

# Apprentissage, incertitude et images médicales

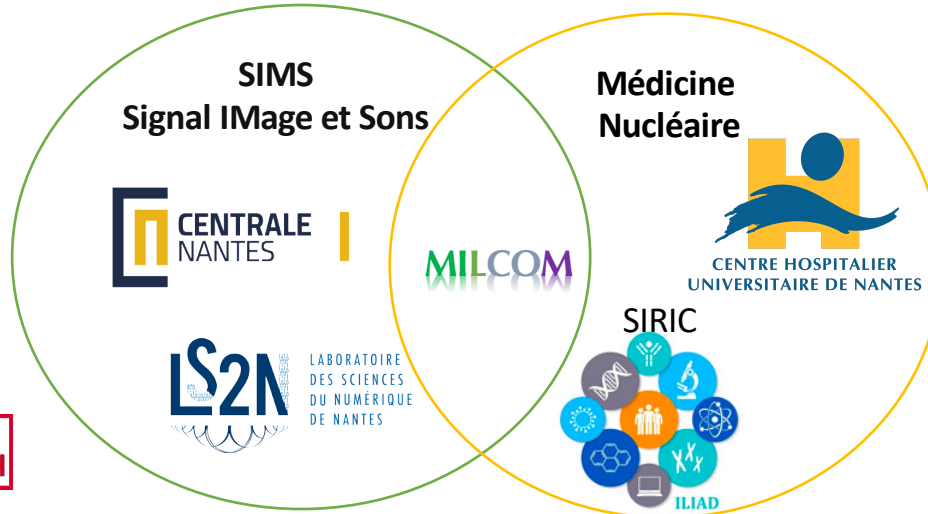
MATEUS Diana (PU - LS2N)

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# MILCOM

Chaire CONNECT TALENT  
(2017-2022)

Multi-modal Imaging and Learning for Computational-based Medicine



Diana Mateus



CE PROJET EST COFINANCÉ PAR  
LE FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL



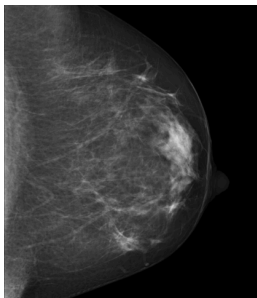
## *L'incertitude dans ...*

### Fractures



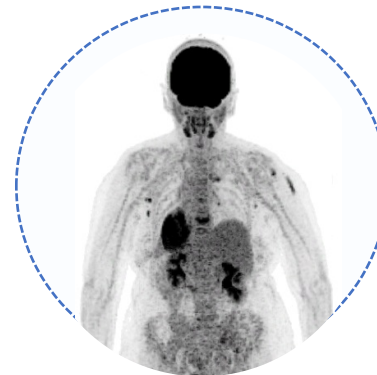
**Classification**  
Localisation faiblement supervisé  
Bruit dans les annotations  
Incertitude

### Cancer du Sein



**Classification**  
Segmentation faiblement supervisé  
Incertitude

### PET Imaging











**Reconstruction**  
Prédiction de la survie  
Amélioration d'image

## Classification de Fractures



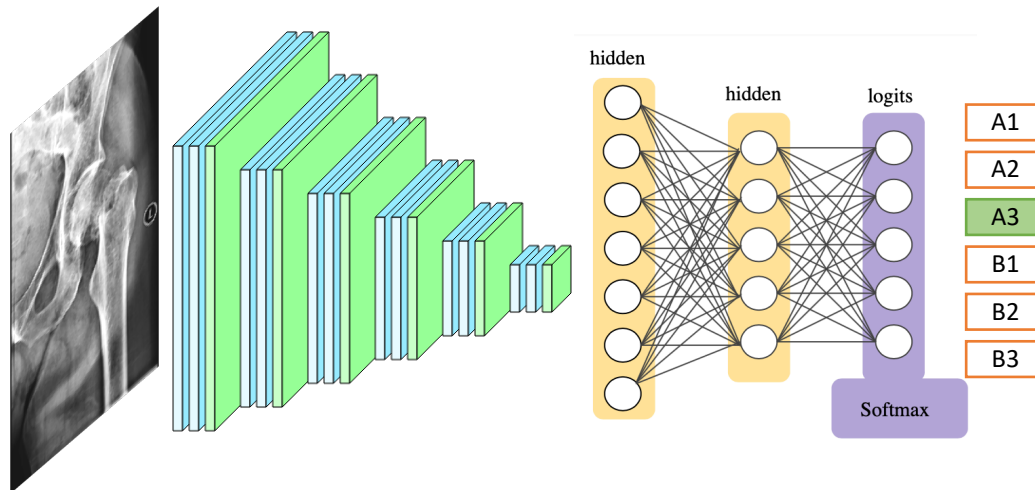
Amelia Jiménez Sánchez

## Classification de Fractures

<p>Trochanter</p> 	<p><b>A1</b> perthrochanteric simple</p> 	<p><b>A2</b> perthrochanteric multifragmentary</p> 	<p><b>A3</b> intertrochanteric</p> 
<p>Neck</p> 	<p><b>B1</b> subcapital, with slight displacement</p> 	<p><b>B2</b> transcervical</p> 	<p><b>B3</b> subcapital, displaced, non impacted</p> 

