CINTI 2015
16th IEEE International Symposium on Computational Intelligence and Informatics

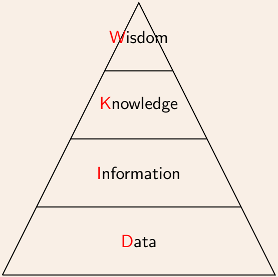
Budapest, Hungary, 19-21/Nov/2015

Analysis and visualization of complex phenomena

J. Tenreiro Machado[1]

[1] Institute of Engineering, Polytechnic of Porto, Dept. of Electrical Engineering, Portugal, jtm@isep.ipp.pt

The DIKW Pyramid

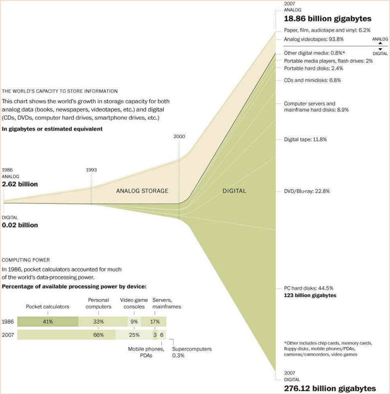


Origin and Criticisms

- The presentation of the relationships among data, information, knowledge, and sometimes wisdom in a hierarchical arrangement has been part of the language of information science for many years.
- "... the model is based on dated and unsatisfactory philosophical positions ..."

Data, Big Data and...

Global Information Storage Capacity



Origin ...

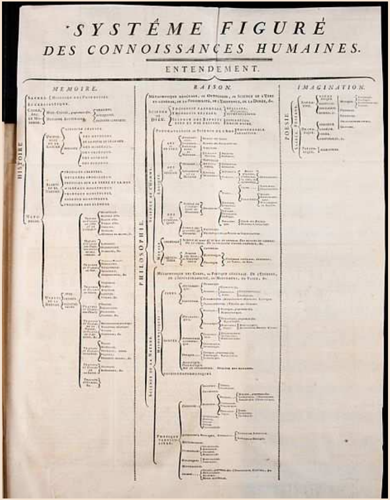
- Big data: A large and complex collection of data sets difficult to handle using traditional data processing applications
  - 2007: 19 exabyte
    1 EB $= 10^{18}$ bytes
  - 2014: 2.7 zettabyte
    1 ZB $= 10^{21}$ bytes
  - Future: yottabyte
    1 YB $= 10^{24}$ bytes

... and Criticisms

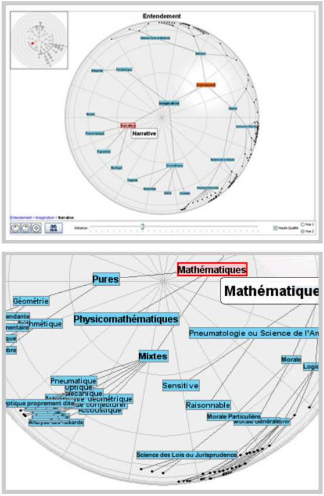
"...we do not know much about the underlying empirical micro-processes that lead to the emergence of the typical network characteristics of Big Data..."

Figurative system of human knowledge

Diderot and d'Alembert, 1751-72

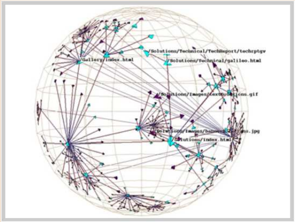


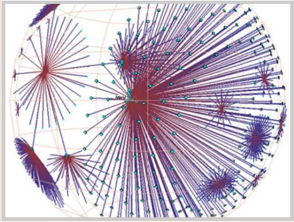
Christophe Tricot, 2006



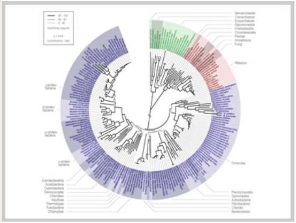
Scientific visualization

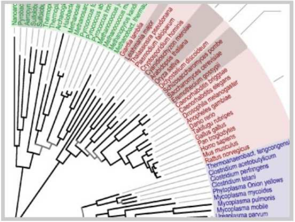
Tamara Munzner, 1998: Exploring large graphs in 3D Hyperbolic Space





