ESCOLA POLITÉCNICA

UNIVERSIDADE DE SÃO PAULO

7TH INTERNATIONAL SYMPOSIUM ON RECURRENCE PLOTS

30 Years Recurrence Plots

SCIENTIFIC PROGRAMME

CAPES FAPESP USP INPE PIK

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CAPES - Coordenação de Aperfeiçoamento de Pessoal de Nível Superior
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Aims

The objective of this Seventh Recurrence Plot Symposium is to encourage the exchange of knowledge and new ideas among scientists working in scientific disciplines of time- and spatial-series analyses. Recurrence plots and their quantifications are general methods for visualizing and analyzing both linear and nonlinear time-series data. After 30 years we continue to witness ongoing technical developments related to recurrence plots in both theoretical and practical domains. Some of these include: linkage of recurrence plots to network theory, inferences regarding directional couplings, identification of various spatio-temporal chaotic patterns, realization of tetherings across multiple scales of emergence, etc. Applications of recurrence plots are ever-expanding into such areas like mathematics, neuroscience, physiology, psychology, weather and climate patterns, financial systems, and linguistics. This symposium will provide a unique forum to facilitate the correlation of recent theoretical developments in recurrence science with applications from various and diverse fields of inquiry. We welcome both theoretical and applied contributions that effectively implement recurrence plots, recurrence quantifications and their related methodologies.

We hope everybody will enjoy the meeting and find new inspirations and cooperations.

Location

The Symposium will be held at the Escola Politćnica (POLI-Polytechnic School) of the University of São Paulo (USP), Travessa 3, Av. Prof. Luciano Gualberto, Butantã, São Paulo.

Lectures

The Wednesday and Friday lectures will take place in the *Auditório Prof. Francisco Romeu Landi*, Av. Prof. Luciano Gualberto, travessa 3, № 380.

The Thursday lectures are in the *Anfiteatro do Prédio de Engenharia Elétrica*, Av. Prof. Luciano Gualberto, travessa 3, № 158.

Posters and discussion will be in a room next to the Anfiteatro in the Prédio de Engenharia Elétrica.
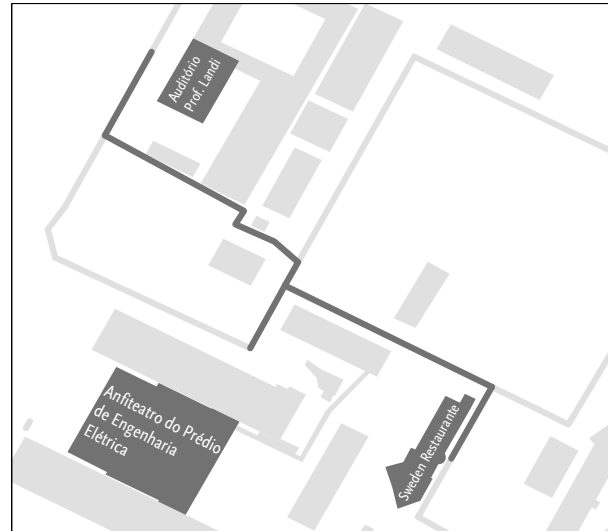
Practical Workshop

In a practical workshop, a hands-on session on the *TsViz Project: A tweet-based mining tool* will be offered. The workshop will take place in the *Lab SOFT* in the Prédio de Engenharia Elétrica, Av. Prof. Luciano Gualberto, travessa 3, № 158 (the same building as the Anfiteatro).

Lunch

A good option for lunch is the *Sweden Restaurant* which is close to the conference venue (4 … 5 minutes walk). It is a self-service restaurant with a great variety of food.

Address: Avenida Professor Luciano Gualberto 908

Social Events

Thursday, August 24

For Thursday, 19:30, we have organised a dinner at the restaurant "Bolinha" located at Av. Cidade Jardim, 53 – Jardim Europa.

Saturday, August 26

Saturday we will have a sightseeing tour that will start early morning and ends in the afternoon. In the morning, we will visit Ibirapuera Park, and after lunch, the Paulista Avenue, in which the visitation to the Museum of Art of São Paulo (MASP) will be possible.

Internet Access

Wireless internet access will be available as *POLI sem fio*. Individual access data will be provided at conference check-in.

Presentations

The speakers have to upload their presentation to the computer in the lecture hall in advance of their talk (in the morning of the day of their talk). The time for the talk is 17 min, plus 3 min discussion (invited talks are 40 min, plus 5 min discussion).

Both MacOS and Windows machines will be available, installed with standard presentation software (PowerPoint, Acrobat, Preview, and Keynote). You may also bring your own computer or presentation device provided that it is fitted with the appropriate VGA output and that you are capable of installing and testing the machine prior to the scheduled session time.

Collection of Presentations

We will provide a platform for sharing the presentations after the symposium in a secure way (password protected web site, secured pdf documents). We will ask the authors of the presentations to give a written permission for this purpose during the symposium. Without such a written permission, presentation files on the presentation computer will be deleted after the symposium.

Note

The symposium will adhere to the rules of good scientific and ethical practice. This means that it is not allowed to copy presentations from the presentation computer. It is also forbidden to take photographs of oral presentations and presented posters without explicitely given permission of the presenter.

Oustanding Poster Award

All posters displayed at the meeting will be evaluated by a committee for an award recognizing excellence in presentation and significance in contribution to nonlinear science. The evaluation criteria comprise the poster display, the significance of the study, and the clarity of the oral presentation including the ability to answers questions.

Program

Tuesday, August 22nd

15:00   Registration (until 17:30)
Golden Tower hotel

Wednesday, August 23rd

Auditório Prof. Francisco Romeu Landi/ Escola Politécnica

8:00   Registration & pay for registrations
Auditório Prof. Francisco Romeu Landi/ Escola Politécnica

9:15   Opening

Methodological Aspects I

9:25   **Reik V. Donner**:
Keynote Lecture The geometry of recurrences – recurrence plots as spatial networks

10:10   ~~**Patrick F. Coutinho**, Diogo C. Soriano, Filipe I. Fazanaro, Romis Attux:~~
~~Recurrence Sparsity: A New Complexity Measure Based on the Gini Index~~

10:30   *Coffee/tea break*

11:00   **T. Prado**, Elbert E. N. Macau, G. Corso, G. Z. dos Santos Lima and S. R. Lopes:
Entropy of recurrence plot configurations and applications to biological and climatological systems

11:20   **Leandro Freitas**, Leonardo L. Portes, Luis A. Aguirre:
Detecting Phase Synchronization Regime in a Three-scroll Chaotic Attractor

11:40   **Jaqueline Lekscha**, Reik V. Donner:
Differential embedding – From theory to application in palaeoclimatology

12:00   **Giuseppe Leonardi**:
Reconsidering the Computation of Entropy in Recurrence Quantification of Categorical Data

12:20   **Elbert E. N. Macau**, Barbara Maximo, Yong Zhou:
Recurrence density enhanced approach

12:40   **N. Marwan**:
What can you see?

13:00   *Lunch*

Applications in Engineering

14:45   **Merten Stender**, Sebastian Oberst, Norbert Hoffmann:
        Why mechanical machines should be treated as complex systems
15:05   **Debora C. Correa**, Michael Small:
        Surrogate methods for melody compositions: investigating music structures with Recurrence Quantification Analysis
15:25   **Giulliana K. L. Pereira de Queiroz**, Silvana Luciene do N. C. Costa, Suzete Élida N. Correia, Vinícius Jefferson Dias Vieira:
        Recurrence and traditional measures of nonlinear dynamic analysis to detect vocal deviations
15:45   **Carsten Brandt**:
        Recurrence Quantification Analysis for Non-Destructive Testing of Porous Carbon Fibre Reinforced Polymers

16:05   *Coffee/tea break*

16:30   **Angela Digulescu**, Ion Candel, Irina Murgan, Cornel Ioana, Alexandru Serbanescu:
        On the use of the phase diagram domain properties for the Instantaneous Frequency Law tracking
16:50   **Costin Vasile**, Ion Candel, Cornel Ioana, Angela Digulescu:
        Phase Space Trajectory Analysis for Electrical Fault vs. Power Line Communication Discrimination
17:10   ~~**Liping Yang**:~~
        ~~Analysis of nonlinear dynamic characteristics of cyclic combustion fluctuation in internal combustion engine~~

Thursday, August 24th

Anfiteatro do Prédio de Engenharia Elétrica

9:00   Welcome & miscellaneous announcements

        Applications in Earth Science

9:15   **Sebastian Oberst**, Daniel Lester, Robert Niven, Bruce Hobbs, Alison Ord, Norbert Hoffmann:
        Application of recurrence plot quantification to mineralising systems in geology
9:35   **Hauke Krämer**, Norbert Marwan, Martin H. Trauth:
        Classifying abrupt transitions in IPCC climate models and paleoclimate proxy data using Recurrence Quantification Analysis
9:55   ~~**F. Cervantes-De la Torre**, J. I. Gonzalez-Trejo, S. B. Gonzalez-Brambila, C. A. Real-Ramirez:~~
        ~~Recurrence plot measures of complexity and its applications to self-potential time series arising from a Mexican seismic zone~~

10:15   ~~**C. A. Real-Ramirez**, F. Cervantes-De la Torre, J. I. Gonzalez-Trejo, S. B. Gonzalez-Brambila:~~
~~Recurrence plot and their application to time series associated solar storm~~

10:35   **Dadiyorto Wendi**, Norbert Marwan, Bruno Merz, Jürgen Kurths:
Change in Flood Hazard Dynamics from Recurrence Perspective

10:55   *Coffee/tea break*

Methodological Aspects II

11:25   **Bruno Rafael Reichert Boaretto**, Roberto Cesar Budzinski Neto, Thiago de Lima Prado, Kalel Luiz Rossi, Sergio Roberto Lopes:
Control of malleability of small-world neural networks

11:45   **Roberto Cesar Budzinski Neto**, Bruno Rafael Reichert Boaretto, Thiago de Lima Prado, Sergio Roberto Lopes:
On stationarity of neural networks at the transition from unsynchronized to synchronized states

12:05   **C. Abud**, I. L. Caldas:
Recurrence criterion to the breakup of invariant curves

12:25   **J. D. Szezech**, M. S. Santos, A. M. Batista, I. L. Caldas, R. L. Viana, S. R. Lopes:
Identifying chimera states with recurrence plot

12:45   *Group photo shoot*

13:00   *Lunch*

14:30   **S. Oliffson Kamphorst**:
Keynote Lecture The very beginning of recurrence plots

15:15   **Yun Chen**, Hui Yang:
Heterogeneous recurrence representation and quantification of dynamic transitions in continuous nonlinear processes

15:35   **Lucas Pagliosa**, Rodrigo Mello:
Using Cross-Recurrence Quantification Analysis to Improve Semi-Supervised Time Series Classification of Positive and Unlabeled Problems

15:55   **Antonio M. T. Ramos**, Alejandro Builes-Jaramillo, GermÃąn Poveda, Bedartha Goswami, Elbert E. N. Macau, JÃijrgen Kurths, Norbert Marwan:
Causality detection based on recurrence plot

16:15   *Coffee/tea break*

16:30   Poster Session

19:30   *Social Event* Dinner at restaurant "Bolinha"

Friday, August 25th

Auditório Prof. Francisco Romeu Landi/ Escola Politécnica

9:00   Welcome & miscellanous announcements

Applications in Life and Social Sciences

9:15   **Daniel Angus**:
Keynote lecture Recurrence plotting for the analysis of the dynamics of conversation

10:00   ~~**Hiba Fatafta**, Wael Karain:~~
~~Non Linear Analysis Of Allergen Protein Ole e6 atomic positions~~

10:20   **Michele L. Gregório**, Rosangela A. Hoshi, Moacir F. Godoy:
The Life and Death in the context of Recurrence Plots

