Cluster Assisted 3D Unsupervised Seismic Facies Analysis - An Example from Osage County, Oklahoma*

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Search and Discovery Article #40832 (2011)
Posted November 14, 2011

*Adapted from oral presentation at AAPG Mid-Continent Section meeting, Oklahoma City, Oklahoma, October 1-4, 2011

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Abstract

Automatic seismic facies analysis aims to classify similar seismic traces based on amplitude, phase, frequency and other seismic attributes. This talk reviews Kohonen Self Organizing Maps as one of the clustering algorithms that can generate 3D seismic facies volumes using multiple attributes as input. To avoid guessing at the number of clusters necessary to represent the data, we have over-defined the number of initial clusters (Prototype Vectors), which after subsequent iterations tends to converge to a lesser number of clusters. After the training is complete, the modified PVs are then color-coded by using a 2D gradational colorscale (Matos et al., 2009). These colored PVs are then compared with the input data. Those traces with similar seismic nature are assigned the same colors, resulting in a 3D seismic facies volume.

If we have well information in certain areas of the survey we can assign their corresponding attribute patterns to Prototype Vectors that will be fixed for all iterations, thereby introducing some supervision in the application. We will be using volumetric attributes such as dip-magnitude, coherency, peak frequency and other mathematically independent and rotationally invariant volumetric attributes to come up with a 3D volume, highlighting variations in seismic facies and depositional environment of the survey area. We will also apply supervision in the application and compare the results.

Selected References

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Zeller, D.E., 1968, The Stratigraphic succession in Kansas: Kansas Geological Survey Bulletin, v. 189, p. 81.

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The 2011 AAPG Mid-Continent Section Meeting
Oklahoma City, Oklahoma
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3rd October 2011

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- Introduction to waveform classification
- Overview of Kohonen Self-organizing maps (SOM) – Training Process
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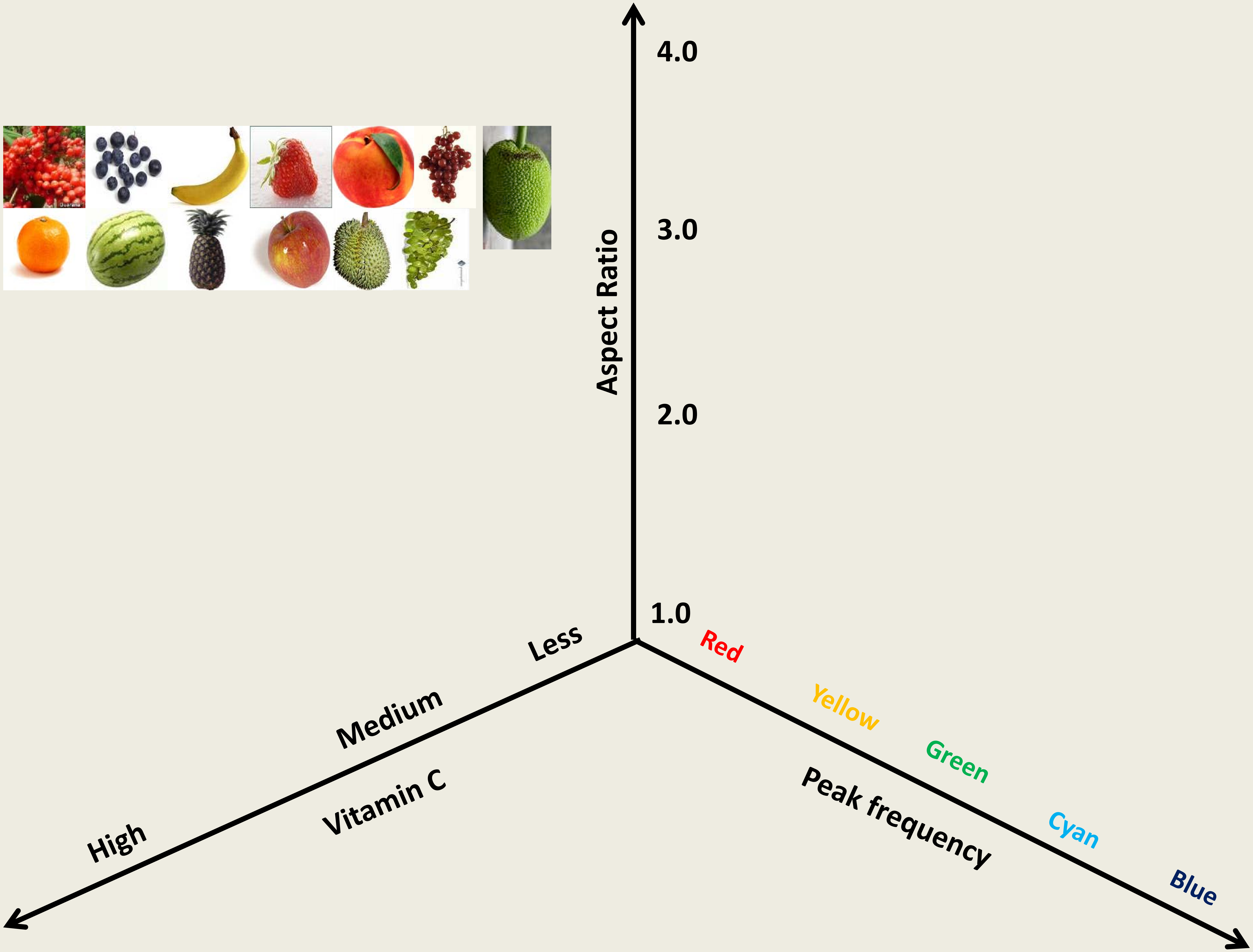
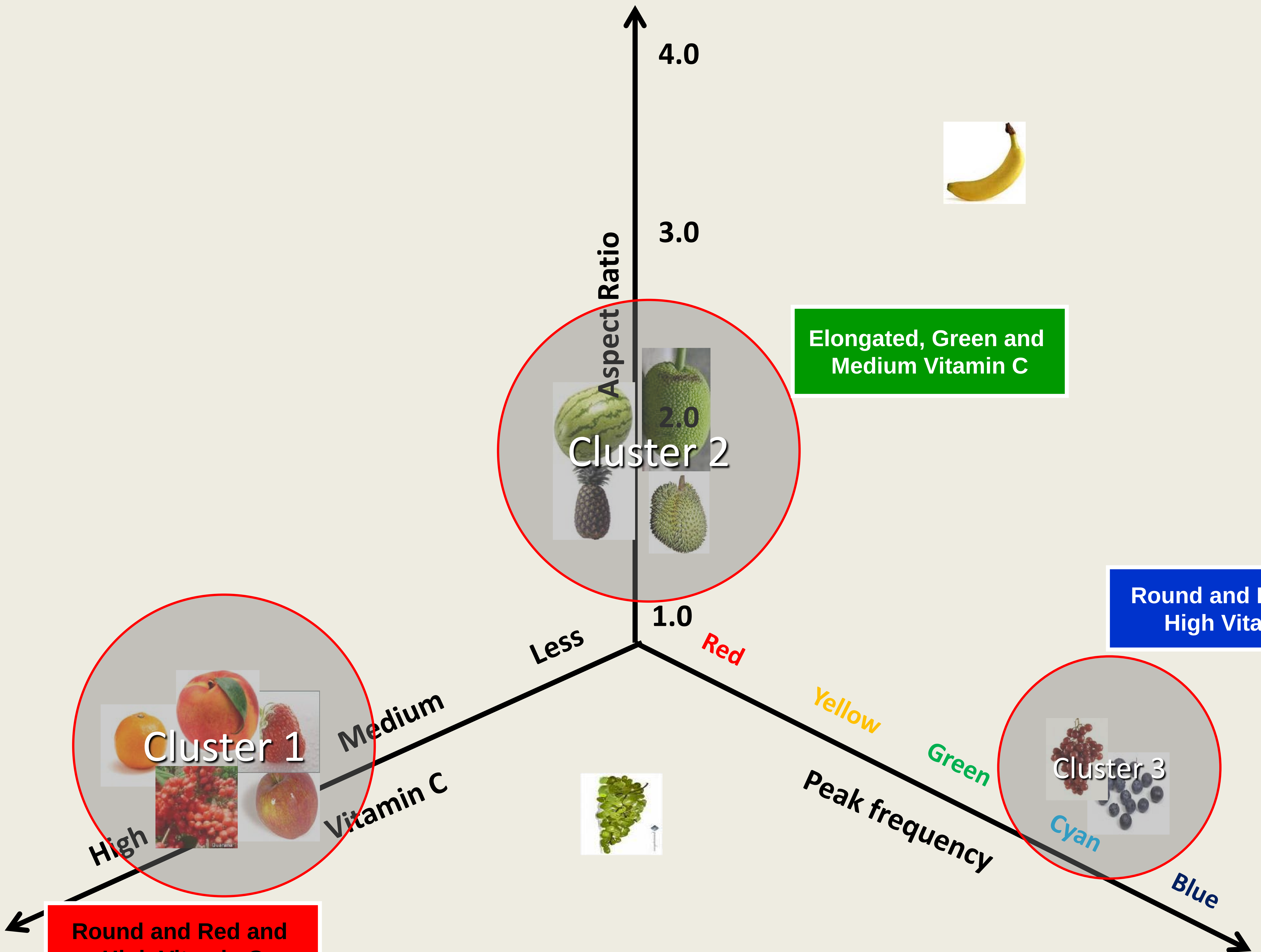
  - 3D Multi-attribute analysis -2
  - Seismic Facies Classification of Mississippian Lime and Chert
- Discussions and Recommendations, Acknowledgements

Classification on the basis of different attributes – Fruits Analogy



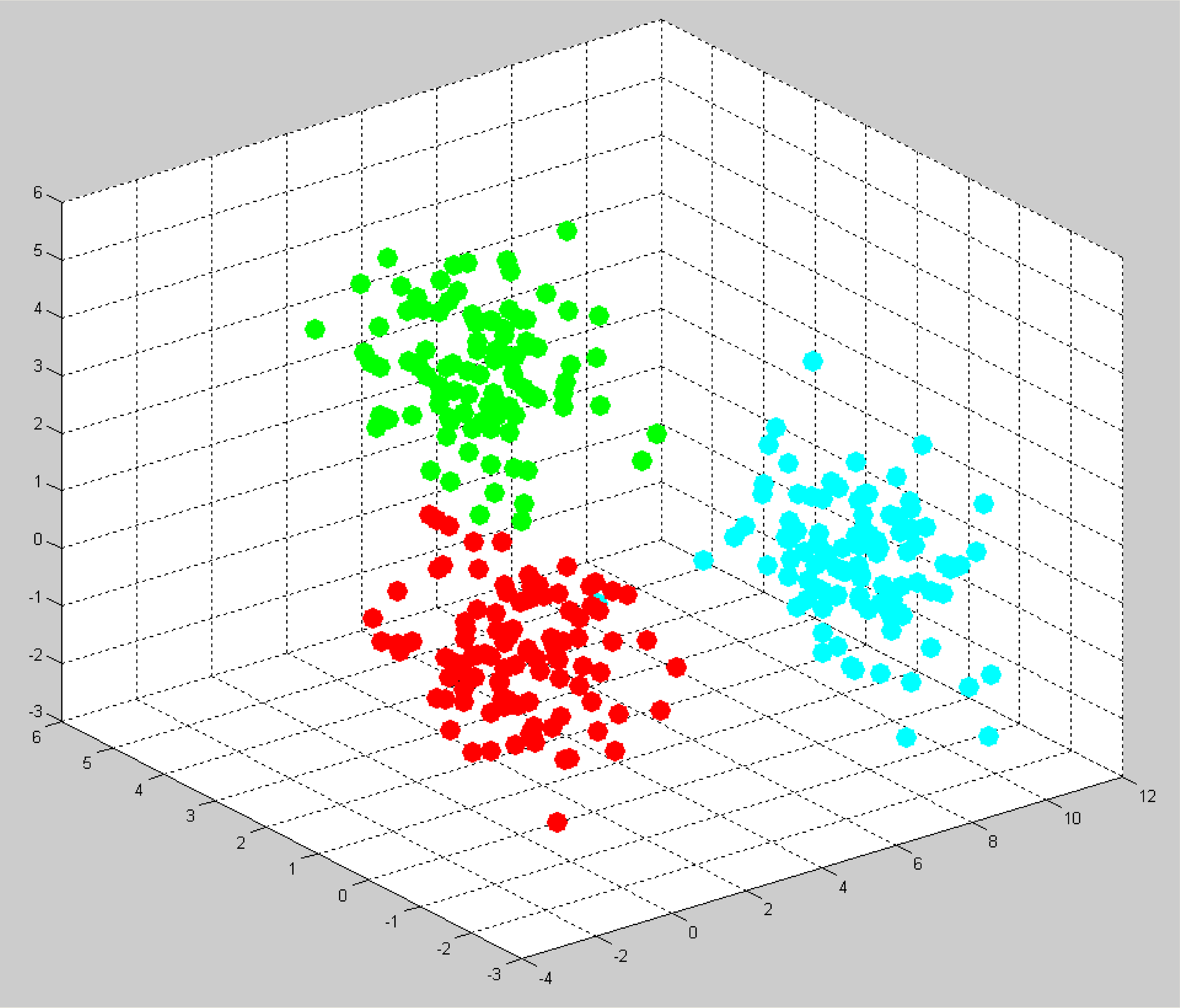
(Modified from Matos)

Classification on the basis of different attributes – Fruits Analogy

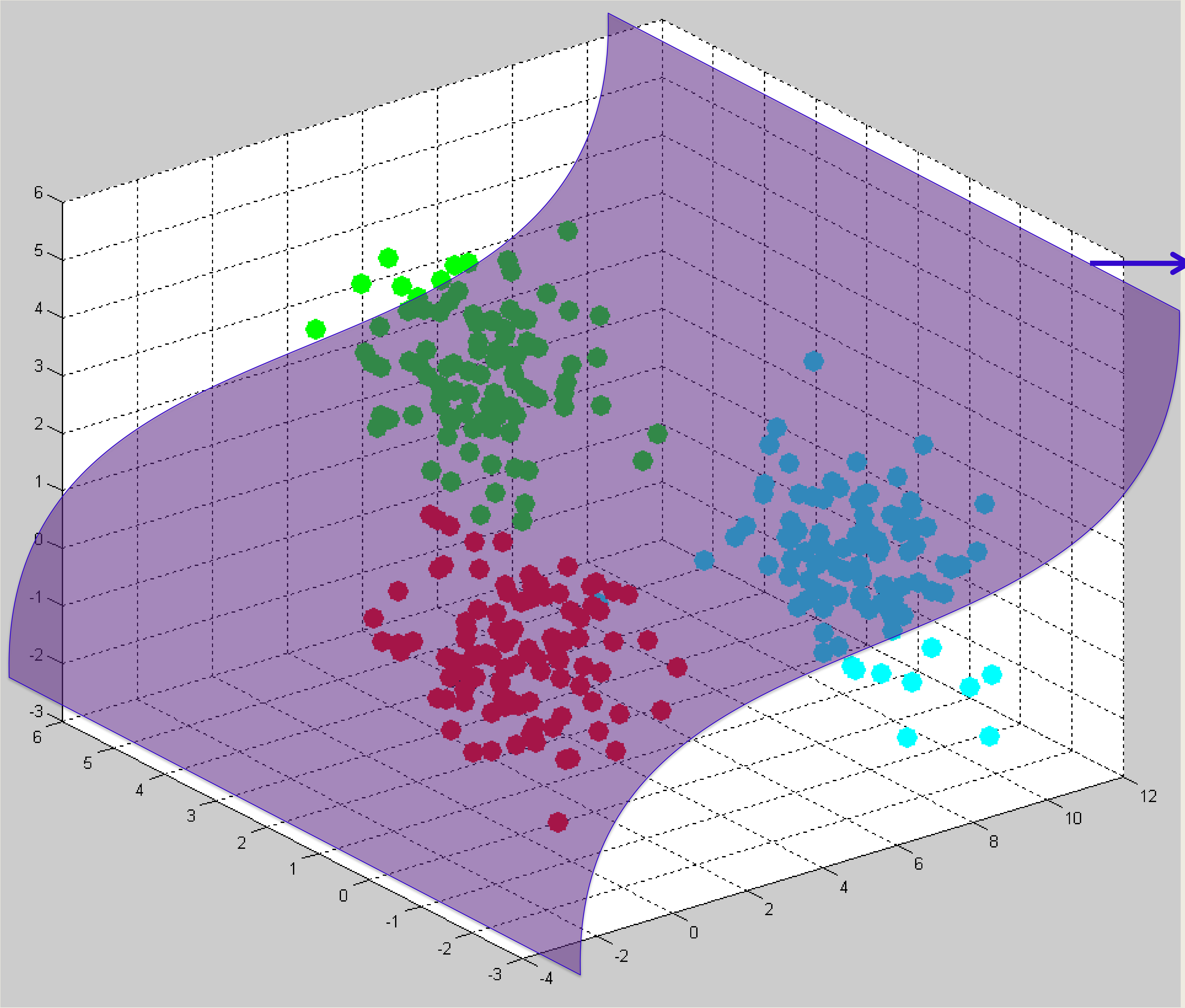


(Modified from Matos)

