Dynamics of complex systems

Lecture 3: Basic time series analysis

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change perspective

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Traditional statistics

Word-item properties → RT

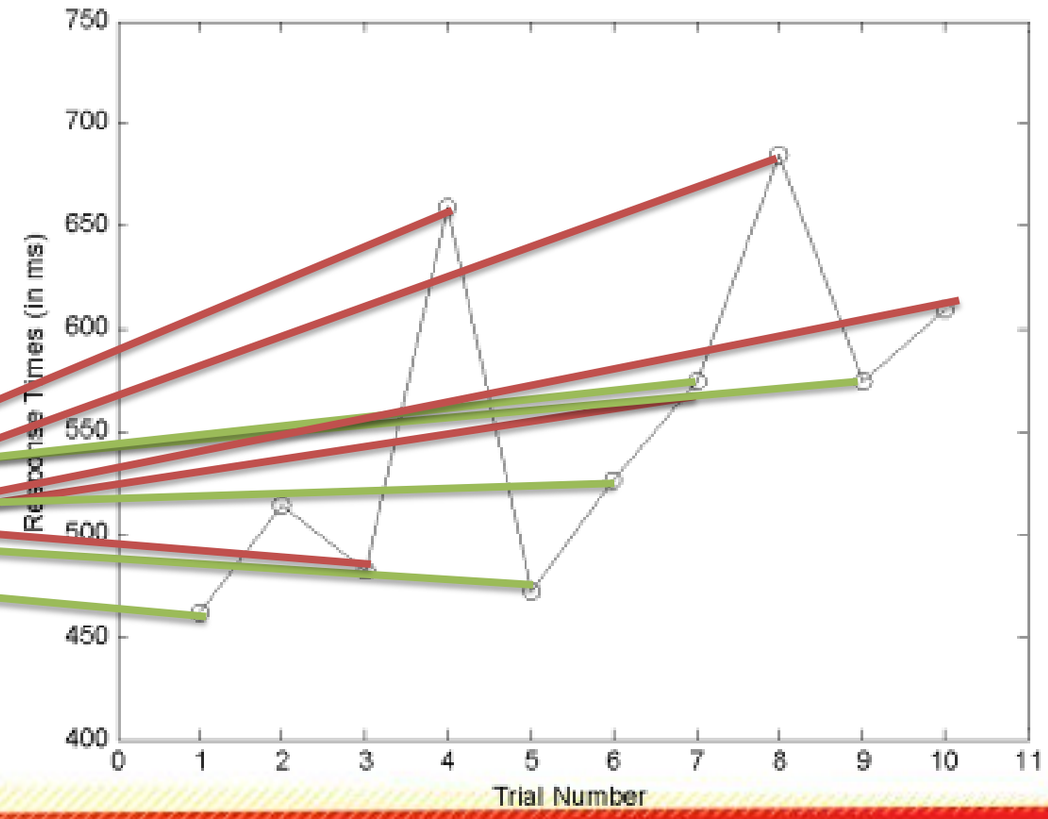
e.g., Word length:

short words → faster responses

long words → slower responses

Fictitious example

Short	Long
768 ms	802 ms



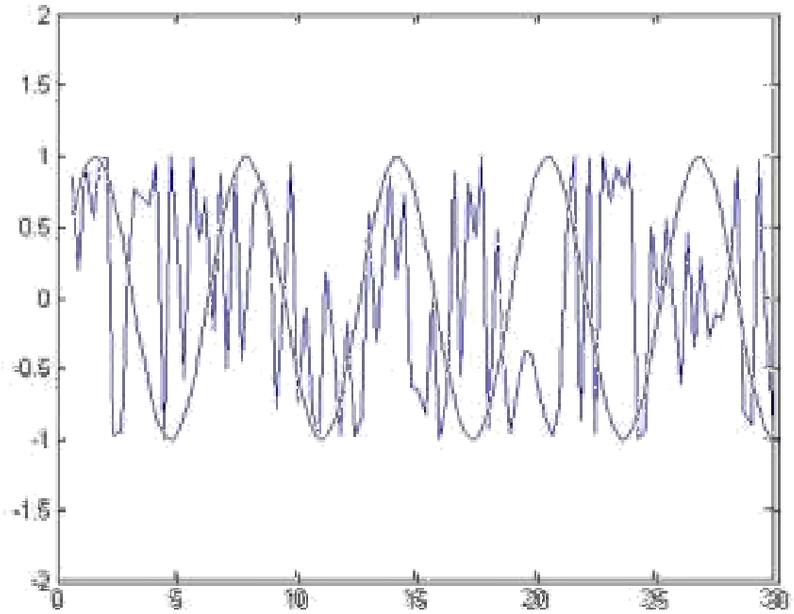
Learn more from variability?

If sequential order is not important
Trial-by-trial variability is random noise

X = T + e
Assumption = each response is independent from one other
➔ No systematic relation over time

Shuffling the data does not change:

- *Mean*
- *SD*
- Treatment effect



Learn more from reading variability?

Assumptions of ANOVA

•Homogeneity of variances

F-test is robust against heterogeneity of variances

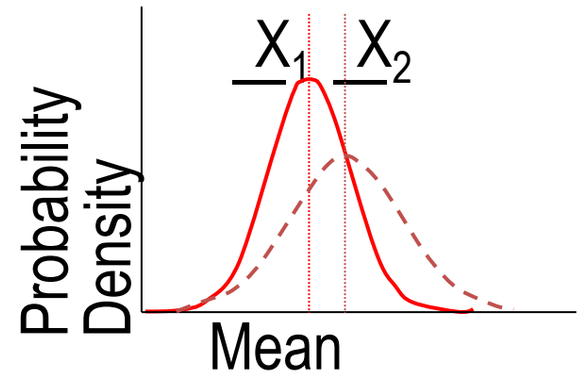
•Normal Distributions

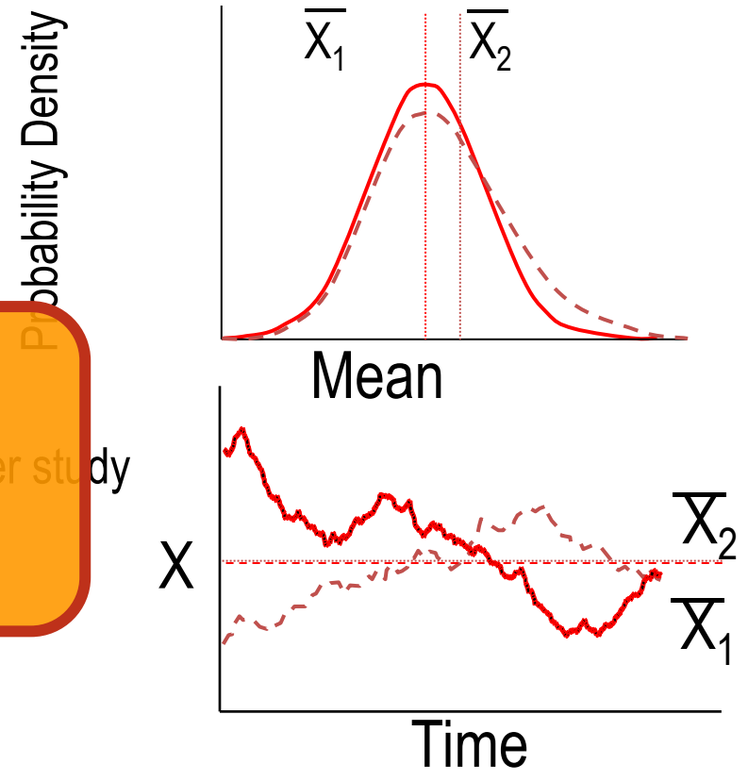
F-test is robust against non-normal data

•Independent Observations

(SYSTEMATIC) CORRELATIONS IN THE DATA

First defense against dependent data is proper study design and randomization





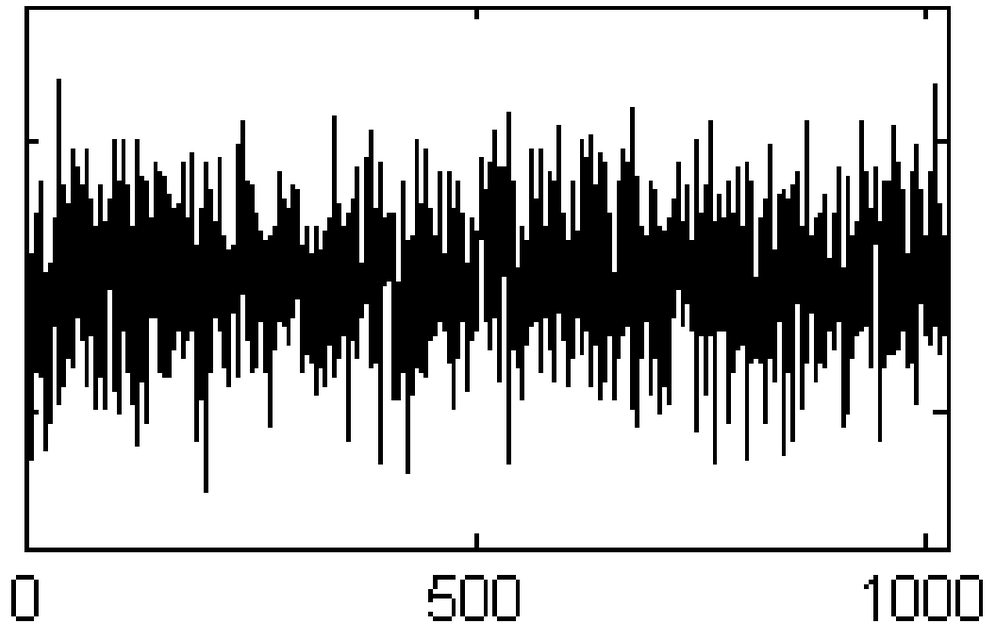
Alternative: Dynamical analysis

Collect RT's of many trial over time

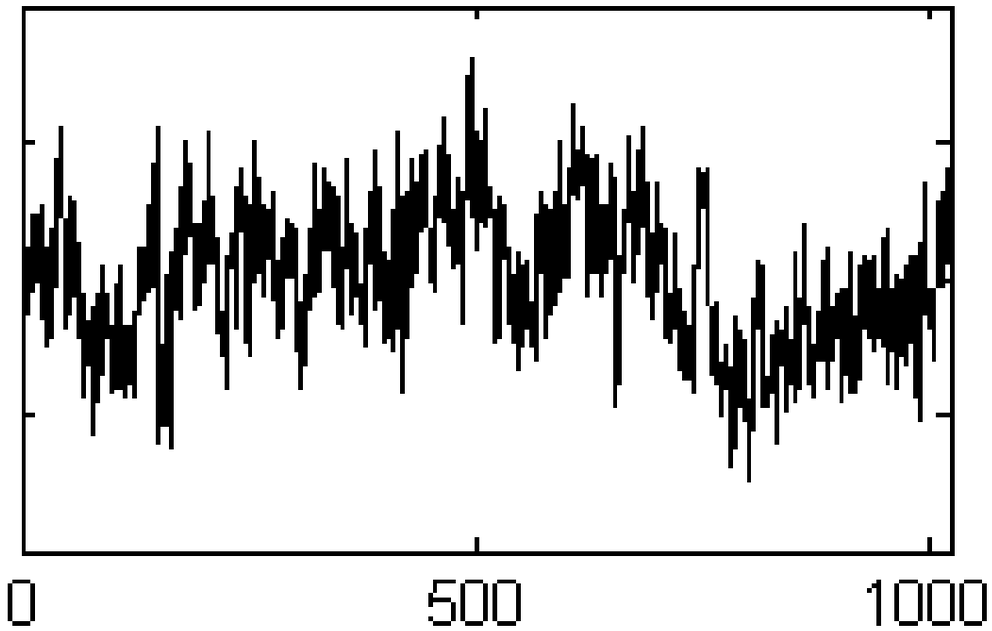
Keep the order of the data points intact

Observe temporal structure of variability

→ How does the process change over time?



Random variability



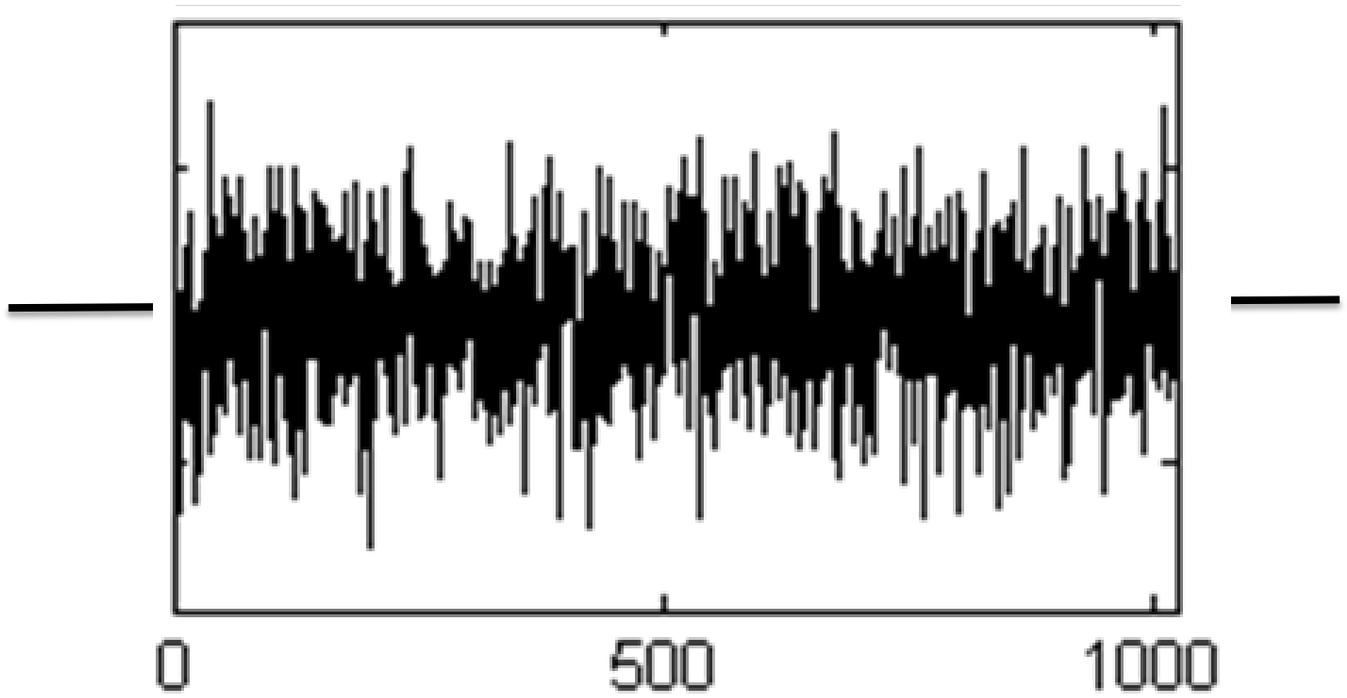
Structured variability

Alternative: How to investigate?