10:40   *Coffee/tea break*

11:10   James P. Hummel, Joseph G. Akar, **Charles L. Webber, Jr.**:
Method for Discretizing Atrial Electrograms for Recurrence Analysis

11:30   **Lisane Valdo**, Vanderlei Cunha Parro, Eduardo Lobo Lustosa Cabral, Jose Carlos de Souza Junior, Sandro Brosco Sakata, Thiago Ricciardi e Vinítcius Ribeiro dos Santos:
Recurrence plots applied in modeling some of the processes involved in determining the alertness of a truck driver

11:50   **Tiago P. Almeida**, Fernando S. Schlindwein, Joao L. Salinet, Xin Li, Gavin S. Chu, Jiun H. Tuan, Peter J. Stafford, G. A. Ng, Diogo C. Soriano:
Recurrence quantification analysis for characterizing atrial electrogram fractionation in human chronic atrial fibrillation

12:10   **Felipe Marcel Neves**, Ricardo Luis Viana, Marcio Roberto Pie:
Recurrence analysis of ant activity patterns

12:30   ~~**Wenjing He**, Nasim Hajari, Irene Cheng, Anup Basu, Bin Zheng:~~
~~Dual eye-tracking for the assessment of team cognition in laparoscopic surgery: Evidences from cross recurrence analysis~~

12:30   **A. M. Batista**, M. S. Santos, F. S. Borges, E. L. Lameu, K. C. Iarosz, J. D. Szezech Jr, I. L. Caldas, E. E. N. Macau, R. L. Viana, J. Kurths:
Application of recurrence plots to the study of neuronal networks

12:50   Closing and poster award

13:30   *Lunch*

15:00   **Rodrigo F. de Mello**, Ricardo A. Rios, Paulo A. Pagliosa, Renato P. Ishii, Caio de Sá Lopes, Fábio Sikansi:
Hands on session TsViz Project: A tweet-based mining tool

Lab SOFT in the Prédio de Engenharia Elétrica

Poster

Poster 1   **V. C. Pereira**, E. D. L. B. Camargo, J. L. Salinet, D. C. Soriano:

Recurrence Quantification Analysis in real time in Labview: simulated ECG evaluation

~~Poster 2~~   ~~**Mohamed Elgendi**:~~

~~Eventogram: A Visual Representation of Main Events in Biomedical Signals~~

Poster 3   **H. Gonzalez-Gomez**, N. P. Garcia-Martinez, O. Infante, H. Perez-Grovas, C. Lerma:

Diagonal properties of cross recurrence plots between heart rate and systolic blood pressure of end stage renal disease patients

Poster 4   **Michele L. Gregório**, Guilherme L. L. Wazen, Rosangela A. Hoshi, Andrew H. Kemp, Moacir F. Godoy:

Recurrence Plot Patterns in Bipolar Disorder: Mania vs Euthymia

Poster 5   **Kelly C. Iarosz**, Ronaldo M. Evaristo, Antonio M. Batista, Ricardo L. Viana, Iberê L. Caldas, José D. Szezech Jr., Moacir F. Godoy:

Study of cardiac signals using recurrence plot

Poster 6   **Leonardo Lopes**, Vinícius Jefferson Dias Vieira, Silvana Costa, Suzete Correia, Mara Behlau:

Performance Evaluation of Recurrence Quantification Measures to Discriminate Individuals with and without Voice Disorders

Poster 7   **Vinicius Vieira**, Silvana C. Costa, Suzete Correia, Washington Costa, Francisco M. de Assis, Leonardo Lopes:

Recurrence Quantification Analysis of Speech Signals

Poster 8   **Taciana A. de Souza**, Micael A. Souza, Silvana Luciene do N. C. Costa, Washington C. de A. Costa, Suzete E. N. Correia, Vinícius J. D.Vieira:

Texture-based analysis of recurrence plots for laryngeal pathologies detection using wavelets and PSO

Poster 9   **Nadja C. Carvalho**, Leonardo L. Portes, Alessandro Beda, Lucinara S. Martins, Luis A. Aguirre:

Recurrence plots for the assessment of patient-ventilator interactions quality during invasive mechanical ventilation

Poster 10   **P. G. Rodrigues**, C. A. Stefano Filho, R. Attux, G. Castellano, D. C. Soriano:

Space-Time Recurrence Counting for Estimating Functional Connectivity in Motor Imagery Brain-Computer Interfaces

Poster 11   **F. S. Borges**, E. L. Lameu, R. R. Borges, P. R. Protachevicz, F. A. S. Ferrari, K. C. Iarosz, A. M. Batista, R. L. Viana, I. L. Caldas:

Recurrence plots to study synchronous behaviour of the brain cortical areas

~~Poster 12~~   ~~**Ralf Cox**, Lisa-Maria van Klaveren, Muriël van der Laan:~~

~~Moved by Art: Postural Dynamics and Appraisal in Viewing Paintings~~

Poster 13   **Ewandson Luiz Lameu**, Fernando da Silva Borges, Kelly Cristiane Iarosz, Antonio Marcos Batista, Elbert Einstein Nereu Macau:

Spatial Recurrence in Networks of Bursting Neurons

Poster 14   **M.S. Santos**, F.S. Borges, K.C. Iarosz, A.M. Batista, R.L. Viana, I.L. Caldas, J.D. Szezech, J. Kurths:

Identification of the chimera states in cat matrix neuronal using recurrence plot

Poster 15   **C. A. S. Batista**, J. D. Szezech Jr., A. M. Batista, E. E. N. Macau and R. L. Viana:

Synchronization of phase oscillators with coupling mediated by a diffusing substance

Poster 16   **M. Mugnaine**, M. S. Santos, A. M. Batista, R. L. Viana, I. L. Caldas, J. D. Szezech:

Application of the recurrence plot for nontwist systems

Poster 17   **Danilo Mendes Rodrigues Pereira**, Filipe Ieda Fazanaro, Ricardo Suyama:

Voice Activity Detection based on Recurrence Plots

Poster 18   **Deniz Eroglu**, Norbert Marwan:

Multiplex Recurrence Networks

Poster 19   **Barbara Maximino da Fonseca Reis**, Margarete Oliveira Domingues, Elbert E. N. Macau:

Wavelet-Recurrence Approach for time series analysis

Poster 20   **Hudson V. T. Mineiro**, S. R. Lopes, T. L. Prado:

Microstates of Recurrence Plots: First Approach

Abstracts

Recurrence plotting for the analysis of the dynamics of conversation

Daniel Angus

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Recurrence plotting of human conversation was pioneered by Dale and Spivey (2006), with their pioneering work examining the coordination patterns between children and caregivers. This approach used n-grams as the base unit of comparison between conversation turns. Years later we adapted this work through the use of natural language processing to create what was called Conceptual Recurrence Plots (Angus, Smith, & Wiles, 2012a, 2012b). This method looked to create a rich conceptual coding of turns in a conversation, and then base comparisons and the construction of a recurrence plot on the conceptual similarity between turns. The approach was packaged into a software platform called Discursis, and since its release in late 2011, the software has been used by scholars in a variety of communication sub-disciplines to help examine health, education, and broadcast discourse. Discursis combines its natural language processing algorithms with interactive recurrence plot outputs (and other visuals) to support both qualitative and quantitative communication analysis tasks (Angus, Rintel, & Wiles, 2013). Discursis builds a data-grounded language model from an input text, codes the input text using this language model, and then renders the coded text visually as a recurrence plot to highlight points of semantic relatedness.

Discursis specifically seeks to model the accommodative aspects of communication, drawing from a strong theoretical foundation in Communication Accommodation Theory (CAT) (Cindy Gallois & Giles, 2015; C. Gallois, Ogay, & Giles, 2005). CAT argues that conversational participants adjust their speech content, vocal patterns, physical gestures and posture, to accommodate (or not accommodate) other participants. Previous studies have revealed positive correlations between Discursis' visual and metric outputs and manually-coded CAT features (Angus, Watson, Smith, Gallois, & Wiles, 2012; Atay et al., 2015; Baker et al., 2015; Watson, Angus, Gore, & Farmer, 2015).

In this talk I will give an overview of the application of recurrence plotting to assist in the analysis and interpretation of conversation dynamics.

References

Angus, D., Rintel, S., & Wiles, J. (2013). Making sense of big text: a visual-first approach for analysing text data using Leximancer and Discursis. International Journal of Social Research Methodology, 16(3), 261-267.

Angus, D., Smith, A., & Wiles, J. (2012a). Conceptual recurrence plots: Revealing patterns in human discourse. IEEE Transactions on Visualization and Computer Graphics, 18(6), 988-997.

Angus, D., Smith, A., & Wiles, J. (2012b). Human Communication as Coupled Time Series: Quantifying Multi-participant Recurrence. IEEE Transactions on Audio, Speech, and Language Processing, 20(6), 1795 - 1807. doi: 0.1109/TASL.2012.2189566

Angus, D., Watson, B., Smith, A., Gallois, C., & Wiles, J. (2012). Visualizing Doctor and Patient Communication: Insights into Effective Doctor-Patient Consultations. Paper presented at the Conference Book 13th International Conference on Language and Social Psychology (ICLASP).

Atay, C., Conway, E. R., Angus, D., Wiles, J., Baker, R., & Chenery, H. J. (2015). An Automated Approach to Examining Conversational Dynamics between People with Dementia and Their Carers. PloS one, 10(12), e0144327.

Baker, R., Angus, D., Smith-Conway, E. R., Baker, K. S., Gallois, C., Smith, A., . . . Chenery, H. J. (2015). Visualising conversations between care home staff and residents with dementia. Ageing and Society, 35(02), 270-297.

Dale, R., & Spivey, M. J. (2006). Unraveling the dyad: Using recurrence analysis to explore patterns of syntactic coordination between children and caregivers in conversation. Language Learning, 56(3), 391-430.

Gallois, C., & Giles, H. (2015). Communication Accommodation Theory The International Encyclopedia of Language and Social Interaction (1st ed., pp. 159-176). Hoboken, NJ: Wiley-Blackwell.

Gallois, C., Ogay, T., & Giles, H. (2005). Communication accommodation theory: A look back and a look ahead. In W. Gudykunst (Ed.), Theorizing about intercultural communication (pp. 121-148). Thousand Oaks, CA: Sage.

Watson, B. M., Angus, D., Gore, L., & Farmer, J. (2015). Communication in open disclosure conversations about adverse events in hospitals. Language & Communication, 41, 57-70.

Recurrence quantification analysis for characterizing atrial electrogram fractionation in human chronic atrial fibrillation

Tiago P. Almeida, Fernando S. Schlindwein, Joao L. Salinet, Xin Li, Gavin S. Chu, Jiun H. Tuan, Peter J. Stafford, G. A. Ng, Diogo C. Soriano

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Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia and radiofrequency catheter ablation is the most accepted interventional procedure for its treatment. During AF ablation, two types of atrial electrograms (AEGs) are usually identified: (i) normal AEGs, with organized discrete activations and; (ii) complex fractionated atrial electrograms (CFAEs), with continuous complex activations. CFAEs have been used as targets for chronic AF ablation, but this strategy has shown suboptimal outcomes due to, among other factors, poor understanding of AEGs dynamics during AF. In this work, we employed recurrence quantification analysis (RQA) for characterizing AEG complexity during chronic AF using the clinical labels provided by the broadly used commercial system, the CARTO (Biosense Webster).

797 AEGs were collected from 18 chronic AF patients undergoing ablation. Automated CFAE classification (Normal AEG or CFAE) was performed in all cases using the CARTO criteria. CARTO calculates the Interval Confidence level (ICL), Average Complex Interval (ACI) and the Shortest Complex Interval (SCI). The AEGs were considered CFAEs if ICL$\geq$4, ACI$\leq$82 ms and SCI$\leq$58 ms. Nine RQA attributes were calculated from the AEGs: DET; Lmax; ENTR; RR; ZIPrate; LAM; TT; Vmax; and L. Eight four linear discriminant analyses (LDA) were performed considering all possible combinations of three RQA attributes, and were compared with the LDA created using the three CARTO attributes.

