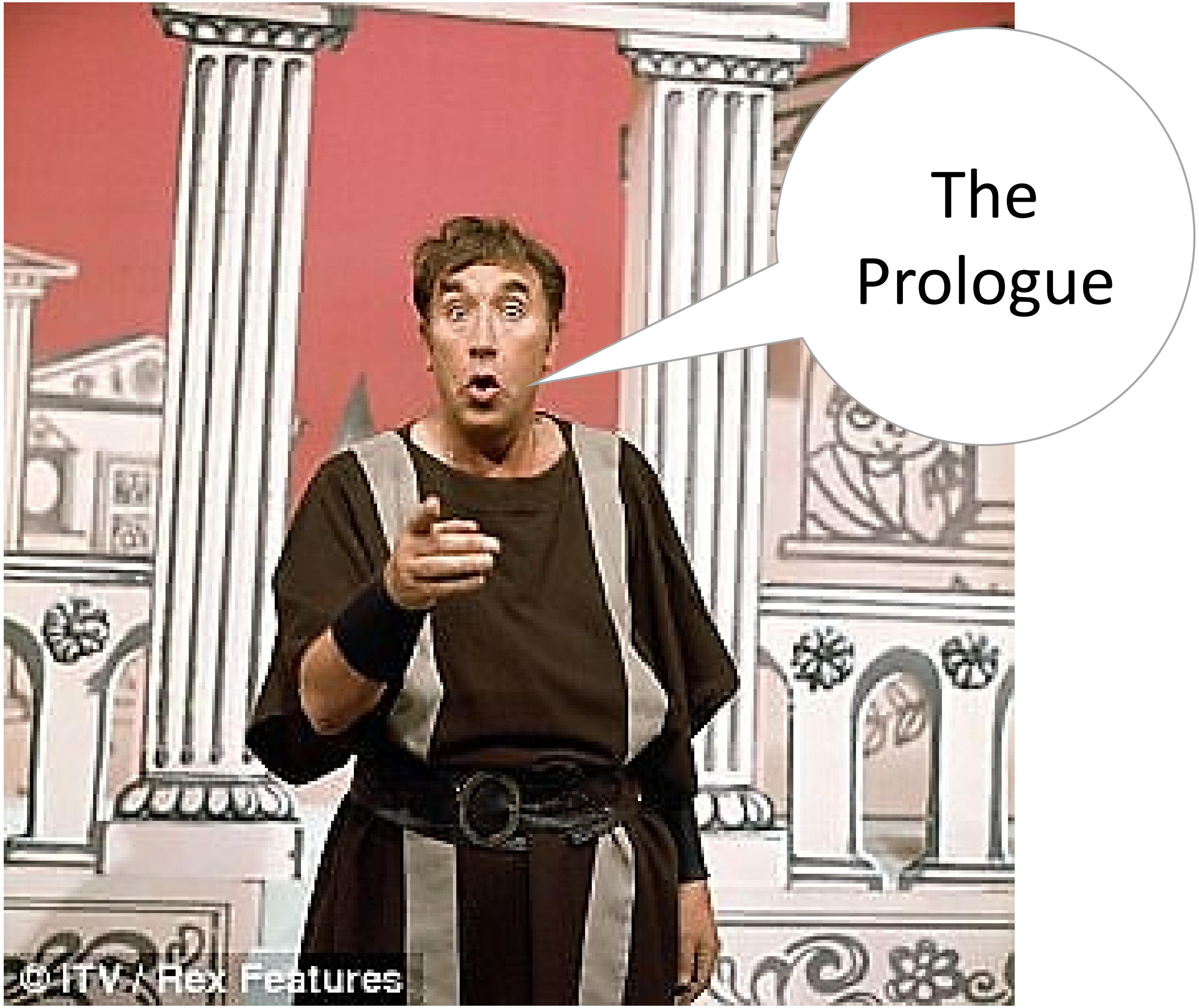
A heuristic for engineering data comparison

Alistair Duffy


The Prologue
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In the early 1990s I was involved in validating the Transmission Line Matrix (TLM) electromagnetic simulation technique.

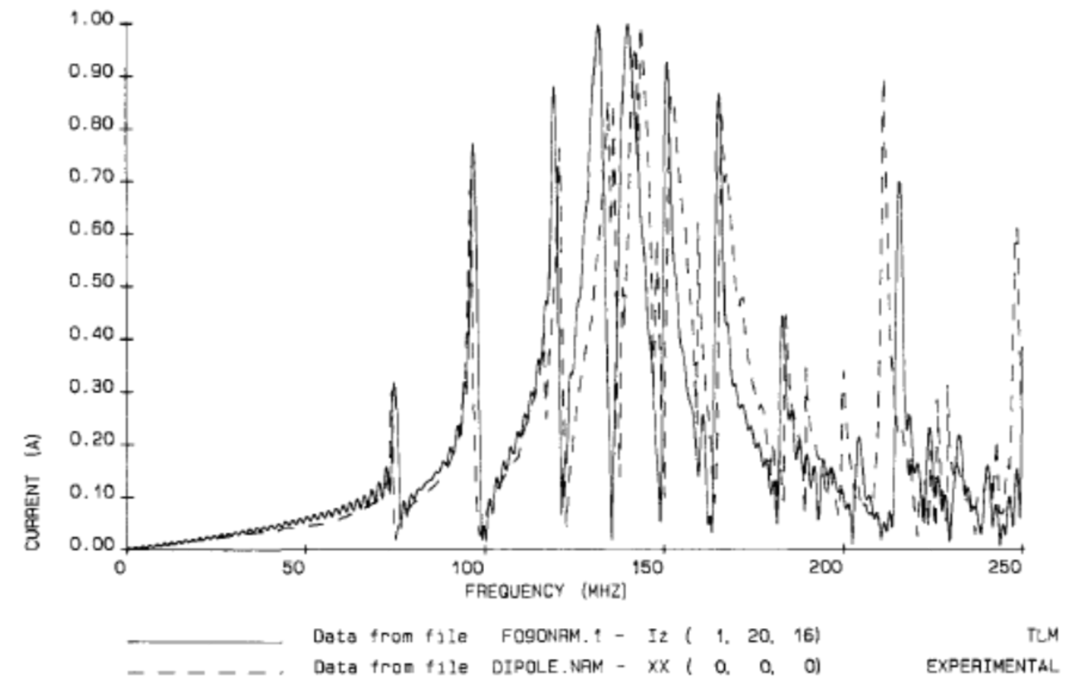


Fig. 10. Dipole current comparison, hybrid variable mesh with experiment.

Validation was frequently done against measurements or other (different) simulation techniques.

Usually, just by looking at the results and commenting on whether they look ok.

It was not robust but there was little alternative: correlation really did not work well for the sort of data being investigated

This is typical of the results being compared.

Duffy *et al*, T-EMC, 1993

More to the point, how could I decide which of these is better

If at all

And if so, by how much … is the benefit of the “improvements” worth the extra time and cost to the method?

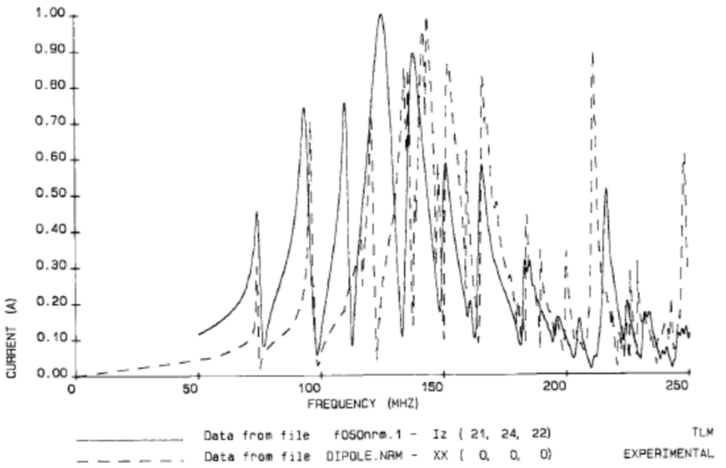


Fig. 8. Dipole current comparison, regular mesh TLM with experiment.

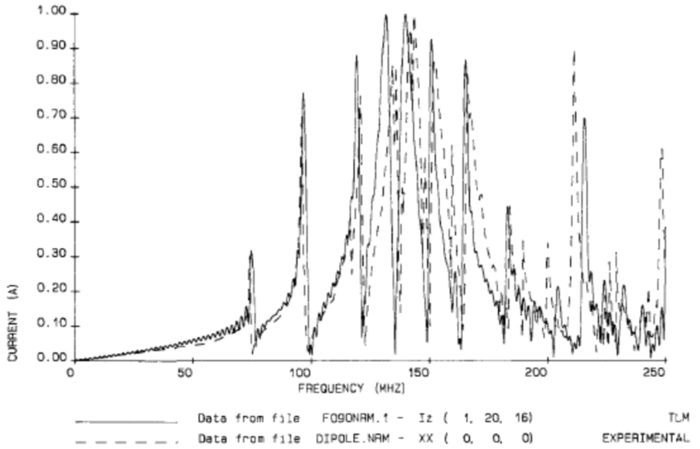


Fig. 10. Dipole current comparison, hybrid variable mesh with experiment.

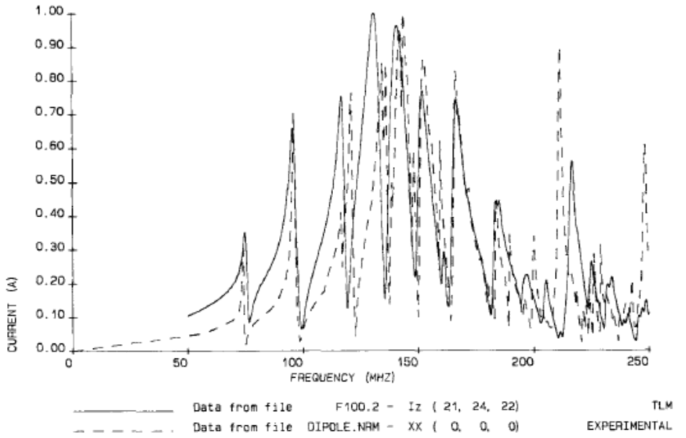
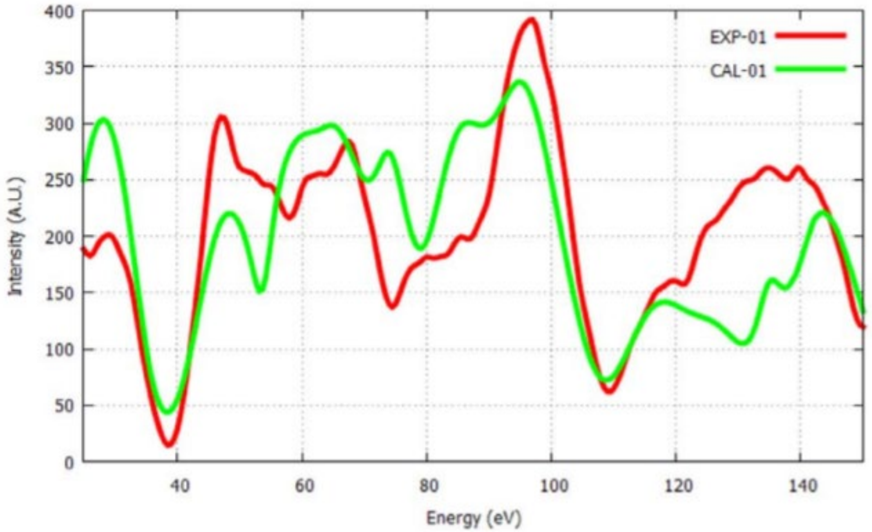


Fig. 12. Dipole current comparison, approximate corrective method with experiment.

Or here, is the approximate method “good enough” compared with the (then) accurate hybrid mesh method?

Clearly, something needed to be done… there was no way to add objectivity to discussions.

Correlation did not really work – on its own, all of the previous figures came out about the same



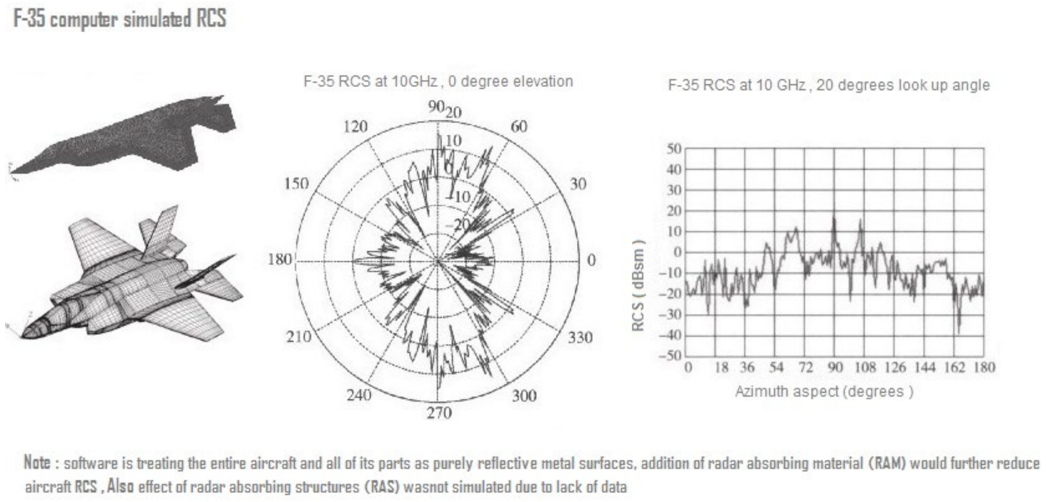
(c) (01) beam, bulk 2H-MoS_2

One class of approaches that seemed to have merit were the Reliability Factors used by surface crystallographers to validate models (Low Energy Electron Diffraction)

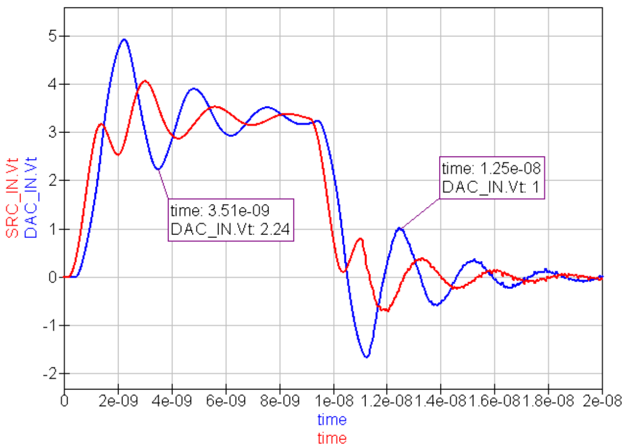
(e.g. Pendry, Van Hove, etc.)

Image taken from: Zhongwei Dai, Wencan Jin, Maxwell Grady, Jerzy T. Sadowski, Jerry I. Dadap, Richard M.Osgood Jr., Karsten Pohl
Surface structure of bulk 2H-MoS_2(0001) and exfoliated suspended monolayer MoS_2: A selected area low energy electron diffraction study
Surface Science, Volume 660, 2017, pp. 16-21

Unfortunately those techniques did not properly discriminate or give the flexibility required



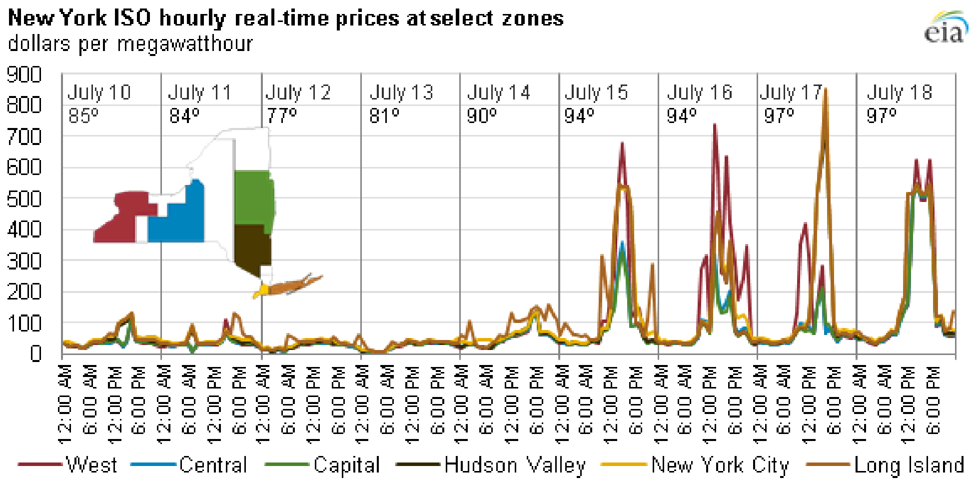
Or signal integrity



The challenge was then to design a method that could work for EMC data ...

Noting other areas have similar data structures. For example in antennas and propagation

Or even energy related…

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CHALLENGE ACCEPTED

Aim

The purpose of this talk is to introduce the FSV (Feature Selective Validation) method, to describe its origin, the process, some applications and possible other areas for investigation

Structure

- Reliability functions
- Rules of engagement
- What is the nature of the data
- FSV: the equations
- Antisocial heuristics: no need for a group anymore
- Refining and extending FSV
- Next steps

Reliability Functions – the foundations of FSV

Zanazzi and Jona (77)

- Used derivatives to emphasize peak positions rather than peak heights
- Second derivatives used to emphasize sharp features
- Derived a single goodness-of-fit for features but did not account for amplitudes

Van Hove (97)

- Defined a five factor formulae
- Looking at comparing position, width, shapes of peaks, shoulders and valleys, numbers of peaks and relative height.
- Again, derivatives used to isolate slopes

Pendry (80)

- Identified Lorenzian (single peaks) are the key.
- Emphasizes comparison of peaks using the analytical expression of peaks.

Reliability Functions – general rules

They use:

- Normalised difference schemes to compare data
- Derivatives to emphasize features
- Multiple components to account for different aspects of the curves

They are not statistics:

- Look to provide empirically- based confidence for comparisons
- E.g. Van Hove suggested that R<0.2 = good, R>0.5 is bad.

$$A = \frac{\sum_{x_{\min}}^{x_{\max}} |I_{\text{set1}}(x) - cI_{\text{set2}}(x)|}{\sum_{x_{\min}}^{x_{\max}} |I_{\text{set1}}(x)|} \quad (2)$$

$$B = \frac{\sum_{x_{\min}}^{x_{\max}} [I_{\text{set1}}(x) - cI_{\text{set2}}(x)]^2}{\sum_{x_{\min}}^{x_{\max}} [I_{\text{set1}}(x)]^2} \quad (3)$$

where c is the fraction of energy range with slopes of different signs

$$D = \frac{\sum_{x_{\min}}^{x_{\max}} |I'_{\text{set1}}(x) - cI'_{\text{set2}}(x)|}{\sum_{x_{\min}}^{x_{\max}} |I'_{\text{set1}}(x)|} \quad (4)$$

$$E = \frac{\sum_{x_{\min}}^{x_{\max}} [I'_{\text{set1}}(x) - cI'_{\text{set2}}(x)]^2}{\sum_{x_{\min}}^{x_{\max}} [I'_{\text{set1}}(x)]^2} \quad (5)$$

and c being the ratio of the average intensities of the datasets. The primes indicate the first derivative with respect to x.

Rules of engagement

In order to develop a new function, we need to decide some rules-of-engagement

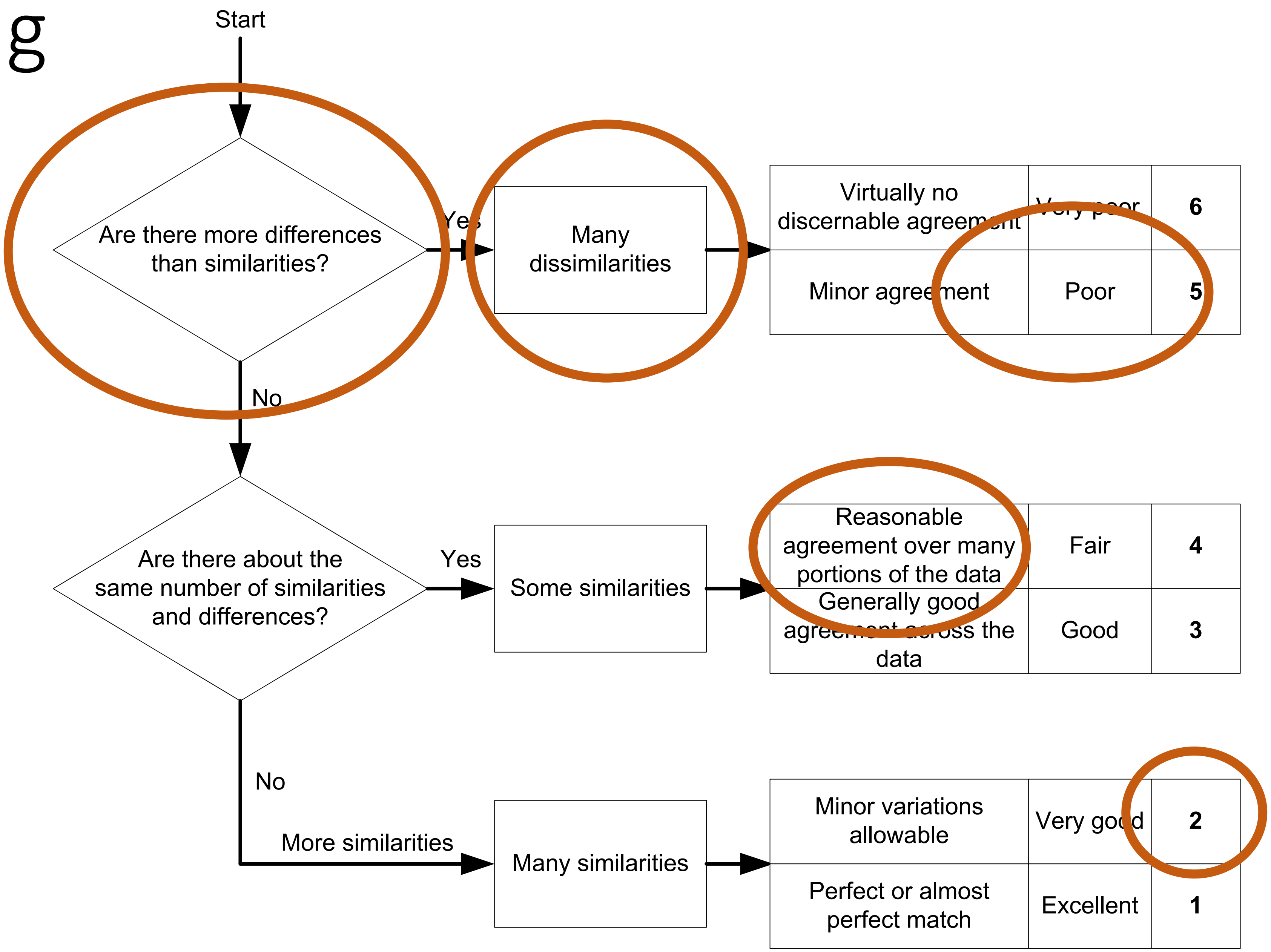
1. Given that all comparisons are done by-eye (to date), that needs to be used as a framework.