## Classification de Fractures

- Base de données annotée
- Réseau de neurones profond



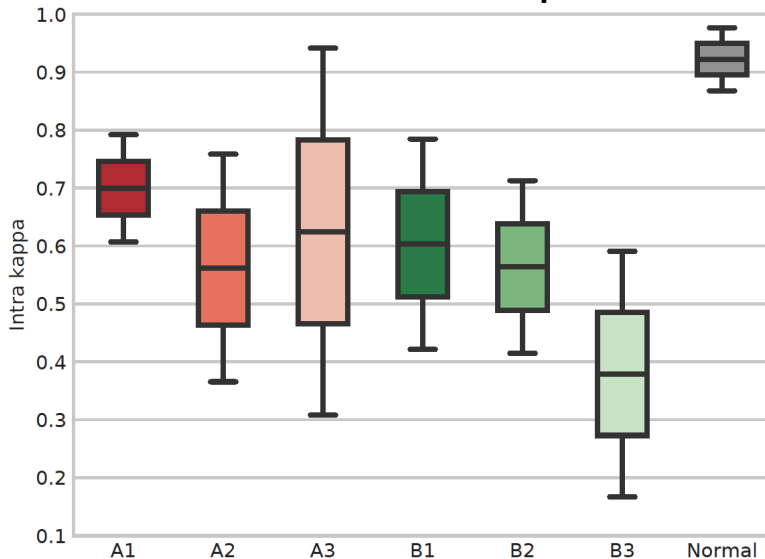
### *Precise proximal femur fracture classification for interactive training and surgical planning*

*Jiménez-Sánchez, A., Kazi, A., Albarqouni, S., Kirchhoff, C., Biberthaler, P., Navab, N., Mateus, D. and Kirchhoff, S., International Journal of Computer Assisted Radiology and Surgery (avr. 2020).*

## Classification de Fractures

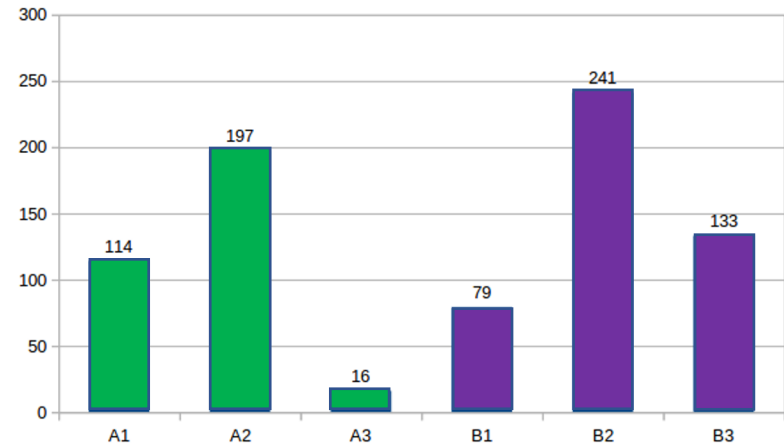
Défis supplémentaires (typiques lors de l'apprentissage avec des données médicales)

### Variabilité intra-expert



Bruit dans les annotations

### Class-imbalance

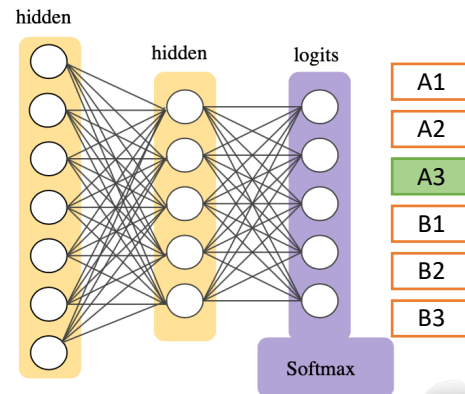
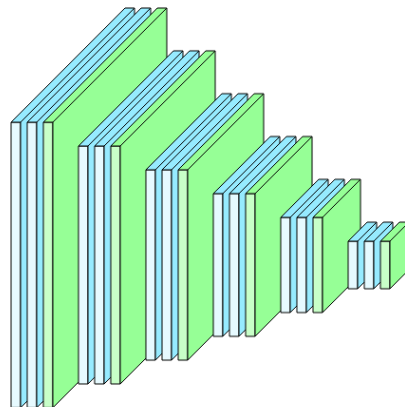


Prédictions biaisés

## Classification de Fractures



Pour quoi faire  
confiance aux  
Données?

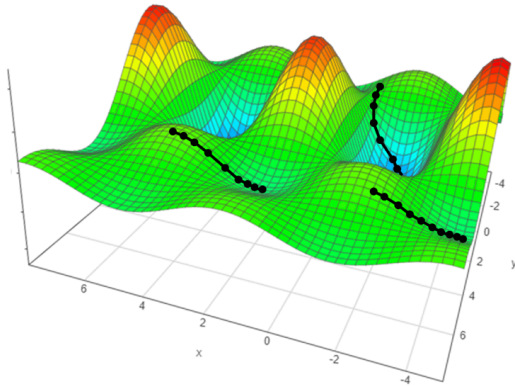


Pour quoi faire  
confiance aux  
Experts?