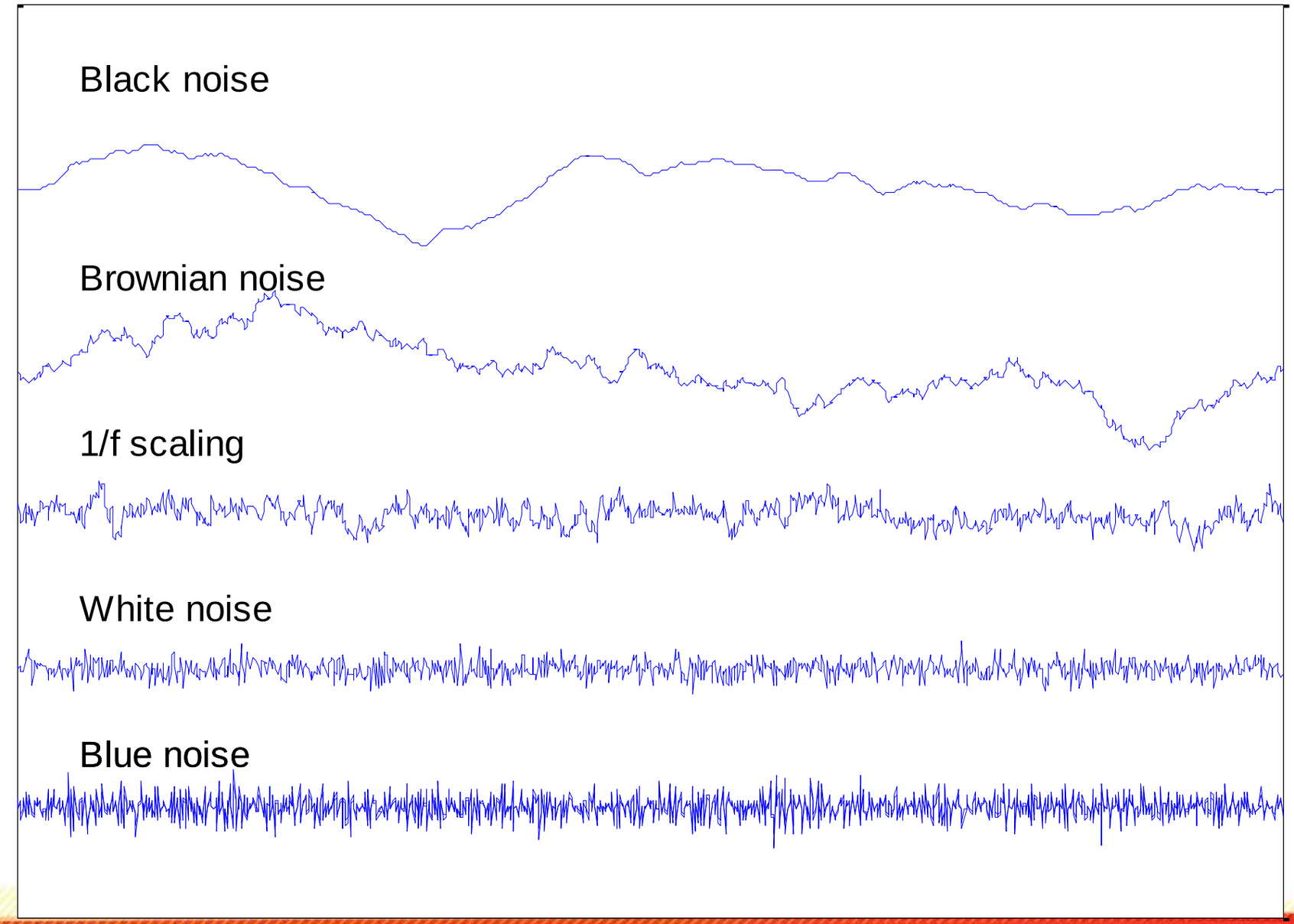
- Fractal dimension
- Relative Roughness
- Sample entropy

Fractal dimension

What is the dimension of a line?
What is the dimension of a rectangle?
What is the dimension of random noise?



Temporal properties of variability: Fractal Dimension



Only slow

Predominantly slow

All time scales

Only fast

Line – like ~ 1

Fractal Dimension

Rectangle– like ~ 2

Temporal properties of variability

Next week:

- More about fractals

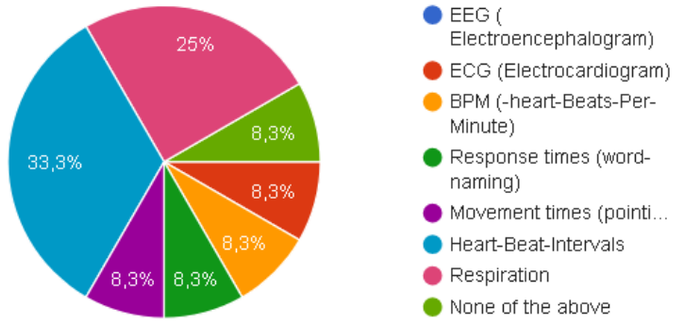
Now:

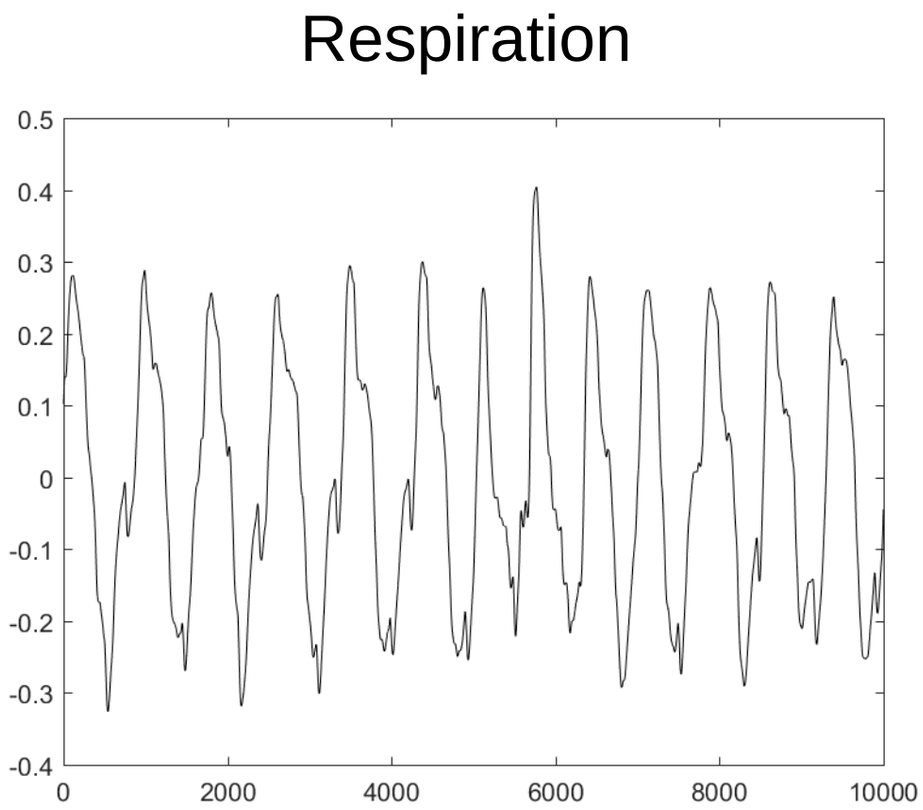
- Intuitive measures
  - Relative roughness
  - Sample entropy

But first:

- A get-to-know-your-data quiz
- THM: plot your data!

Data quiz: goo.gl/VB5Ltz





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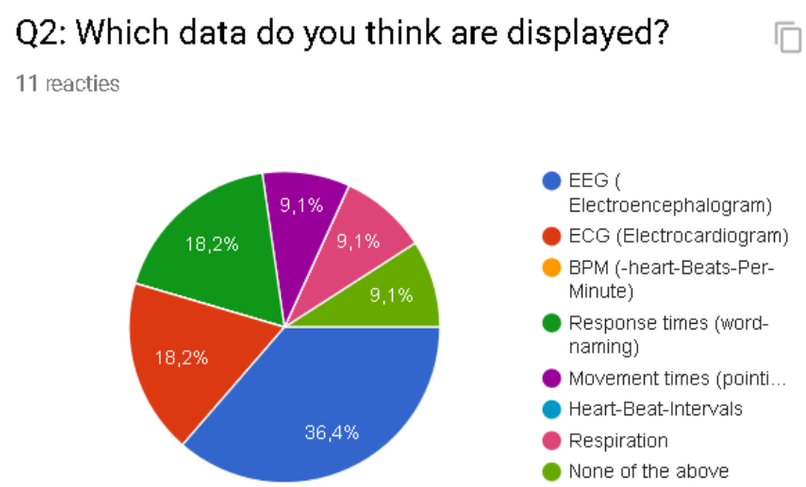

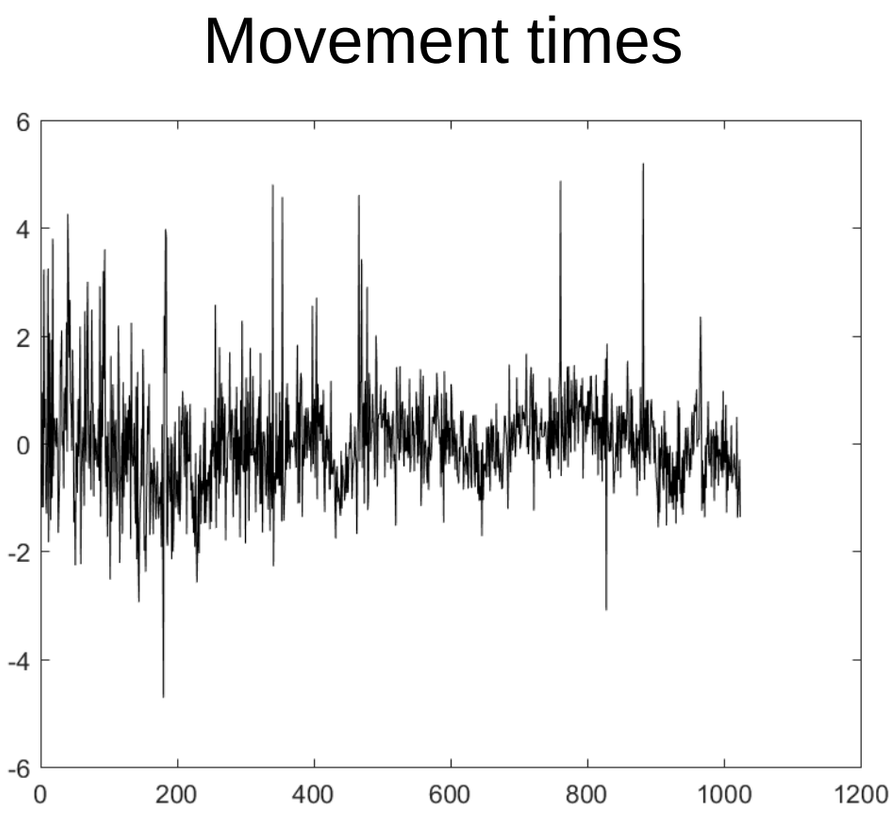

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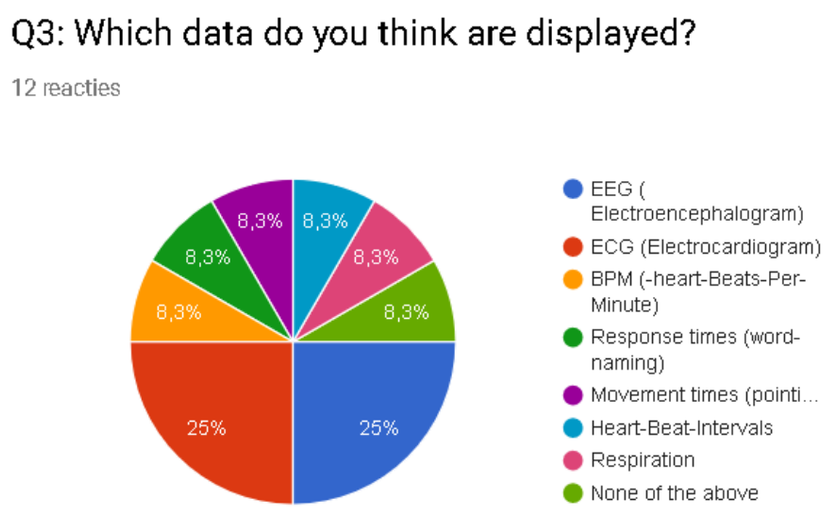

