Image Processing for Materials Characterization: Issues, Challenges and Opportunities

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Outline

1. Motivation
2. Material images
3. Challenges and oportunities
4. The special session
5. Conclusions

Outline

Motivation

Periods in mankind's history are often named after specific materials :

stone age

bronze age

iron age

Motivation

Periods in mankind's history are often named after specific materials :

stone age

bronze age

iron age

Industrial breakthroughs remain related to particular material

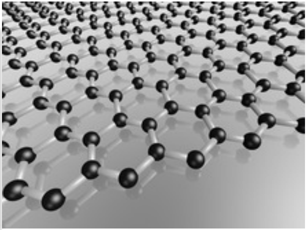
steel

silicon

Motivation

Today's applications

- Semi-conductors
- Sensors,
- Drug carriers,
- Catalysts, etc.



- Materials technology is evolving from materials discovered in Nature by chance to designed materials, that repair themselves, adapt to their environment, capture and store energy or information, help elaborate new devices and sensors, etc.
- Materials are now designed from scratch with initial blueprints, starting from atoms and molecules. Example : Graphene.

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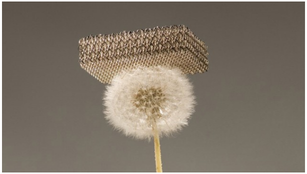

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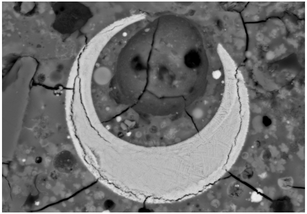
The traditional, human, vision-based interpretation of material images misleading...



Scanning electron microscopy : Polymer-charged concrete (©F. Moreau, IFPEN)

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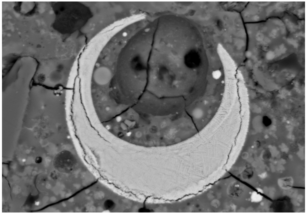

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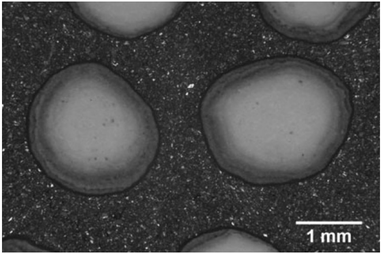
Taking physical properties into account...

... is at the heart of sucessful image analysis in material science

Outline

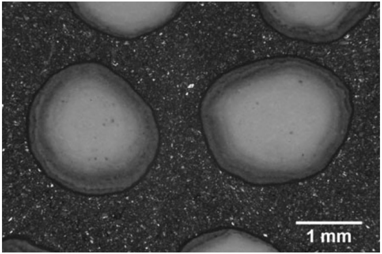
Catalysts at a coarse level of observation



Catalysts with metallic palladium crust (©IFPEN).

Optical microscopy

Catalysts at a coarse level of observation



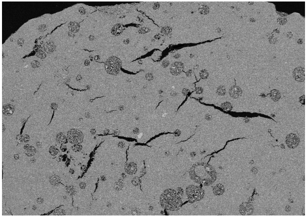
Catalysts with metallic palladium crust (©IFPEN).

Optical microscopy

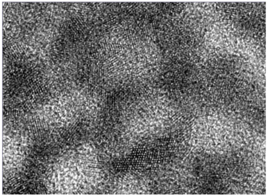
Goals

- measure the crust thickness (avoids invasive probe techniques)
- related with the efficiency of catalysts, to improve the conversion of hydrocarbons into chemical products.

Catalysts

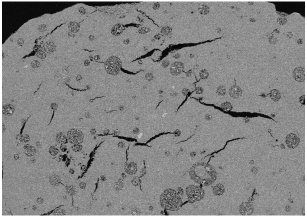


Scanning electron microscopy : catalyst section.



Atomic structure of a ceria nanoparticle (©Rhodia).

Catalysts



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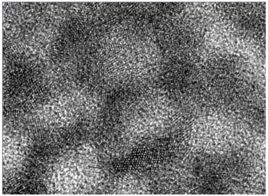
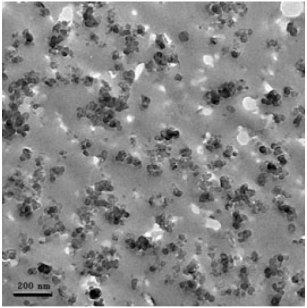


Atomic structure of a ceria nanoparticle (©Rhodia).