## Classification de Fractures

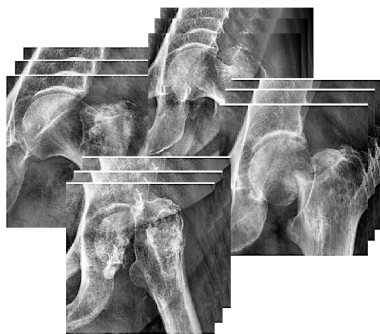


L'optimisation **non convexe** par **descente stochastique du gradient (SGD)** dépend de

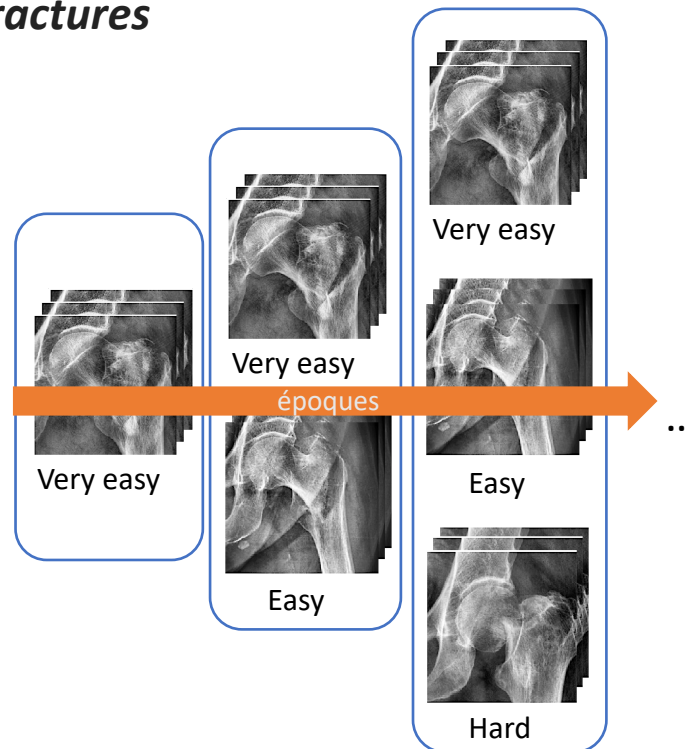
- L'initialisation
- **Les données** (sélection, ordre, poids, ...)

## Classification de Fractures

SGD **randomise** toutes les images avant chaque époque



Un **curriculum** ordonne les données présentés à l'optimiseur

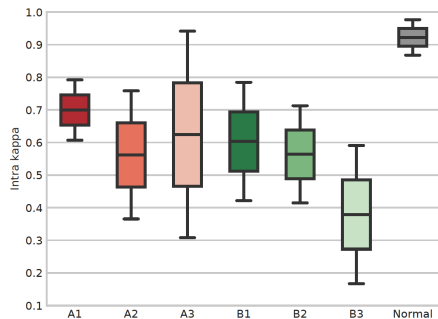


### **Curriculum learning.**

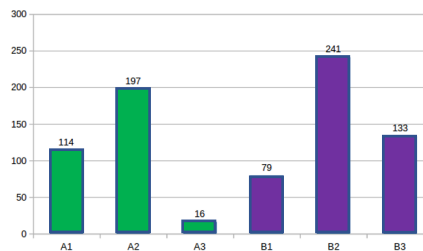
Bengio, Y., Louradour, J., Collobert, R., Weston, J. ICML 2009

## Classification de Fractures

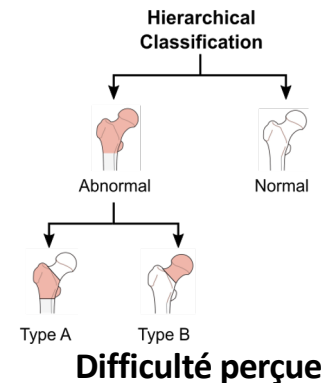
### Curriculum Learning (Connaissances apriori)



