15th EXPERIMENTAL CHAOS
& COMPLEXITY CONFERENCE

Quantifying the Inherent Chaos of Human Movement Variability

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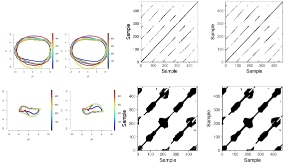
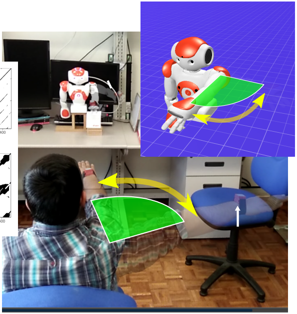
Madrid, Spain, 4-7 June 2018





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OVERVIEW

MOVEMENT VARIABILITY

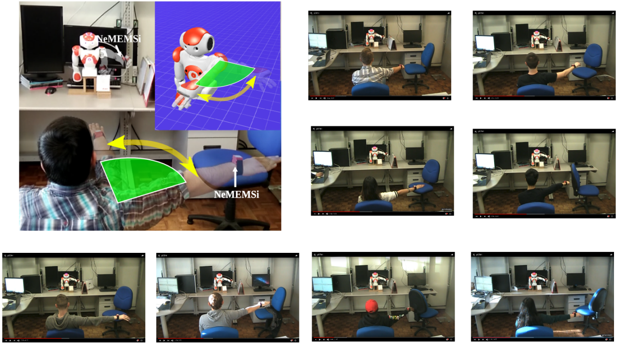
WHAT IS MOVEMENT VARIABILY?

* MOVEMENT VARIABILITY (MV) is defined as the variations that occur in motor performance across multiple repetitions of a task.

* MV is also considered as 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 M. et al. 2018)

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

RSS

RECONSTRUCTED STATE SPACE (RSS) THEOREM

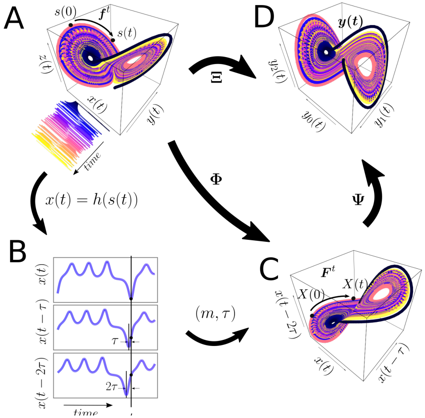


Figure adapted from (Casdagli et al. 1991, Uzal et al. 2011)

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 $x(n) = [x(1), x(2), \dots, x(N)]$, a reconstructed state space matrix is defined as

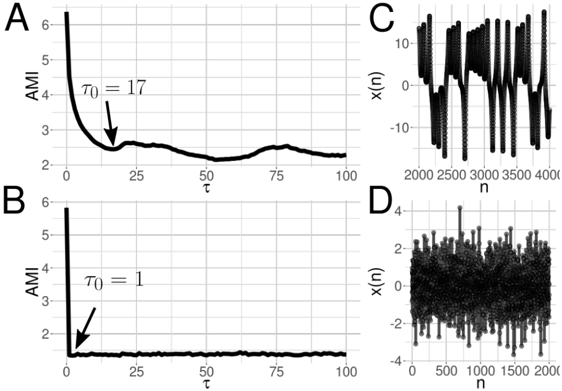
$$\mathbf{X}_{\tau}^{m} = \begin{pmatrix} \tilde{x}(n) \\ \tilde{x}(n-\tau) \\ \vdots \\ \tilde{x}(n-(m-1)\tau) \end{pmatrix}^{T}$$

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)

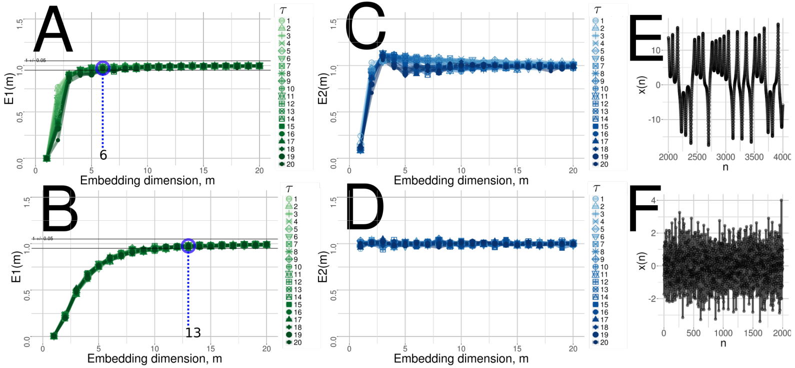


Work in progress (Xochicale M. et al. 2018)

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

[Kabiraj et al. 2012 in **Chaos: An Interdisiplinary Journal of Nonlinear Science**]

FALSE NEAREST NEIGHBOURS (FNN)



Work in progress (Xochicale M. et al 2018)

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

RQA

RECURRENCE PLOTS

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

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

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

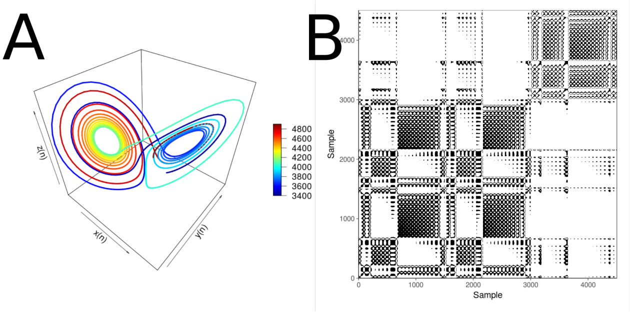


Figure is adapted from (Marwan et al. 2007).

