



**HAL**  
open science

## **Knot shape assessment on various species through X-ray CT scanning**

Adrien Krähenbühl, Fleur Longuetaud, Jean-Baptiste Morisset, Francis Colin, Isabelle Debled-Rennesson, Bertrand Kerautret, Frédéric Mothe

► **To cite this version:**

Adrien Krähenbühl, Fleur Longuetaud, Jean-Baptiste Morisset, Francis Colin, Isabelle Debled-Rennesson, et al.. Knot shape assessment on various species through X-ray CT scanning. International Union of Forest Research Organisation (IUFRO), Jul 2012, Lisbon, Portugal. hal-00768816

**HAL Id: hal-00768816**

**<https://hal.science/hal-00768816v1>**

Submitted on 24 Feb 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## Knot shape assessment on various species through X-ray CT scanning

A. Krähenbühl<sup>1</sup>   F. Longuetaud<sup>2</sup>   J-B. Morisset<sup>2</sup>  
F. Colin<sup>2</sup>   I. Debled-Rennesson<sup>1</sup>   B. Kerautret<sup>1</sup>  
F. Mothe<sup>2</sup>

<sup>1</sup>LORIA, Université de Lorraine

<sup>2</sup>INRA, LERFoB

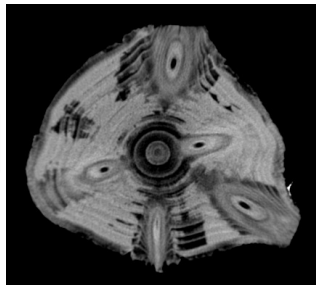
IUFRO  
July 9, 2012

# Context

Knots are the prolongation of branches inside the stem.  
Size and shape of knots / branches directly impact:

- tree growth and physiology
- architectural tree models
- wood quality (structural or aesthetic uses)
- lumber cutting optimisation & grading

X-ray CT scanning is specially well adapted to knot measurements



# Plan

## Manual measurements of knot features

- What can be seen?

- The tool

- Application to species classification

## Automatic algorithm for knot features

- 3DKnotDM

- Measurements

- Limits

- Work in progress

## Conclusion

# Plan

## Manual measurements of knot features

What can be seen?

The tool

Application to species classification

## Automatic algorithm for knot features

3DKnotDM

Measurements

Limits

Work in progress

## Conclusion

# Plan

## Manual measurements of knot features

What can be seen?

The tool

Application to species classification

## Automatic algorithm for knot features

3DKnotDM

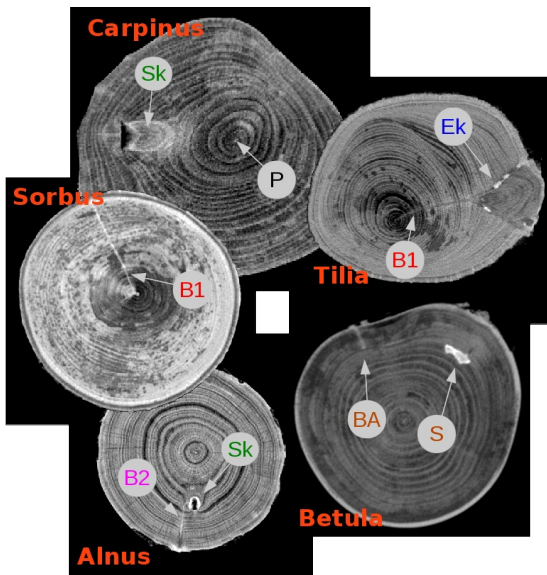
Measurements

Limits

Work in progress

## Conclusion

# Sequential knots, epicormic knots and bud traces



**P** Pith  
**S** Scars

**Sk** Sequential knot  
**Ek** Epicormic knot

**B1** Trace of 1ry bud  
**B2** Trace of 2ry bud  
**BA** Trace of adv. bud



# Plan

## Manual measurements of knot features

What can be seen?