Variabilité intra-expert



Class-imbalance

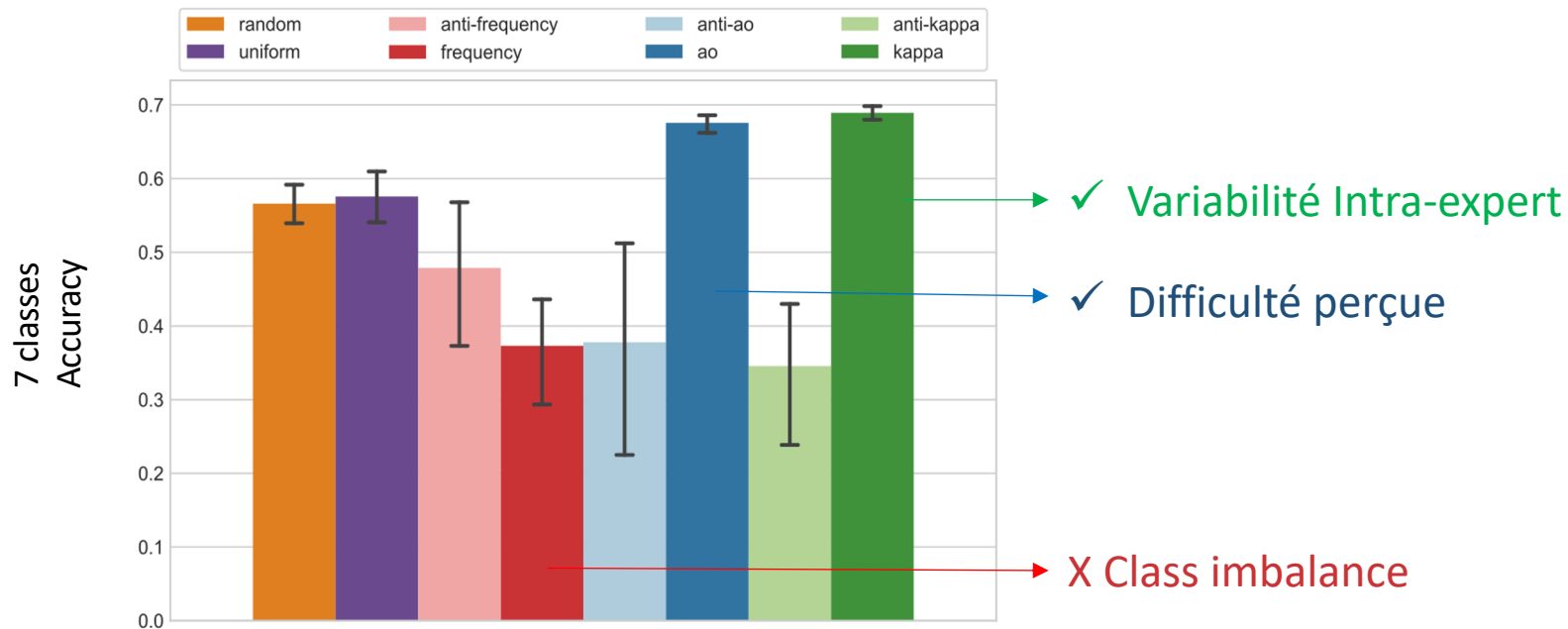


Difficulté perçue

### Medical-based Deep Curriculum Learning for Improved Fracture Classification

Jiménez-Sánchez, A., Mateus, D., Kirchhoff, S., Kirchhoff, C., Biberthaler, P., Navab, N., Gonzalez, M., Piella, G.  
Int. Conf on Medical Image Analysis and Computer Aided Interventions (MICCAI 2019)

## Classification de Fractures

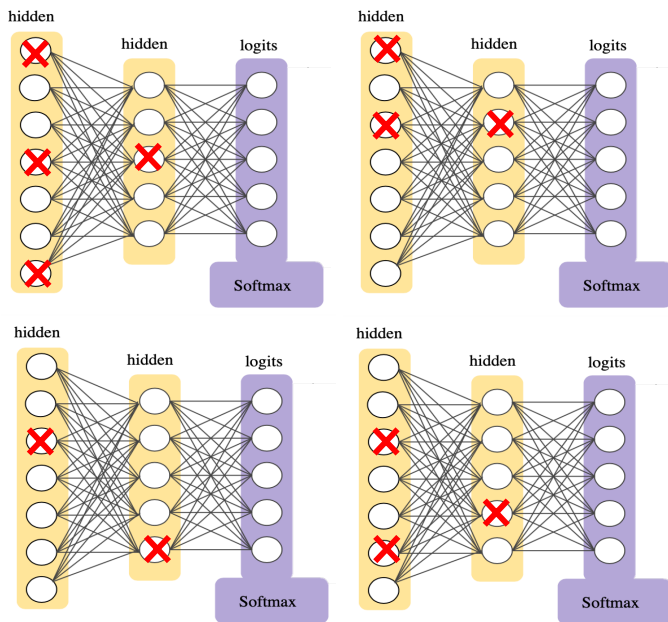


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## Classification de Fractures

### Uncertainty with MonteCarlo (MC) Dropout

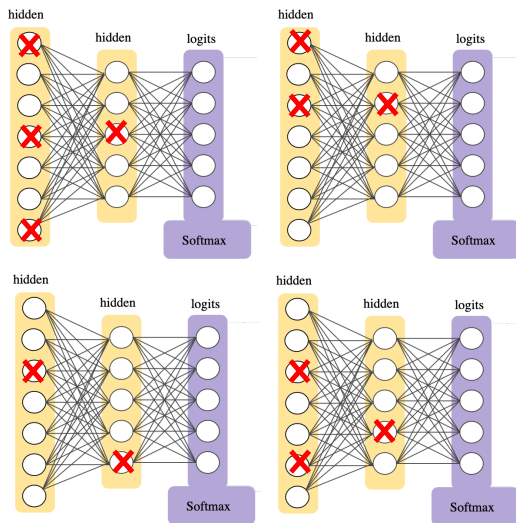


- **Dropout (train)** = Choisir aléatoirement quelques neurones et les mettant à 0 pendant le
- **Dropout (test)** = Echantillonnage stochastique de la distribution de sortie.
- **Output = distribution** (intégrale MC)
- **Incertitude = l'entropie** des prédictions

***Dropout as a Bayesian approximation: Representing model uncertainty in deep learning.***

Gal, Yarin, and Zoubin Ghahramani. international conference on machine learning. 2016.