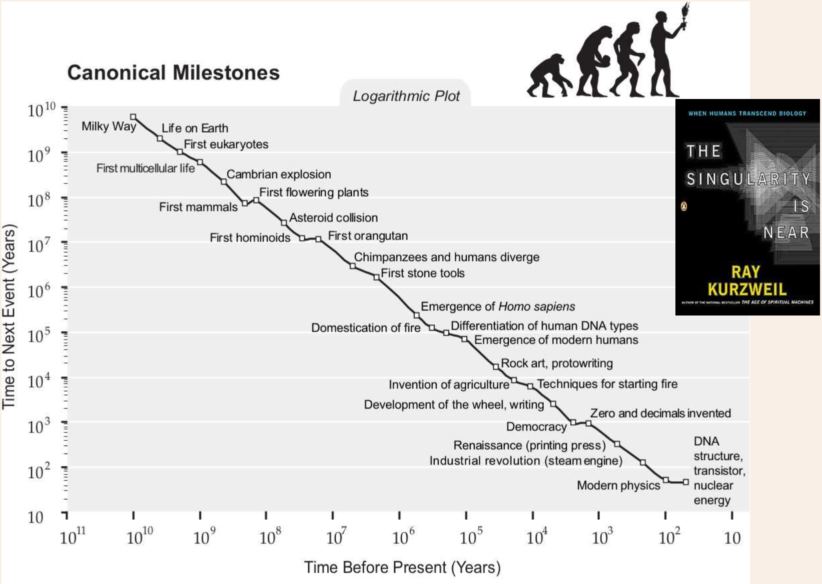
F. D. Ciccarelli (et al), 2006: Tree of Life





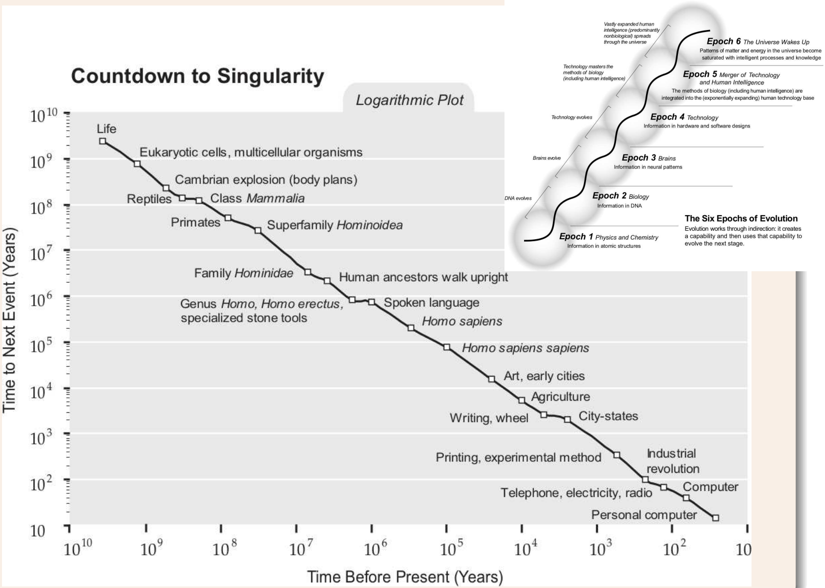
http://www.visualcomplexity.com/vc/

The Singularity Is Near, Ray Kurzweil, 2005

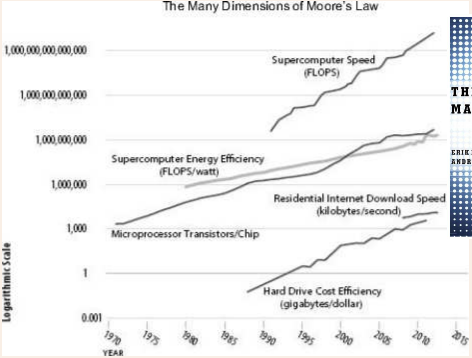


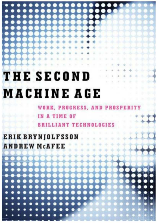
Canonical milestones based on clusters of events from thirteen lists.

Progress milestones

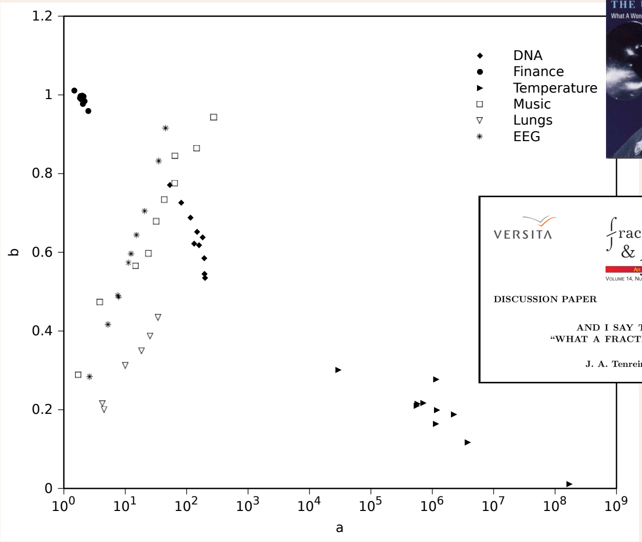


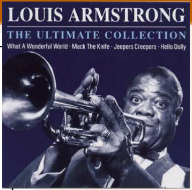
The Second Machine Age, E. Brynjolfsson and A. McAfee, 2014





A map of Fourier parameters (a, b) (2011)?