The tool

Application to species classification

## Automatic algorithm for knot features

3DKnotDM

Measurements

Limits

Work in progress

## Conclusion



## Software design

*Gourmands*: ImageJ plugin to record knot location & shape.



## Software design

*Gourmands*: ImageJ plugin to record knot location & shape.

### Outputs

- 3D location
- azimuth
- leaning angle
- length
- diameter



## Software design

*Gourmands*: ImageJ plugin to record knot location & shape.

### Outputs

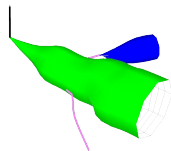
- 3D location
- azimuth
- leaning angle
- length
- diameter
- + hierarchical organisation
- + pith density & trajectory

## Software design

*Gourmands*: ImageJ plugin to record knot location & shape.

### Outputs

- 3D location
- azimuth
- leaning angle
- length
- diameter
- + hierarchical organisation
- + pith density & trajectory
- + 3D view



# Utilisation

## Processing time

scanning:	10 min / m
measurements:	1 hour / m

## Drawbacks

- accuracy 0.2 to 1mm / pixel
- ∅ not measured in longitudinal direction (circular section assumed)
- low contrast for wet wood
- operator effect unquantified



[1] F. Colin et al, 2010

*Tracking rameal traces in sessile oak trunks with X-ray computer tomography: biological bases, preliminary results and perspectives.*  
Trees-structure and Function.



*Fagus*

# Plan

## Manual measurements of knot features

What can be seen?

The tool

Application to species classification

## Automatic algorithm for knot features

3DKnotDM

Measurements

Limits

Work in progress

## Conclusion

## Objective

Classify log species based on internal knot architecture.

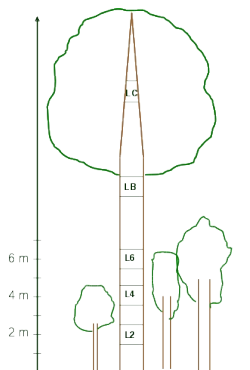


## Objective

Classify log species based on internal knot architecture.

### Sampling

Species	Common name	# trees	# logs
<i>Robinia pseudo-acacia</i>	Black locust	2	5+5
<i>Sorbus torminalis</i>	Wild	2	4+5
<i>Alnus glutinosa</i>	Alder	2	5+5
<i>Betula pendula</i>	Birch	2	5+5
<i>Carpinus betulus</i>	Hornbeam	1	0+5
<i>Quercus rubra</i>	Red oak	2	2+5
<i>Acer platanoides</i>	Norway maple	2	3+1
<i>Fraxinus excelsior</i>	European ash	2	2+4
<i>Fagus sylvatica</i>	European beech	2	5+5
<i>Prunus avium</i>	Wild cherry	2	5+3
<i>Ulmus minor</i>	Field elm	2	5+5
<i>Abies alba</i>	Silver fir	2	3+3
<i>Tilia platyphyllos</i>	Lime	2	5+5
<i>Populus tremula</i>	Aspen	2	5+5
Total	14 species	27	115



14 species, 2 trees per species, 2-5 logs per tree  
(thanks to InterReg European Project CoForKo)

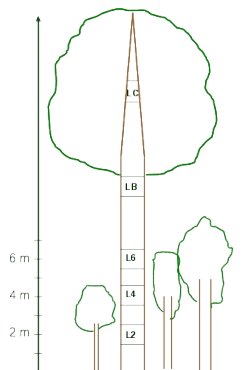


## Objective

Classify log species based on internal knot architecture.

