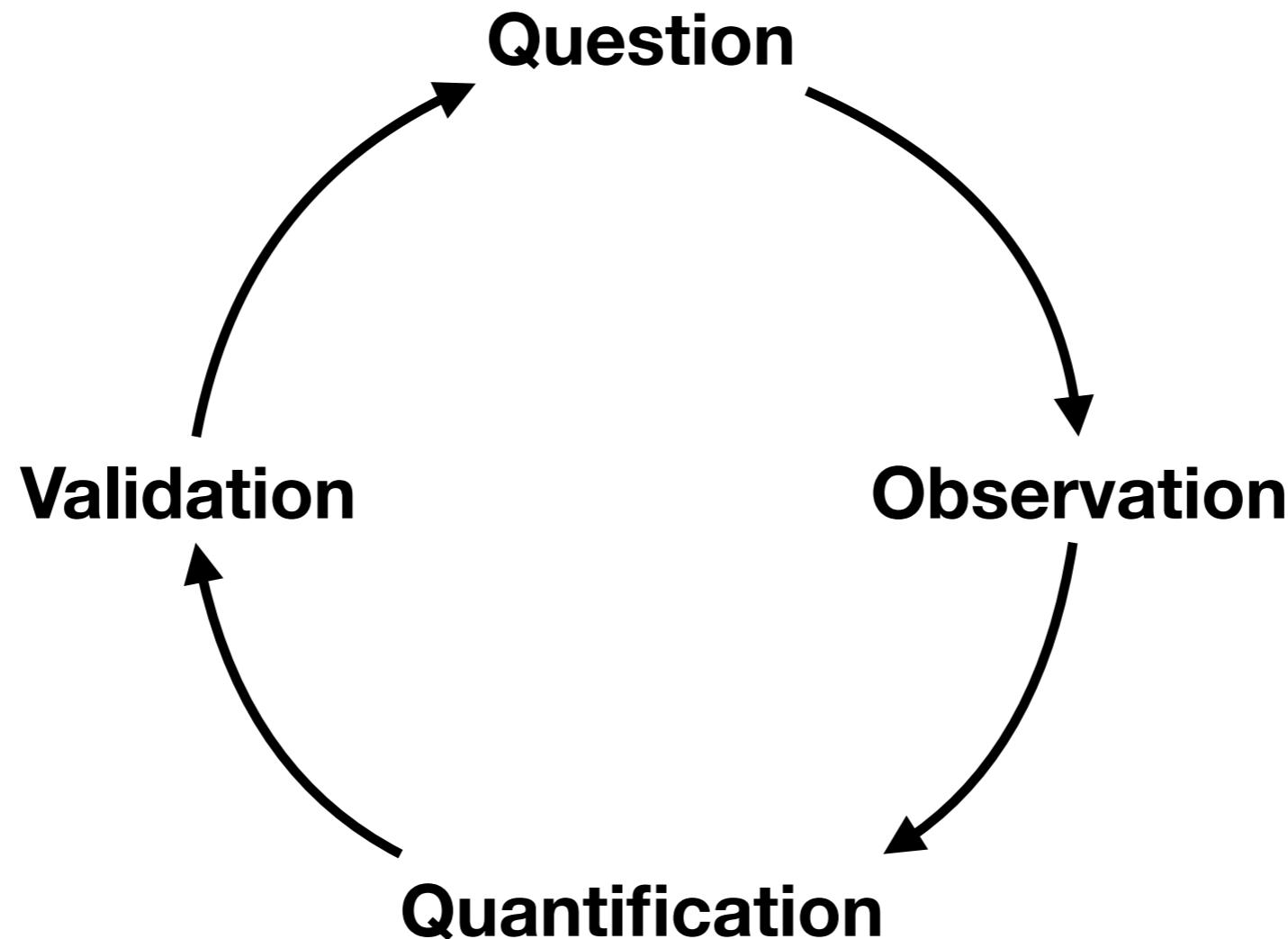


Reconstruction d'embryons à partir d'images 4D

Emmanuel FAURE
emmanuel.faure@lirmm.fr

HMIN318
20/11/2019

Workflow



Plan présentation

1 Introduction Biologie du développement

2 Protocoles d'acquisition et images 4D

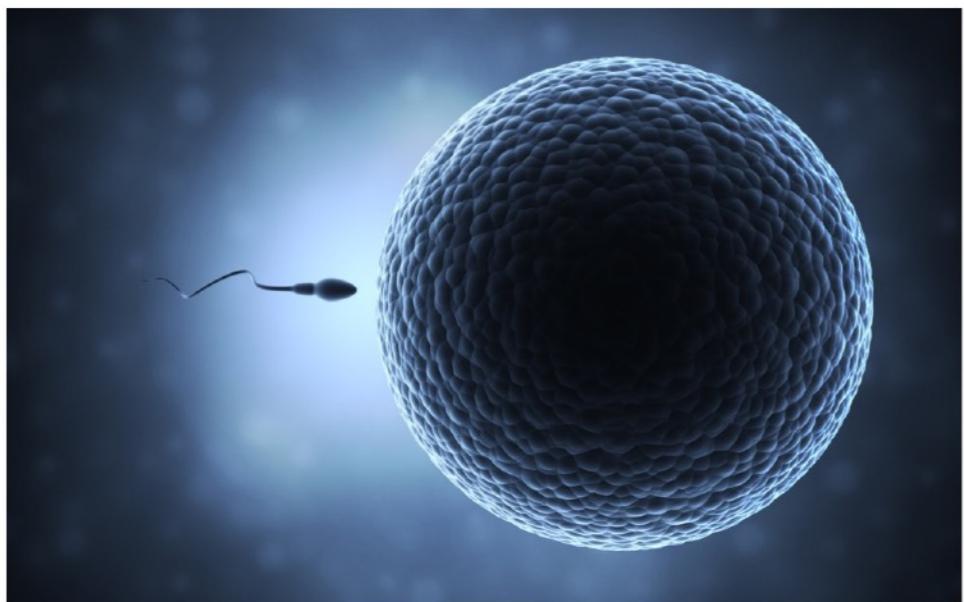
3 Reconstruction phénoménologique de la morphogenèse à partir d'images 4D

(Filtres, Détection, Segmentation, Suivi cellulaire)

4 Que faire ensuite avec ces données reconstruites ?

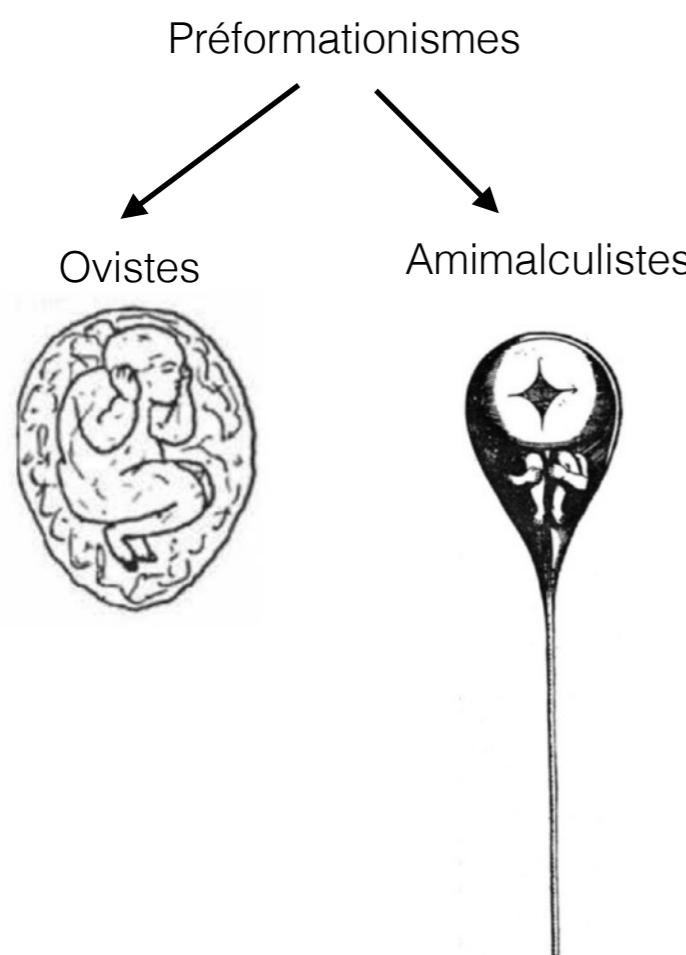
- Validation de données
- Visualisation de données

Embryogenèse



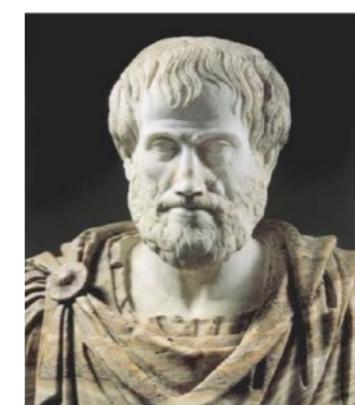
Théorie de la Préformation

Dans l'œuf, l'adulte préexiste en version miniature



Théorie de l'Epigenèse

De nouvelles structures s'ajoutent progressivement au cours du développement



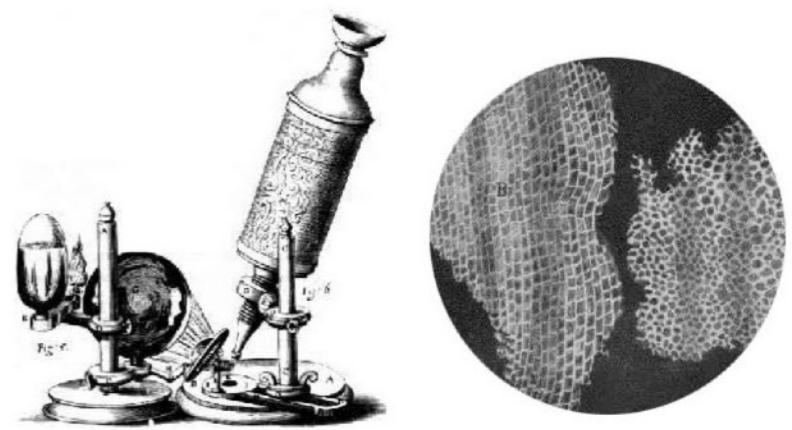
Aristote

Hippocrate pensait que nous héritions de petits morceaux de toutes les parties de nos parents.

Aristote pensait que nous grandissions à partir de formes indistinctes qui se développent à l'intérieur de maman à cause de papa.

Théorie cellulaire

- Tout organisme vivant est composé d'une ou plusieurs cellules
- La cellule est l'unité élémentaire de la vie
- Tout cellule provient d'une autre cellule

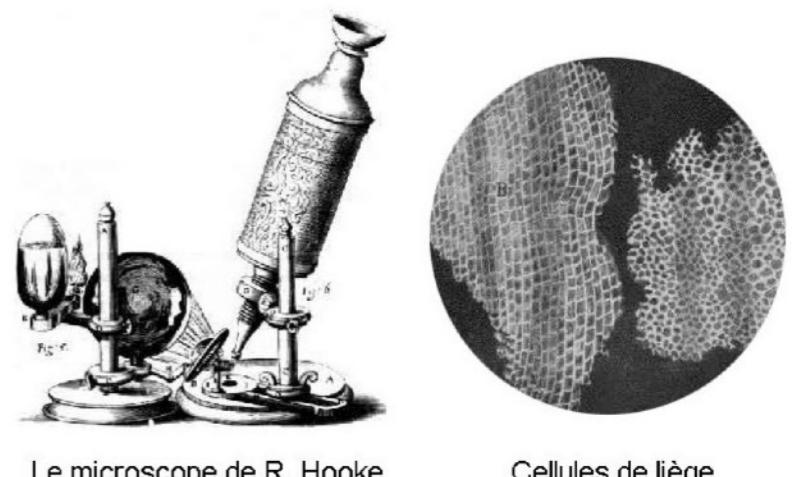


Le microscope de R. Hooke

Cellules de liège

Théorie cellulaire

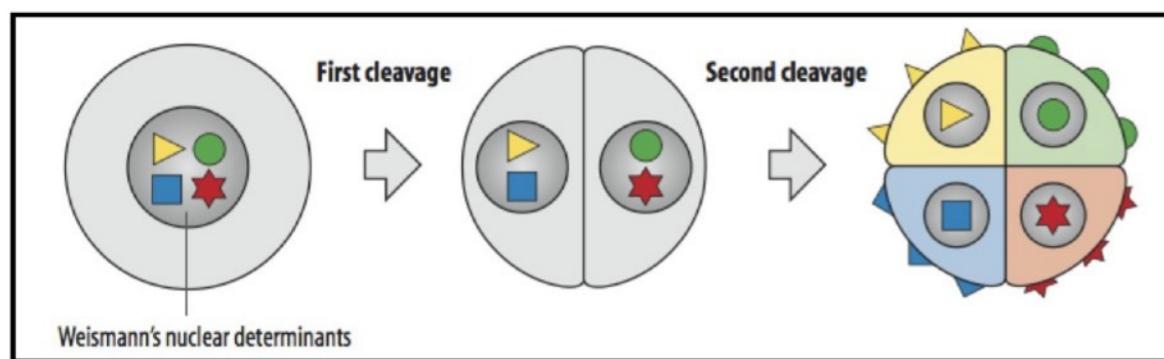
- Tout organisme vivant est composé d'une ou plusieurs cellules
- La cellule est l'unité élémentaire de la vie
- Tout cellule provient d'une autre cellule



Le microscope de R. Hooke

Cellules de liège

Théorie du développement mosaïque

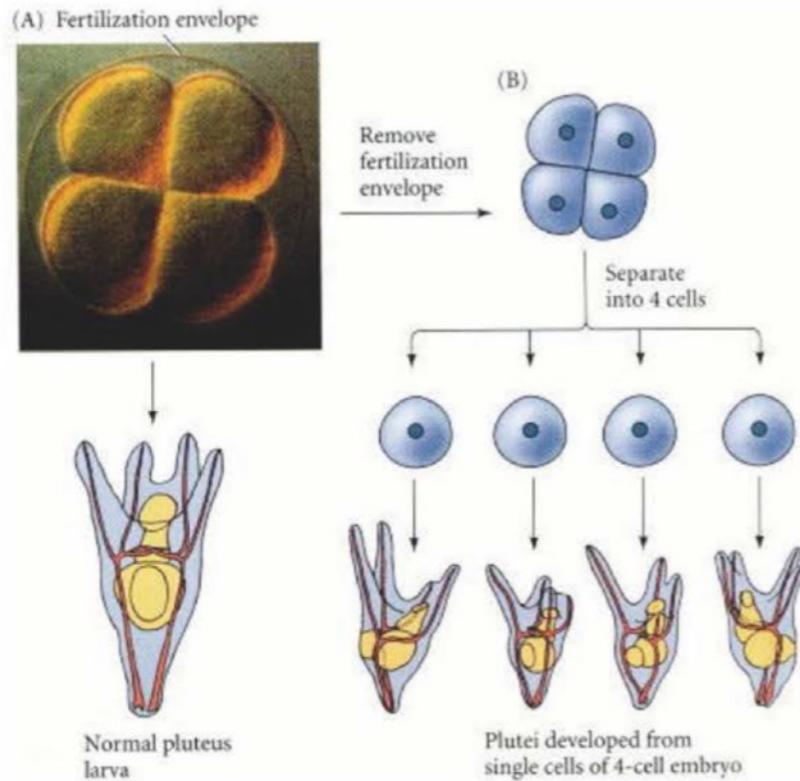


August Weismann

Le noyau comporte des déterminants qui sont partagés de manière asymétrique entre les filles

Embryologie expérimentale

19ème siècle

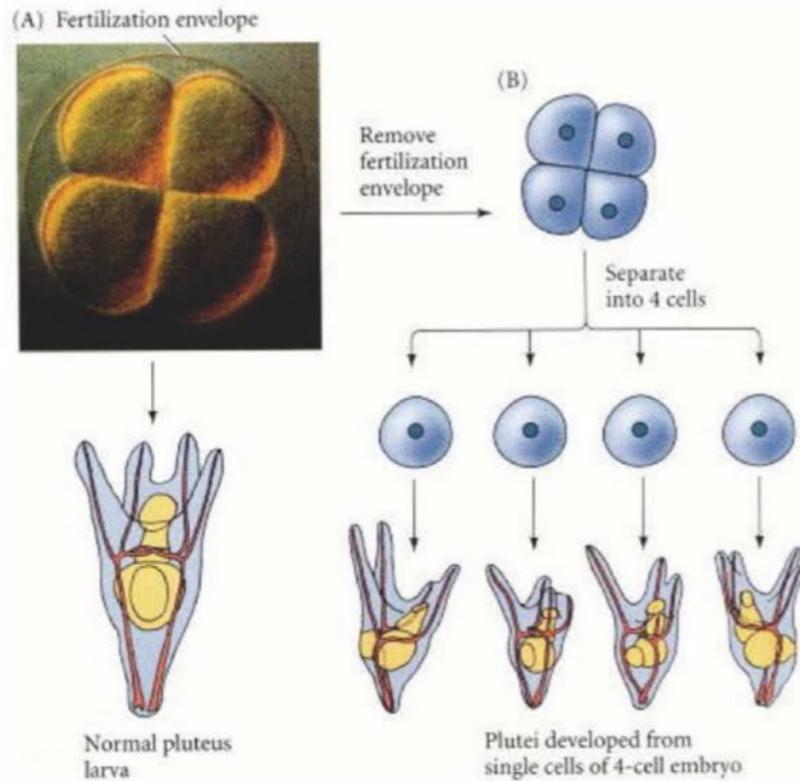


Chaque cellule d'un embryon
d'oursin précoce a la capacité de
donner un oursin

Hans Drisch

Embryologie expérimentale

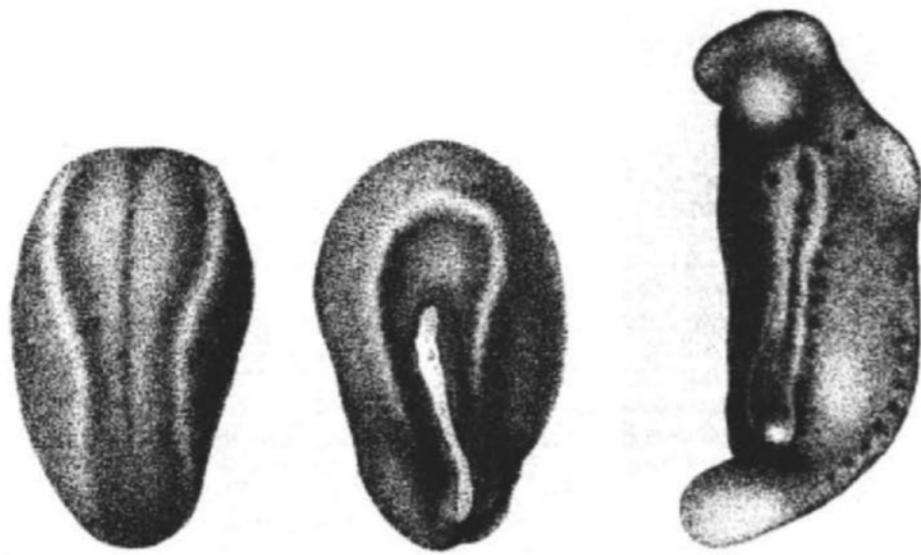
19ème siècle



Hans Drisch

Chaque cellule d'un embryon d'oursin précoce a la capacité de donner un oursin

Embryogenèse

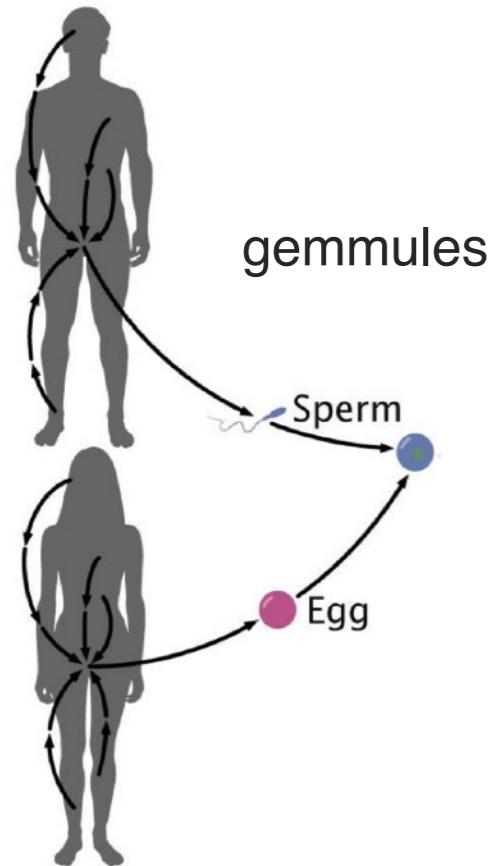


Hans Spemann

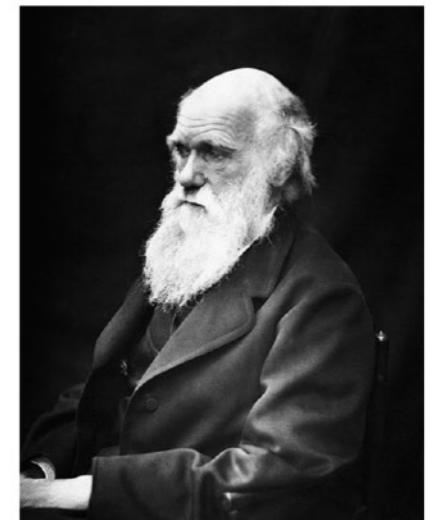
Différentiation cellulaire par signaux chimiques

Pangenèse

19ème siècle



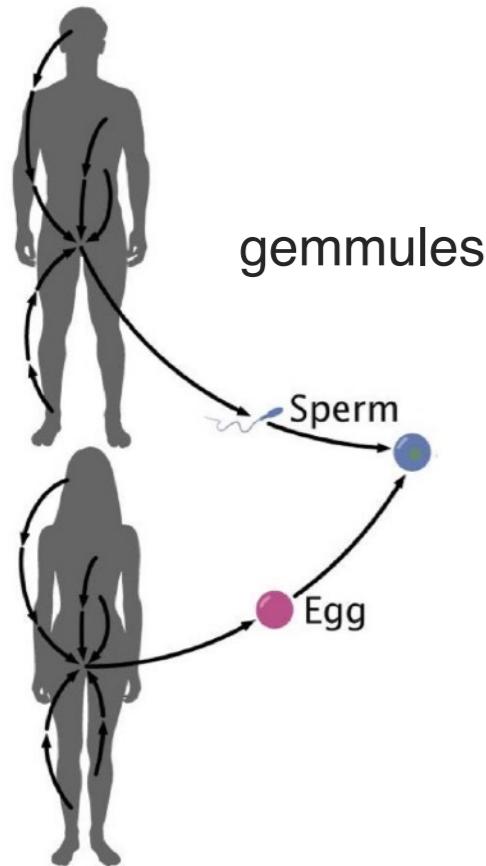
L'ensemble de l'organisme
participe à l'hérédité



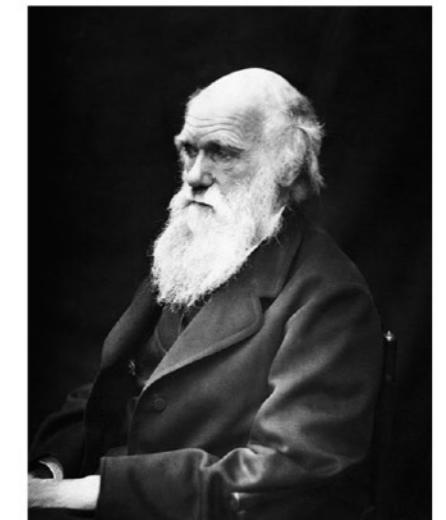
Charles Darwin

19ème siècle

Pangenèse

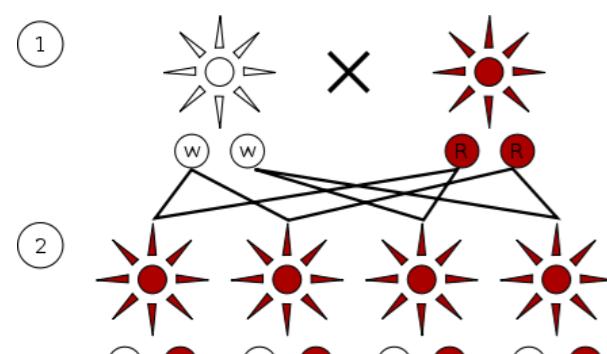


L'ensemble de l'organisme
participe à l'hérédité



Charles Darwin

Lois de Mendel

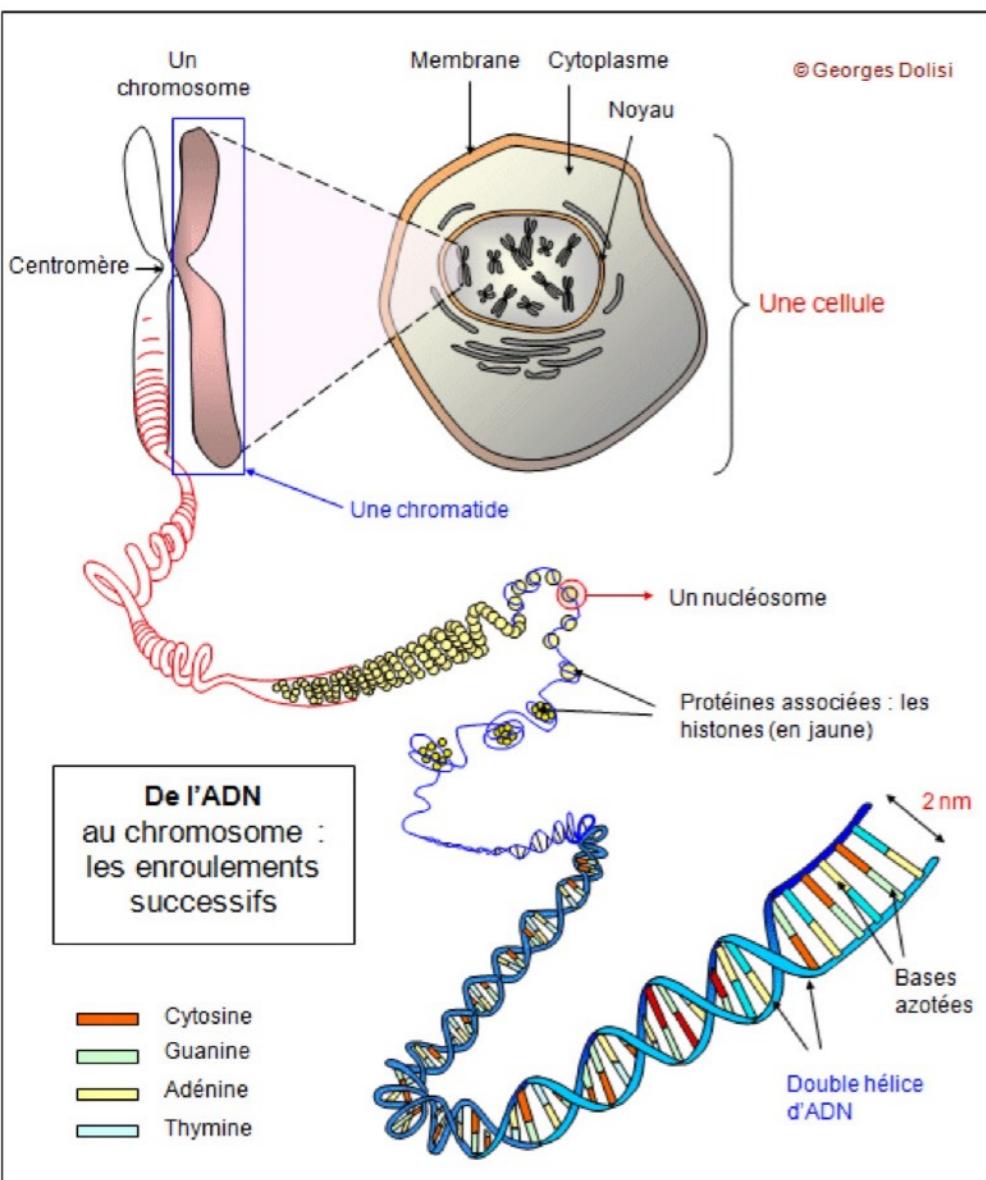


Facteurs héréditaires

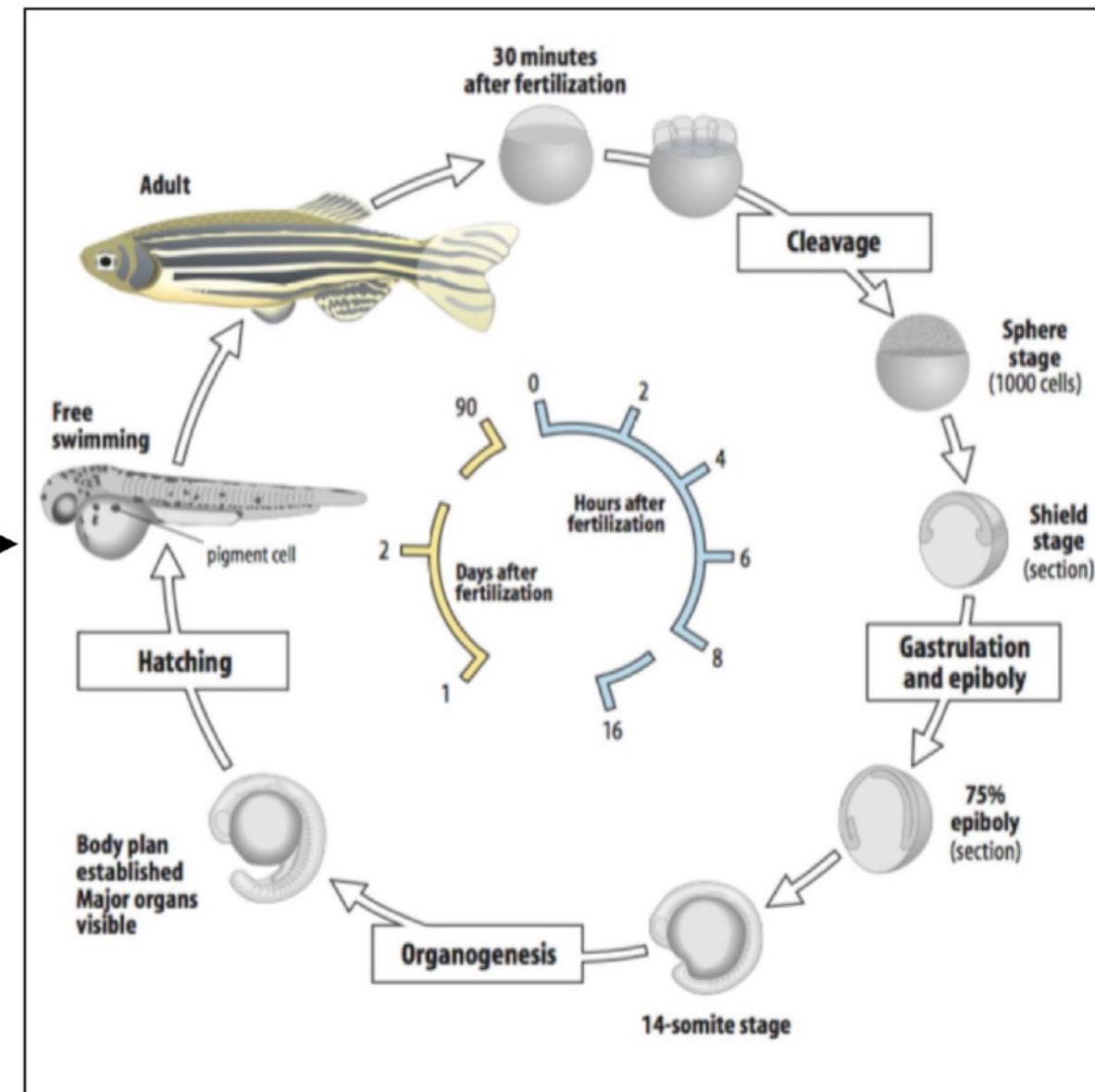


Gregor Mendel

Comment l'information génétique contrôle le développement ?

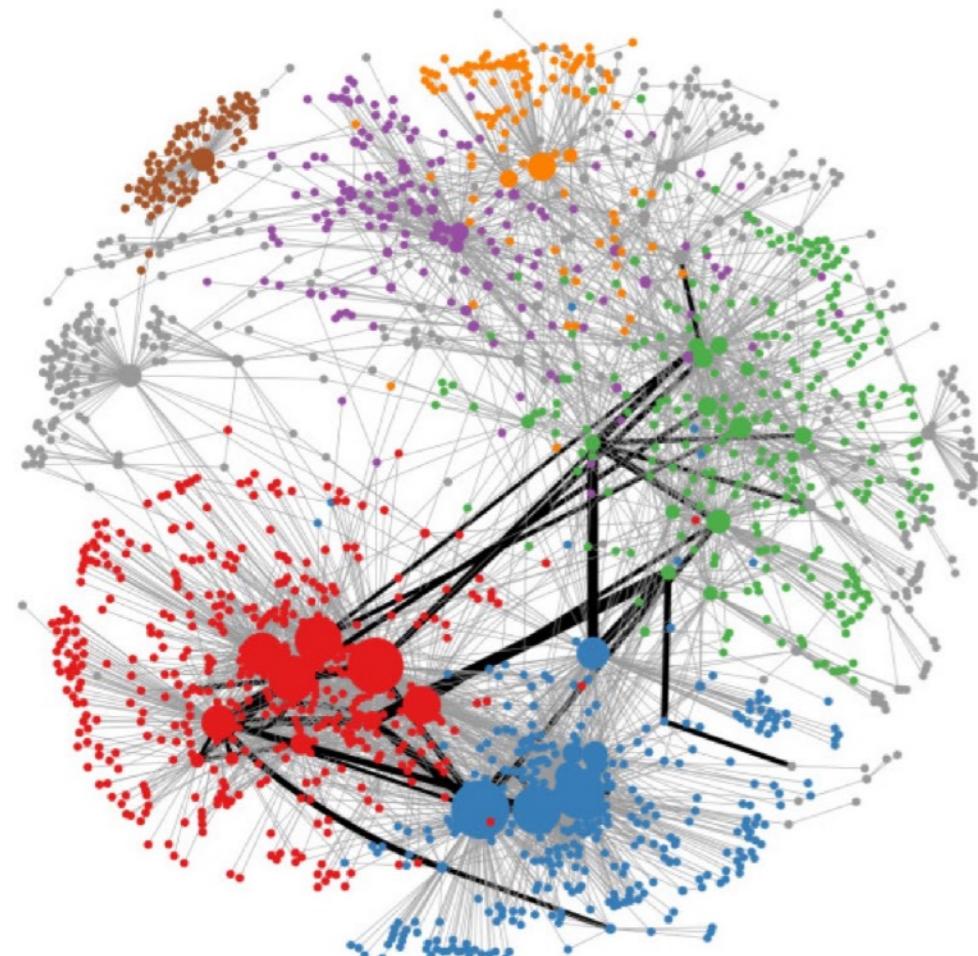


?



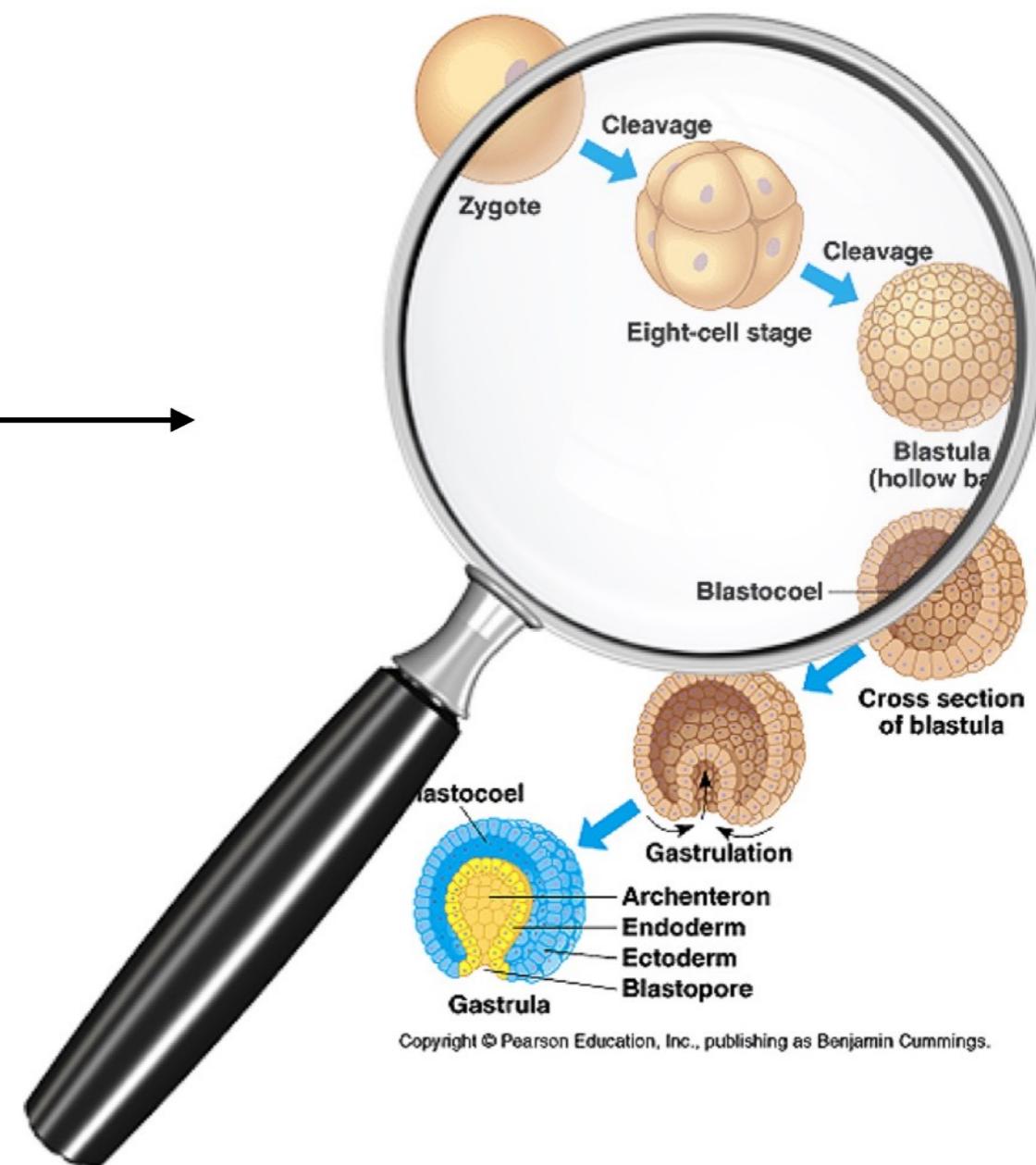
Comment l'information génétique contrôle le développement ?

Réseau de régulation génétique

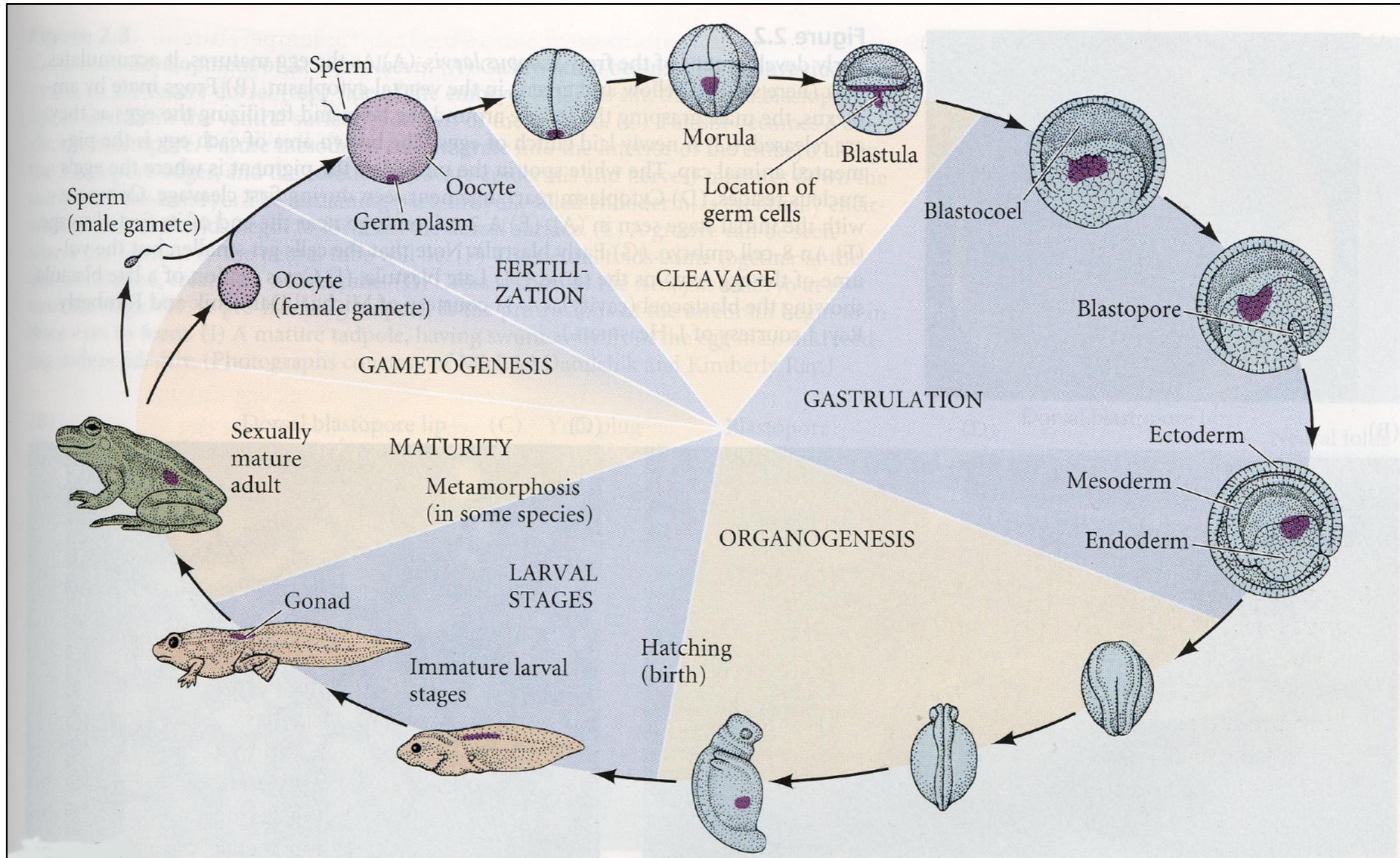


?

Stade de développement



Que veut on observer ?

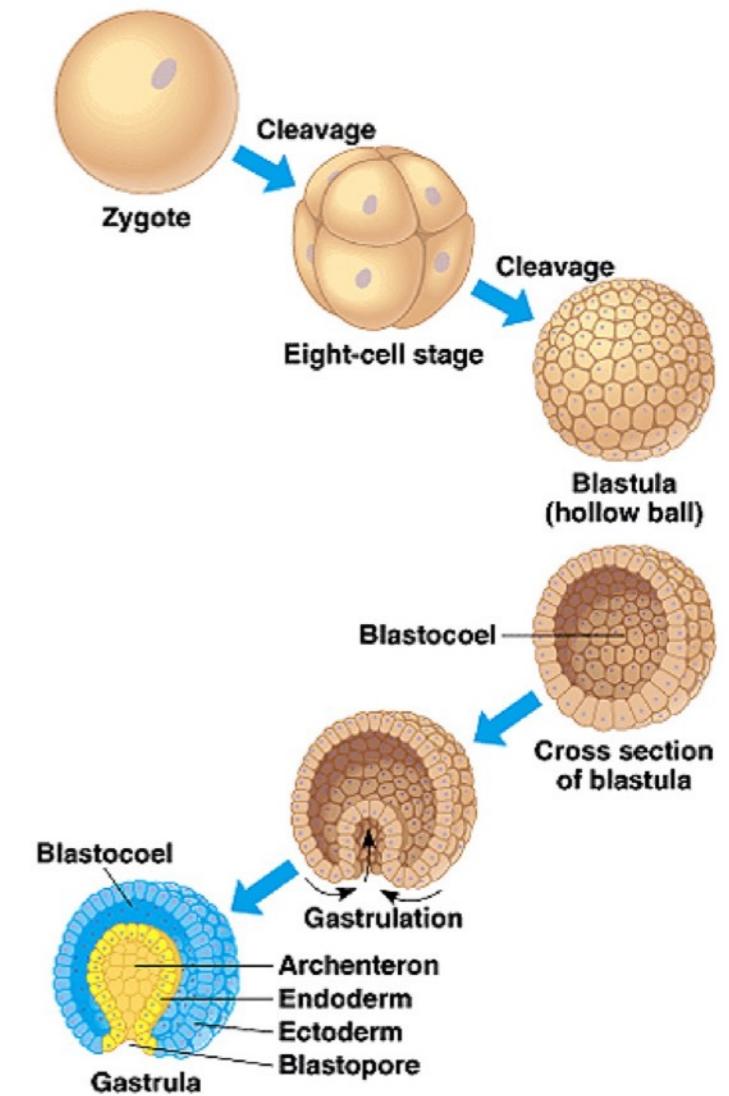
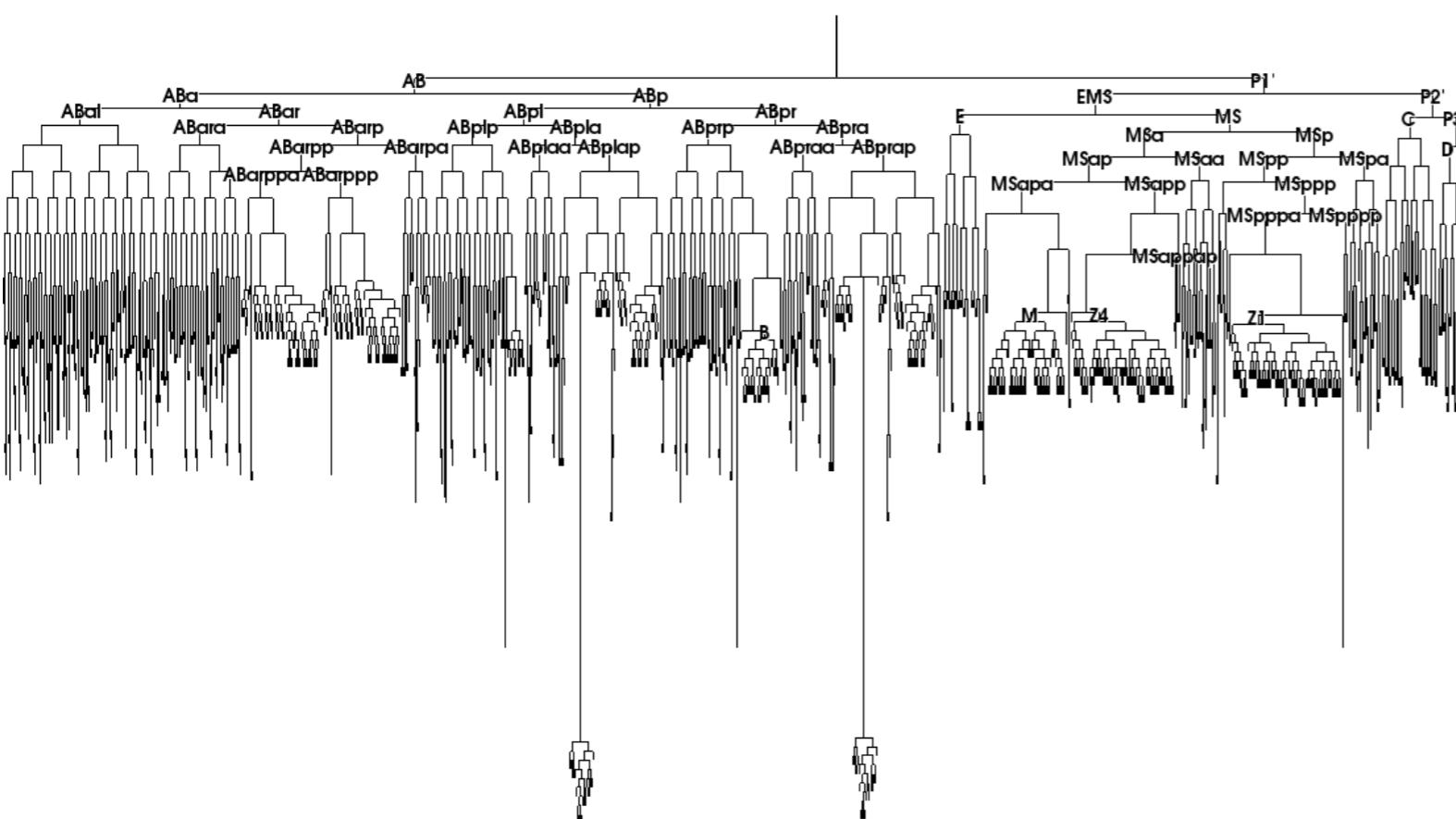


L'embryon à l'échelle cellulaire !

Suivi cellulaire

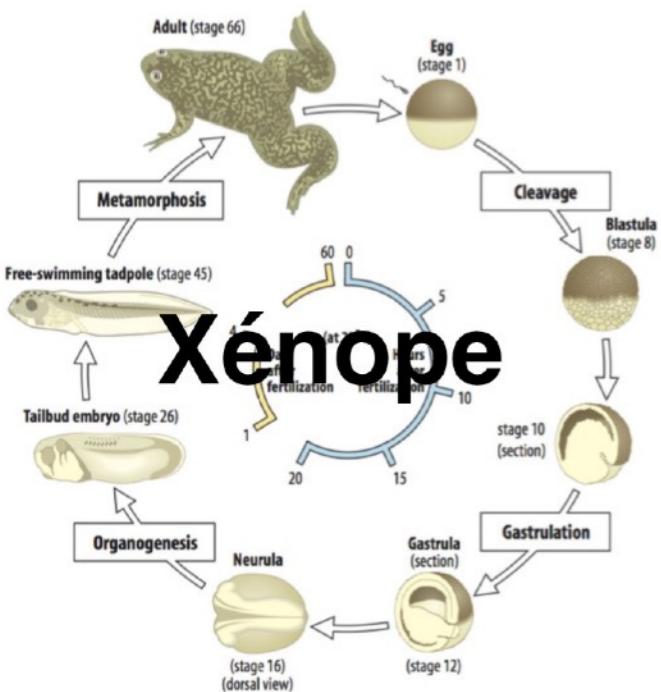
Arbre de lignage cellulaire

[*Caenorhabditis elegans* , Sulston 1983]

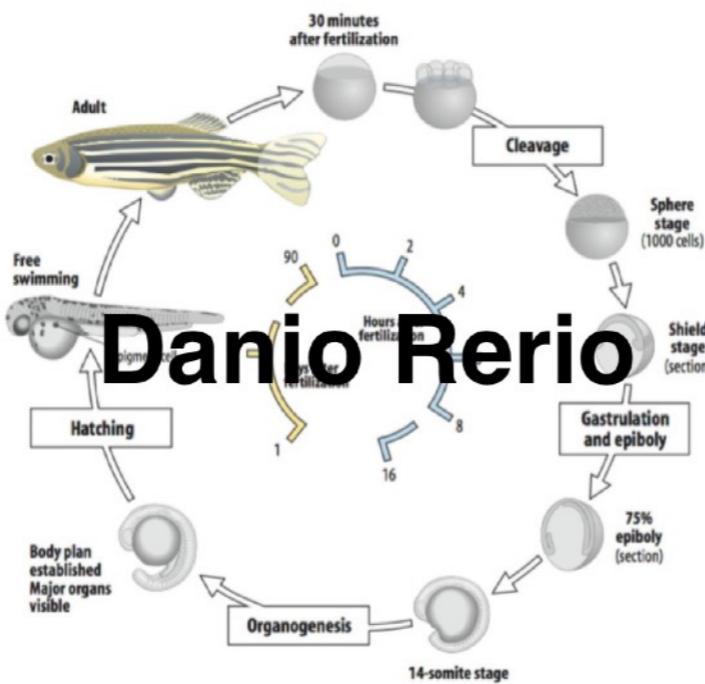


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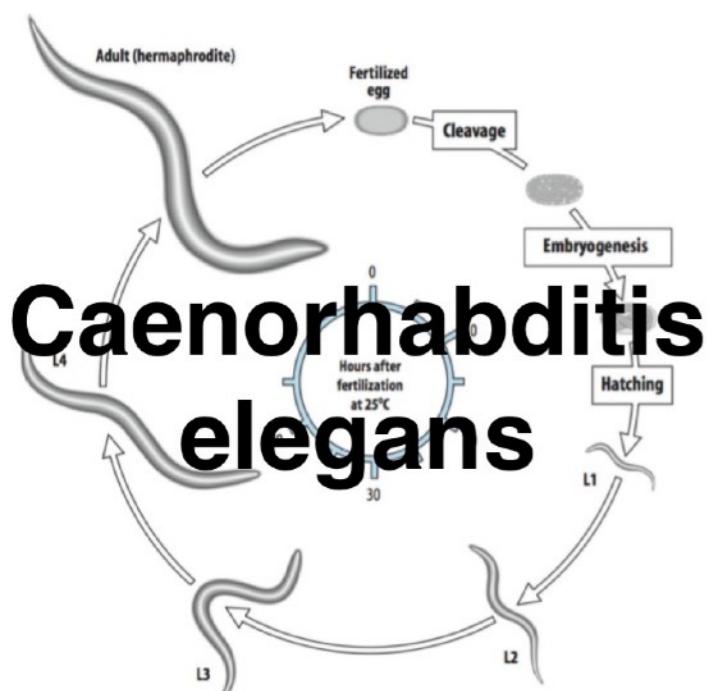
Modèle de la biologie du développement



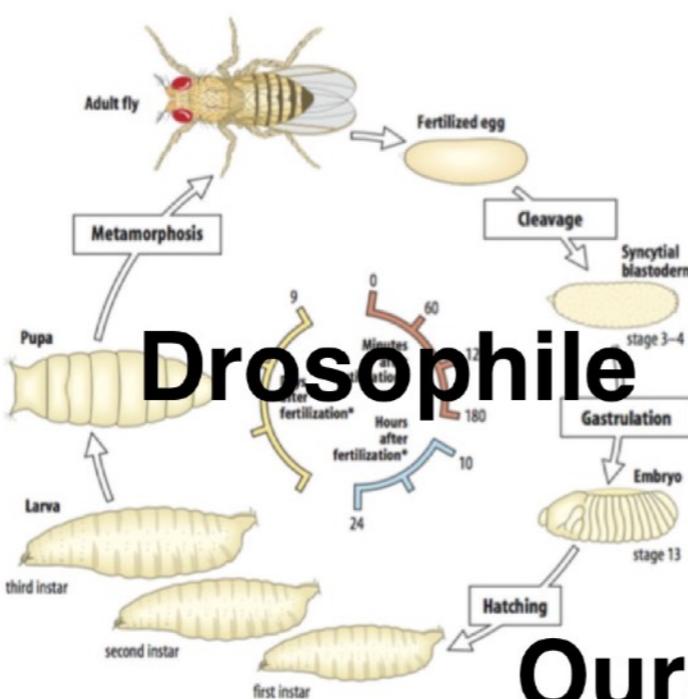
Xénope



Danio Rerio



Caenorhabditis elegans



Drosophile

- taille
- position phylogénétique
- transparence
- accessibilité
- cycle de vie
-

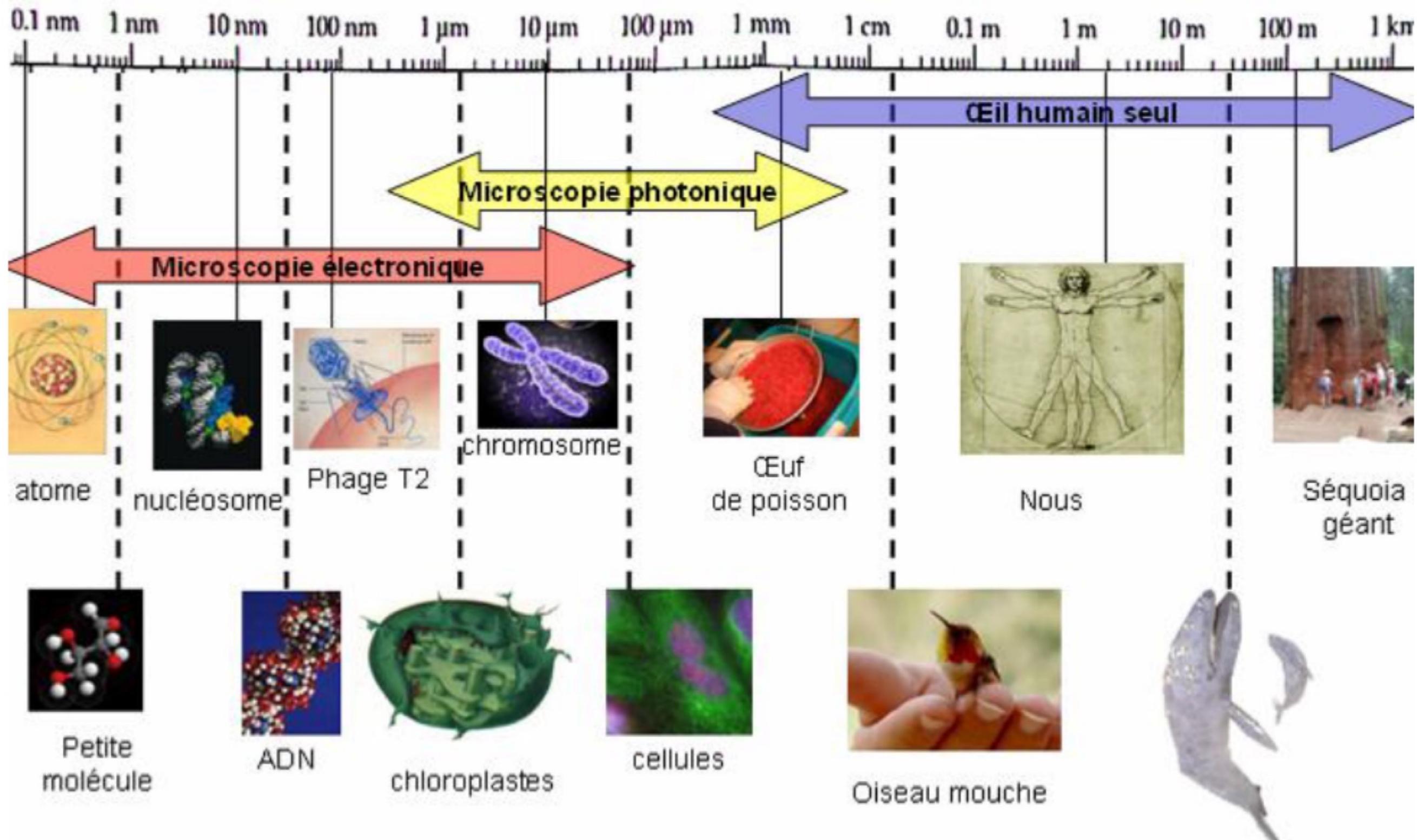
Oursin, Ascidies, Souris ! ...

Comment peut-on l'observer ?



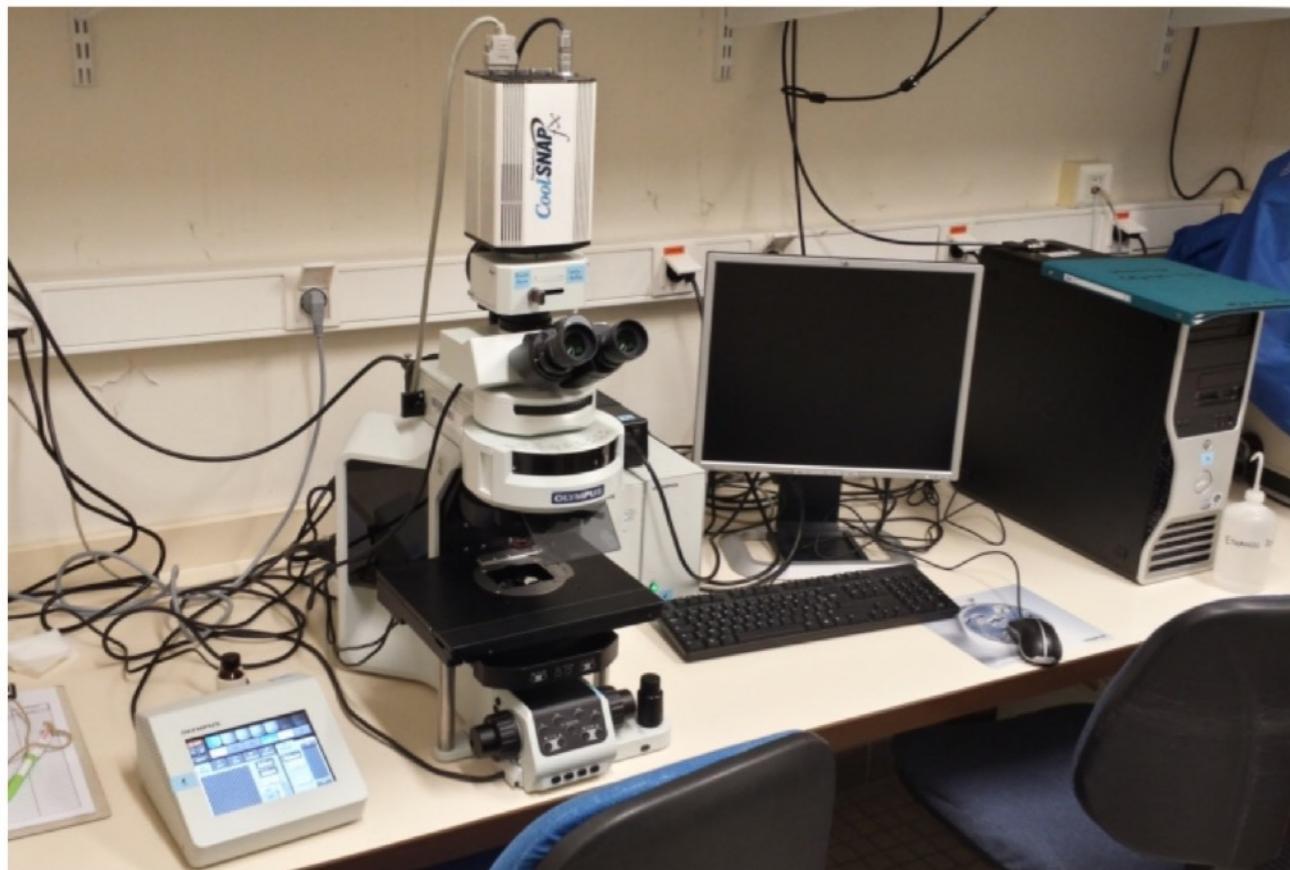
au microscope !

Quel microscope ?



Microscope à contraste interférentiel (Normarski 1950)

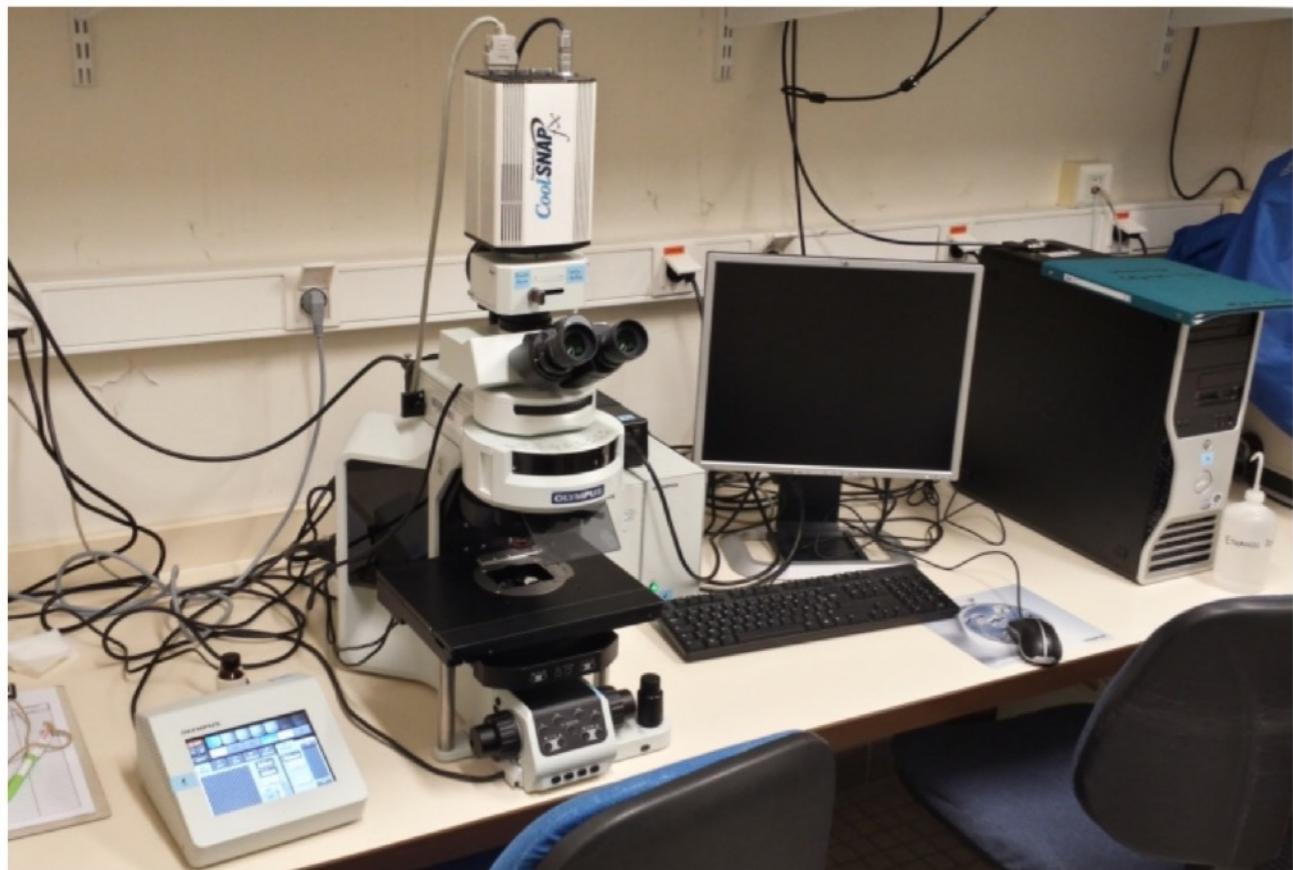
exploite les interférences de deux faisceaux d'une onde lumineuse traversant un échantillon



Kimmel 1995

Microscope à contraste interférentiel (Normarski 1950)

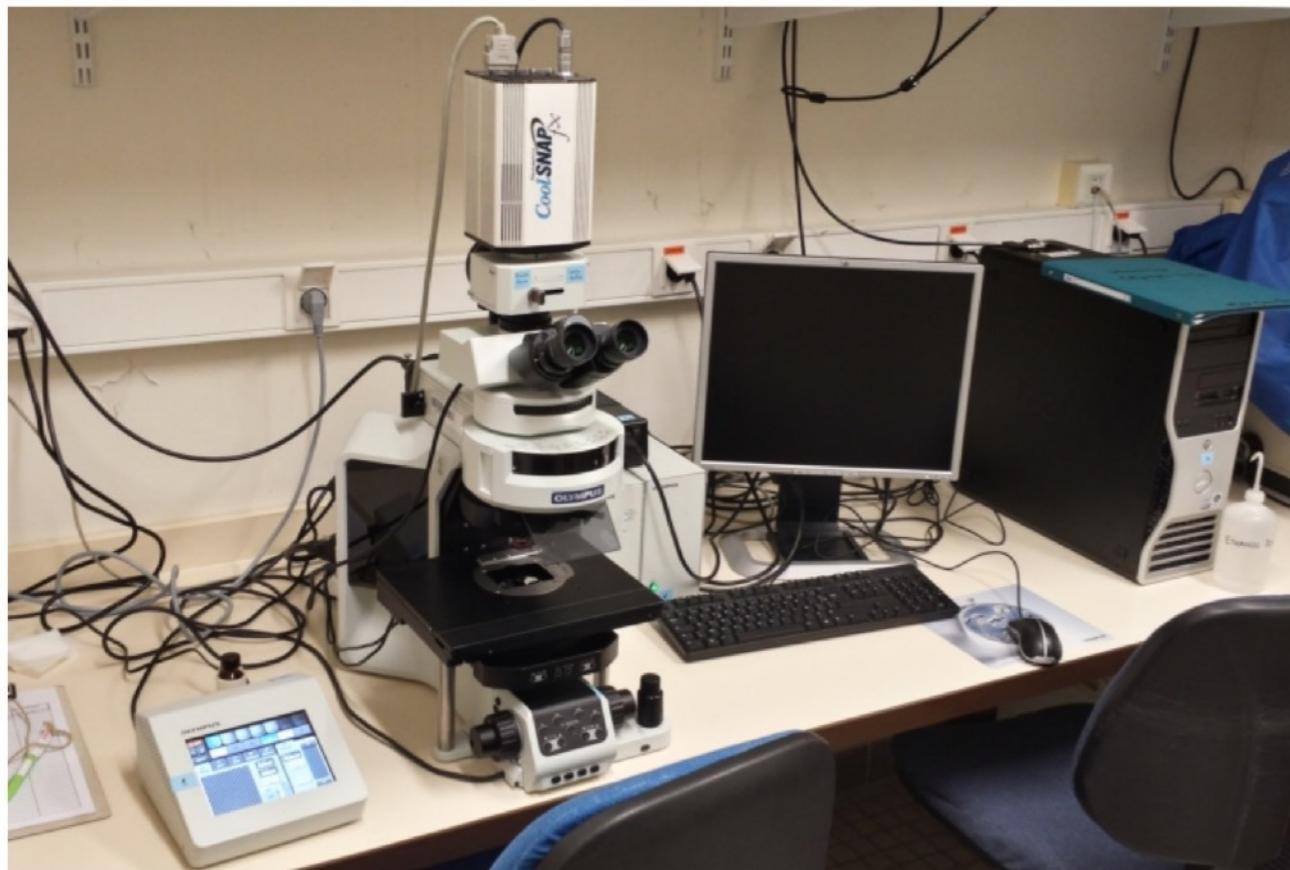
exploite les interférences de deux faisceaux d'une onde lumineuse traversant un échantillon



Kimmel 1995

Microscope à contraste interférentiel (Normarski 1950)

exploite les interférences de deux faisceaux d'une onde lumineuse traversant un échantillon

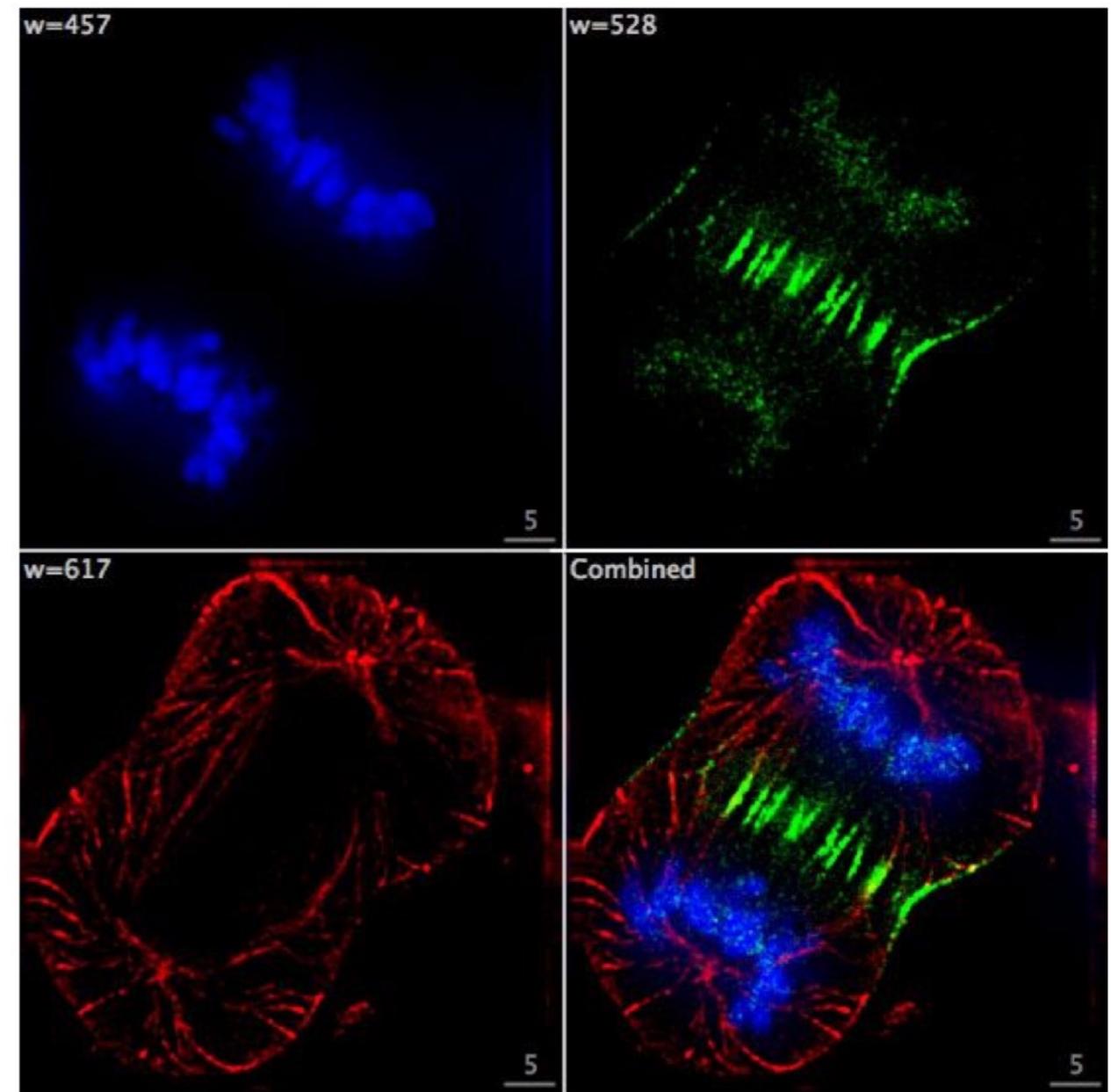
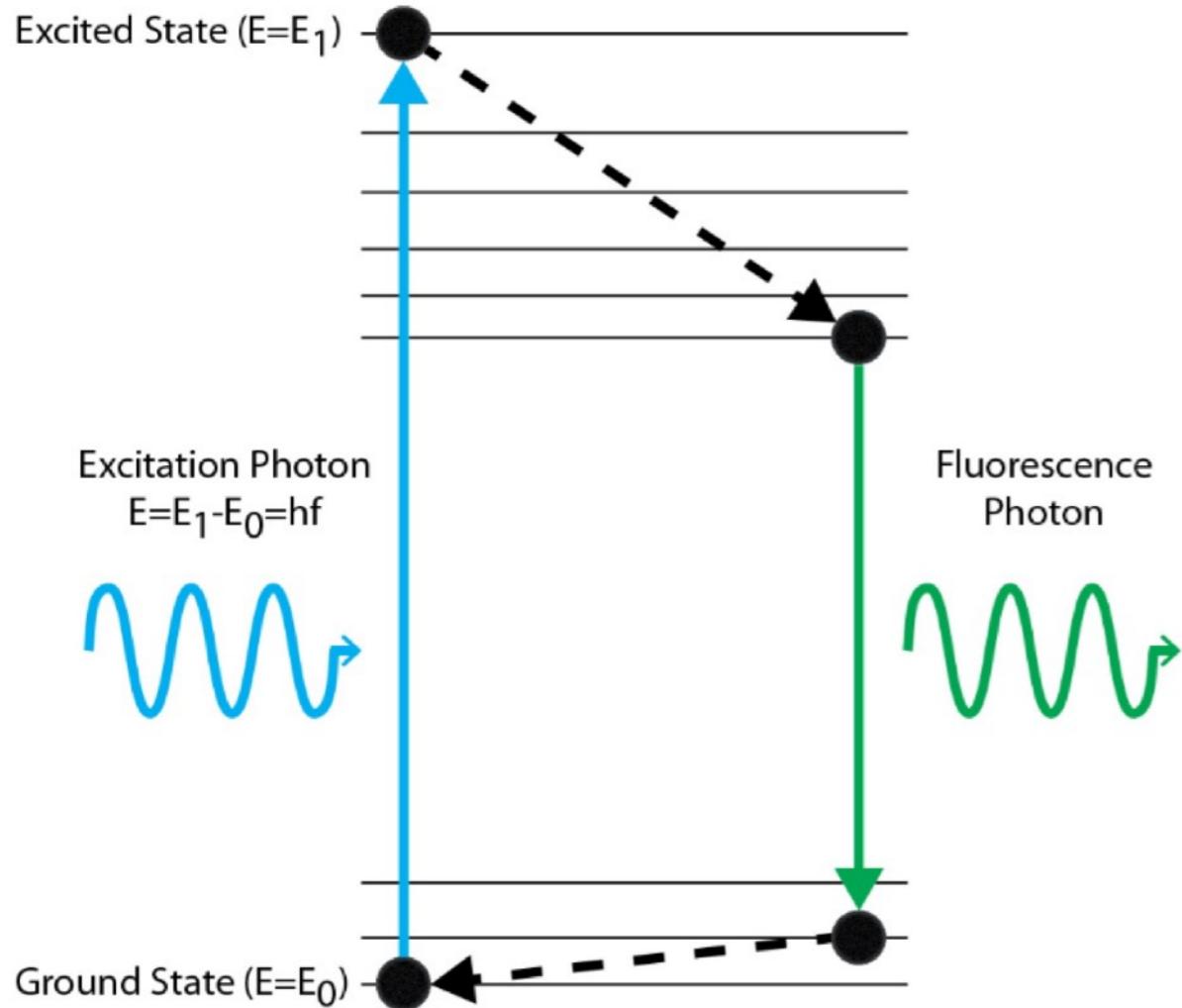


Kimmel 1995

→ Images 2D + temps

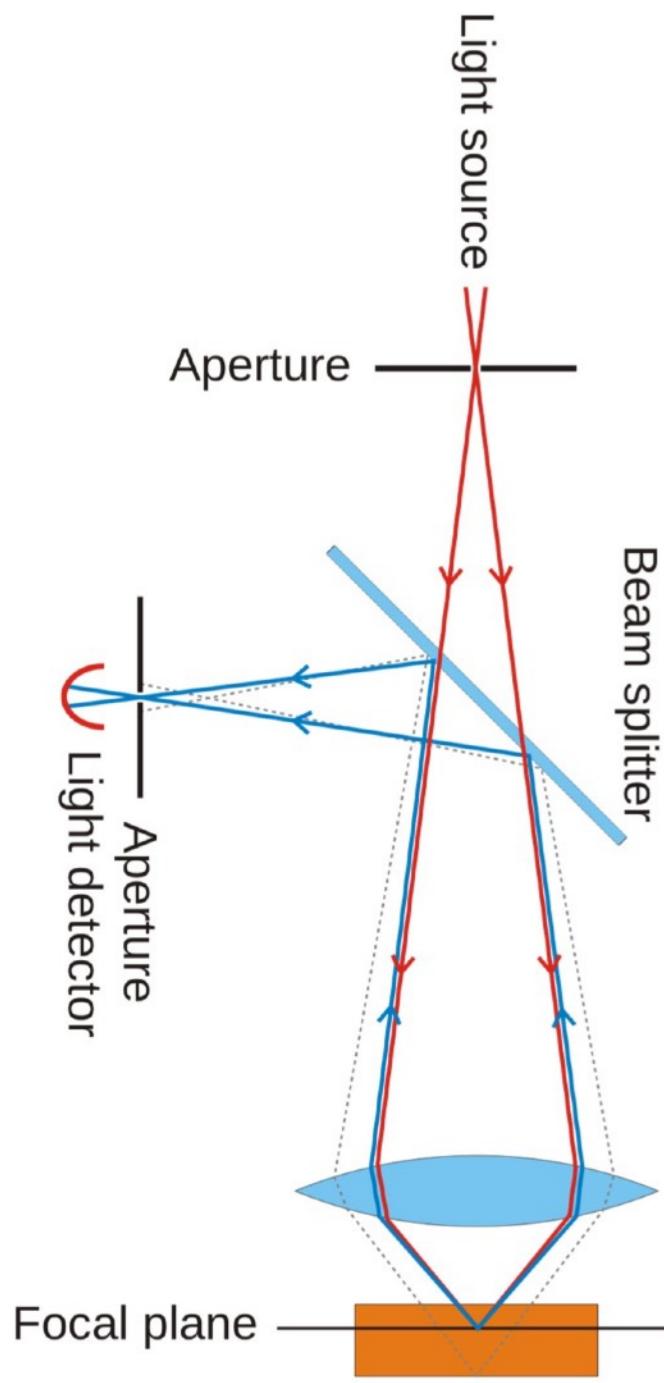
Fluorescence (Stokes 1852)

La fluorescence est la propriété que certains corps ou **molécules** ont à émettre une **lumière** après avoir été excités avec une lumière d'énergie supérieure. Ainsi, un objet excité par une longueur d'onde émettra une **fluorescence** à une longueur d'onde supérieure.



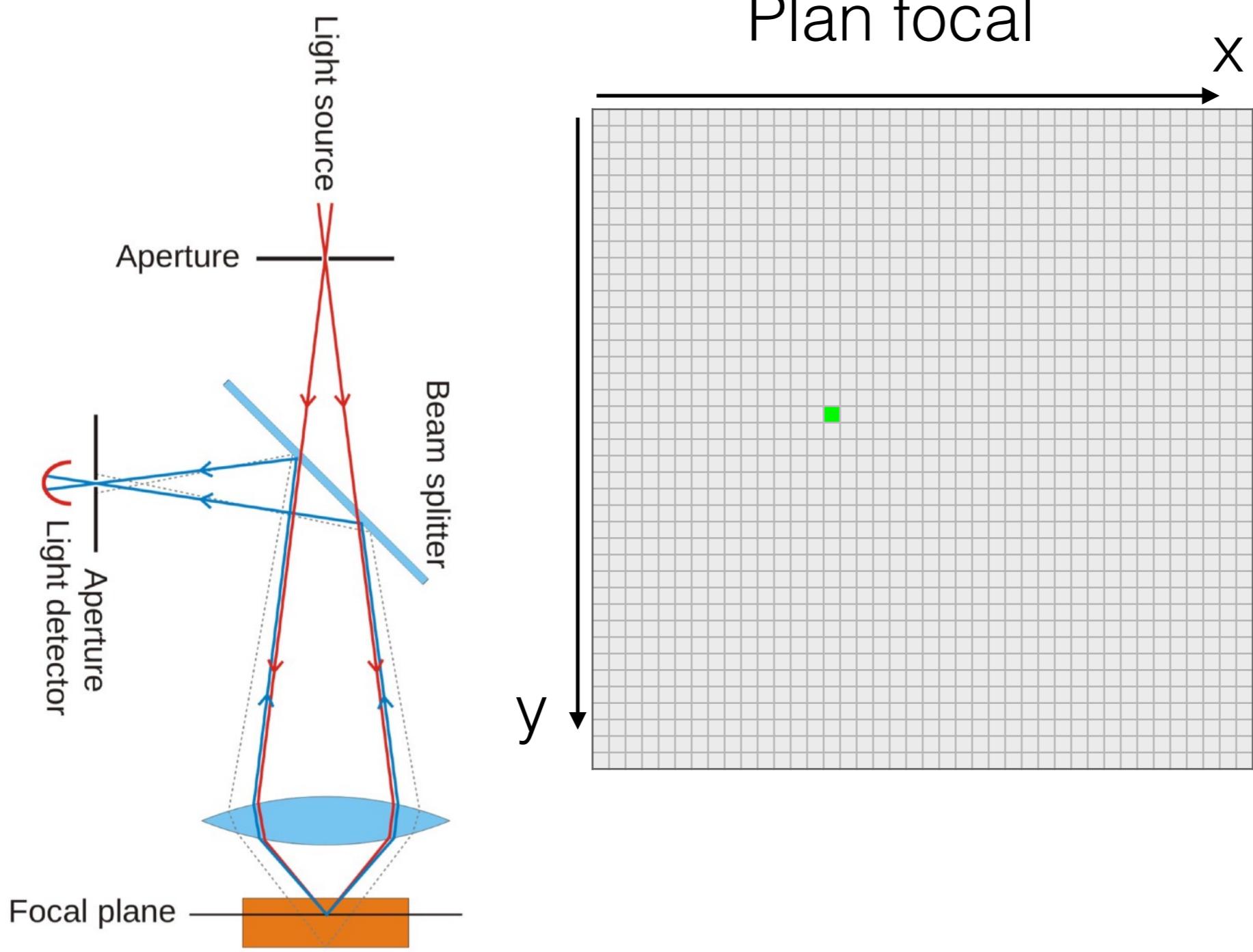
Microscope confocal

(Minsky 1953 , commercialisé en ~1980)



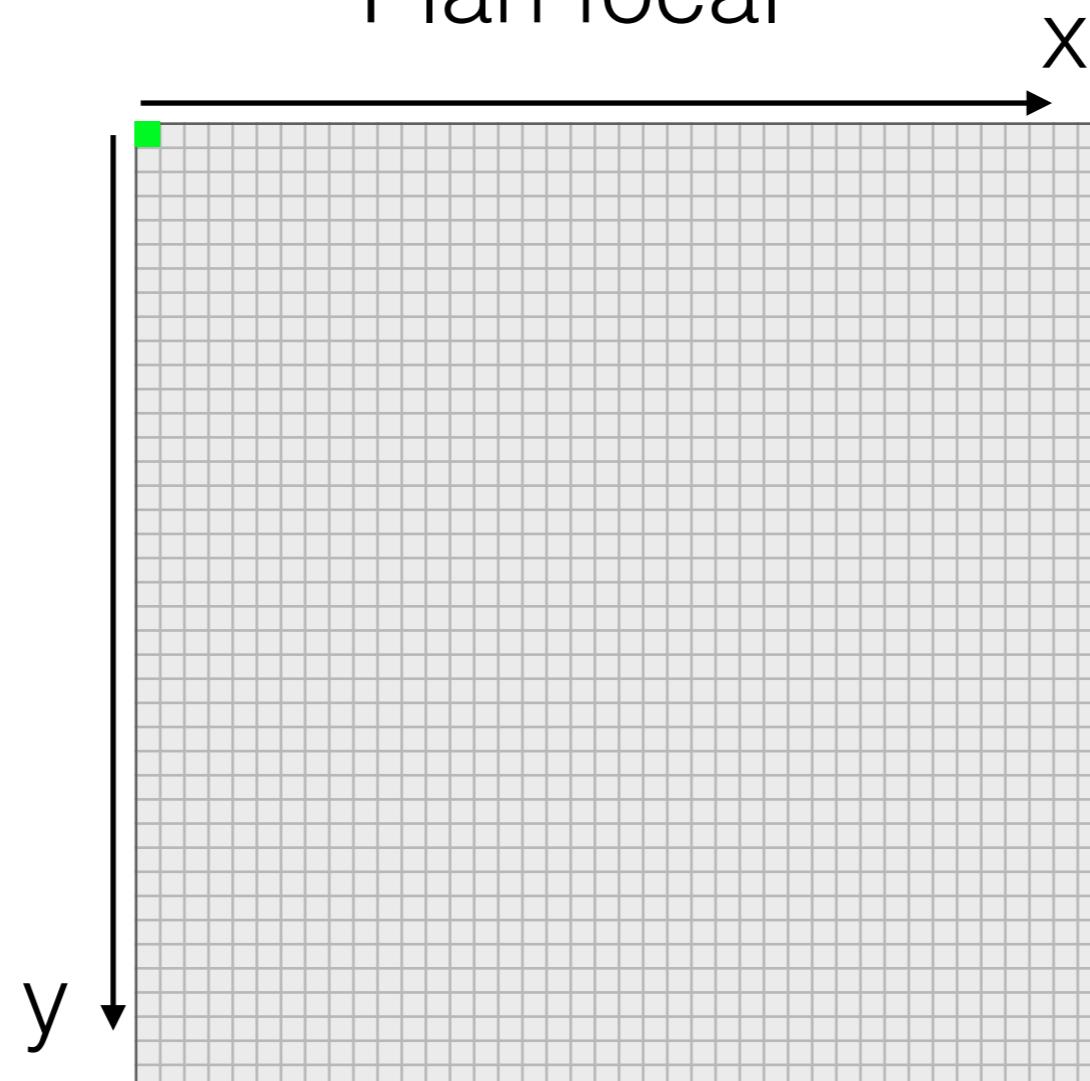
Microscope confocal

(Minsky 1953 , commercialisé en ~1980)



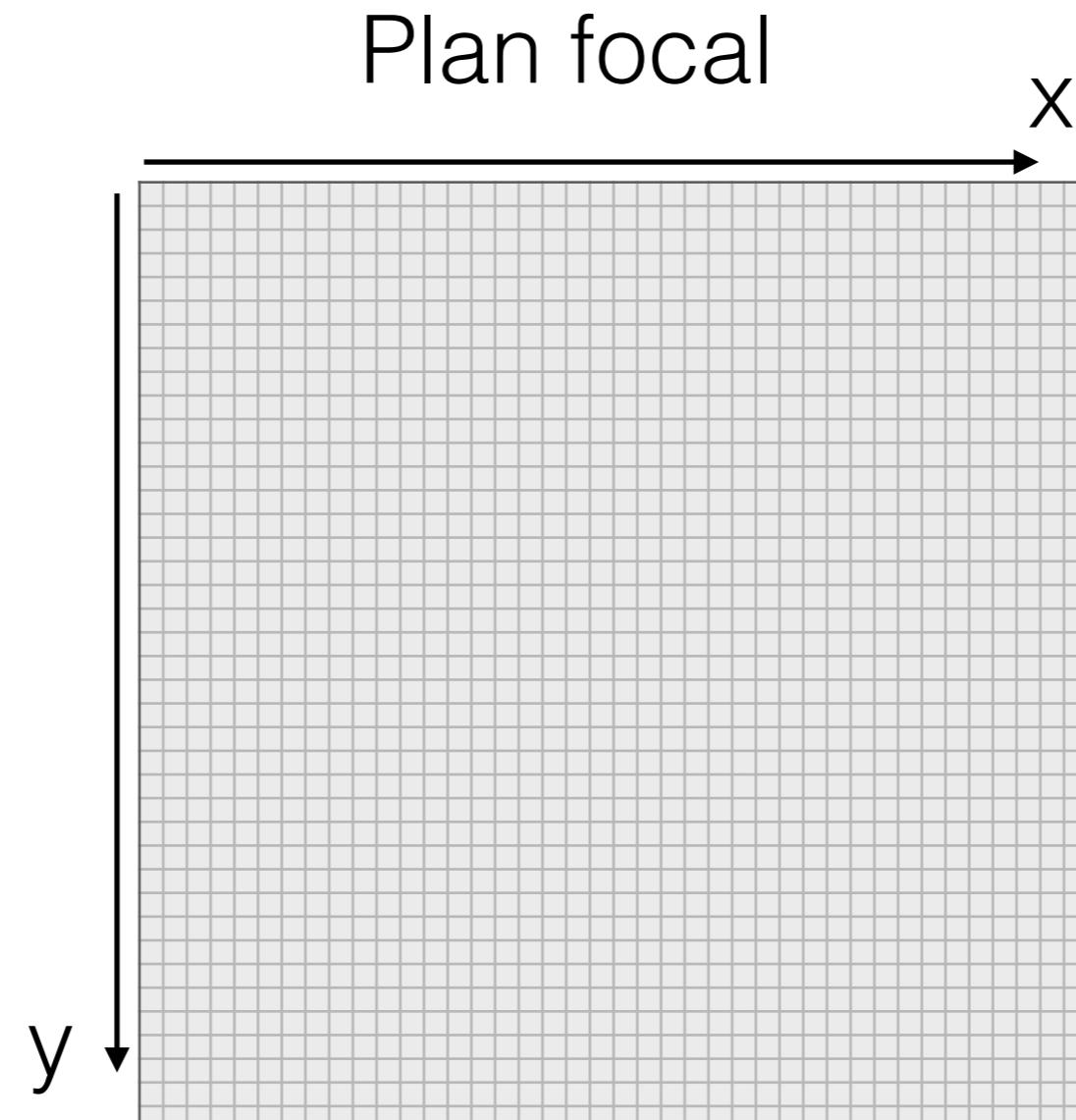
Microscope confocal

Plan focal



Microscope confocal

balayage laser



Microscope confocal

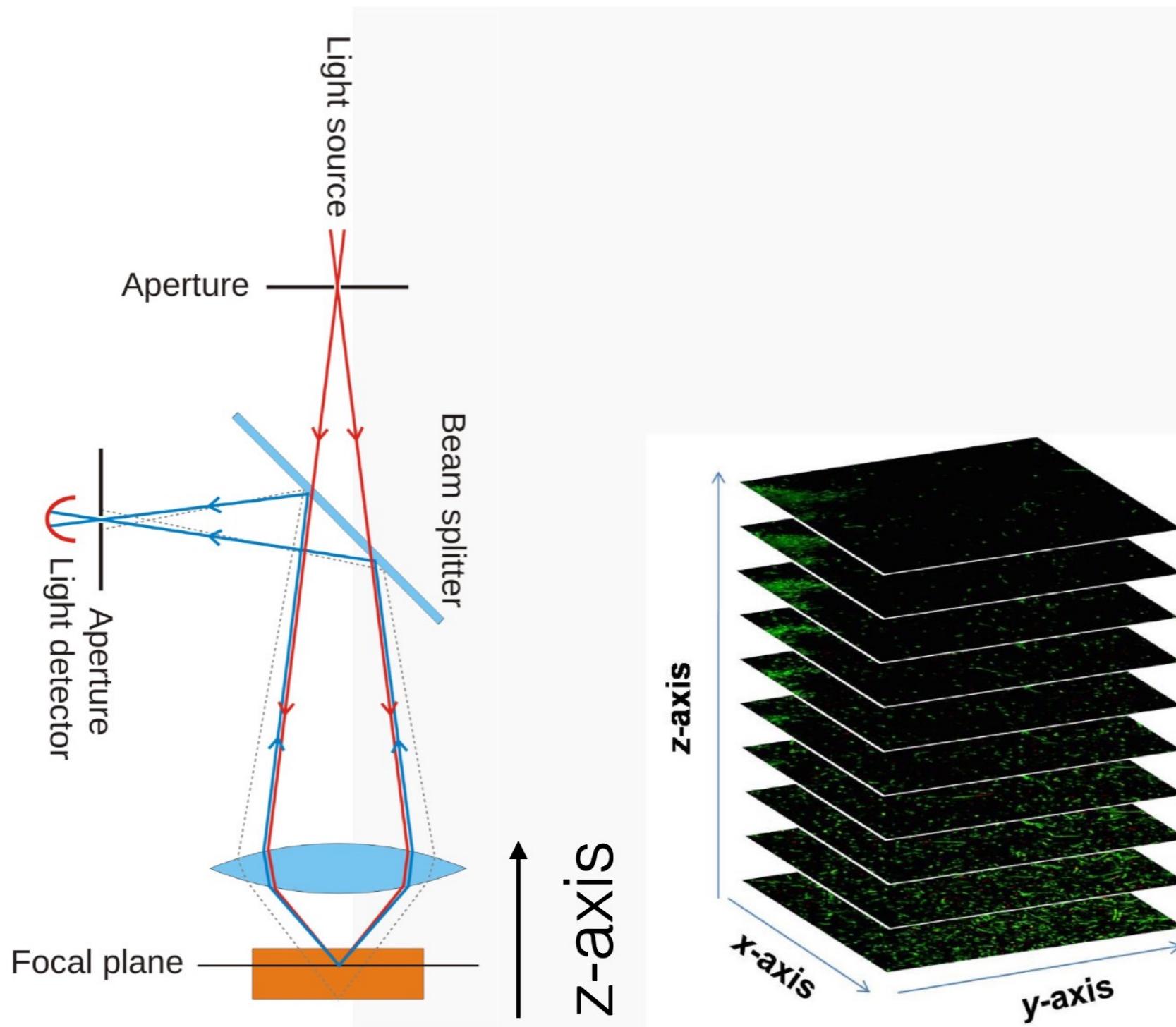
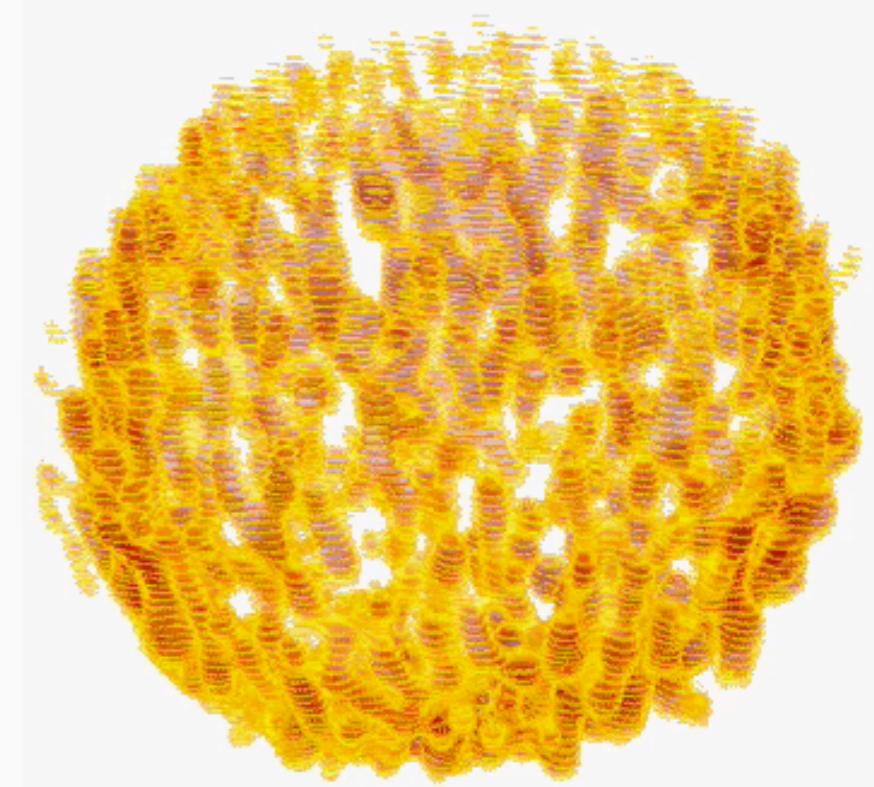


Image 3D



Microscope confocal

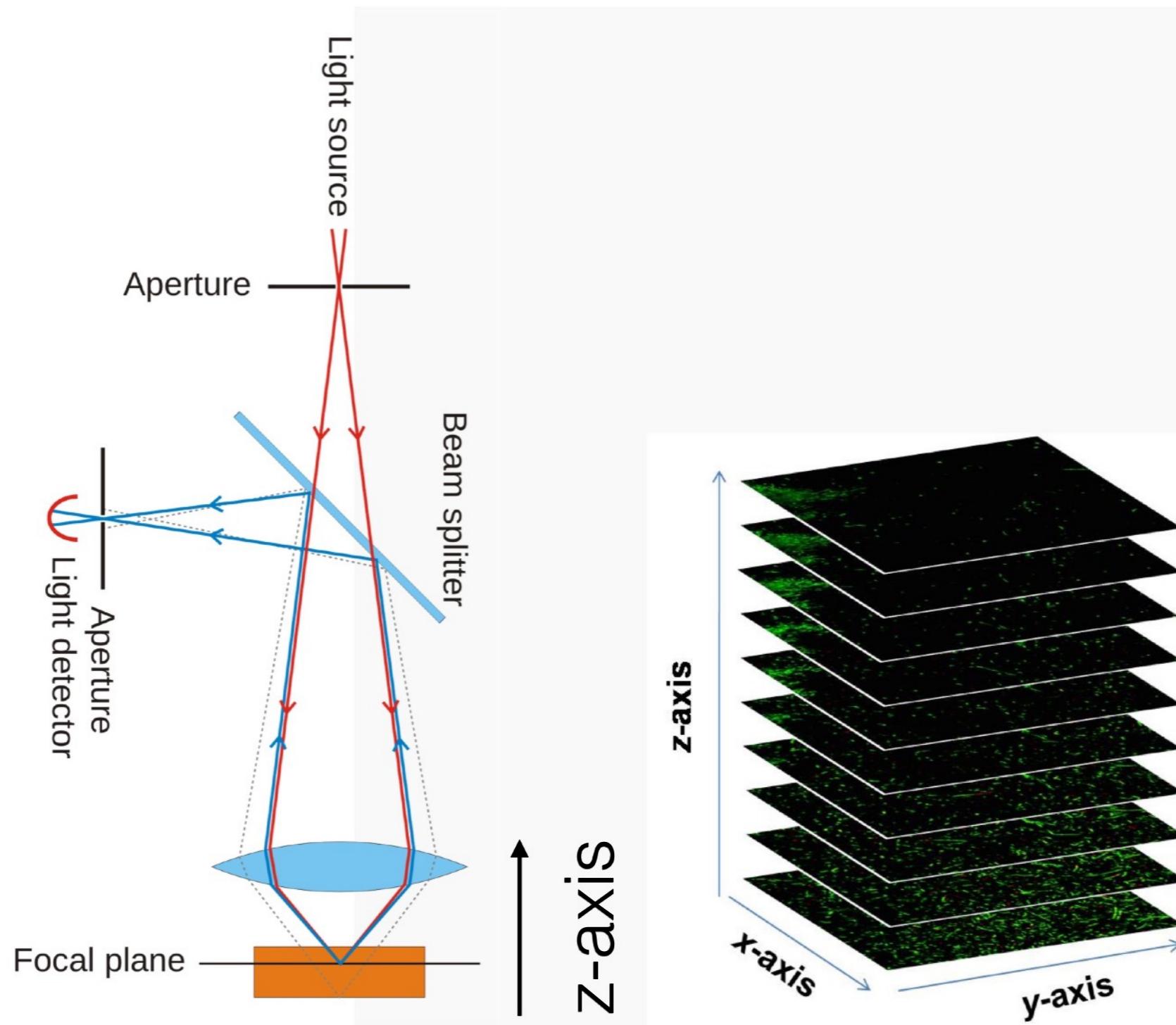
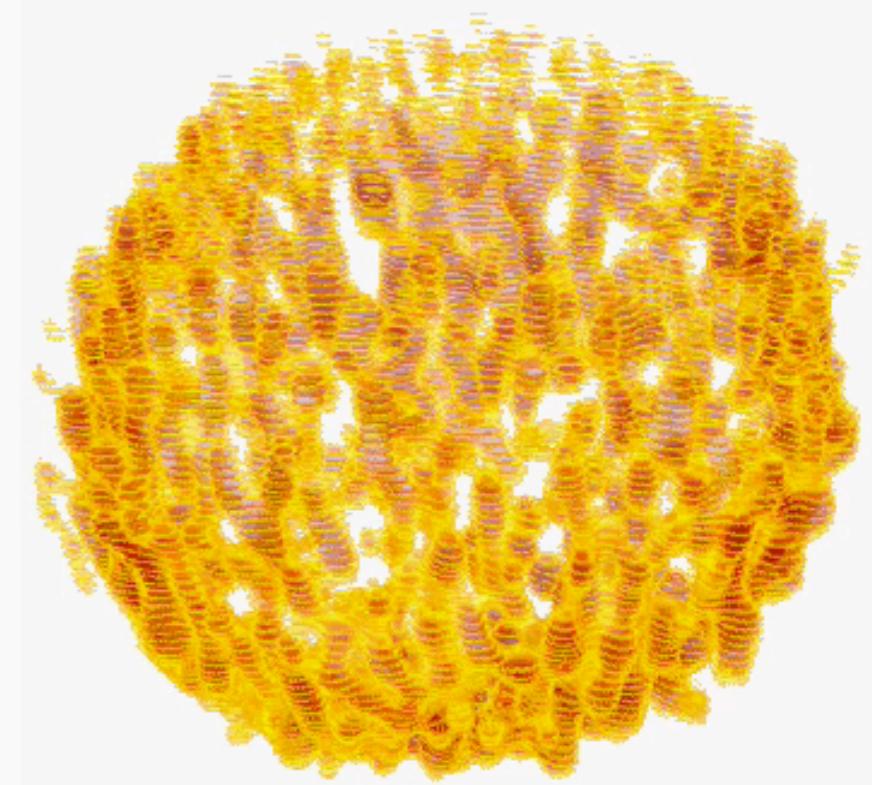
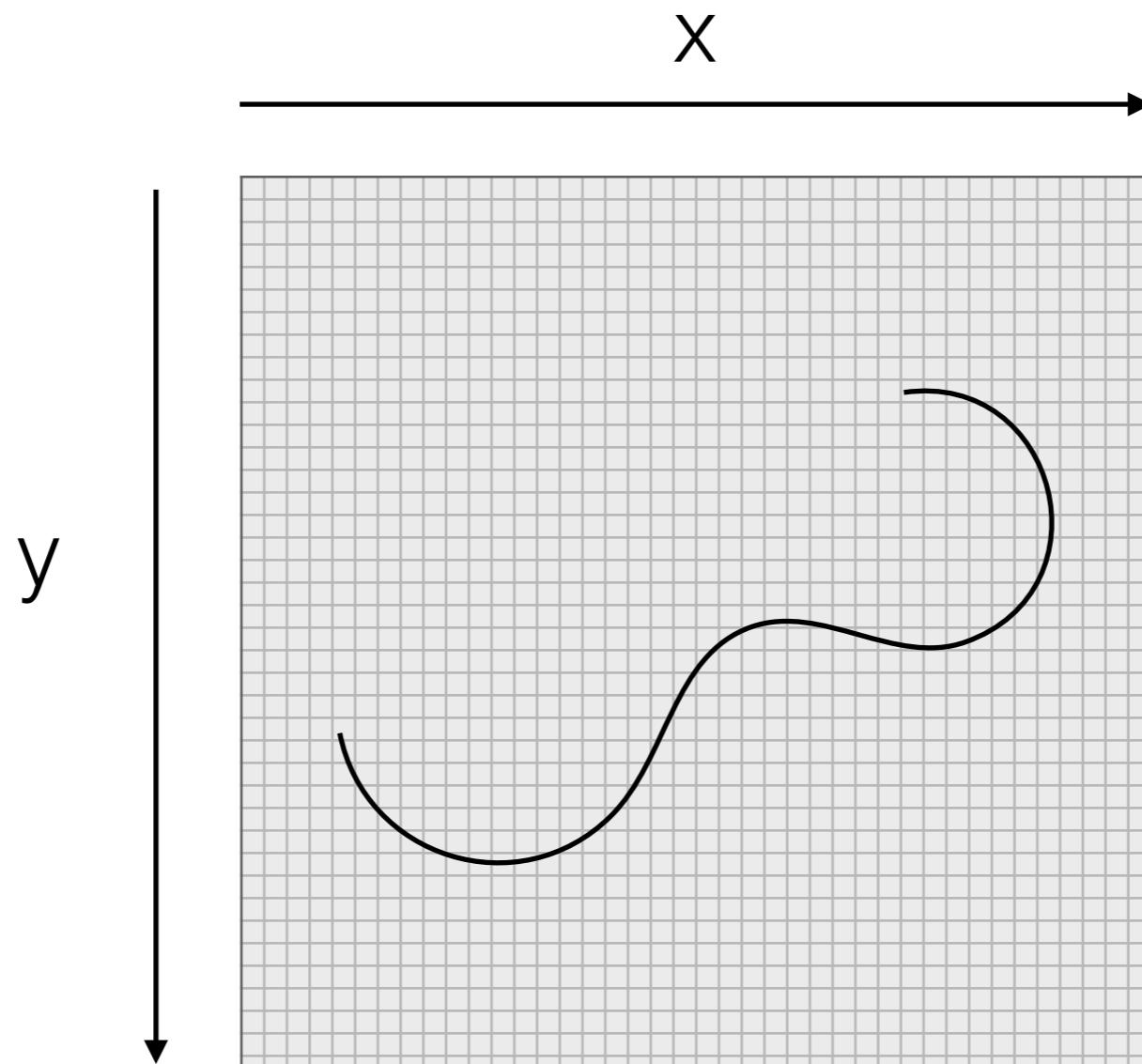


