FIBER ORIENTATION MEASUREMENTS IN COMPOSITE MATERIALS

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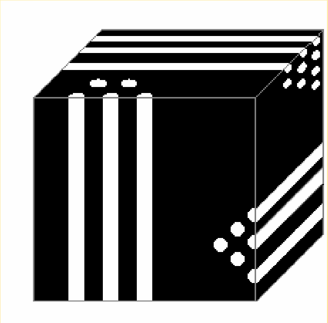
Objectives

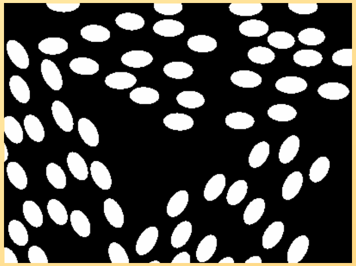
- We aim at the characterization of fibrous composite materials by image processing.
  - To compute the **fiber orientation** scattering.
  - To estimate the volume **fiber ratio** in each **main direction** of the material.
- We propose a new approach:
  - for the measurement of **fiber orientation.**
  - based on the observation of a **single section**.
- Our approach operates :
  - for anisotropic materials with **2 or more principal fiber directions**.
  - On **cylindrical fibers**, bundled in **threads**.

Overview of our approach

1. Sample preparation:
   – Choice of the **section plane** and **image acquisition;**

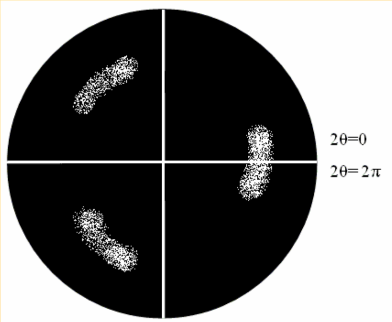


Material sample

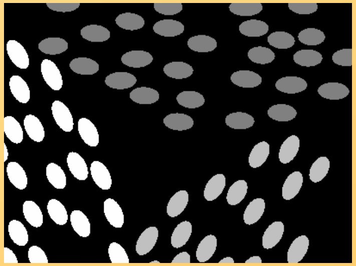


Section plane after image acquisition

2. Image processing:
   – **Fiber detection**;
   – **Fiber parameter estimation**;
   – **Thread segmentation and fiber labeling**;



Fiber orientation distribution



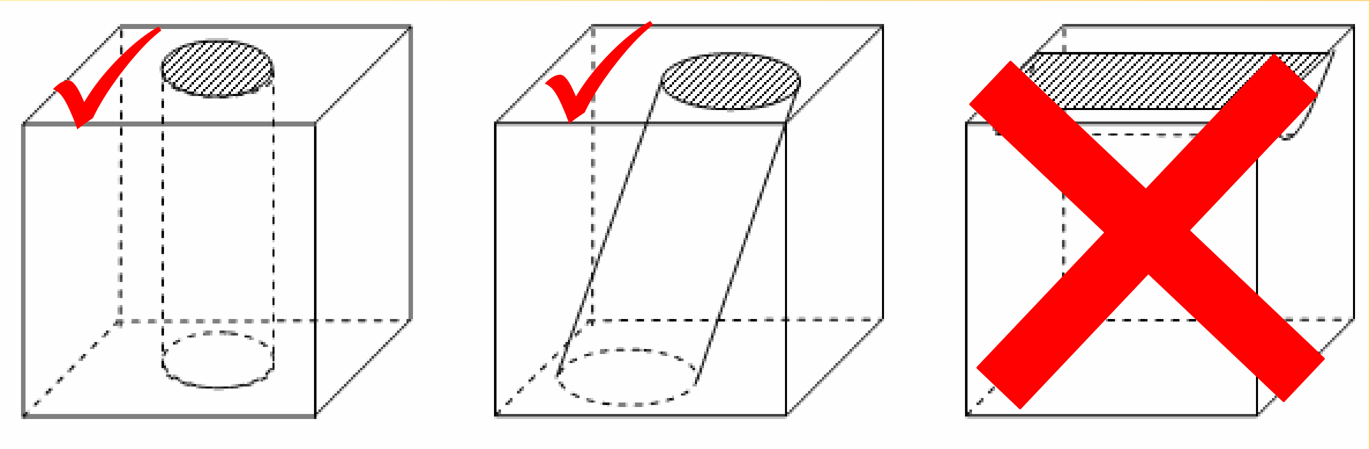
After fiber labeling

3. Computation of **fiber** and **thread characteristics.**

Sample preparation: Optimal section plane

- *First rule for the choice of the section plane:*
  - *The images on the section plane must be representative of the material volume.*

