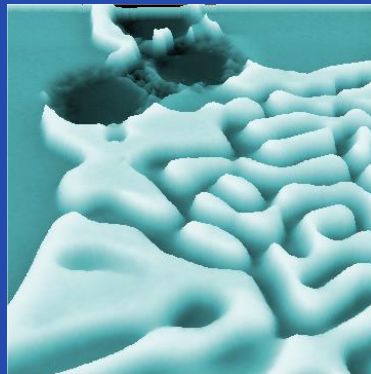




THE CHARACTERIZATION POSSIBILITIES OF PARTICLE DISPERSION IN MULTIPHASE MATERIALS

Zoltán Gácsi¹, Tamás Bubonyi¹, Péter Barkóczy¹

¹ University of Miskolc, *Institute of Physical Metallurgy and Metalforming*



*15th International Symposium on Novel
and Nano Materials (ISNNM)*

SZÉCHENYI 2020



HUNGARIAN
GOVERNMENT

European Union
European Regional
Development Fund



INVESTING IN YOUR FUTURE



Content

- Description possibilities of **multiphase materials structure**
- **Image processing** and analysis
- **Covariance** function, **Radial distribution** function, Voronoi and morphological mosaics
- **CProb algorithm** and software



Materials structure and properties

Mechanical
properties

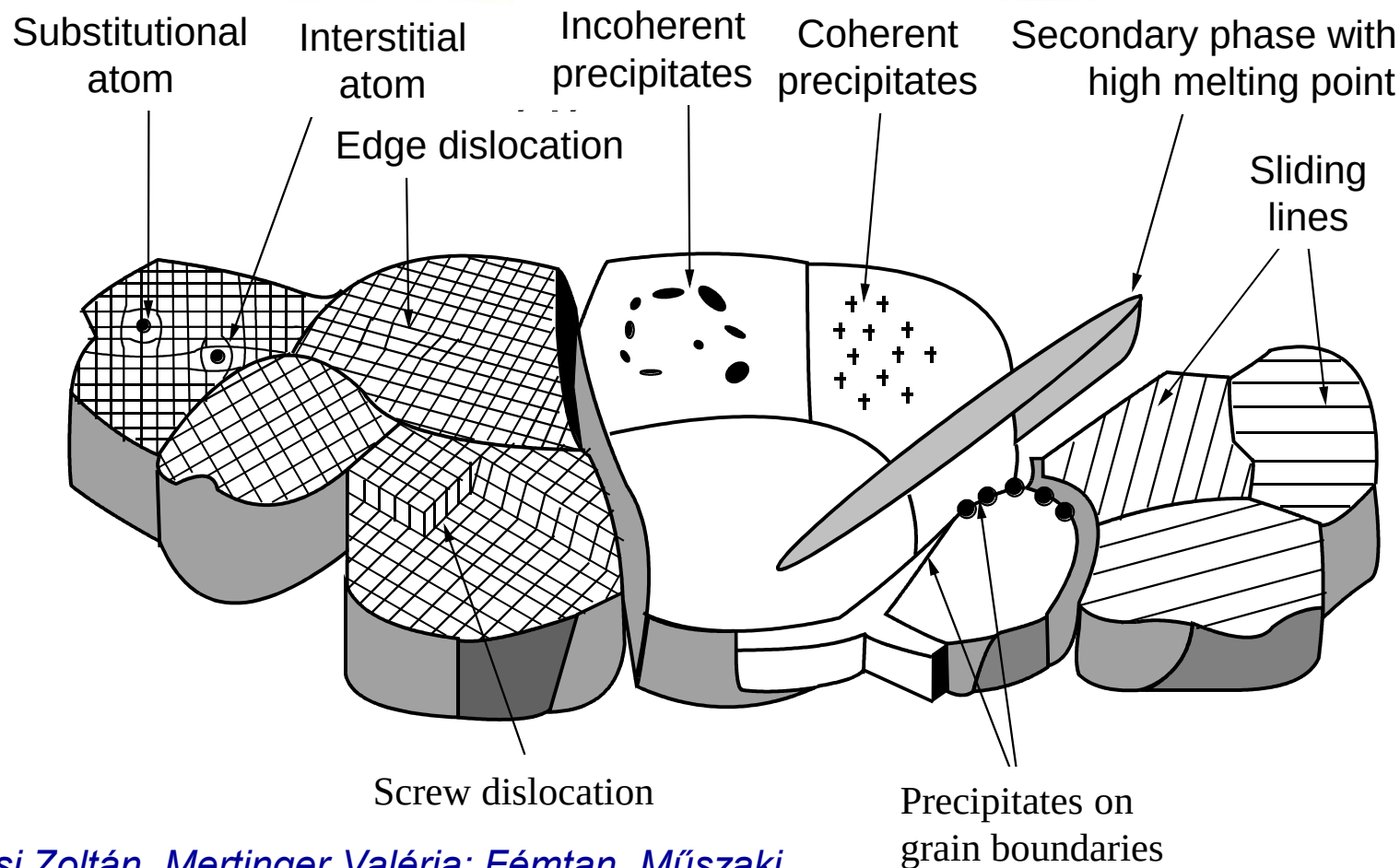
STRUCTURE

- Nano scale (atomic bonds)
- Micro scale (phases, particles, grains, orientation, distribution)
- Macro scale

Functional
properties

Gácsi Zoltán; Simon Andrea; Pázmán Judit: Fémkompozitok, Miskolci Egyetem, Miskolc, 2011.

Multiphase materials structure



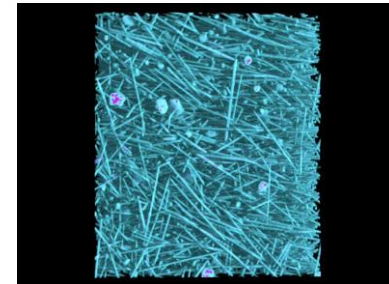
Gácsi Zoltán, Mertinger Valéria: *Fémten. Műszaki Könyvkiadó. Budapest, 2000.*



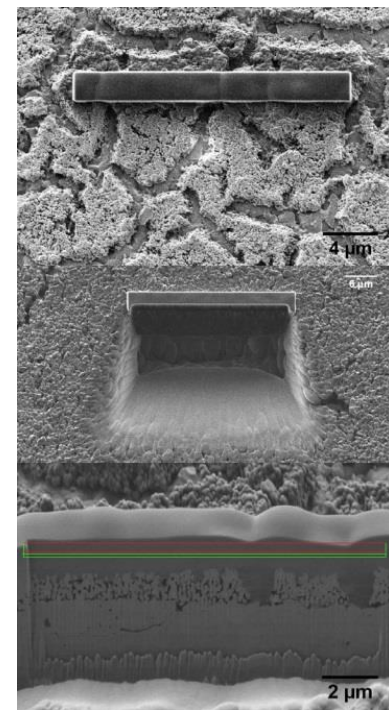
Characterization possibilities of multiphase materials structure

- More parameter (**vectorial description**) instead of simple scalar values (linear particle size, area fraction, grains diameter)
- **Complex imaging equipment** (method, resolution)
- **Modern mathematical - statistical methods** (piles, matrix, machine learning)
- **Increasing the resolution**: millimeter, micro-, submicrometer, nanometer
- **2D, 3D imaging devices**
- Combination of **traditional** and **modern methods**

Zoltán Gácsi: The Application of Digital Image Processing to Materials Science, Materials Science Forum. Materials Science, vols. 414-415, pp. 213-220, 2003. (IF= 0,602)