How to minimize inherent variability

2. We need guidelines for development

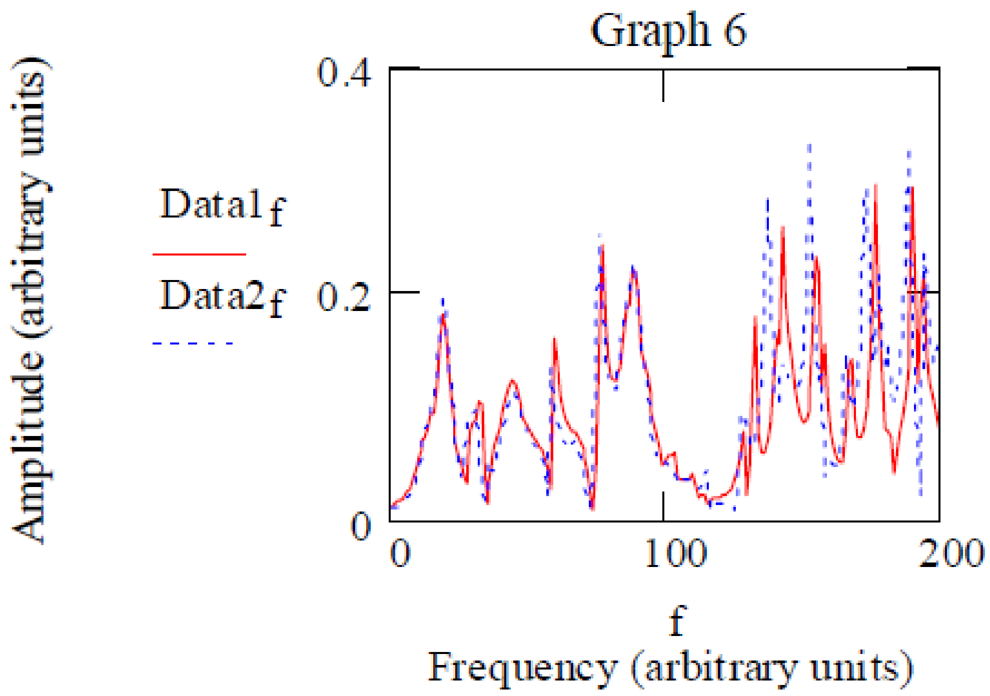
Visual rating scale

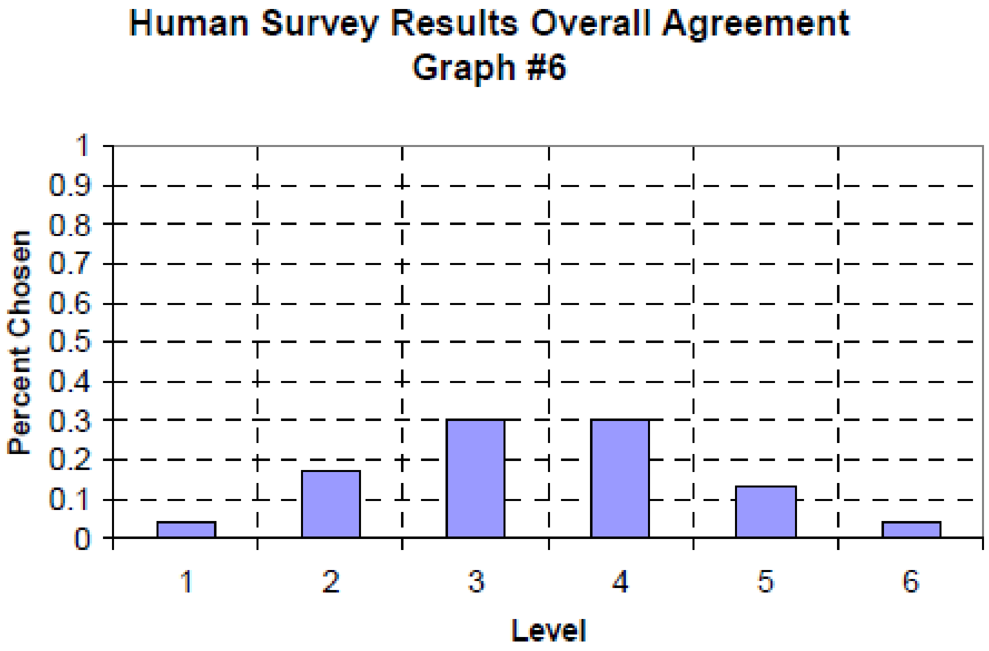
- “yardstick” for visual comparison
- Based on Cooper-Harper scale.



Visual rating scale

Get histograms from groups.

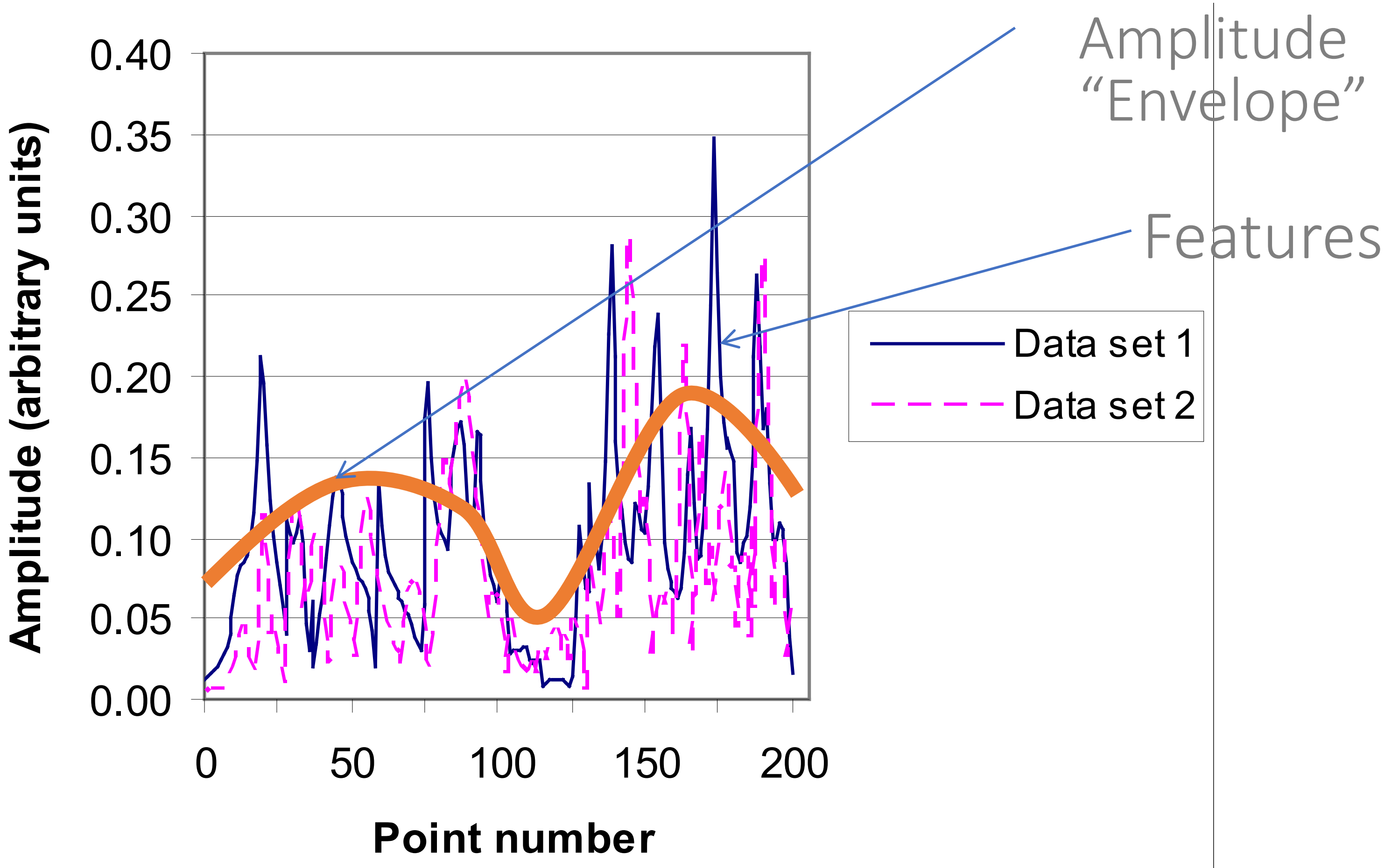




Design Principles

1. Implementation of the validation technique should be simple
2. The technique should be computationally straightforward
3. The technique should mirror human perceptions and be largely intuitive
4. The method should not be limited to data from a single application area
5. The technique should provide tiered diagnostic information
6. The comparison should be commutative.

What are the things to look at here?



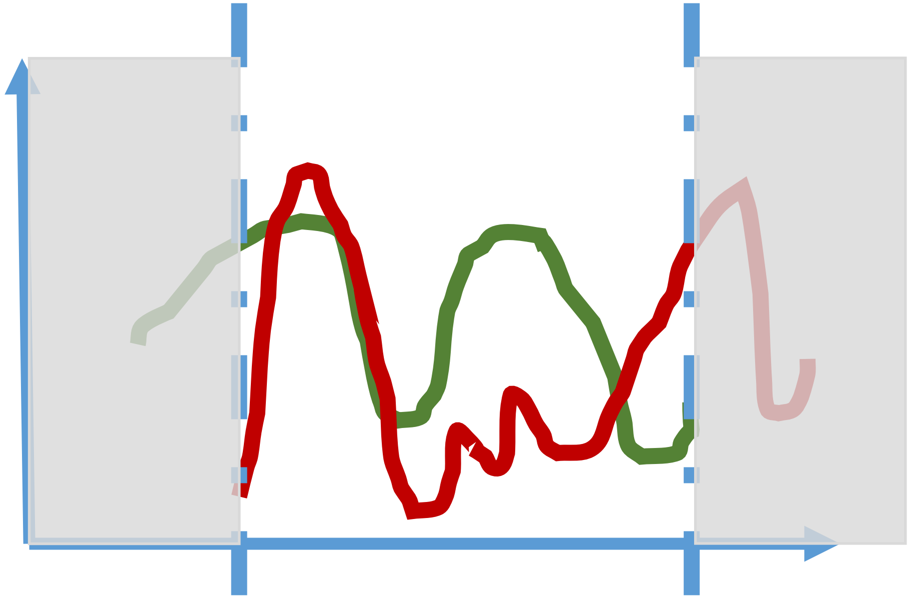
This suggests we need an overall measure comprising of measures based on the envelope and the features:

- **GDM**
- **ADM**
- **FDM**

General process

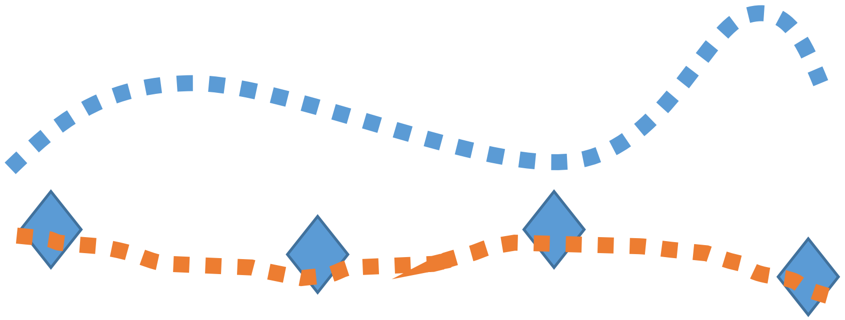
Make the data coincident:

Select only the overlapping portion of the data.

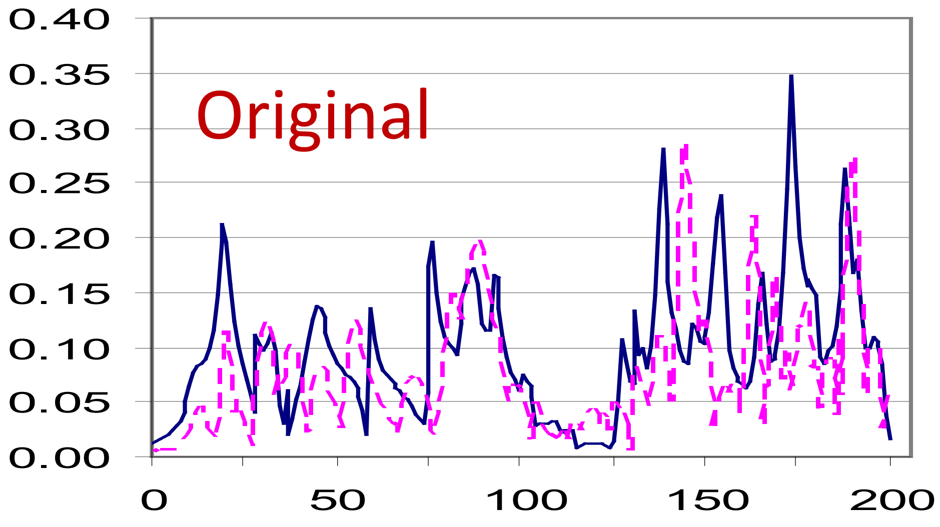


Ensure the data points align. Interpolate as necessary.

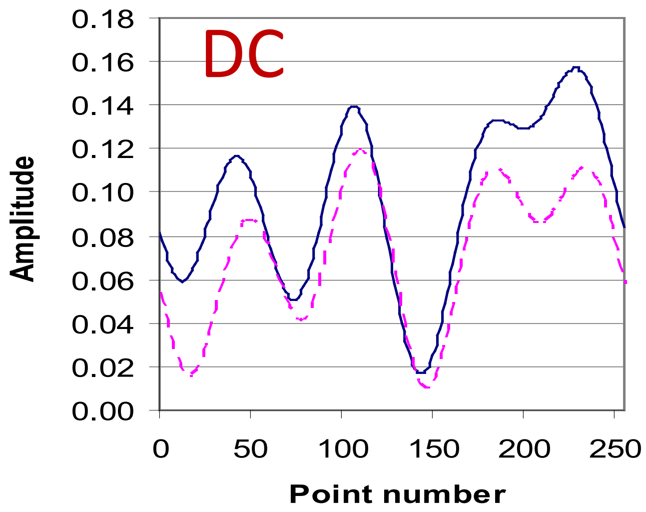
Over-sample one data set if necessary

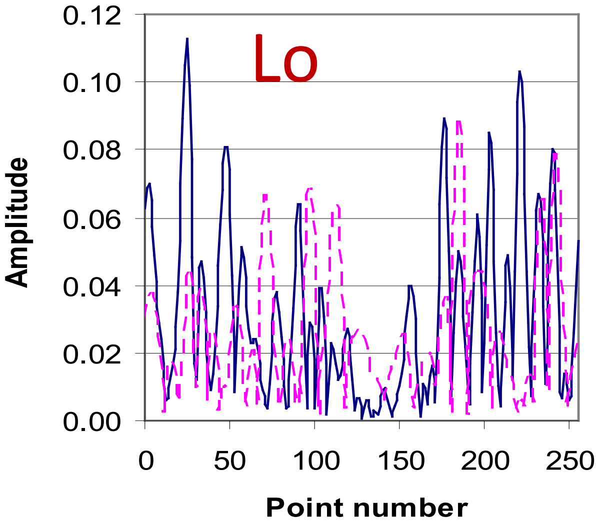


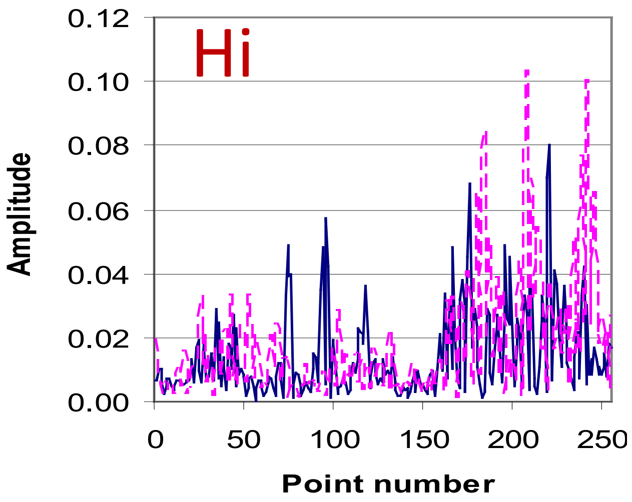
Filter



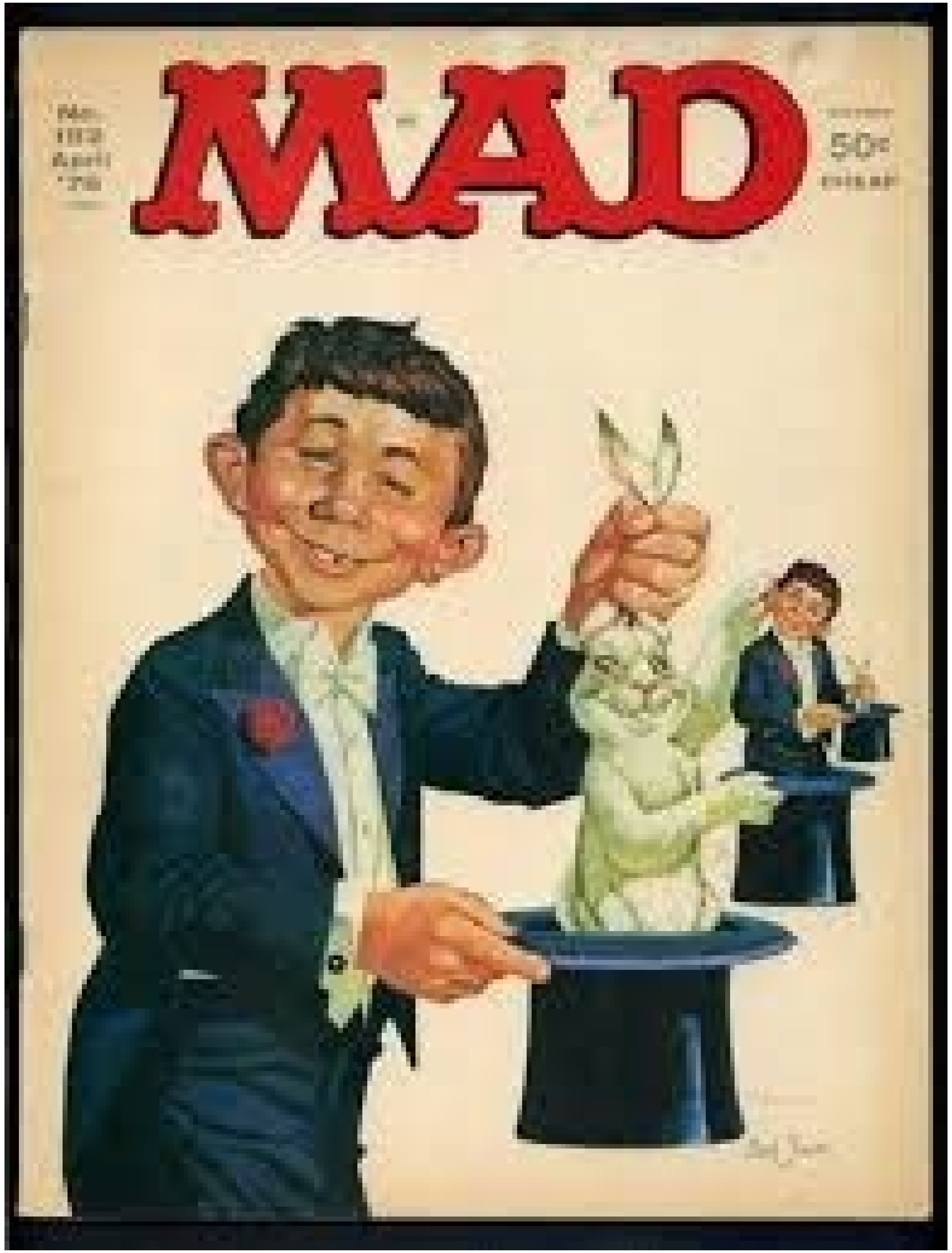
- The original data is filtered into three regions
  - DC
  - Lo
  - Hi







And now…



… for the magic

ADM

$$ADM(n) = \left|\frac{\alpha}{\beta}\right| + \left|\frac{\chi}{\delta}\right| \exp\left\{\left|\frac{\chi}{\delta}\right|\right\}$$

$$\alpha = \left(\left|\mathrm{Lo}_1(n)\right| - \left|\mathrm{Lo}_2(n)\right|\right)$$

$$\chi = \left(\left|\mathrm{DC}_1(n)\right| - \left|\mathrm{DC}_2(n)\right|\right)$$

$$\beta = \frac{1}{N}\sum_{i=1}^{N}\left[\left(\left|\mathrm{Lo}_1(i)\right| + \left|\mathrm{Lo}_2(i)\right|\right)\right]$$

$$\delta = \frac{1}{N}\sum_{i=1}^{N}\left[\left(\left|\mathrm{DC}_1(i)\right| + \left|\mathrm{DC}_2(i)\right|\right)\right]$$

