Public Defence of Kristin Norell‘s Doctoral Thesis „Analysis of digital end face images of coniferous logs in sawmill industry“

The Opponent‘s View

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Outline

- General Informations
- Image & Signal Processing in Wood Technology
- Some Basics in Wood Anatomy
- Pith Detection Techniques
- Annual Ring Analysis
- Kristin‘s Thesis
  - Overview
  - Solutions
- Questions for the Discussion

Salzburg University of Applied Sciences FHS

Location: Puch Urstein / Salzburg

Salzburg University of Applied Sciences FHS

Location: Kuchl (Wood Techn. & Design)

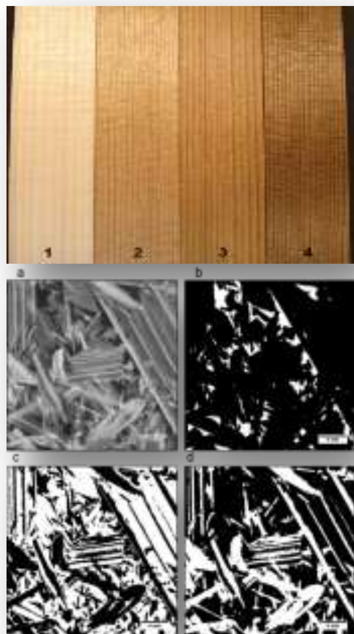
Image & Signal Processing in Wood Technology

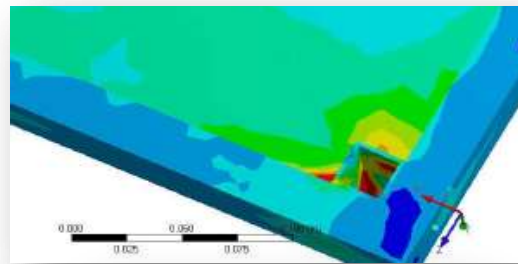
- General Informations
- **Image & Signal Processing in Wood Technology – Selected Examples**
- Some Basics in Wood Anatomy
- Pith Detection Techniques
- Annual Ring Analysis
- Kristin's Thesis
    - Overview
    - Solutions
- Questions for the Discussion

Image & Signal Processing in Wood Technology

Supplier Manufacturer Customer

Multisensory Technologies



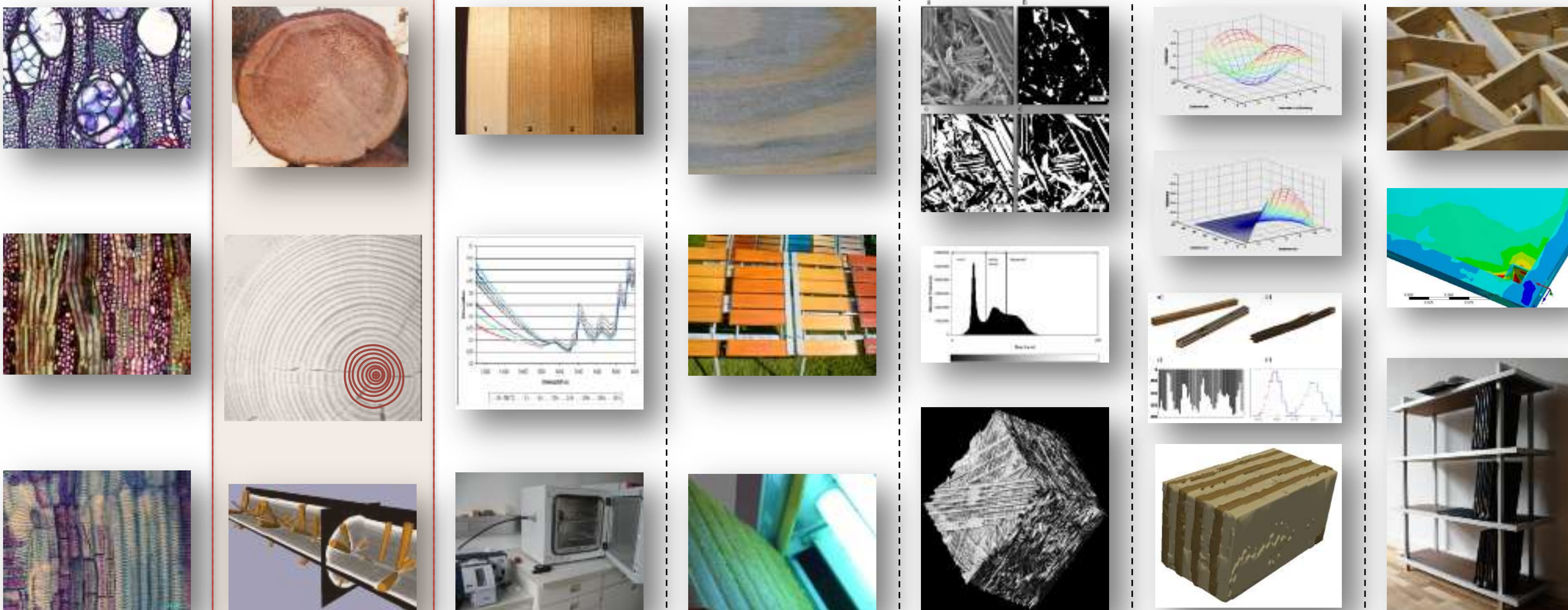


Analog-, Digital-, Thermal-, Microwave-, Ultrasonic-, CT-, MRI-, Neutron – Imaging Techniques