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

RECURRENCE PLOT PATTERNS

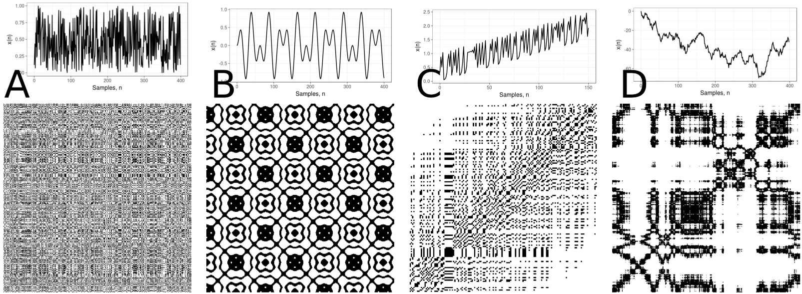


Figure is adapted from (Marwan et al. 2007)

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.

RECURRENCE QUANTIFICATION ANALYSIS (RQA)

REC enumerates the black dots in the RP.

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

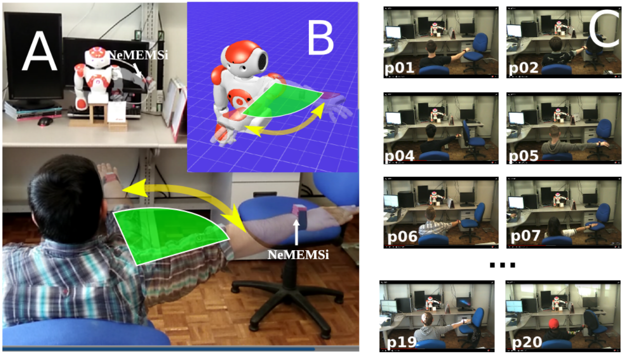
RATIO is the radio of DET to REC. *(useful to discover dynamic transitions)*.

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

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

EXPERIMENT

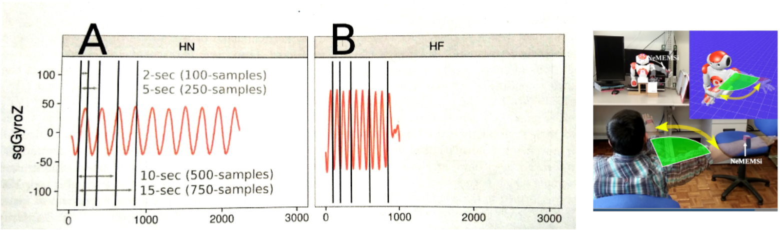
HUMAN-HUMANOID IMITATION ACTIVITIES



Work in progress (Xochicale M. 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

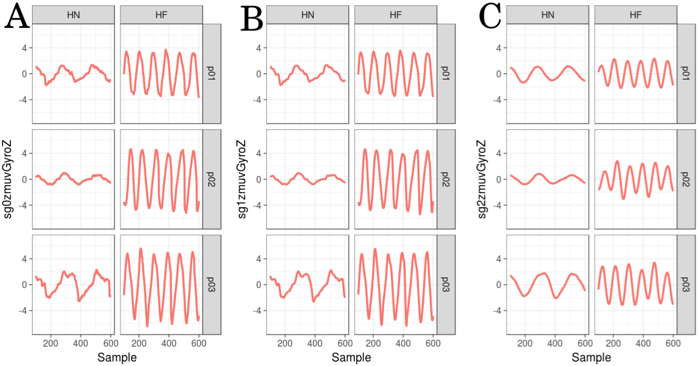


Work in progress (Xochicale M. et al. 2018)

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

RESULTS

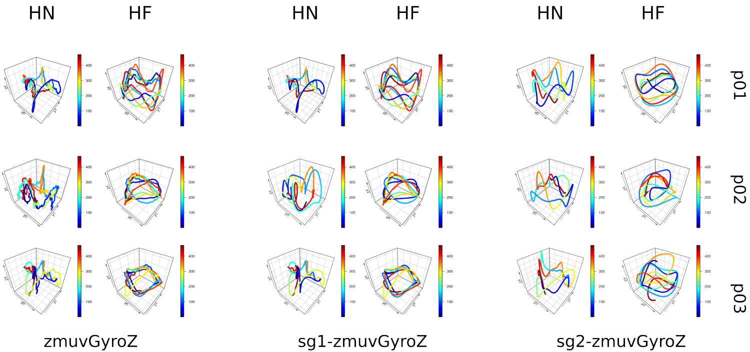
FROM RAW TO SMOOTHED TIME SERIES



Work in progress (Xochicale M. et al. 2018)

