

Processing Cardiographic Signals

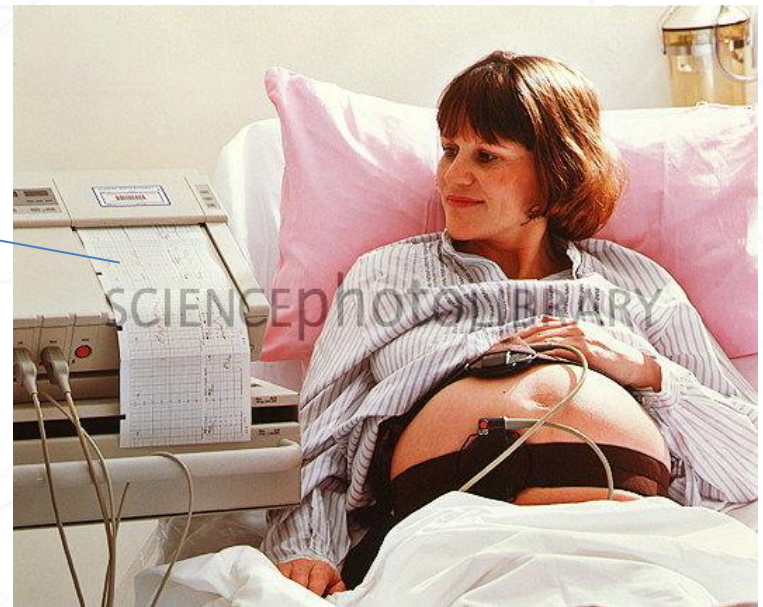
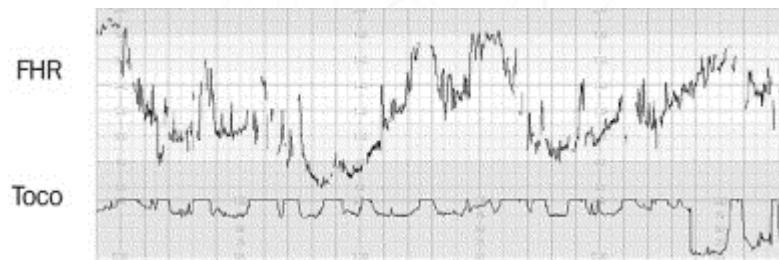
The use of compression in cardiographic signal to detect fetus at risk.

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Cardiotocography

- **Cardiotocography:** recording the fetal heart rate (FHR) and uterine contractions (Toco).



- Widely used for fetal monitoring during labor.