VERSITA

Fractional Calculus & Applied Analysis

An International Journal for Theory and Applications

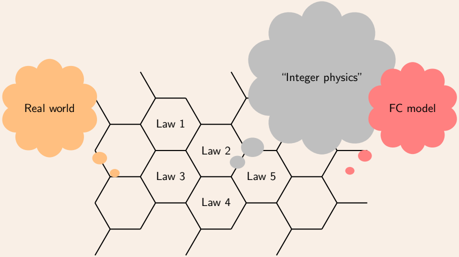
VOLUME 14, NUMBER 4 (2011) (Print) ISSN 1311-0454 (Electronic) ISSN 1314-2224

DISCUSSION PAPER

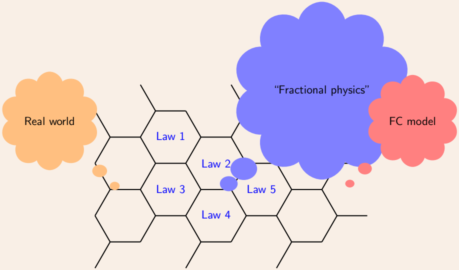
AND I SAY TO MYSELF:
"WHAT A FRACTIONAL WORLD!"

J. A. Tenreiro Machado

Integer Order Physics



Fractional Order Physics



Classical Physics

Table 18–1 Classical Physics

Maxwell's equations

I. $\nabla \cdot \boldsymbol{E} = \frac{\rho}{\epsilon_0}$ (Flux of $\boldsymbol{E}$ through a closed surface) = (Charge inside)/ϵ_0

II. $\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$ (Line integral of $\boldsymbol{E}$ around a loop) = $-\frac{d}{dt}$(Flux of $\boldsymbol{B}$ through the loop)

III. $\nabla \cdot \boldsymbol{B} = 0$ (Flux of $\boldsymbol{B}$ through a closed surface) = 0

IV. $c^2 \nabla \times \boldsymbol{B} = \frac{\boldsymbol{j}}{\epsilon_0} + \frac{\partial \boldsymbol{E}}{\partial t}$ c^2(Integral of $\boldsymbol{B}$ around a loop) = (Current through the loop)/ϵ_0 $+ \frac{\partial}{\partial t}$(Flux of $\boldsymbol{E}$ through the loop)

[Conservation of charge

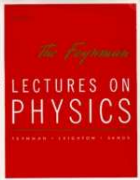
$\nabla \cdot \boldsymbol{j} = -\frac{\partial \rho}{\partial t}$ (Flux of current through a closed surface) = $-\frac{\partial}{\partial t}$(Charge inside)]

Force law

$$\boldsymbol{F} = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B})$$

Law of motion

$\frac{d}{dt}(\boldsymbol{p}) = \boldsymbol{F}$, where $\boldsymbol{p} = \frac{m\boldsymbol{v}}{\sqrt{1 - v^2/c^2}}$ (Newton's law, with Einstein



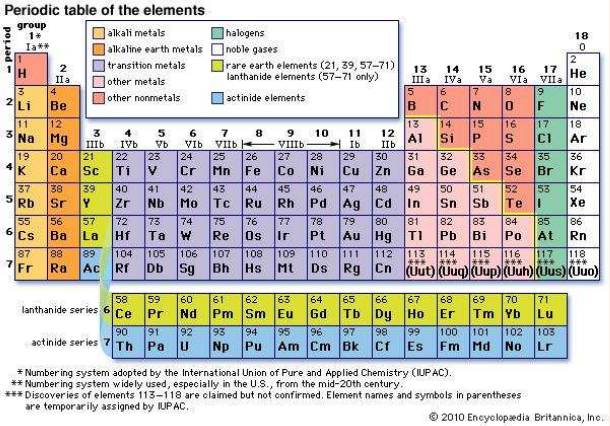
Gravitation

$$\boldsymbol{F} = -G\frac{m_1 m_2}{r^2}\boldsymbol{e}_r$$

The periodic table of chemical elements

Lavoisier (1789), John Newlands (1865), Lothar Meyer (1864), Dmitri Mendeleev (1989), Glenn Seaborg (1943)

Present day



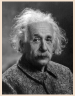
The Intelligent Universe? The Universe is Understandable?

- Pierre-Simon Laplace

  If someone knows the precise location and momentum of every atom in the universe, their past and future values for any given time are entailed; they can be calculated from the laws of classical mechanics.

- Albert Einstein

  God doesn't play dice with the world.

- Stephen Hawking

  God not only plays dice, but sometimes throws them where they cannot be seen.