Nano CT



FIB SEM



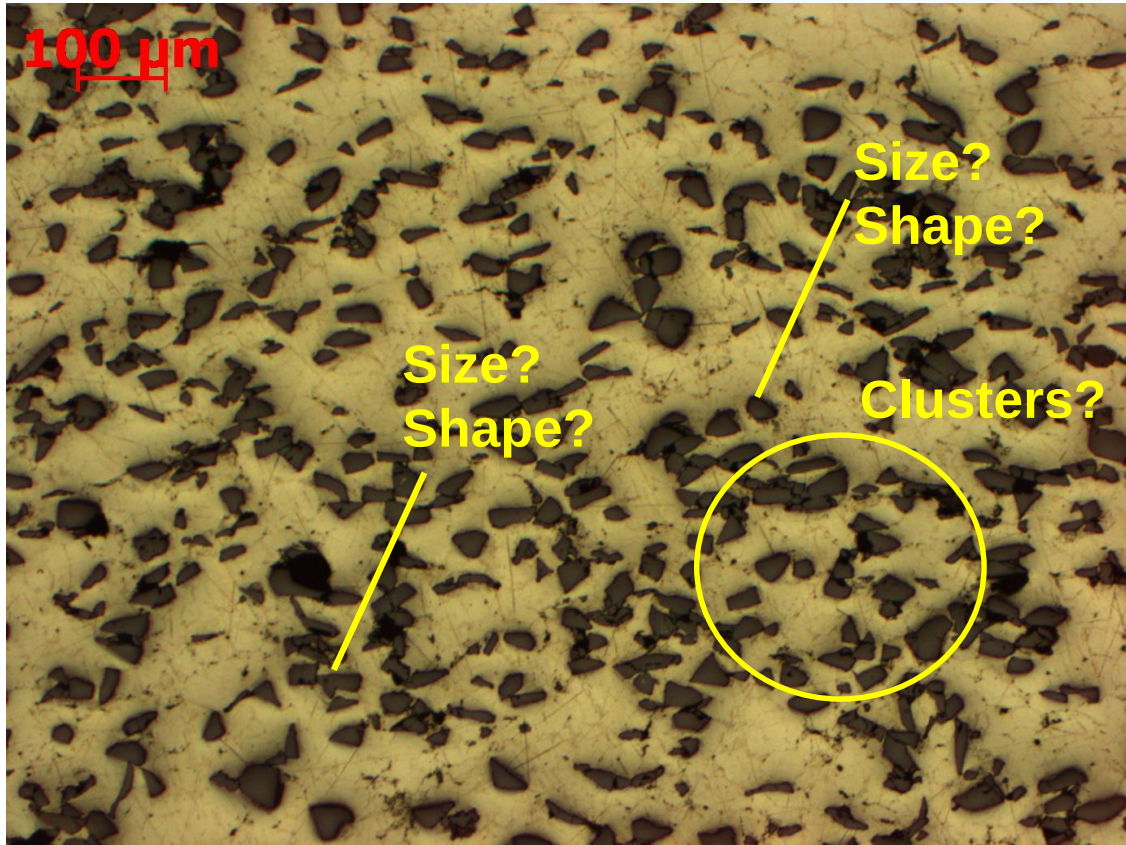
Main questions

The full range **description** of the microstructure of **multiphase (composite) materials** needs:

- **Volume (area) fraction** of phases
- **Size and size distribution** of phases (particles, grains)
- **Shape** (2D, 3D) of the particles, grains
- **Spatial orientation** of the particles, grains (microstructural anisotropy)
- **Spatial distribution** of the particles, grains (random, ordered, clustered)

G Gergely, D Koncz-Horvath, Z Weltsch, Z Gacsi: Development of crack detection method with 2 dimensionally generated 3 dimensionally reconstructed images in THT solder joints ARCHIVES OF METALLURGY AND MATERIALS 62:(2) pp. 1033-1038. (2017)

Particle reinforced composites



Multiphase
materials

Al-SiC_p

Judit Pázmán, Viktor Mádai, József Tóth, Zoltán Gácsi: Investigation of the microstructure of Al/SiC(Ni) p composites. MATERIALS SCIENCE FORUM 729: pp. 470-475. (2013)

Image processing and analysis



Imaging device

Digital
image



Computer

Image

Data

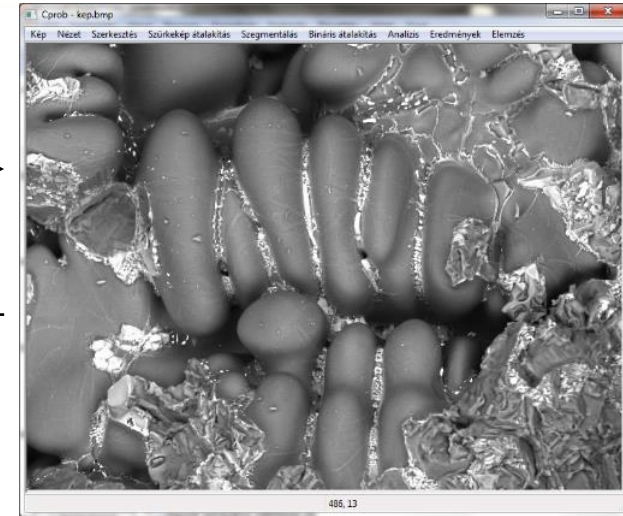


Image processing and
analysis software

Image processing = image transformation, from image to image

Image analysis = data from image

Gácsi Zoltán, Sárközi Gábor, Réti Tamás, Kovács Jenő, Csepeli Zsolt, Mertinger Valéria: Sztereológia és Képelemzés. WellPress-PHARE. Miskolc



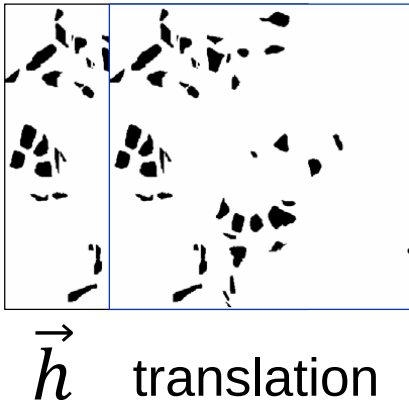
Description of the microstructure

Methods:

- 1) Evaluation of degree of ordering** (covariance function)
- 2) Evaluation of degree of clustering** (radial distribution function, cluster analysis)
- 3) Analysis of neighborhood of the objects** (nearest neighbors, morphological mosaics)
- 4) Classification according to shape** (template matching, statistical, neural-network, ...)

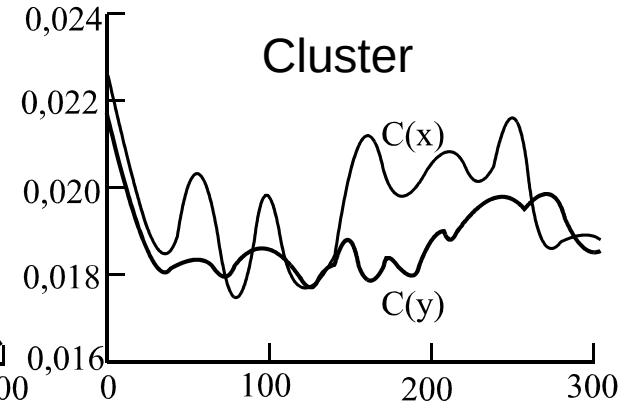
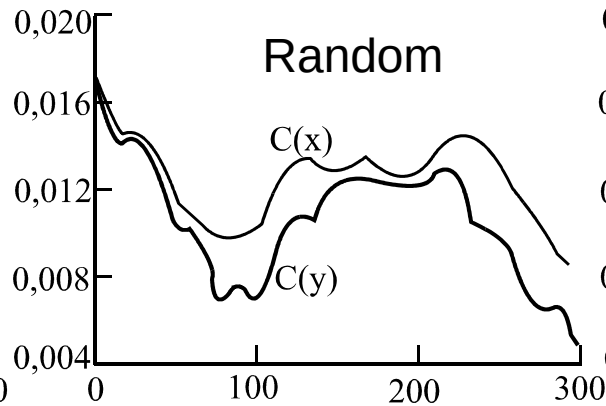
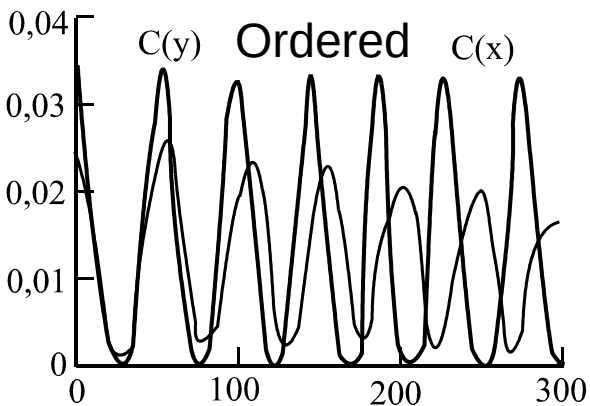
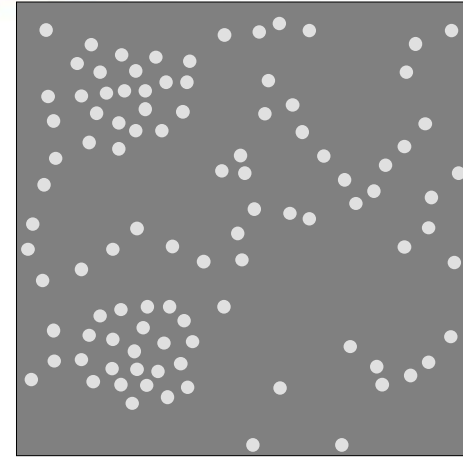
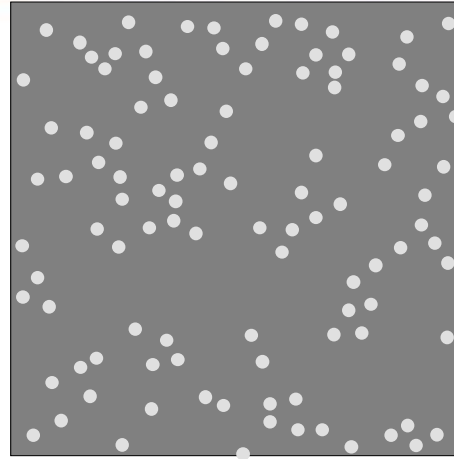
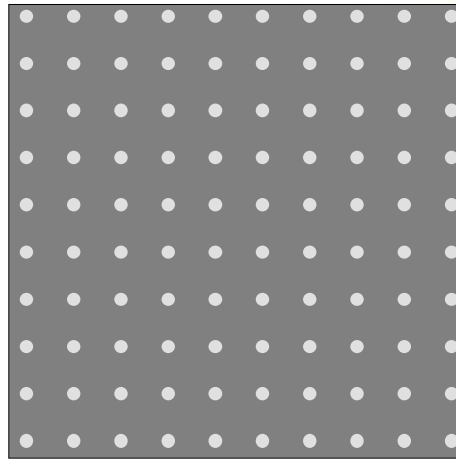
Covariance function