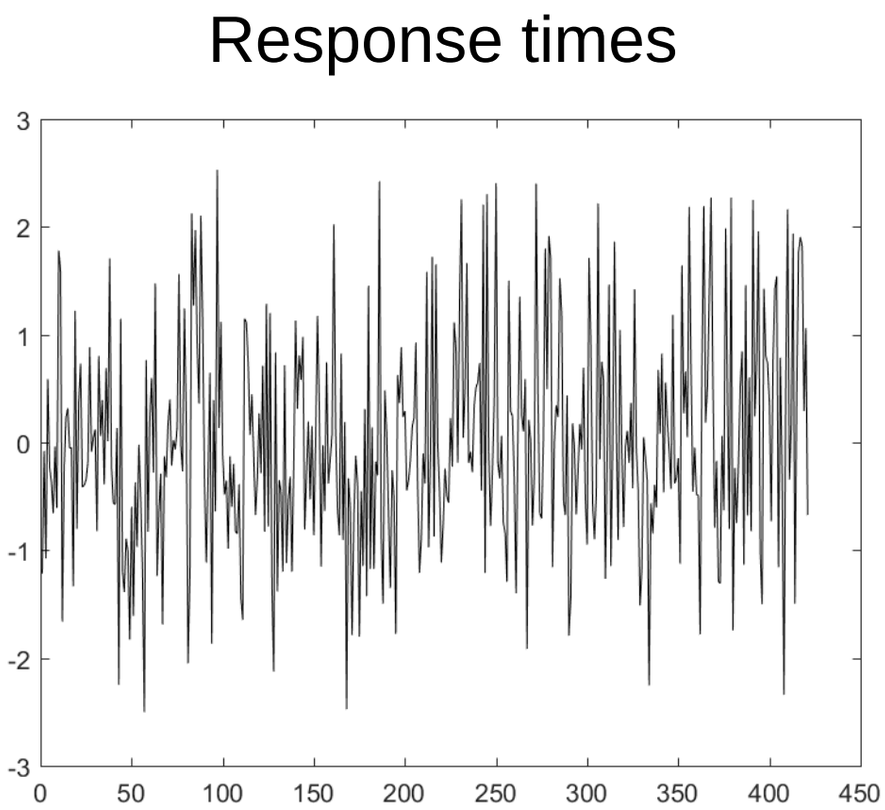

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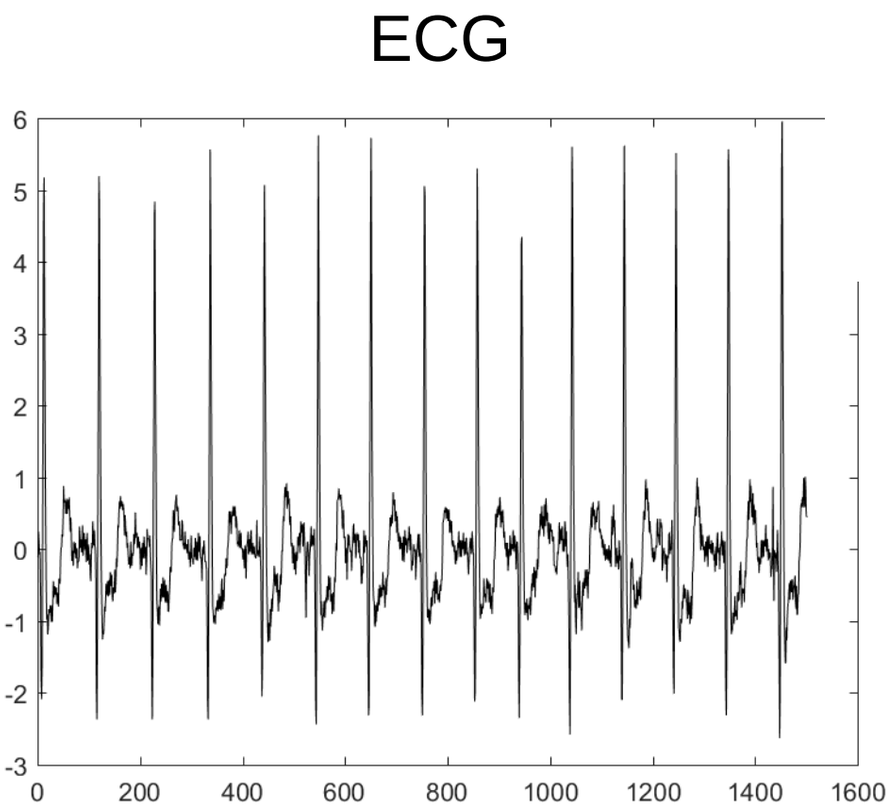

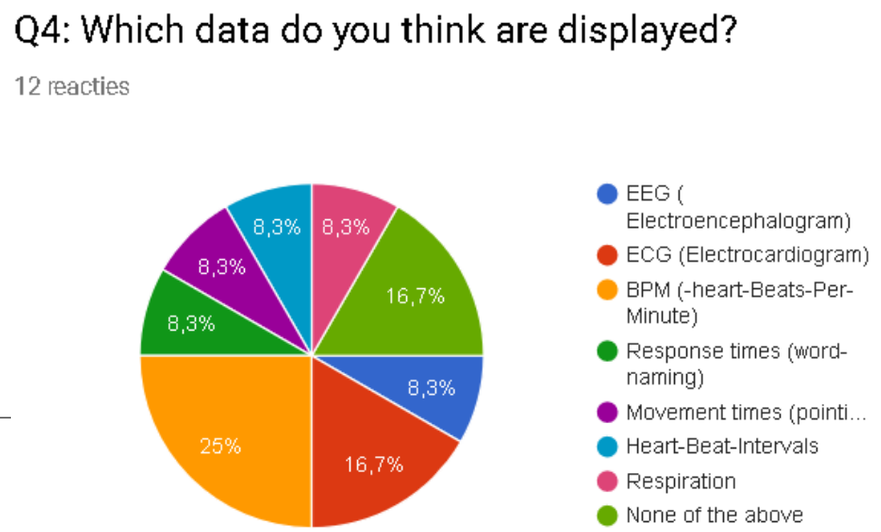

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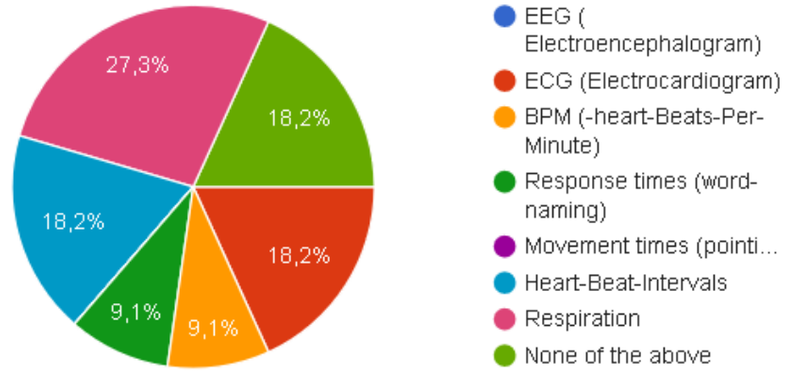

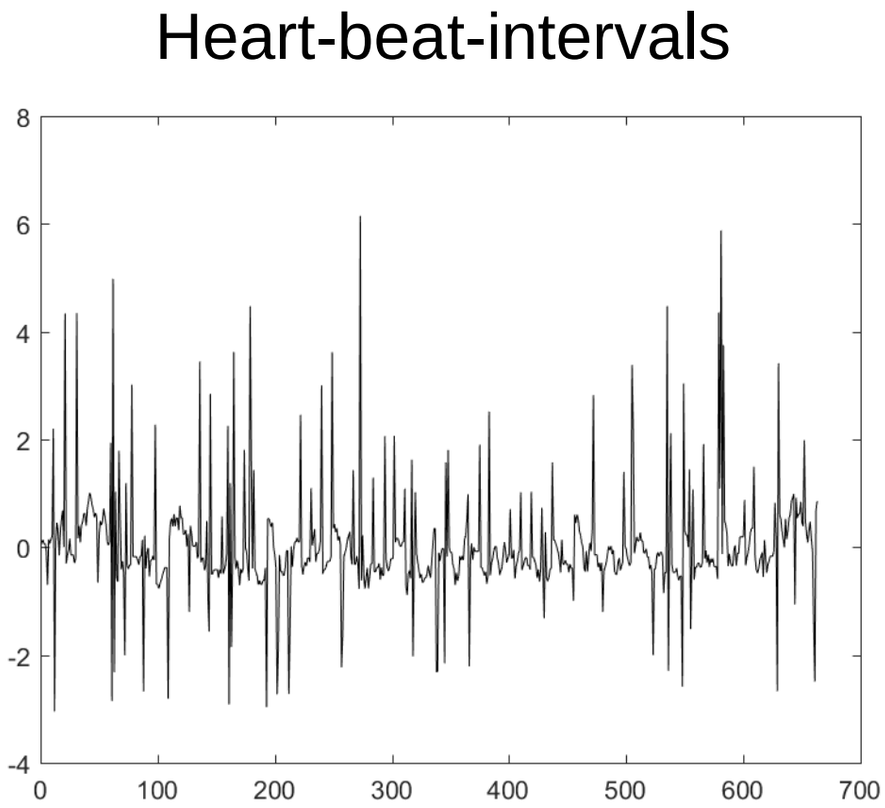

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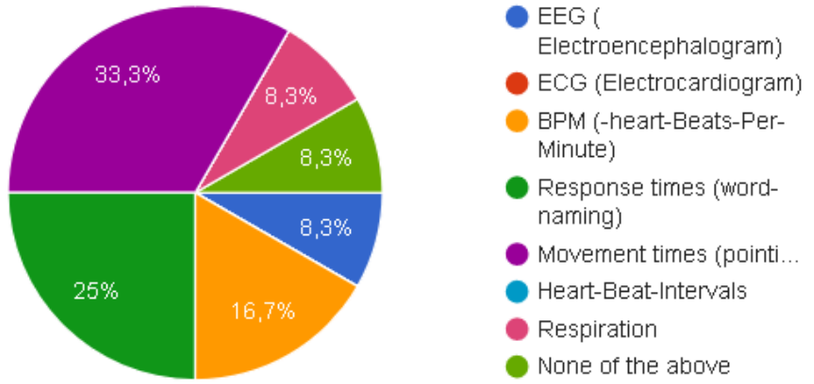

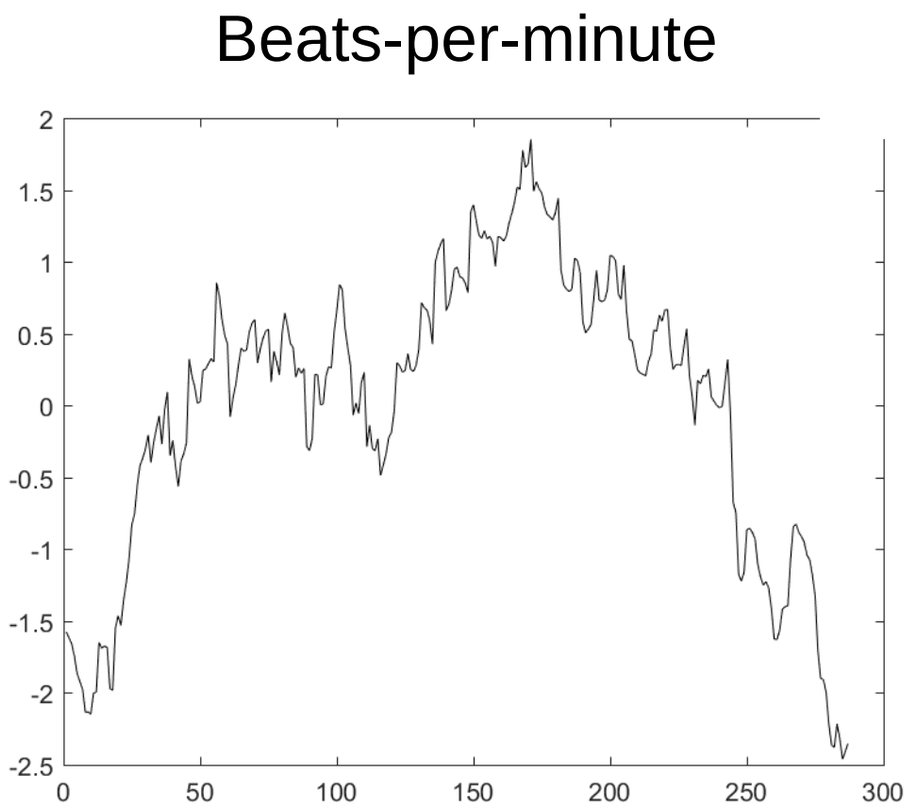

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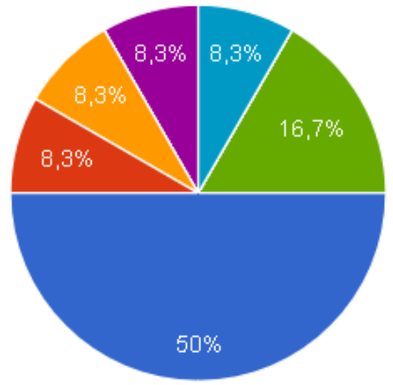
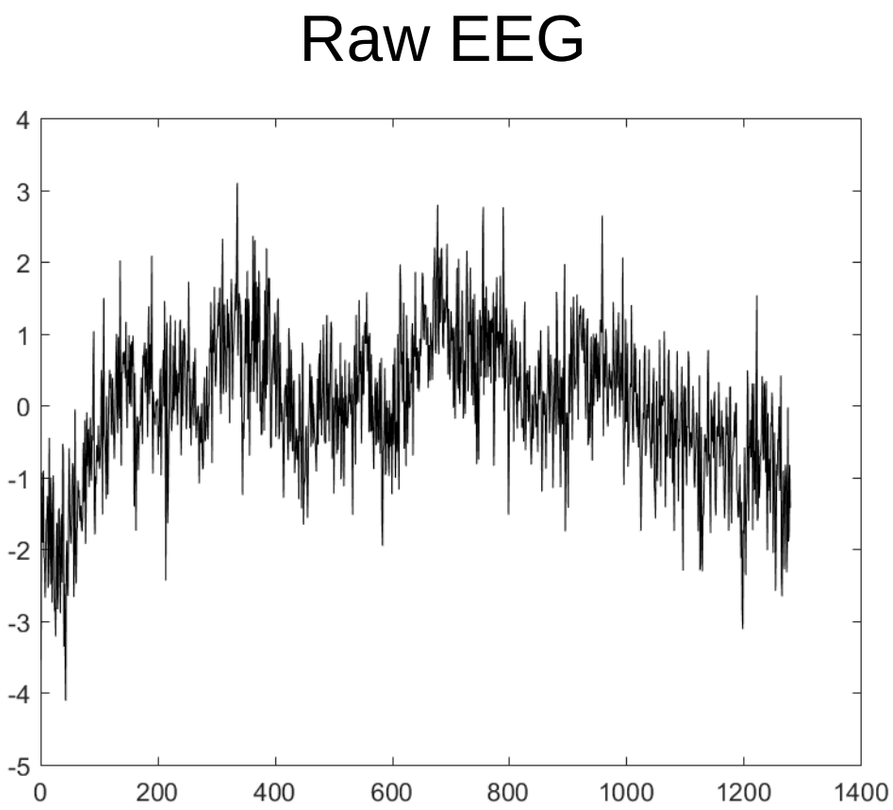


- EEG (Electroencephalogram)
- ECG (Electrocardiogram)
- BPM (-heart-Beats-Per-Minute)
- Response times (word-naming)
- Movement times (pointi...
- Heart-Beat-Intervals
- Respiration
- None of the above