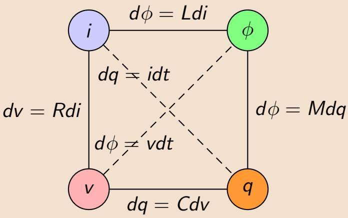
- Ian Stewart

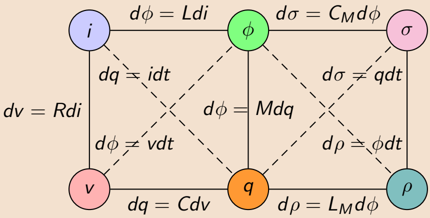
  

  The question is not so much whether God plays dice, but how God plays dice

Memristor

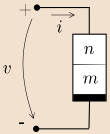
- In 1971 Leon Chua noticed the symmetry between electrical elements and variables and proposed the 4th element Memristor
- In 1980 Chua introduced the "Periodic table of all two-terminal elements"
- In 2012 Jeltsema and Dòria-Cerezo proposed higher order elements
- In 2013 Machado proposed complex order elements



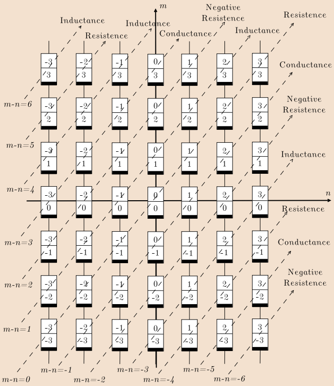


Generalized one-port higher-order elements

- Relation between $v(t)$ and $i(t)$:
  $\frac{d^n}{dt^n} u(t) = f\left(\frac{d^m}{dt^m} i(t)\right), \; n, m \in \mathbb{Z}$
- $(n, m) = \{(0,0), (-1,0), (0,-1), (-1,-1)\}$:
  resistor, inductor, capacitor and memresistor



Periodic table of all two-terminal circuit elements



Collaboration with

- António M. Lopes
- Institute of Mechanical Engineering, Faculty of Engineering, University of Porto

Collecting and Processing Data

- We analyse 25 complex systems, each with several instances
- For each category, $i = 1, \cdots, 25$, are adopted $1, \cdots, p$ instances ($4 \leq p \leq 10$)
- Total of 167 time series
- Each time-series $x_i^p(t)$ is:
  - normalized
  - processed by the Fourier Transform (FT)
- The amplitude spectrum is approximated by a Power Law (PL) function
- The PL parameters are compared

Fourier analysis: Criticism

- Is not a *model*
- It is the characterization of *one* system manifestation
- Signal artefacts are "diluted" in Fourier global representation
- PL may be not characterize completely

Fourier analysis: Advantages

- Robust
- Direct interpretation
- Usable in a wide range of signals

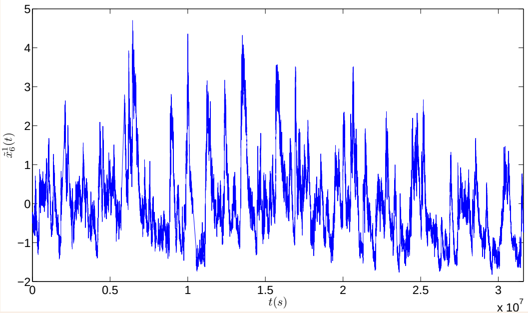
Complex Systems

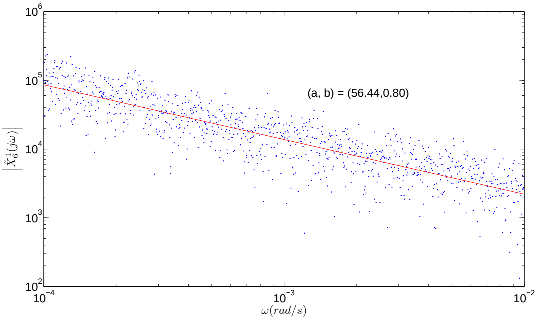
1. Stock markets (ST)
2. Musical sounds (MU)
3. Internet bytes rate (IB)
4. Internet packets rate (IP)
5. Atmospheric temperatures (AT)
6. Solar data (SD)
7. River flow (RF)
8. U.S. tornadoes (TO)
9. Earthquakes (EQ)
10. Ozone concentration (OZ)
11. Tectonic plates motion (TP)
12. Electroencephalograms (EEG)
13. Electrocardiograms (ECG)
14. Arterial Pressure (AT)
15. Heart RR interval (RR)
16. Human gait (HG)
17. Seismic waves (SW)
18. Human DNA
19. Lake level (LL)
20. Life expectancy (LE)
21. Int. trade openness (ITO)
22. Gross domestic product (GDP)
23. Rainfall (RA)
24. Population density (PD)
25. CO2 emissions (CO2)