$$KOV(\bar{\bar{B}}, \vec{h}) = E \left\{ Mes \left[(\bar{\bar{B}}) \cap (\bar{\bar{B}} + \vec{h}) \right] \right\}$$



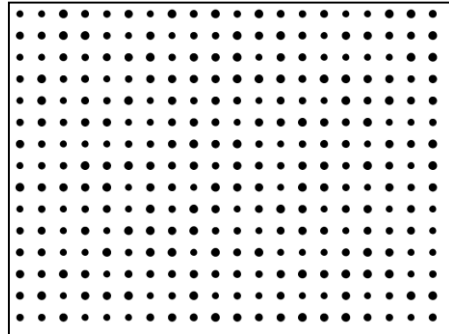
- **B binary pile** (matrix) of the microstructural elements (binary image)
- **h vector of translation** (shift)
- **Mes metrics of the binary piles common part**
- **E expected value**

Covariance function

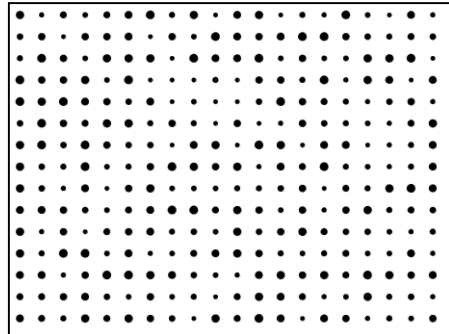


Wejrzanowski T., Rozniatwsi K., Kurzydowski K. (2001). Computer Aided Description of the Materials Microstructure: Analysis of Homogeneity of the Spatial Distribution of Particles. *Image Analysis & Stereology*. 20, p. 71.

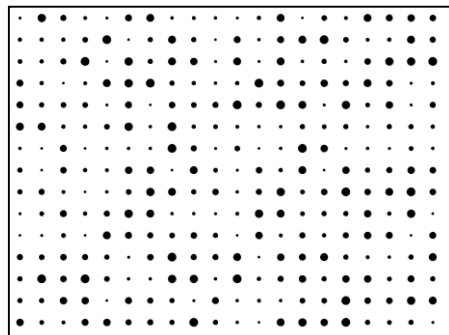
Covariance function



$r = 20 \text{ pix}$



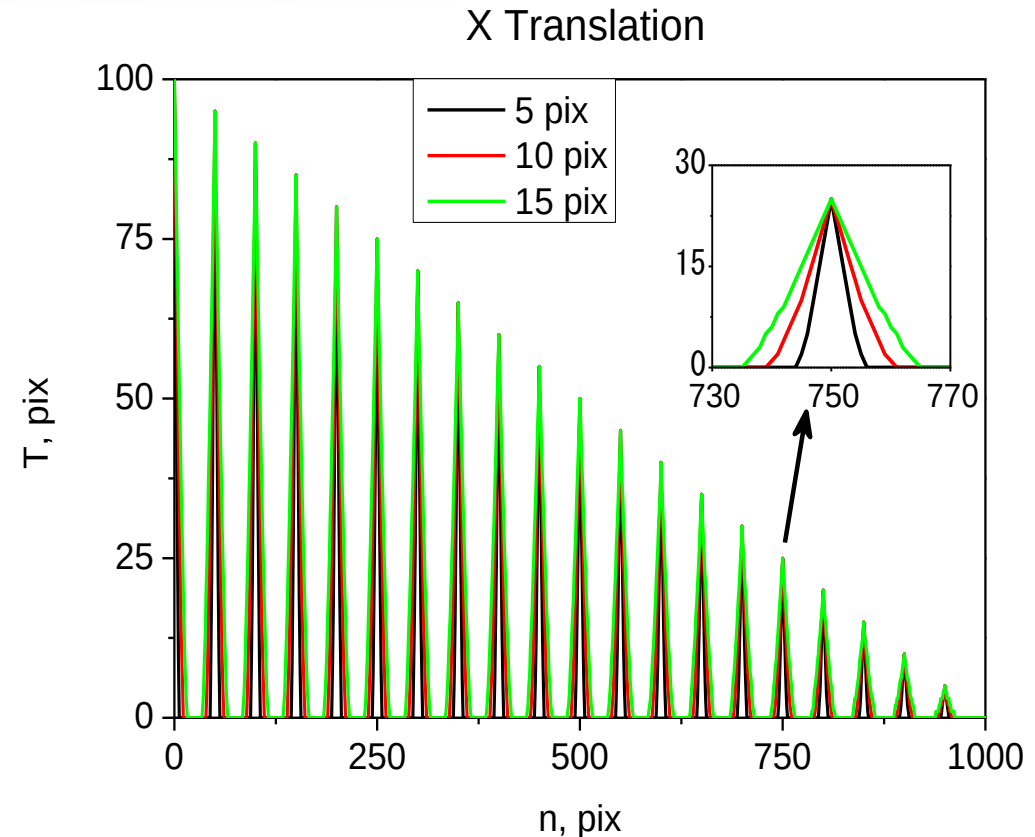
$r \pm 5 \text{ pix}$



$r \pm 10 \text{ pix}$

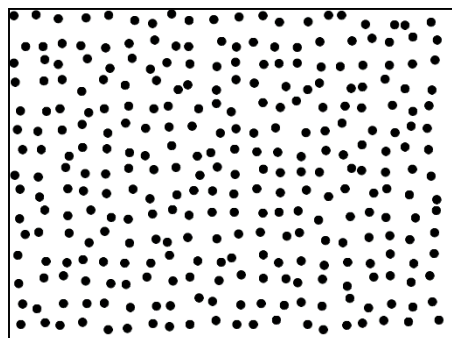
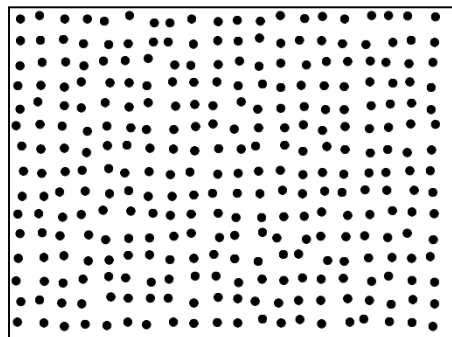
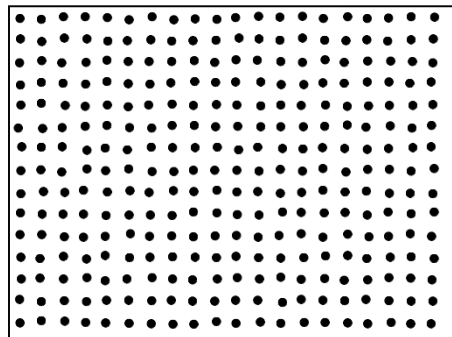