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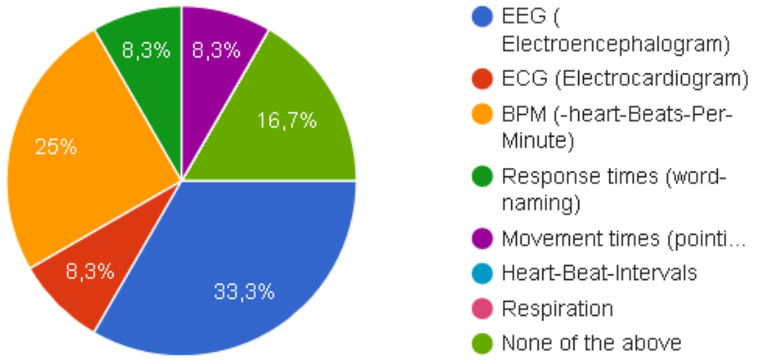
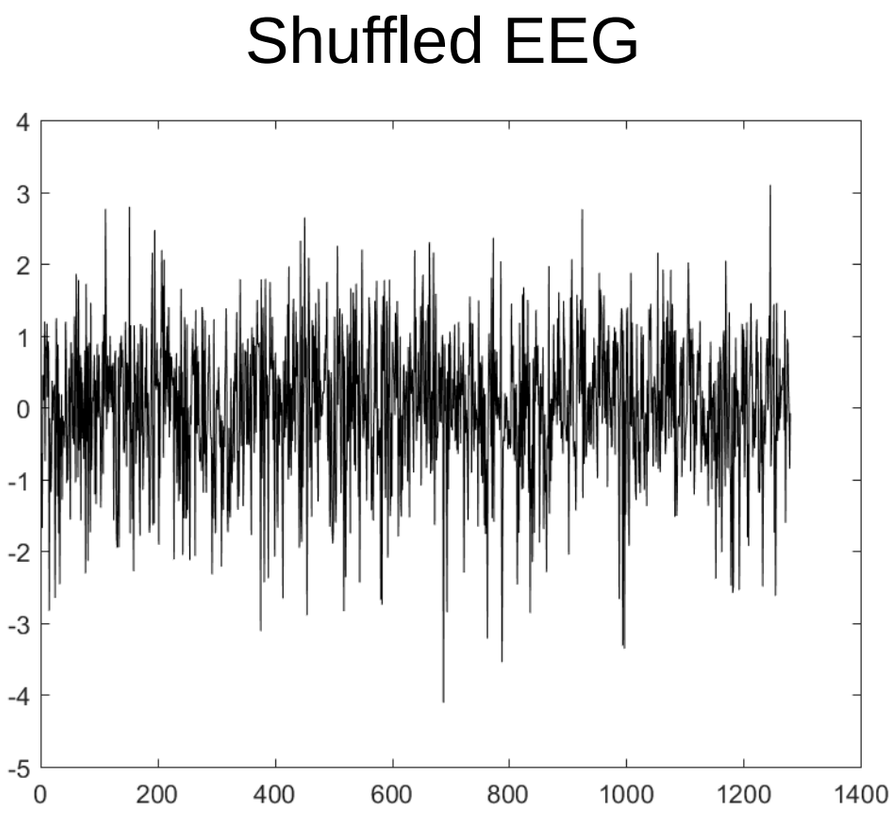
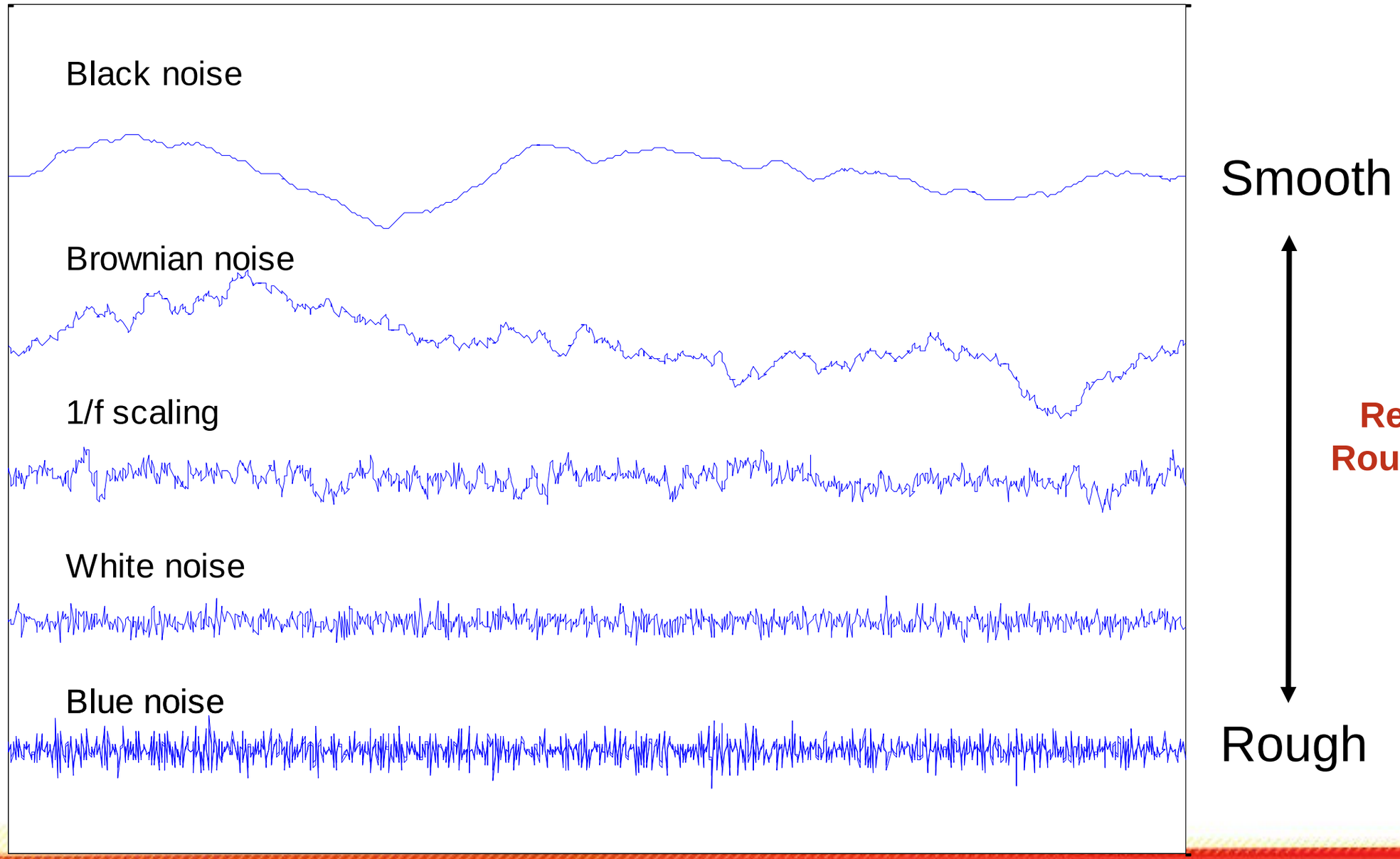




Temporal properties of variability: Relative Roughness

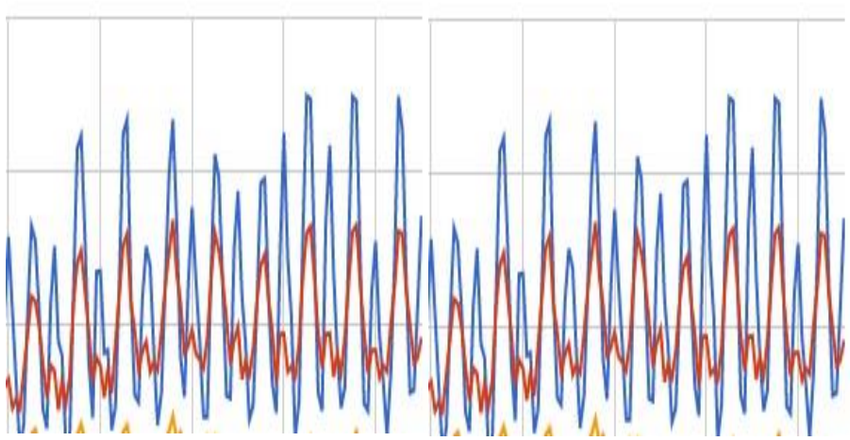


Temporal properties of variability: Relative Roughness

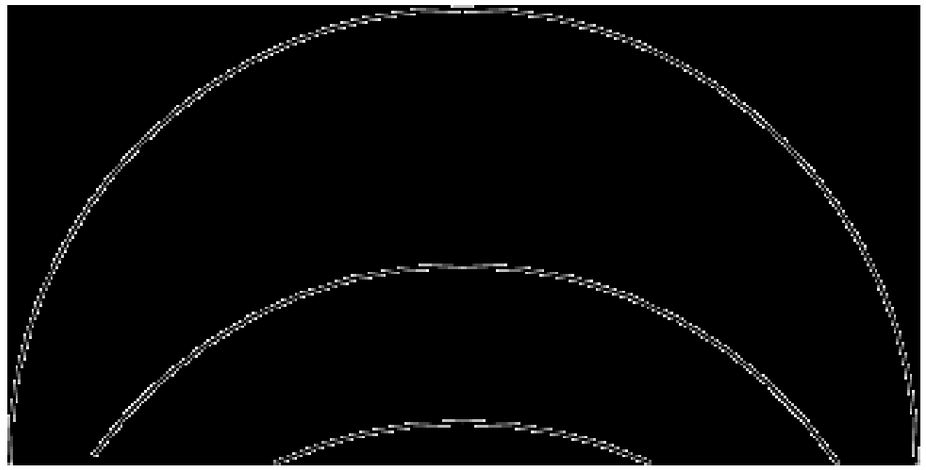
Relative roughness of a time series is:

$$RR = \frac{\text{local variance}}{\text{global variance}}$$

Local variance:
Fast changes



Global variance:
Slow changes



Temporal properties of variability: Relative Roughness

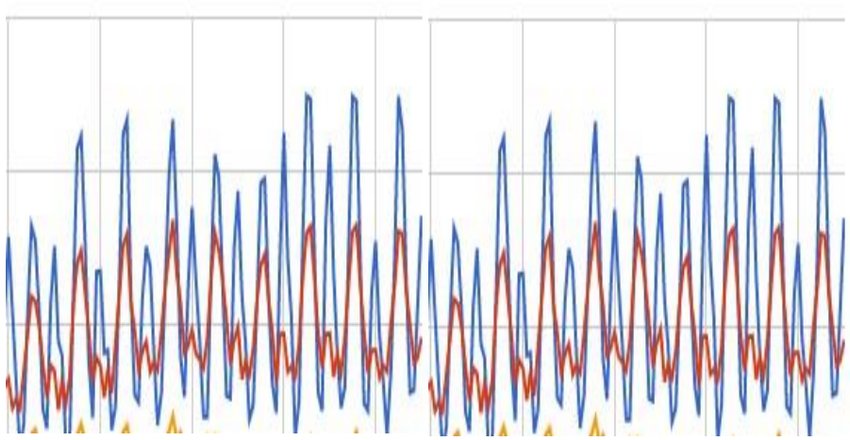
Relative roughness of a time series is:

$$RR = 2\left[1 - \frac{\gamma_1(x_i)}{\mathrm{Var}(x_i)}\right]$$

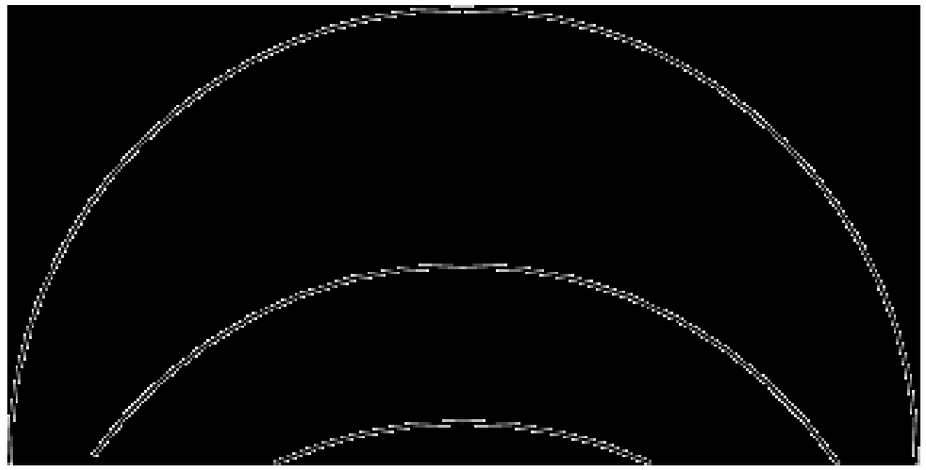
Lag 1 auto-(co)variance

Overall variance

Local variance:
Fast changes



Global variance:
slow changes



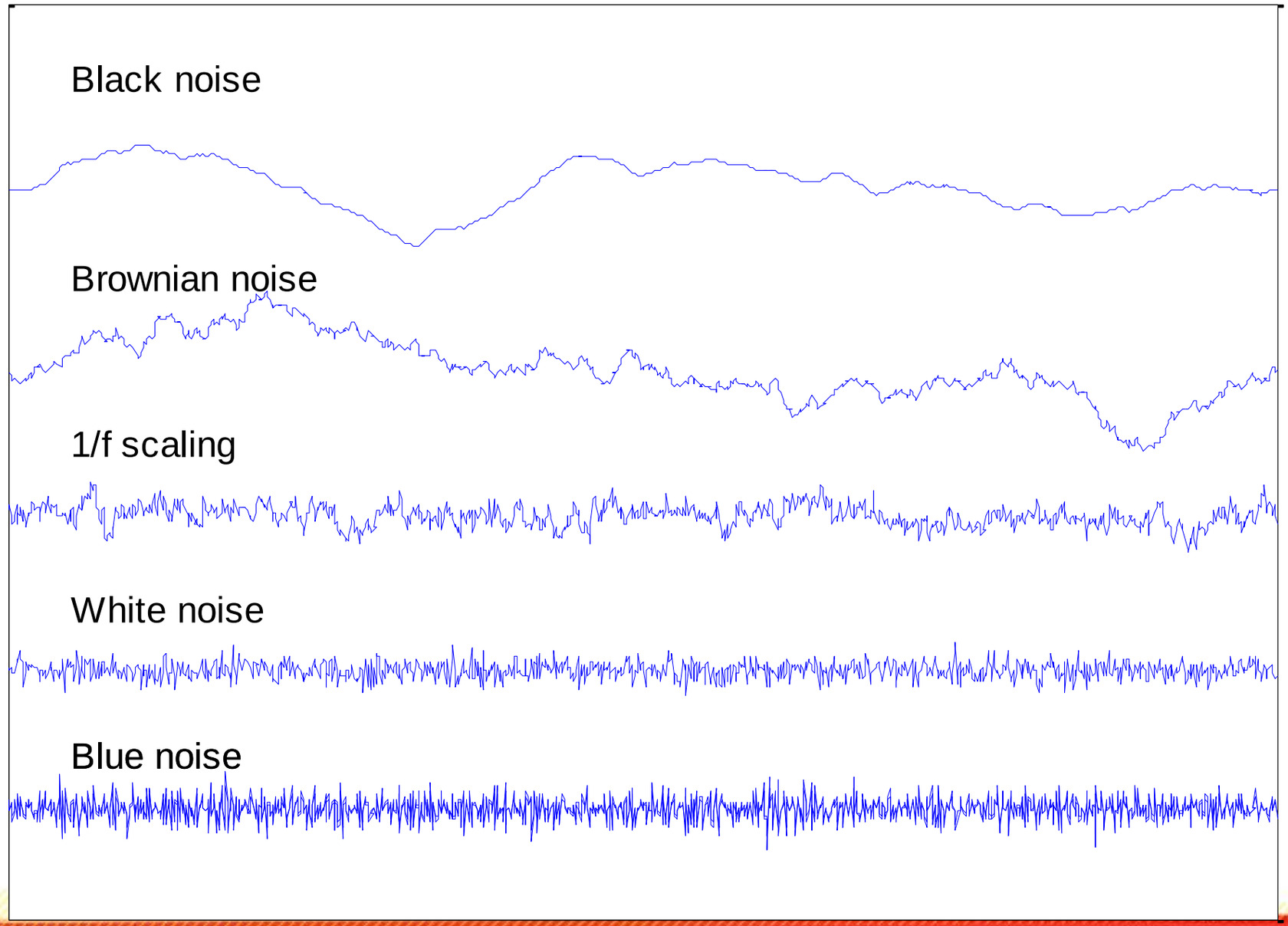
Temporal properties of variability: Relative Roughness