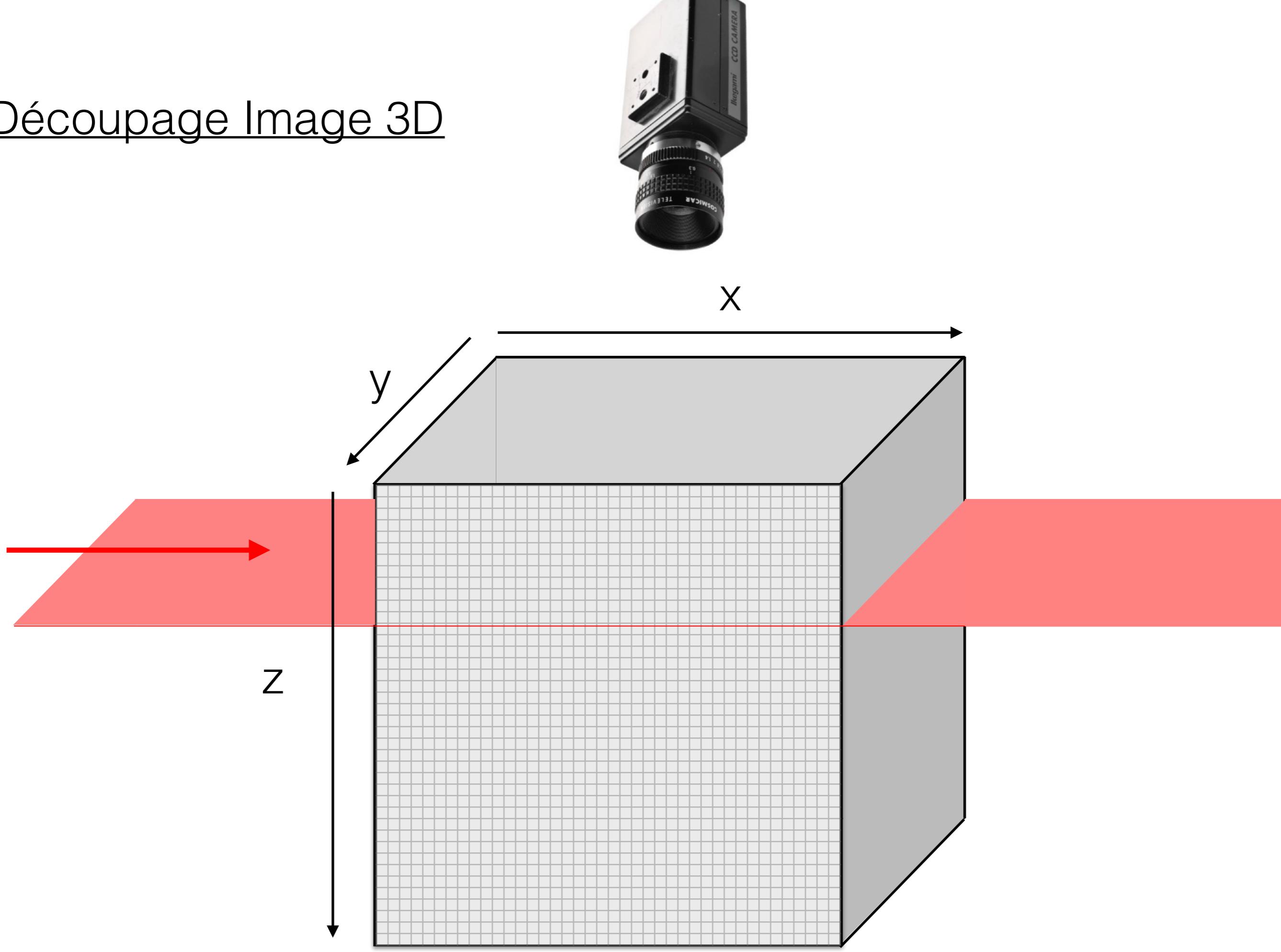
Image 3D



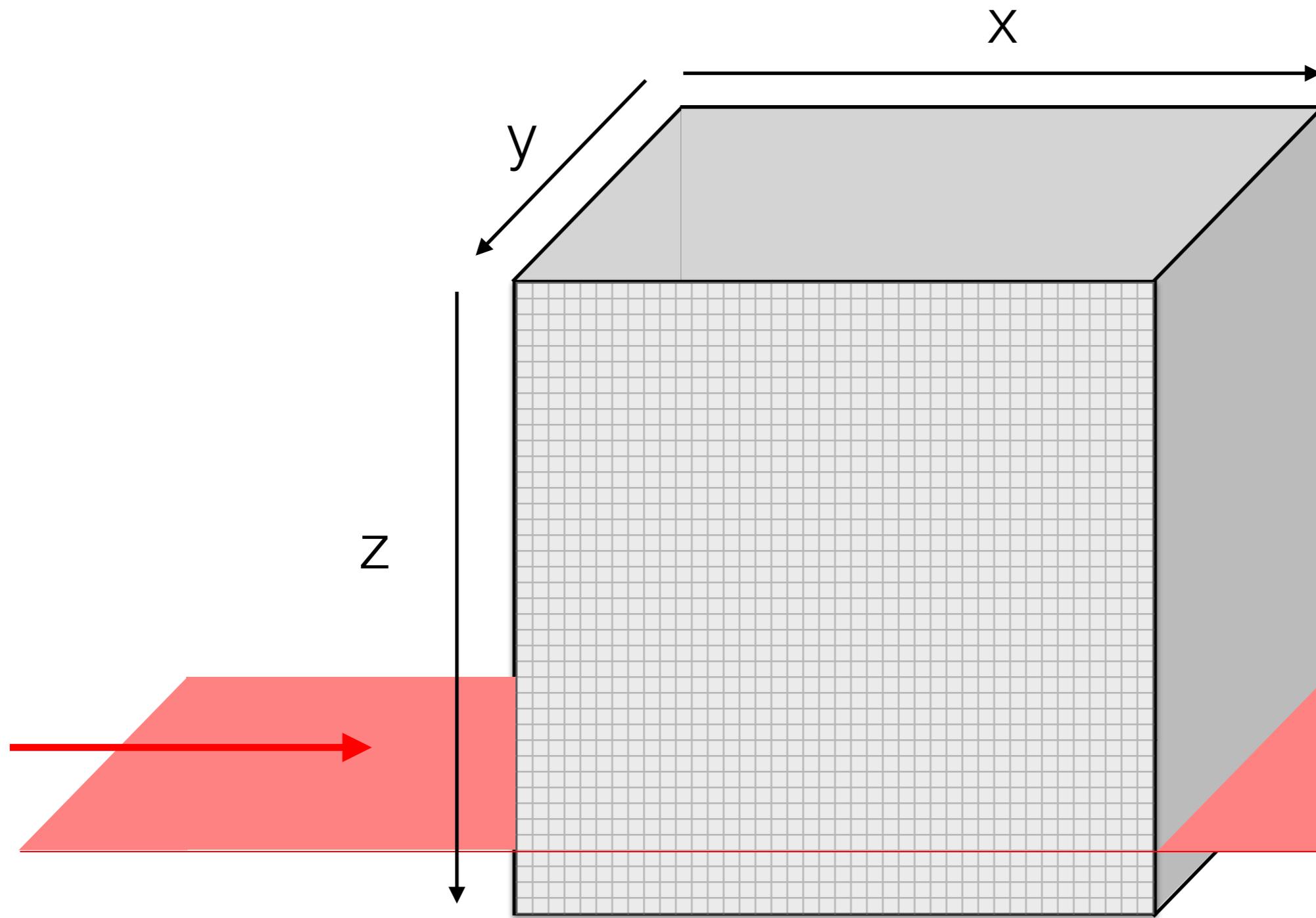
Découpage Image 2D

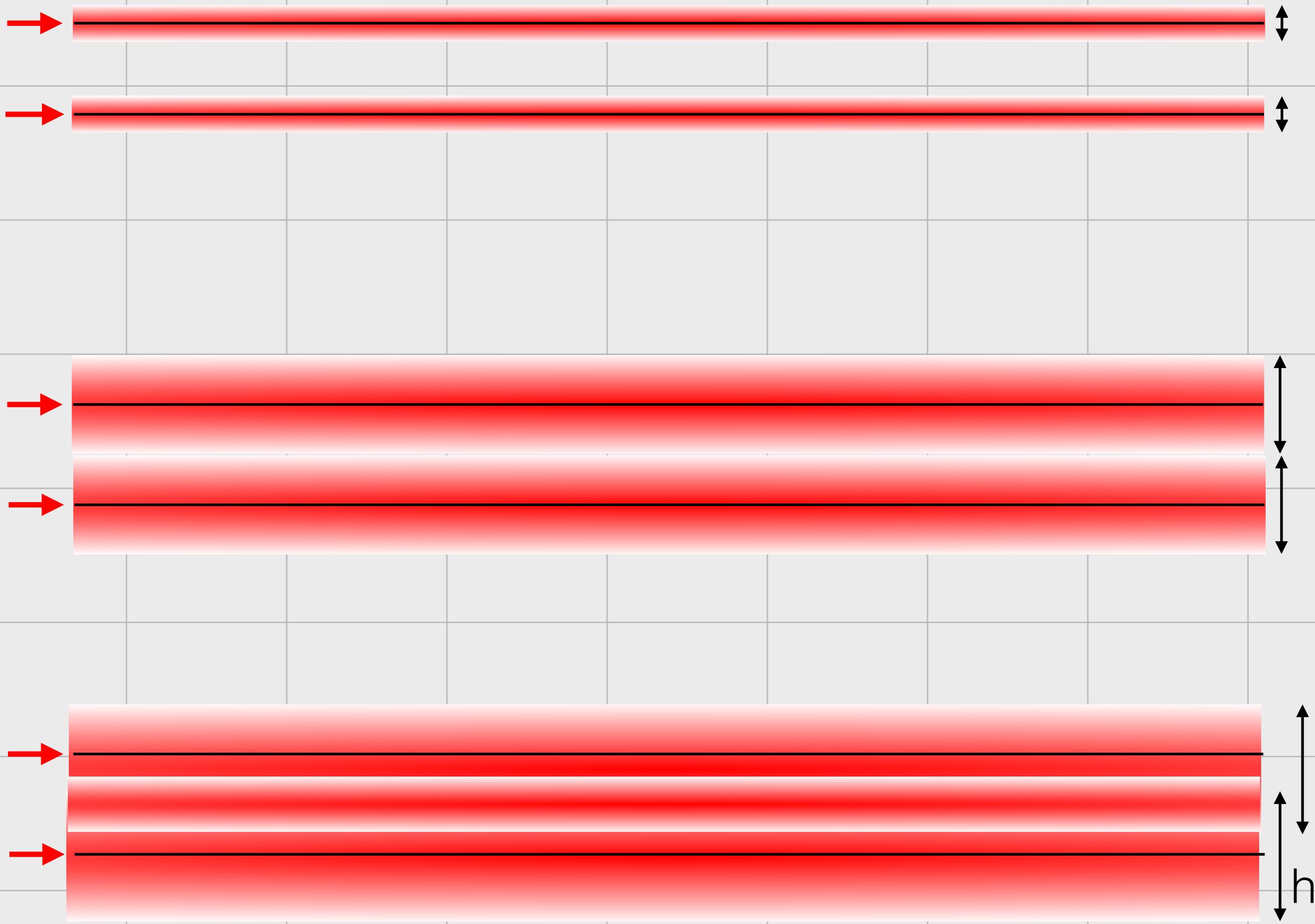


Découpage Image 3D



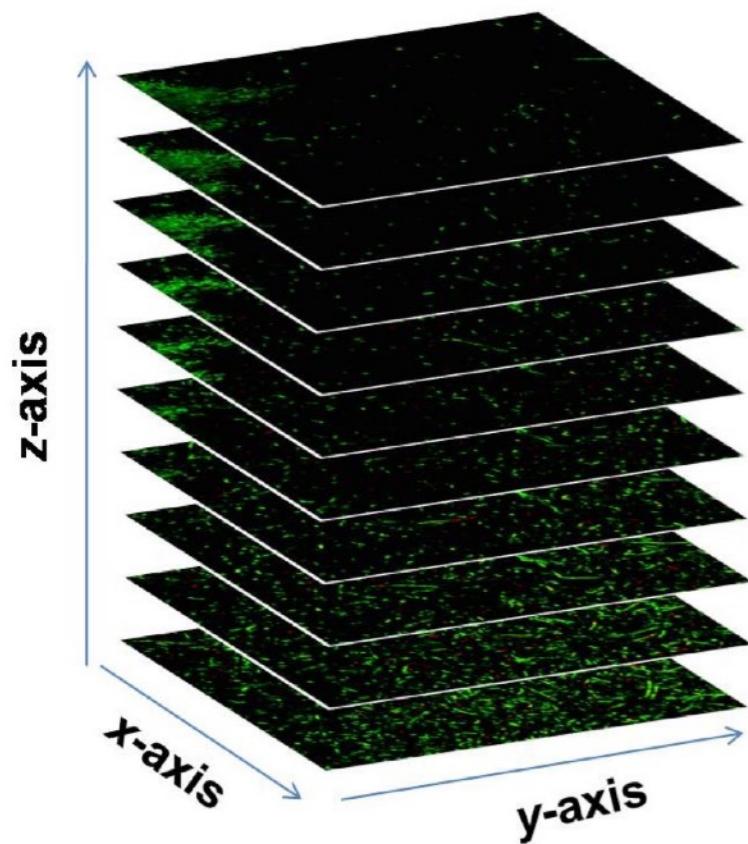
Découpage Image 3D





Microscope confocal

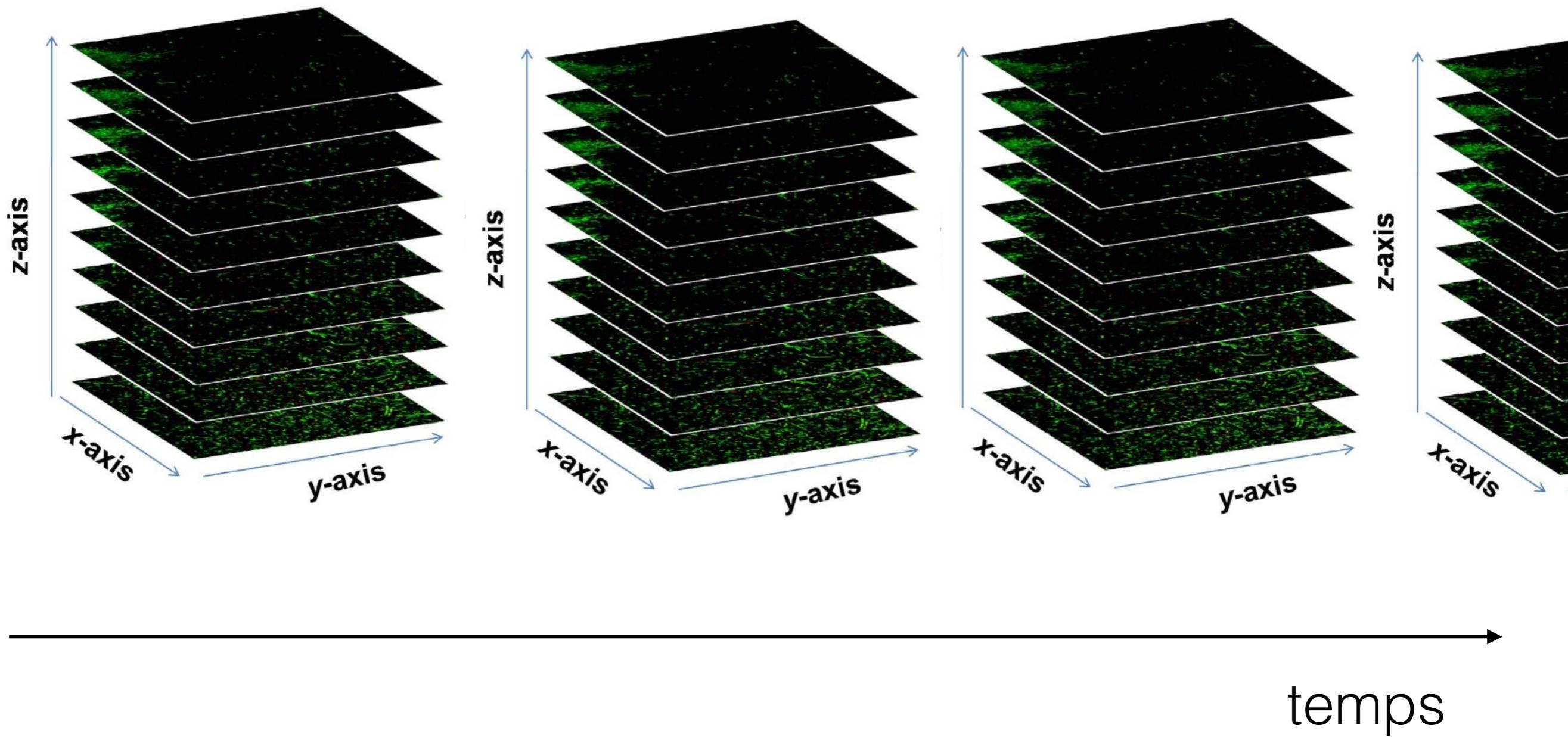
2min



Microscope confocal

Image 4D

2min



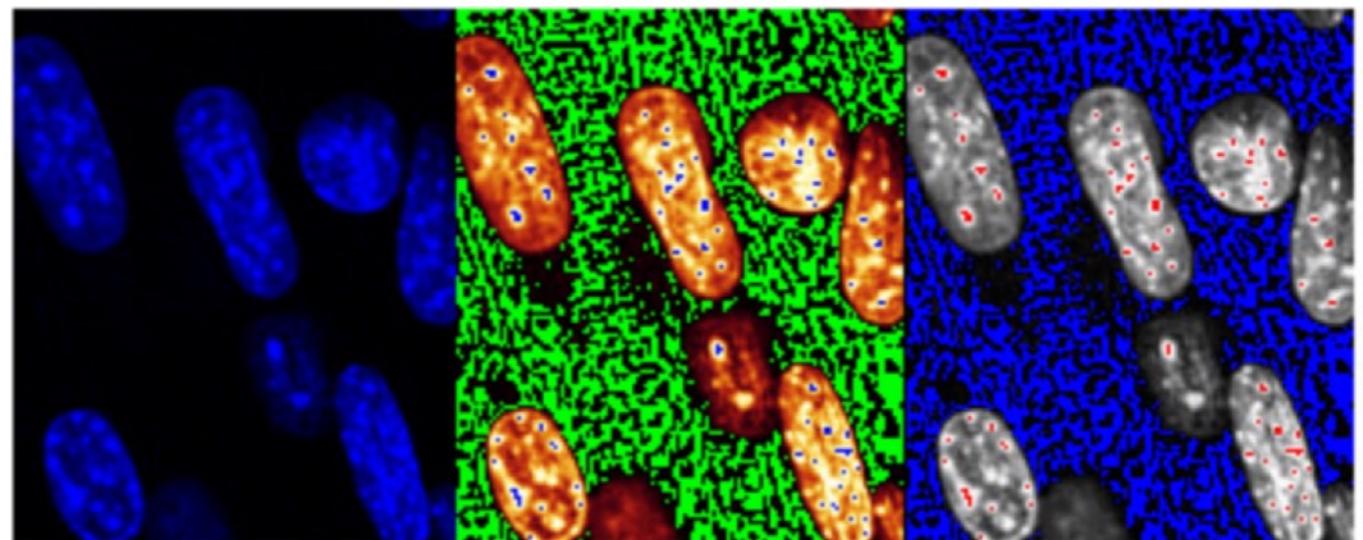
Microscope confocal



Microscope confocal

Puissance Laser

Sensibilité des
déTECTEURS



Green = 0
Blue = max

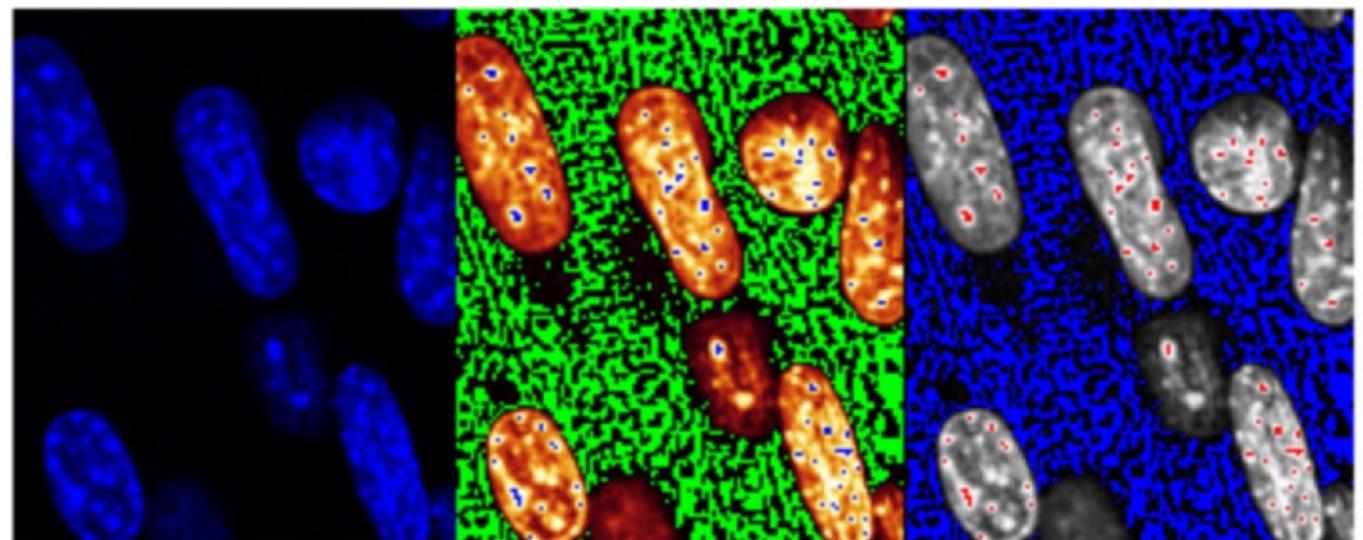
Blue = 0
red = max

Microscope confocal

Puissance Laser

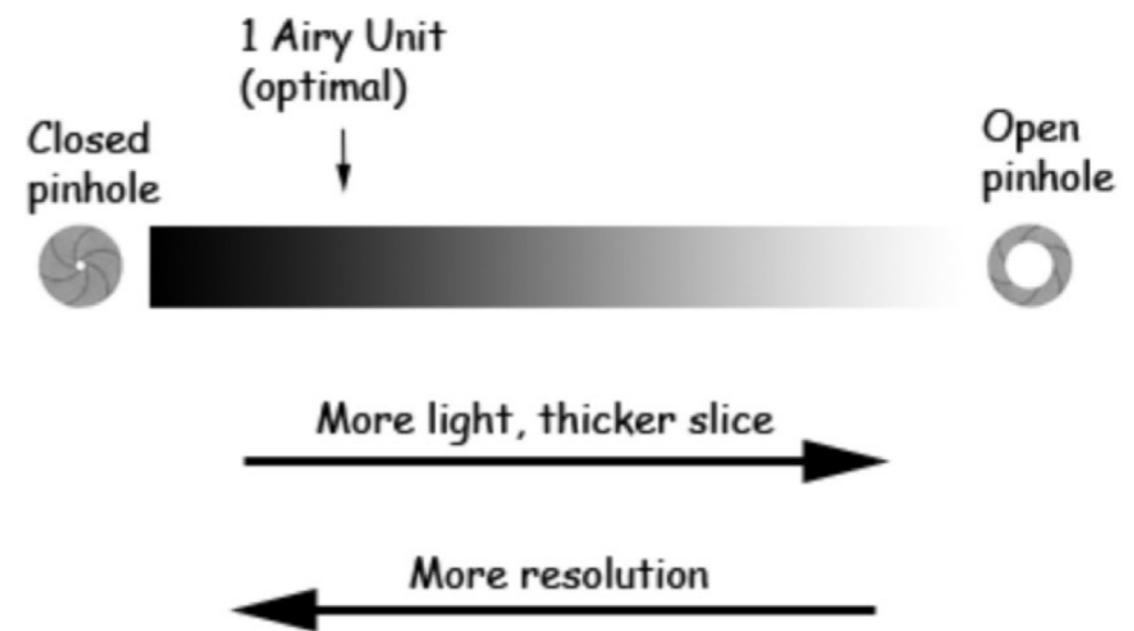
Sensibilité des
déTECTEURS

Ouverture



Green = 0
Blue = max

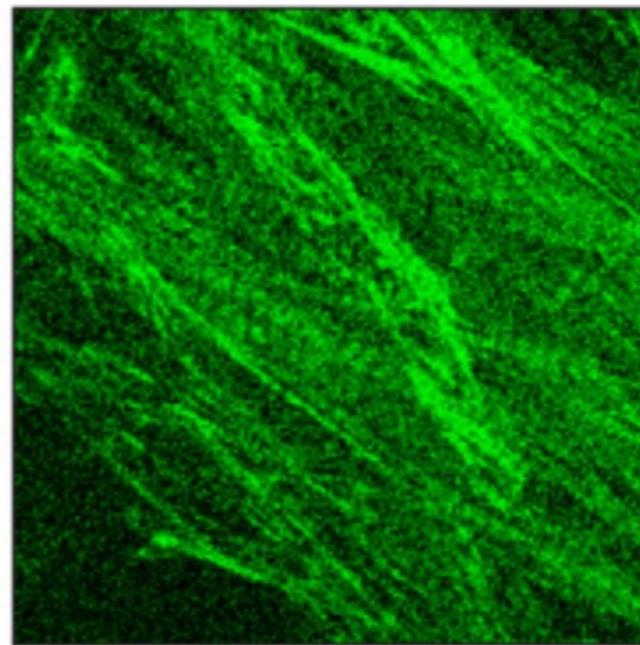
Blue = 0
red = max



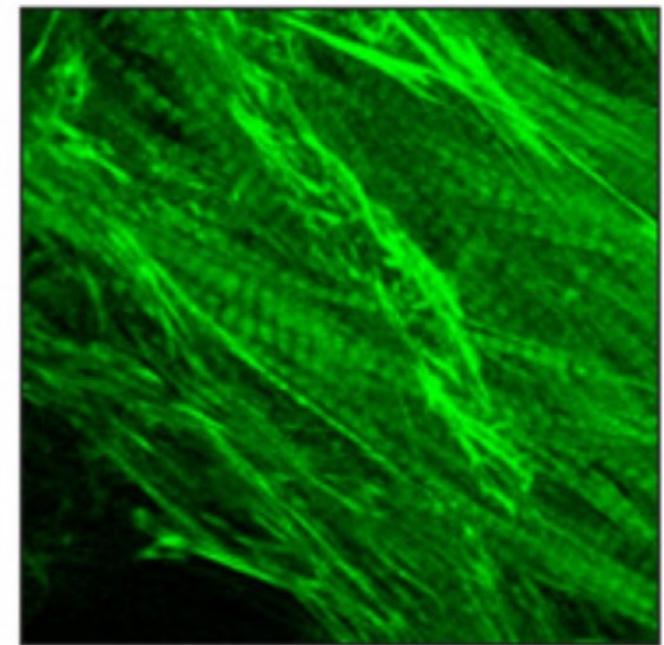
Microscope confocal

Nombre de
passes

Average 1



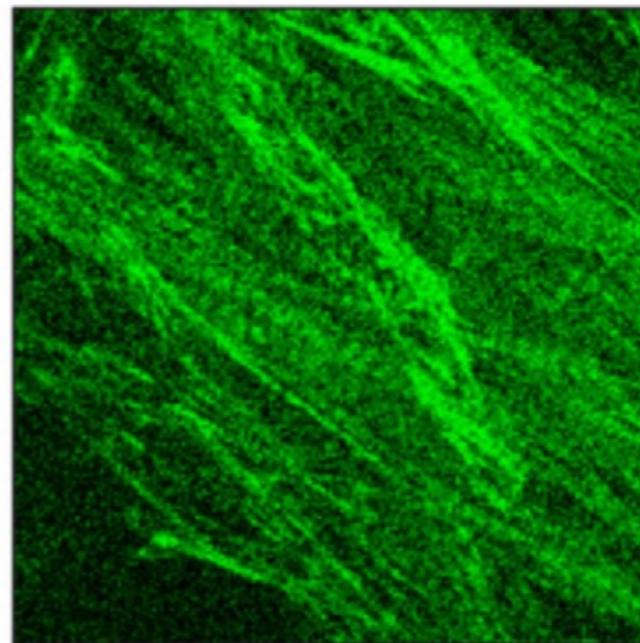
Line average 8



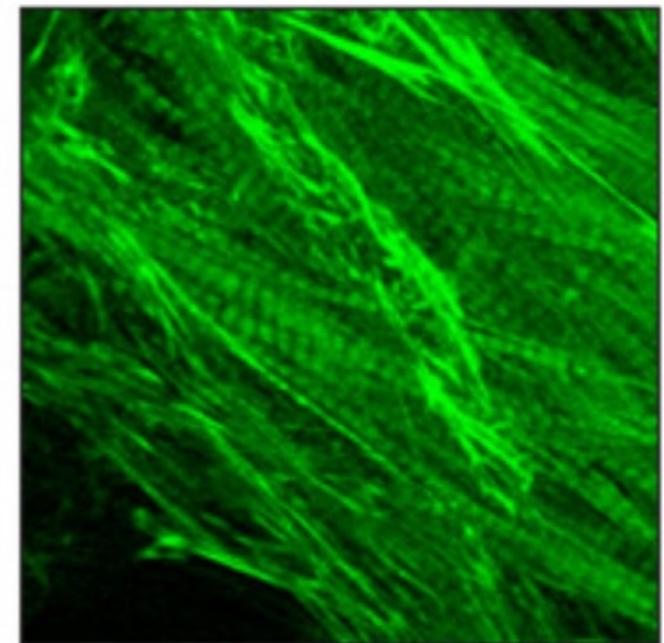
Microscope confocal

Nombre de passes

Average 1

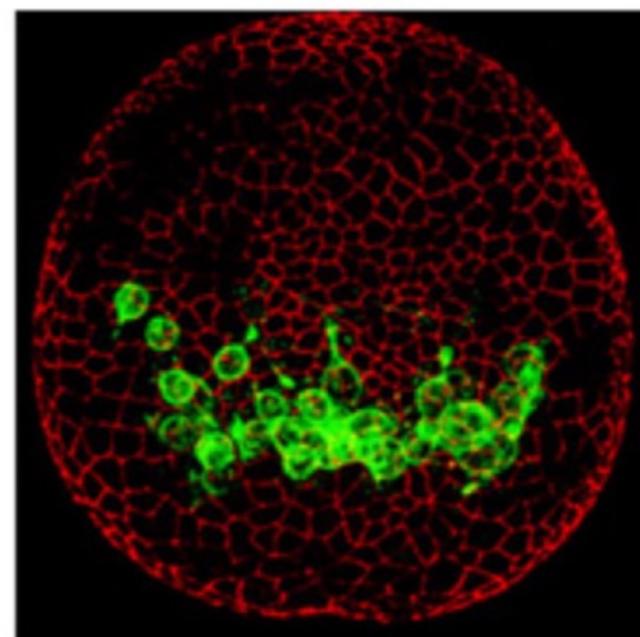


Line average 8

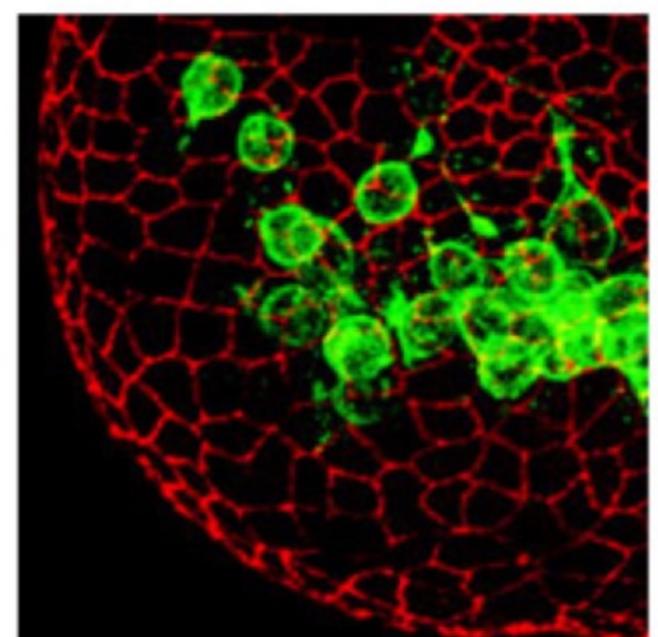


Zoom

Zoom 1x



Zoom 2x



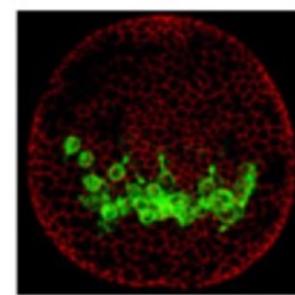
Microscope confocal

Nombre de pixel

Δxy

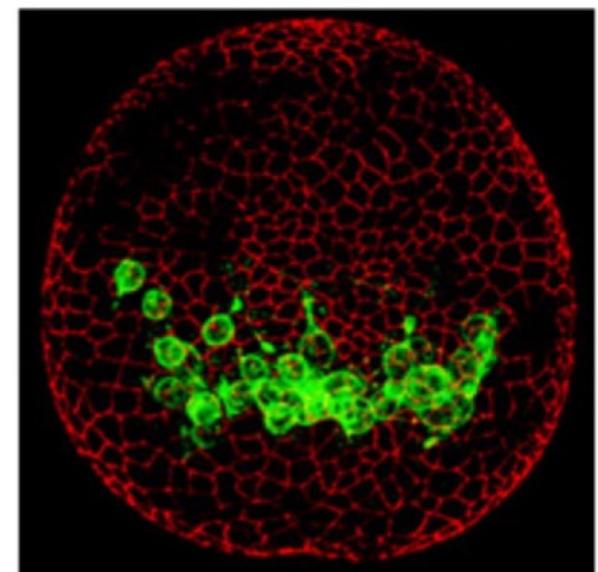
Same area, different
number of pixels

512 by 512



About 0.5 MB

1024 by 1024



About 2.0 MB

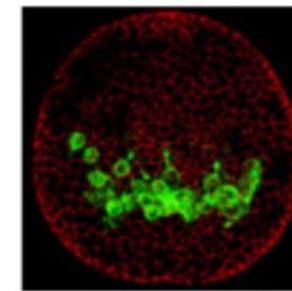
Microscope confocal

Nombre de pixel

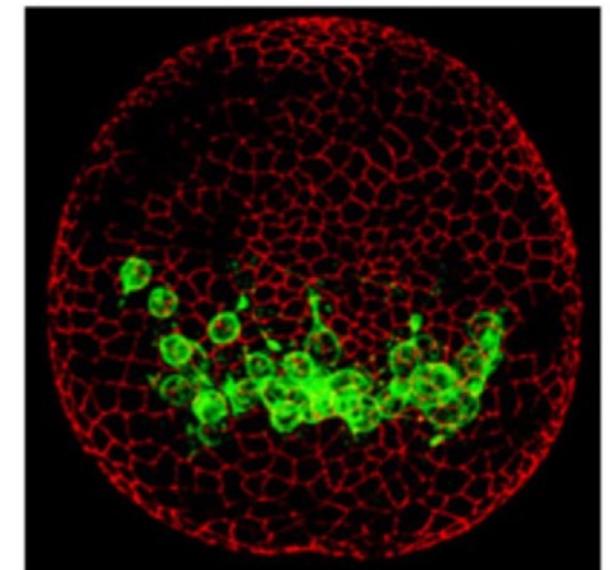
Δxy

Same area, different
number of pixels

512 by 512

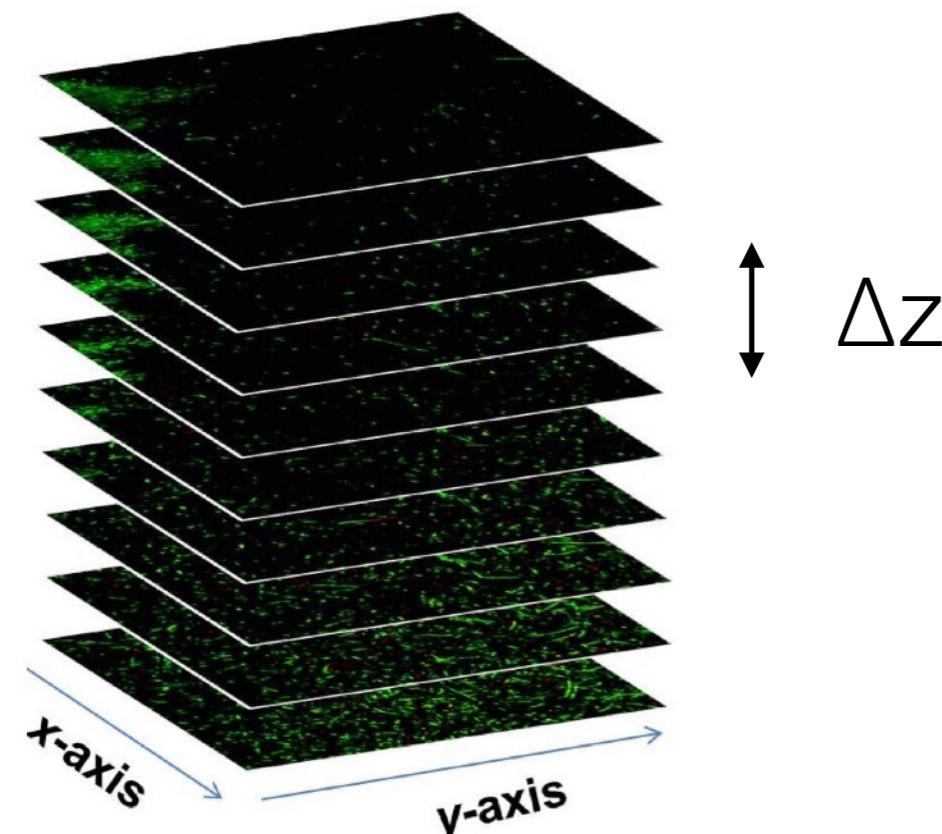


1024 by 1024



About 0.5 MB

About 2.0 MB



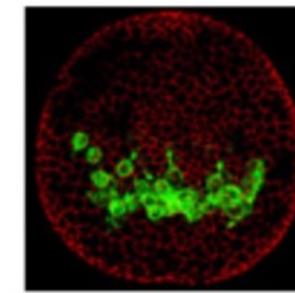
Microscope confocal

Nombre de pixel

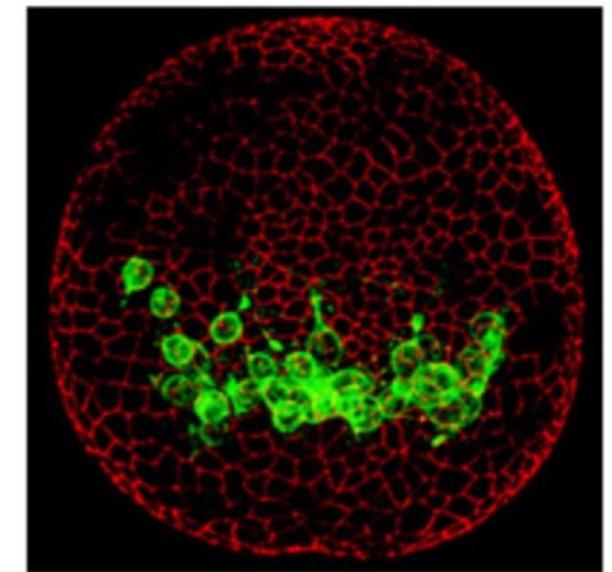
Δxy

Same area, different
number of pixels

512 by 512

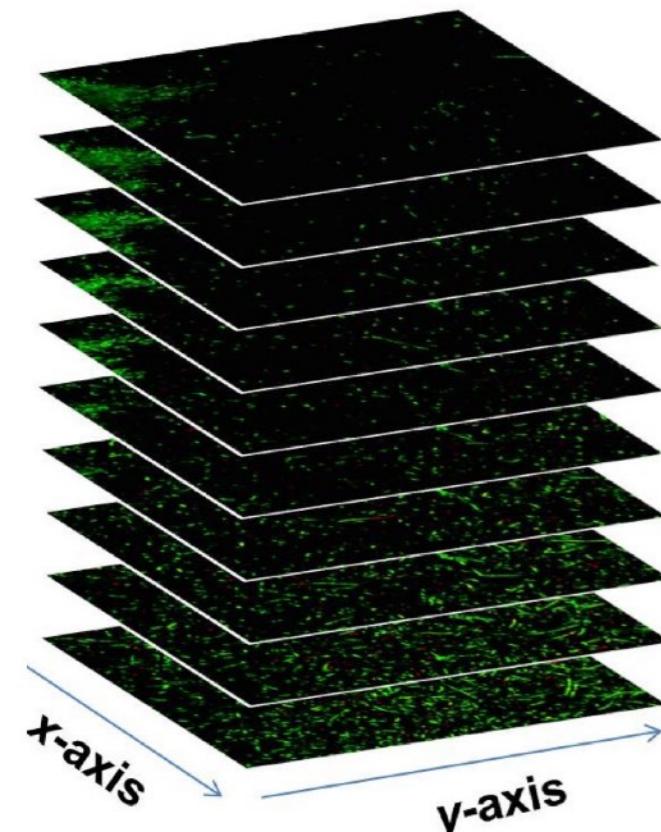


1024 by 1024



About 0.5 MB

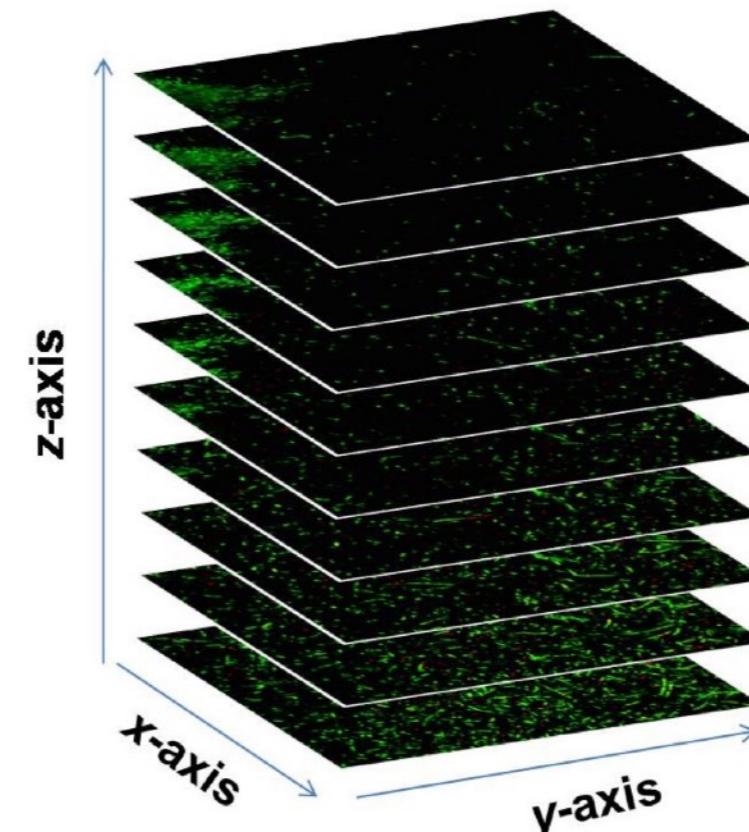
About 2.0 MB



↔

Δz

Δt



Microscope confocal

Objectifs

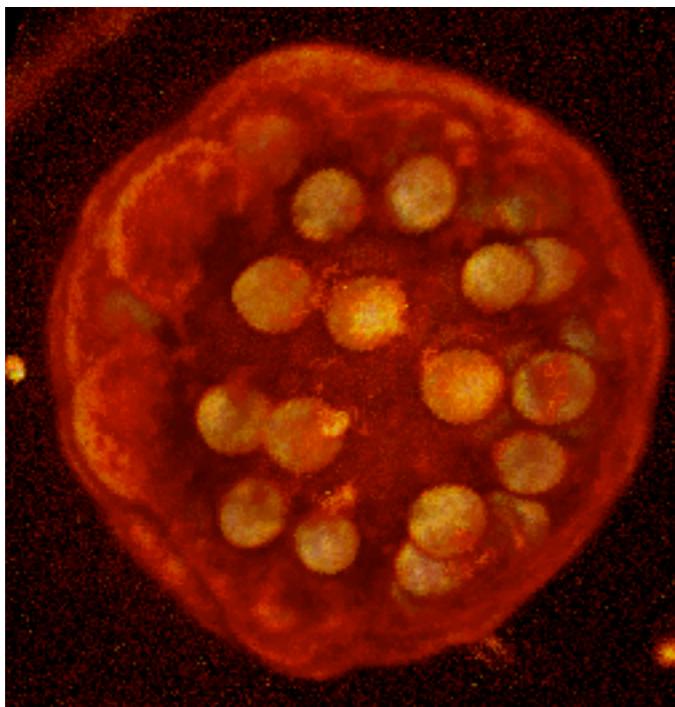
Résolution spatial
Résolution temporelle
Ratio Signal sur bruit

Microscope confocal

Objectifs

Résolution spatial
Résolution temporelle
Ratio Signal sur bruit

Photoblanchiment
Phototoxicité



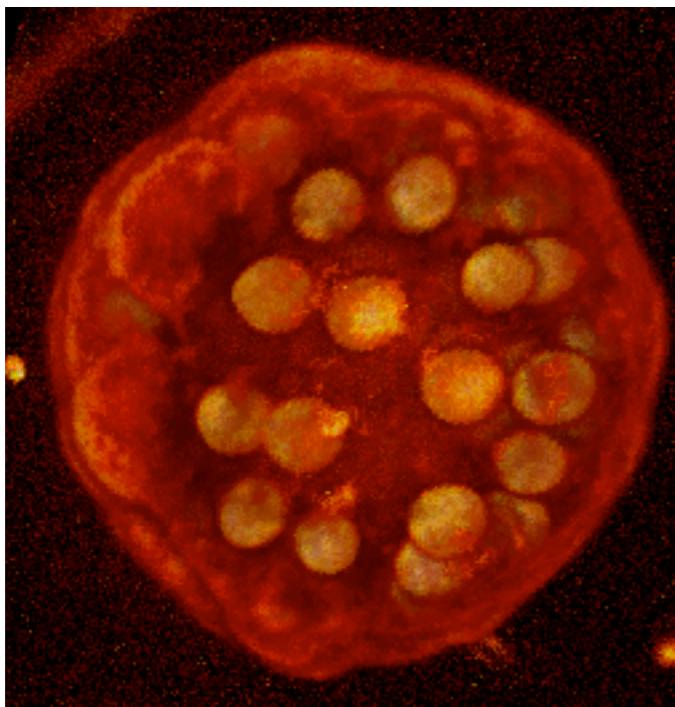
Microscope confocal

Objectifs

Résolution spatial
Résolution temporelle
Ratio Signal sur bruit

Photoblanchiment
Phototoxicité

Les embryons bougent

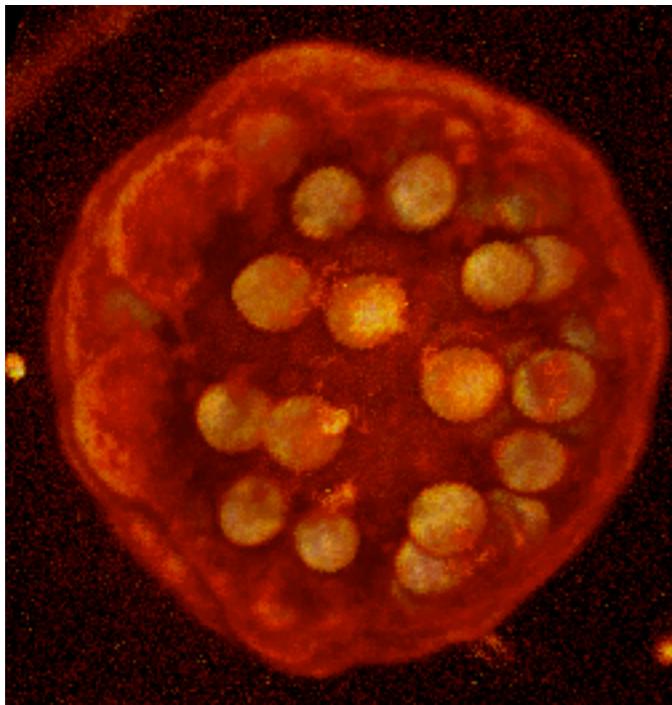


Microscope confocal

Objectifs

Résolution spatial
Résolution temporelle
Ratio Signal sur bruit

Photoblanchiment
Phototoxicité

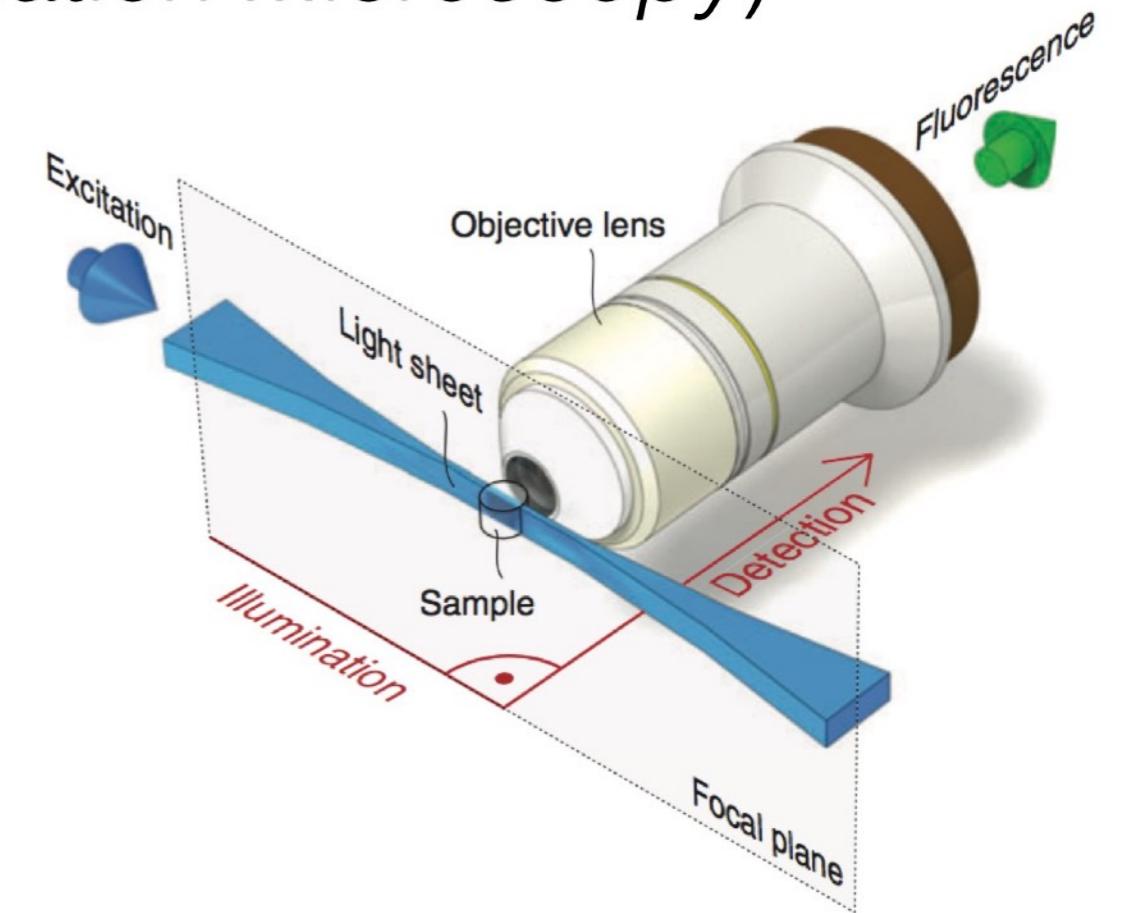


Les embryons bougent

photons \sim density \cdot object size \cdot resolution \cdot
signal \cdot time period \cdot repetitions



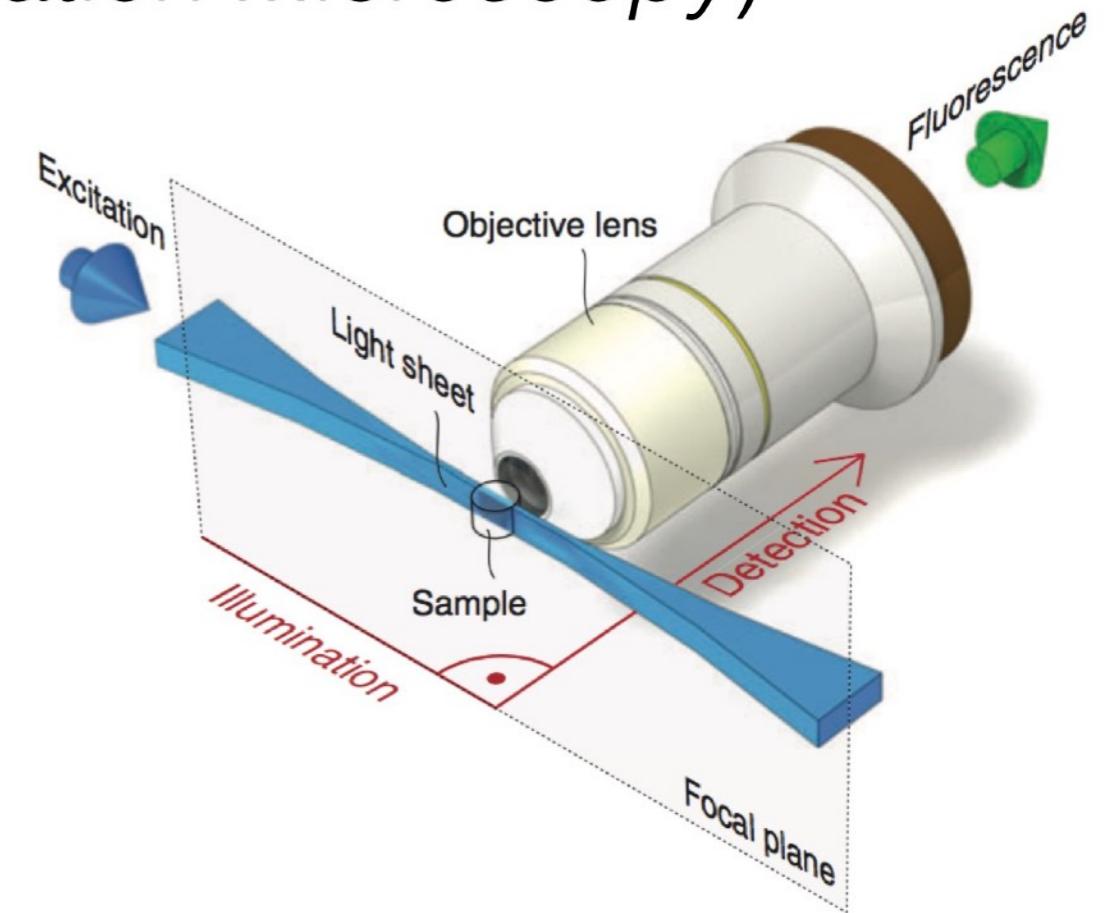
Microscope SPIM (*Selective Plane Illumination Microscopy*)



Huisken 2004

Microscope SPIM (*Selective Plane Illumination Microscopy*)

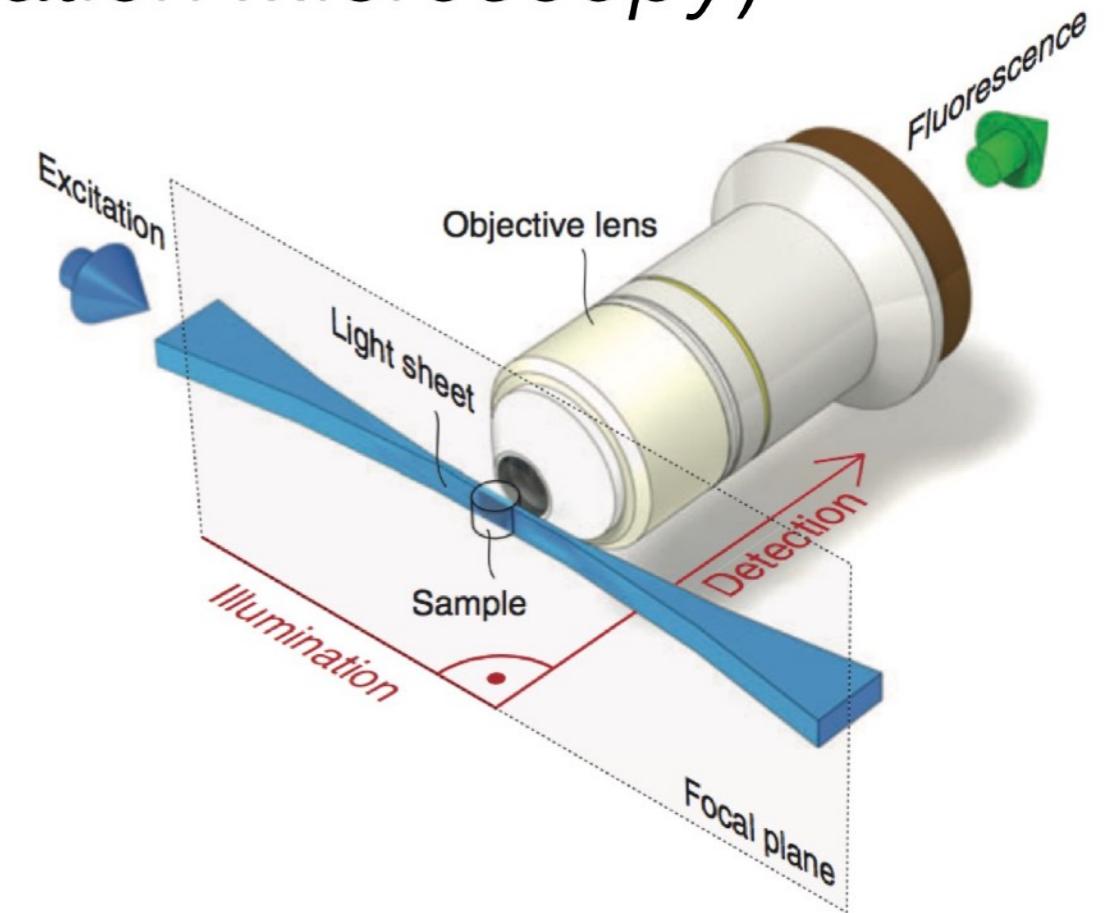
Beaucoup plus rapide



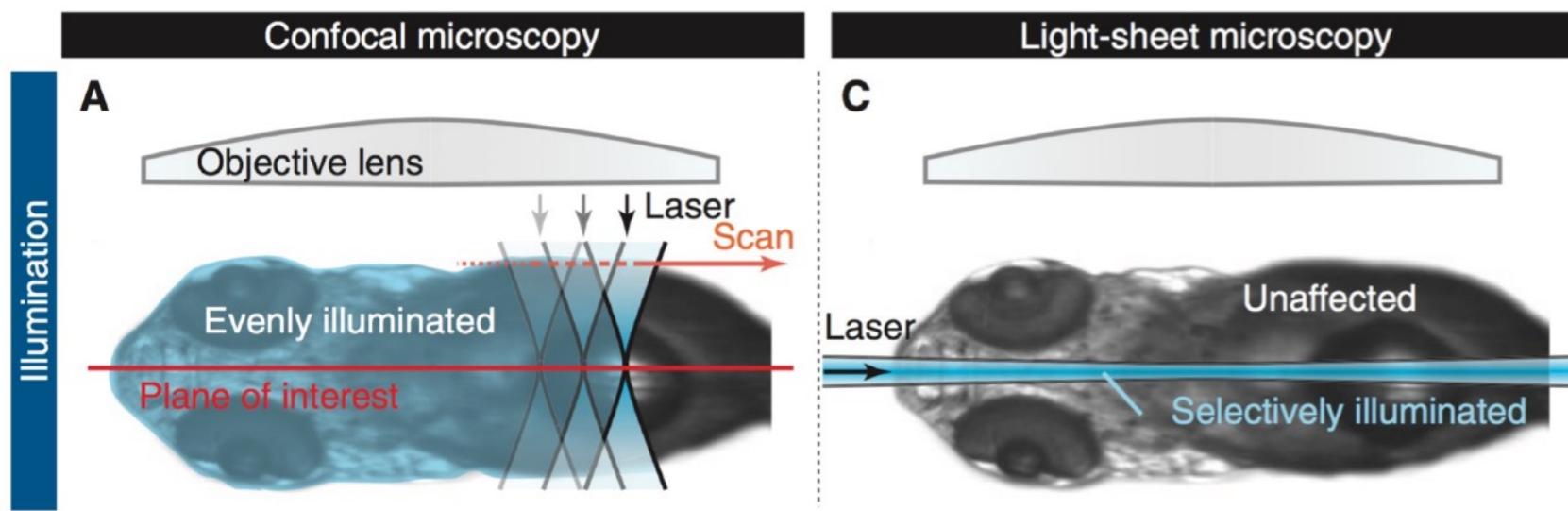
Huisken 2004

Microscope SPIM (Selective Plane Illumination Microscopy)

Beaucoup plus rapide



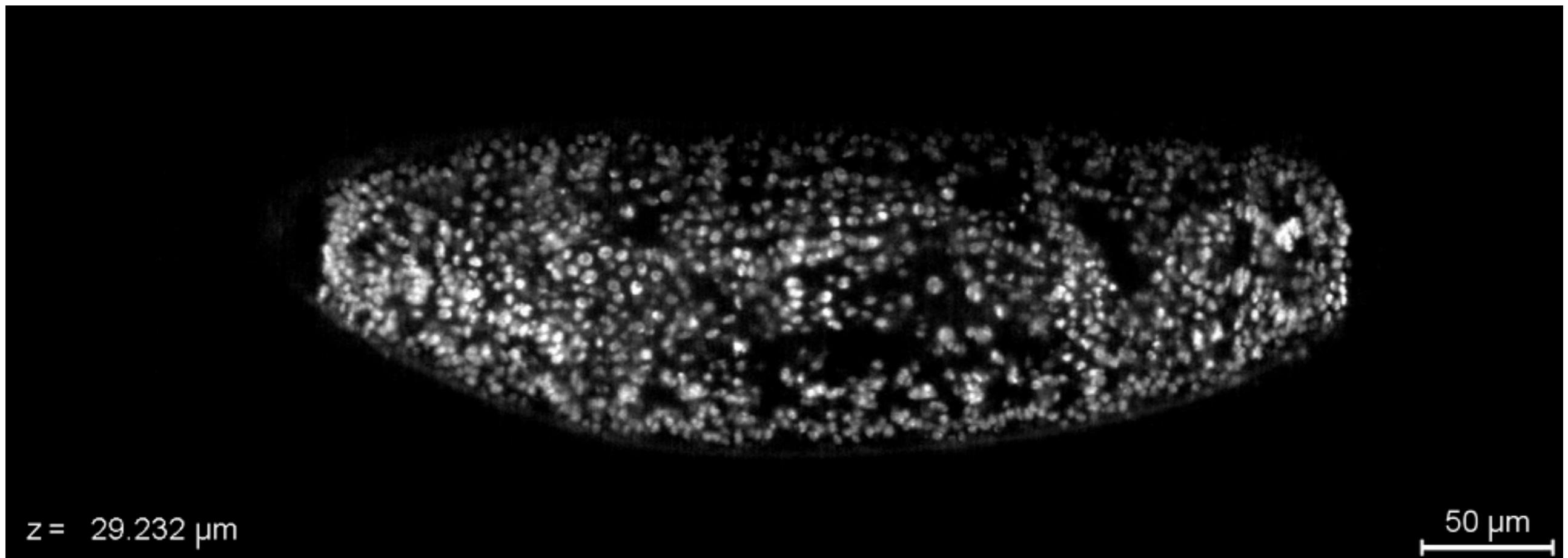
Huisken 2004



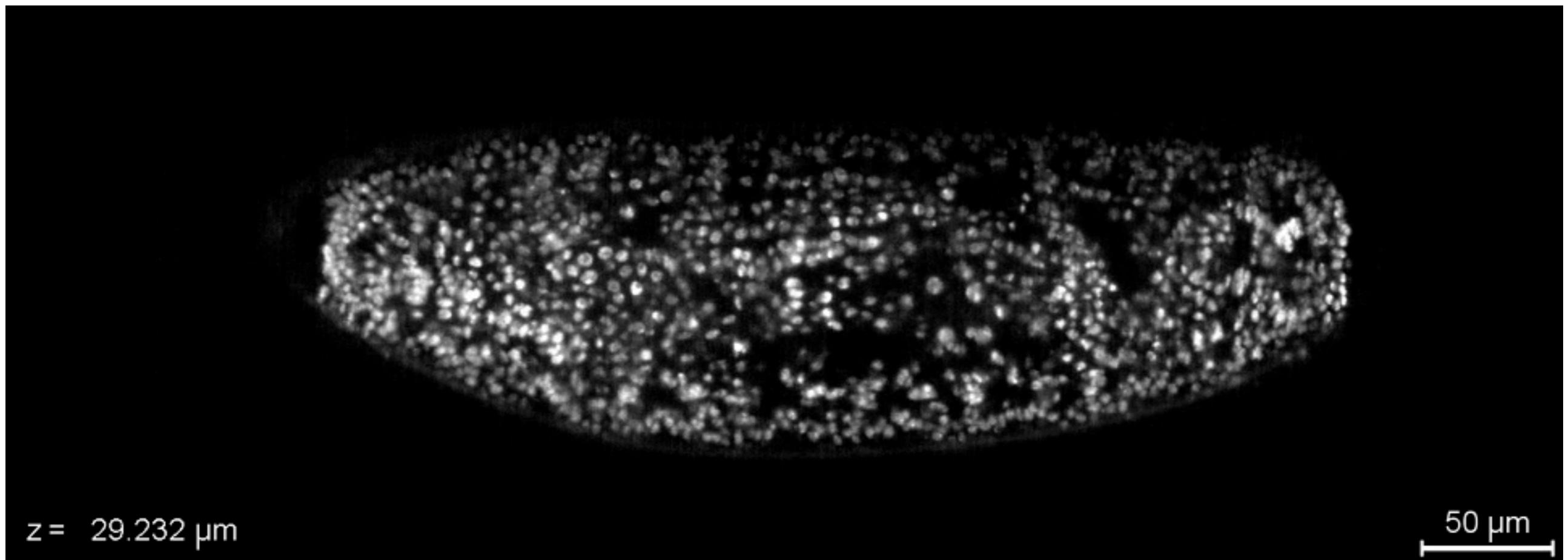
Moins d'illumination

Huisken 2009

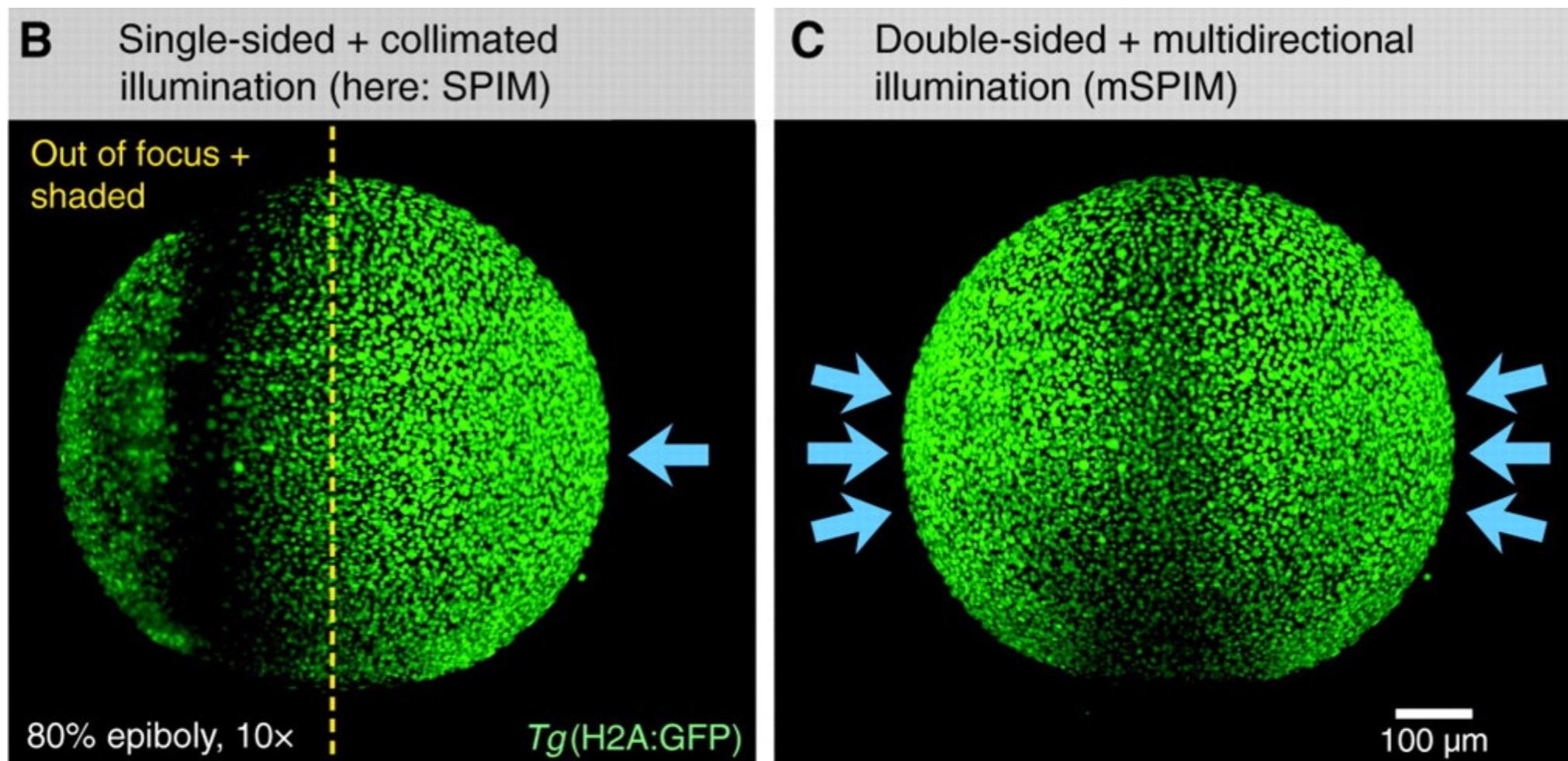
Microscope SPIM
(*Selective Plane Illumination Microscopy*)



Microscope SPIM
(*Selective Plane Illumination Microscopy*)

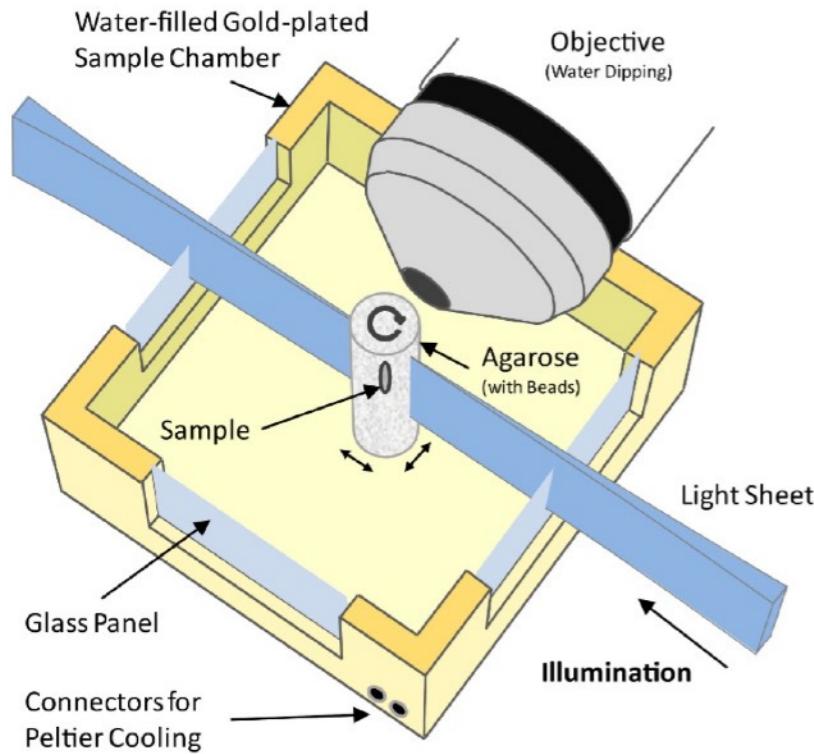


SPIM : Multiples Illuminations

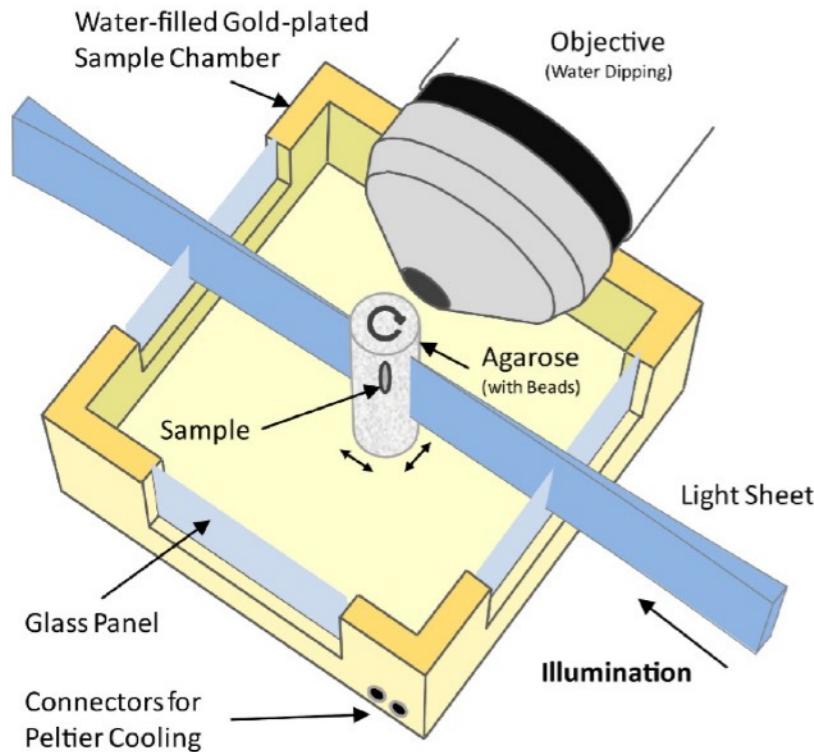


Huisken 2009

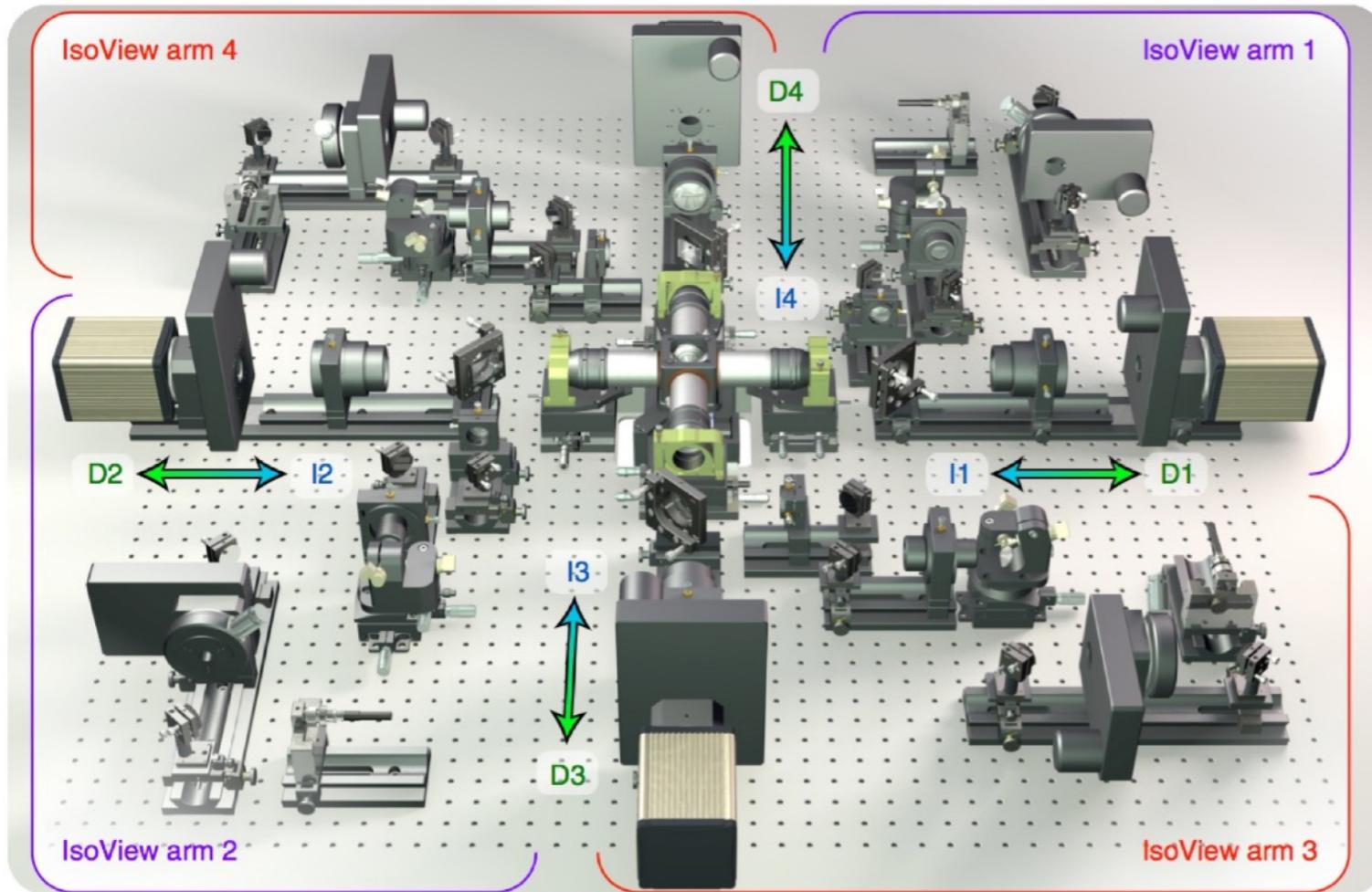
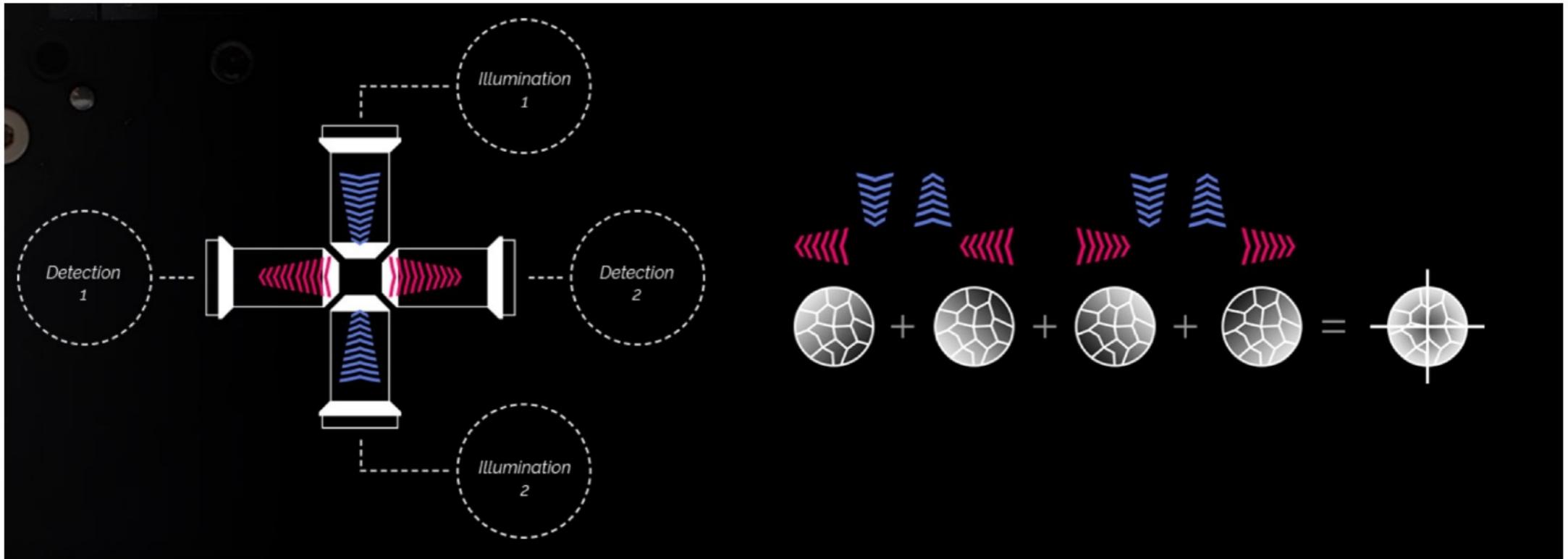
SPIM : Multiples Angles



SPIM : Multiples Angles



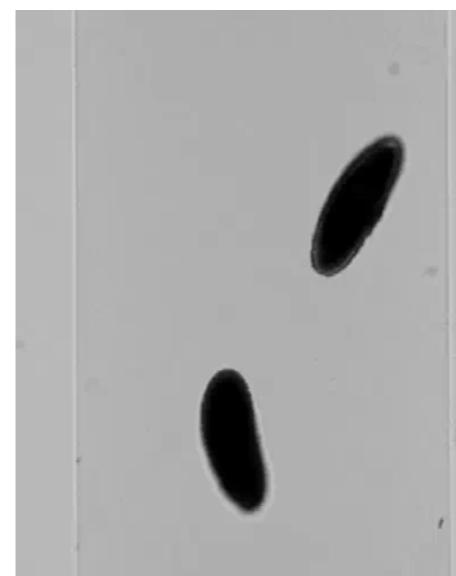
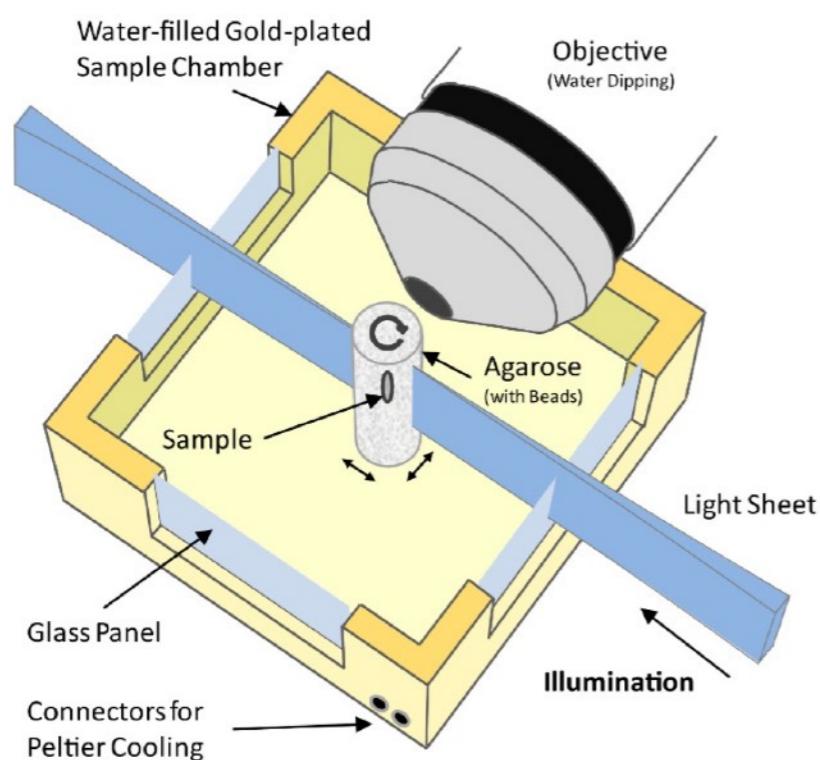
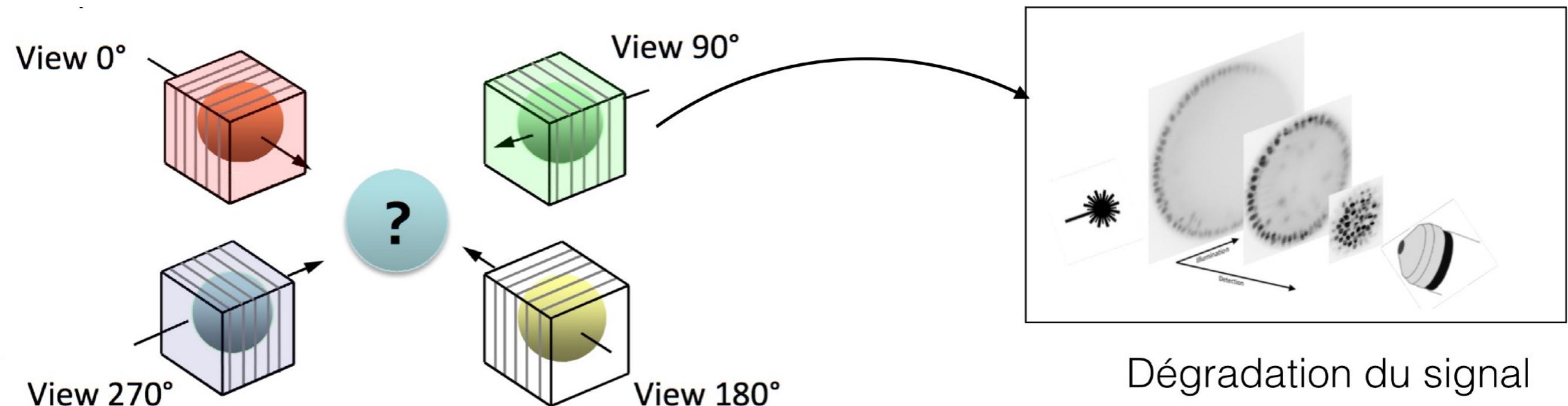
SPIM : Multiples Vues



Chhetri 10/2015

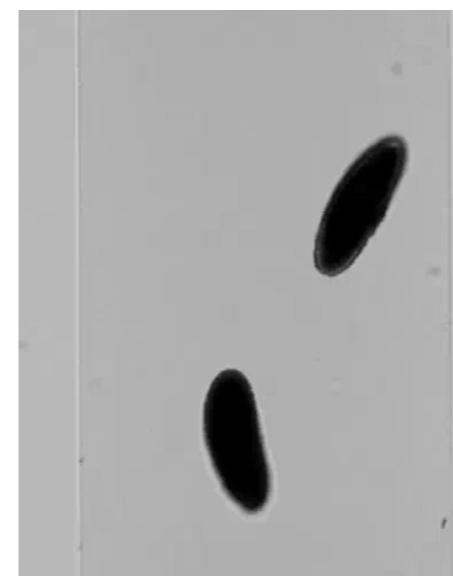
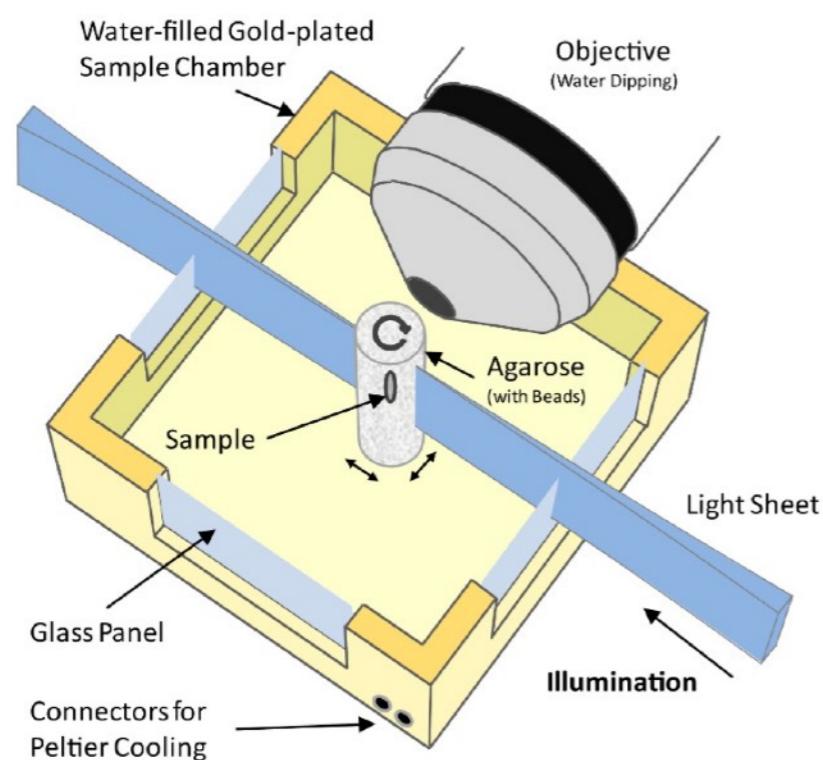
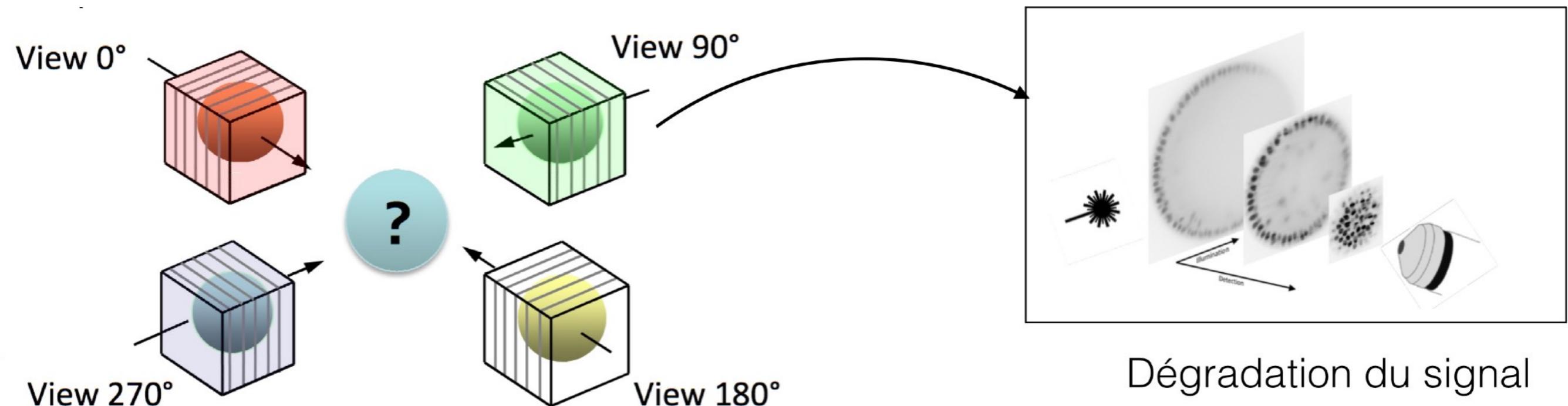
SPIM : Recalage et Fusion

Spatial



SPIM : Recalage et Fusion

Spatial



SPIM : Recalage et Fusion

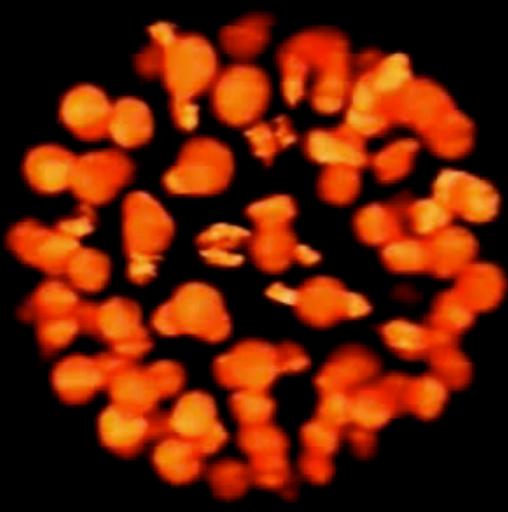
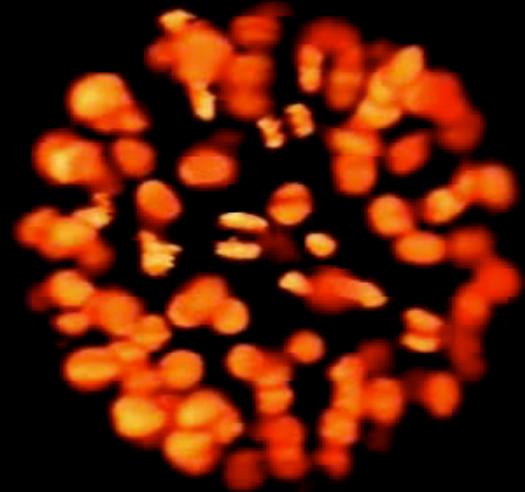
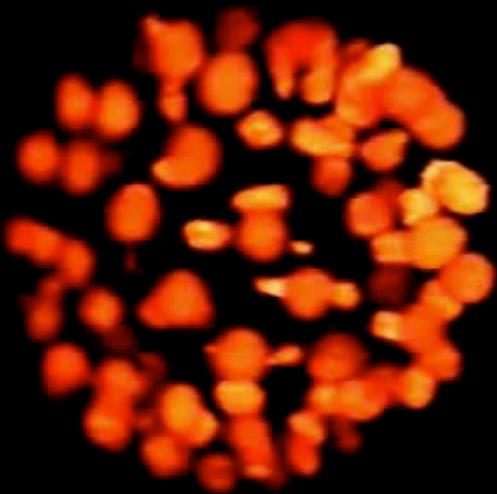
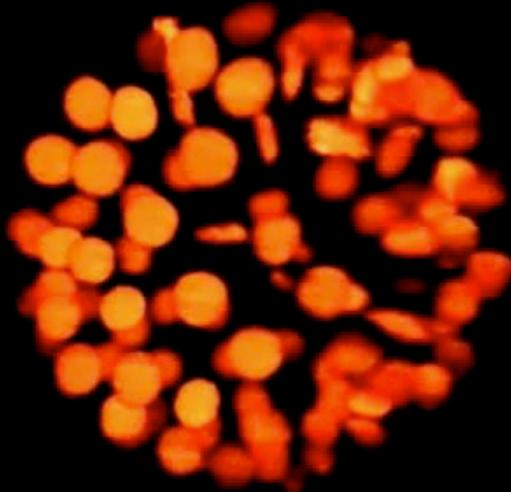
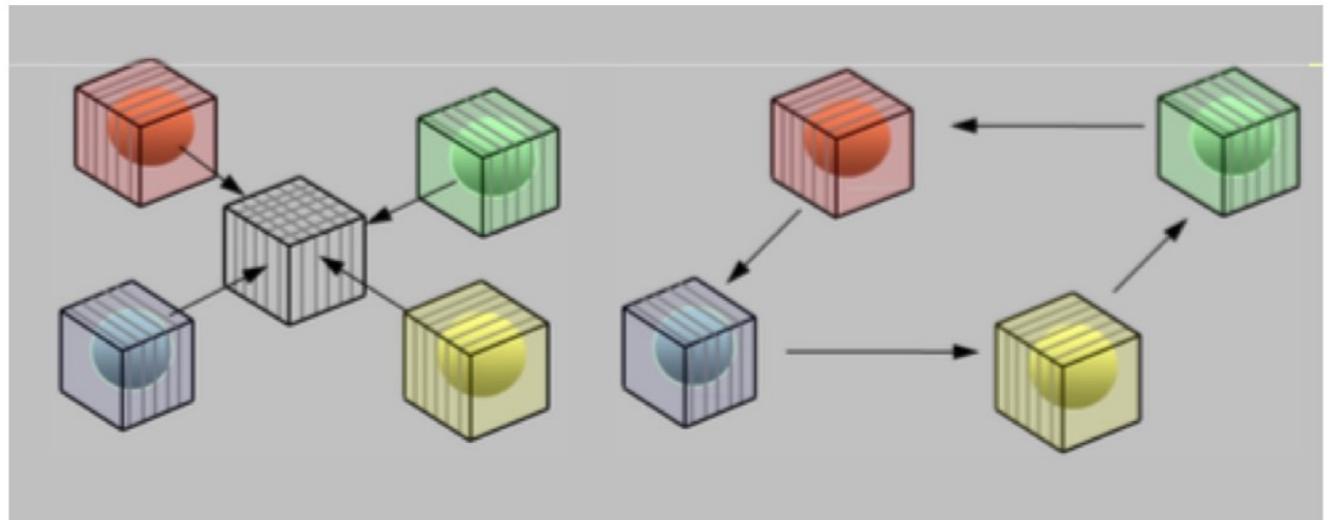
Temporel

SPIM : Recalage et Fusion

Temporel

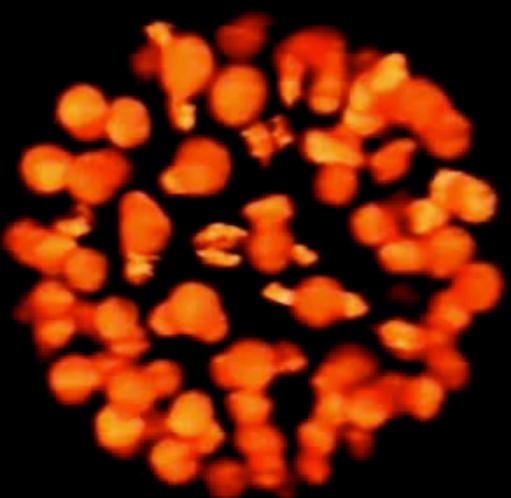
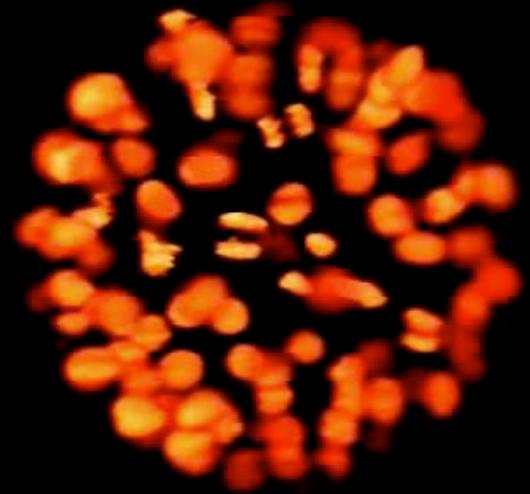
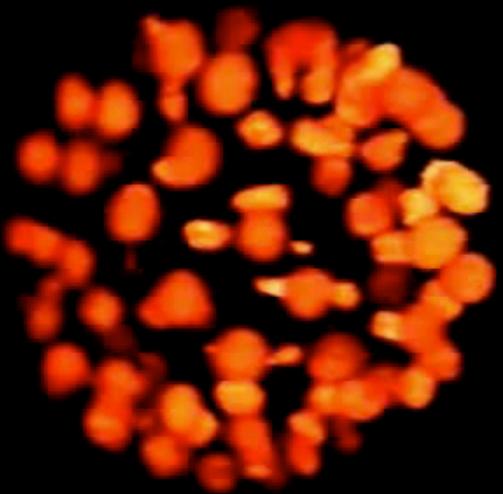
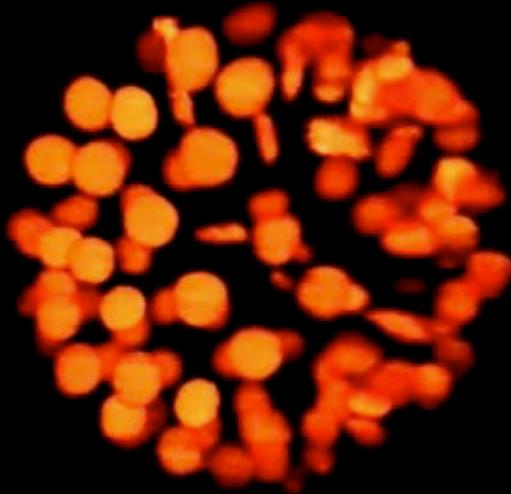
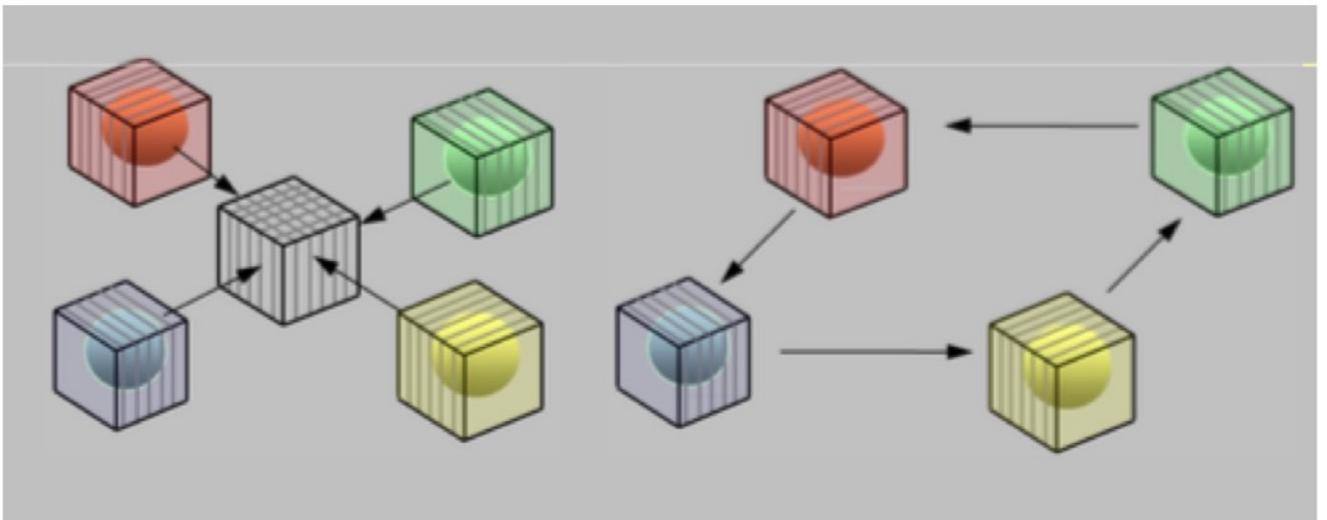
Recalage sur l'intensité

Très lent

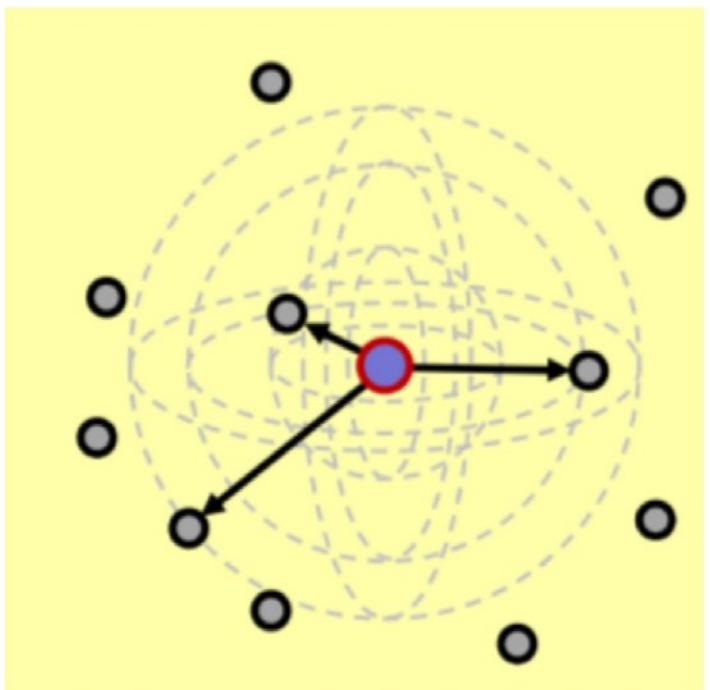


Recalage sur l'intensité

Très lent

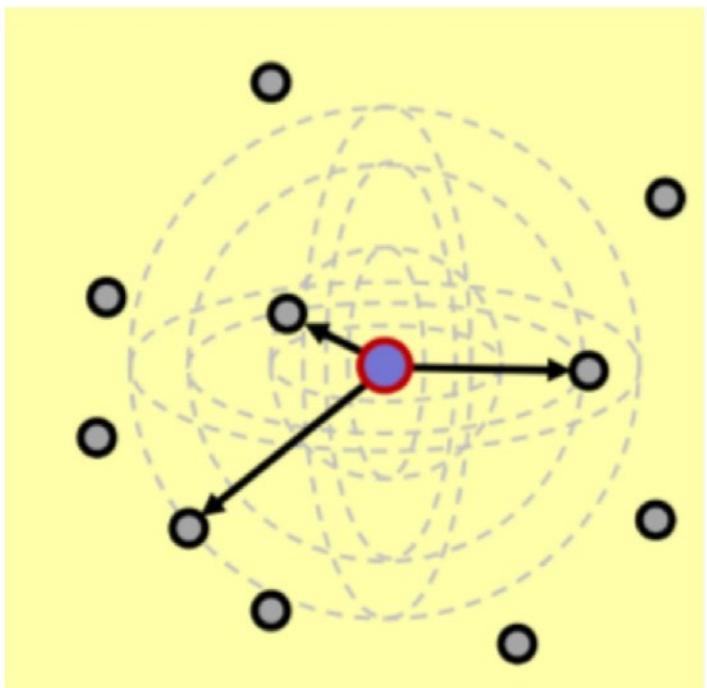


Recalage à l'aide de repères

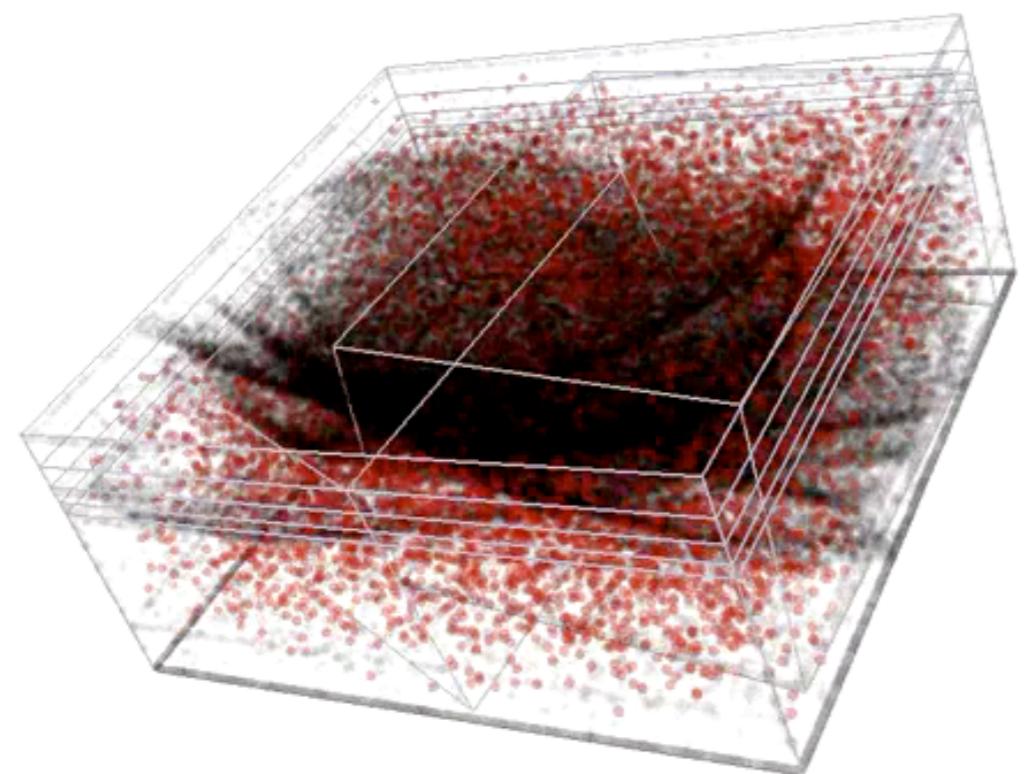


Très rapide, et très bon résultats mais nécessite d'injecter des micro-billes

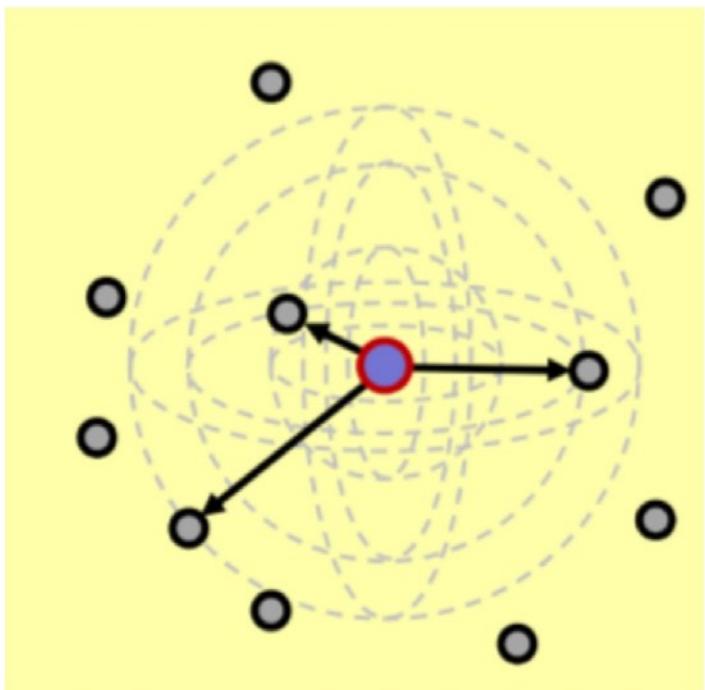
Recalage à l'aide de repères



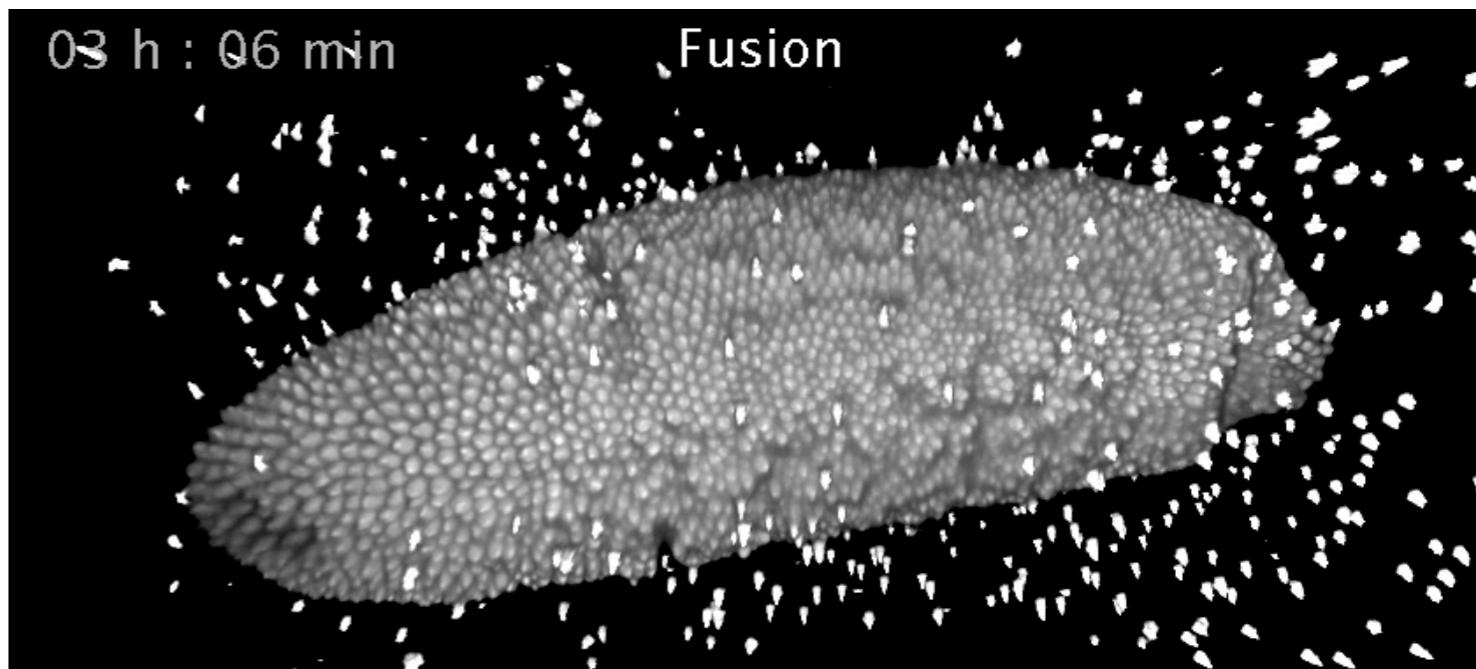
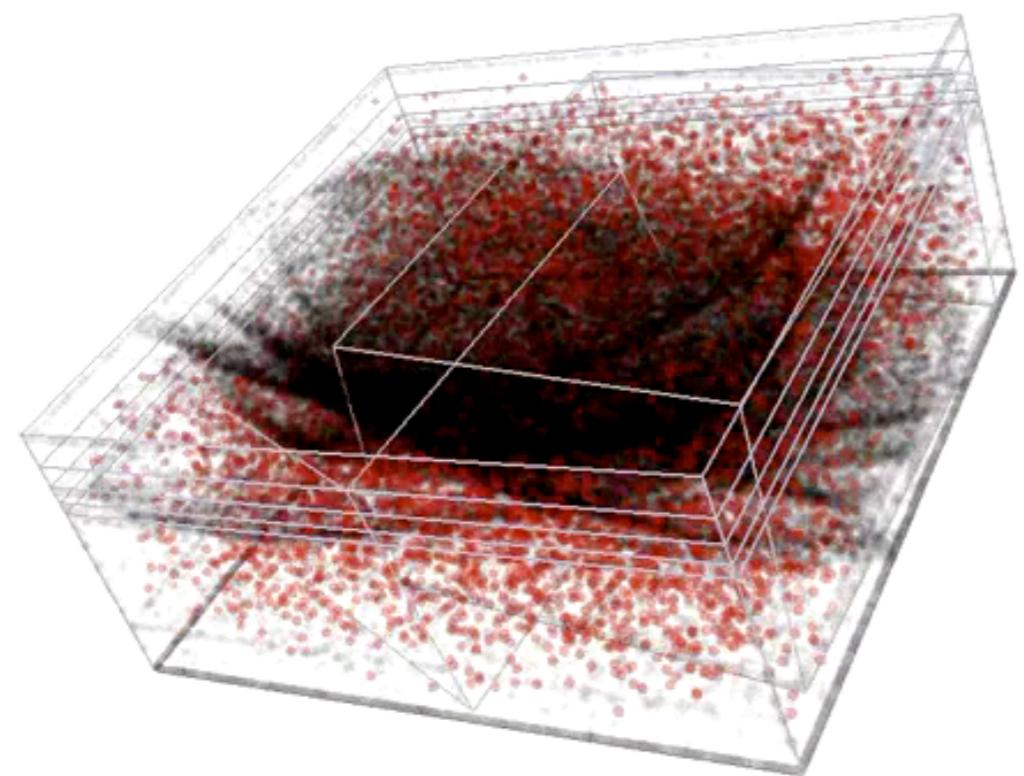
Très rapide, et très bon résultats mais nécessite d'injecter des micro-billes