$r \pm 15 \text{ pix}$



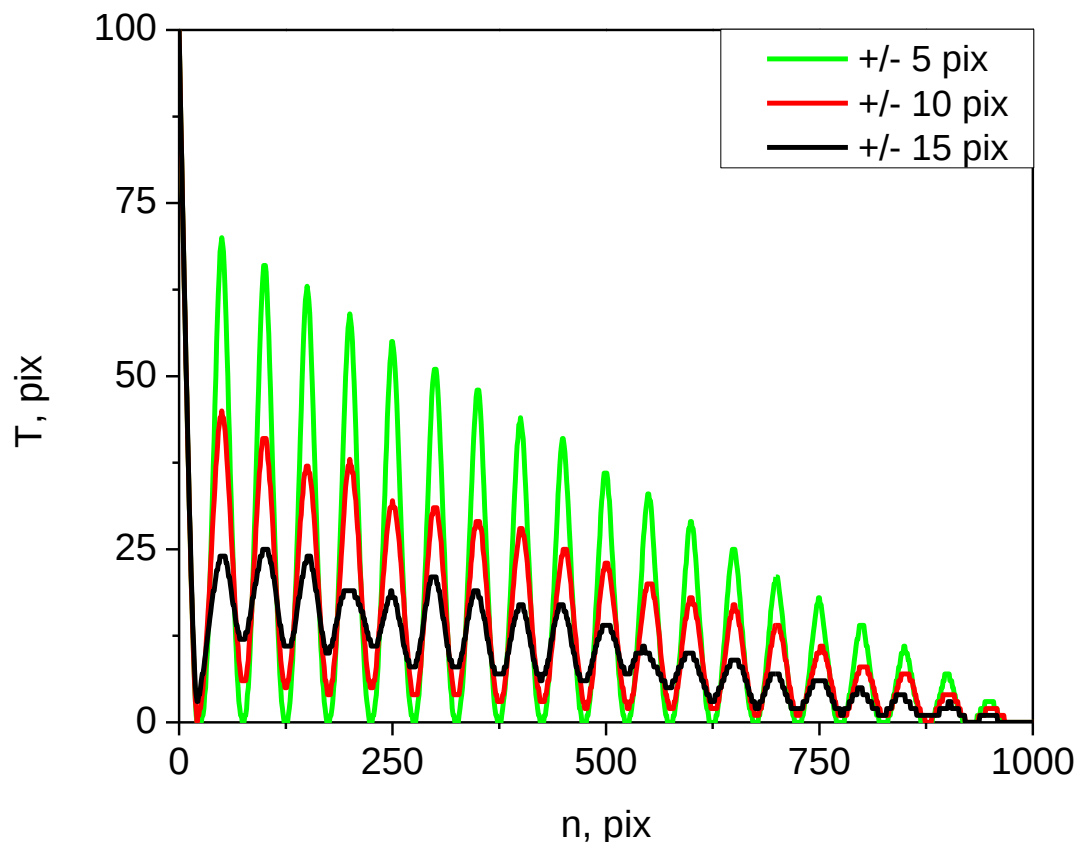
The covariance shows the regular nature and the periodicity of the microstructure

Covariance function



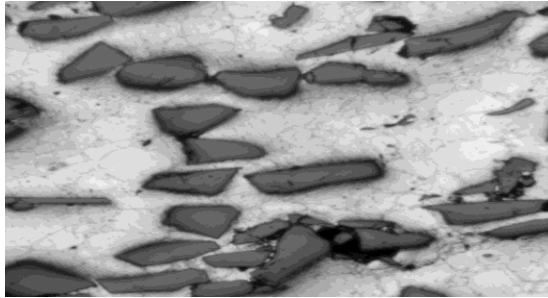
$d = 40$ pix

X Translation



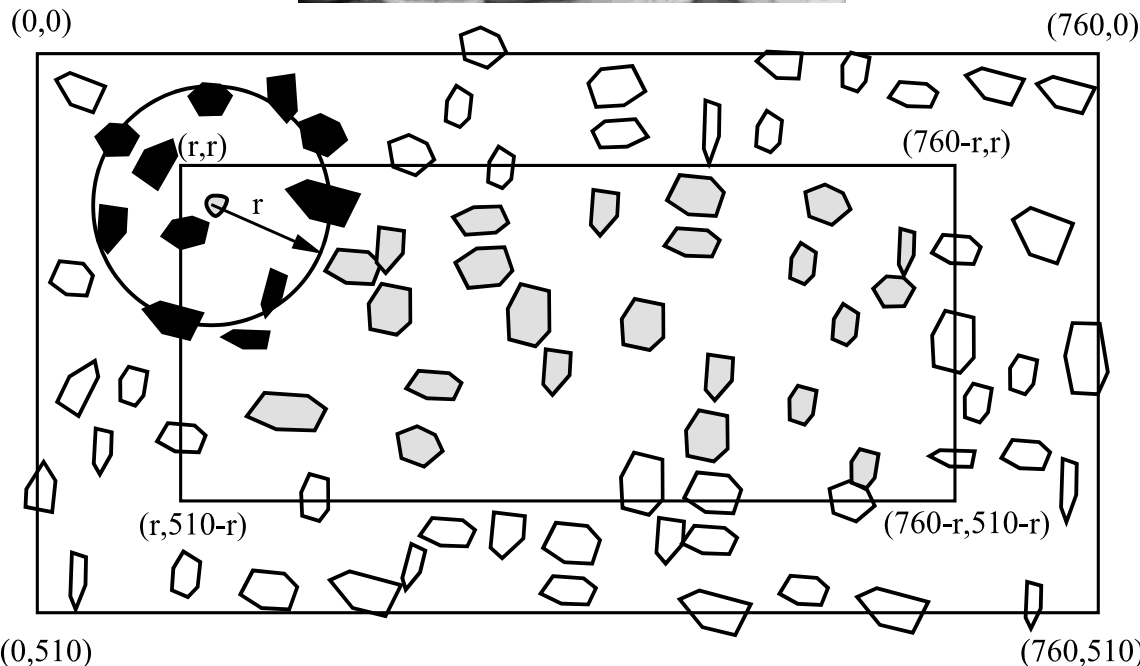
The covariance reveals the low level of ordering

Clustering



Radial distribution function:

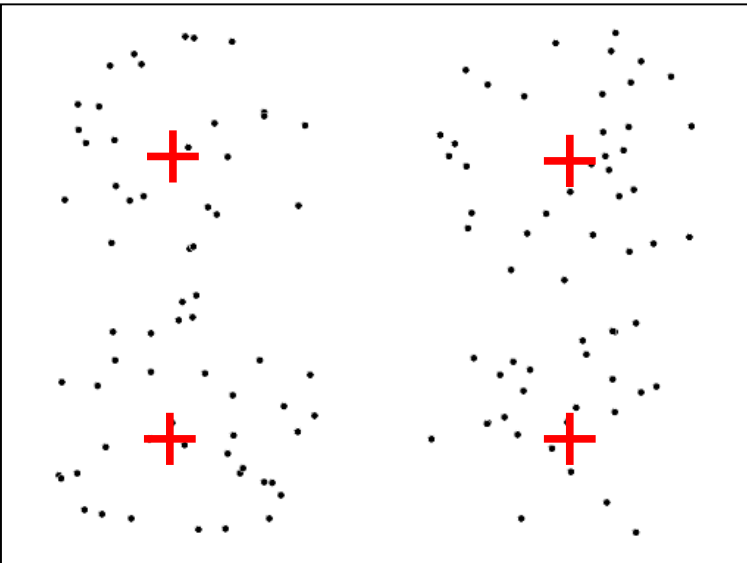
$$H(r) = \frac{N_{ra}}{N_a}, \mu m^0$$



N_{ra} : the mean number of particles per unit area inside the circle,

N_a : the mean number of particles on visual field.