Image & Signal Processing in Wood Technology

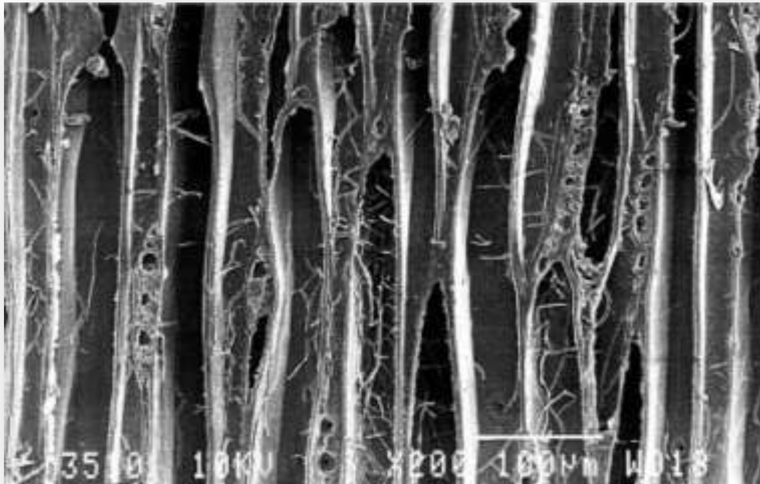
Supplier — Manufacturing — Customer

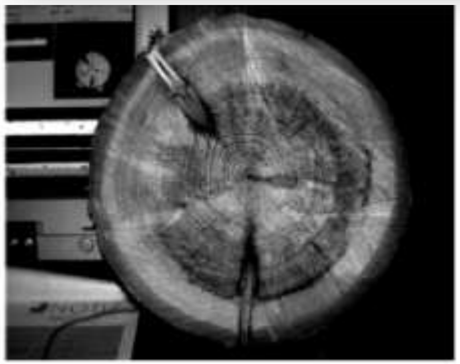
Characterization	Grading Sorting	Modification	Surface	Material	Modeling	Products