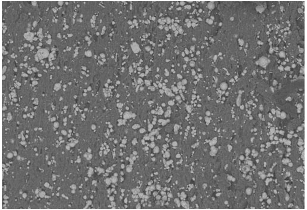
Goals

- 1st image : characterization of the area in black (cracks), the round shapes (pores) and the white dots (zeolite inclusions)
- 2nd image : segmentation into pores, ceria, silica

Rubber

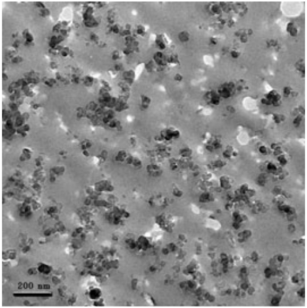


Filled rubber's microstructures (©Michelin)



Composite material with elastomer matrix (©EADS).

Rubber



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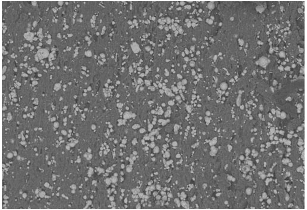

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Goal

- deduce physical properties from 3D microstructure simulations

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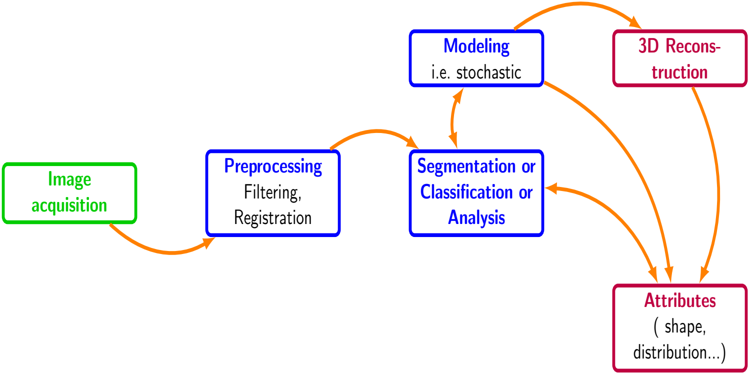
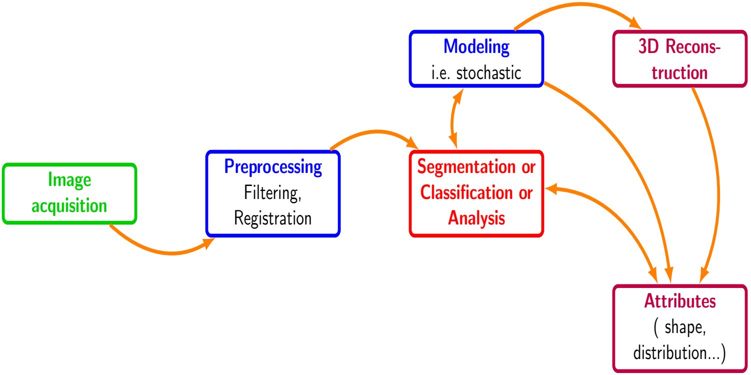
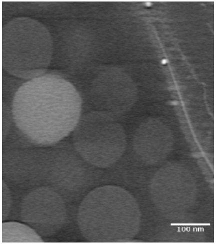
Classical material image analysis pipeline

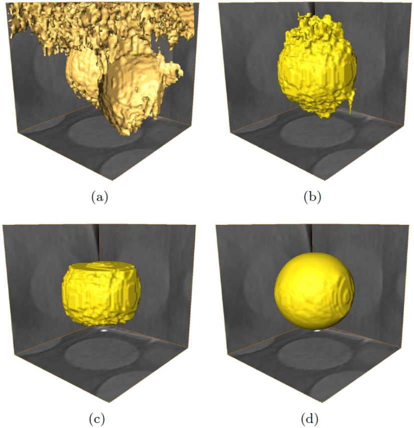


Segmentation



Segmentation – blob-shaped objects

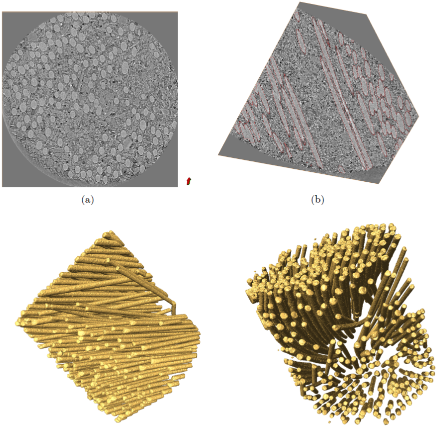




[Marak, PhD thesis, 2012]