A total of 307 (39% of total 797) AEGs were classified as CFAEs by CARTO. As expected, the LDA using the three CARTO attributes achieved a high hit rate (93% overall; 98% for CFAEs; 89% for Normal AEGs). The LDA using RQA attributes with best classification was achieved with DET, ZIPrate and Vmax (70% overall hit rate; 51% for CFAEs; 82% for Normal AEGs). These RQA attributes were also effective in significantly discriminating Normal AEGs and CFAEs (Normal AEGs vs CFAE, respectively [Mean$\pm$SD]. DET: 0.98$\pm$0.03 vs 0.97$\pm$0.02; ZIPrate: 0.20$\pm$0.08 vs 0.26$\pm$0.05; Vmax: 505$\pm$731 vs 275$\pm$166; p<0.0001 for all cases).

This work takes a first step towards the characterization of AEGs using RQA complexity measures, in which we have identified the best RQA-based three-dimensional space attribute and compared it with the CARTO criteria. The attained difference between the classification performances motivates the analysis of AEGs during AF using unsupervised methods with either the CARTO criteria, or an alternative paradigm based on RQA, or even the combination of those methods.

Application of recurrence plots to the study of neuronal networks

A. M. Batista, M. S. Santos, F. S. Borges, E. L. Lameu, K. C. Iarosz, J. D. Szezech Jr, I. L. Caldas, E. E. N. Macau, R. L. Viana, J. Kurths

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There is a plethora of cognitive tasks, such as memory, attention, perceptual awareness, thought, language, and consciousness, in which the role of the cerebral cortex is vital. The surface of the cerebral cortex, usually called gray matter, contains neurons and their fibres. These neurons are grouped together into functional or morphological units, called cortical areas, each of them playing a well-defined role in the processing of information in the brain. Hence the theoretical understanding of the principles of organisation and functioning of the cerebral cortex can shed light on the knowledge of many distinct and important subjects in neuroscience. If complex cognitive behaviours are to be modelled, a tractable behaviour to be studied is coherent state. We propose to use recurrence plots as diagnostic tool to identify coherent and incoherent states in neuronal networks.

Synchronization of phase oscillators with coupling mediated by a diffusing substance *Poster*

C. A. S. Batista, J. D. Szezech Jr., A. M. Batista, E. E. N. Macau and R. L. Viana

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We investigate the transition to phase and frequency synchronization in a one-dimensional chain of phase oscillator cells where the coupling is mediated by the local concentration of a chemical which can diffuse in the interoscillator medium and it is both secreted and absorbed by the oscillator cells, influencing their dynamical behavior. This coupling has the advantage of having a tunable

parameter which makes it possible to pass continuously from a global to a local coupling form. We have verified that synchronous behavior depends on the coupling strength and coupling length.

Control of malleability of small-world neural networks

Bruno Rafael Reichert Boaretto, Roberto Cesar Budzinski Neto, Thiago de Lima Prado, Kalel Luiz Rossi, Sergio Roberto Lopes

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The study of synchronization in chaotic states has started in the 90's with the pioneers research papers about the synchronization of oscillators. Since them, it is possible to find applications of synchronized states in several areas of science, specially in physics. A large number of papers is devoted to the control of those synchronized states. Currently, some works shows that for a neural networks at the small-world connection topology, there are regions of low coupling where the network presents malleable behavior (sensitive to small perturbations of a parameter). Here we use recurrence analysis as a tool to differentiate network's behavior. Recurrence quantifiers show to be better to detect some dynamical behaviors when compared with Kuramoto's order parameter. We Integrate a small-world neural network with 2000 neurons using the Huber-Braun model, is which a variation of the Hodgkin-Huxley model. The objective of this work is to produce a lesion at the network in such a way that it is possible to control it's malleability. The lesions are made in three different ways: the first type is the elimination lesion, the second type is the removal of connections, these two types change the connection topology of the system. As a third type, we suppose a change of a biological parameter of the Huber-Braun model. We show that, between these three types, the last one shows better results concerning the control of the malleable behavior in the network even without changing connection topology.

Recurrence plots to study synchronous behaviour of the brain cortical areas
Poster

F. S. Borges, E. L. Lameu, R. R. Borges, P. R. Protachevicz, F. A. S. Ferrari, K. C. Iarosz, A. M. Batista, R. L. Viana, I. L. Caldas

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The human brain is divided into different cortical areas that are anatomically connected forming a large network. We have built a network of networks, in which the networks are connected among themselves according to human brain matrix. This matrix was constructed by

diffusion tensor image tractography for brain with and without Alzheimer's disease. As local dynamics we consider the adaptive exponential integrate-and-fire neuron in a network with excitatory and inhibitory synapses. Moreover, we use recurrence plots in spatial series to study synchronous behaviour between cortical areas of the human brain. Finally, we compare the results between Alzheimer's disease and normal patients.

Recurrence Quantification Analysis for Non-Destructive Testing of Porous Carbon Fibre Reinforced Polymers

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An approach to use Recurrence Quantification Analysis (RQA) for the Non-Destructive Evaluation of Carbon Fibre Reinforced Polymers (CFRP) on porosity is presented. Ultrasonic testing is the standard method for the 100% inspection of Airbus aircraft CFRP parts. In general, the pulse echo method with one probe is deployed. A pulse is sent into the part and the reflections, echoes out of the part (intermediate echoes) and from the opposite side (back-wall echo) are recorded. The state of the art industrial method for evaluation on porosity utilises the back-wall echo. Small pores in the part summing up to an amount of few percent of the part's volume do not deliver echoes that can be directly evaluated. However, they cause additional reflections that reduce the ultrasonic energy reaching the back-wall. Thus, the back-wall echo (BWE) is a measure for the amount of porosity. In certain situations, like e.g. spherically shaped regions in CFRP parts, the back-wall echo cannot be used for porosity evaluation due to geometrical influences. The intermediate echo time series shall be used to create an alternative to the BWE, a BWE equivalent.

It is shown that RQA features can present a proper BWE equivalent. An embedding is performed on the intermediate echo time series and subsequently the dynamical system is reconstructed in state space. The optimum RQA parameters are determined. Results showing a good correlation between determinism and the BWE on a fabric CFRP material with artificial porosity from last RQA symposium proceedings book are resumed. These results are enhanced by a different determination of the goodness of BWE equivalent, looking at true positive rate and false positive rate for a classification into "porous/non-porous". Furthermore, new results on unidirectional CFRP material with "naturally" introduced porosity are shown. Here, especially ratio, determinism divided by recurrence rate, proves as a universal back-wall echo equivalent when determined with angular distance as metric.

On stationarity of neural networks at the transition from unsynchronized to synchronized states

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The brain is one of the most complex parts of the human body and even in current days there are many questions with no answers about it. In this way, there are great efforts on world level to develop researches in order to make possible a better understanding of this organ. The current work has the objective of studying the behavior of neural networks regarding the stationarity displayed by the dynamic of these networks considering the coupling strength parameter of the network's neurons. Therefore, the work simulates a 1024 neurons network, at a small world topology, using the Huber-Braun model, which is a modified model from Hodgkin-Huxley model. For numerical simulation, its uses the Adams' method. The analyses are made using conceptions of recurrence plots, specifically, through the quantifier called determinism, which expresses ideas of density of recurrent points and the existence of diagonal structures on recurrence plots, that are linked to temporal dynamics of systems. The new recurrence analyses obtained by determinsm are compared with the known results generated by a familiar parameter of analysis on dynamic systems: the Kuramoto's order parameter. The results show that the recurrence analyses produce new information about dynamic behavior. Considering the coupling parameter interval before the transition to synchronized behavior, it is possible to notice the existence of different asymptotic behaviors, stationary and a non-stationarity ones.

Recurrence criterion to the breakup of invariant curves

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In phase space with two degrees of freedom, the confinement depends on the invariant tori that limits the chaotic orbit transport. Greene's residue criterion [1], relating the existence of an invariant torus to the stability of a family of periodic orbits nearby, has been used to study the persistence of invariant tori under perturbation. Here, we report an alternative procedure to characterize the invariant tori breakup and estimate the corresponding critical parameters. The new procedure is based on the Slater's theorem that states that an irrational translation over a circle returns to an arbitrary interval in at most three different recurrence times [2]. This result has a connection with two dimension area-preserving maps, for which quasiperiodic orbits in invariant tori have irrational rotations

in invariant circles. The new procedure has been applied to obtain the breakup diagram in the parameter space of bidimensional symplectic maps, as the standard twist and nontwist maps [3], and the Ullmann map used to describe chaotic transport in plasma physics [4].

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Recurrence plot and their application to time series associated solar storm

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Solar storms consist of three major components: solar flares, solar proton events and coronal mass ejections (CMEs). Not all solar storms produce all of these elements, but the largest solar storms tend to it. CMEs can interact with Earth's magnetic field to produce geomagnetic storm, this produce a temporary disturbance of the Earth's magnetosphere and equatorial ring of currents. There is a global index, the disturbance storm time Dst, which was devised as a mean for characterizing the level of disturbance observed in the equatorial regions. In this work we study the dynamic of index Dst by means recurrence plot (RP)

Recurrence plot measures of complexity and its applications to self-potential time series arising from a Mexican seismic zone

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Since several years ago, electro-telluric stations located in several sites of Mexico records signals of the self-potential of the ground. Some of these stations are located along the coast of Guerrero state, near the Middle American Trench, which is the border between Cocos and North American tectonic plates. In this work, we study time se-

ries of self-potential signals arising from Acapulco station (16.85°N, 99.9°W), linked to the Middle American Trench. This work analyzes time series corresponding to the 1995 year. An earthquake of magnitude Mw 7.4 occurred in this year. The theory of dynamical systems allows to appreciate the richness of behavior of the world around us. The self-potential time series show a complex behavior, but the Recurrence Plots (RP) theory provides a valuable tool for studying this kind of systems

Heterogeneous recurrence representation and quantification of dynamic transitions in continuous nonlinear processes

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Many real-world systems are evolving over time and exhibit dynamical behaviors. In order to cope with system complexity, sensing devices are commonly deployed to monitor system dynamics. Online sensing brings the proliferation of big data that are nonlinear and nonstationary. Although there is rich information on nonlinear dynamics, significant challenges remain in realizing the full potential of sensing data for system control. This paper presents a new approach of heterogeneous recurrence analysis for online monitoring and anomaly detection in nonlinear dynamic processes. A partition scheme, named as Q-tree indexing, is firstly introduced to delineate local recurrence regions in the multi-dimensional continuous state space. Further, we design a new fractal representation of state transitions among recurrence regions, and then develop new measures to quantify heterogeneous recurrence patterns. Finally, we develop a multi-variate detection method for on-line monitoring and predictive control of process recurrences. Case studies show that the proposed approach not only captures heterogeneous recurrence patterns in the transformed space, but also provides effective online control charts to monitor and detect dynamical transitions in the underlying nonlinear processes.

Surrogate methods for melody compositions: Investigating music structures with Recurrence Quantification Analysis

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What sort of process underlies music composition? We know that the perception of music is mainly controlled by expectations, which can be related to the presence of recurrent structures in music. In this work, we are proposing to investigate the presence of recurrence in music by treating the time series comprising a melody as empirical data from a stochastic or dynamical processes. With this in mind, the use of surrogate data offers a regime to test the hypotheses of the driving mechanism of the system responsible for the composition, so that one can investigate to what extent such methods can capture the process by which the original sequence of notes is generated. One way to address the recurrence behaviour of a time series is by means of the Recurrence Quantification Analysis (RQA). Thus, we follow this strategy and test the hypothesis that the surrogate data is of the same class as the original composition with the use RQA measures on the top of recurrence plots of melodies from different methods of surrogate. We use linear and nonlinear classes of surrogate data, the first one represented by the traditional algorithms of Theiler, and the second one represented by a network random walk determined by a Markov model trained with the original song.