Cardiotocography

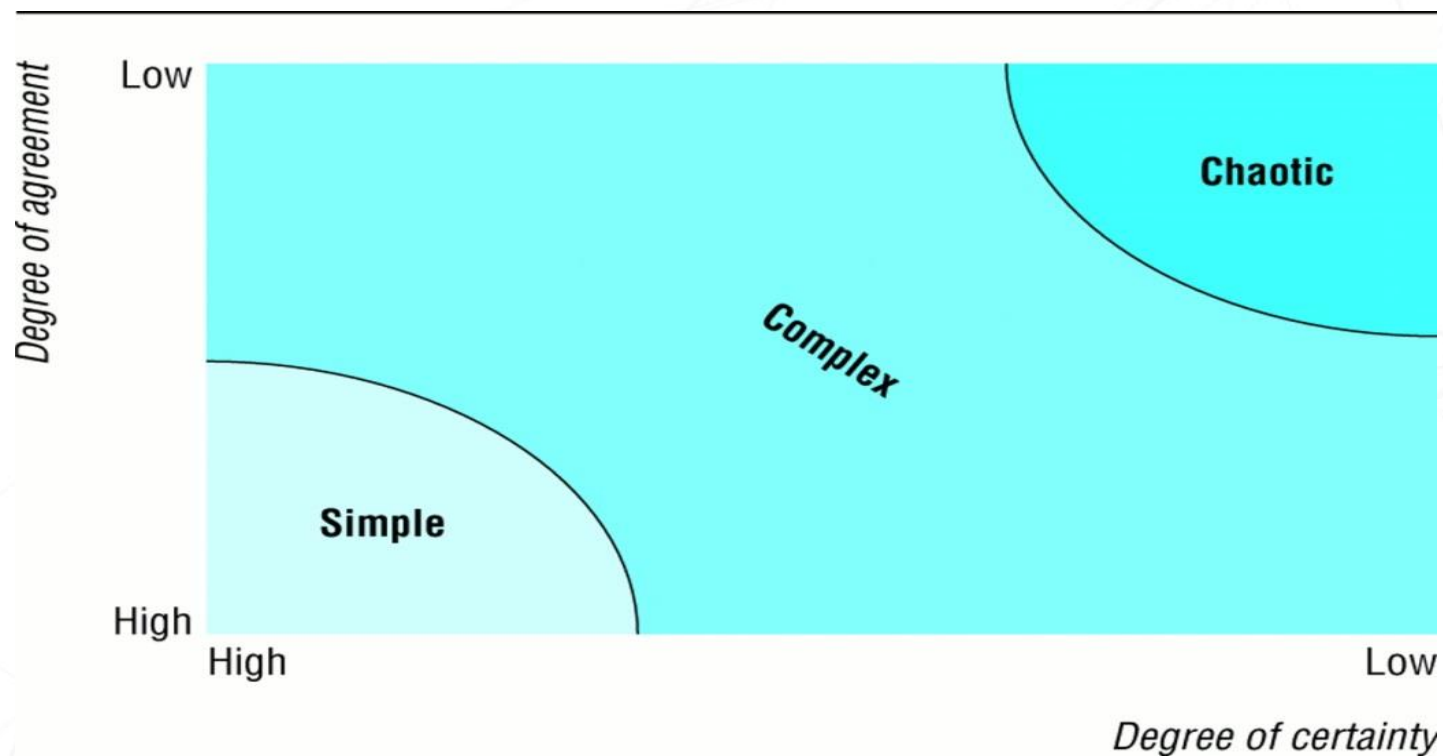
evaluate the fetal health condition and allow the obstetrician to intervene to prevent potential compromise and irreversible damage

however

with high inter-observer interpretation disagreement¹⁻²

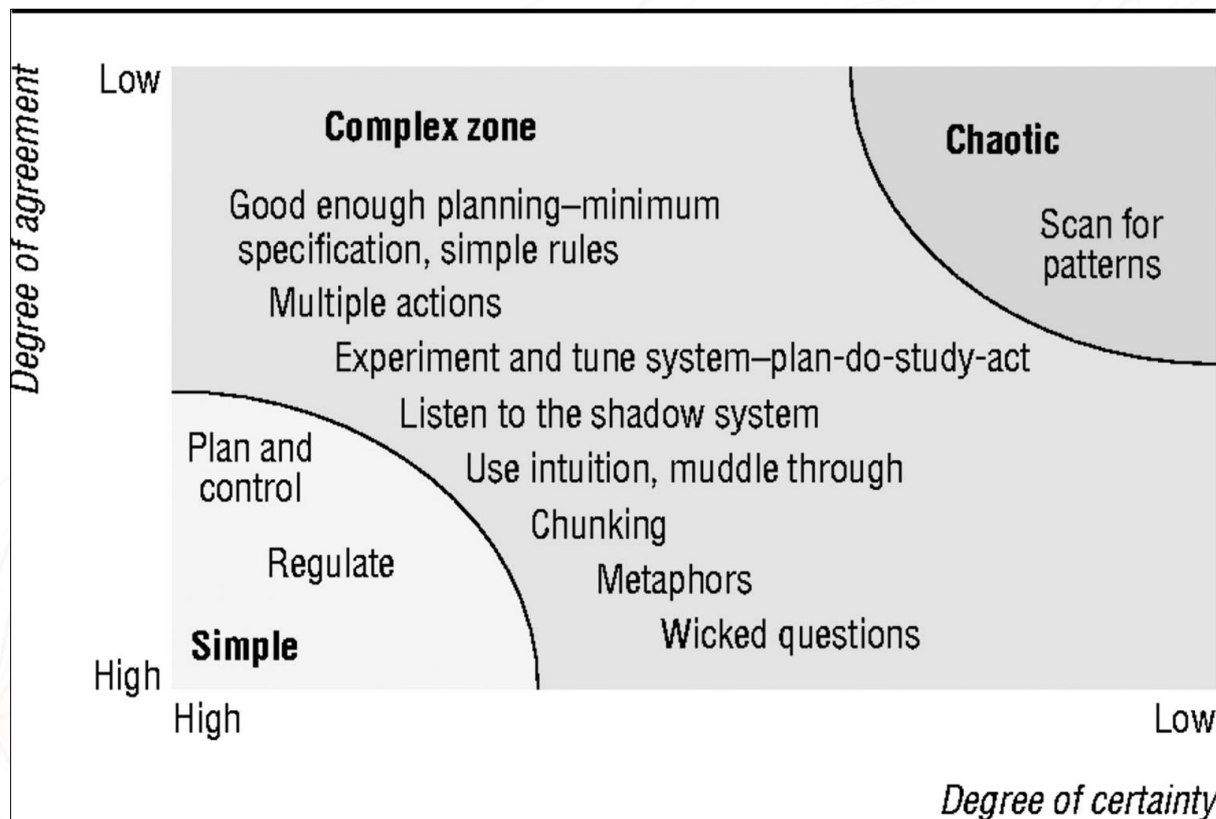
1. Bernardes J, Costa-Pereira A, Ayres-de-Campos D, van Geijn HP, Pereira-Leite L. Evaluation of interobserver agreement of cardiotocograms. *Int J Gynaecol Obstet.* 1997 Apr;57(1):33-7.
2. Ayres-de-Campos D, Bernardes J, Costa-Pereira A, Pereira-Leite L. Inconsistencies in classification by experts of cardiotocograms and subsequent clinical decision. *Br J Obstet Gynaecol.* 1999 Dec;106(12):1307-10.