### Sampling

Species	Common name	# trees	# logs
<i>Robinia pseudo-acacia</i>	Black locust	2	5+5
<i>Sorbus torminalis</i>	Wild	2	4+5
<i>Alnus glutinosa</i>	Alder	2	5+5
<i>Betula pendula</i>	Birch	2	5+5
<i>Carpinus betulus</i>	Hornbeam	1	0+5
<i>Quercus rubra</i>	Red oak	2	2+5
<i>Acer platanoides</i>	Norway maple	2	3+1
<i>Fraxinus excelsior</i>	European ash	2	2+4
<i>Fagus sylvatica</i>	European beech	2	5+5
<i>Prunus avium</i>	Wild cherry	2	5+3
<i>Ulmus minor</i>	Field elm	2	5+5
<i>Abies alba</i>	Silver fir	2	3+3
<i>Tilia platyphyllos</i>	Lime	2	5+5
<i>Populus tremula</i>	Aspen	2	5+5
Total	14 species	27	115



14 species, 2 trees per species, 2-5 logs per tree  
(thanks to InterReg European Project CoForKo)

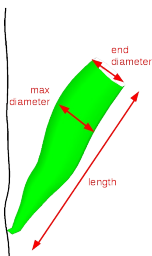
13 angiosperms vs. 1 gymnosperm.

## Data used in classification

20 variables computed from *Gourmands* outputs:

### Considered variables

sequential branches	length relative length (/ log radius) sd relative length inclination sd inclination initial inclination (median) diameter relative diameter (/ log diameter) sd relative diameter diameter / length min diameter (1st decile) max diameter (last decile) diameter decrease (end diam. / max diam.)
number / m of	sequential knots epicormic knots all buds primary buds secondary buds adventive buds
angle between 2 successive buds/branches (phyllotaxic angle)	

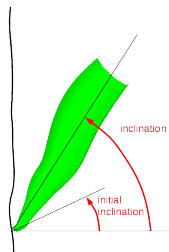


## Data used in classification

20 variables computed from *Gourmands* outputs:

### Considered variables

sequential branches	length relative length (/ log radius) sd relative length inclination sd inclination initial inclination (median) diameter relative diameter (/ log diameter) sd relative diameter diameter / length min diameter (1st decile) max diameter (last decile) diameter decrease (end diam. / max diam.)
number / m of	sequential knots epicormic knots all buds primary buds secondary buds adventive buds
angle between 2 successive buds/branches (phyllotaxic angle)	

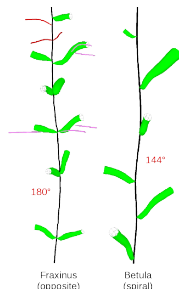


## Data used in classification

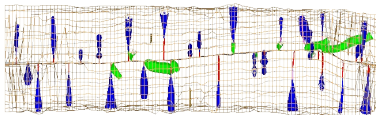
20 variables computed from *Gourmands* outputs:

### Considered variables

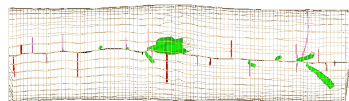
sequential branches	length relative length (/ log radius) sd relative length inclination sd inclination initial inclination (median) diameter relative diameter (/ log diameter) sd relative diameter diameter / length min diameter (1st decile) max diameter (last decile) diameter decrease (end diam. / max diam.)
number / m of	sequential knots epicormic knots all buds primary buds secondary buds adventive buds
angle between 2 successive buds/branches (phyllotaxic angle)	



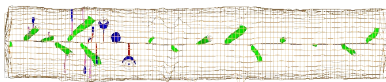
# Visualisation 1/2



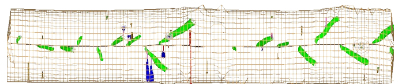
*Robinia pseudo-acacia*



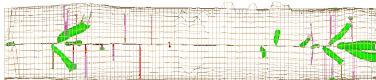
*Sorbus torminalis*



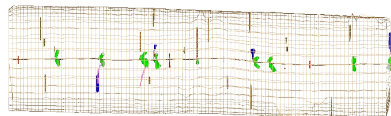
*Alnus glutinosa*



*Betula pendula*



*Quercus rubra*



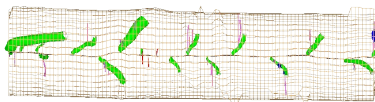
*Acer platanooides*

Tree #1 – log #2 (4m height) for each species,

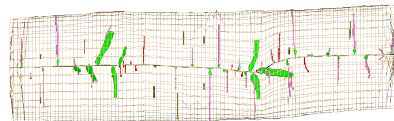
Knot shape assessment through X-ray CT scanning – A. Krähenbühl et al.