Recurrence Sparsity:
A New Complexity Measure Based on the Gini Index

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In this work, we propose a new metric for recurrence quantification based on the Gini index, widely used, in the field of Economics, to study income inequality. The basis of the proposed approach is that it is possible to quantify the recurrence structure of time series by analyzing the sparsity of the diagonals of its associated map. The Gini index is used to assess the aforementioned degree of sparsity, and the property that it assumes values exclusively between zero and one appeared to be quite useful. Interestingly, the method can be understood as translating the time series into a domain in which sparsity plays a key role, something that occurs in the field of signal processing in other contexts (e.g. blind source separation).

The proposal was tested using periodic, chaotic and stochastic signals, and the values of the Gini index had a distinct behavior in each case, which indicates that it is an effective metric. A comparison with classical metrics is also provided, which allows an initial reflexion on possible points of contact. An immediate perspective for future work is to carry out an extensive comparative analysis including a significant range of paradigms, signals and systems.

Moved by Art: Postural Dynamics and Appraisal in Viewing Paintings *Poster*

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From an ecological psychological point of view, bodily movement, perceptual judgement and observed (spatial) structure should be closely related while experiencing a work of art. In the current experimental study, participants looked at 10 life-sized paintings by Jackson Pollock and Piet Mondriaan on a large screen, for 100 seconds each, at a distance of about 2 meter. Participants were standing on a balance board (100 Hz) to measure their postural sway and used a tablet to rate the beauty and complexity of each painting and the extent to which they felt drawn-towards and moved-by it. Nonlinear time-series techniques, in particular recurrence quantification analysis, were used to quantify the postural dynamics. Results suggest a sophisticated interplay between painting, postural sway and appraisal. There were significant differences between paintings in the temporal organization of the medio-lateral (i.e. side-by-side) postural sway. Additionally, postural dynamics was related to scores of feeling moved-by and drawn-towards a painting.

On the use of the phase diagram domain properties for the Instantaneous Frequency Law tracking

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Time-frequency analysis is naturally the way of characterization of non-stationary signals. One fundamental parameter of any non-stationary signal is the Instantaneous Frequency Law (IFL) of its components. The Instantaneous Frequency Law estimation is usually subject of tracking in time-frequency domain, especially in the case of complex time-frequency structures. Using the concept of phase diagram representation of a signal, related to the concept of nonlinear dynamic systems, we aim to track the Instantaneous Frequency Law of a signal, providing a new method for the estimation of the frequency's evolution in time. The main advantage of this approach is the capability of phase diagram representation to highlight the signal's phase continuity, very useful for an accurate IFL tracking. An alternative to the classical approaches, our method is based on the time-frequency continuity exploiting, very helpful especially in the case of crossing and/or close time-frequency structures. We show that the continuity property is naturally visible in the phase diagram domain.

Knowing that a sine wave's trajectory in the phase diagram is an ellipse, the concept of IFL tracking in the phase diagram is the following: when the system returns in a previously visited point on the trajectory (a recurrent state) – namely the position vector of the trajectory has performed a complete rotation of the ellipse – the speed of rotation of the position vector is directly related to the local frequency of the signal. This criterion is then applied on a sliding window, allowing an accurate IFL tracking of the signal's components.

Further developments will focus on investigating the capability of instantaneous frequency law tracking in the phase diagram, trying to take advantage of the phase continuity of the phase trajectory. Namely, the IFL tracking can be successfully based on the association of the time-frequency points according to the continuity criteria that could be efficiently exploited in the phase diagram domain. In the case of the multi-lag phase diagram analysis, this continuity will be defined in a more robust manner since the random noise effect will be minimized when looking to different lags.

Results in the particular applicative context of acoustic sensing will prove the potential of this approach with respect of conventional ones based on the IFL tracking in the spectrogram domain.

The geometry of recurrences – recurrence plots as spatial networks

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Classical recurrence quantification analysis and recurrence time statistics comprise a variety of useful characteristics based on diagonal and vertical line structures of either recurrences or non-recurrences, which address different aspects of the dynamical complexity of the time series under study. As a complementary viewpoint, recent developments have demonstrated that recurrence plots can be equally characterized from a geometric perspective. Specifically, the underlying recurrence matrix has a straightforward interpretation as the adjacency matrix of a complex network in the underlying dynamical system's (reconstructed) phase space. The construction of such recurrence networks yields a specific type of random geometric graphs that is uniquely characterized by the system's invariant density and the neighborhood range of the considered recurrence definition. The latter observation allows establishing analytical links between certain properties encoded in the recurrence plot and the spatial organization of the studied system in its phase space.

In my talk, I will review the mathematical background of recurrence network analysis and illustrate the usefulness of corresponding network properties for discriminating qualitatively different dynamical states and identifying dynamical changes in a system's nonlinear variability. In particular, I will highlight the practical relevance of recurrence network transitivity as a proxy for a generalized notion of fractal dimension, which can be estimated from a recurrence plot without the need of studying any scaling characteristics with varying recurrence threshold. Based on some real-world geophysical examples, I will finally demonstrate that recurrence network analysis is at least equally suited for characterizing distinct dynamical states of a system as compared to classical measures of recurrence quantification analysis.

Eventogram: A Visual Representation of Main Events in Biomedical Signals
Poster

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Biomedical signals carry valuable physiological information and many researchers have difficulty interpreting and analyzing long-term, one-dimensional, quasi-periodic biomedical signals. Traditionally, biomedical signals are analyzed and visualized using periodogram, spectrogram, and wavelet methods. However, these methods do not offer an informative visualization of main events within the processed signal. This work attempts to provide an event-related framework to overcome the drawbacks of the traditional visualization methods and describe the main events within the biomedical signal in terms of duration and morphology. Electrocardiogram and photoplethysmogram signals are used in the analysis to demonstrate the differences between the traditional visualization methods, and their performance is compared against the proposed method, referred to as the "eventogram" in this paper. The proposed method is based on two event-related moving averages (TERMA framework) that visualizes the main time-domain events in the processed biomedical signals. The traditional visualization methods were unable to find dominant events in processed signals while the eventogram was able to visualize dominant events in signals in terms of duration and morphology. Moreover, eventogram-based detection algorithms succeeded with detecting main events in different biomedical signals with a sensitivity and positive predictivity $> 95\%$. The output of the eventogram captured unique patterns and signatures of physiological events, which could be used to visualize and identify abnormal waveforms in any quasi-periodic signal.

Non Linear Analysis Of Allergen Protein Ole e6 atomic positions

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The linear correlations of atomic positional fluctuations have been studied using the Dynamic cross-correlation map (DCCM) and the non-linear methods of Cross Recurrence Plots (CRPs) and Joint Recurrence Plots (JRPs). The latter is shown to be more suitable for characterizing protein motion that is non-linear by nature. In fact literature has shown that the DCCM has been used extensively to study protein dynamics (the linear correlation).

In this work, we introduce for the first time the usage of the two non-linear methods the CRPs and JRPs as a complementary methods to detect correlation between protein residue atom. Time series of the distances for the atoms of Ole e6 allergen protein from a reference position, extracted from molecular dynamic simulation, are analyzed. The results are compared to those provided by DCCM. In comparison to DCCM, JRPs and CRPs found to detect most of the correlations present in DCCM. In addition these methods were able to detect a small number of significant correlations between distant residues which are not detected by DCCM. Synchronization between residues is shown to be more defined at 100 ps than at 1 ns. Neighboring residues, contrary to what is expected, do not show a general trend of synchronization. A randomization test is used to differentiate between real and artificial dynamics.

In conclusion, JRPs and CRPs can be used to study structure and dynamics of other well known proteins, with already well characterized collective motions. Also JRP can be used to investigate the communication path between different parts of a given protein and to know more about how information is transmitted through the protein, and how far residues in the protein communicate.

TsViz Project:
A tweet-based mining tool

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The last decades have been characterized by the design and development of new technological tools to allow faster communication among people. In that context, Twitter, created in 2006, reached an enormous popular-

ity as a microblogging service, where users can publish short messages called tweets. In particular, the social network disseminates the use of hashtags, which are part of the text, to promote topics, subjects and/or causes. Twitter also provides an Application Programming Interface (API) that allows to capture and query published tweets. Therefore one can write its own application to monitor messages under specific hashtags. In 2015, we started the development of the TsViz project, funded by CNPq/Brazil, to monitor and extract useful information from tweets. Our main goal is to model the public opinion over time and how they relate to different topics. In that sense, we have been monitoring Brazilian political and economic situation to provide evidence on how people have been facing particular issues. TsViz has a module to continuously collect tweets under the hashtags of interest, while another one is responsible for processing texts and transform them into different time series. Time series correspond to different sorts of analysis, including, but not limited to, i) the novelty level each new tweet adds to the historical information; ii) the sentiment analysis associated to every new tweet; iii) the most relevant words associated to each hashtag over time, etc. While analyzing the time series we decided to employ immerse time series into phase spaces, using Takens embedding theorem, and the Cross-Recurrence Quantification Analysis to compare how the trajectories of different time windows of the same series behave while assessing the length of the longest diagonal line segment (excluding the main diagonal). From that, we obtained a Concept Drift detection approach to point out the most relevant events associated with a given hashtag. For example, while analyzing the novelty level each new tweet added to the historical information for the hashtag dilmabr (the one used by the Brazil's former president), we observed the most relevant events were associated to the exact date the impeachment was voted in the House of Representatives, the exact date Petrobras (the main Brazilian oil company) confirmed the corruption to the stockholders, and the date Fidel Castro died (one of her main allies). Recently, we have been working on a web interface to provide all those results and interaction to end users.

Detecting Phase Synchronization Regime in a Three-scroll Chaotic Attractor

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Since phase synchronization (PS) phenomenon between coupled chaotic oscillators was discovered, many ways to characterize PS were studied. Multiple-scroll chaotic attractors represent an additional challenge to identifying PS regime, especially when a well defined rotation plane is not readily available. This work presents the application of recurrence quantification analysis (RQA) to detect PS regime in coupled Li oscillators, which exhibit a multiple scroll attractor with bounding torus of genus-three. The RQA analysis is done with the cross correlation coefficient between the probability of recurrence (CPR) and the joint probability of recurrence (JPR). The results are compared to other methods (e.g. M-SSA, mean phase coherence, phase difference measured by Poincaré section) and the main aspects are discussed.

The Life and Death in the context of Recurrence Plots

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The study of recurrence data in a phase space is important to investigate the dynamics of biological systems and has raised a special interest in Medicine. In the clinical field, heart rate variability (HRV) and recurrence quantification analysis (RQA) have become relevant tools to verify the deterministic characteristics in healthy and diseases conditions and its counterparts, Life and Death.

The aim of the present study was to recognize visual patterns of recurrence plots at life and death states in full-term newborns, healthy young adults and individuals with brain death. We selected 30 full-term newborns (1-3 days old), 30 healthy young adults (20.2±1.2 years old) and 4 adults with brain death. Time series of 1,000 beat-to-beat RR intervals were captured with Polar Advantage S810i equipment and to exclude ectopic beats or noise effects data were appropriately filtered according to T-RR Filter 1.1 beta software (Pillat VG & Santos L, 2013). Recurrence plots were constructed using Visual Recurrence Analysis 5.01 software (Eugene Kononov, May 2007) with the following parameters: dimension=10, time delay=1, ratio=70, line=2 and scheme Volcano. Some variables were also studied: The standard deviation of successive RR intervals (SDNN), Recurrence Rate (REC%), Determinism (DET%), Laminarity (LAM) and MaxLine (Lmax). Data were expressed as mean±SD. Statistical analysis was performed with commercially available software (StatsDirect version 1,9,15 – 2002) using one-way ANOVA and the Tukey post test for multiple comparisons between groups. A P-value < 0.05 was accepted as significant.