Latent Space and Principal Component

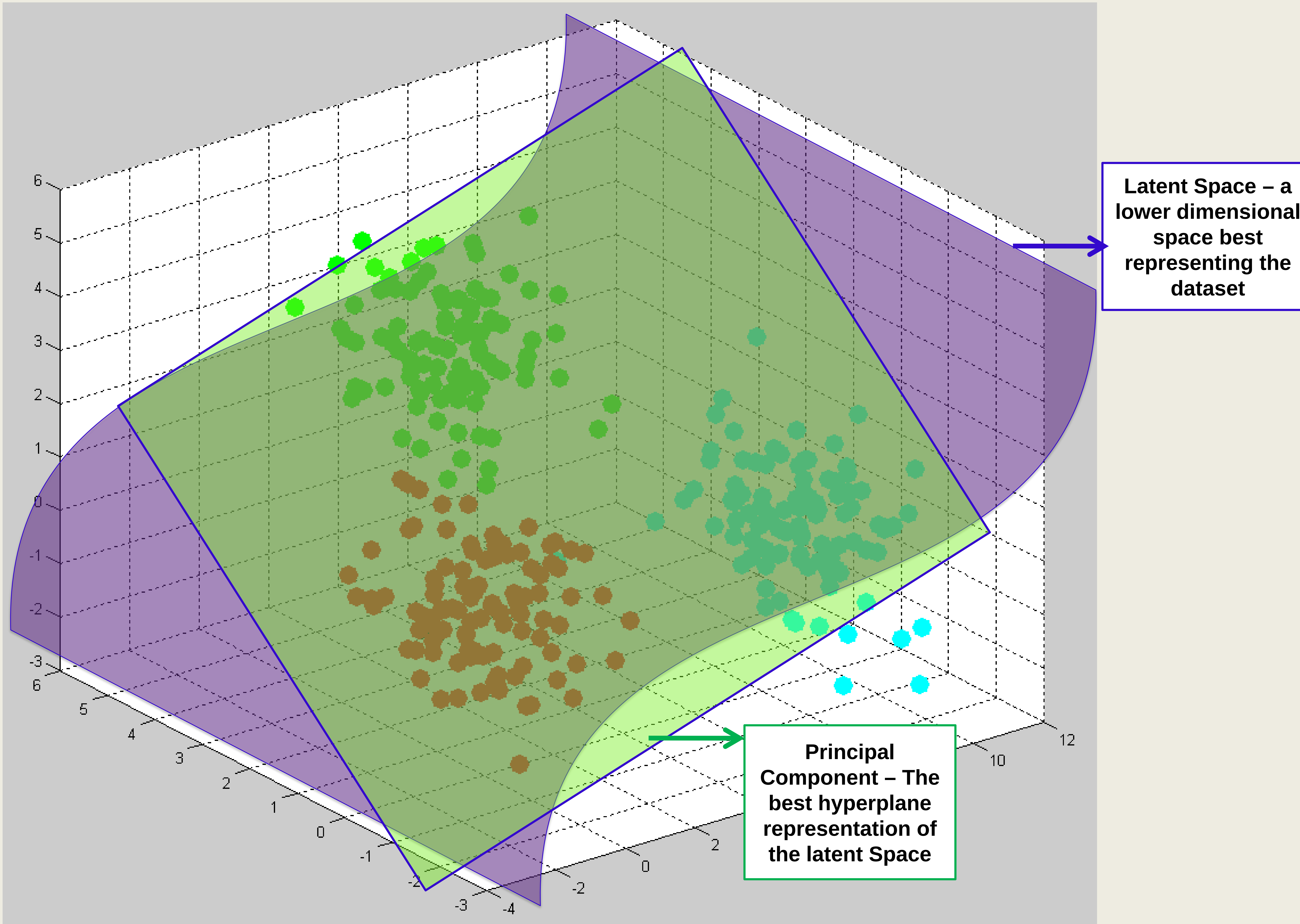


Latent Space and Principal Component

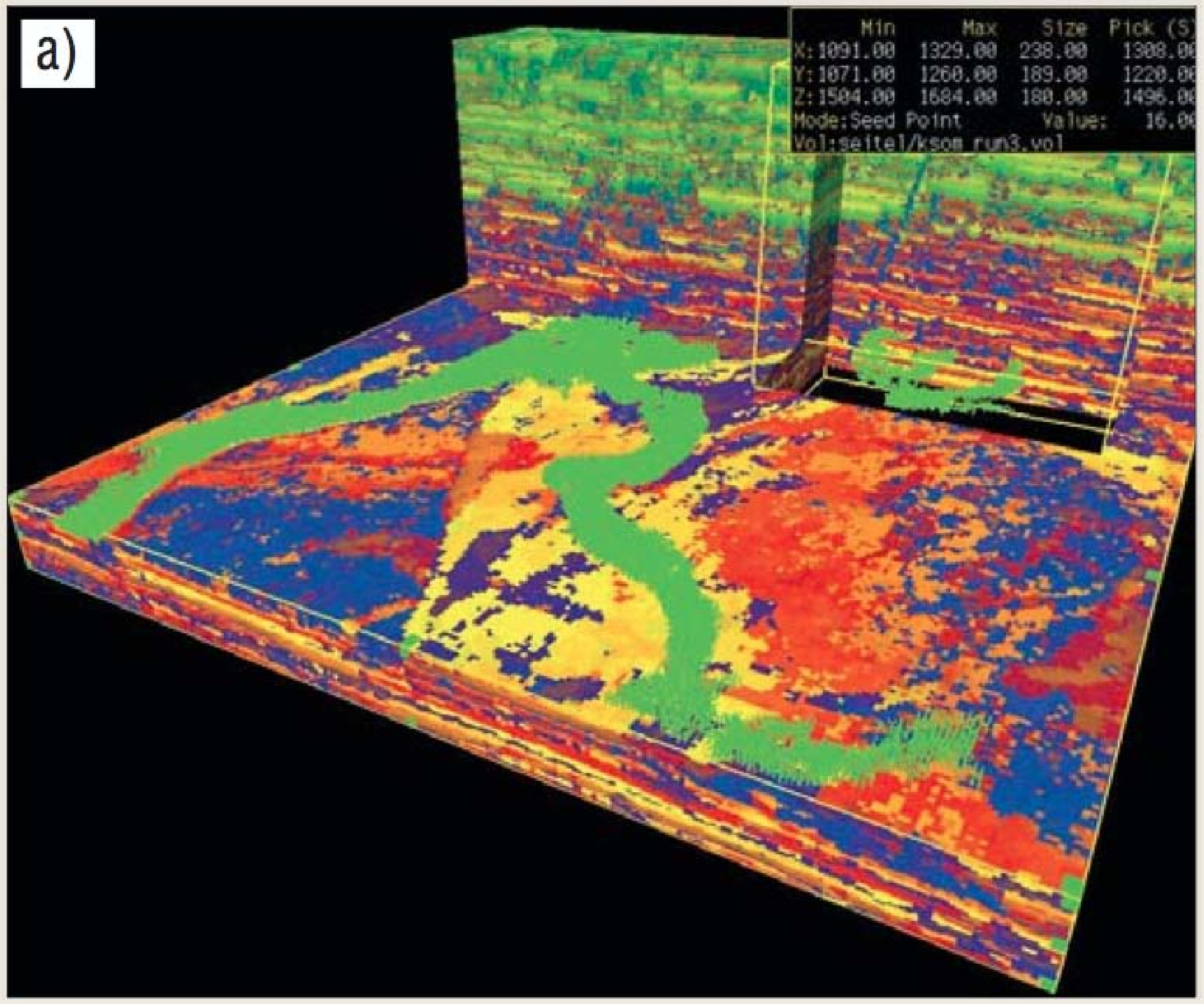


Latent Space – a lower dimensional space best representing the dataset

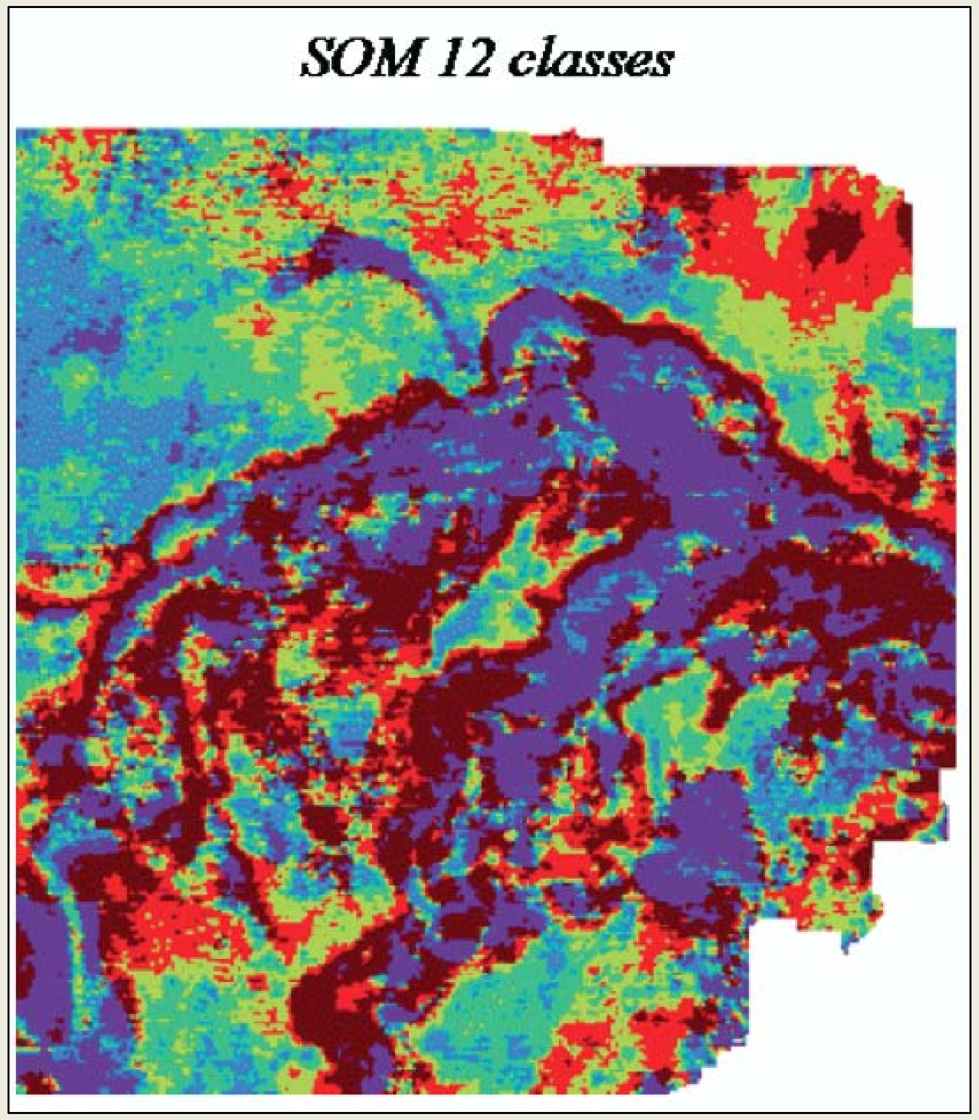
Latent Space and Principal Component



Examples of alternative cluster workflows



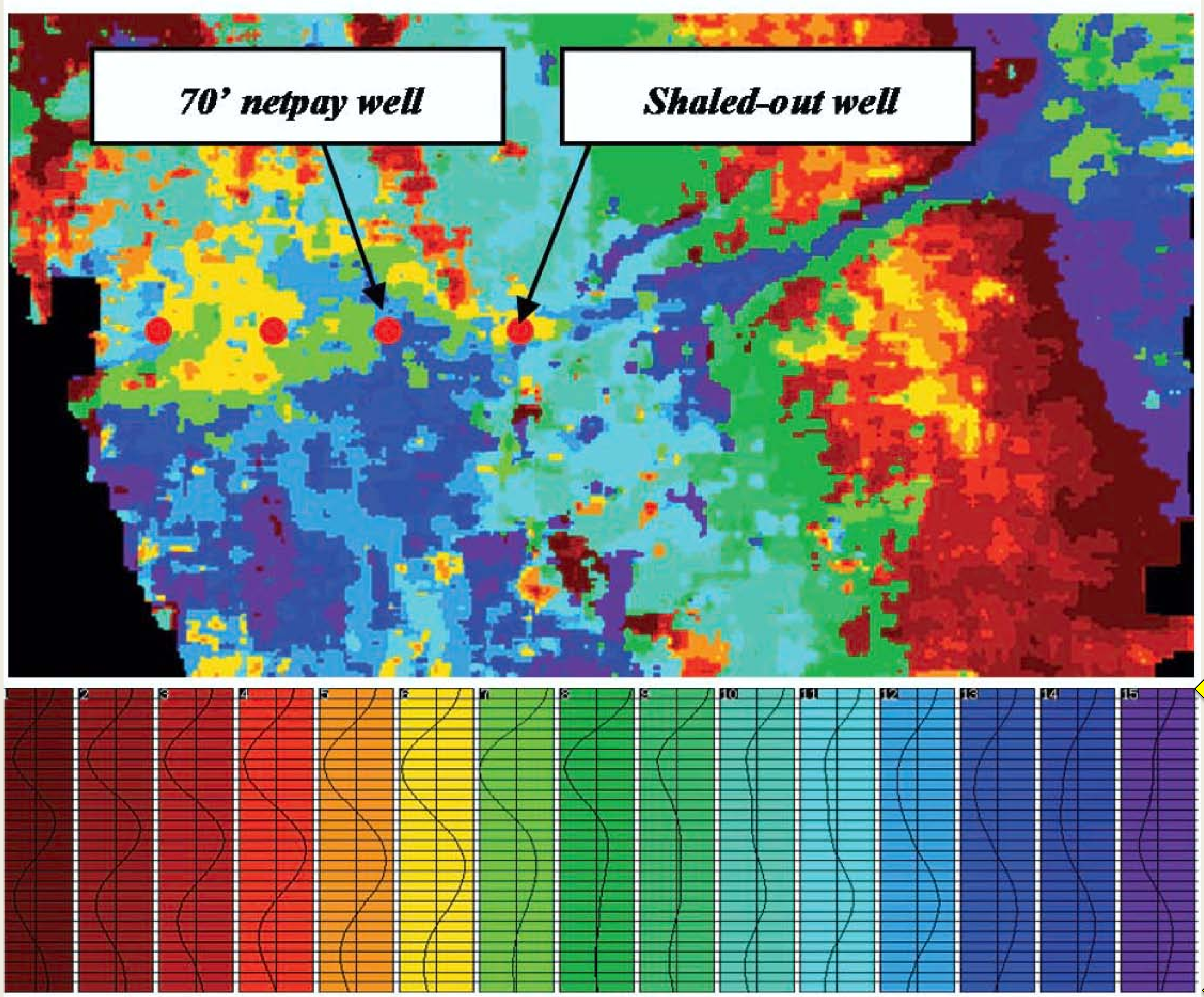
1. Each voxel contains a vector of attributes
(e.g. Strecker et al., 2002)



2. Each map location contains a vector of amplitudes
(e.g. Coleou et al., 2003)

3. Each map location contains a vector of attributes (e.g. Stephens 2011)

Introduction : Waveform Classification



" Waveform classification" of the seismic amplitude data considering by coloring each x, y of the data correlating with the most similar waveform of the classes

Seismic amplitude of the 1st sample

Seismic amplitude of the Nth sample

(Coleou etal 2003)

Kohonen Self Organizing Maps (SOM) analysis on three Gaussian distributions

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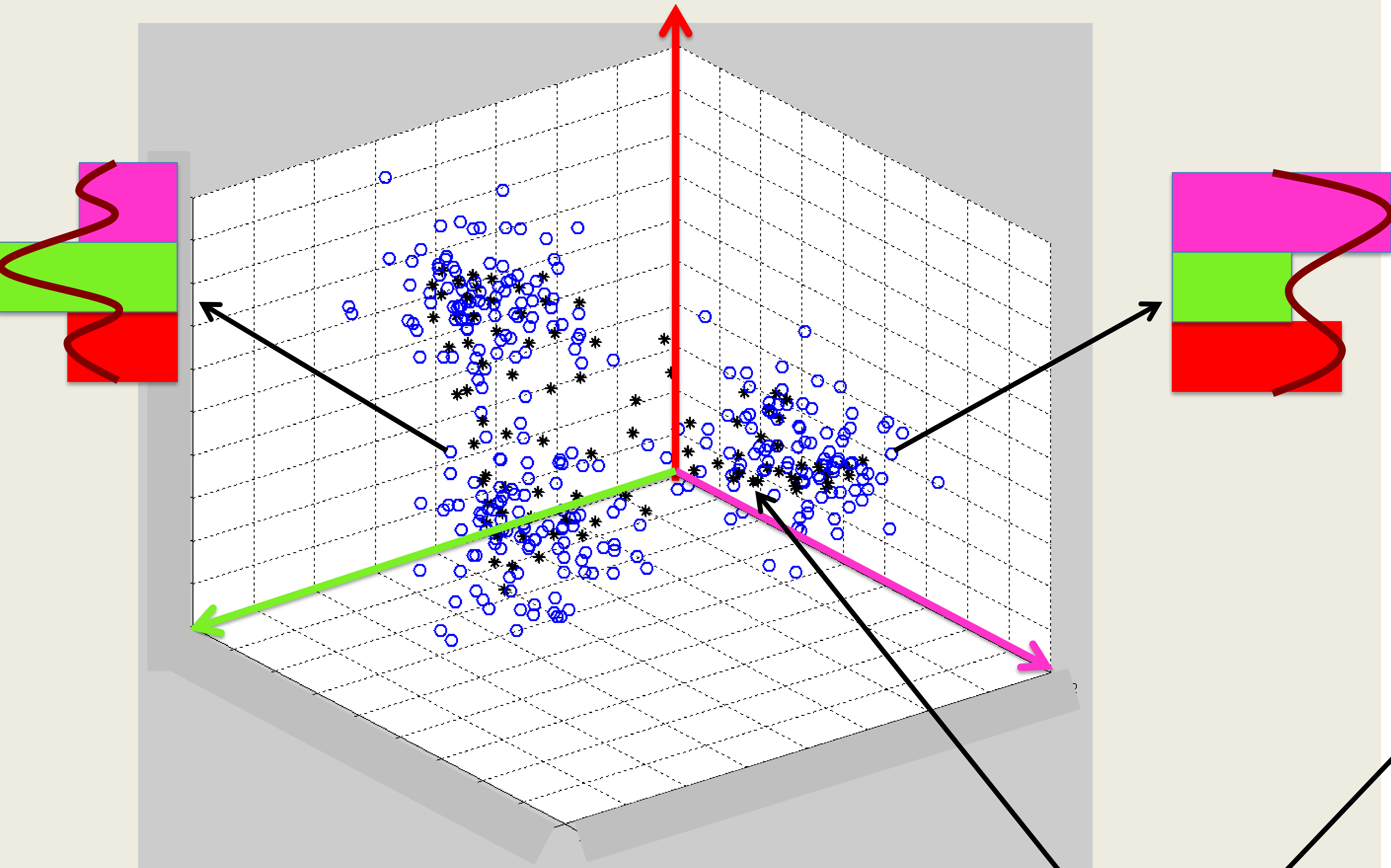
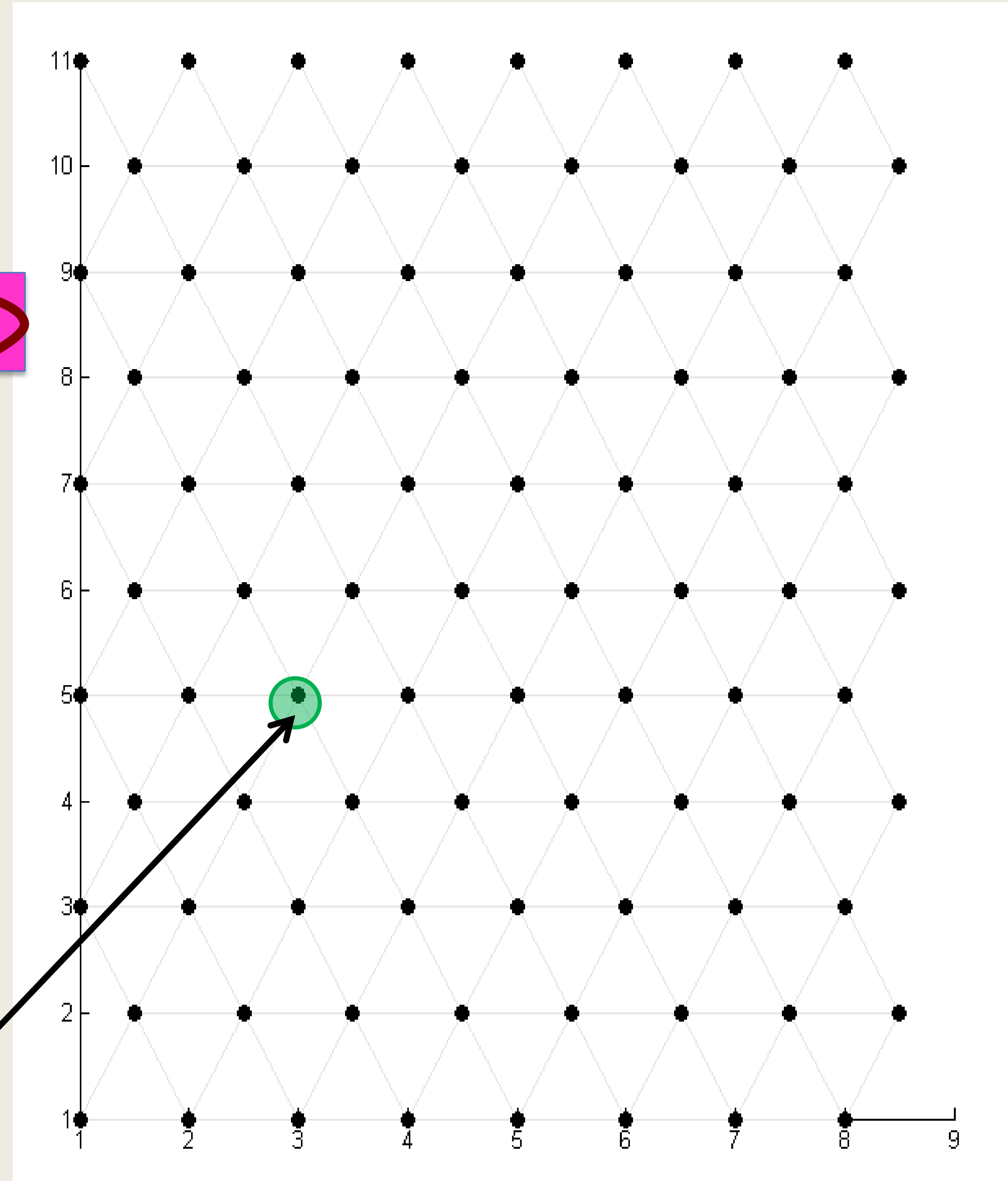
Input data (O) and Prototype vectors (*)