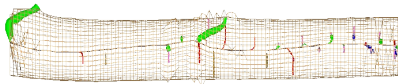
## Visualisation 2/2



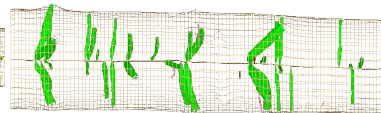
*Fagus sylvatica*



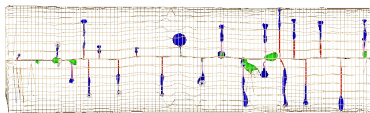
*Prunus avium*



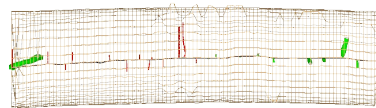
*Ulmus minor*



*Abies alba*



*Tilia platyphyllos*



*Populus tremula*

Tree #1 – log #2 (4m height) for each species,



# Classification methods

2 methods tested

- 1 Regression Tree (*R package rpart*)

# Classification methods

2 methods tested

- 1 Regression Tree (*R package rpart*)
- 2 Score based method (*R script*)

Scores computed for each species  $i$  using  $n$  variables  $x_j$ :

$$Score_i = \frac{1}{n} \sum_{j=1}^n \frac{|x_j - \bar{x}_{ij}|}{\sigma_{ij}}$$

minimal score  $\Rightarrow$  predicted species



## Classification methods

2 methods tested

- 1 Regression Tree (*R package rpart*)
- 2 Score based method (*R script*)

Scores computed for each species  $i$  using  $n$  variables  $x_j$ :

$$Score_i = \frac{1}{n} \sum_{j=1}^n \frac{|x_j - \bar{x}_{ij}|}{\sigma_{ij}}$$

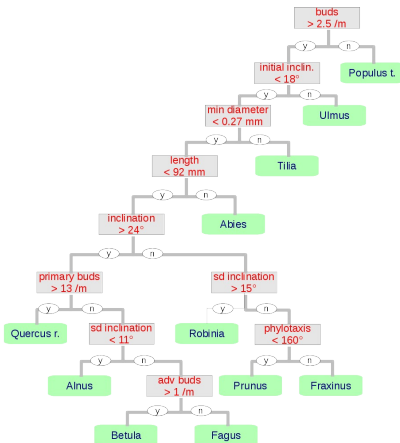
minimal score  $\Rightarrow$  predicted species

### In both cases

- calibration using the full data-set
- cross-validation for each log using other logs as training data