We detected a clear pattern of recurrence plot for each group. The Death is linear compared to Life, which has progressive more variability from newborns to young adults. The variables confirmed this picture showing

the Death Group with the lowest values for SDNN (8.3±1.5 ms) and the highest for REC% (42.7±3.7), DET% (99.6±0.17), LAM (99.4±0.5) and Lmax (990.3±0.5) compared to the Life Group, newborns and young adults, respectively: SDNN (36.6±16.0; 56.7±20.3 ms),REC% (39.1±7.1; 22.5±3.9); DET% (99.5±0,7; 96.5±1.5), LAM (98.8±3.5; 83.9±11.7); Lmax (722.0±272.0; 214.2±142.1). For all comparisons the P-value was < 0.001.

Recurrence Plots are efficient tools to distinguish the Life and Death. The variables confirm that the heart rate variability is progressively lower in immature or disease conditions, specifically in death.

Diagonal properties of cross recurrence plots between heart rate and systolic blood pressure of end stage renal disease patients *Poster*

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Cross recurrence plot (CRP) analysis allows to study how two related variables or processes evolve in time. Some dynamical measurements based on diagonal lines (Diagonal Analysis, DA) evaluate the association strength of the two given variables. Using quantitative indexes computed for different lags, the evolution of the association strength and direction can be recognized. In this work, we analyze the dynamical association between inter-beat intervals (IBI) and systolic blood pressure (SBP) obtained from the same physiological recordings during supine position and active standing (AS) in two groups: healthy persons and end stage renal disease (ESRD) patients, to assess their dynamical association as well as its evolution in direction. Non-invasive blood pressure recordings were obtained from 22 healthy subjects (age 28 ± 6 years, 10 were female) and 11 ESRD patients (age 30 ± 9 years, 5 female) during 15 minutes in supine position followed by 15 minutes during AS. The embedding delays for CRP were estimated by the crosscorrelation (CC) function, embedding dimension estimated by the FNN method was fixed to 10, and a fixed amount of neighbours with recurrence rate (RR) < 10 %. Mean values of the RR, Determinism (Det) and Mean Diagonal Length (Lm) were obtained for lags from -40 to 40 heart beats in both directions: IBI →Âǎ SBP (+) and SBP →Âǎ IBI (−). We compared all quantitative indexes between groups and positions ($p < 0.05$ was considered significant). In the healthy group during supine position the maximum RR computed from (−) direction was larger than in (+) direction. The mean Det was larger in ESRD patients during supine position in both directions (+) and (−). During orthostatism, CC and the maximum RR from (+) direction were larger in ESRD patients. Interestingly, the statistic difference between (+) and (−) direction depends on the lag: for lags above zero, RR, Det and Lm measured from (−) direction were larger than those from (+) direction, in both groups and positions. For lags between 10 and 20 this difference in RR was inverted, i.e., RR was larger in the (+) direction. The dynamical response of IBI and SBP to AS corroborates the strong covariation of these cardiovascular variables. The diagonal lines are intermittent and not always parallel, showing that there is not a defined and unique rhythm. This suggests the activation of different influences at different times towards the heart and blood vessels in response to AS.

Recurrence Plot Patterns in Bipolar Disorder: Mania vs Euthymia *Poster*

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Changes in autonomic nervous system (ANS) is related to many mood disorders including bipolar disorders (BD). According to this fact, recurrence quantification analysis (RQA) may be important to investigate dynamics of biological systems and to verify the deterministic characteristics before and after BD treatment.

The present study aimed to recognize what are the visual patterns of recurrence plots in maniac and euthymic phases of BD and the respective variables of recurrence. We selected 20 male patients (35,5±12,9 years old) hospitalized in the maniac phase of BD. Psychiatric diagnosis and symptoms were assessed by Mini International Neuropsychiatric Interview (MINI) and Bech-Rafaelsen mania scale (BRMS), respectively. Electrocardiographic series (15 minutes of duration in resting state) were captured using Polar Advantage S810i equipment. Noise effects were appropriately filtered according to T-RR Filter 1.1 beta (Pillat VG & Santos L, 2013). Recurrence plots were constructed using Visual Recurrence Analysis 5.01 software (Eugene Kononov, 2007) with the following parameters: dimension=10, time delay=1, ratio=70, line=2 and scheme Volcano. Quantitative variables were also studied: Recurrence Rate (REC%), Determinism (DET%), Laminarity (LAM), Trapping Time (TT), Shannon Entropy (SE) and MaxLine (Lmax). Statistical analysis was performed with commercially available software (StatsDirect version 1,9,15 – 2002) using paired T test to compare pretreatment and post-treatment conditions. Results were expressed as mean±SD. A P-value < 0.05 was accepted as significant.

Was identified a distinct pattern of recurrence for both groups, where pretreatment patients presented a more

linear aspect, compared to patterns displayed after treatment, showing evident more variability and so more homeostasis, after treatment. The studied variables confirmed this observation showing the Pretreatment Group with the highest values for REC% (34.2±6.6), DET% (92.7±13.0), LAM (88.2±22.8), Shannon Entropy (5.1±0.4), Lmax (737.2±277.0) and TT (18.0±7.0), in comparison to after treatment: REC% (28.2±7.3), DET% (88.0±17.1), LAM (80.8±24.9), Shannon Entropy (4.6±0.5), Lmax (446.2±307,1) and TT (12.0±6.5). For all comparisons, the P-value was < 0.05.

Recurrence Plots are important tools to differentiate visually Mania vs Euthymia in BD. The recurrence variables are significantly higher in mania, improving with treatment, when euthymia is reached.

Dual eye-tracking for the assessment of team cognition in laparoscopic surgery: Evidences from cross recurrence analysis

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To use dual eye-tracking to record surgeons' eye motions simultaneously during laparoscopic surgery, and use cross recurrence analysis (CRA) to reveal shared cognition toward team goals. 17 subjects formed 22 dyad laparoscopic teams. The camera holder was required to move the endoscope for the primary operator to transfer an object between pins located in different locations inside a training box. Task time was used to divide the teams into elite and poor performance teams. Shared gaze behaviors between two surgeons in a team were reported by gaze overlap and time when two team member achieved the highest cross recurrence rate. The cross recurrence rate was calculated based on spatial and temporal features of gaze data of two team members by using CRA.

The results indicate that team members in elite teams were overlapped better throughout the whole procedure than poor teams (36% vs. 29%, p = 0.018) and also overlapped better during the tool transportation time (51% vs. 30%, p = 0.023). CRA also revealed a higher recurrence rate between two team members in the elite teams(78.06%) than in the poor teams (34.41%; p = 0.042). Further analysis showed that team members in poor teams displayed a 2.25 sec gaze delay during transportation; whereas the delay dropped to 0.26 sec in the elite teams (p = 0.032). also in the elite teams the camera holder's gaze was ahead of the primary performer, whereas in the poor teams the camera holder's gaze was behind.

This is a first study using CRA to describe dual eye-tracking in laparoscopic surgery. CRA on dual eye-tracking in a surgical team is proved to be a powerful tool for revealing team cognition, and can serve to improve the training quality of surgical teams.

Study of cardiac signals using recurrence plot *Poster*

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The cardiovascular system is responsible for supplying the human organs with blood. It is composed by the heart, the arteries, and the veins. The heart has as function to pump blood throughout the body, that is realised by means of contractions. The human heart beats an average 72 beats per minute and pumps 0.07 liters of blood per beat. The contraction and relaxation of the heart is obtained by a single cycle of the electrocardiogram signal (ECG), namely the ECG records the electrical activity of the heart. Time the electrical activity from the heart, and the electrocardigraph are used as a tool for the diagnosis of cardiac abnormalities, as well as recurrence plots are a good tool for complex systems study. The recurrence technique is successfully applied in the analysis of cardiac signals. In this work, we consider autoregressive process in a mathematical model based on coupled differential equations in order to model electrocardiogram signals and with the recurrence plot we can visualize the behaviour of trajectories in the phase space and still show all times in which a state of a dynamic system repeats itself.

Classifying abrupt transitions in IPCC climate models and paleoclimate proxy data using Recurrence Quantification Analysis

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In many data driven disciplines, categorising abrupt transitions / regime changes are of high interest. The different aspects of recurrence can help to identify and characterize subtle changes in systems dynamics. Besides the identification of transitions, recurrence methods can help to provide a better understanding of the underlying process of these transitions by statistically describing the dynam-

ical characteristics, e.g. the predictability, determinism and complexity of the dynamical system. For example, the characteristic block structures in the recurrence plot can be used to identify different types of intermittency. In general, changes between different dynamics are visually well expressed in recurrence plots. The introduction of selected recurrence quantifiers (such as recurrence rate, determinism, or laminarity) together with a running window approach has paved the way for a quantitative recurrence analysis of transitions and therefore allow a classification of different transition types.

In this work first results of such recurrence based classification is shown. We demonstrate it by analysing prototypical models of transitions as well as on real world data related to palaeoclimate. The prototypical models are selected from a catalogue of transition types which have been used and discussed in models presented in the reports of the Intergovernmental Panel on Climate Change (IPCC)[1]. In the palaeoclimate example we consider two Potassium time series of two drilling cores from the Chew Bahir Bassin, which is part of the Hominin Sites and Paleolakes Drilling Project (HSPDP).

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Spatial Recurrence in Networks of Bursting Neurons *Poster*

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In this work, we analyze an application of recurrence plots in the study of dynamic patterns in neural network at a given time instant. We consider spatial recurrence plots as a diagnostic tool to verify the synchronization in a neural network with dynamics of chaotic bursts given by coupled Rulkov maps for different topologies. We observe that different patterns of synchronization depend on the network topology, the intensity of the coupling between neurons and the threshold used to evaluate the Euclidean distance between the firing phases. The use of this tool in networks has been effective in specifying with spatial resolution the regions of intense neural synchronization.

Differential embedding – From theory to application in palaeoclimatology

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Analysing data from palaeoclimate archives such as tree rings or lake sediments offers the opportunity of inferring information on past climate variability. Often, such data sets are univariate and a proper reconstruction of the system's higher dimensional phase space can be crucial for further analyses. In this study, we revisit the concept of differential embedding as an alternative approach to time-delay embedding and aim at bringing it closer to application.

Differential embedding relates the system's higher dimensional coordinates to the derivatives of the measured time series. For implementation, this requires robust and efficient algorithms to estimate derivatives from possibly irregularly sampled data. For this purpose, we consider several approaches: (i) central differences adapted to irregular sampling, (ii) a generalised version of discrete Legendre coordinates [1] and (iii) the concept of Moving Taylor Bayesian Regression [2]. We then systematically evaluate the performance of differential and time-delay embedding by comparing geometrical properties of the embedded attractors to those of the original attractor for two paradigmatic model systems – the R"ossler and the Lorenz system. The quality of the phase space reconstruction is quantified using recurrence network analysis.

Our results suggest that differential embedding can indeed be an alternative to time-delay embedding for unequally spaced time series. Hence, using differential embedding and recurrence network methods to analyse palaeoclimate data sets opens up good prospects of gaining new insights into past climate variability. We demonstrate the potential of this approach for real-world applications by applying derivative embedding in combination with recurrence network analysis to some well-studied palaeoclimate data sets from Mexico and South America.

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Reconsidering the Computation of Entropy in Recurrence Quantification of Categorical Data

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In this work, I will propose a new method for the computation of informational entropy from Recurrence Plots (RPs) when the analyzed time series are categorical in nature. When categorical time series are analyzed, the parameters of the recurrence analysis are usually simplified, so that no embedding in multidimensional space is typically assumed (i.e. embedding = 1) and recurrence is tantamount to exact matching of the numerically coded categories (i.e. radius = 0). Yet such a simplified parameterization brings about some notable changes in the appearance of the resulting RPs which has consequences for the computation of the typical dynamical measures we usually extract. Specifically, a categorical RP is mostly composed of rectangular structures rather than line structures (diagonal and horizontal/vertical), over which recurrence quantification measures were originally proposed (Marwan, Romano, Thiel, and Kurths, 2007; Webber and Zbilut, 1994; Zbilut and Webber, 1992).