Representation of the data in 2D latent space



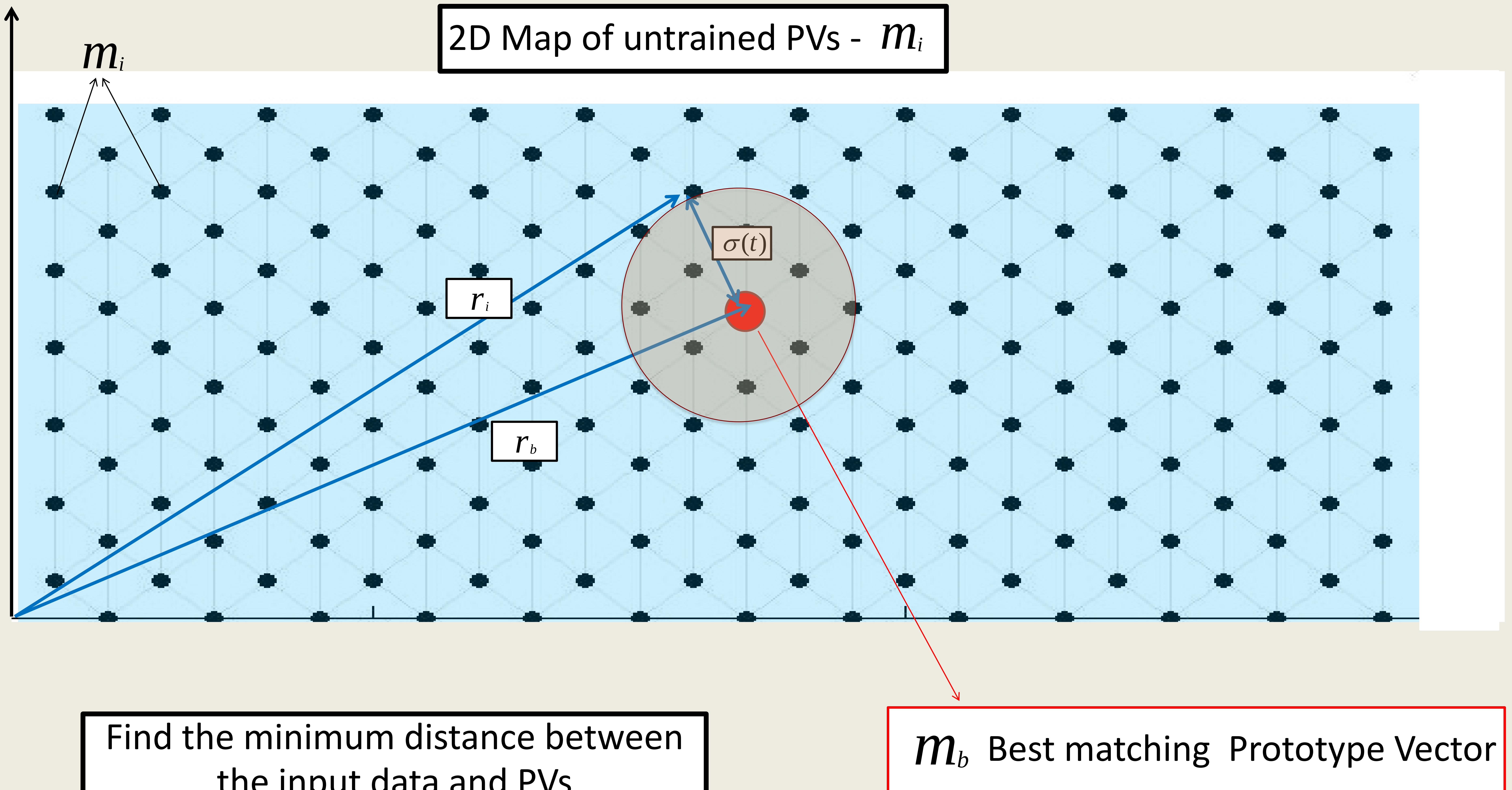
Prototype Vector (PV)

2D Grid Dimension : 11 x 7

Three Gaussian Distribution with centers shifted from each other

Representing the Gaussian distribution in 2D latent space

Finding the Best Matching Prototype Vector – Step 1



Find the minimum distance between the input data and PVs

$$\|x - m_b\| = MIN\{\|x - m_i\|\}$$

Neighborhood training of the PVs – Step 2
Initial learning radius

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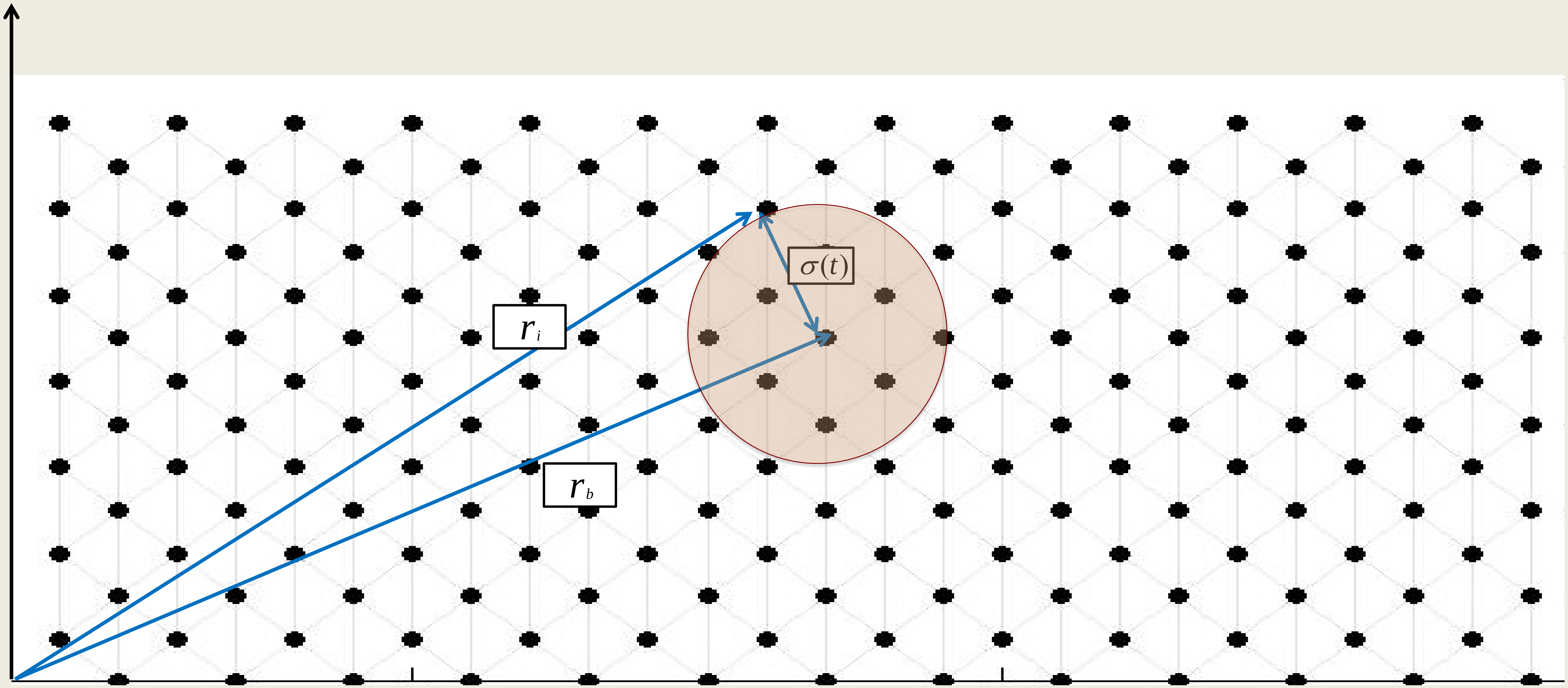


Neighborhood Updating Rule

$$m_i(t+1) = m_i(t) + \alpha(t)\, h_{bi}(t)[x - m_i(t)] \xrightarrow{if} \|r_i - r_b\| \le \sigma(t)$$

$$m_i(t+1) = m_i(t) \xrightarrow{if} \|r_i - r_b\| \ge \sigma(t)$$

where ,

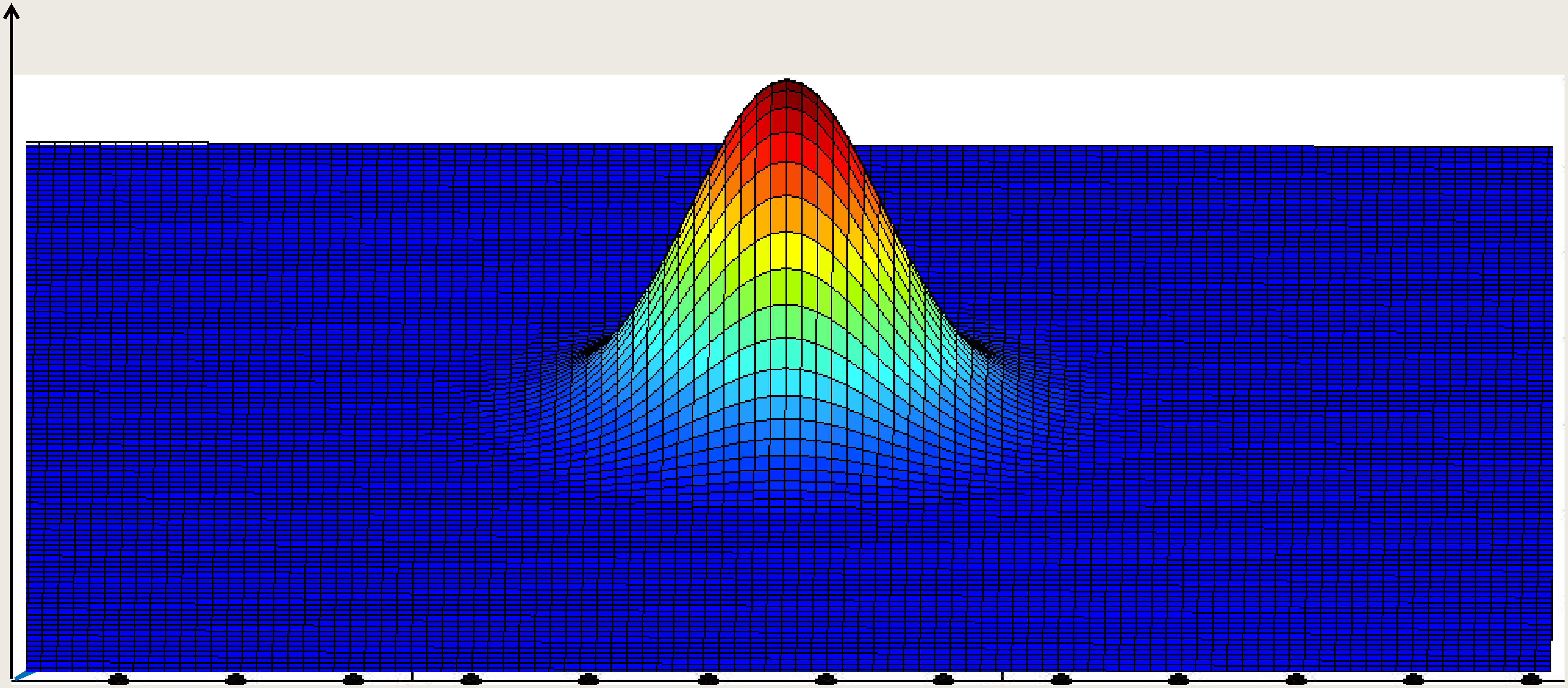
$$h_{bi}(t) = e^{-\frac{\|r_i - r_b\|^2}{2\sigma^2(t)}}$$

$$\alpha(t) = 0.1 e^{-(0.01t/T)}$$

$\sigma(t)$ Neighborhood width

t Iteration

Neighborhood training of the PVs – Step 2
Initial learning radius



Neighborhood Updating Rule

$$m_i(t+1) = m_i(t) + \alpha(t)\, h_{bi}(t)[x - m_i(t)] \quad \xrightarrow{if} \quad \left\| r_i - r_b \right\| \le \sigma(t)$$

$$m_i(t+1) = m_i(t) \quad \xrightarrow{if} \quad \left\| r_i - r_b \right\| \ge \sigma(t)$$

where ,

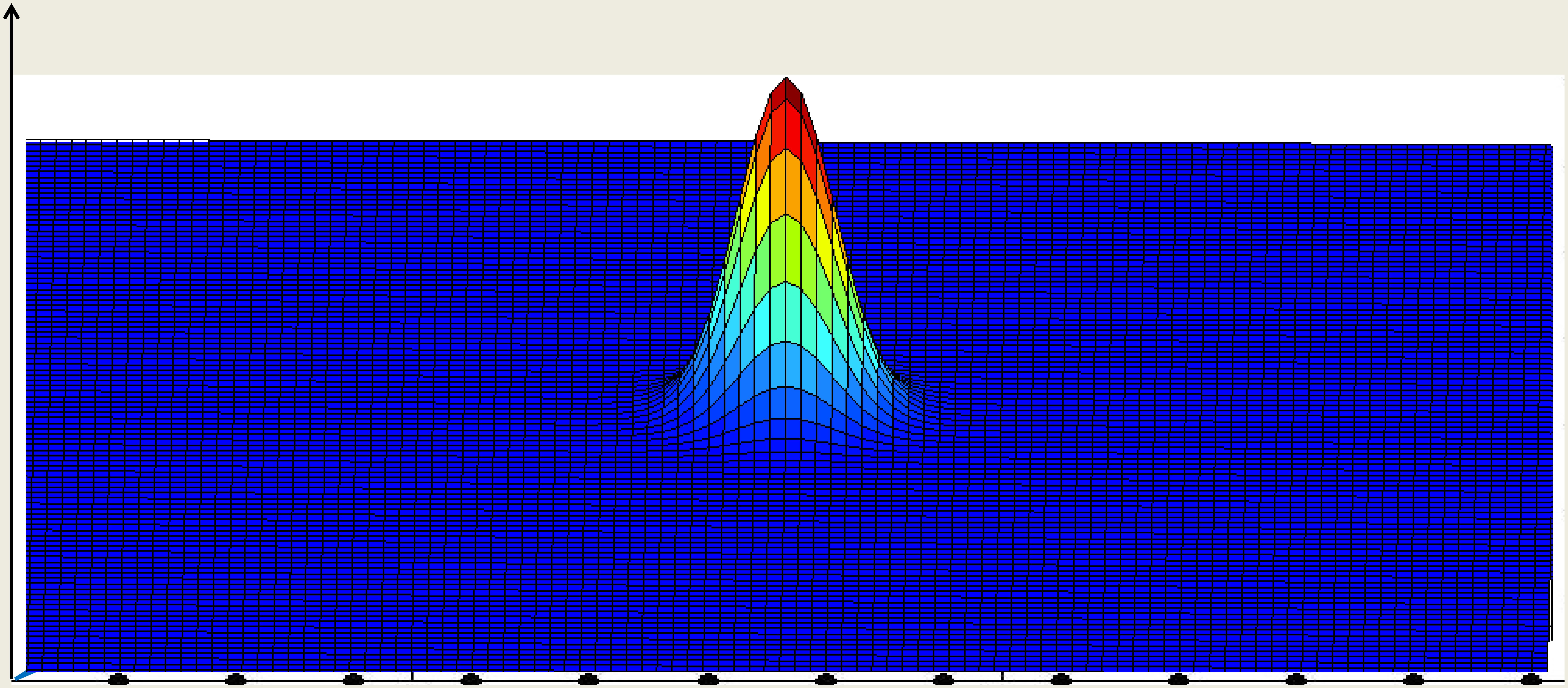
$$h_{bi}(t) = e^{-\frac{\left\| r_i - r_b \right\|^2}{2\sigma^2(t)}}$$

$$\alpha(t) = 0.1 e^{-(0.01t/T)}$$

$\sigma(t)$ Neighborhood width

t Iteration

Neighborhood training of the PVs – Step 2 Initial learning radius – decreasing with iterations