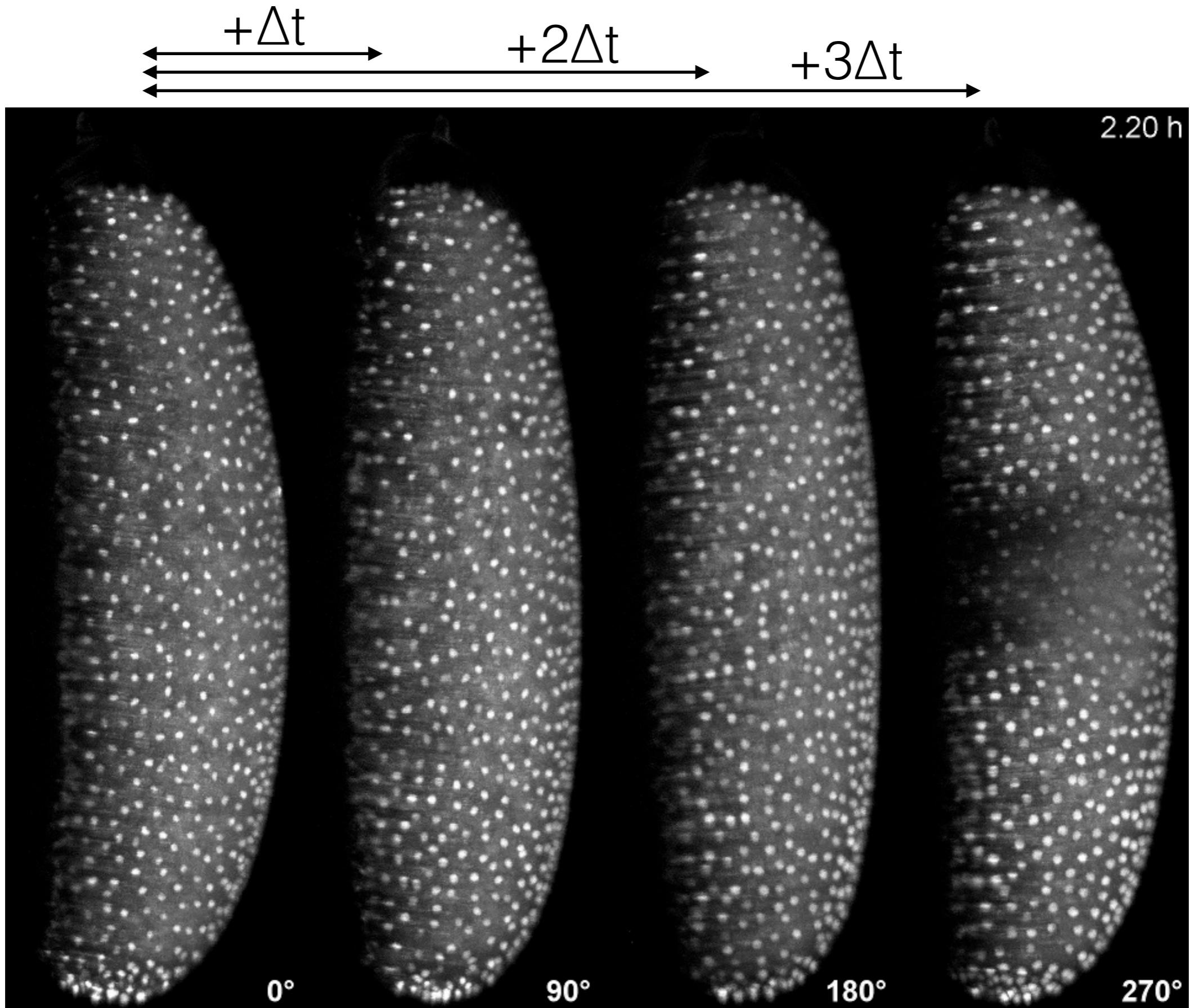
Recalage à l'aide de repères



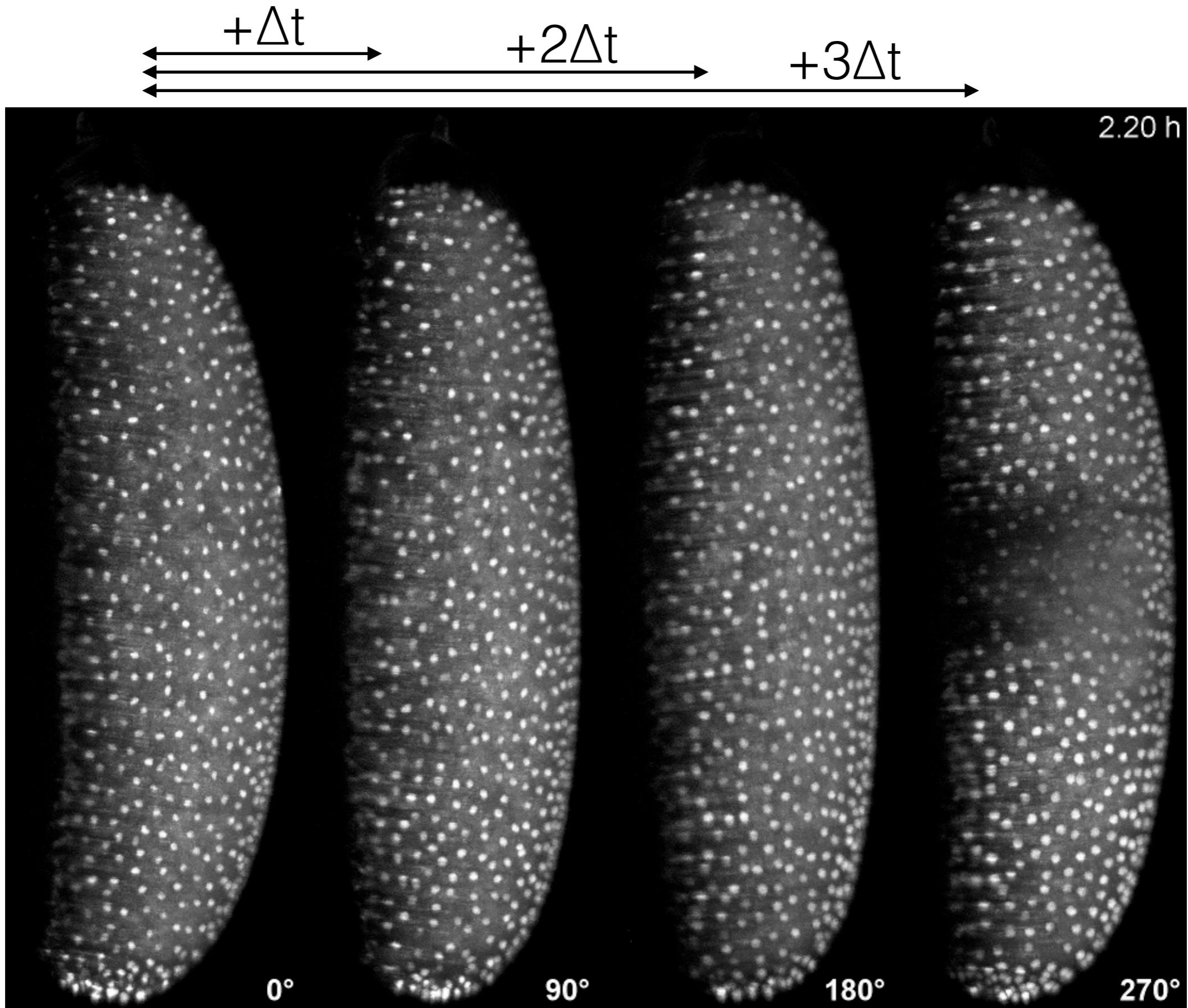
Très rapide, et très bon résultats mais nécessite d'injecter des micro-billes



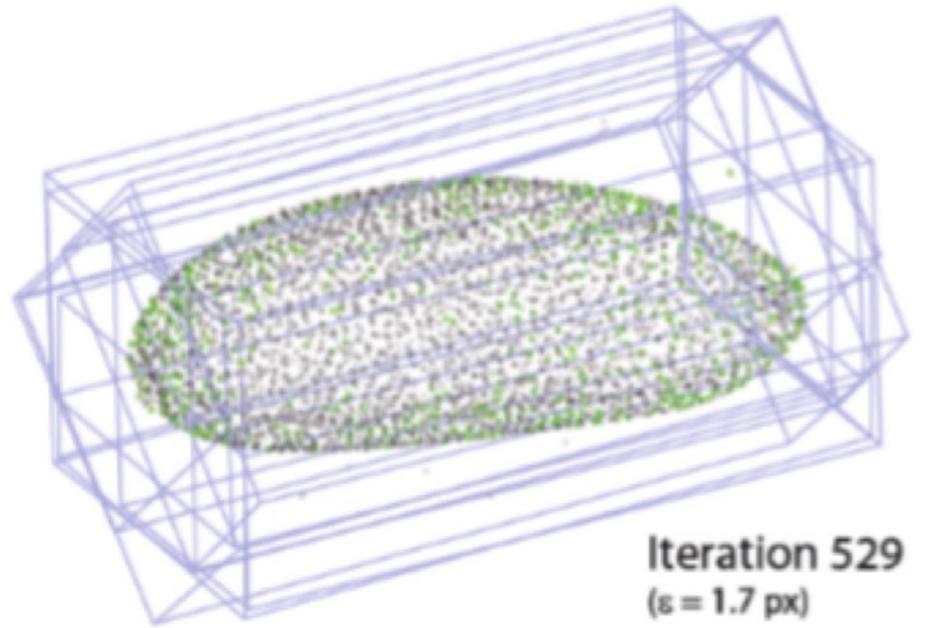
Problèmes du recalage à partir d'images



Problèmes du recalage à partir d'images



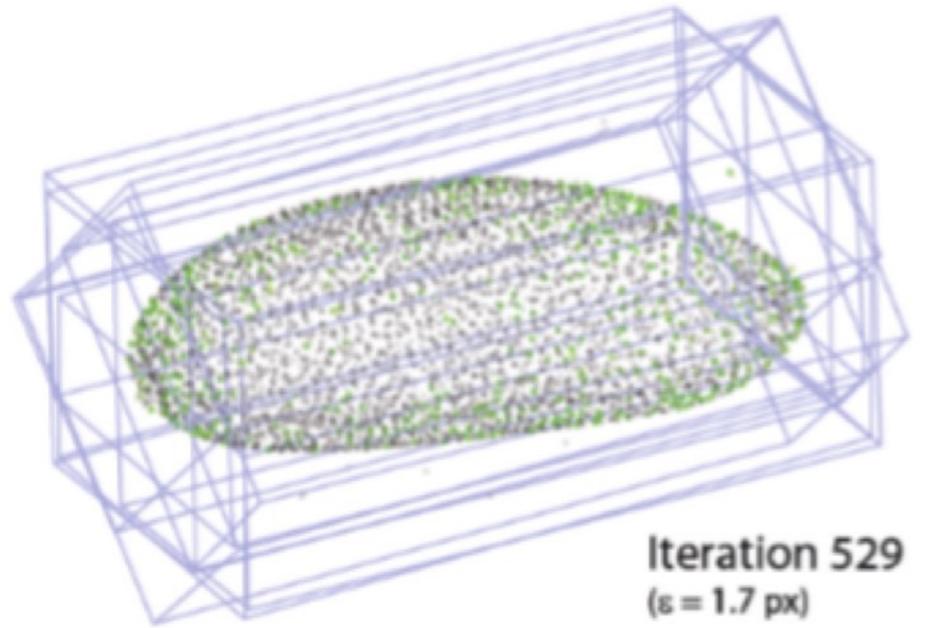
Recalage à l'aide des segmentations



Rapide, mais dépend de la qualité des images et des algorithmes de segmentations

Keller 2008

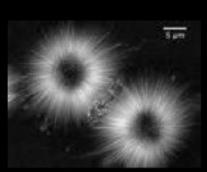
Recalage à l'aide des segmentations



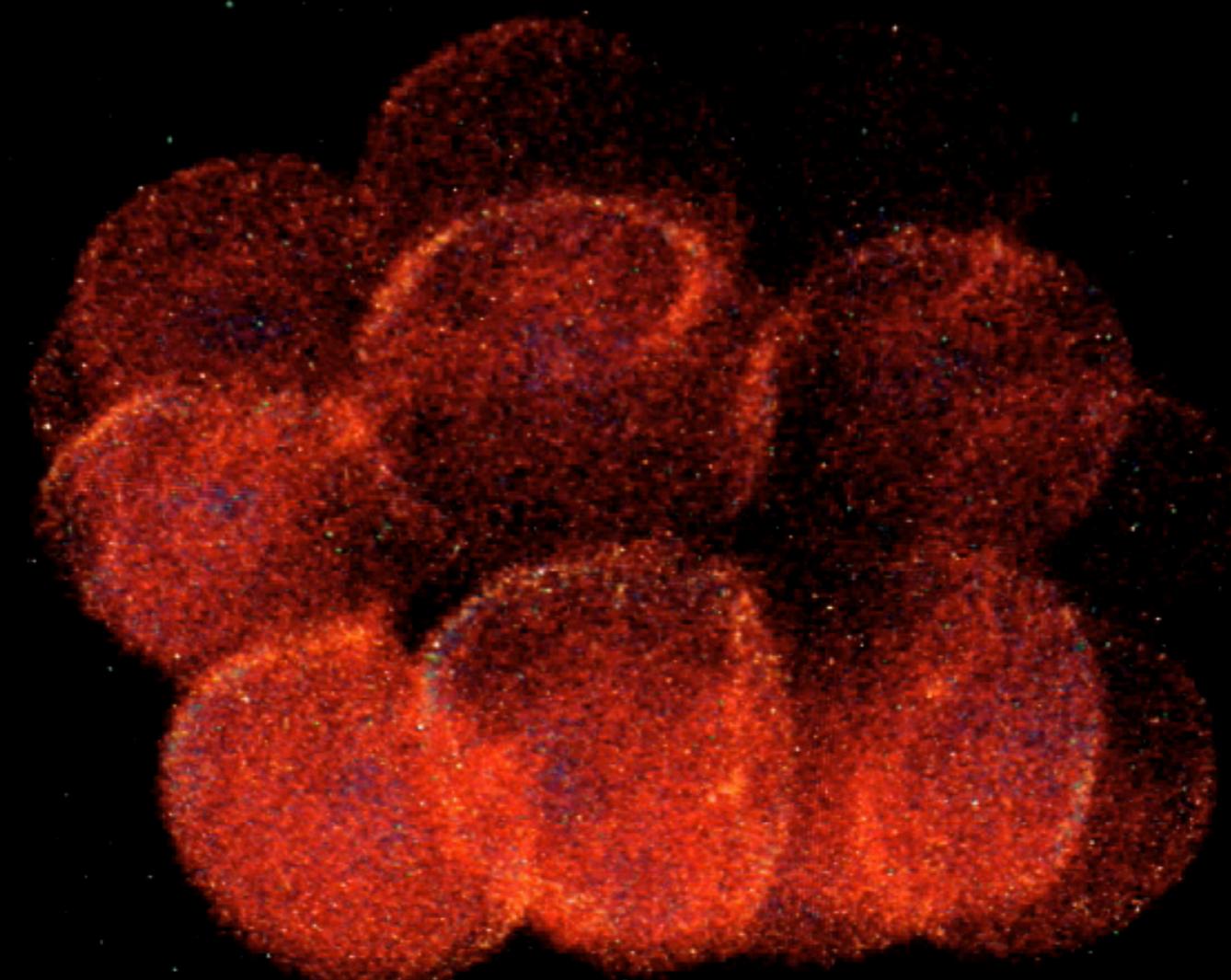
Rapide, mais dépend de la qualité des images et des algorithmes de segmentations

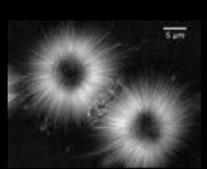
Keller 2008

Qu'observe t'on ?

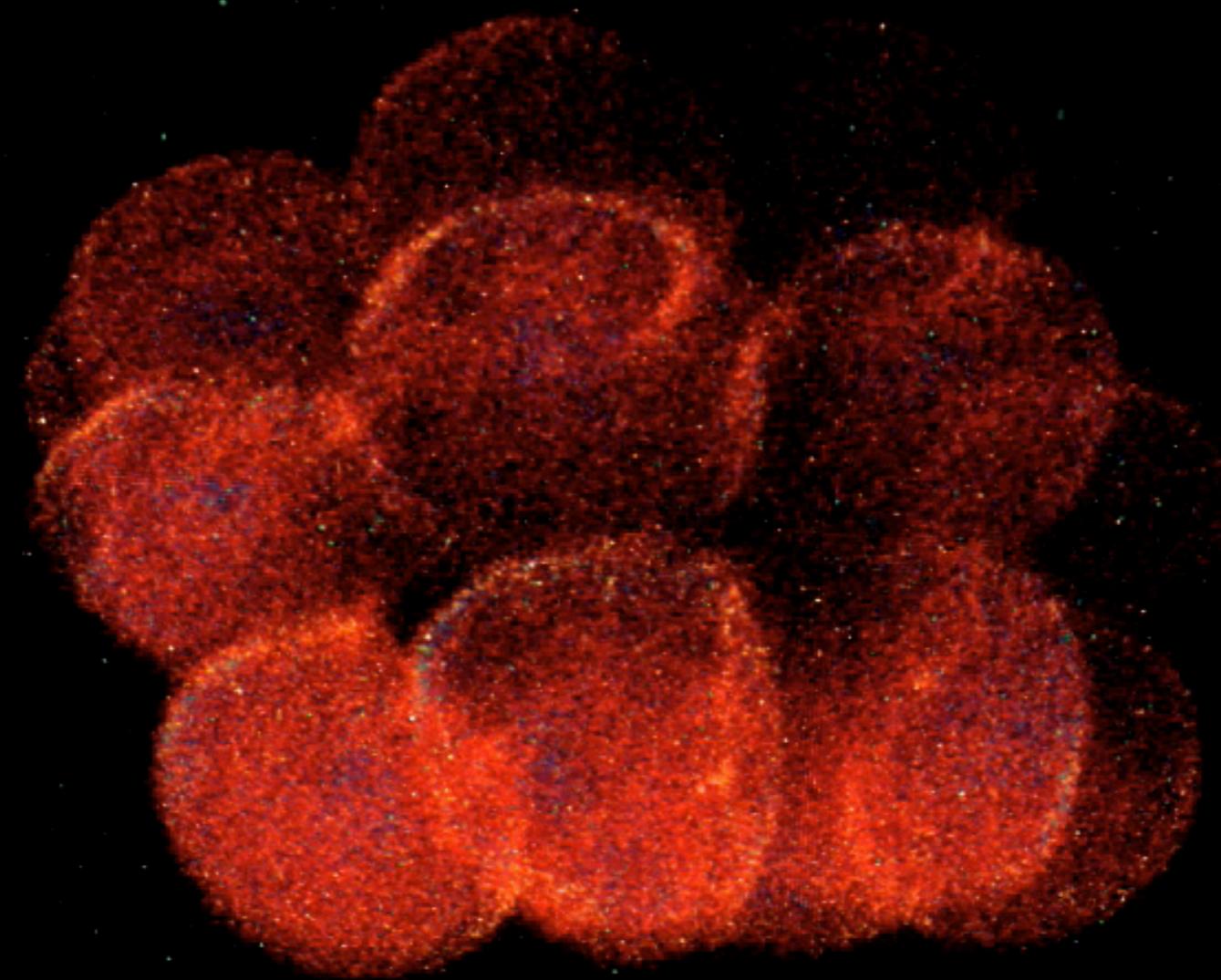


Sea Urchin



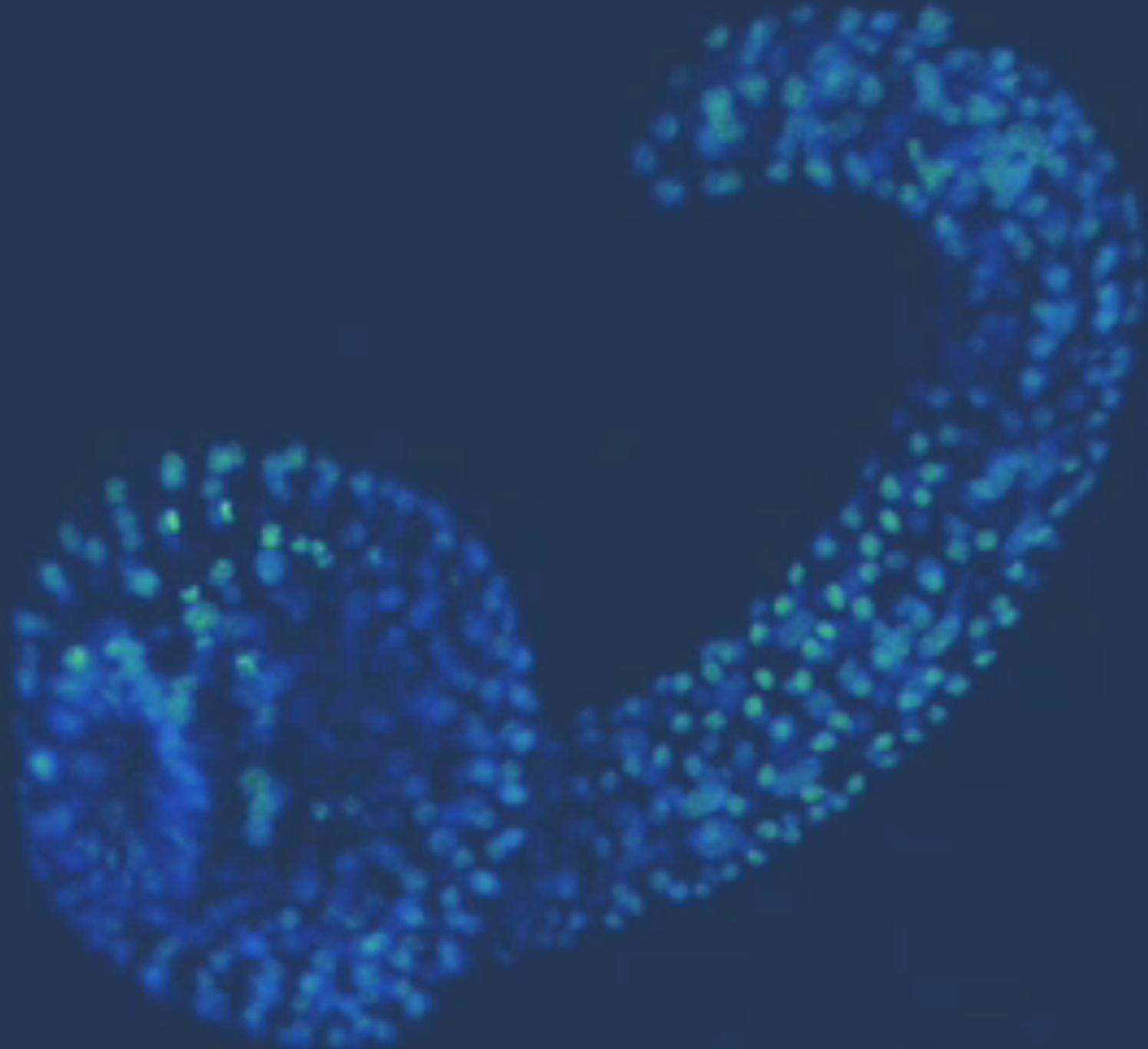


Sea Urchin



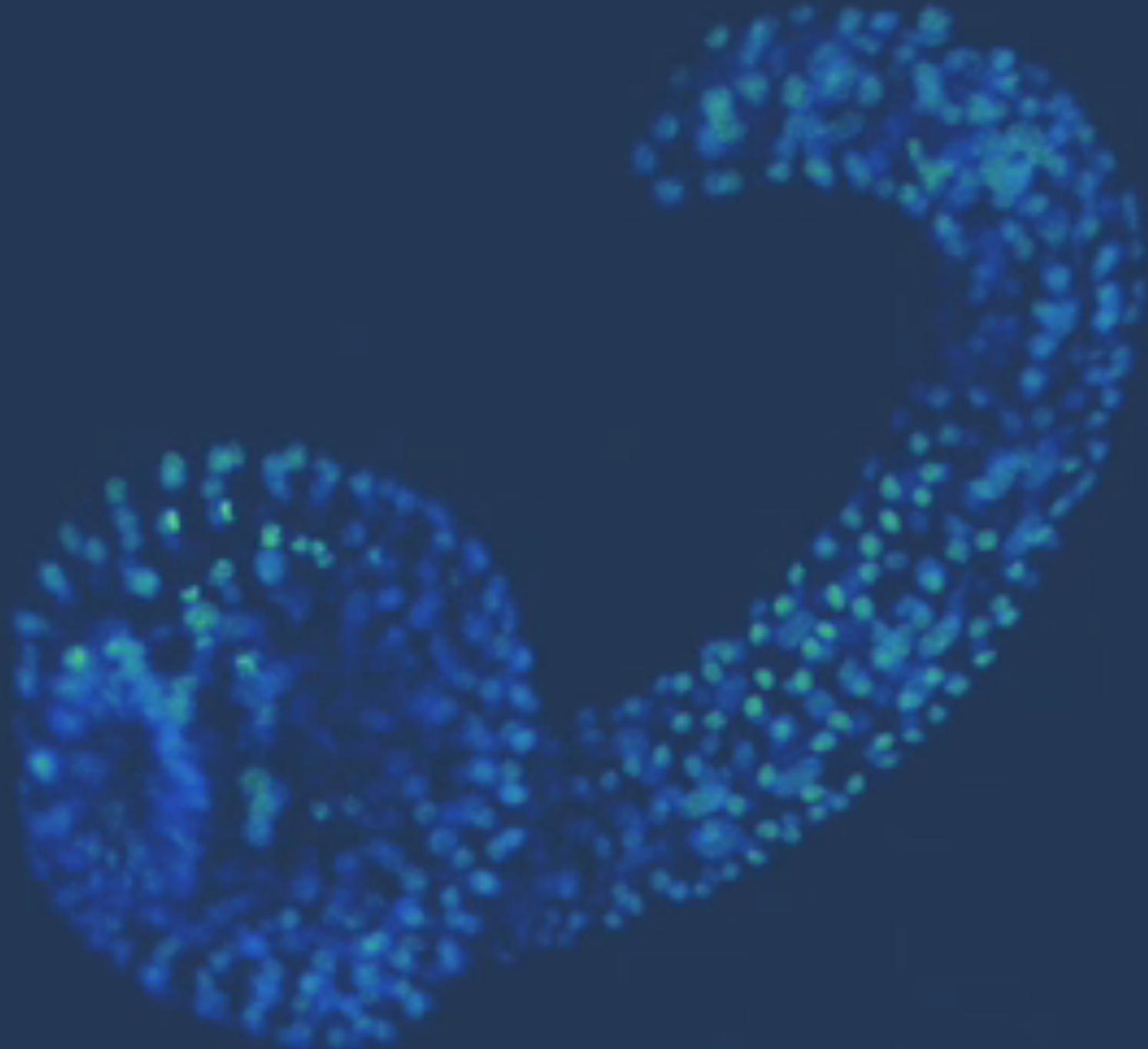


Phallusia Mamillata



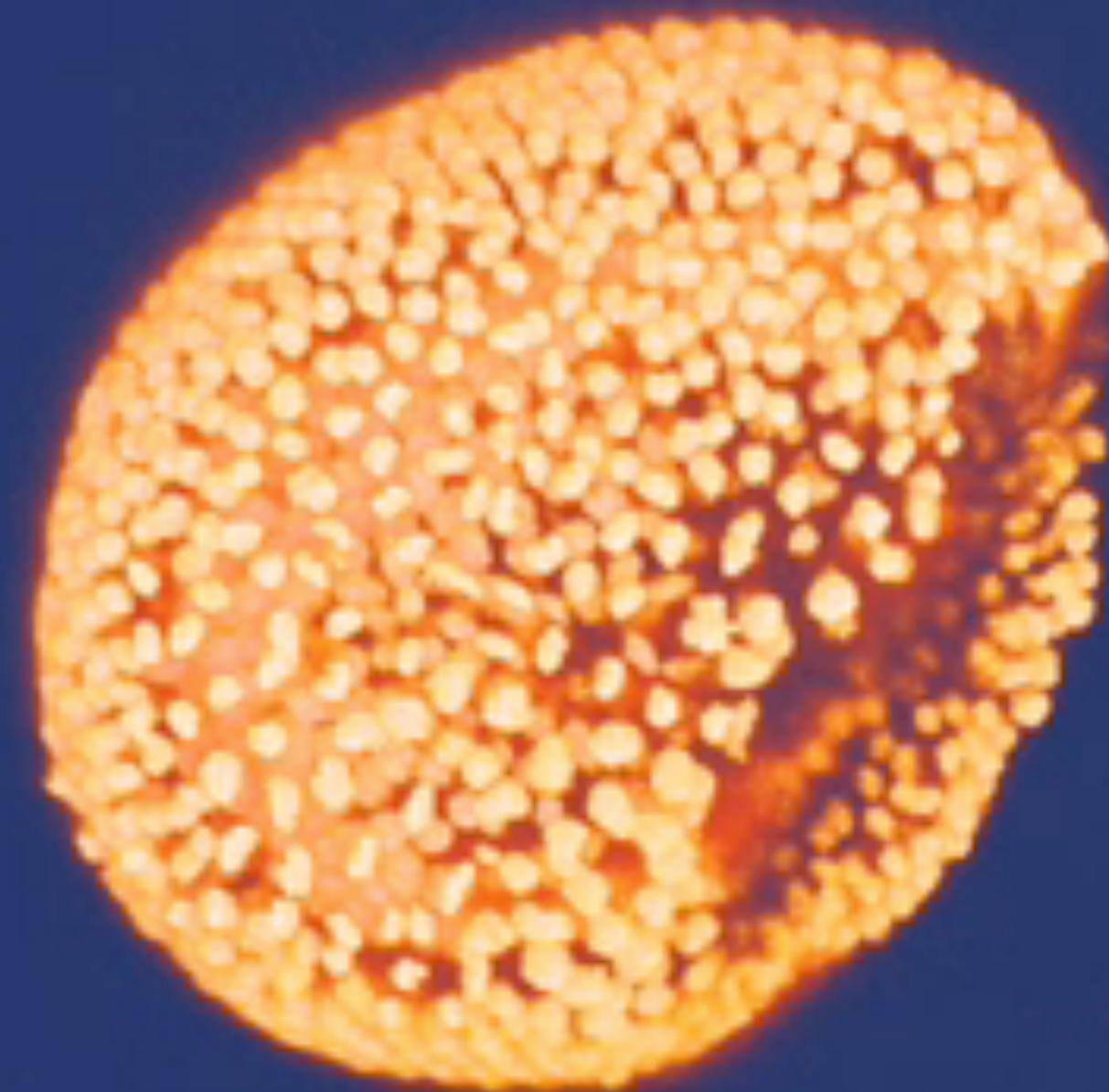


Phallusia Mamillata



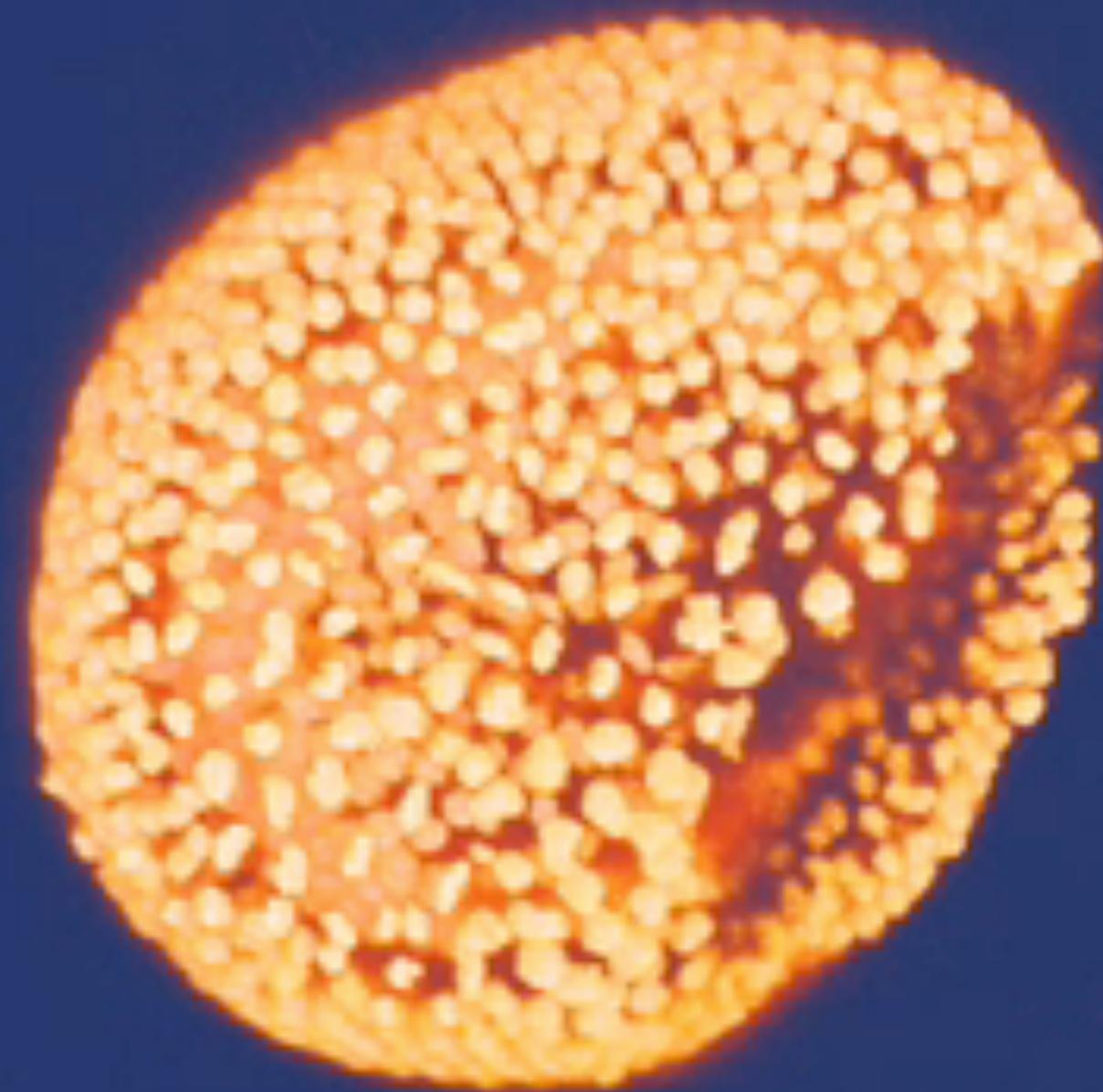


Amphioxus



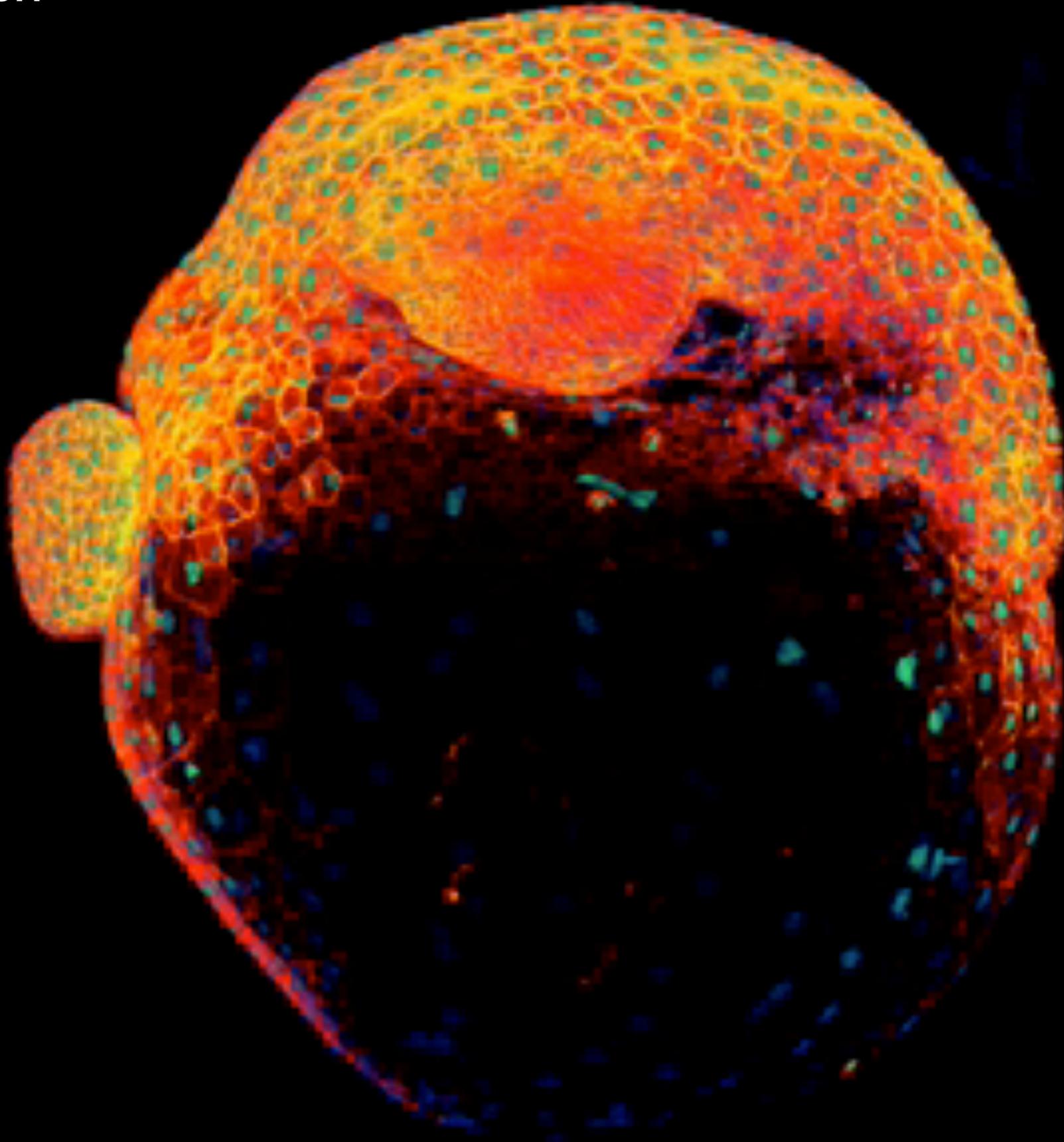


Amphioxus



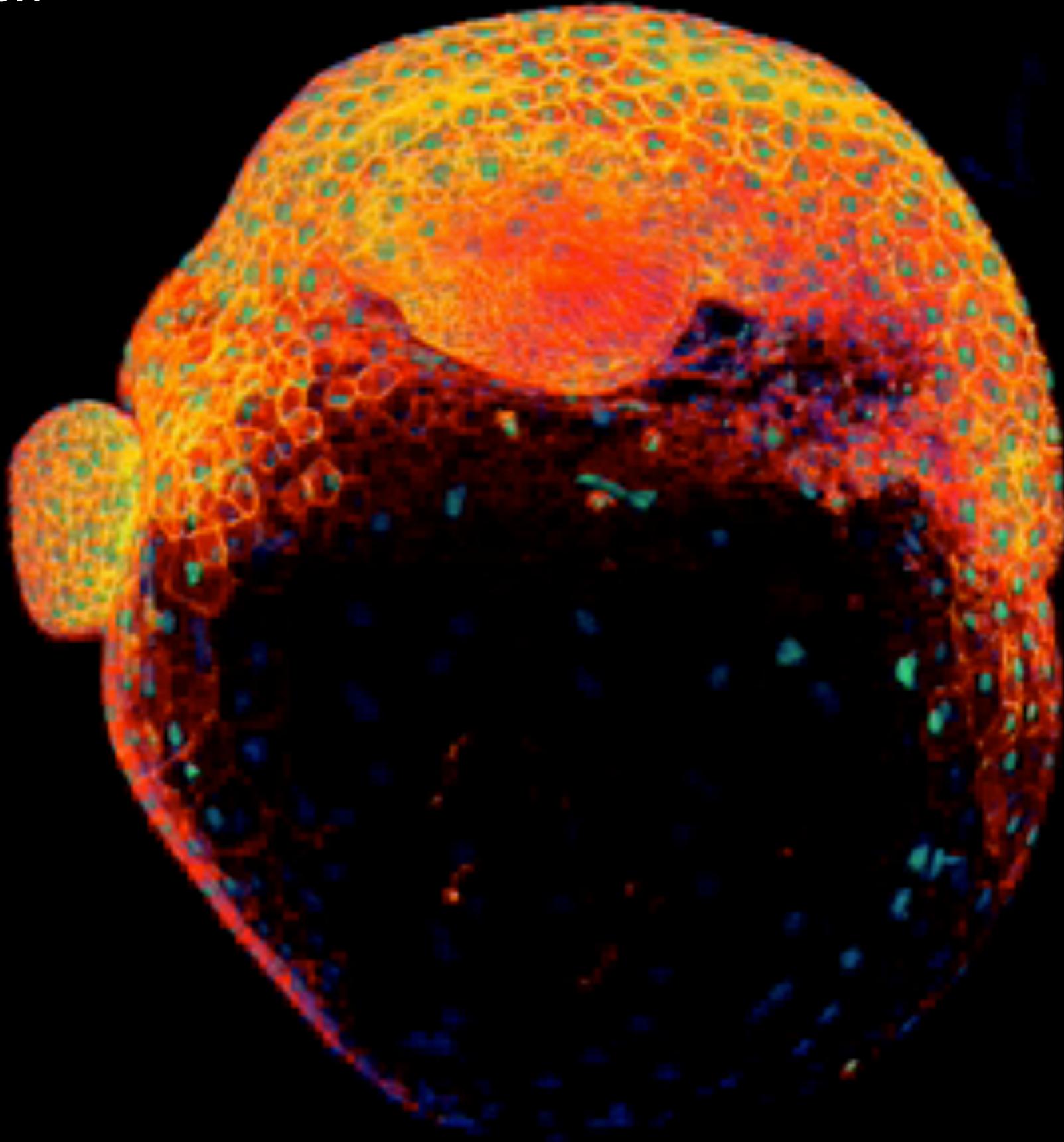


Zebrafish





Zebrafish





Zebrafish



Zebrafish



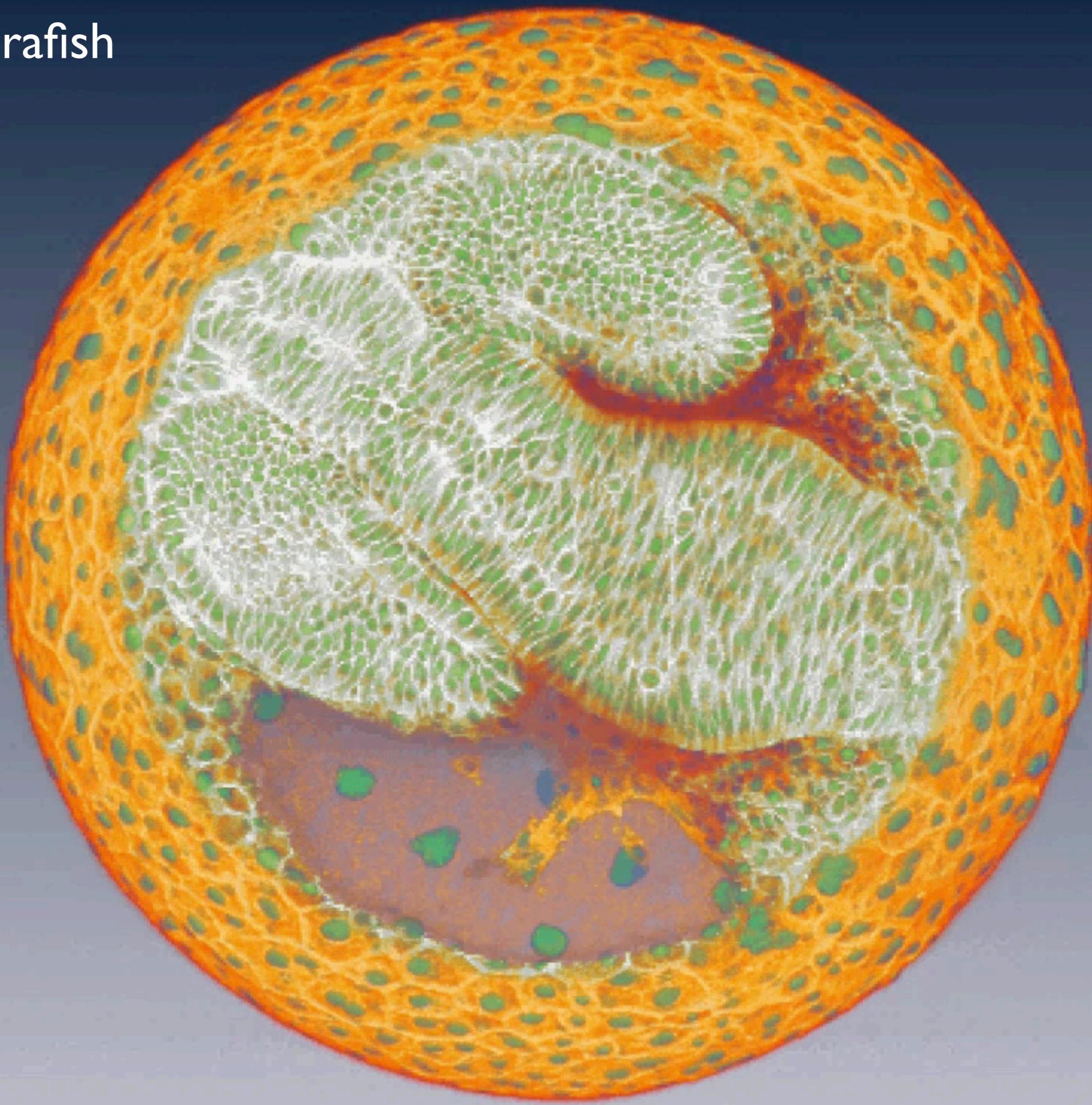
Zebrafish



Zebrafish

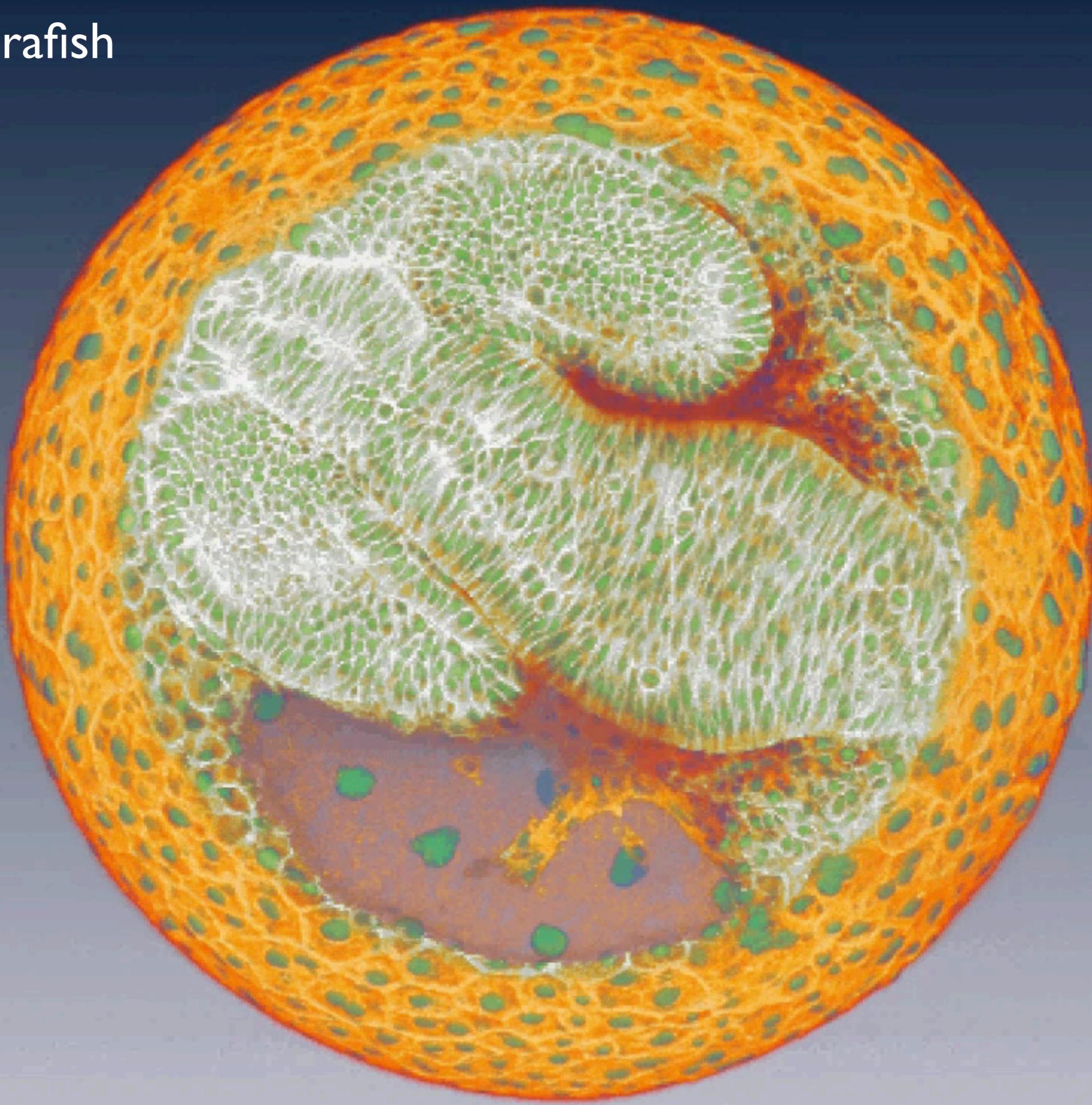


Zebrafish



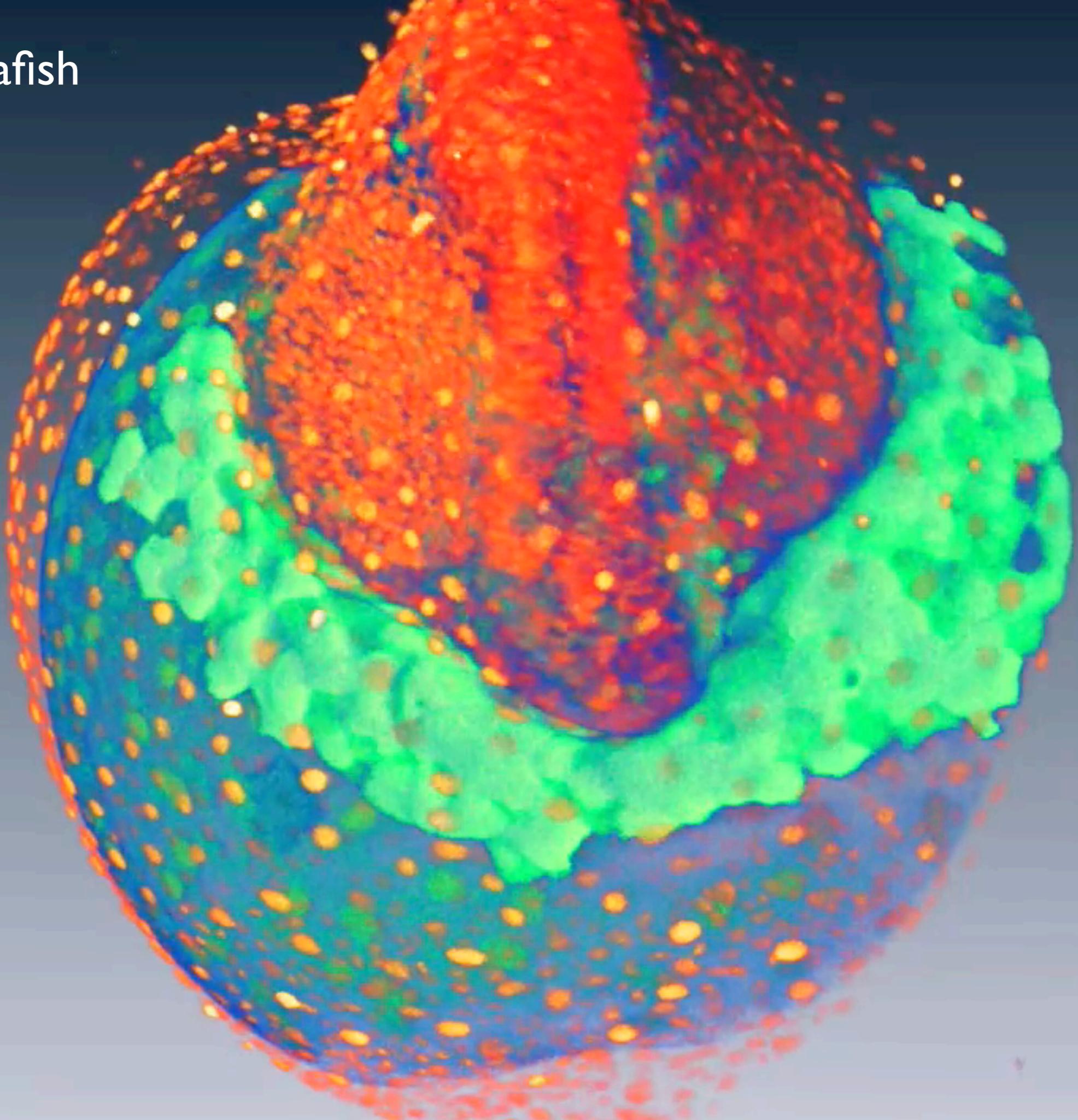


Zebrafish



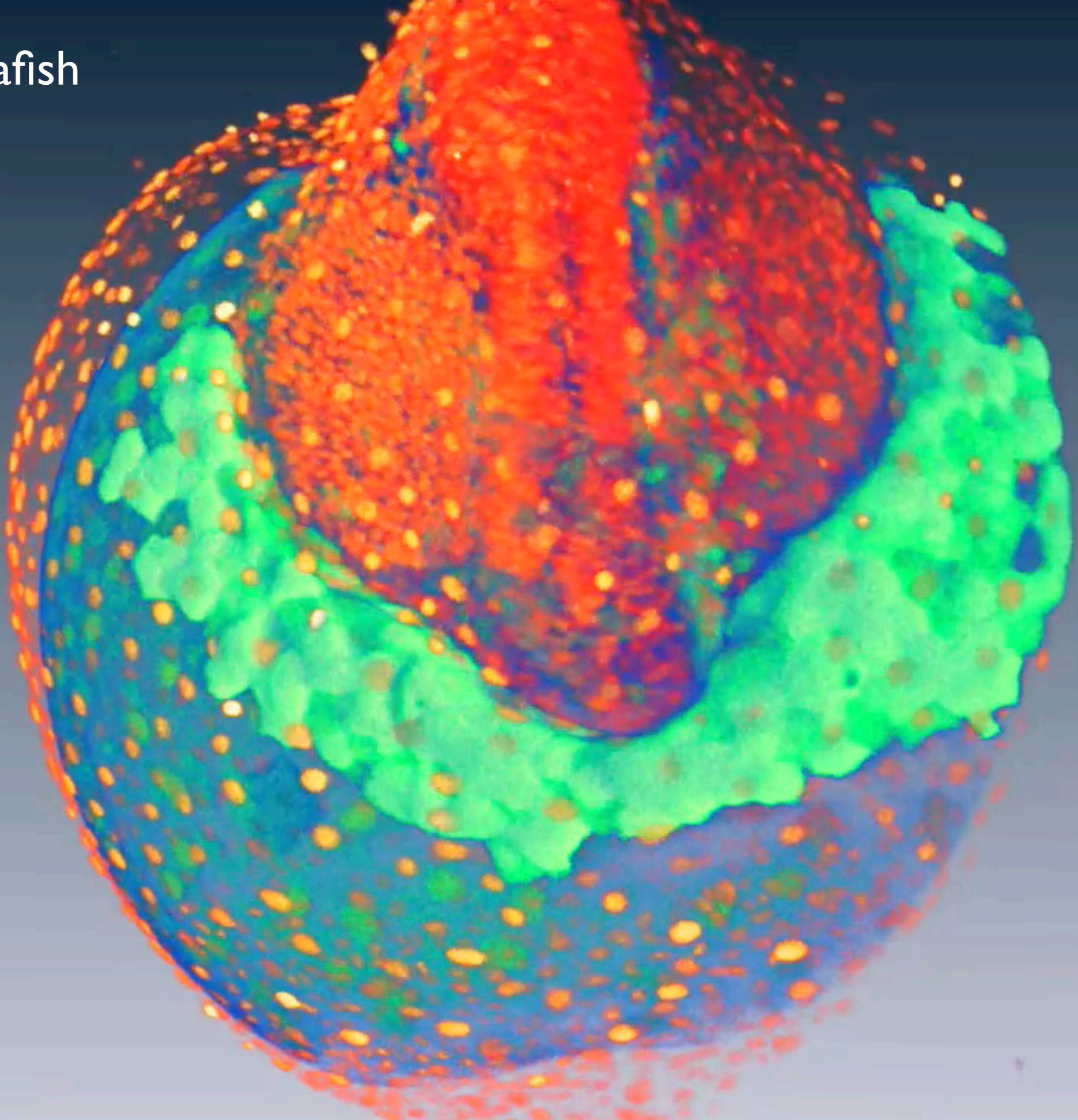


Zebrafish





Zebrafish





Zebrafish



Zebrafish

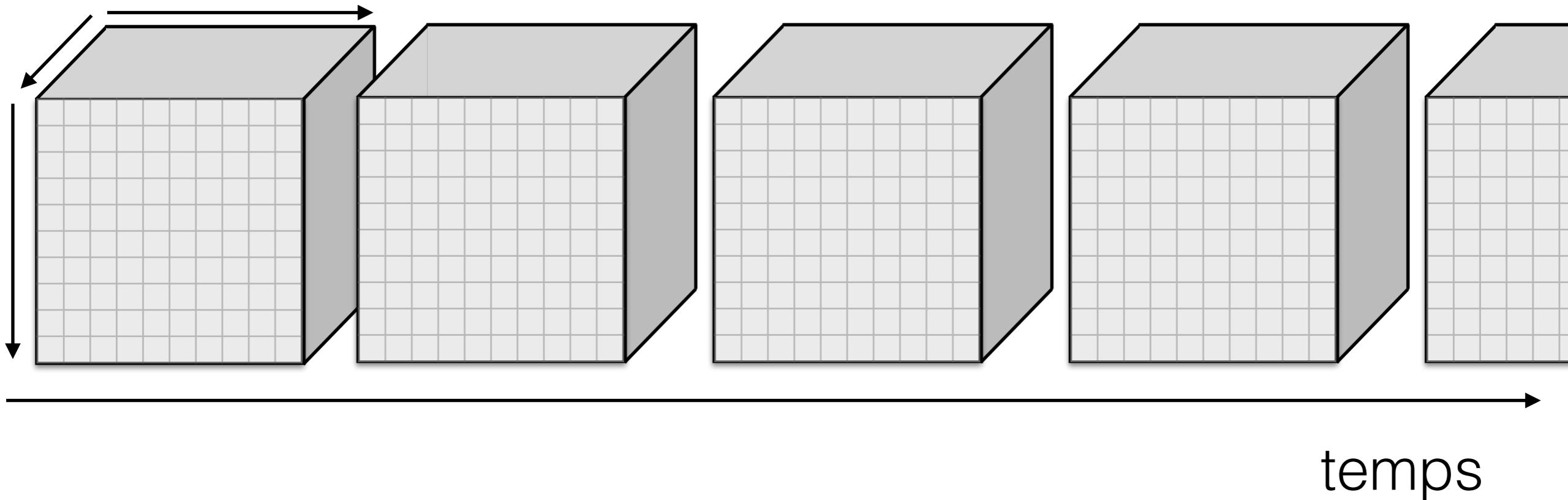
Taille Image 4D

Acquisition standard:

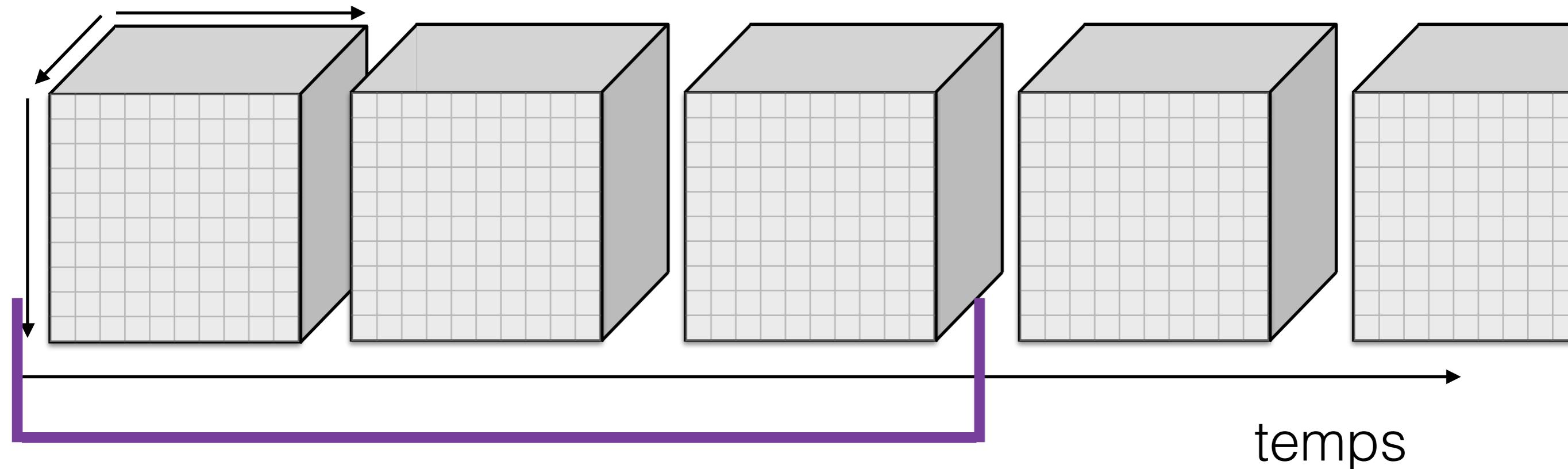
X * Y * Z * Temps * Canaux * Angle : 1000 * 1000 *
200 * 1000 * 2 * 4

- + de mille milliards de voxels / embryons
- plusieurs terabytes / embryons
- très bon taux de compression ~90%

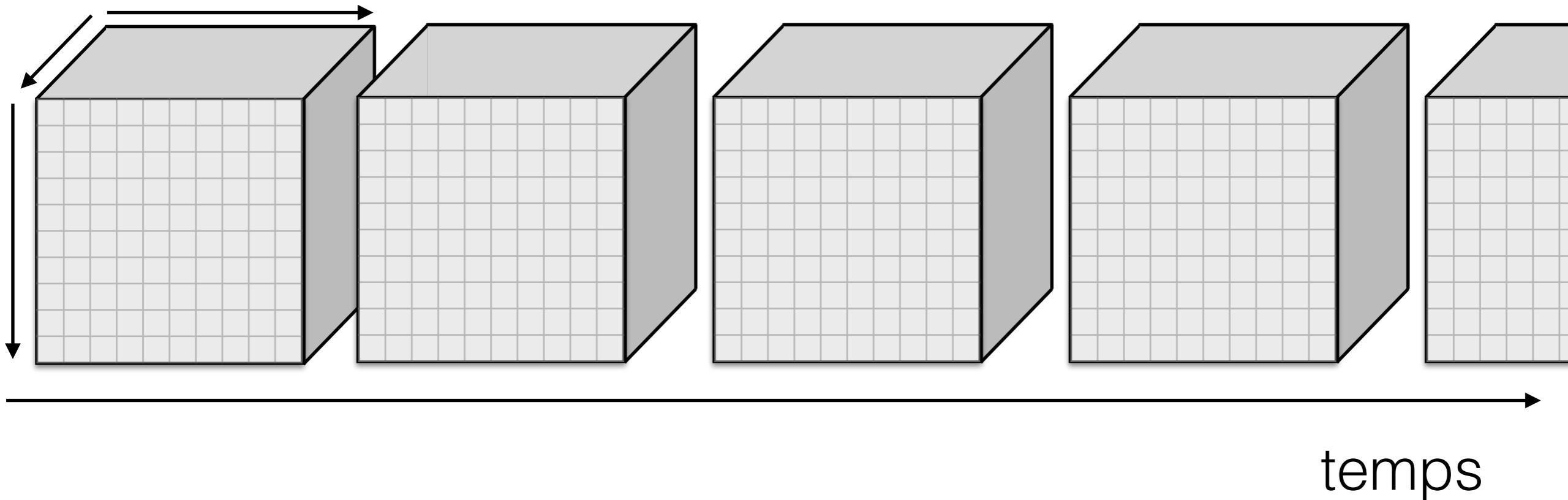
Comment parcourir les images 4D ?



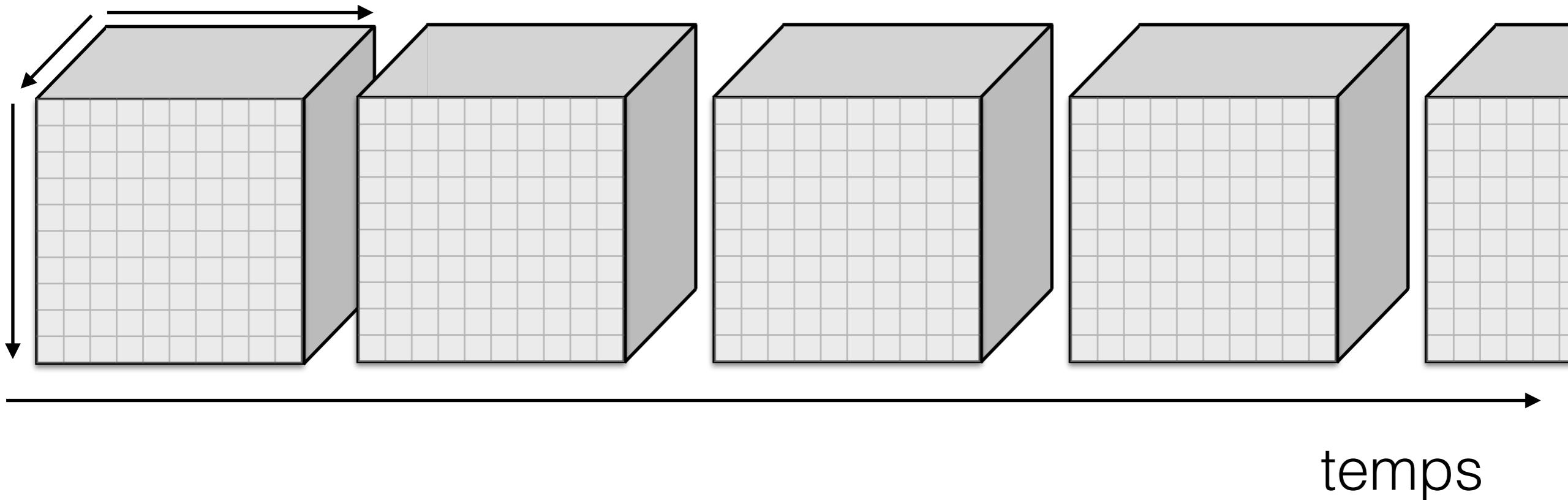
Comment parcourir les images 4D ?



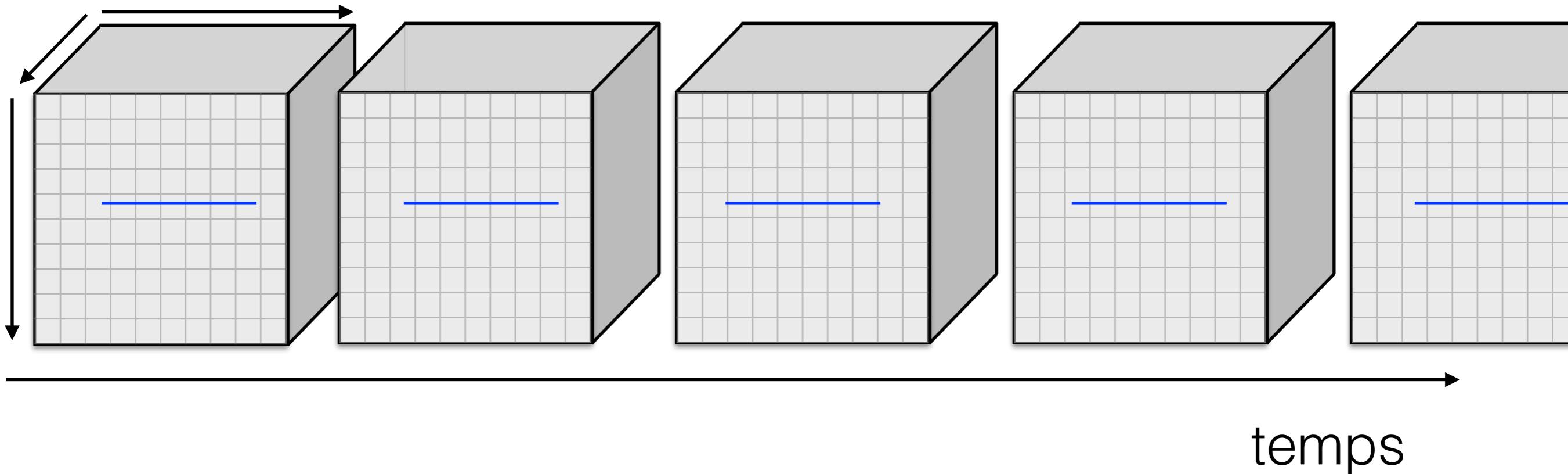
Comment parcourir les images 4D ?



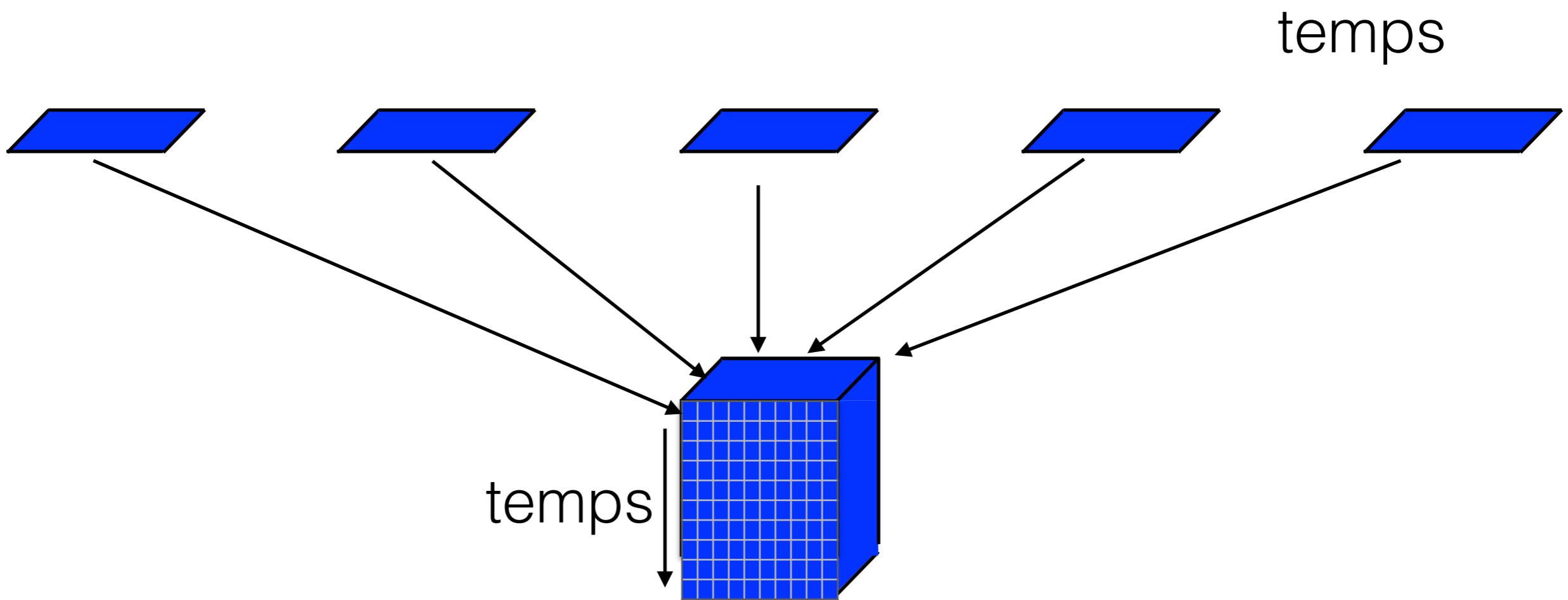
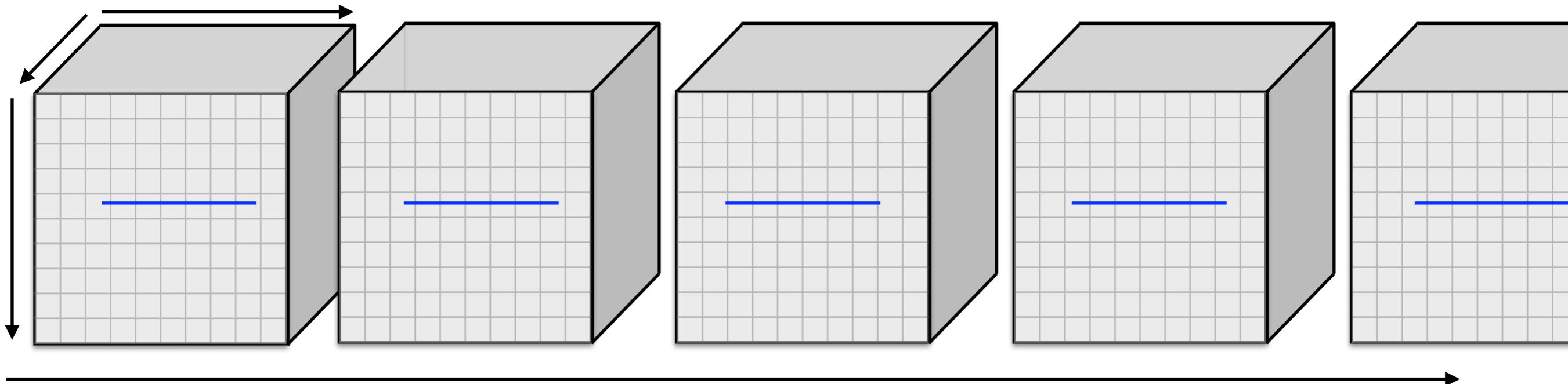
Comment parcourir les images 4D ?



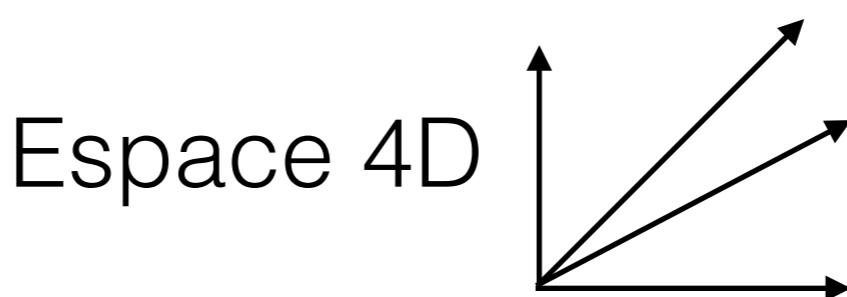
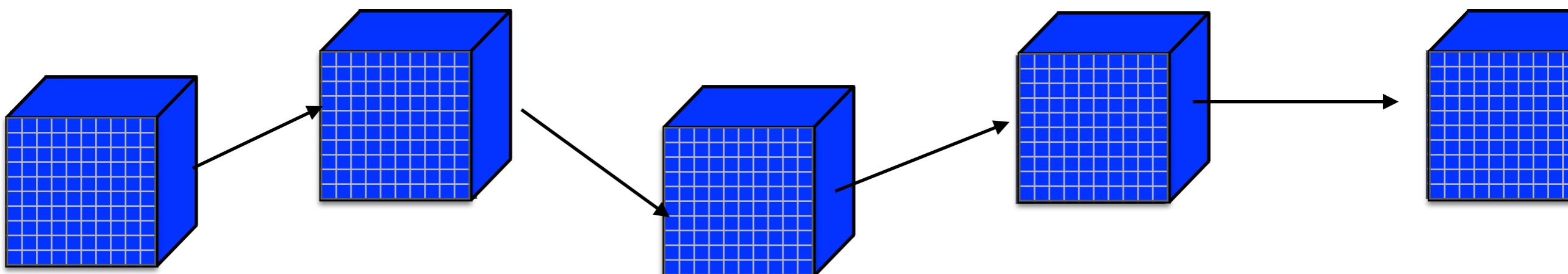
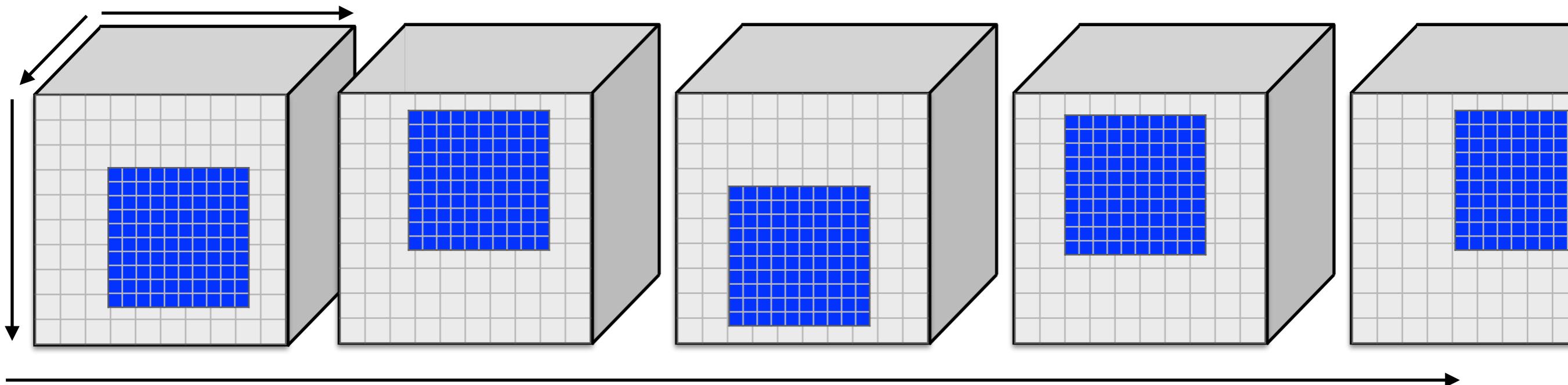
Comment parcourir les images 4D ?



Comment parcourir les images 4D ?

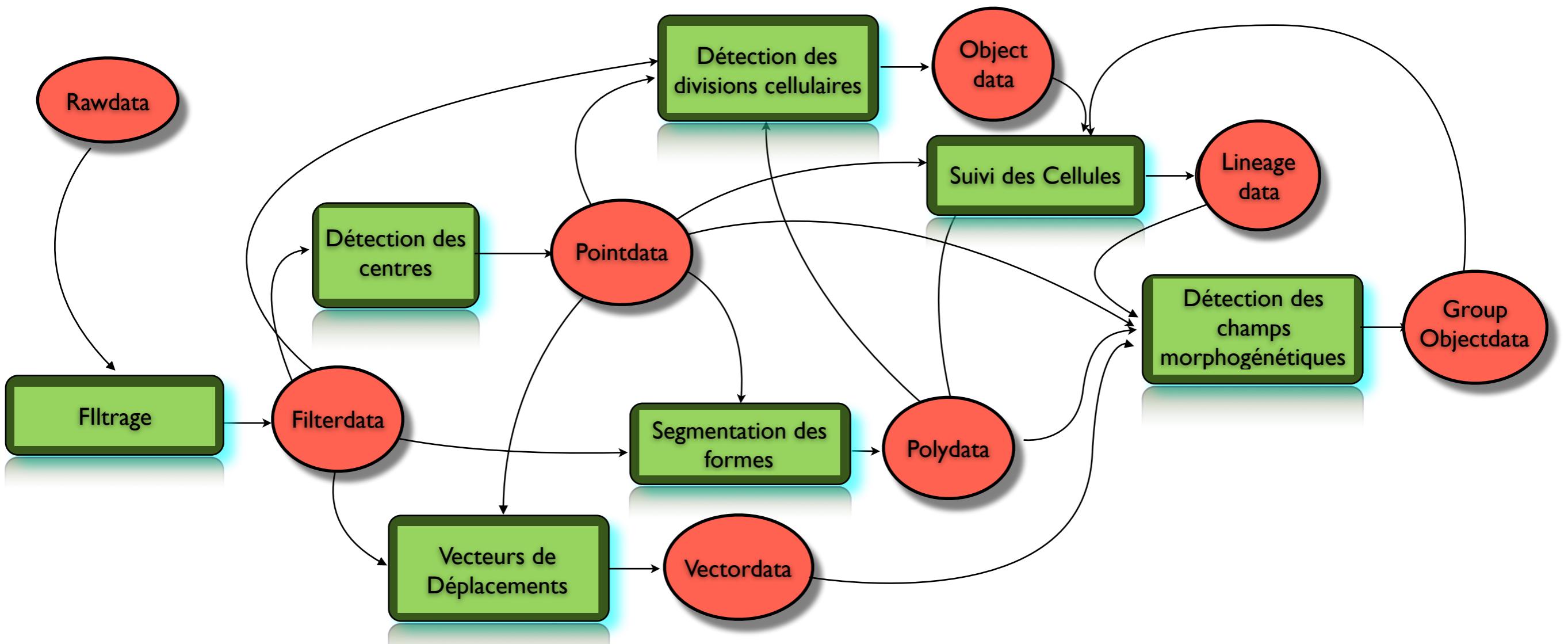


Comment parcourir les images 4D ?

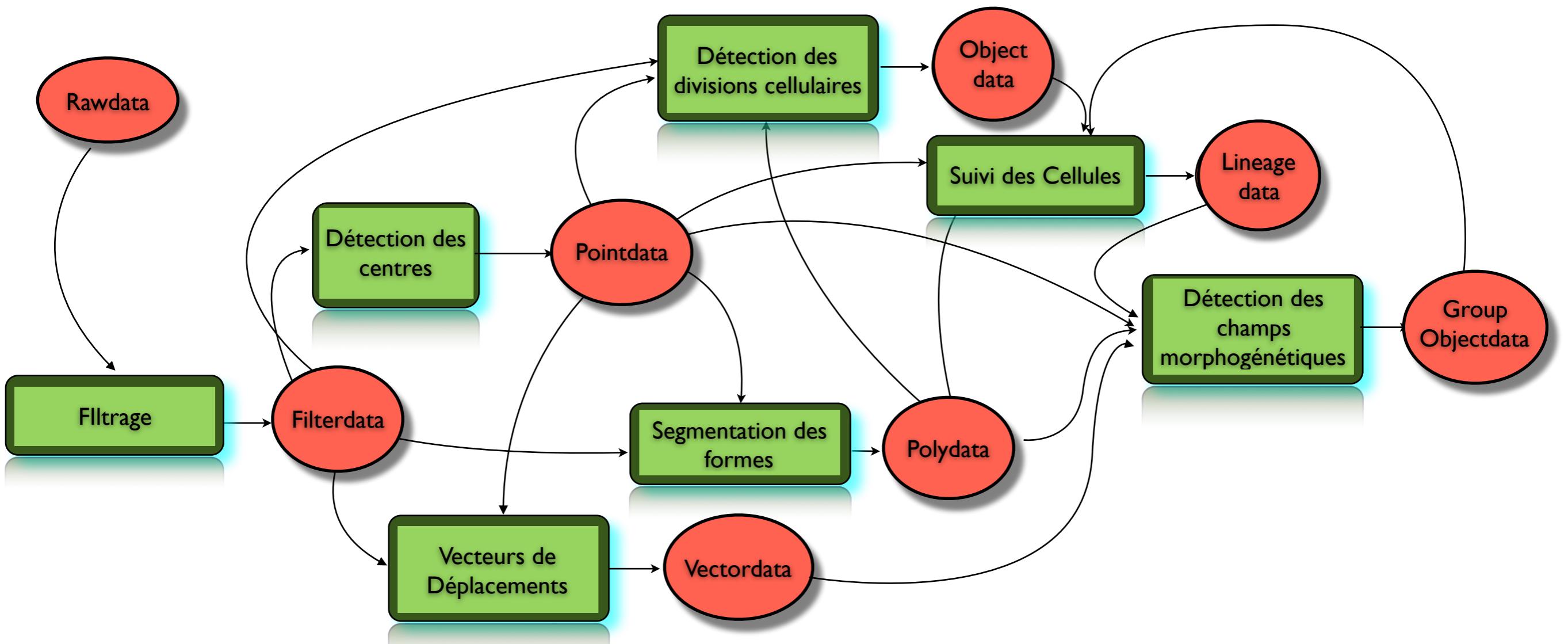


Reconstruction d'images 4D

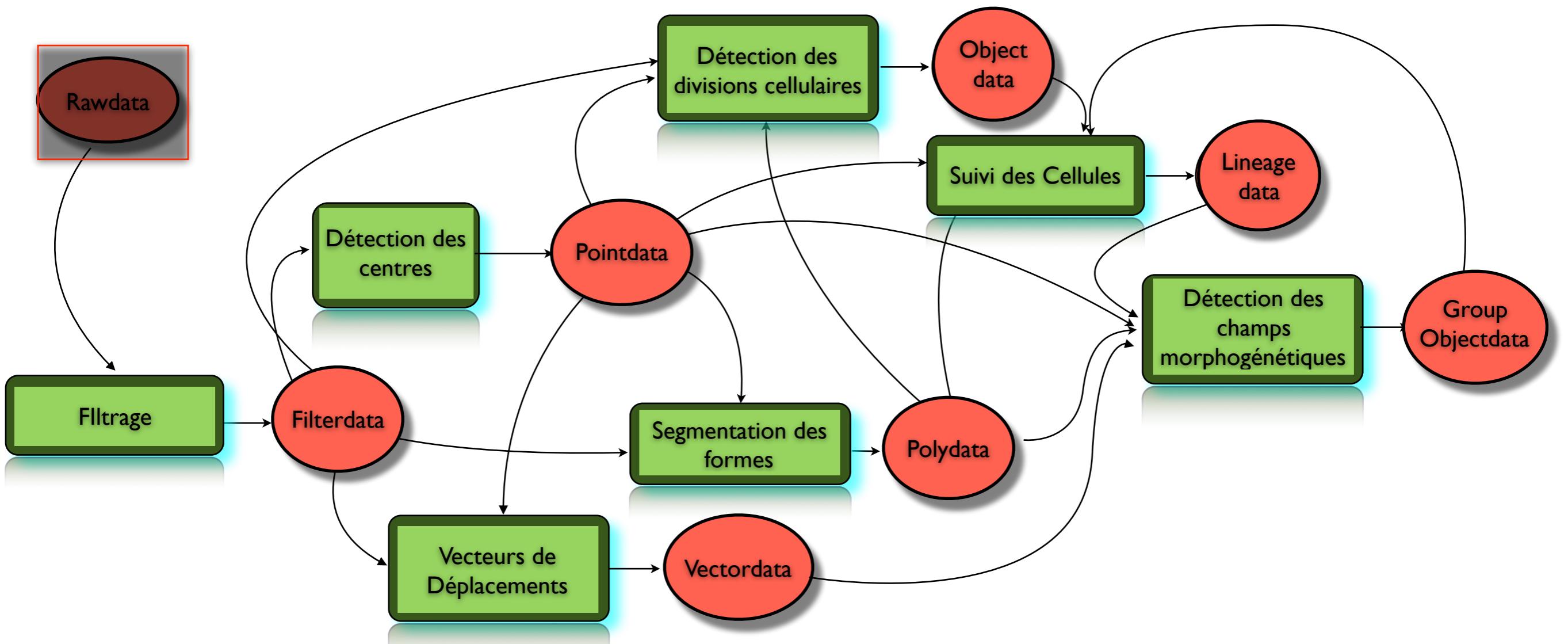
Reconstruction Image 4D



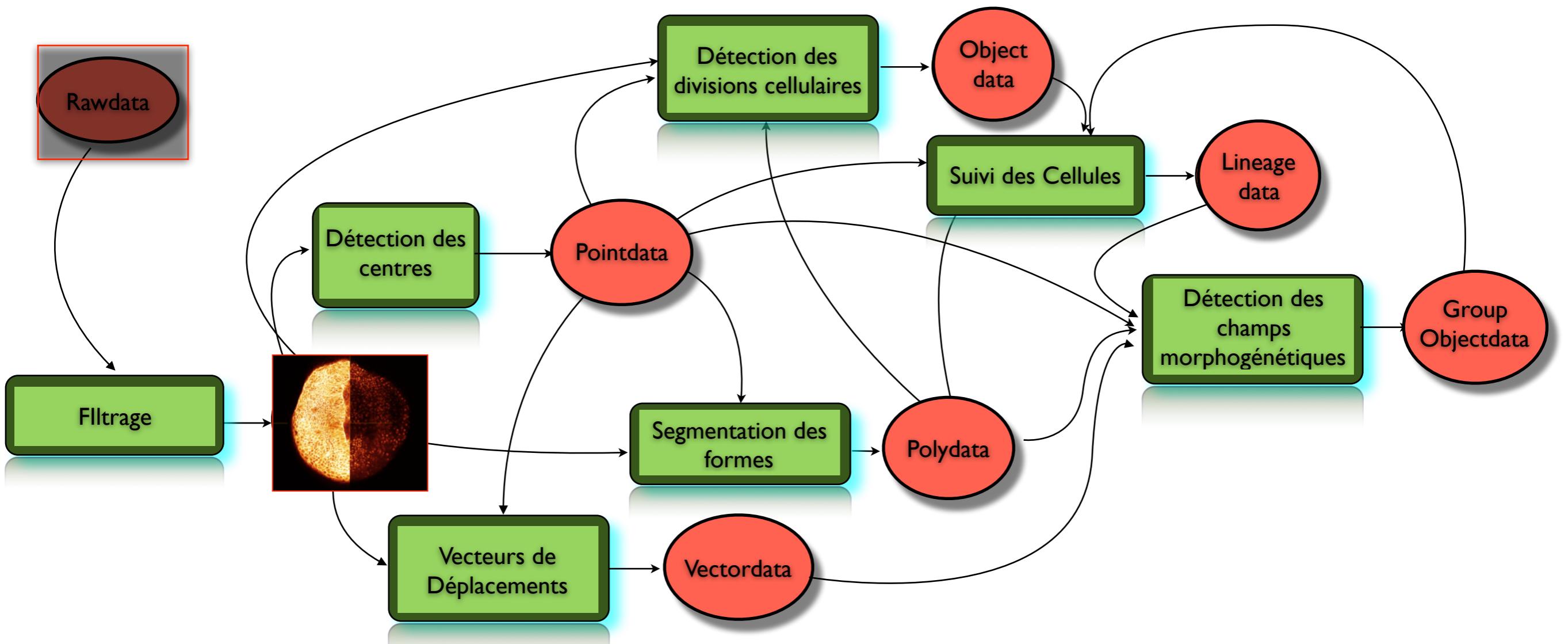
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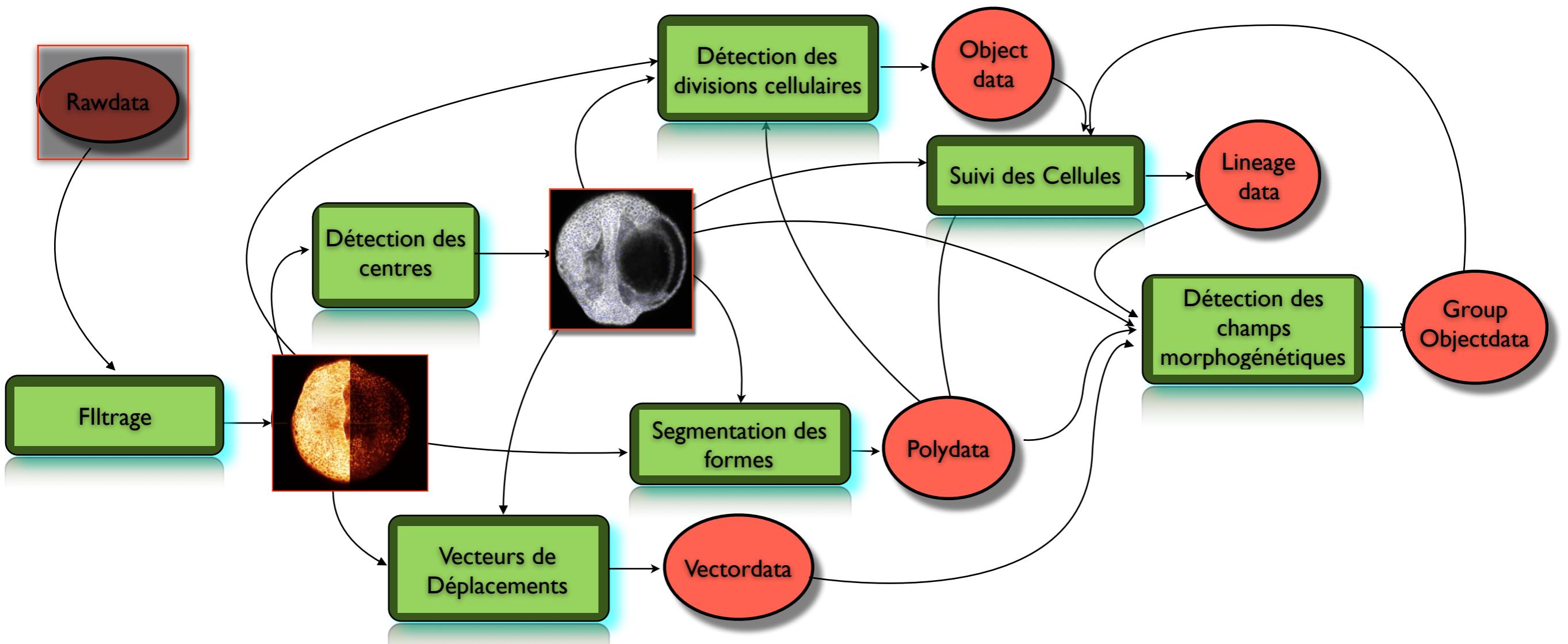
Reconstruction Image 4D



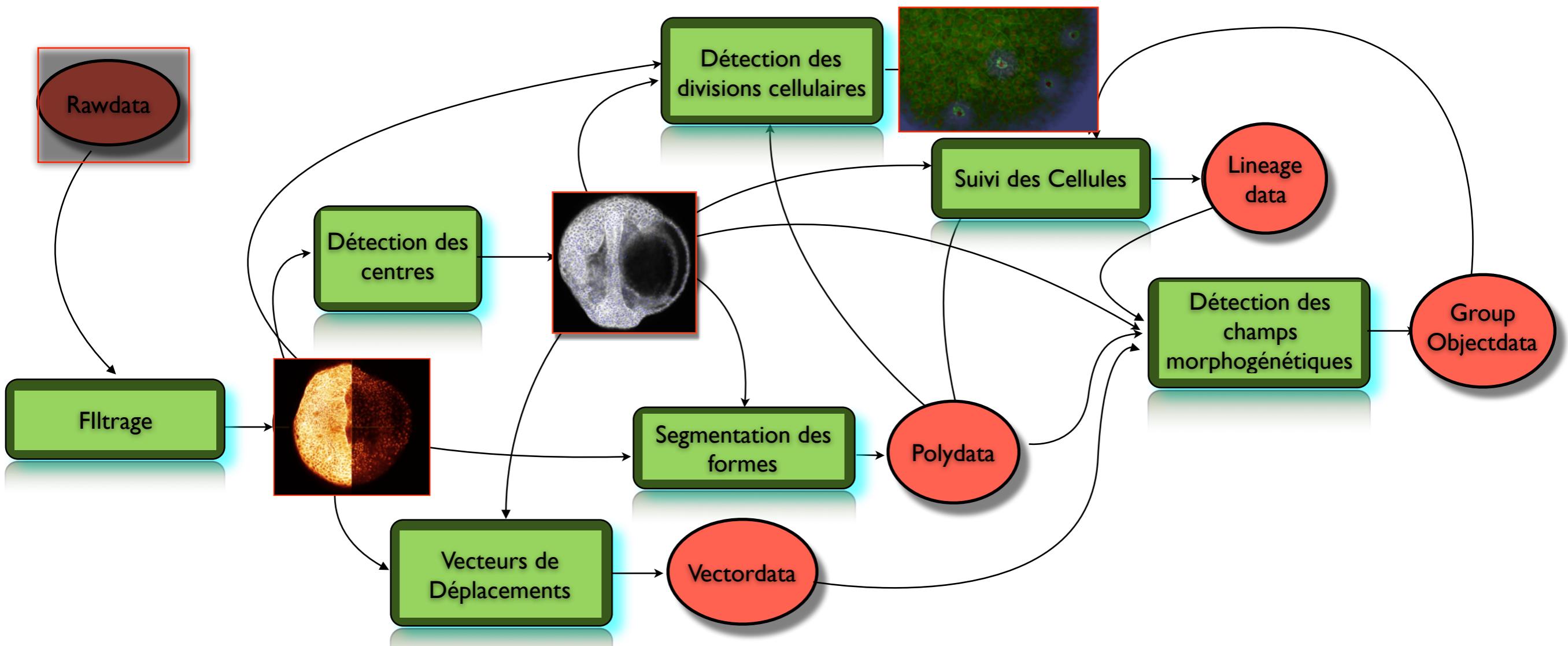
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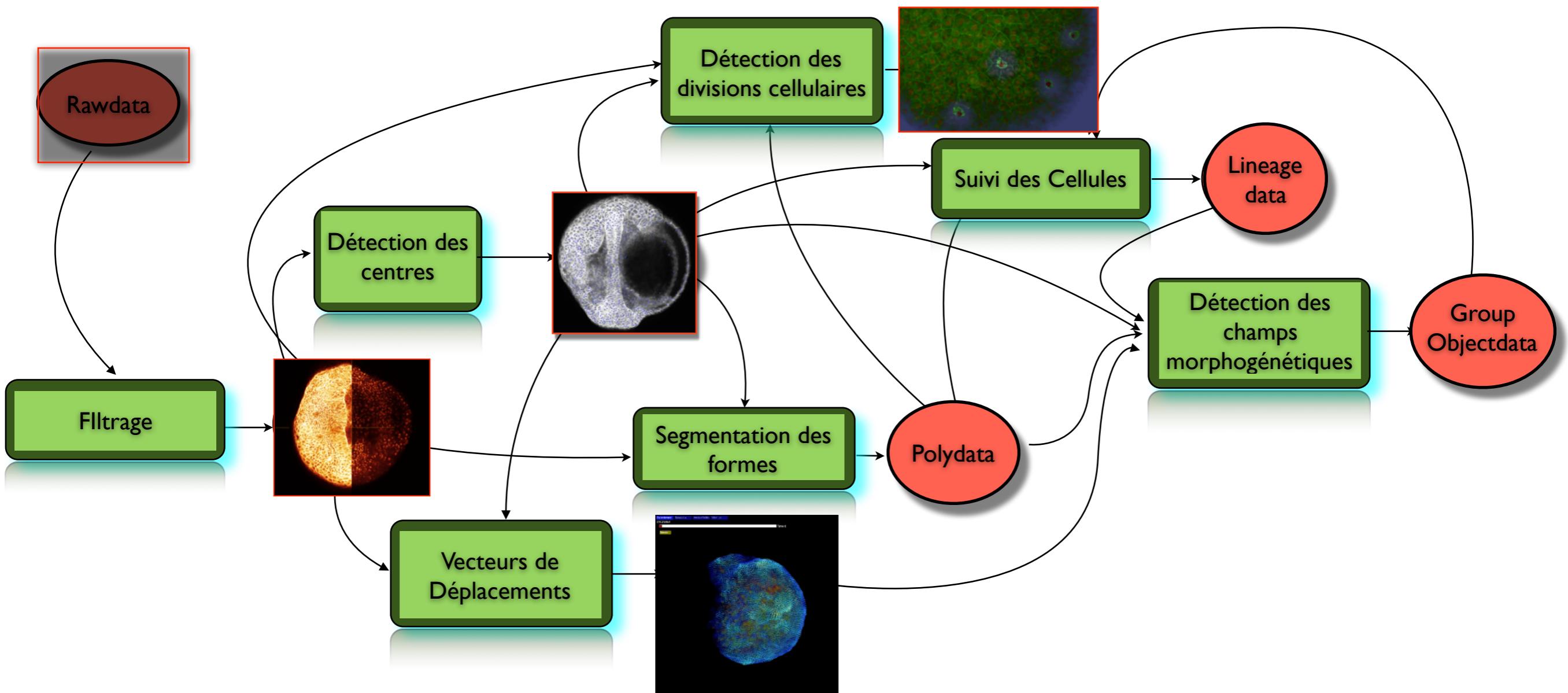
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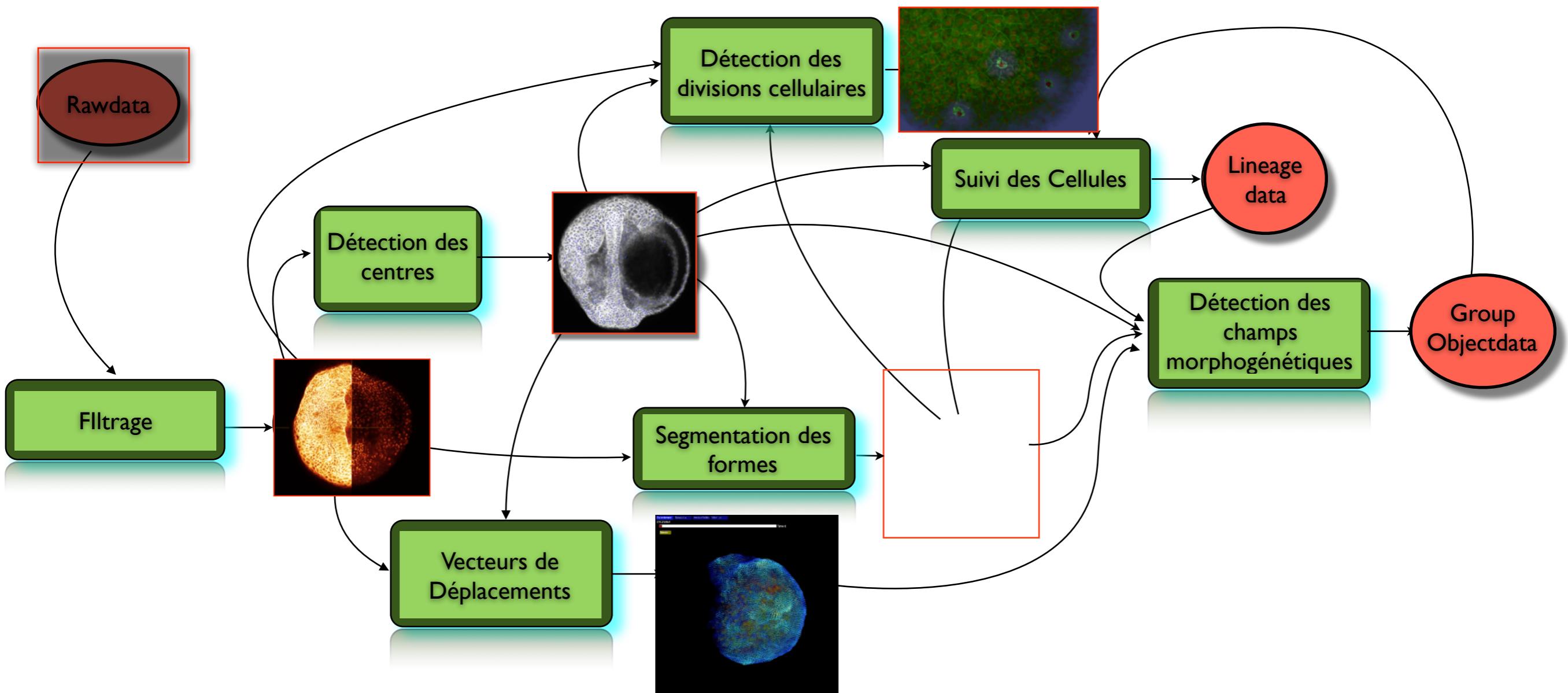
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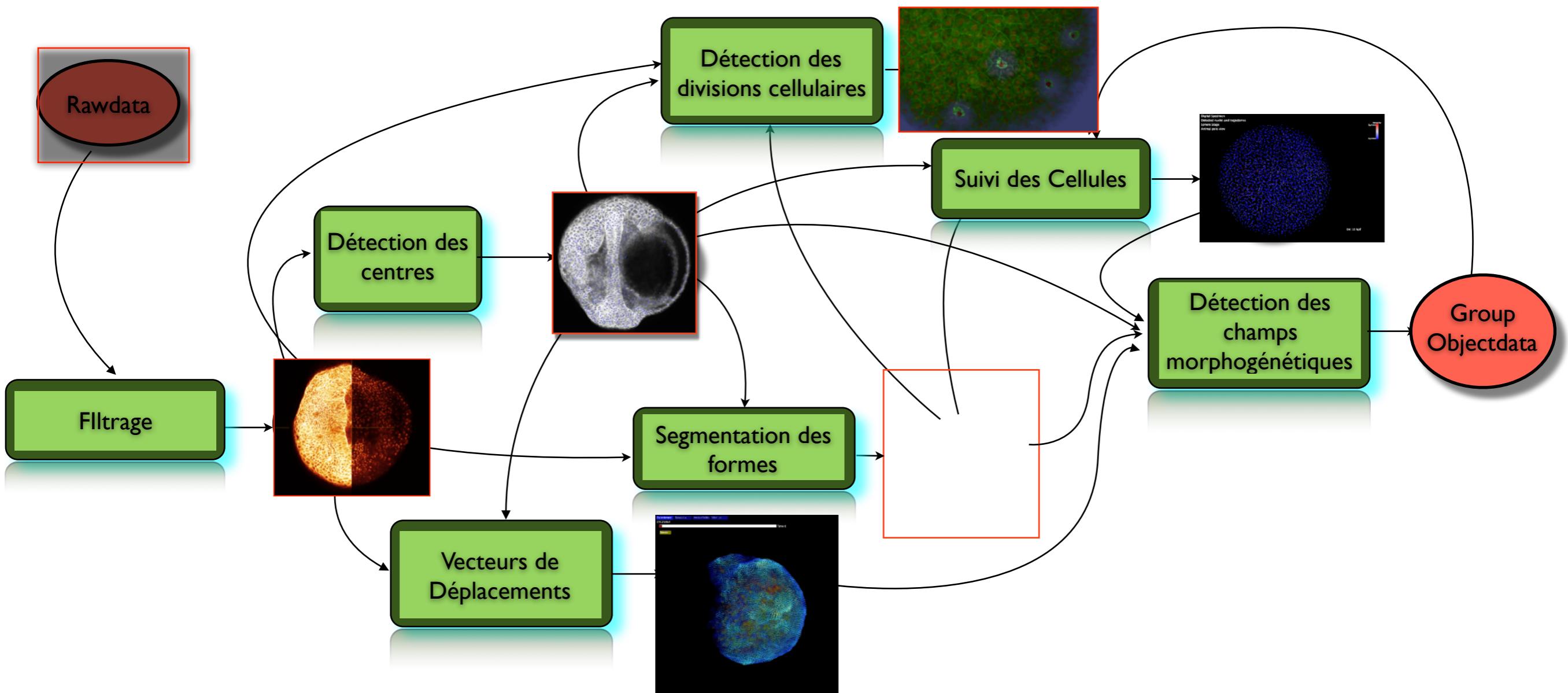
Reconstruction Image 4D



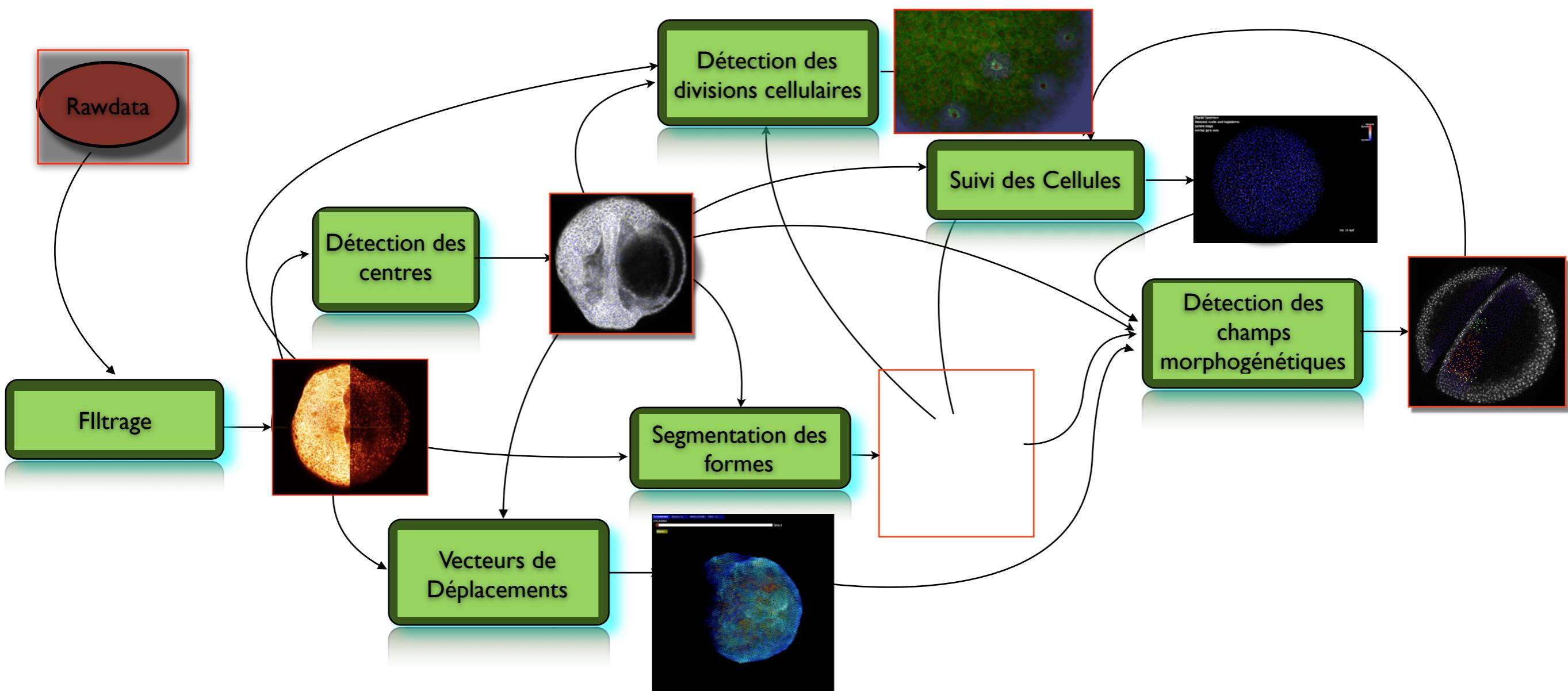
Reconstruction Image 4D



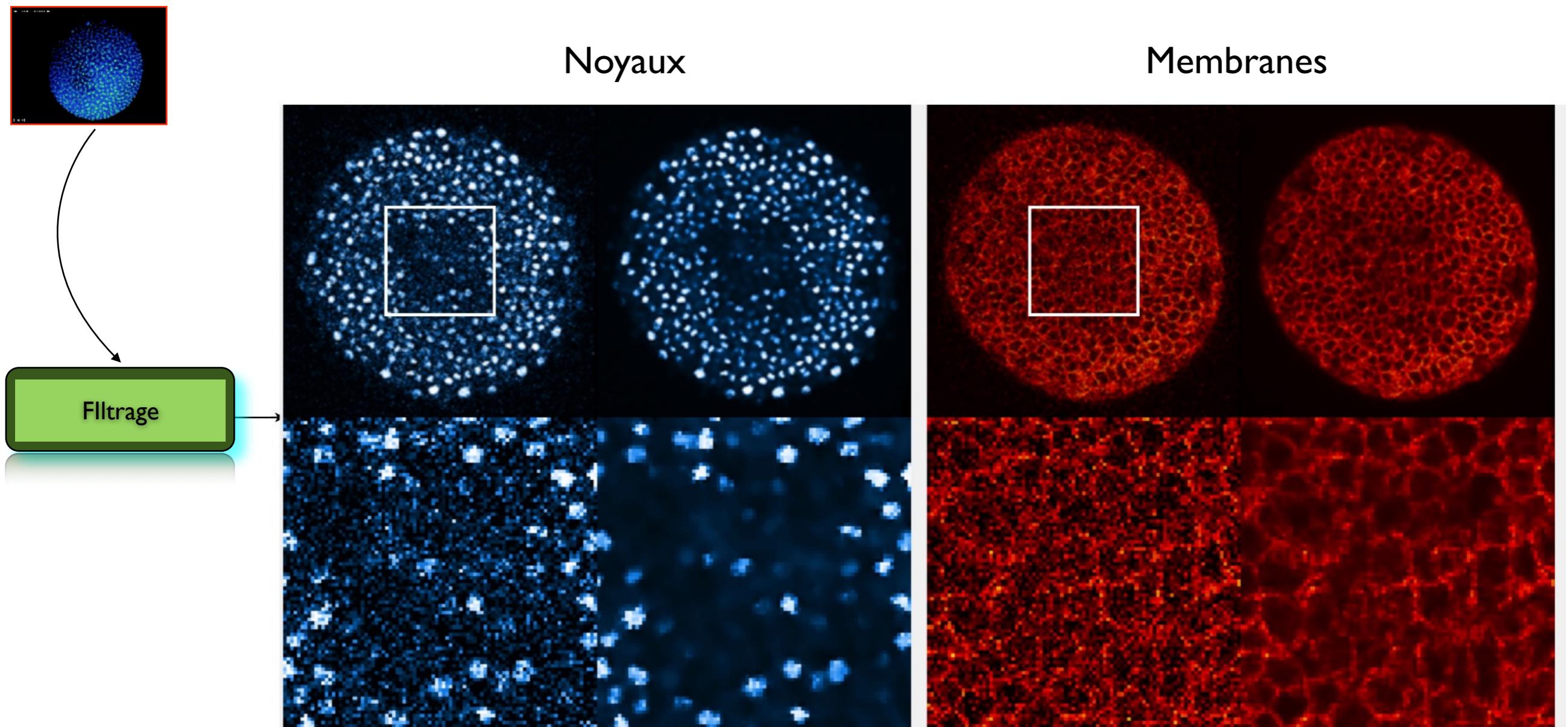
Reconstruction Image 4D



Reconstruction Image 4D

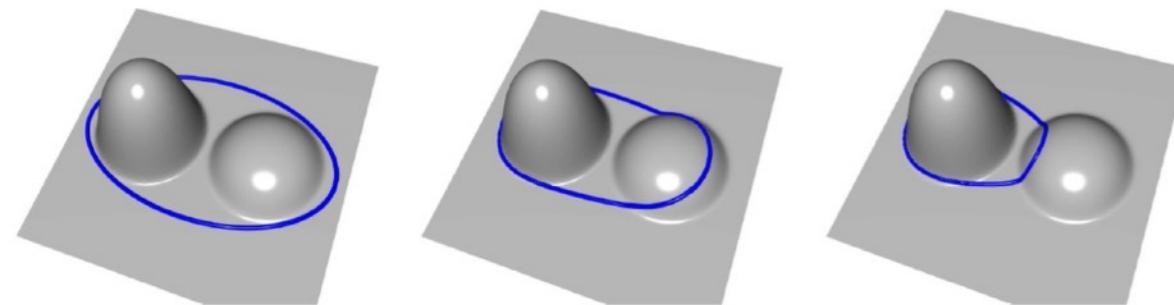


Filtres non linéaire



Intégrité des contours : on souhaiterait éliminer le bruit sans rendre flous les frontières des objets.