Starting from this observation I consider some consequences on the distribution of diagonal lines in a RP and propose the areas of the rectangular structures as a basis for an alternative computational procedure to extract a non-biased measure of entropy for the categorical case, showing the viability of such a choice with simulated data. Simulated time series data are chosen to represent the whole range of cases in which informational entropy should logically go from minimal to maximal values. Quantification of standard, diagonal-line based measure of entropy on these simulated time series does not follow the expected pattern of results, while the alternative computation of entropy I propose, very closely match such a pattern.

It is suggested that Recurrence Quantification Analysis of categorical time series could have special characteristics that need to be carefully studied and evaluated in future studies, especially because of the popularity of recurrence analysis methods in fields of study (e.g. in the behavioral sciences) where this kind of time series are very frequent.

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Performance Evaluation of Recurrence Quantification Measures to Discriminate Individuals with and without Voice Disorders *Poster*

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In this work recurrence quantification measurements (RQM) are applied for discriminating individuals with and without voice disorders. A total of 541 recorded sustained / ε /, and visual laryngeal examination. The overall deviation of each voice sample was determined in a 100-point visual scale. 52 normal individuals samples (normal larynx and reduced overall deviation of less than 35.5points) and 489 dysphonic subjects samples (structural or functional changes and higher vocal deviation of more than 35.6 points) were submitted to a 12 RQMs extraction such as formation of recurrence points (determinism, DET; type 1 and type 2 recurrence time, T1 and T2; and transitivity, TRANS), diagonal lines (average and maximum length of diagonal lines, Lmax and Lmed; Shannon entropy, ENTR; and divergence, DIV) and vertical structures (average and maximum length of vertical lines, TT and Vmax; laminarity, LAM; and entropy of type 1 recurrence time, RPDE). We also analyzed parameters related to recurrent vocal production system topology (immersion dimension, m; reconstruction step, τ; and neighborhood radius, Radius). A total of 15 measures were obtained. Quadratic discriminant analysis and accuracy, sensitivity and specificity of performance measures were used to investigate discriminatory power of QRMs, as well as cross-validation of random signals' combination with and without disturbance. Single measurements, such as ENTR, Lmed and TRANS had only acceptable performance ratings of $\geq 70\%$ to discriminate between individuals with and without voice disorders with an accuracy. Combined measurements achieved good performance related to the individual ones. The combination of 8 parameters, such as Lmed, ENTR, TT, Vmax, τ, m, RADIUS, and TRANS, produced the highest accuracy of 83.27%. RQMs related to formation of diagonal lines showed acceptable performance of $\geq 70\%$ in classifying individuals with and without voice disorders. Combination of RQMs showed improved discrimination between study groups, with good performance and higher sensitivity and specificity.

Recurrence density enhanced approach

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We present a transformation method, entitled Recurrence Density Enhancement Approach (RDE), that aims to highlight the main recurrence structures of a given recurrence plot (RP). Our method results in a figure with a reduced number of points yet preserving the main and fundamental properties of the original plot. The existing measures of quantification analysis are applied to characterize the underlying dynamical system. Our evaluation results indicate that our proposed appproach allows to discriminate different dynamic regimes adequately, while using a reduced set of points from the original RP.

What can you see?

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Recurrence plots exhibit features and patterns which are characteristic for typical dynamics. How difficult does it be to visually recognize the dynamics from the recurrence plot? Does everybody see the same or judges the different patterns with similar importance? In this (interactive) talk we will figure out the subjective nature of visual inspection and discuss the difficulties. It finally underlines the importance of applying objective quantifiers such as recurrence quantification analysis.

Multiplex Recurrence Networks *Poster*

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The complex nature of a variety of phenomena in physical, biological, or earth sciences is driven by a large number of degrees of freedom which are strongly interconnected. Although the evolution of such systems is described by multivariate time series (MTS), so far research mostly focuses on analyzing these components one by one.

Recurrence based analyses are powerful methods to understand the underlying dynamics of a dynamical system and have been used for many successful applications including examples from earth science, economics, or chemical reactions. The backbone of these techniques is creating the phase space of the system. However, increasing the dimension of a system requires increasing the length of the time series in order get significant and reliable results. This requirement is one of the challenges in many disciplines, in particular in palaeoclimate, thus, it is not easy to create a phase space from measured MTS due to the limited number of available obervations (samples). To overcome this problem, we suggest to create recurrence networks from each component of the system and combine them into a multiplex network structure, the it multiplex recurrence network (MRN). We test the MRN by using prototypical mathematical models and demonstrate its use by studying high-dimensional palaeoclimate dynamics derived from pollen data from the Bear Lake (Utah, US). By using the MRN, we can distinguish typical climate transition events, e.g., such between Marine Isotope Stages.

Wavelet-Recurrence Approach for time series analysis *Poster*

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We propose a classification method based on recurrence plot, discrete wavelet transform, and support vector machines. The proposed methodology works as follows: a signal is decomposed into N levels using the discrete wavelet transform. For each decomposition level, the time series are transformed into a recurrence plot and a set of characteristics, extracted by the recurrence quantification analysis and the recurrence network, are used to form the input vector for the classifier. The results showed that the discrete wavelet transform can help the process of obtaining characteristics and distinguishing between different class types. The effectiveness of our methodology is verify by applying it to time series from the logistic map.

Voice Activity Detection based on Recurrence Plots *Poster*

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Voice Activity Detection is an important problem in many speech/audio applications, including speech coding and automatic speech recognition, and several algorithms have been proposed in the literature exploring different metrics of signals (such as spectral flatness and short-time energy). In this paper we present a new methodology for the detection of silence parts of a speech or audio signal

based on the information provided by the recurrence plots of the signal. The proposed method was able to correctly classify silence/activity parts even in conditions simulating a noisy environment, performing better than the algorithm included in the G.729 codec – commonly used in Voice Over IP (VoIP) applications.

Microstates of Recurrence Plots: First Approach *Poster*

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Recurrence plots are binary matrices where the trajectories of a dynamical system in the phase space are evaluated against another embedded trajectory. Given the exponential increase of the amount of data available in the information era, this graphical methodology based on visual qualification of patterns in the matrix has natural limitations, which lead to the advent of the recurrence quantification analysis (RQA) and more recently to recurrence networks (RN). Over more than twenty years this area has evolved and still has much to be done. With such a retrospect, in this work we propose a novel specific way to decompose the recurrence plot, that is capable to maintain the known evaluations but increase the possibilities of analysis. The so called micro-states of the recurrence plot will be presented as dynamical components with their own specific meaning, and applied as first approach to classical nonlinear systems with evidences of some advantages over well known (RQA). In conclusion, it will be shown the next guidelines, possible improvements and applications to real data.

Application of the recurrence plot for nontwist systems *Poster*

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The problem of fluids and plasmas could be described in dynamical systems by use of nontwist systems. The common feature of those systems are the presence of the shearless curves, which affect the transport properties in phase space. Actually, the shearless curve behaves like a barrier separating trajectories of phase space. However, depending of the parameters of our system, the rate of chaotic transport could increase or decrease, even after breakdown of the shearless curves. We show that the phase space has the coexistence of islands and chaotic sea, this coexistence can be analyzed by using the recurrence plot. In particular, the determinism of the recurrence plot provides us an easy way to distinguish the periodic structures from chaotic trajectories. The boundaries of these periodic structures are formed by islands in phase space, nonetheless they are not smooth curves. From these boundaries, could appears some regions with a phenomena of trajectories trapping called stickiness. Once again, we present how recurrence plot are an useful tool to determine the presence of these traps.

Recurrence analysis of ant activity patterns

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Measuring complexity in biological systems is an inherently difficult endeavor, particularly because of their intrinsic nonlinear and noisy nature. Fortunately, computational tools from the recent years offer better ways to obtain qualitative reliable data, such as the computational tracking of individuals, at least in the study field of the animal behavior. The combination of these new methods of data collection and nonlinear analysis could be an interesting way to study several phenomena of biological complexity. Thus, in this study, we used recurrence quantification analysis (RQA) and recurrence plots (RPs) to compare and examine the activity dynamic patterns of isolated, single individuals of ant species, as well as a solitary/gregarious beetle species, to explore varying levels of social complexity. RQA and RPs quantify the number and duration of recurrences of a dynamical system, resulting in a detailed description of its behavior, including the quantification of signals that could be stochastic, deterministic, or both. Our data resulted in 150 time series of two hours each (N= 300 hours). The implications of our study are threefold. First, we found significant differences between the activity dynamics of the gregarious beetles and the highly complex social ant species, the ants have more unpredictable patterns of activity than the beetle species. Second, workers from the different ant species varied with respect to their dynamics, presenting deterministic behavior mixed with stochastic signals, which even could be an indicative of low dimensional chaotic dynamics. Finally, considerable differences were found among minor and major caste (i.e. workers and soldiers) of the same (dimorphic) ant species, major workers appear to have a less predictable activity behavior than minor workers. The results obtained are very related with the biology and natural history of the species. To the best of our knowledge, the present study provided the first application of recurrence analysis to the study of animal ac-

tivity, as well as one of the first applications to biological phenomena outside the study of physiological and cardiac rhythms. The data generated by this kind of analysis could be interesting for behavioral ecologists as to physicists and correlated fields interested in the modelling and theoretical investigations of biological complex systems.

Application of recurrence plot quantification to mineralising systems in geology

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According to the Minerals Council Australia 44% of today's exploration projects try to discover gold deposits – a consequence of the risen gold price. However, exploration of an optimal mineral deposit is expensive with respect with time and the equipment required. Expenditure costs are increasing and decrease the profitability of mining companies: remaining gold deposits are more often sparse, difficult to delineate from economically less important mineral deposits, and of increasingly lower grade with depth – a significant general problem for the Australian mining sector. Innovative approaches of exploring and detecting prospective mining sites and to analyse test bore data are sought.

Mineralogy and elementary decomposition are commonly measured using hyper spectral imaging combined with chemical analyses using a range of statistical techniques; equilibrium chemistry dominates. However, episodic oscillations and non-equilibrium processes are characteristic behaviours of orogenic gold systems and are also properties of nonlinear dynamical systems. Usually these oscillations are attributed to external system processes such as seismic events, adiabatic fault-valve or suction pump/piston behaviours. We assume that the processes involved are aseismic, non-adiabatic as well as internal to the mineralizing system, as hydrothermal, nonlinear dynamical open-flow chemical reactor. The feedback relations between thermo-chemical deformation processes lead to episodic behaviours in temperature and fluid pressures and result in depositing vein filling materials, pyrite and gold both in space and time.

The Gray-Scott model of reaction-diffusion is a well-known analytical model used to study the variety of reaction patterns of chemical species. The Gray-Scott model data, with and without noise contamination, is used here as a benchmark system to study the applicability of nonlinear time series analysis to study spatio-temporal episodic fluctuations of a uni-directionally coupled and flow-driven mineralising system. Recurrence plots, recurrence rate spectra and recurrence time probabilities are applied to detect recurring, possibly chaotic spatio-temporal structures.

We apply the same analysis techniques as used to study the Gray-Scott model to analyse the test bore data of the Imperial deposit of the Western Australian Yilgarn mine to study the intermittency of interval depths of amphibole, carbonate and sericite concentrations. The dynamics indicates clear recurring structures for sericite, which would otherwise easily neglected using conventional Fourier based techniques. Our results show that a mineralising system, as exemplified by the test bore data has dominant by deterministic processes, which are coupled to higher dimensional dynamics. The suitability of the Gray-Scott model to benchmark chemical processes as found in mineralising systems is discussed.

The very beginning of recurrence plots

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A personal narrative of how recurrence plots where created and used for the first time.