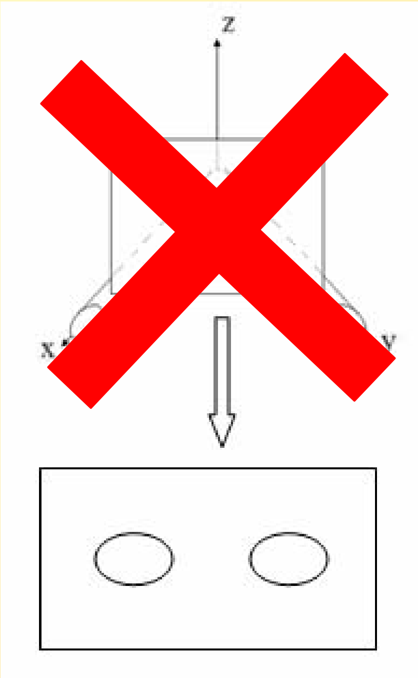
  ⇒ ***Avoiding longitudinal sections*** *allows for a correct estimation.*



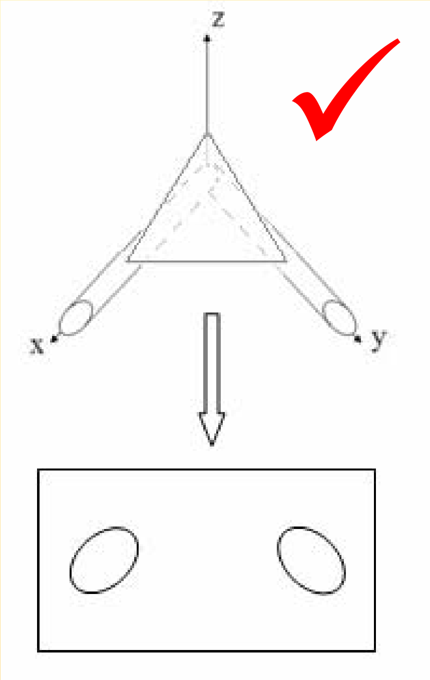
Sample preparation : Optimal section plane

Material with two orthogonal directions :