Only slow

Predominantly slow

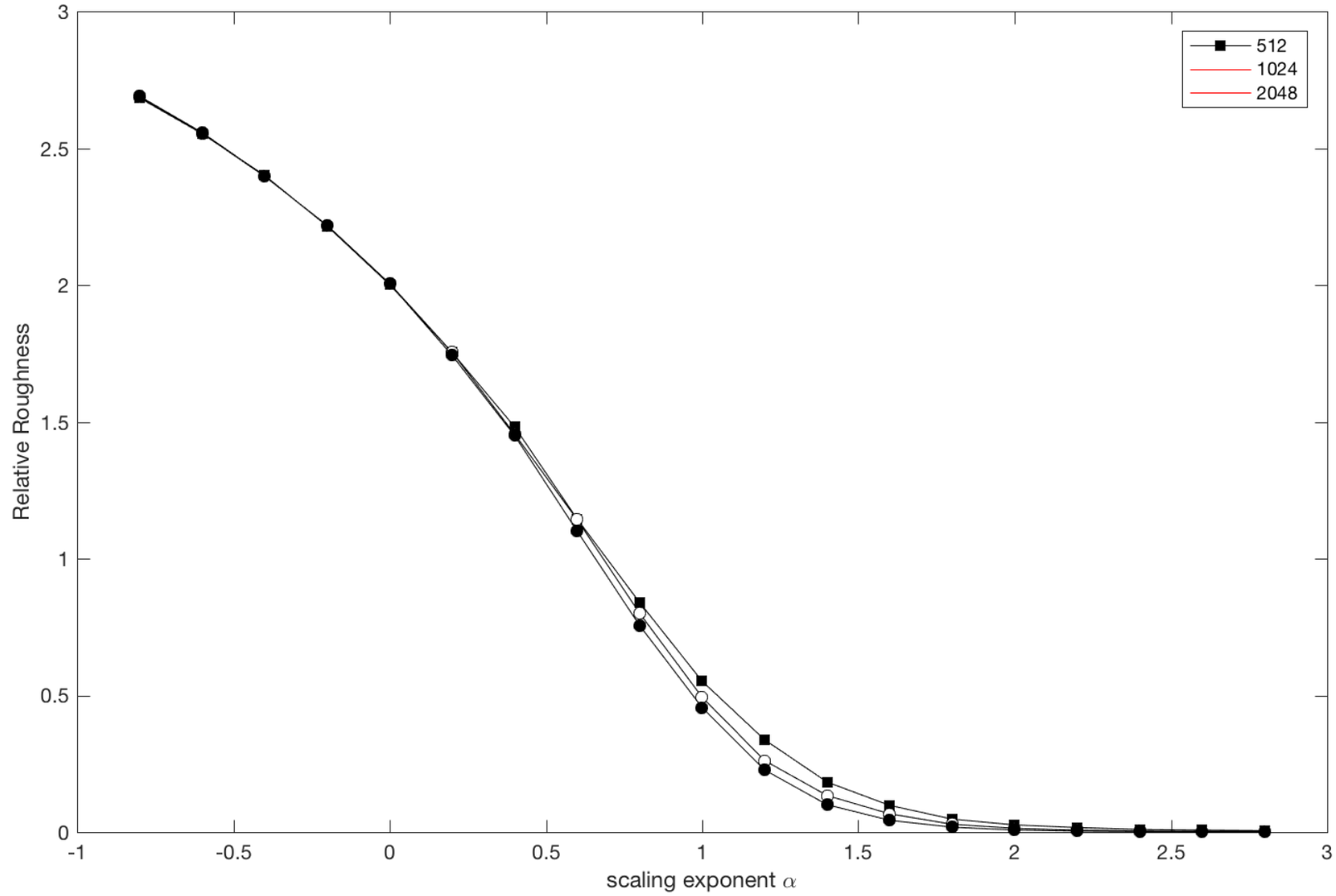
All time scales

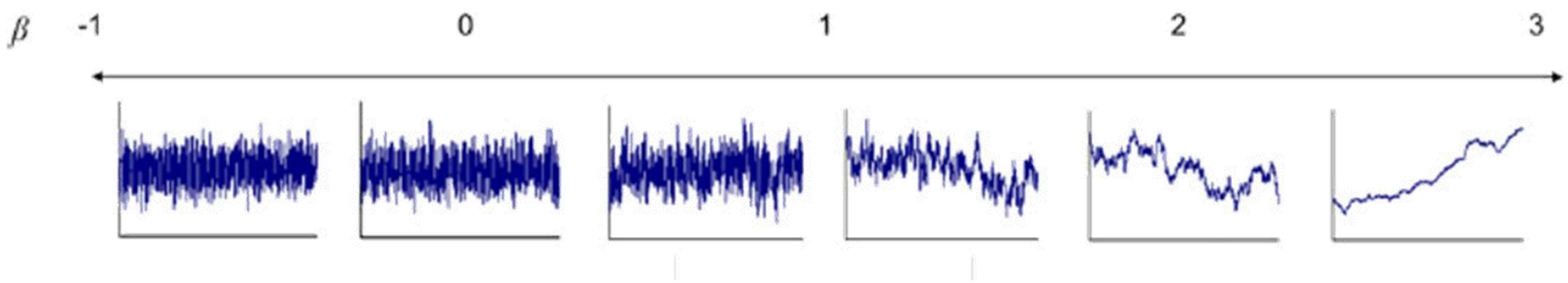
Only fast



Global variance
>
Local variance

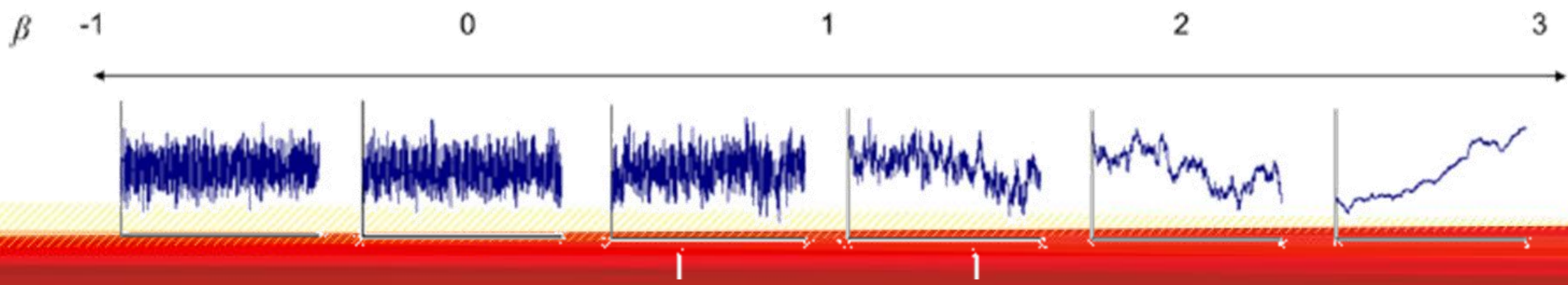
Local variance
>
Global variance


512
1024
2048
Relative Roughness
scaling exponent α
3
2.5
2
1.5
1
0.5
0
-1
-0.5
0
0.5
1
1.5
2
2.5
3

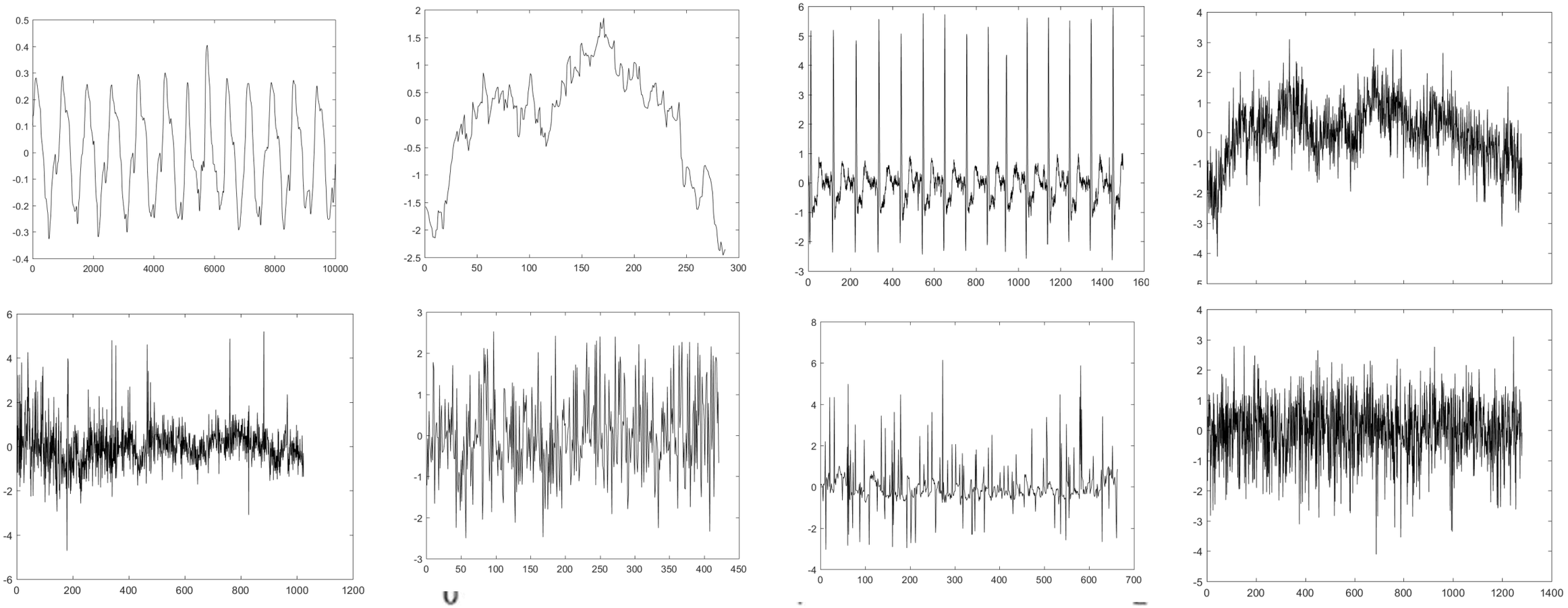

β
-1
0
1
2
3

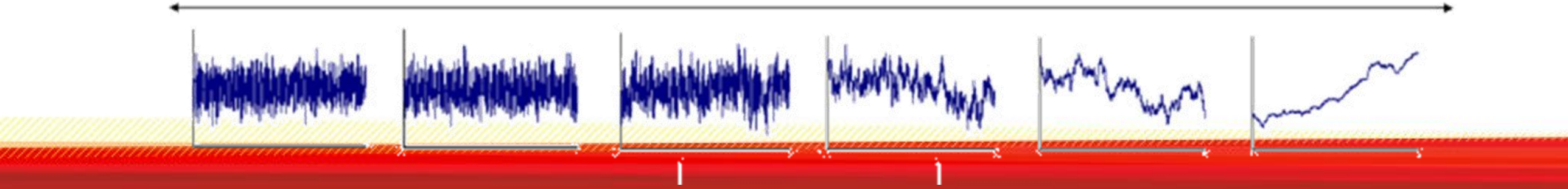
Data quiz: Relative roughness

#	Data Type	Relative Roughness	
1	Respiration	0.0002	smoothest
2	BPM	0.06	…
3	ECG	0.31	…
4	EEG	0.77	…
5	MT pointing	1.94	…
6	RT Word-naming	1.94	…
7	HBI	2.01	…
8	NA (random EEG)	2.07	roughest



Data quiz: Relative roughness





Entropy as a complexity measure

No obvious link with Roughness

- Different way to tap into dynamics

Entropy is a probabilistic measure

- Measure of uncertainty
- Measure of irregularity

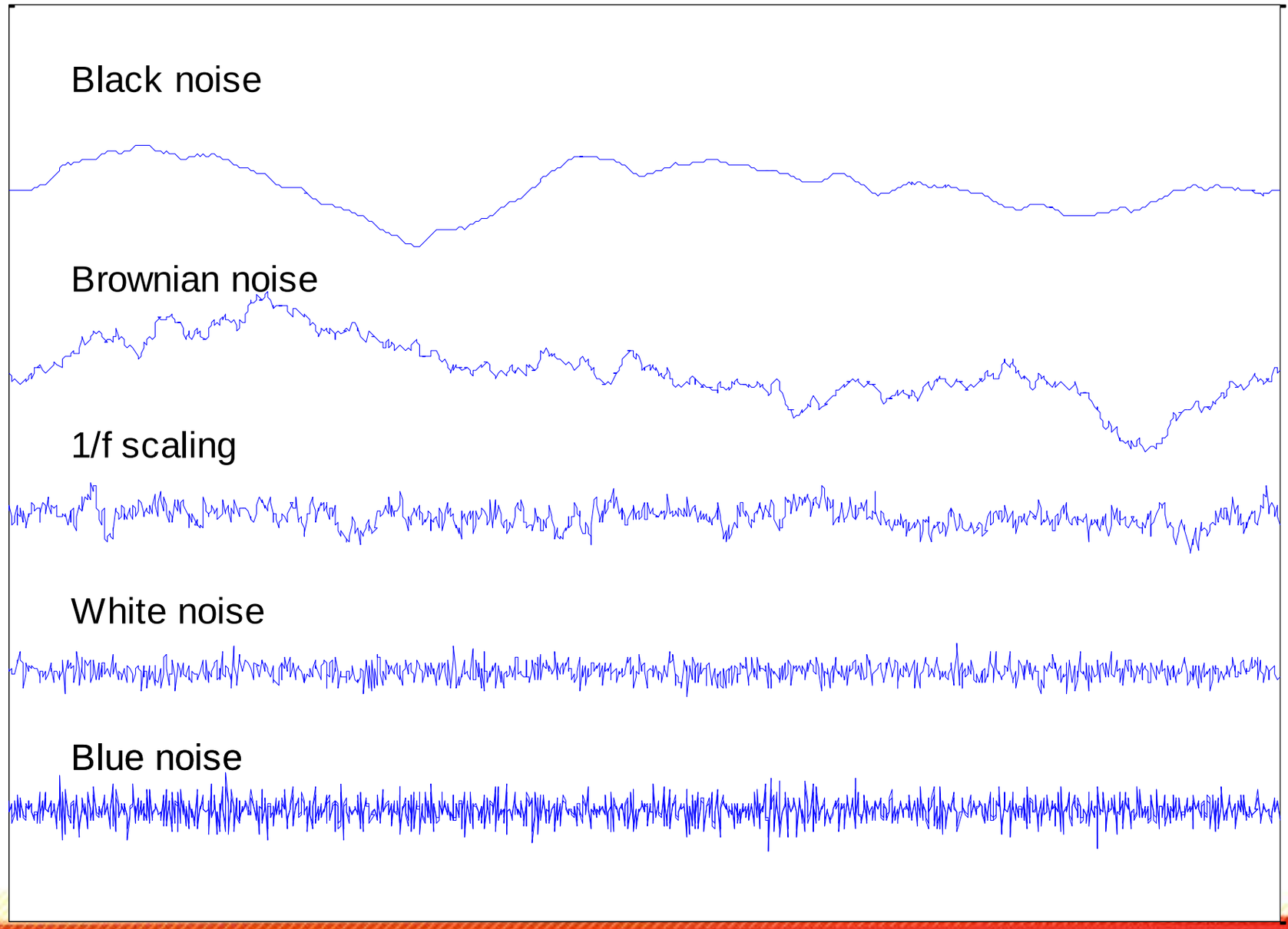
Temporal properties of variability: Sample entropy