## Classification de Fractures Self-paced Learning



$$\tilde{P}(y = t \mid x, \theta) = \frac{1}{L} \sum_{l=1}^L P(y = t \mid l, \theta_l),$$

Approximate the  
output distribution  
with MC integration

$$\tilde{\sigma}_t = \tilde{P}(y = t \mid x, \theta)$$

$$s = - \sum_{t=1}^T \tilde{\sigma}_t \cdot \log \tilde{\sigma}_t.$$

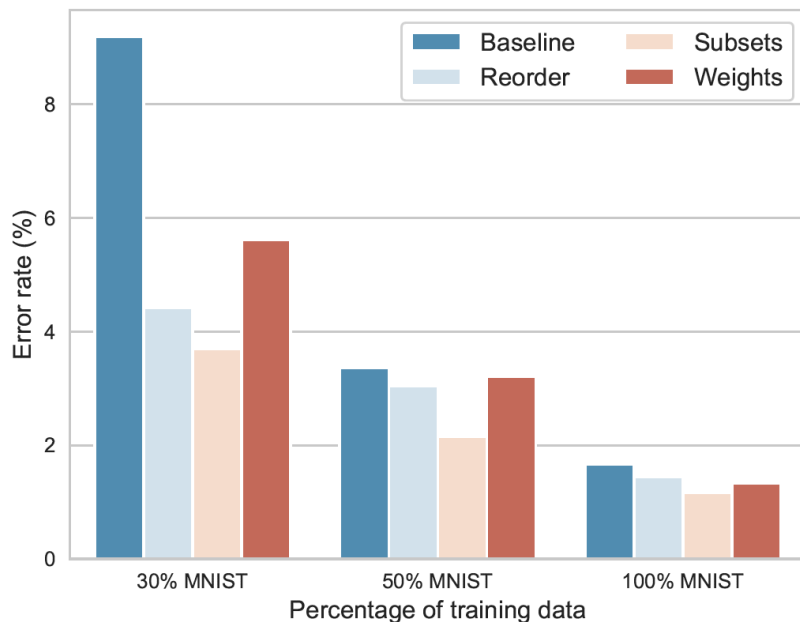
**Predictive entropy**  
(entropy of the averaged pred)

**Curriculum learning for annotation-efficient medical image analysis:  
scheduling data with prior knowledge and uncertainty,**

Amelia Jiménez-Sánchez and Diana Mateus and Sonja Kirchhoff and Chlodwig Kirchhoff and Peter Biberthaler and Nassir Navab and Miguel A. González Ballester and Gemma Piella, Arxiv 2020 (under review)

## Classification de Fractures Self-paced Learning

Limited amount of data



(b) Uncertainty-driven CL.

	Baseline	Weights	
		Prior K.	Uncertainty
Class-imbalance	2.53	2.31	2.22
Label Noise	9.46	8.49	<b>5.42</b>

Self-paced learning

- ✓ Imbalance
- ✓ Label-noise
- ✓ Peu de données

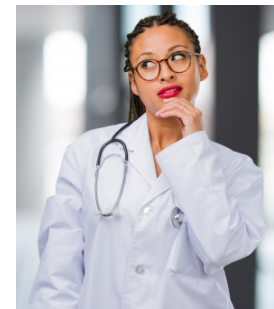
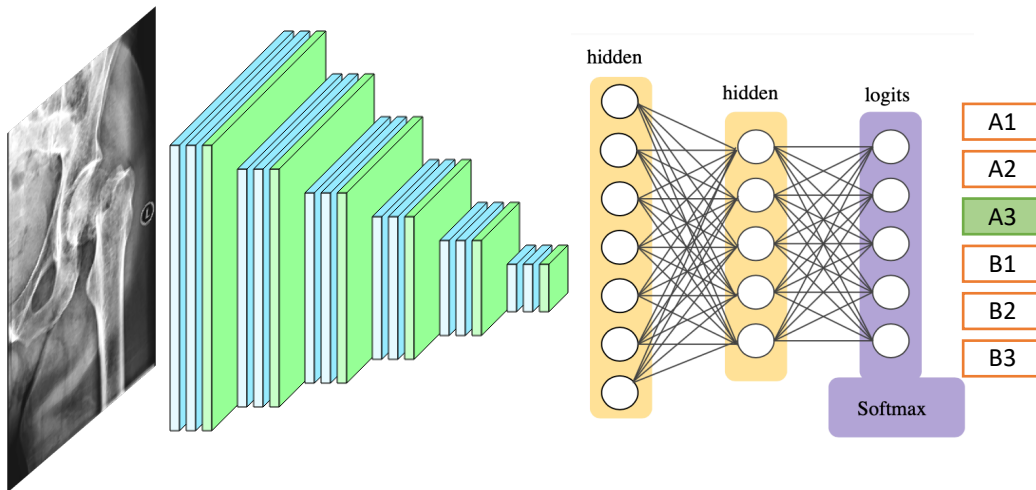
## *Cancer du sein*