Section ⊥ to the material plane

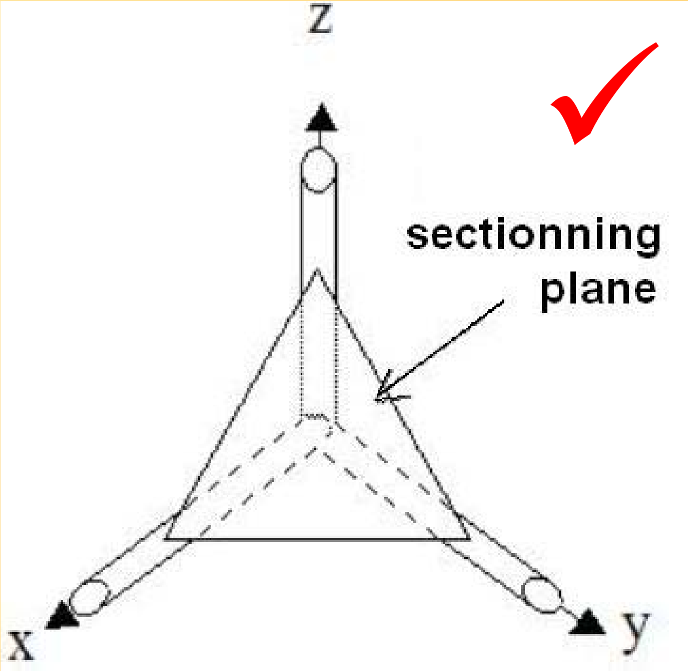


Oblique section

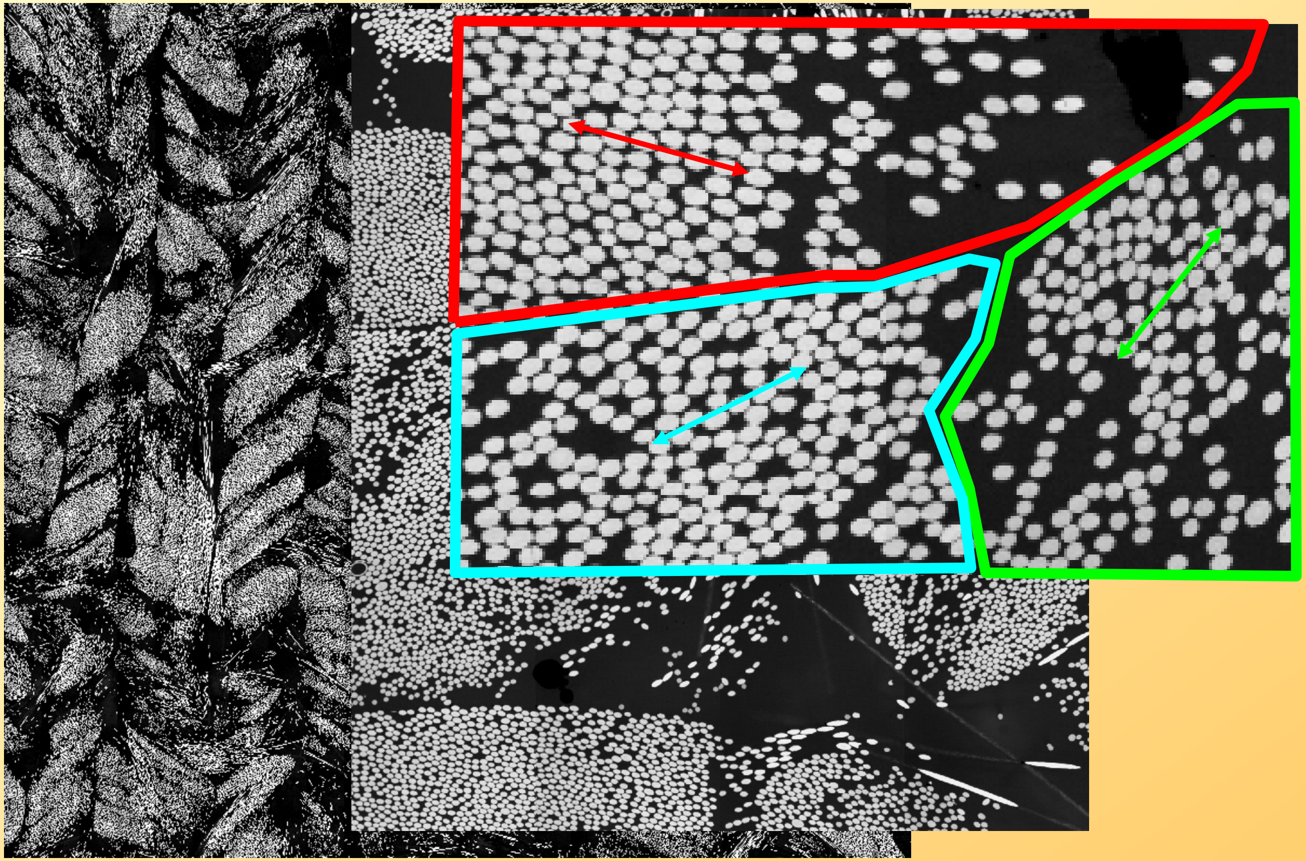


Material with three Orthogonal directions :

Oblique section



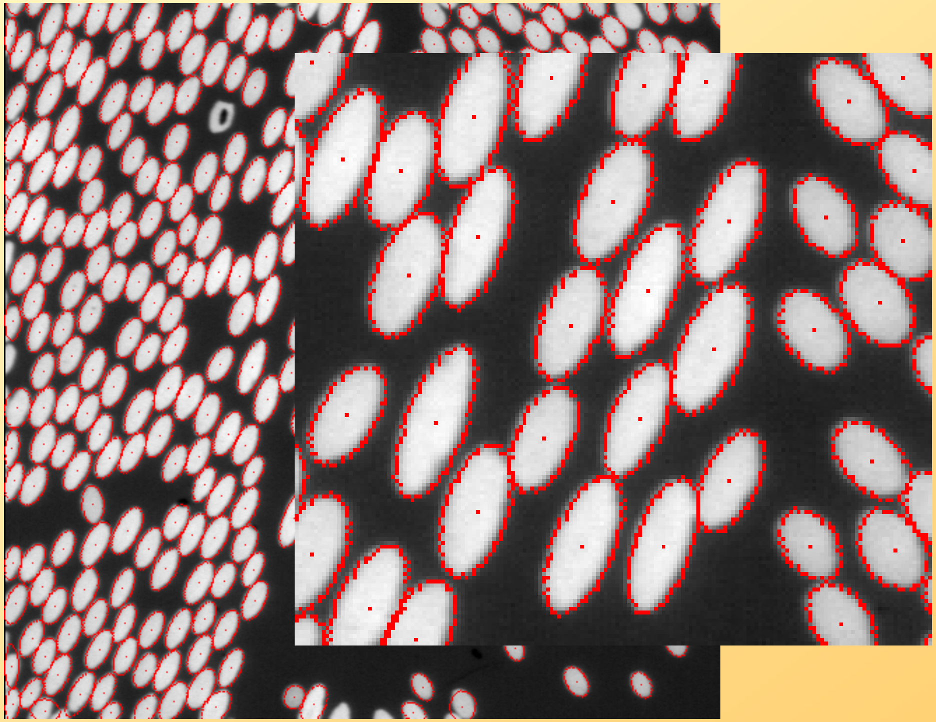
Example of oblique section



Carbon reinforcement made of threads (~1000 cylindric fibers).
Threads weaved in two orthogonal directions (X and Y).
Layers of weaves are needled in a third orthogonal direction Z.