Kristin's Thesis

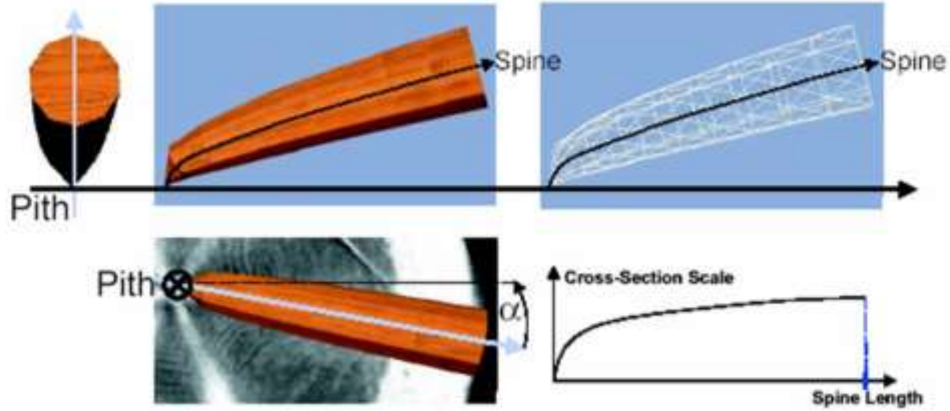
Feature-detection

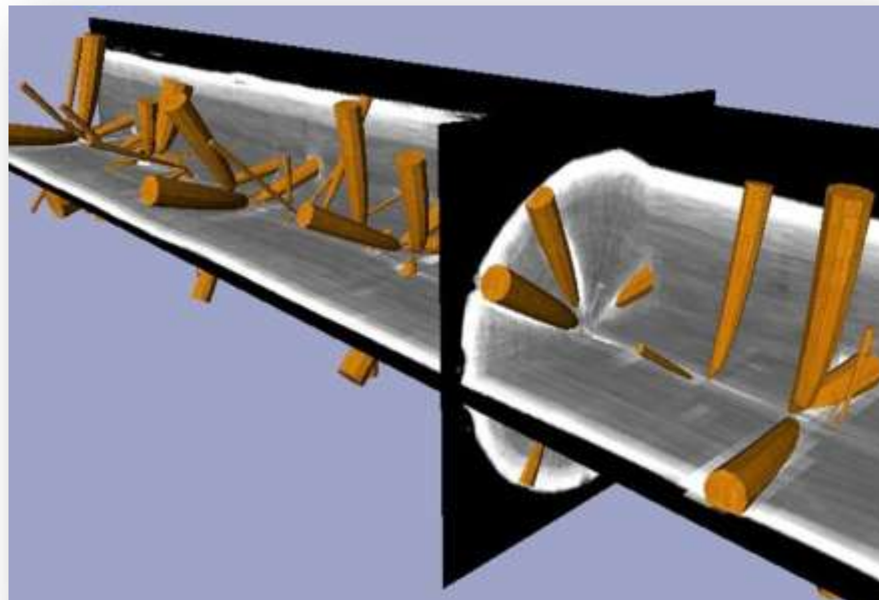




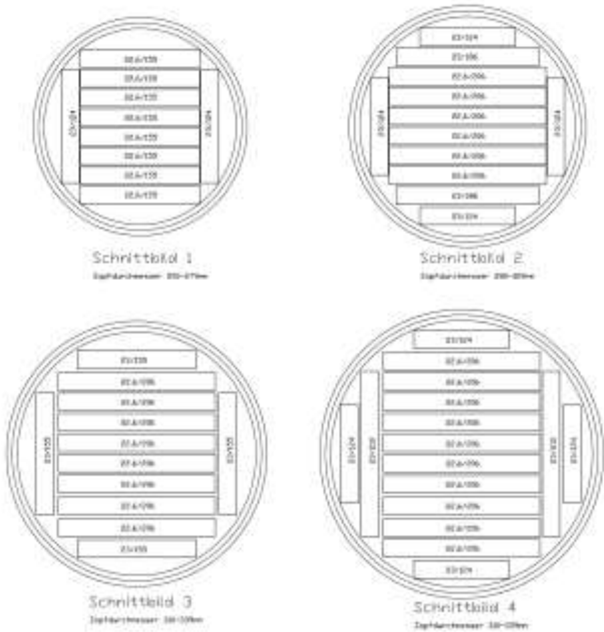
Alexander Petutschnigg

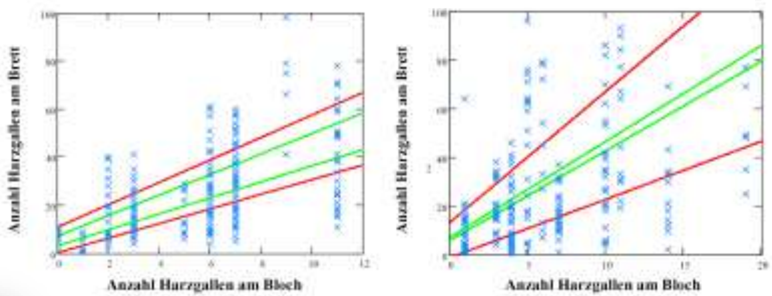
Modeling of Features



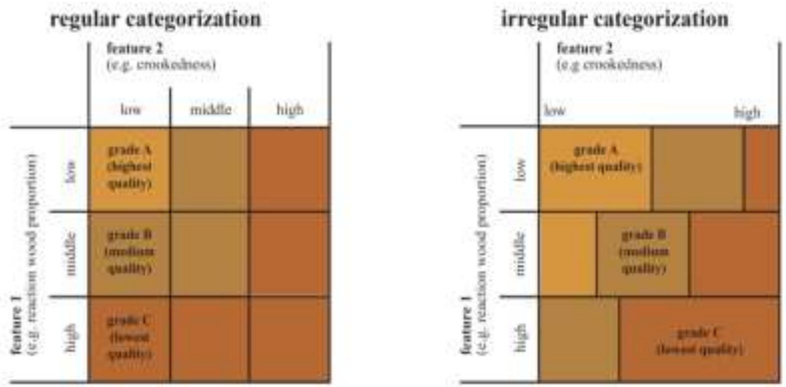


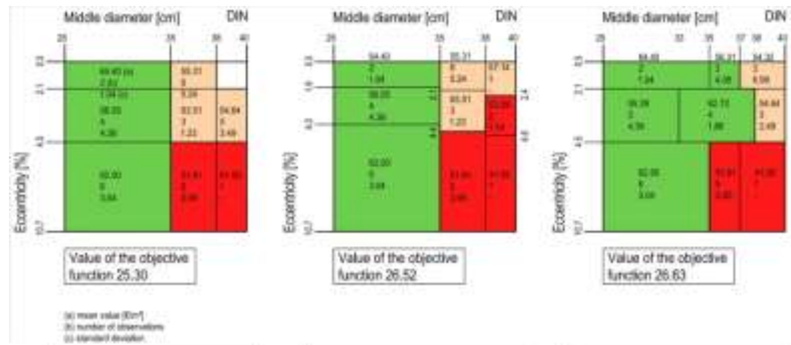
Optimization

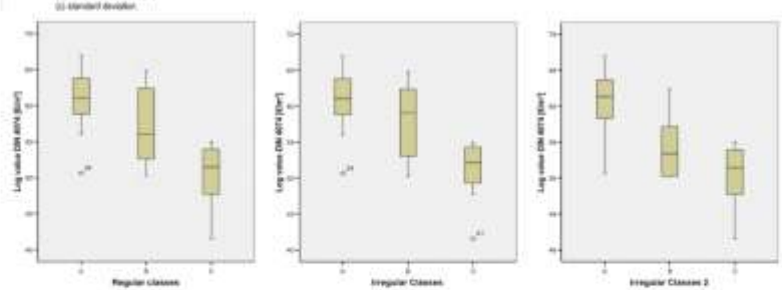




Grading Strategies