Signal analysis

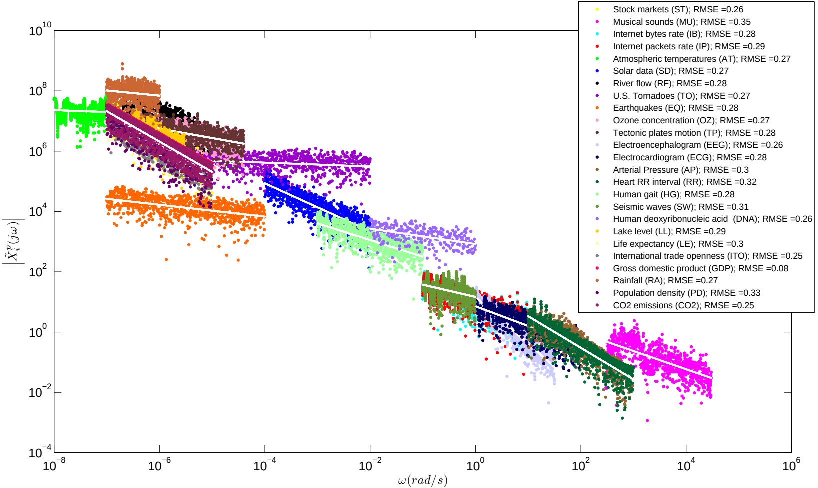
- The FT is a classical, powerful and robust signal processing tool for the analysis of systems dynamics
- Time series representation $x_i^p(t) = \sum_{k=1}^{T} A_k \delta(t - t_k)$
- The time-series $x_i^p(t)$, is normalized (to unit power spectral density) by:
  $\tilde{x}_i^p(t) = \frac{x_i^p(t) - \mu_i^p}{\sigma_i^p}$
  where μ_i^p and σ_i^p represent the mean and standard deviation values of $x_i^p(t)$, respectively, and t represents time.
- The FT is calculated:
  $$\mathcal{F}\{\tilde{x}_i^p(t)\} = \tilde{X}_i^p(j\omega) = \int_{-\infty}^{+\infty} \tilde{x}_i^p(t) e^{-j\omega t} dt$$
- The corresponding PL approximation is:
  $|\mathcal{F}\{\tilde{x}_i^p(t)\}| = |\tilde{X}_i^p(j\omega)| \simeq a\omega^{-b}, a \in \mathbb{R}^+, b \in \mathbb{R}$
- The parameters (a, b) reveal underlying characteristics of the systems dynamics.

Signal example: Solar data (SD)

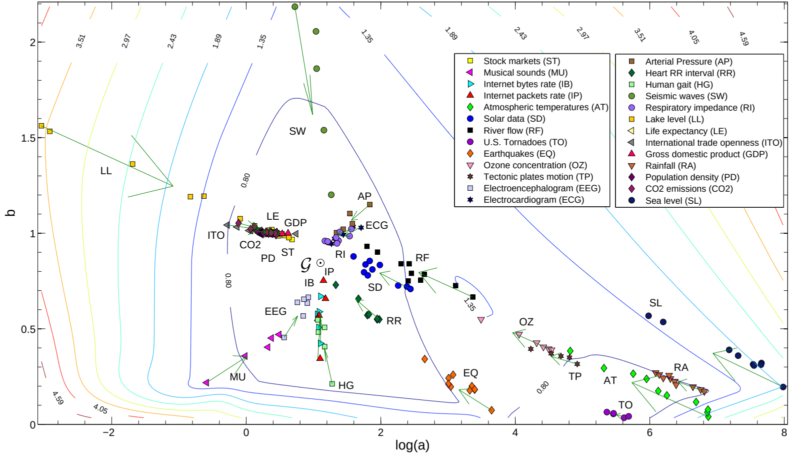




Fourier map: Amplitudes



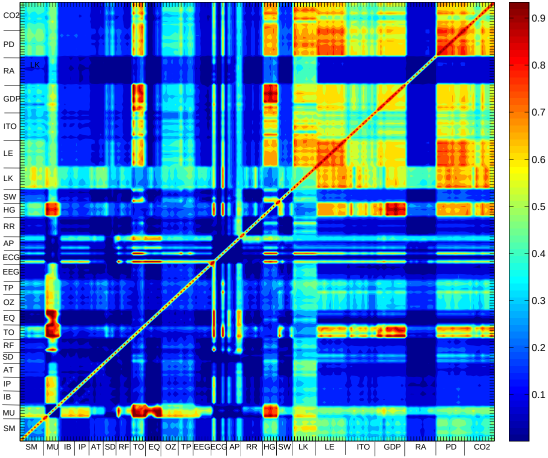
Map of Fourier parameters (a, b) (2014)