FDM

- The Feature Difference Measure is constructed from:

$$FDM(f) = 2\left(\left|FDM_1(f) + FDM_2(f) + FDM_3(f)\right|\right)$$

FSV

- Where

$$FDM_1(f) = \frac{\left|\mathrm{Lo}_1{}'(f)\right| - \left|\mathrm{Lo}_2{}'(f)\right|}{\frac{2}{N}\sum_{i=1}^{N}\left[\left(\left|\mathrm{Lo}_1{}'(i)\right| + \left|\mathrm{Lo}_2{}'(i)\right|\right)\right]}$$

$$FDM_2(f) = \frac{\left|\mathrm{Hi}_1{}'(f)\right| - \left|\mathrm{Hi}_2{}'(f)\right|}{\frac{6}{N}\sum_{i=1}^{N}\left[\left(\left|\mathrm{Hi}_1{}'(i)\right| + \left|\mathrm{Hi}_2{}'(i)\right|\right)\right]}$$

$$FDM_3(f) = \frac{\left|\mathrm{Hi}_1{}''(f)\right| - \left|\mathrm{Hi}_2{}''(f)\right|}{\frac{7.2}{N}\sum_{i=1}^{N}\left[\left(\left|\mathrm{Hi}_1{}''(i)\right| + \left|\mathrm{Hi}_2{}''(i)\right|\right)\right]}$$

FSV

- The Global Difference Measure (GDM) is given by:

$$GDM(f) = \sqrt{ADM(f)^2 + FDM(f)^2}$$

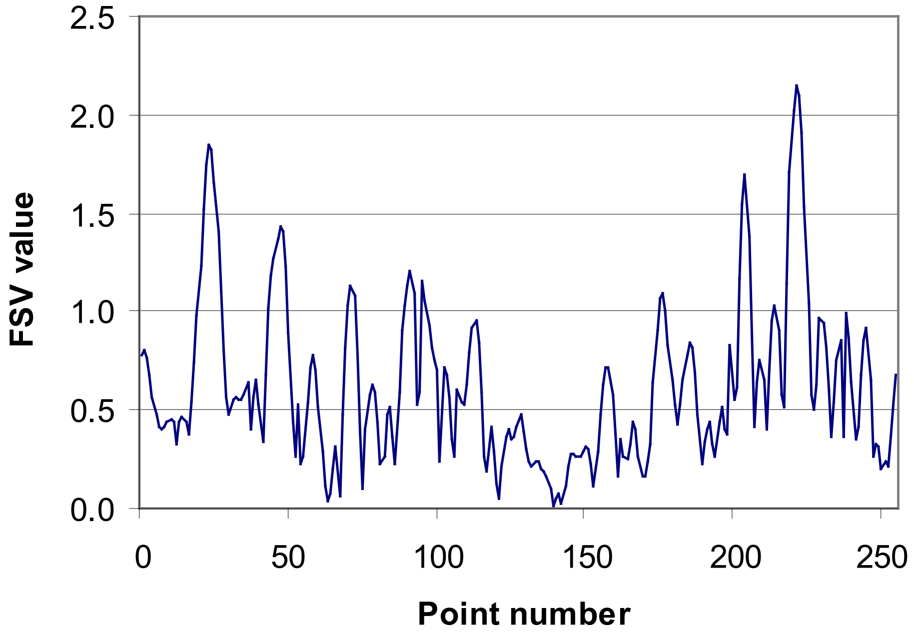
- Single figure 'goodness-of-fit' values are obtained by taking a mean value of the ADM, FDM and GDM.

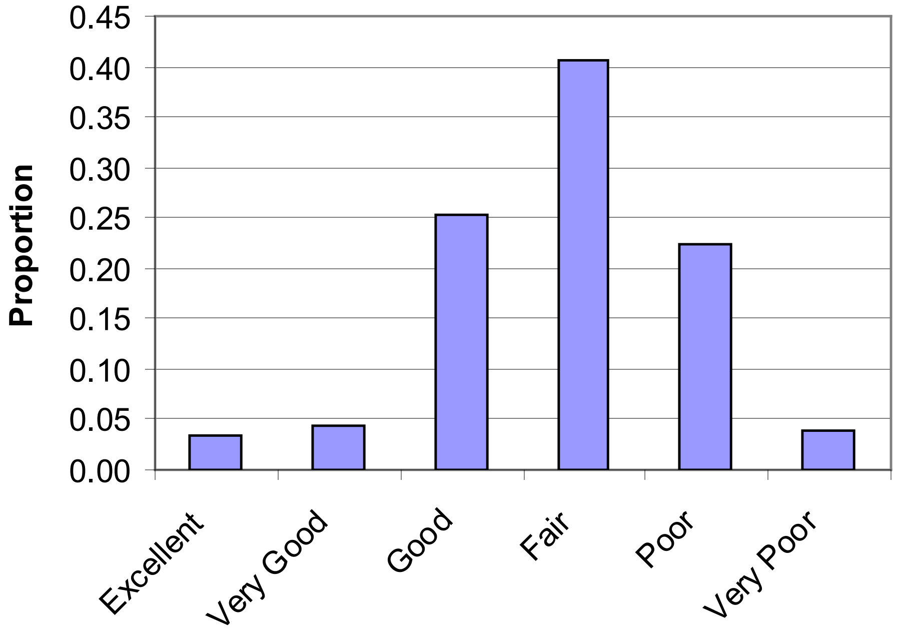
FSV

- Values can be related to natural language descriptors:

FSV value (quantitative)	FSV interpretation (qualitative)
Less than 0.1	Excellent
Between 0.1 and 0.2	Very good
Between 0.2 and 0.4	Good
Between 0.4 and 0.8	Fair
Between 0.8 and 1.6	Poor
Greater than 1.6	Very poor

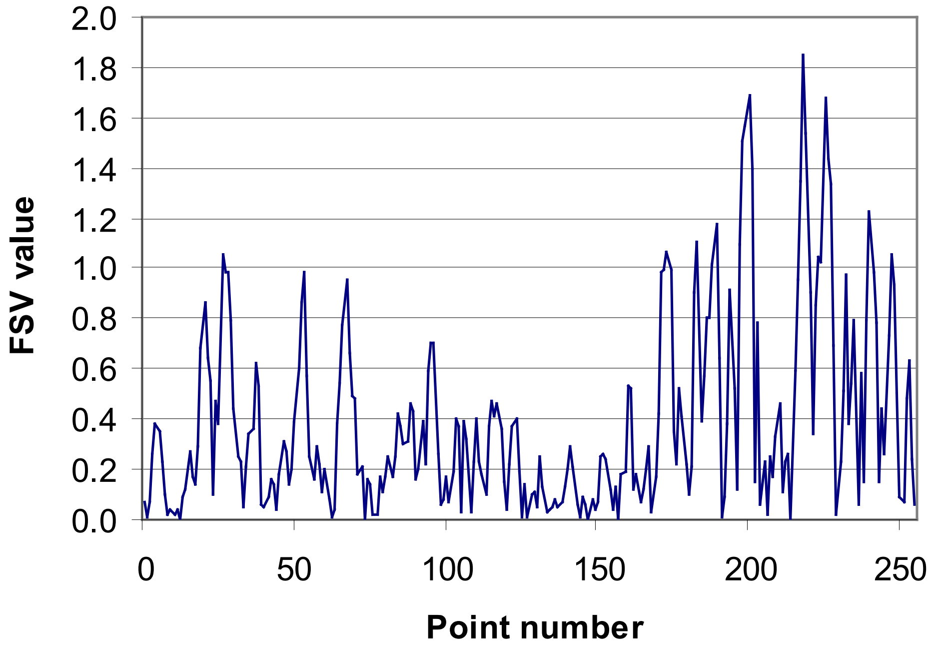
ADM

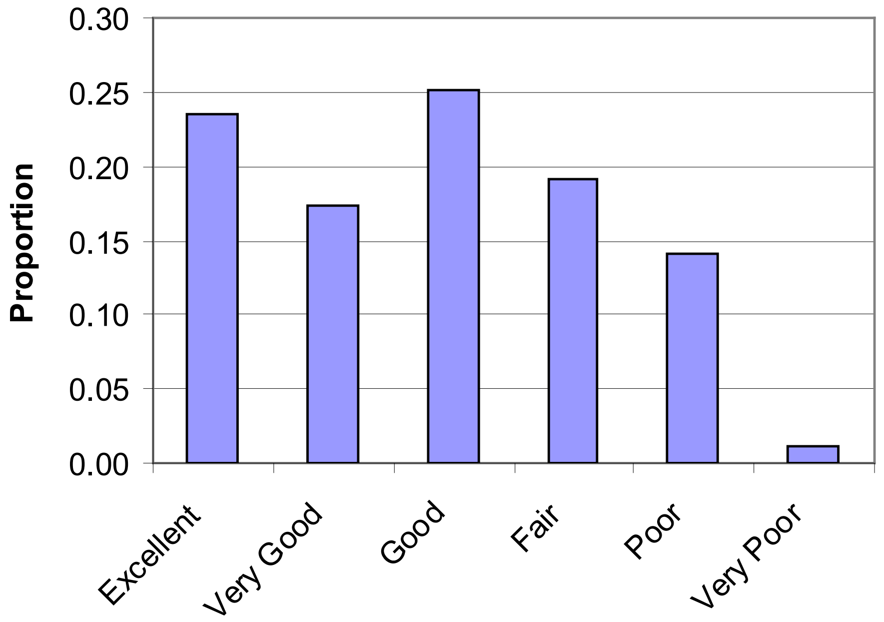




- Mean value = 0.62

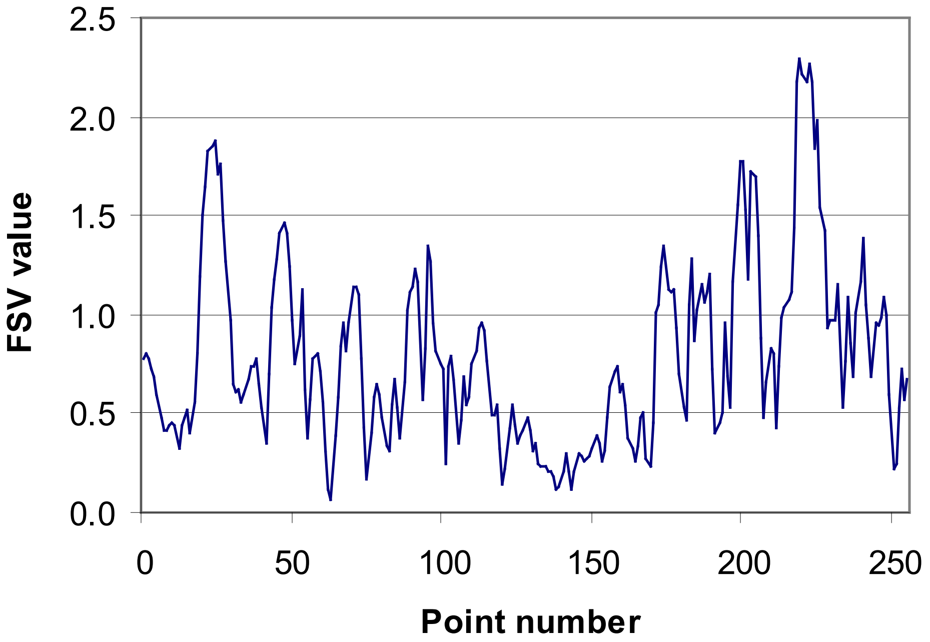
FDM

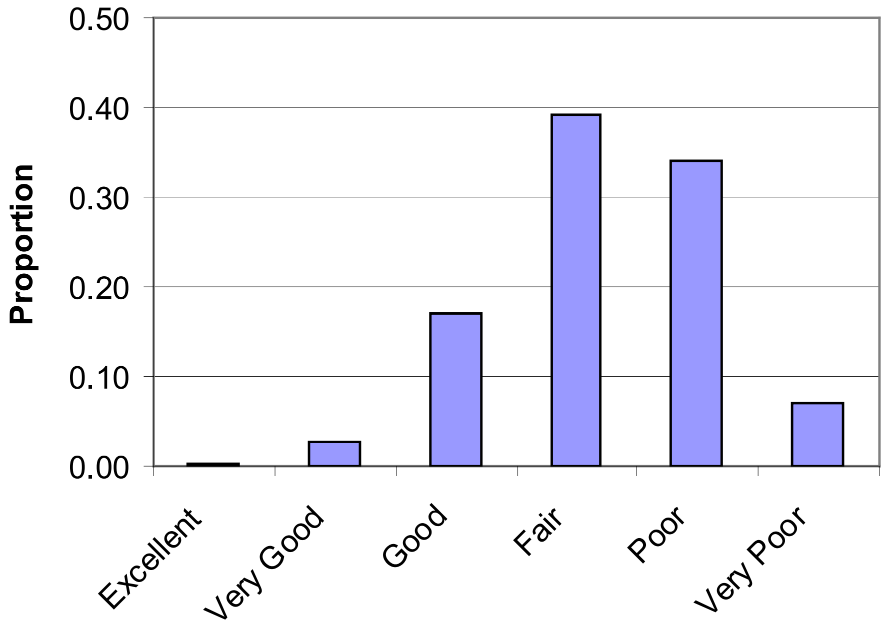




- Mean value = 0.39

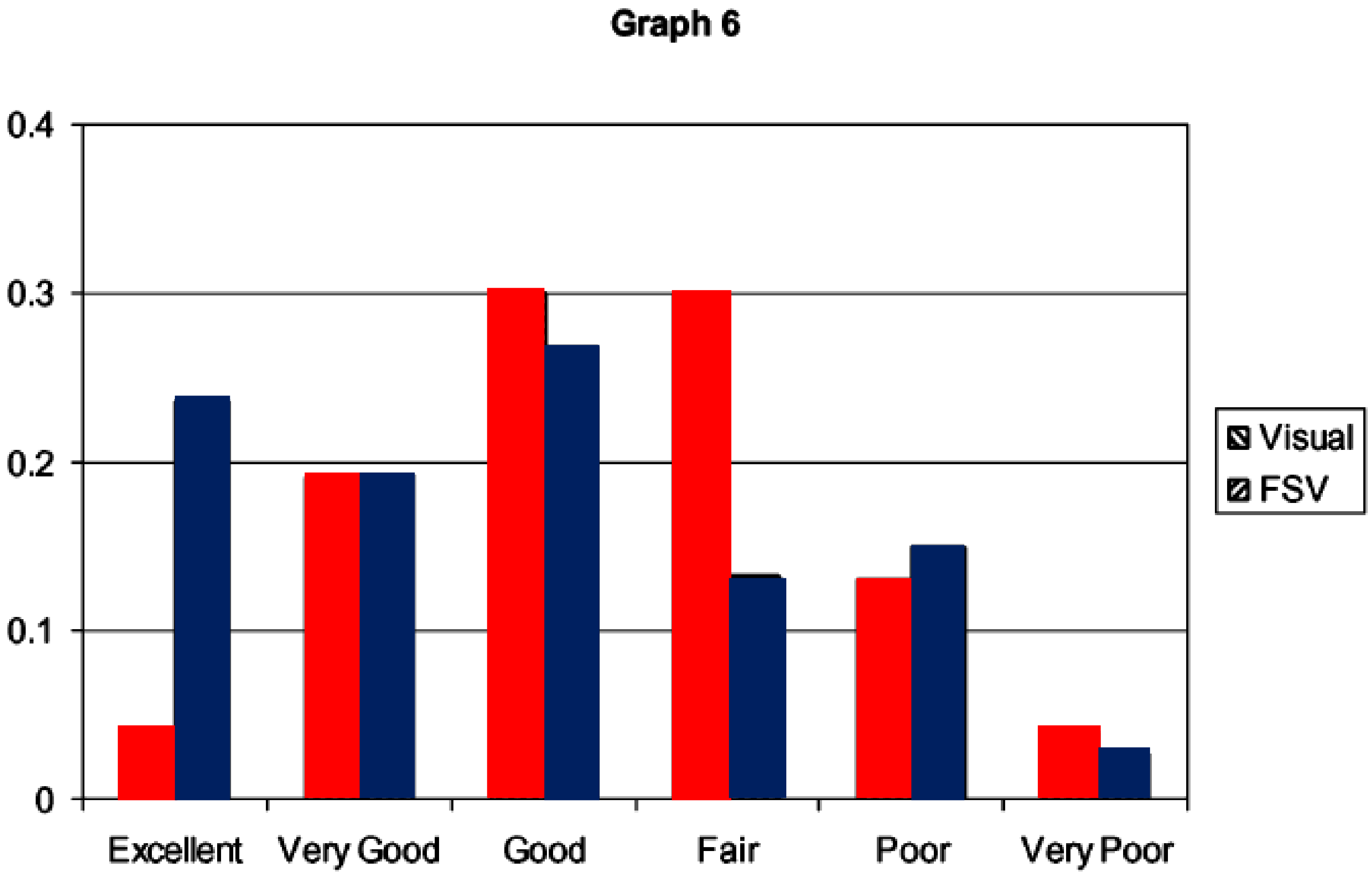
GDM





- Mean value = 0.8

Comparison - typical agreement from similar comparison (2004 survey)



FSV Developments

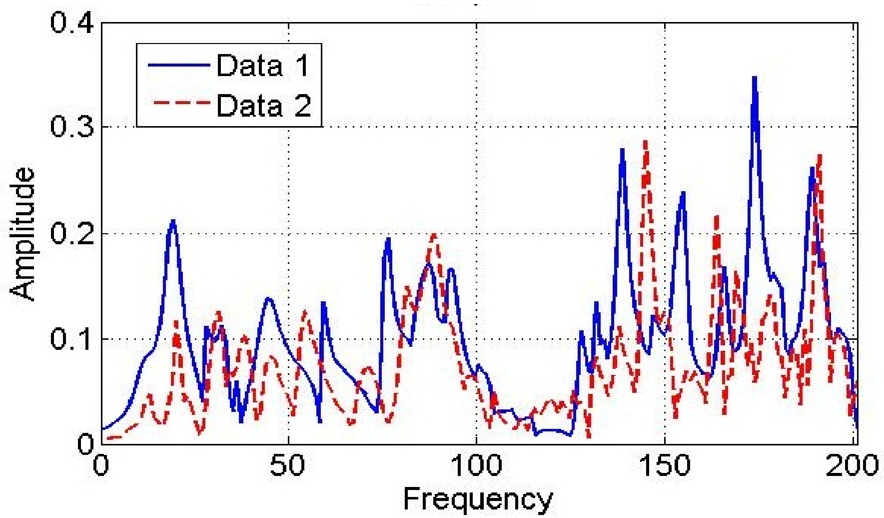
- Before moving into multiple degrees of freedom, it is interesting to look at some developments in 1D that will migrate to nD

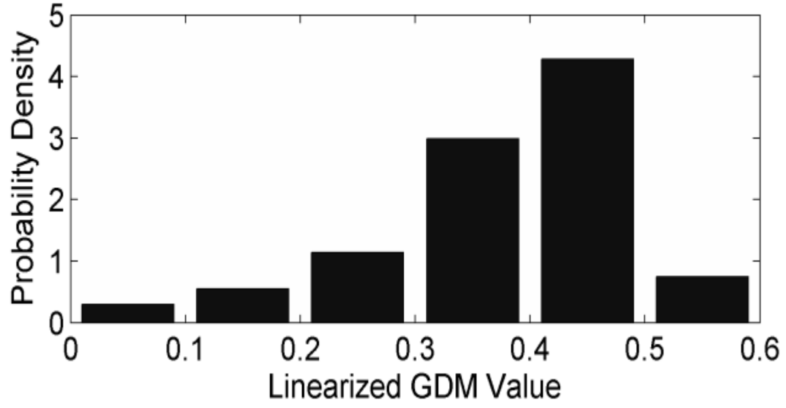
- First, histograms and density functions

- The original approach used six ‘bins’.
- “Excellent” etc. can be confusing
  - E.g. it may have a different meaning for EMC or microwave engineers.
  - So, what benefit might there be to using a continuous distribution function rather than a histogram?
    - More refined comparison
    - The use of non-parametric statistics (e.g. Kologorov- Smirnov test)

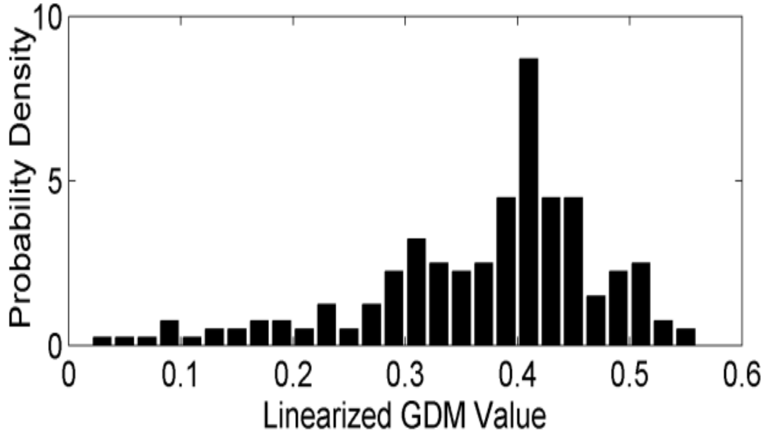
Estimate of The Probability Density Functions