The certainty-agreement diagram



Paul E Plsek, Trisha Greenhalgh. Complexity science: The challenge of complexity in health care *BMJ* 2001;323:625-628

The certainty-agreement diagram



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Automated analysis: Omniview SisPorto

- automated approaches:



Automatic estimation of:

uterine contractions

fetal heart rate baseline

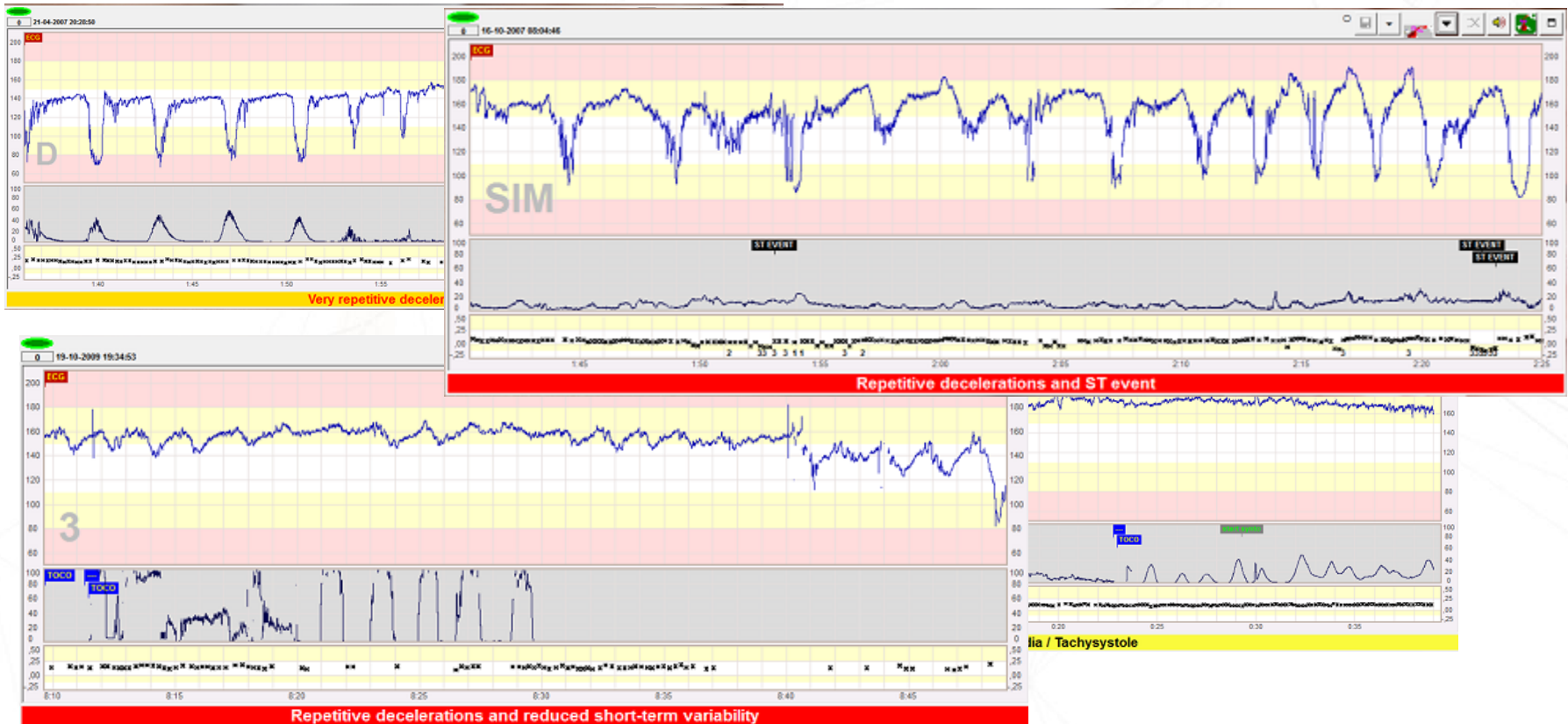
identification of accelerations

identification of decelerations

quantification of short- and long-term variability



Automated analysis: Omniview SisPorto



Automated analysis

- Challenge:
 - signal processing and pattern recognized techniques to identify fetus at risk

Complexity

- **different approaches** based on nonlinear dynamics, chaos and complexity has been considered, which recognizes **irregularity**, **subjectivity** and **uncertainty** as intrinsic and fundamental
- **complexity** - quantifies the amount of structured information.

Entropy

- Shannon entropy: average **unpredictability** in a random variable
- With the goal of quantification of the **amount of regularity** in (heart rate) time-series data:
 - Pincus presented the Approximate Entropy (ApEn) and later
 - Richman and J.R. Moorman presented Sample Entropy (SampEn)

Entropy

- A low ApEn value is associated with high degree of regularity.
 - a time series containing many repetitive patterns has a small ApEn;
 - a less predictable process has a higher ApEn.
- In the particular case of fetal heart rate (FHR) tracings, entropy measures have been widely used to detect different pathologies.

Compression

- However, we believe, that **compression** can be effectively applied as an **alternative measure of complexity** to the widely used entropy in biological signals.
- Compression is a measure of system complexity, but has been used to a lower extent in the analysis of biomedical signals.

Compression

- Kolmogorov complexity:
the smallest representation of the object.
- A new clustering method **CompLearn** based on Kolmogorov Complexity, a well-studied notion of information content in individual objects, was introduced.

Cilibrasi R. and Vitanyi P. M. B.. Clustering by compression. IEEE Trans Information Theory, 2005; 51(4): 1523-45.

- You can try it in: <http://www.complearn.org/>

Compression

- Good results were obtained using this approach in different areas, including:
 - literature¹
 - music²
 - computer virus and internet traffic analysis³

1. Cilibrasi R, Vitanyi PMB. Clustering by compression. Information Theory, IEEE Transactions on. 2005;51(4):1523-45.

2. Cilibrasi R, Vitanyi P, de Wolf R, editors. Algorithmic clustering of music. Web Delivering of Music, 2004 WEDELMUSIC 2004 Proceedings of the Fourth International Conference on; 2004 13-14 Sept. 2004.

3. Wehner S. Analyzing worms and network traffic using compression. J Comput Secur. 2007;15(3):303-20.

CompLearn

Input: a set of files

1. File translations, if necessary.
2. Calculation of Normalized Compression Distance (NCD).
3. Representation, unrooted binary tree.

Output: hierarchical clustering.