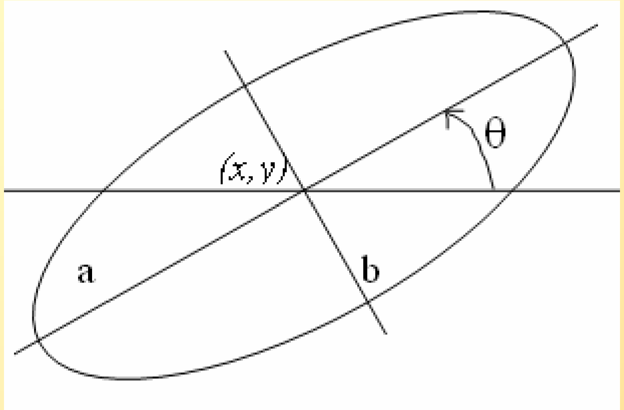
Image processing stage: Ellipse parameter estimation

- Ellipse detection:
  - Using segmentation and pattern recognition algorithms.

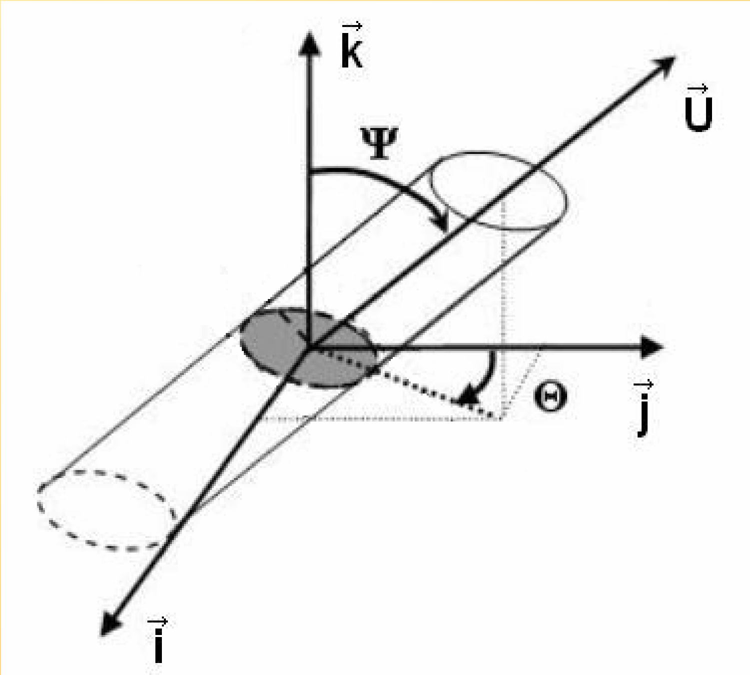


Relation between ellipse and fiber parameters

- Ellipse parameters (a, b, θ) relate to the fiber parameters (Θ, ψ)



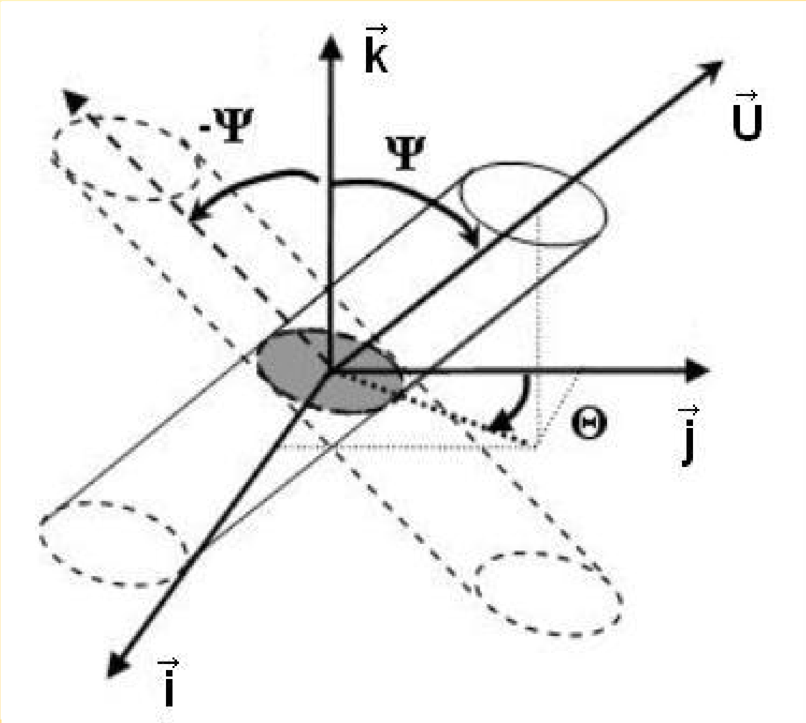
$$\begin{cases} \Theta = \theta \\ \cos(\psi) = \dfrac{b}{a} \end{cases}$$



  - **Orientation** Θ is in [0;π].
  - **Fiber inclination** ψ is in [-π/2;π/2]..