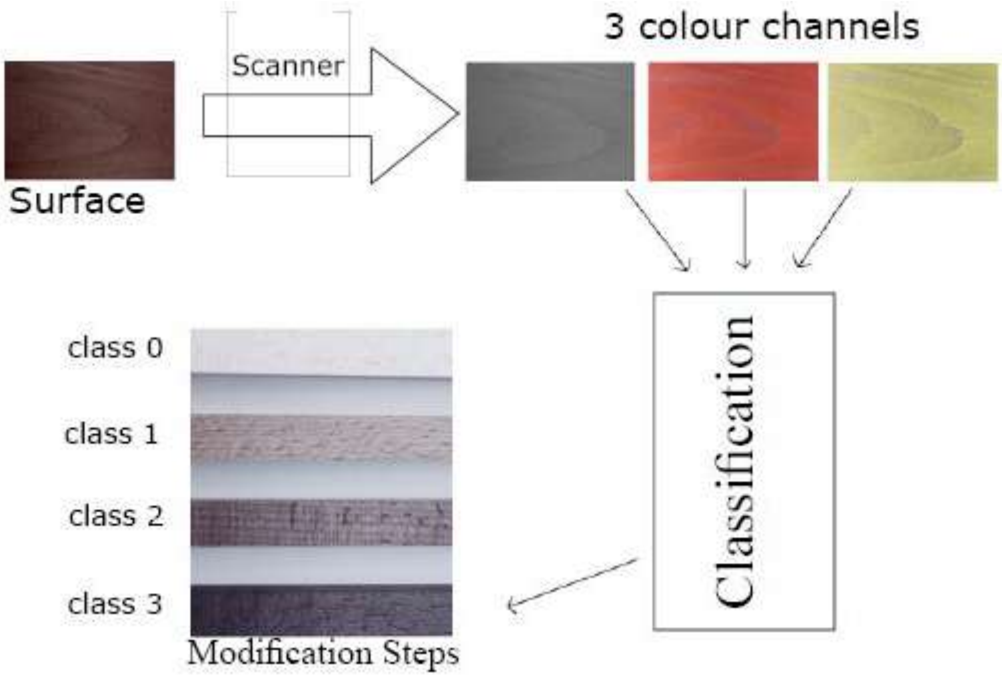


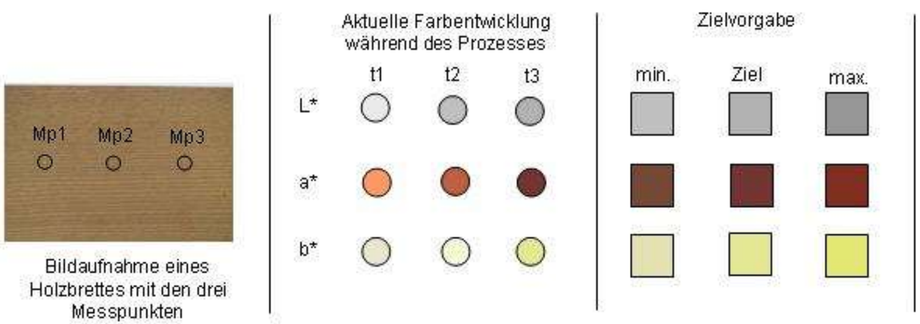




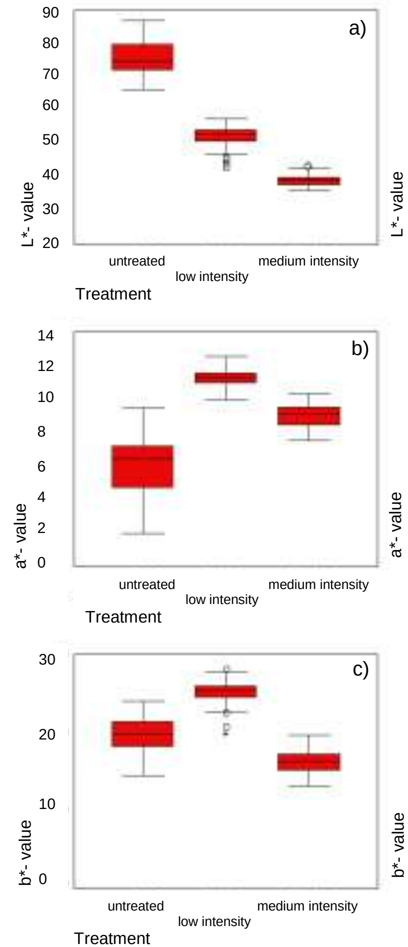
Alexander Petutschnigg

Spectroscopy



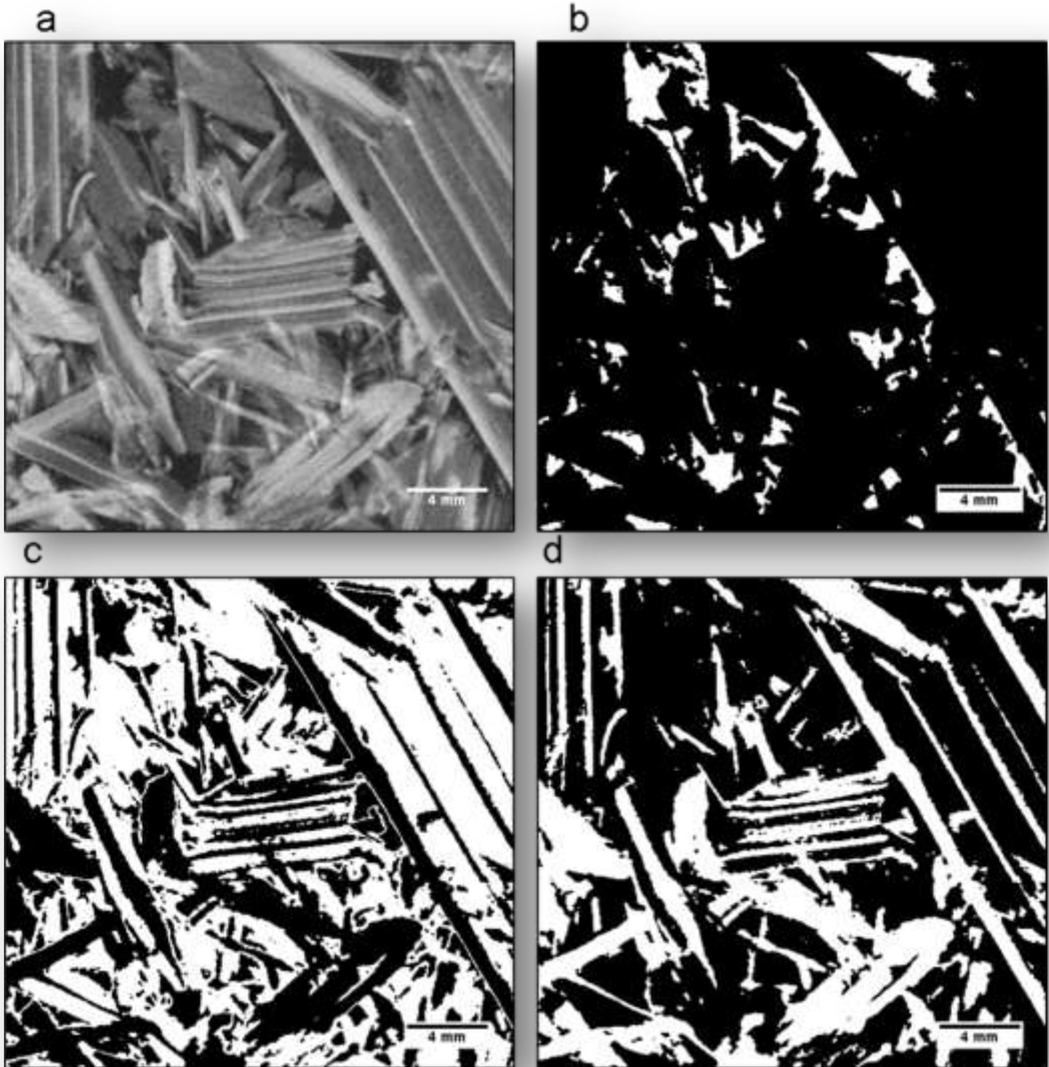


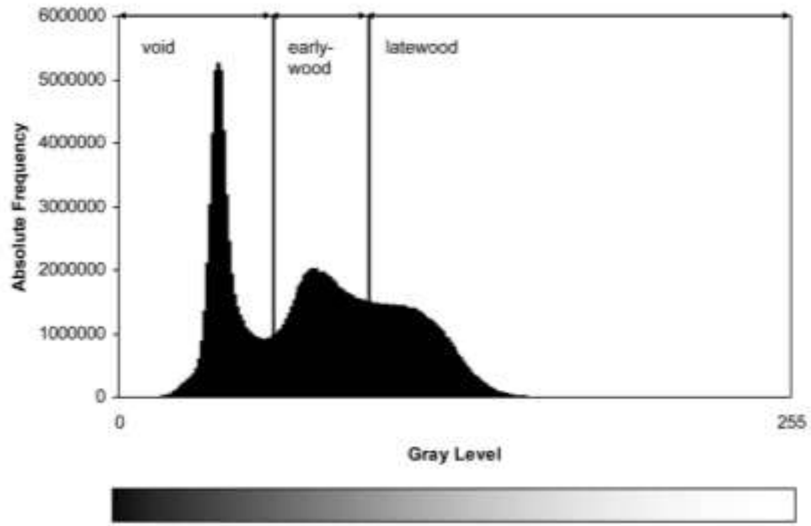
Colour Analysis



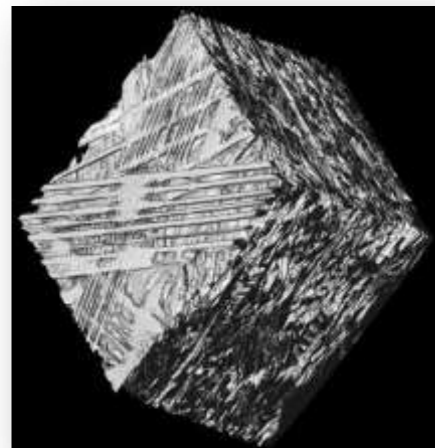
Thomas Schnabel

Characterization of Wood Based Products



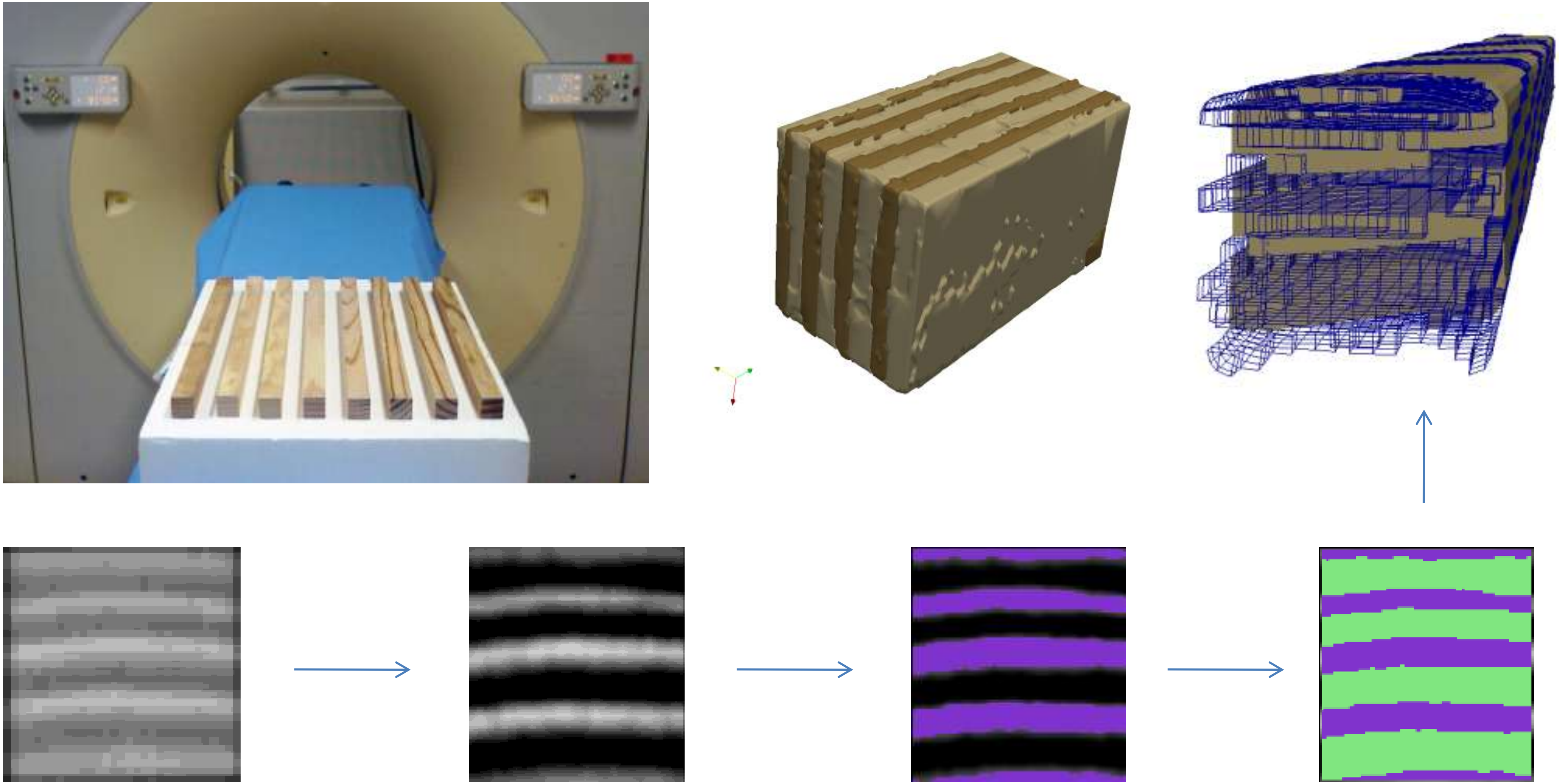


3D - Modeling