Neighborhood Updating Rule

$$m_i(t+1) = m_i(t) + \alpha(t)\, h_{bi}(t)[x - m_i(t)] \xrightarrow{if} \|r_i - r_b\| \le \sigma(t)$$

$$m_i(t+1) = m_i(t) \xrightarrow{if} \|r_i - r_b\| \ge \sigma(t)$$

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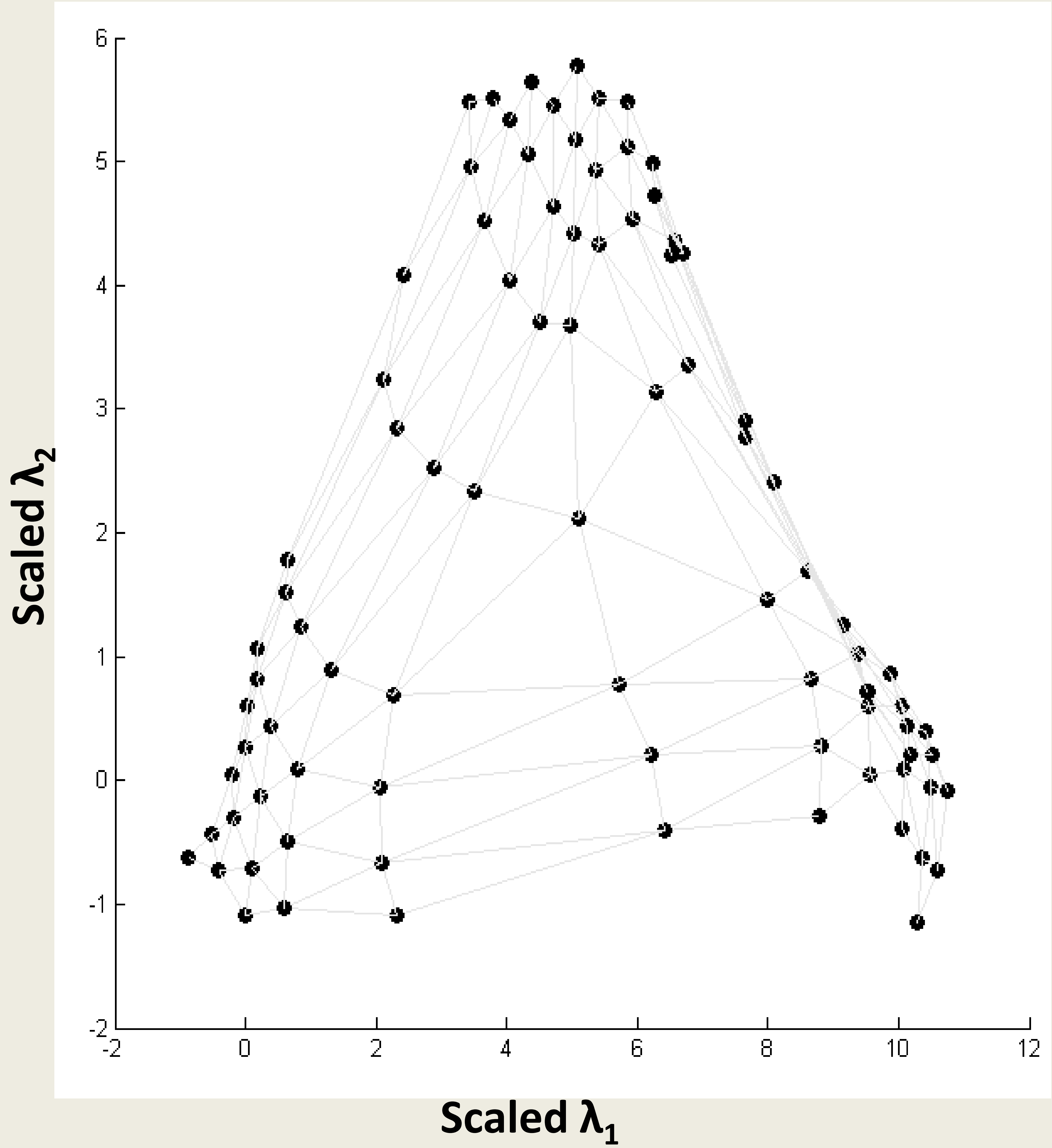
$$\alpha(t) = 0.1e^{-(0.01t/T)}$$

$\sigma(t)$ Neighborhood width

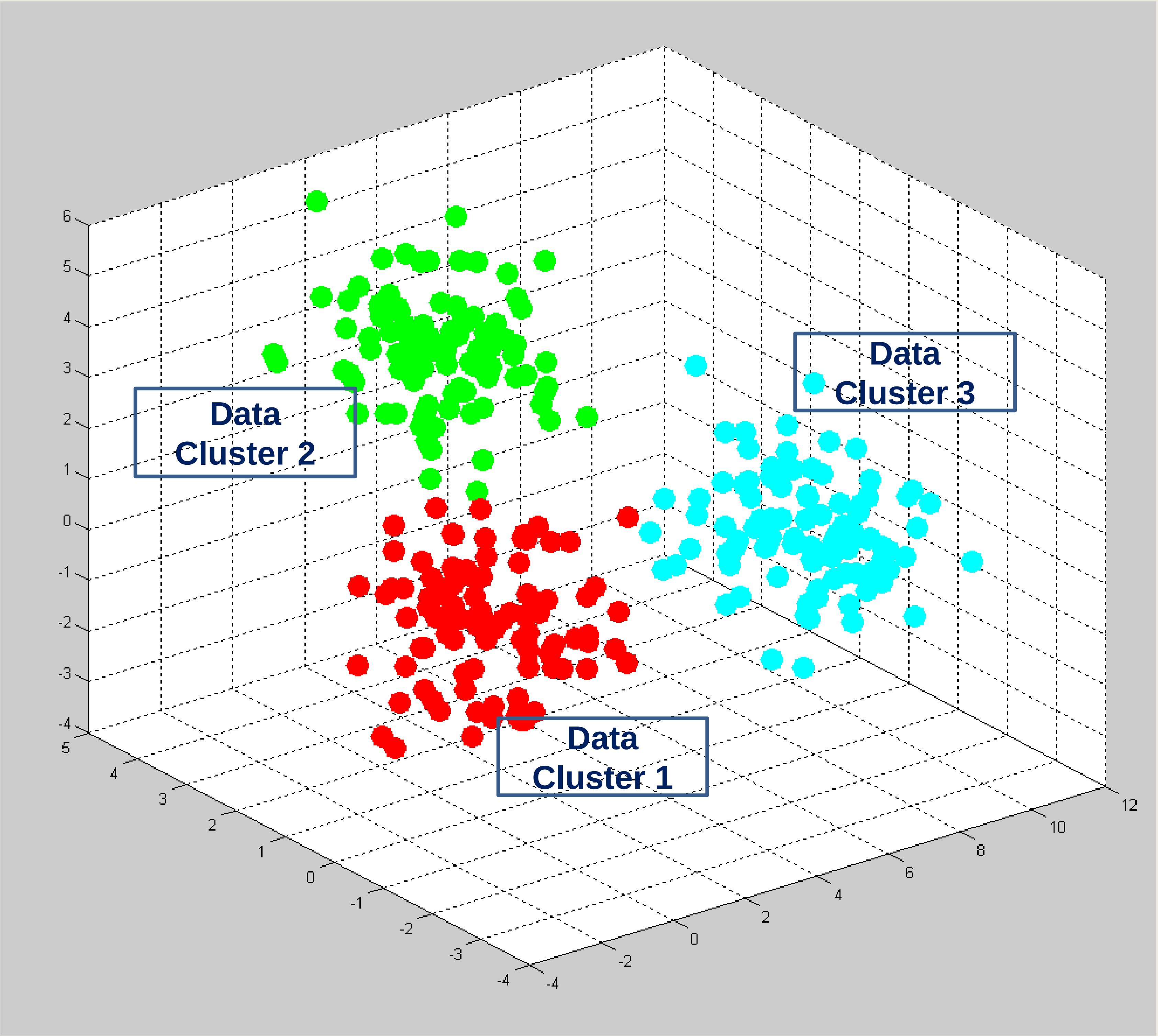
t Iteration

Classification of the input data

Trained PVs

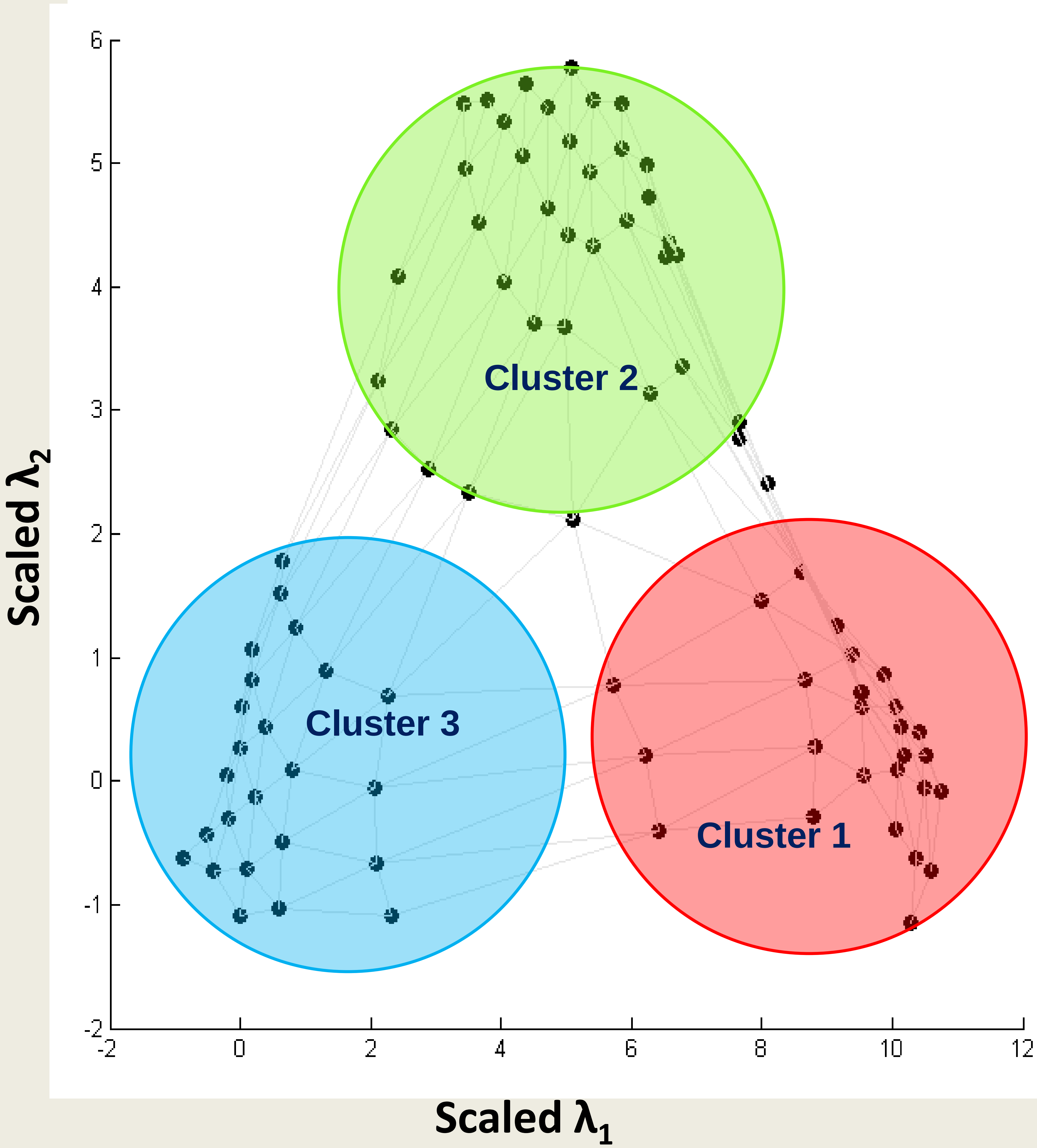


Color-coding the input according to the trained clusters

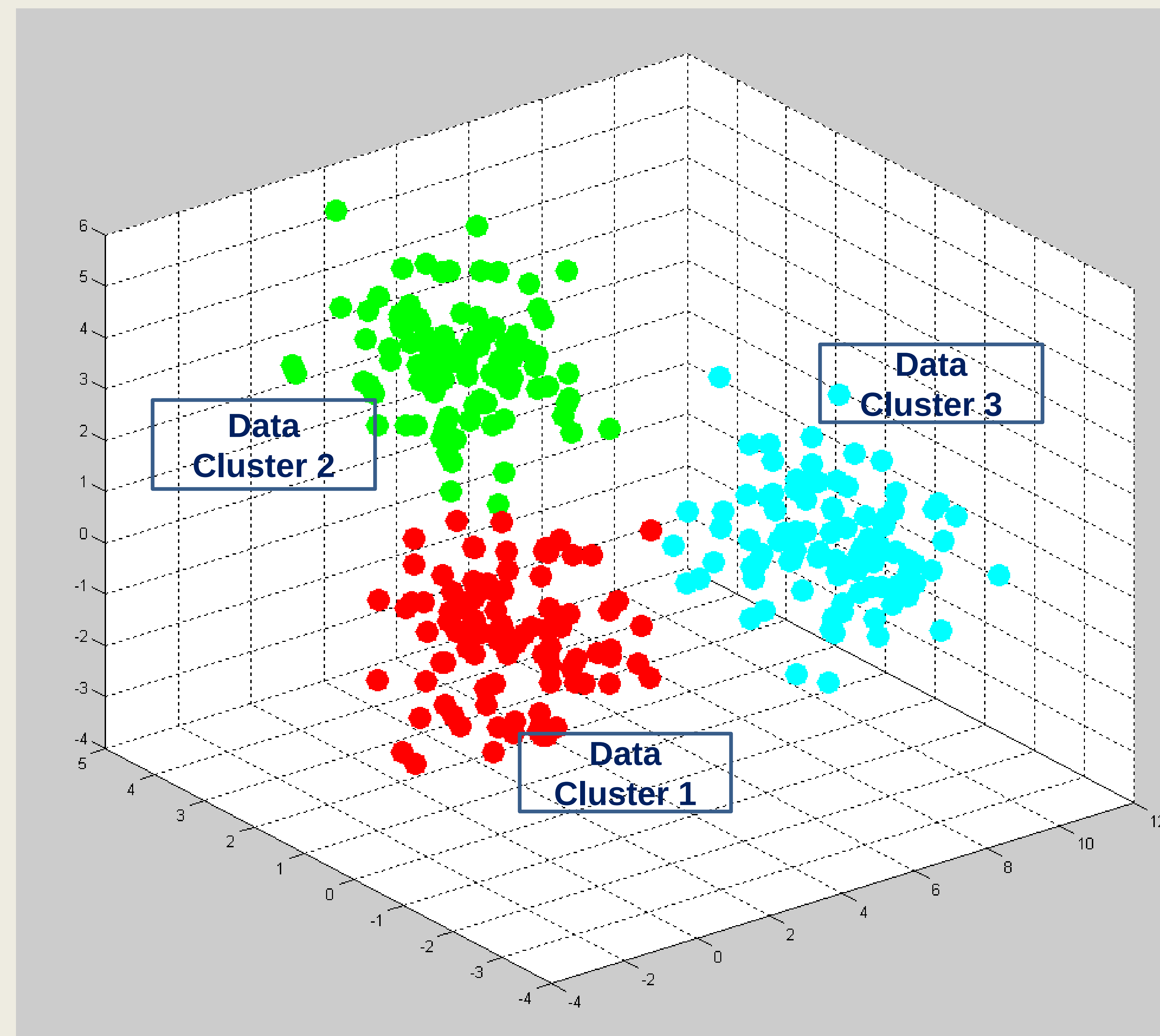


Classification of the input data

Assigning colors to different Clusters



Color-coding the input according to the trained clusters



Visualization scheme used in our analysis : Assigning 2D gradational HSV Colors to the clustered PVs

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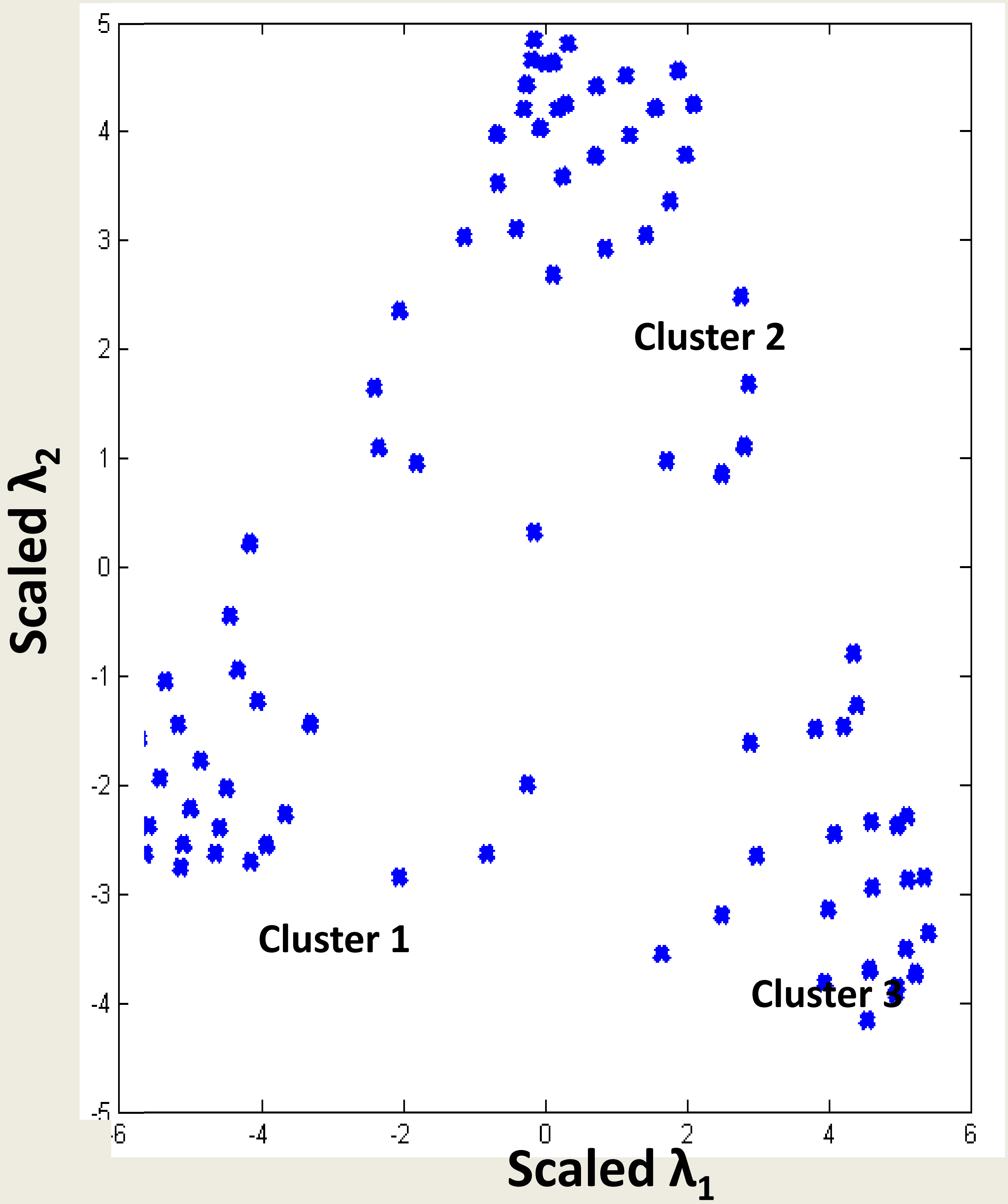
Trained PVs



(Matos 2009)

Visualization scheme used in our analysis : Assigning 2D gradational HSV Colors to the clustered PVs