- Histogram difficulty



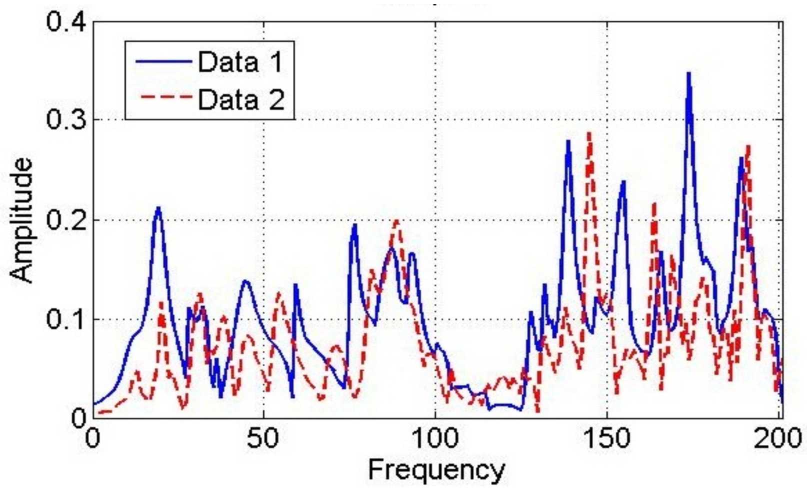


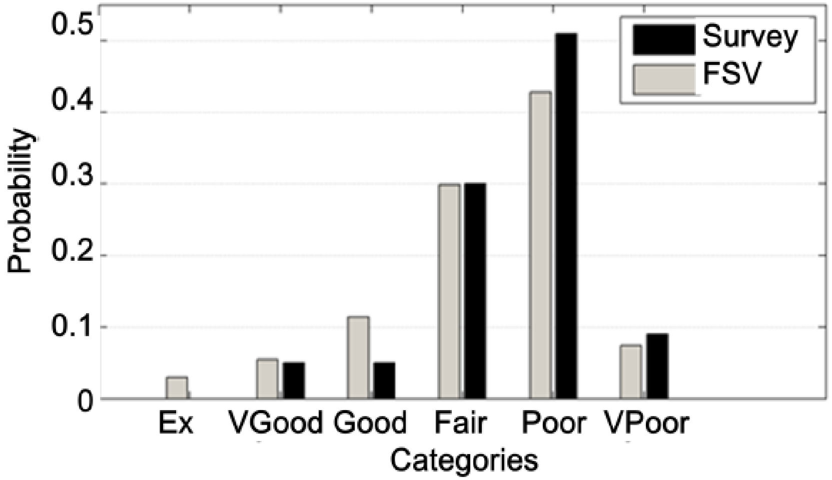
6 bins

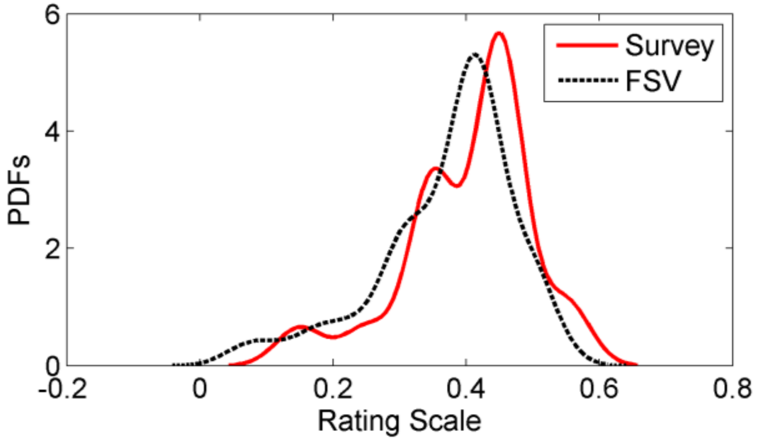


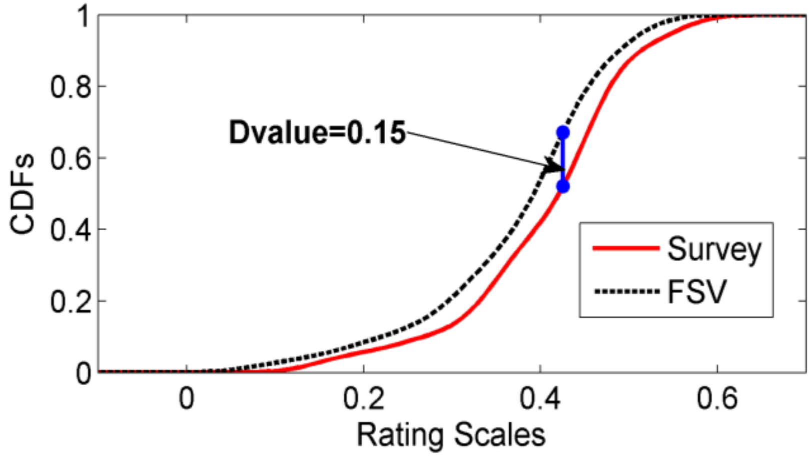
30 bins

PDF example – FSV verification









PDF example – FSV verification

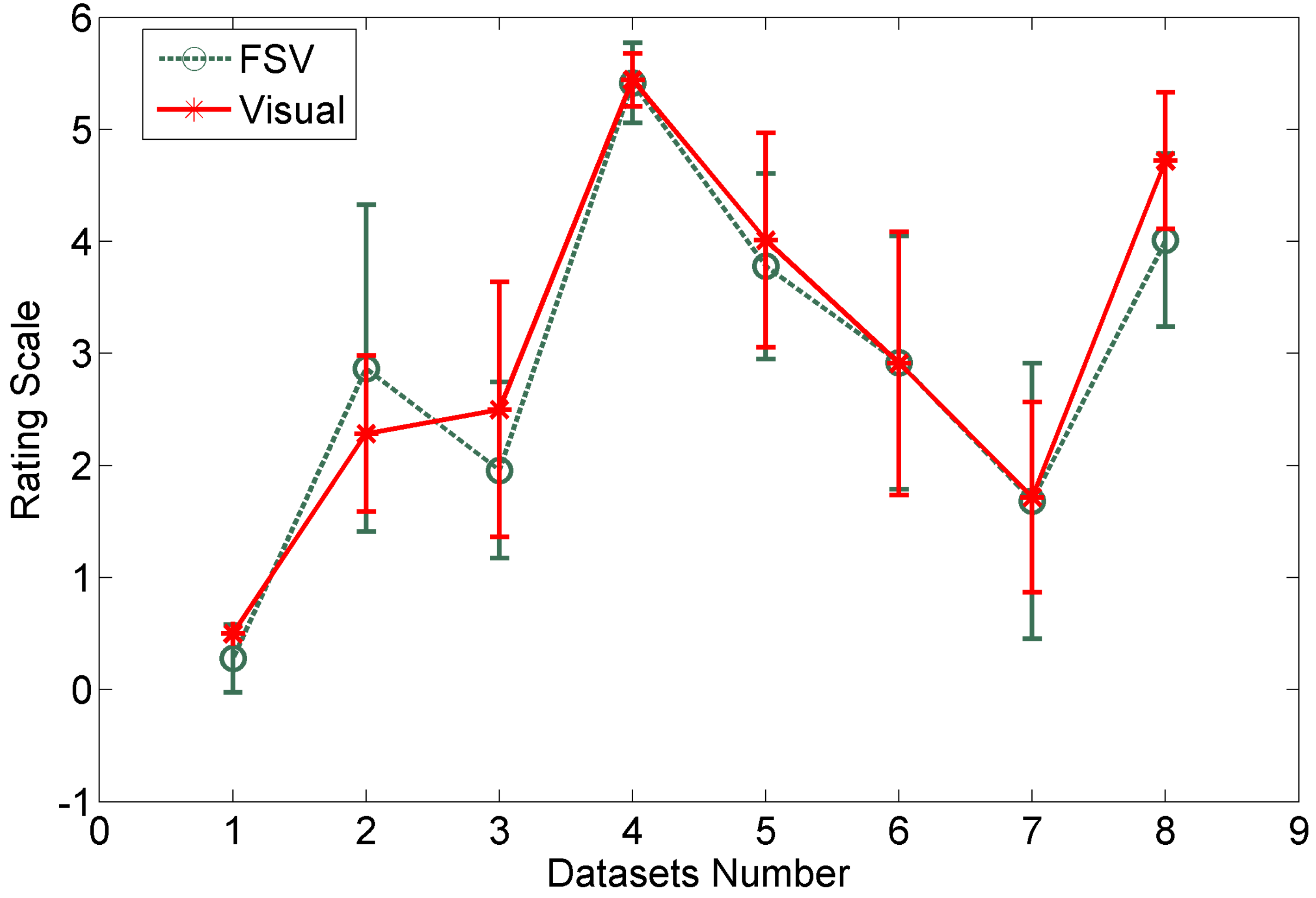
- The critical value of statistic D for different significance level can be decided by

$$D_{Critical} = k \cdot \sqrt{(N_1 + N_2)/(N_1 \cdot N_2)}$$

- where N_1 and N_2 are the length of datasets under comparison. For 95% confidence, *k* is 1.36, for 90% confidence, *k* is 1.22.

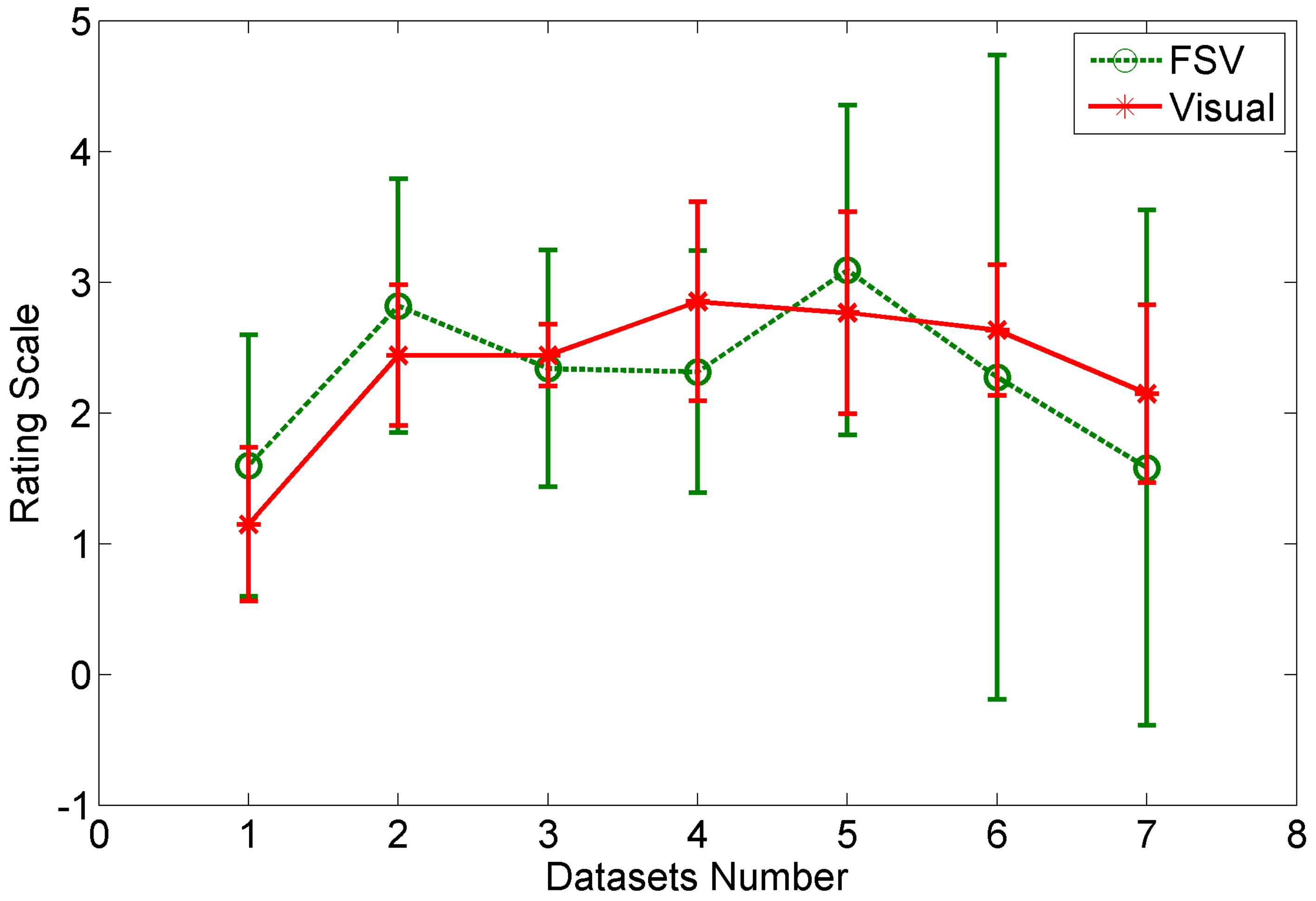
- Here the $D_{Critical}$ for 90% confidence is 0.17 with $N_1 = N_2 = 100$
- In this case, the null hypothesis is accepted.

Applying this to various survey results – adding in 1sd error bars from the distributions



2004 Survey

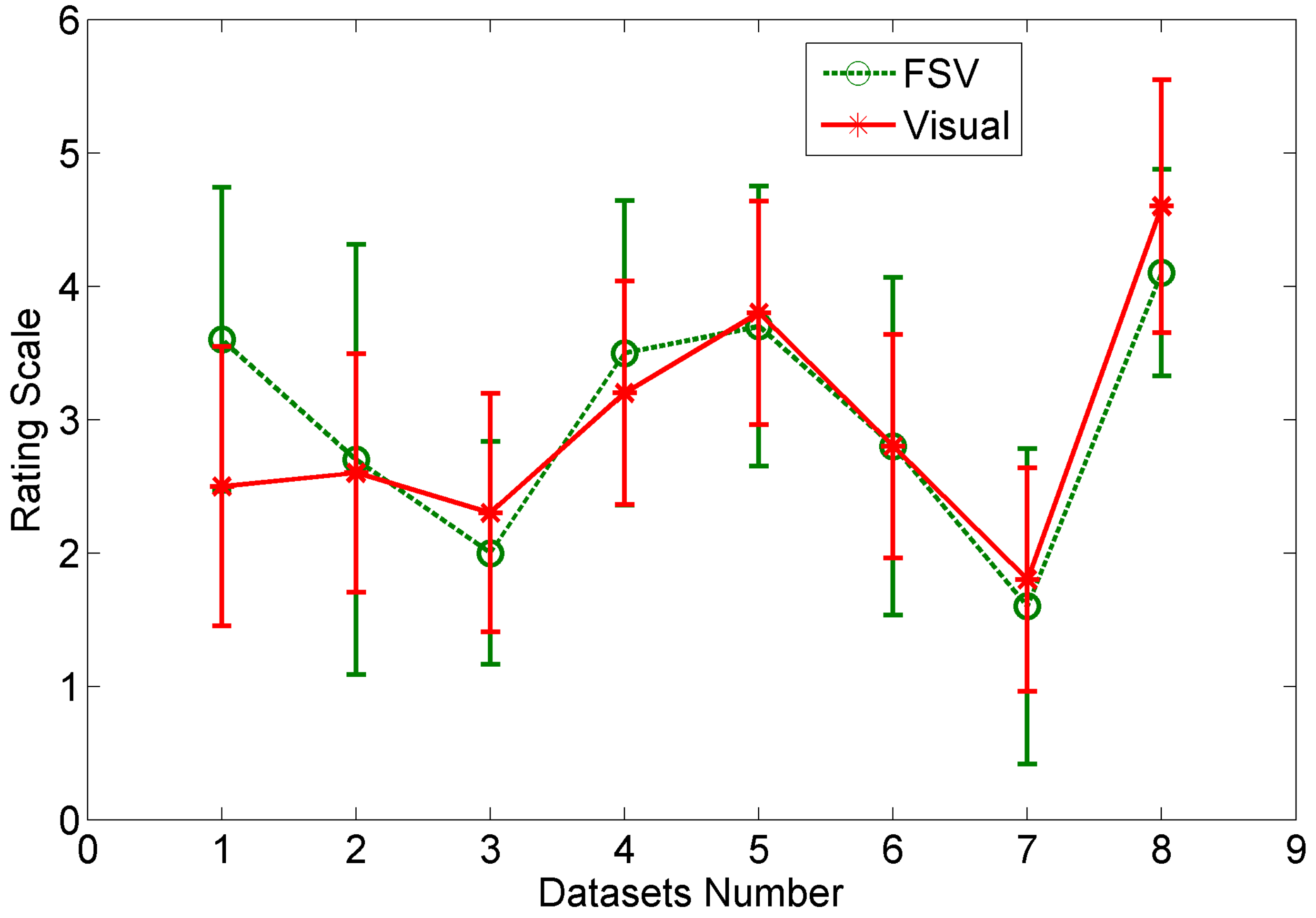
Applying this to various survey results – adding in 1sd error bars from the distributions



2011 Survey

Transients using dynamic boundary allocation – coming up.

Applying this to various survey results – adding in 1sd error bars from the distributions



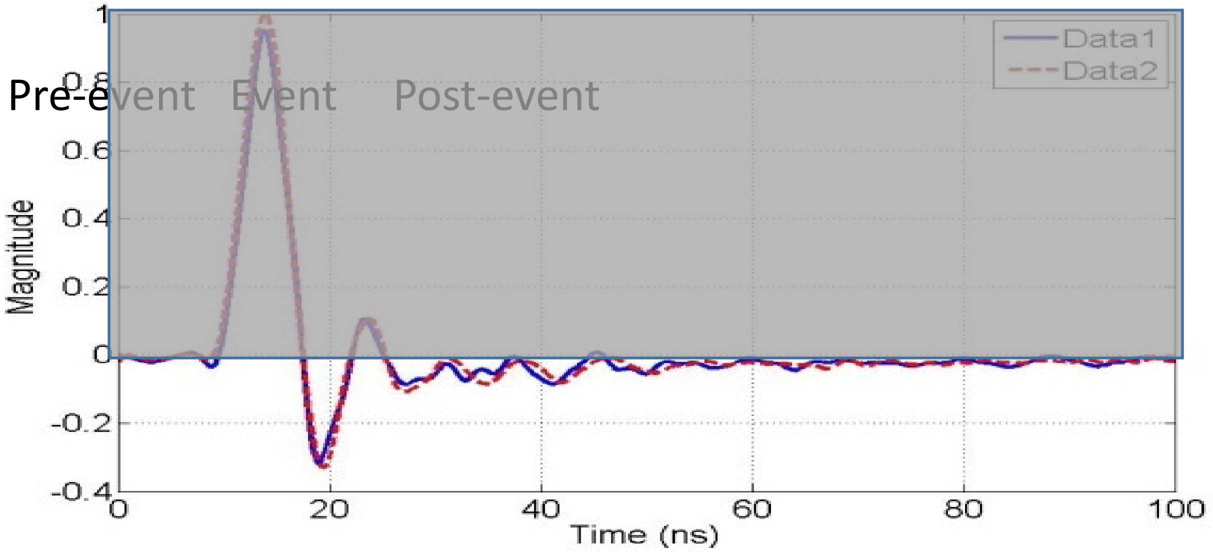
2013 Survey

A HIGH FIVE DOESN'T EVEN CUT IT.

HIGH SIX!