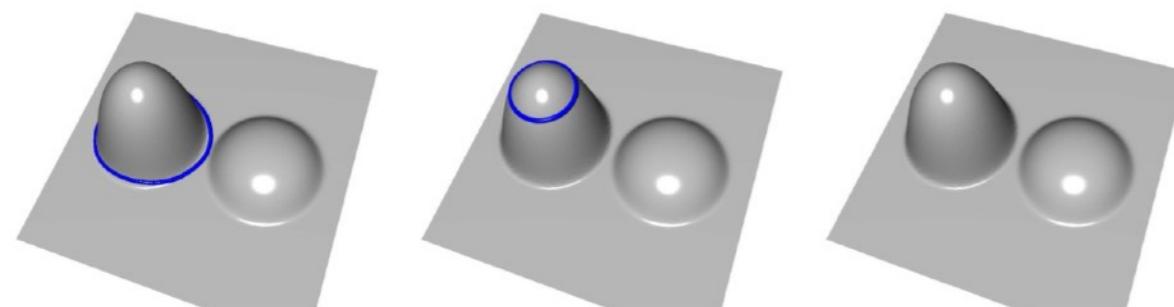
Geodesic Mean curvature Flow



(a)

(b)

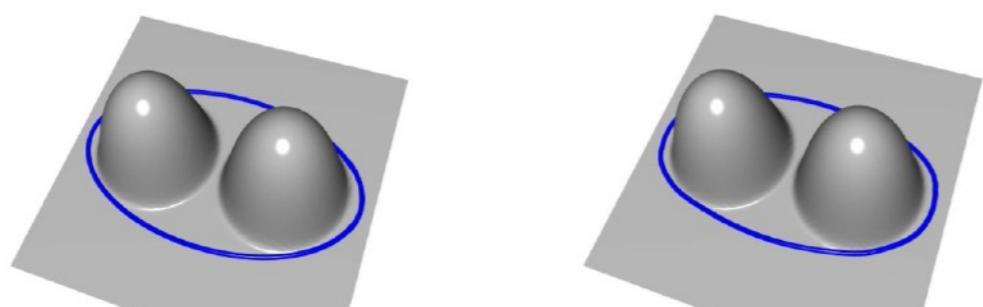
(c)



(d)

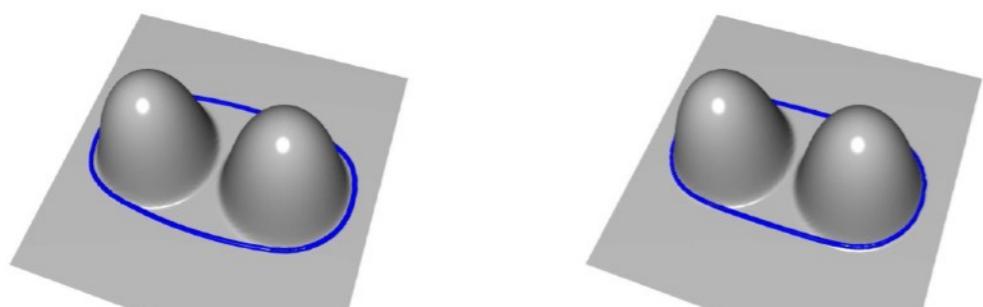
(e)

(f)



(a)

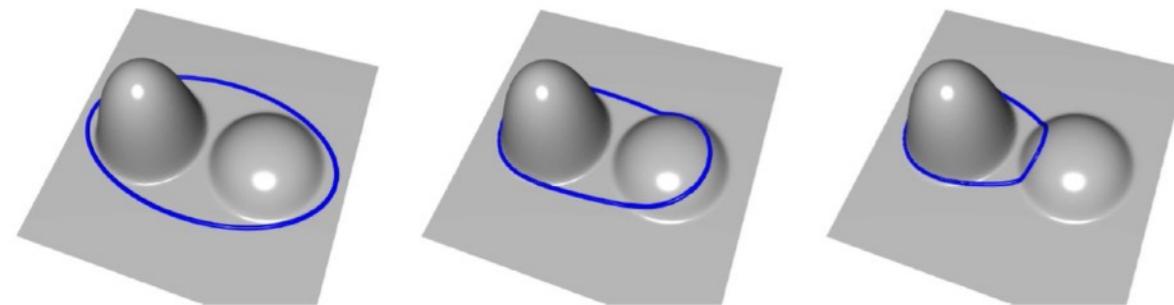
(b)



(c)

(d)

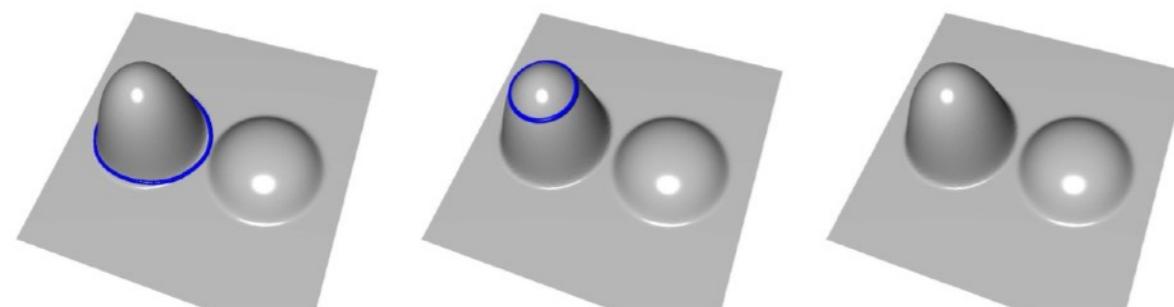
Geodesic Mean curvature Flow



(a)

(b)

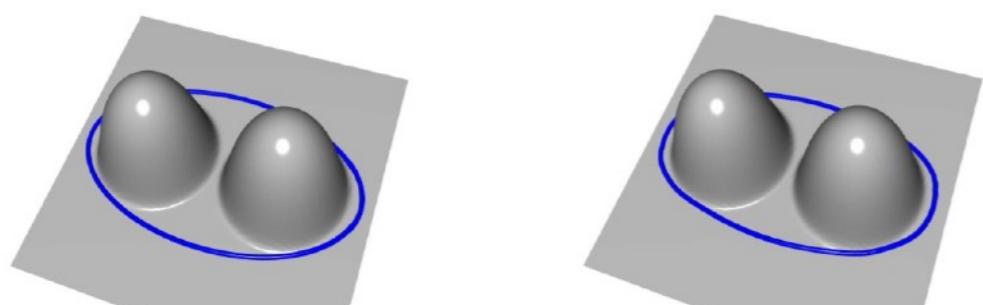
(c)



(d)

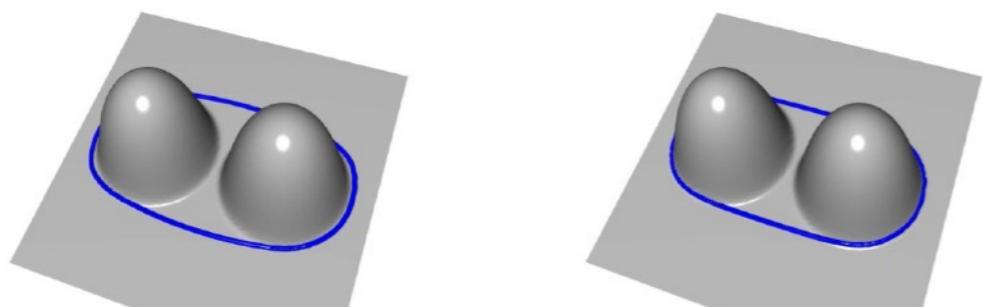
(e)

(f)



(a)

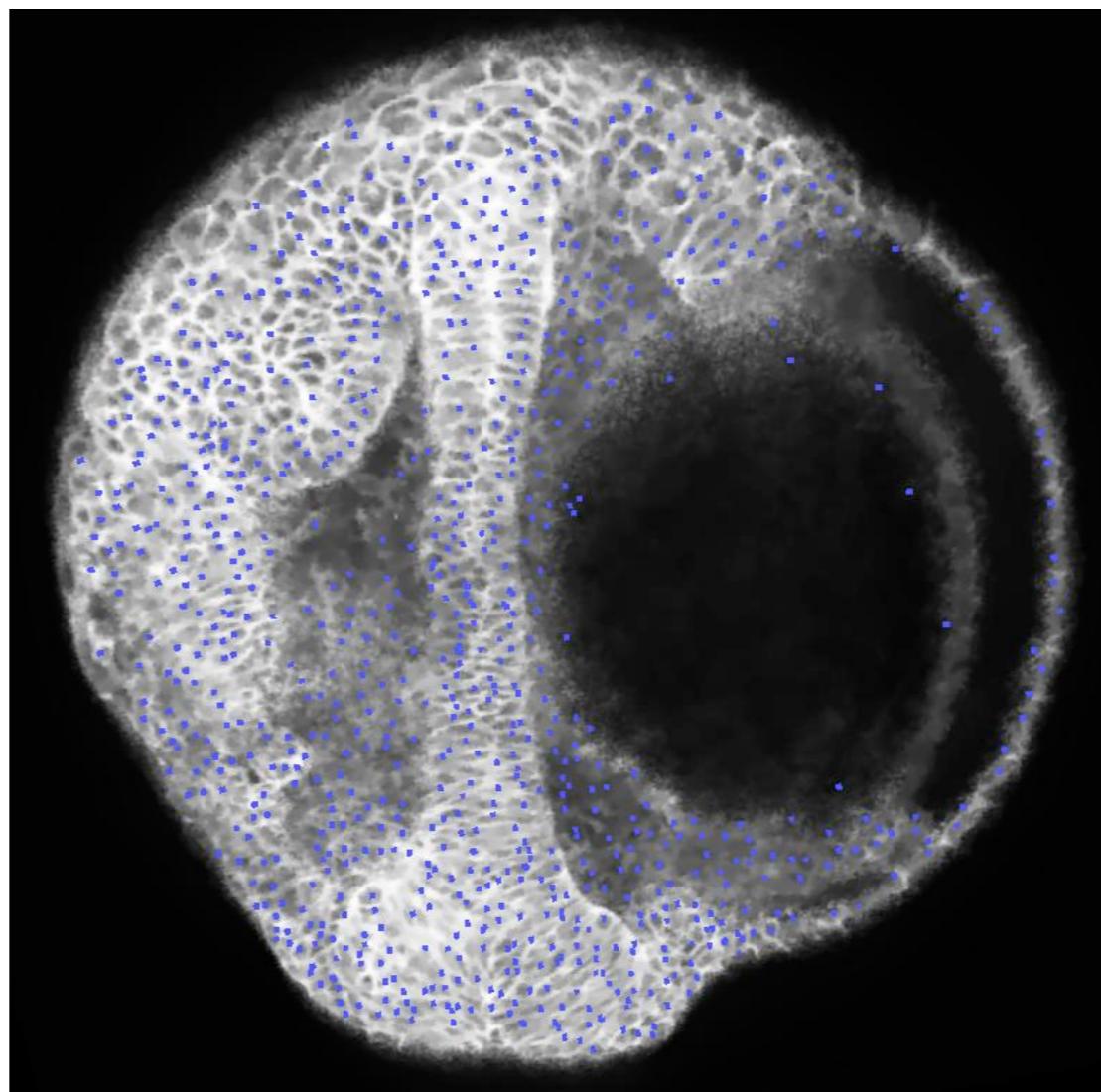
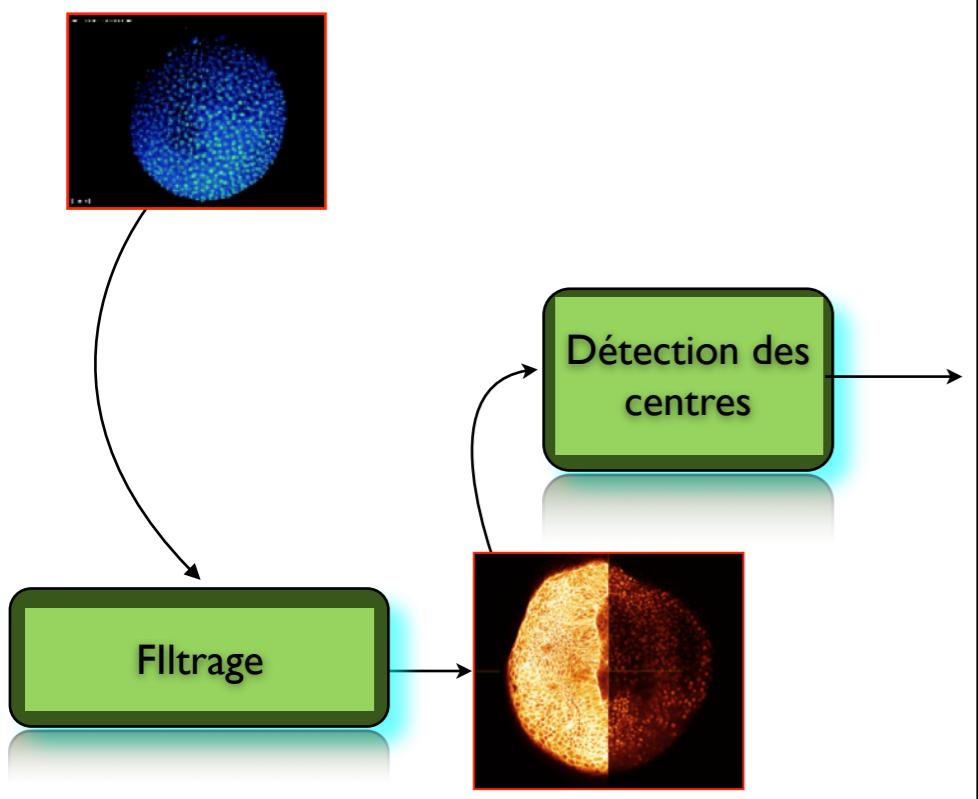
(b)



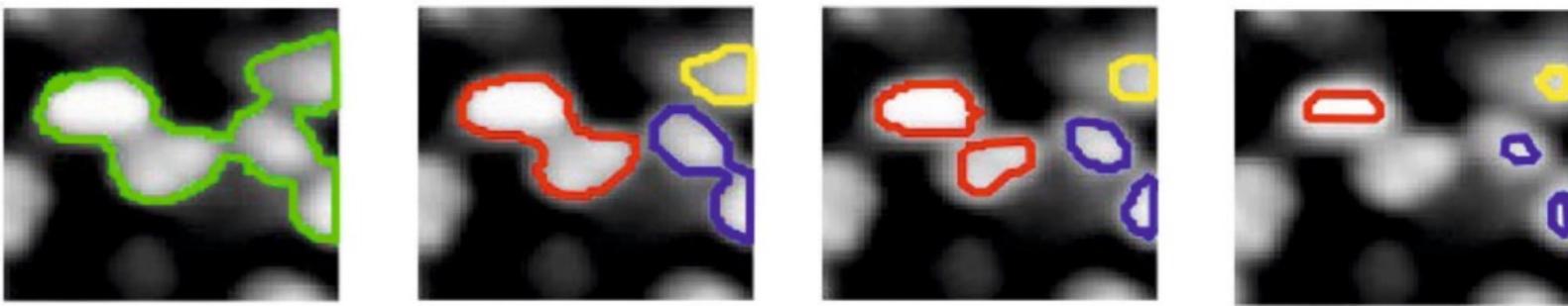
(c)

(d)

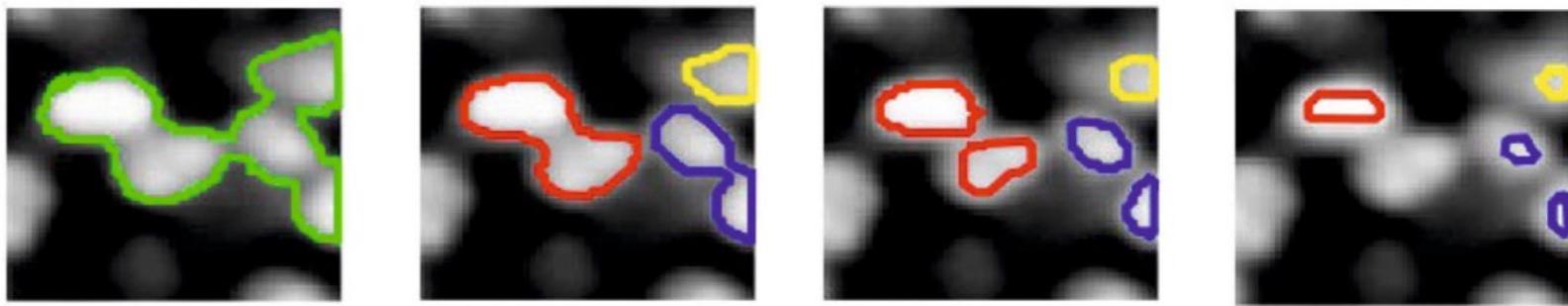
Identification des cellules



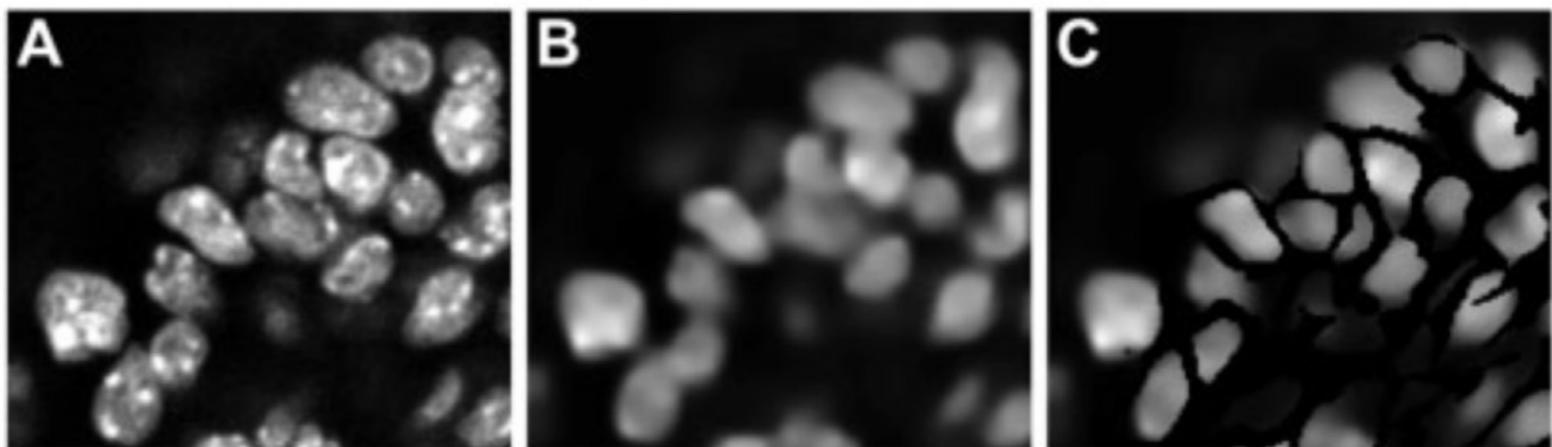
Morphologie Mathématique



Morphologie Mathématique

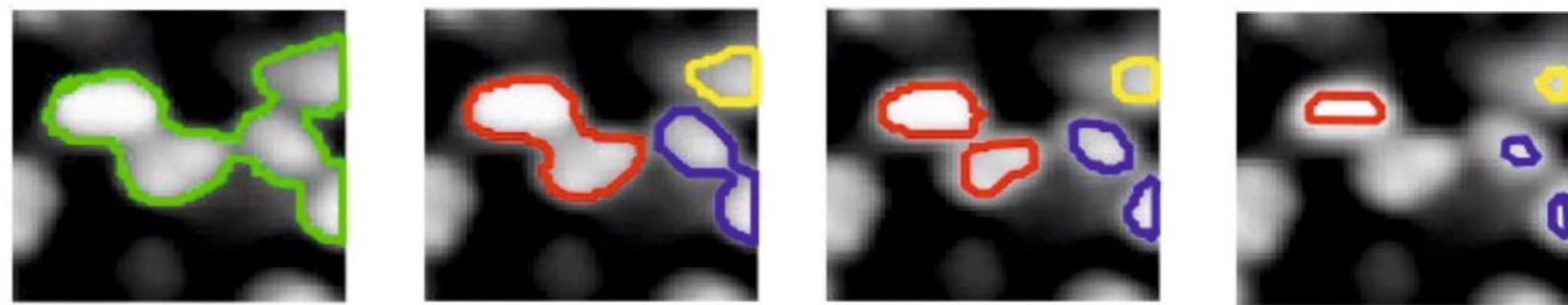


Soustraction de l'image
des membranes

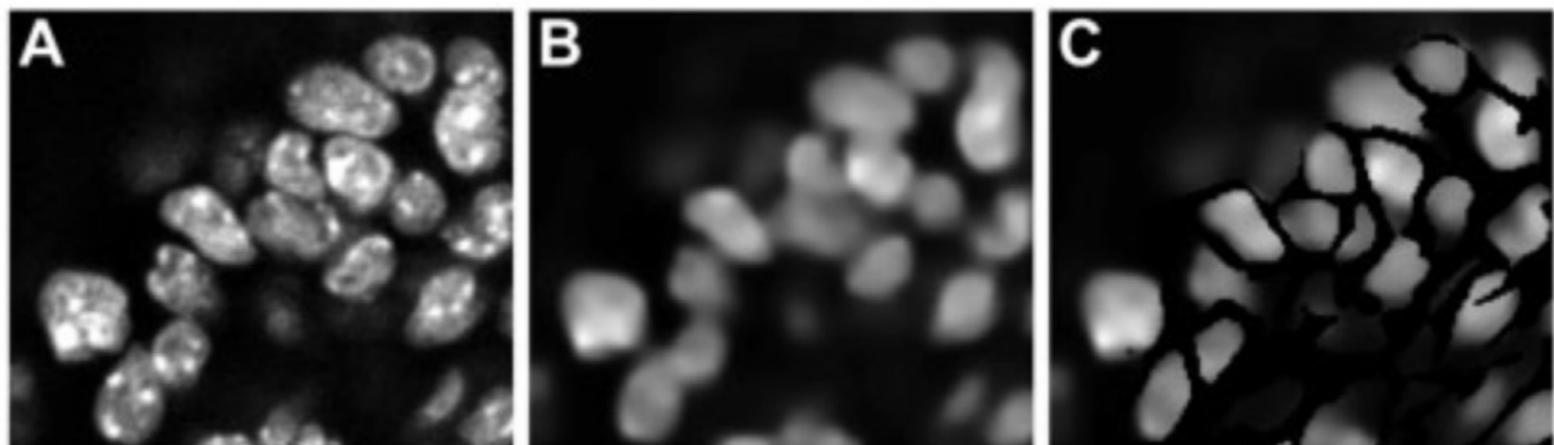


Pop 2013

Morphologie Mathématique

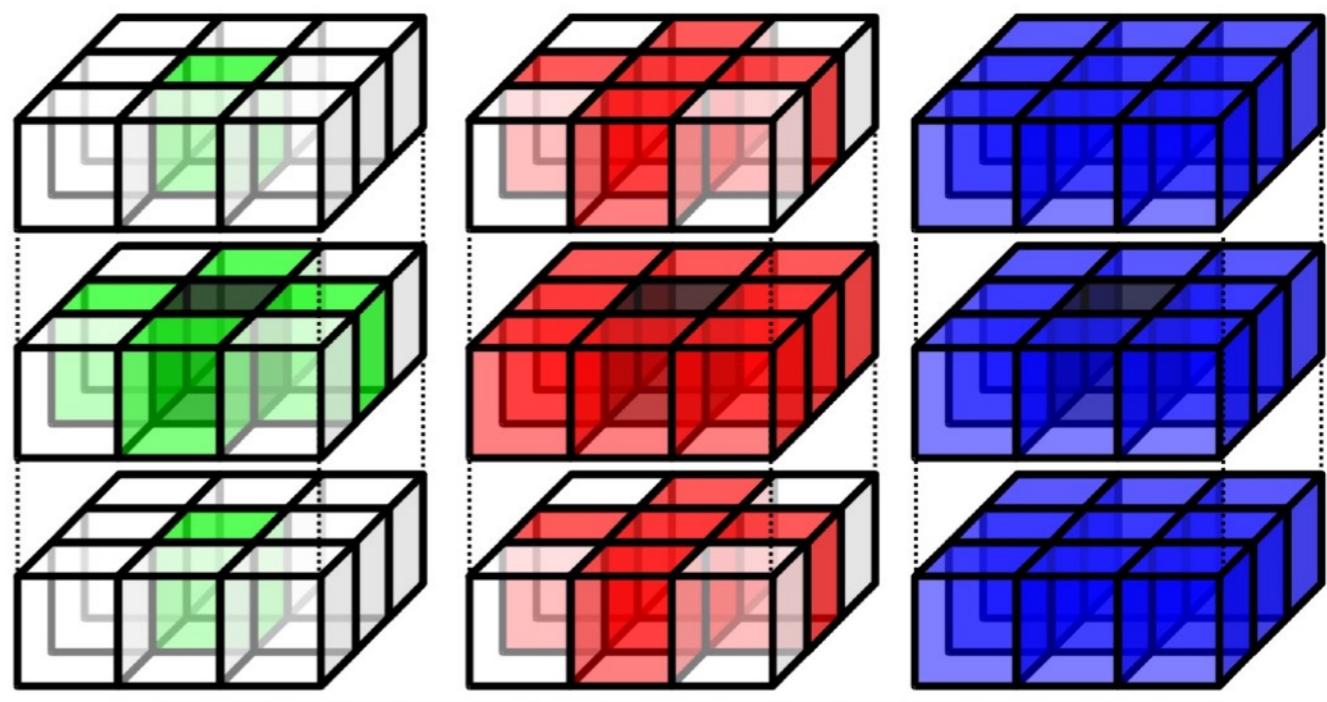


Soustraction de l'image des membranes



Pop 2013

Labels par composantes connexes

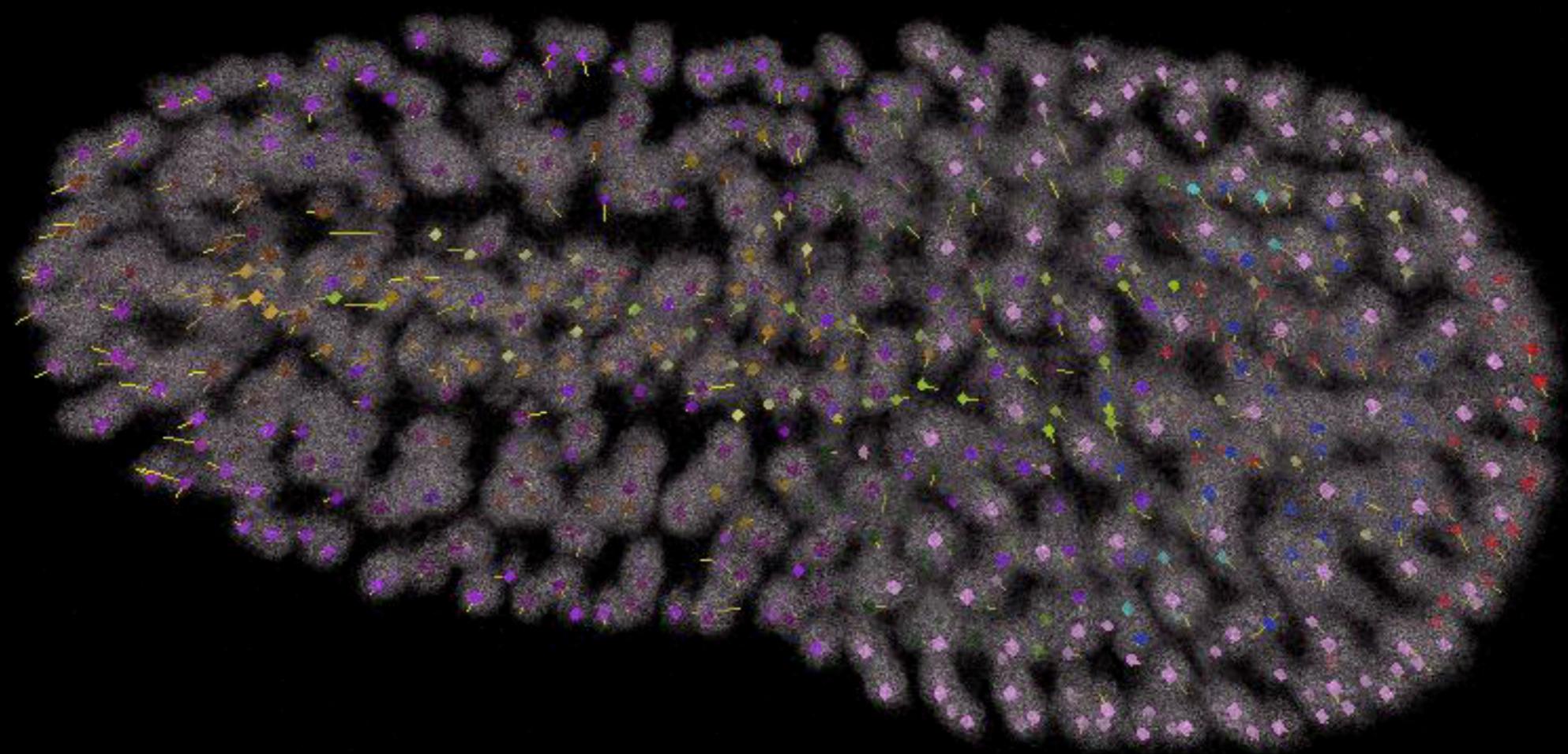


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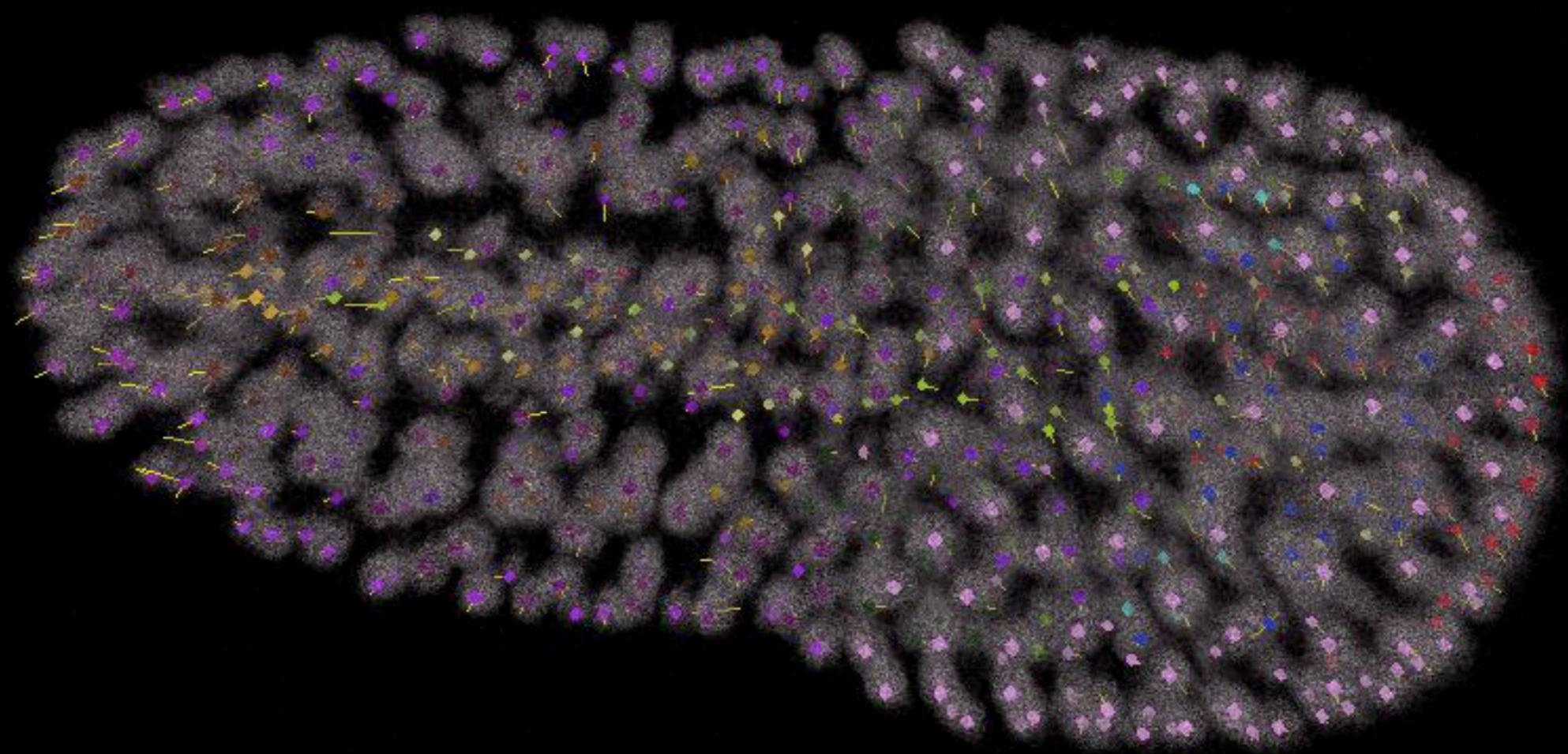
18

26

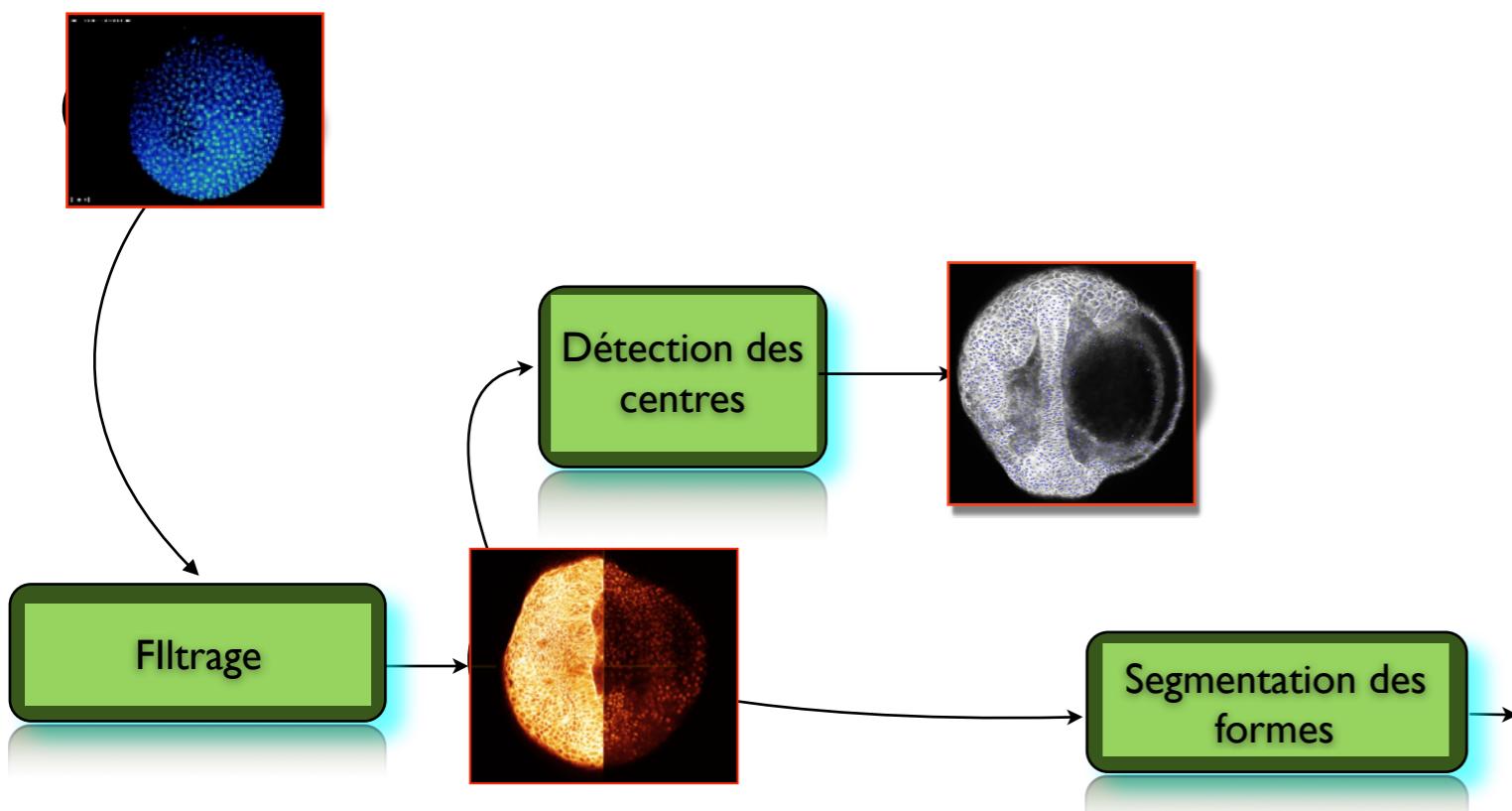
time 62



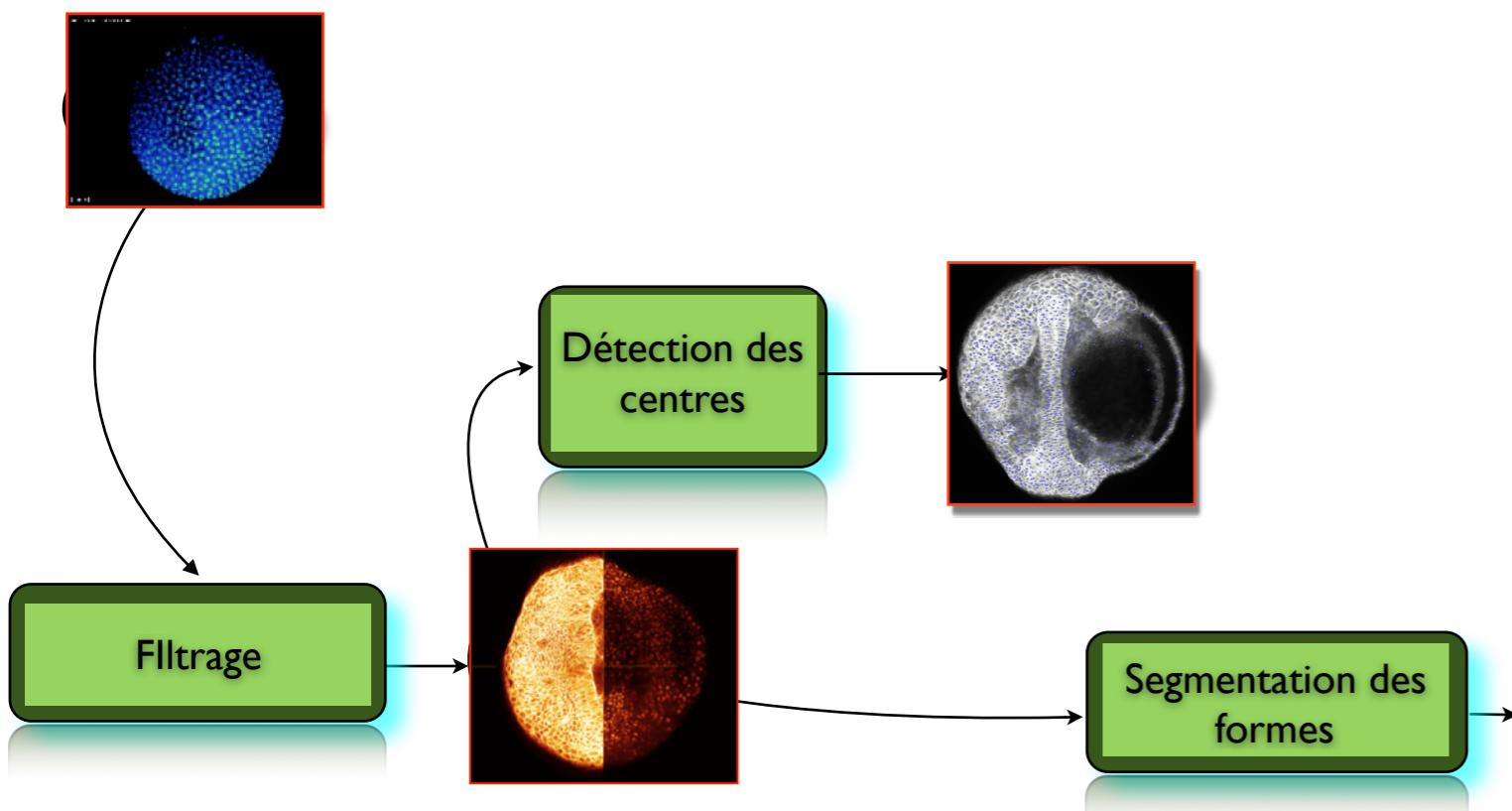
time 62



Segmentation 3D

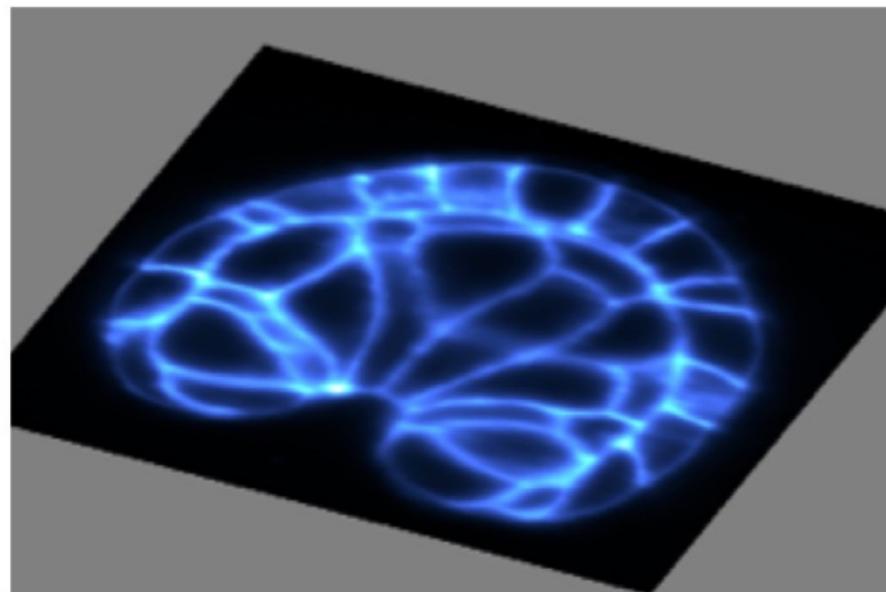


Segmentation 3D

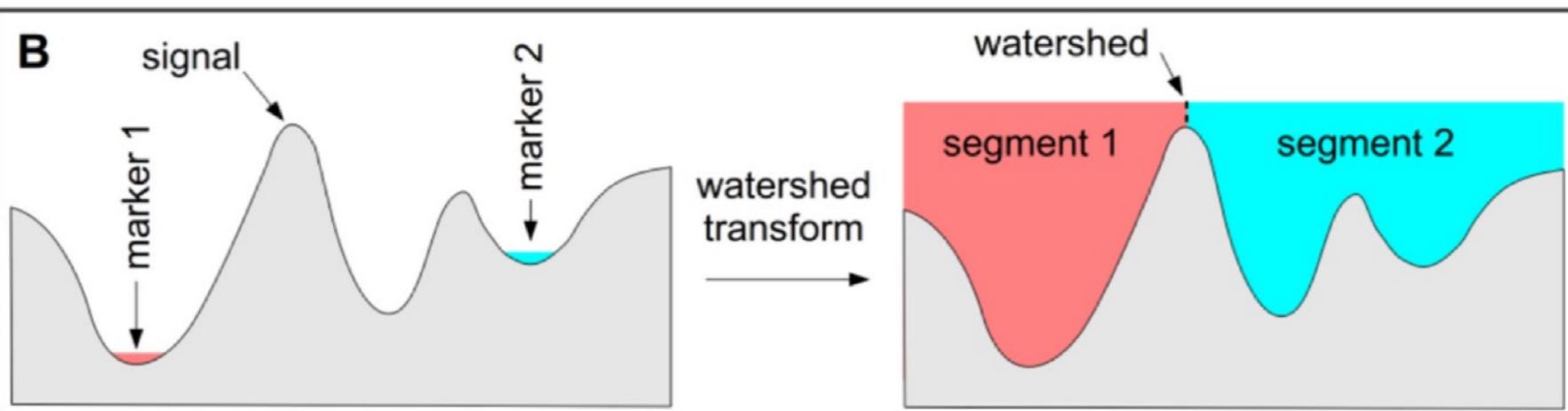
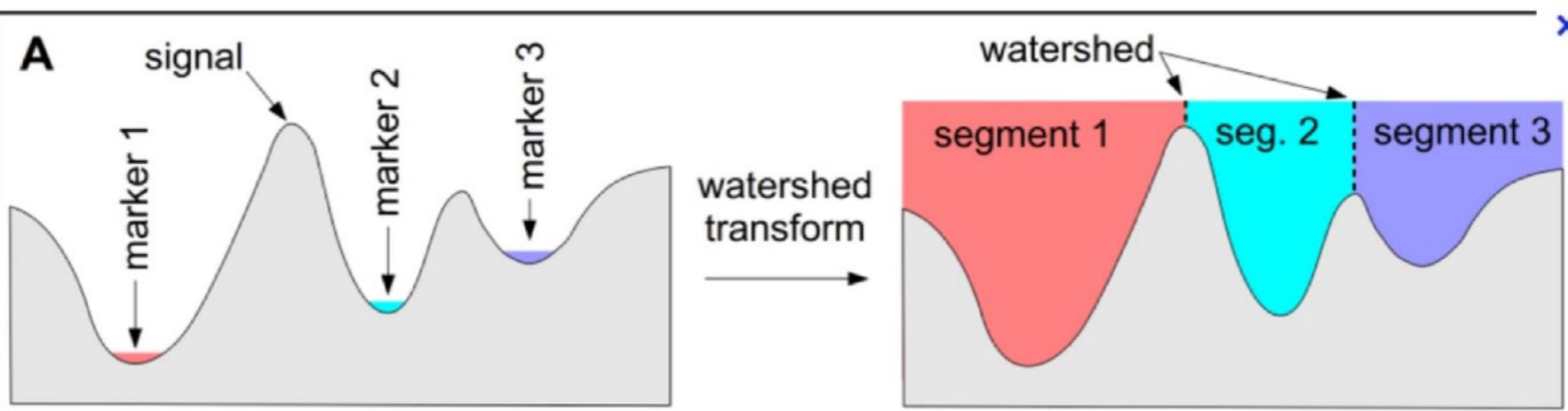
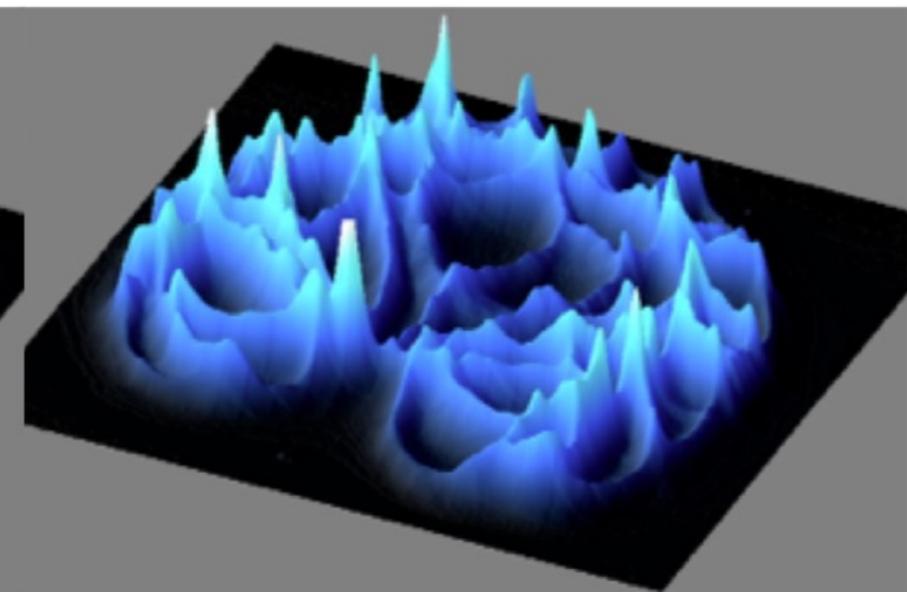


Watershed

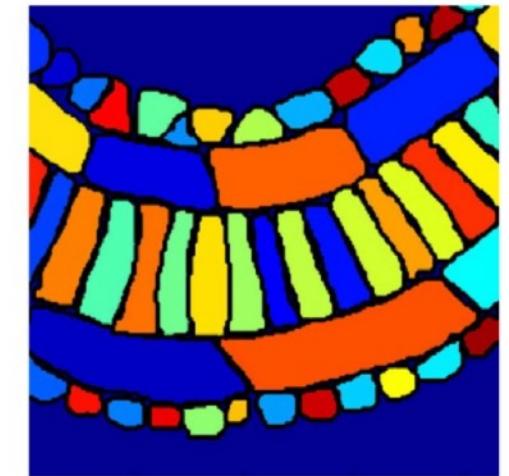
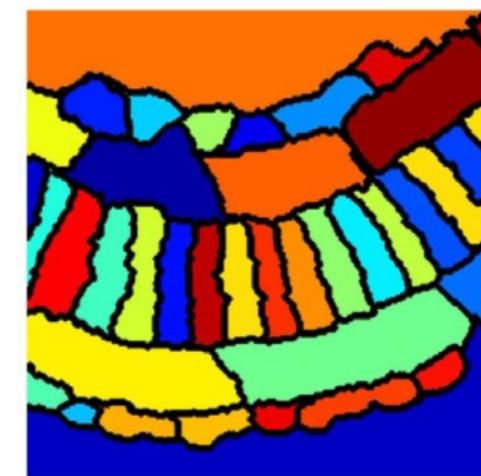
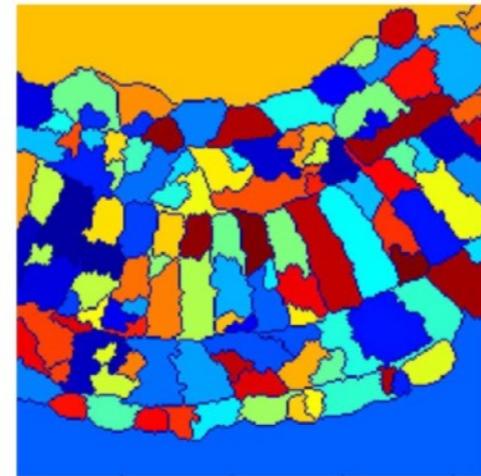
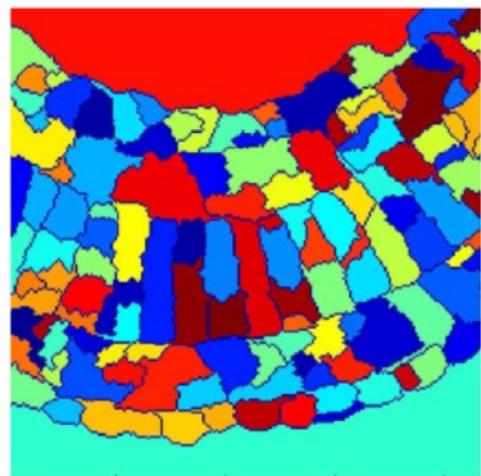
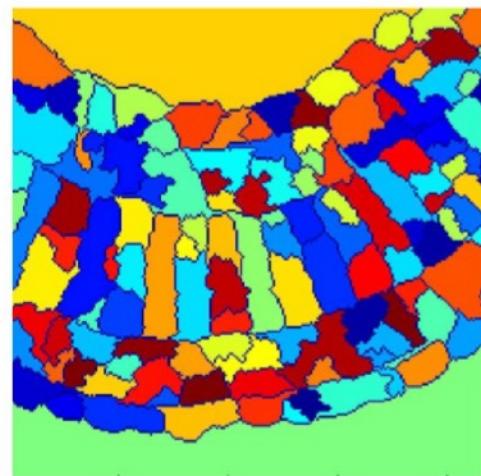
Intensity image



Intensity image as a landscape



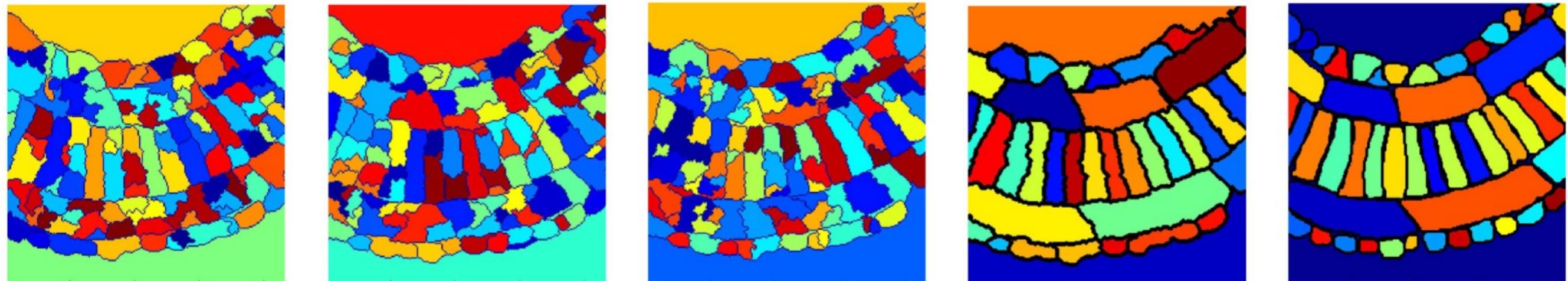
Watershed



Random seed

Delibaltov 2013

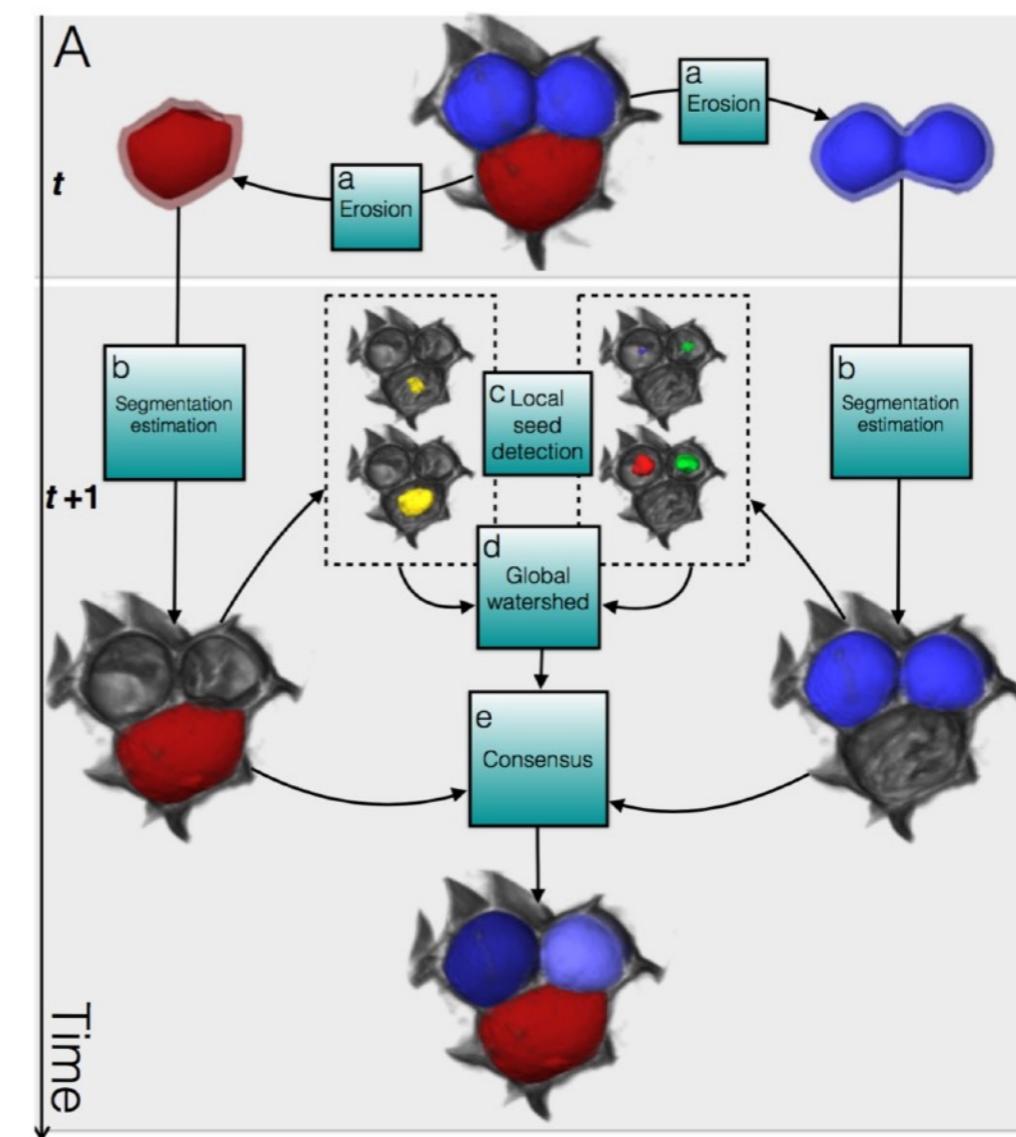
Watershed



Random seed

Delibaltov 2013

Watershed 4D



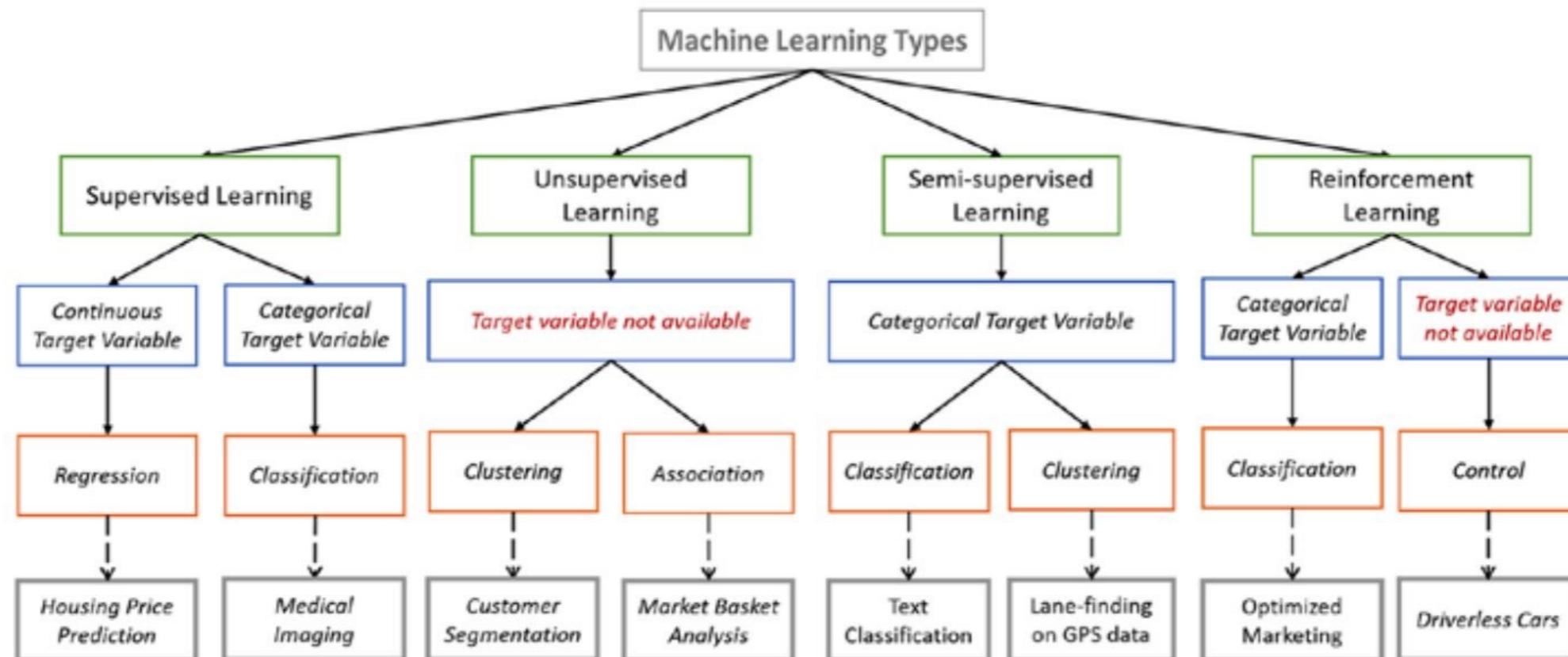
Guignard 2015

Deep Learning ?

Deep Learning ?

Classical methods do not improve with data

Which methods ? Which tasks ? Which models ?



Which methods ? Which tasks ? Which models ?

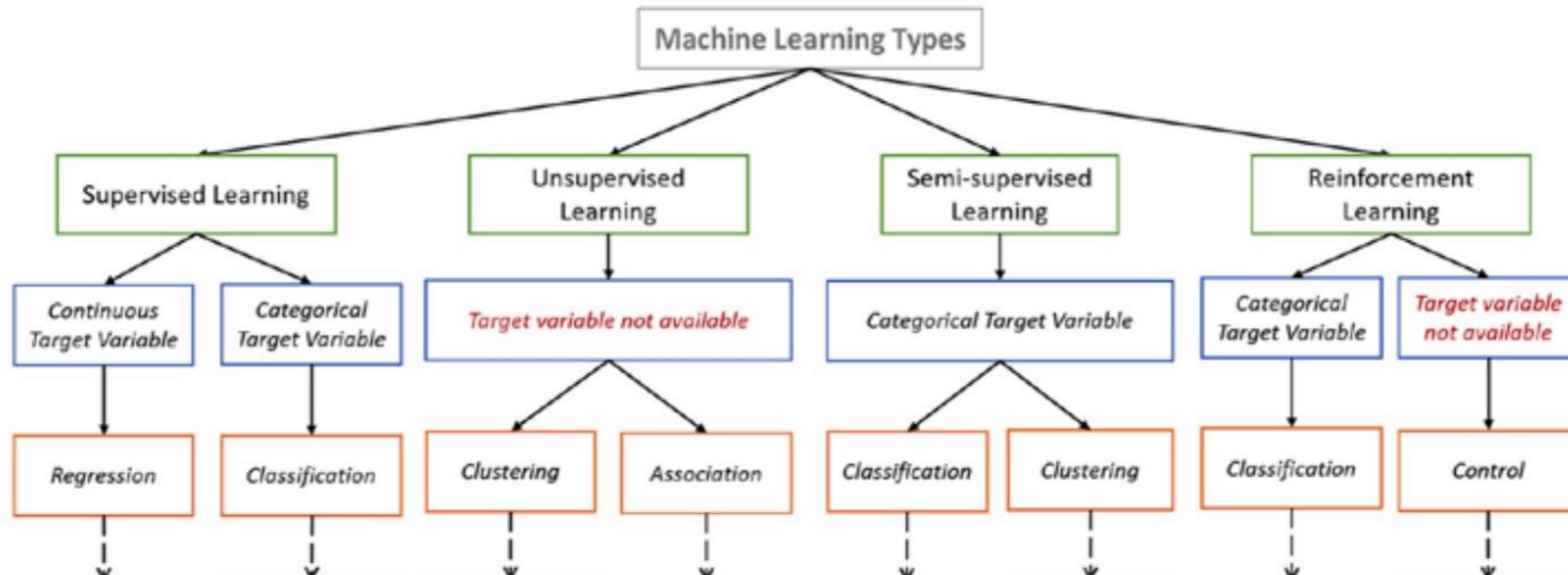
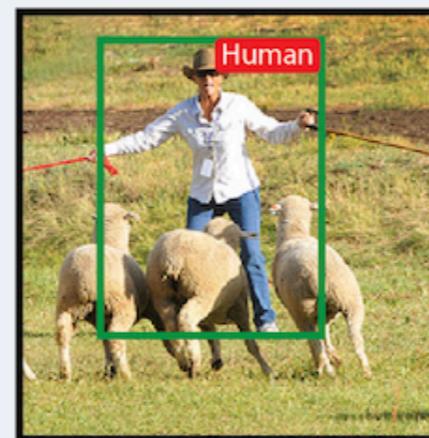


Image Classification

Classify an image based on the dominant object inside it.

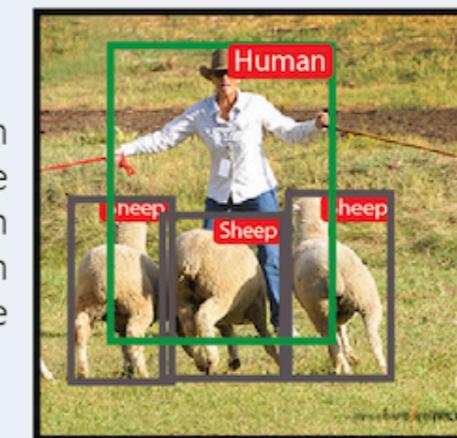
datasets: MNIST, CIFAR, ImageNet



Object Localization

Predict the image region that contains the dominant object. Then image classification can be used to recognize object in the region

datasets: ImageNet



Object Recognition

Localize and classify all objects appearing in the image. This task typically includes: proposing regions then classify the object inside them.

datasets: PASCAL, COCO



Semantic Segmentation

Label each pixel of an image by the object class that it belongs to, such as human, sheep, and grass in the example.

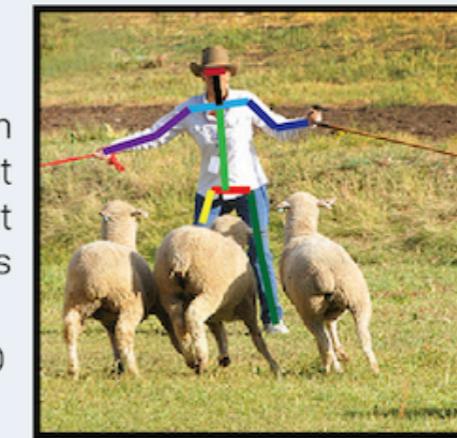
datasets: PASCAL, COCO



Instance Segmentation

Label each pixel of an image by the object class and object instance that it belongs to.

datasets: PASCAL, COCO



Keypoint Detection

Detect locations of a set of predefined keypoints of an object, such as keypoints in a human body, or a human face.

datasets: COCO

Instance Segmentation : Deep Learning

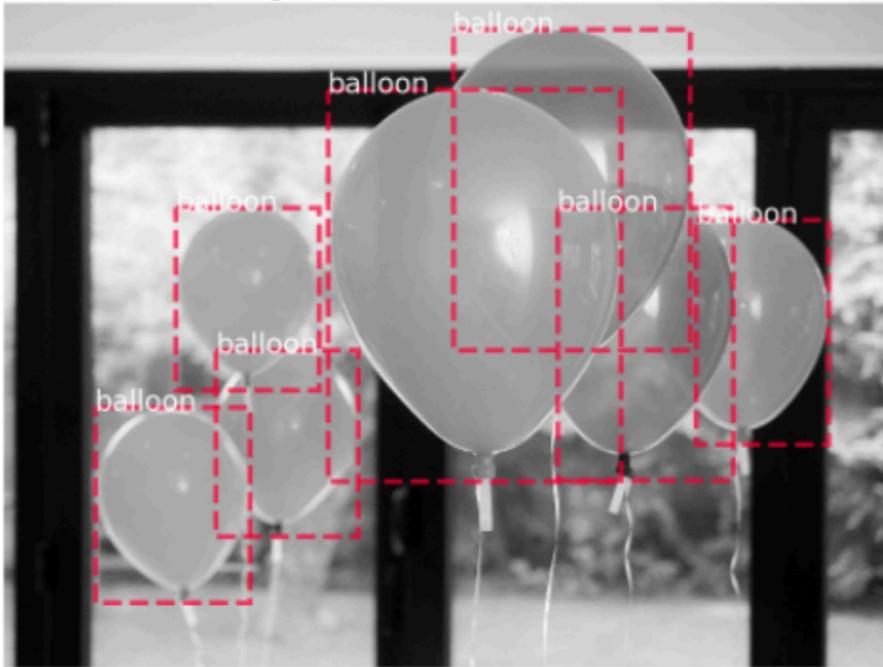
Classification



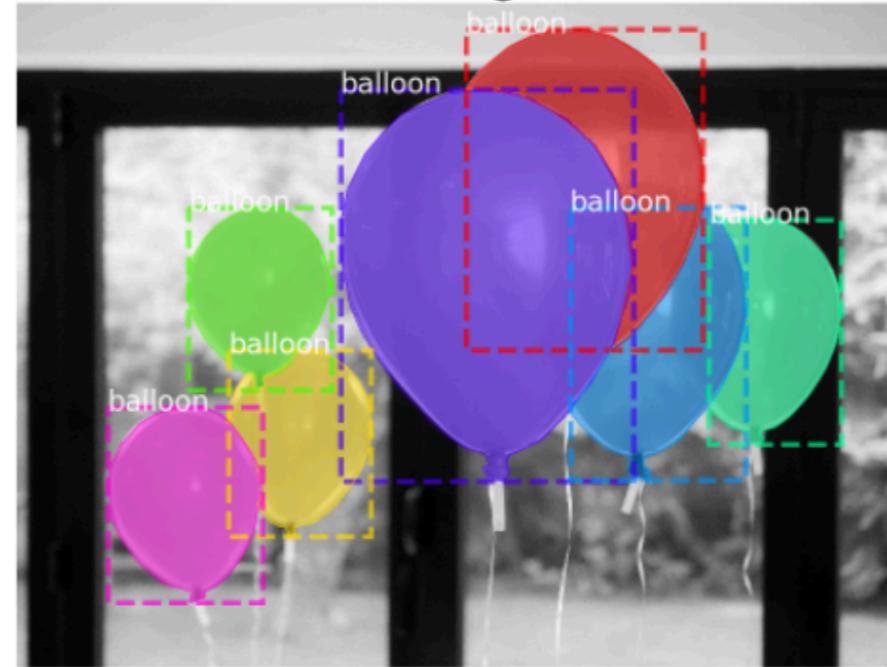
Semantic Segmentation



Object Detection

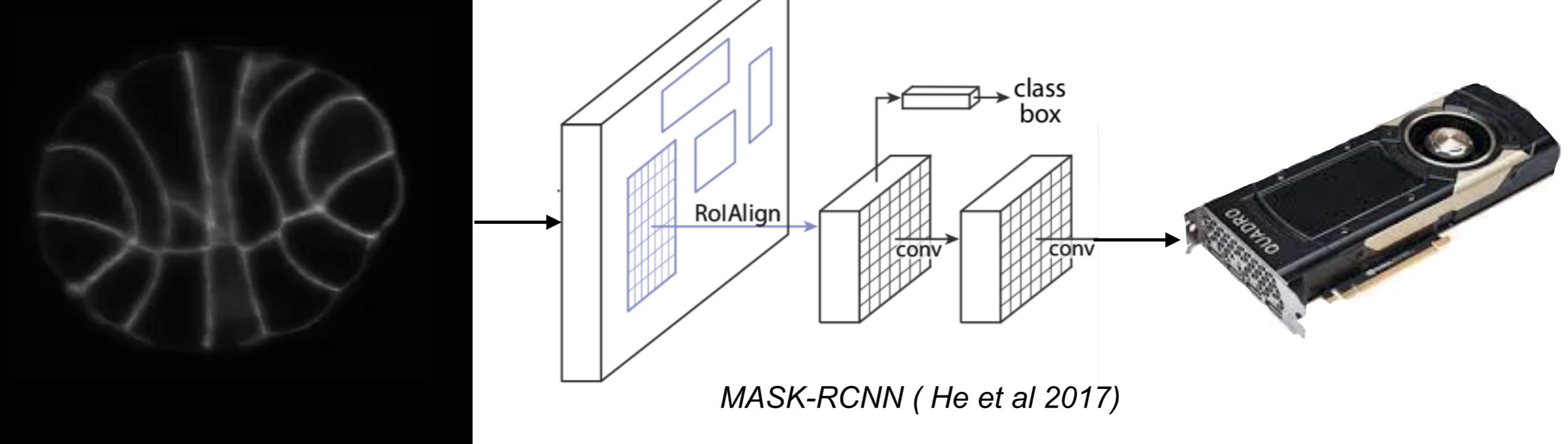


Instance Segmentation



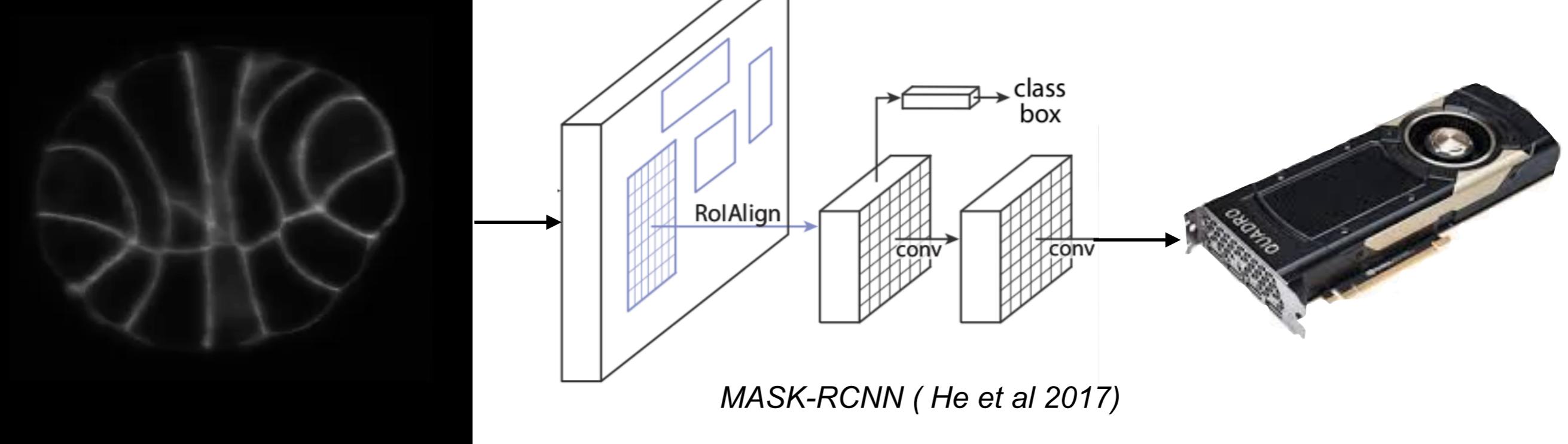
How ?

802x516x586



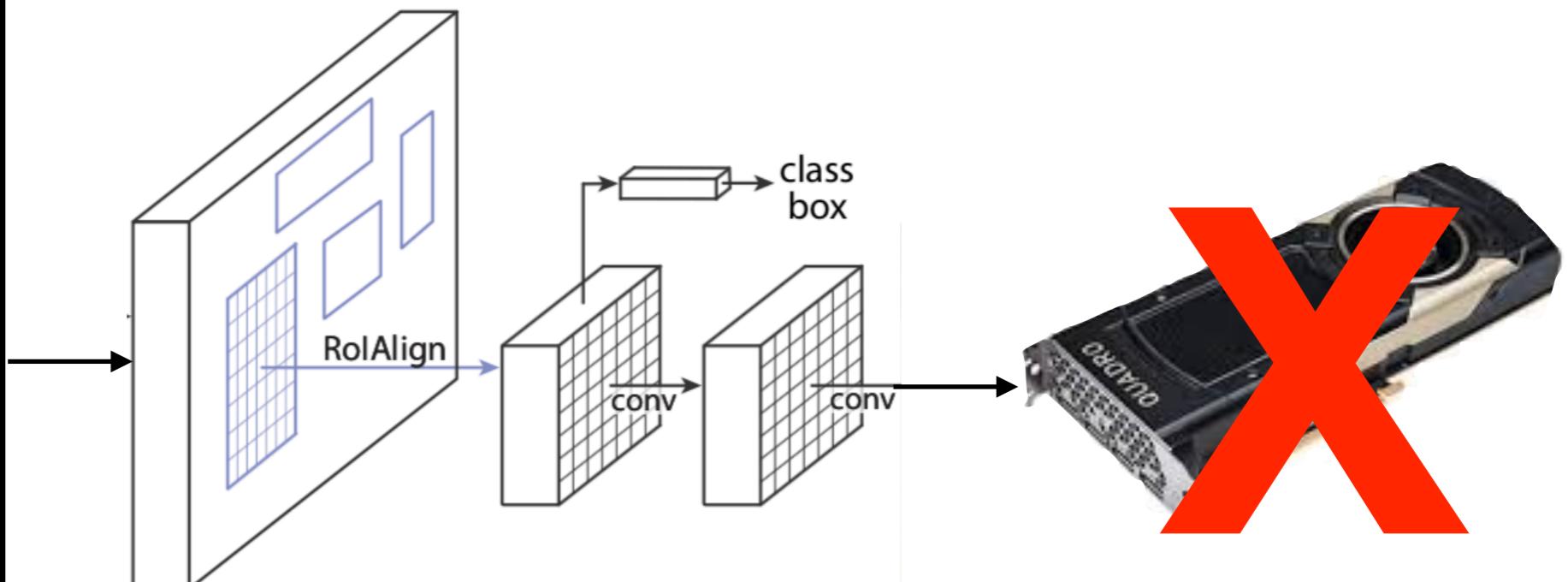
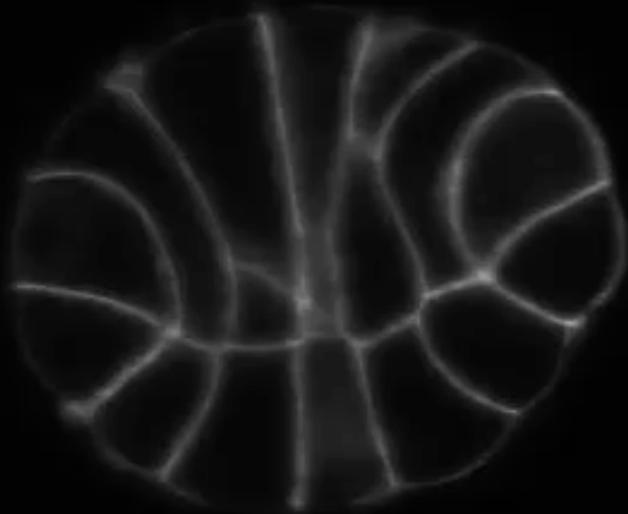
How ?

802x516x586

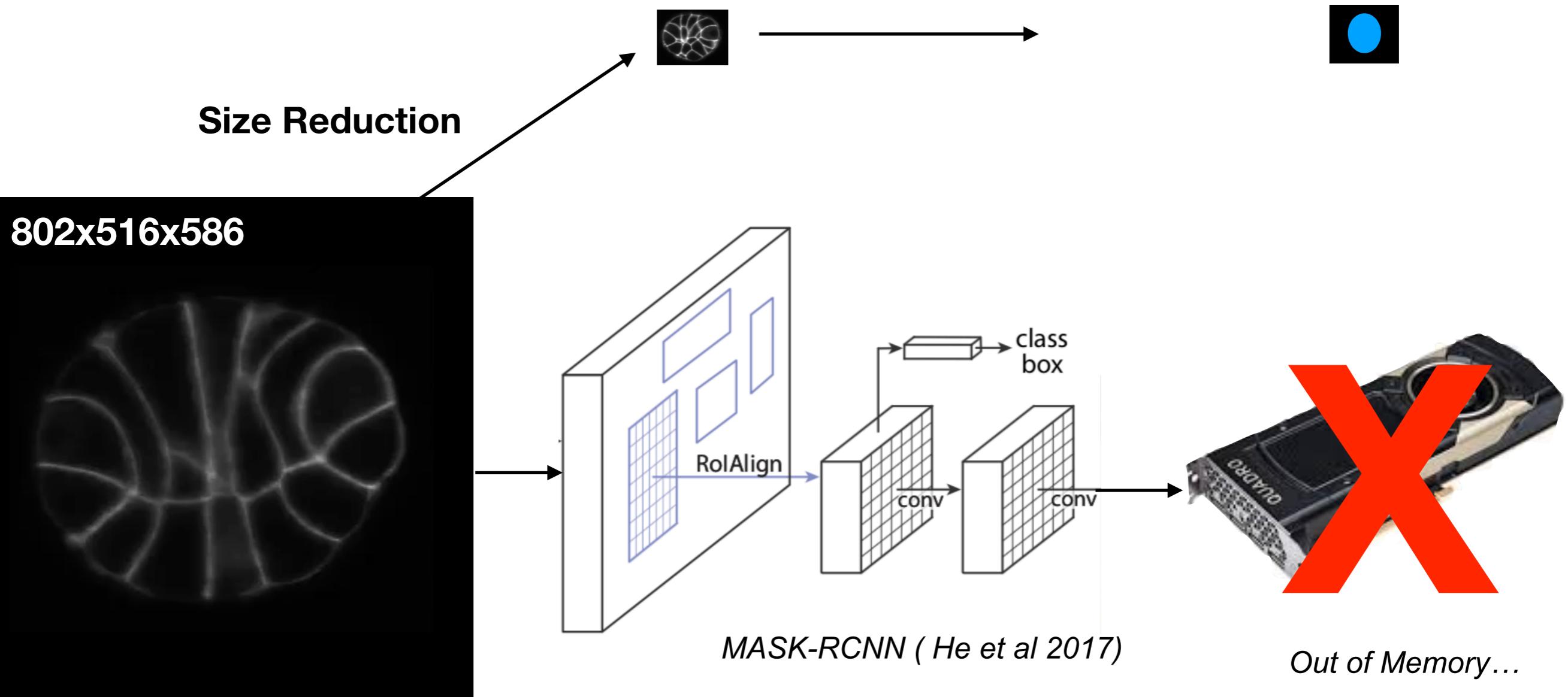


How ?

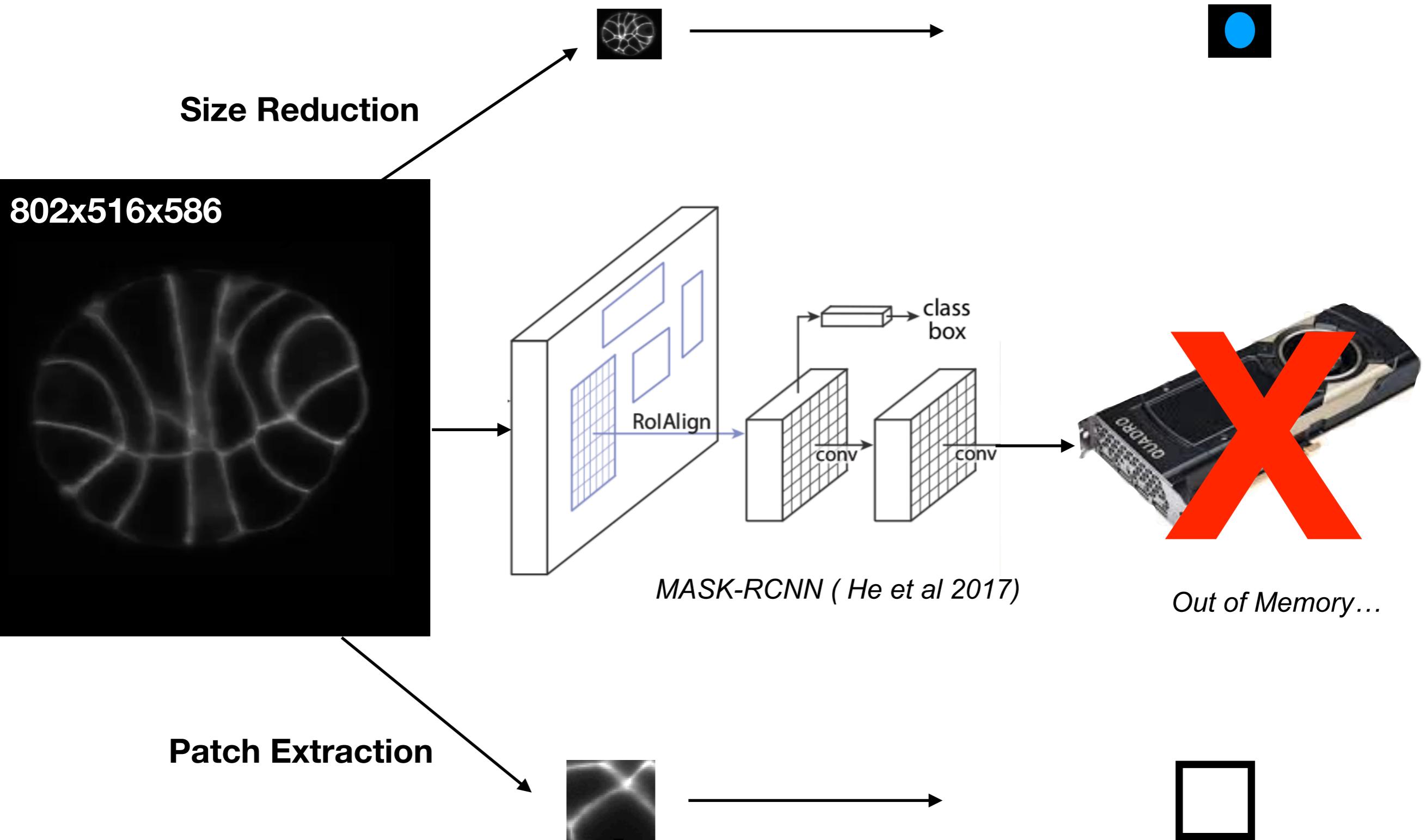
802x516x586

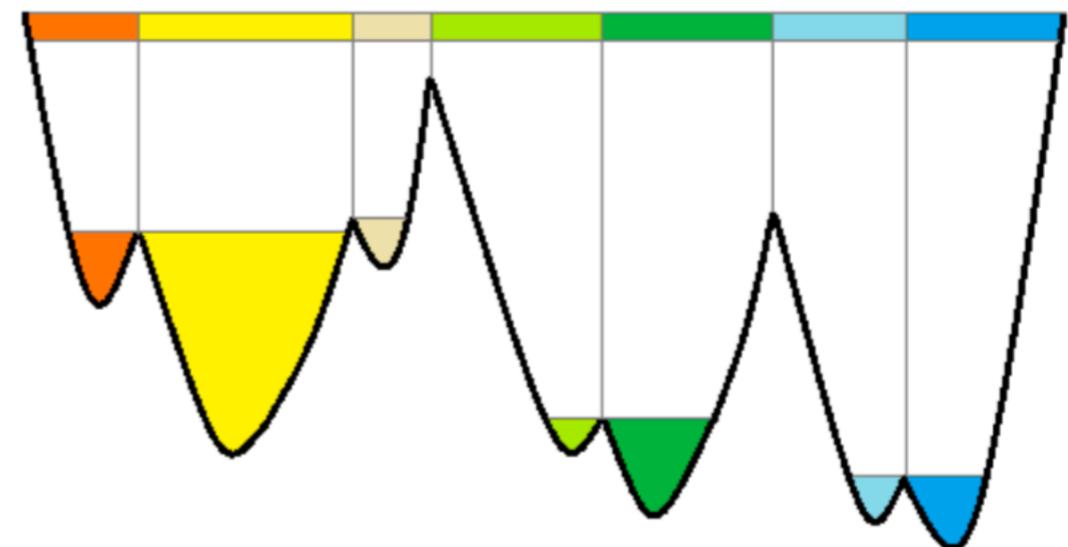


How ?

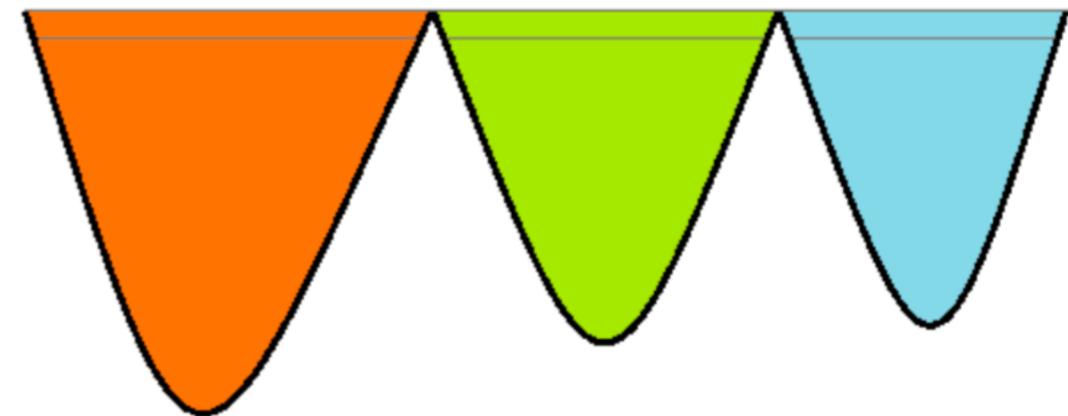


How ?



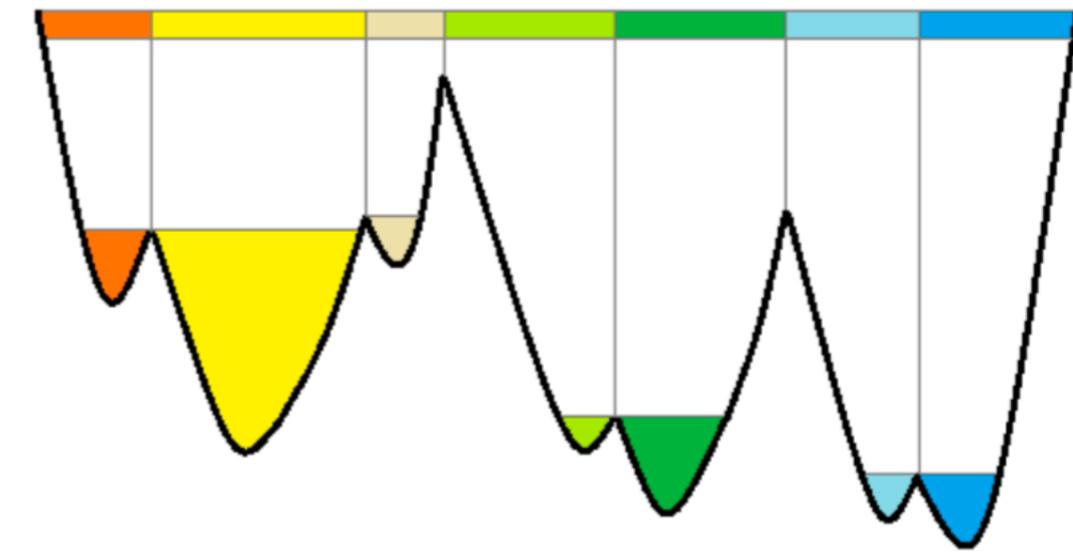
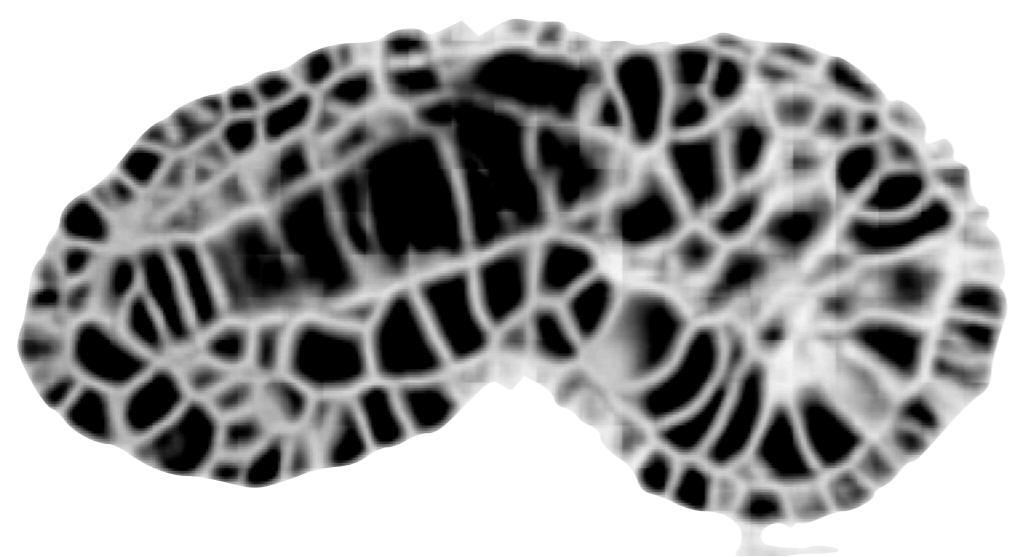
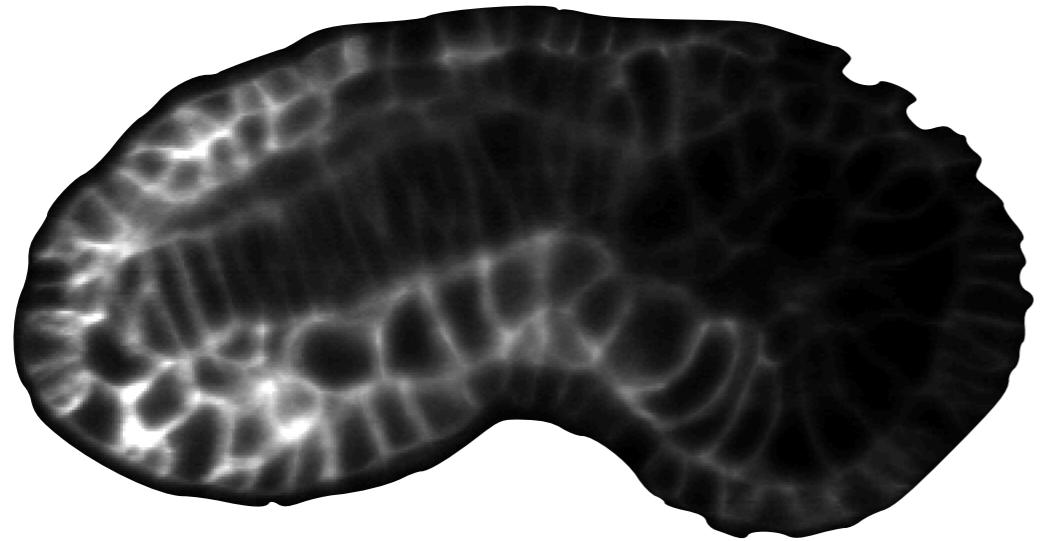


(a) Traditional Watershed Energy

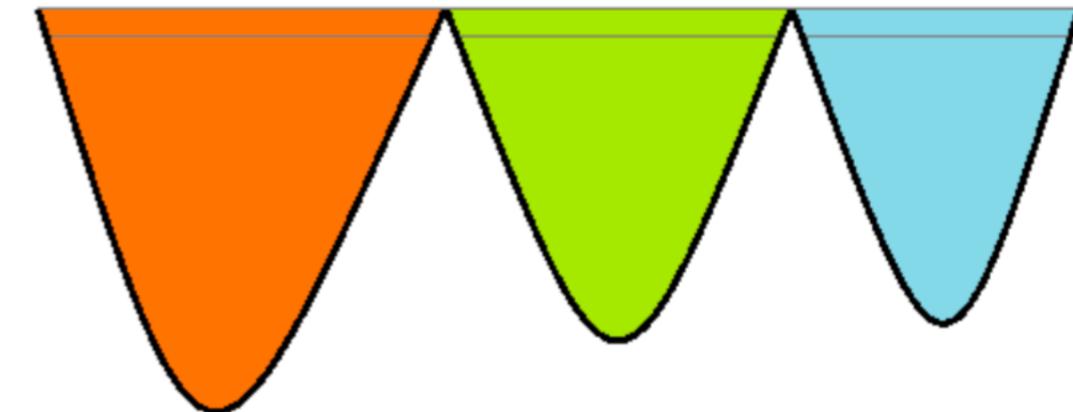


(b) Our learned energy

Figure 2: Conceptual 1-D comparison between the traditional watershed transform and our deep watershed transform. The resulting instances are represented as colors across the top.



(a) Traditional Watershed Energy



(b) Our learned energy

Figure 2: Conceptual 1-D comparison between the traditional watershed transform and our deep watershed transform. The resulting instances are represented as colors across the top.