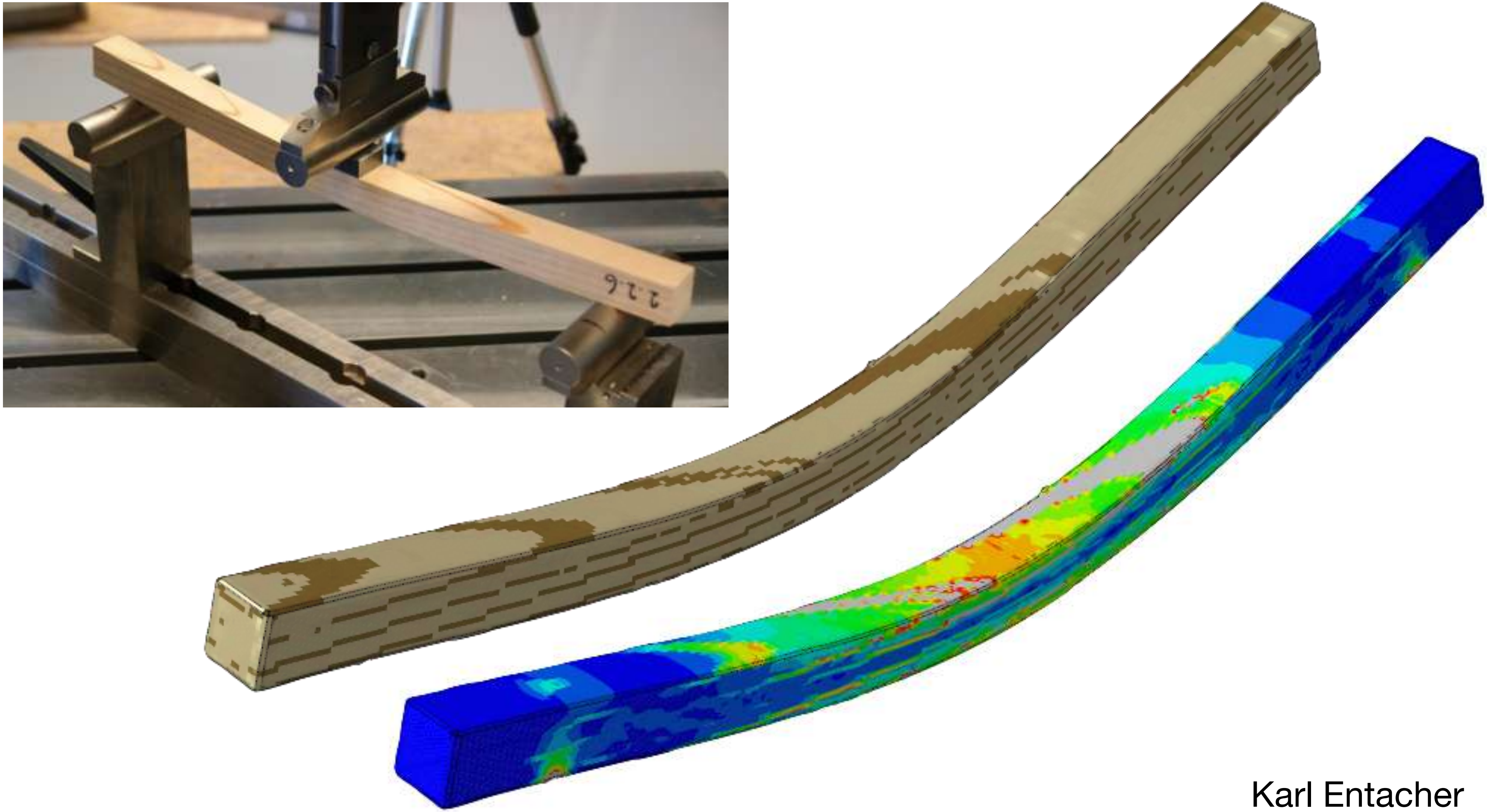
Gernot Standfest

Finite Element Modeling of Wood from CT-Data



Karl Entacher

Finite Element Modeling of Wood from CT-Data



Karl Entacher

Research Groups – Wood Image Processing

- A. Grönlund, J. Oja, J. Skog, M. Ekevad, J. Nyström and many other colleagues from Division of Wood Science and Technology, Luleå University of Technology, Skellefteå http://www.ltu.se/ske/wood/
- P. Österberg, H. Ihalainen, R. Ritala. Tampere University of Technology, Finland http://www.mit.tut.fi/ (Doctoral Defense 09.06.2010).
- P. Gjerdrum, The Norwegian Forest and Landscape Inst. http://www.skogoglandskap.no/
- J.-M. Leban, F. Longuetaud, F. Mothe, and colleagues from Laboratoire des Ressources Foret – Bois, INRA, Nancy, France https://www.nancy.inra.fr/foret_bois_lerfob_eng/
- U.H. Sauter et al. FVA Forest Res. Institute Baden-Wurttemberg, Dept. Forest Utilisation, http://www.fva-bw.de/
- T. Hanning, M. Kellner, R. Kickingereder, former staff from FORWISS Passau (Project Intelliwood) http://www.forwiss.uni-passau.de/
- W. Gindl, J. Konnerth, U. Müller, A. Teischinger and colleagues from Univ. of Natural Resources and Applied Life Sciences, Vienna, Austria http://forschung.boku.ac.at
- A. Rinnhofer et al. Joanneum Research Austria, http://www.joanneum.at/