Orientation ambiguity

- The ellipse parameters give access to the 3-D fiber direction but an ambiguity remains:



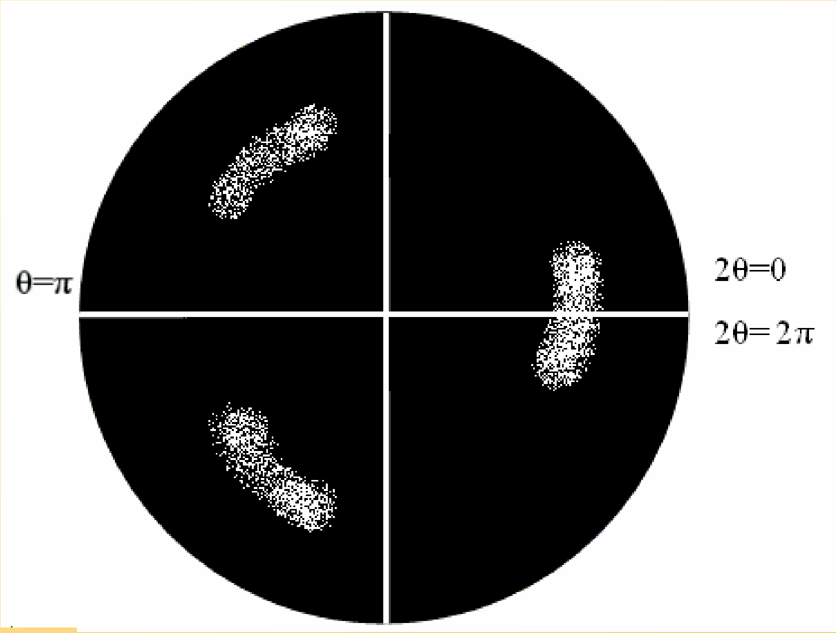
$$\psi = \pm\psi' \quad where \quad \psi' = \arccos\frac{b}{a} \in \left[0, \frac{\pi}{2}\right]$$

Two symmetric fibers regarding the section plane, remain **indistinguishable** on this particular plane.

Fiber and thread labeling: the polar graph

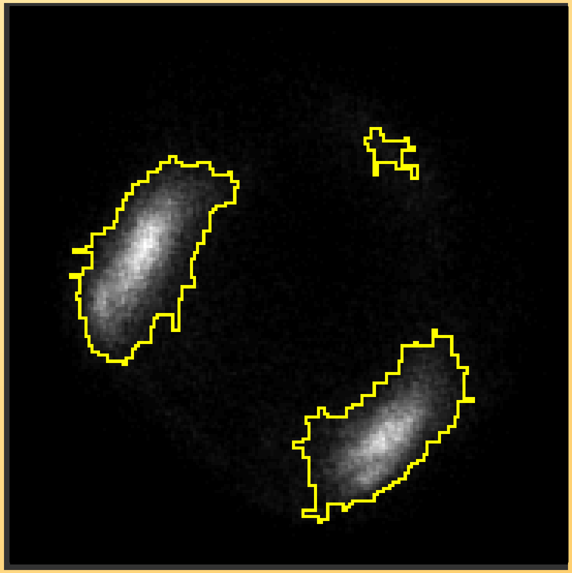
- To depict the set of fiber orientation, we map each pair *(Θ, ψ')* into a **polar graph**.

  - Using a **polar graph** takes into account the **periodic nature** of **Θ**.
  - *(Θ, ψ')* $\rightarrow$ argument 2Θ and modulus ψ'.
  - Taking **2Θ** instead of Θ **avoids** spurious **discontinuities**.



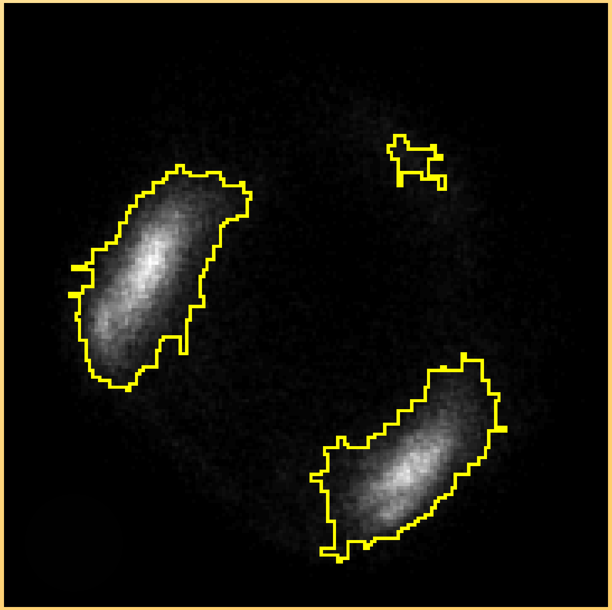
Fiber Labelling : Main directions identification

- Conversion of the **polar graph** into a **grey level image**.
- **Segmentation** of the blobs (thresholding).
- **Morphological dilation** and elimination of the small area to ensure one and only **one blob by main direction**.
- Fibers inside a given blob are used to compute the **mean value** of the **blob direction**.