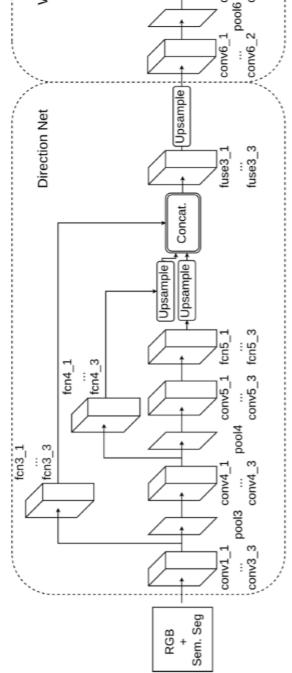
Deep Watershed Transform for Instance Segmentation

Min Bai Raquel Urtasun

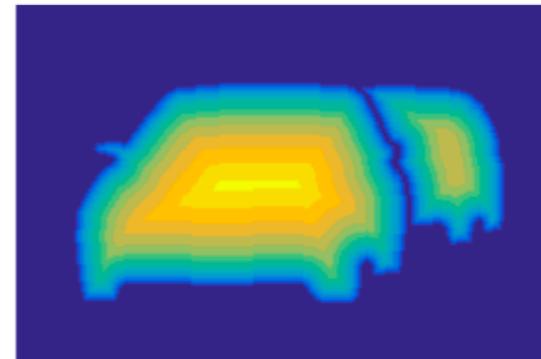
Department of Computer Science, University of Toronto

{mbai, urtasun}@cs.toronto.edu

RAWDATA



Distance MAP



Learn

Threshold

Segmentation



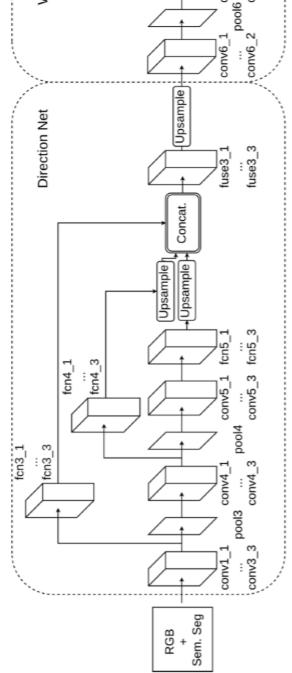
Deep Watershed Transform for Instance Segmentation

Min Bai Raquel Urtasun

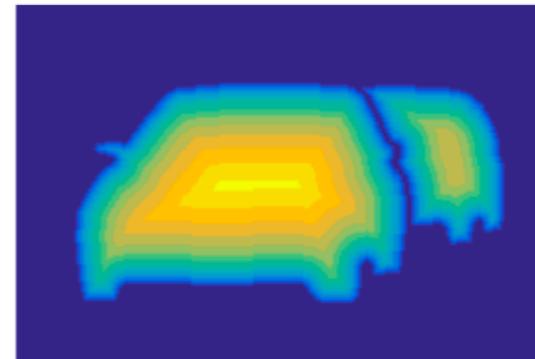
Department of Computer Science, University of Toronto

{mbai, urtasun}@cs.toronto.edu

RAWDATA



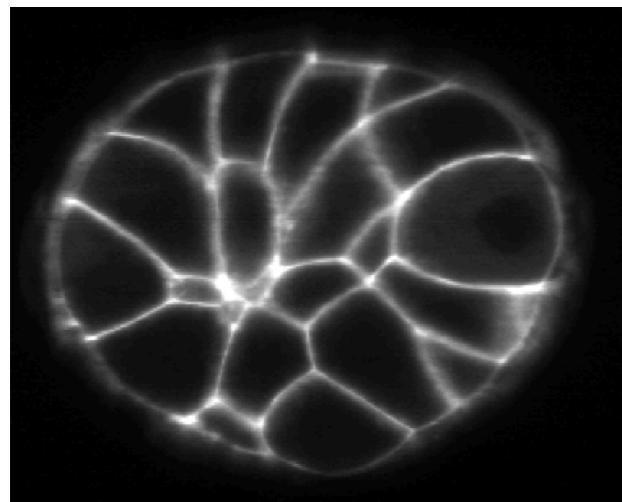
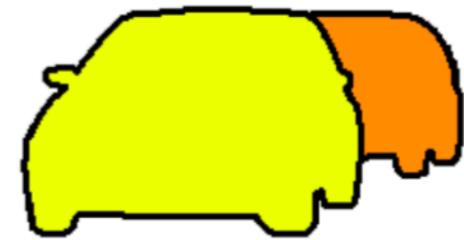
Distance MAP



Learn

Segmentation

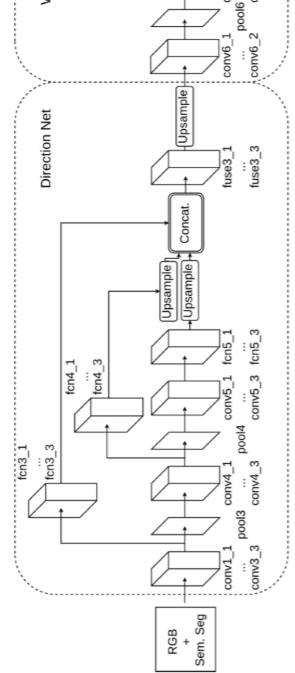
Threshold



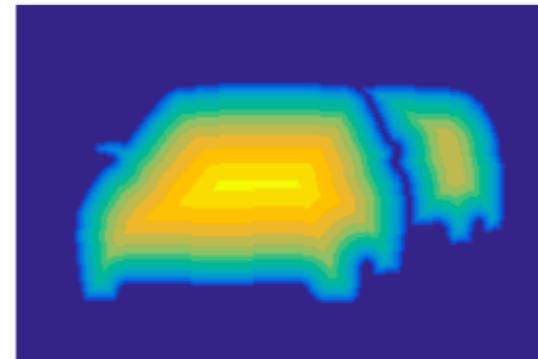
Deep Watershed Transform for Instance Segmentation

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Department of Computer Science, University of Toronto
{mbai, urtasun}@cs.toronto.edu

RAWDATA



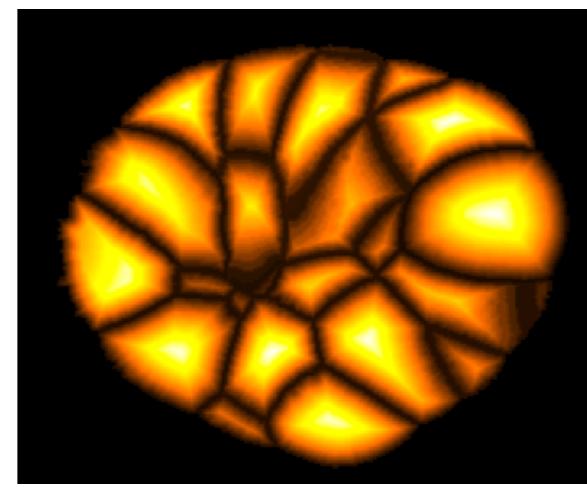
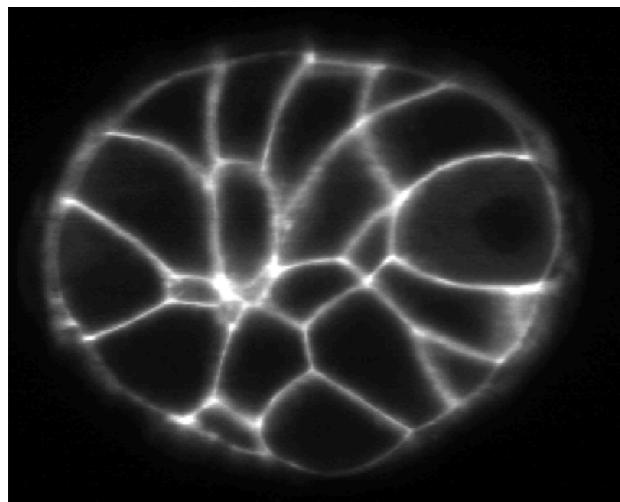
Distance MAP



Learn

Segmentation

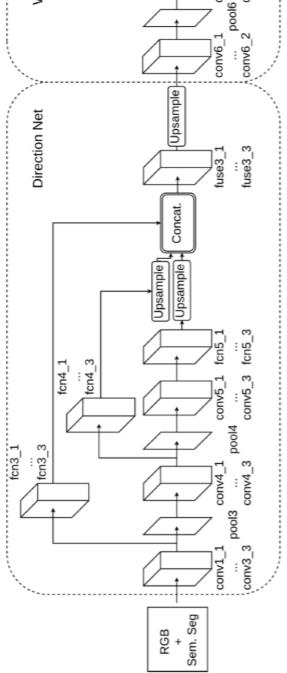
Threshold



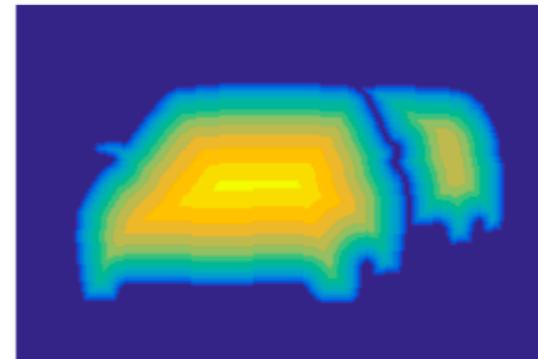
Deep Watershed Transform for Instance Segmentation

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RAWDATA



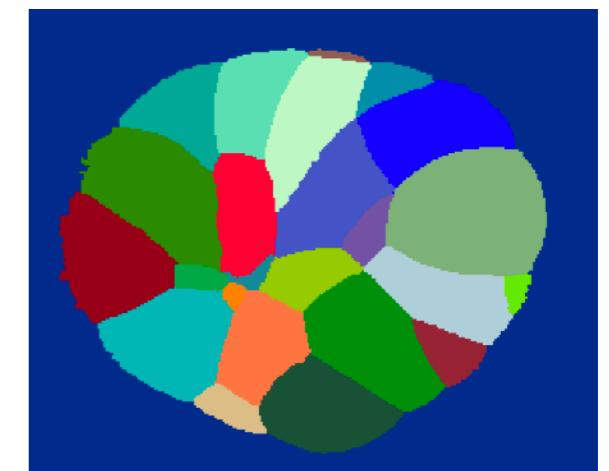
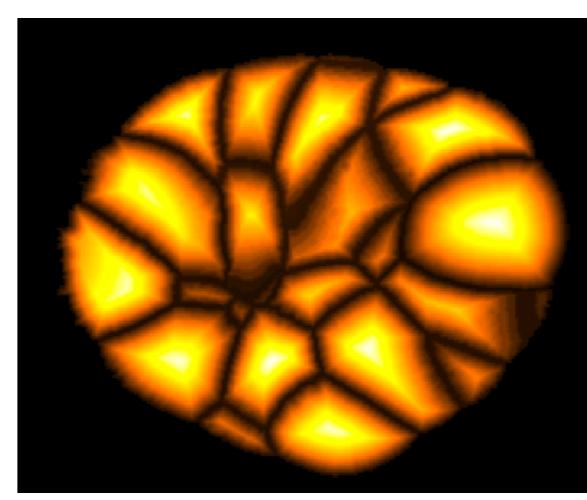
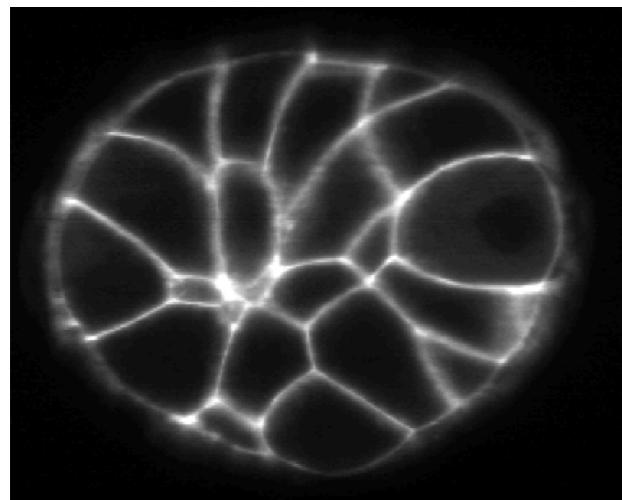
Distance MAP



Learn

Segmentation

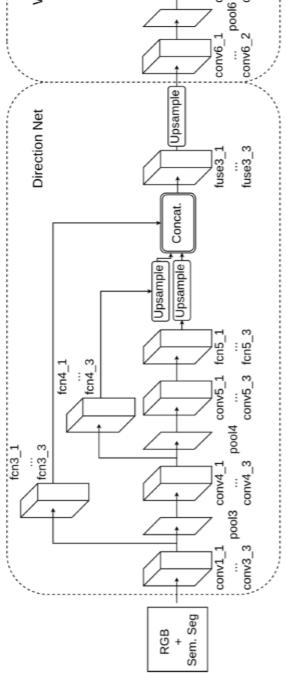
Threshold



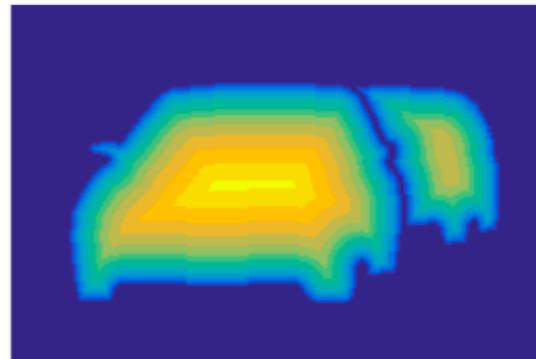
Deep Watershed Transform for Instance Segmentation

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{mbai, urtasun}@cs.toronto.edu

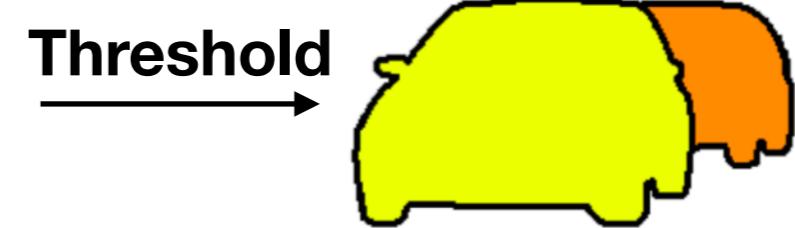
RAWDATA



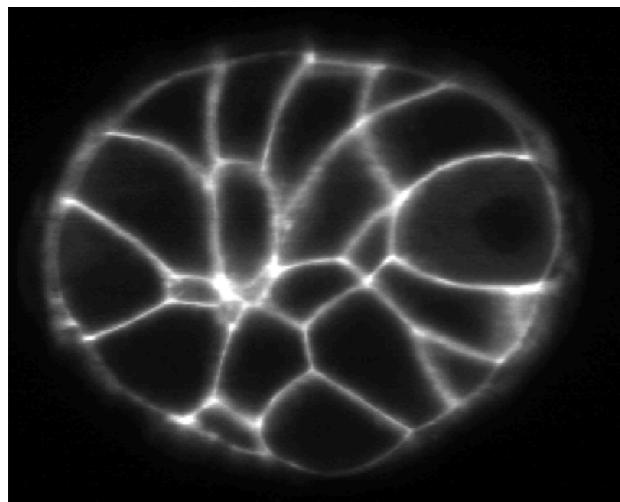
Distance MAP



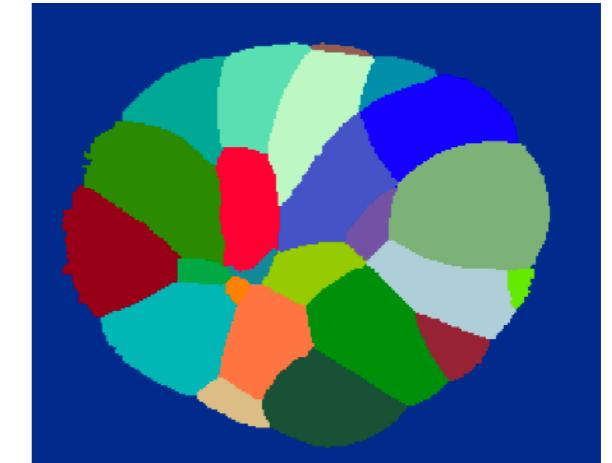
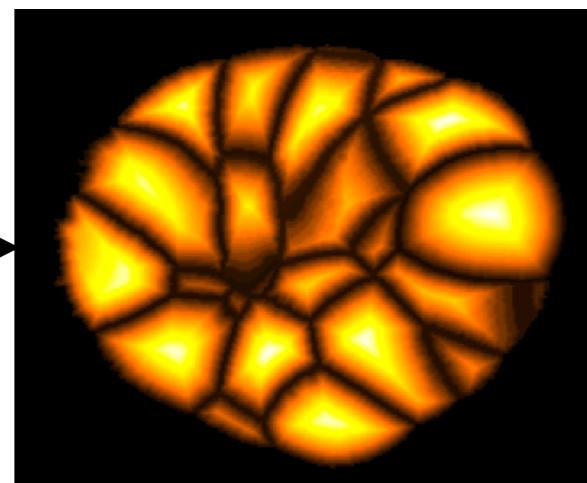
Segmentation



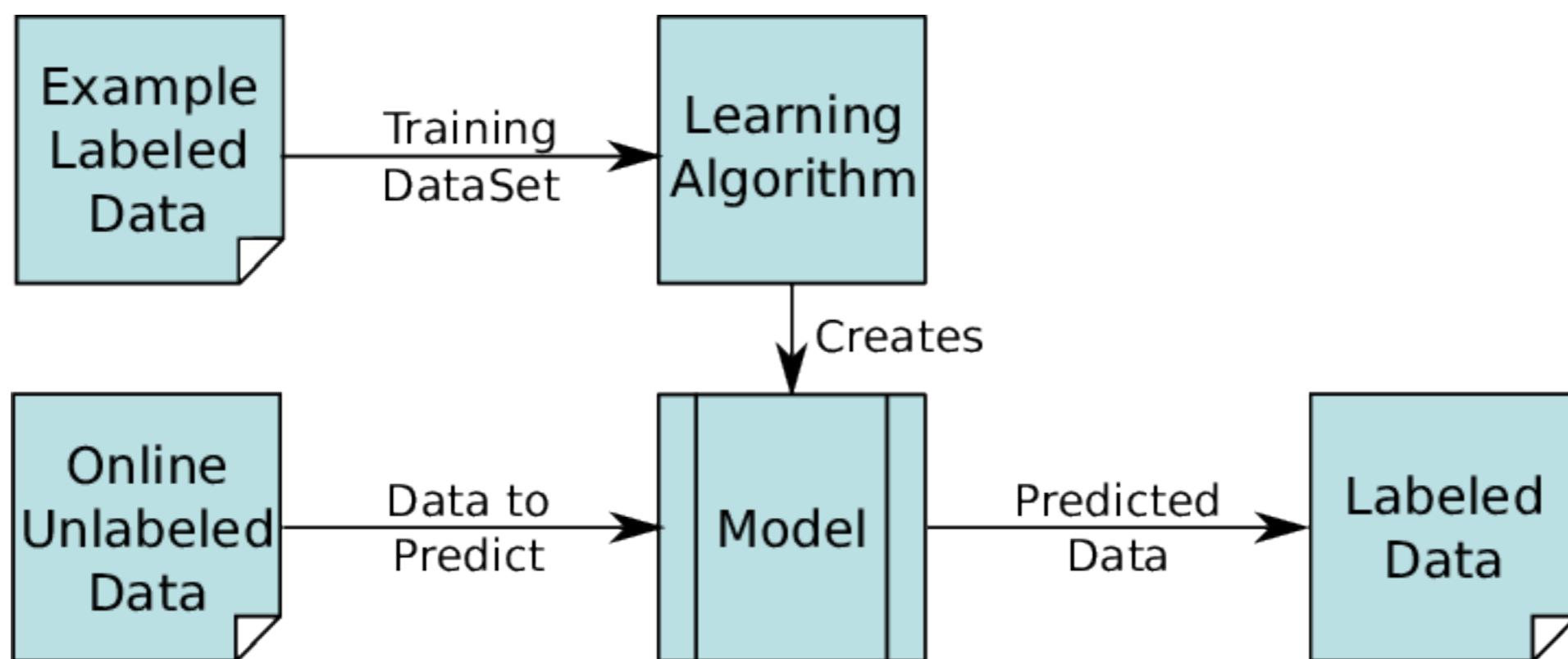
Learn



Learn

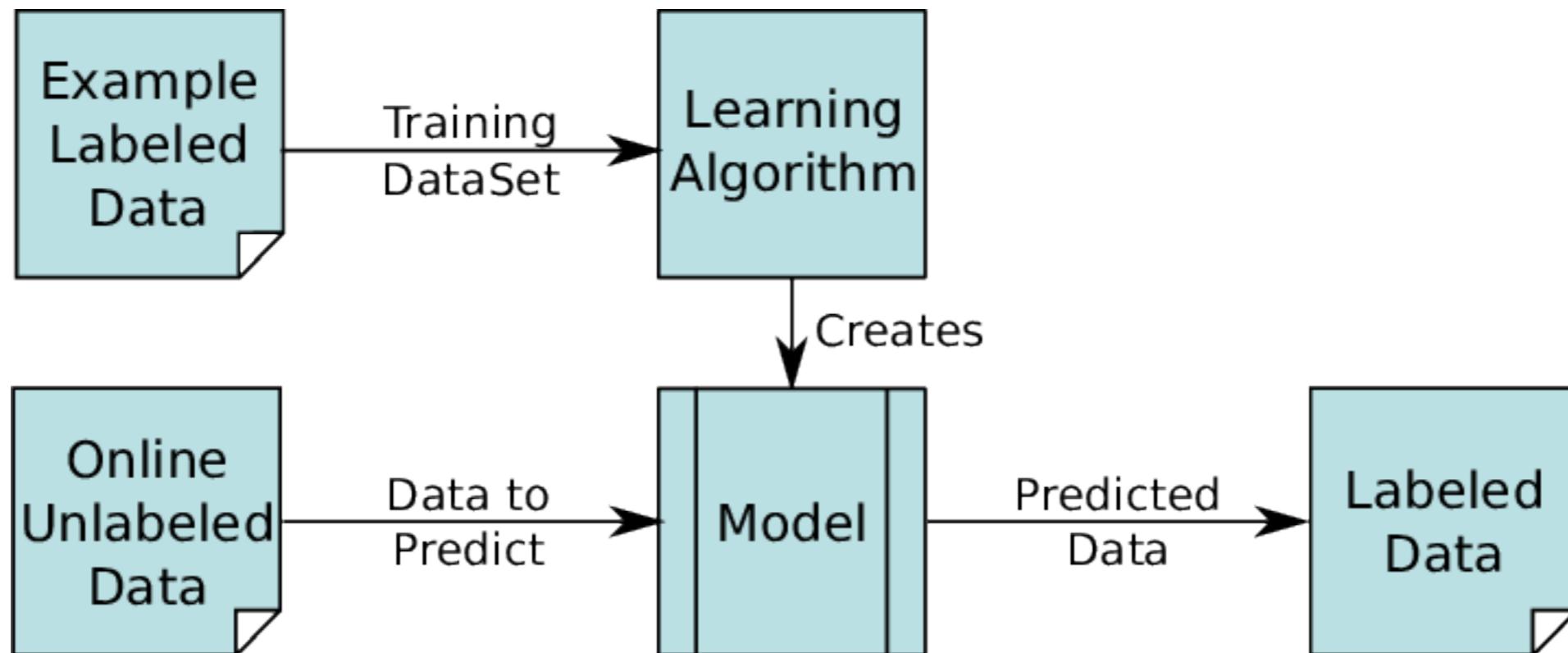


Machine Learning Scheme



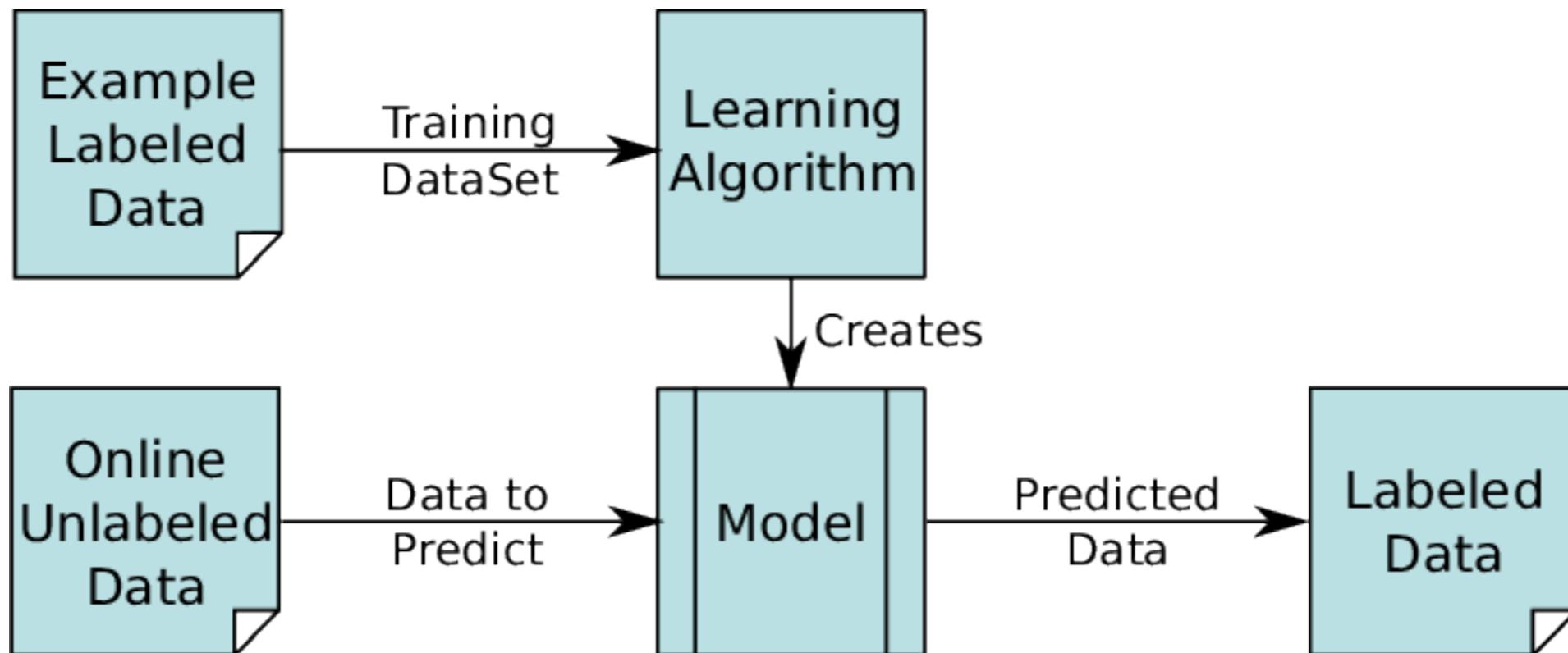
Machine Learning Scheme

Embryo 1 et 2



Machine Learning Scheme

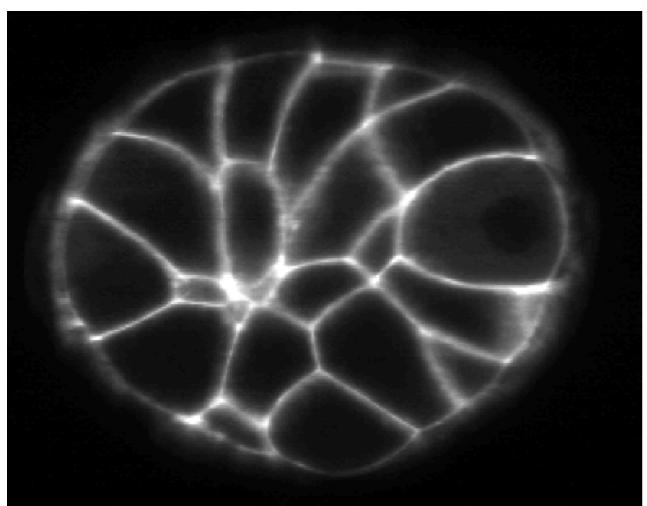
Embryo 1 et 2



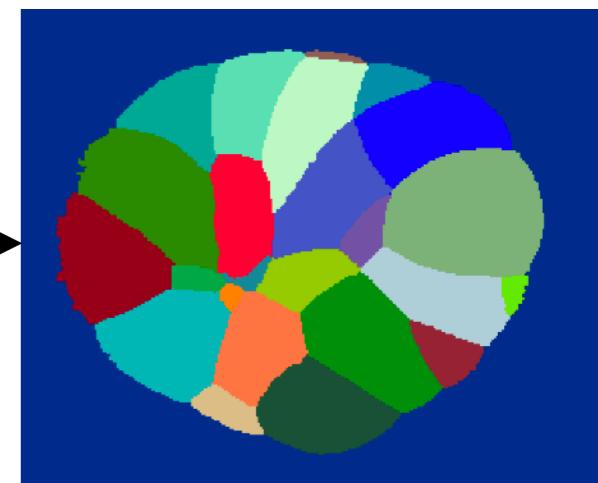
Embryo 3

Emb 1 et 2 -> Labeled Data

Data



Ground Truth

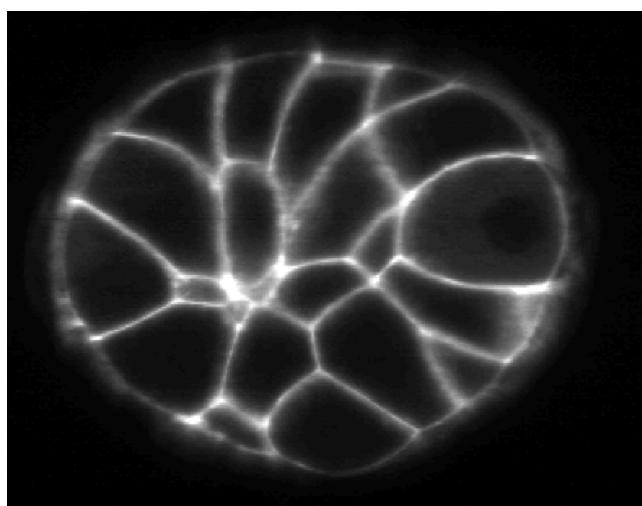


Manual Reconstruction

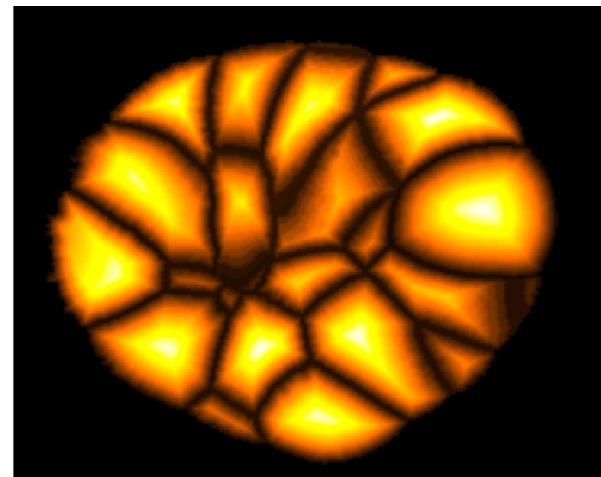


Emb 1 et 2 -> Labeled Data

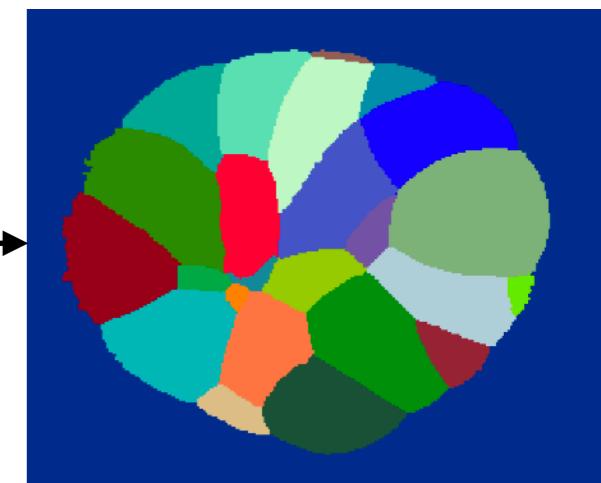
Data



Manual Reconstruction



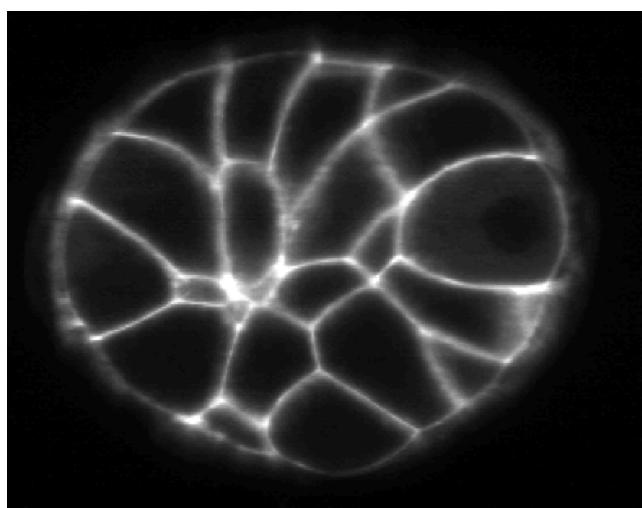
Ground Truth



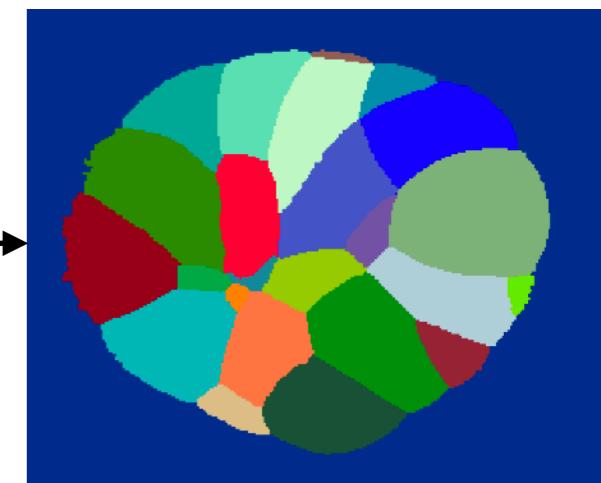
Distance map function

Emb 1 et 2 -> Labeled Data

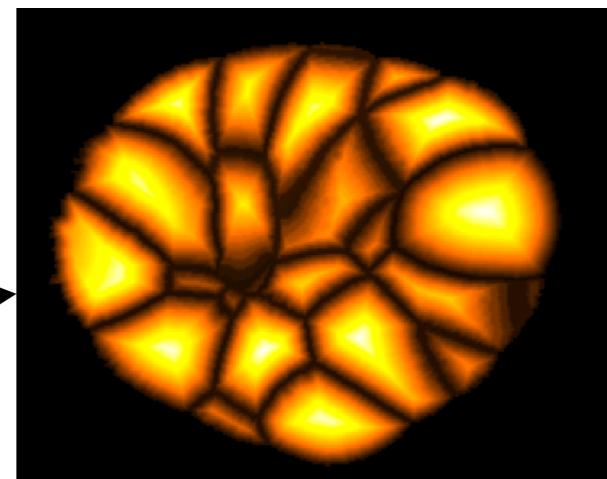
Data



Ground Truth



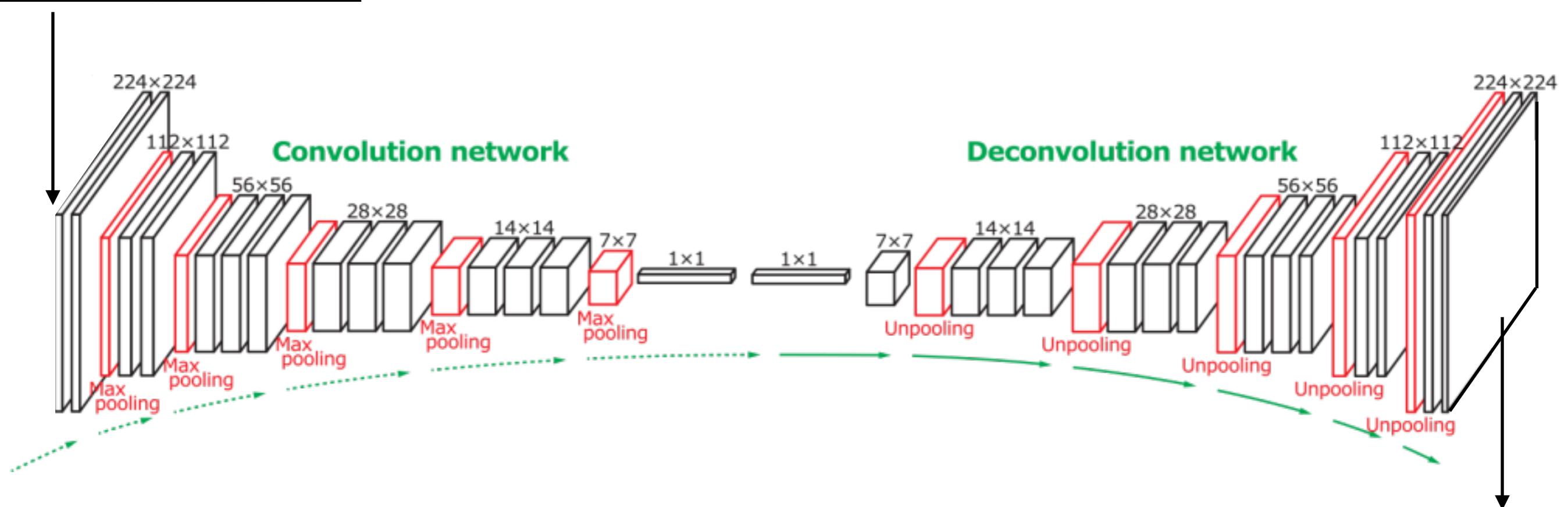
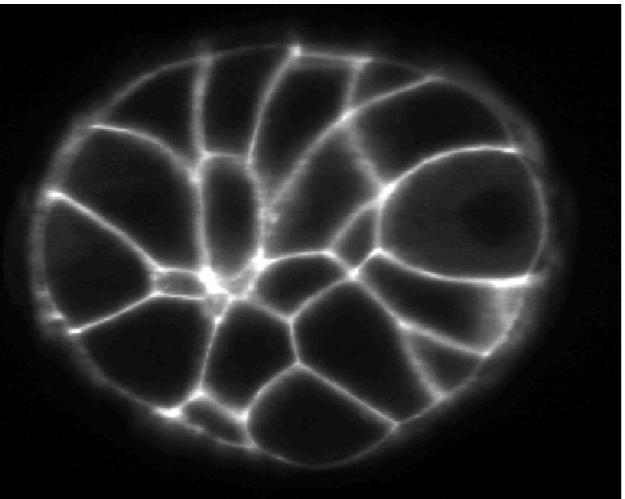
Manual Reconstruction



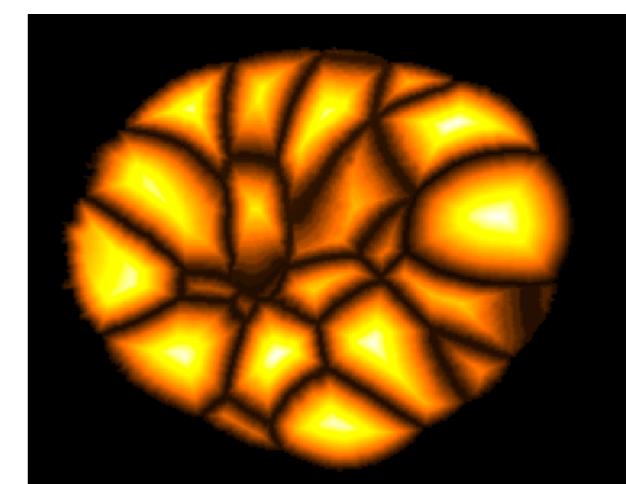
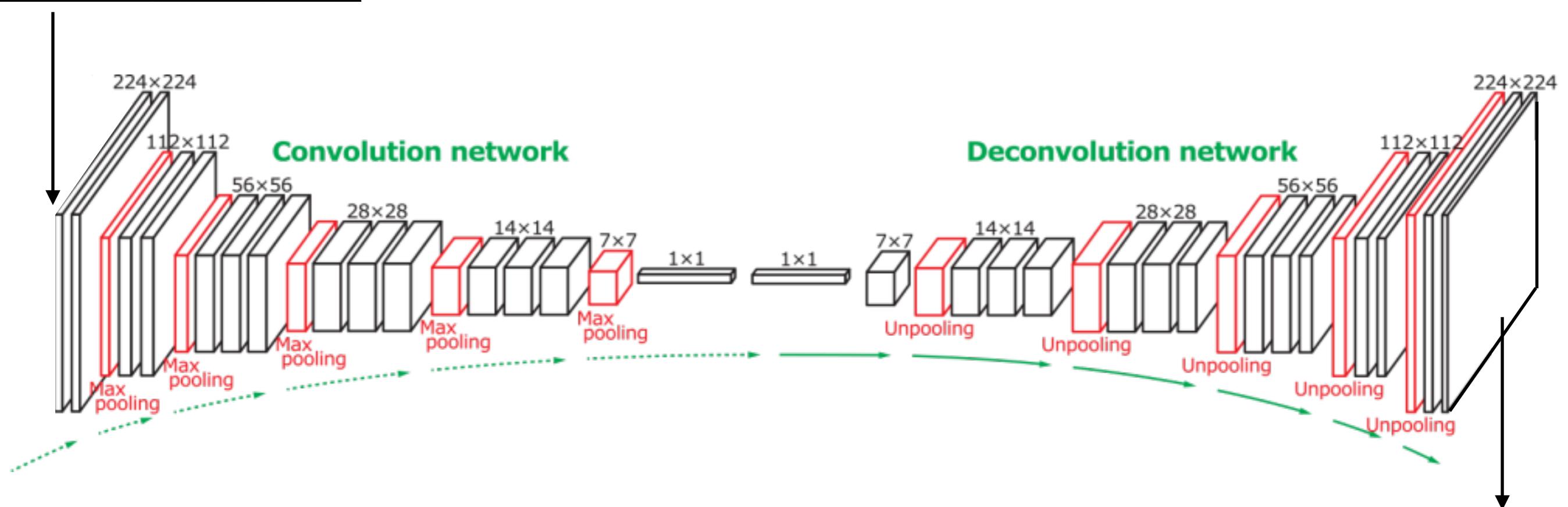
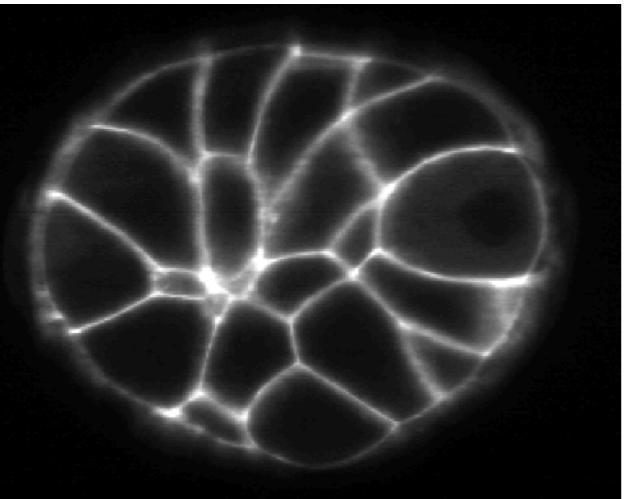
Learn

Distance map function

Fully Convolutional Regression Networks



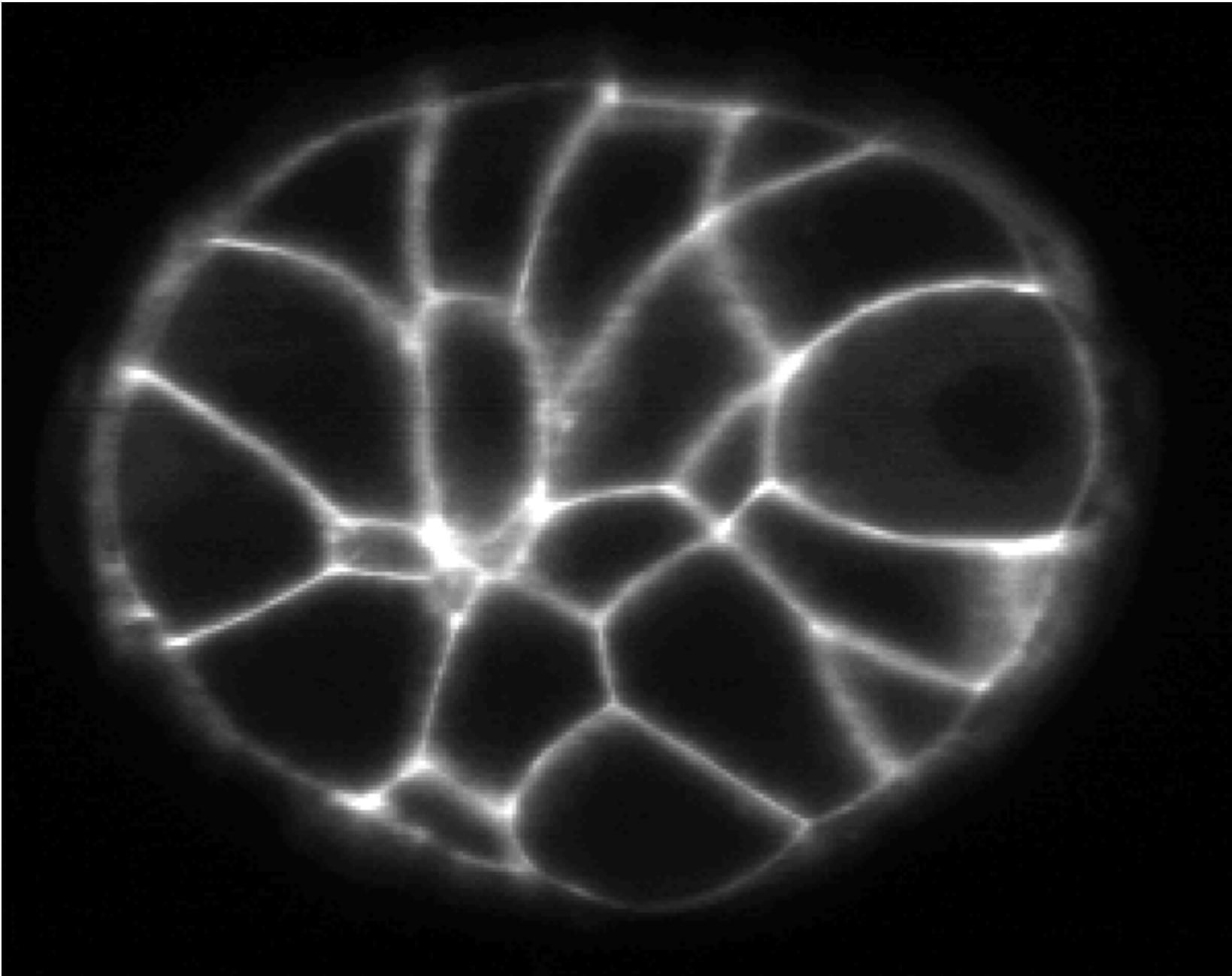
Fully Convolutional Regression Networks



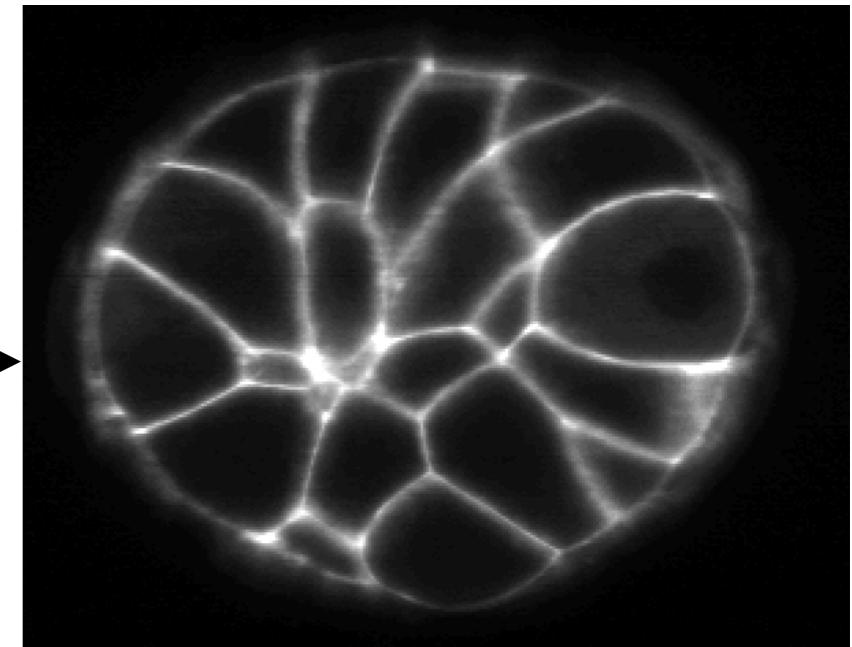
3D Data Extraction

Resample /2

802x516x586

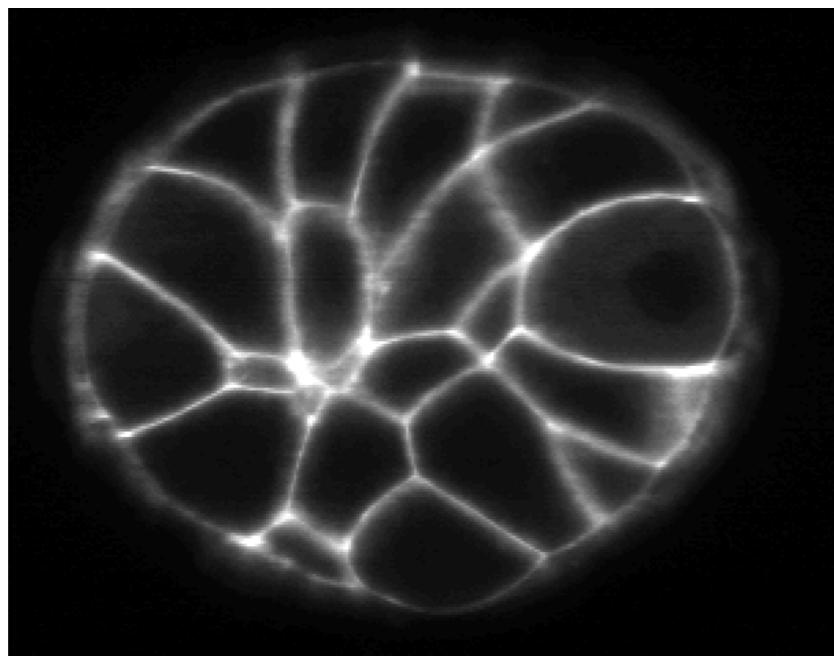


401x258x293

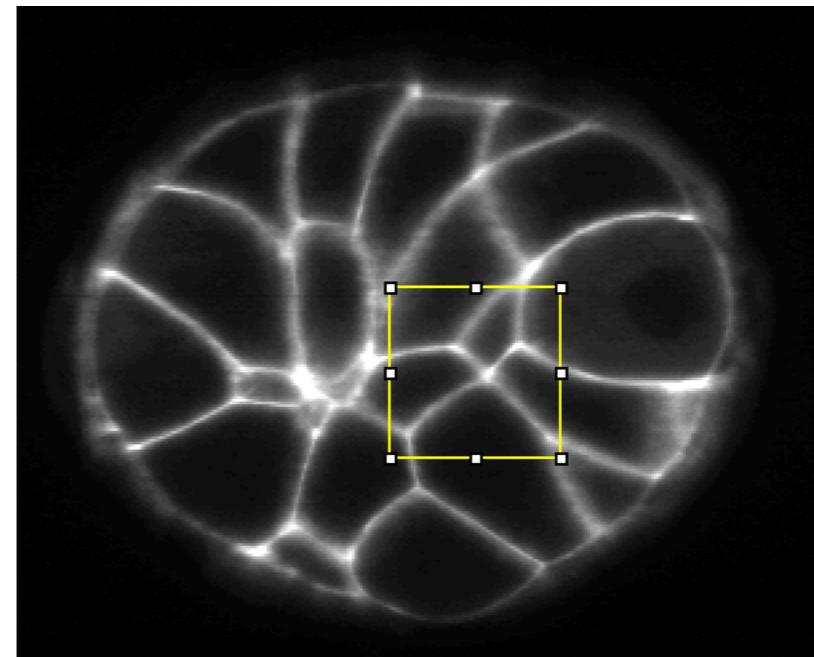


Patch Extraction

401x258x293



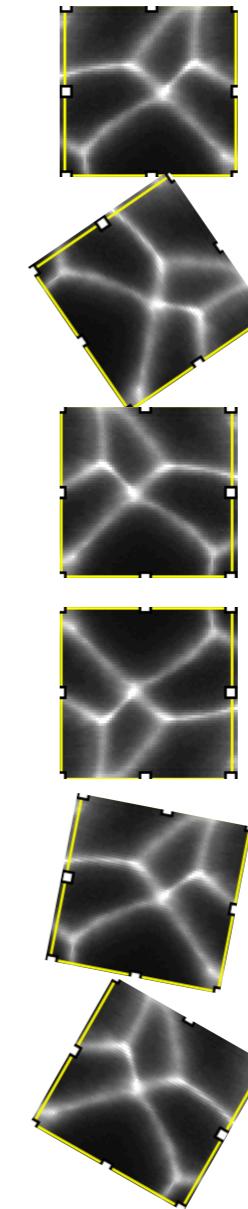
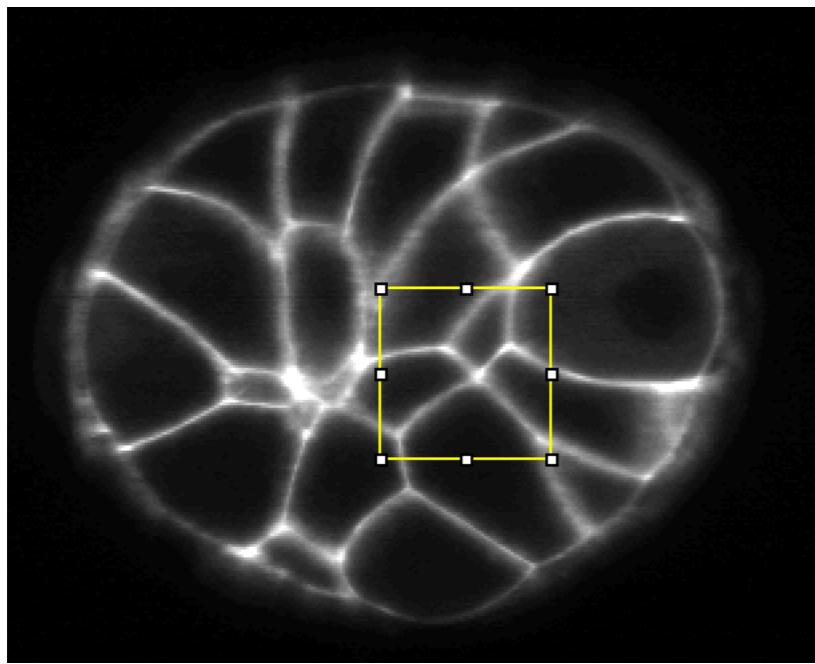
64x64x64



100 Random Patches / Time step

Data Augmentation

64x64x64



Flip + Elastic + Rotation

5 augmentation / Patches

Computation time

Trainable params: 4,094,657

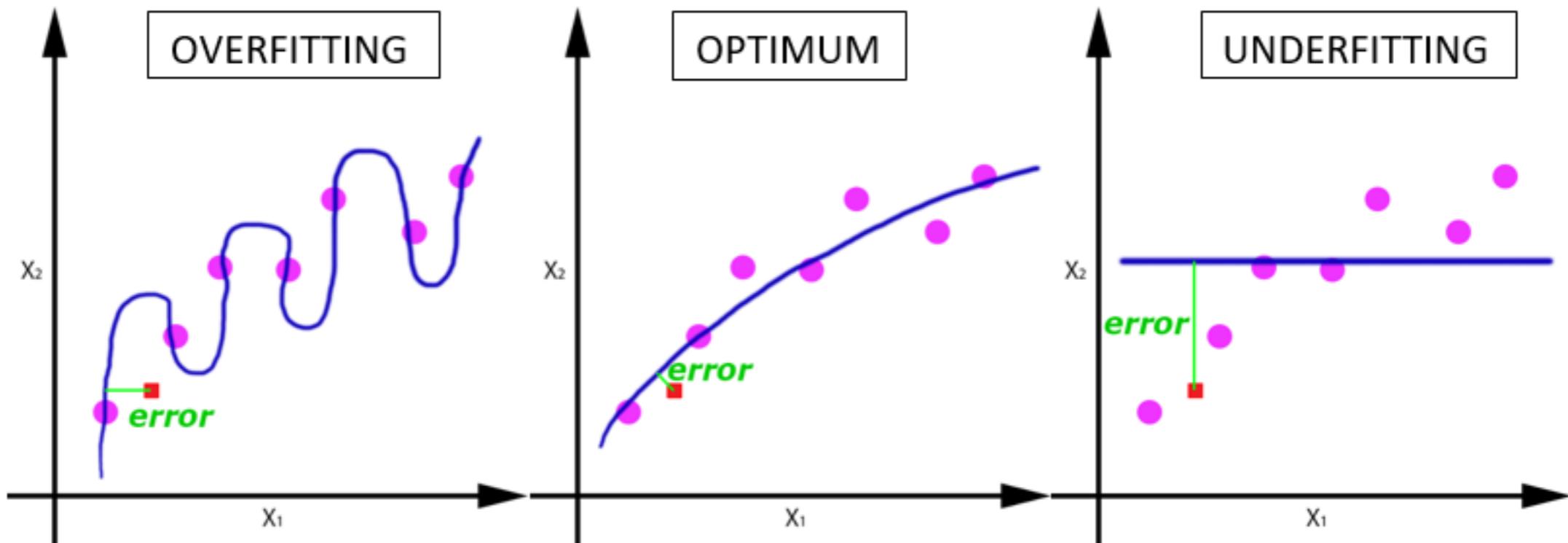
Training : 1 week at least ...

On

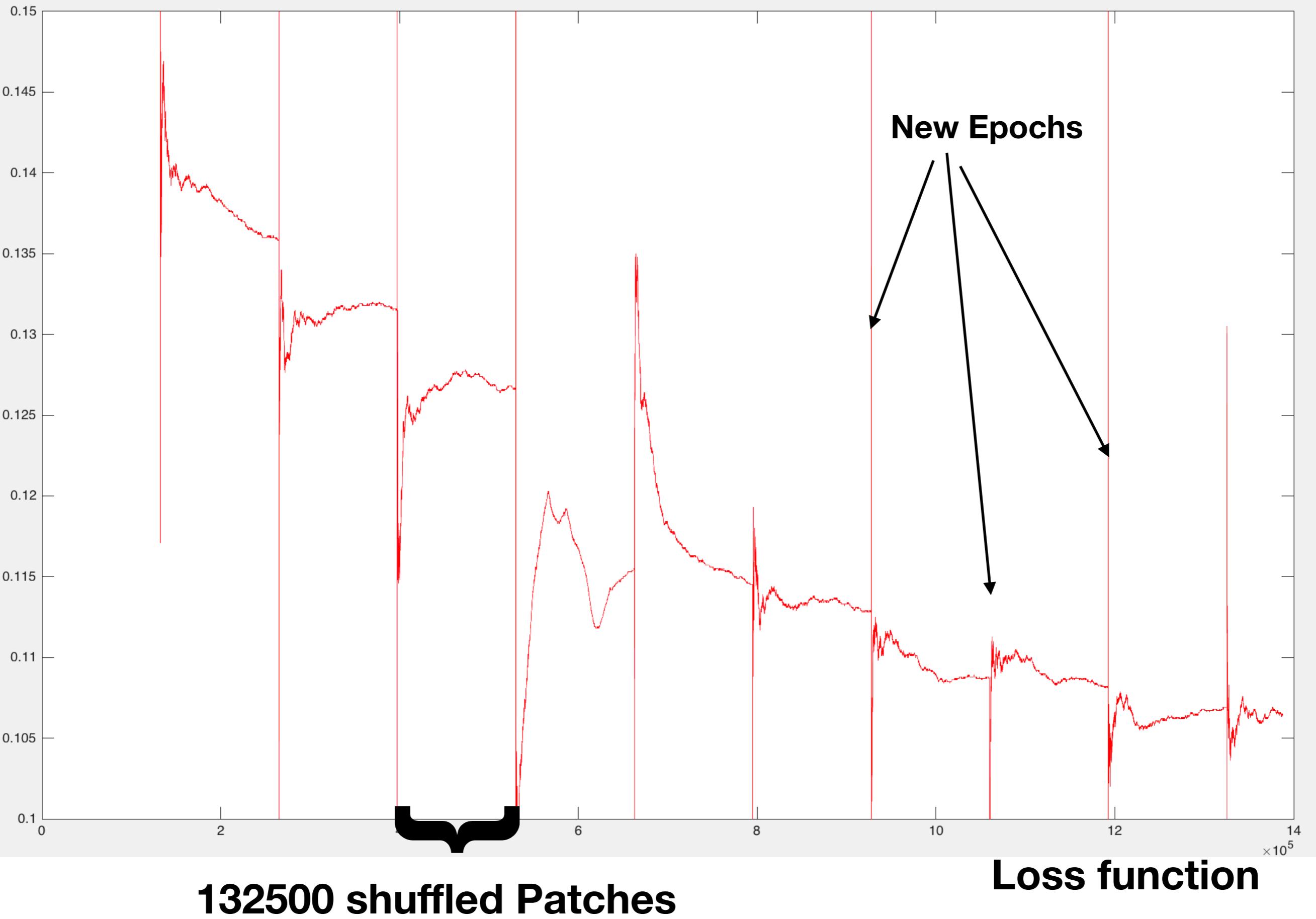
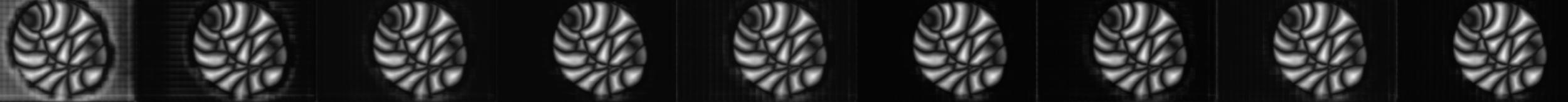
4 x Nvidia GTX 1080TI (11Go RAM - 3584 Cores)

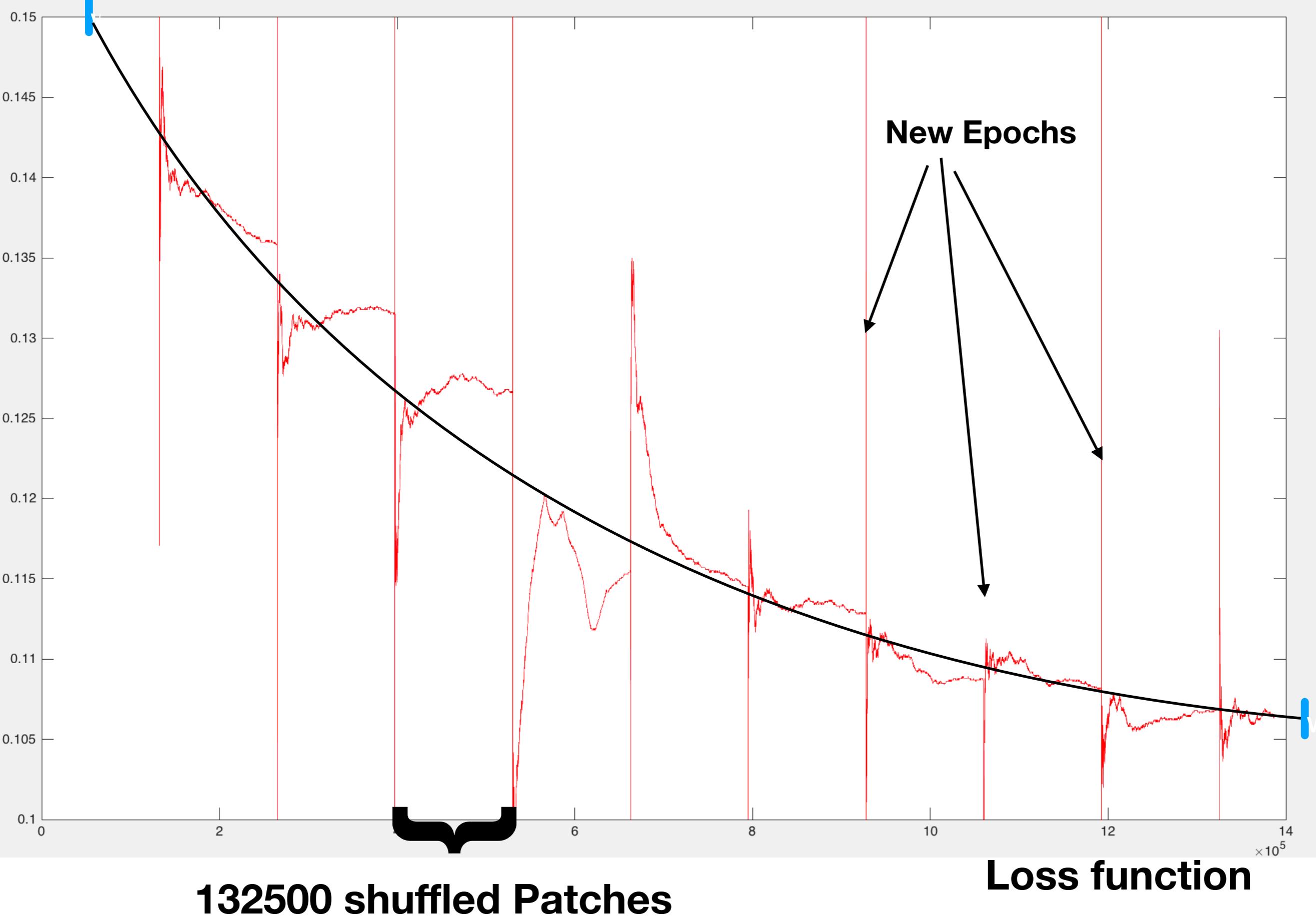
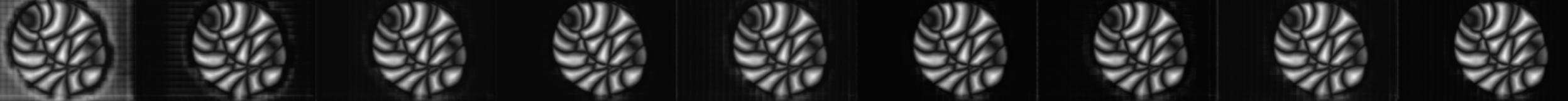
Prediction : 5 Min / time step

Learning

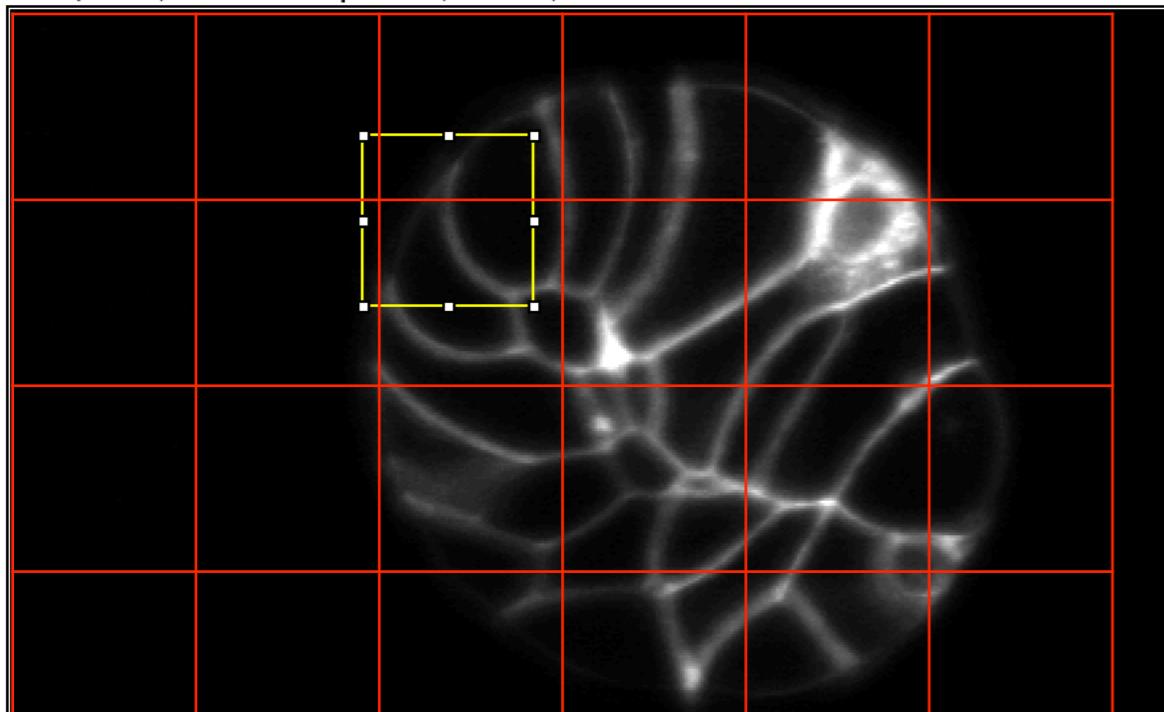


Epochs

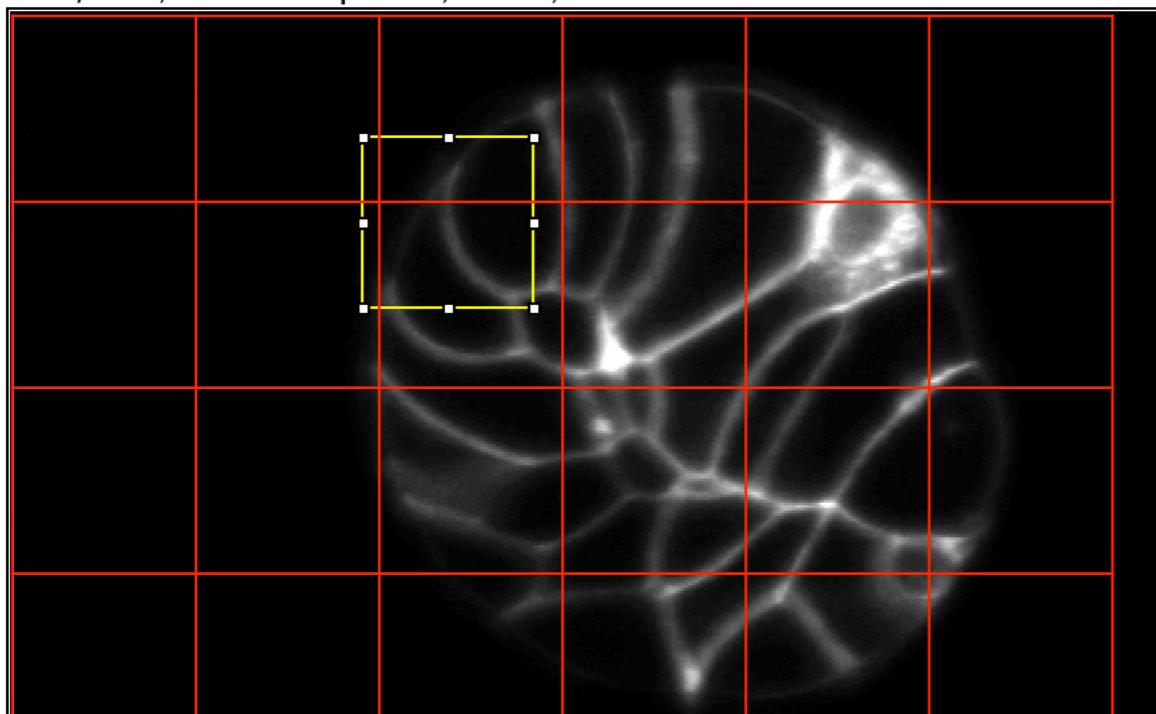




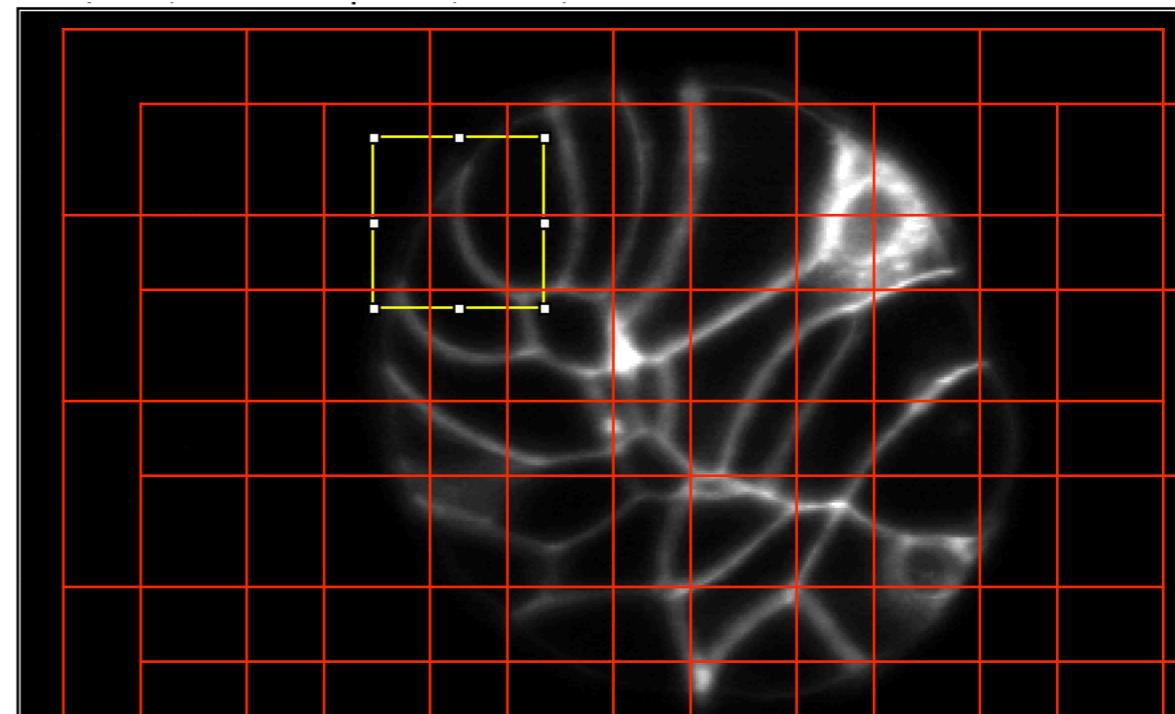
Patches Extraction



Patches Extraction

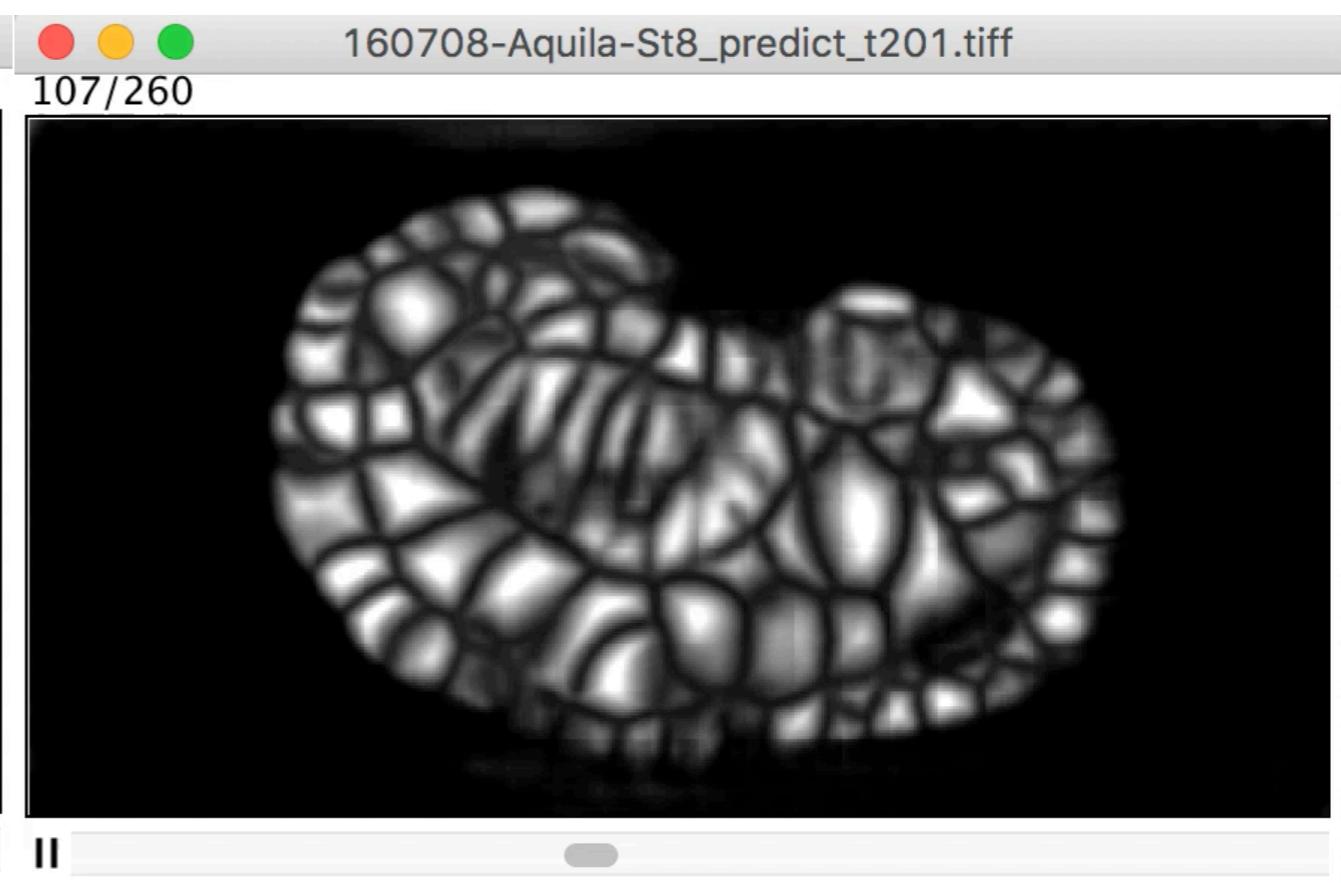
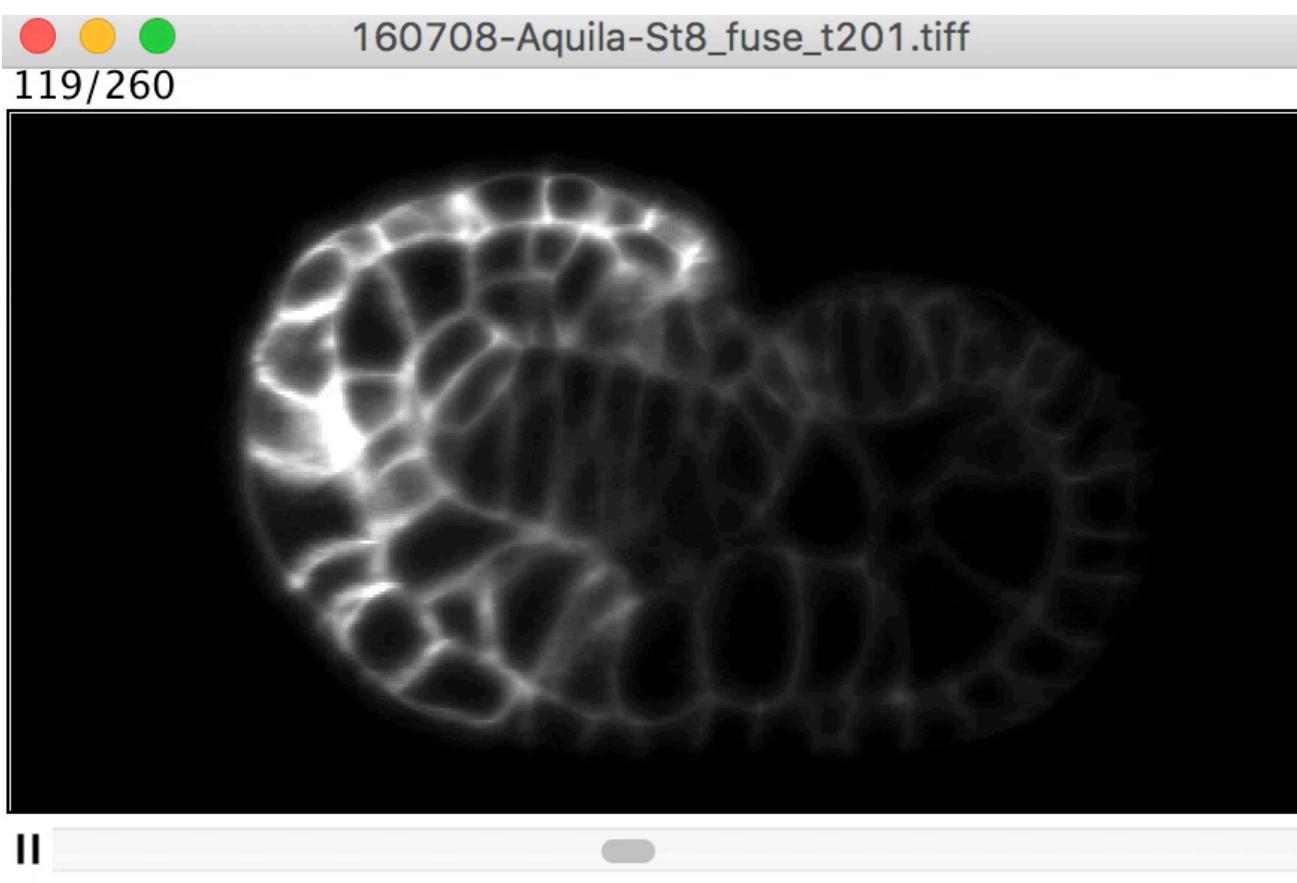


Sliding Patches Extraction

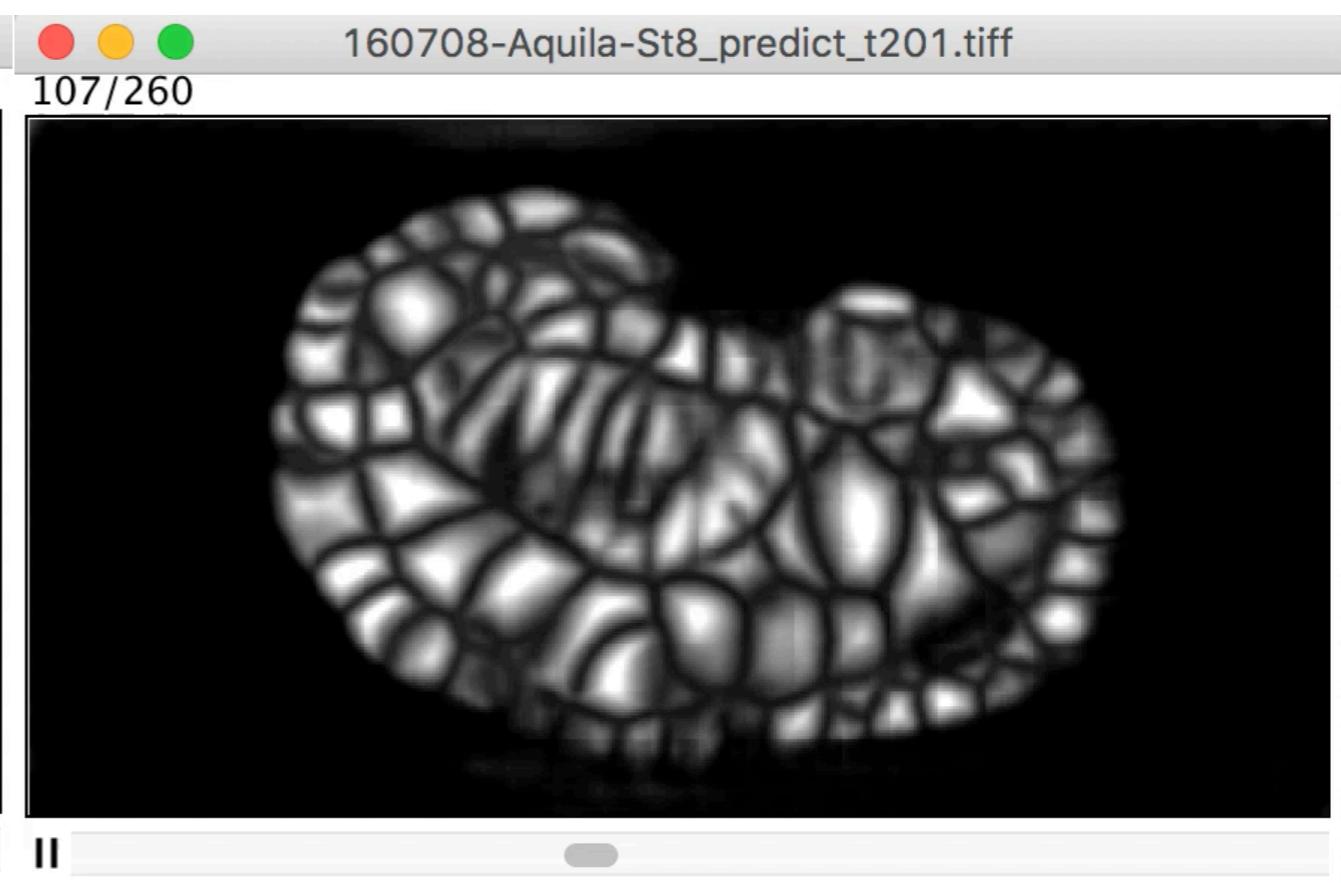
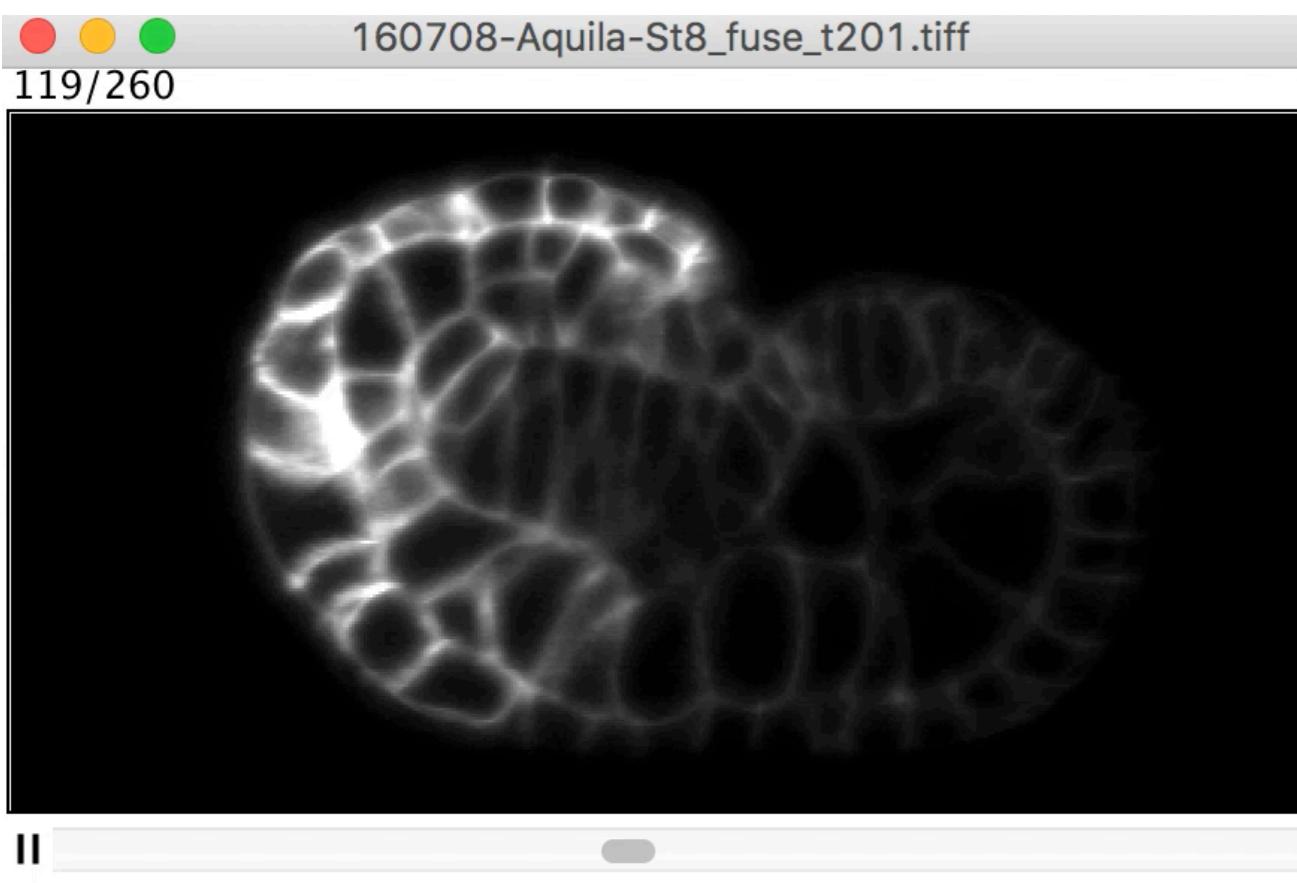


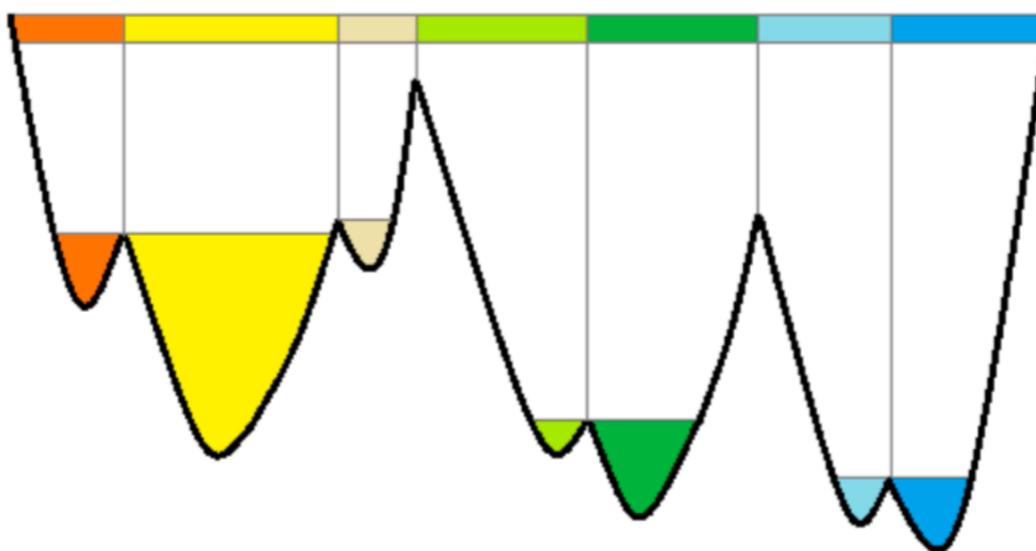
Average Patches Prediction

Best Prediction after 10 Epochs

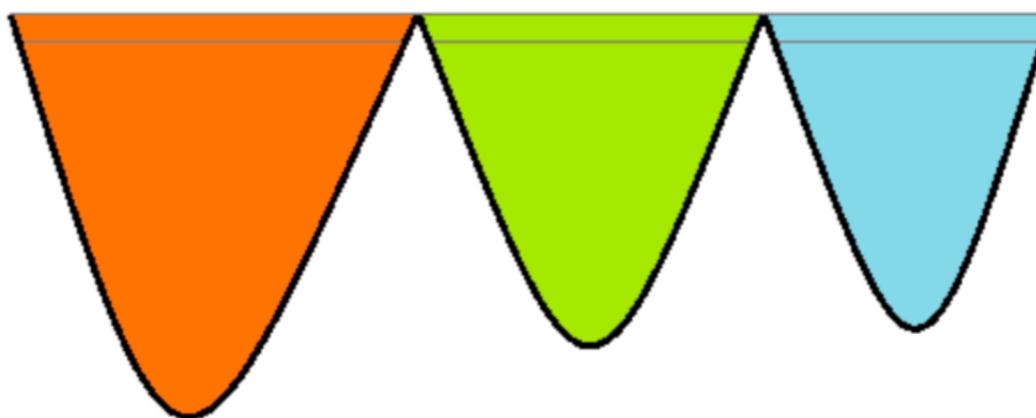


Best Prediction after 10 Epochs



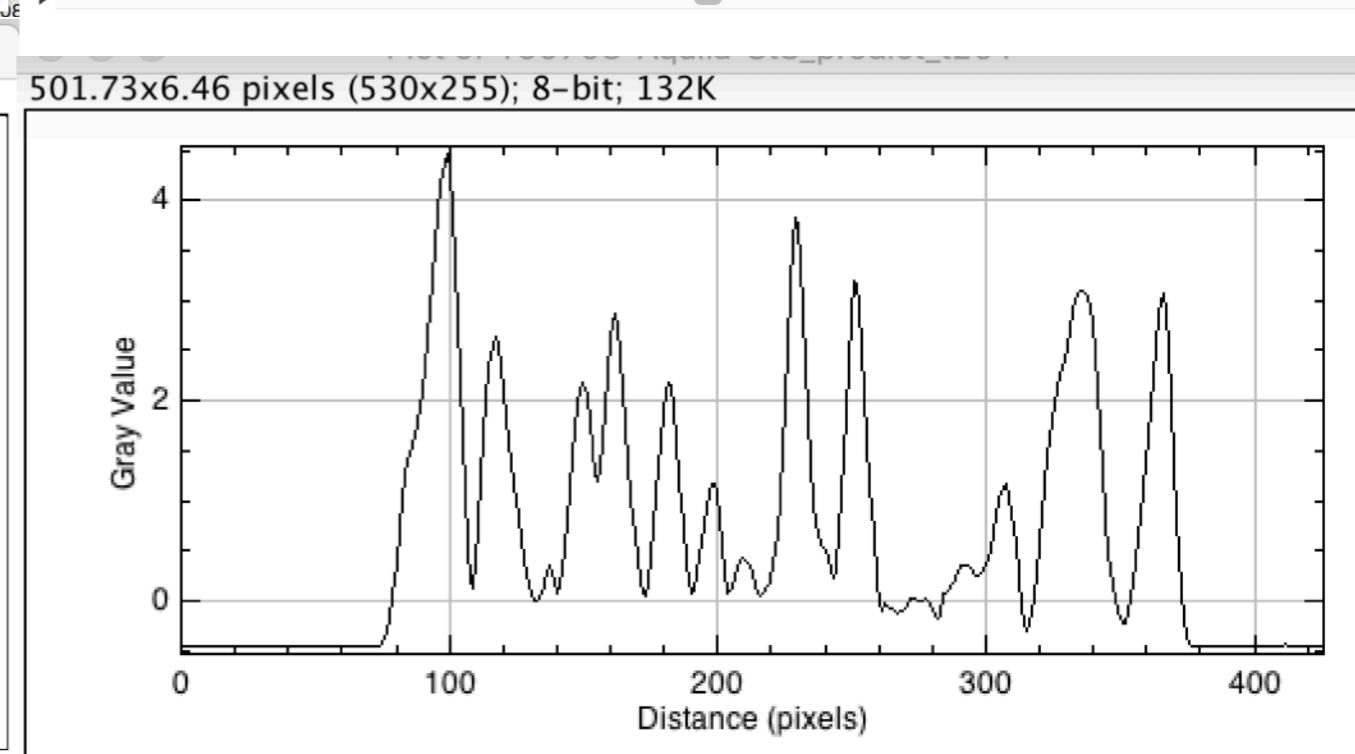
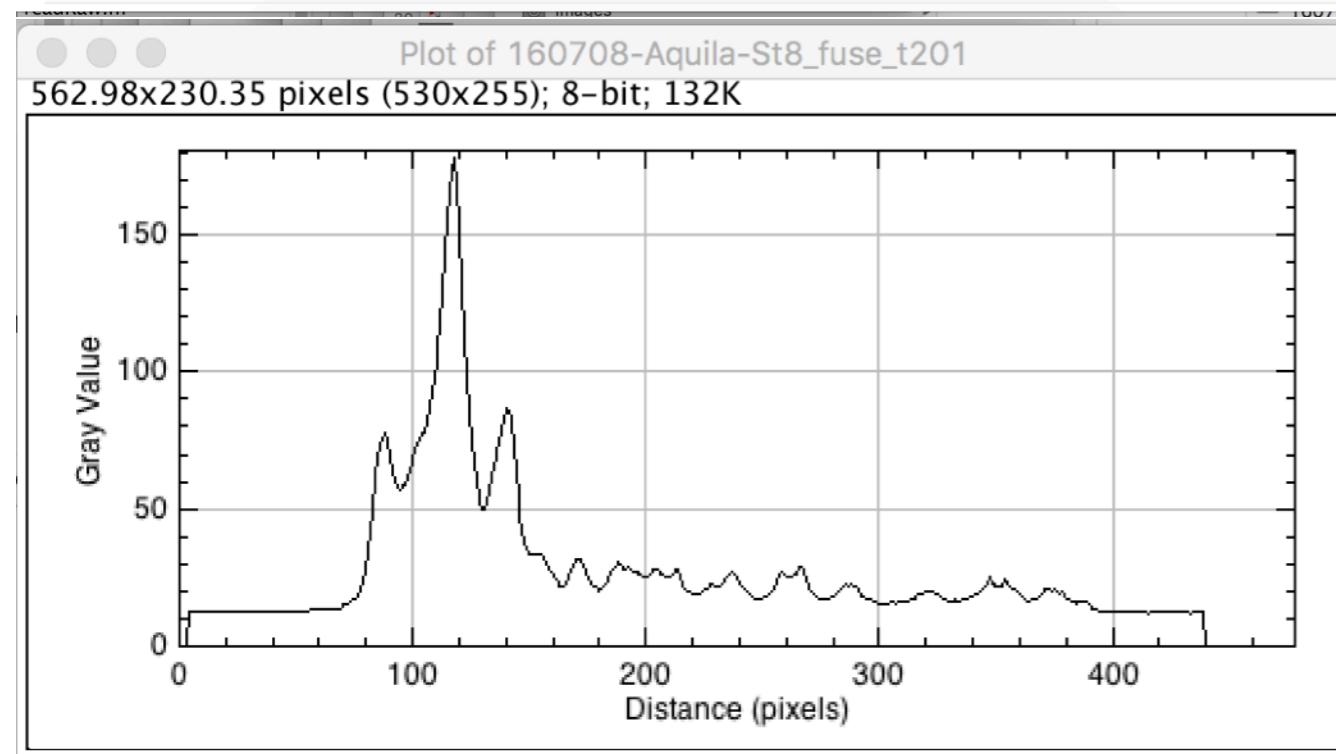
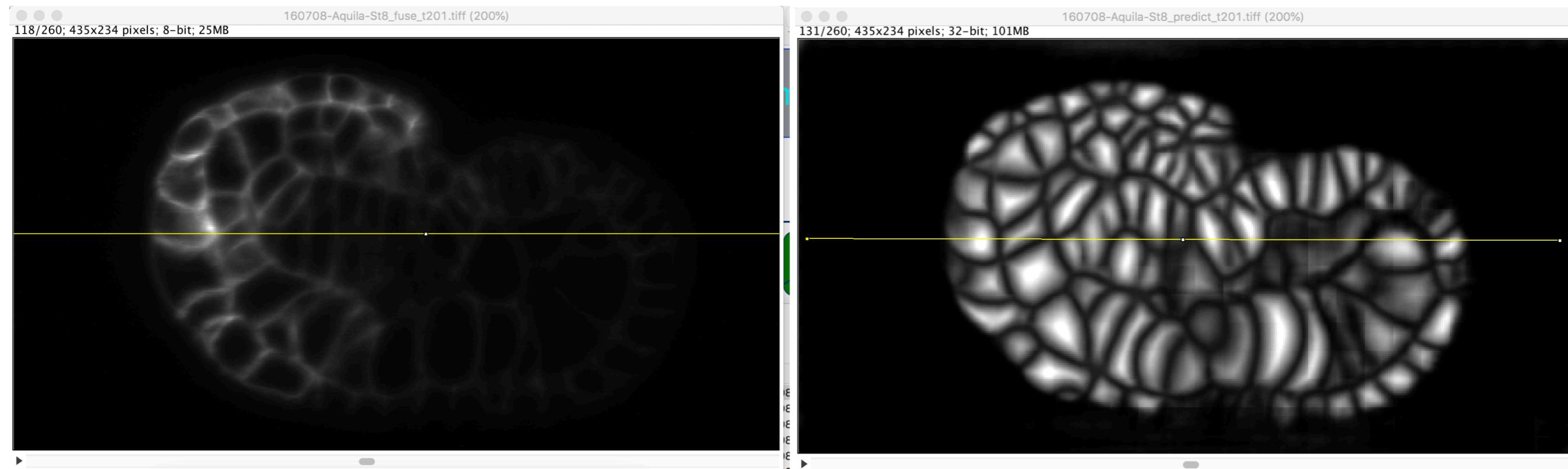


(a) Traditional Watershed Energy



(b) Our learned energy

Figure 2: Conceptual 1-D comparison between the traditional watershed transform and our deep watershed transform. The resulting instances are represented as colors across the top.



List

Save...

More »

Live

List

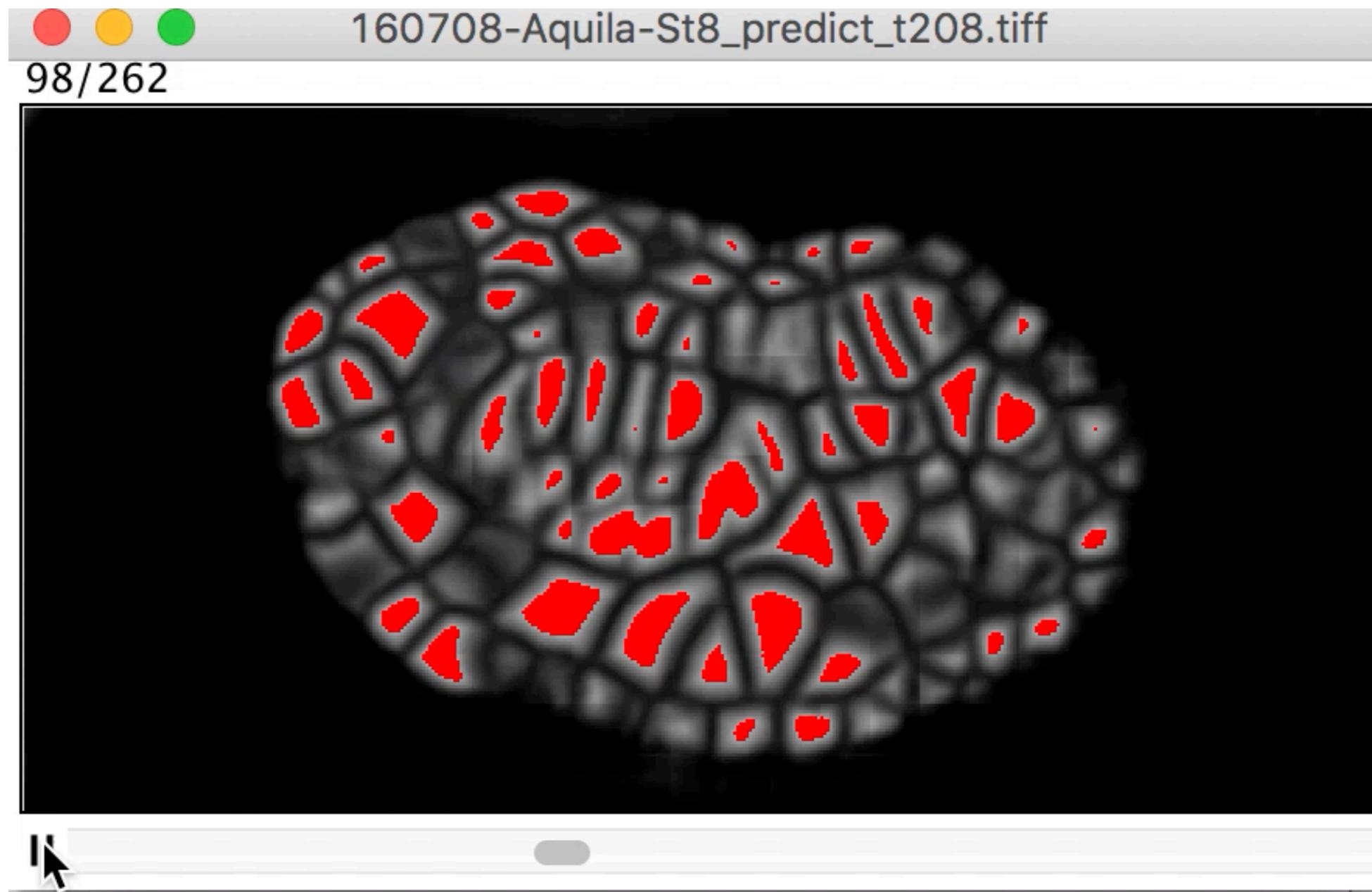
Save...