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

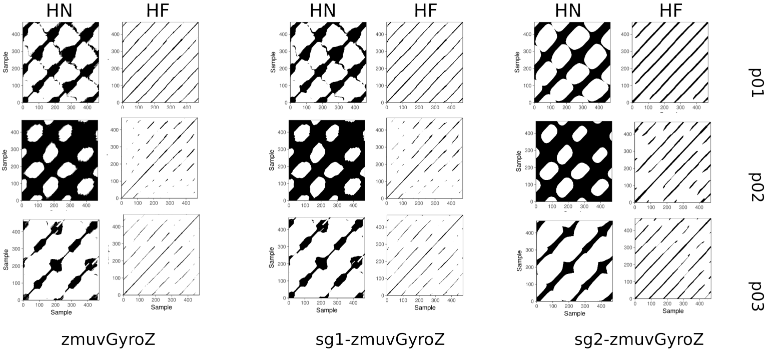
RECONSTRUCTED STATE SPACES



Work in progress (Xochicale M. et al. 2018)

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

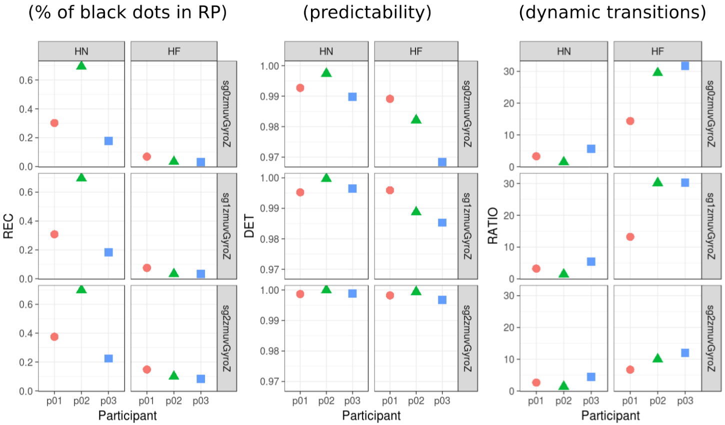
RECURRENCE PLOTS



Work in progress (Xochicale M. et al. 2018)

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

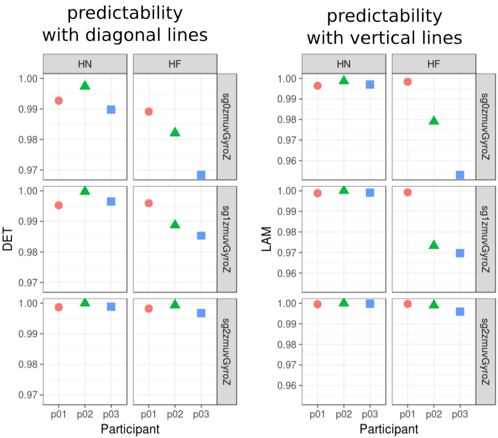
RQA WITH REC, DET & RADIO



Work in progress (Xochicale M. et al. 2018)

Figure 12: REC & RATIO

RQA WITH DET & LAM



Work in progress (Xochicale M. et al. 2018)

Figure 13: REC

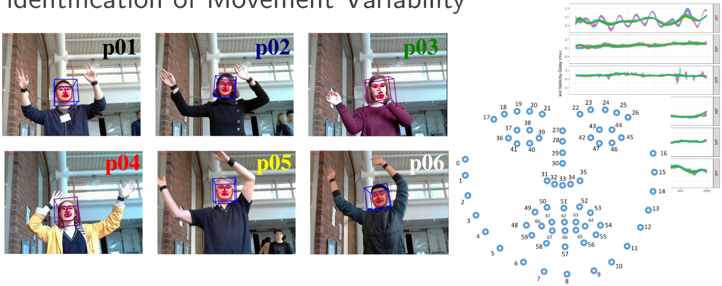
CONCLUSIONS AND FUTURE WORK

CONCLUSIONS

- (+) RSS and RQA can potentially be used to quantify arm movement variability. However,
- (-) RSS and RQA are sensitive to window length, embedding parameters or thresholds.

FUTURE WORK

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



Work in progress (Xochicale M. et al. 2018)

Figure 14: Pilot experiment for quantification of MV for complex movements and changes in facial expressions.

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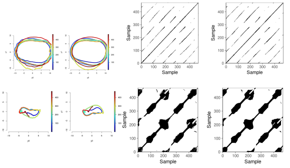

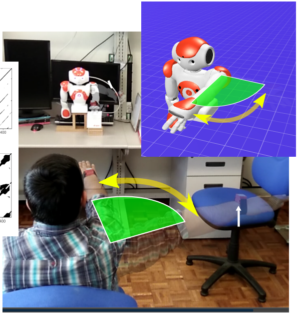

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https://github.com/mxochicale/eccc2018

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