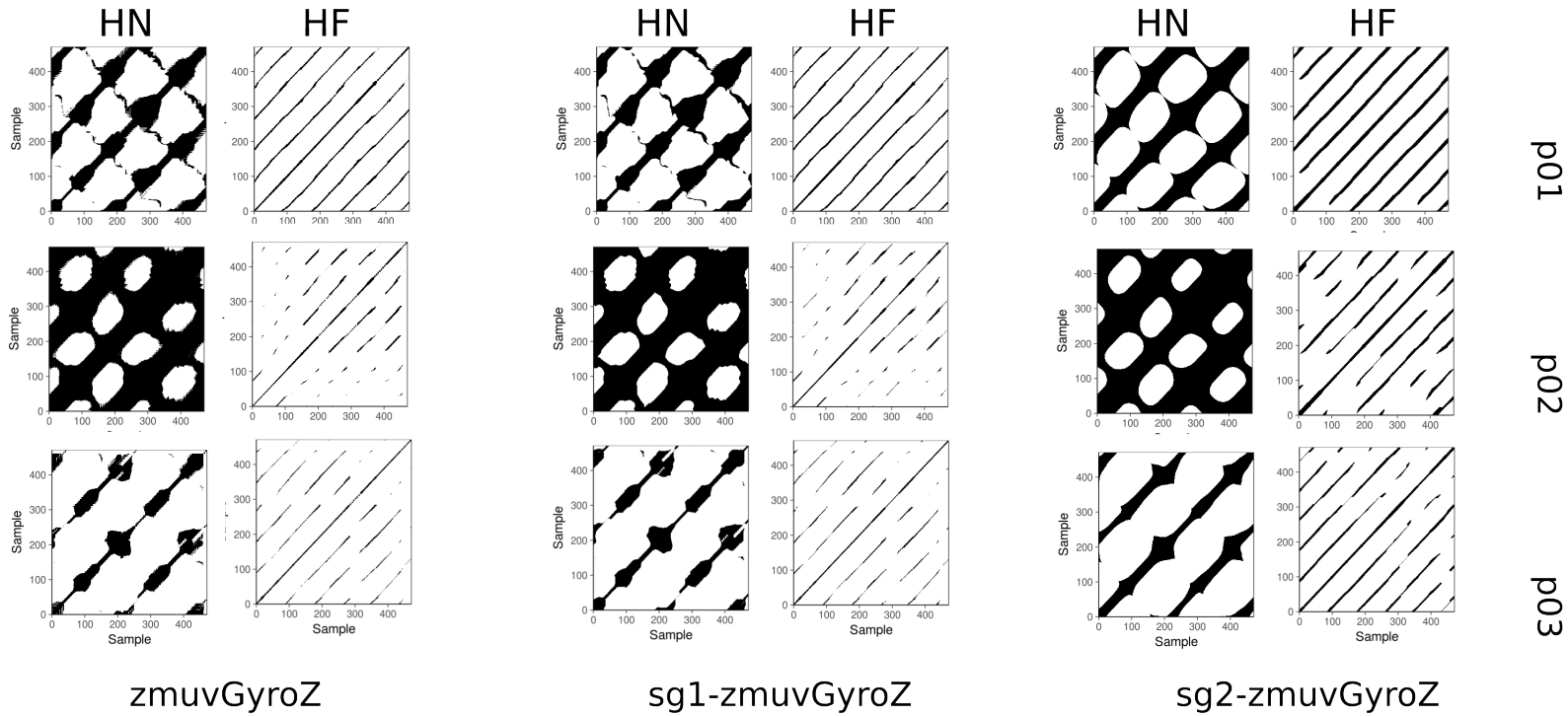
RECONSTRUCTED STATE SPACES



Work in progress (Xochicale et al. 2018)