# Results: Regression Tree

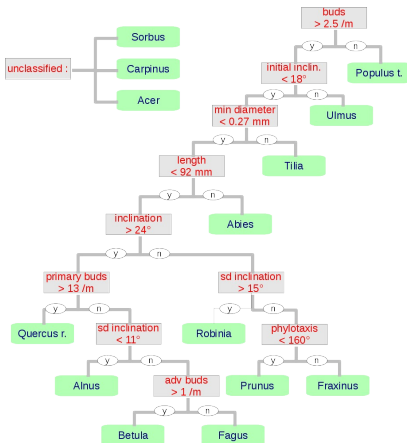
## Calibration tree after pruning



Unstable nodes pruned based on internal cross-validation

# Results: Regression Tree

## Calibration tree after pruning

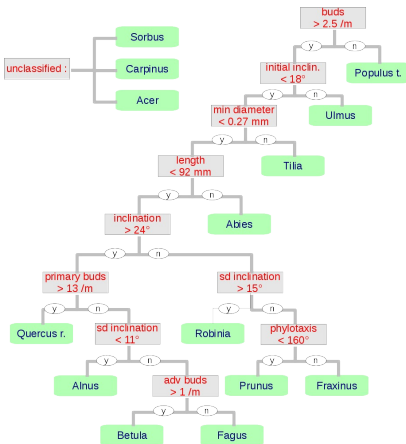


Unstable nodes pruned based on internal cross-validation

3 misclassified species

# Results: Regression Tree

## Calibration tree after pruning



Unstable nodes pruned based on internal cross-validation

3 misclassified species

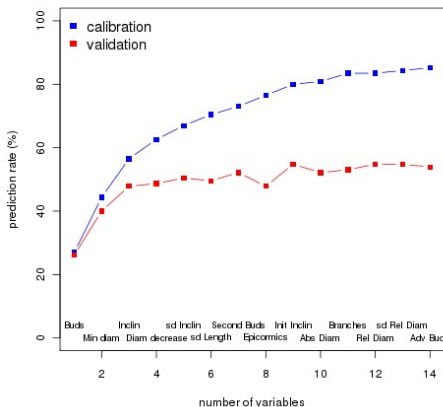
### Detection rates

calibration	70.4 %
validation	33.0 %

## Results: Score based method

Step by step method to select the best variables

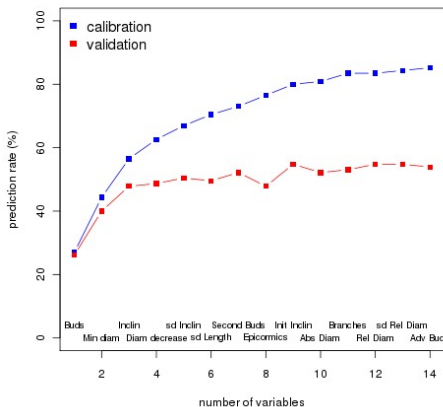
Same variables applied in validation



## Results: Score based method

Step by step method to select the best variables

Same variables applied in validation



### Detection rates

calibration	82.6 %
validation	53.9 %

## Results: Score based method

### Detection rates per species (validation)

Log species	Detected species													Detect. rate (%)	
	Rob	Sor	Aln	Bet	Car	Que	Ace	Fra	Fag	Pru	Ulm	Abi	Til		Pop
Robinia	<b>7</b>	0	0	0	0	0	0	0	1	0	1	0	1	0	70
Sorbus	0	<b>0</b>	0	0	1	3	0	0	4	1	0	0	0	0	0
Alnus	0	0	<b>6</b>	0	2	0	0	0	2	0	0	0	0	0	60
Betula	0	0	2	<b>6</b>	1	0	0	0	1	0	0	0	0	0	60
Carpinus	1	0	0	0	<b>1</b>	1	0	0	2	0	0	0	0	0	20
Quercus	0	2	1	0	0	<b>3</b>	0	0	0	0	1	0	0	0	43
Acer	0	0	0	0	0	0	<b>1</b>	0	1	1	1	0	0	0	25
Fraxinus	0	0	0	0	0	0	1	<b>3</b>	1	0	0	0	0	1	50
Fagus	0	0	3	0	0	0	1	0	<b>4</b>	0	2	0	0	0	40
Prunus	0	0	0	0	1	0	1	0	0	<b>6</b>	0	0	0	0	75
Ulmus	0	1	0	0	0	0	1	0	0	0	<b>8</b>	0	0	0	80
Abies	0	0	0	0	0	0	0	0	0	2	0	<b>3</b>	0	1	50
Tilia	0	0	2	0	0	0	0	0	0	0	1	0	<b>7</b>	0	70
Populus	0	0	0	0	0	0	0	0	1	2	0	0	0	<b>7</b>	70