Only slow

Predominantly slow

All time scales

Only fast



Low entropy

Sample Entropy

High entropy

Entropy in time series data

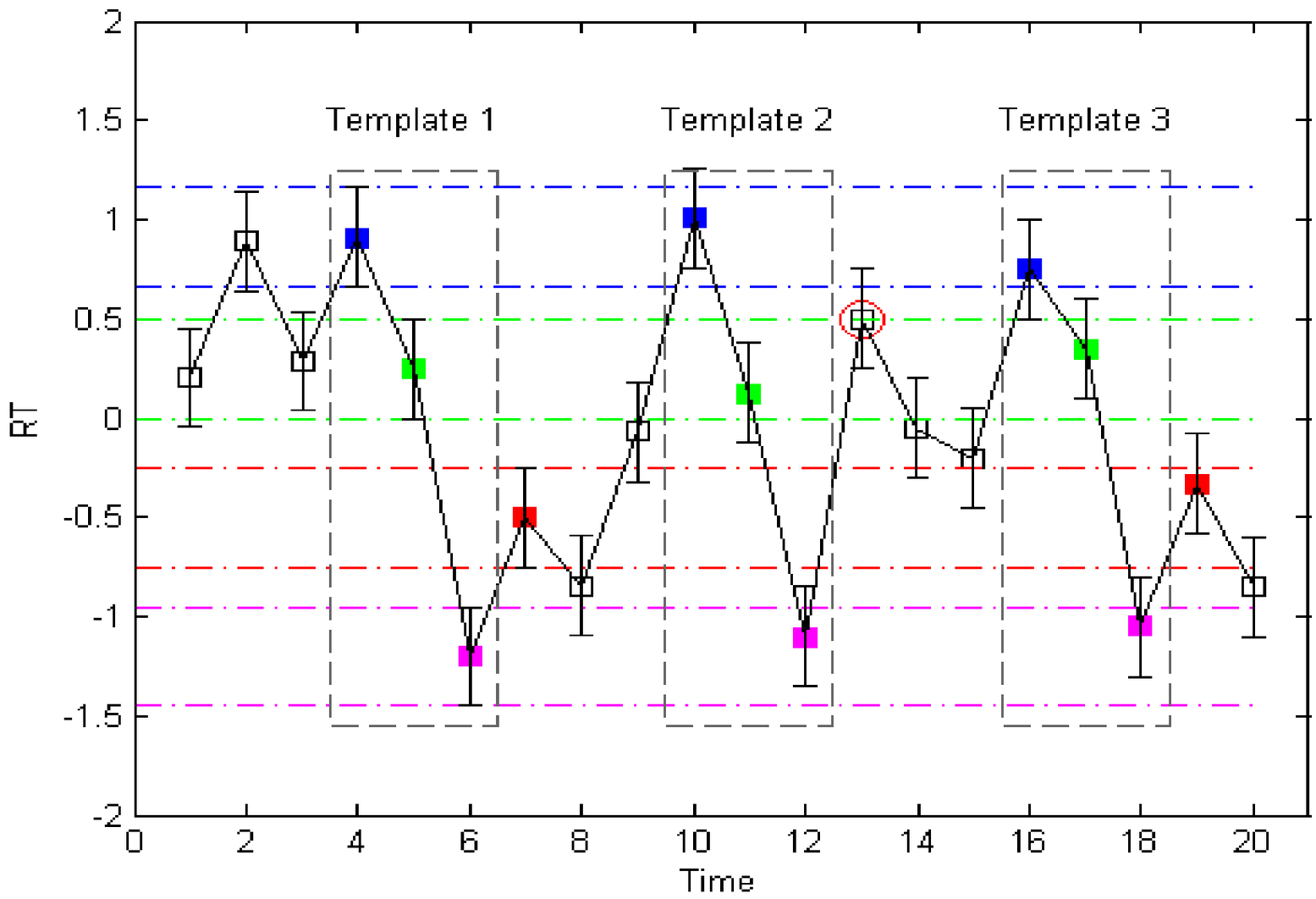
Sample entropy

- The negative natural logarithm of the conditional probability that a dataset of length *N*, having repeated itself within a tolerance *r* for *m* points, will also repeat itself for *m* + 1 points.

- P = *A*(*k*)/*B*(*k*)
  - A: # of data segment of length m+1 are within distance < *r*
  - *B: #* of data segment of length m are within distance < *r*

- SampEn (*m*, *r*, *N*) = −ln P

- SampEn: the negative natural log (-ln) of the conditional probability that the pattern of *m*+1 points (■-■-■-■) will match if a pattern of *m* points (■-■-■) did match



Sample entropy

Determine *m*

- the length of compared runs of data
- E.g., 3 data points

Determine *r*

- Tolerance range
- E.g., 1 standard deviation

Sample entropy

A small value (e.g., 0.05)

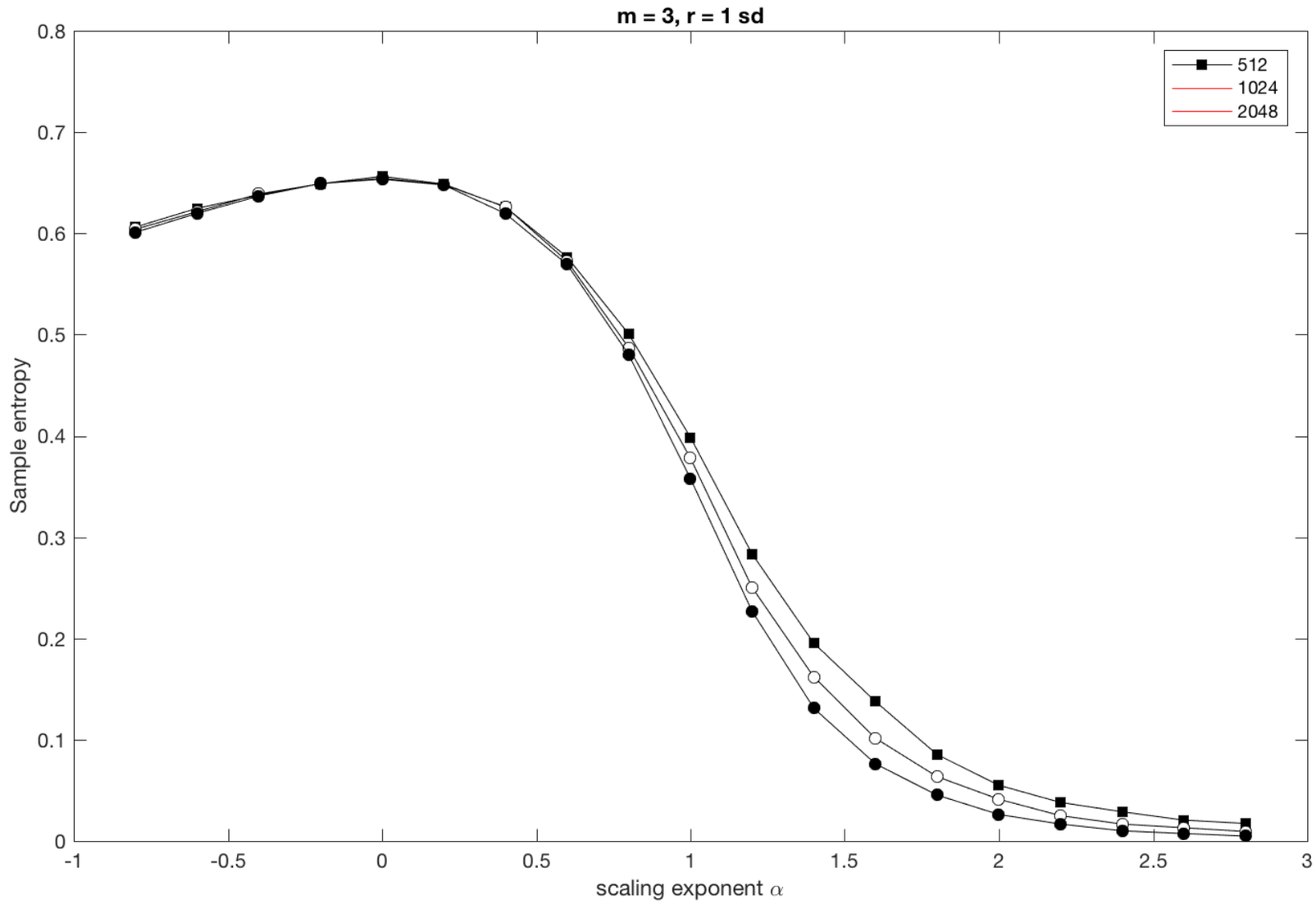
- sequence is regular and predictable
- a high probability of repeated template sequences in the data

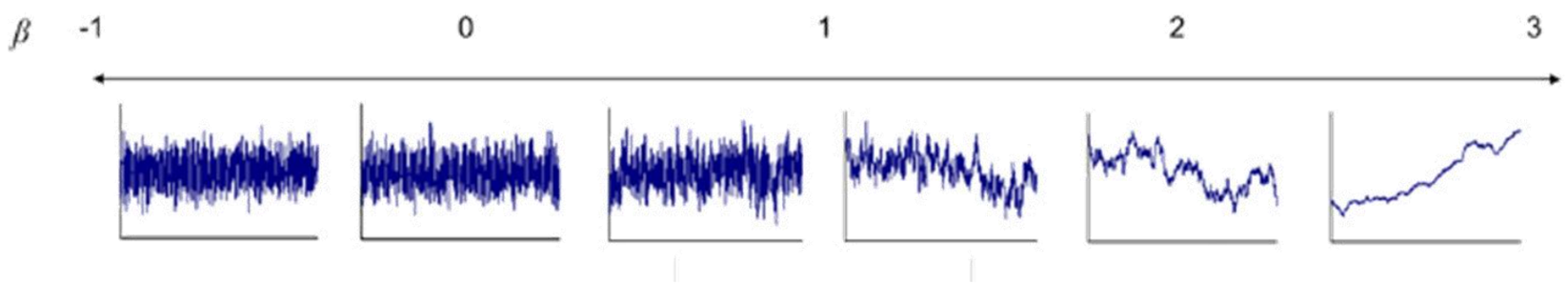
A large value (e.g., 1.5)

- sequence is irregular and unpredictable
- a low probability of repeated template sequences in the data

NOTE: absolute values will change in function of your parameter choices for *m* and *r*

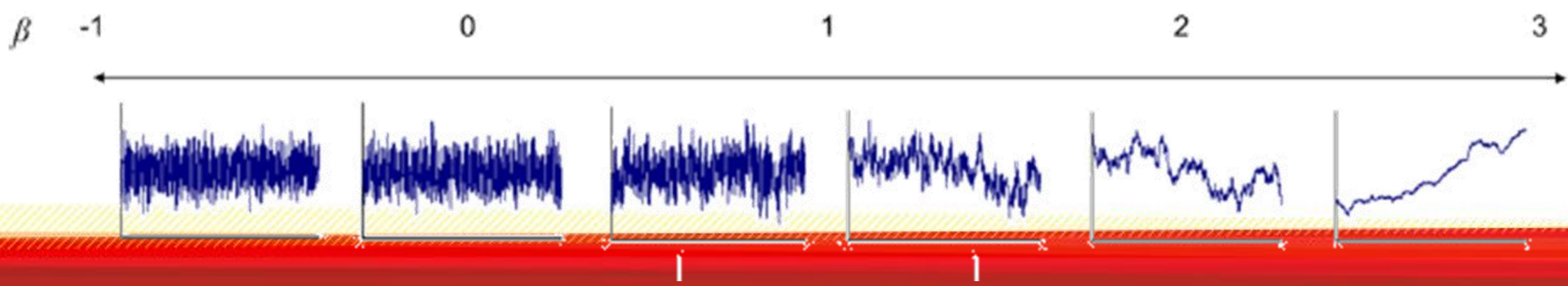
- the number of matches can be increased by choosing small *m* (short templates) and large *r*(wide tolerance).


m = 3, r = 1 sd
512
1024
2048
Sample entropy
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-1
-0.5
0
0.5
1
1.5
2
2.5
3
scaling exponent α