Figure 10: RSS computed with $(m = 7, \tau = 5)$

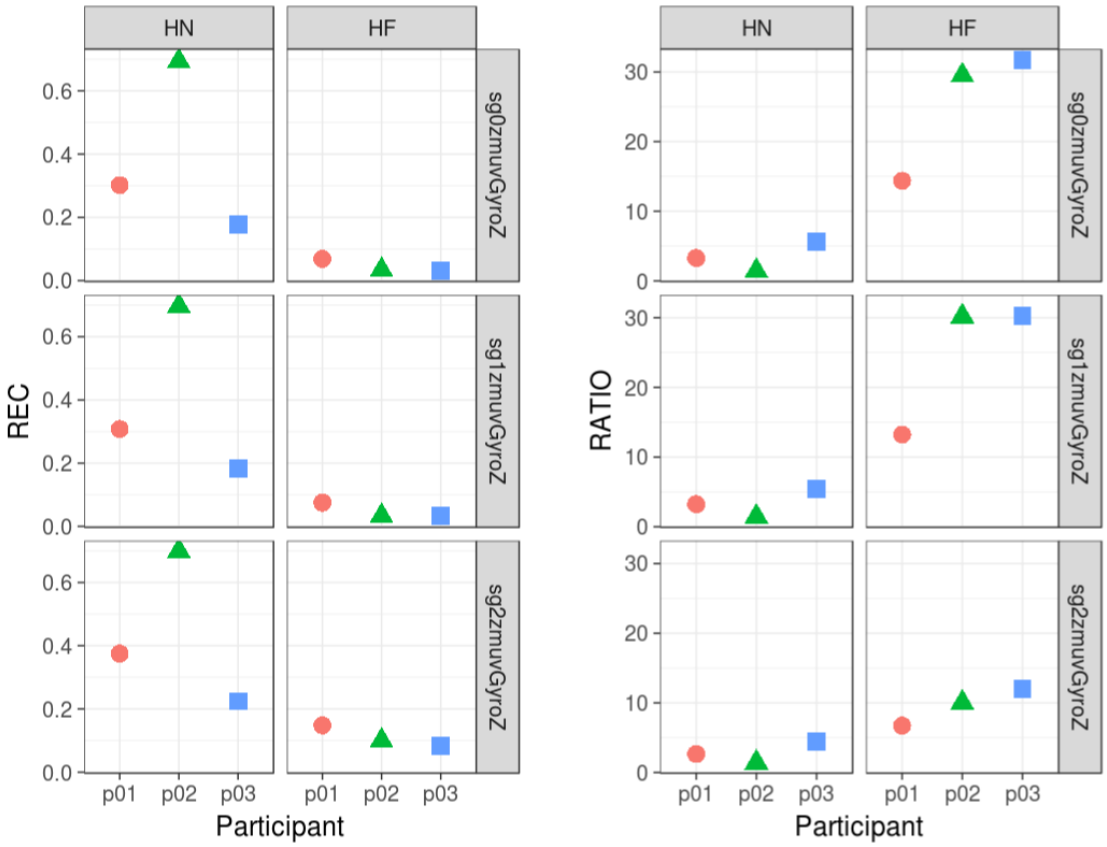
RECURRENCE PLOTS



Work in progress (Xochicale et al. 2018)