Using Cross-Recurrence Quantification Analysis to Improve Semi-Supervised Time Series Classification of Positive and Unlabeled Problems

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The area of Semi-Supervised classification has grown attention in the past years due to the cost to label every single instance on a dataset. Positive and Unlabeled (PU) methods, more precisely, were proposed to identify noisy or special instances in this scenario. This type of problem receives few labeled examples from a single class of interest to proceed with the classification of unseen instances, which are labeled when they hold similar properties with the known class. According to the literature, most of the recent studies applied on time series compute similarity measurements on the time domain using either the Euclidean Distance or the Dynamic Time Warping-Delta, followed by a self-training approach based on the 1-Nearest Neighbor (1-NN) algorithm. Despite time domain measurements permit the analysis of local series shapes, they

disconsider temporal recurrences, which are commonly found in natural phenomena (e.g. population growth, climate studies). By disregarding recurrence features, they lead to poor and inconsistent classification performances, as we show. This drawback motivated us to propose the use of the Maximum Diagonal Line of the Cross-Recurrence Quantification Analysis (MDL-CRQA) as similarity measurement, which is applied on the time series phase space. The phase space is obtained after applying Takens' immersion theorem on the time series, unfolding temporal relationships and dependencies among data observations. As consequence, by comparing phase spaces, we can assess how their trajectories evolve along time, including their periodicities and temporal cycles. Experimental results confirm MDL-CRQA improves classification results for PU time series when compared against the mostly used time-domain similarity measurements.

Recurrence Quantification Analysis in real time in Labview: simulated ECG evaluation *Poster*

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In the last few decades RQA has become an important tool for understanding dynamical systems and time series analysis with increasing popularity among researchers. Despite of such increase, there is a lack of works dealing with RQA in real time due to its inherent computational cost. Aiming to provide an exploratory study concerning this, we replicated the RQA algorithm in Labview framework using an affordable hardware and software – Intel Core i7-4702MQ 2.2GHz (8 cores), 16GB RAM and Windows 64bits – and evaluated this strategy for RQA feature extraction in different simulated EGCs undergoing heart rhythm disorders.

The Labview interface offers the possibility of visualizing the time series and the underlying recurrence plot (RP) obtained to set its reconstruction parameters and observe the following RQA measures: Recurrence Rate (RR), Shannon's Entropy (ENTR), Determinism (DET) and Longest Diagonal (Lmax). The ECG simulation was performed using the Labview's Biomedical Toolkit, which offers nine types of ECG (healthy and 8 pathologies) and the mentioned RQA-based measures were used to classify the heart rhythm and conduction disorders. Recurrence plot parameters were established as: embedding dimension 5, delay 5 and threshold 0.25.

The computational gain analysis per core revealed that 4 cores can execute the same task 3 times faster, being no significant improvement after that. The proposed framework can also deal with sampling acquisitions up to 1200 Hz without accumulating samples in the processing queue. The ECG classification was effectively achieved when using a three-dimensional parameter space defined by: RR, ENTR and DET, and a least-square classifier for defining the 9 classes. The algorithm was trained with 70 observations and tested with 30 observations for each class, being the latter 99.6% correctly classified.

Recurrence and traditional measures of nonlinear dynamic analysis to detect vocal deviations

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In recent years techniques of digital processing of speech signals have been used as an additional tool in the evaluation of vocal deviations, bringing greater convenience to the patient. In this research, we used the Recurrence Measures Determinism, Shannon's Entropy, Mean length of diagonal lines, Maximum length of vertical lines and Transitivity combined with some traditional measures of nonlinear dynamic analysis Reconstruction step, First Minimum of the Mutual Information Function and Correlation Dimension. With the use of these measures as representative features of vocal disorders, the detection of breathiness, roughness and strain deviations was made, compared to normal and ones. It was also evaluated the intensity of the deviations, discriminating between grades 1, 2 and 3, which correspond to normal voices, with mild and moderate deviation, respectively. As a classifier, the MLP (Multilayer Perceptron) neural network was used. Measuring the performance of the measures individually and in combination, an average accuracy of 99.33% was obtained between healthy and changed voices, with the measurements First Minimum of the Mutual Information Function, Correlation Dimension, Maximum length of vertical lines, Mean Length of diagonal lines and Determinism. Regarding the discrimination between the intensity of the degrees of deviations, a mean accuracy of 94.5% was found in the discrimination between normal voices and moderate deviation, with the combination of Determinism, Entropy, Transitivity, and First Minimal Functions, Mutual Information and Maximum length of vertical lines.

Recurrence plots for the assessment of patient-ventilator interactions quality during invasive mechanical ventilation *Poster*

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Inappropriate patient-ventilator interactions' (PVI) quality is associated with adverse clinical consequences, such as patient anxiety/fear and increased need of sedative and paralytic agents, to mention just a few. Bedside monitoring ideally require the critical care professional to constantly observe the waveforms of the measured signals associated with a careful observation of patients physical signs - an impracticable approach considering a daily routine of intensive care units, and being prone to errors due to subjectivity. Thus, technological devices/tools to support the recognition and monitoring of different PVI quality is of great interest. In the present study we investigate two such tools, based on recent landmark studies which applied recurrence plots (RPs) and recurrence quantification analysis (RQA) techniques in non-invasive mechanical ventilation. Our aim is in how this approach could be transposed in a it practical way to the routine of professionals in it critical care (which are not familiar with dynamical systems theory methods and concepts). Two representative time series of each of three typical PVI "scenarios" regarding PVI quality, found in critical care units during invasive mechanical ventilation, were selected from data of 6 critically ill patients (a total of 36 samples). First, both the (i) main signatures in RPs and the (ii) respective signals that provide the most (visually) discriminant RPs were identified. This allows one to propose a visual identification protocol for PVIs' quality through the RPs overall aspect. Support for the effectiveness of this it visual based assessment tool is given by a blind test with real data. Then, an it RQA based assessment tool was investigated, aiming the quantification of the previous RPs visual aspect. A statistical analysis shows that both the recurrence rate and the Shannon entropy are able to identify the selected PVI scenarios. The main findings are that the joint use of RPs derived from peak airflow and the respiratory cycle duration ($Q_{\max}$ and τ_Q, respectively) graphically distinguished the studied scenarios of patient-ventilator interactions; such graphical differences have shown to have quantitative support by the joint use of the corresponding recurrence rates or of the Shannon entropies.

Entropy of recurrence plot configurations and applications to biological and climatological systems

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Recurrence plots are binary matrices where the trajectories of a dynamical system in the phase space are evaluated against another embedded trajectory. Due to the exponential increasing of the amount of data available due the advent of the information era, this graphical methodology based on visual qualification of patterns in the matrix has suffered natural limitations. Great part of these restrictions were overhauled by the recurrence quantification analysis (RQA), which extract different features from recurrence plot (e.g. vertical lines, diagonal lines, density of recurrent or non-recurrent points) and presents new dynamical insights on recurrent dynamics. In this scenario the necessity on the development of more suitable tools to quantify recurrence estates is an important topic. In our work we propose a new recurrence analysis tool based on the concept of information entropy, where the micro-states are specific configurations of the recurrence matrix and contain most of recurrence dynamical information of the traditional (RQA) methodologies. This novel methodology can be applied in a large array of systems, with few (or many) disposable data and parameters to adjust, and without previous base on the source of data. In our results this technique will be applied to canonical dynamical systems on nonlinear dynamics, biological and climatological series of data. In conclusion will be discussed some future perspectives, possible applications and extra improvements.

Causality detection based on recurrence plot

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We will present the Recurrence Measure of Conditional Dependence (RMCD), a recent data-driven causality inference method using the framework of recurrence plots. The RMCD incorporates the recurrence behavior into the transfer entropy theory. We will discuss how this methodology can reveal the lagged coupling of some paradigmatic models and how it reveals causal relations of climate systems. For instance, RMCD detects the influence of the Pacific Ocean temperatures on the South West Amazon rainfall during the 2010 droughts, as well as its influence absence during 2005.

Space-Time Recurrence Counting for Estimating Functional Connectivity in Motor Imagery Brain-Computer Interfaces *Poster*

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Brain-Computer Interfaces (BCIs) define alternative communication systems aiming to map brain signals onto control commands for assistive devices. Moreover, BCIs can also contribute for a better understanding of mechanisms underlying different cognitive tasks by inducing and recognizing stable neuronal electrical patterns. This work presents a BCI performance comparison between four different approaches for evaluating brain functional connectivity based on the recorded surface EEG: Pearson correlation, Spearman correlation, phase coherence – estimated by Hilbert Transform – and Space-Time Recurrence counting, introduced here as the joint spatial recurrences counting between electrodes samples in a time window. An EEG-BCI motor-imagery (MI) database containing training and testing datasets of four tasks – left hand, right hand, feet and tongue – for nine subjects was analyzed (BCI competition IV - dataset 2a [1]). Connectivity was represented by an adjacency matrix, built considering similarities between all pairs of the 22 electrodes for each MI task. Feature extraction was performed considering classical graph metrics: degree, clustering coefficient, betweenness and eigenvector centralities; and the attributes were selected based on a cluster measure given by the Davies-Bouldin index. Finally, a least squares classifier was used and the classification error was obtained based on training and testing datasets. We used a correlation threshold of 0.3, synchronization threshold of 0.32, and the parameters used in Space-Time Recurrence, distance threshold (ϵ) and counting threshold (ϕ), were 2.1 and 0.5. These parameters were chosen based on the best performance attained in order to compare the strategies. As a result, Space-Time Recurrence exhibited the best performance, obtaining an error of 0.57 ± 1.22 considering all subjects and classes, being significantly better than phase synchronization (*p*-value=0.013). Pearson correlation, Spearman correlation and phase coherence errors were, respectively, 0.630 ± 0.068, 0.632 ± 0.067 and 0.658 ± 0.814. These results point to the possibility of using space-time recurrence counting between electrodes to compute similarity and support the use of network metrics as features in the BCI context.

References
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Identification of the chimera states in cat matrix neuronal using recurrence plot *Poster*

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Neuronal systems have been modeled by complex networks in distinct description degrees and display rich dynamics behaviors. Among these behaviors we can have the hybrid where the networks exhibit simultaneously one coherent and other incoherent domain, known of the literature as chimera states. In this work, we study the existence of chimera states in a network where considering the connectivity between the neurons of the network based on the cat cerebral cortex, where the local dynamics is governed by the Hindmarsh-Rose model. The Hindmarsh-Rose equations are a well known model of neuronal activity that has been considered to simulate membrane potential in neuron science. We examine under which conditions chimera states are present, as well as the affects induced by intensity of coupling on the neurons of the network. This route we can identify the regions where chimera states arise by analyse through of the recurrence plot. We identify two different class of chimera states: spiking chimera with desynchronized spikes, and bursting chimera with desynchronized bursts. Furthermore, we discovered that chimera states with desynchronized spikes are less robust to neuronal noise than with desynchronized bursts.

Texture-based analysis of recurrence plots for laryngeal pathologies detection using wavelets and PSO. *Poster*

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The acoustic analysis of the speech signal due to its noninvasive nature and its low cost, has proved an effective tool to aid in the diagnosis of vocal disorders caused by diseases in the larynx. In this work, a method based on analysis of texture of recurrence plots is employed, that characterize the dynamics of the speech production system. The recurrence plots have large and small-scale patterns,

whose texture variations represent the voice signal behavior, providing information about the state of normalcy or changes in voice quality. Small-scale patterns can be seen as texture features and serve as the basis for a quantitative analysis of the recurrence plots. Digital images processing techniques are used for texture analysis contained in the recurrence plots, based on two-dimensional wavelet transform. In order to discriminate between healthy and pathological signals, several texture descriptors are extracted from each subband coefficients obtained by two-dimensional wavelet decomposition. In this study, two approaches were applied, which differ in the way of extraction of representative patterns of signals: extraction of texture descriptors directly from the subbands of wavelet transform; and extracting the Haralick descriptors from the co-occurrence matrix. The best results were obtained with Haralick descriptors, using Multilayer Perceptron neural network, in the classification, with the optimization algorithm (Particle Swarm Optimization) used in the selection of the most representative features.