Clustering

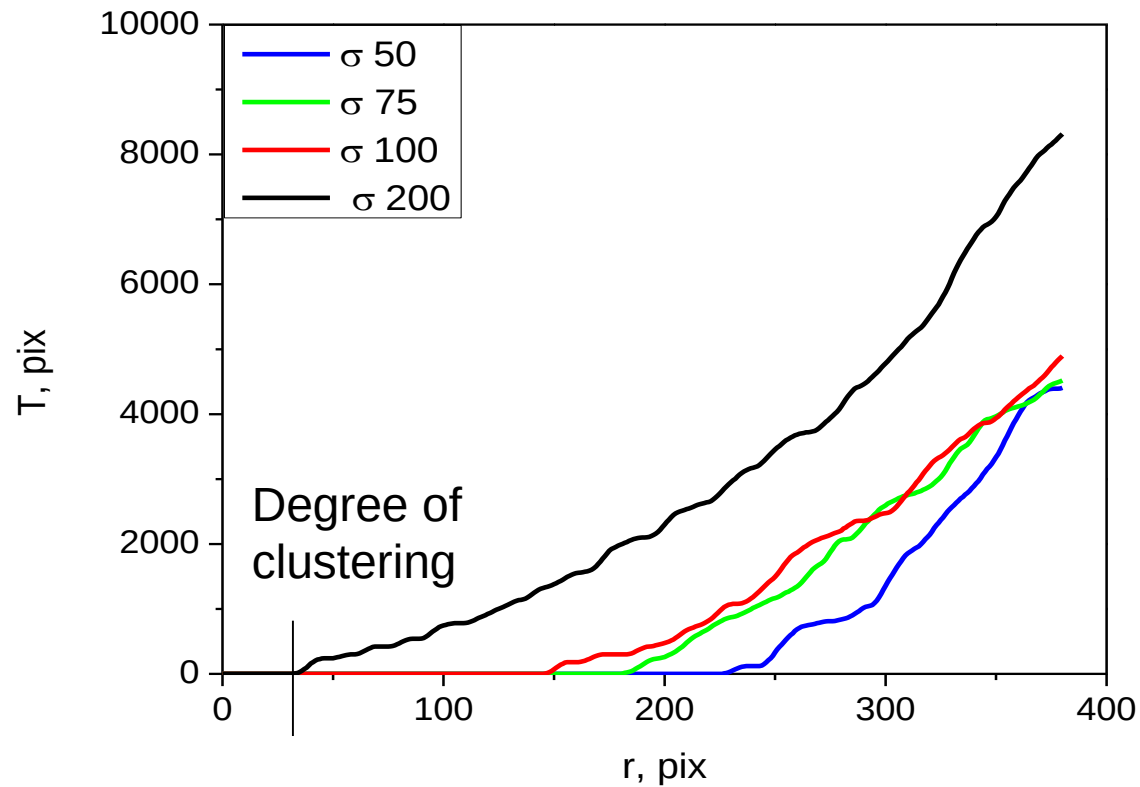


- **4 clusters**, fixed cluster centers
- **Position of object** determined by Monte-Carlo with normal distribution
- **The cluster centers** are the means of the distributions
- The **superposition of the probabilities** used in Monte-Carlo method
- **Standard deviation (s)** used as description of clustering (dispersion).

Clustering

4 clusters, different dispersion

RDF area



$\sigma=200$ pix

$\sigma=100$ pix

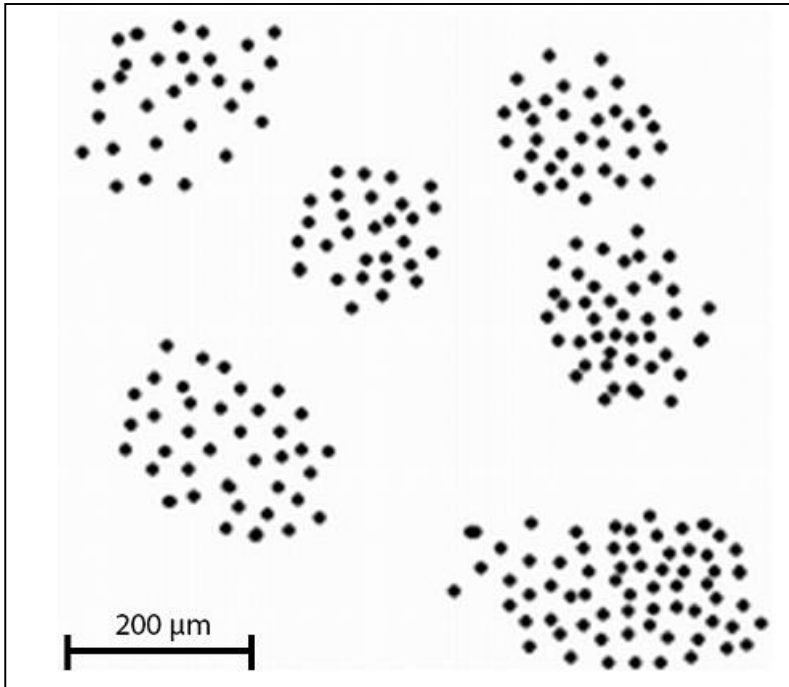
$\sigma=75$ pix

Clustering

Inner distance inside the clusters

$$d_{inner} = \frac{\sum_{i=1}^n \sum_{j=1}^n (1 - d_{ij}) \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{(n-1)^2}$$

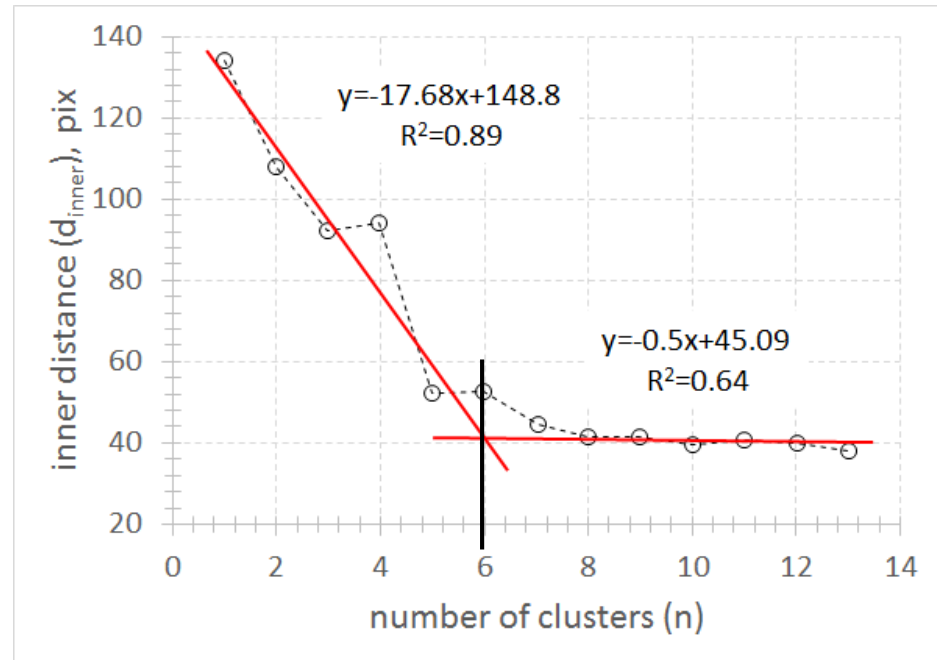
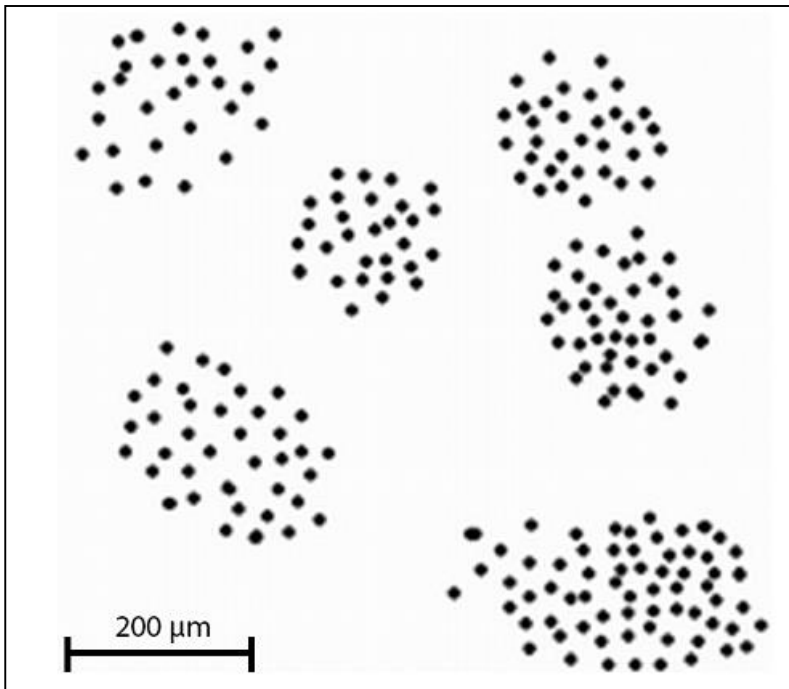
- Prescribe fix n cluster centers of the clustering algorithm (ex. K-means).
- The algorithm calculate the centers and d_{inner}
- d_{inner} decreasing as a function of n .
- The decrement is rapid to the real number of clusters then it becomes slow