More »

Live

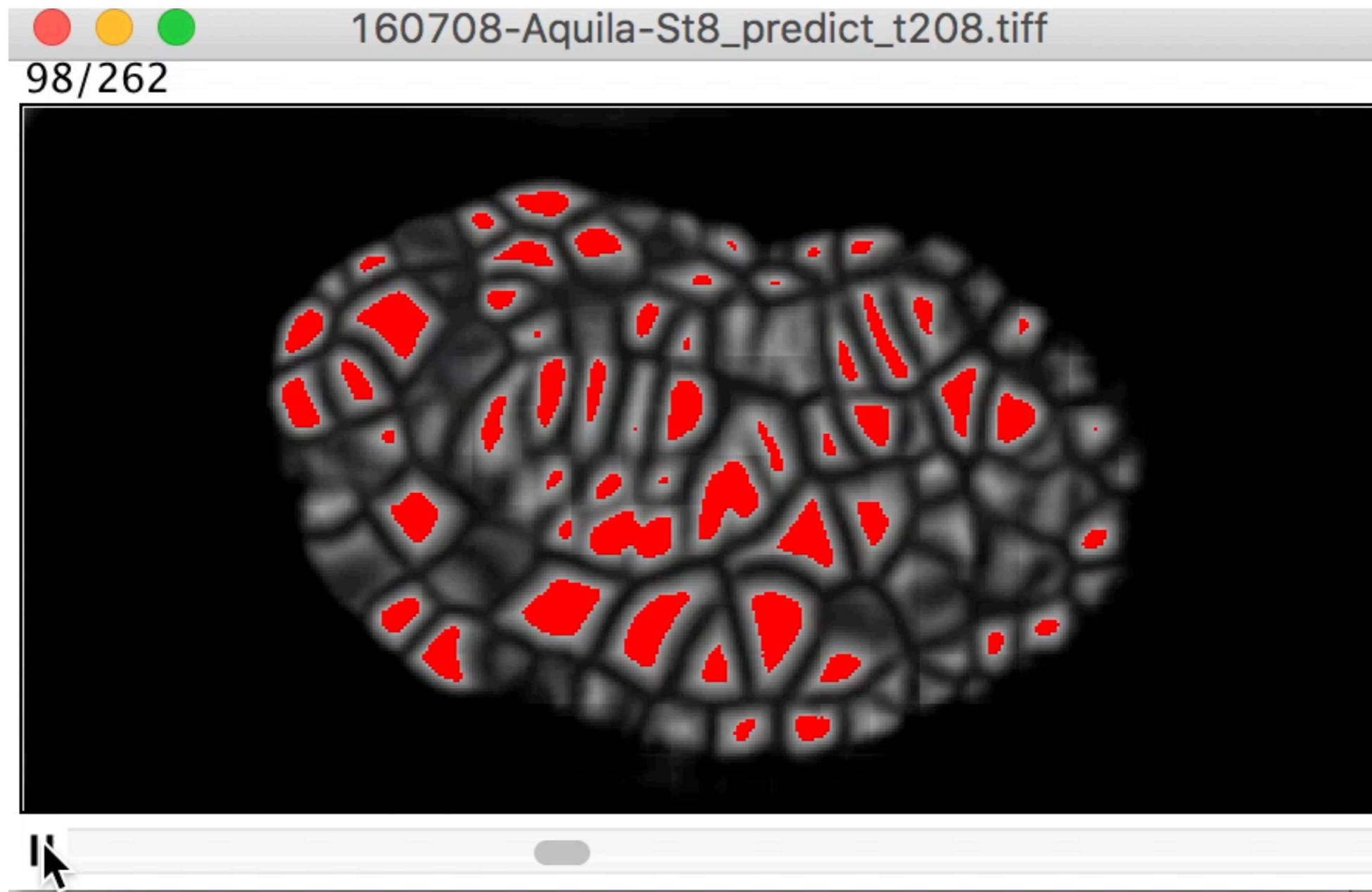
Simple Segmentation : Threshold

T=201



Simple Segmentation : Threshold

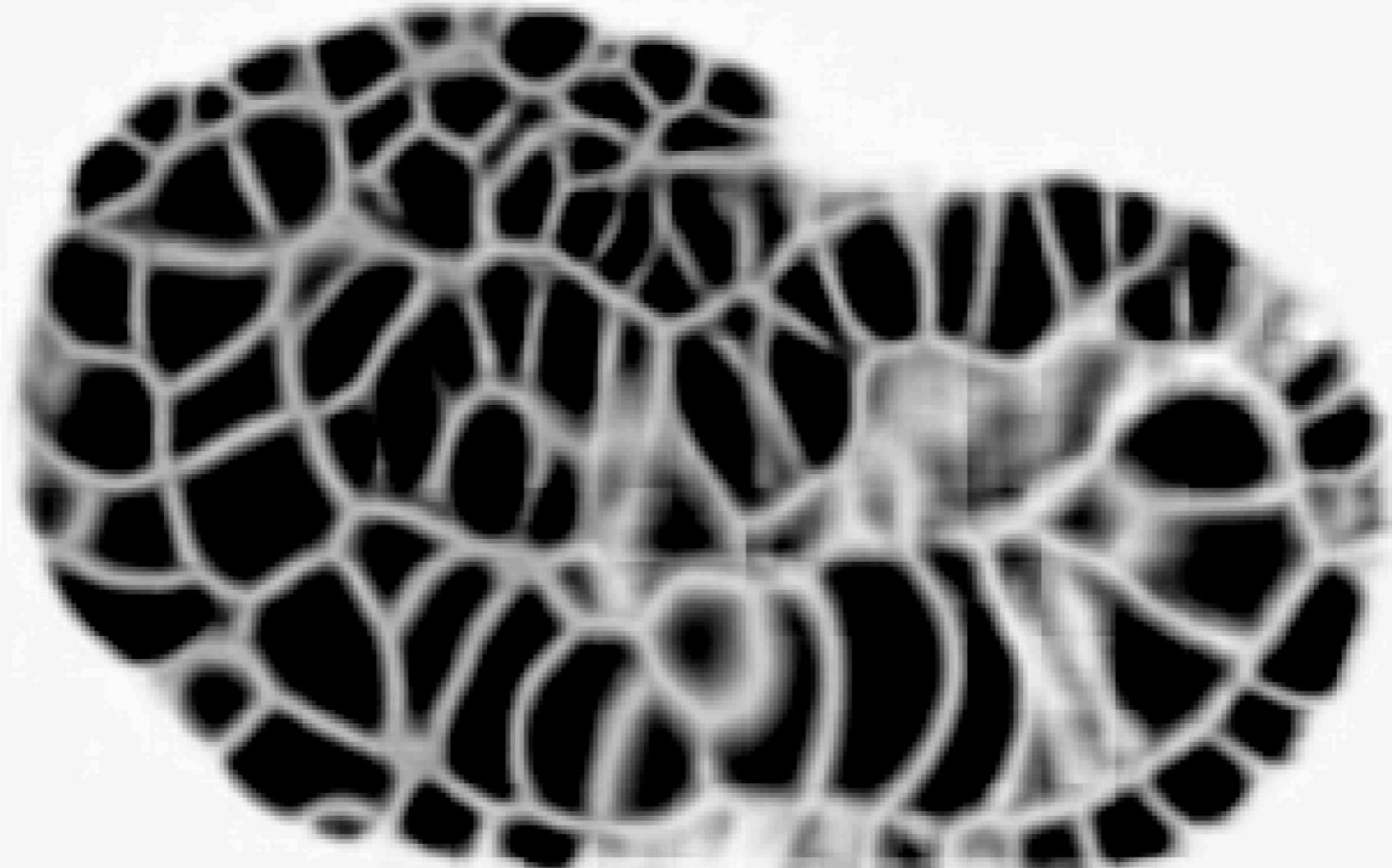
T=201



Invert Prediction

160708-Aquila-St8_predict_t201.tiff (300%)

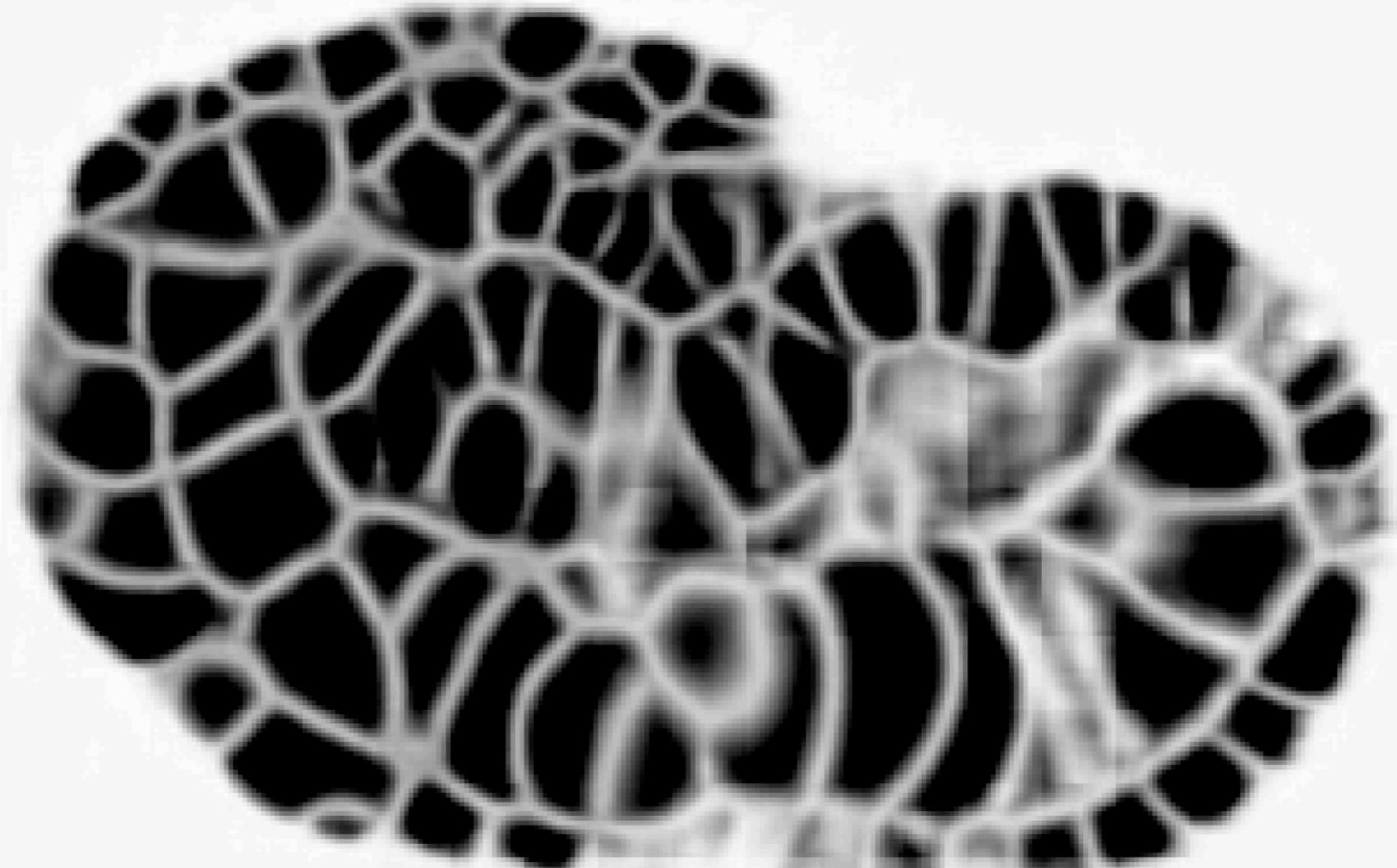
132/260



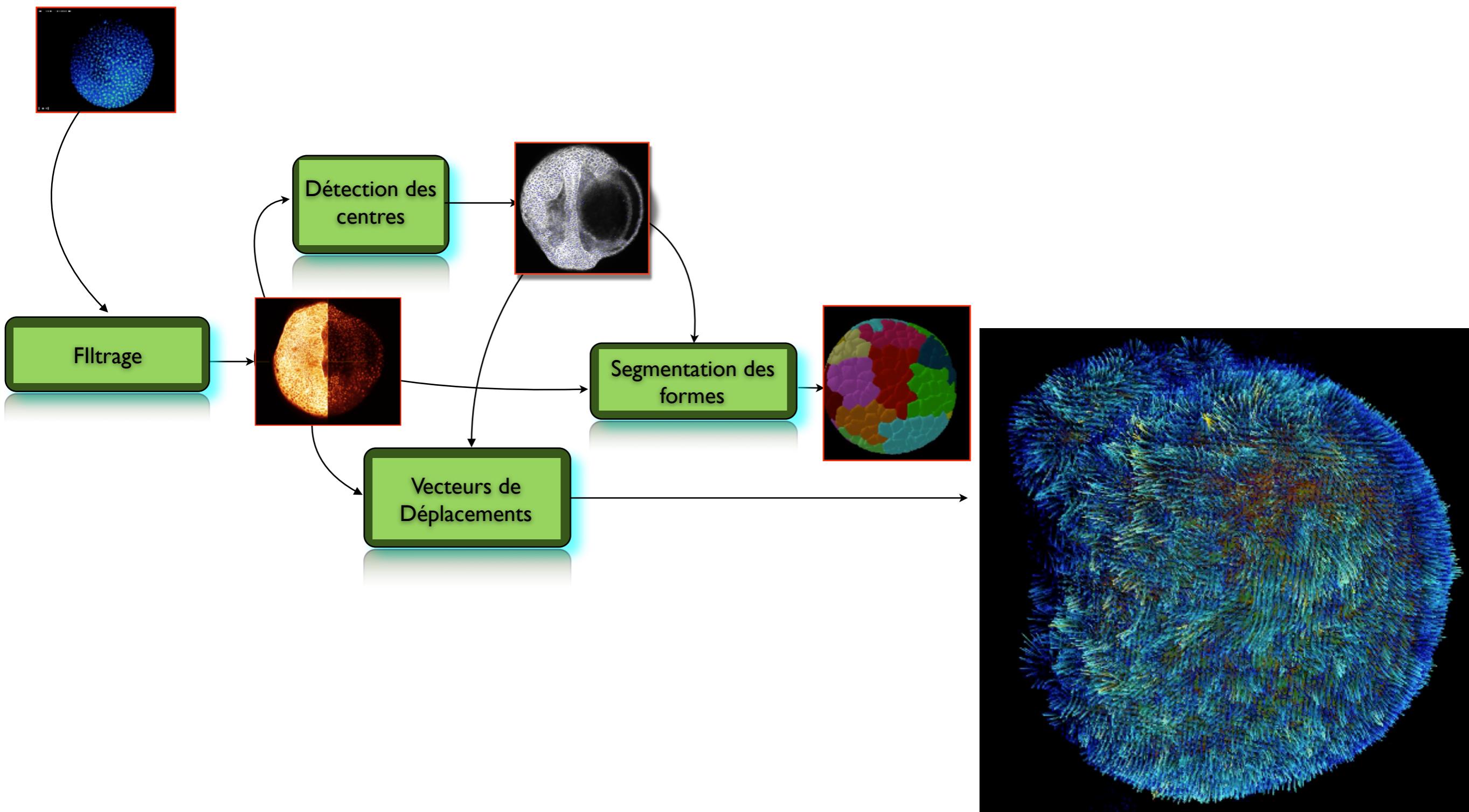
Invert Prediction

160708-Aquila-St8_predict_t201.tiff (300%)

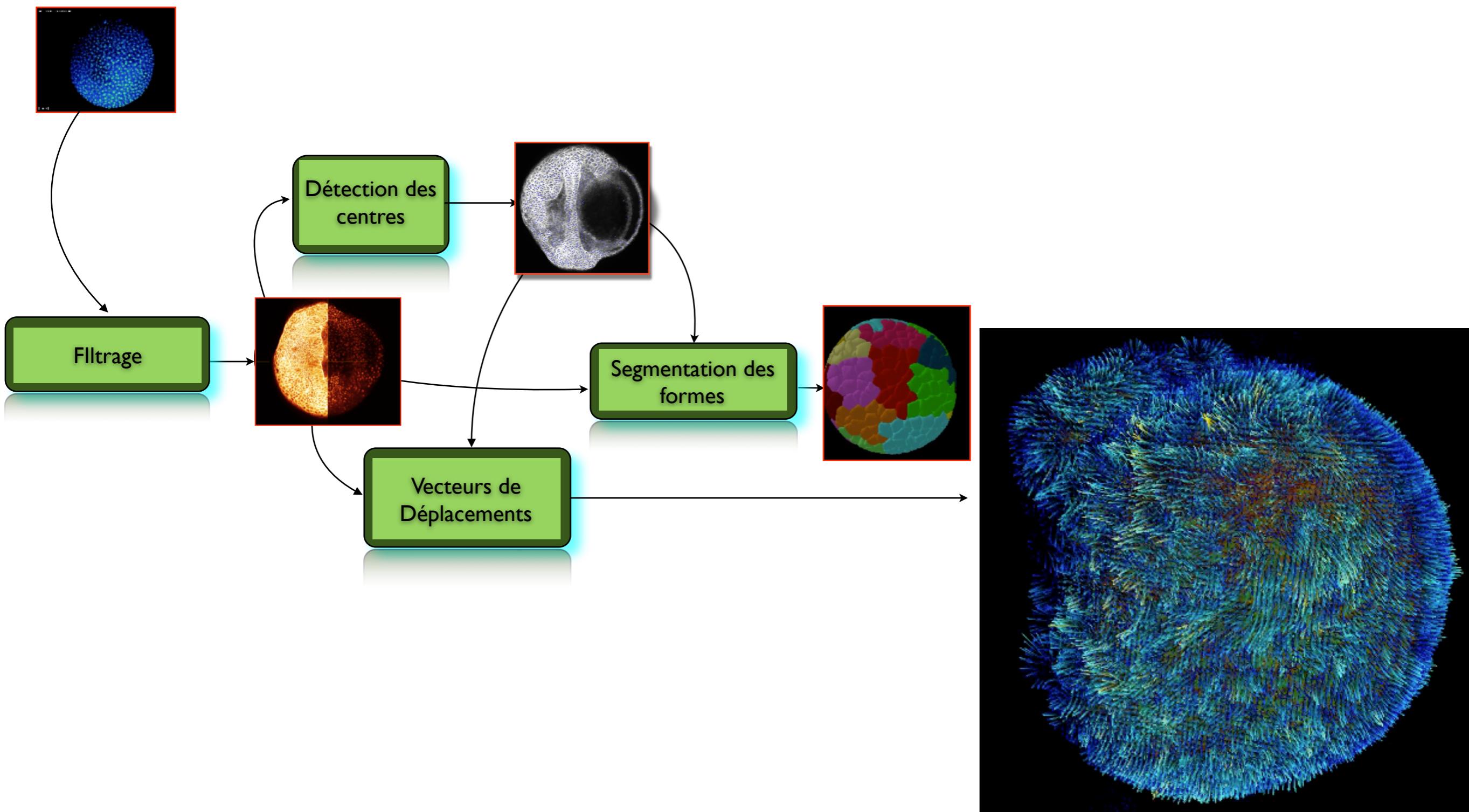
132/260



Reconstruction Image 4D



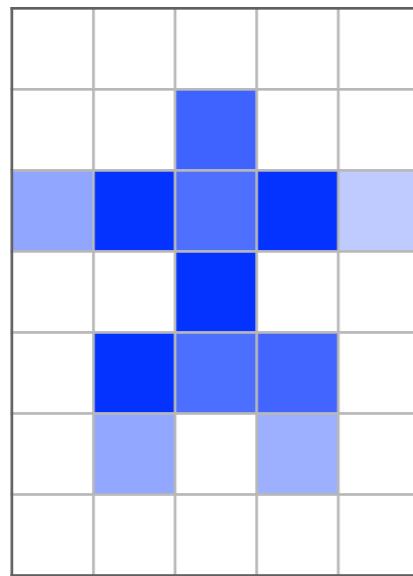
Reconstruction Image 4D



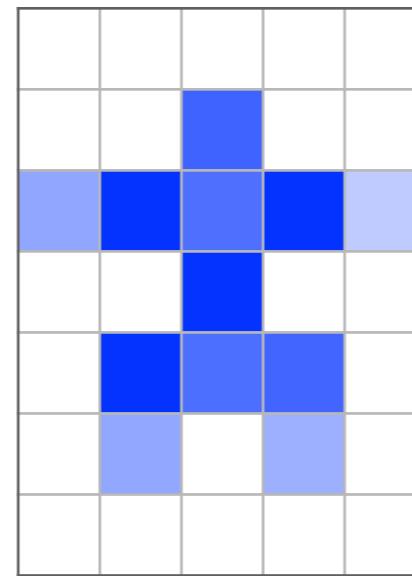
Vecteurs de déplacements (Flot optique)

Recalage non rigide

t



$t + \Delta t$

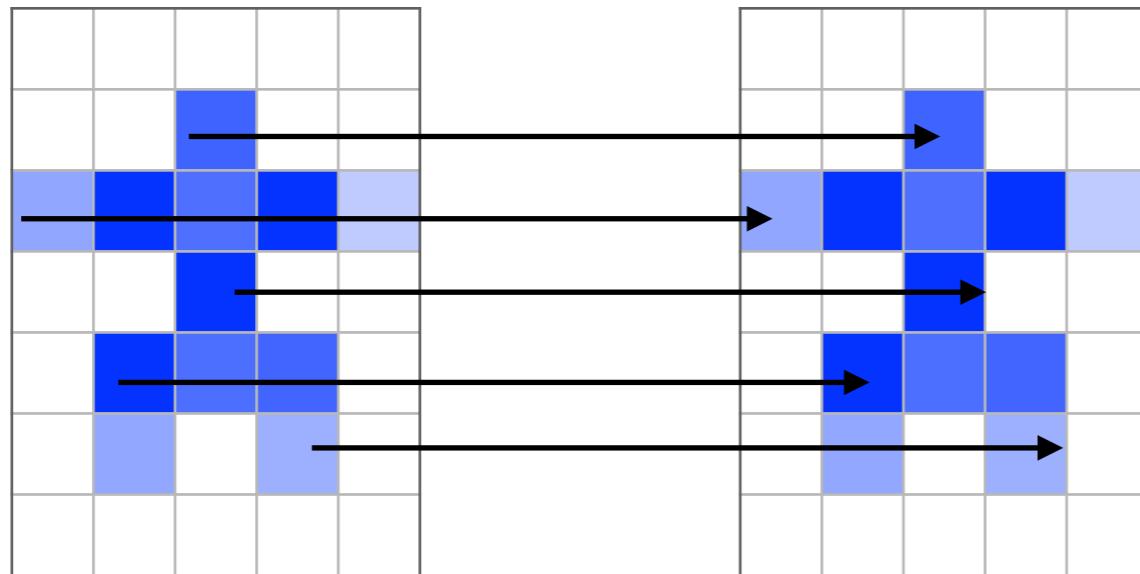


Vecteurs de déplacements (Flot optique)

Recalage non rigide

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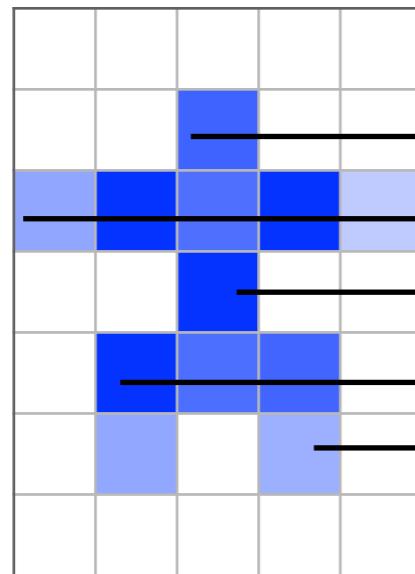
$t + \Delta t$



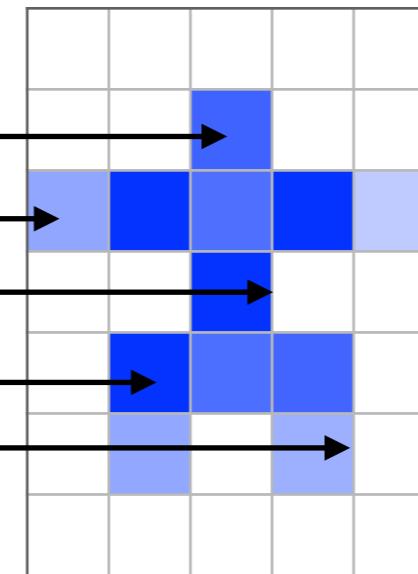
Vecteurs de déplacements (Flot optique)

Recalage non rigide

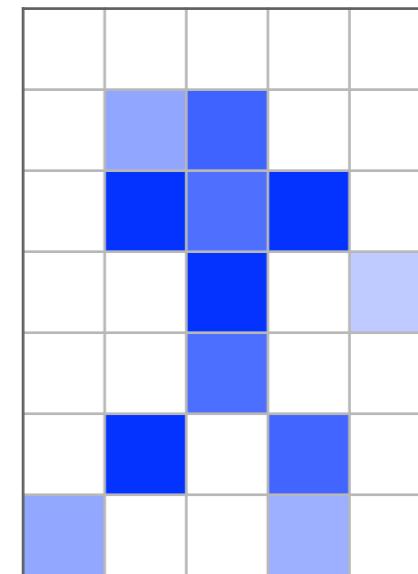
t



$t + \Delta t$

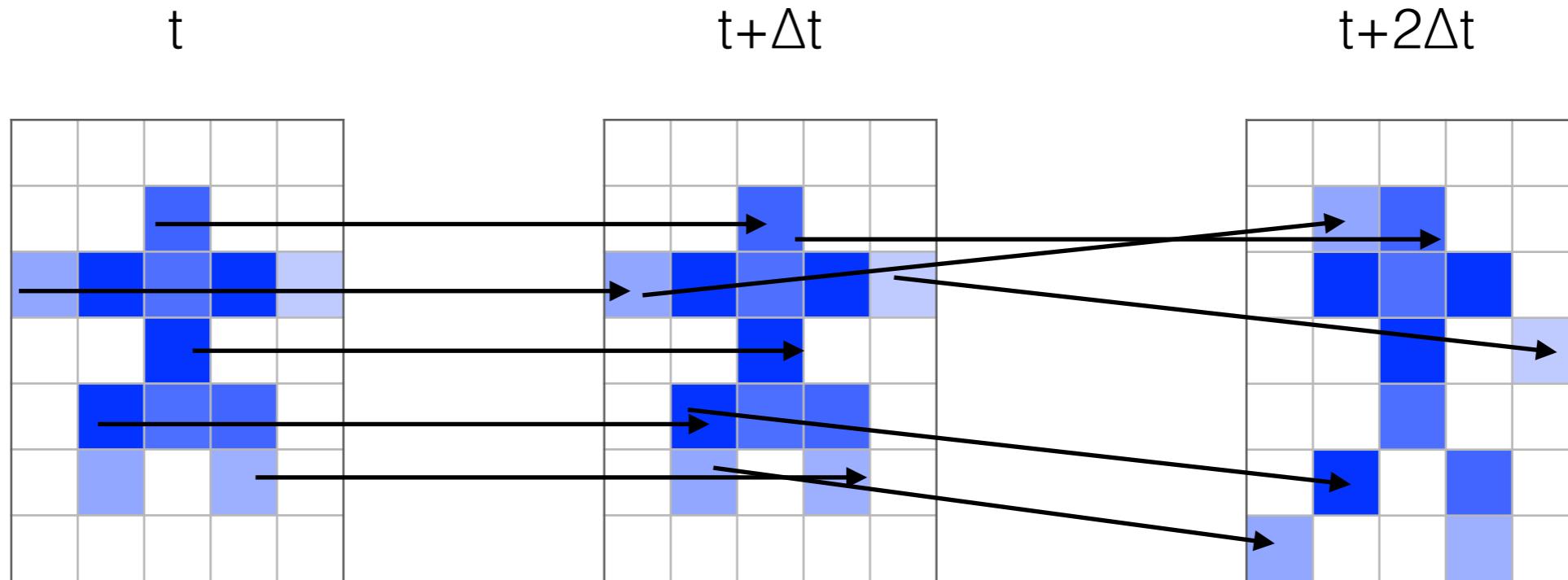


$t + 2\Delta t$



Vecteurs de déplacements (Flot optique)

Recalage non rigide



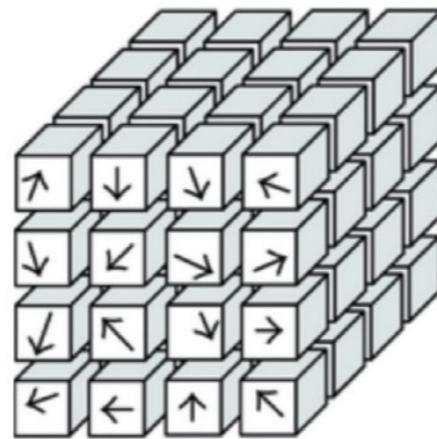
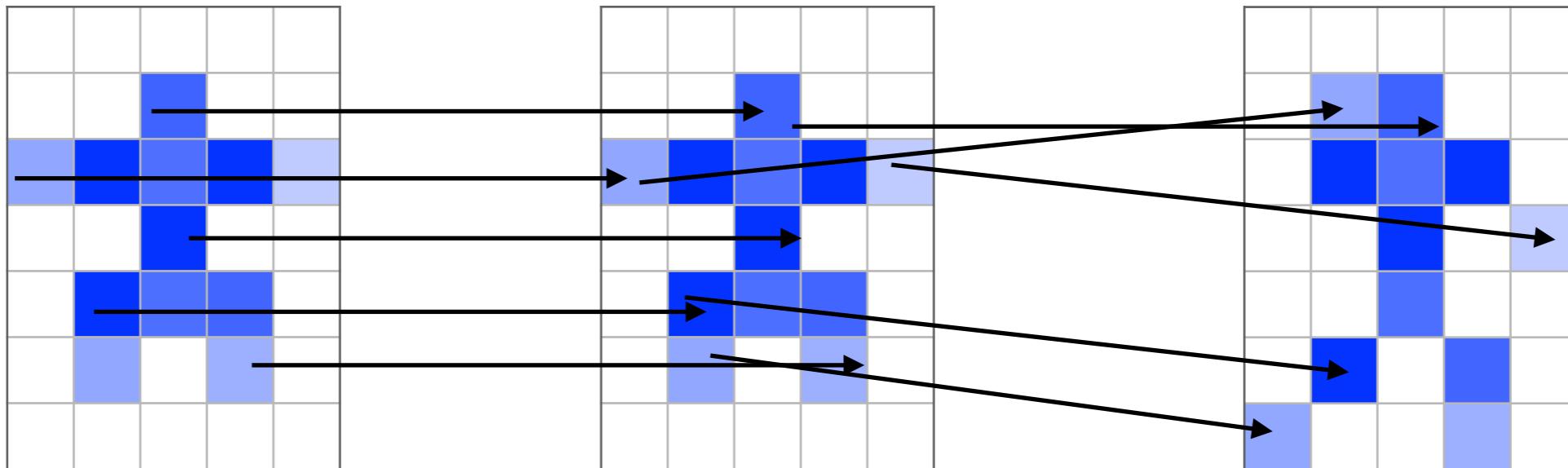
Vecteurs de déplacements (Flot optique)

Recalage non rigide

t

$t + \Delta t$

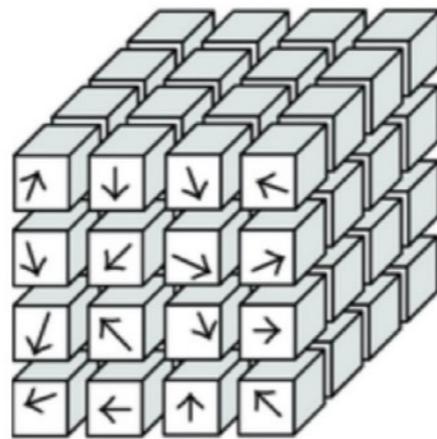
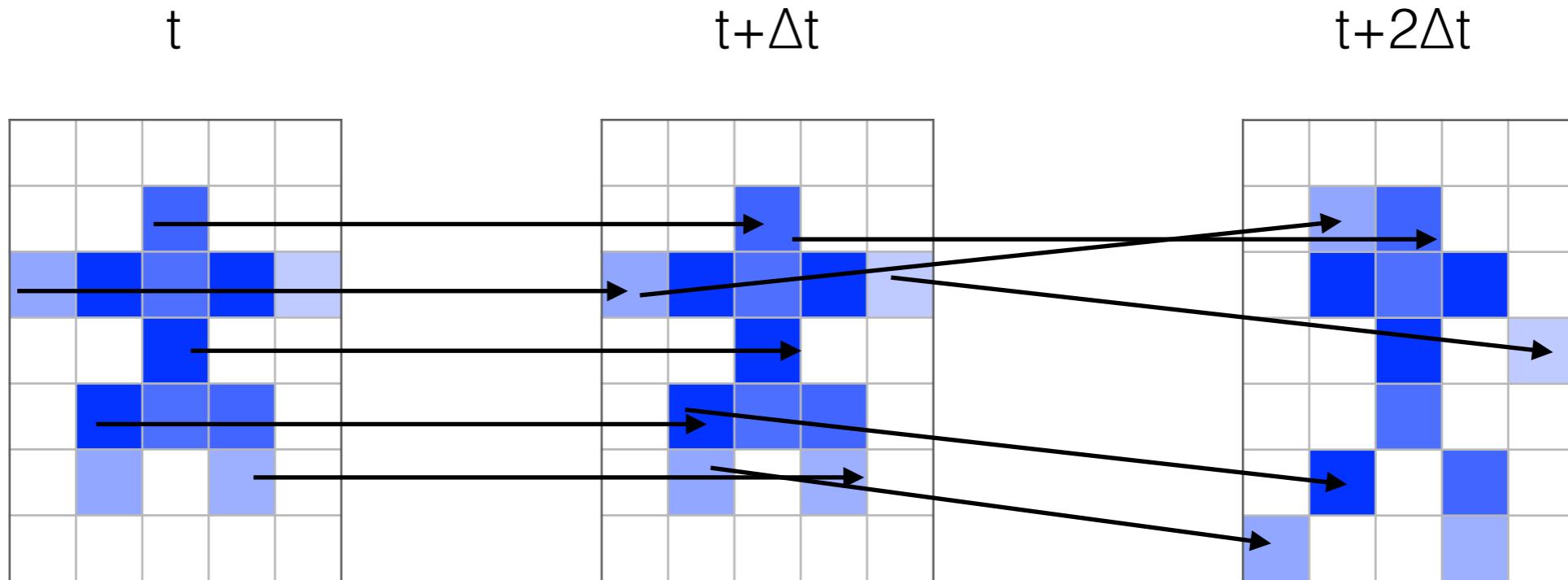
$t + 2\Delta t$



4D

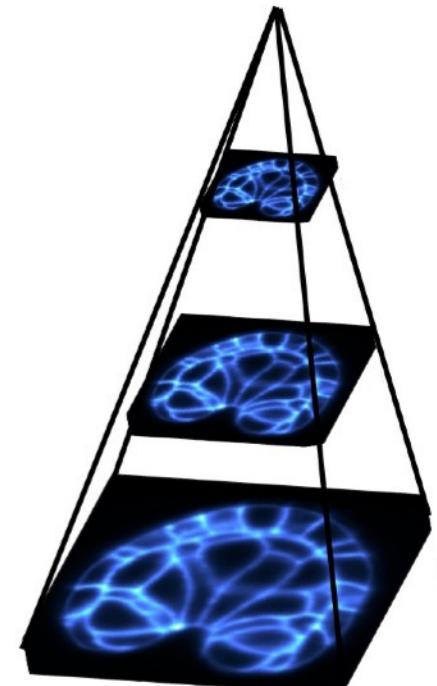
Vecteurs de déplacements (Flot optique)

Recalage non rigide



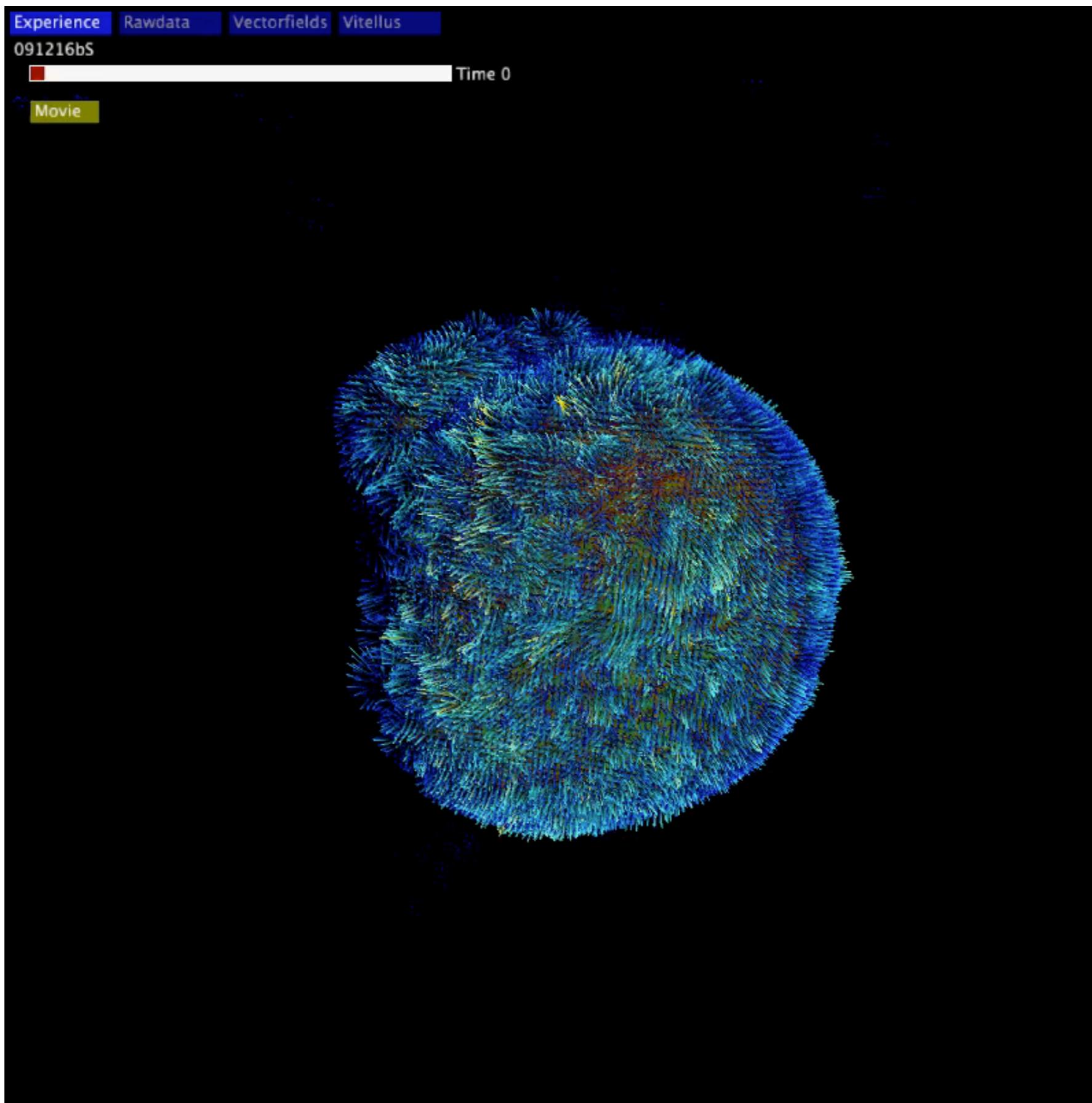
4D

Hypothèse : invariance de l'intensité de chaque voxel entre 2 images

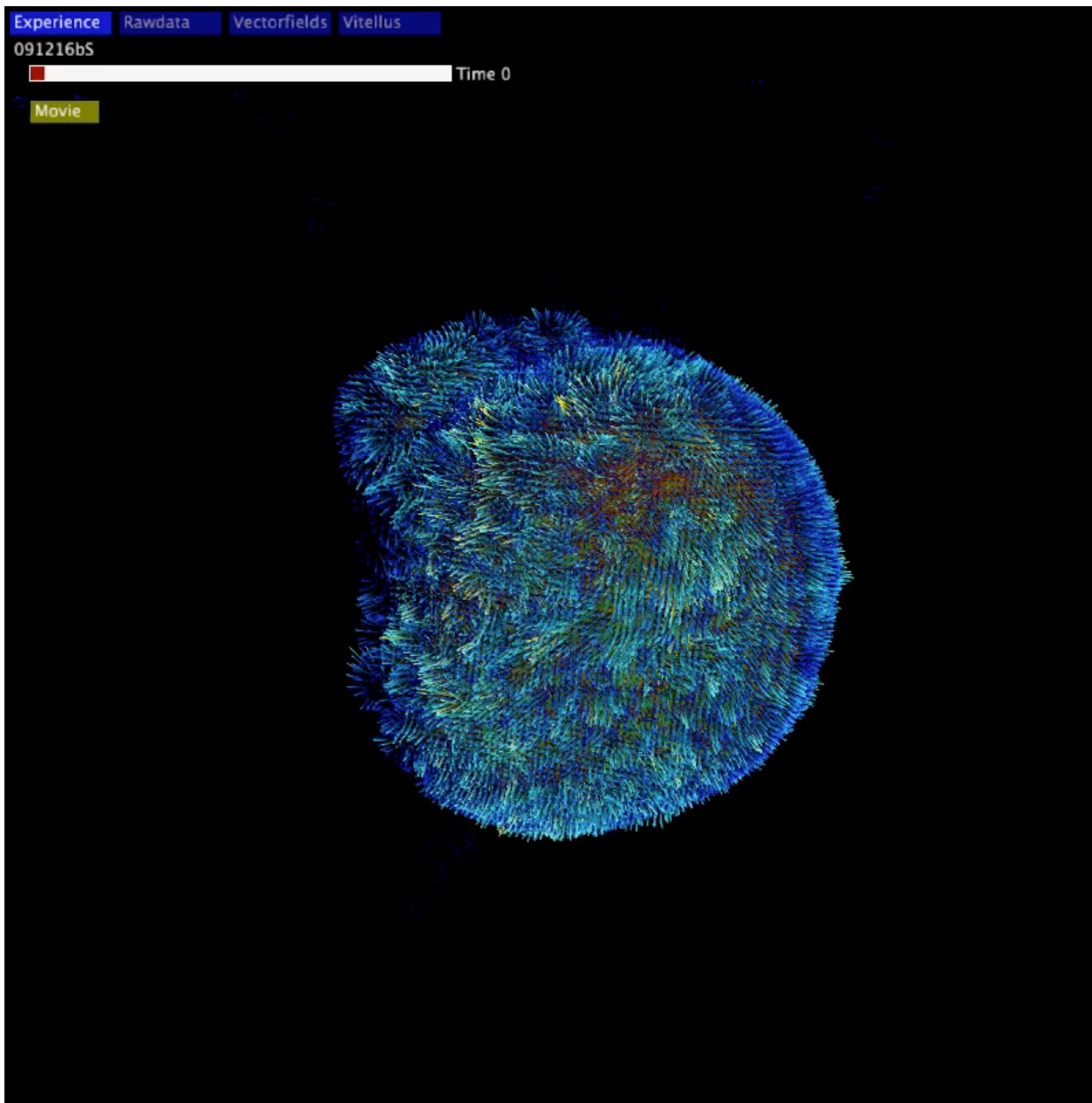


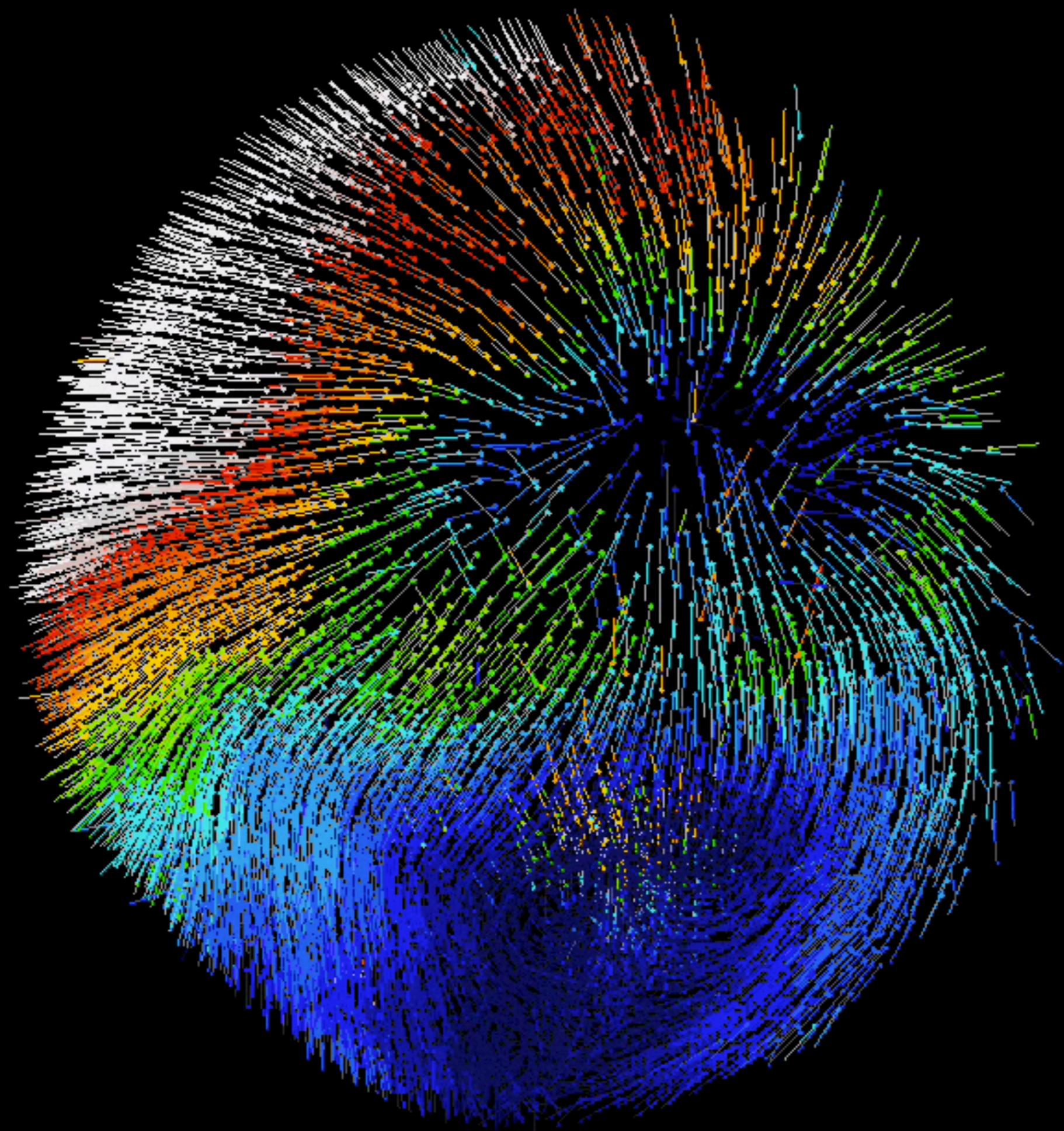
Approche multi-résolution

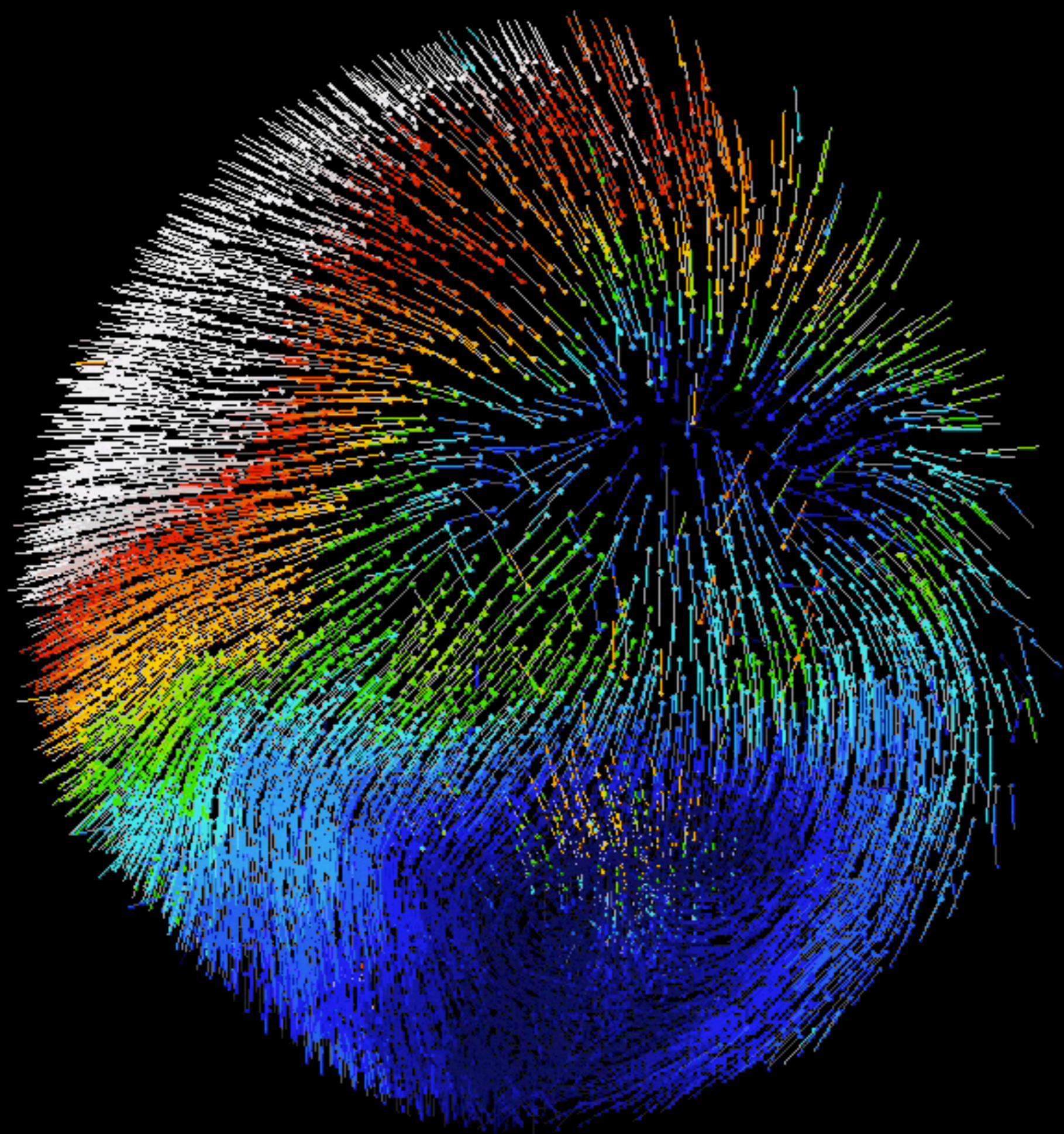
Moyenne spatial et temporel



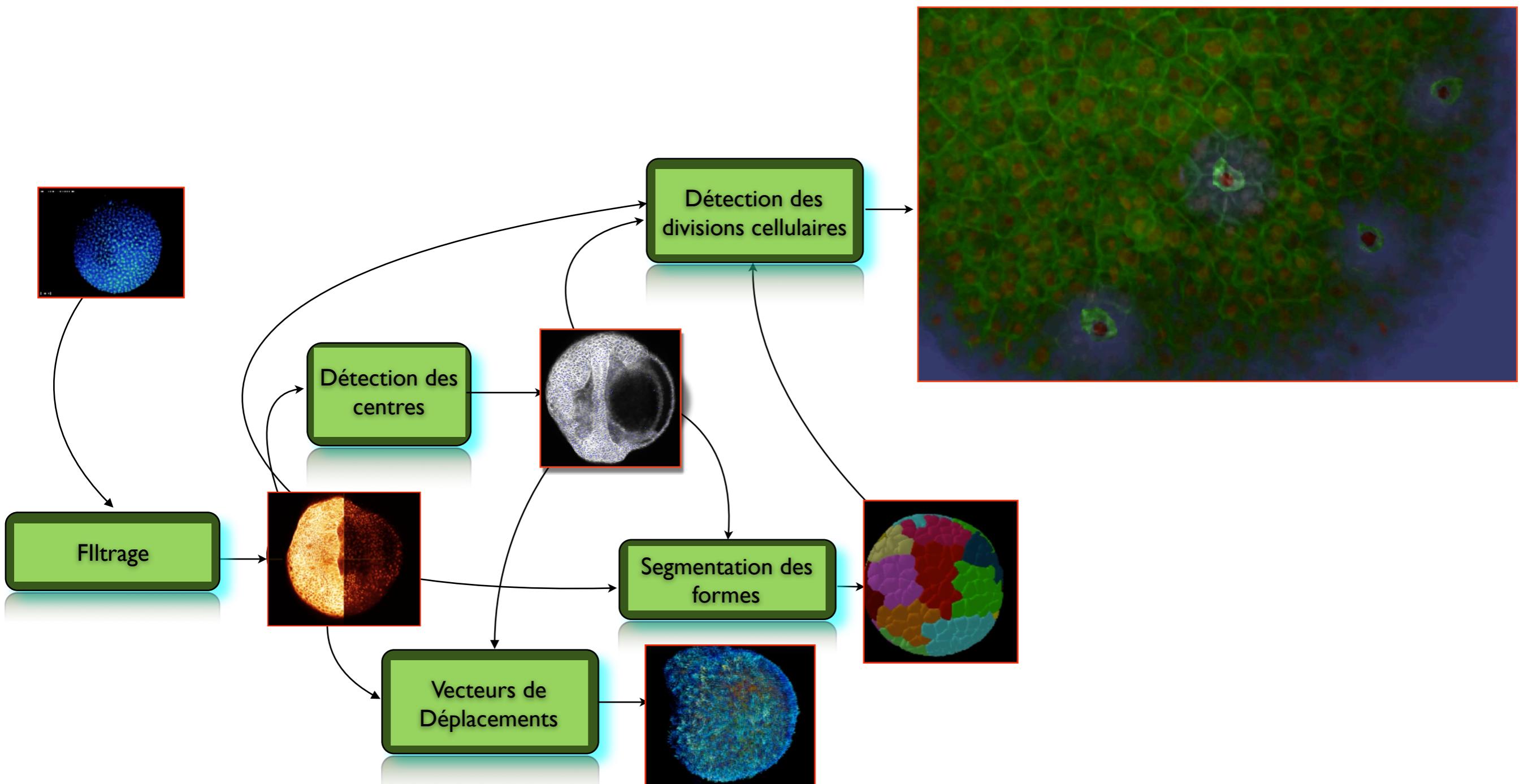
Moyenne spatial et temporel



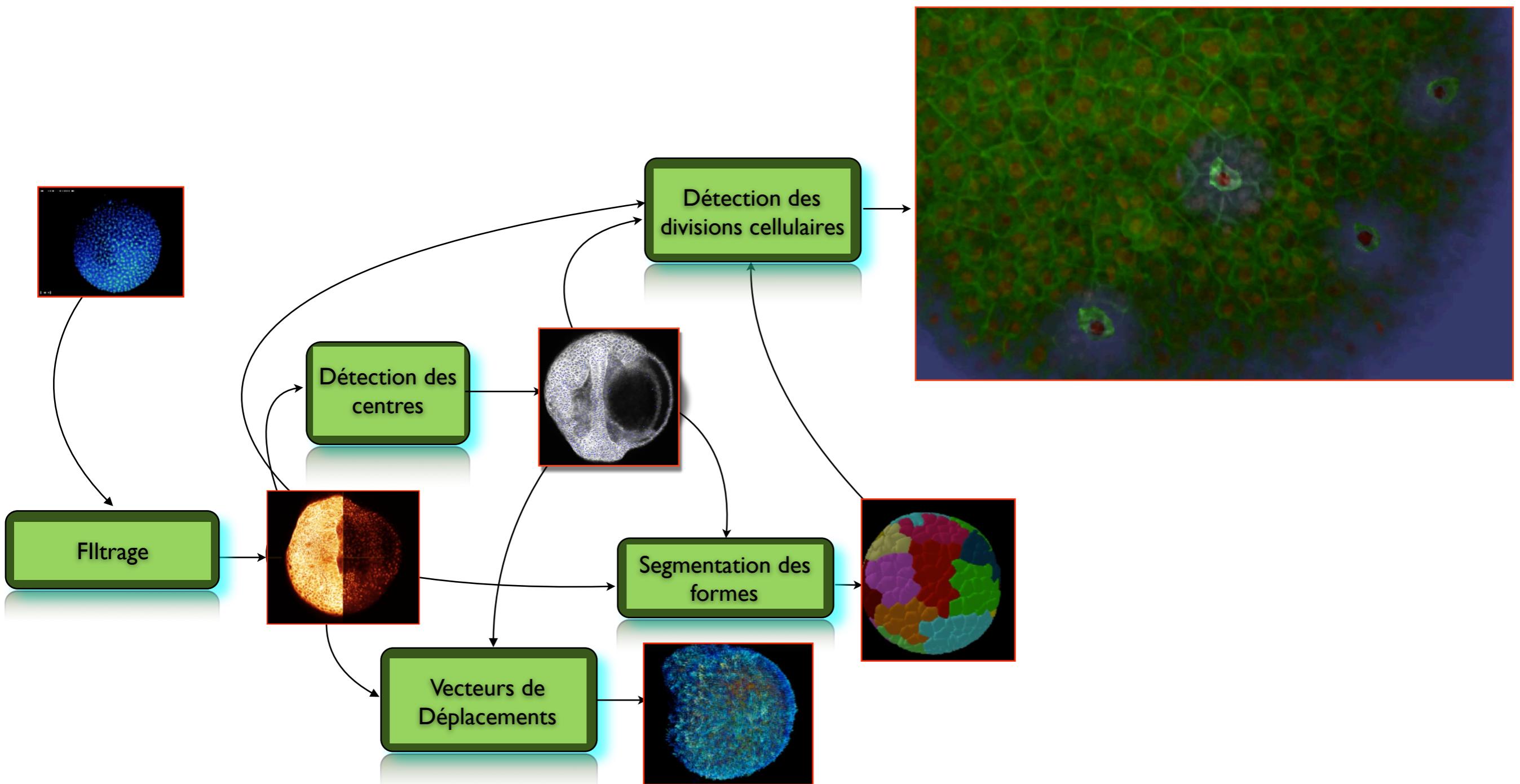




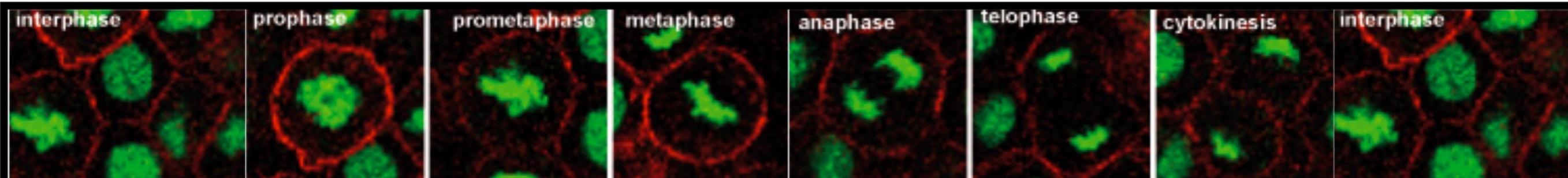
Reconstruction Image 4D



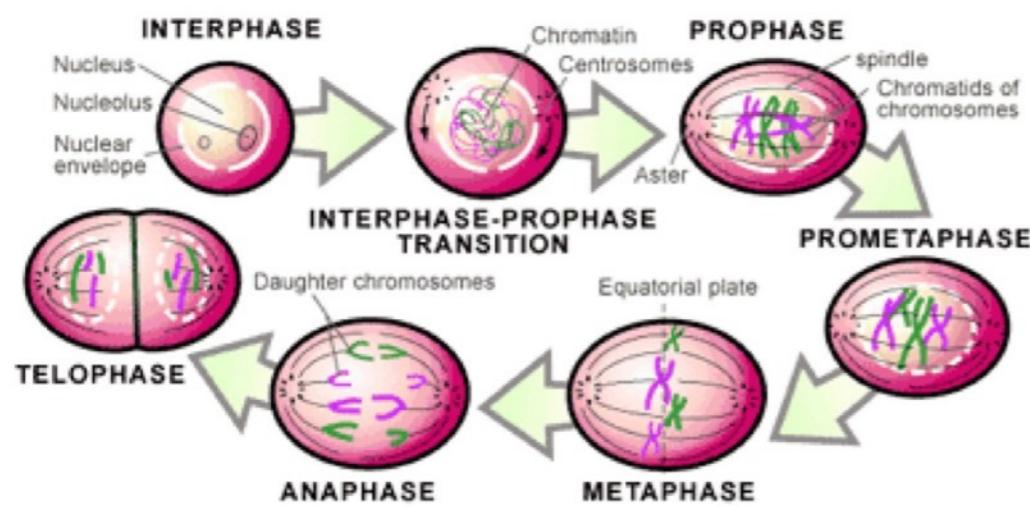
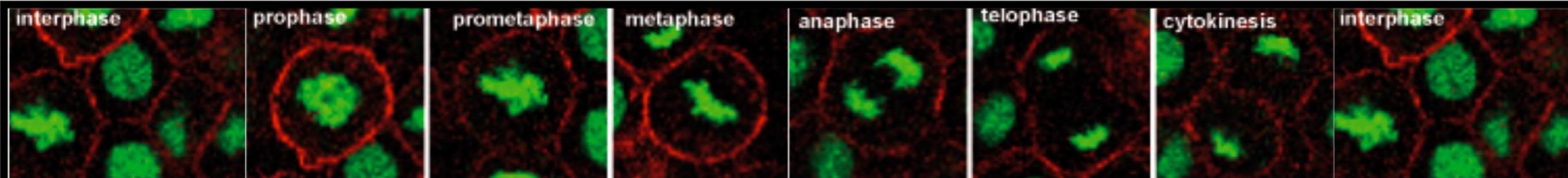
Reconstruction Image 4D



Détection des divisions cellulaires



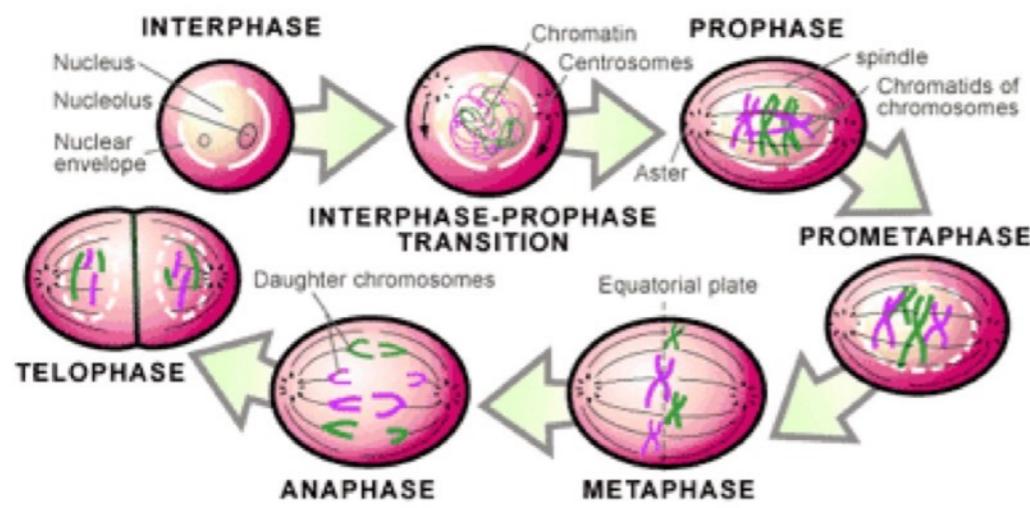
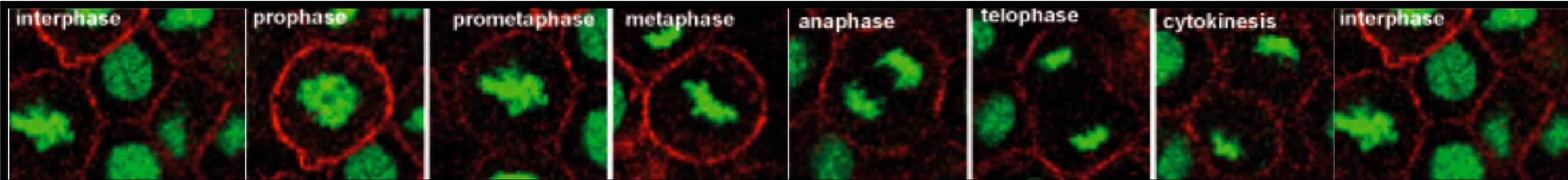
Détection des divisions cellulaires



- **Prophase** : Membrane : shape + convex
- **Prometaphase** : Nucleus : volume down
- **Metaphase** : Nucleus : higher intensity
- **Anaphase** : 2 closest nuclei , 1 Membrane.
- **Telophase** : Membrane : shape change
- **Cytokinesis** : 2 Membranes

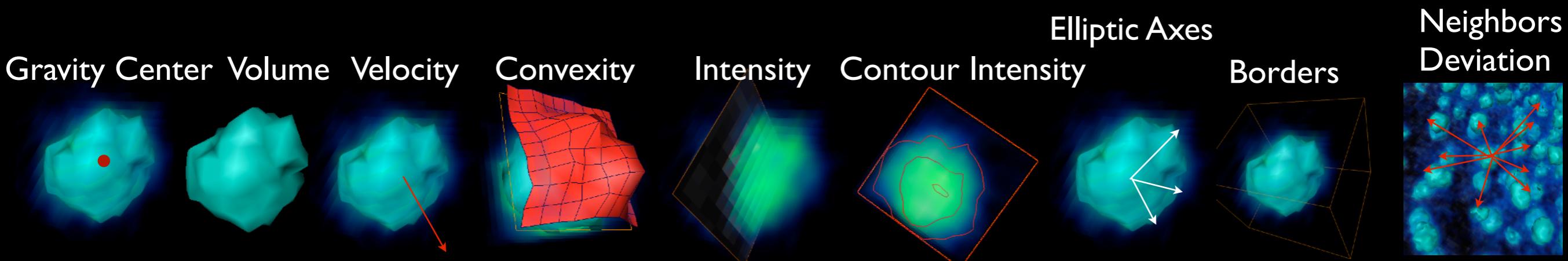
+ Interphase → 7 classes

Détection des divisions cellulaires

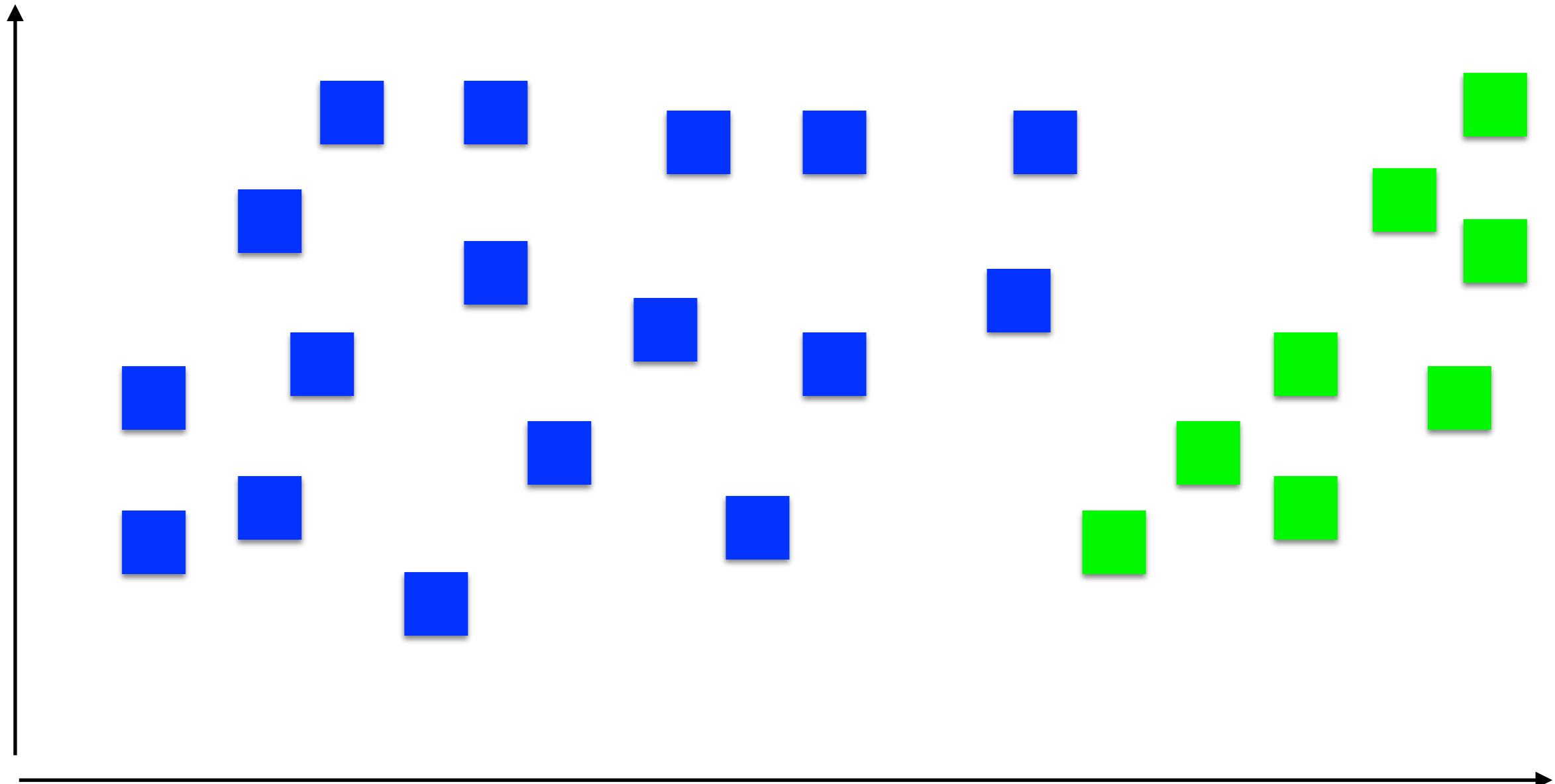


- **Prophase** : Membrane : shape + convex
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+ Interphase → 7 classes

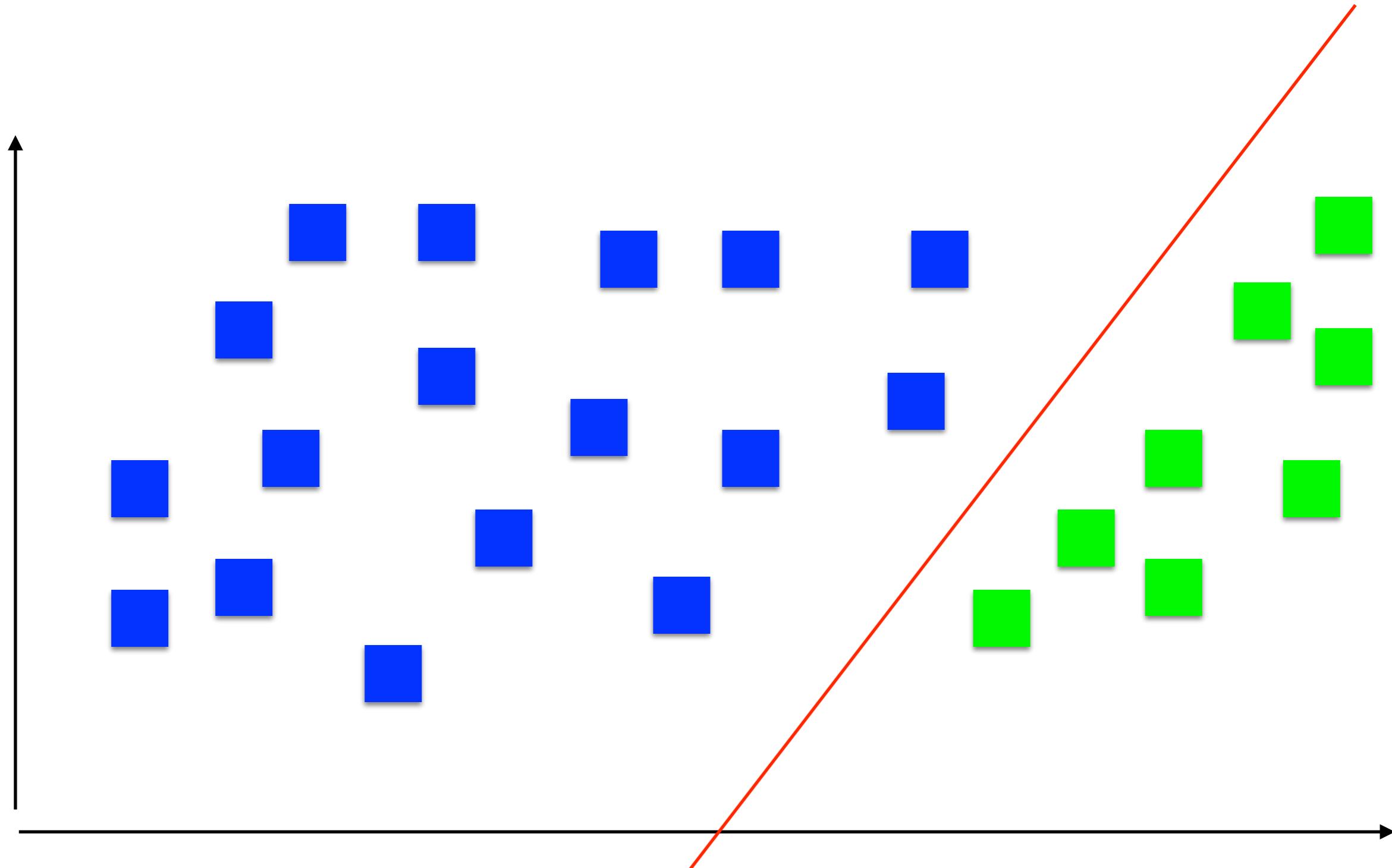


Très courte introduction à la classification



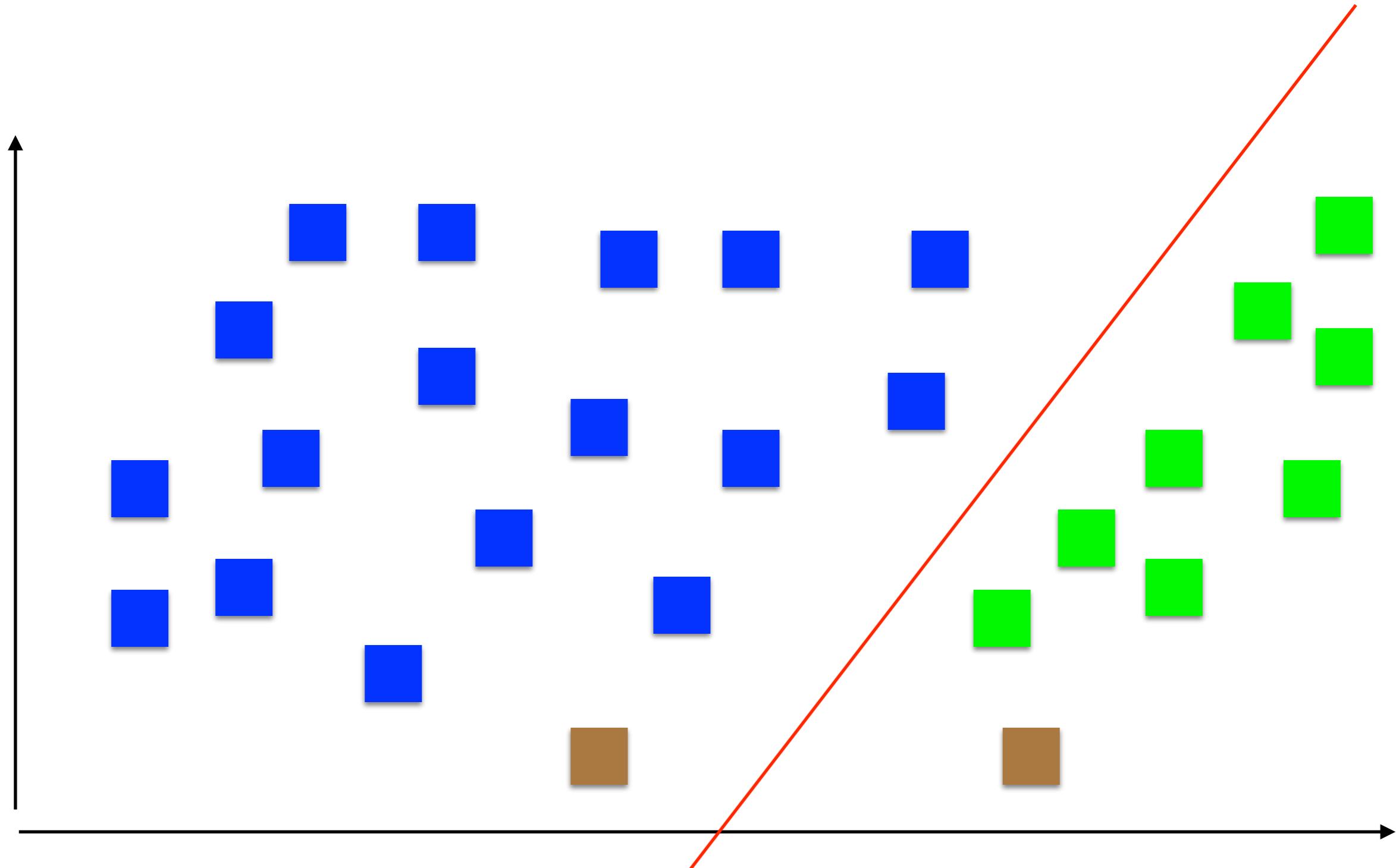
Classification supervisée

Très courte introduction à la classification



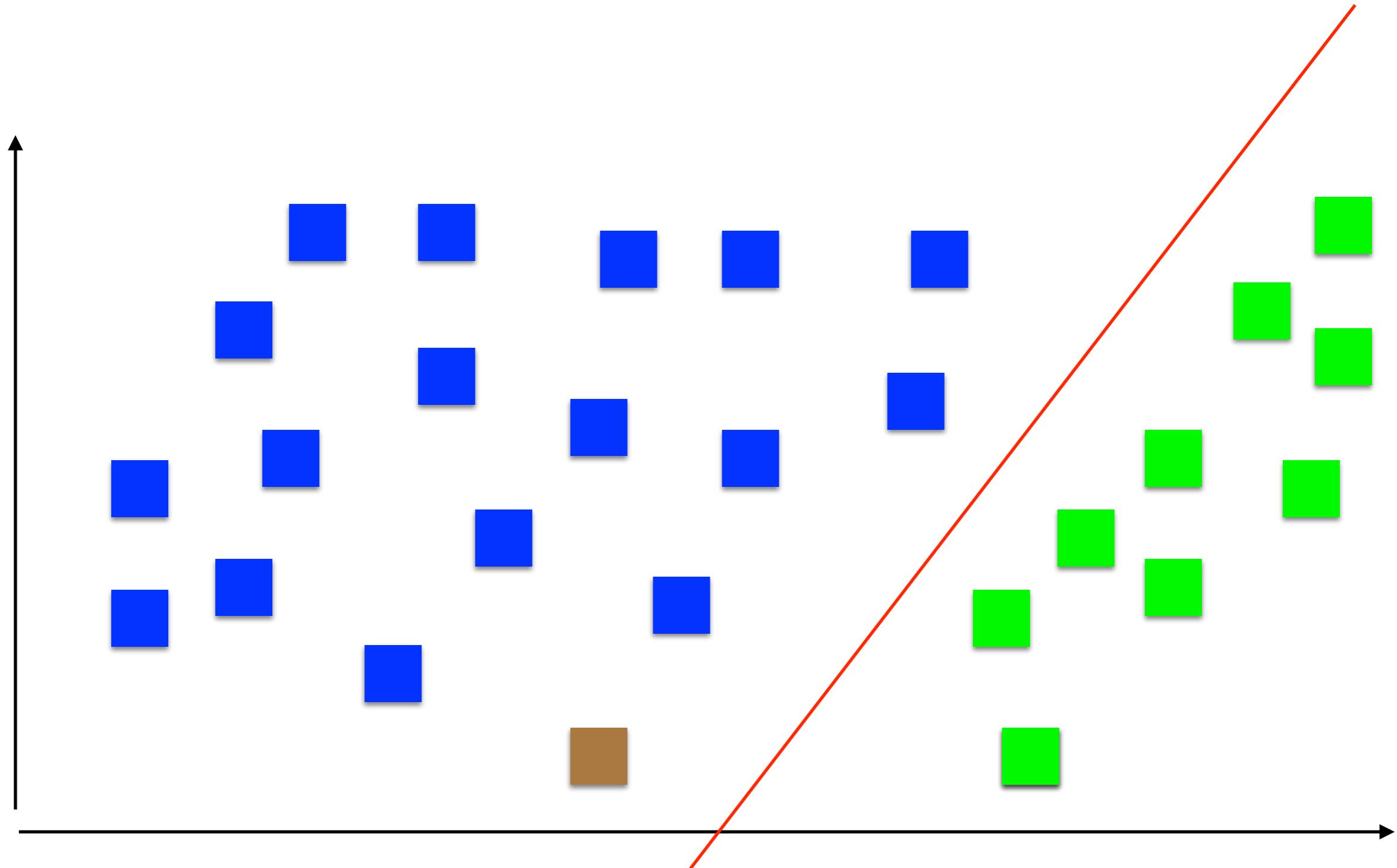
Classification supervisée

Très courte introduction à la classification



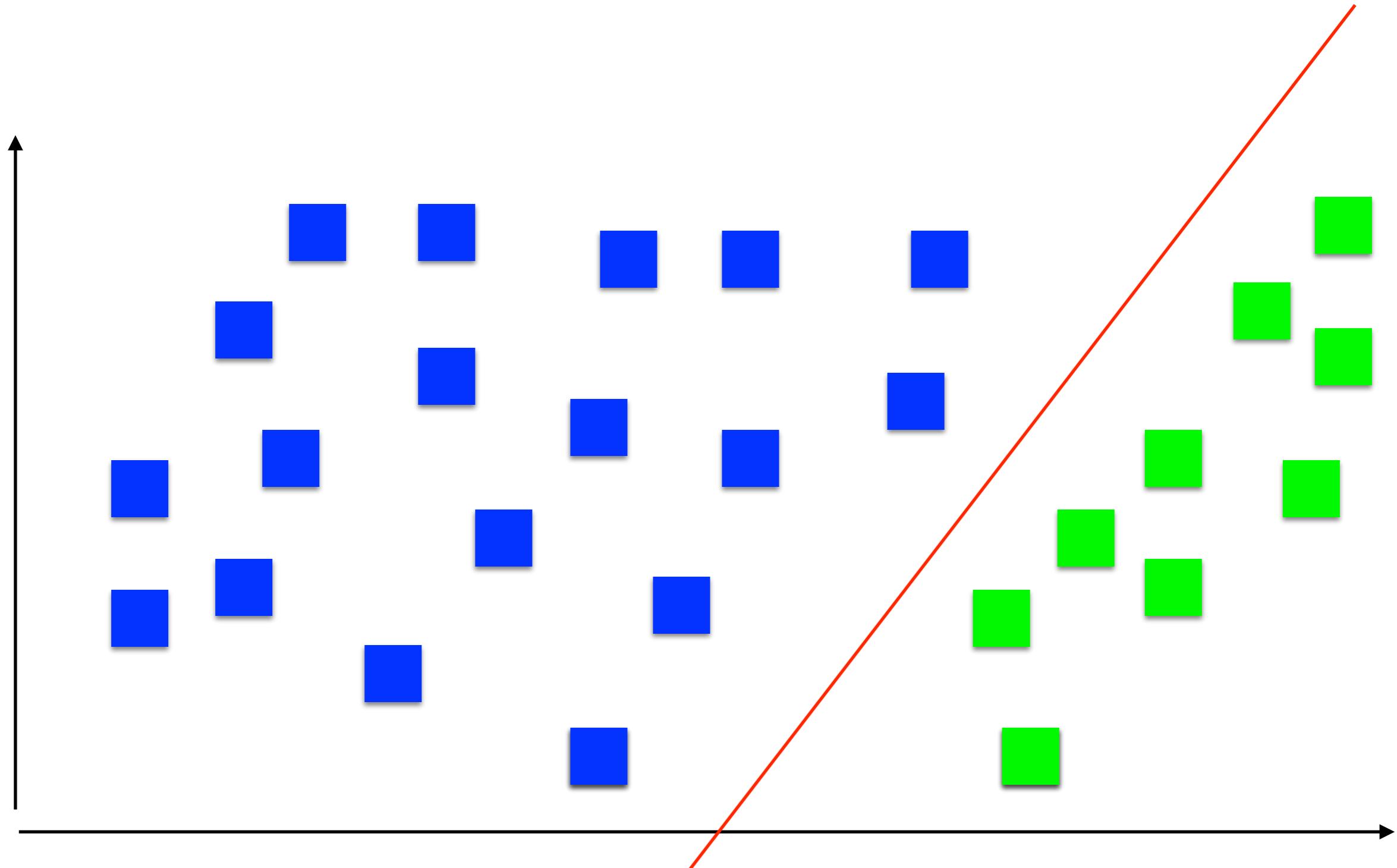
Classification supervisée

Très courte introduction à la classification



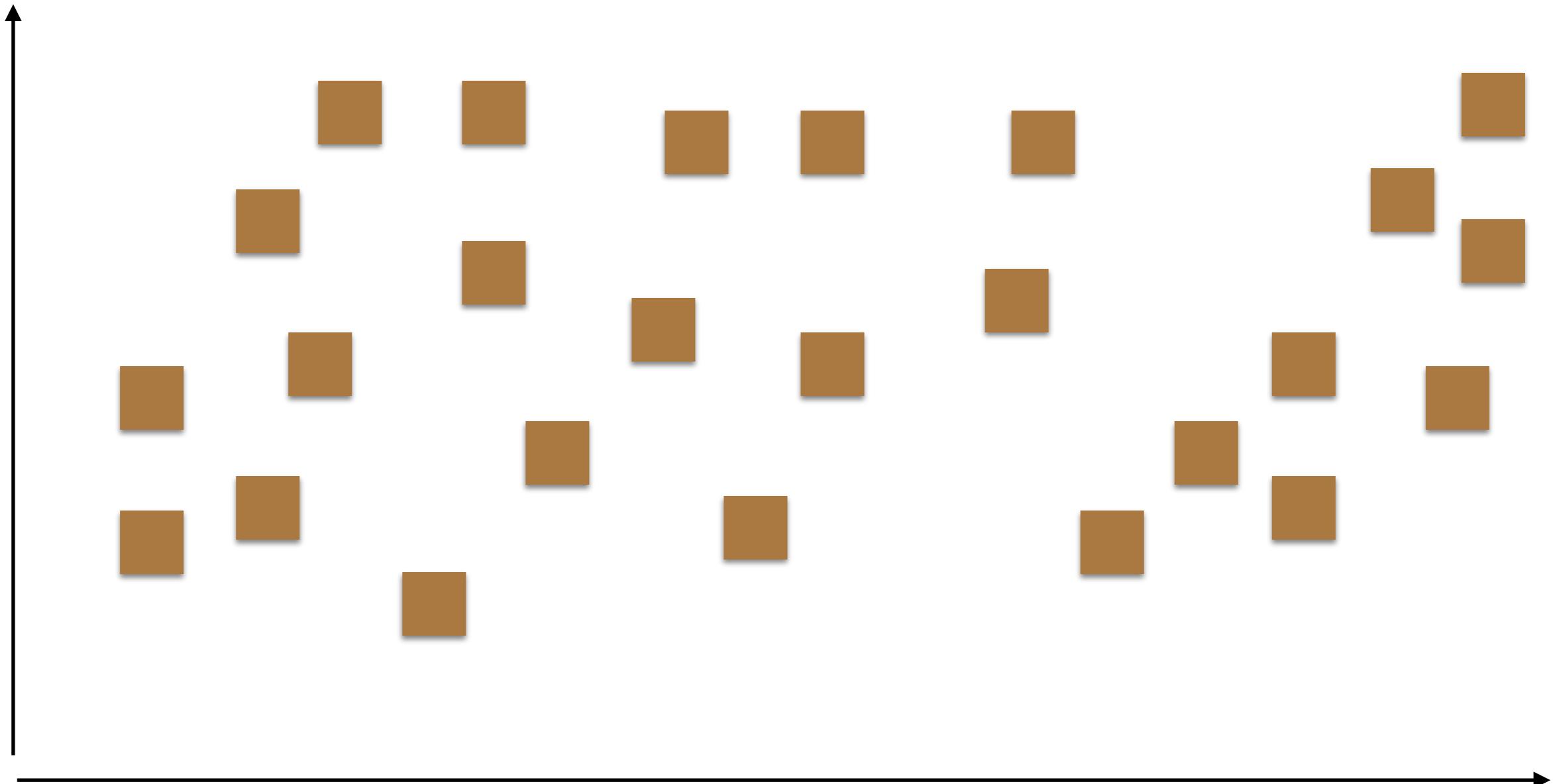
Classification supervisée

Très courte introduction à la classification



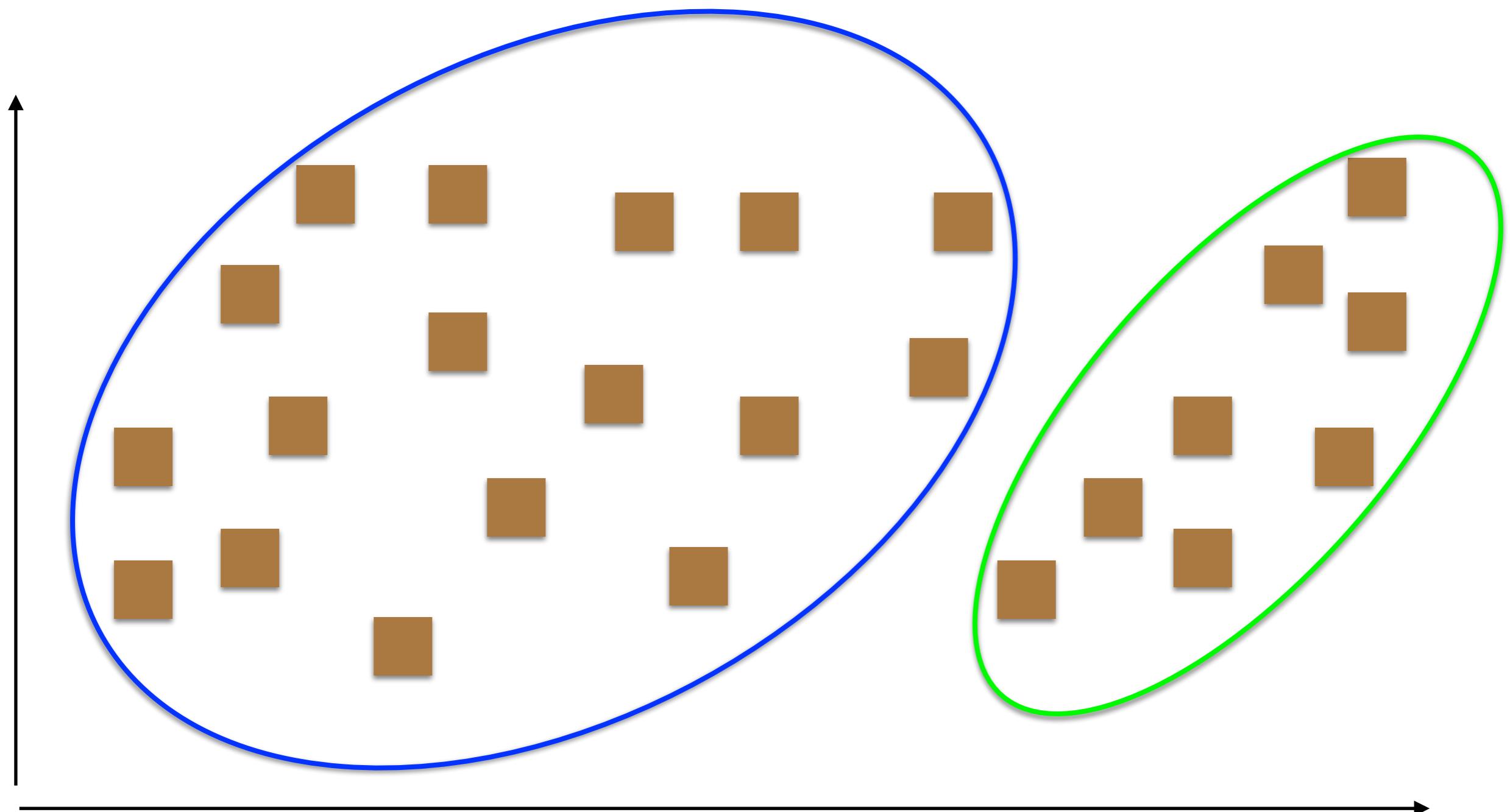
Classification supervisée

Très courte introduction à la classification



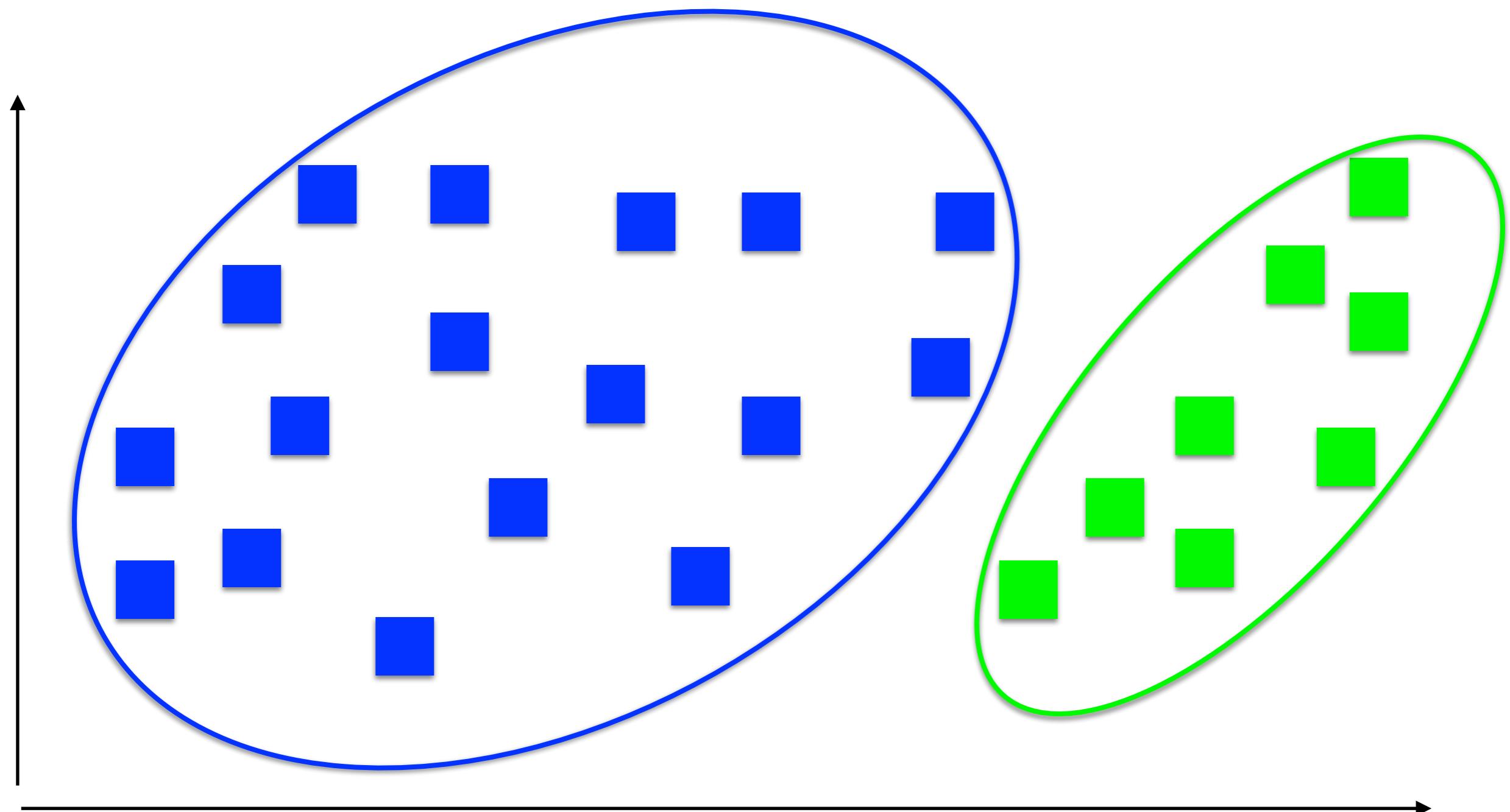
Classification non-supervisée

Très courte introduction à la classification



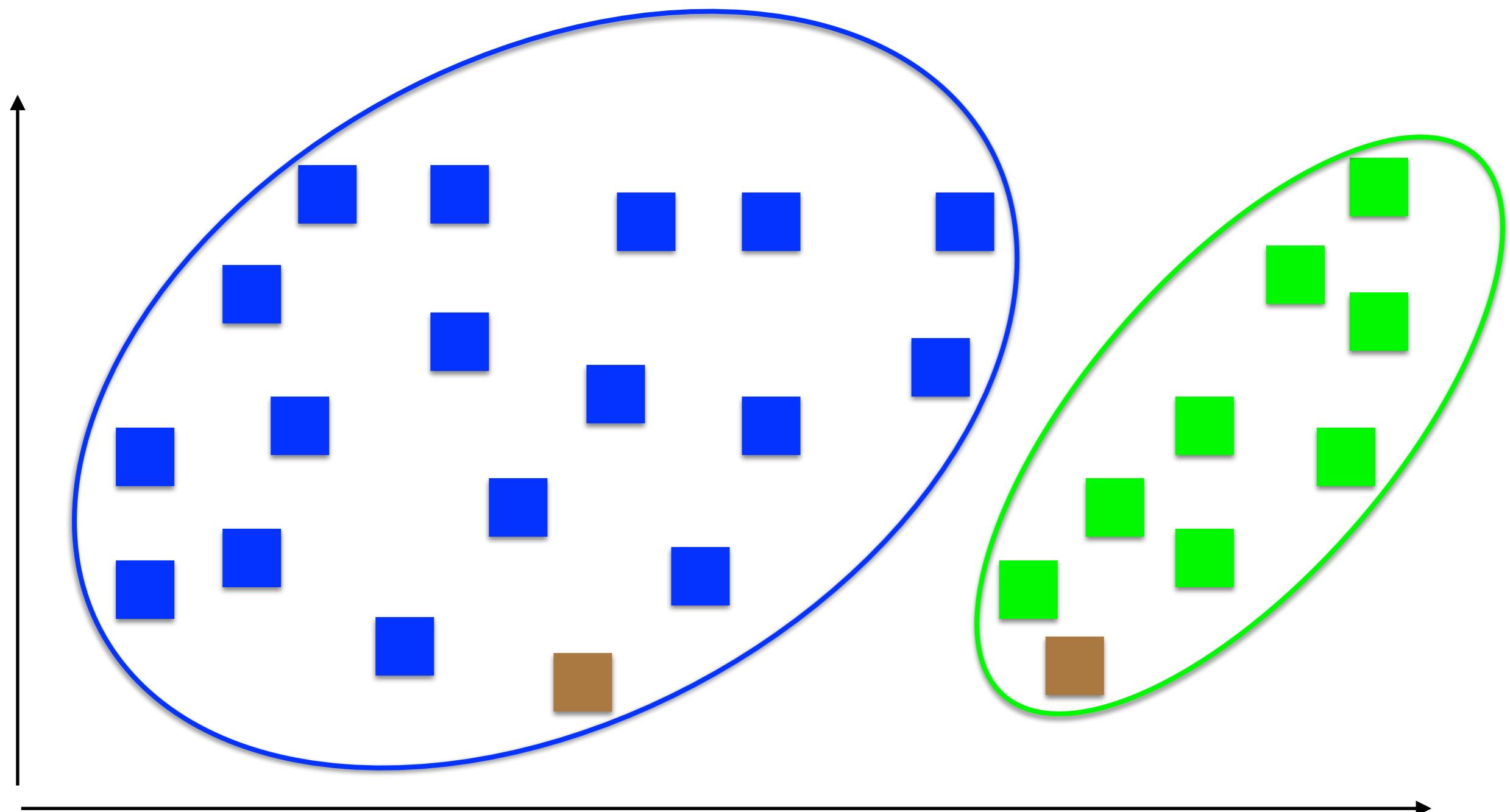
Classification non-supervisée

Très courte introduction à la classification



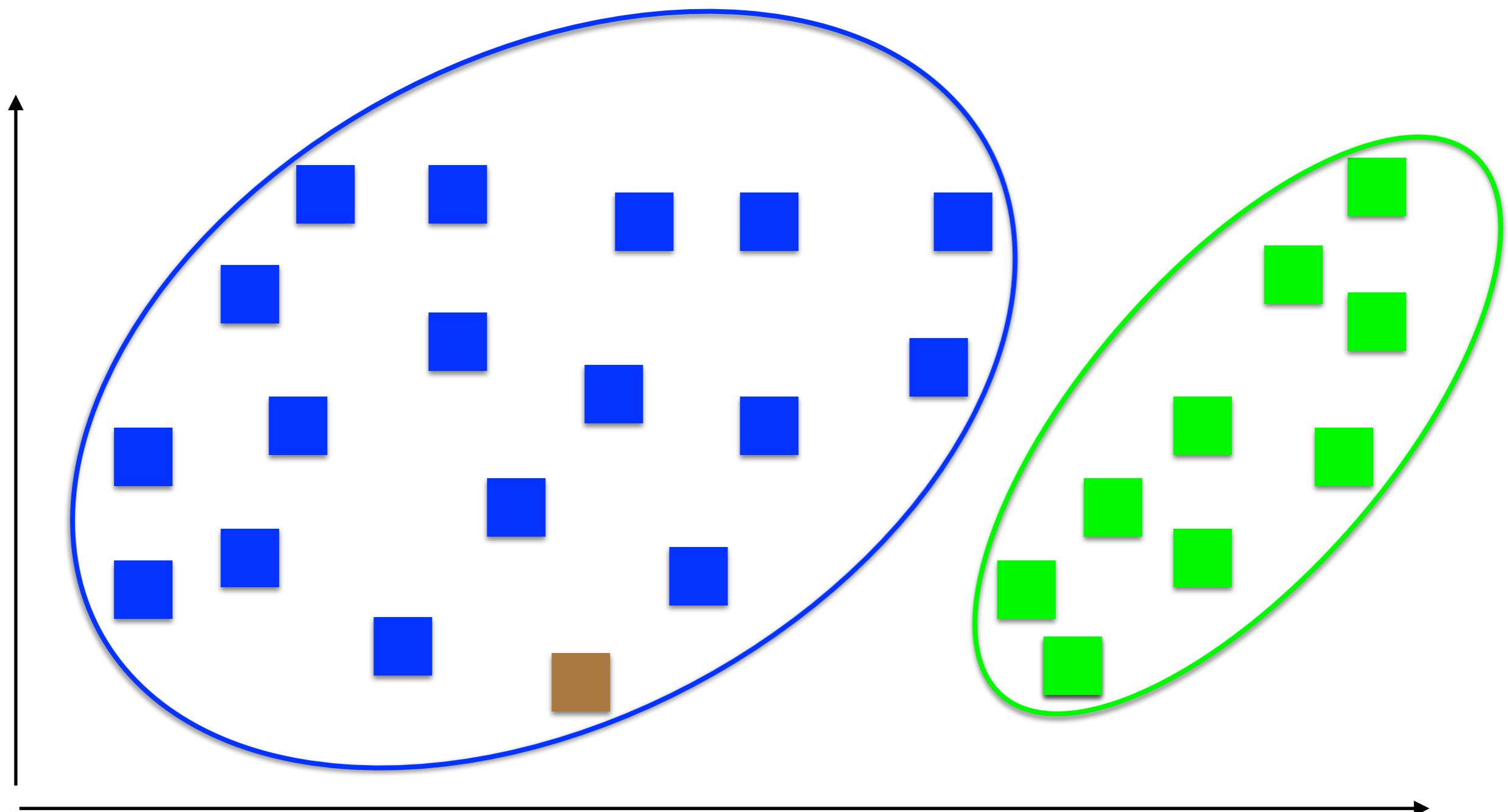
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Très courte introduction à la classification



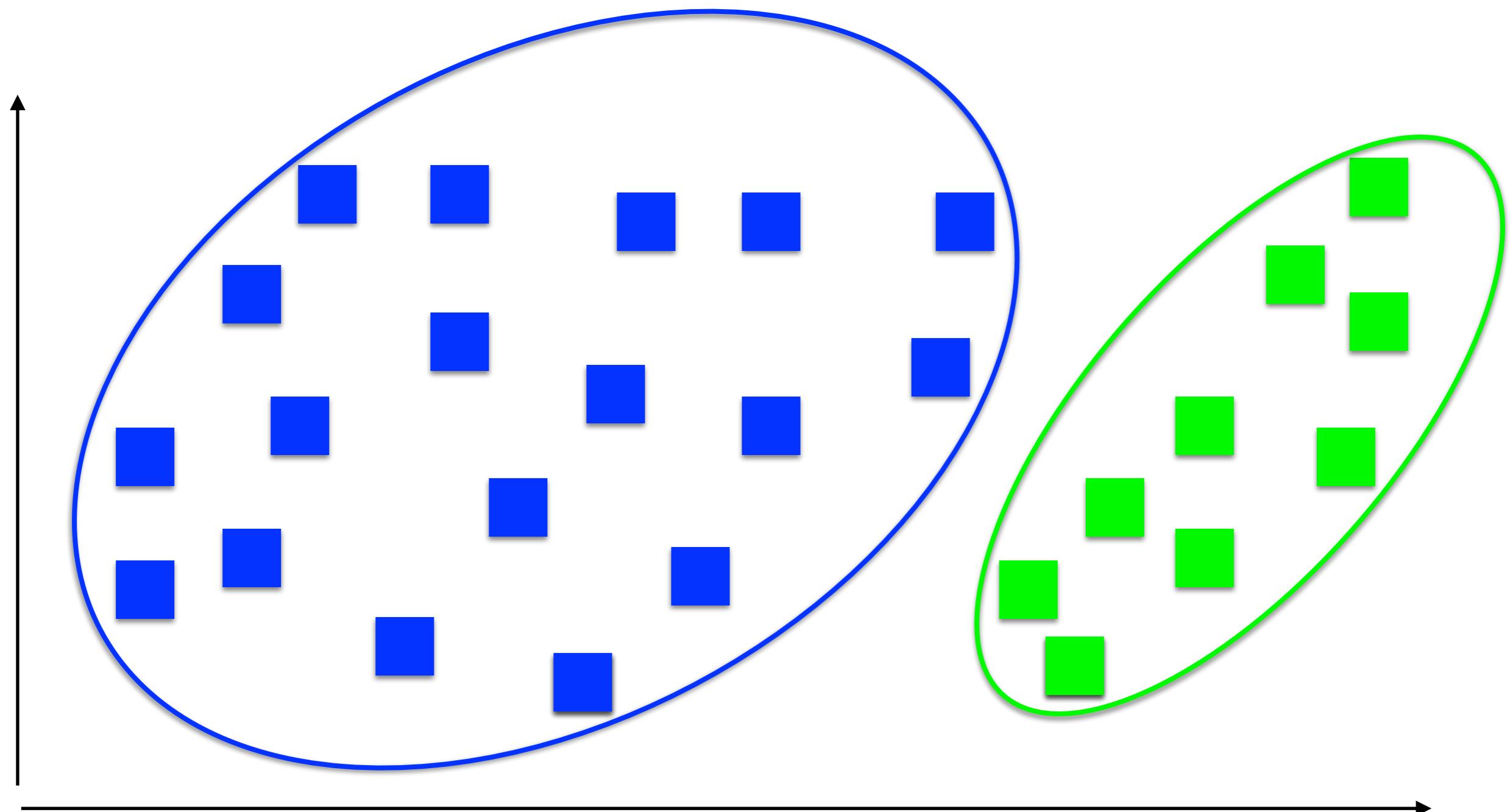
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Très courte introduction à la classification



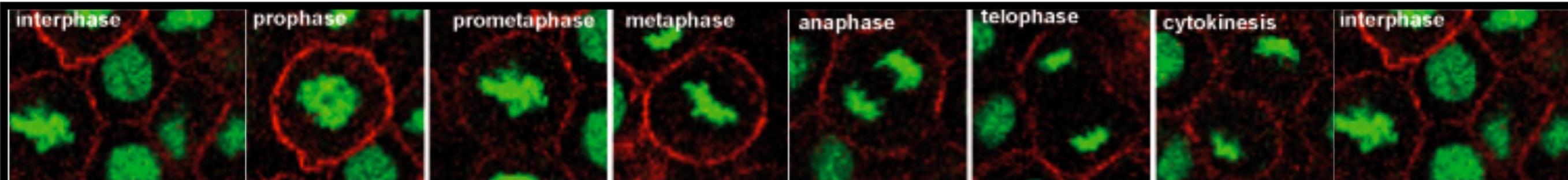
Classification non-supervisée

Très courte introduction à la classification



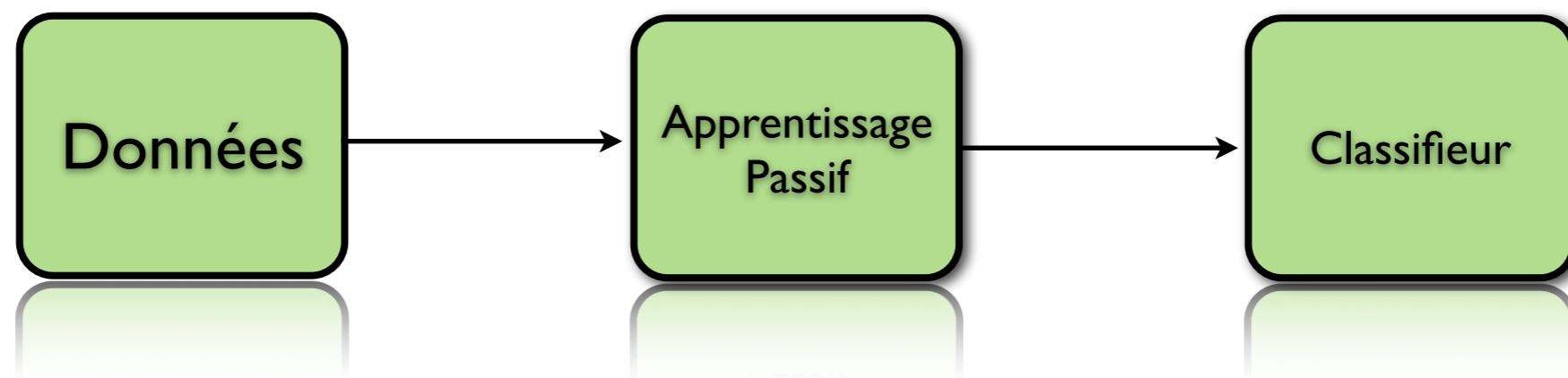
Classification non-supervisée

Détection des divisions cellulaires

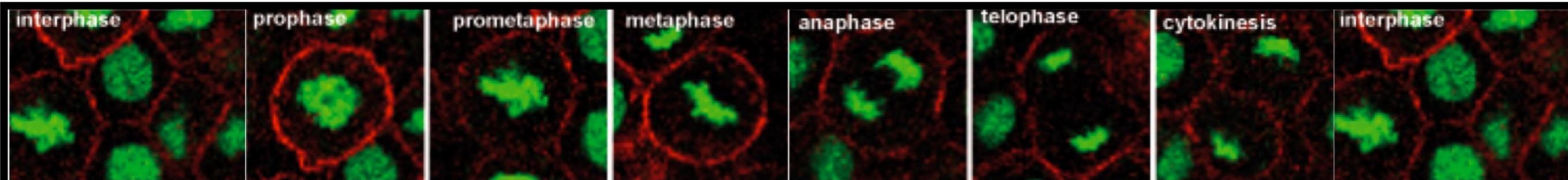


Apprentissage supervisé
annotation experte très longue

Apprentissage non supervisé
~0.5% cellules en division

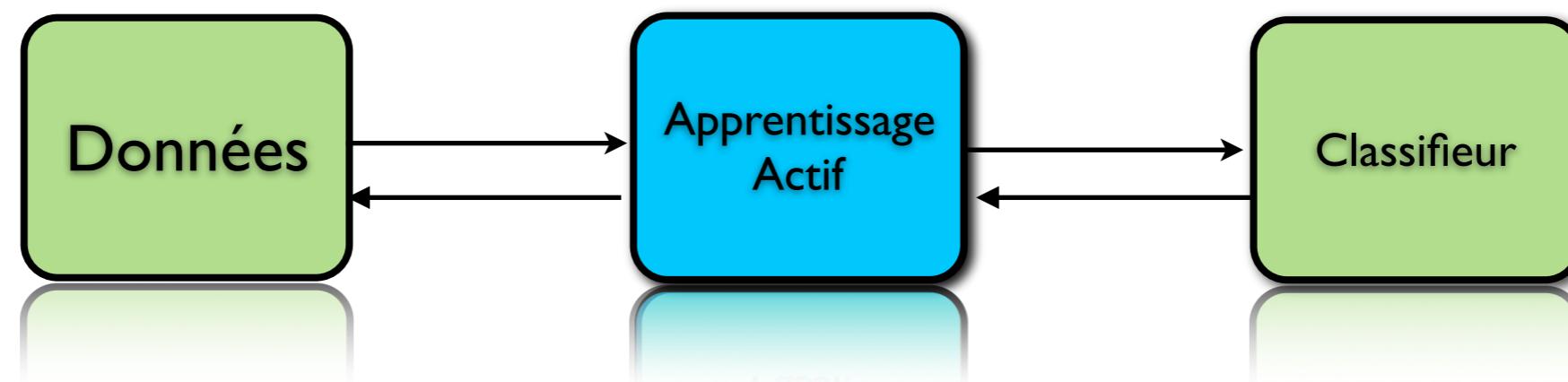


Détection des divisions cellulaires



Apprentissage supervisé
annotation experte très longue

Apprentissage non supervisé
~0.5% cellules en division



Détection des divisions cellulaires

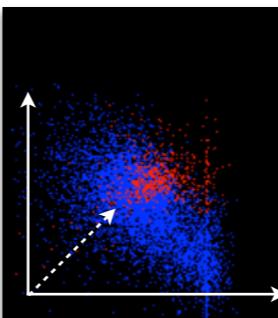
- Pré - classification définie par la connaissance
- Estimation de densité
- 1er embryon
 - a) Annotation manuelle à la frontière des clusters
 - b) Extension des labels dans l'espace et le temps
 - c) Redéfinition des frontières
- 2ème Embryon

Apprentissage actif

Détection des divisions cellulaires

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- Estimation de densité
- 1er embryon
 - a) Annotation manuelle à la frontière des clusters
 - b) Extension des labels dans l'espace et le temps
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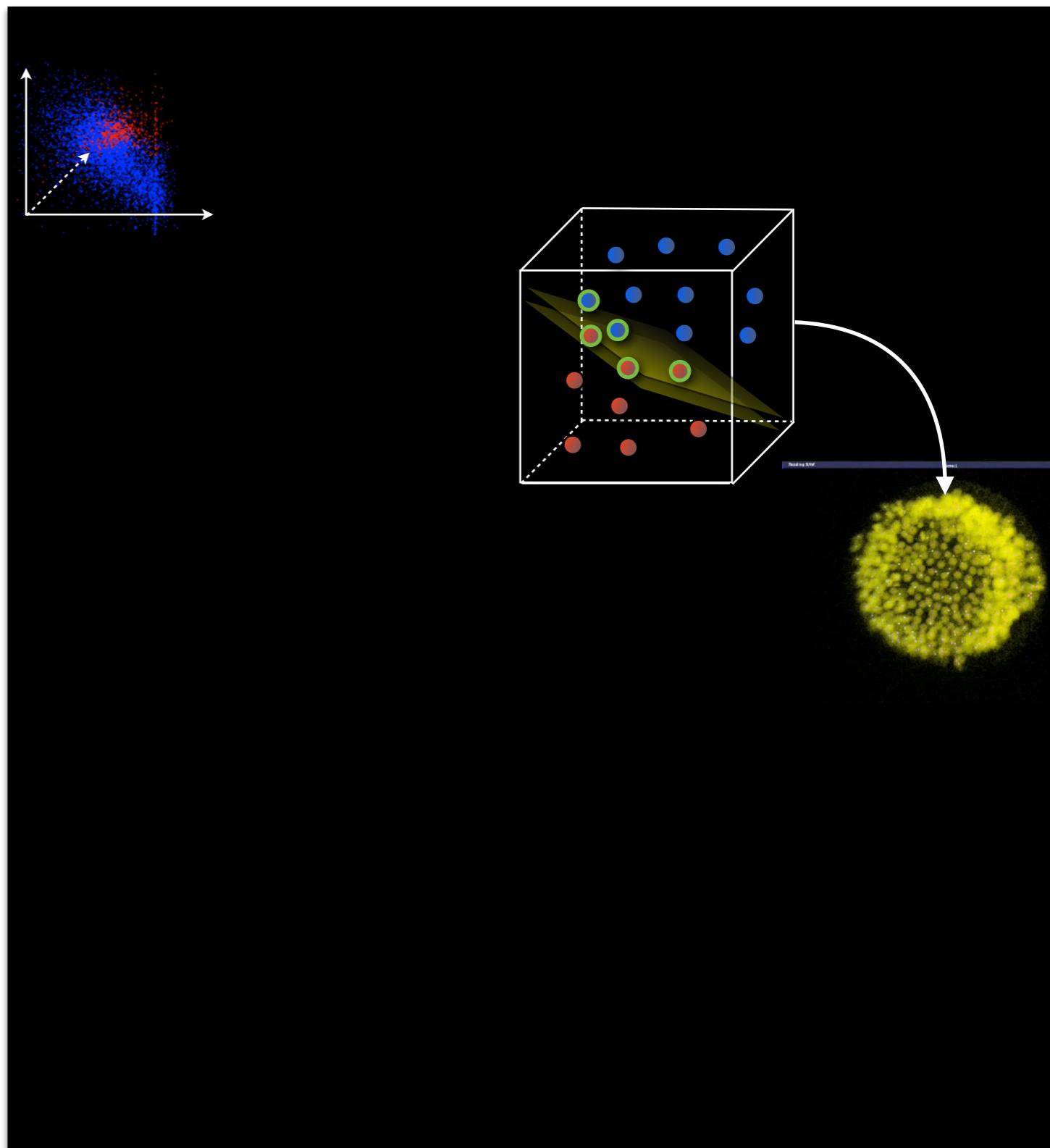
Apprentissage actif



Détection des divisions cellulaires

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- Estimation de densité
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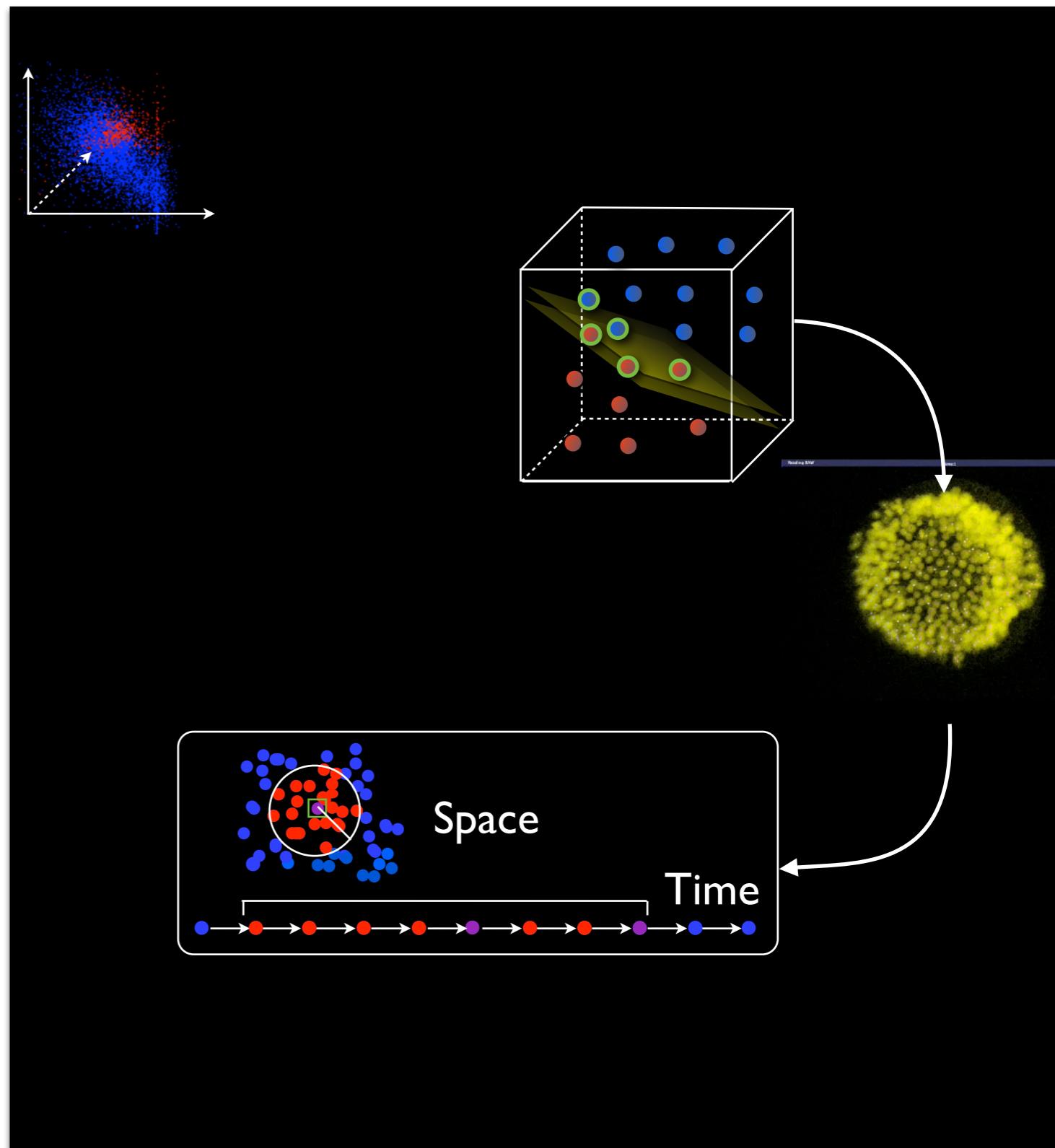
Apprentissage actif



Détection des divisions cellulaires

- Pré - classification définie par la connaissance
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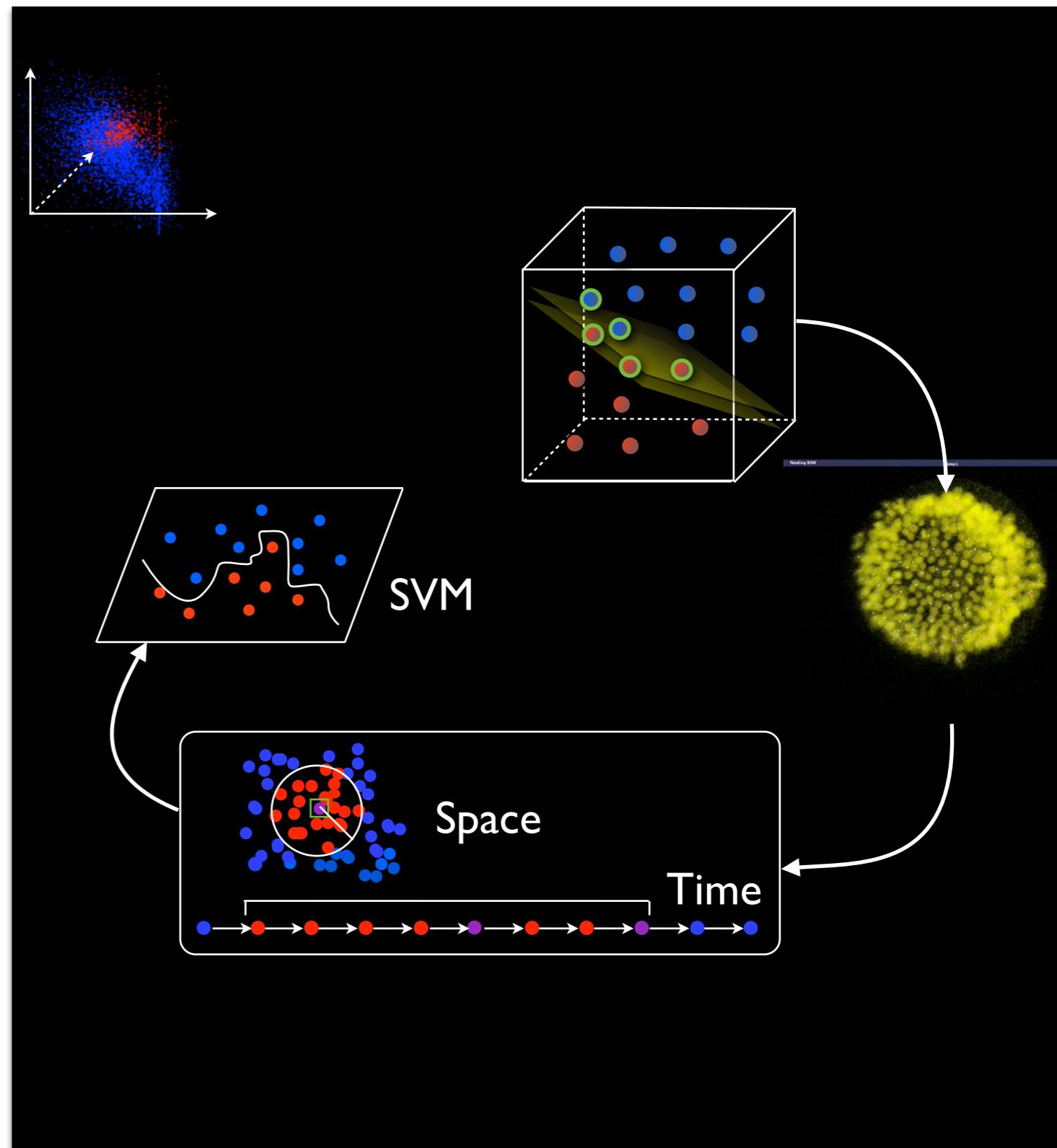
Apprentissage actif