FSV Developments – Transients

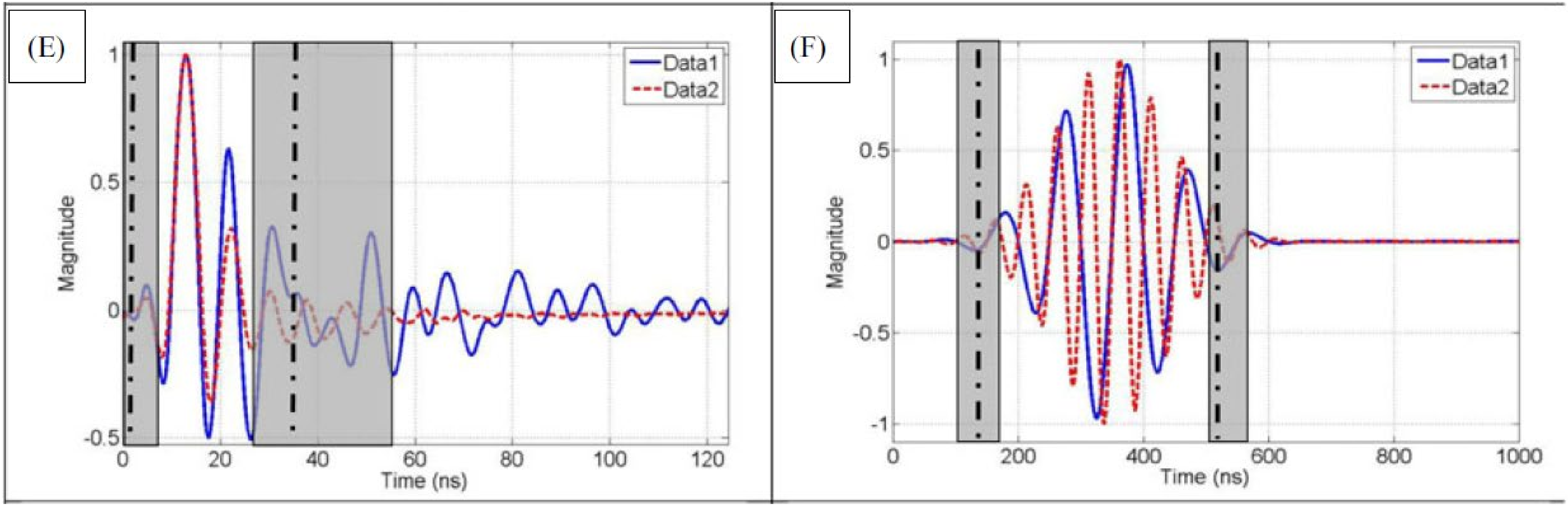
- Transient-type phenomena can be difficult.
  - Particularly with variability in periods.
  - Negative going portion



Transients

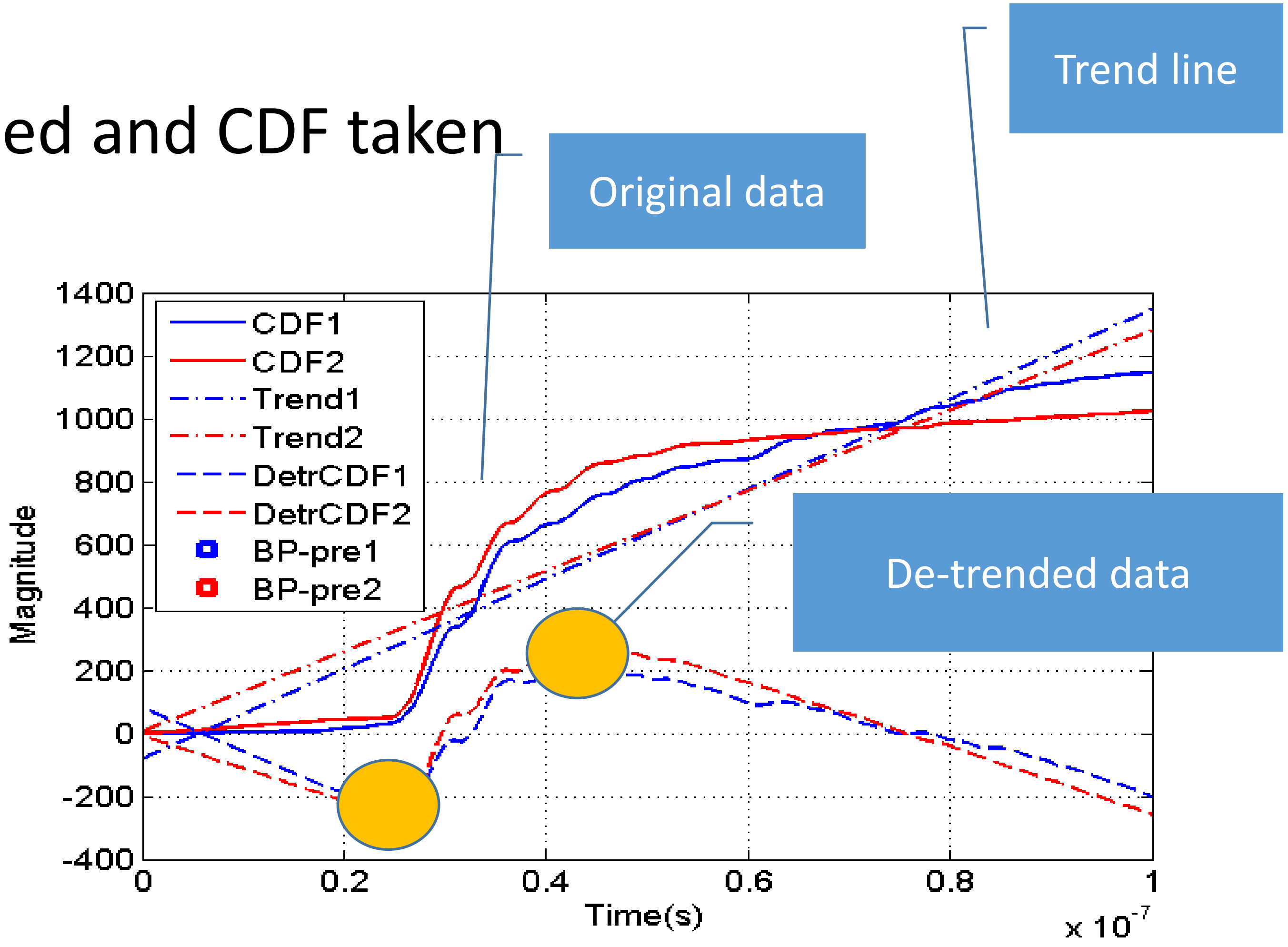
- Negative going data
  - Translate to the positive half plane
    - Does not appear to affect results
  - Needs further investigation
- Weight individual regions separately
  - Pre-event = 5%
  - Event = 70%
  - Post-event = 25%
  - Again, for further study
- Dynamically allocate region boundaries

Where do people put boundaries between regions?



Transients – region allocation

- Magnitude used and CDF taken



Region boundaries occur at the turning points of the de-trended curve

Structure

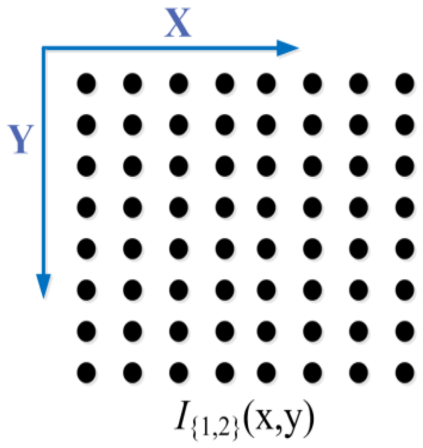
- FSV in 1D
- **Extending to 2D**
- Extending to nD

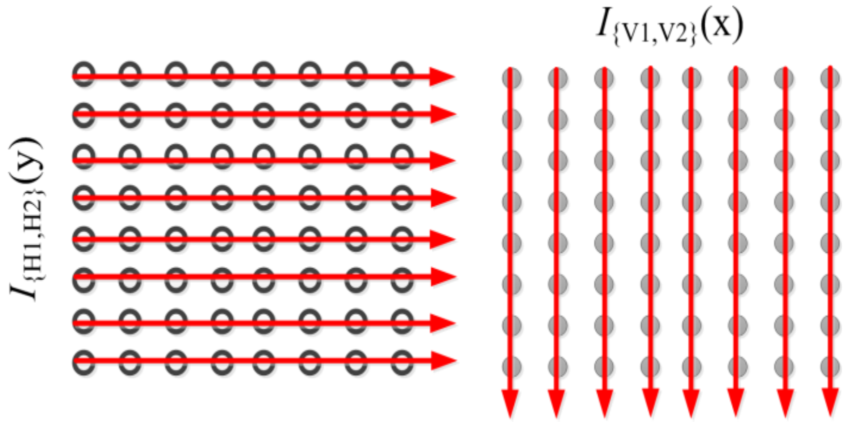
Moving beyond 1D

- 1D development was strongly based on visual assessment for verification of FSV
- Going beyond 1D means that some data will be difficult or even impossible to visually verify.
  - Fly-by-wire!
- Initial 2D development was based on replacing 1D Fourier Transforms and Derivatives with 2D equivalents.
  - While this worked well, it was not suited to:
    - Computationally efficient higher dimensionality
    - Large aspect ratios in the data
- So, Take a simpler approach!

Moving to 2D data

- To keep to the original design rules, convert 2D (or nD) to 1D data, compare and recombine.





Apply 1D to each line and column.

At each point, take the mean value to keep FSV in the normal range

2D in more detail

$$ADMi(x,y) = \sqrt{K_V\,ADMi_V(x,y)^2 + K_H\,ADMi_H(x,y)^2}$$

$$K_V = 1 - K_H$$

- If horizontal and vertical data is equally weighted (the default option)

$$ADMi(x,y) = \frac{\sqrt{ADMi_V(x,y)^2 + ADMi_H(x,y)^2}}{\sqrt{2}}$$

- Similar for FDM

Effect on GDM

$$GDMi(x,y) = \sqrt{ADMi(x,y)^2 + FDMi(x,y)^2}$$

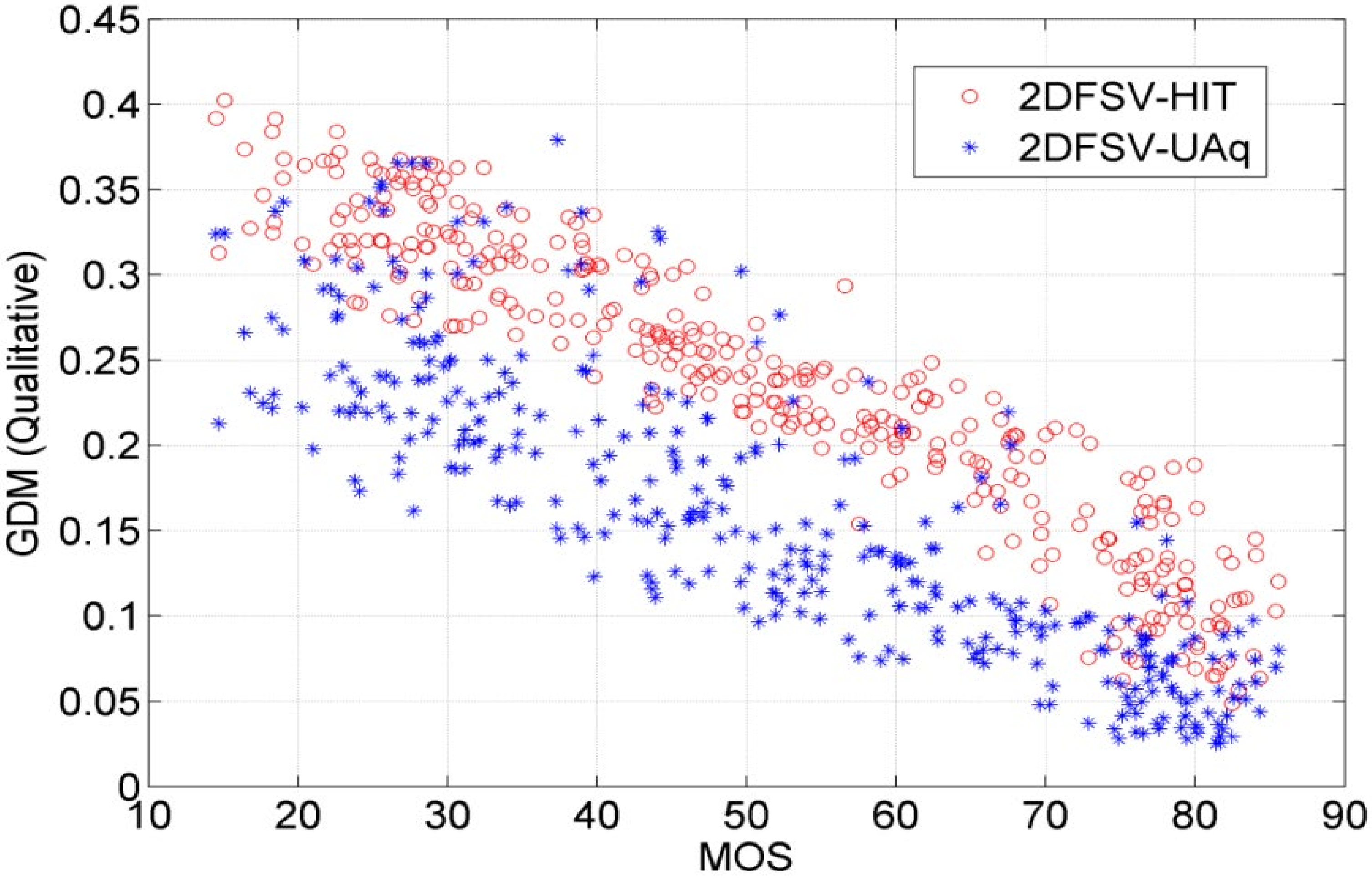
$$= \sqrt{\frac{ADMi_V(x,y)^2 + FDMi_V(x,y)^2 + ADMi_H(x,y)^2 + FDMi_H(x,y)^2}{2}}$$

$$= \frac{\sqrt{GDMi_V(x,y)^2 + GDMi_H(x,y)^2}}{\sqrt{2}}$$

Verification of 2D

- For consistency use visual assessment
- The LIVE database contains hundreds of pictures visually assessed to provide a Mean Opinion Score (MOS)
  - Viewers asked to provide their opinion of quality
- Useful to compare the two approaches
  - 2D transforms (UAq)
  - Repeated 1D (HIT)

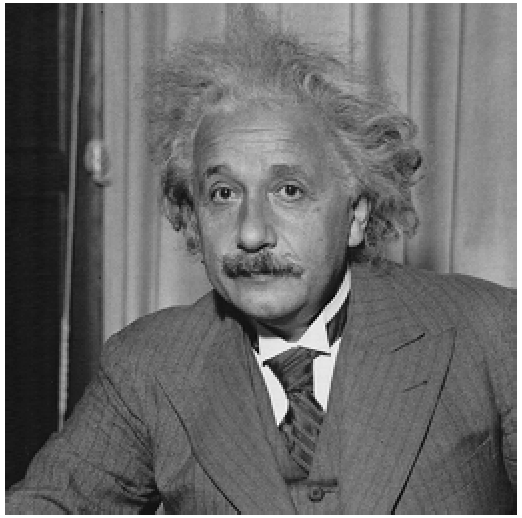
FSV vs MOS



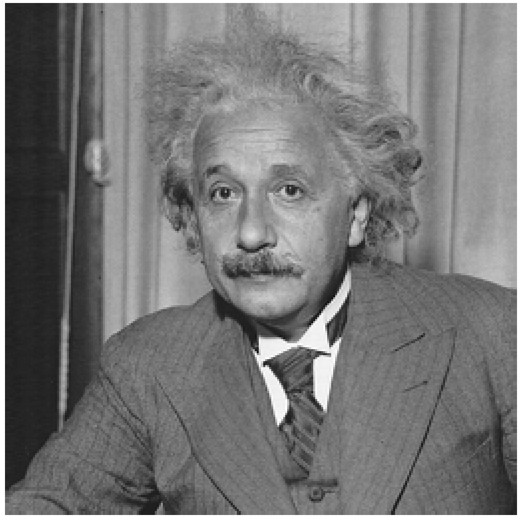
2DFSV-HIT
2DFSV-UAq
GDM (Qualitative)
MOS
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10
20
30
40
50
60
70
80
90

Images Overview

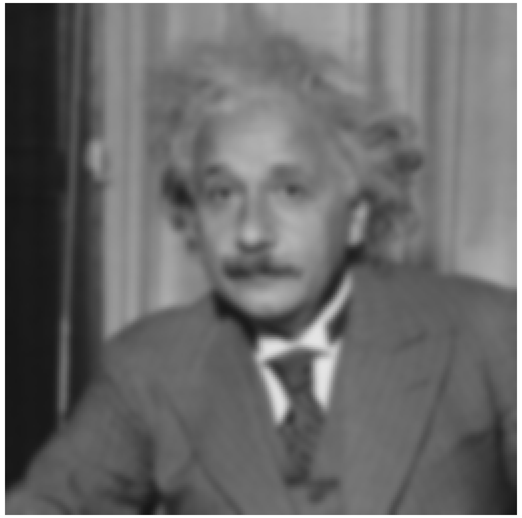
Original 256x256 pixel



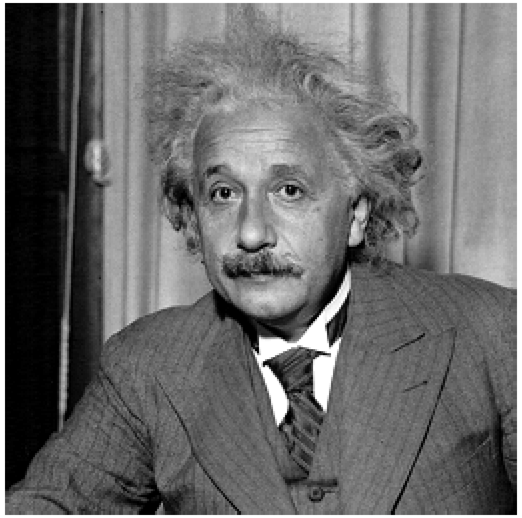
Meanshift 256x256 pixel



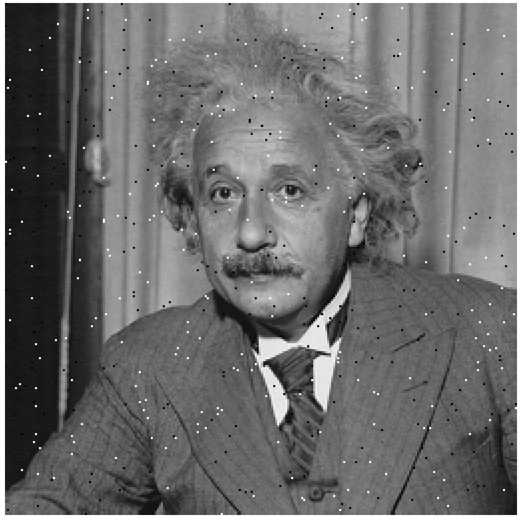
Blur 256x256 pixel



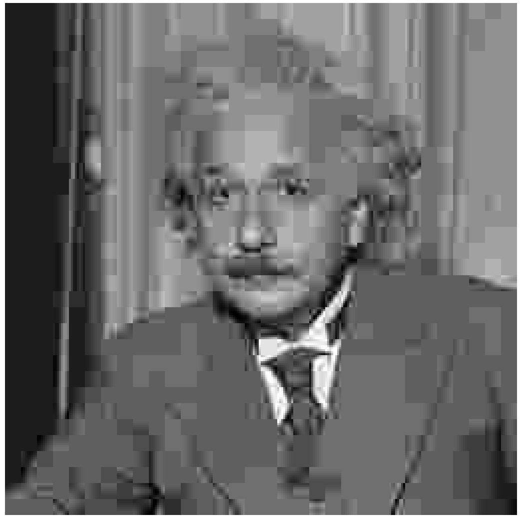
Contrast 256x256 pixel



Impulse 256x256 pixel

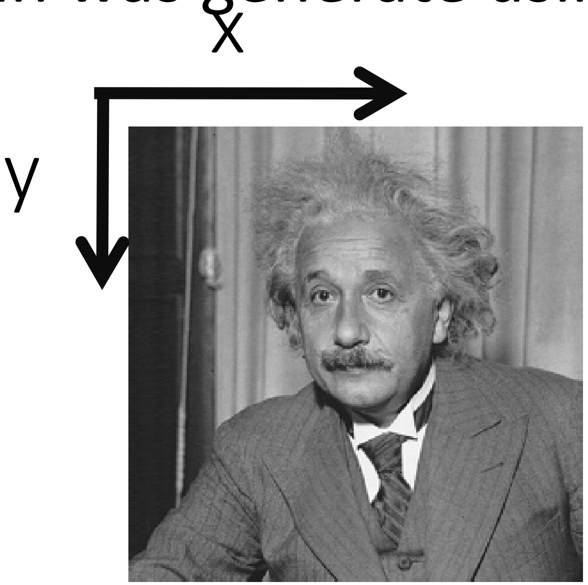


Jpeg 256x256 pixel

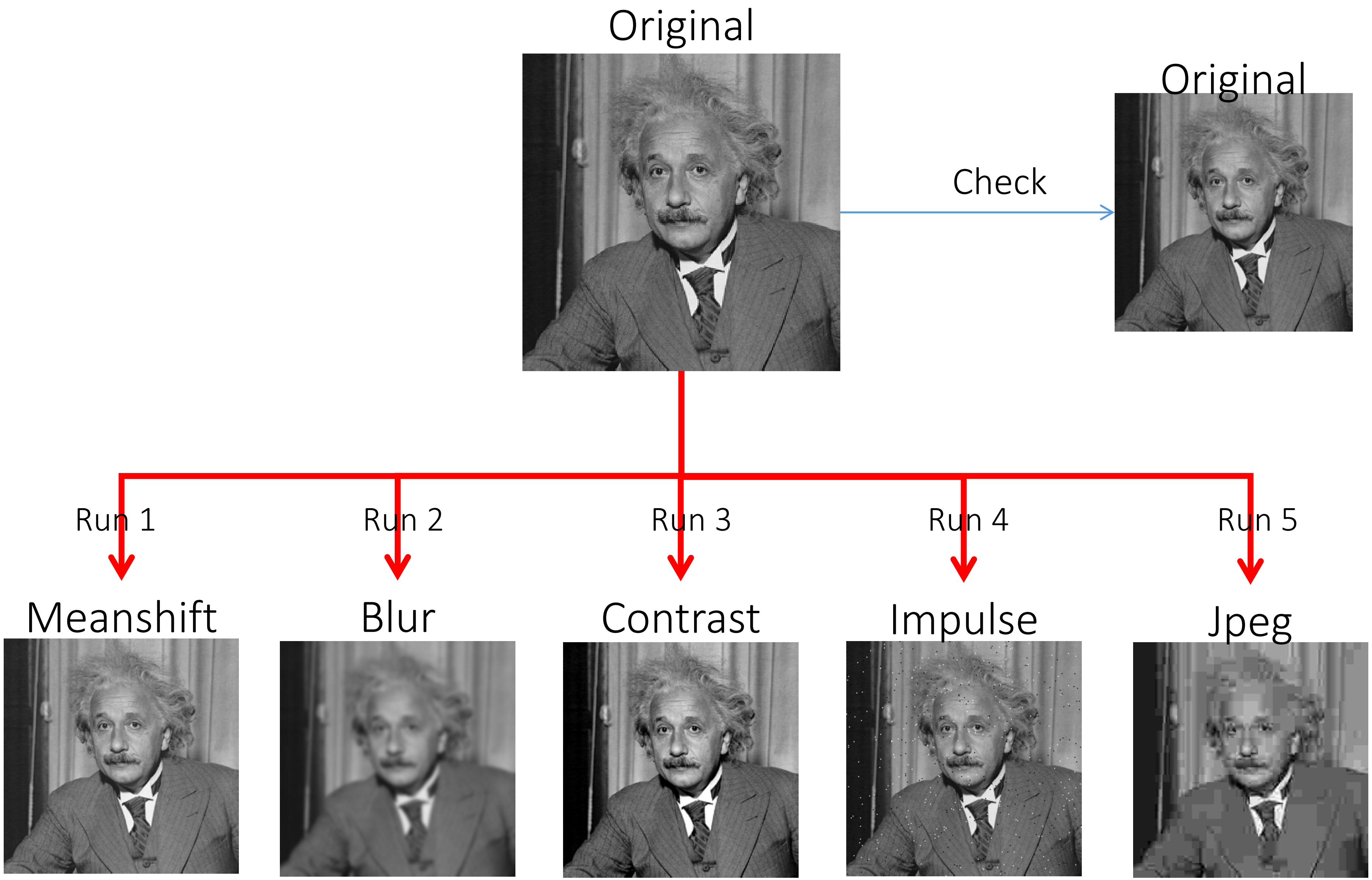


From .gif data to Numerical Data

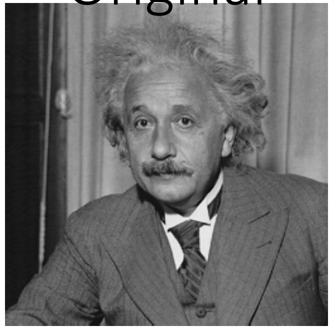
- To convert GIF image into numerical data was used the MatLab imread() function.
- Imread function convert .gif image into:
  - NxM numerical matrix in case of B/W image
  - Nx3 matrix in case of RGB image (colour)
- The domain was generate using this assumption:



FSV 2D Analisys

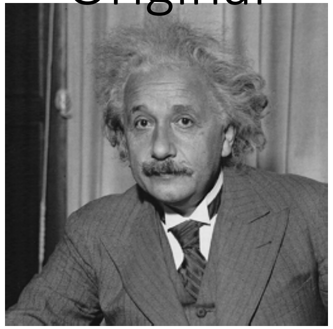


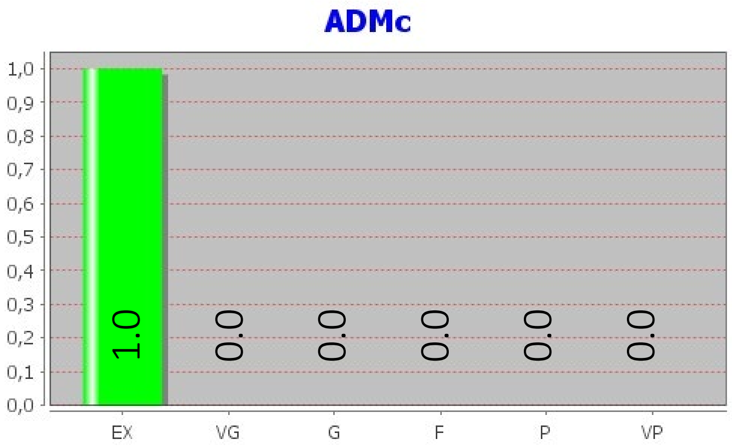
Original

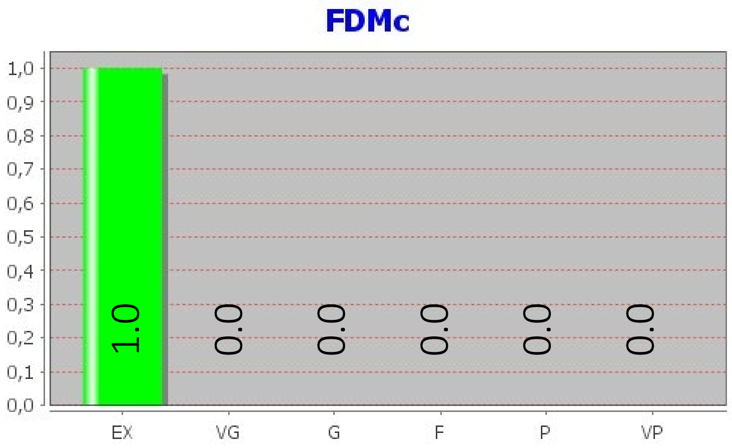


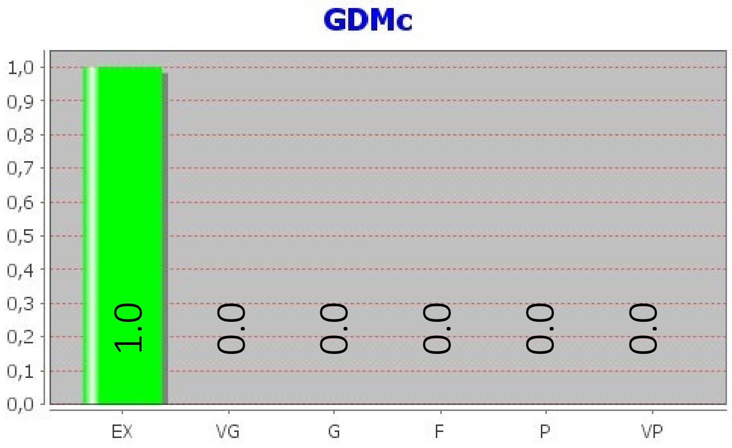
Vs.

Original

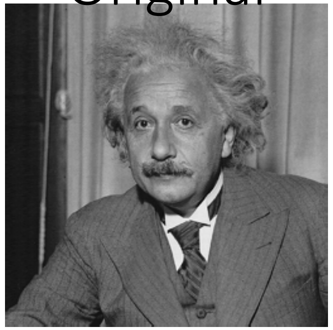






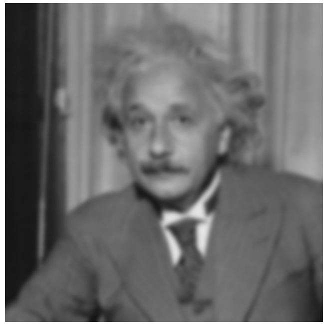


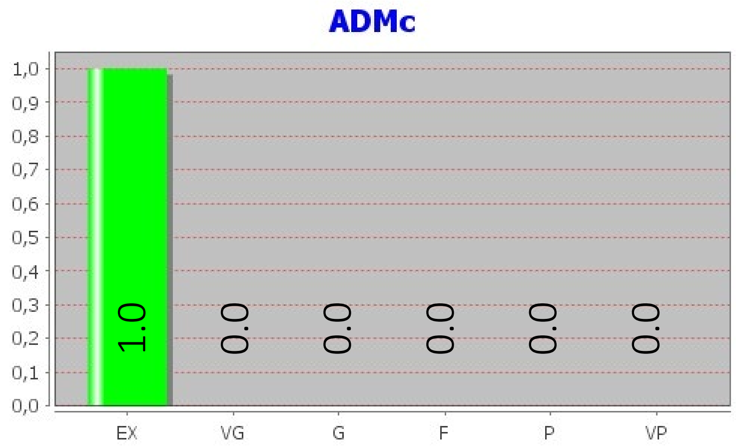
Original

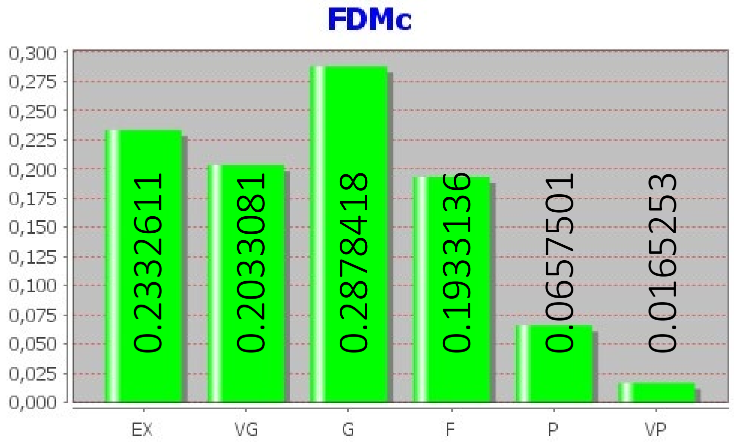


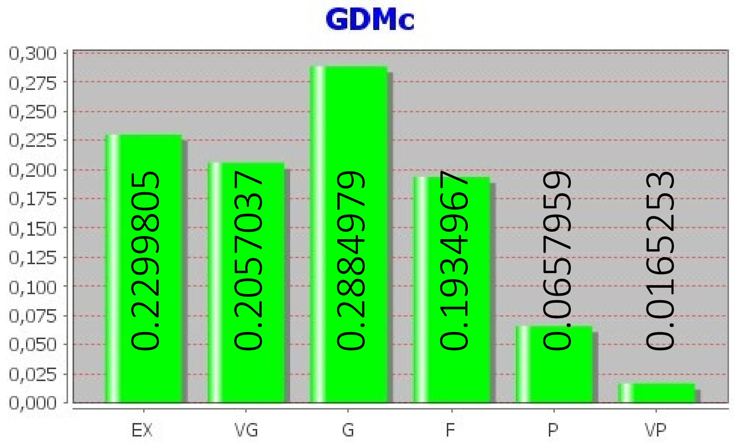
Vs.

Blur

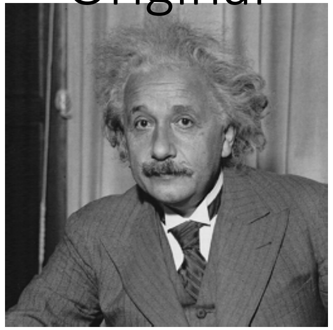






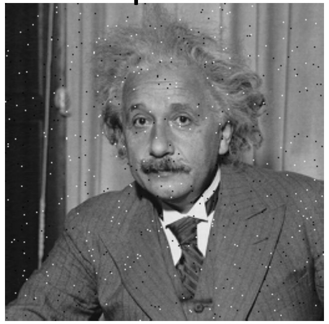


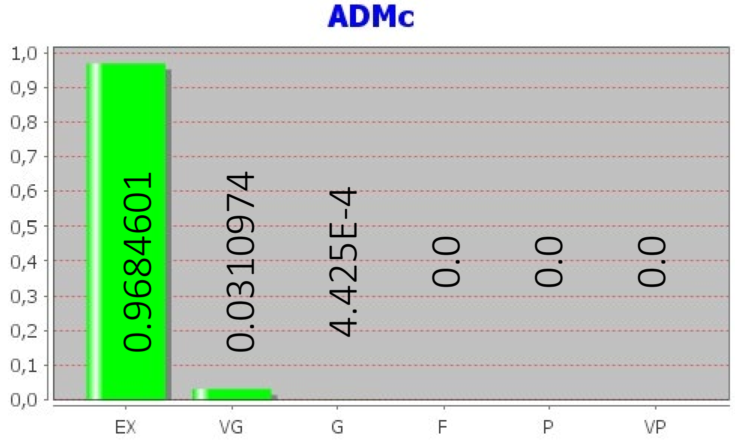
Original

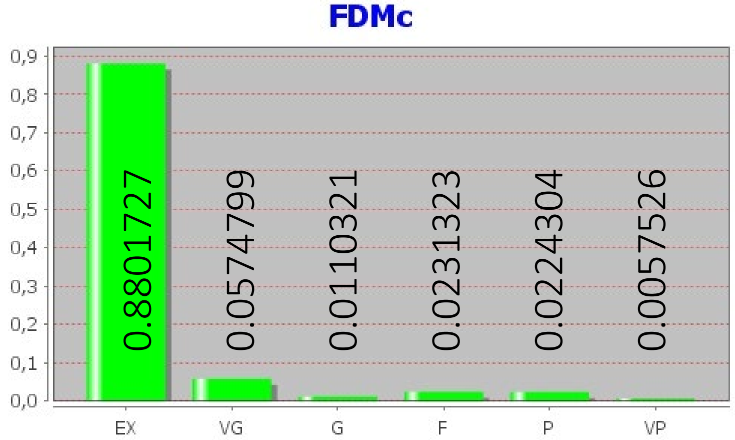


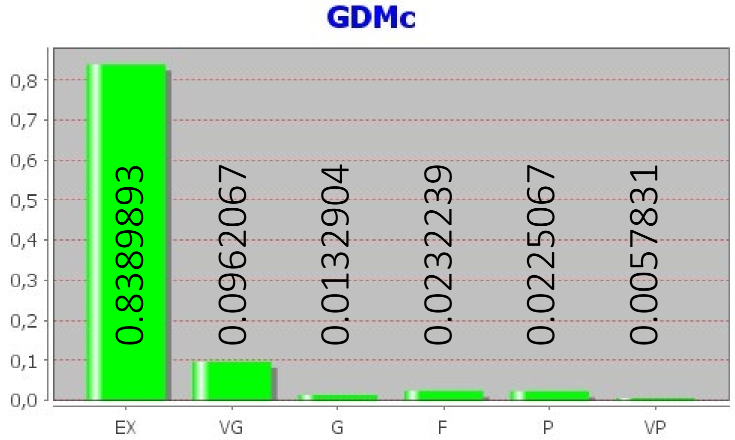
Vs.

Impulse



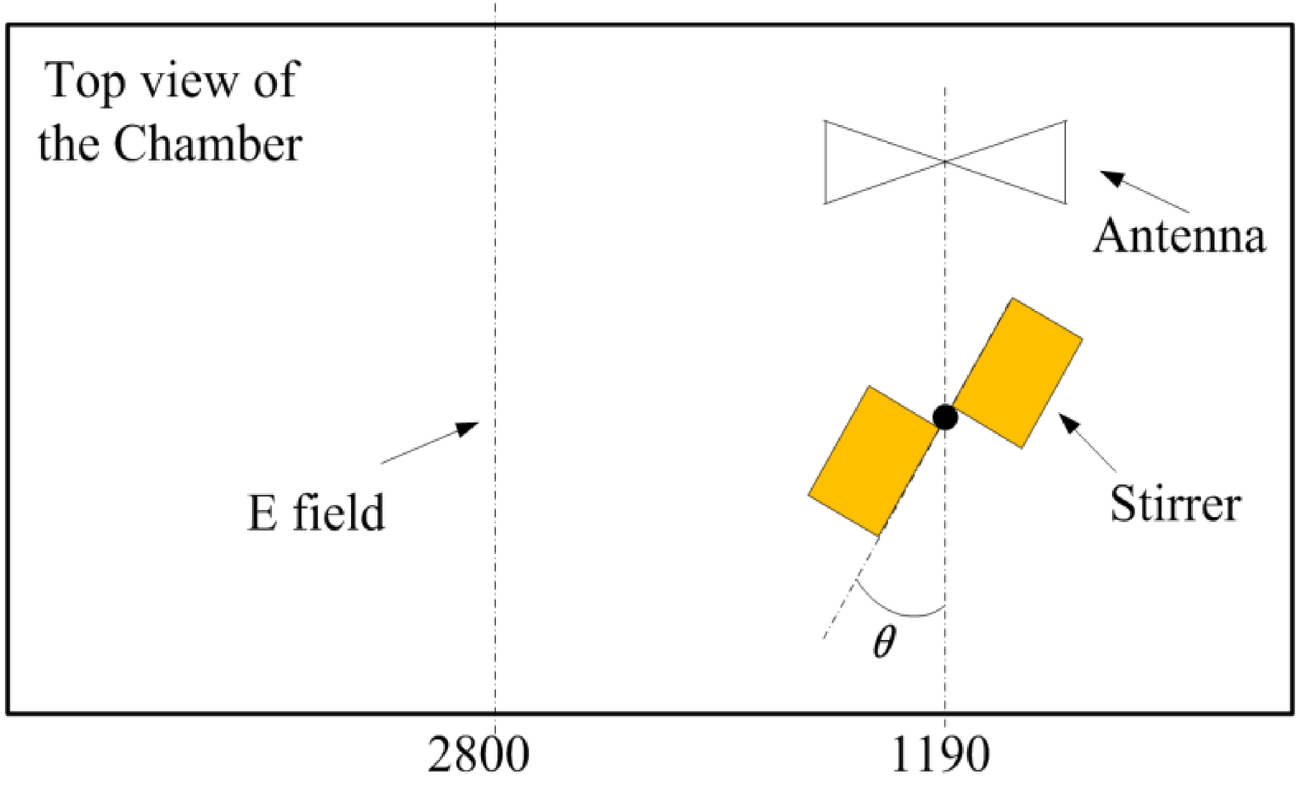






2D EMC data

- Consider fields in a reverberation chamber as a function of the stirrer position



Processed Data

Images	Data (θ)
Image-1	E2800-field (0)
Image-2	E2800-field (2)
Image-3	E2800-field (5)
Image-4	E2800-field (10)
Image-5	E2800-field (15)
Image-6	E2800-field (20)
Image-7	E2800-field (25)
Image-8	E2800-field (30)
Image-9	E2800-field (35)
Image-10	E2800-field (90)
Image-11	E1190-field (25)

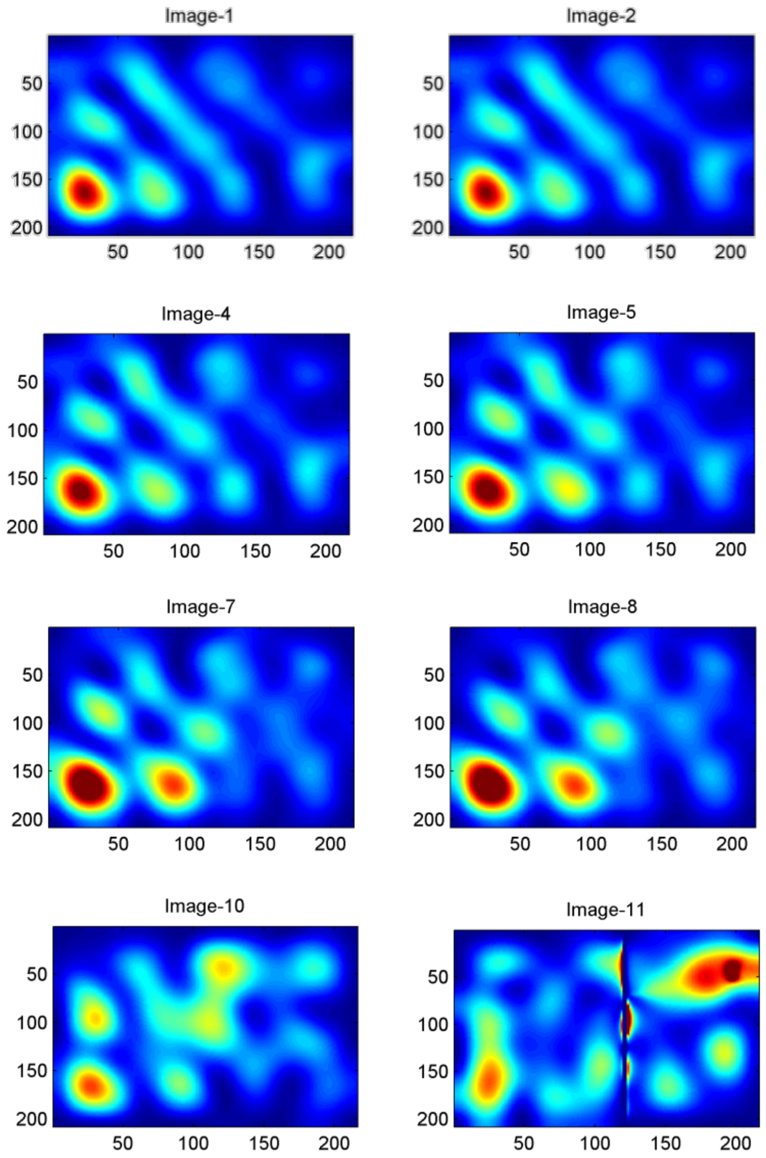
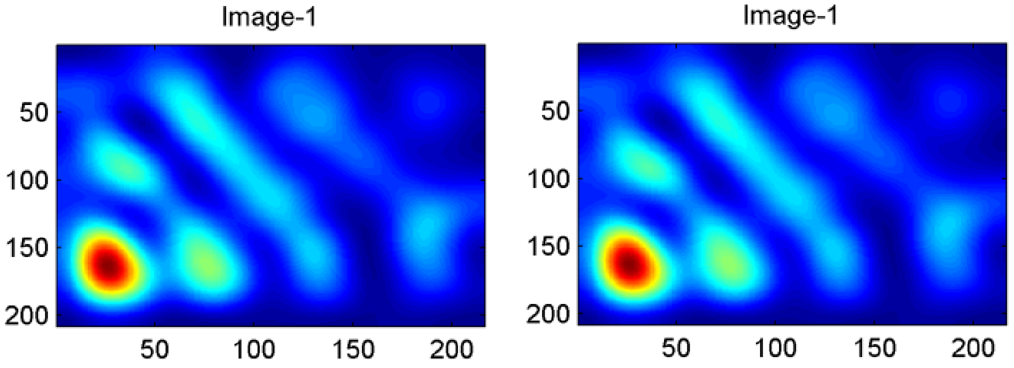