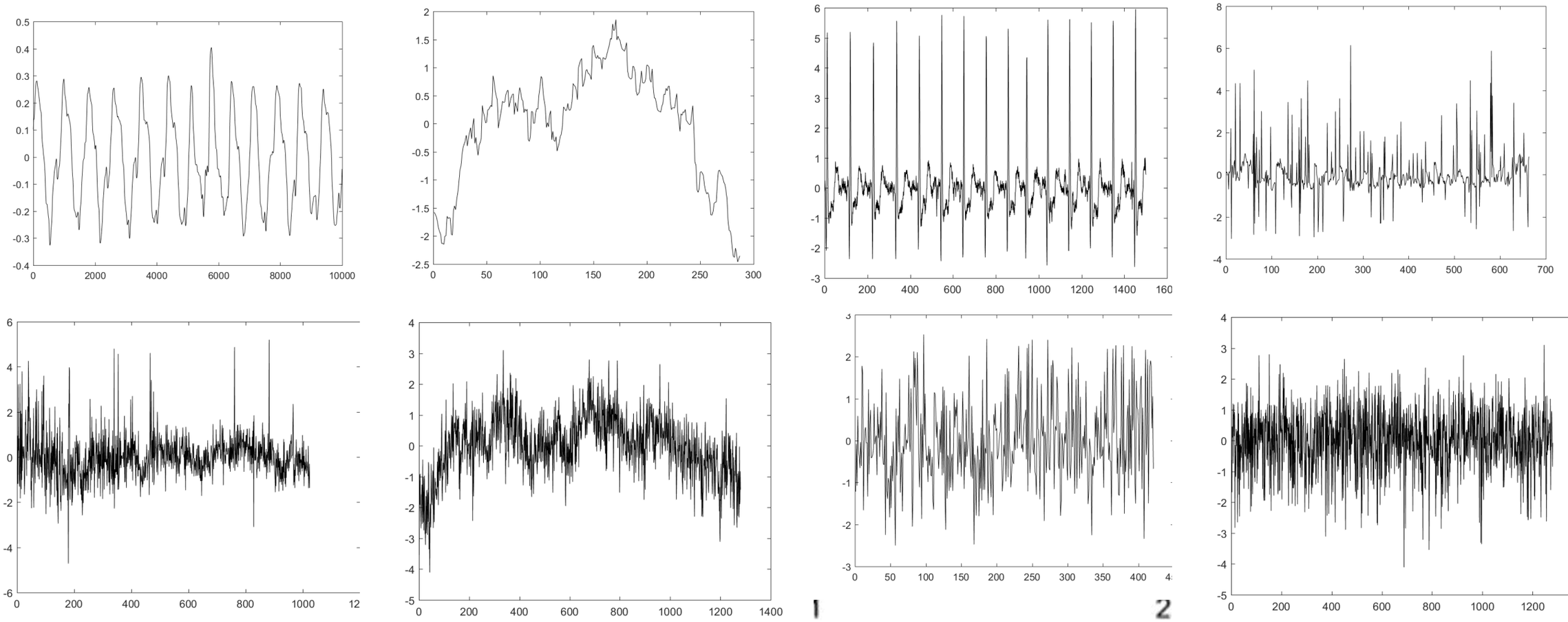

β
-1
0
1
2
3

Data quiz: Relative roughness

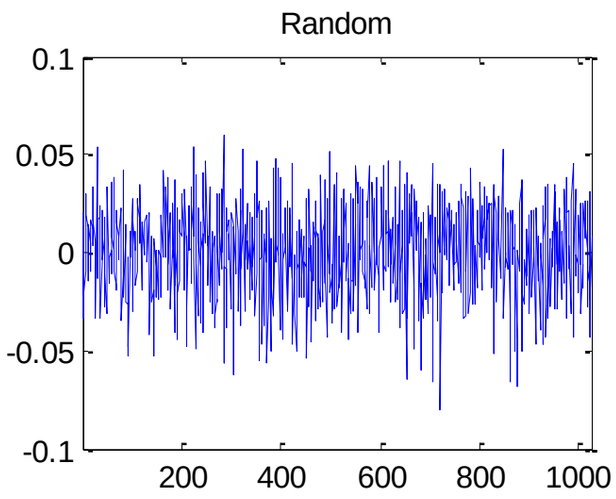
#	Data Type	Sample entropy	
1	Respiration	0.006	Low entropy
2	BPM	0.06	…
3	ECG	0.08	…
7	HBI	0.25	…
5	MT pointing	0.43	…
4	EEG	0.44	…
8	NA (random EEG)	0.63	…
6	RT Word-naming	0.65	High entropy



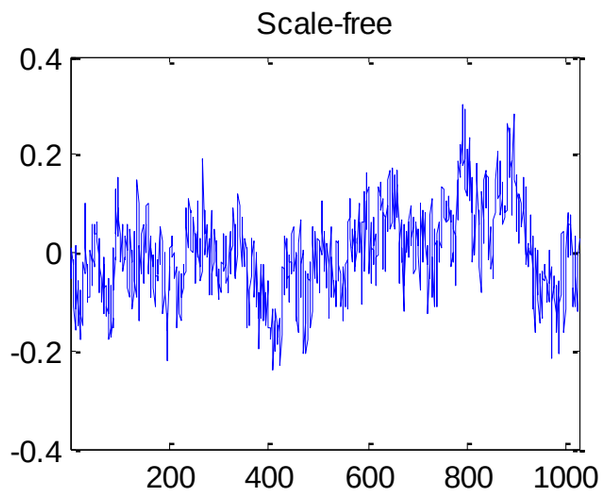
Data quiz: Sample entropy

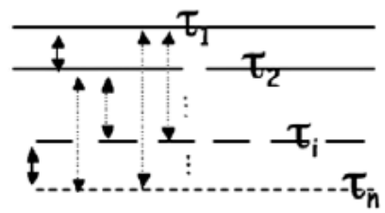


Time series analysis: sum up

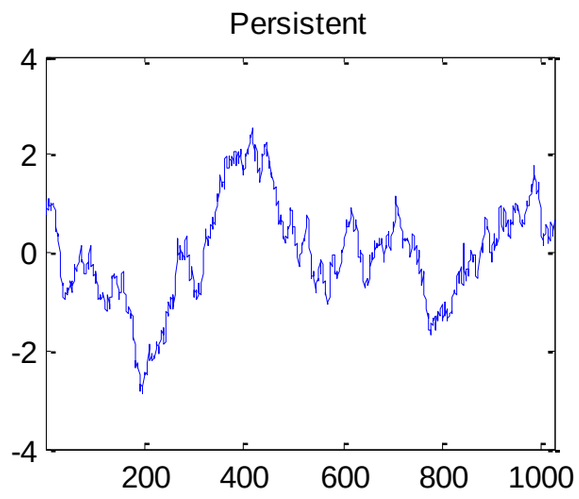


- Flexible
- Disorganized
- No slow time scales
- Unconstrained
- Many degrees-of-freedom





Dynamics at all time scales contribute to the process



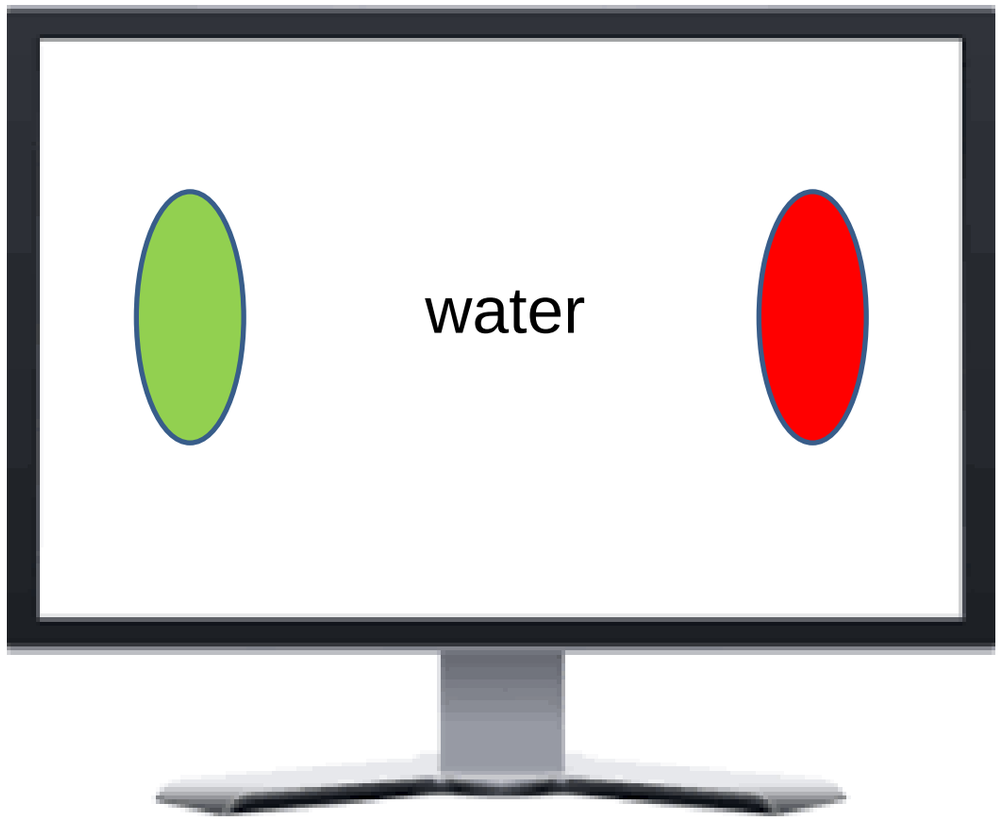
- Rigid
- Order
- Predominantly slow time scales
- Constrained
- Few degrees-of-freedom

Linear Statistics

Complexity measures

Learning disabilities and dynamics: lexical decision

- 128 existing words (HF or LF)
- 128 non-existing words:
  - INW
  - LNW
  - PSH
- Yes or no responses
- Fast + accurate
- 11 to 12 years old

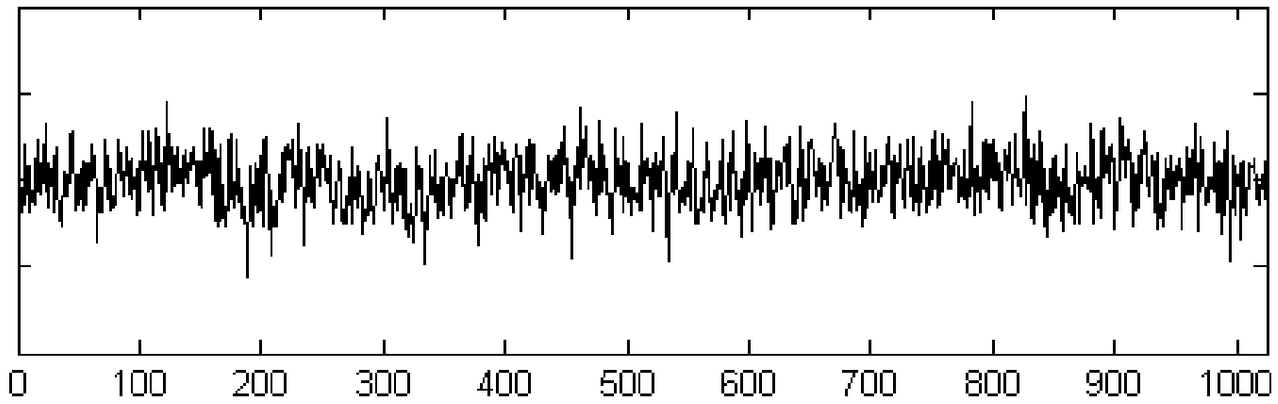


- RT, accuracy, Sample entropy
- Eén-minuut test – ‘one-minute-test’
- Klepel

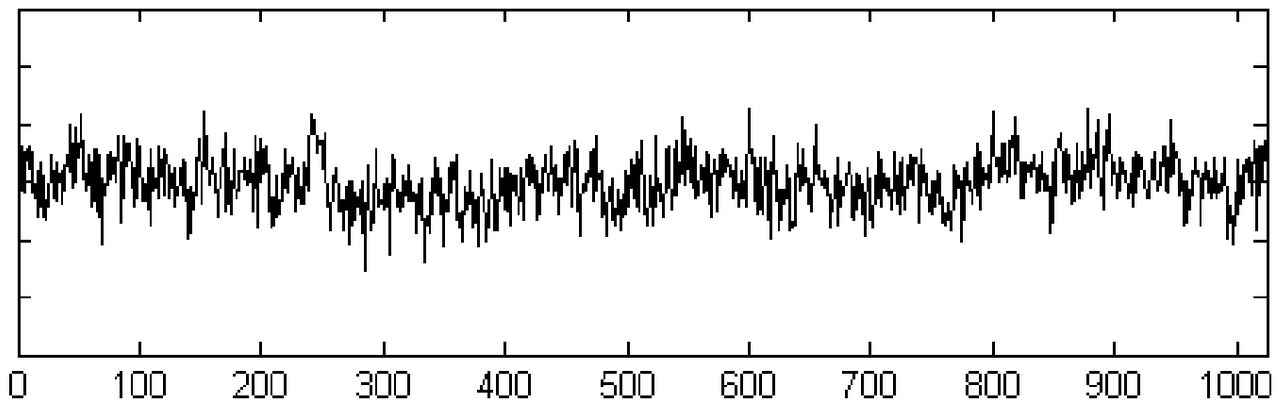
Lexical-decision task with high and low frequency words

HF and LF words	Illegal nonwords	Legal nonwords	pseudohomophones
early	mruab	ambun	ambur
later	rbuht	dranz	burth
pearl	rneag	sleam	surve
think	tnkio	topit	knyfe
cobra	xodye	wheeb	shair
apron	wlteo	brate	sneez
large	hsutr	relin	kurse
ruler	iwirth	veest	shurt