## Results: Score based method

### Detection rates per species (validation)

Log species	Detected species													Detect. rate (%)	
	Rob	Sor	Aln	Bet	Car	Que	Ace	Fra	Fag	Pru	Ulm	Abi	Til		Pop
Robinia	<b>7</b>	0	0	0	0	0	0	0	1	0	1	0	1	0	70
Sorbus	0	<b>0</b>	0	0	1	3	0	0	4	1	0	0	0	0	<b>0</b>
Alnus	0	0	<b>6</b>	0	2	0	0	0	2	0	0	0	0	0	60
Betula	0	0	2	<b>6</b>	1	0	0	0	1	0	0	0	0	0	60
Carpinus	1	0	0	0	<b>1</b>	1	0	0	2	0	0	0	0	0	<b>20</b>
Quercus	0	2	1	0	0	<b>3</b>	0	0	0	0	1	0	0	0	<b>43</b>
Acer	0	0	0	0	0	0	<b>1</b>	0	1	1	1	0	0	0	<b>25</b>
Fraxinus	0	0	0	0	0	0	0	<b>1</b>	<b>3</b>	1	0	0	0	1	50
Fagus	0	0	3	0	0	0	1	0	<b>4</b>	0	2	0	0	0	40
Prunus	0	0	0	0	1	0	1	0	0	<b>6</b>	0	0	0	0	75
Ulmus	0	1	0	0	0	0	1	0	0	0	<b>8</b>	0	0	0	80
Abies	0	0	0	0	0	0	0	0	0	2	0	<b>3</b>	0	1	50
Tilia	0	0	2	0	0	0	0	0	0	0	1	0	<b>7</b>	0	70
Populus	0	0	0	0	0	0	0	0	1	2	0	0	0	<b>7</b>	70

Very low detection rates for Sorbus, Carpinus & Acer



# Applications of the manual measurement tool

For species classification:

- Two classification methods gave similar results
- Detection failed for 3 species
  - ⇒ find more species-specific architectural variables?
  - ⇒ include other CT measurements (bark, density...)?
  - ⇒ larger sampling?
  - ⇒ grouping species based on knot architecture?

## Applications of the manual measurement tool

For species classification:

- Two classification methods gave similar results
- Detection failed for 3 species
  - ⇒ find more species-specific architectural variables?
  - ⇒ include other CT measurements (bark, density...)?
  - ⇒ larger sampling?
  - ⇒ grouping species based on knot architecture?

### Other applications

- Knot shape modelling & epicormics ontogeny  
(see presentations by E. Duchâteau & J-B. Morisset)

## Applications of the manual measurement tool

For species classification:

- Two classification methods gave similar results
- Detection failed for 3 species
  - ⇒ find more species-specific architectural variables?
  - ⇒ include other CT measurements (bark, density...)?
  - ⇒ larger sampling?
  - ⇒ grouping species based on knot architecture?

### Other applications

- Knot shape modelling & epicormics ontogeny (see presentations by E. Duchâteau & J-B. Morisset)
- Validation of automatic algorithms
  - ⇒ **A. Krähenbühl**

# Plan

Manual measurements of knot features

What can be seen?

The tool

Application to species classification

Automatic algorithm for knot features

3DKnotDM

Measurements

Limits

Work in progress

Conclusion

# Plan

## Manual measurements of knot features

What can be seen?

The tool

Application to species classification

## Automatic algorithm for knot features

3DKnotDM

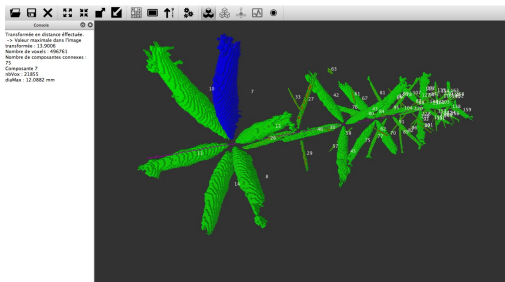
Measurements

Limits

Work in progress

## Conclusion

# Automatic knot segmentation



3DKnotDM software developed in [1].