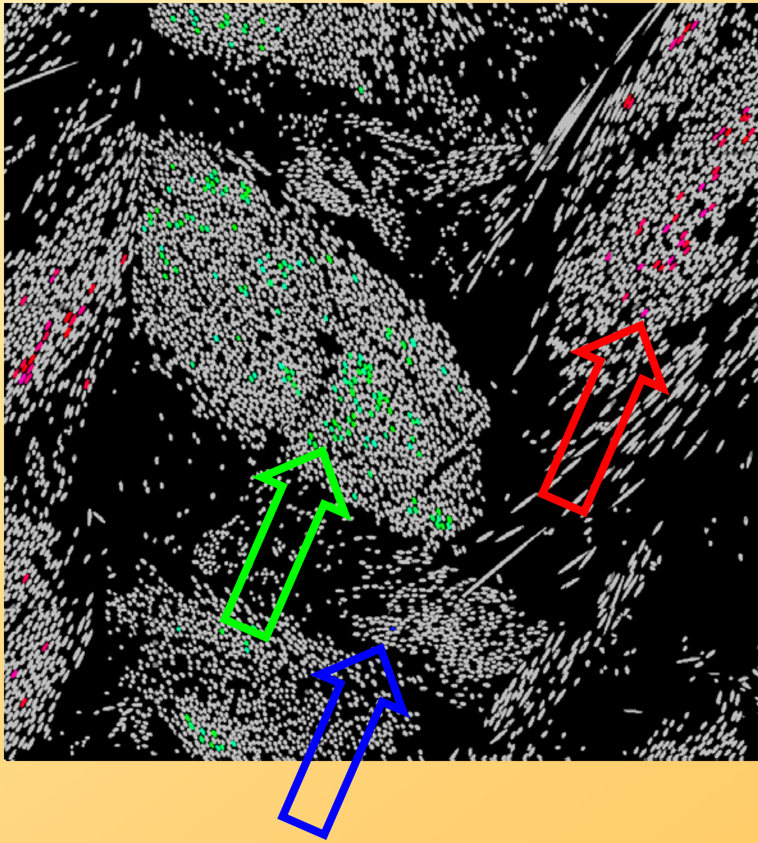
Fiber Labelling : Main directions identification

- The mean directions of the blobs still suffer from the **orientation ambiguity**.
- The user is in charge of the correction of the ambiguity.
  - He associates each blob with its true orientation.
  - Using a priori knowledge on the main directions of the material.
  - Thus, he gets rid of the ambiguity for the blob.



Thread segmentation (1/3)

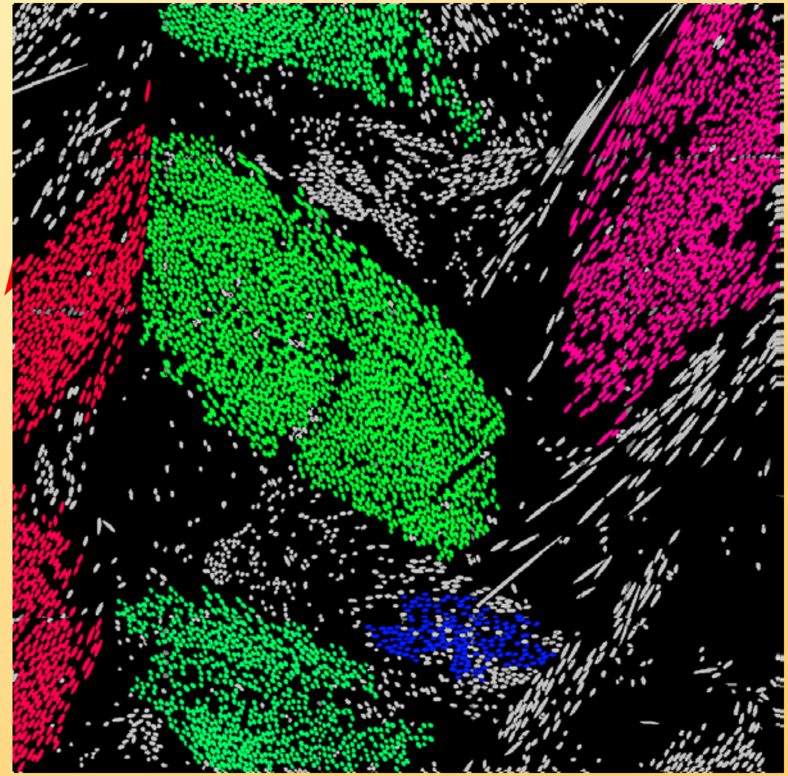
- Thread kernel selection :
  - For each blob, fibers showing a **direction close to** its **mean directions** constitutes its **fiber kernel**.
  - **kernel fibers** must be surrounded by at least **6 similar fibers**.



- Fiber orientation ambiguity
  - We correct the **orientation ambiguity** of each **fiber** in the kernel.