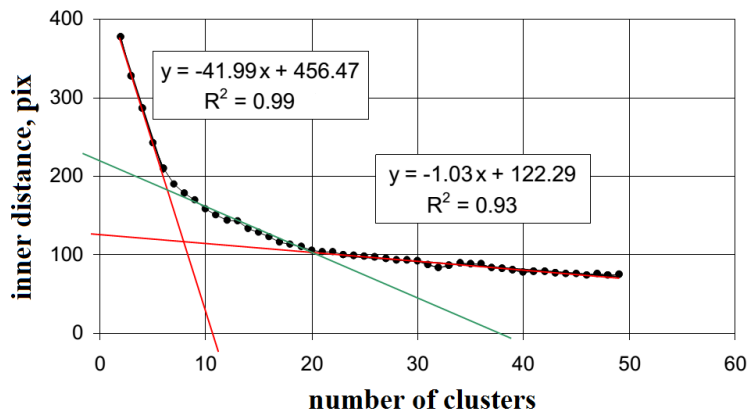
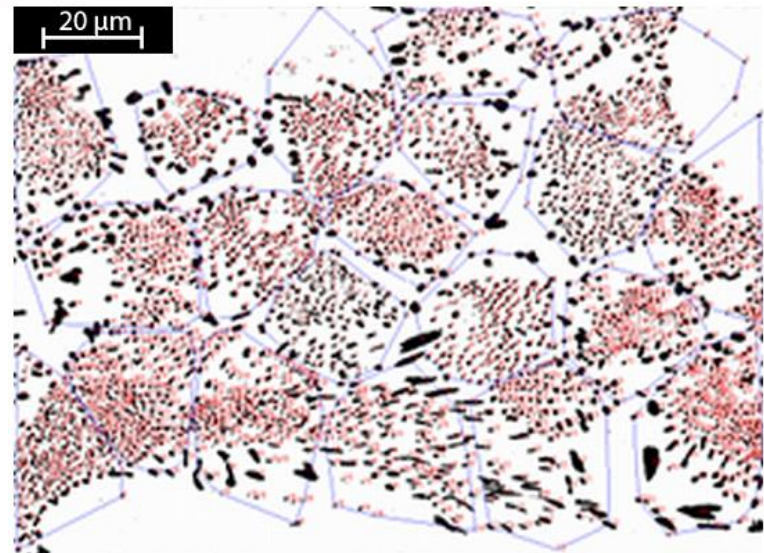
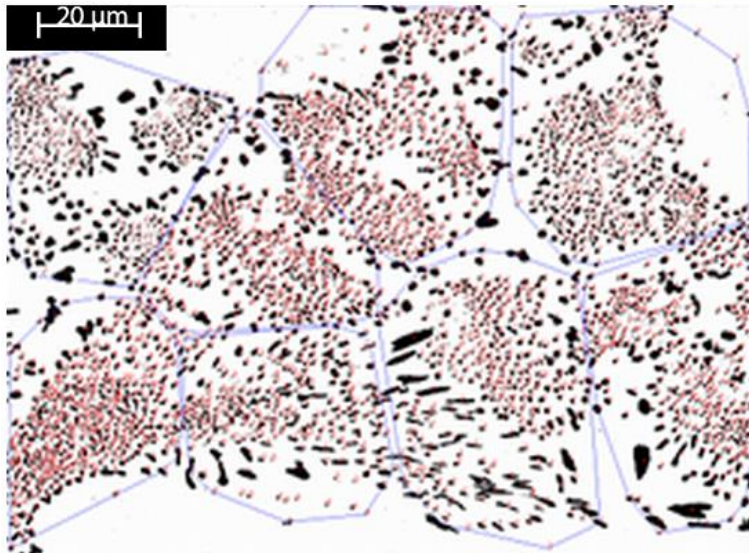
Clustering

Inner distance in the clusters

$$d_{inner} = \frac{\sum_{i=1}^n \sum_{j=1}^n (1 - d_{ij}) \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{(n-1)^2}$$



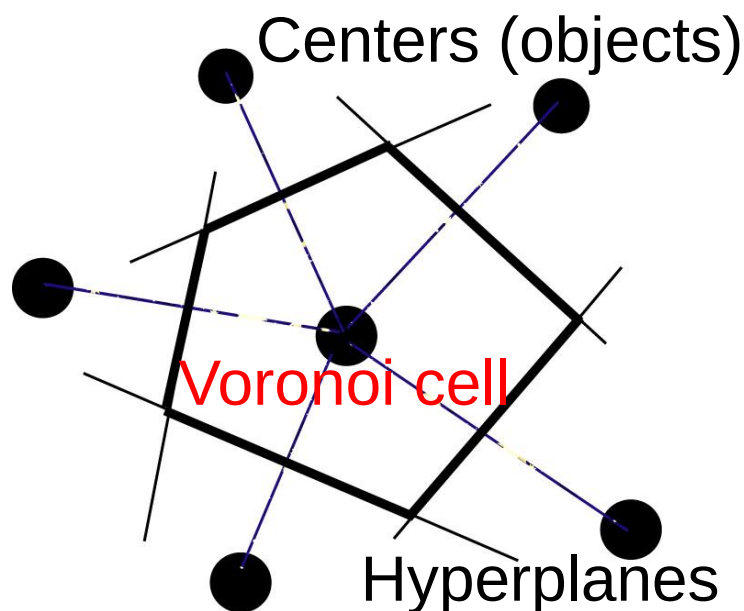
Clustering



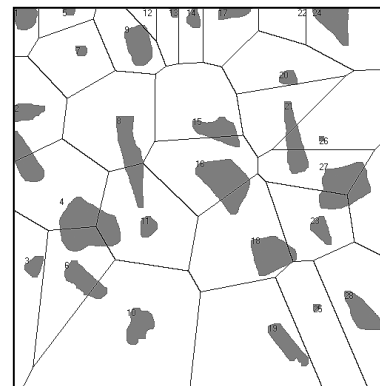
Clusters in clusters,
EN-AW-8006 Al-Fe-Mn alloy
3 slopes describe the curve with
2 intersection (7 big 20 small
clusters)

Clustering – Randomness?

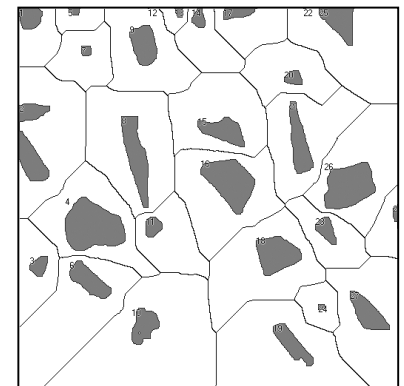
- **Voronoi tessellation** shows the particle which contains the closest points to the given **particle center**
- **Morphologic tessellation** shows the particle which contains the closest points to the given **particle boundary**