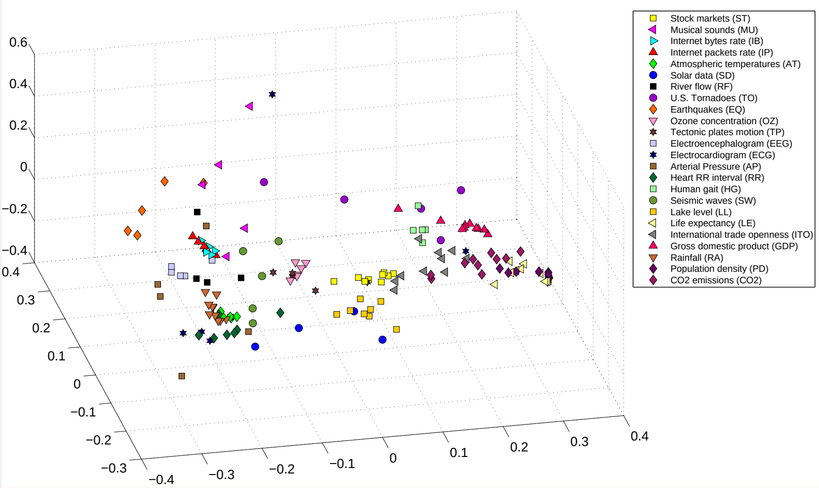
Statistical comparison: Normalized mutual information

- 160 time series (excluded DNA)
- Histograms with $M = 200$ bins
- $I_N(X_m, X_n) = \frac{I(X_m, X_n)}{H(X_m, X_n)}$, $m, n = 1, \cdots, 160$
  - $I(X_m, X_n) = \sum_{x_m \in X_m} \sum_{x_n \in X_n} p(x_m, x_n) \ln \frac{p(x_m, x_n)}{p(x_m)\, p(x_n)}$
  - $H(X_m, X_n) = -\sum_{x_m \in X_m} \sum_{x_n \in X_n} p(x_m, x_n) \ln p(x_m, x_n)$
- Visualization
  - 160×160 matrix of $I_N(X_m, X_n)$
  - Multidimensional Scaling (MDS), 2- and 3-dimensional maps
  - Successive (agglomerative) clustering and average-linkage method
    - Tree
    - Dendrogram

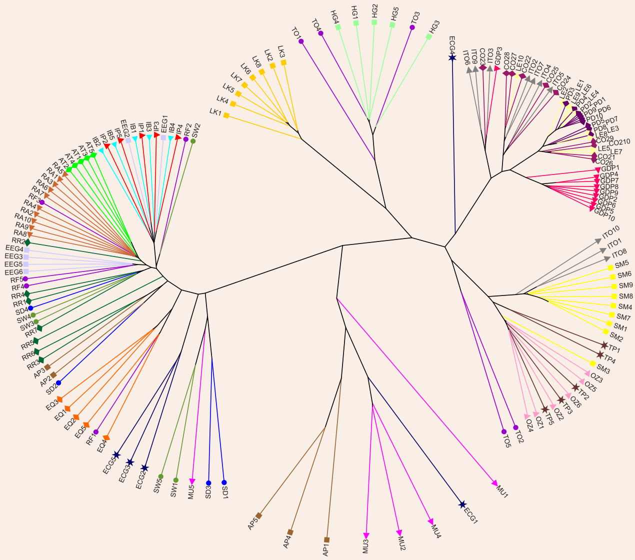
Normalized mutual information: Matrix



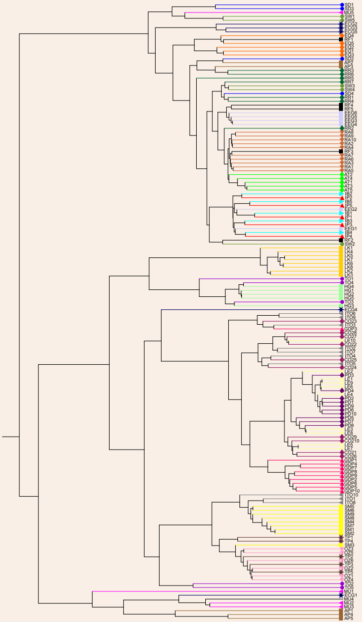
Normalized mutual information: MDS 3D



Normalized mutual information: Tree



Normalized mutual information: Dendrogram



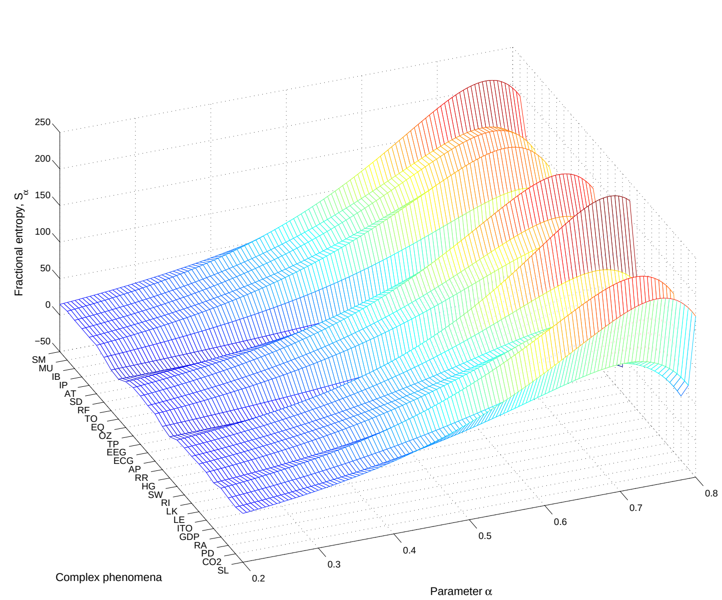
New experiments: 26 complex phenomena (190 time series)