Image 1 vs. Image 1



ADMtot	FDMtot	GDMtot
0	0	0

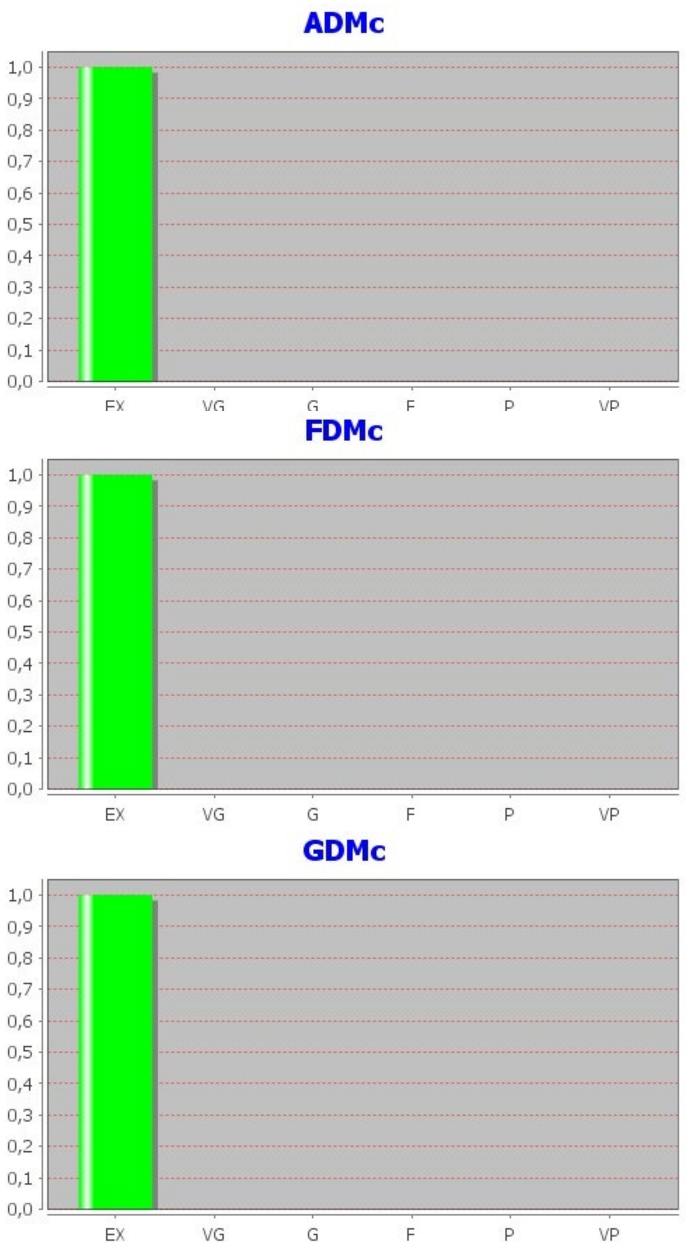
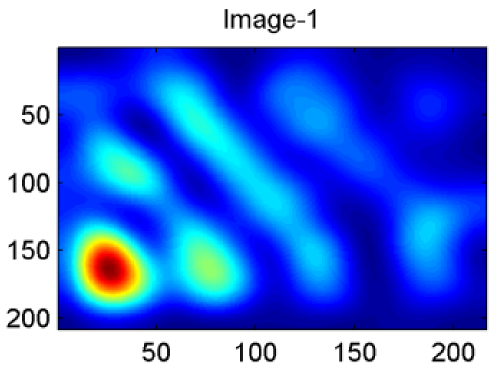
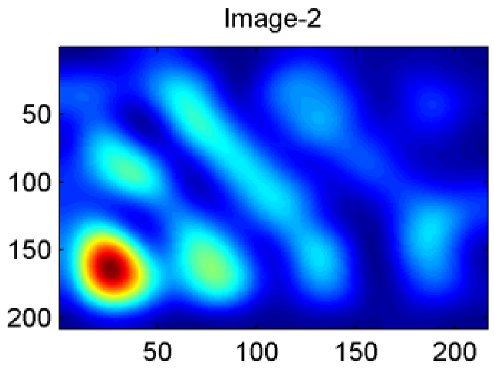
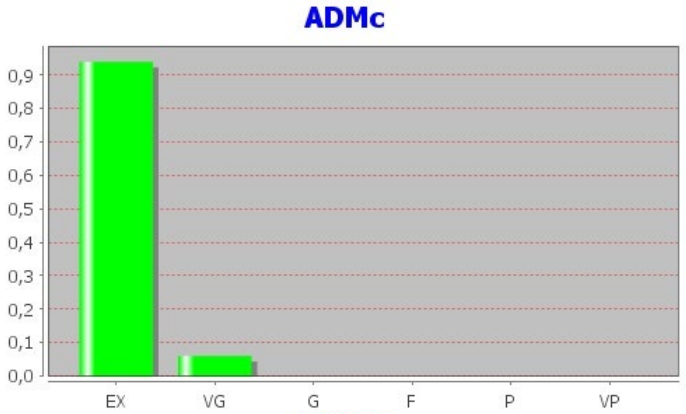


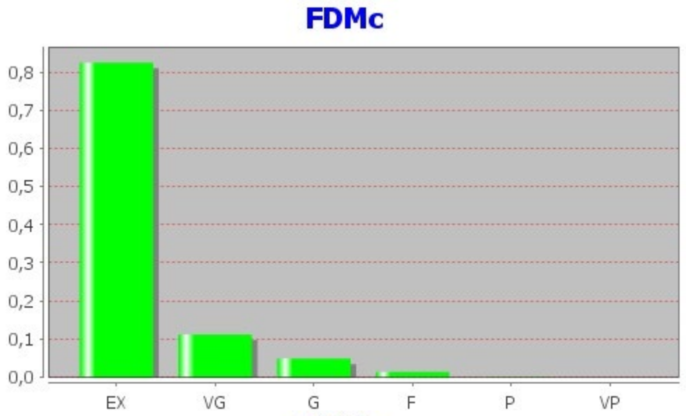
Image 1 vs. Image 2





ADMtot	FDMtot	GDMtot
0.1043	0.1336	0.1889





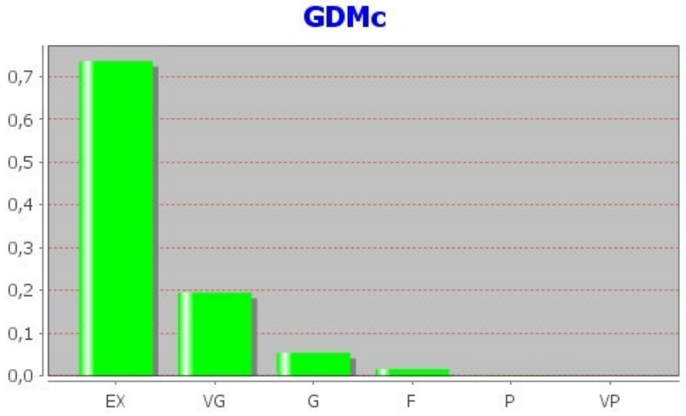
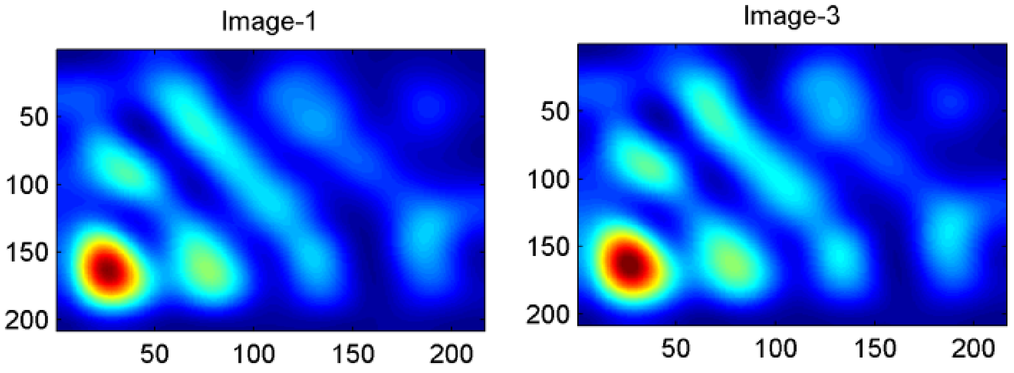
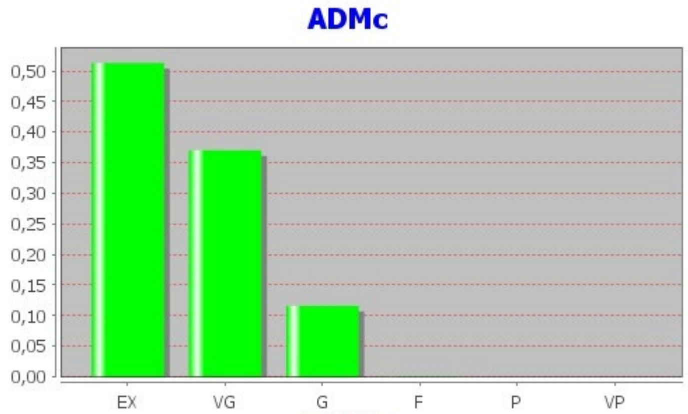
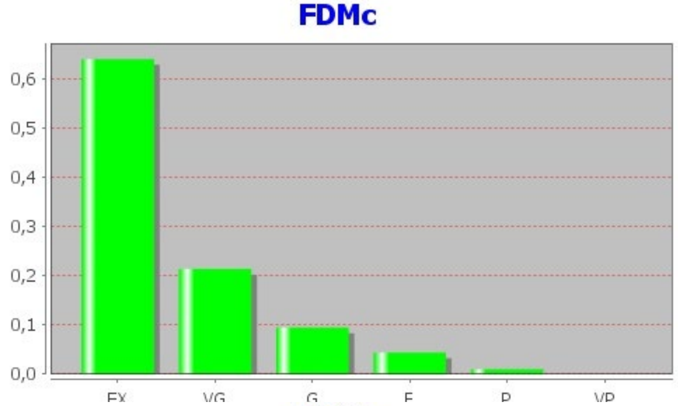


Image 1 vs. Image 3



ADMtot	FDMtot	GDMtot
0.2308	0.2349	0.3671





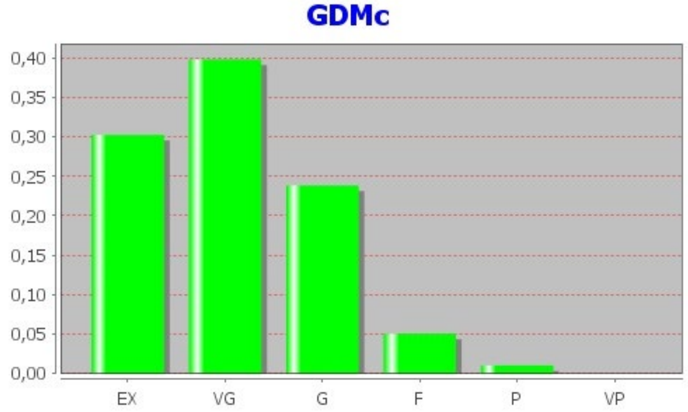
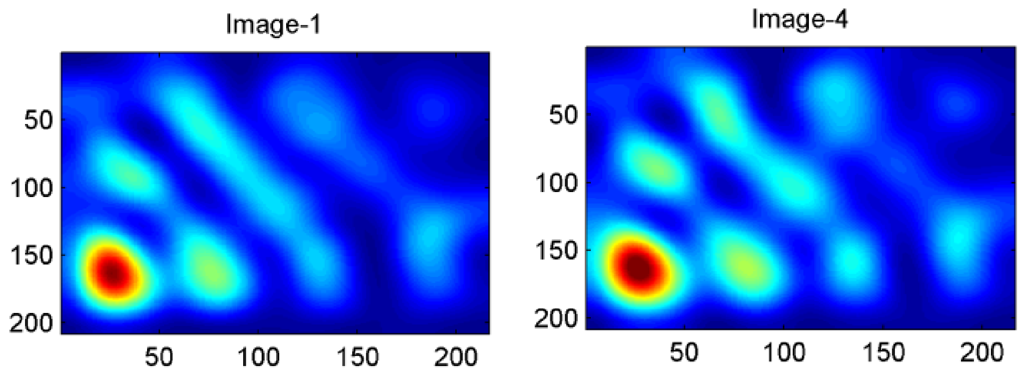
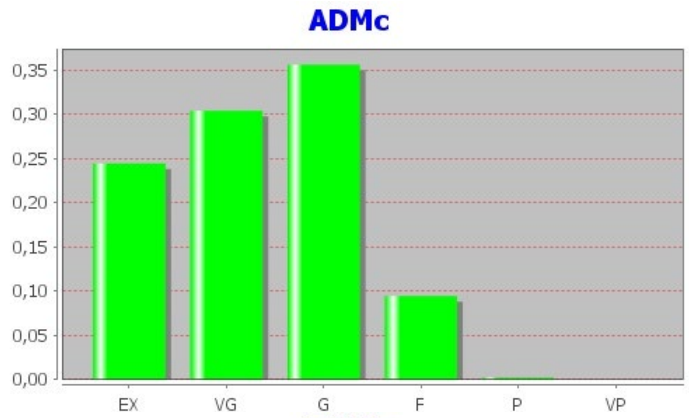
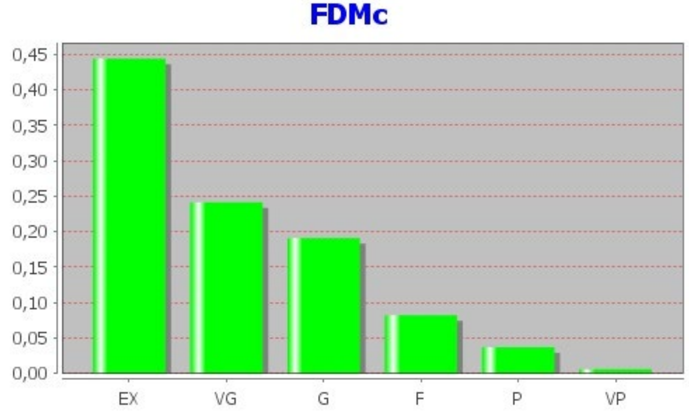


Image 1 vs. Image 4



ADMtot	FDMtot	GDMtot
0.4071	0.3757	0.6177





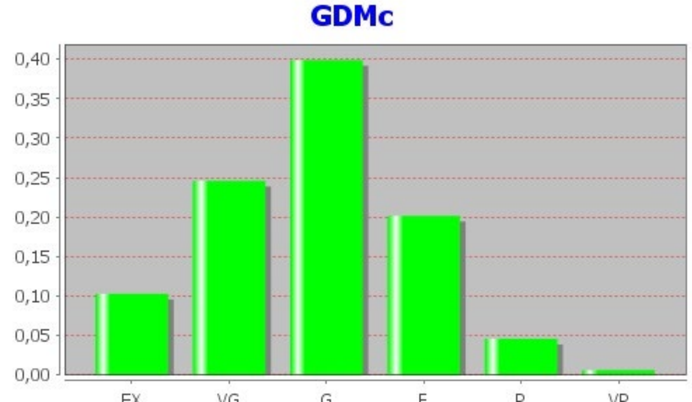
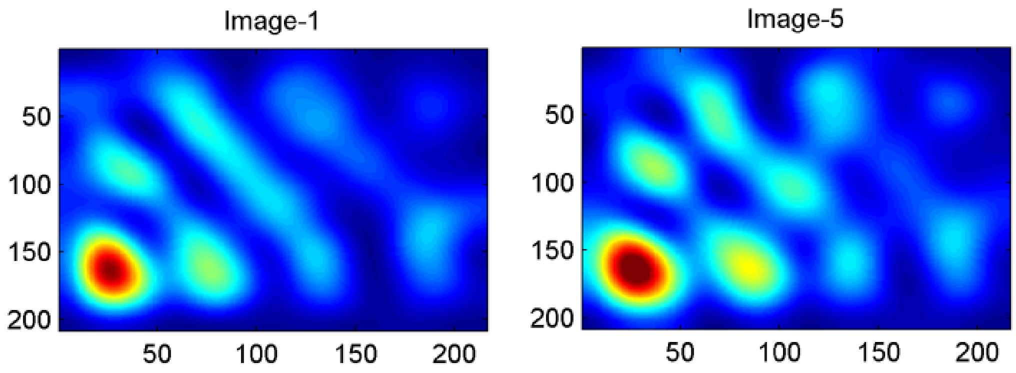
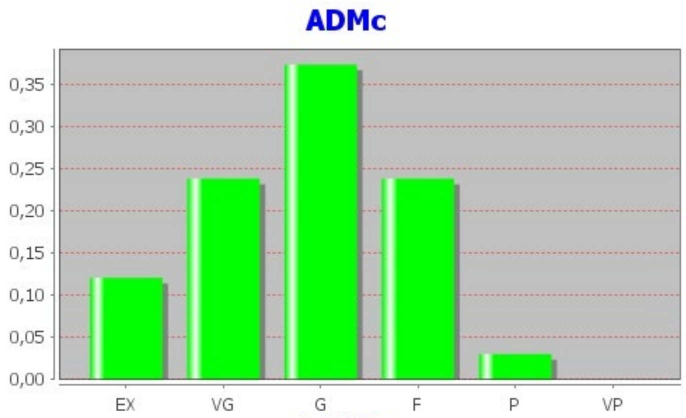
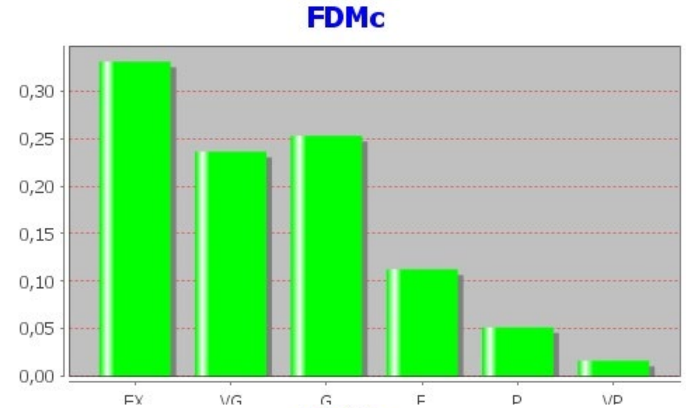


Image 1 vs. Image 5



ADMtot	FDMtot	GDMtot
0.5212	0.4660	0.7840





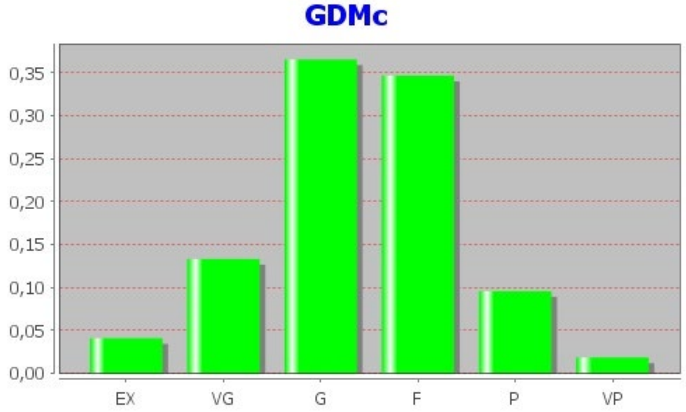
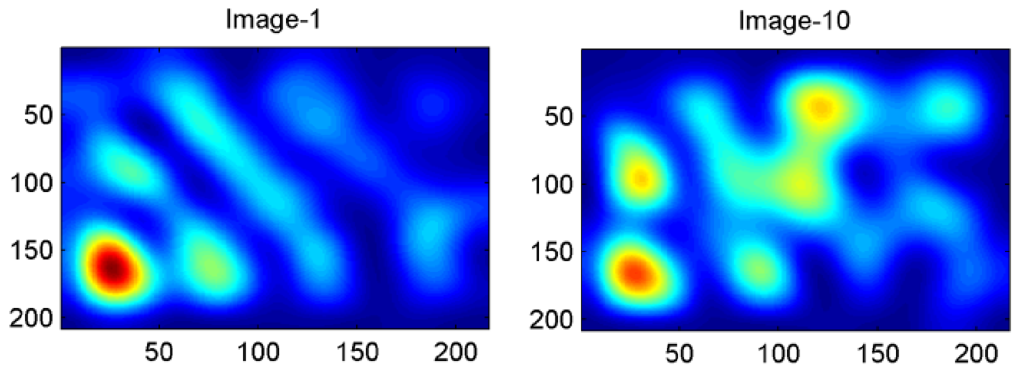
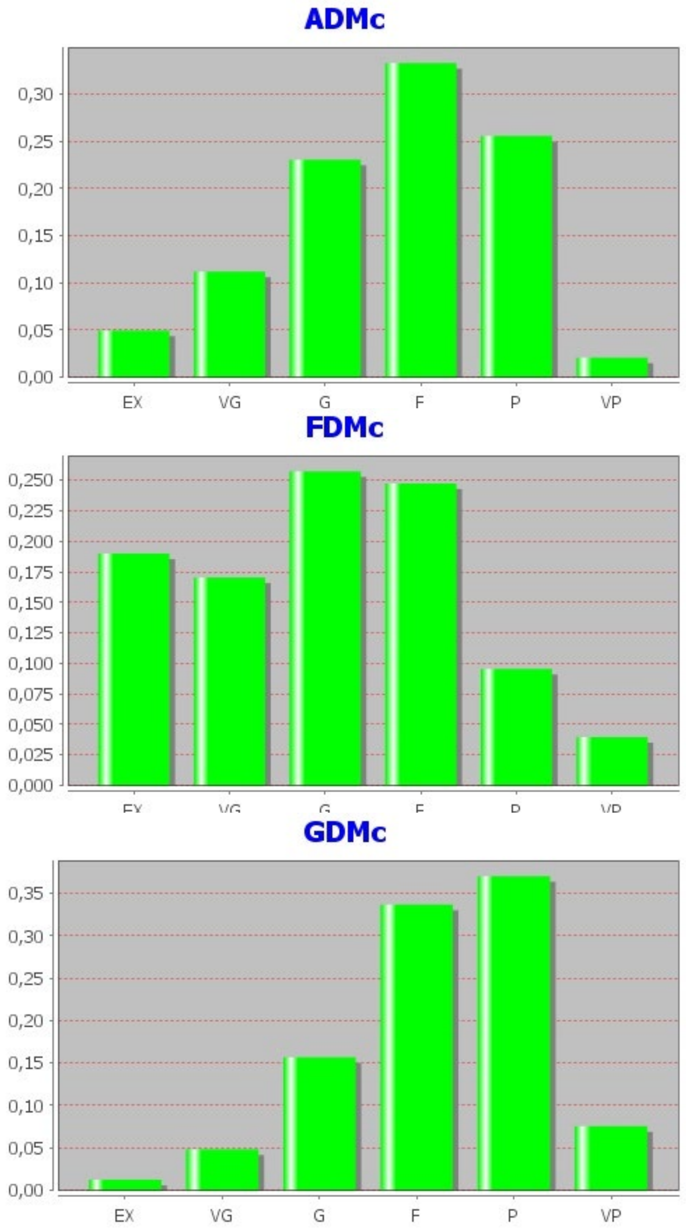