Thread segmentation (2/3)

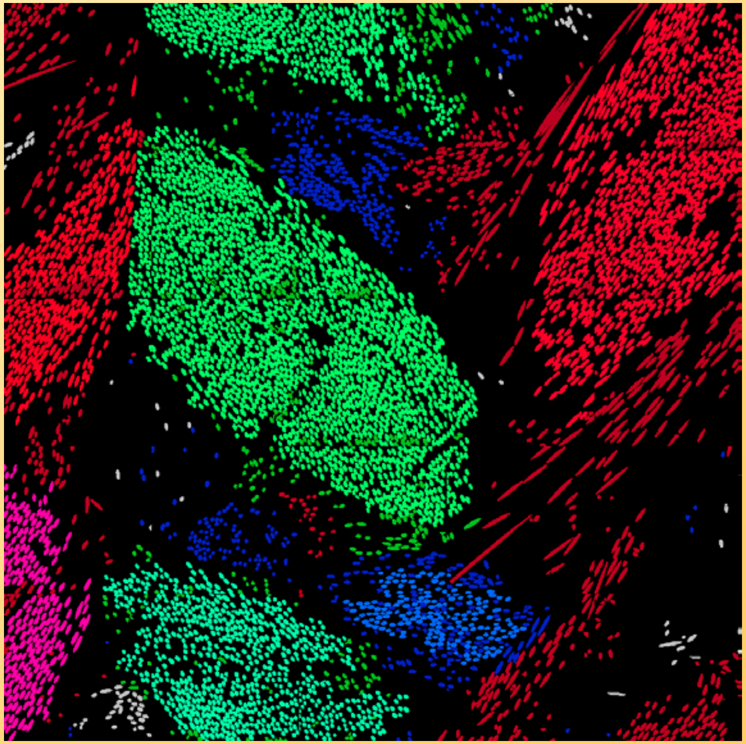
- Propagation within a thread
  - Knowing that fibers are bundled in threads, **labels** of the **kernel fibers** are **spread to neighboring fibers**.
  - Thus, **bundles of labeled fibers** grow around the **kernels**.



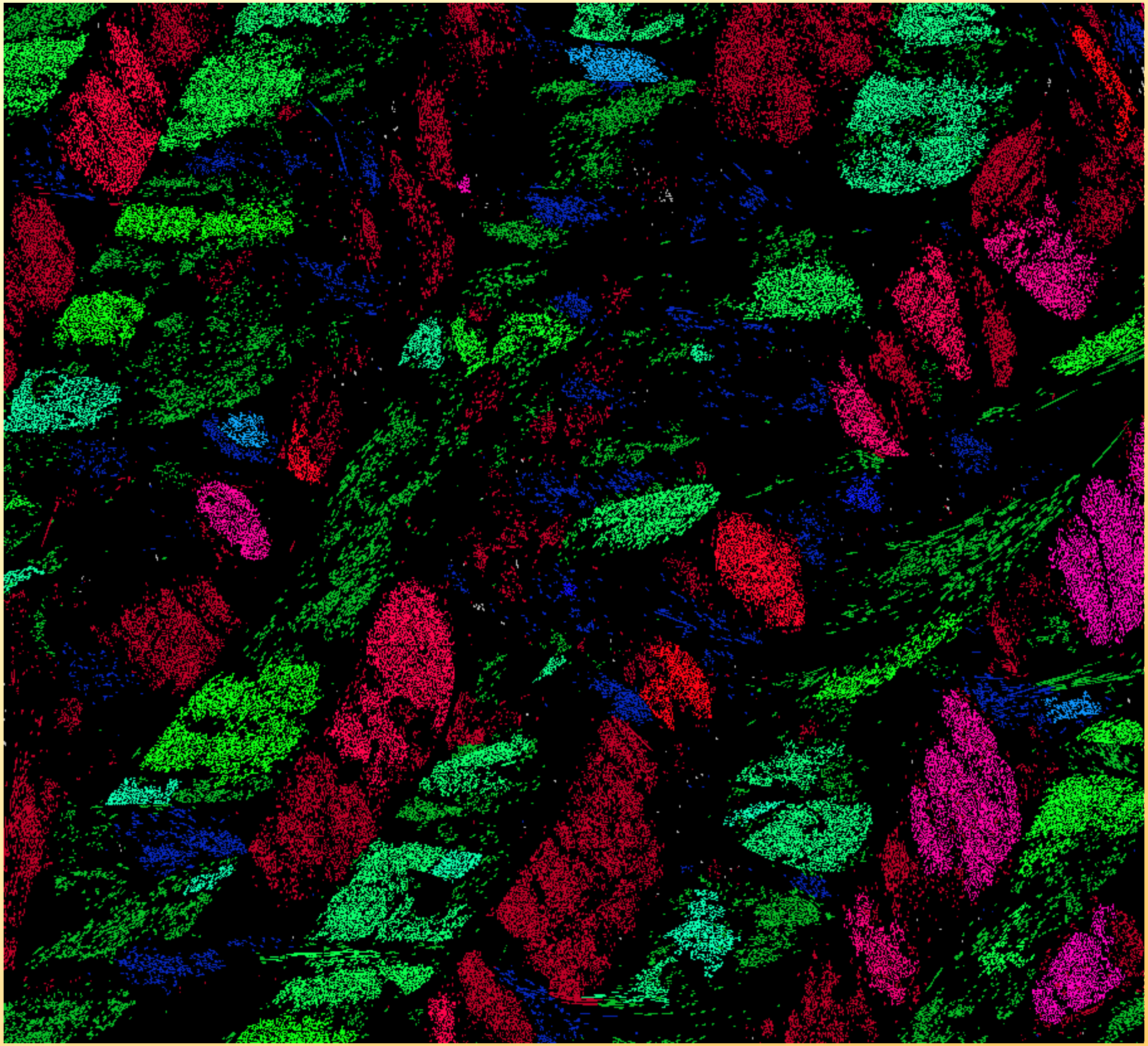
- At this stage, some fibers remain unlabeled.