CompLearn

- This clustering system is unique in that it can be described as *feature-free*
- *There are no parameters to tune*, and no domain-specific knowledge went into it.
- Using general-purpose data compressors gives us a parameterized family of features automatically for each domain

CompLearn

$$NCD(x, y) = \frac{C(x, y) - \min\{C(x), C(y)\}}{\max\{C(x), C(y)\}}$$

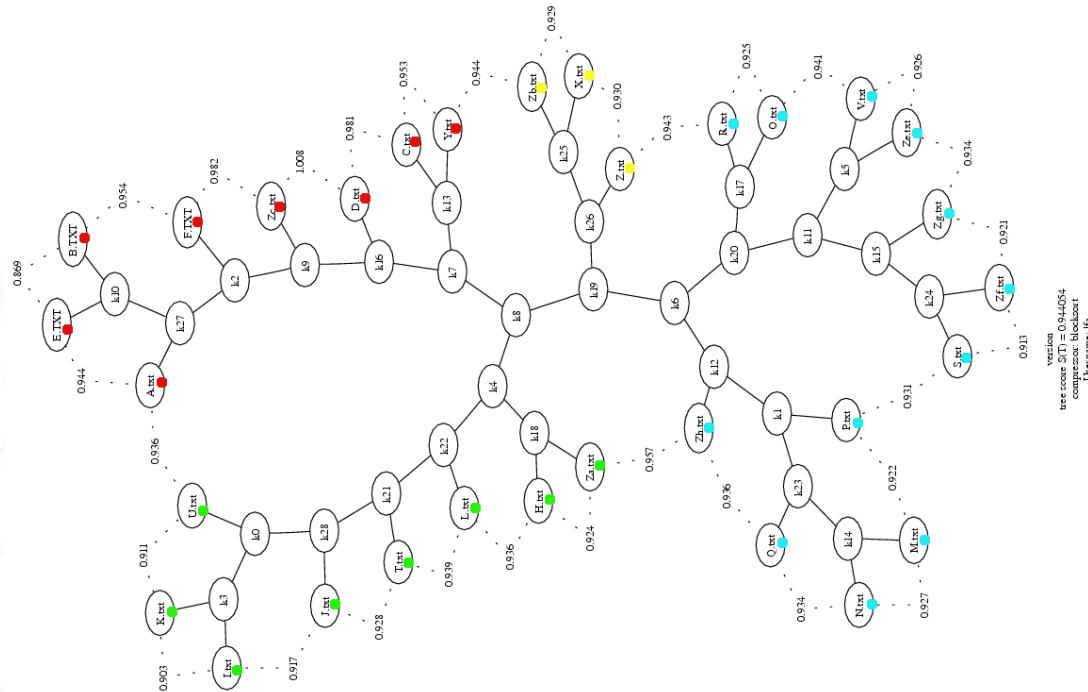
Computing NCD of every FHR with every other FHR yields a 2-dimensional symmetric **distance matrix**

Next step is transforming this array of distances into something easier to grasp

Use the **Quartet Method** to construct an unrooted binary **tree** from the NCD matrix

CompLearn

In 2006 we applied to cardiocographic tracings



Costa-Santos C, Bernardes J, Vitányi P, Antunes L. **Clustering Fetal Heart Rate Tracings by Compression**. *Proceedings of 19th IEEE International Symposium of Computer-Based Medical Systems CBMS 2006*; 685-90.

Learning by Compression

Keogh showed that when clustering heterogeneous data and anomaly detection in *time sequences*, the compression approach outperforms every known data-mining method.

Keogh, E., S. Lonardi, and C.A. Ratanamahatana, Towards parameter-free data mining, in Proceedings of the tenth ACM SIGKDD international conference on Knowledge discovery and data mining. 2004, ACM: Seattle, WA, USA. p. 206-215.

PAQ8L compressor

- PAQ8 represents a series of lossless compressors with the world's highest compression ratio. PAQ8L, based on Dynamic Markov compression, was released in 2007.
- We believe that these compressors can be successfully used in the medical field as well.

Entropy versus compression

- 68 cardiotocographic tracings:
 - 48 delivered fetuses with umbilical artery pH in the normal (N) range
 - 10 delivered fetuses with umbilical arterial pH mildly acidemic (MA) fetuses
 - 10 delivered fetuses with umbilical arterial pH moderate-to-severe acidemic (MSA) fetuses