Image 1 vs. Image 10



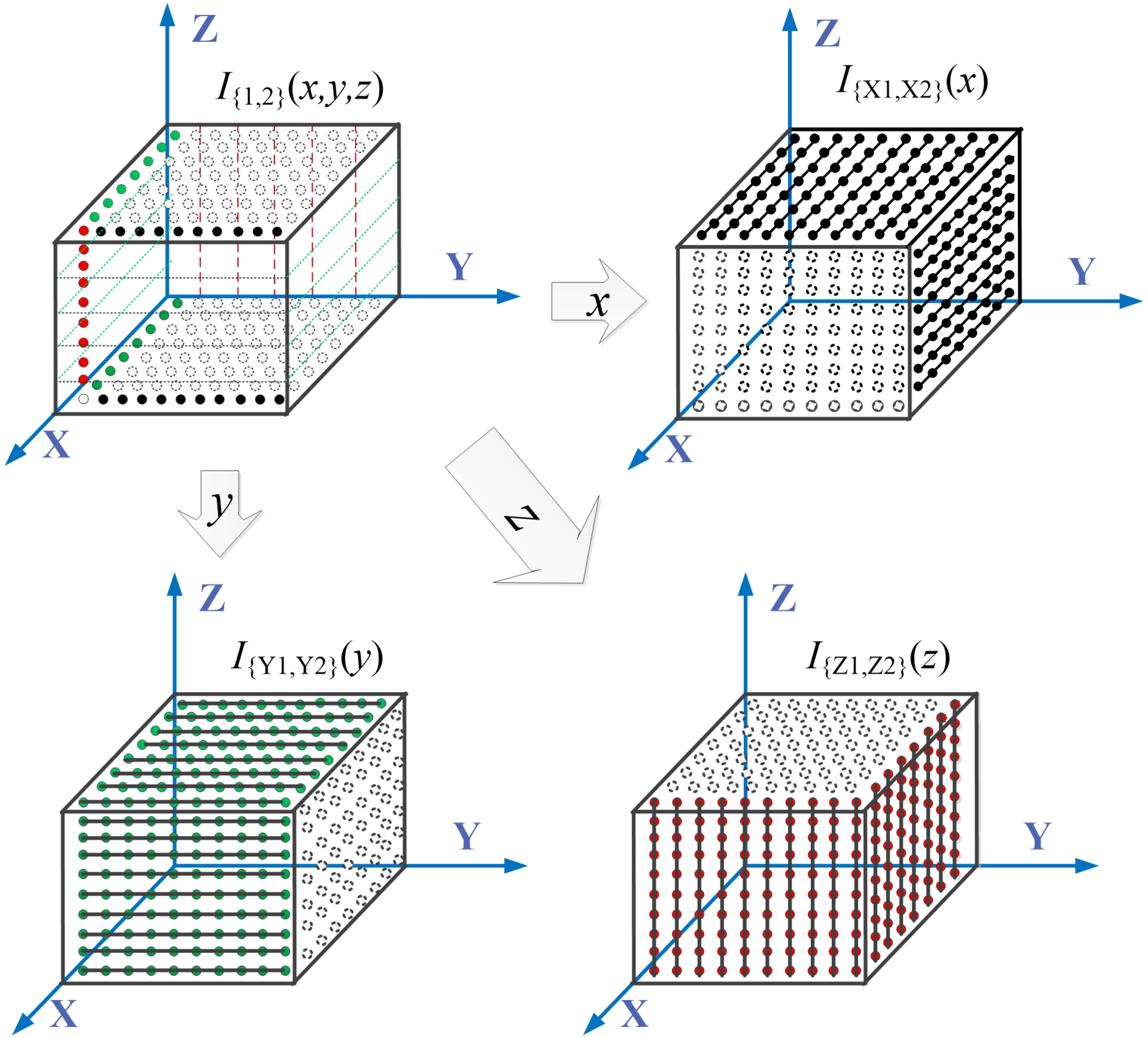
ADMtot	FDMtot	GDMtot
0.8631	0.6176	1.1943



Structure

- FSV in 1D
- Extending to 2D
- **Extending to nD**

Extension to 3D



- Follow the same concept as with 2D

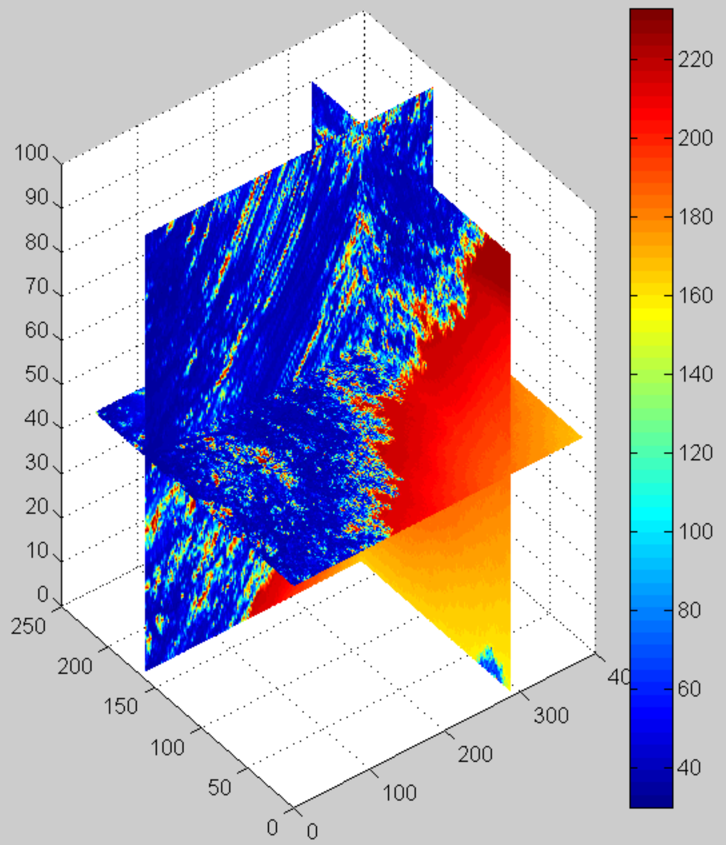
How to verify

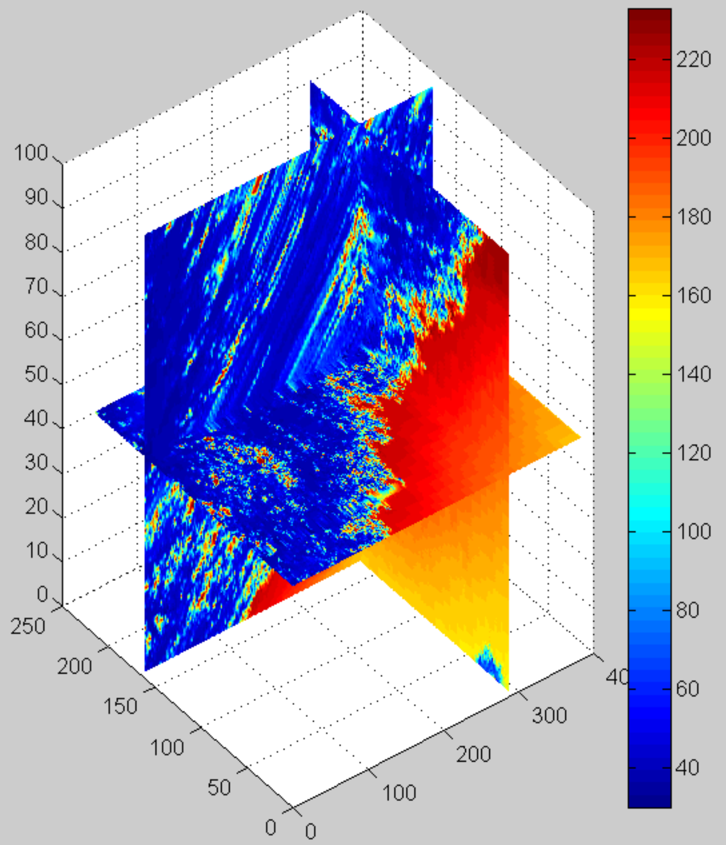
- Use the LIVE Video Quality Database
  - 150 distorted videos
  - Mean opinion score (MOS) obtained
- Convert to 3D for comparison
- Look at level of agreement between MOS and FSV using Spearman Rank-Order Correlation

Typical image from the database

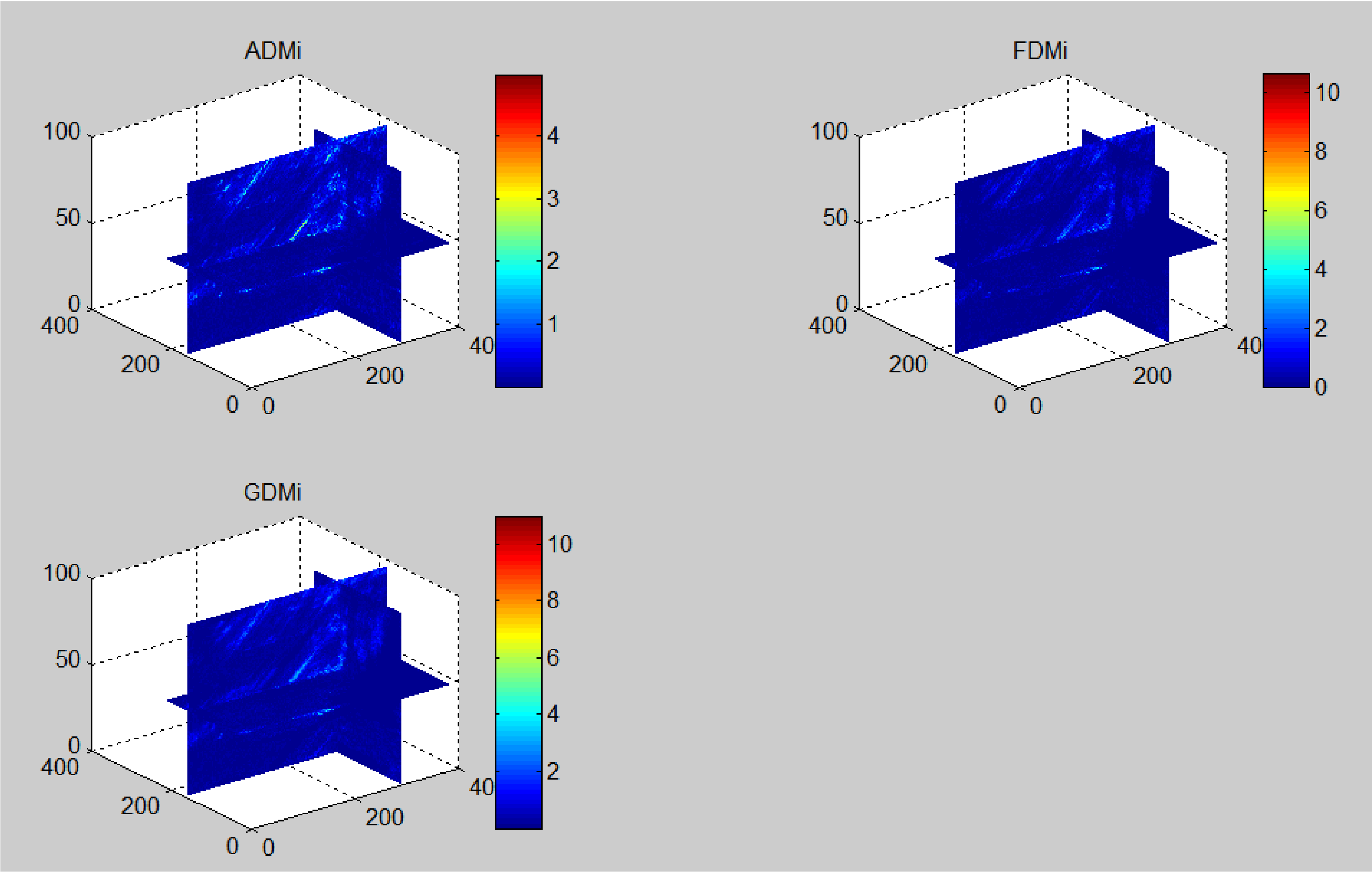
Blue Sky Video

3D Data under tests





3D FSV results

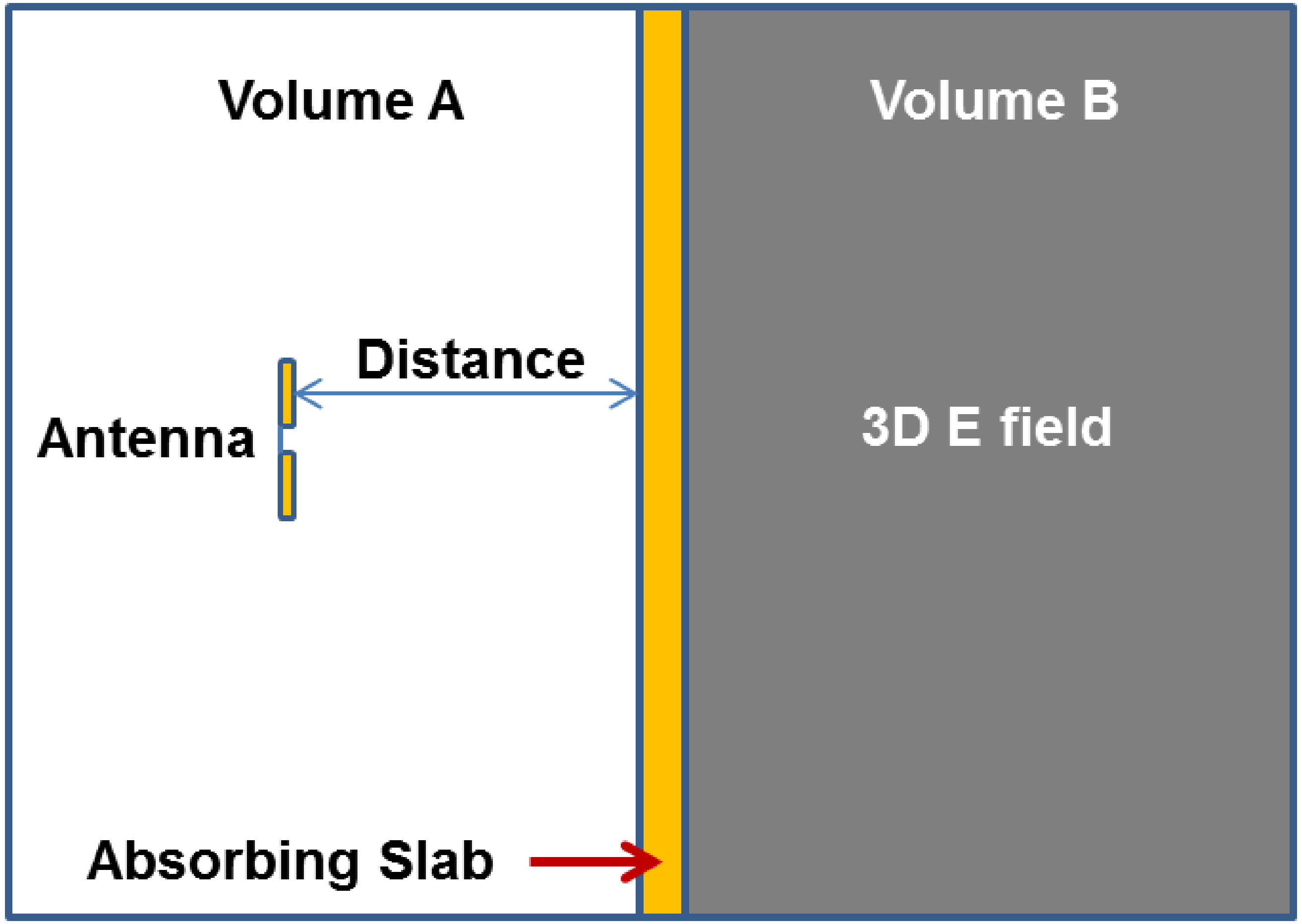


Results

FSV performs very similarly to other techniques used to process data

Clearly a good sign!

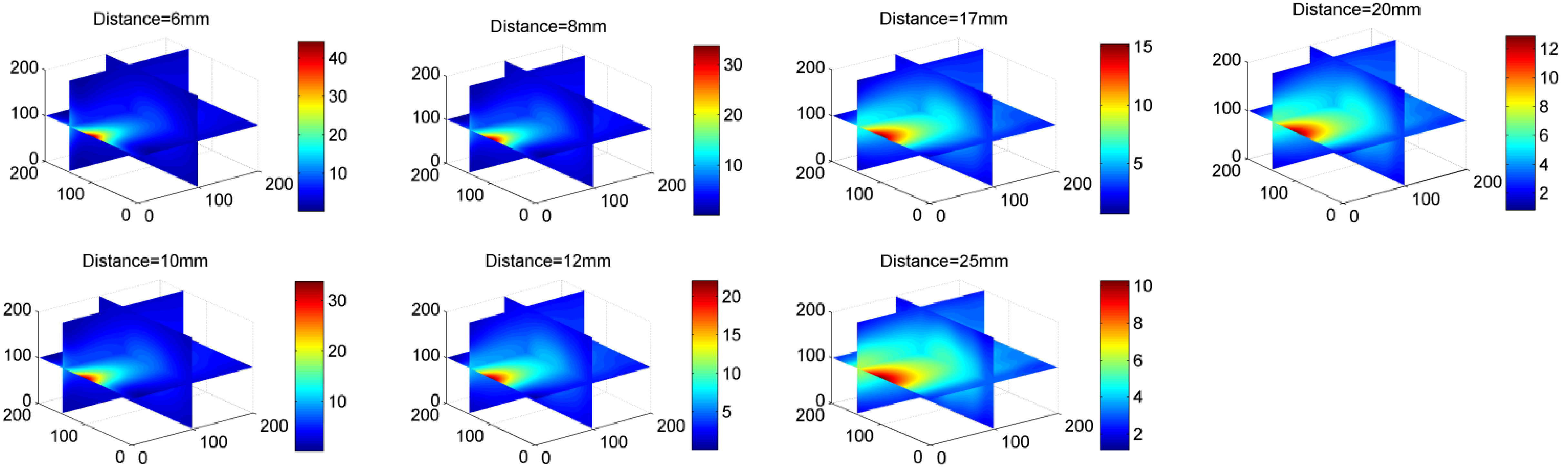
Electromagnetic appications



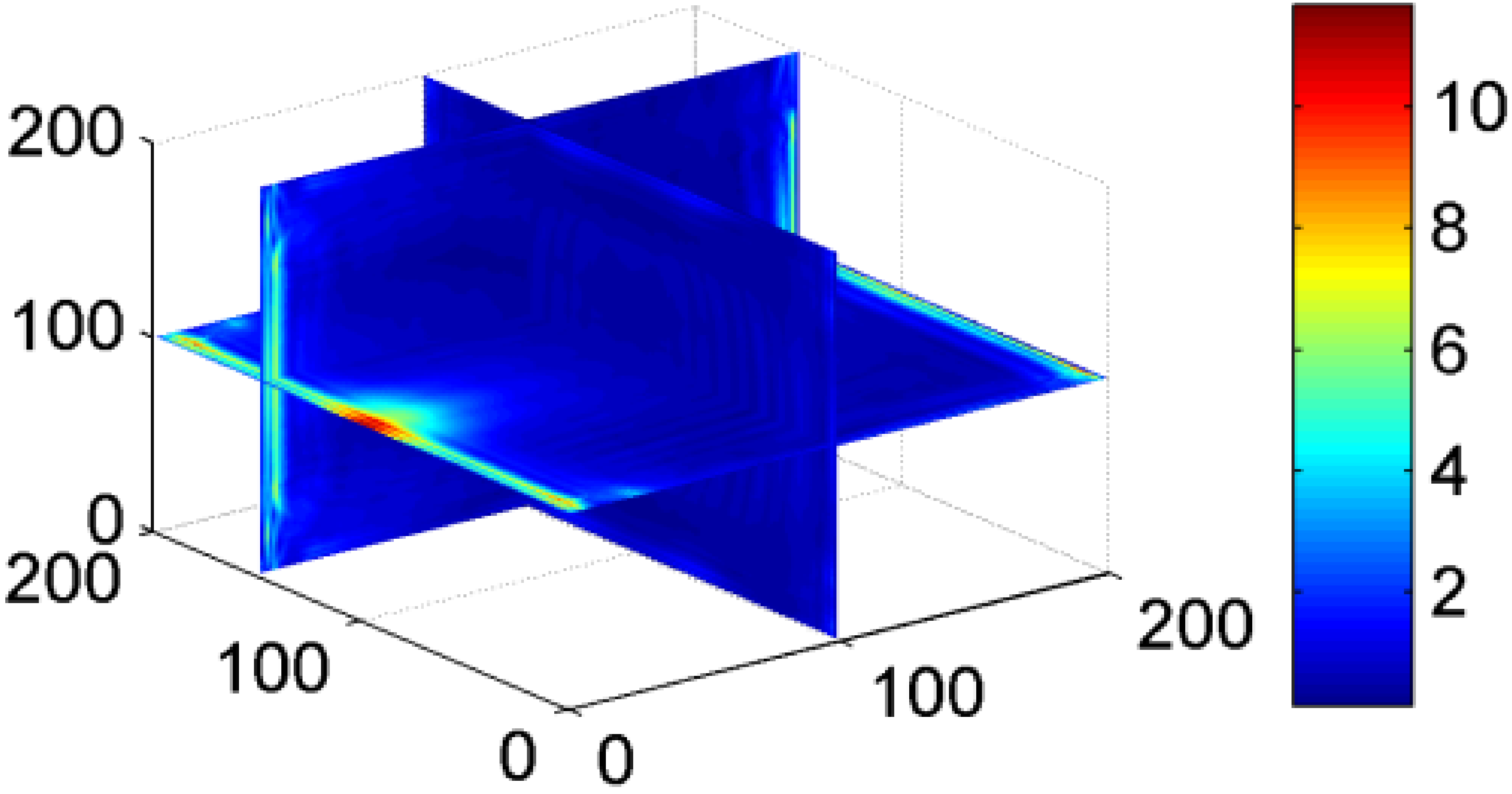
How does the field in volume B change as the antenna is moved further from the absorbing slab.

(Simulated using CST)

Field slice-through



Point-by-point analysis in 3D domain



Overall GDM = 1

What comes next

- More intensive implementation and verification in nD EMC environments.

Multiple degrees of freedom

- In principle, follow the same pattern

- In the words attributed to Albert Einstein (but probably weren't his): "Everything should be kept as simple as possible, but no simpler"


Any
Questions?