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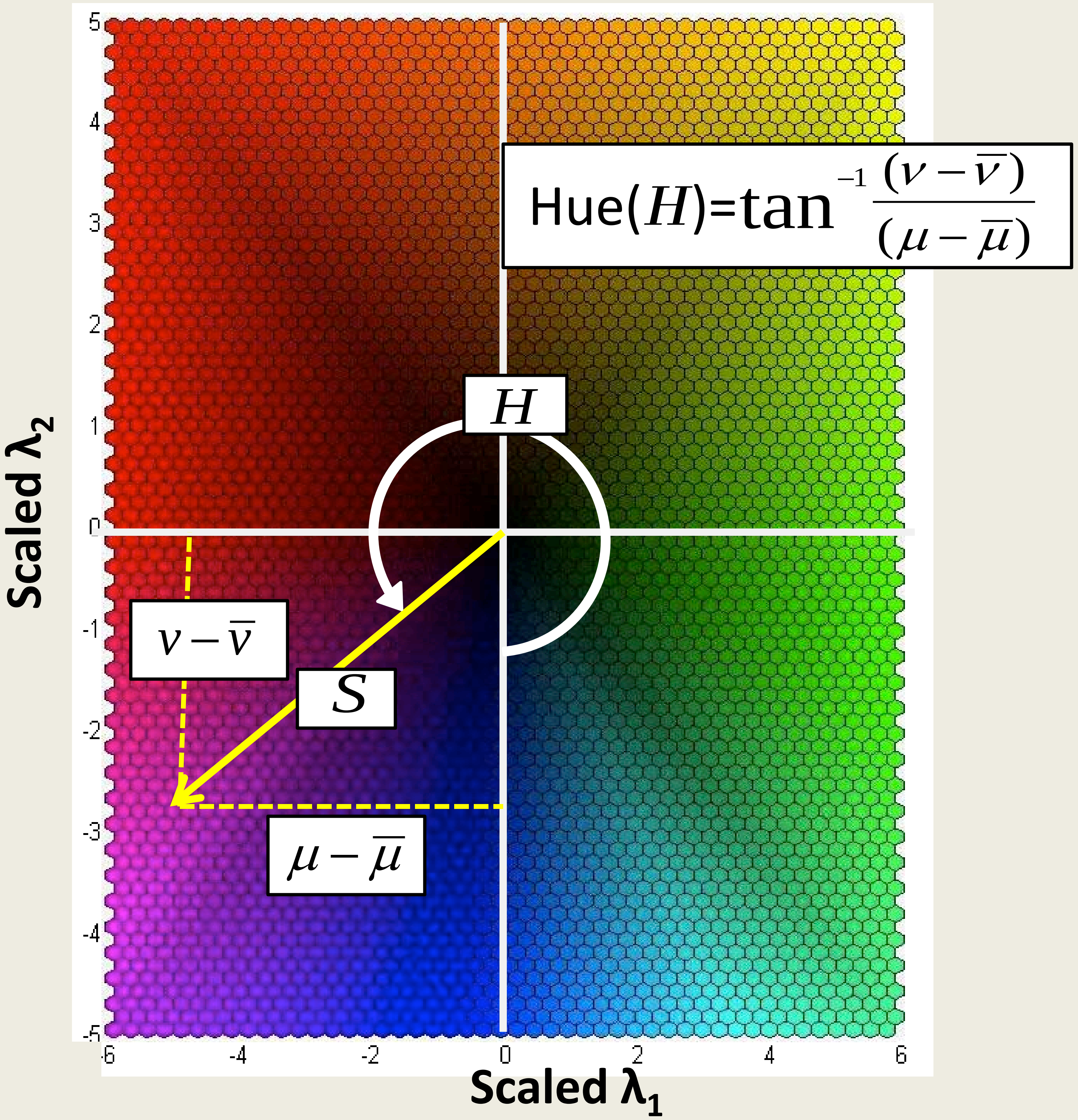
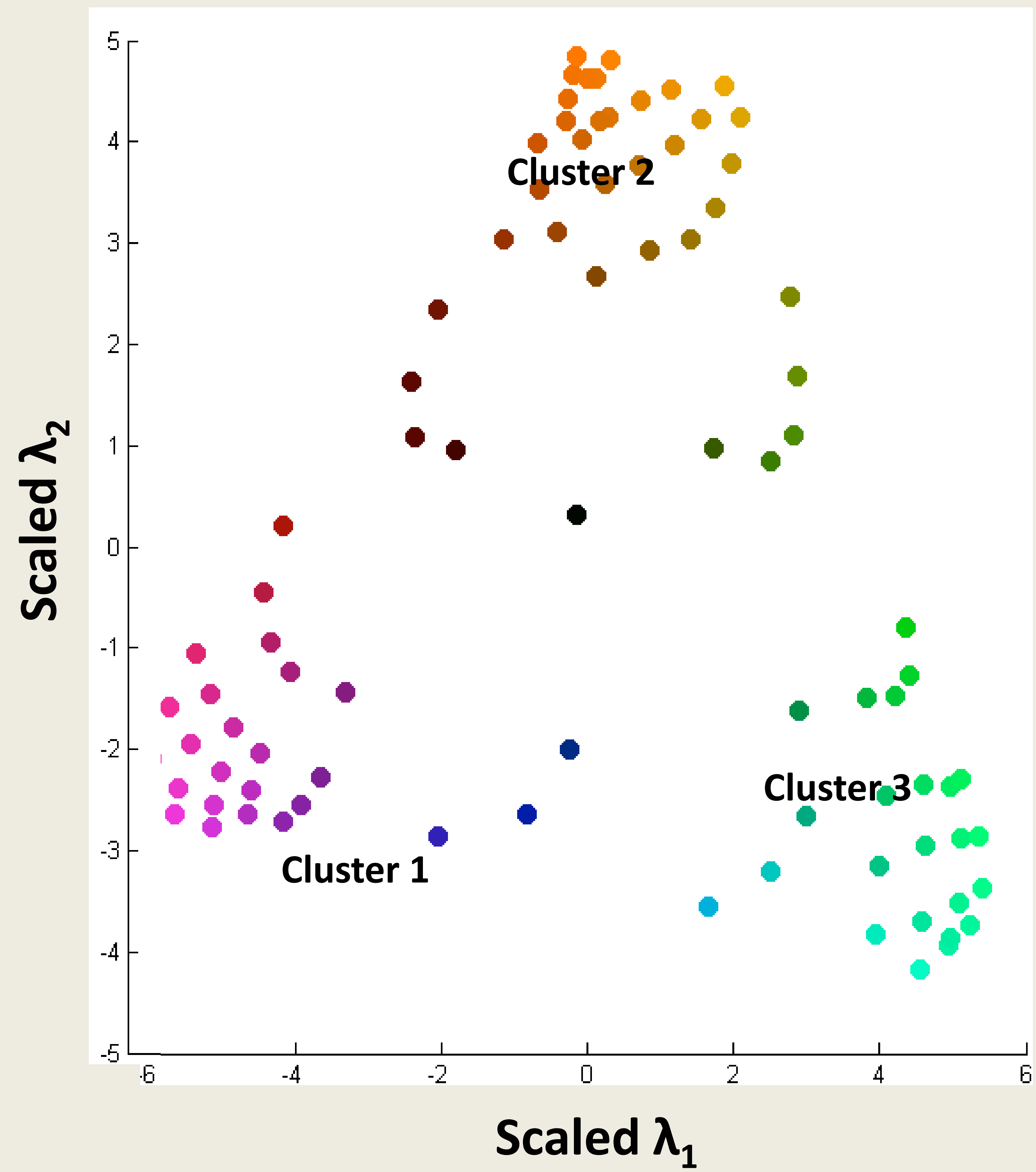
Trained PVs



$$\text{Saturation }(S)=\sqrt{\left[(\mu-\bar{\mu})^2+(\nu-\bar{\nu})^2\right]}$$

HSV colors assigned



(Matos 2009)

3D multi-attribute SOM clustering analysis

3D SOM Analysis – a schematic

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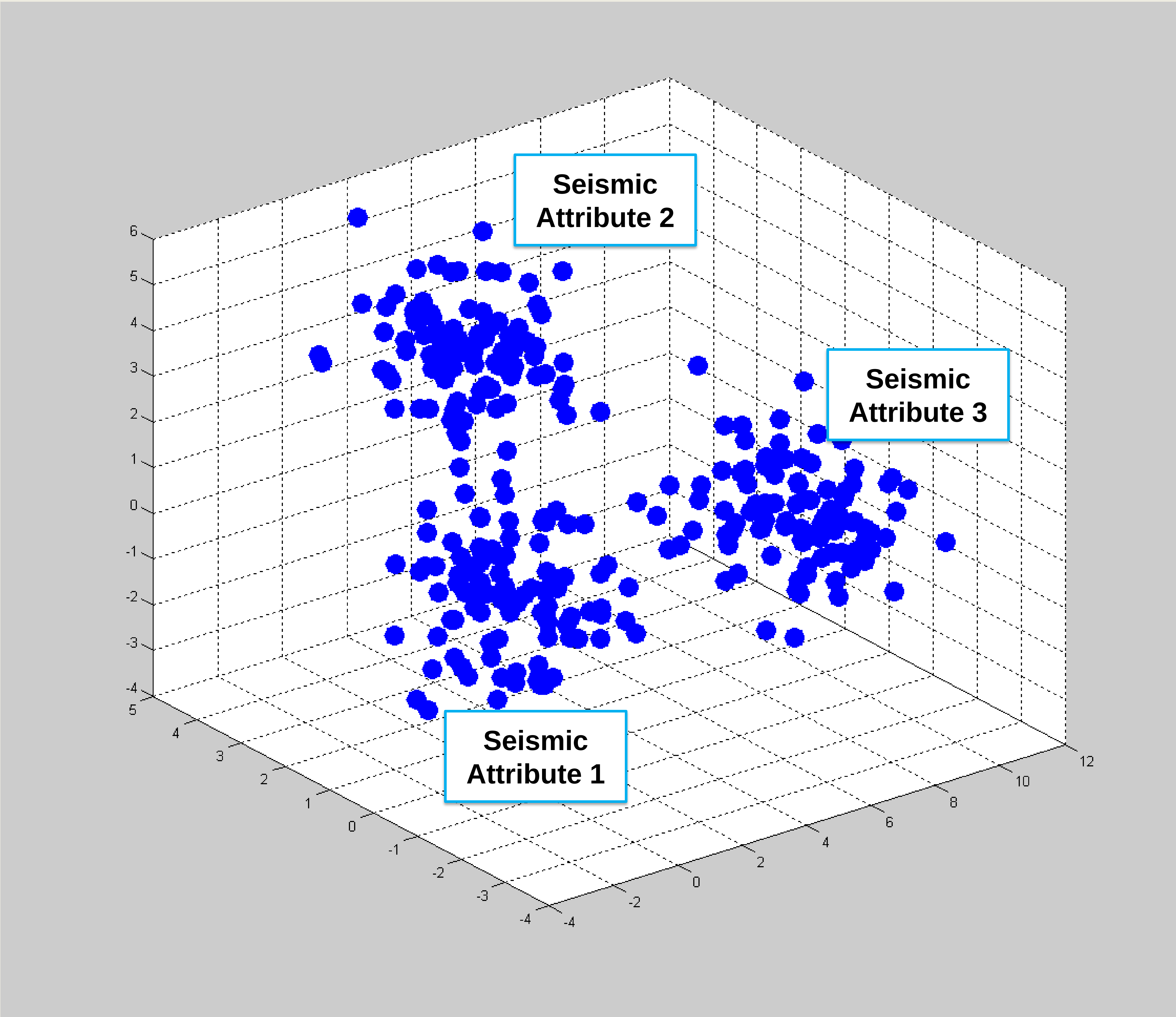

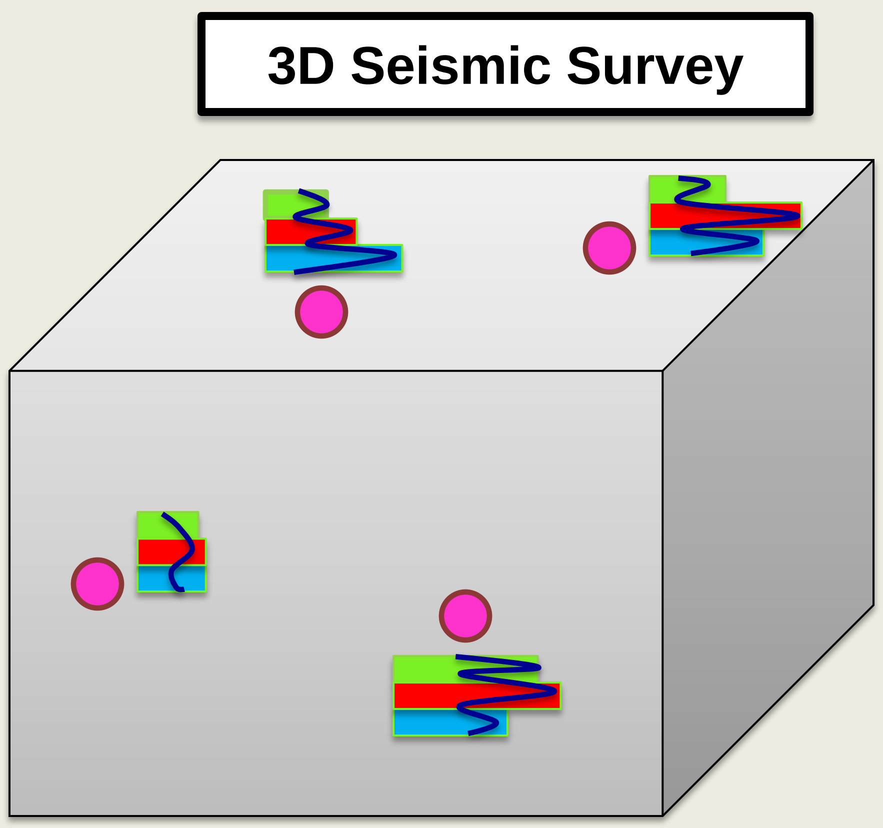

Thus each location of the 3D data can be represented by a vector Ψ_{ij}

where
i= n traces &
j= 1,2,3

Step 1: Seismic Data Normalization

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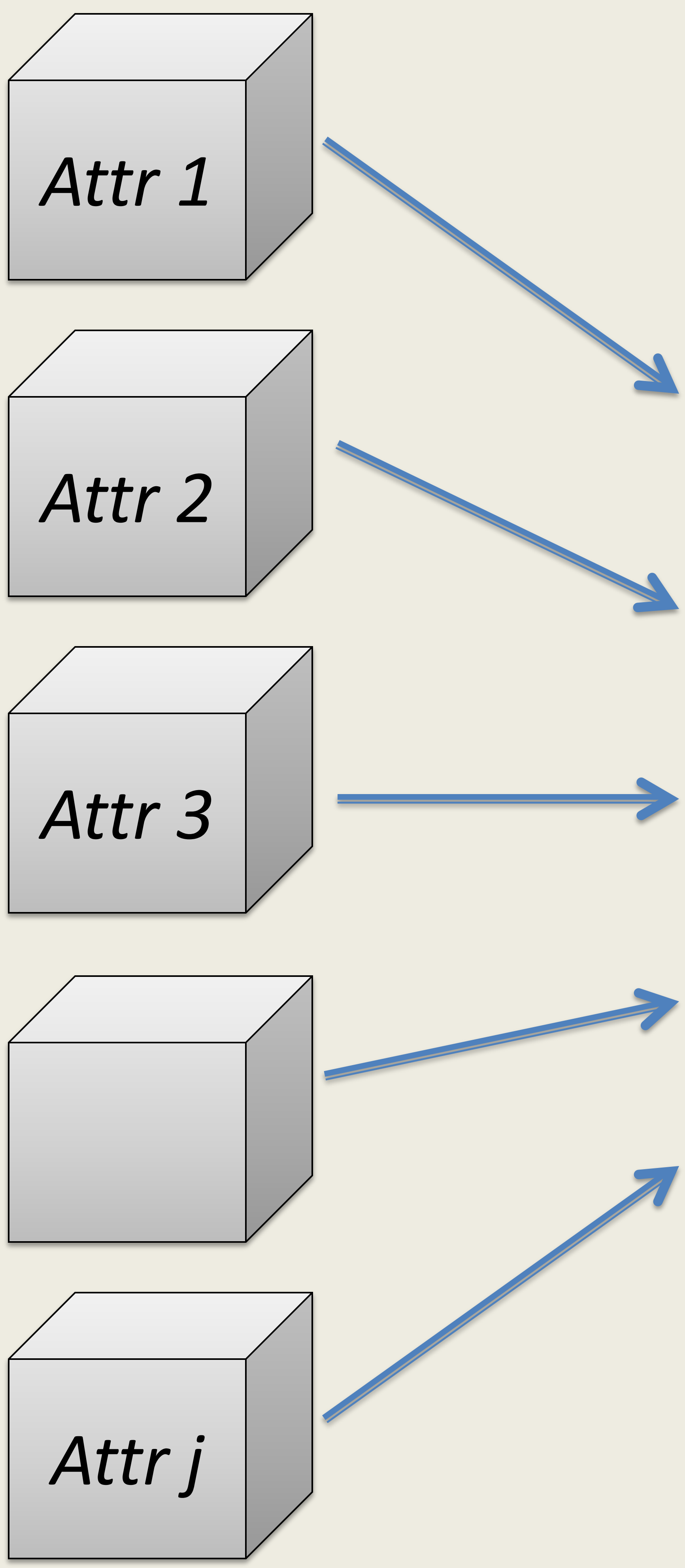
j Attribute Volumes



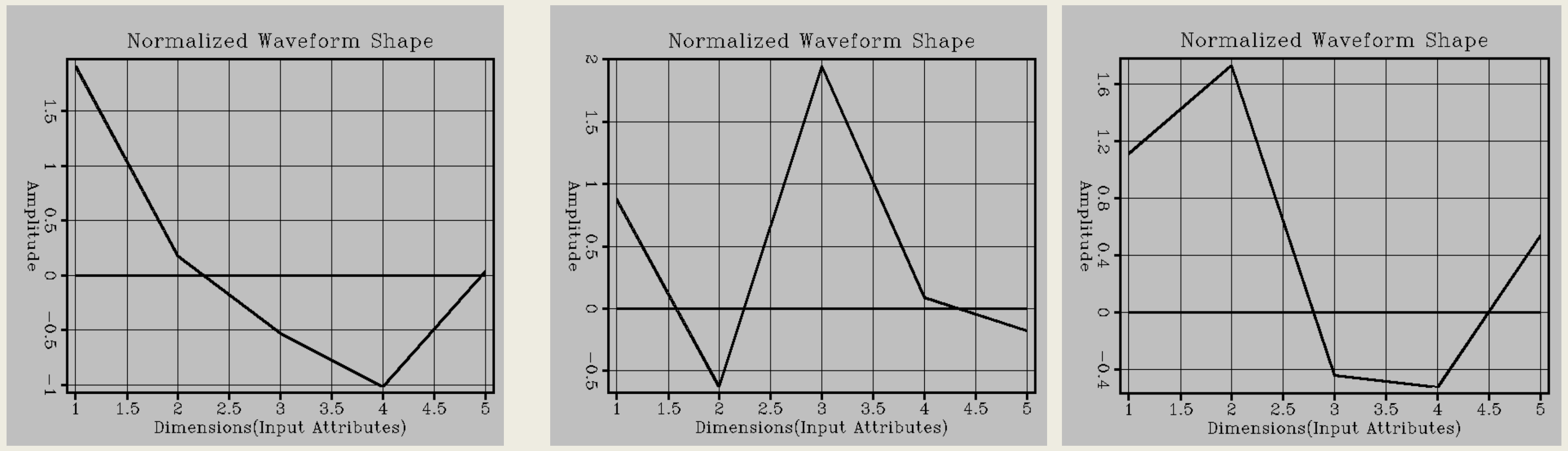
Normalize and store the different attributes values to each sample location *(x, y, z)* in the dataset

$$(x_{i,}y_i, z_i, \Psi_{ij}) \xrightarrow{where} i = ntraces \quad \xrightarrow{where} j = nattributes$$

"4D dataset"

With each *(x, y, z)* location is a *j* dimensional vector equal to the *j* number of input attributes taken