Voronoi cell

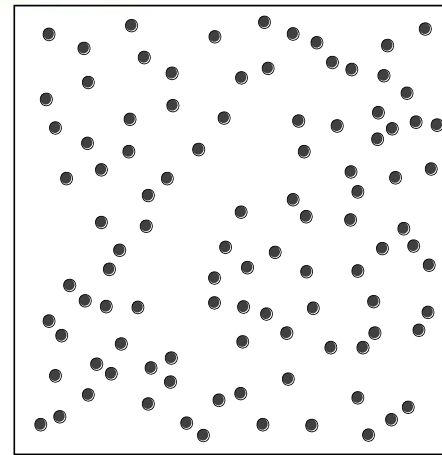
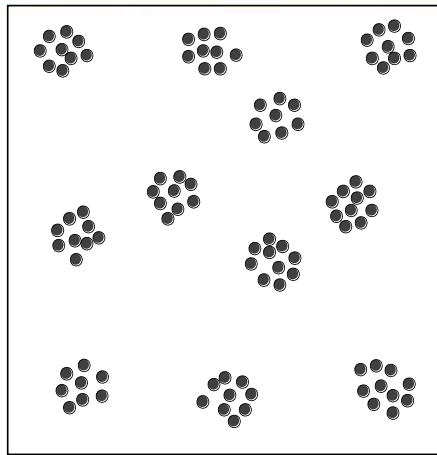
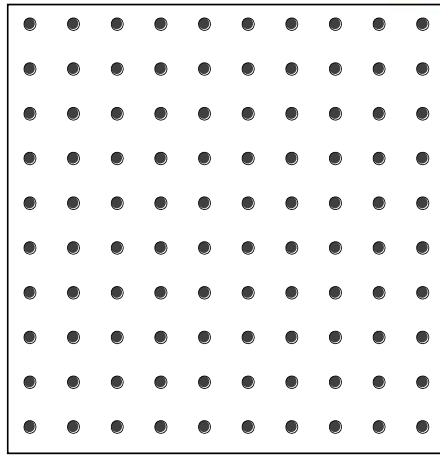


Morphologic cell

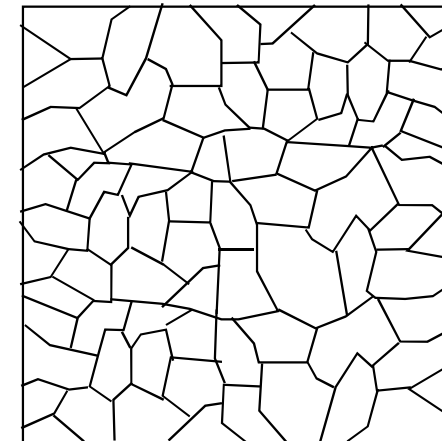
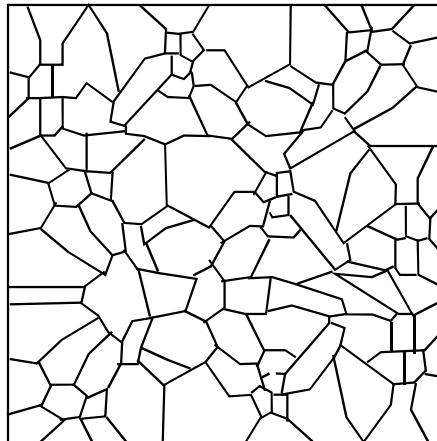
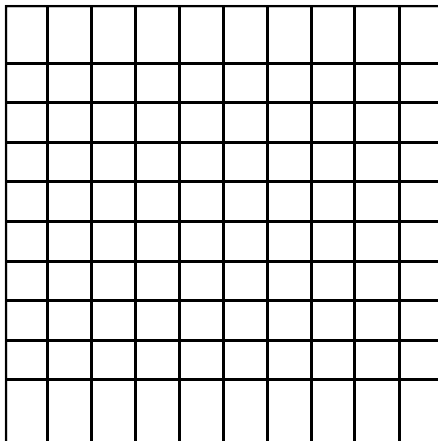


$$M_i = \{m_i : d(m_i, p_i) < d(m_i, p_{j \neq i})\}$$

Clustering – Randomness?