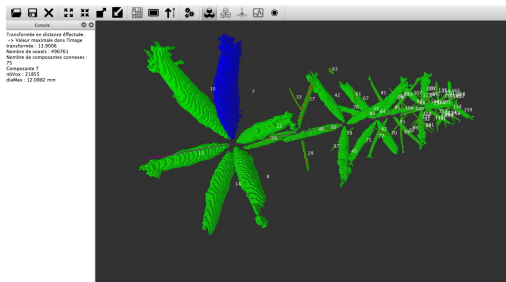


[1] F. Longuetaud and al., 2012

*Automatic knot detection and measurements from X-ray CT images of wood: A review and validation of an improved algorithm on softwood samples.*, Computers and Electronics in Agriculture.



# Automatic knot segmentation



3DKnotDM software developed in [1].

## 1 Thresholding based on knot density

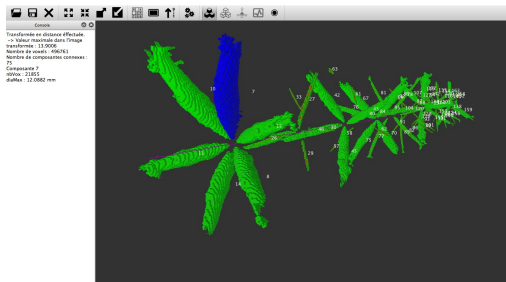


[1] F. Longuetaud and al., 2012

*Automatic knot detection and measurements from X-ray CT images of wood: A review and validation of an improved algorithm on softwood samples.*, Computers and Electronics in Agriculture.



# Automatic knot segmentation



3DKnotDM software developed in [1].

- ① Thresholding based on knot density
- ② Extraction of connected components



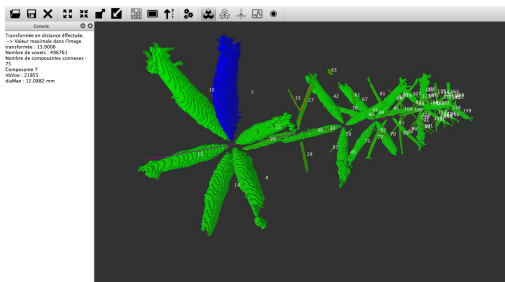
[1] F. Longuetaud and al., 2012

*Automatic knot detection and measurements from X-ray CT images of wood: A review and validation of an improved algorithm on softwood samples.*, Computers and Electronics in Agriculture.





# Automatic knot segmentation



3DKnotDM software developed in [1].

- ① Thresholding based on knot density
- ② Extraction of connected components
- ③ Computation of several knot's features.



[1] F. Longuetaud and al., 2012

*Automatic knot detection and measurements from X-ray CT images of wood: A review and validation of an improved algorithm on softwood samples.*, Computers and Electronics in Agriculture.



# Plan

Manual measurements of knot features

What can be seen?

The tool

Application to species classification

Automatic algorithm for knot features

3DKnotDM

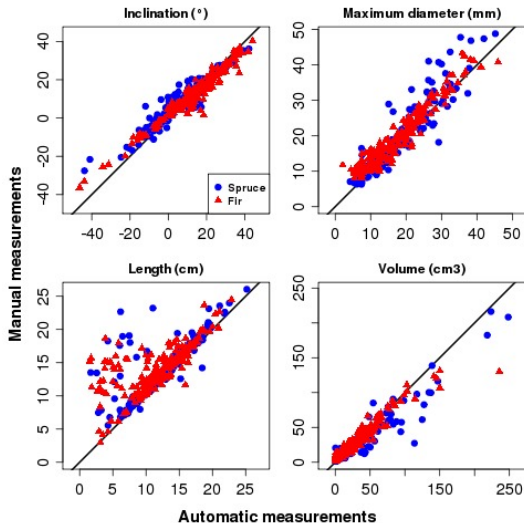
Measurements

Limits

Work in progress

Conclusion

# Automatic vs. manual



Great correlation between feature measures.



# Plan

Manual measurements of knot features

What can be seen?