Mickael Tardy

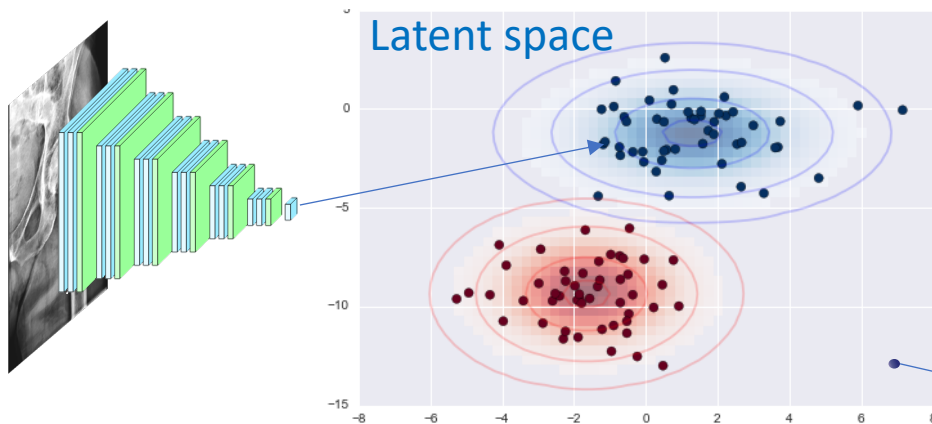


## Classification de Fractures



Pour quoi faire  
confiance à la  
machine?

## Classification de mammographies Incertitude dans l'espace latent



**Latent space** = output of penultimate layer

**Uncertainty** = Mahalanobis distance to the training set

**Uncertain point**

***Uncertainty measurements*** for the reliable classification of mammograms

Mickael Tardy, Bruno Scheffer, Diana Mateus

*Int. Conf. on Medical Image Computing and Computer Aided Interventions 2019*

## Classification de mammographies

### Incertitude par la logique subjective

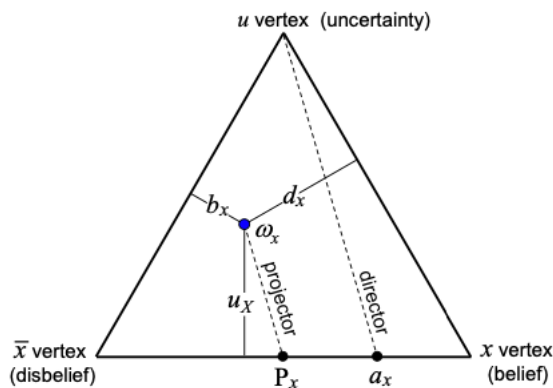


Fig. 2. Visualisation of a Binomial Opinion

**Subjective logic** is a type of probabilistic logic that explicitly takes **epistemic uncertainty** and source trust into account.

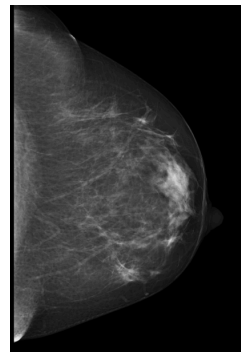
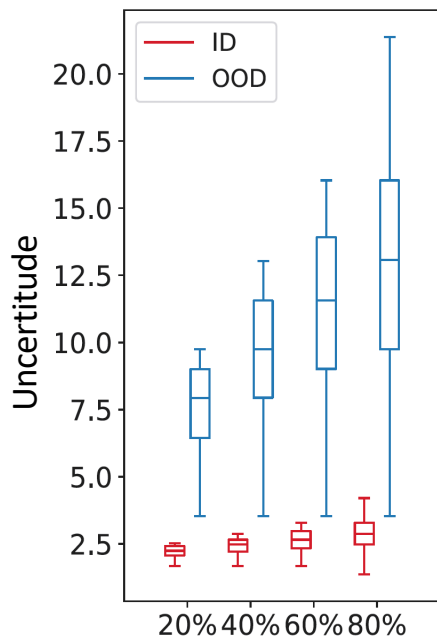
$$u(x) = \frac{T}{\sum_{t=1}^T \exp f(x)}$$

Sortie du réseau

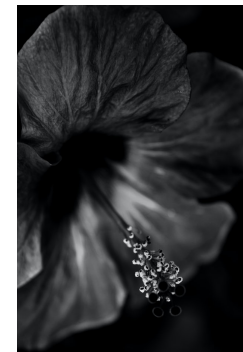
### **Uncertainty measurements** for the reliable classification of mammograms

Mickael Tardy, Bruno Scheffer, Diana Mateus

Int. Conf. on Medical Image Computing and Computer Aided Interventions 2019



In-distribution  
(ID)