1. Stock markets (ST)
2. Musical sounds (MU)
3. Internet bytes rate (IB)
4. Internet packets rate (IP)
5. Atmospheric temperatures (AT)
6. Solar data (SD)
7. River flow (RF)
8. U.S. tornadoes (TO)
9. Earthquakes (EQ)
10. Ozone concentration (OZ)
11. Tectonic plates motion (TP)
12. Electroencephalograms (EEG)
13. Electrocardiograms (ECG)
14. Arterial Pressure (AT)
15. Heart RR interval (RR)
16. Human gait (HG)
17. Seismic waves (SW)
18. Respiratory impedance (RI)
19. Lake level (LK)
20. Life expectancy (LE)
21. Int. trade openness (ITO)
22. Gross domestic product (GDP)
23. Rainfall (RA)
24. Population density (PD)
25. CO2 emissions (CO2)
26. Sea level (SL)

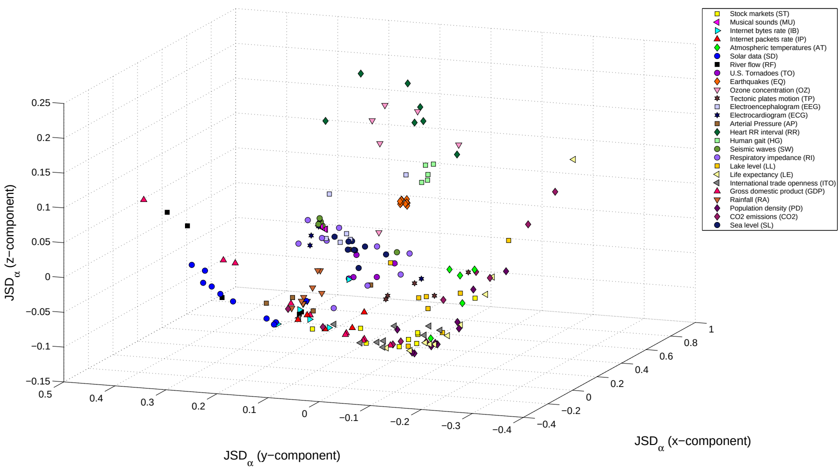
New signal analysis

- Normalize the time-series $x_i^p(t)$:
  $\tilde{x}_i(t) = \frac{x_i(t)-\mu_i}{\sigma_i}$,
  where μ_i and σ_i represent the mean and standard deviation values of $x_i(t)$, respectively, and t represents time.
- Consider entropy of fractional order, $\alpha \in \mathbb{R}$:
  $$S_\alpha = \sum_i \left\{ -\frac{p_i^{-\alpha}}{\Gamma(\alpha+1)} \left[\ln p_i + \psi(1) - \psi(1-\alpha)\right] \right\} p_i$$
- Use the (fractional) Jensen-Shannon divergence that measures the similarity between two probability distributions, P and Q:
  $JSD_\alpha (P \parallel Q) =$
  $\frac{1}{2}\sum_i p_i \left\{ \frac{p_i^{-\alpha}}{\Gamma(\alpha+1)} \left[\ln p_i + \psi(1) - \psi(1-\alpha)\right] \right\} +$
  $\frac{1}{2}\sum_i q_i \left\{ \frac{q_i^{-\alpha}}{\Gamma(\alpha+1)} \left[\ln q_i + \psi(1) - \psi(1-\alpha)\right] \right\} -$
  $\sum_i m_i \left\{ \frac{m_i^{-\alpha}}{\Gamma(\alpha+1)} \left[\ln m_i + \psi(1) - \psi(1-\alpha)\right] \right\}$
  where $M = \frac{1}{2}(P+Q)$.