Micro-
structure



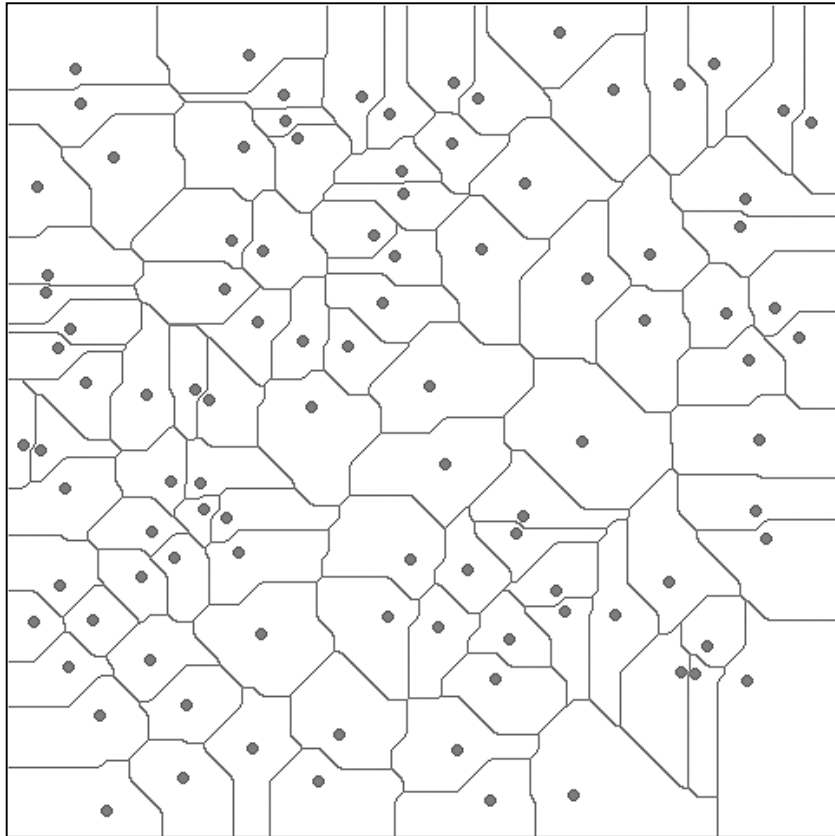
Morpho-
logic cells

Ordered

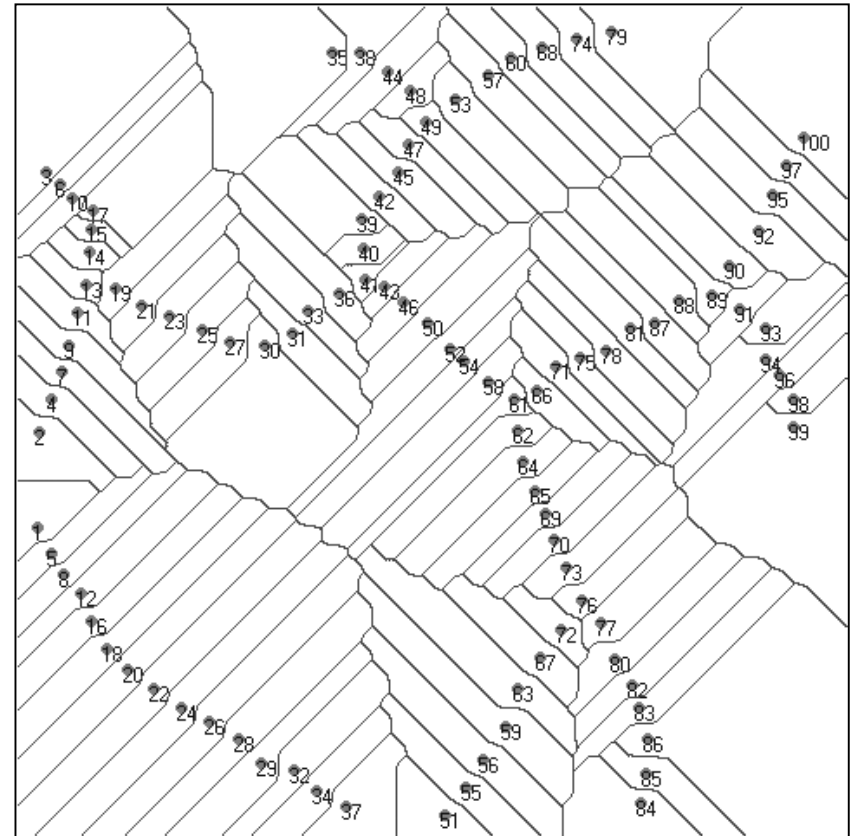
Clustered

Random

Different particle arrangement

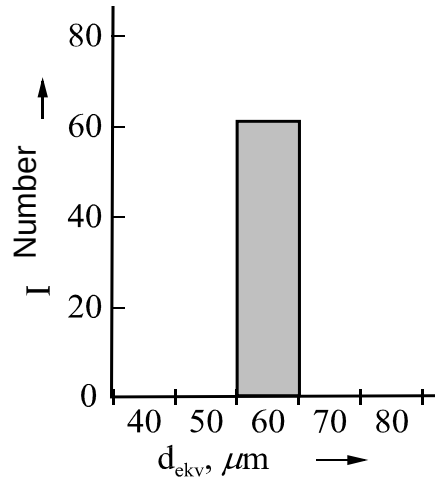
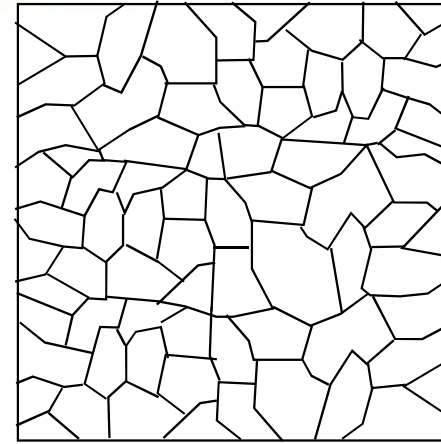
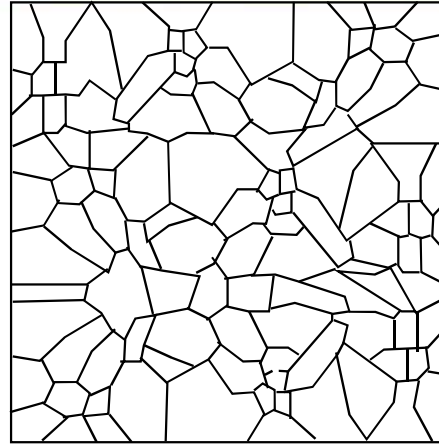
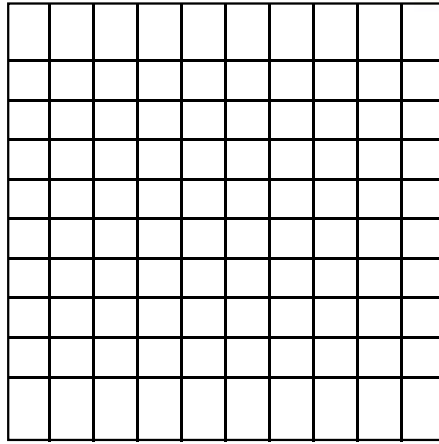


Particles arrangement are random

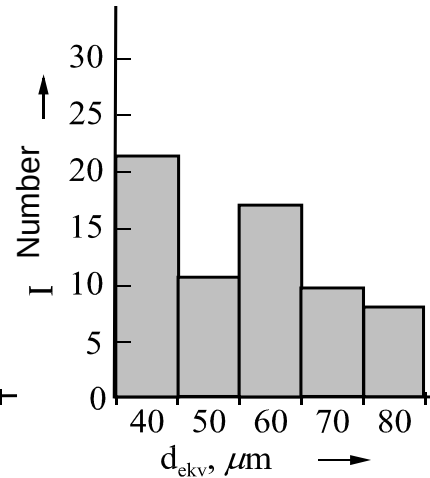


Particles arrangement are ordered in boundary

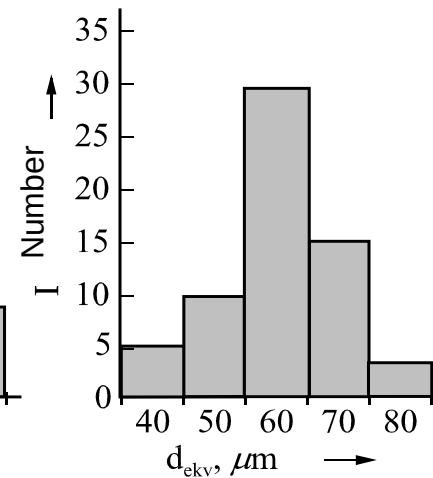
Clustering – Randomness?



Narrow



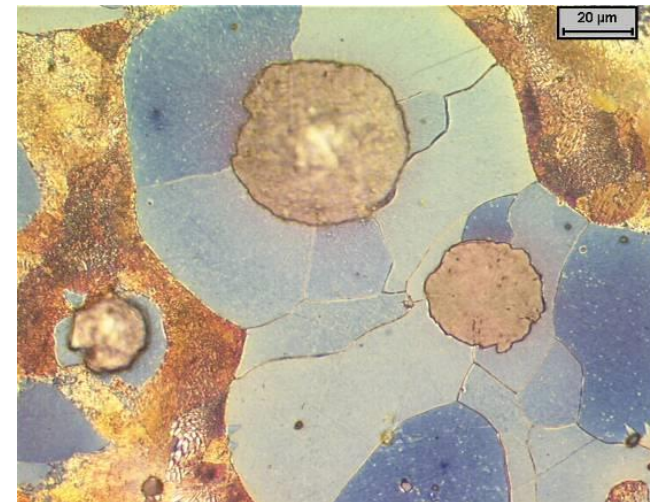
Bimodal



Monomodal

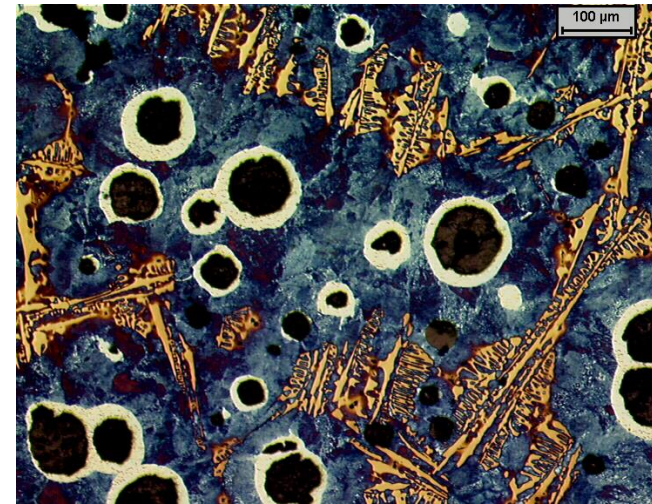
CProb algorithm and software

- General purpose **image processing** and **analysis**
- Free for **research** and **education**
- **Conventional** and **modern methods** for microstructural description and evaluation
- **Industrial standard software** in:
 - microstructural characterization of **steels**
 - evaluation of **cast irons**
 - characterization of **aluminum alloys**
 - special image based **quality control**



CProb algorithm and software

- Conventional **image processing algorithm** of **color, grayscale and binary images**
- **Conventional measurement of field and object** features (area, diameters, perimeter, etc.)
- Classification according to **shape descriptors**
- Analysis of **spatial distribution** (covariance function, radial distribution, morphologic tessellation, cluster analysis)
- Possibilities to **automated image analysis**

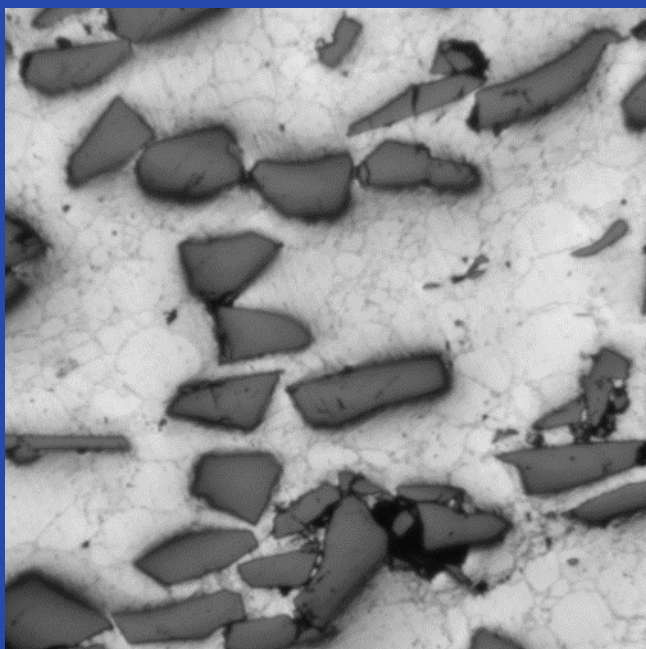




MISKOLC
EGYETEM
UNIVERSITY OF MISKOLC

„Sustainable operation of the workshop of excellence for the
research and development of crystalline and amorphous
nanostructured materials”
GINOP-2.3.2-15-2016-00027

Thank you for your kind attention!



*15th International Symposium on Novel
and Nano Materials (ISNNM)*

SZÉCHENYI 2020



HUNGARIAN
GOVERNMENT

European Union
European Regional
Development Fund



INVESTING IN YOUR FUTURE