(a) Optimal threshold ; (b) Watershed ; (c) Graph cuts ; (d) Continuous maximum flows

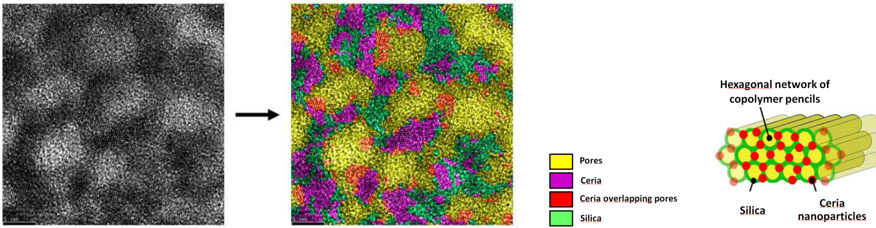
Segmentation – thin objets


(a) (b) (c) (d)

Issue and technic

- Issue : Segmenting elongated objects such as fibers is complicated
- Technic : Continous Max Flows [Appleton, Talbot, PAMI 2006]

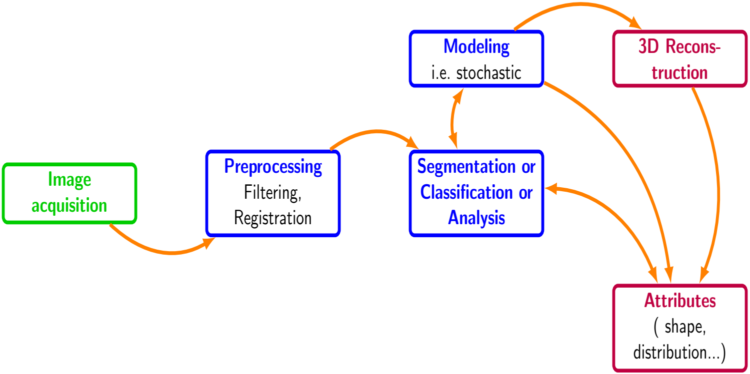
Analysis



Issue and technic

- Issue : contours of the objects to segment (nanostructured ceriasilica composite catalysts) not well defined
- Technic : Morphological approach [Moreaud et al., J. of Microscopy 2008]

Modeling


Modeling
i.e. stochastic
3D Recons-
truction
Image
acquisition
Preprocessing
Filtering,
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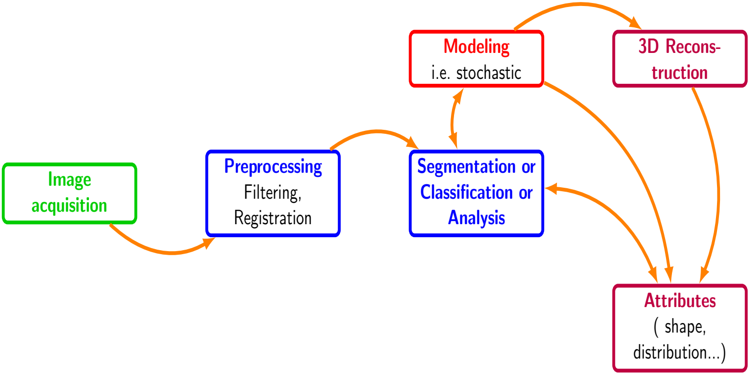
Segmentation or
Classification or
Analysis
Attributes
(shape,
distribution...)

Modeling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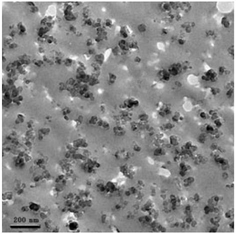
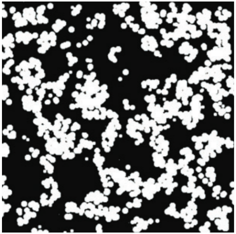
Microstructure stochastic modeling