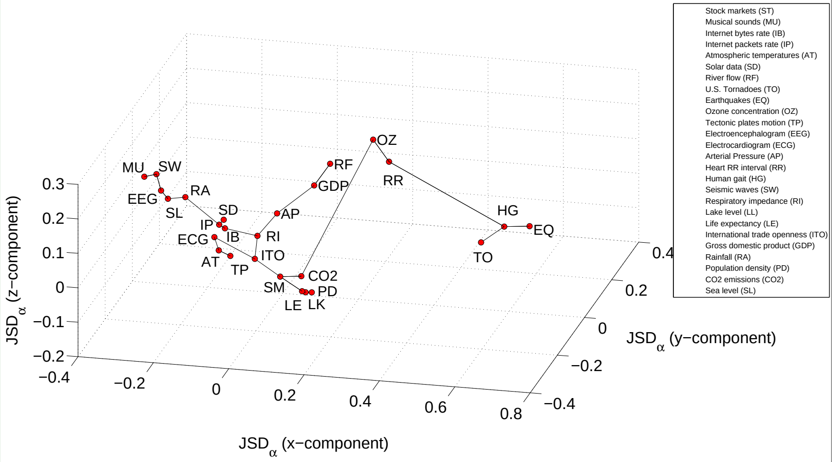
Fractional entropy S_α versus complex phenomena for $\alpha \in [0.2, 0.8]$



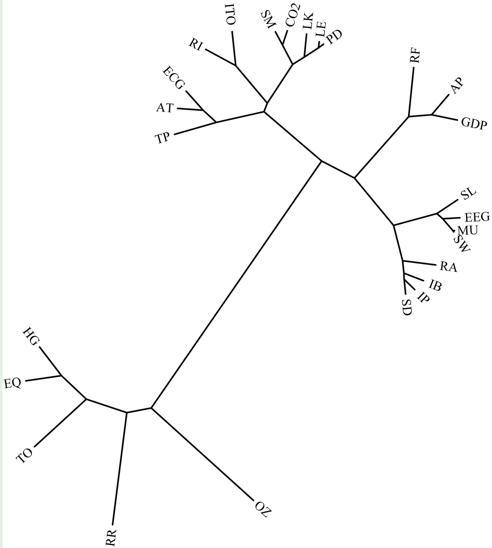
MDS 3D based on JSD_α ($\alpha = 0.75$)



MDS 3D based on JSD_α ($\alpha = 0.75$) and the superimposed pathway



Visualization tree generated by the hierarchical clustering based on JSD_α ($\alpha = 0.75$)



Stock markets (ST)
Musical sounds (MU)
Internet bytes rate (IB)
Internet packets rate (IP)
Atmospheric temperatures (AT)
Solar data (SD)
River flow (RF)
U.S. Tornadoes (TO)
Earthquakes (EQ)
Ozone concentration (OZ)
Tectonic plates motion (TP)
Electroencephalogram (EEG)
Electrocardiogram (ECG)
Arterial Pressure (AP)
Heart RR interval (RR)
Human gait (HG)
Seismic waves (SW)
Respiratory impedance (RI)
Lake level (LL)
Life expectancy (LE)
International trade openness (ITO)
Gross domestic product (GDP)
Rainfall (RA)
Population density (PD)
CO2 emissions (CO2)
Sea level (SL)

Conclusions

- The association of:
  - computational algorithms
  - mathematical models

  capture phenomena and properties overseen by classical approaches
- Recent studies encourage the analysis of natural and artificial phenomena by means of:
  - advanced data processing algorithms
  - new visualization techniques

Entropy: An Open Access Journal, www.mdpi.com/journal/Entropy

Special Issue: Complex and Fractional Dynamics

- Entropy-based techniques in complexity, nonlinearity, and fractionality
- Fractional dynamics
- Fractals and chaos
- Complex dynamics
- Nonlinear dynamical systems
- Evolutionary computing
- Transportation systems
- Geosciences

Special Issue: Computational Complexity

- Agent based modeling and simulation
- Complex networks
- Data mining and knowledge discovery
- Intelligent systems
- Advanced computational applications
- Quantum information science

Guest Editors

J. A. Tenreiro Machado, António M. Lopes

Entropy

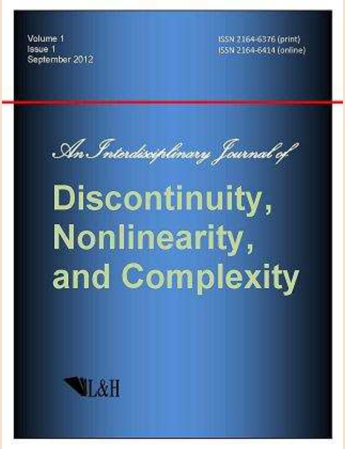
- Research papers only: Full length & Short communications & Review
- Open Access
- ISI Impact Factor 2014: 1.502, Ranks 34/78 (Q2) in the category ‘Physics, Multidisciplinary’
- Thorough peer review (single blind)

http://www.mdpi.com

https://lhscientificpublishing.com/Default.aspx

Journal of Applied Nonlinear Dynamics

Discontinuity, Nonlinearity, and Complexity



Contact

- J. A. Tenreiro Machado
- Institute of Engineering, Polytechnic of Porto
- Dept. of Electrical Engineering, Porto, Portugal
- `http://www.isep.ipp.pt/~jtm`
- jtm@isep.ipp.pt