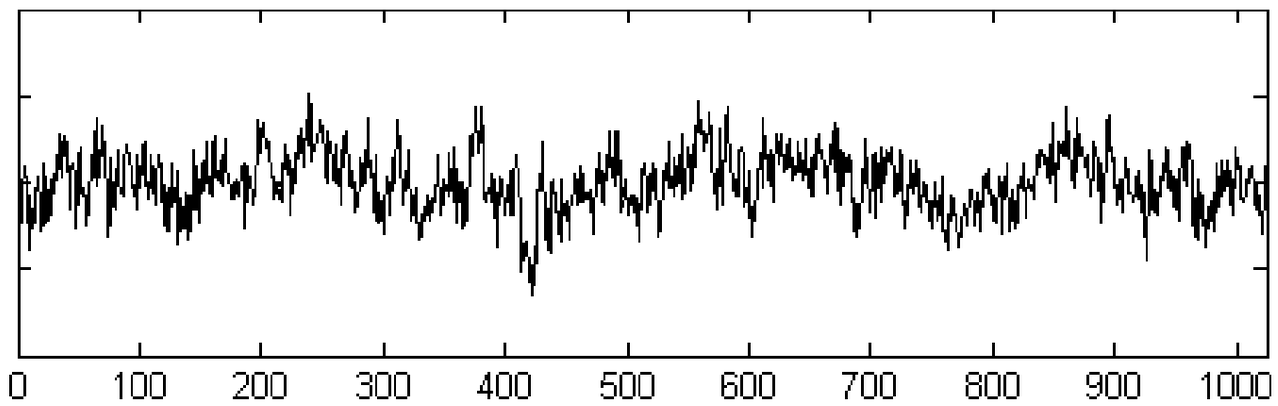
Words and PSH



Words and LNW



Words and INW



High entropy

Decision ambiguity

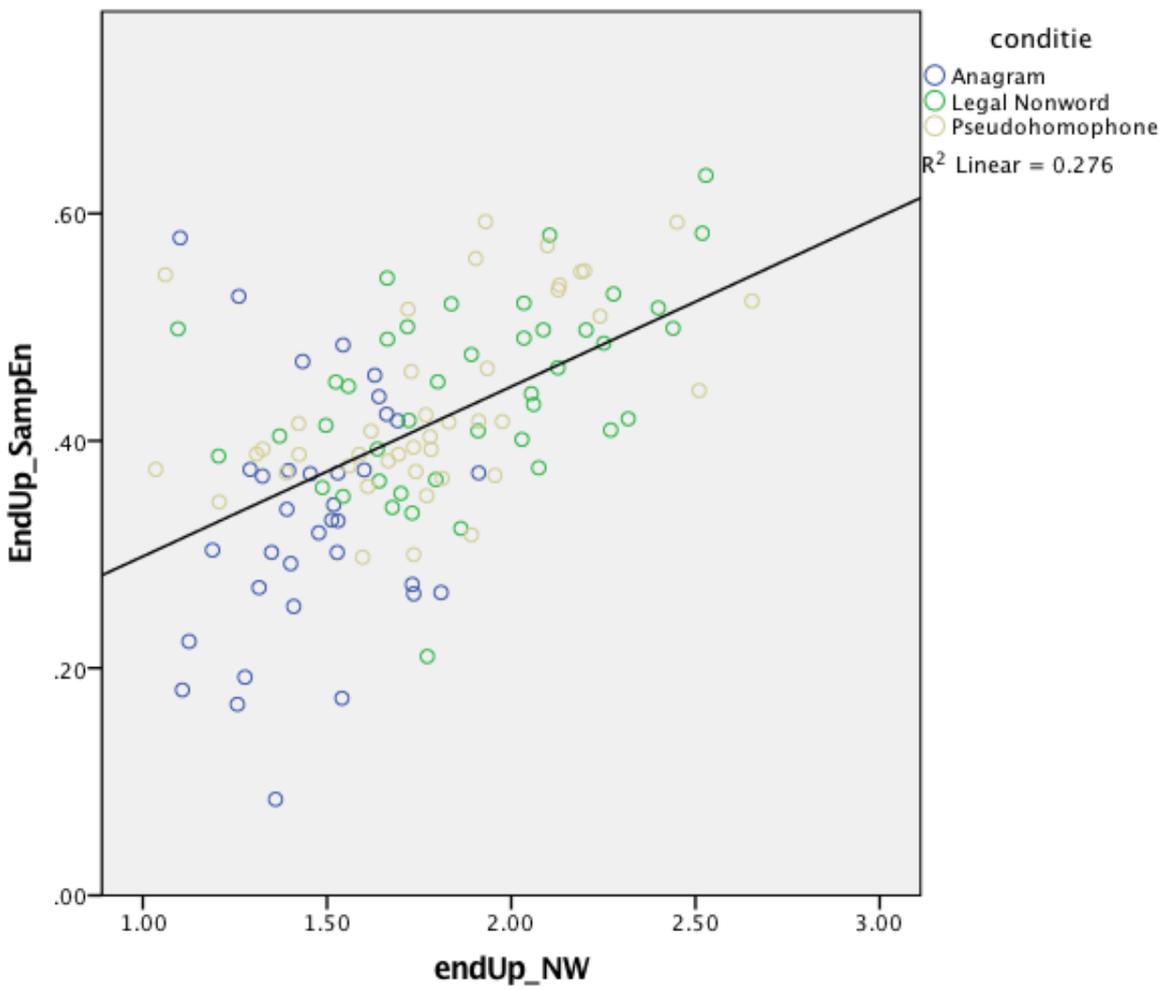
Low entropy

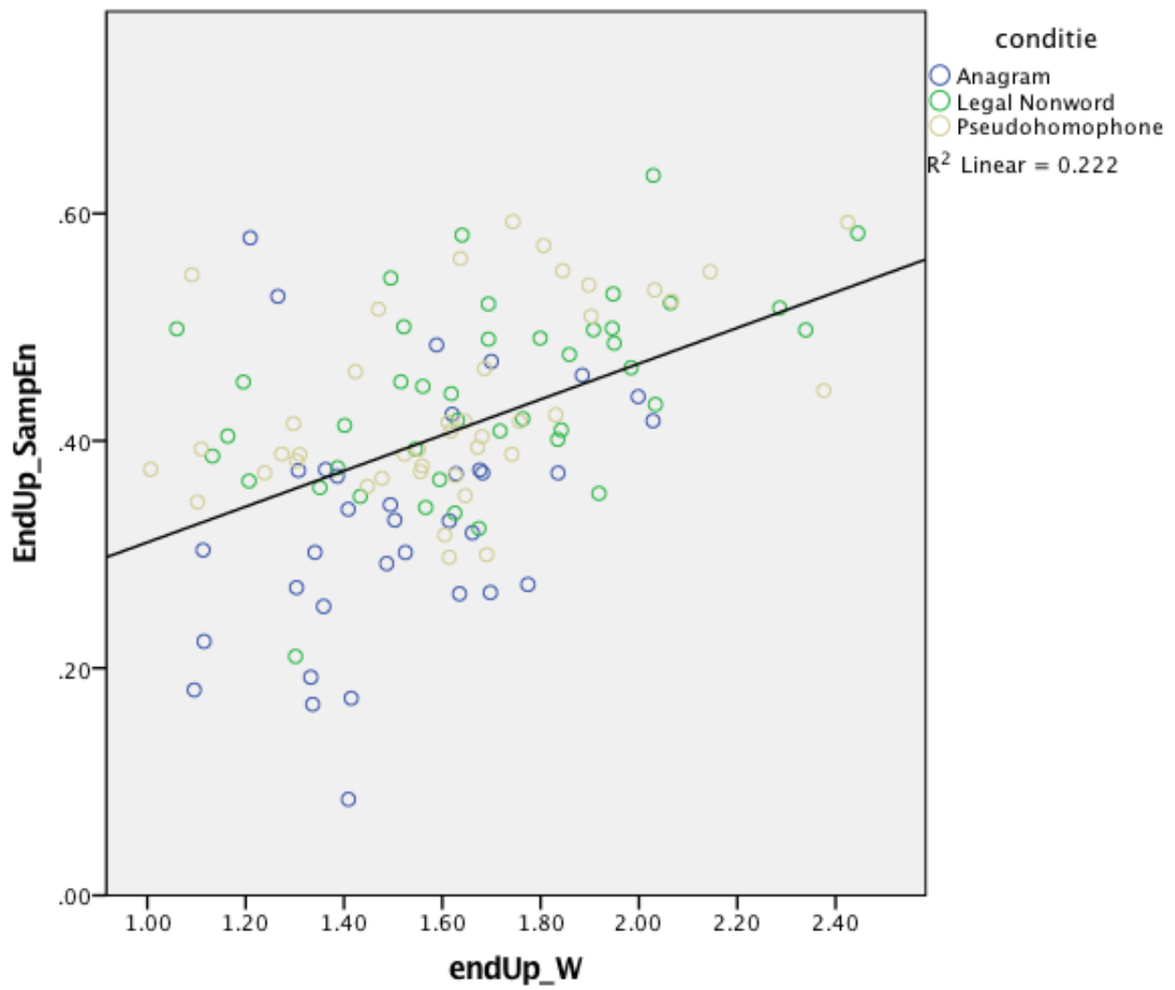
		INW		LNW		PSH		INW		LNW		PSH	
		M (*SD*)					*F*(2,116)	% Accuracy (*SD*)					*F*(2,116)
Word trials													
	High frequency	802(230)	=	919(268)	=	886(244)	2.21	88.9(11.6)	=	85.6(16.6)	=	91.7(7.9)	2.47
	Low frequency	841(231)	<	1044(290)	=	1023(276)	6.39**	85.4(10.8)	>	75.5(14.4)	=	81.5(8.0)	7.34**
	Frequency advantage	39(103)	<	125(102)	=	137(117)	9.14***	3.5(5.4)	<	10.1(6.8)	=	10.2(5.5)	15.18***
Nonword Trials													
		771(182)	<	1194(289)	=	1129(299)	27.24***	90.9(12.0)	>	82.2(15.5)	>	73.6(12.7)	15.48***
	Lexicality advantage	-50(118)	<	217(187)	=	179(140)	33.18***	-3.8(11.5)	=	-1.7(18.0)	<	13.0(13.3)	15.54***
All Trials								89.5(10.0)	>	81.8(12.5)	=	80.4(8.0)	8.11**
	Sample Entropy	.341(.107)	<	.446(.089)	=	.441(.084)	15.12***						

* p < .05, ** p < .01, ***p <.001

Correlations are Shown Between Sample Entropy (SampEn) and Response Times (RT) on High-Frequency (HF), Low-Frequency(LF) , Word (W) and NonWord (NW) Stimlui, and Standardized Reading tests (EMT and Klepel).

			HF	LF	W	NW	EMT	KLEPEL
SampEn	INW	N = 35	.26	.30	.29	.22	.06	.32
	LNW	N = 42	.35*	.30	.33*	.22	-.14	-.19
	PSH	N = 42	.46**	.56**	.52**	.58**	-.44**	-.40**





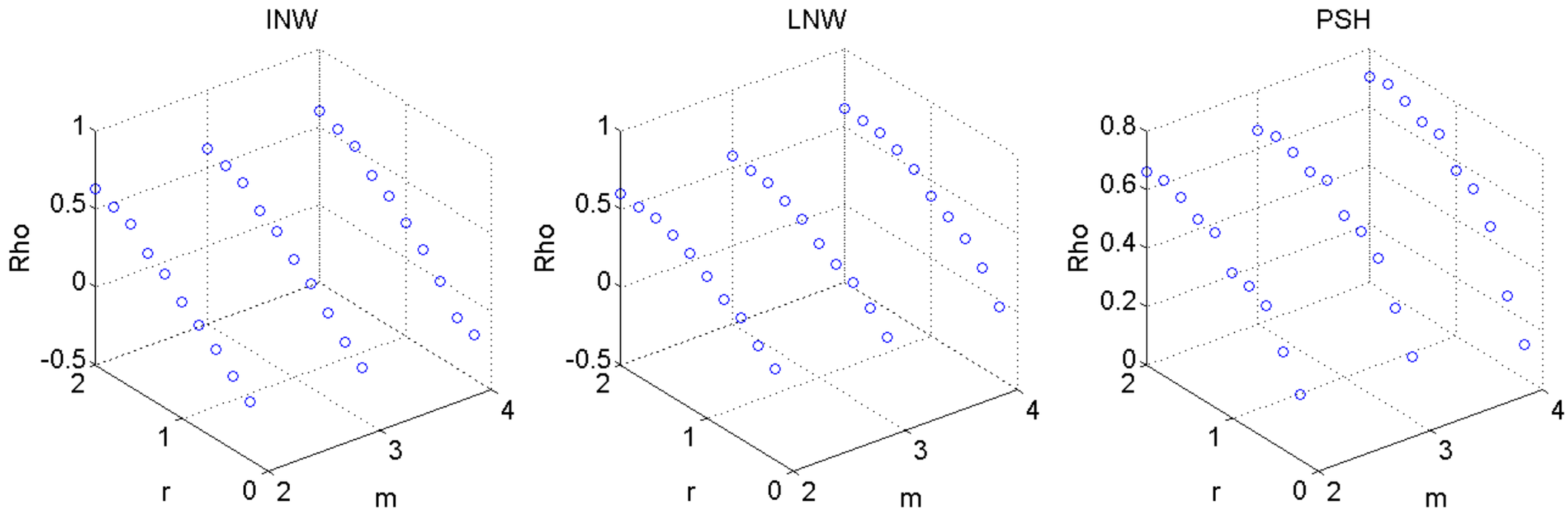


Fig. 4. Different values of *m* (x-axis), diferent values of *r* (y-axis), correlation between word RTs and SampEn (z-axis).

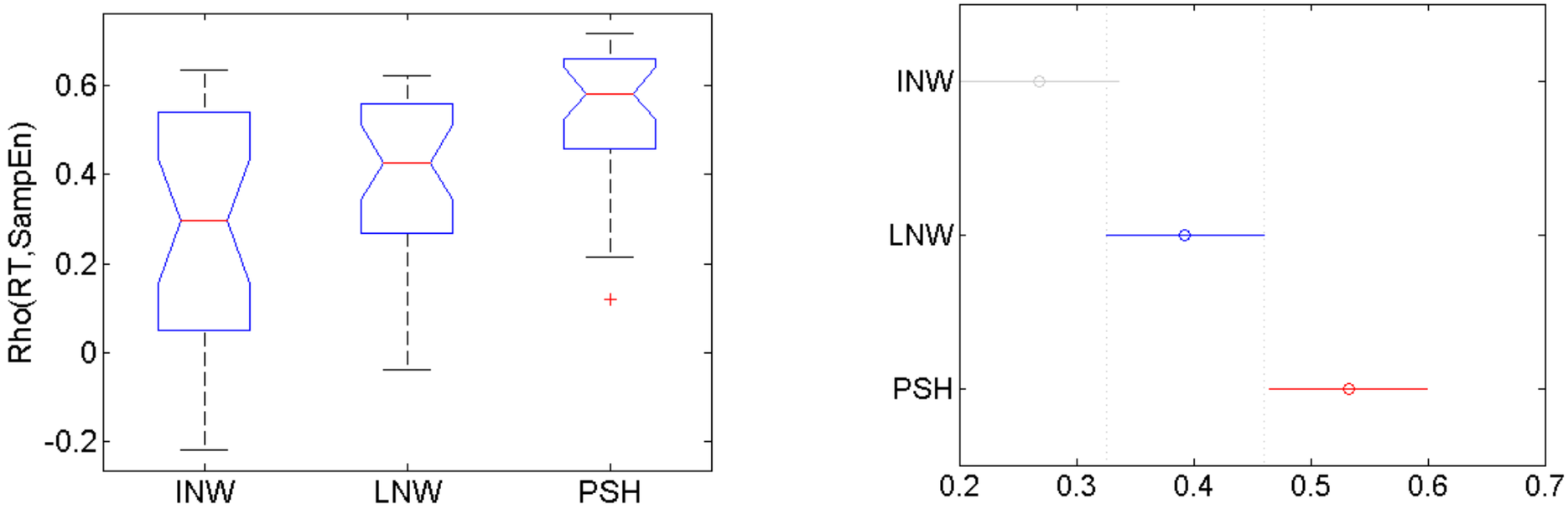


Fig. 5. a) boxplot from the ANOVA. b) Bonferroni outcomes