Détection des divisions cellulaires

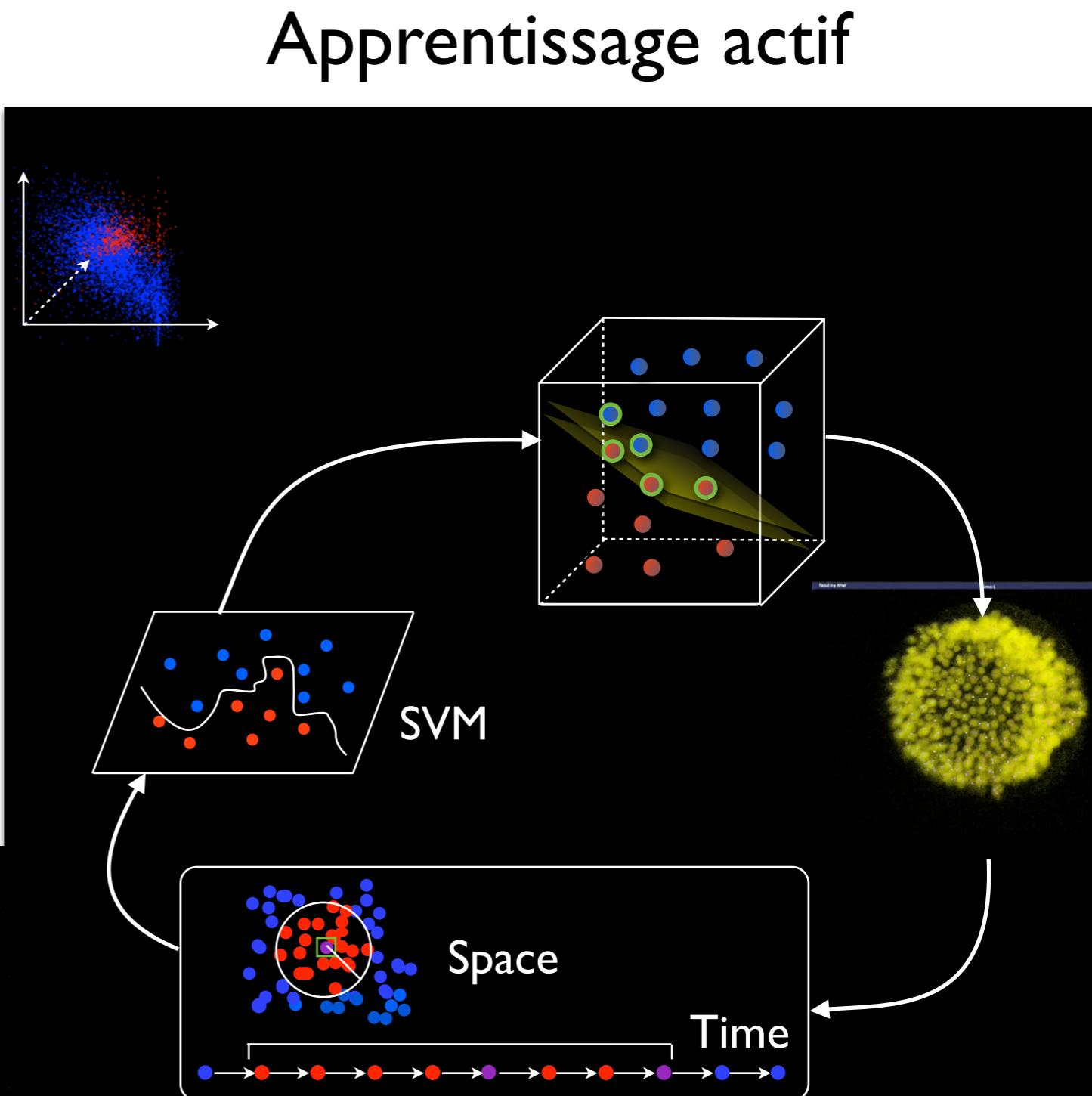
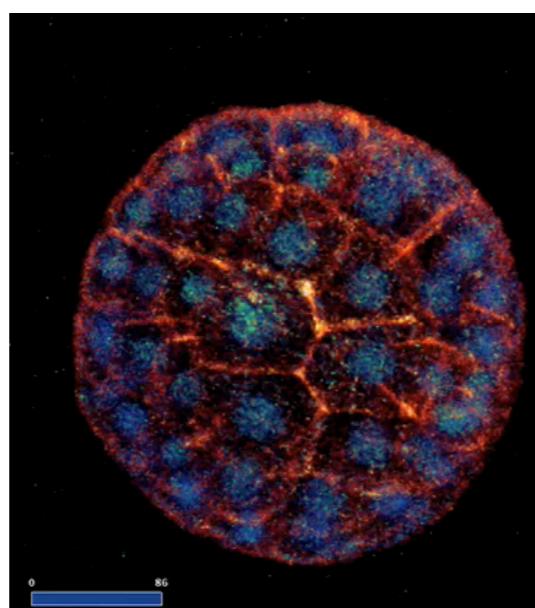
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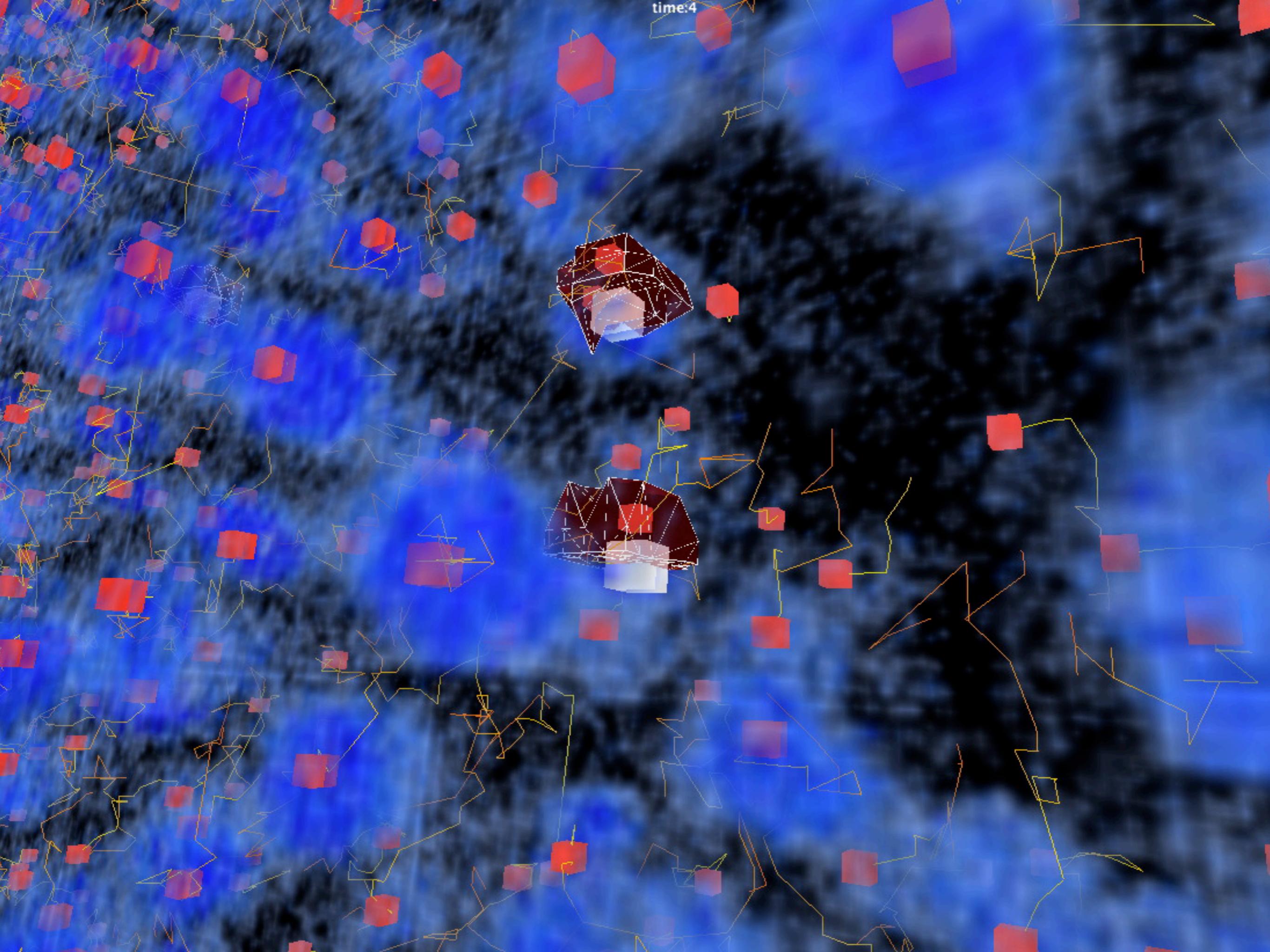
Apprentissage actif

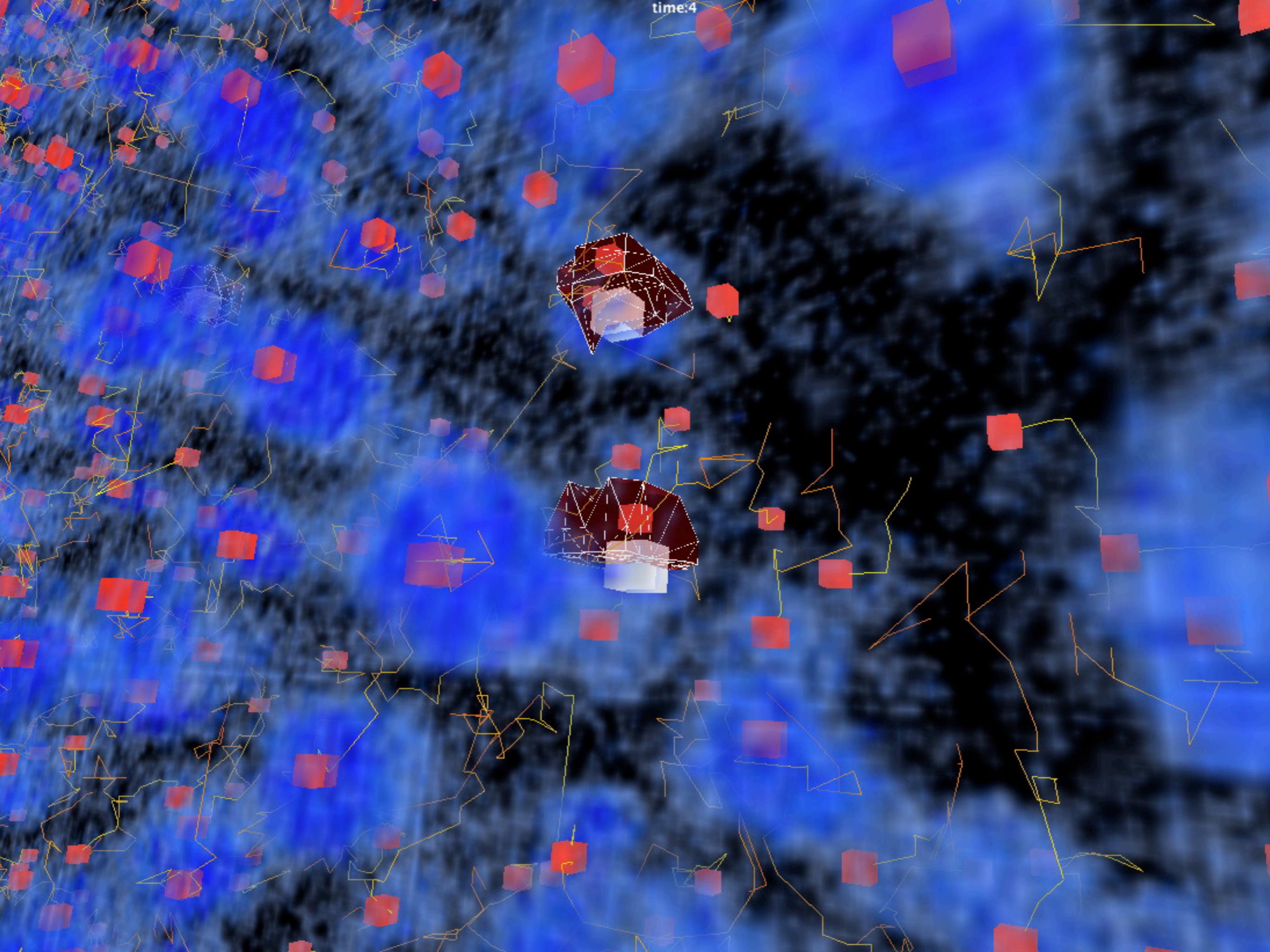


Détection des divisions cellulaires

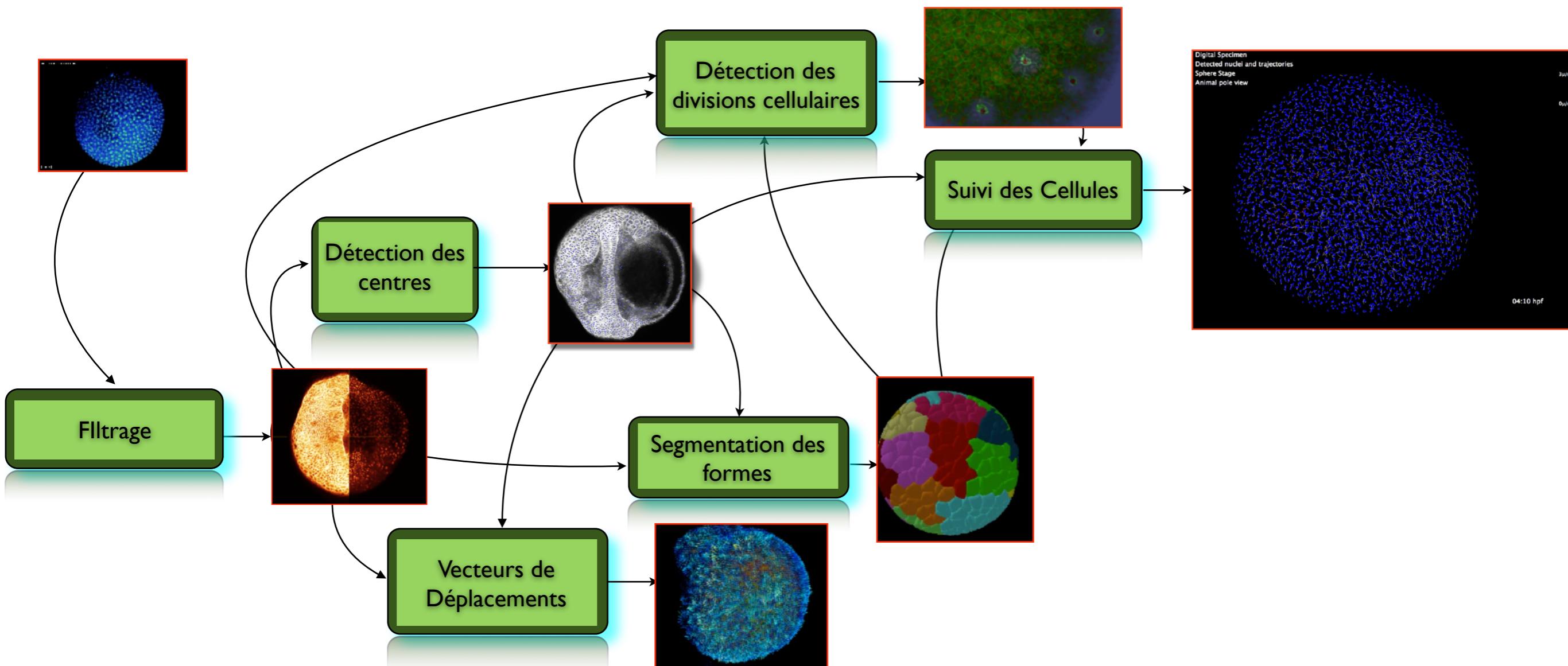
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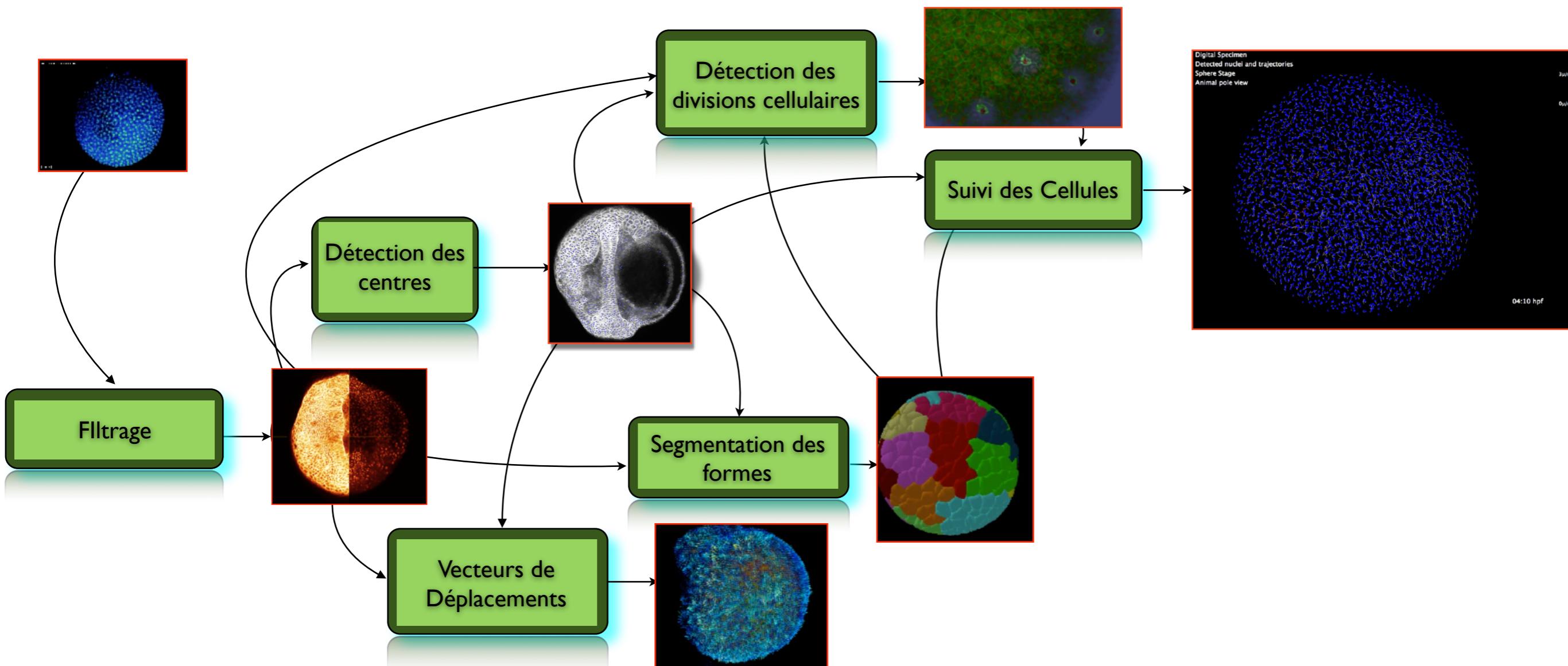




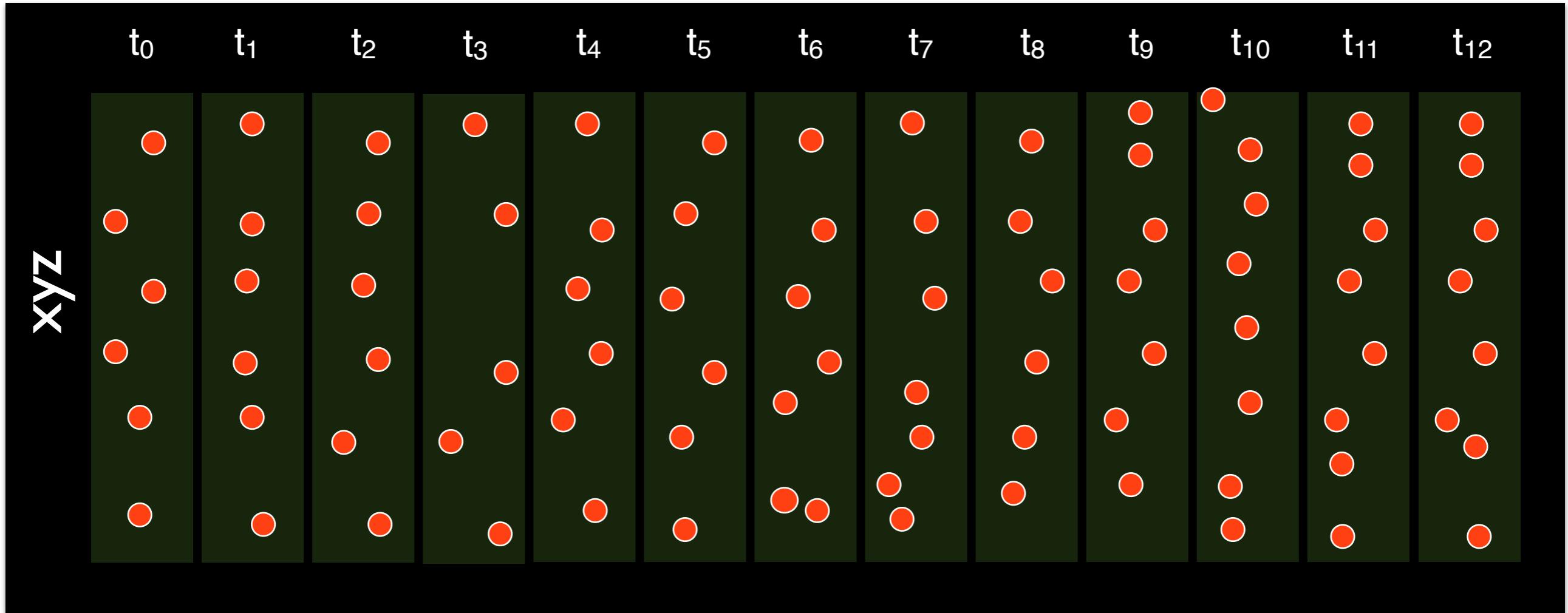
Reconstruction Image 4D



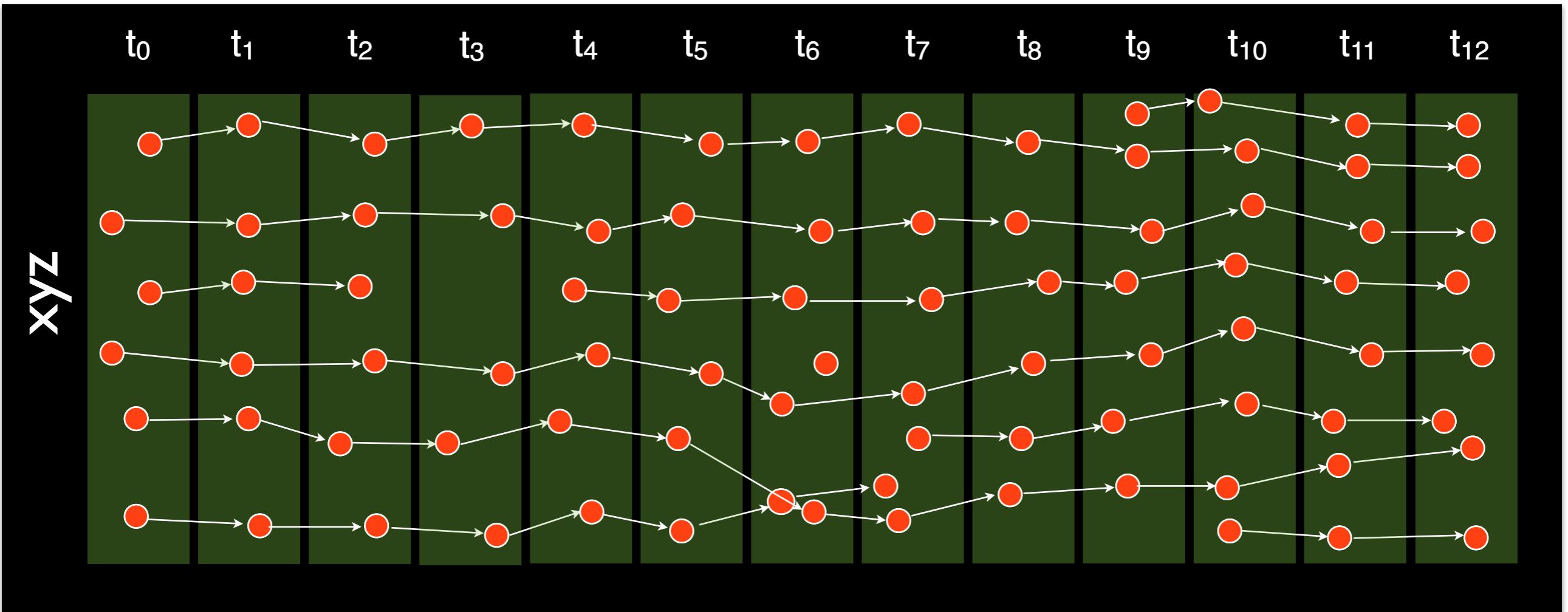
Reconstruction Image 4D



Suivi cellulaire par plus proche voisins

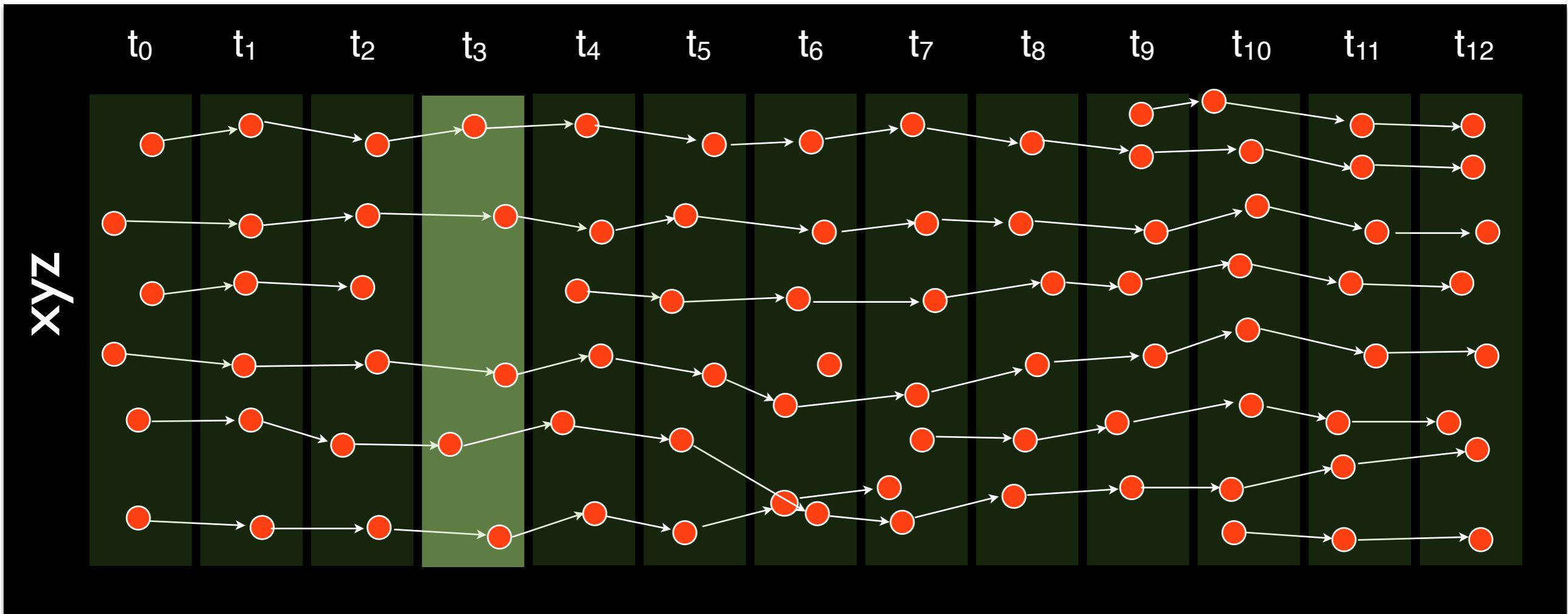


Suivi cellulaire par plus proche voisins



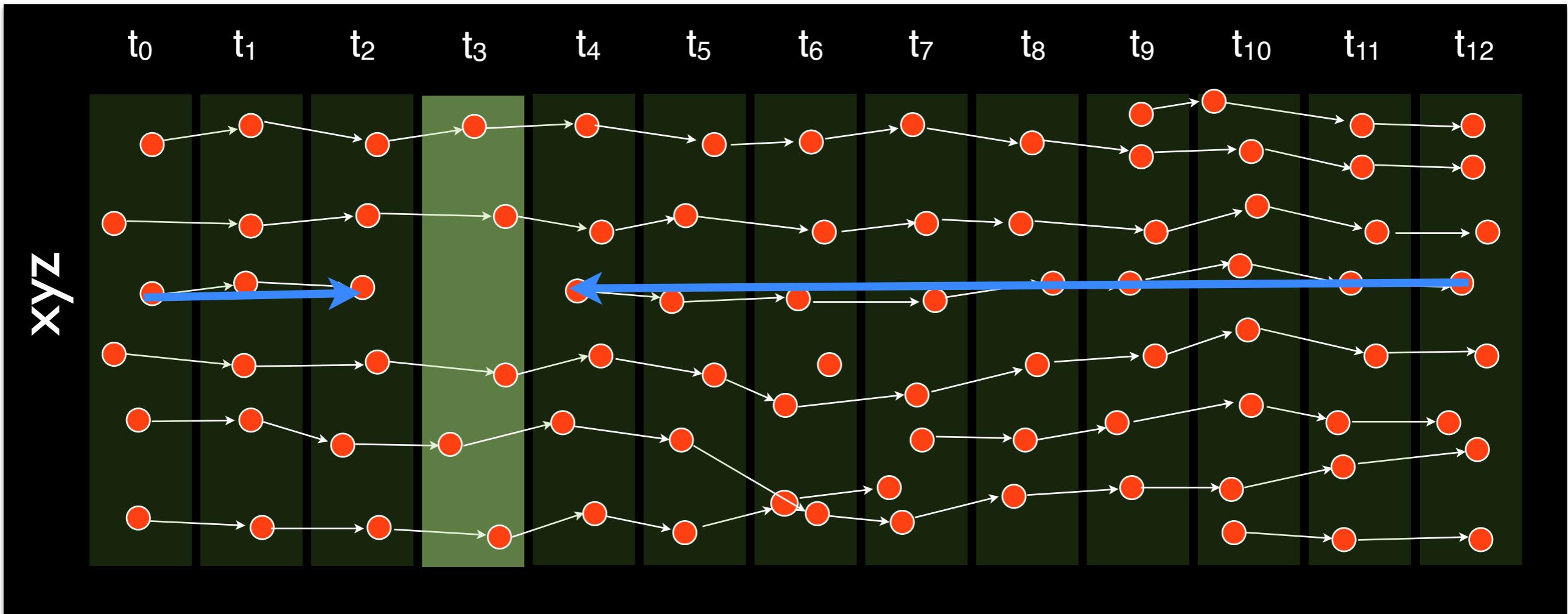
~ 90% de bons liens

Erreurs



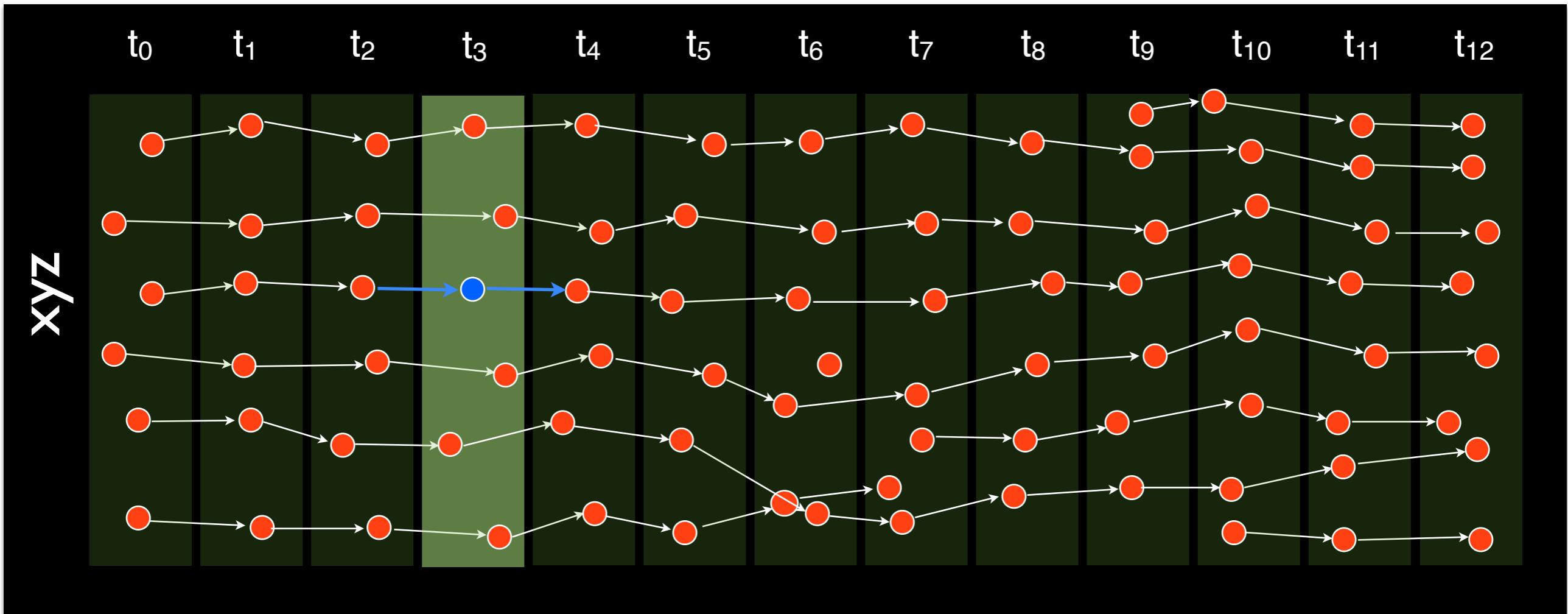
Faux Négatif

Erreurs



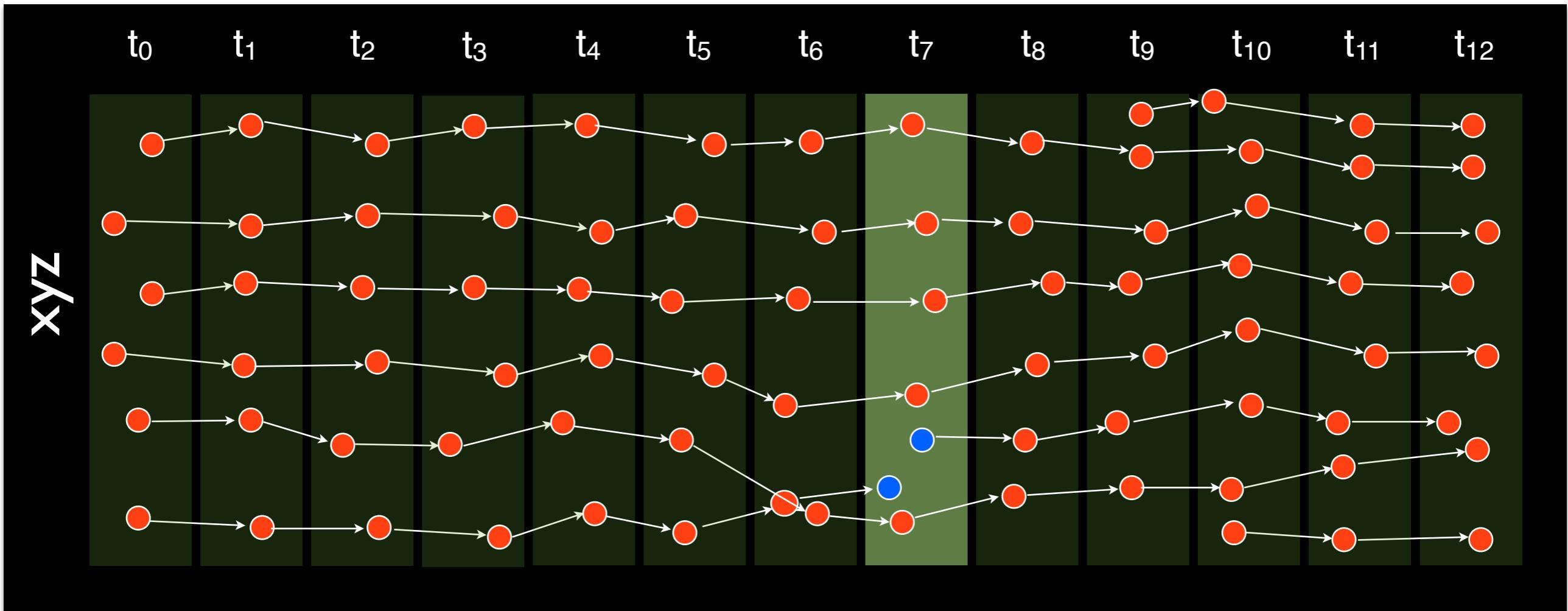
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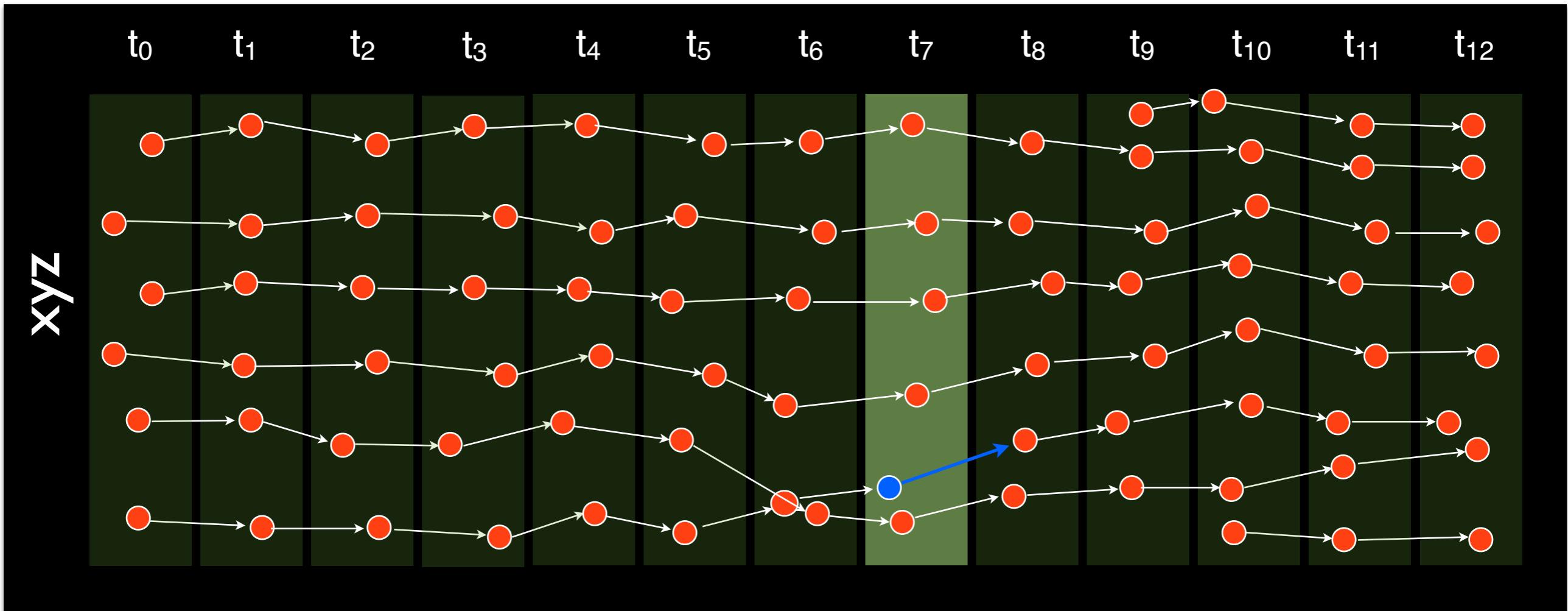
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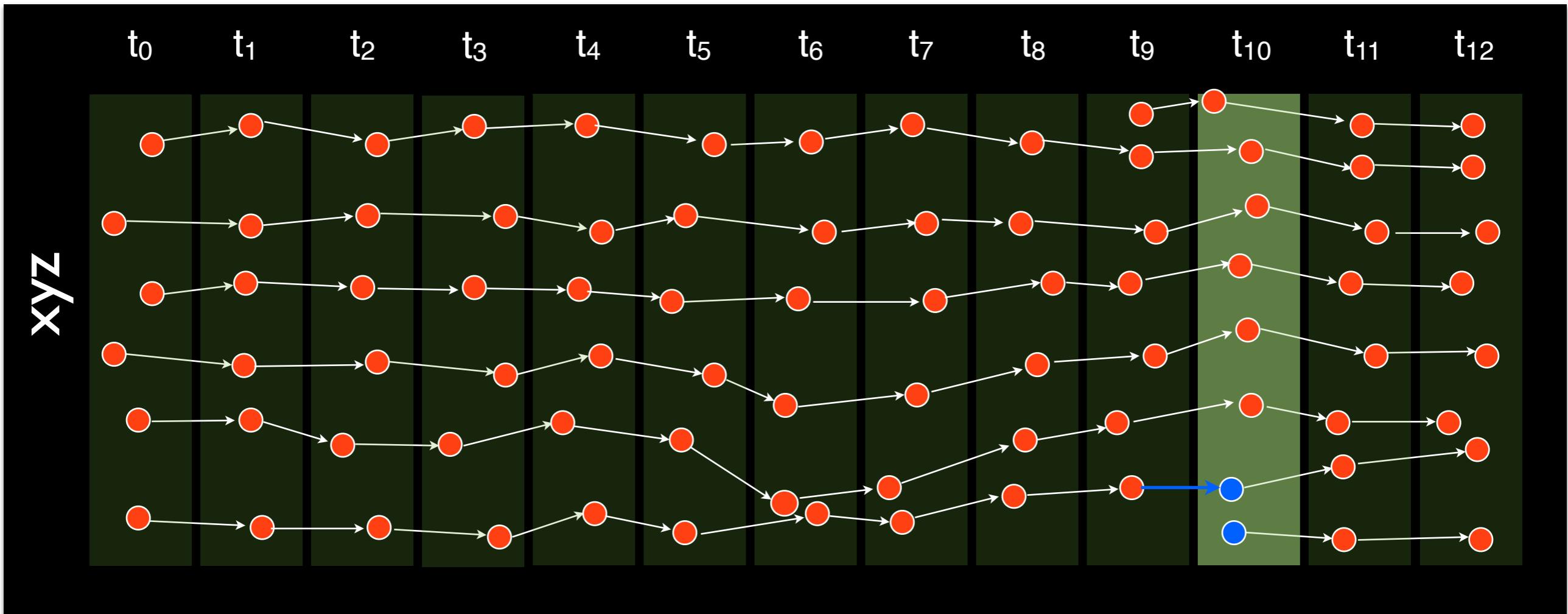
Faux positifs

Erreurs



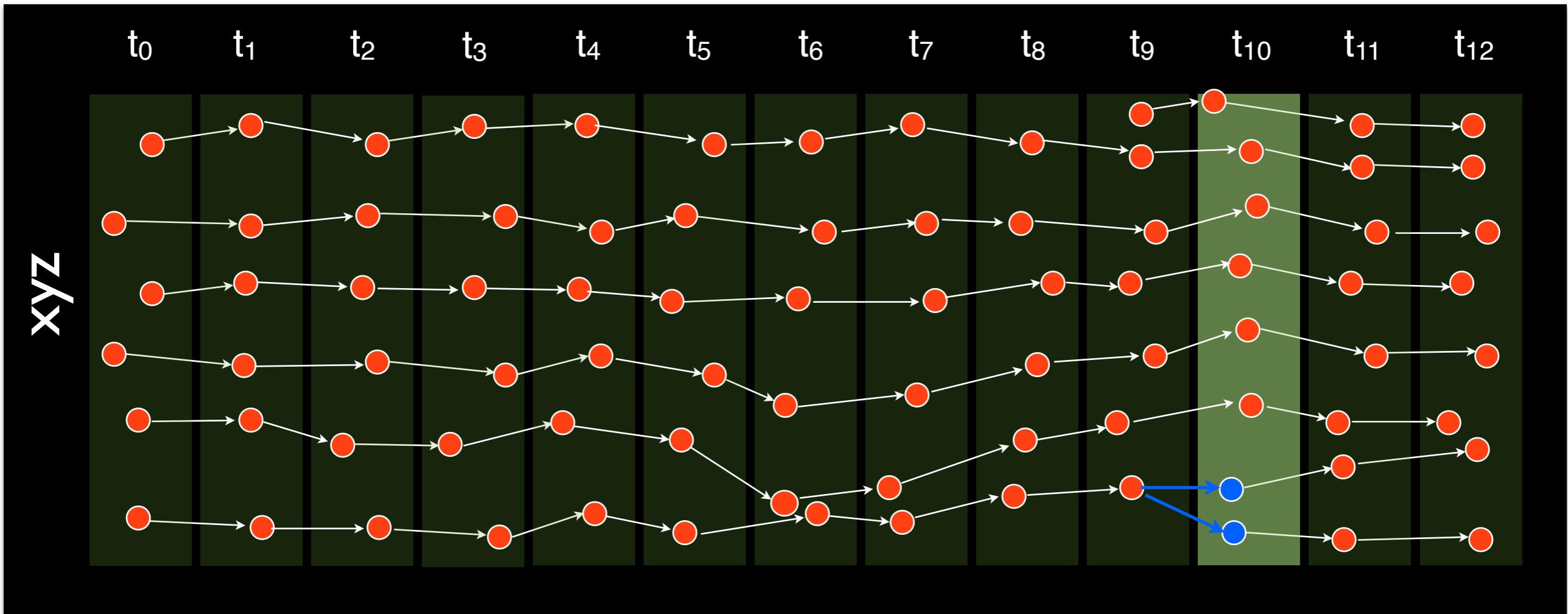
Faux positifs

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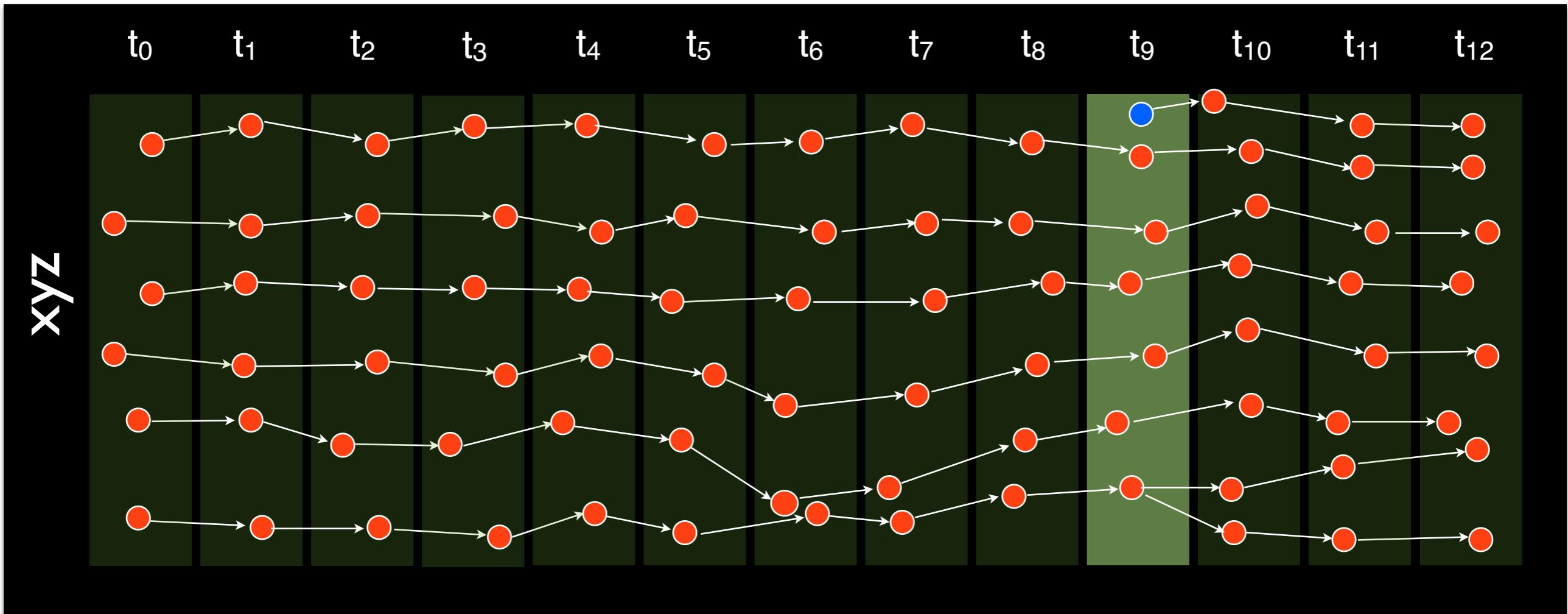
Cellule en division

Erreurs



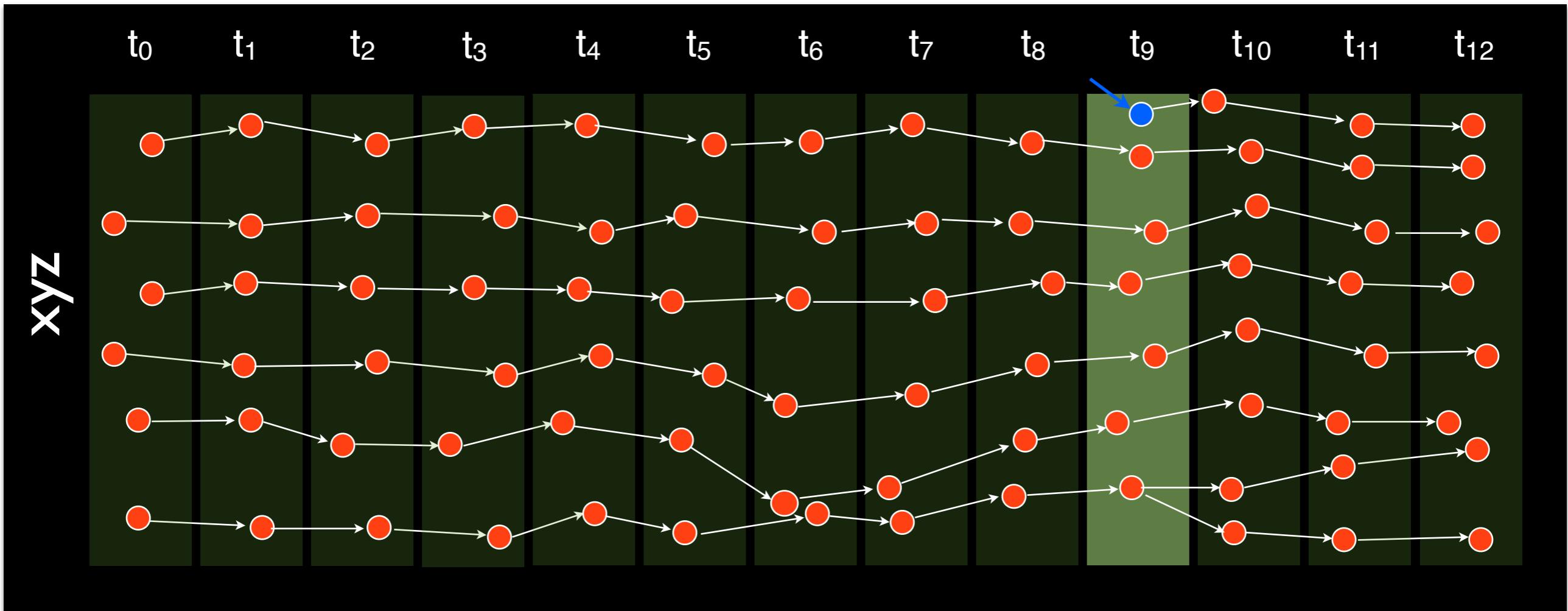
Cellule en division

Erreurs



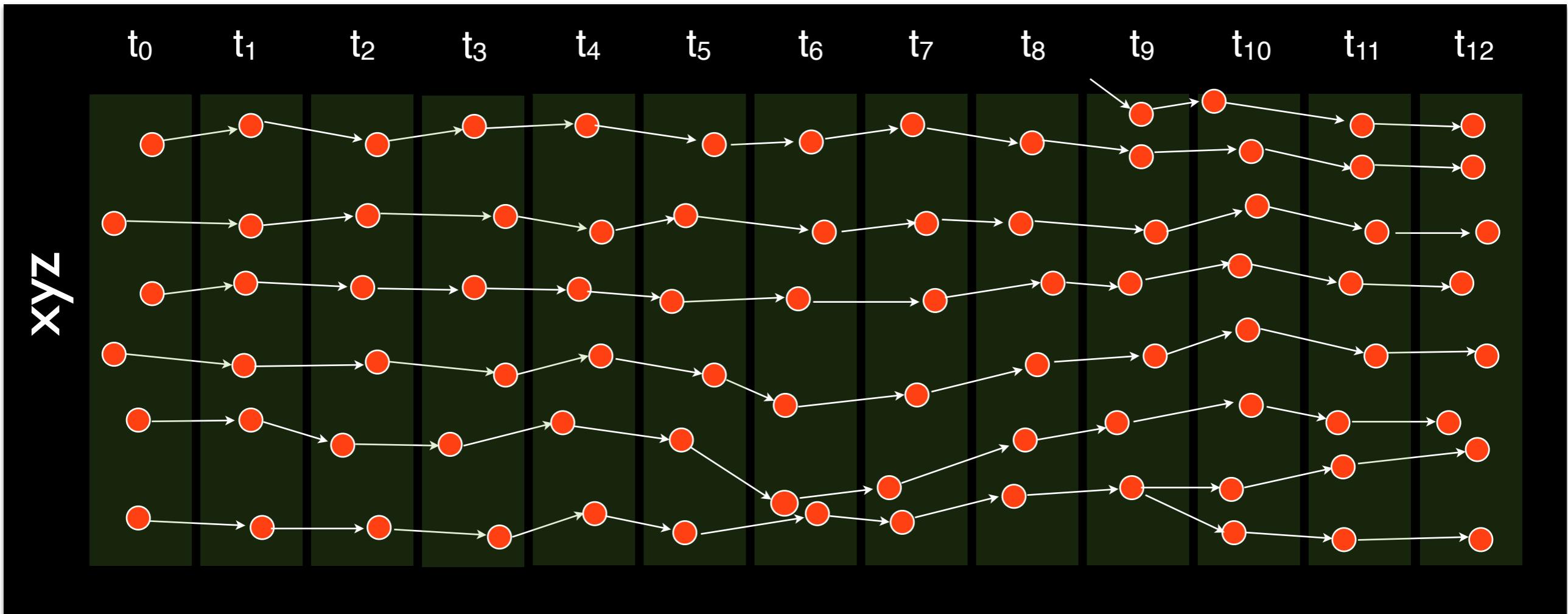
Limite de l'image

Erreurs



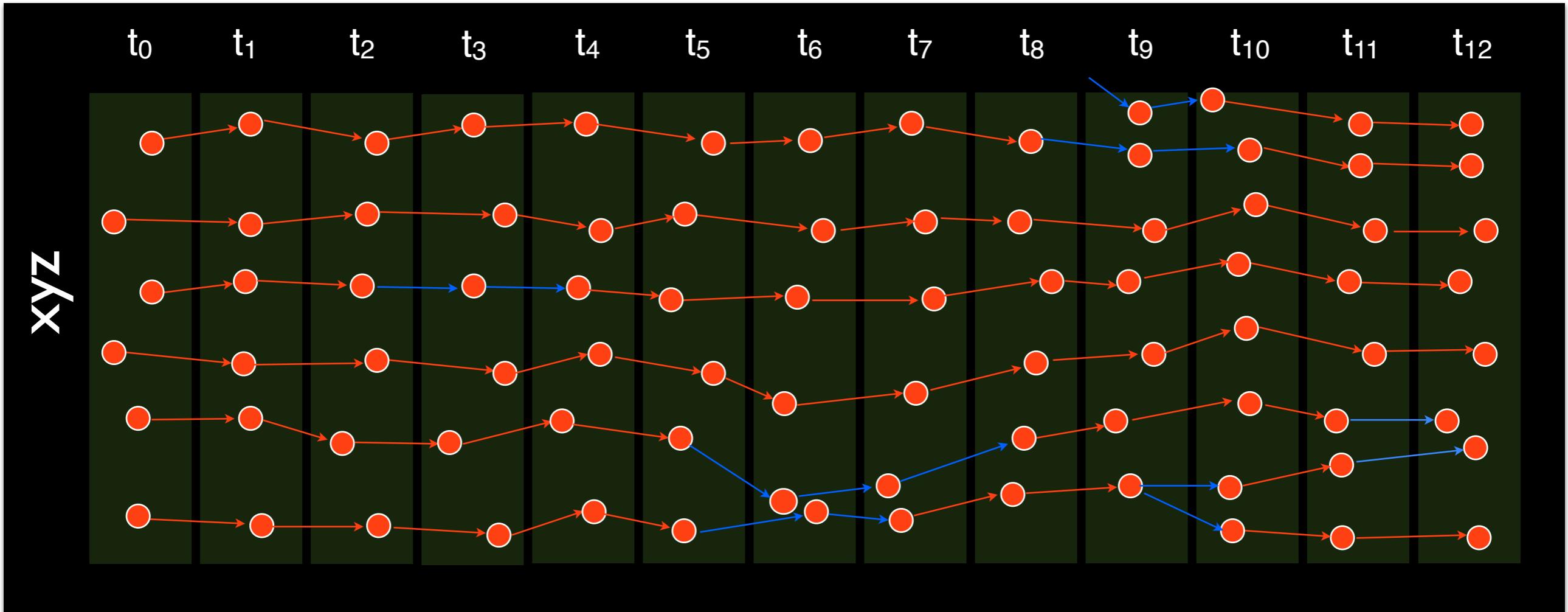
Limite de l'image

Erreurs



100% bon liens ?

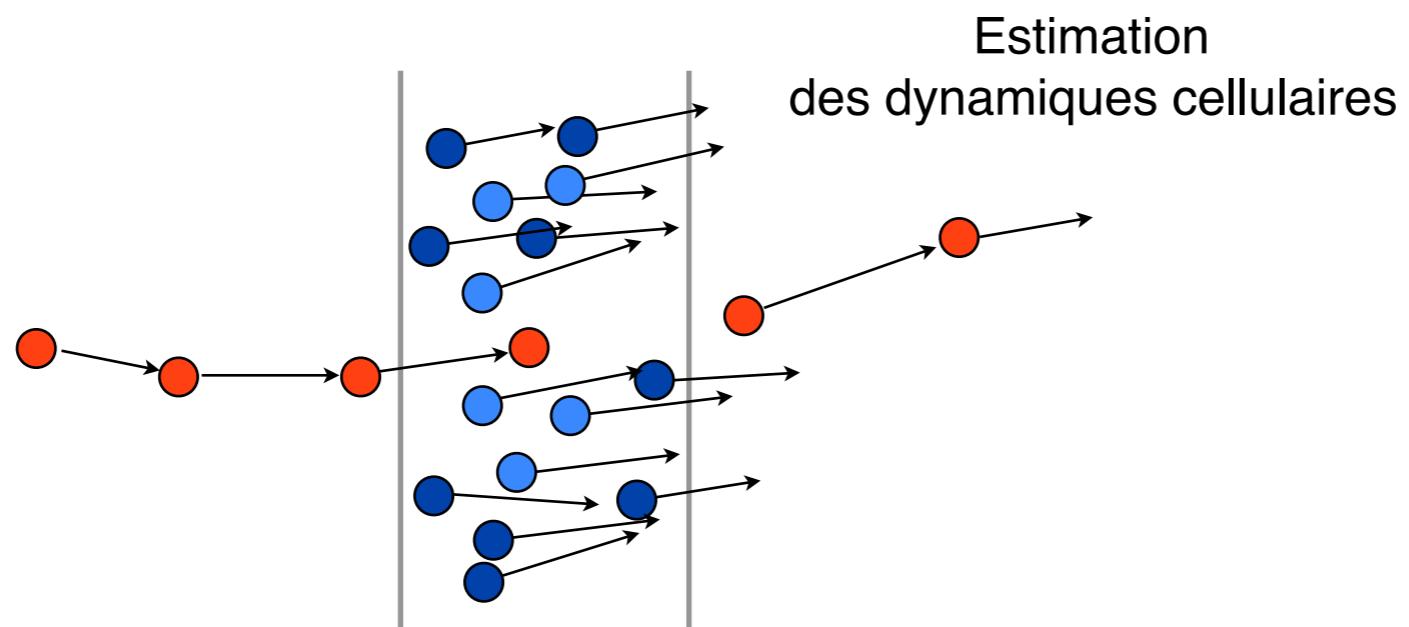
Reconstruction probabiliste



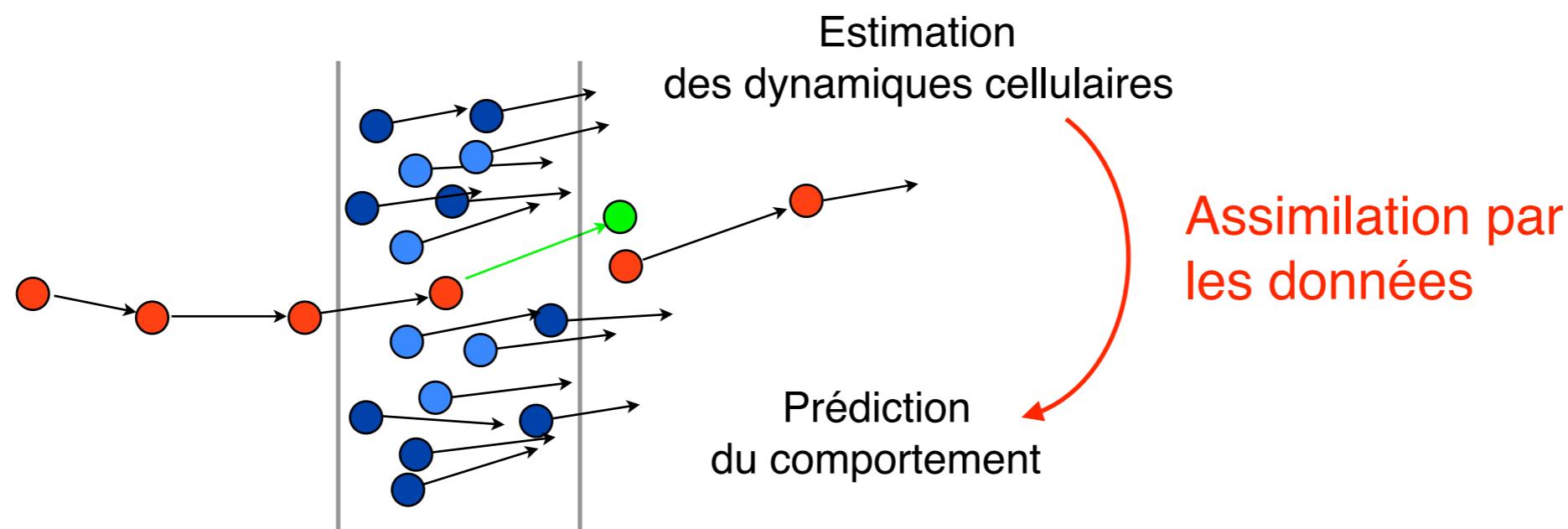
$\rightarrow P(\text{link}) = 1$ $\rightarrow P(\text{link}) < 1$

Suivi cellulaire probabiliste par maximisation de la vraisemblance

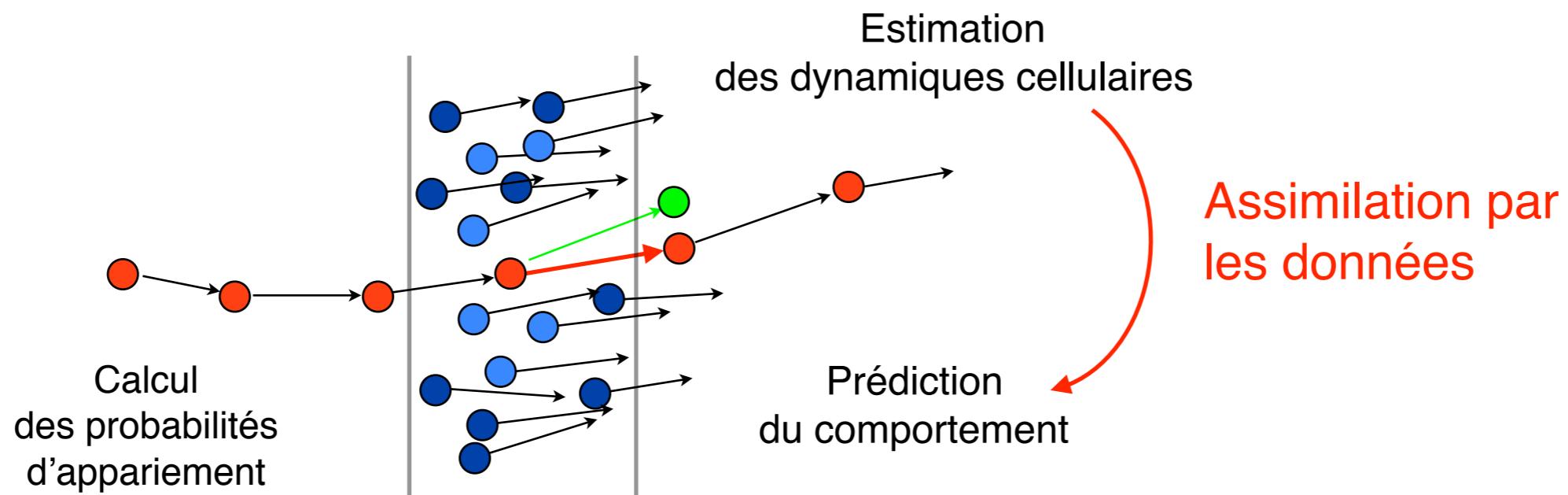
Suivi cellulaire probabiliste par maximisation de la vraisemblance



Suivi cellulaire probabiliste par maximisation de la vraisemblance

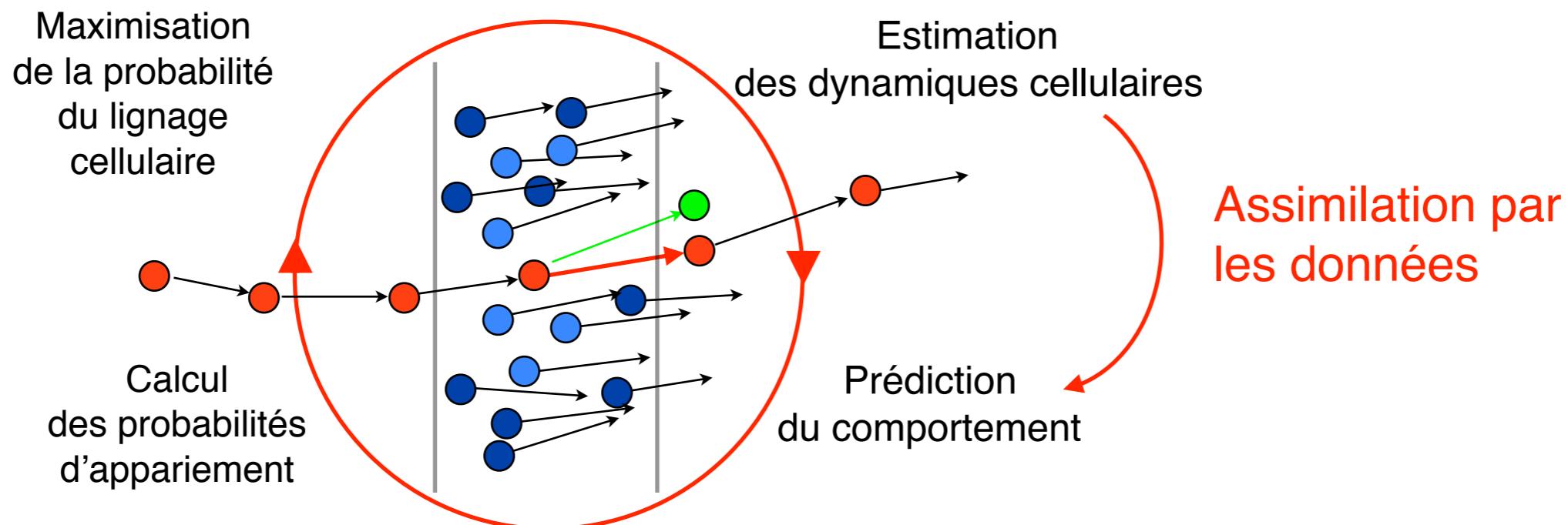


Suivi cellulaire probabiliste par maximisation de la vraisemblance



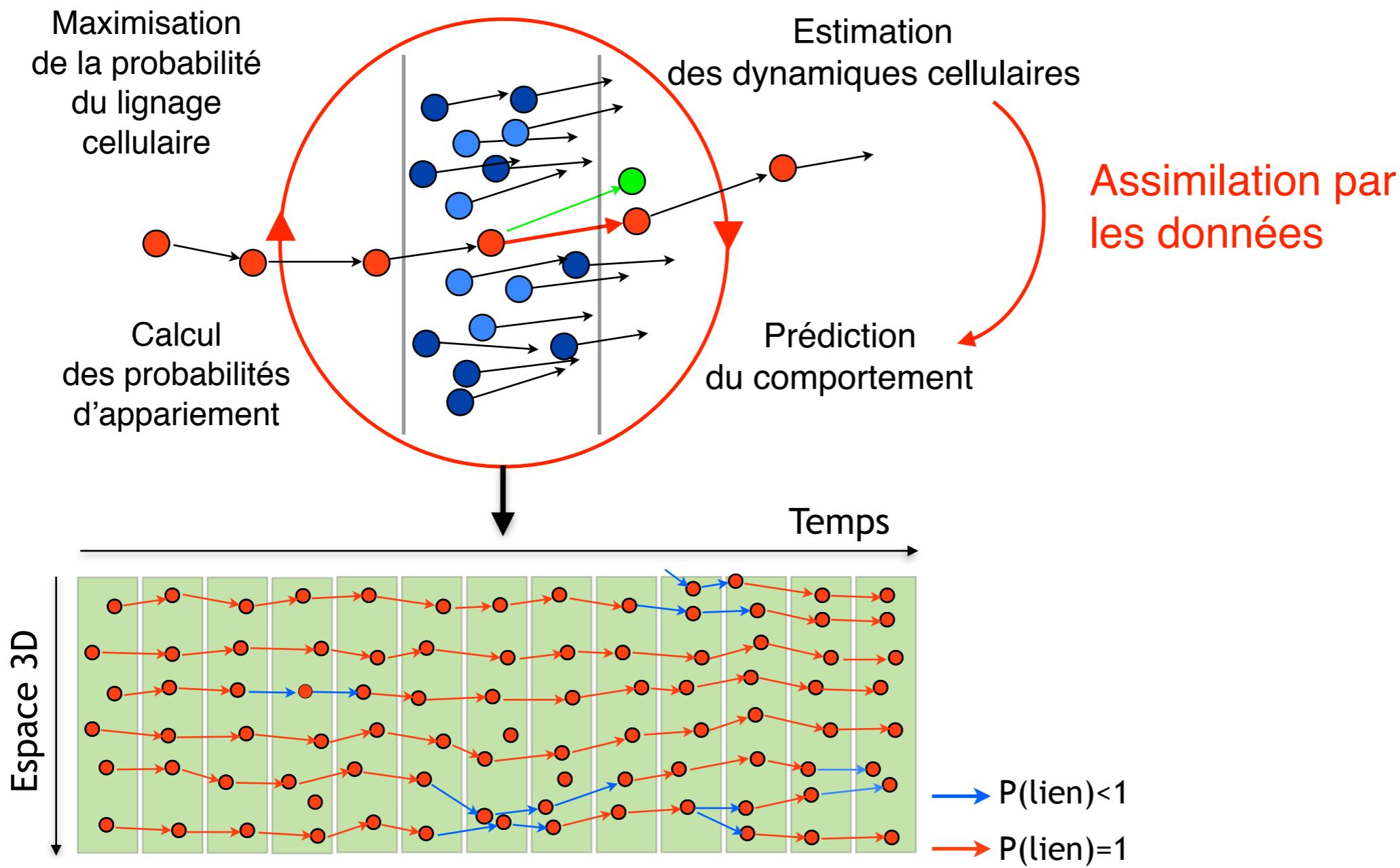
Suivi cellulaire probabiliste par maximisation de la vraisemblance

Propagation des certitudes par itération (Algorithme EM)



Suivi cellulaire probabiliste par maximisation de la vraisemblance

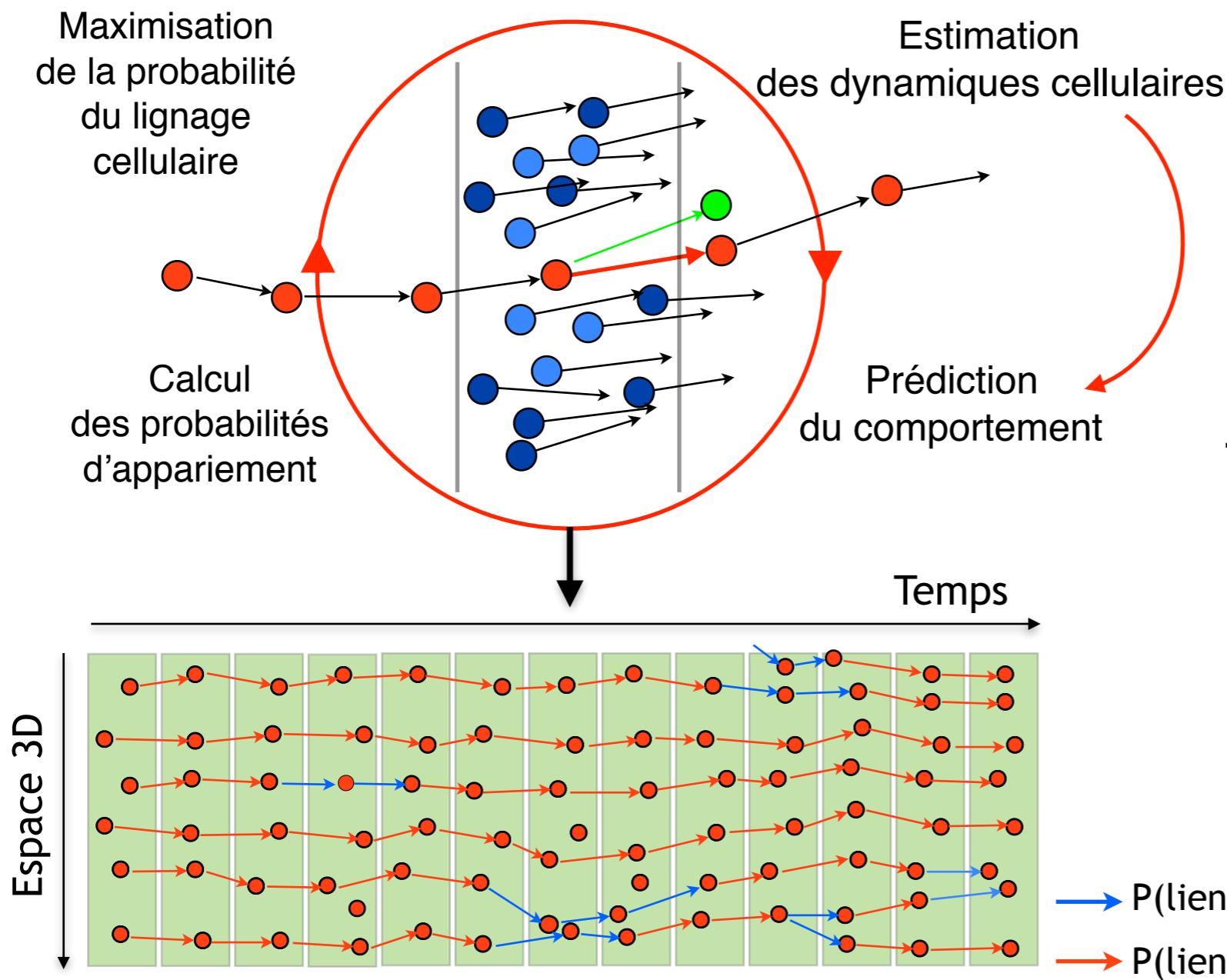
Propagation des certitudes par itération (Algorithme EM)



Embryon numérique avec une probabilité associée à chaque lien

Suivi cellulaire probabiliste par maximisation de la vraisemblance

Propagation des certitudes par itération (Algorithme EM)



Assimilation par les données

Résultats :

Test : plusieurs organismes

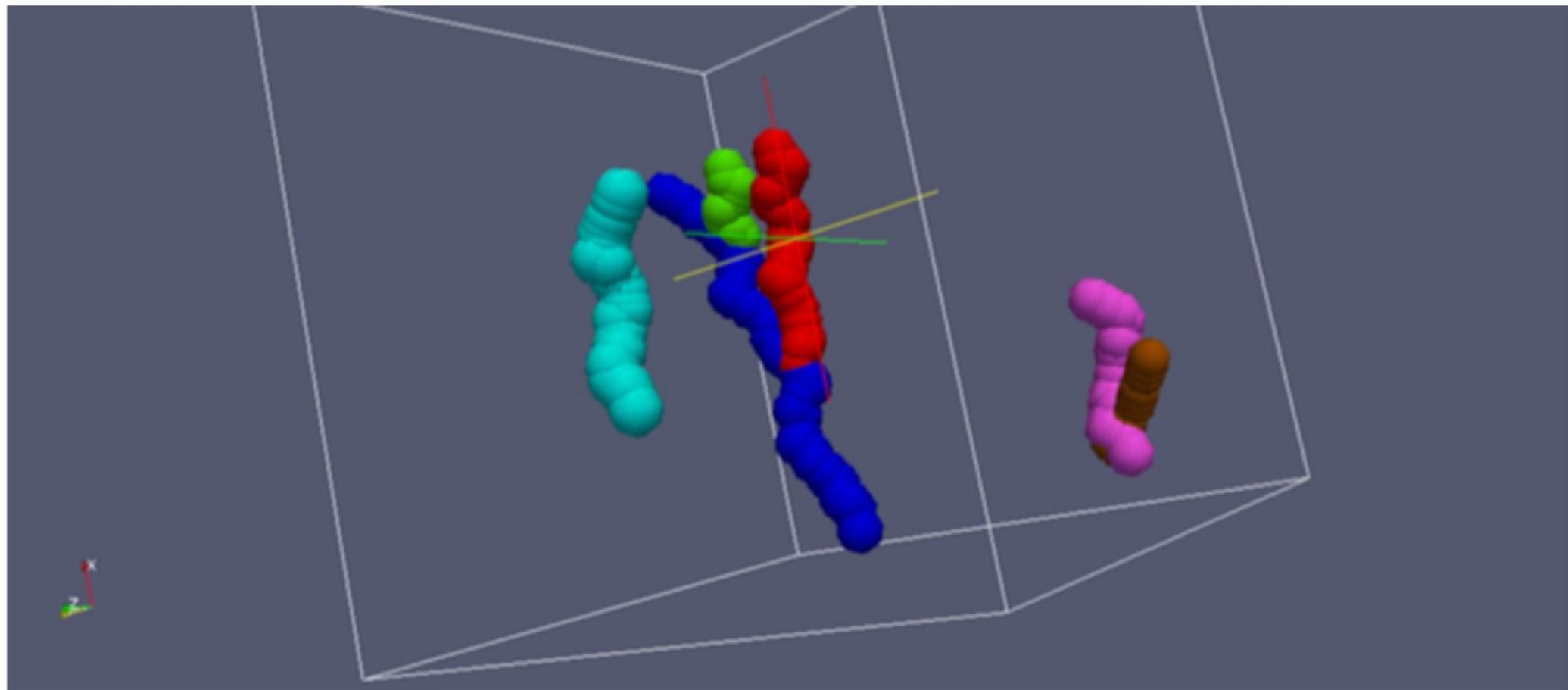
Evaluation : % d'erreurs \leq autres méthodes

Méthode sans paramètres

Lignage cellulaire facilement corrigible

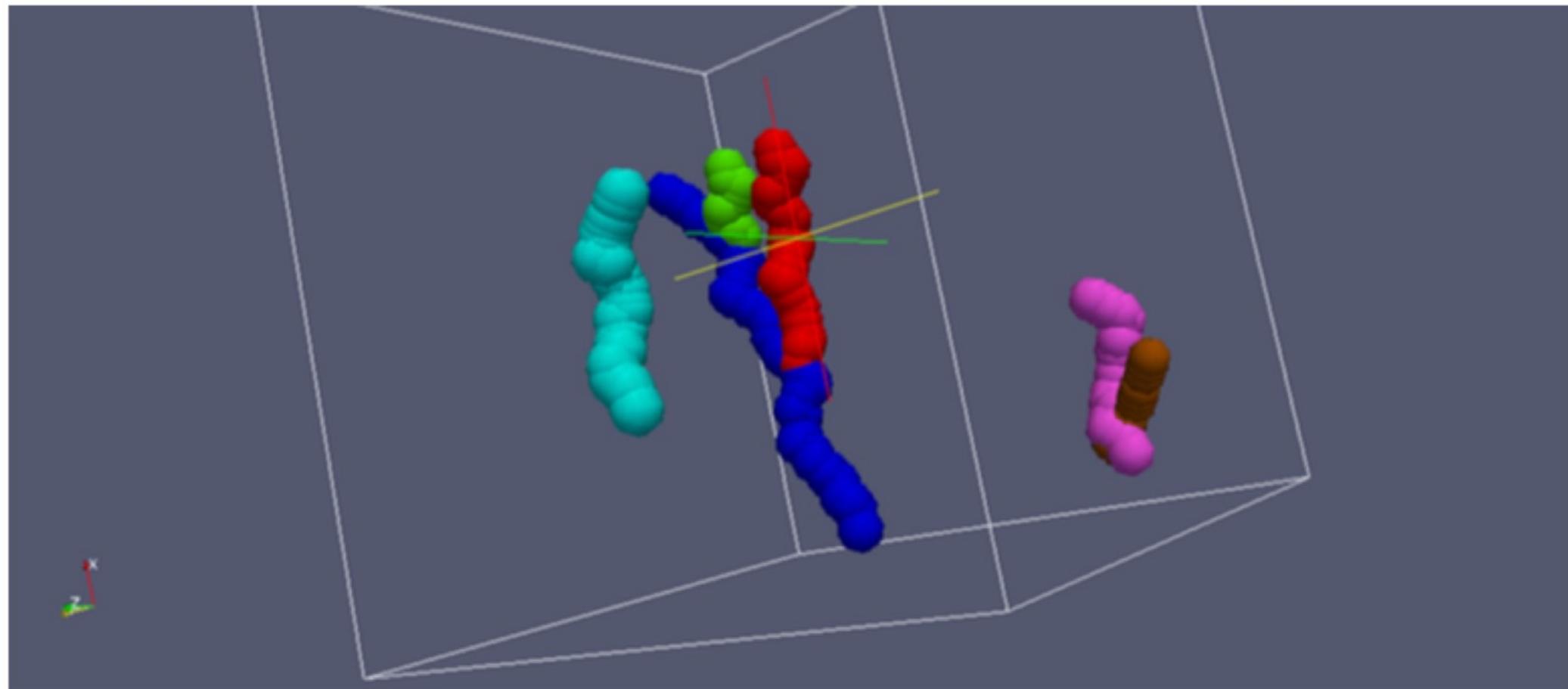
Embryon numérique avec une probabilité associée à chaque lien

Segmentation de trajectoires 4D : 3D projection



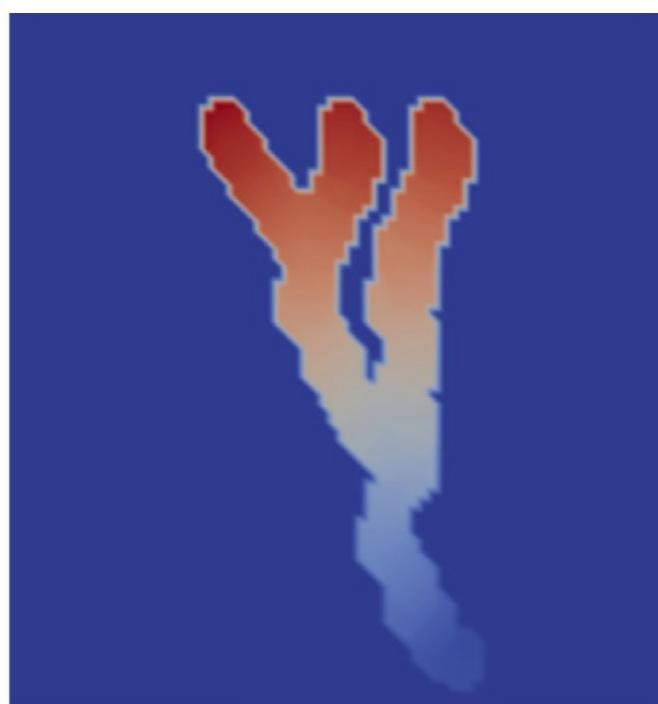
Mikula 2014

Segmentation de trajectoires 4D : 3D projection

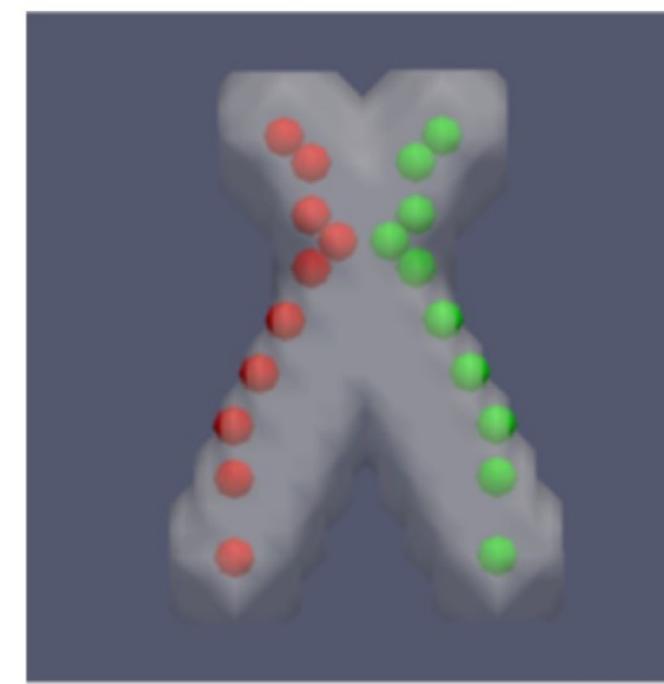


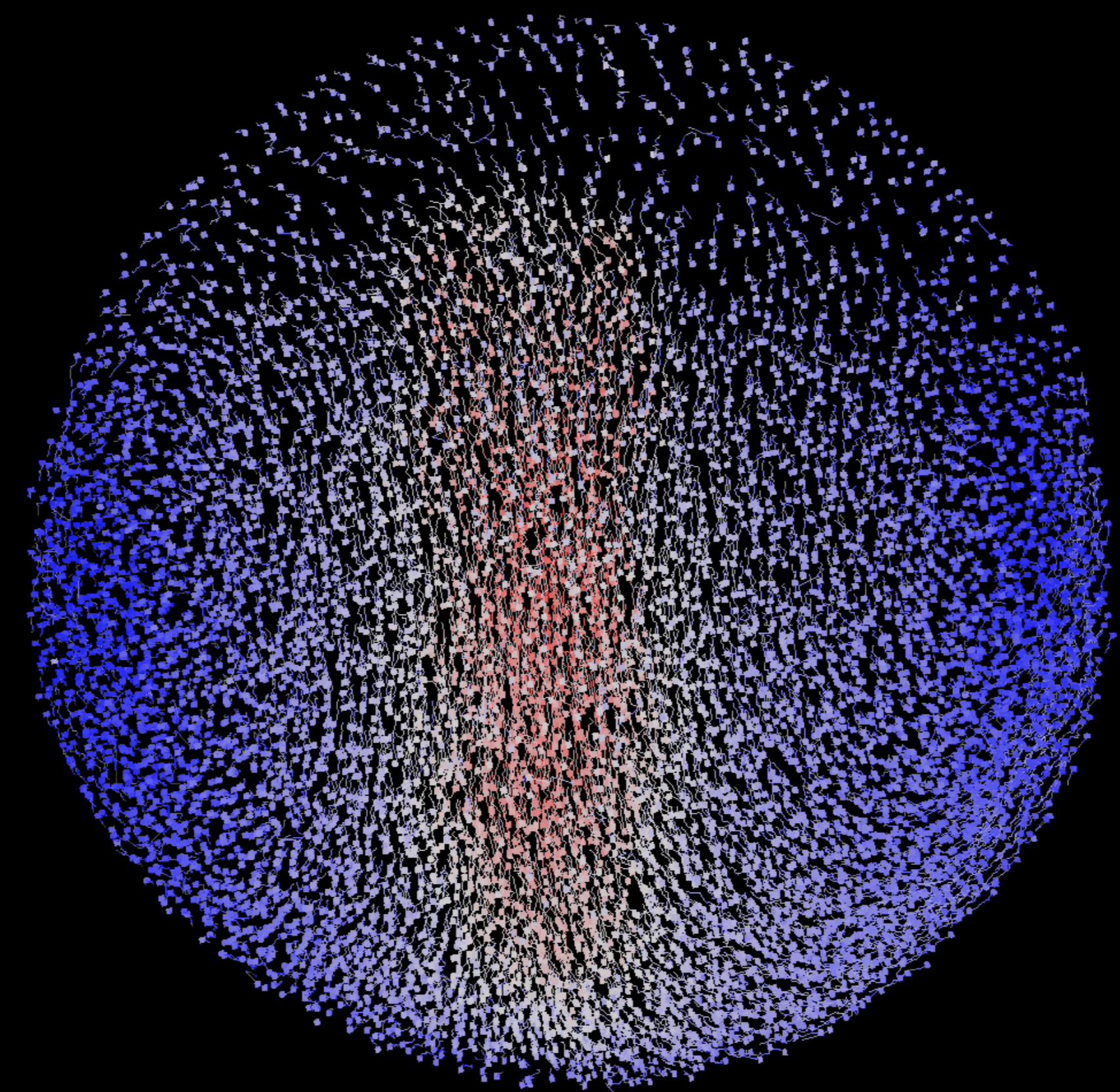
Mikula 2014

Divisions

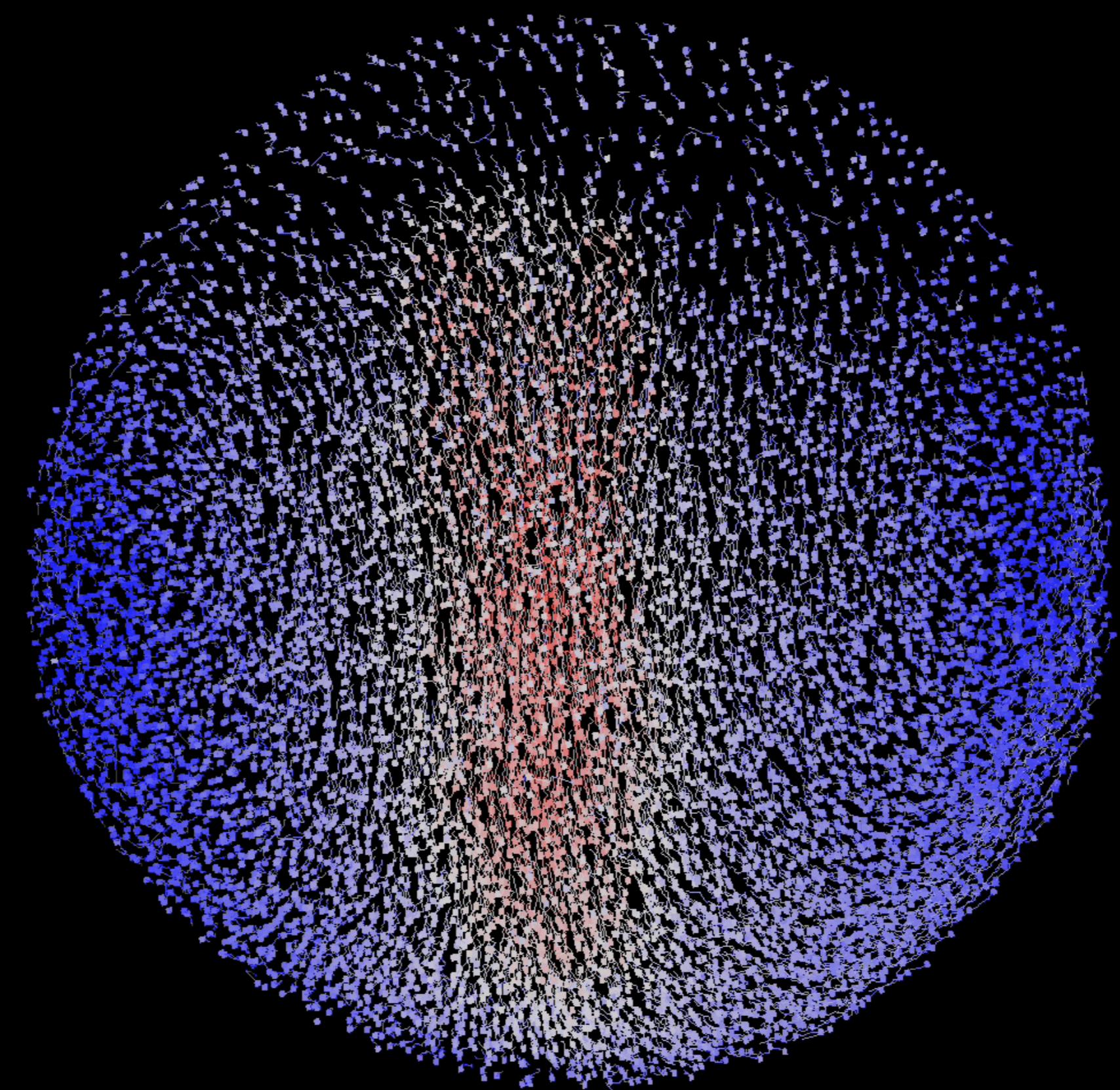


2 trajectoires



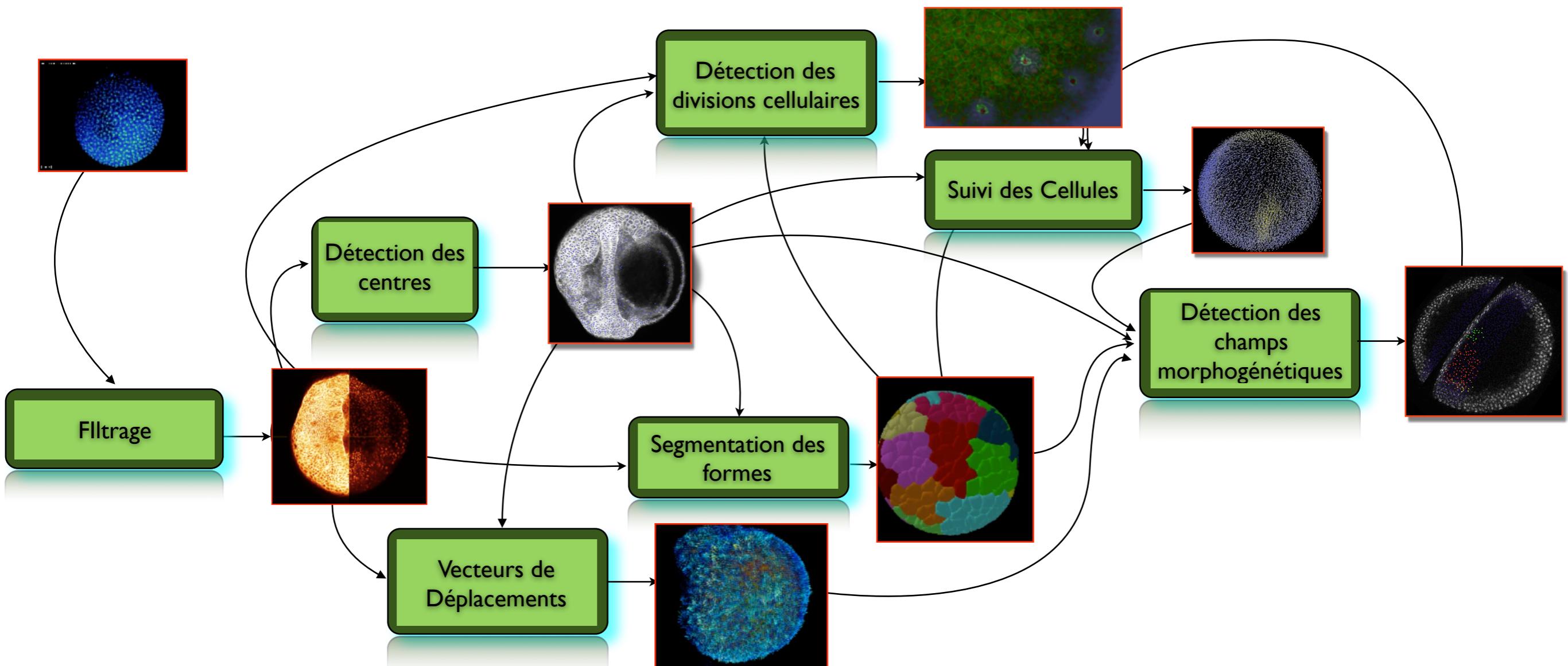


9h6mn15

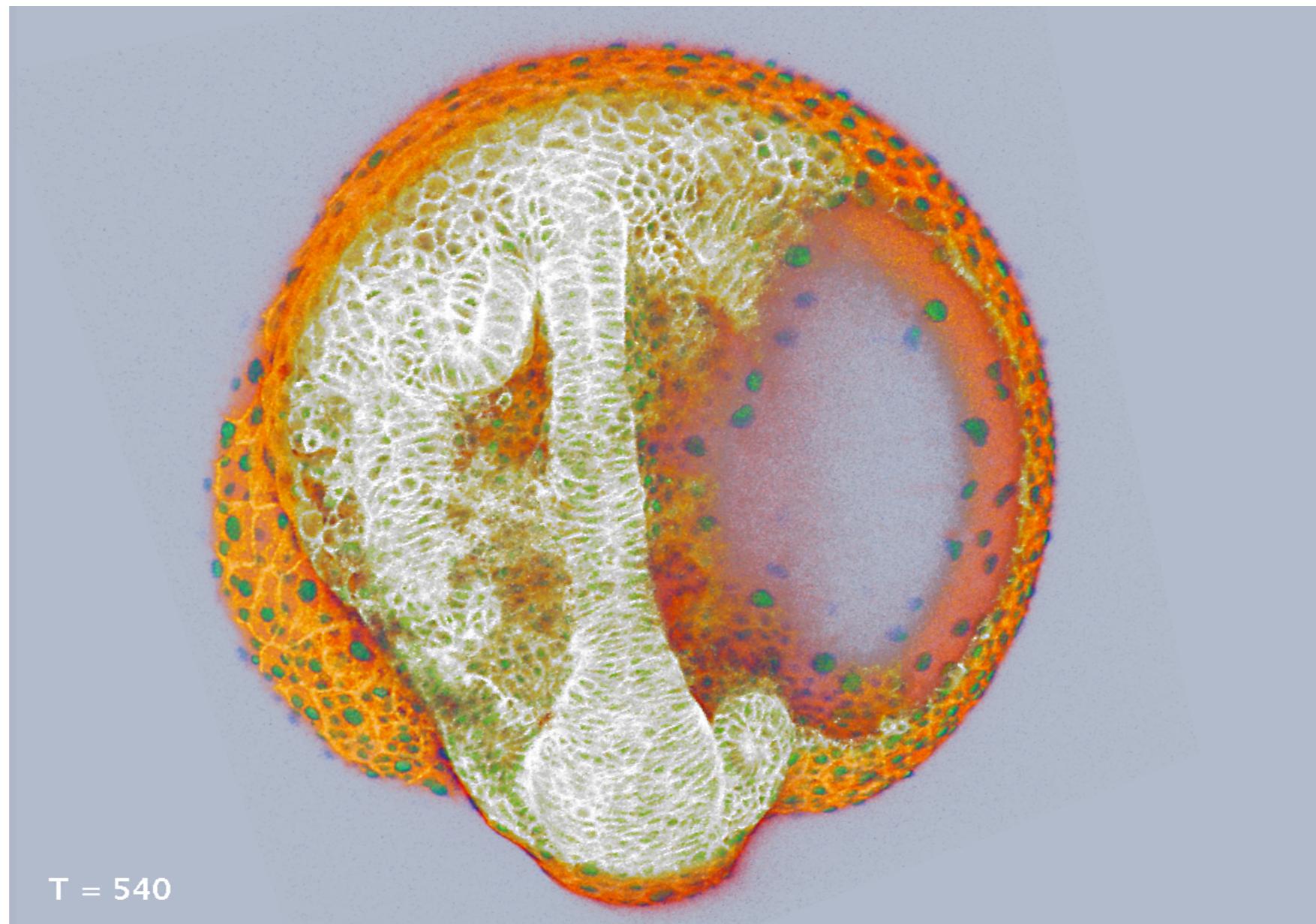


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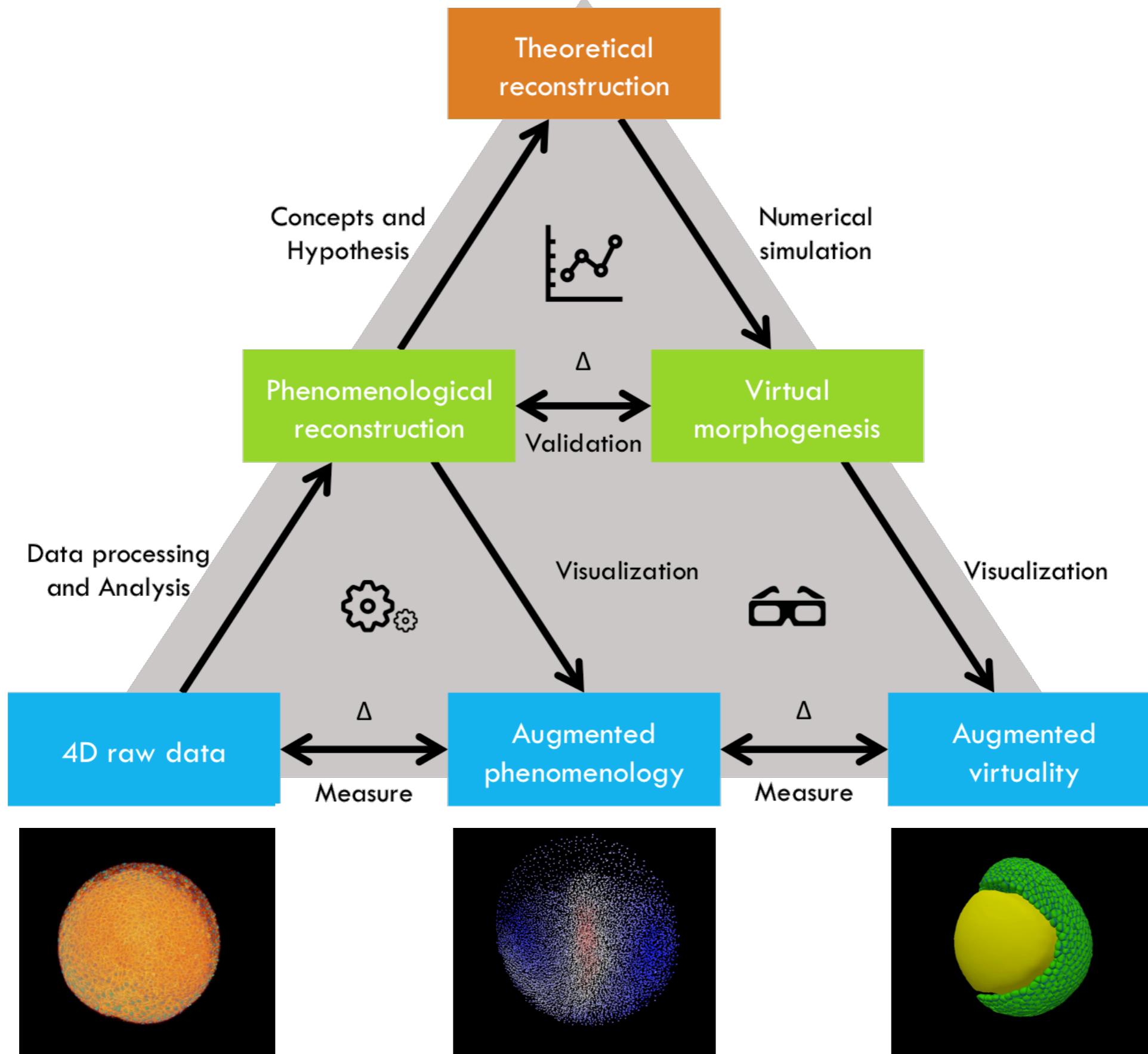
Reconstruction Image 4D



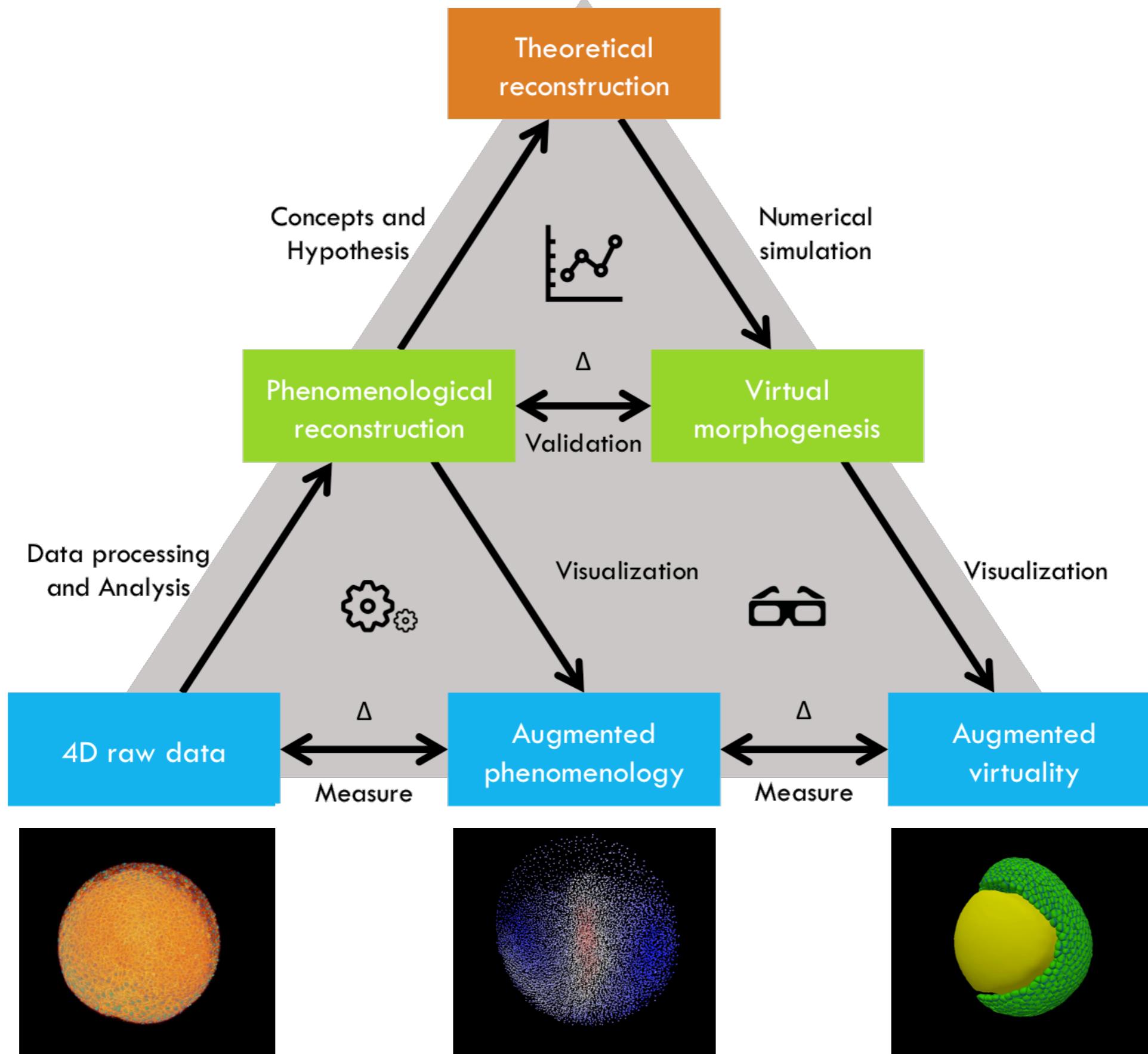
Champs morphogénétiques



Approche épistémologique



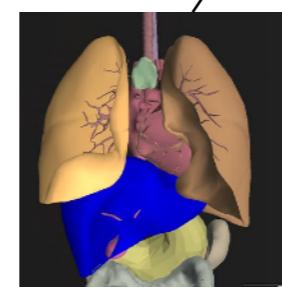
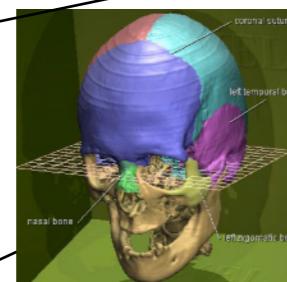
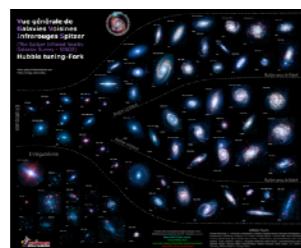
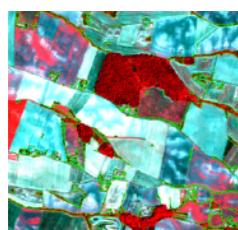
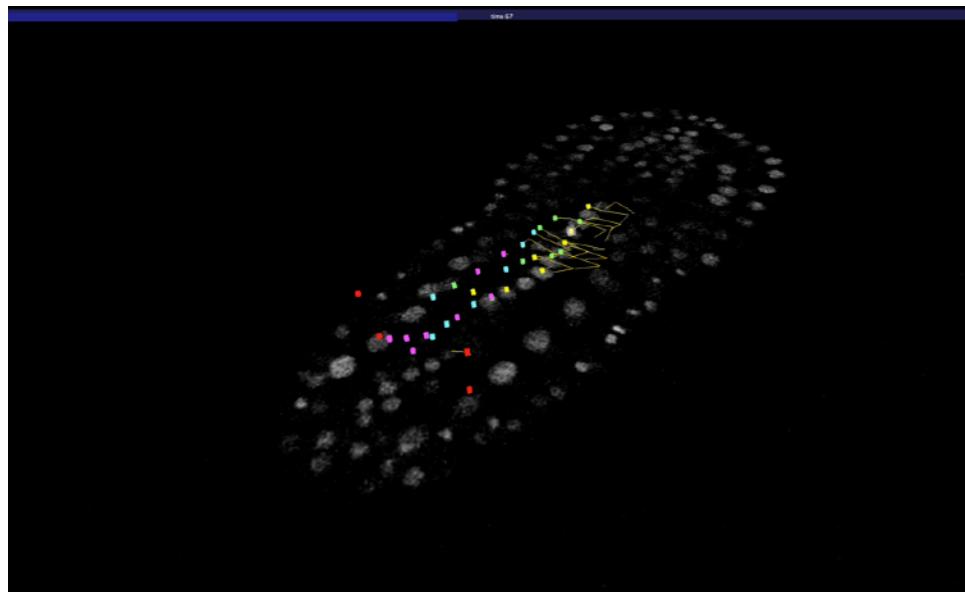
Approche épistémologique



Vérité terrain

Pourquoi ?