Normalized waveform shapes Ψ_{ij} at $(x_{i,}y_i, z_i)$



Step 2: Creating the initial 2D map of PVs

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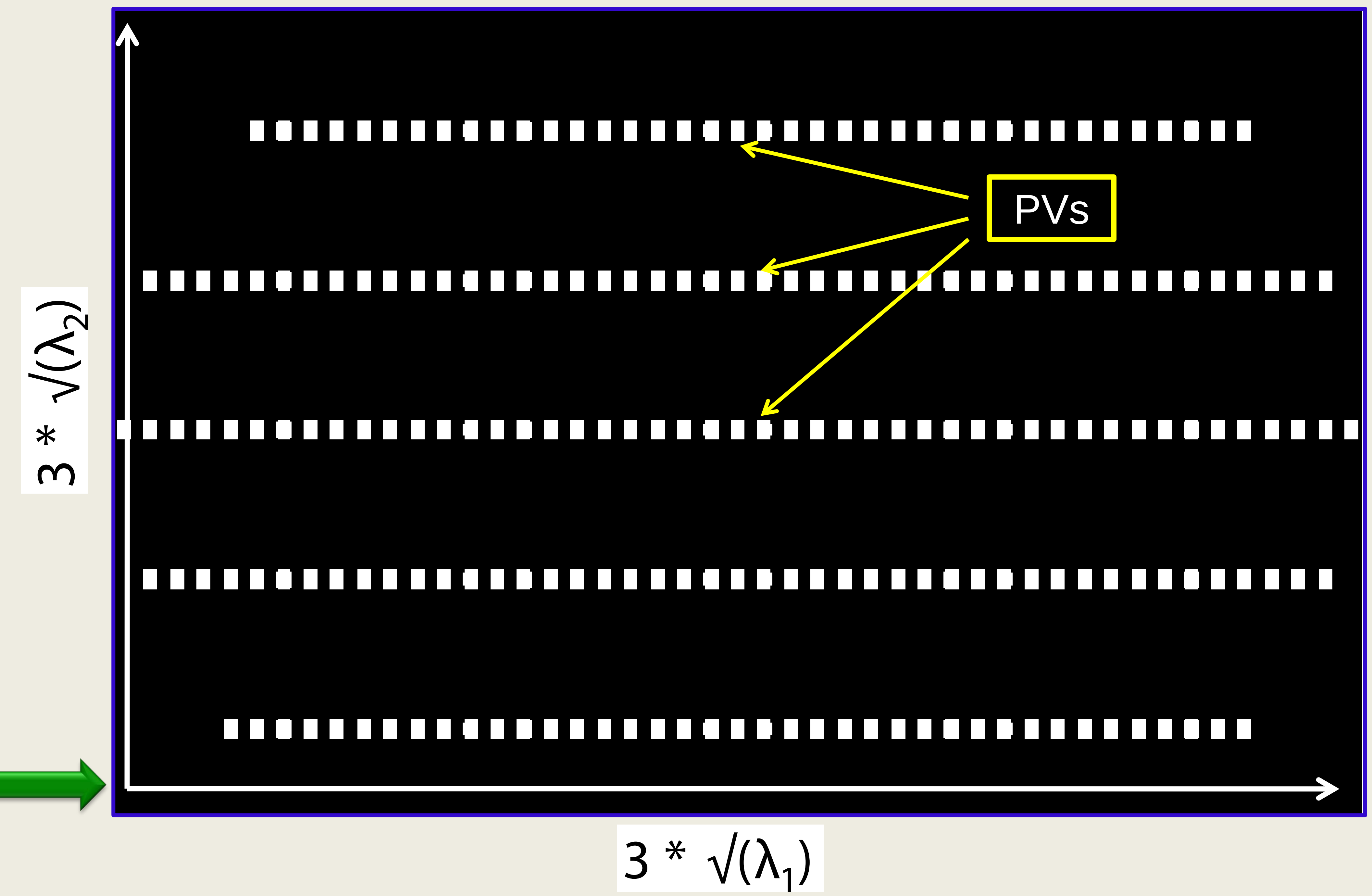
Form a Covariance Matrix with the “4D dataset”

Principal Component analysis with the “4D dataset”

Calculate the 1st two eigenvalues and eigenvectors

Project the 2 eigenvectors into this 2D latent space defined by the 2 eigenvalues

2D Map of Untrained PVs



Form a 2D map of initial prototype vectors which will be trained with SOM neighborhood training rule

Step 3: Creating the seismic facies volume

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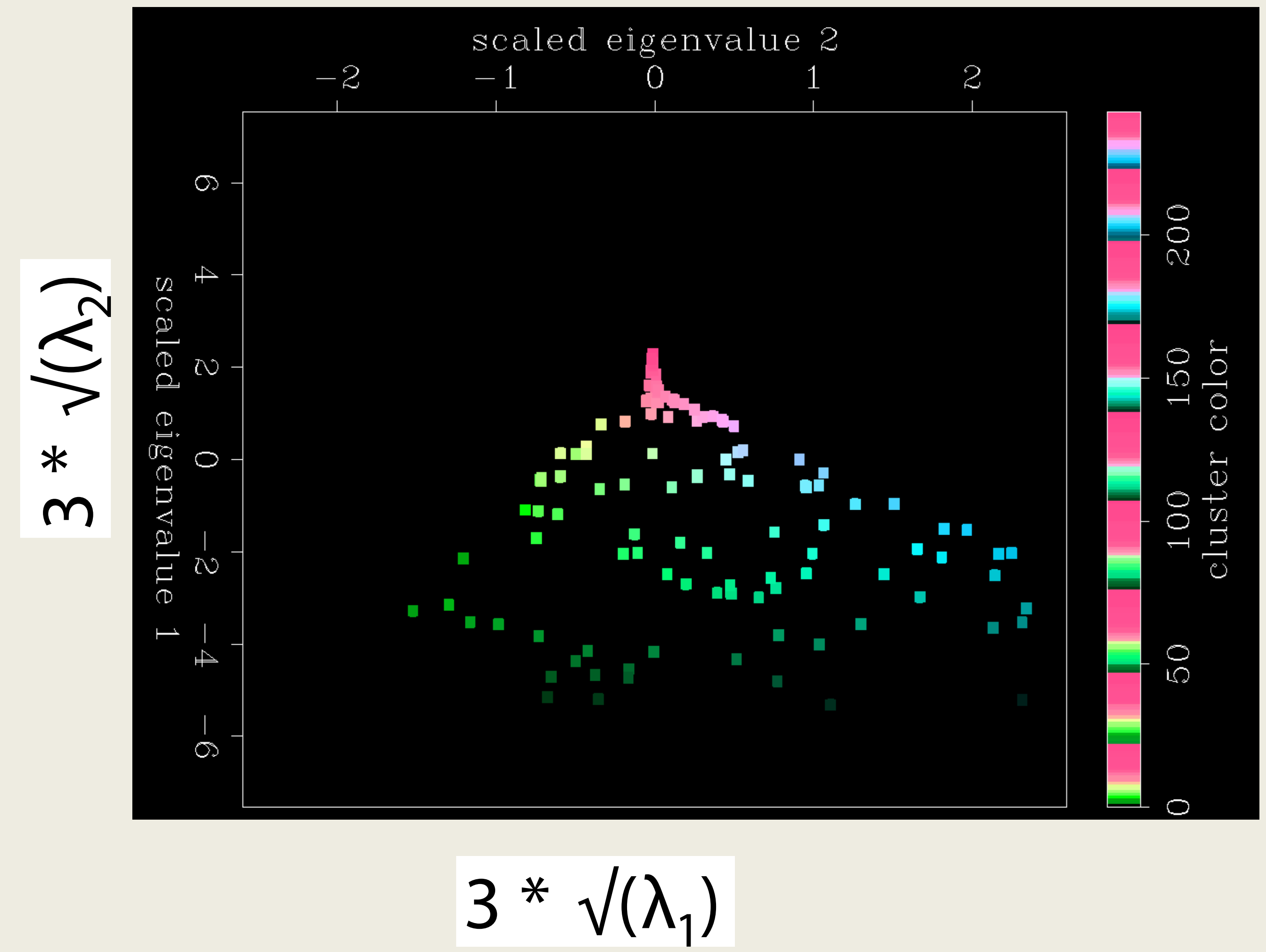
Finish Training of the PVs to form clusters

↓

Colorcode the latent space with 2D HSL colorscale →



↓

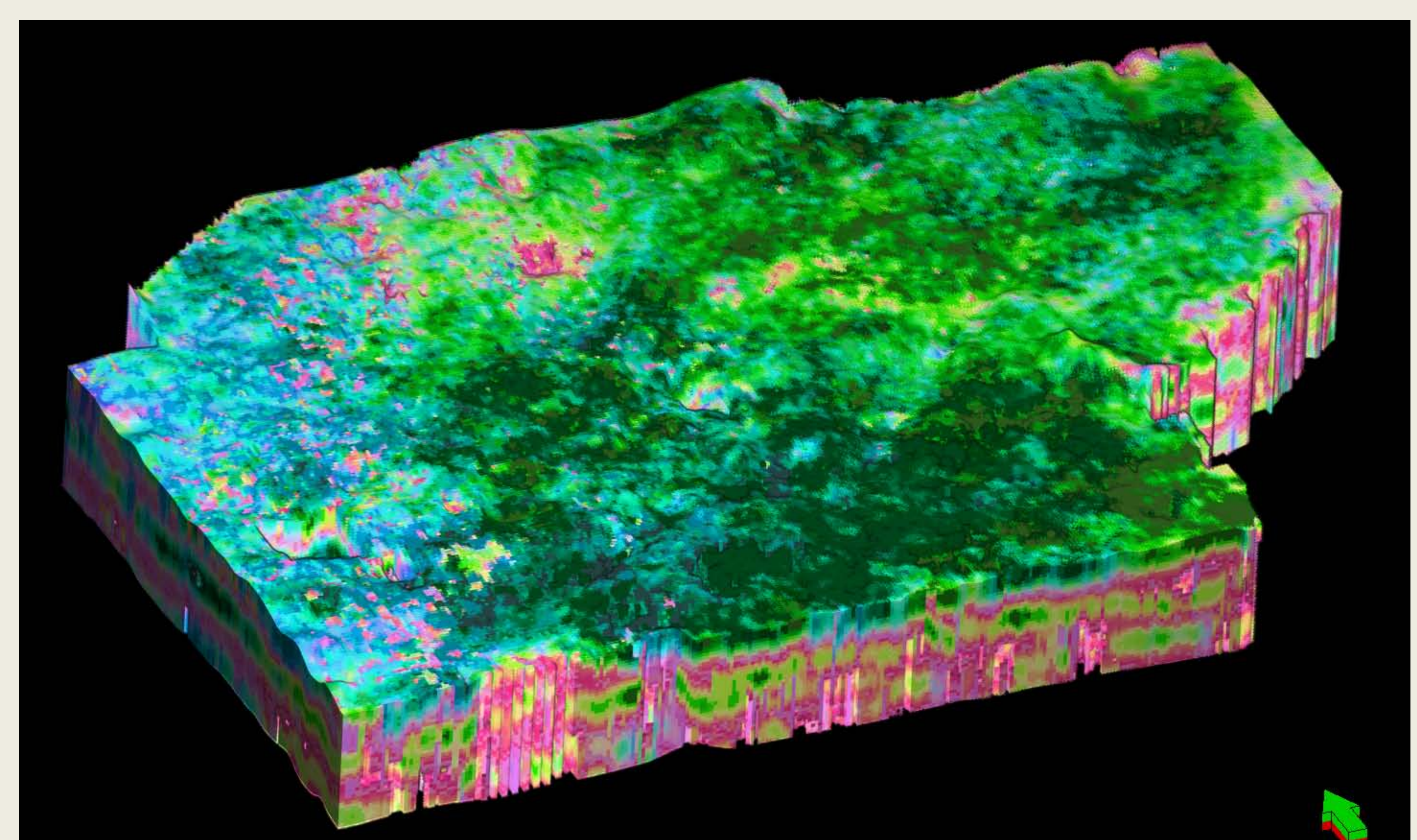
The trained PVs are compared back to each $(x_{i,} y_i, z_i)$ location

↓

Each sample $(x_{i,} y_i, z_i)$ is colorcoded according to the most similar trained PVs

↓

Output Seismic Facies 3D Volume →



3D Multi-attribute cluster analysis on Osage County 3D dataset

General Stratigraphy of Osage County

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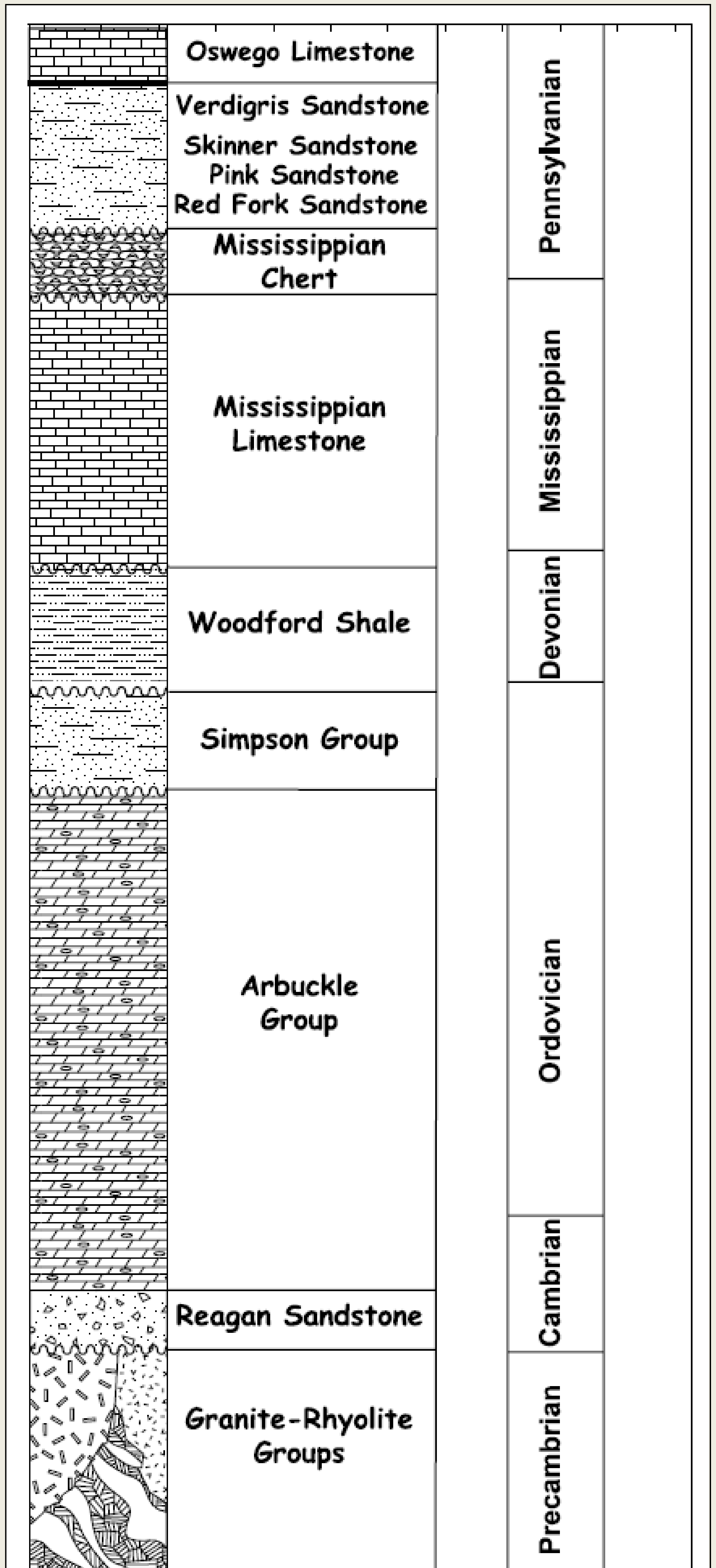
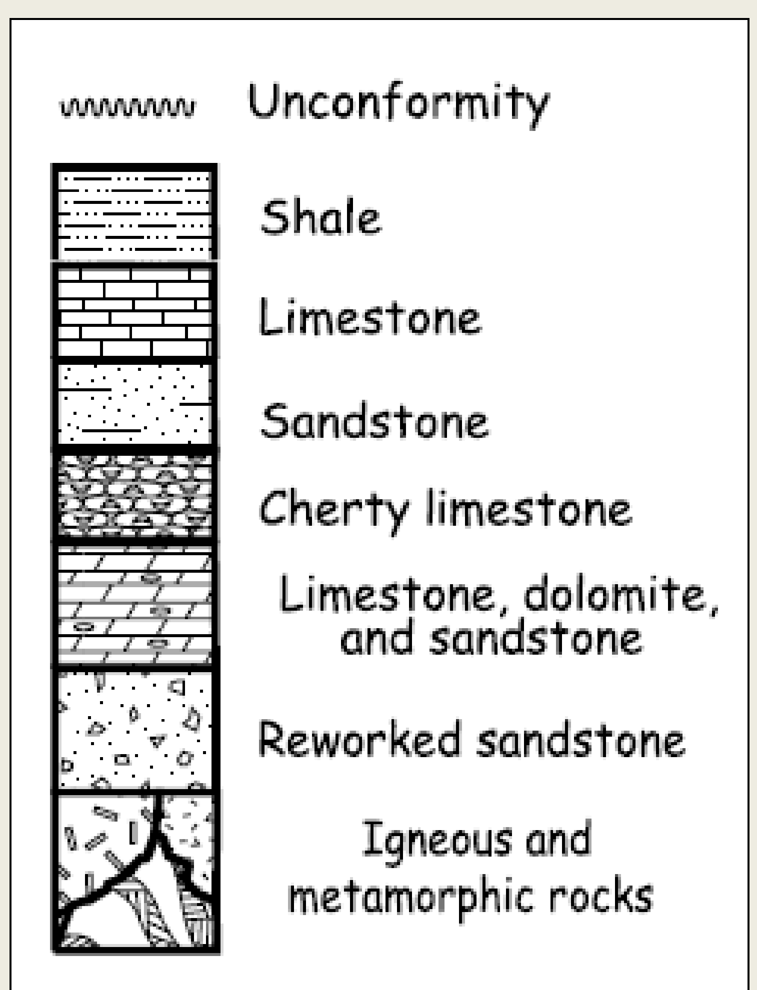
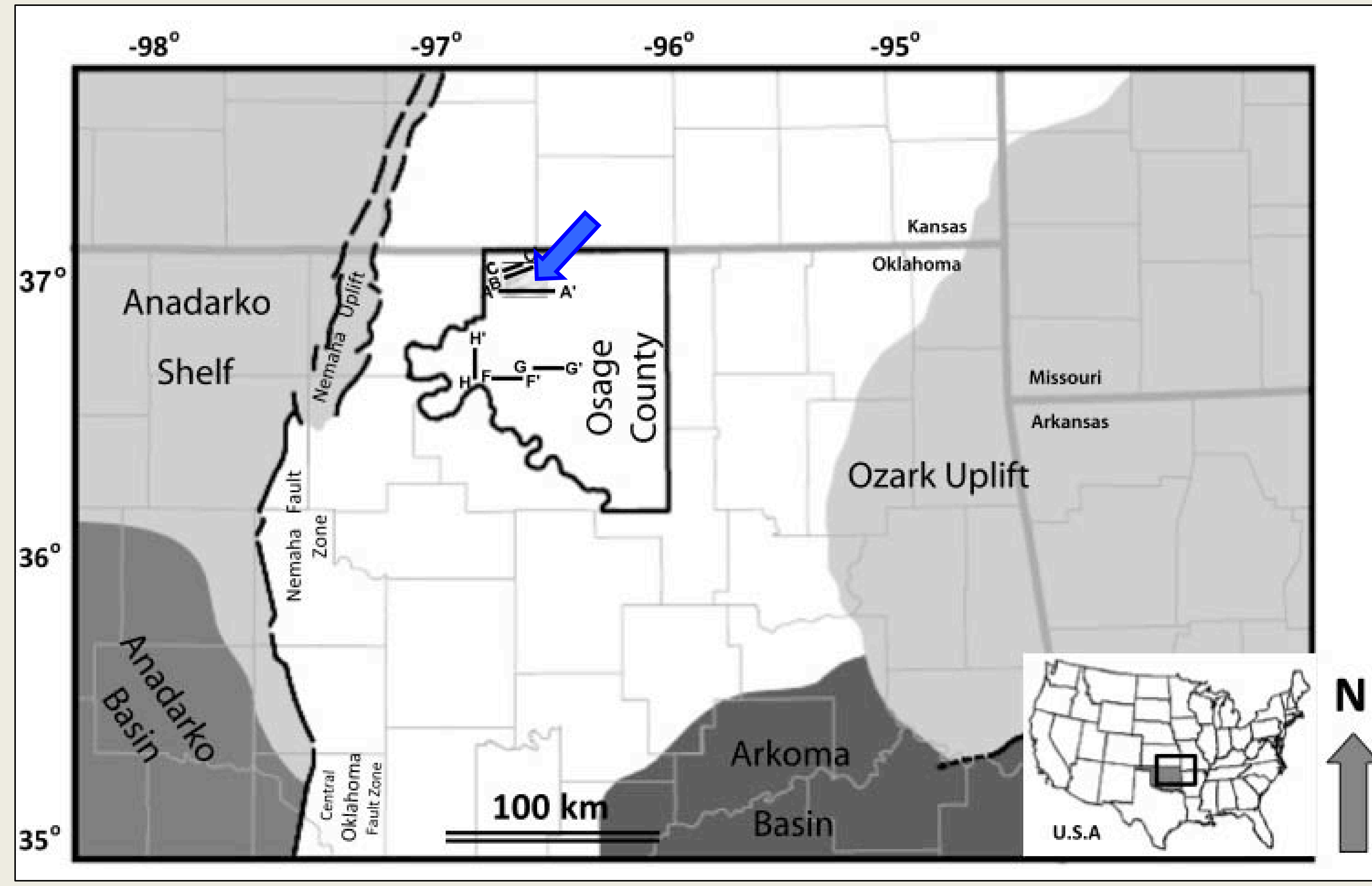