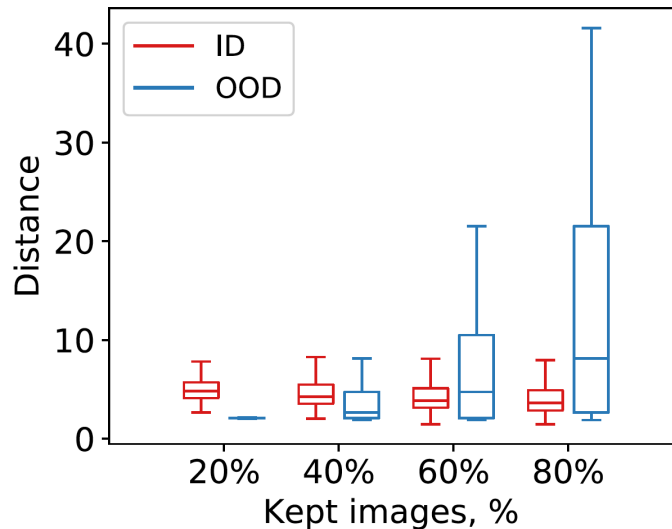
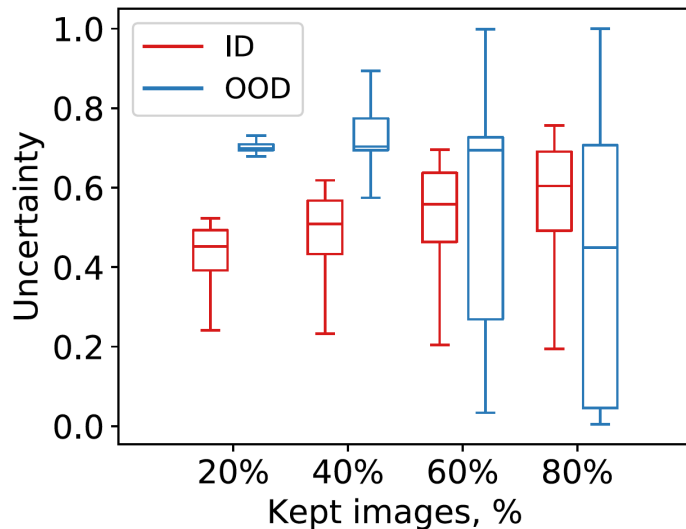
Out of  
Distribution  
(OOD)

**Uncertainty measurements** for the reliable classification of mammograms

Mickael Tardy, Bruno Scheffer, Diana Mateus

Int. Conf. on Medical Image Computing and Computer Aided Interventions 2019

Two mammographic machines



**Uncertainty measurements** for the reliable classification of mammograms

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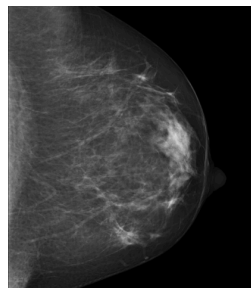
## Fractures



### Classification

Localisation faiblement supervisé  
Bruit dans les annotations  
Incertitude

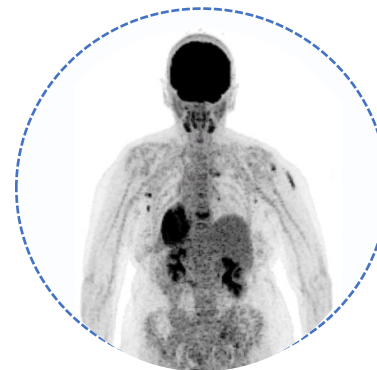
## Cancer du Sein



### Classification

Segmentation faiblement supervisé  
Incertitude

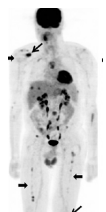
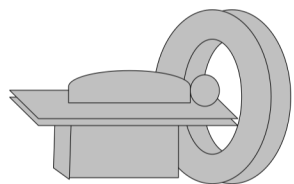
## Myélome Multiple



### Prédiction de la survie

Radiomics  
Amélioration d'image

## Reconstruction d'images TEP



Comment améliorer les  
images?

(Acquisition, algorithmes  
pour produire les images,  
fusion de données, ...)