- analyses des données
- amélioration des algorithmes
- évaluation des méthodes



Validation manuelle

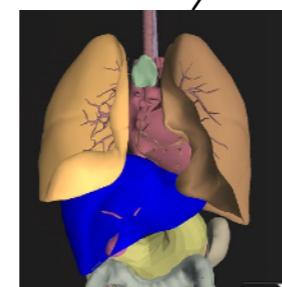
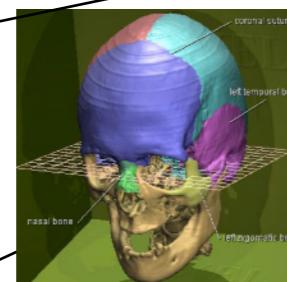
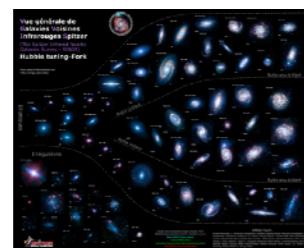
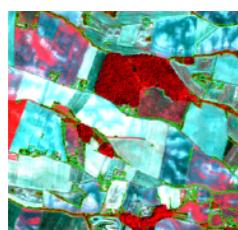
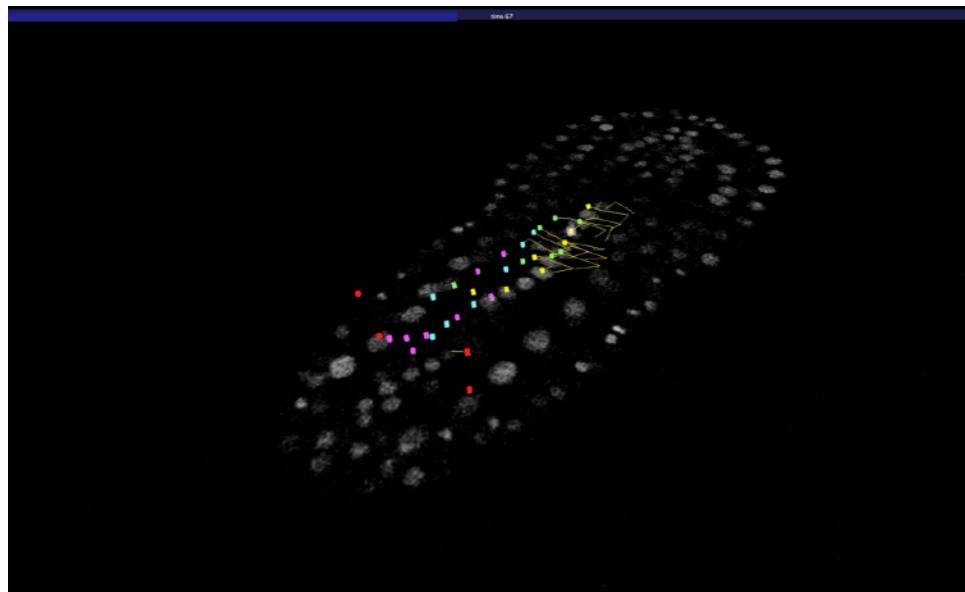
- détection
- classification
- segmentation
- tracking



Vérité terrain

Pourquoi ?

- analyses des données
- amélioration des algorithmes
- évaluation des méthodes

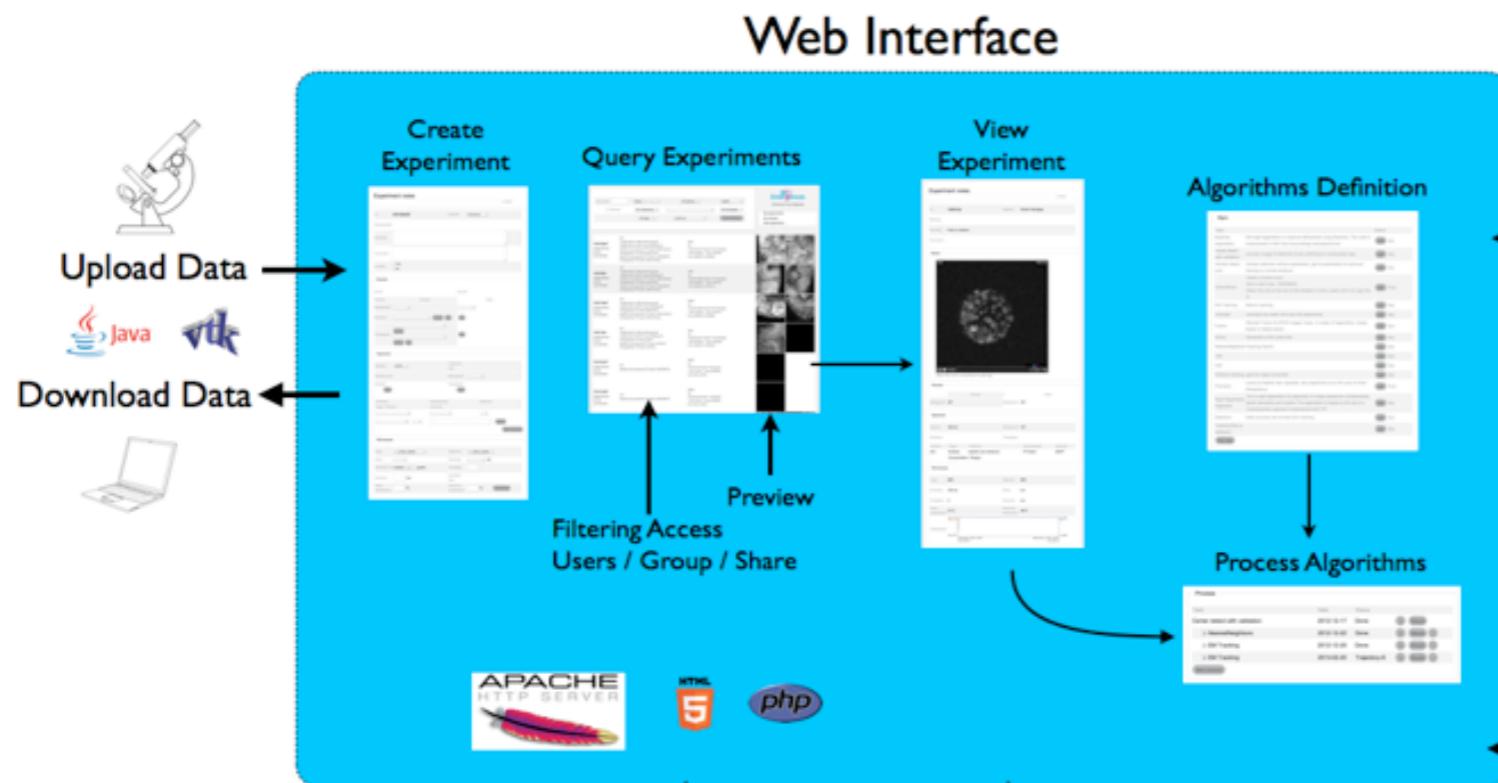


Validation manuelle

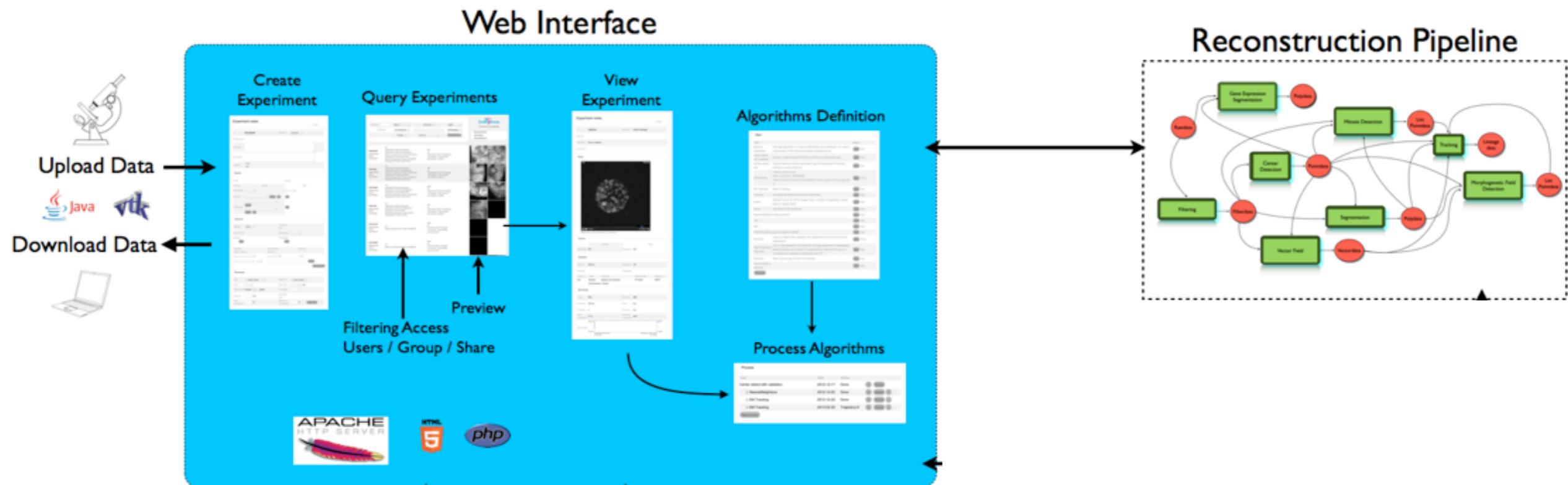
- détection
- classification
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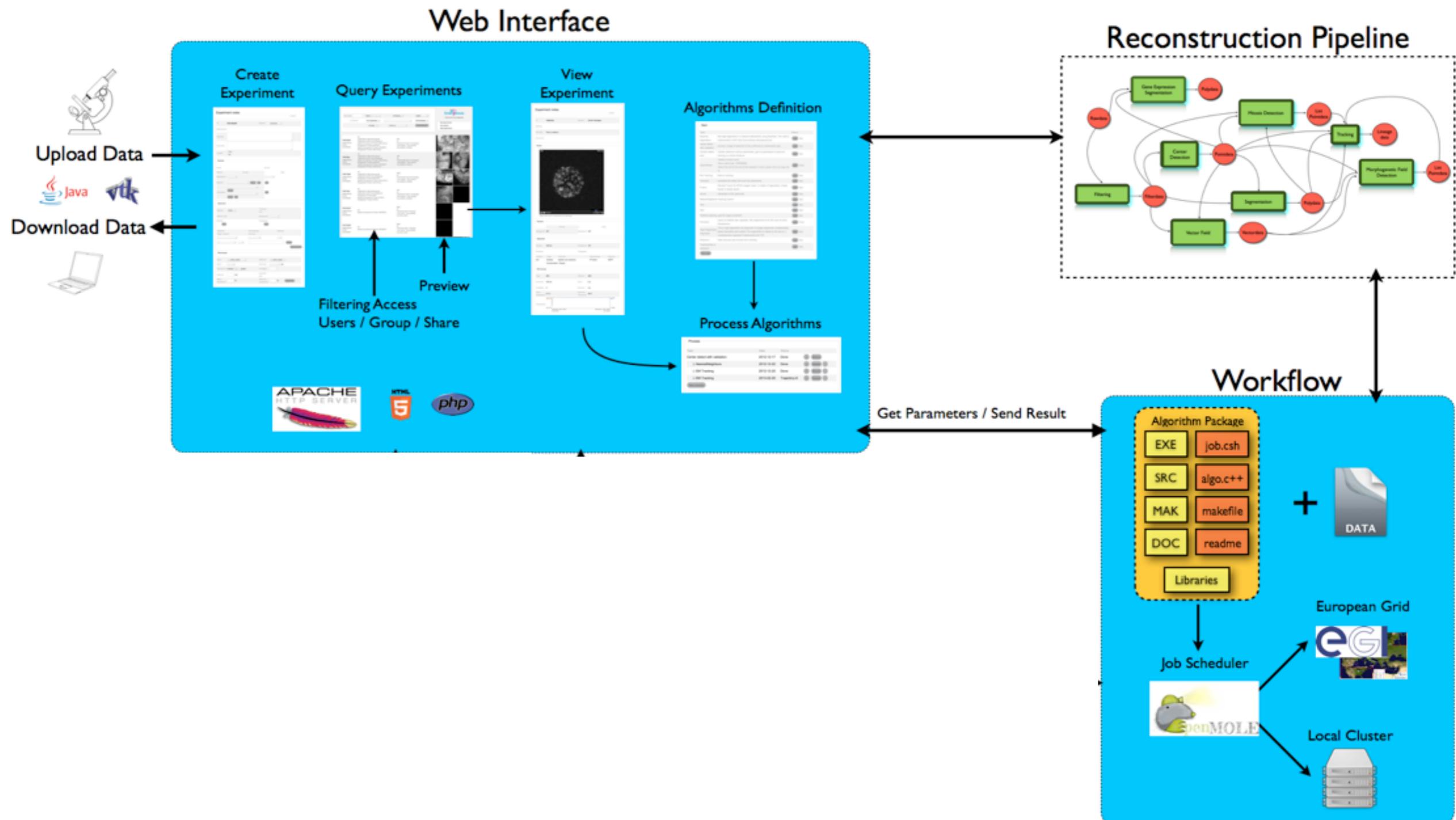
Traitements des données 4D



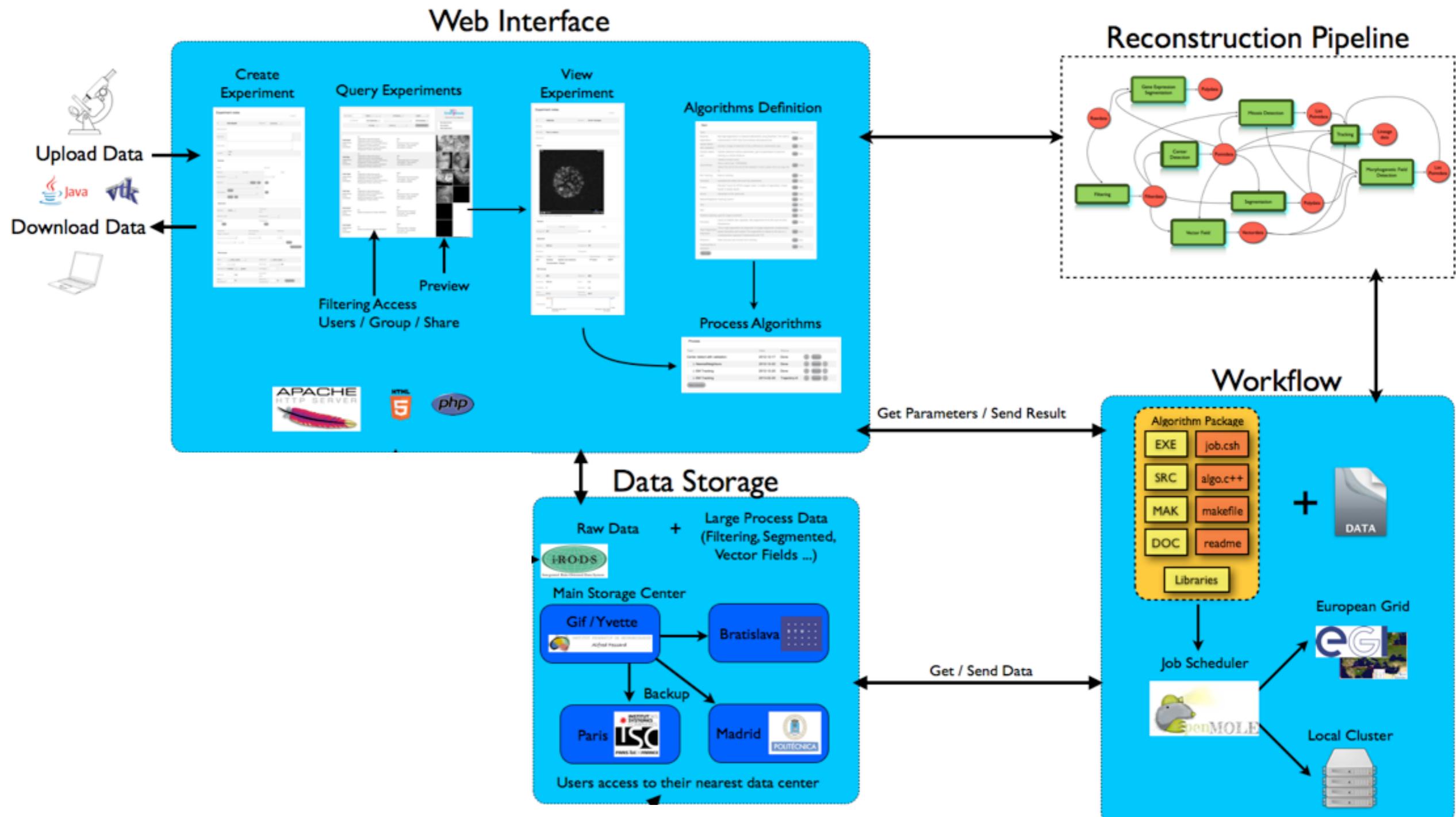
Traitements des données 4D



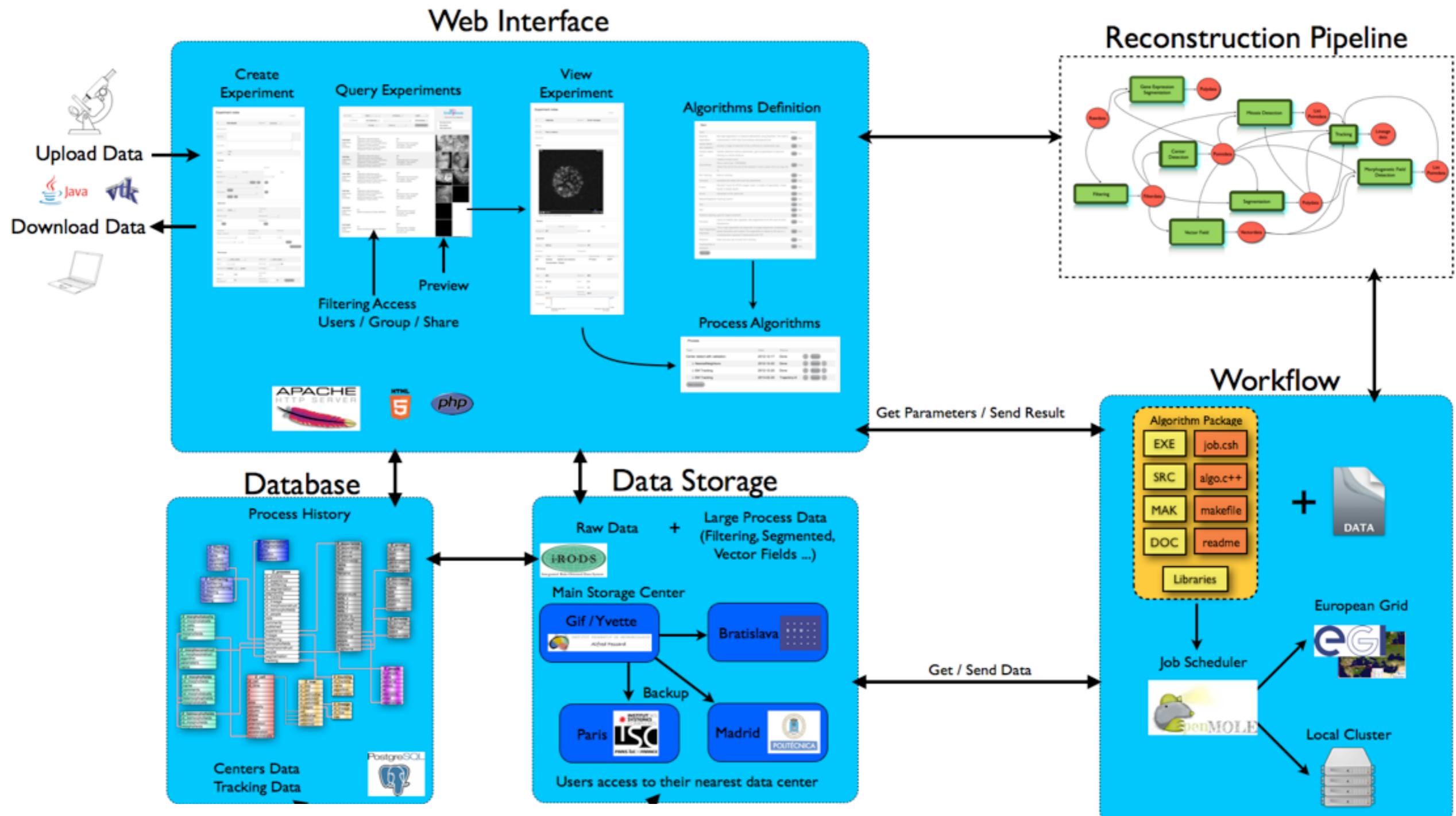
Traitements des données 4D



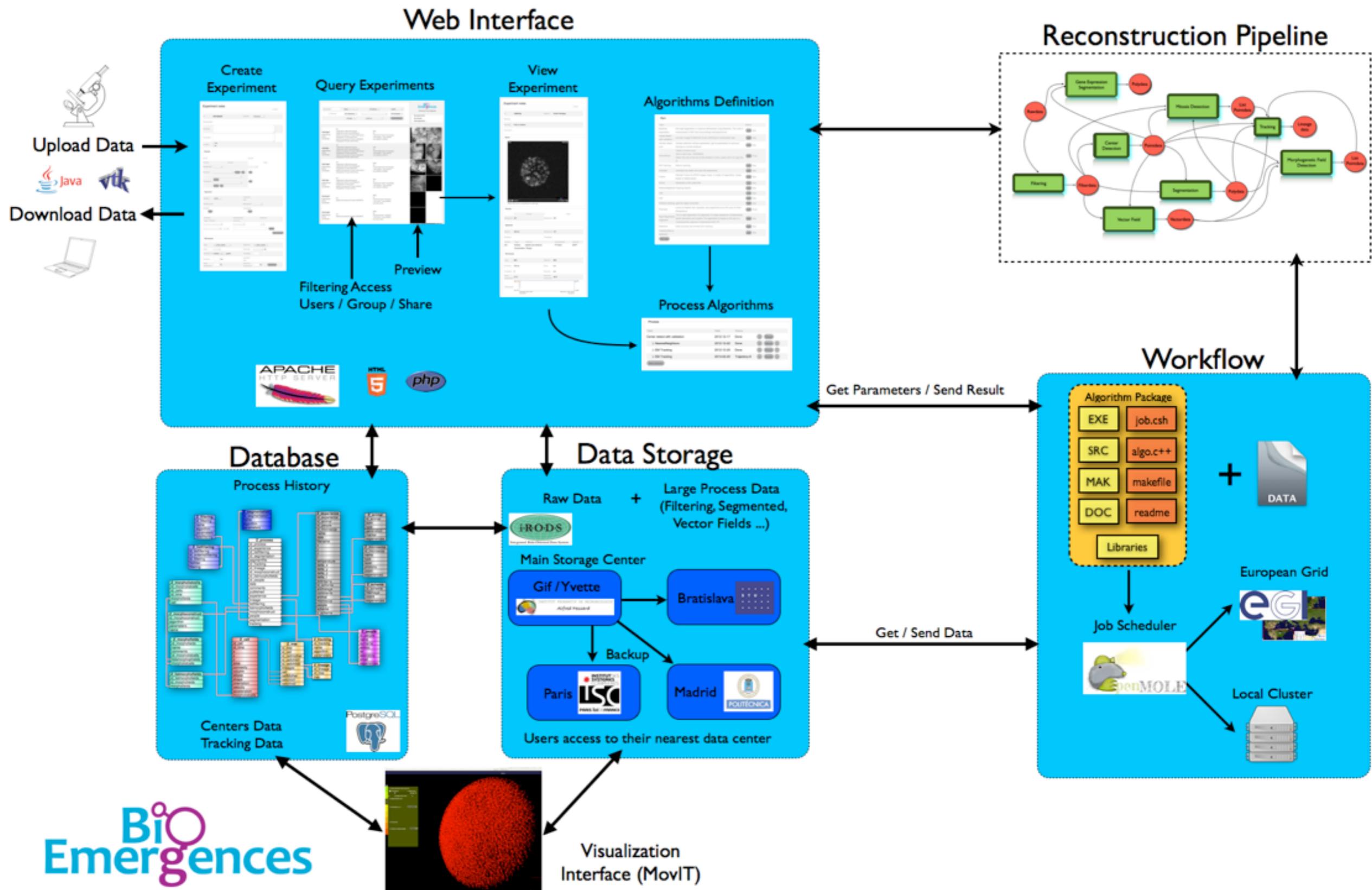
Traitements des données 4D



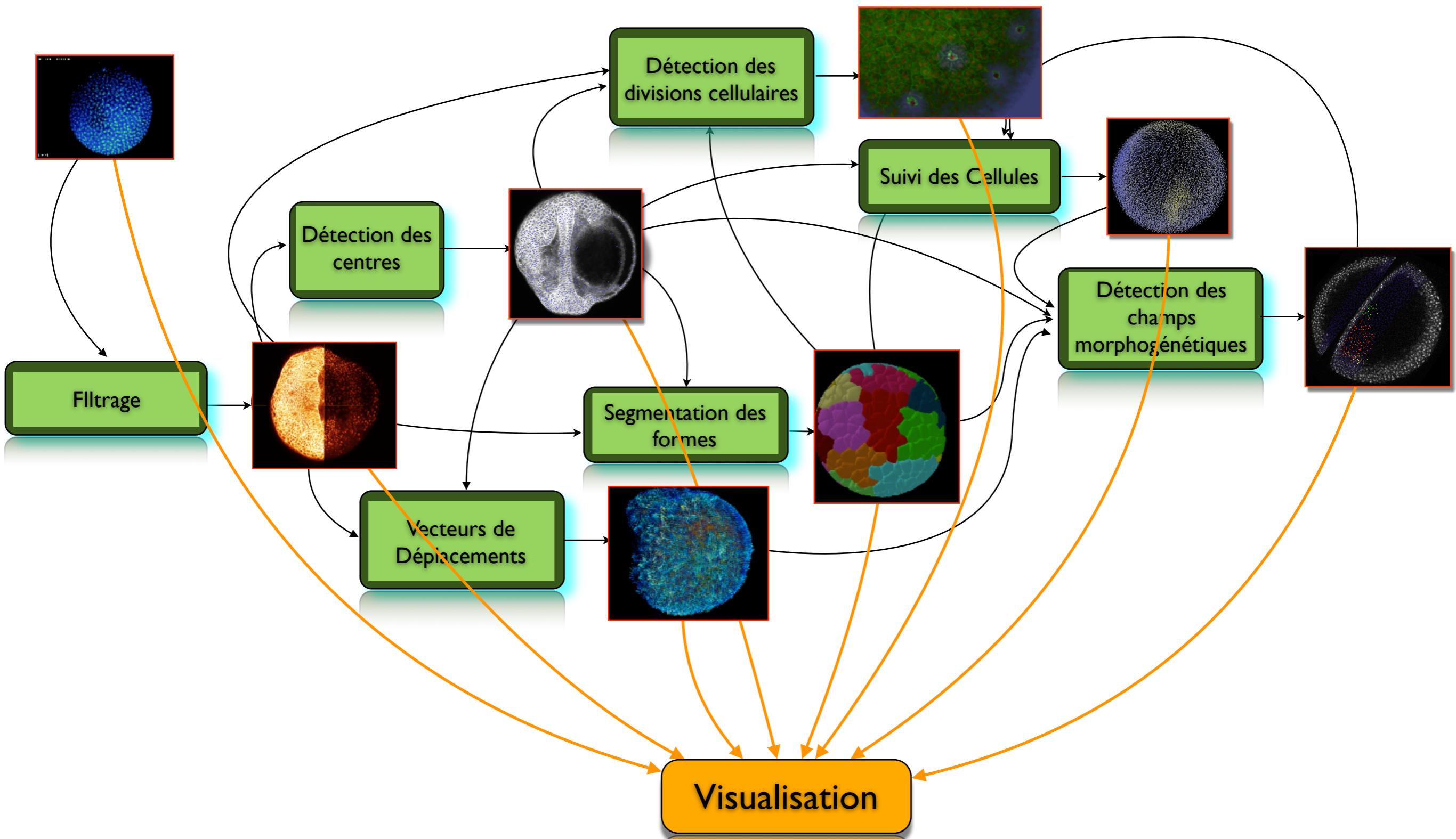
Traitements des données 4D



Traitements des données 4D



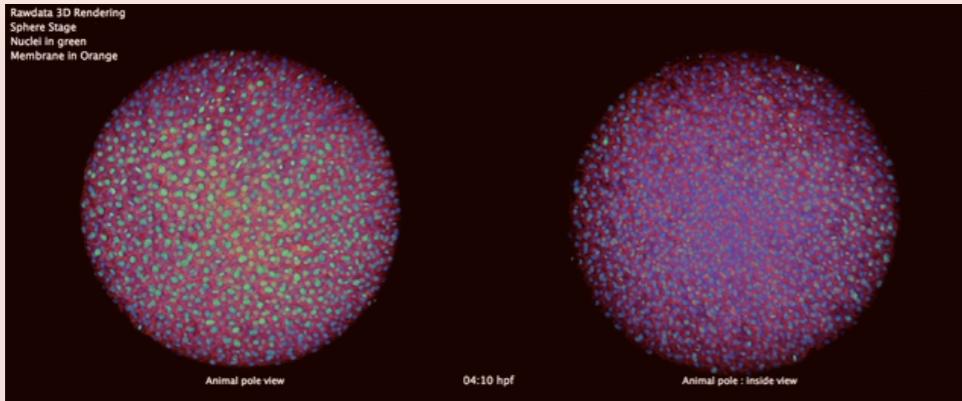
Visualisation d'images 4D



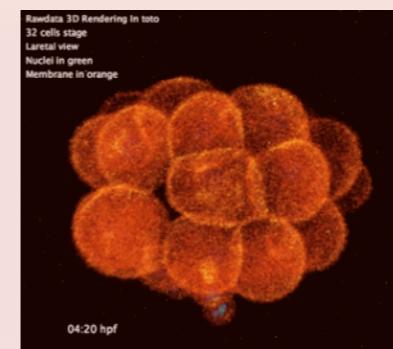
MovIT : Interface de Visualisation Interactive

[Faure & al Nature Communication 2016]

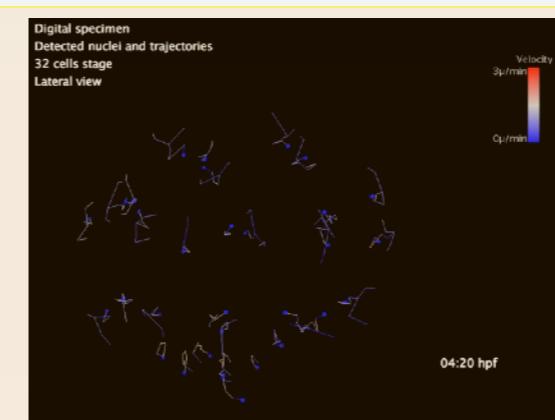
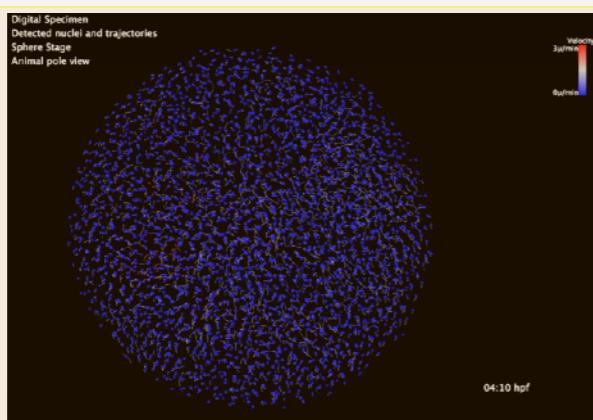
Zebrafish



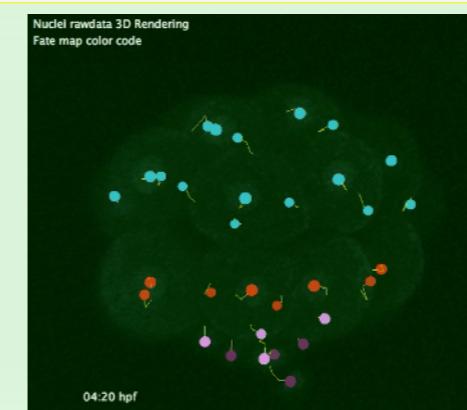
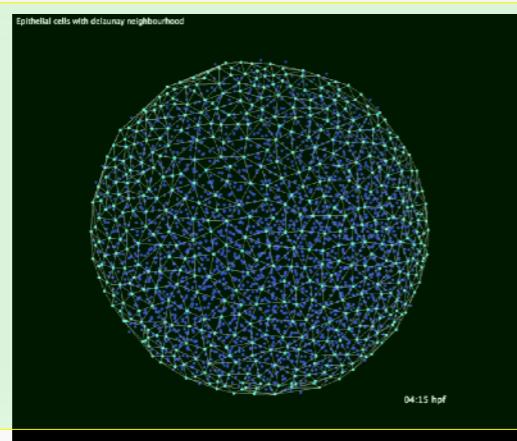
Sea Urchin



Observation



Digitizing

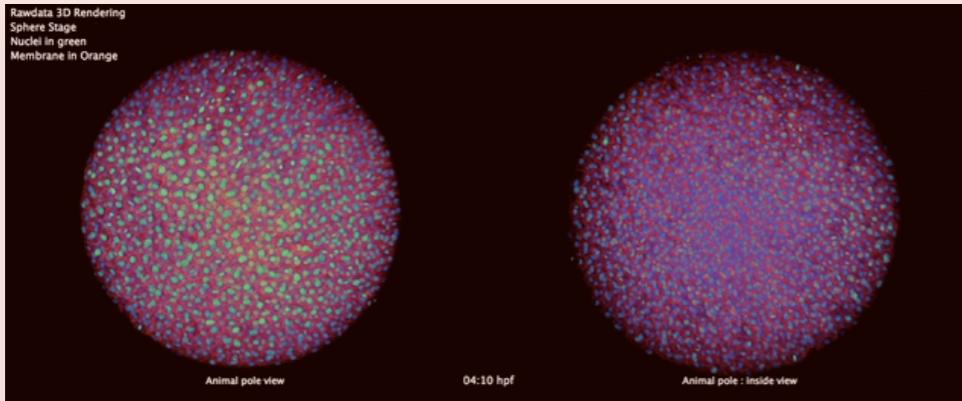


Abstraction

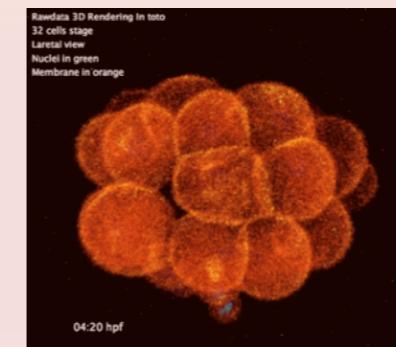
MovIT : Interface de Visualisation Interactive

[Faure & al Nature Communication 2016]

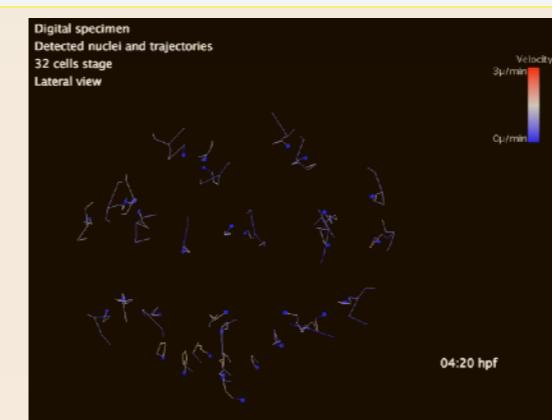
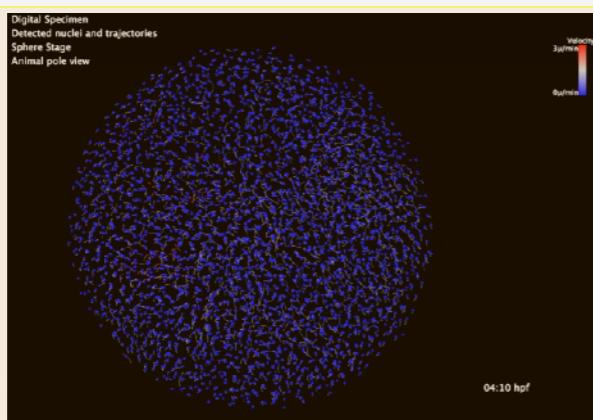
Zebrafish



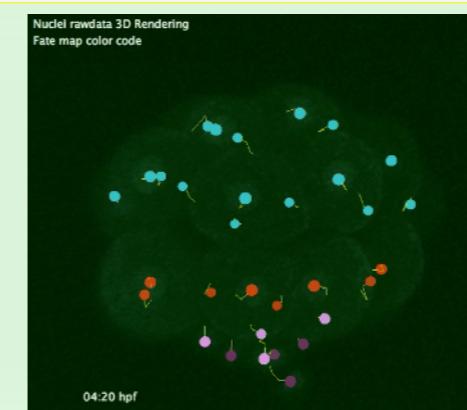
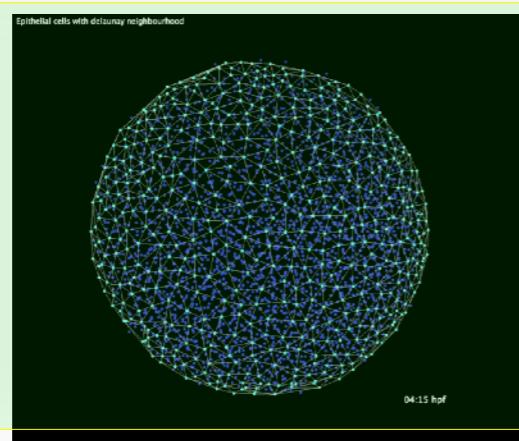
Sea Urchin



Observation

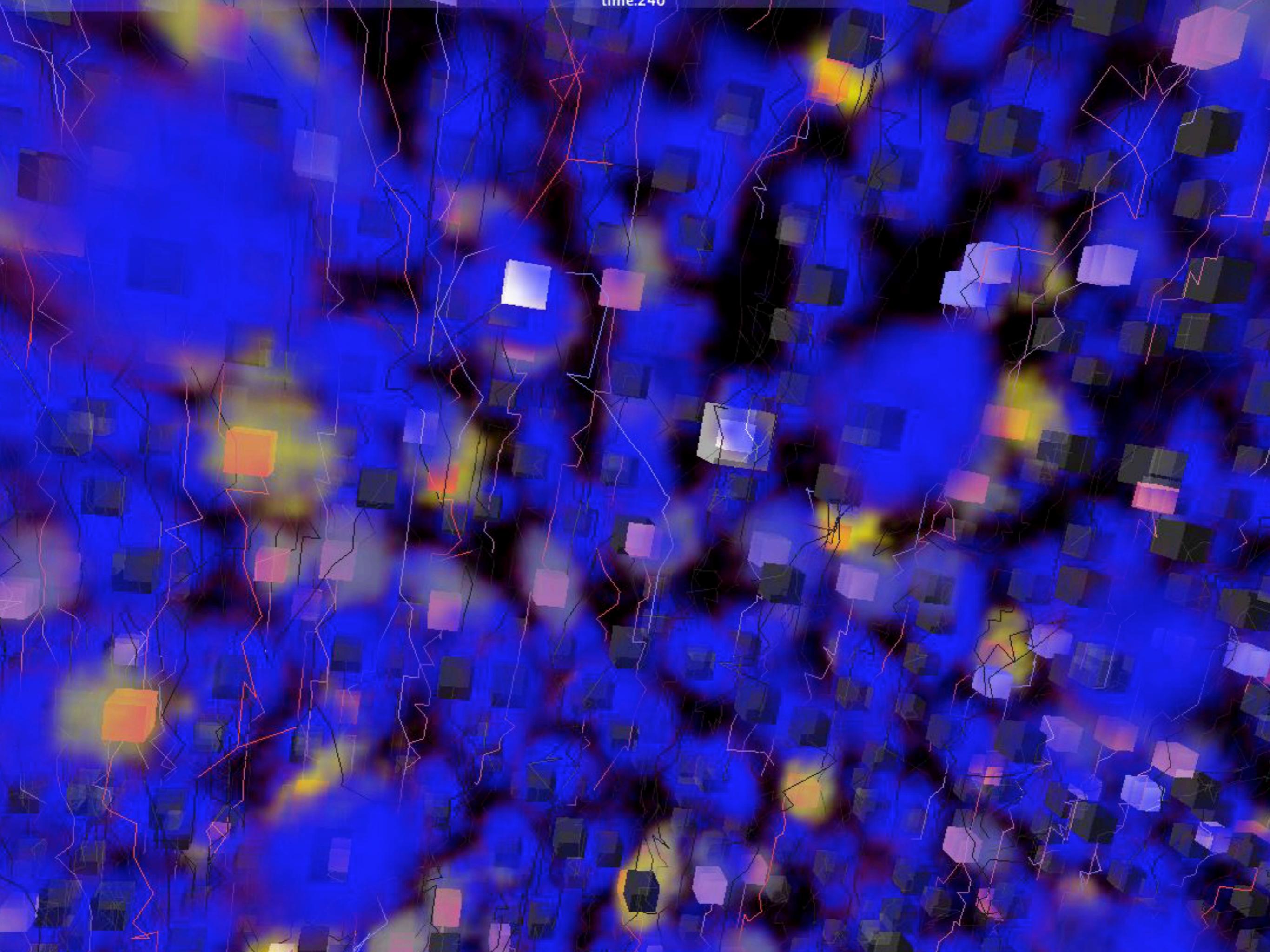


Digitizing

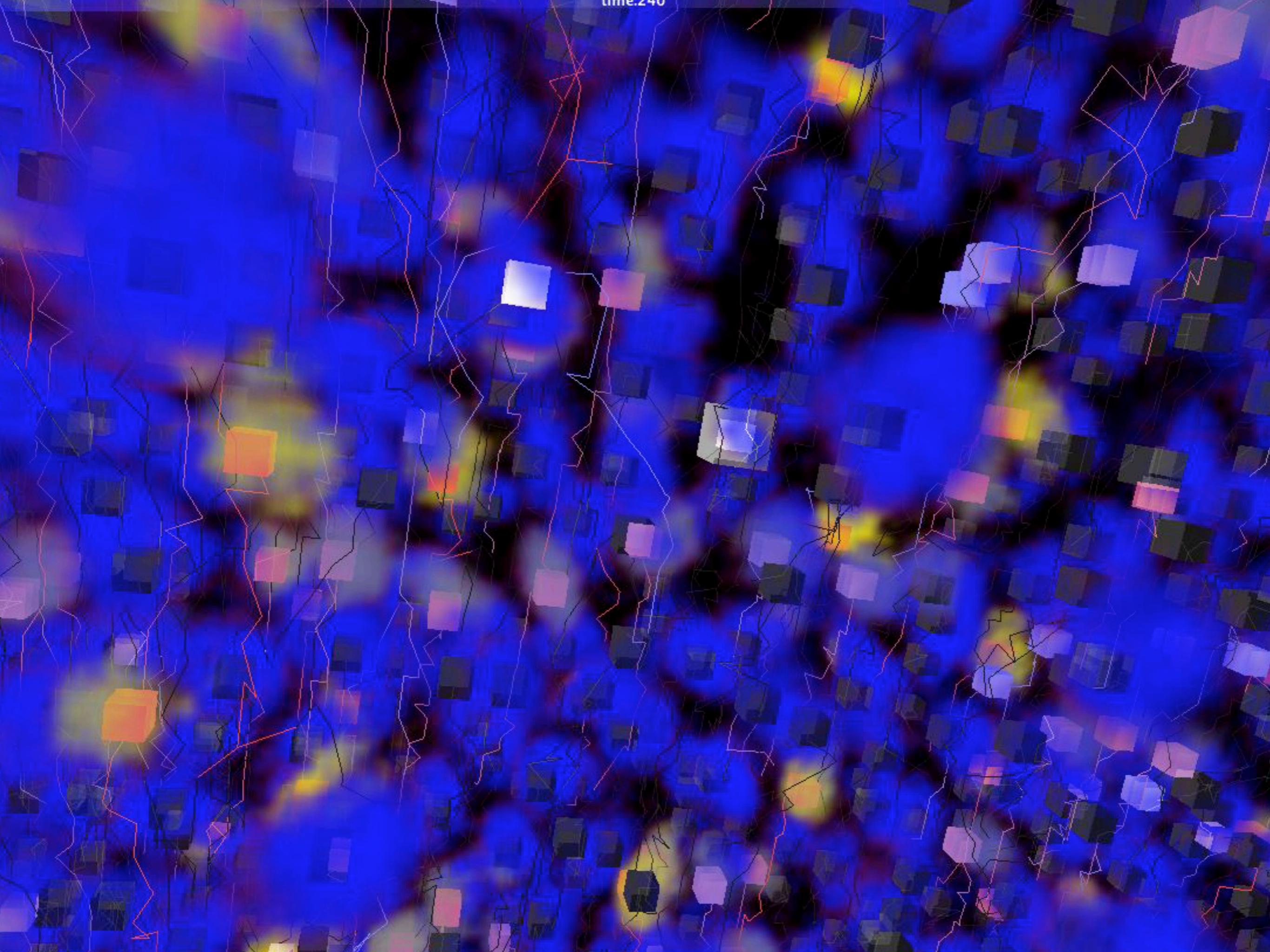


Abstraction

time.240

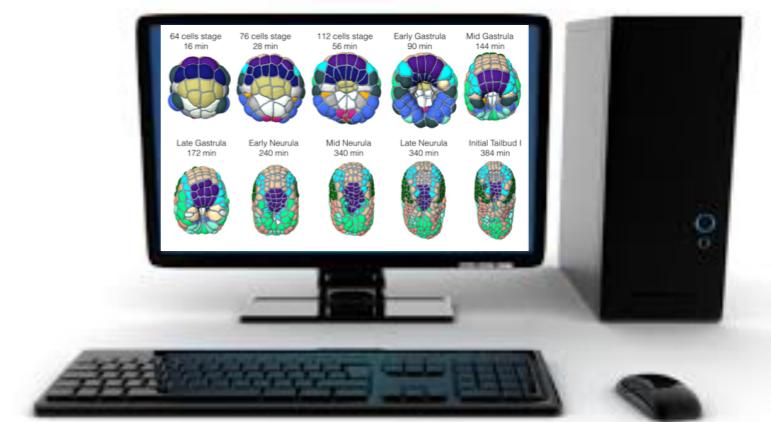


time.240



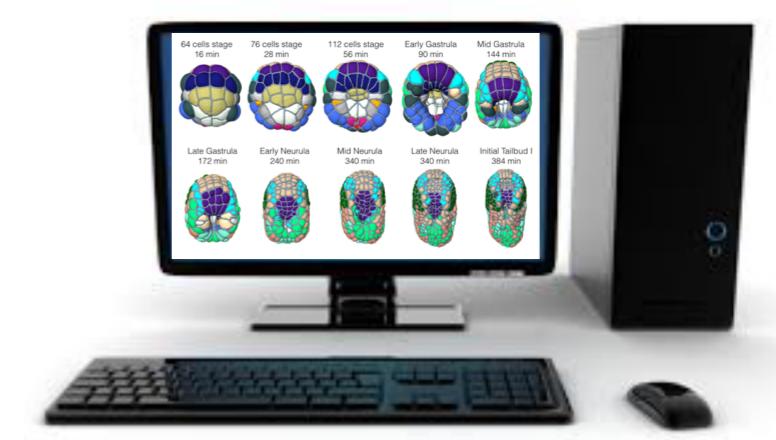
Data Visualisation and Validation

How do we visualize and validate 4D dataset ?



How do we visualize and validate 4D dataset ?

a biologist...

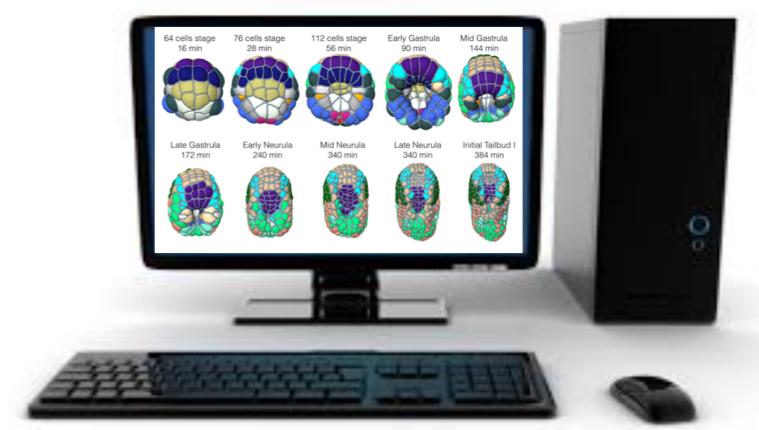


How do we visualize and validate 4D dataset ?

a biologist...

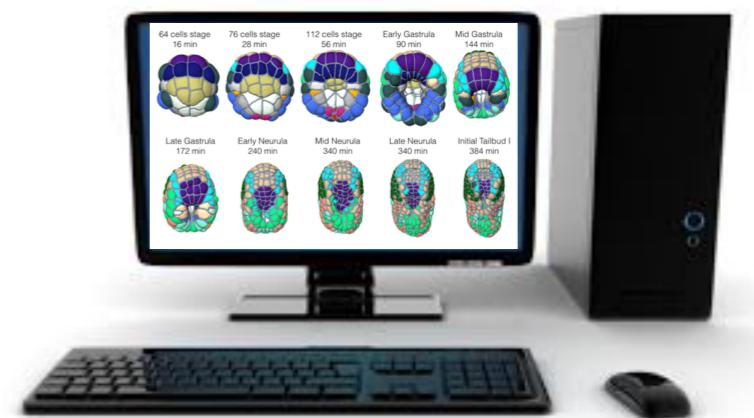


?



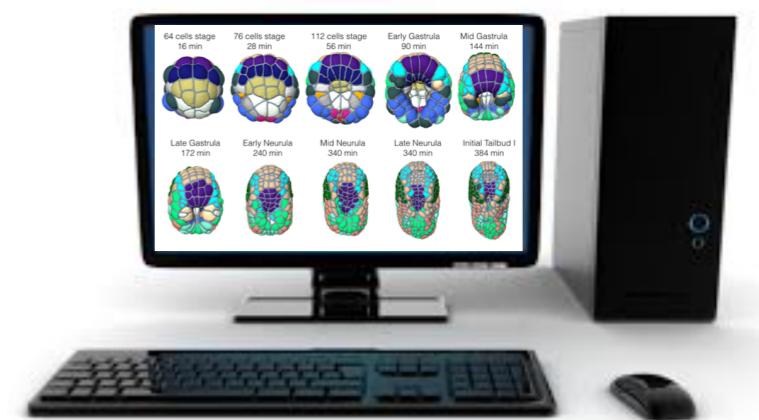
How do we visualize and validate 4D dataset ?

a biologist...



How do we visualize and validate 4D dataset ?

a biologist...



How do we visualize and validate 4D dataset ?

a biologist...

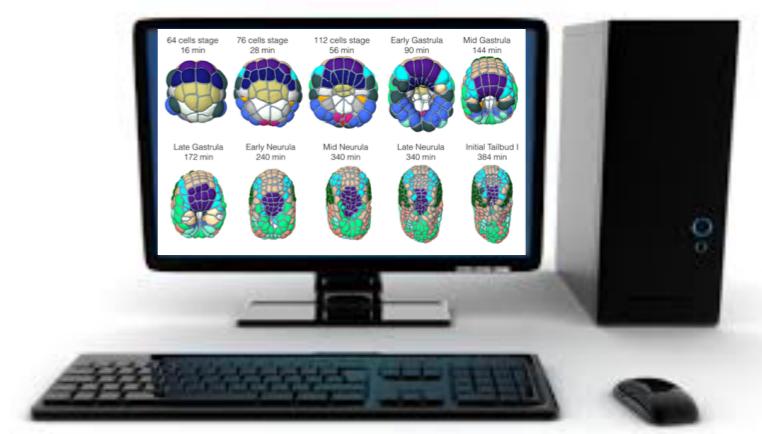


How do we visualize and validate 4D dataset ?

a biologist...

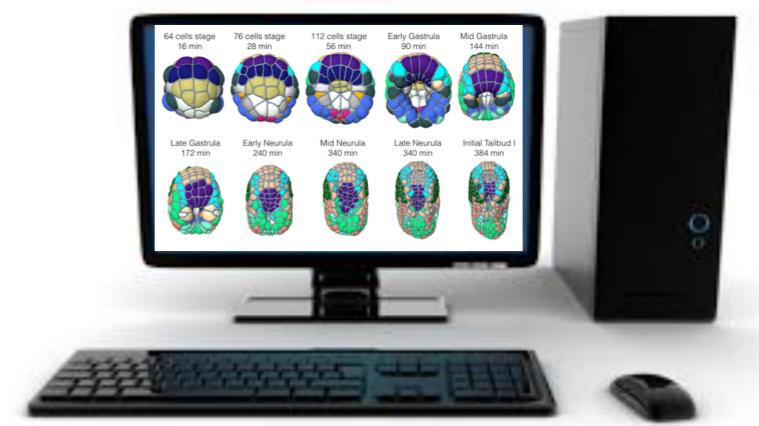


?



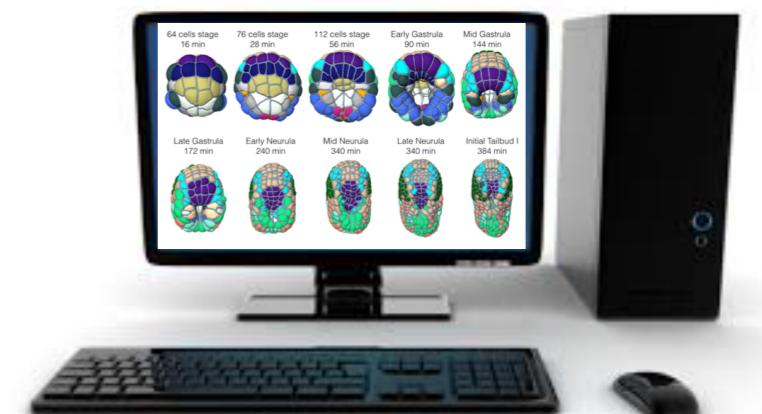
How do we visualize and validate 4D dataset ?

a biologist...



How do we visualize and validate 4D dataset ?

a biologist...



How do we visualize and validate 4D dataset ?

a biologist...



Context : BIG-DATA



Today

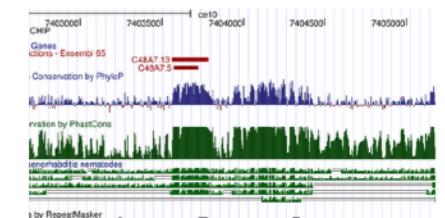
DNA - sequencing



BioInformatics



Genomic Browser



Context : BIG-DATA



Today

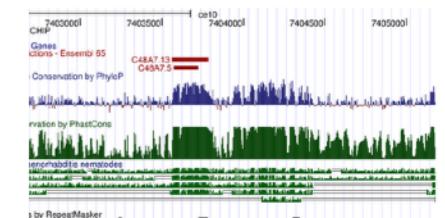
DNA - sequencing



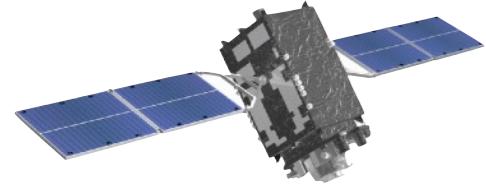
BioInformatics



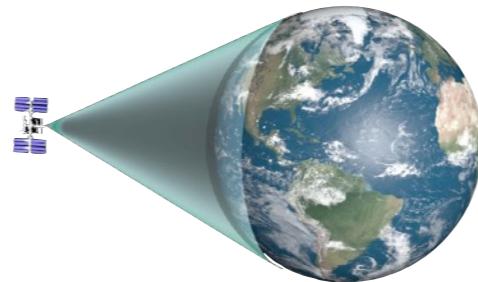
Genomic Browser



Satellite, Map



Earth Reconstruction



Google Maps



Context : BIG-DATA

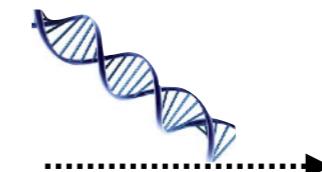


Today

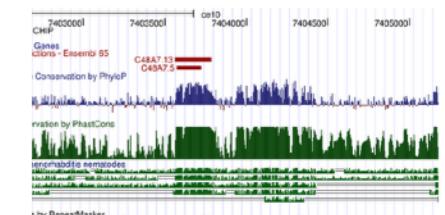
DNA - sequencing



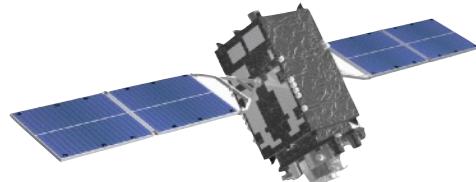
BioInformatics



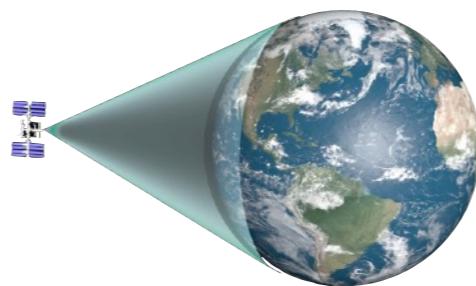
Genomic Browser



Satellite, Map



Earth Reconstruction



Google Maps

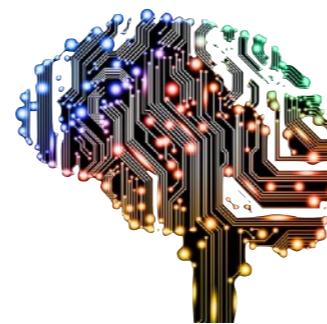


Tomorrow, data will be in 3D

3D Observation



Machine Learning



Interact, share



Context : BIG-DATA



Today

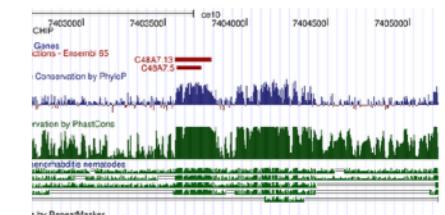
DNA - sequencing



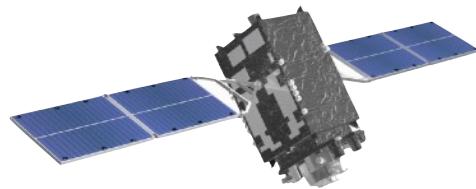
BioInformatics



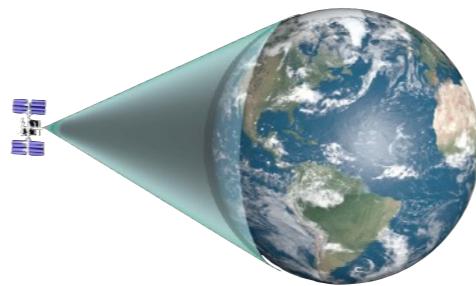
Genomic Browser



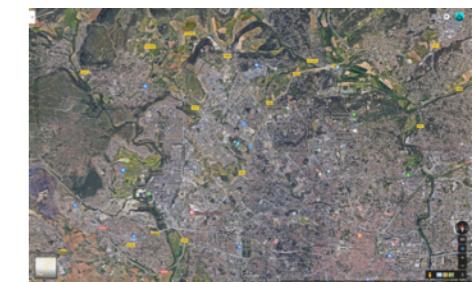
Satellite, Map



Earth Reconstruction



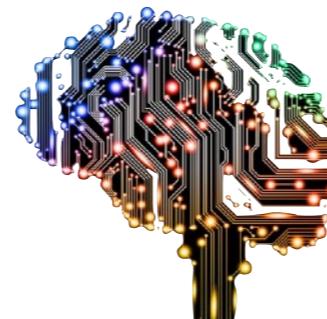
Google Maps



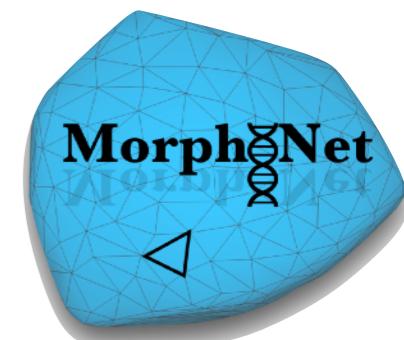
3D Observation



Machine Learning



Interact, share



Tomorrow, data will be in 3D





3D Imaging

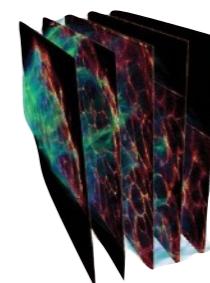




3D Imaging



3D , 4D Images



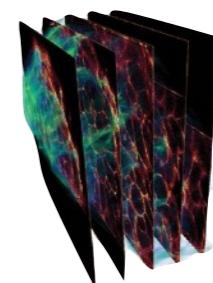
Terabytes...



3D Imaging

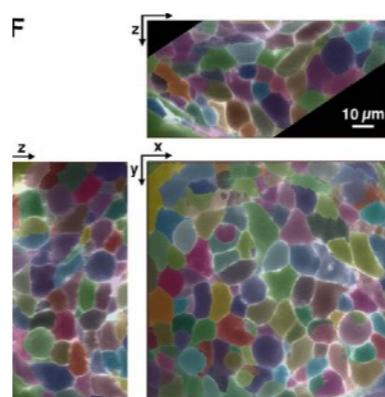


3D , 4D Images



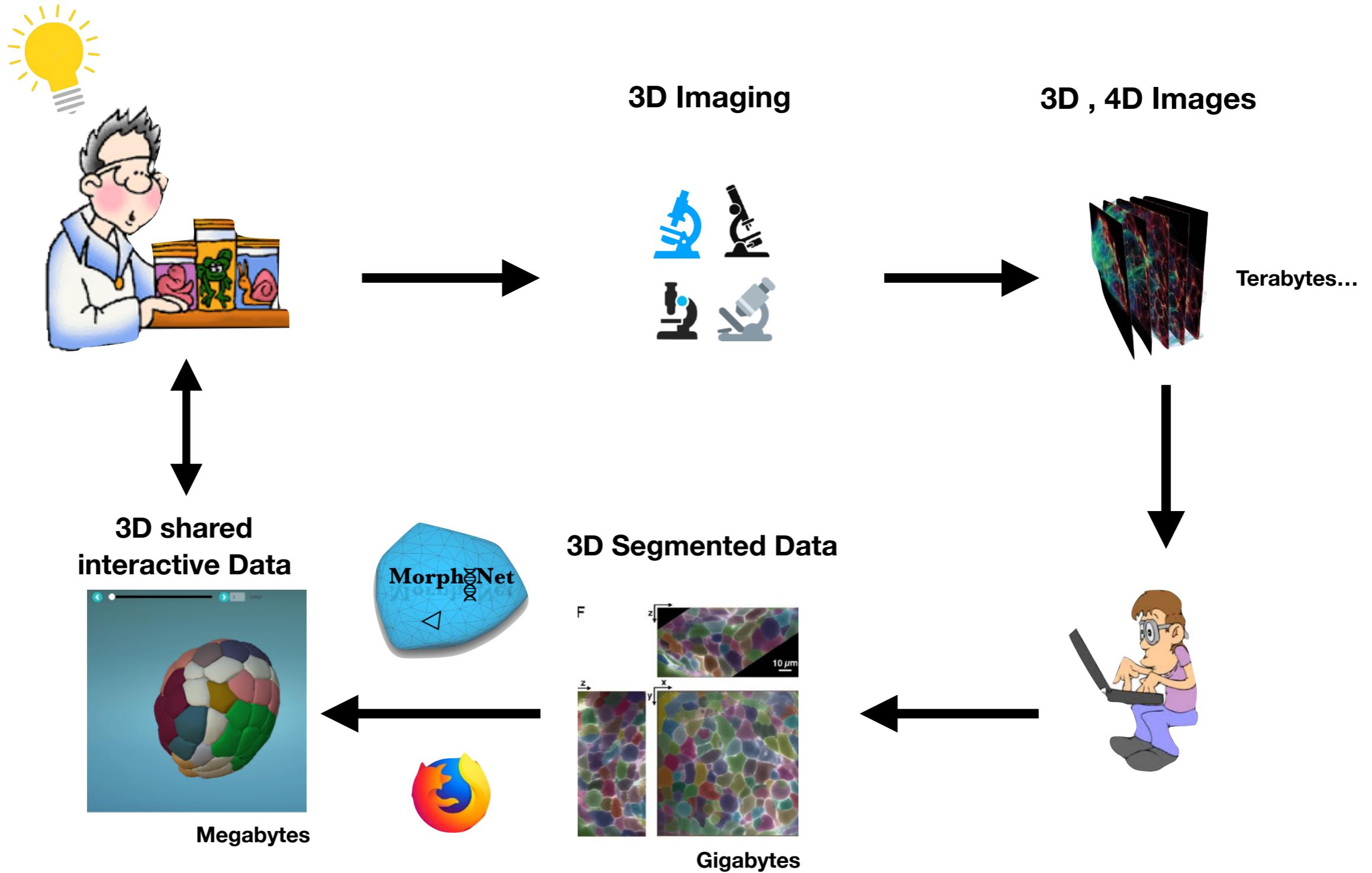
Terabytes...

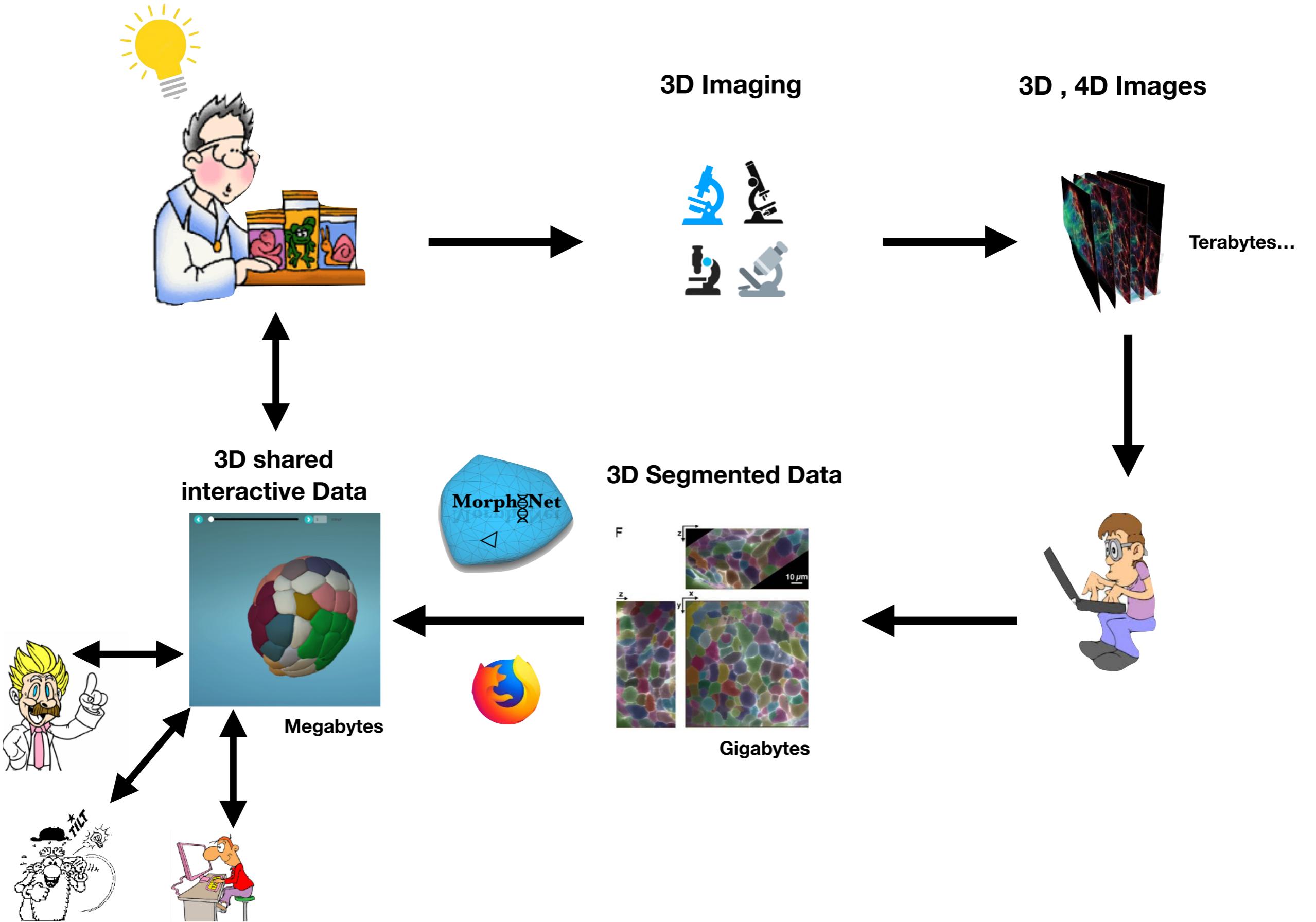
3D Segmented Data

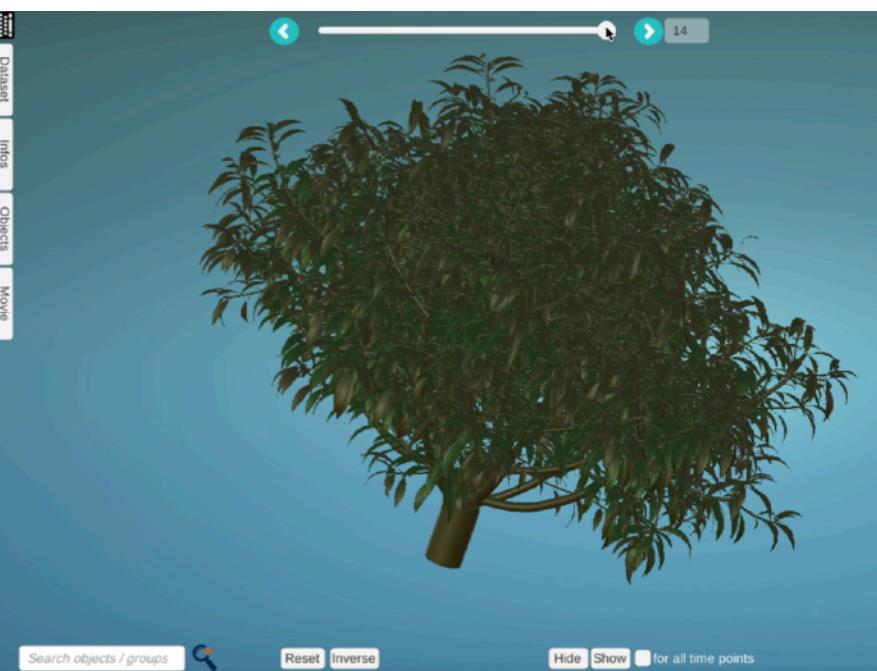
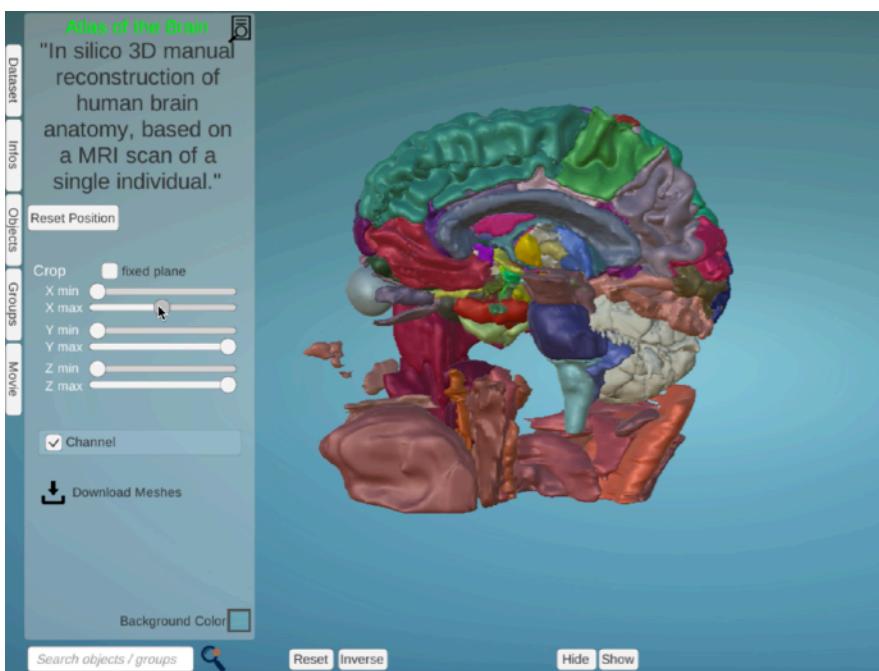
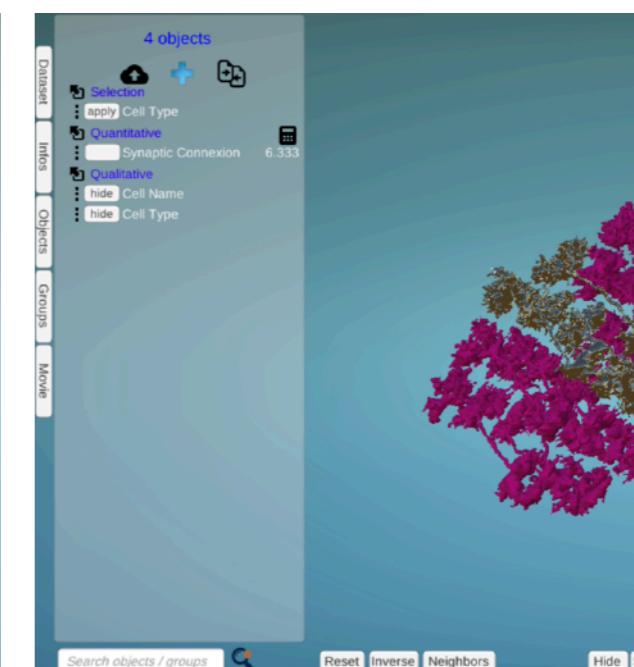
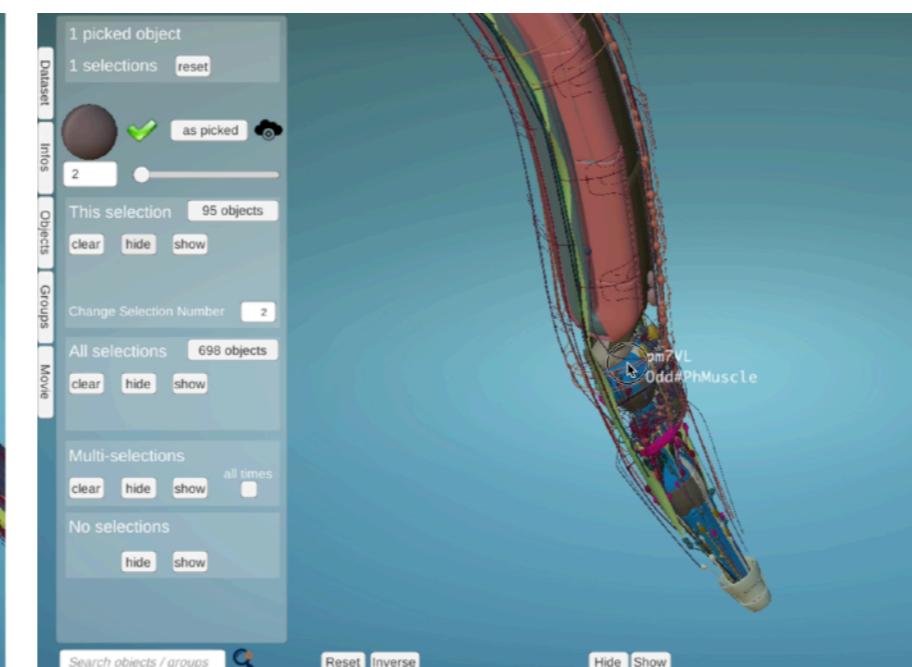
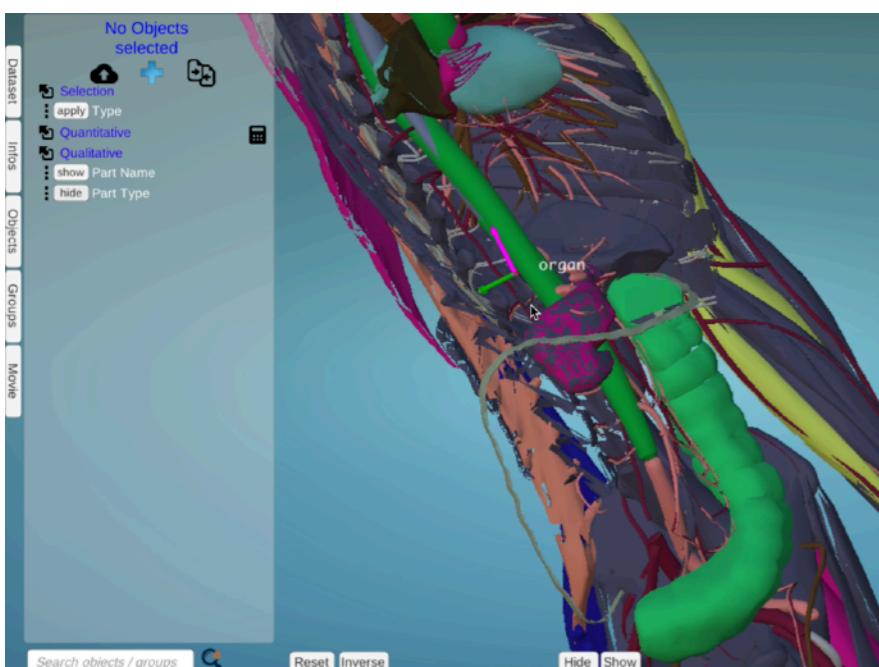
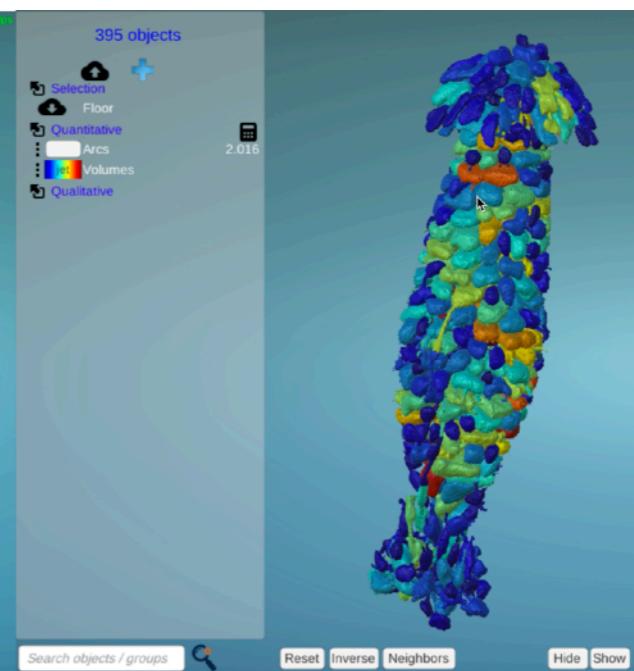
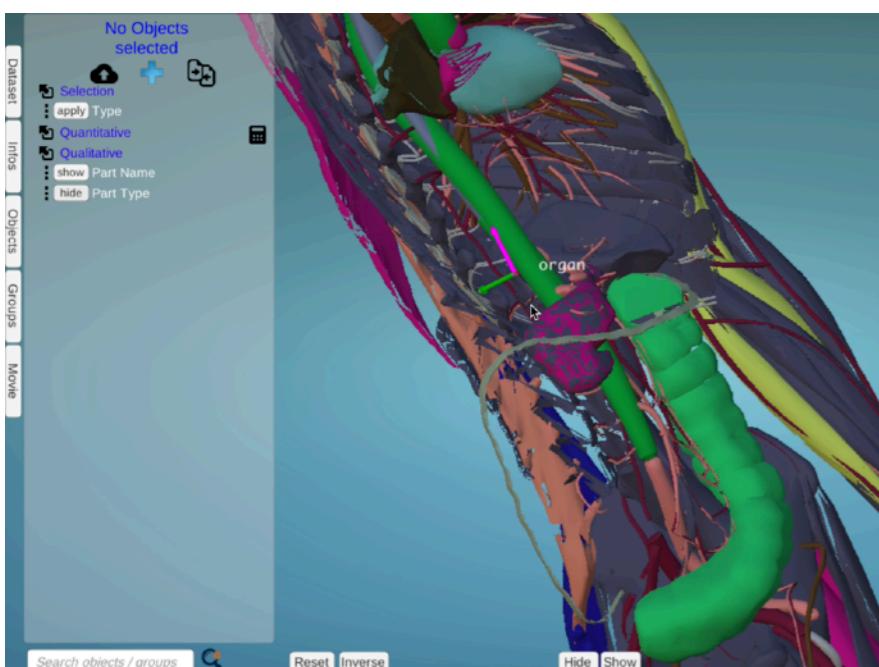


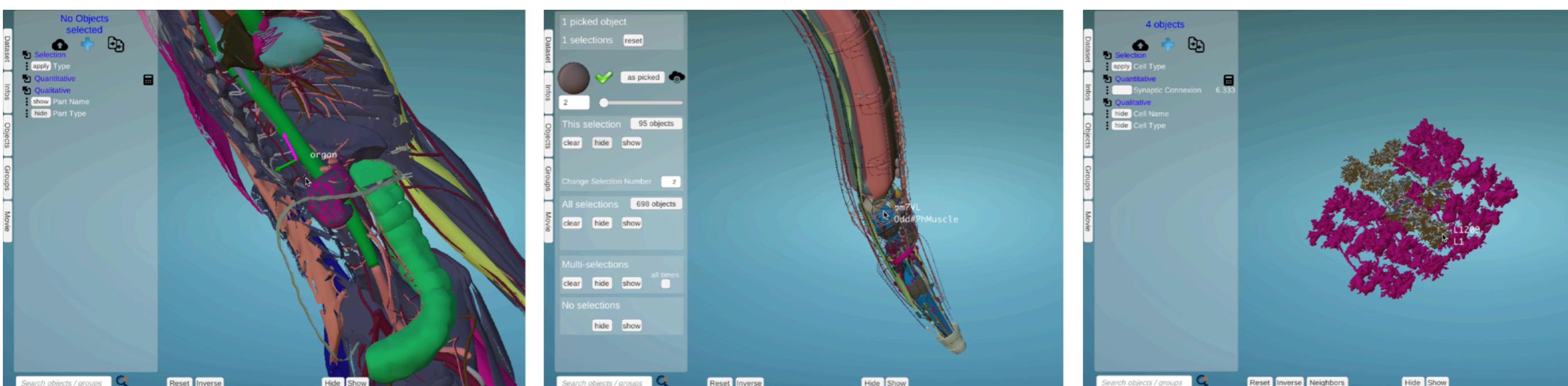
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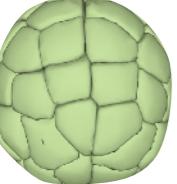


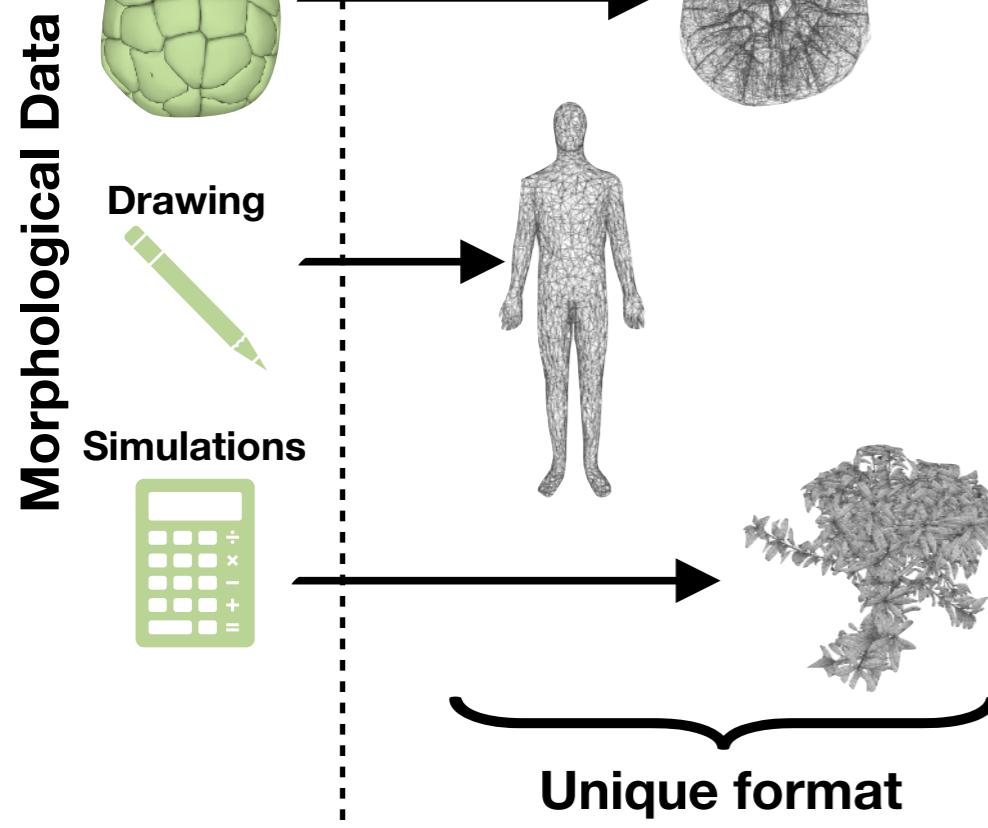


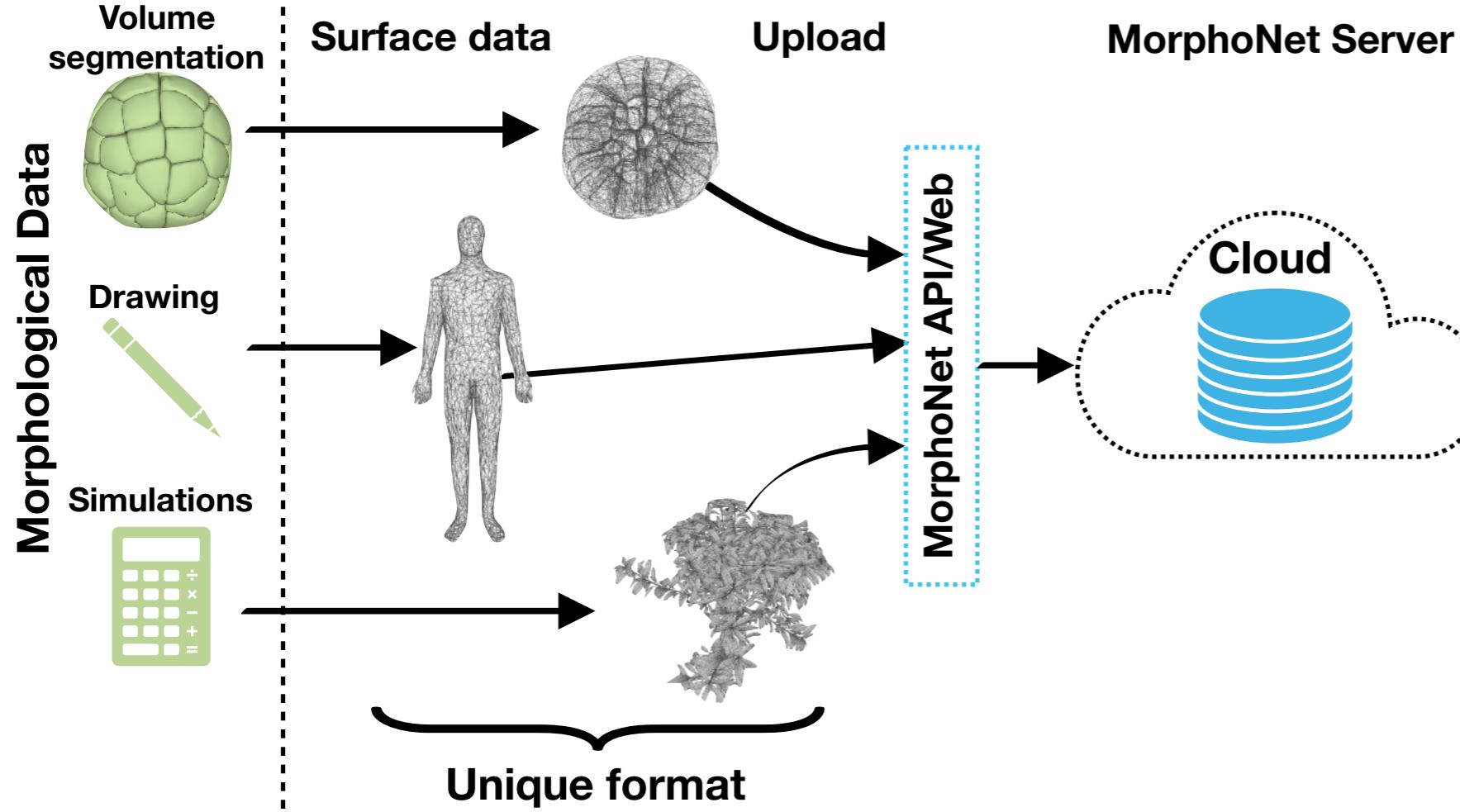


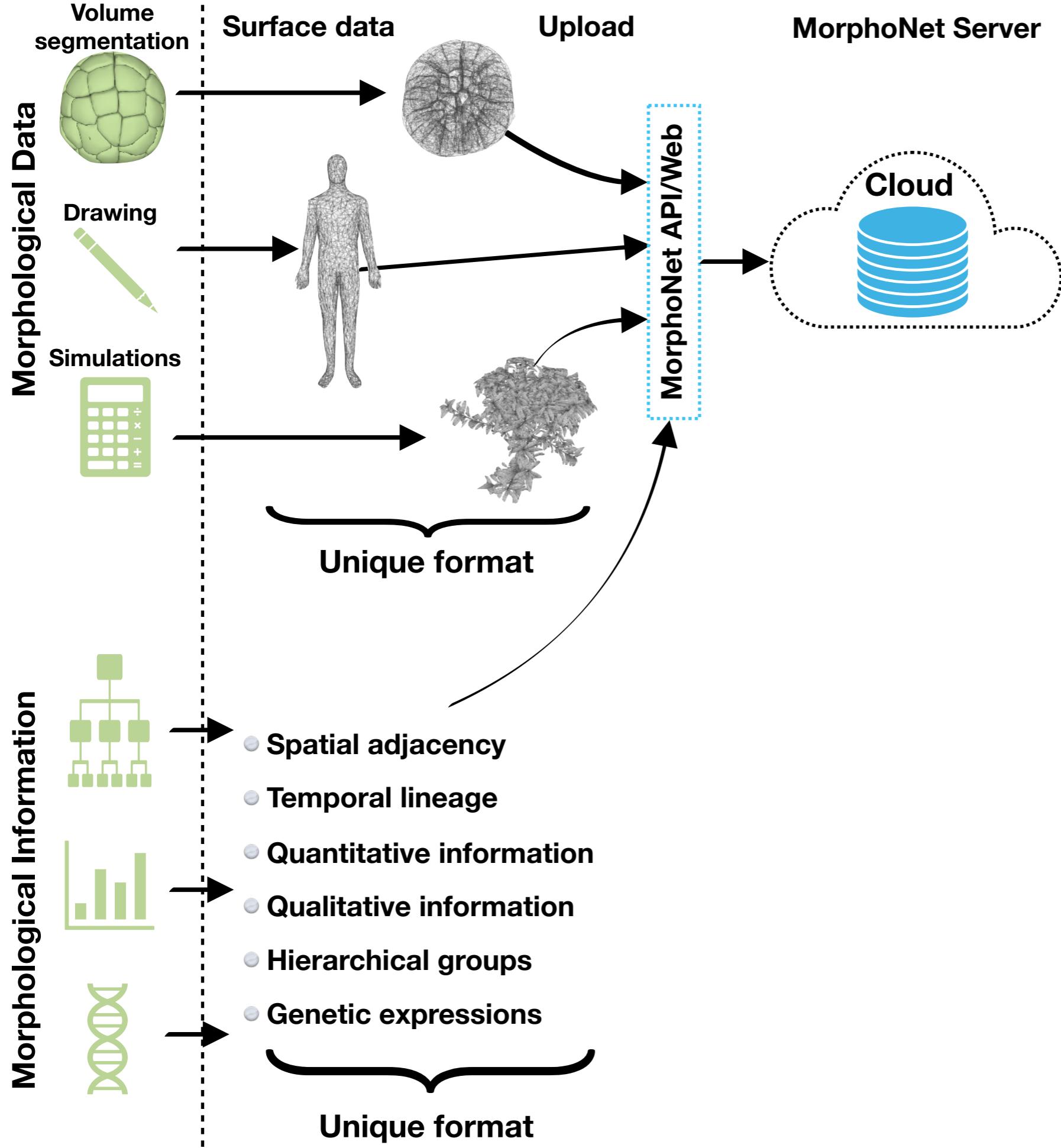


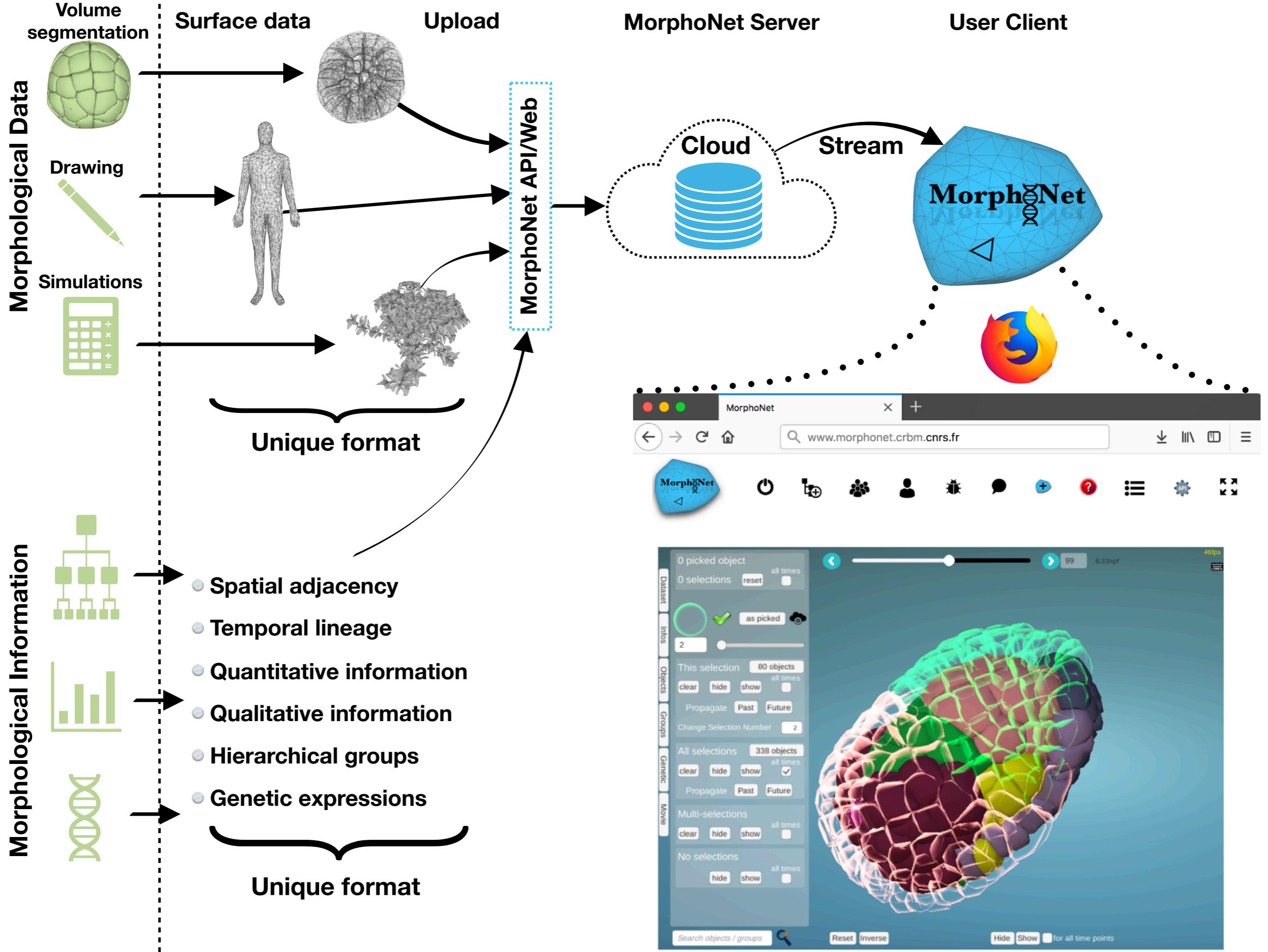
Morphological Data

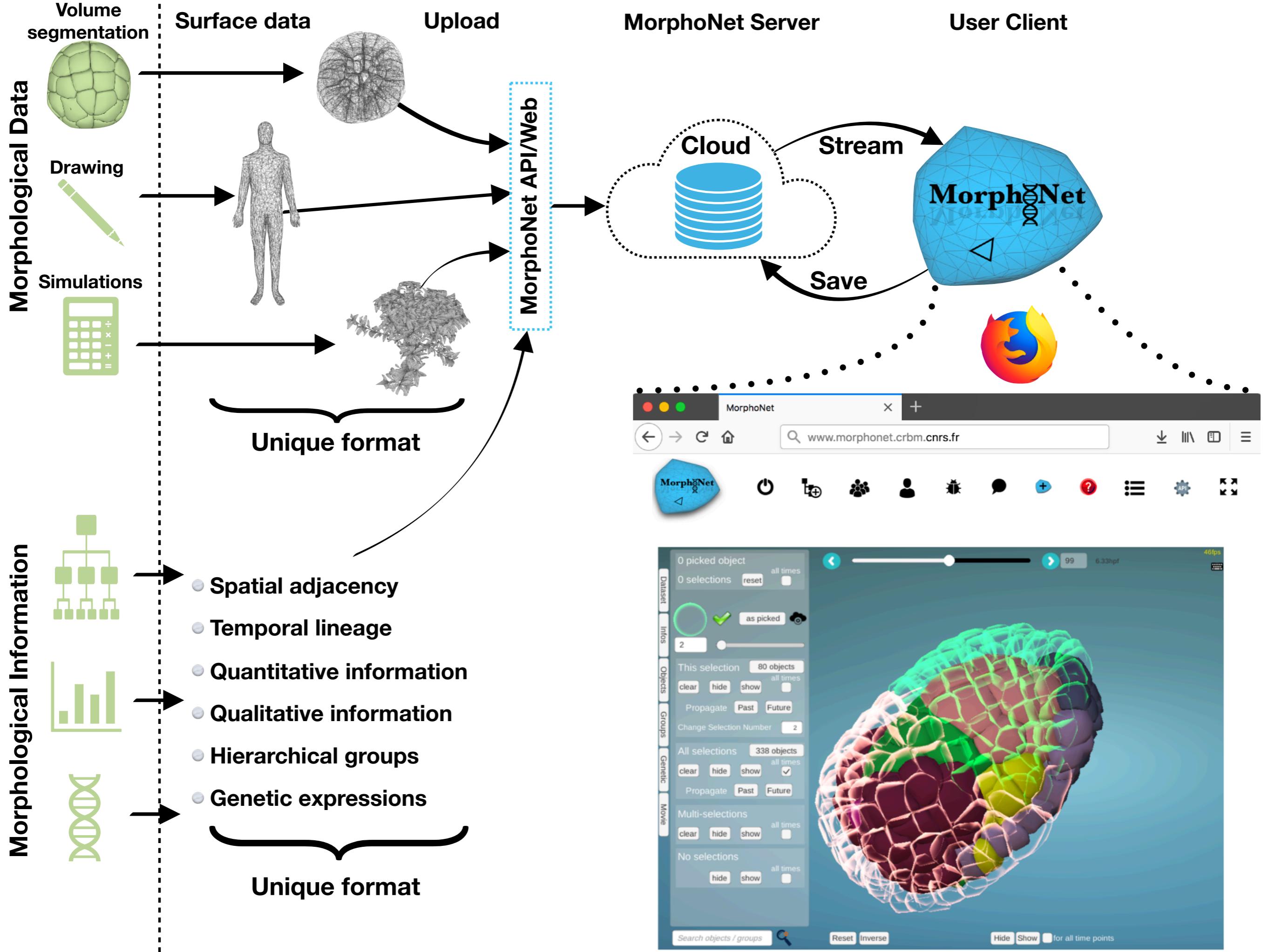
- Volume segmentation 
- Drawing 
- Simulations 

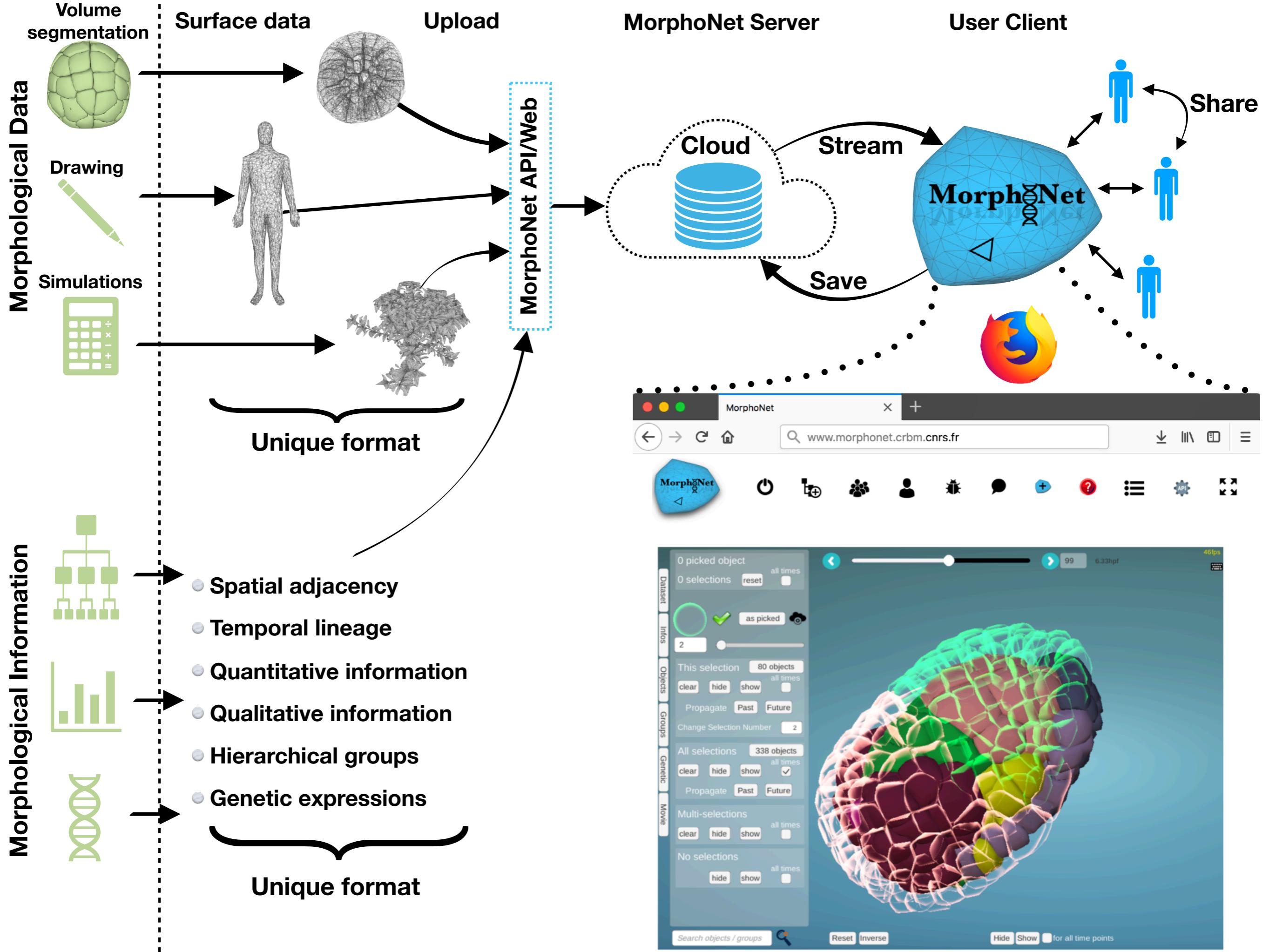


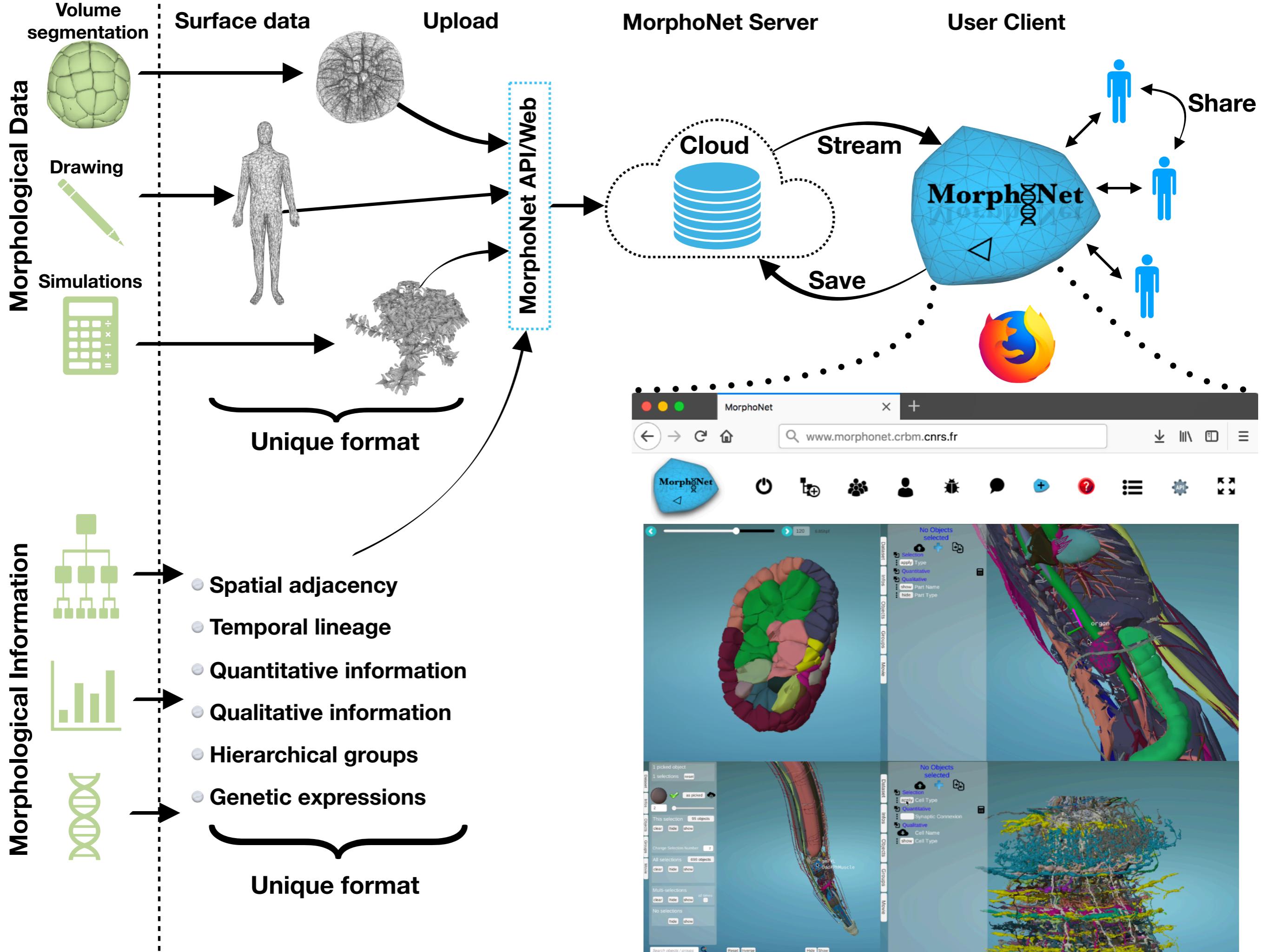












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live cell imaging and microSCOPy



Fate:Anterior
Left Right:left
Lineage:36
Numbers:0,903
neighs_try:3



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Visualization of large data sets in
live cell imaging and microSCOPy



Merci !