Zeller (1968), Thorman and Hibpshman (1979) and Franseen et al., 2004

Major Geologic province in Oklahoma , Osage County and survey location



Modified from Northcutt and Campbell (1995)

3D Multi-attribute Analysis – Case 1

Main features to identify: **Facies distribution within the survey.**

Volumetric attributes: 3D volumes used for the analysis

1) Peak frequency Magnitude
2) Sobel filter similarity
3) Coherent Energy
4) Texture Attribute 1 (GLCM Variance)
5) Texture Attribute 2 (GLCM Entropy)

→ **3D Multiattribute Analysis and coloring of the each sample location** $(x_{i,}y_i, z_i)$

→ **Output 3D seismic Facies Volume**

Seismic Section

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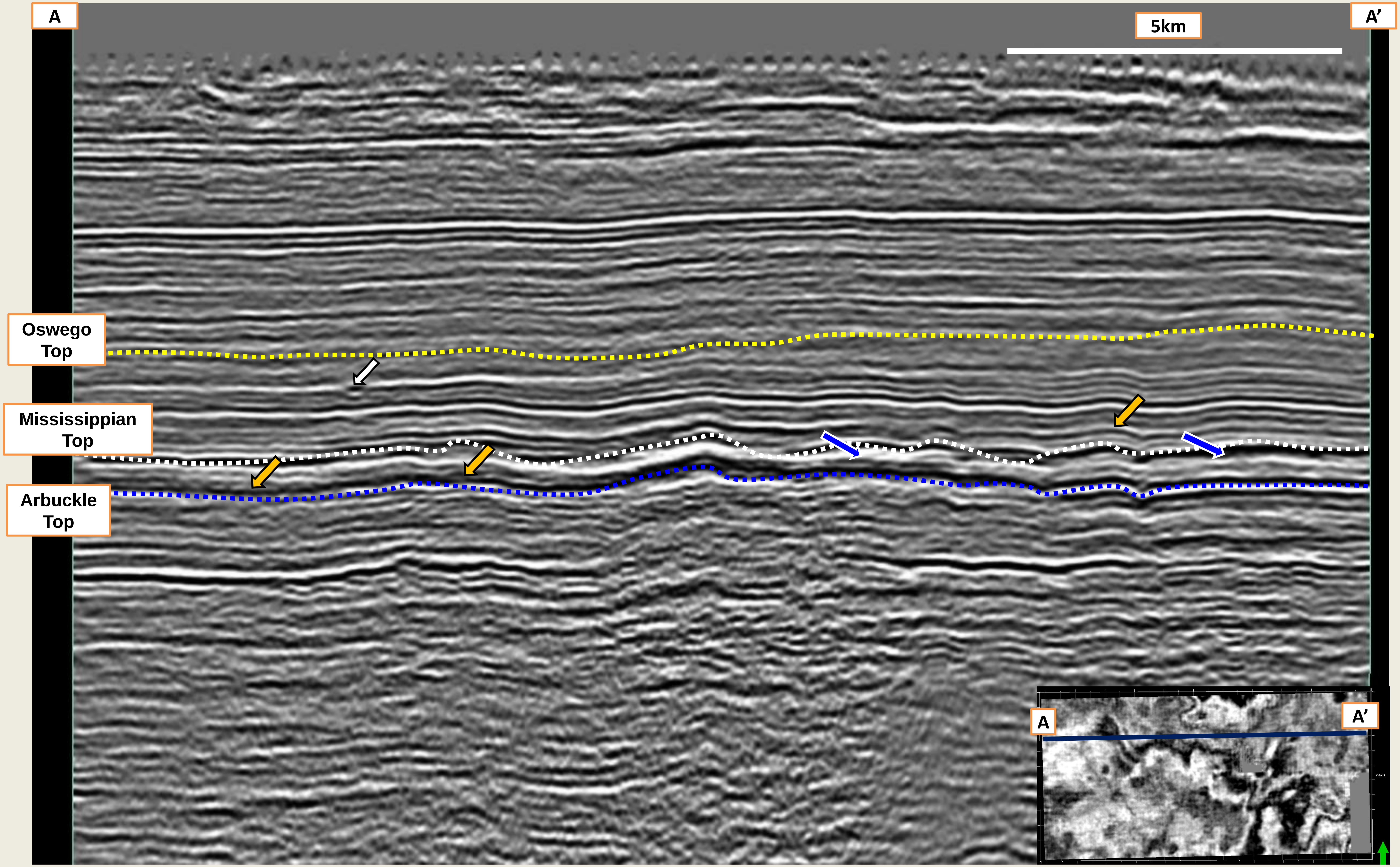

Seismic Section overlayed by the seismic facies classified section

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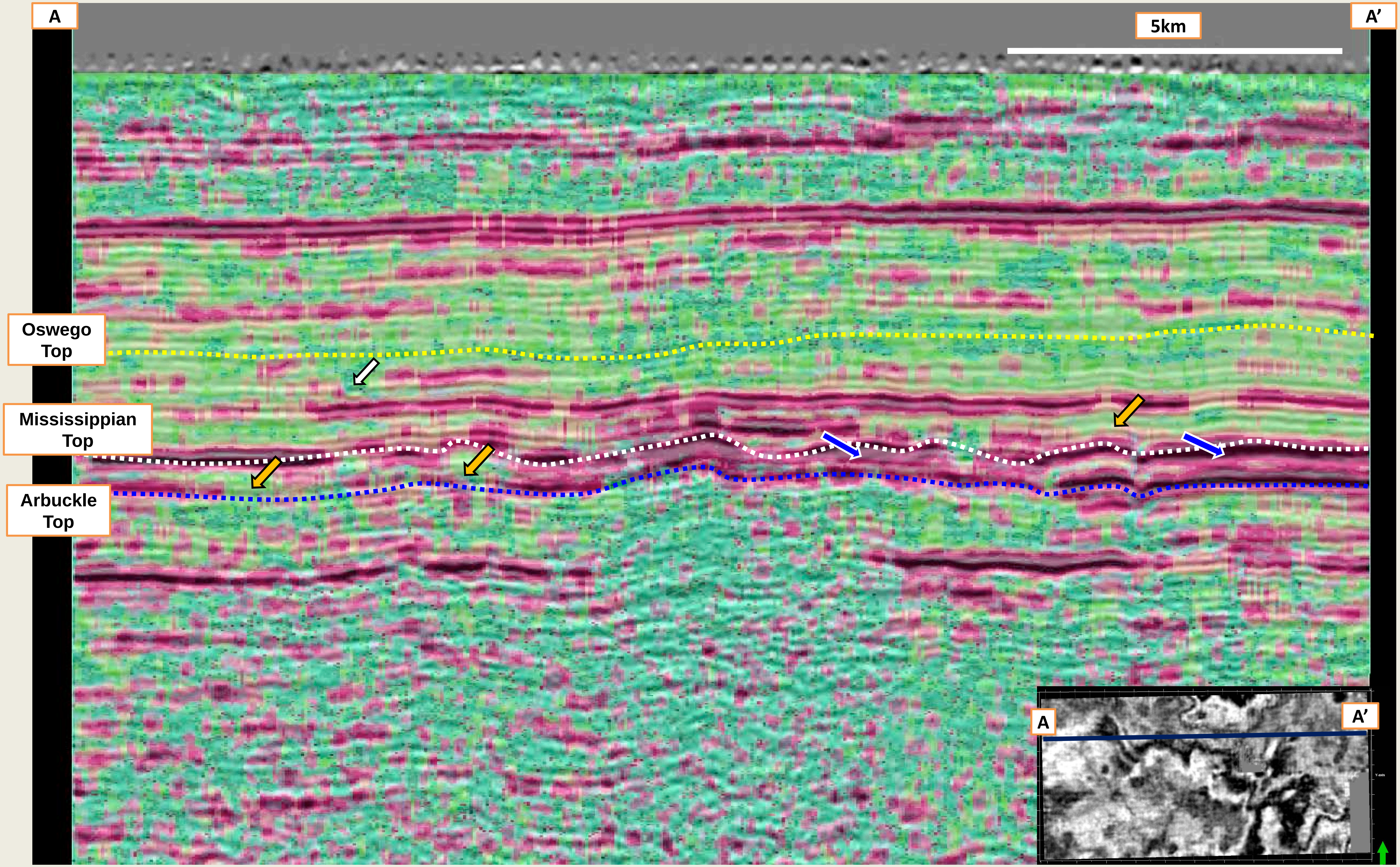

3D multiattribute analysis : Average waveforms of different formations

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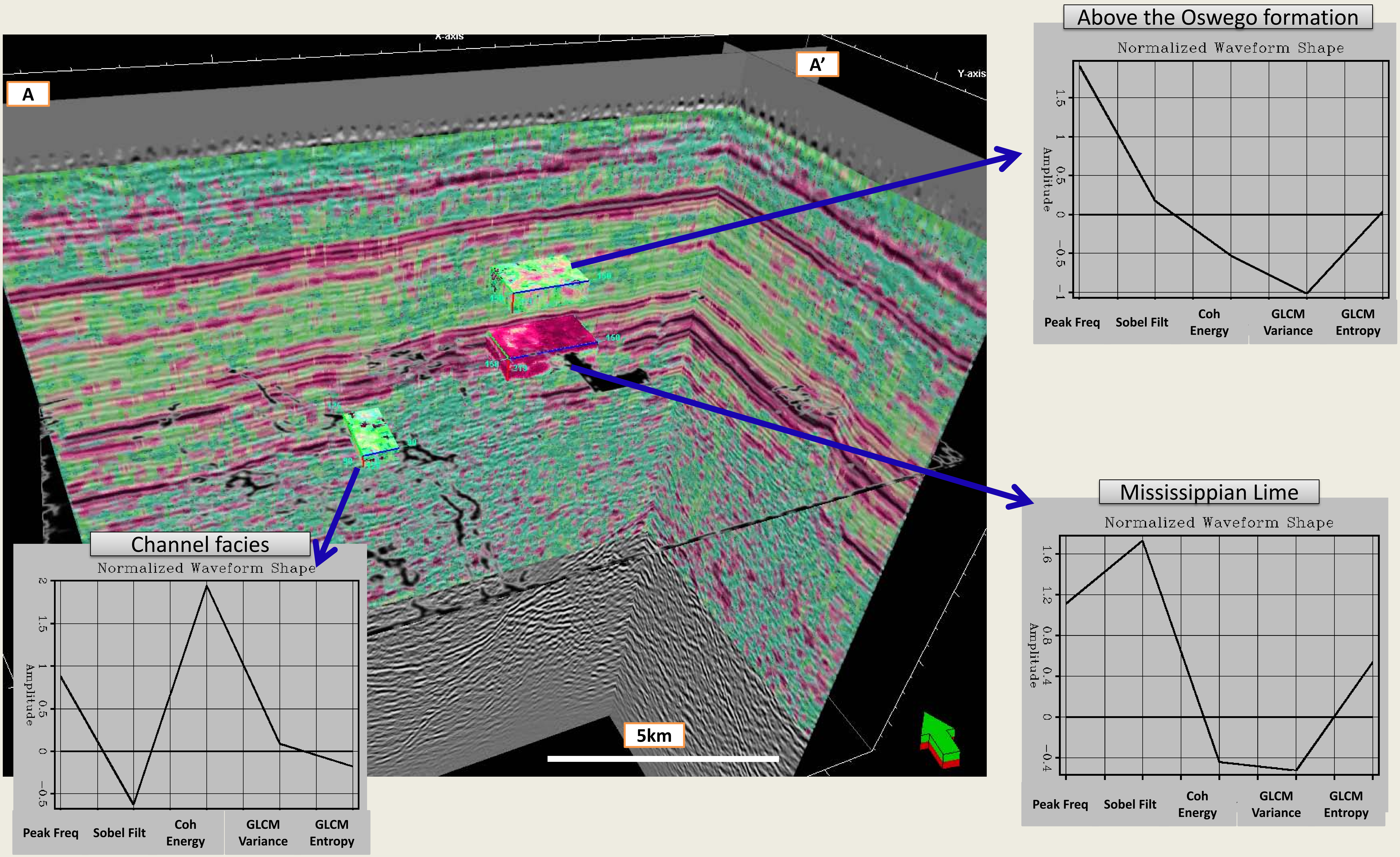

The seismic facies volume overlain by the coherency cube

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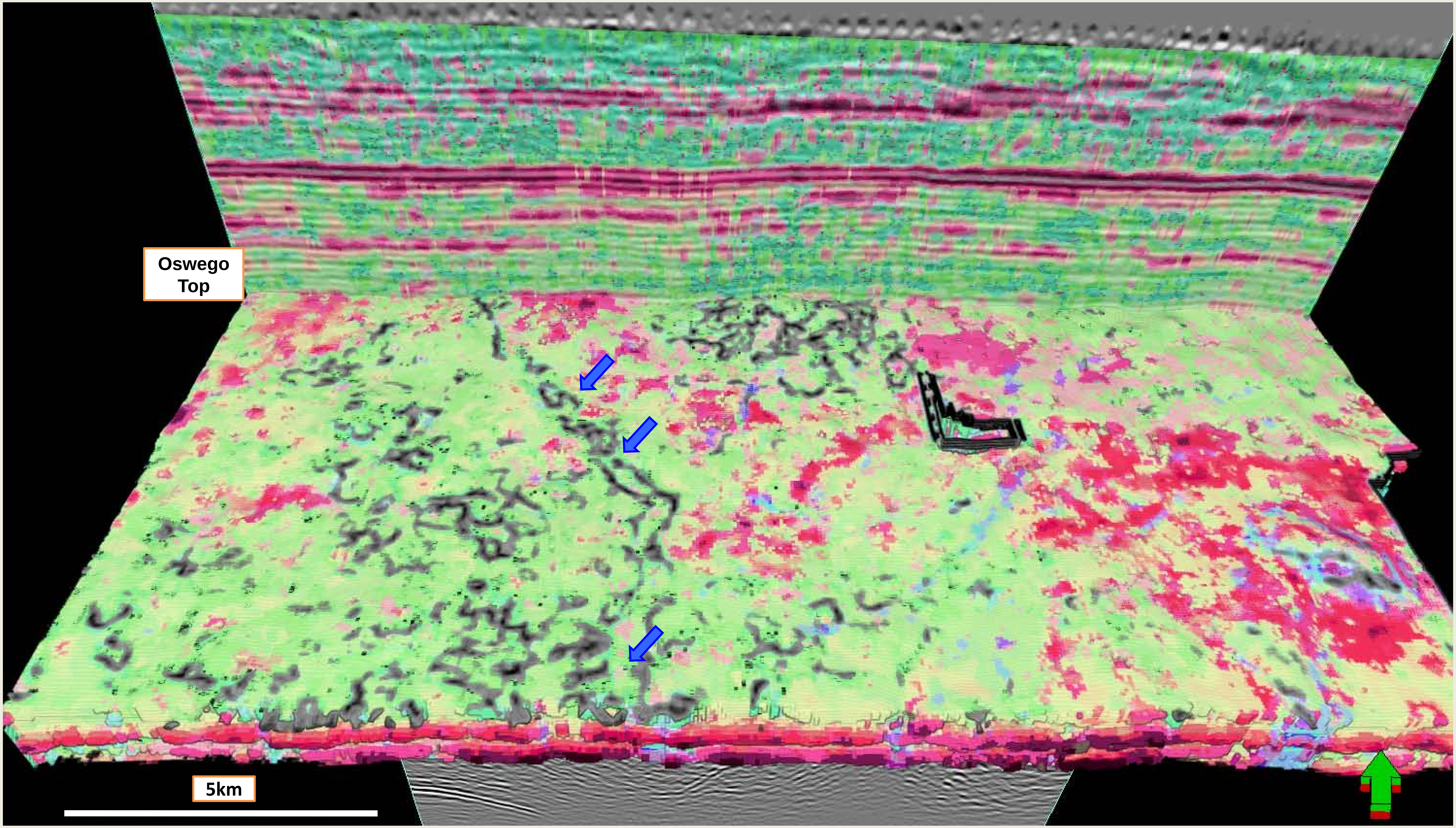