Figure 11: Recurrence Plots computed with $(m = 7, \tau = 5, \epsilon = 1)$

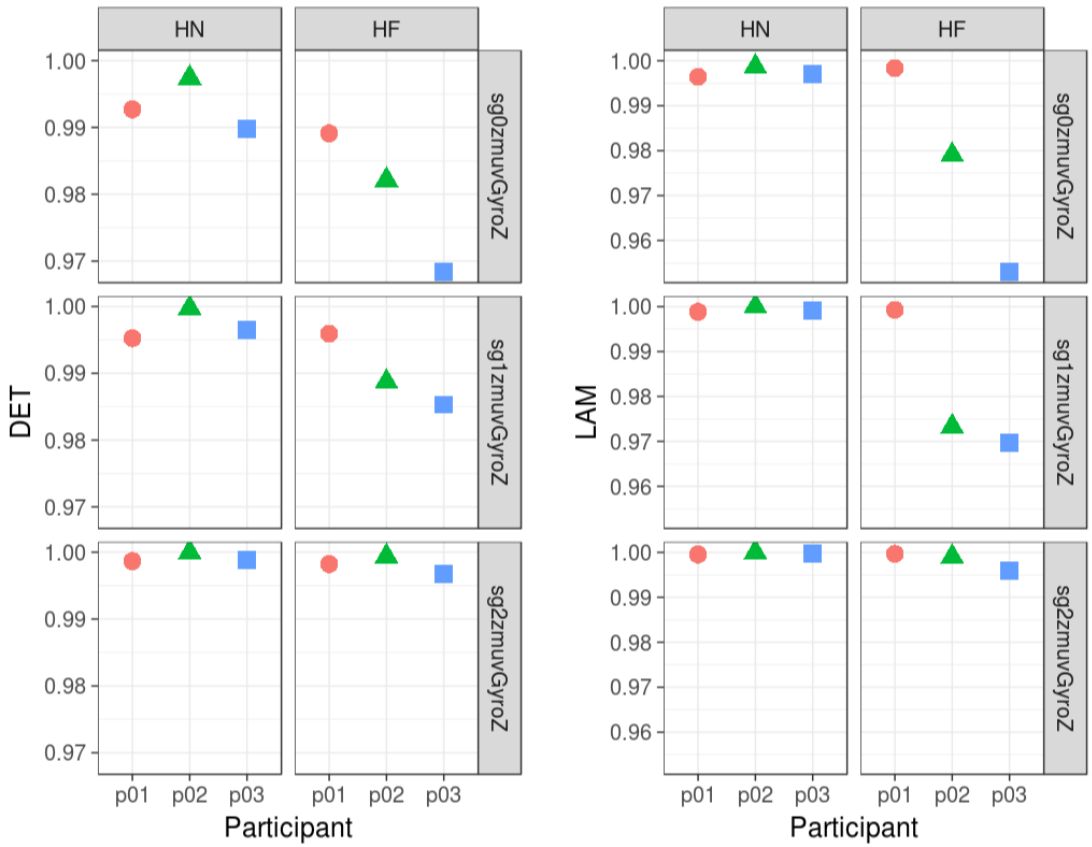
REC & RATIO



Work in progress (Xochicale et al. 2018)

Figure 12: REC

DET & LAM

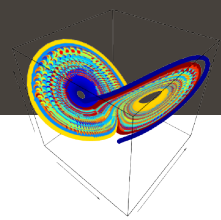


Work in progress (Xochicale et al. 2018)

Figure 13: REC

CONCLUSIONS AND FUTURE WORK

CONCLUSIONS FUTURE WORK



- (+) Quantification for Arm Movement and Head Pose Estimation Variability with Nonlinear Dynamics is possible. However,
- (-) the timeseries from the landmarks are mounted on the pose location of the head.

- Test other techniques of Nonlinear Dynamics, e.g. Lyapunov Exponents, Recurrent Quantification Analysis
- Use of Convolutional Neural Networks for automatic identification of Movement Variability

FUTURE WORK

Work in progress (Xochicale et al. 2018)

Figure 14: Quantifiying both:
(a) Movement Variability and (b) Changes in Facial Expressions.

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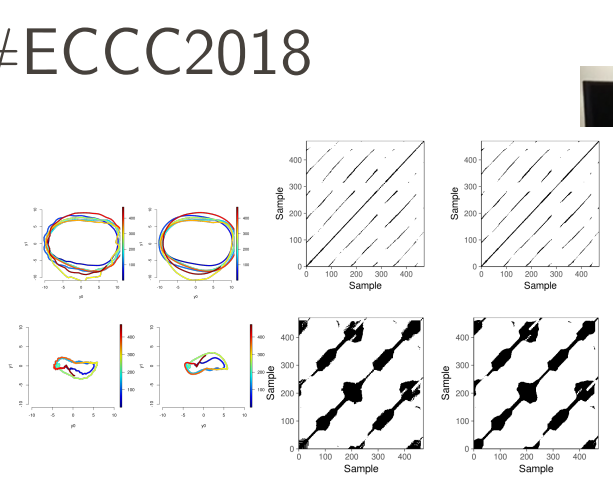

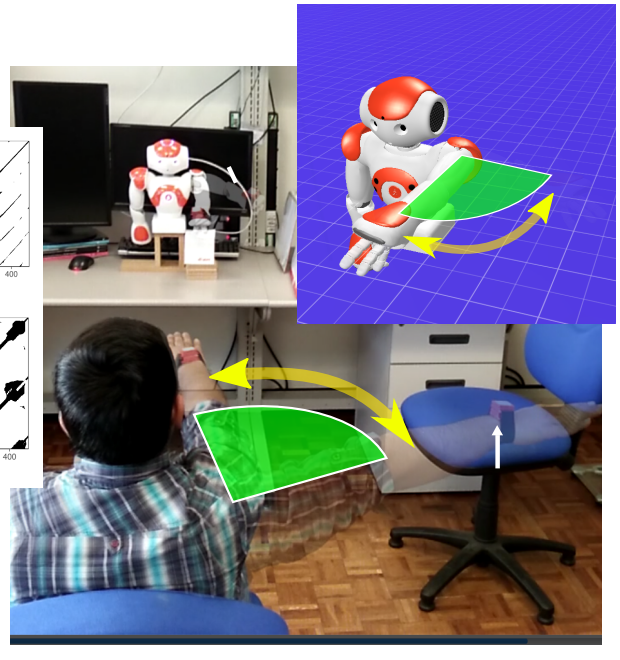

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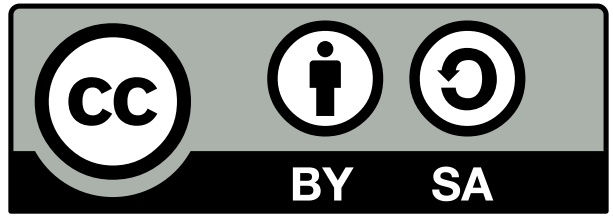

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