All traces were resampled at a frequency of 2Hz

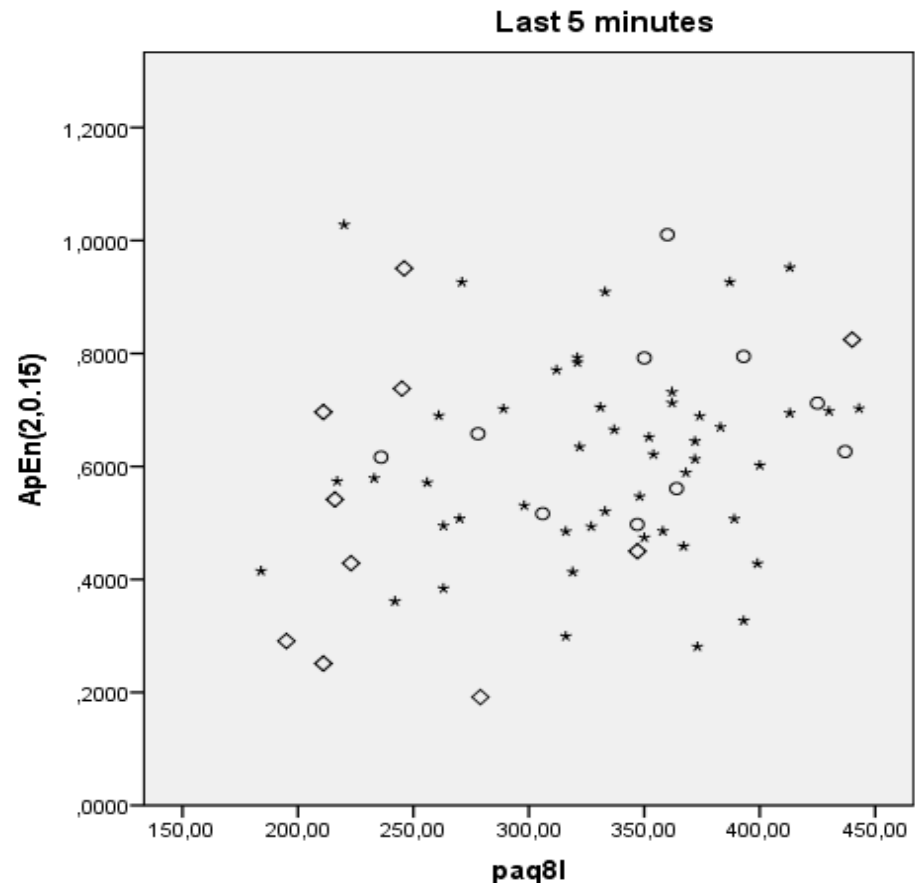
Entropy versus compression

Median, first (Q_1) and third(Q_3) quartiles of complexity measures of fetal heart rate (FHR) tracings from moderate-to-severe acidemic (MSA), mildly acidemic (MA) and normal (N) fetuses in the **final 5 min segments**.

	MSA		MA		N		p
	Median	(Q_1, Q_3)	Median	(Q_1, Q_3)	Median	(Q_1, Q_3)	
Entropy							
ApEn(2,0.1)	0.585	(0.525, 0.733)	0.738	(0.686, 0.774)	0.682	(0.555, 0.739)	0.207
ApEn(2,0.15)	0.496	(0.291, 0.738)	0.642	(0.561, 0.792)	0.607	(0.490, 0.702)	0.304
ApEn(2,0.2)	0.351	(0.251, 0.553)	0.582	(0.469, 0.795)	0.516	(0.420, 0.627)	0.044
SampEn(2,0.1)	0.476	(0.325, 0.658)	0.598	(0.540, 0.985)	0.541	(0.402, 0.615)	0.149
SampEn(2,0.15)	0.309	(0.172, 0.636)	0.459	(0.403, 0.632)	0.434	(0.320, 0.549)	0.338
SampEn(2,0.2)	0.231	(0.172, 0.307)	0.369	(0.308, 0.637)	0.341	(0.256, 0.404)	0.036
Compression							
paq8l	234.0	(211.0, 279.0)	355.0	(306.0, 393.0)	335.0	(293.5, 372.5)	0.009
bzip2	283.5	(270.0, 382.0)	444.0	(404.0, 501.0)	426.5	(362.5, 488.0)	0.017

Entropy versus compression

Scatter plot of indices ApEn(2,0.15) and paq8l for the final 5 min segments, comparing normal fetuses (*), mildly academic fetuses (circle) and moderate–severe academic (MSA) fetuses (◇).



Comclusions

- Compression - rarely been used
- Compressors can be an alternative to the widely used entropy metrics
- Allows the computation in real time – smaller running times
- Low correlation – combination of the entropy and compression

Thank You!