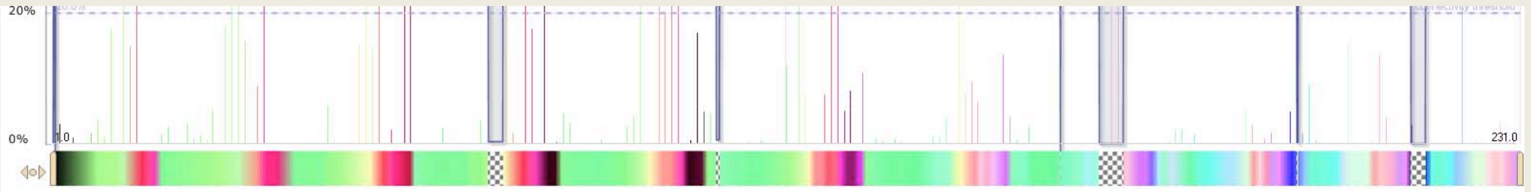

3D seismic facies volume of the Mississippian Lime and the Chert formation

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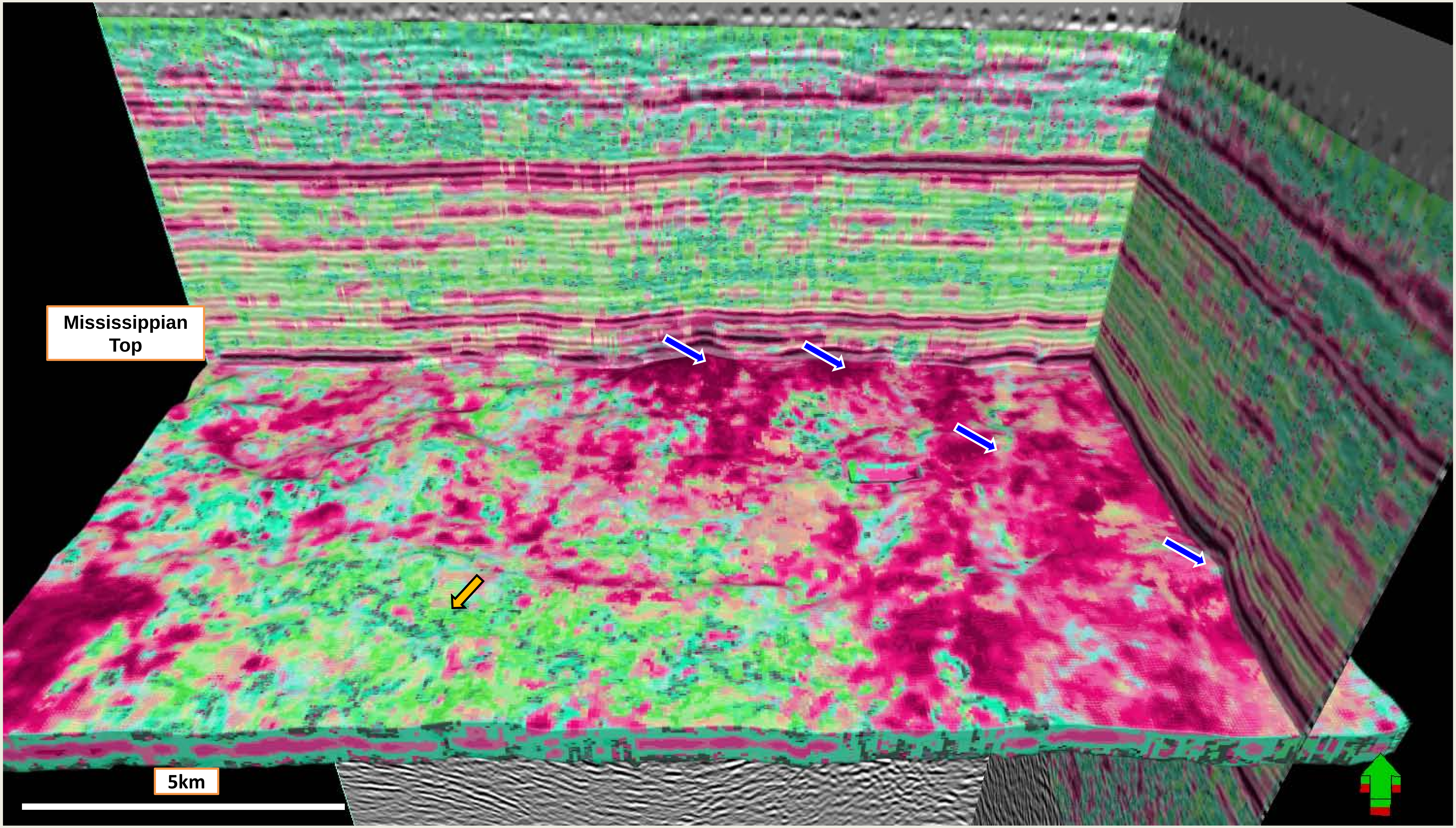

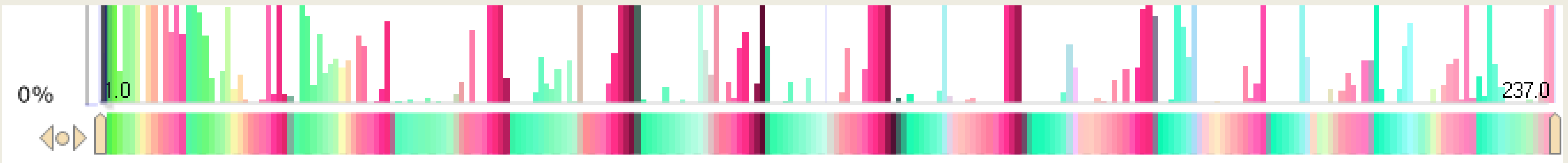

3D Multi-attribute Analysis – Case 2

Main features to identify: Different lithological settings within the survey. Comparing the seismic facies volume from the previous analysis with a different set of input attributes

Volumetric attributes: 3D volumes used for the analysis

1) Reflector Convergence magnitude
2) Coherency
3) Coherent Energy
4) Dip Magnitude

→ **3D Multiattribute Analysis and coloring of the each sample location** $(x_{i,} y_i, z_i)$

→ **Output 3D seismic Facies Volume**

3D seismic facies volume below the Oswego formation

Attribute-Assisted Seismic Processing and Interpretation

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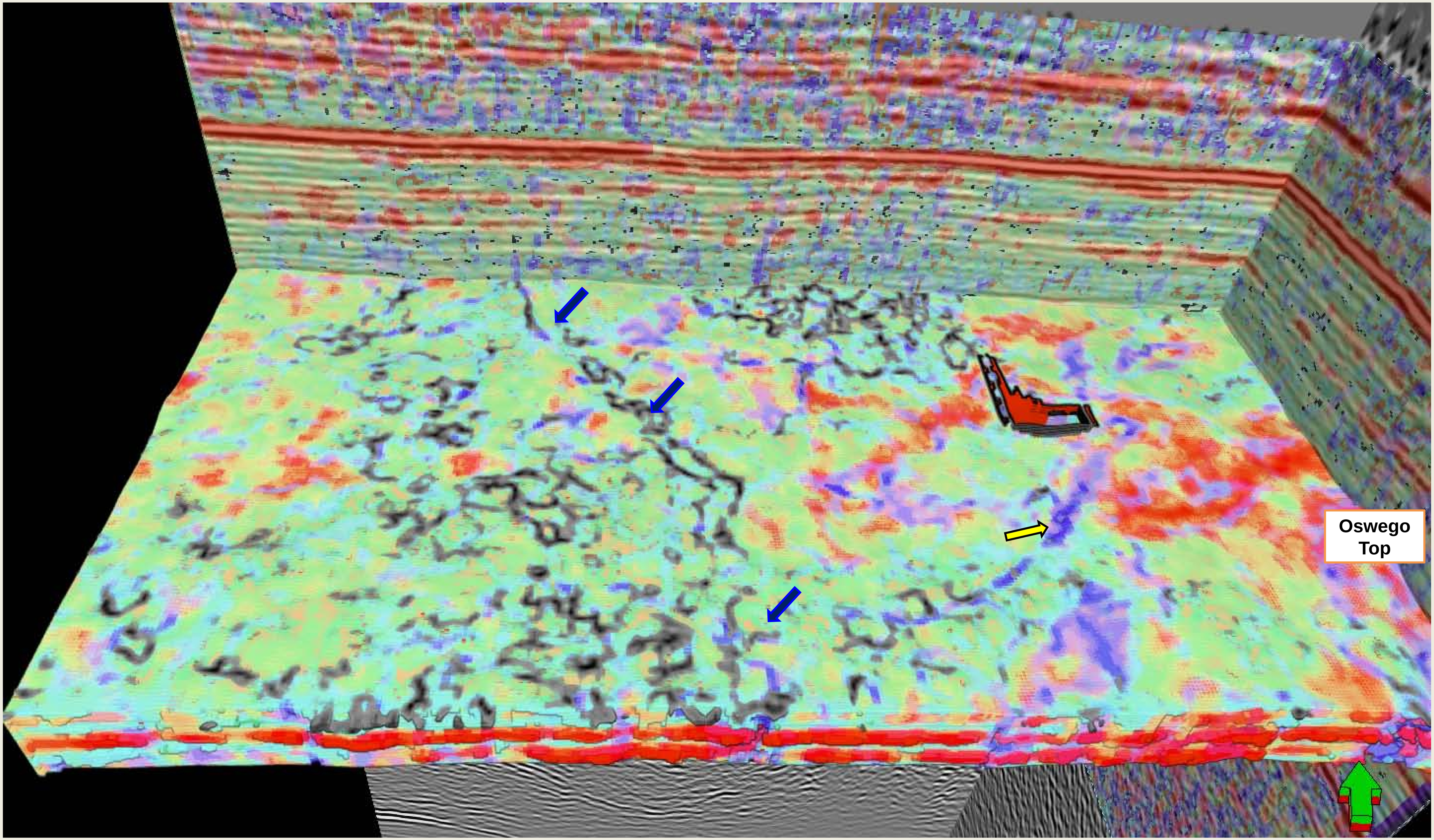

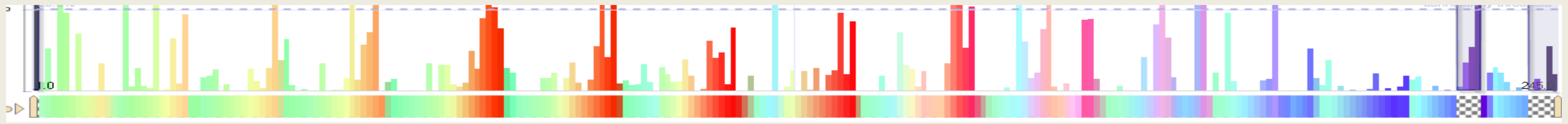

5km

3D seismic facies volume below the Oswego formation

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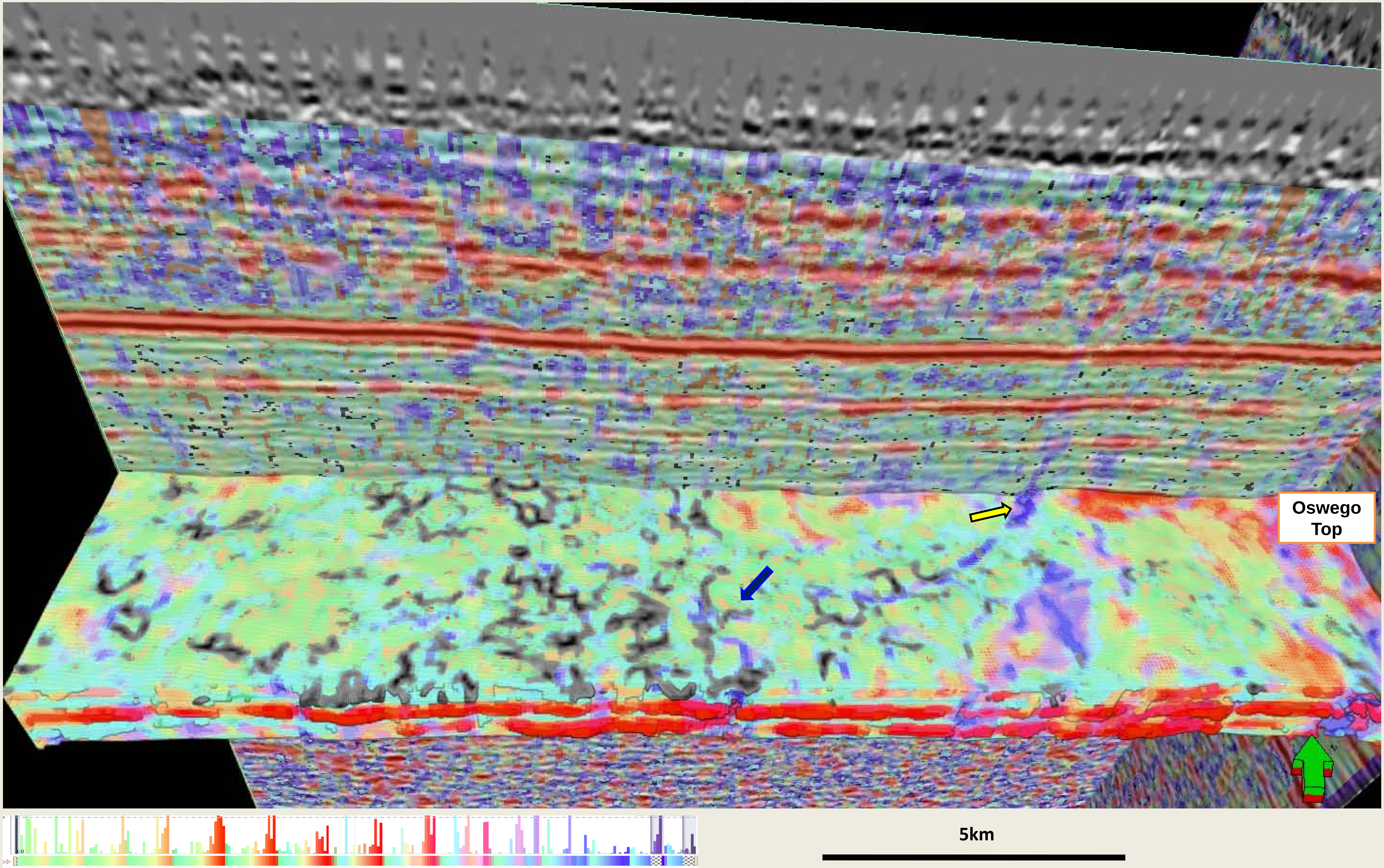

3D seismic facies volume of the Mississippian Lime and the chert formation

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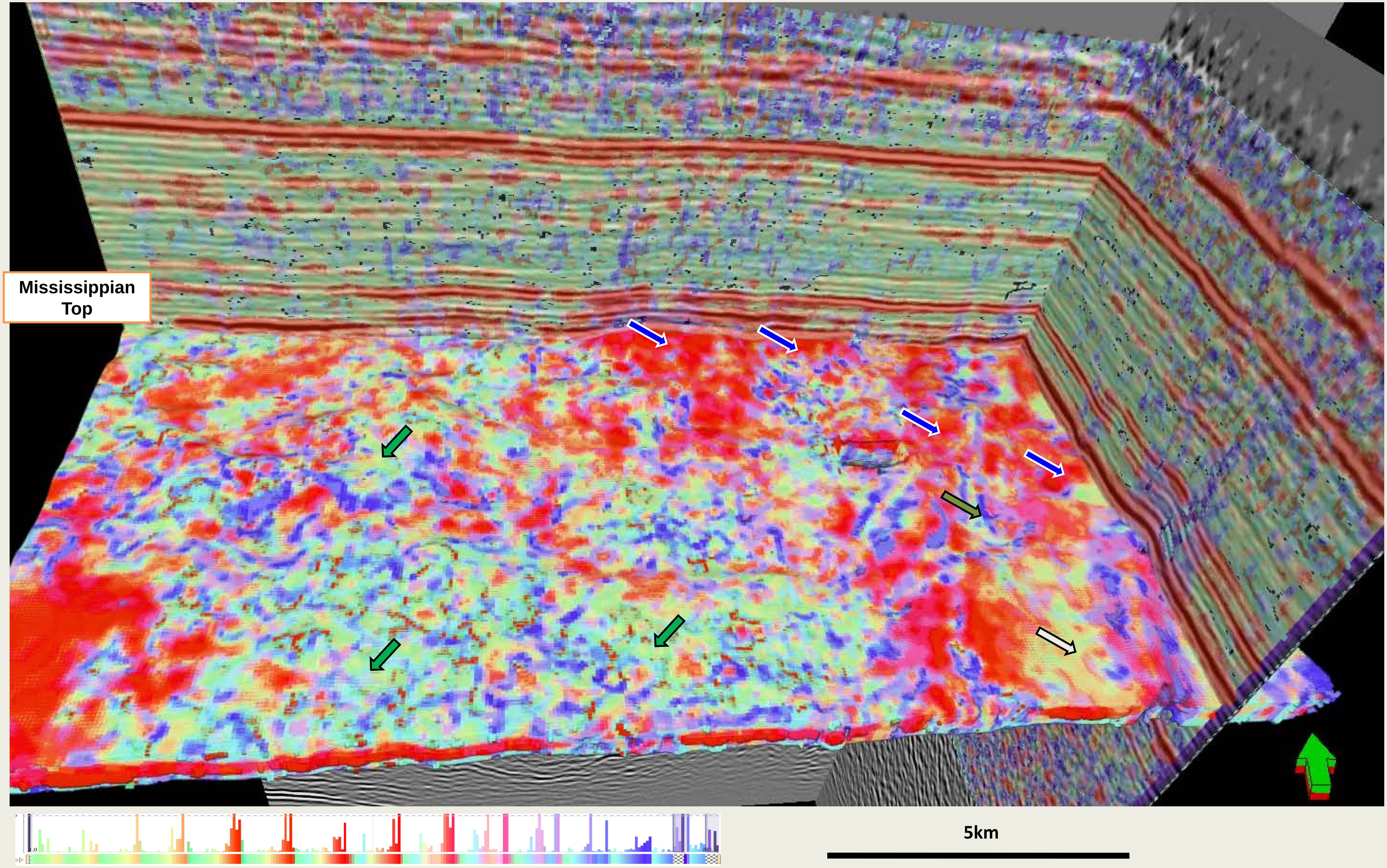

Workflow for (1) 3D seismic Facies Classification (2) Reservoir quality and Completion quality through 3D multi-attribute analysis

Proposed workflow for (1) Seismic Facies classification (2) Reservoir quality and completion quality

Seismic Facies Classification

1) Spectral Decomposed volumes
2) Texture attributes
3) Coherency volumes
4) Coherent energy

and a suite of other mathematically independent rotationally invariant attributes

→ Try out different combinations with these suites of volume → 3D clustering

Reservoir and Completion Quality

1) Lambda-Rho
2) Mu-Rho
3) Inverted Intercept
4) Inverted Gradient
5) Density volume (from Geo-statistical Analysis)
6) AVAz Anisotropy

and a suite of other rock physics volumes

→ Try out different combinations with these suites of volume → 3D clustering

Correlate the output 3D seismic facies volume with the *log, production data and the regions of good wells*

Discussions and Recommendations

- This multi-attribute facies analysis provides a volumetric estimation of seismic facies. The heterogeneous nature of the chert reservoir is highlighted with the subtle color variation of the zone between the Mississippian Lime and the Arbuckle top.

- The power of classification is heavily dependent on the choice of attributes (Barnes and Laughlin, 2002)

- Multi-attribute analysis of the second set of volumetric attributes show the structural boundaries better within the seismic facies volume .

- Seismic facies in the volume should be interpreted and calibrated to well information and rock properties.

Acknowledgements

- Spyglass Energy Group for the dataset.
- OU Attribute Assisted Seismic Processing and Interpretation (AASPI) Consortium sponsors
- Schlumberger Petrel® software for visualization