Accuracy rates obtained in the classification process were: 88.49% for healthy voices versus pathological voices; 91.27% between healthy voices and voices affected by paralyzes in the vocal folds; 86.56% between healthy voices and voices affected by edema; and 91.79% among healthy voices and voices affected by nodules.

Why mechanical machines should be treated as complex systems

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Nonlinear time and recurrence analysis have proven to be highly successful for a very diverse field of nonlinear dynamical processes. Typically, this data driven method is applied to systems that cannot be modelled in a bottom-up manner due to complexities or uncertainties involved but can be quantified via measurements. Well-known examples range from natural sciences, medicine and biology (physiology) to finance and earth science to only mention a few. Focus is on analyzing the output, i.e. observations instead of trying to mathematically detail the systems. Friction brakes, turbo machinery and many other highly sophisticated mechanical machines reveal a plethora of unwanted and possibly safety critical noise and vibration phenomena, which today's engineers can only partly relate to operational conditions or system configurations. Analysis approaches are mostly limited to the concept of assembling models of little parts: geometrical, material and dynamical properties of each part are determined, from which a mathematical model of the complete machine is created following the pure form of linearity (superposition principle). This bottom-up approach has been applied successfully in many disciplines with the aid of advanced material models, discretization strategies, model order reduction methods and high performance computing. However, system inherent nonlinearities and their interaction, multi-physics, different time and length scales and unknown operational conditions often cause large discrepancies between experimental results and the mathematical models for numerous engineering structures, making high-fidelity modelling of a synthesized machine an ambitious task.

Considering those modeling challenges in machine dynamics and the limited modeling improvements made in recent years, we pose the provocative question: why do we not as engineers look at a machine and its dynamics as if it was a brain, a stock market or a planet's climate system, i.e.apply a complex system understanding? Building on previous work we sketch why a machine exhibiting multiple vibration phenomena should be treated as a complex system and be analyzed by appropriate methodologies. On the example of friction-excited vibrations as found in brake systems we outline today's engineering approaches to modeling of the in most instances poorly understood dynamics. Augmenting previous works on low-dimensional chaotic cores in such vibrations, an in-depth nonlinear time series and recurrence analysis of vibration signals from a commercial brake system is conducted. The results contradict the prevailing engineering understanding of regular dynamics and underline the potential of a complex system understanding of mechanical machines.

Identifying chimera states with RPs

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Synchronization effects are a common phenomenon in networks with applications in the most diverse areas, such as in biological systems and neuroscience, engineering, economics and science. More recently, the possibility has been observed for simultaneous coexistence in a single network of incoherent (non-synchronized) and coherent (synchronized) states. This coexistence of coherent and incoherent states were called chimera states. The existence of these chimera states has applications in neural networks as in the case of certain species of birds that remain in a semi-alert state, in which one part of the brain falls asleep (synchronized state) while another part remains active (non-synchronized state). We show that recurrence plots provide graphical representations to identify chimera states. Also, the recurrence plots can be used as a tool to identify chimera states and detect the chimera collapse.

Recurrence plots applied in modeling some of the processes involved in determining the alertness of a truck driver

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Obtaining mathematical models to estimate workers' alertness has been explored in the last decades aiming the establishment of systems that allow the planning and the reduction of the risk of accidents. The concept can be perfectly applied to drivers in general. The proposed system involves several low-power electronic sensors that monitor a driver's physiological signals in order to estimate the level of alertness. The model in question was proposed by researcher Simon Folkard of Swansea University. The model is based on the division of alertness into three independent processes: circadian, homeostatic and inertial sleep cycles. The project in question aims at estimating real-time alert level from these signals. Results obtained for modeling the homeostatic cycle using the actigraphy computed by recurrence plots will be presented in a way comparative to the gold standard: polysomnography. A detailed statistical study was also conducted. General aspects for modeling the circadian cycle's rhytidty using recurrence plots is also in progress and will be presented.

Phase Space Trajectory Analysis for Electrical Fault vs. Power Line Communication Discrimination

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Electrical faults pose an important problem to electrical installations worldwide, be it production facilities or distribution systems. In this context, it is easy to assess the economic repercussions of a fault, when power supply is cut off downstream of its location, while also realizing that an early detection of the on-site smaller scale faults would be of great benefit.

An important obstacle for electrical fault detection is the presence of power line communication, which also generate high frequency content and higher amplitudes than that of classical electrical faults, such as partial discharges. We propose a methodology for differentiating between fault signals and communication signals based on phase space embedding and exploiting features for an accurate identification. The phase space allows the visualization of features that are more difficult to observe in the classical time-amplitude representation and where energy thresholding is impossible.

The objective of this work is to differentiate between signals originating from partial discharges and power line communication, using their respective phase space trajectories. These are two types of signals which are wide band in frequency, high in amplitude and sufficiently random so as to impede parametric modelling.

It is difficult to use energy-thresholding to discriminate between the two, either in time or frequency. The time series is embedded in an m-dimensional phase space, as described by Takens & Abarbanel.

We then proceed to compute the points with the highest concentration of visited states, using a bi-variate histogram, and identifying their global maxima.

We perform searches of the shortest trajectories beginning with the previously computed feature, in the following 4 directions: upper, lower, to the left & to the right of the high concentration point. This approach exploits the deterministic and structured nature of the phase space scatter plots of the power line communication signals. It is explained because of the fixed number of amplitude levels, that are the amplitude modulation part of the PLC system.

In the extended version of our work, we proceed to check for orthogonality between the vectors resulted from the searches and we use it as a discrimination feature between the partial discharge and the PLC signal categories.

Recurrence Quantification Analysis of Speech Signals *Poster*

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It is understood that the speech production is carried out by a non-linear dynamic system with characteristics such as: temporal variation of the vocal tract shape, resonances related to its physiology, losses due to viscous friction on the inner walls of the vocal tract, the softness of these walls, the sound radiation on the lips, nasal coupling and flexibility (dynamic behavior) related to the vibra-

tion of the vocal folds. Recurrence Quantification Analysis (RQA) has been employed in speech signals for assessment and vocal monitoring. Promising results have been obtained in the application of this technique in pathological voice discrimination, considering laryngeal pathologies as vocal fold paralysis, Reinke's edema and nodules. Structural changes in the larynx caused by these pathologies cause less formation of diagonal structures (which are more present in healthy signals because they have more regularity in the vocal fold vibration). Furthermore, it occurs an increase of the vertical/horizontal structures of the Recurrence Plots (RP's), indicating the presence of chaos established by the change of the vibration standard in the vocal folds. The maximum length of the diagonal lines (Lmax) of the RP's recognized the presence of laryngeal pathologies with an accuracy over 96%. Combining Lmax with other measures, such as the average length of the diagonal lines (Lmed), the trapping time (TT) and the maximum length of the vertical lines (Vmax), it is possible to discriminate between pathologies with an accuracy over 80%. RQA was also applied to assess vocal disorders in children. Concerning the individual measure performance, the trapping time and maximum length of the diagonal lines showed the best classification potential to discriminate between healthy and disturbed voices, with accuracy rates above 80%. Also, tests were carried out to evaluate the Recurrence Quantification Analysis performance in the speaker recognition application. In the task of text-dependent speaker recognition, the measures Lmax, ENTR (Shannon's Entropy) and LAM (laminarity) provided an accuracy up to 100% using an artificial neural networks classifier. These results show that Recurrence Quantification Analysis is a promising technique to characterize the vocal production system behavior and represent its structure changes. These measures, either alone or combined, may be considered to develop a useful tool to be applied in speaker recognition, laryngeal pathologies diagnosis and detection of voice disorders and its intensitiy.

Method for Discretizing Atrial Electrograms for Recurrence Analysis

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Atrial fibrillation (AF) and other cardiac dysrhythmias present with abnormal wavefront directions and altered activation timings as recorded by biopolar electrodes. Myocardial electrograms are used, theoretically, to select specific ablation sites in attempts to disrupt local dynamics and terminate reentry pathways responsible for AF ($\sim$70% clinically successful).

AF waves are highly recurrent and amenable to recurrence analysis. However, the problem is that when RQA is applied to continuous electrograms, mandatory information about multiple wavefront directions and local activation timings are not discernable. To overcome these severe limitations, we reduced each local activation event to two discrete markers (based on electrical zero-crosses) while preserving the directions of approaching wavefronts. Sequences of paired points over time formed a vector which we term the electrogram conformation (EC), an estimate of wavefront direction (WD). To analyze the data by RQA, a new parameter (SKIP) was introduced which compared the discretized vector, complex by complex (Hummel window).

For proof of concept, a 2-dimensional computer simulation was created on a 40×40 grid. The electrical activity at each site was recorded by a single unipolar electrode which registered wavefronts originating from either spiral waves or wavebreaks. The actual WD at each site was determined by comparing relative activation timings of the local (surrounding) intracellular recordings. The EC was determined by looking at the timings and directions of the first 2 zero crosses within each activation. Individual complexes were selectable by setting SKIP to 1.

Regions of spiral wave reentry (periodic) and, separately, regions of wavelet breakup (chaotic) were readily distinguished by RQA of WD (reference control) as well as by RQA of EC (test vector). Comparisons of the two methods showed high correlations of respective recurrence variables. These results suggest that the discretized EC may be implemented as a surrogate for WD in human AF, thereby more accurately pin-pointing ablation sites for arrhythmia extinction. The Hummel window is fully applicable to other discretized signals.

Change in Flood Hazard Dynamics from Recurrence Perspective

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Temporal changes in flood hazard systems are known to be difficult to detect and attribute due to multiple drivers that include processes that are non-stationary and highly variable. Often such analysis of change is quantified from single points perspective (i.e. extreme values) that may subject to high errors and uncertainties. In contrast, the hydrological signature derived from the time series could provide a better picture of a process characteristic resulting from the drivers and hence a step closer to understanding the change of process and is less prone to artifacts caused by single point analysis.

This study focuses on the application of recurrence based data analysis techniques (recurrence plot) for understanding and quantifying spatio-temporal changes in flood hazards in Germany through its hydrological signature. The recurrence plot is known as an effective tool to visualize the dynamics of phase space trajectories i.e. constructed from a time series by using an embedding dimension and a time delay, and it is known to be effective in analyzing non-stationary and non-linear time series. The emphasis will be on the identification of characteristic recurrence properties that could associate typical dynamic behavior to certain flood situations.

Analysis of nonlinear dynamic characteristics of cyclic combustion fluctuation in internal combustion engine

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Internal combustion engine (ICE) which can be classified as spark ignition (SI) engine and compression ignition (CI) engine is a typical and complex nonlinear dynamic system. For a four-stroke ICE, an engine working cycle is composed of intake, compression, expansion and exhaust strokes. In theory, the duration of each engine working cycle is approximately same when engine speed is held constant, however the cyclic combustion process of ICE is separated by the intake and exhaust, which leads to the intermittent heat release, at the same time the combustion qualities of air and fuel mixture in cylinder are influenced by many factors such as amounts of fuel and air, the composition of the burned gases supplied to the cylinder, aerodynamics in cylinder, etc. So the indicated pressure exhibits cycle-to-cycle variations of internal cylinder pressure which results in reducing the engine output power, especially when engine operates at the condition of lean mixture or lower speed and load. However, the mechanism of combustion instabilities is different for SI engine and CI engine because of different combustion modes. In this paper, the hidden rhythms and dynamic complexity of a combustion system in high dimensional phase space for SI engine and CI engine have been examined and compared using non-linear embedding theory, recurrence plots (RPs) and recurrence qualification analysis (RQA), the research results may provide useful information to indentify the complex combustion process and improve control strategies of ICE operating under different combustion mode.