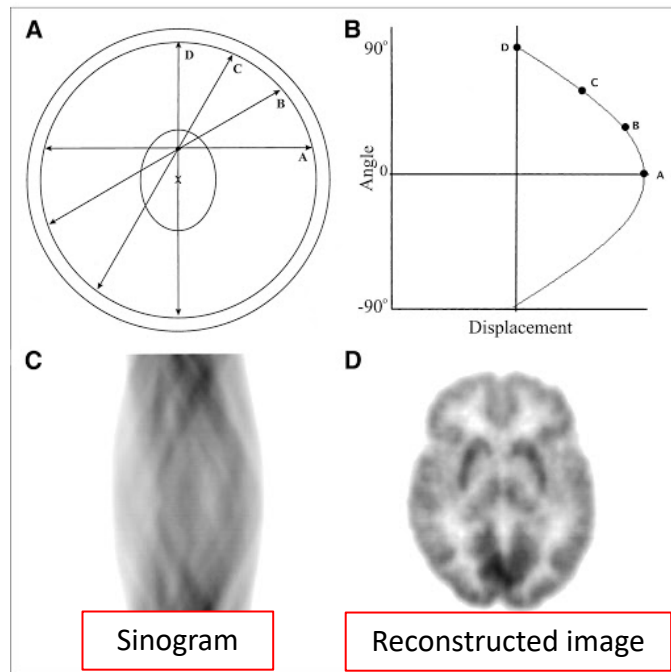


Maël  
Millardet



Hernan  
Carrillo Lindado

## Reconstruction d'images TEP



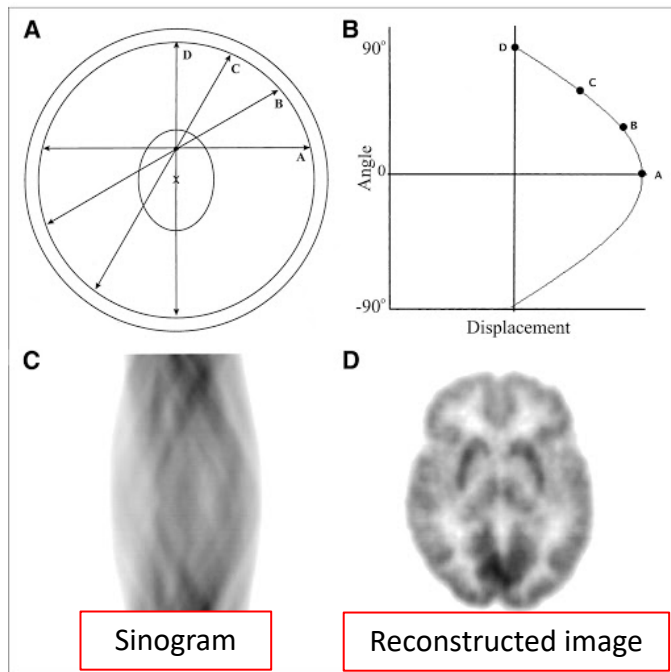
La Tomographie par Emission de Positrons TEP:

- Est une forme d'**imagerie computationnelle**: requiert d'un algorithme pour reconstruire l'activité associée à chaque pixel
- L'algorithme résout un **problème inverse** avec de méthodes:
  - Classiques: Itératives
  - Apprentissage: profond

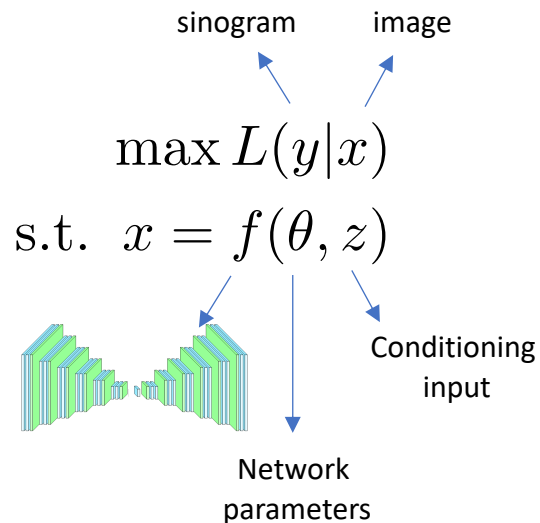
Source: Frederic H. Fahey, DSc. "Data Acquisition in PET Imaging",  
J. Nucl. Med. Technol. **June 1, 2002** vol. 30 no. 2 **39-49**



## Reconstruction d'images TEP



*Proposition 1: approche combinant une méthode itératives et apprentissage*

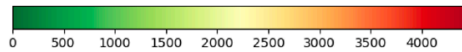
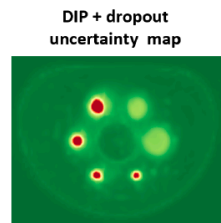
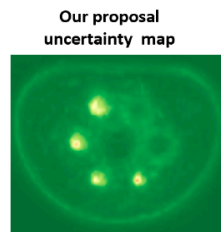
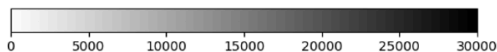
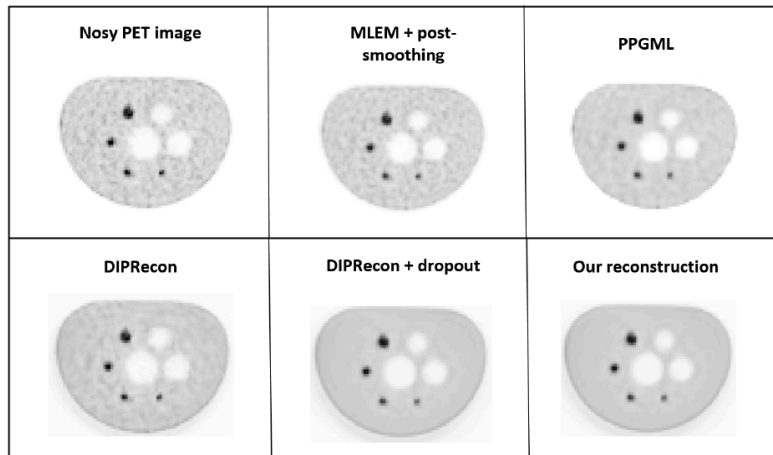


L'image reconstruite est la sortie d'un réseau de neurones profond

Image source: Frederic H. Fahey, DSc. "Data Acquisition in PET Imaging", J. Nucl. Med. Technol. **June 1, 2002** vol. 30 no. 2 39-49

Gong et al. (2019) "PET Image Reconstruction Using Deep ImagePrior". IEEE Transactions on Medical Imaging

## Reconstruction d'images TEP



*Proposition 2:*  
*estimer l'incertitude de la reconstruction*

*Approximate Bayesian Inference*

- *Dropout*
- *Stochastic Gradient Langevin Dynamics SGLD*

### **Low-count PET image reconstruction with Bayesian inference over a Deep Prior**

Hernan Camilo Carrillo Lindado, Maël Millardet, Thomas Carlier, Diana Mateus. SPIE Medical Imaging - Image Processing Fev 2021

## Incertitude pour

- Guider l'optimisation
- Détecter les prédictions incertaines
- Connaitre la incertitude d'une image computationnelle