The tool

Application to species classification

Automatic algorithm for knot features

3DKnotDM

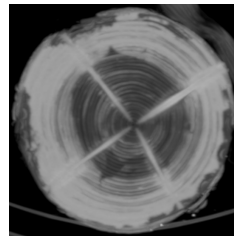
Measurements

Limits

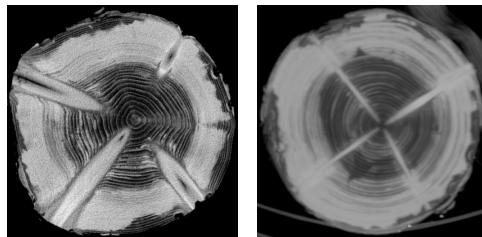
Work in progress

Conclusion

# Segmentation of knots with sapwood



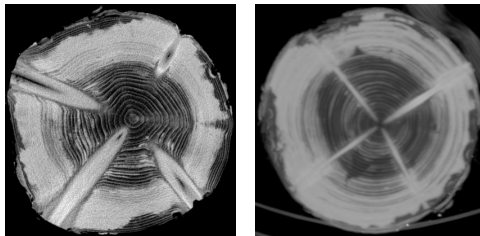
# Segmentation of knots with sapwood



## Problem

Density/intensity of sapwood and knots are similar.

# Segmentation of knots with sapwood



## Problem

Density/intensity of sapwood and knots are similar.

## Consequences

- ⇒ Unefficient thresholding
- ⇒ Knots merged after connected component extraction

# Plan

Manual measurements of knot features

What can be seen?

The tool

Application to species classification

Automatic algorithm for knot features

3DKnotDM

Measurements

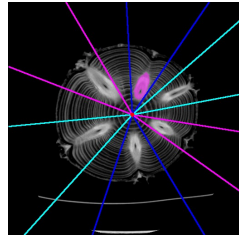
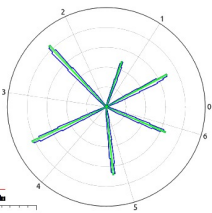
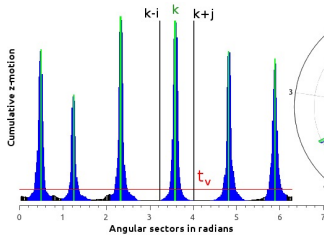
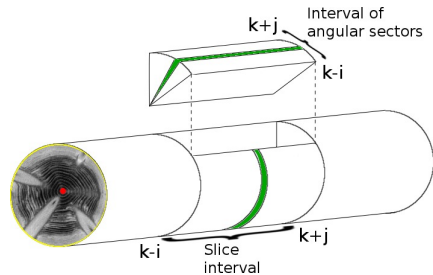
Limits

Work in progress

Conclusion



# Knot area detection



# Plan

## Manual measurements of knot features

What can be seen?

The tool

Application to species classification

## Automatic algorithm for knot features

3DKnotDM

Measurements

Limits

Work in progress

## Conclusion

## Conclusion

Tools for analysing knots on CT scan of wood are available:

- A manual tool for detailed knot architecture measurements, designed for research studies

### Gourmands plugin

[https://www.nancy.inra.fr/foret\\_bois\\_lerfob\\_eng/boite\\_a\\_outils/tomographie\\_x](https://www.nancy.inra.fr/foret_bois_lerfob_eng/boite_a_outils/tomographie_x)

Contact: *frederic.mothe@nancy.inra.fr*

## Conclusion

Tools for analysing knots on CT scan of wood are available:

- A manual tool for detailed knot architecture measurements, designed for research studies

### Gourmands plugin

[https://www.nancy.inra.fr/foret\\_bois\\_lerfob\\_eng/boite\\_a\\_outils/tomographie\\_x](https://www.nancy.inra.fr/foret_bois_lerfob_eng/boite_a_outils/tomographie_x)

Contact: *frederic.mothe@nancy.inra.fr*

- An automatic tool for fast detection of knots, oriented toward industry (in development)

### 3DKnotDM

<http://www.loria.fr/equipes/adage/3DKnotDM>

Contact: *adrien.krahenbuhl@loria.fr*



**Thanks for your attention !**