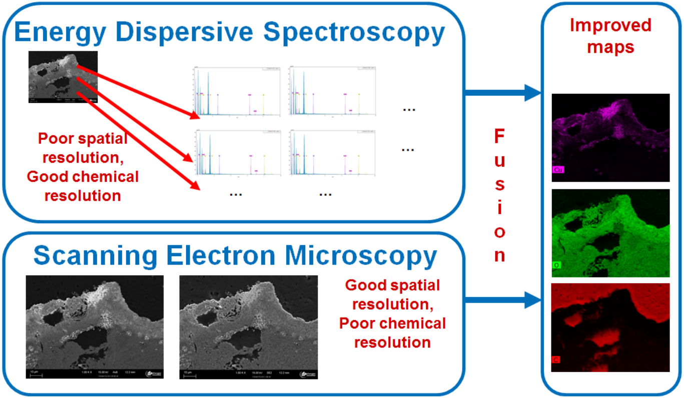




Issue and technic

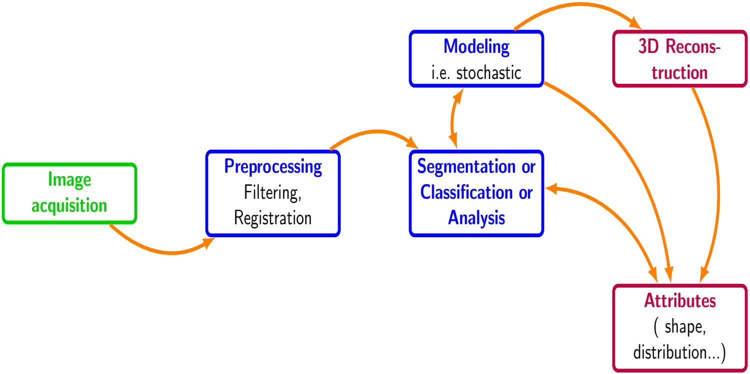
- Issue : Extract physical properties such as conductivity from rubber images
- Technic : multiscale microstructure modeling [Jean et al., J. of Microscopy 2010]

Multi-modality



Related to works in hyperspectral imaging [Noyel, Angulo, Jeulin : Morphological segmentation of hyperspectral images, Image Anal. Stereol, 2005]

Pre-processing



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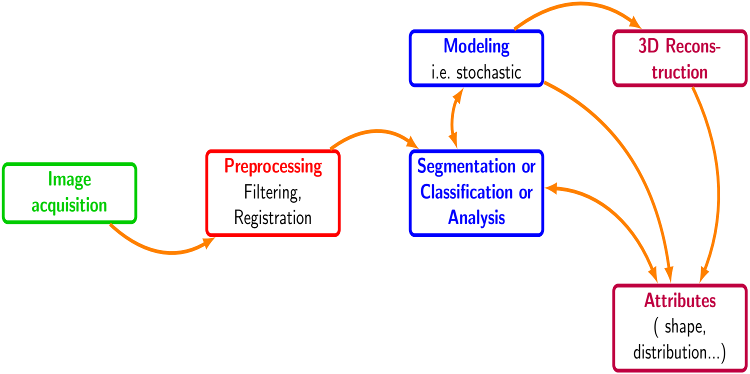
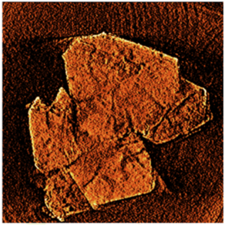
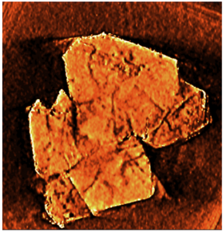


Parallel computing





Issue and technic

- Issue : Tomographic acquisitions lead to noisy images and large data volumes to filter
- Technic : Fast 3D bilateral filter on the GPU [Cokelaer and Moreaud, ECS 2013] Speed gain using GPUs : $60\times$ faster than quad-core CPU implementations

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An overview of the special session

1. Structure Tensor Based Synthesis of Directional Textures for Virtual Material Design **Texture Synthesis, Virtual Material**
    - 2D texture image synthesis
2. Image Processing In Experiments On, And Simulations Of Plastic Deformation Of Polycrystals **Fast Fourier Transform, Edge Detection**
    - Peaks segmentation in 2D diffractogram images to reconstruct 3D objects
3. Physics of MRF Regularization for Segmentation of Materials Microstructure Images **Segmentation, Priors**
    - Analogy between physics of interfaces and MRF segmentation of 2D images
4. Morse theory and persistent homology for topological analysis of 3D images of complex materials **Skeletonisation, Watershed transform**
    - Topologically accurate joint skeleton and 3D watershed segmentation
5. Volume-Based Shape Analysis for Internal Microstructure of Steels **Image-based Shape Analysis, Multi-labeled Volumes**
    - 3D segmentation and classification

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Conclusions

Summary

- Material images acquired by indirect devices, subject to noise, lead to large data volumes to analyse
- Material science is an interesting field of application for image processing methods
- Possible interaction between the two domains is wide
- The goal of this special session is to draw the image processing community attention to these new possibilities