Thread segmentation (3/3)

- **Unlabelled remaining fibers** are generally located outside the threads.
  - They can be either **rejected,**
  - Or they can be assigned to the **closest thread**.

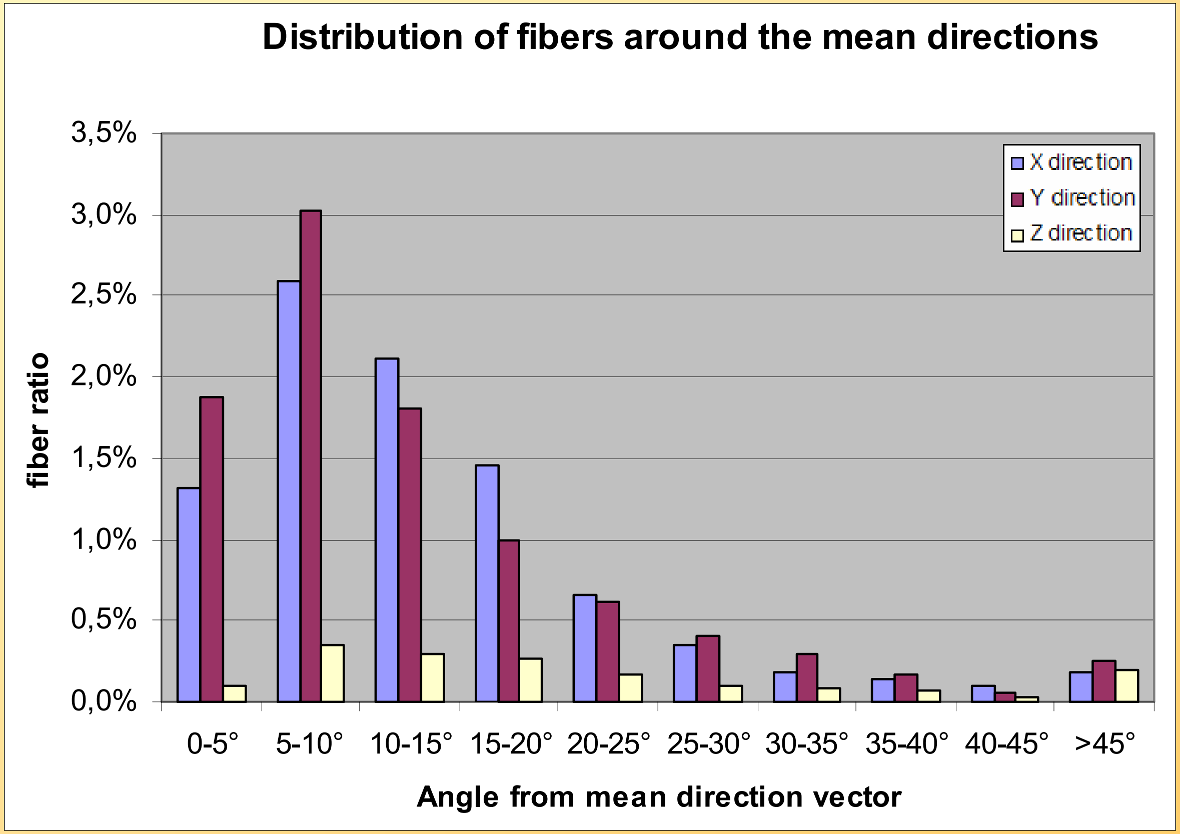


Final result (large scale)



Last stage: Fiber and Thread characteristics

	Global	X direction	Y direction	Z direction
Surface Ratio	20.3%	9.1%	9.5%	1.7%



Summary

- A new framework for the estimation of fiber orientation on fibrous composite materials
  - Using a **single section** of the material.
- Based on
  - An **oblique section plane**.
  - A **polar representation** of fiber parameter to find the main material directions.
  - A **thread segmentation algorithm** results in the complete classification of the fibers.
- Successful application to the characterization of carbon/carbon composite materials.

Prospectives works

- Other aspects are currently under study.
  - The reliability of 3-D parameter estimation by image processing of 2-D sections.
  - The generalization of such a framework to any kind of materials or to materials showing any type of structures .

Thank you for your attention!