Some Basics in Wood Anatomy

- General Informations
- Image & Signal Processing in Wood Technology
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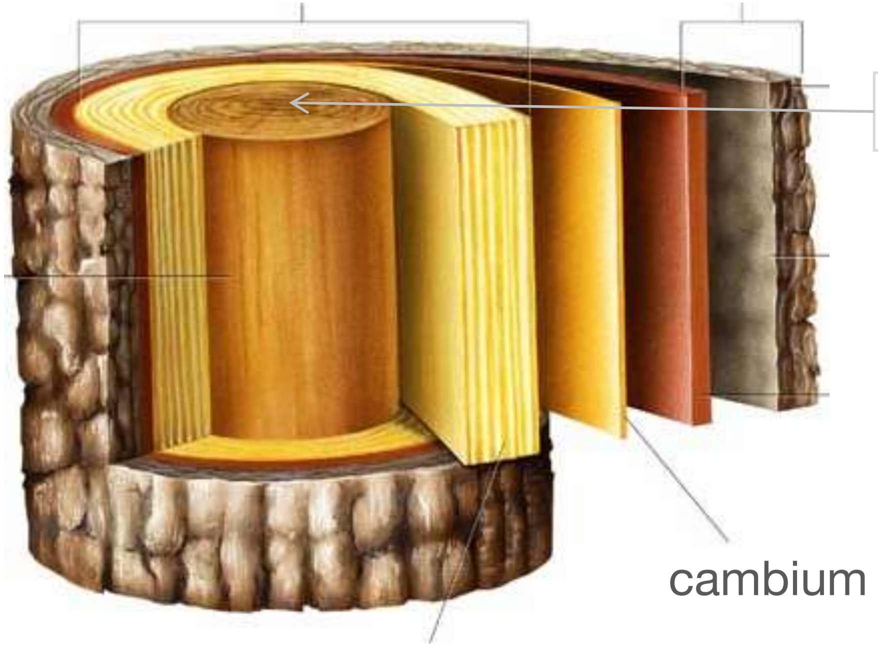
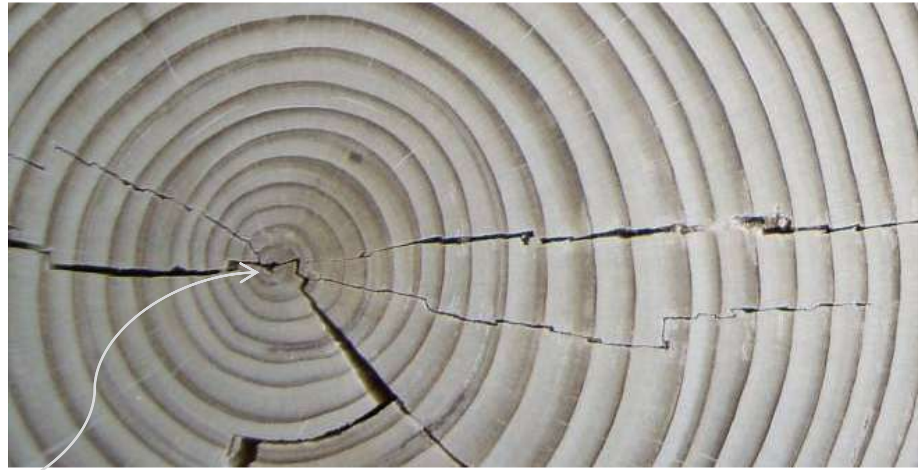
Some Wood Basics

Some basic terms in wood anatomy
Example: coniferous tree





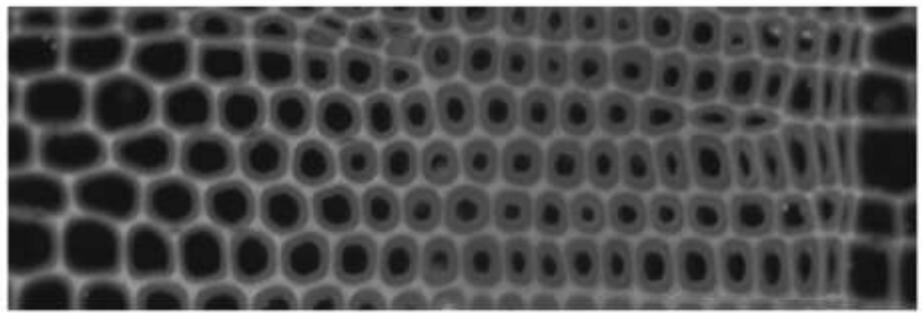


Figure 1: Wood cells from pine seen on micro level with earlywood to the left, growing through a smooth transition towards latewood. To the right, the sharp transition from latewood to earlywood is visible. The piece of wood is approximately 26.2×8.7 μm. [Image acquisition: Bettina Selig] K. Norell (1)

http://www.millerandlevine.com/

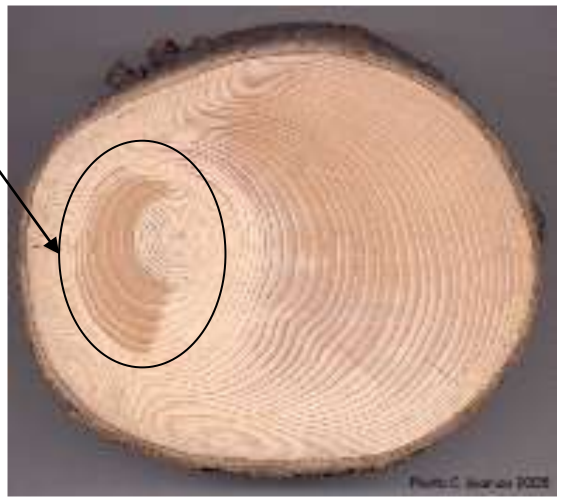
Wood Basics - Special Features

Cracks

Knots

Rot
Stain

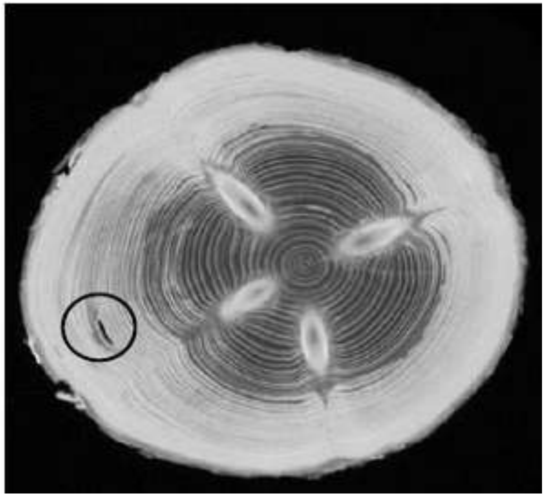
Compression
(Reaction)
Wood Areas



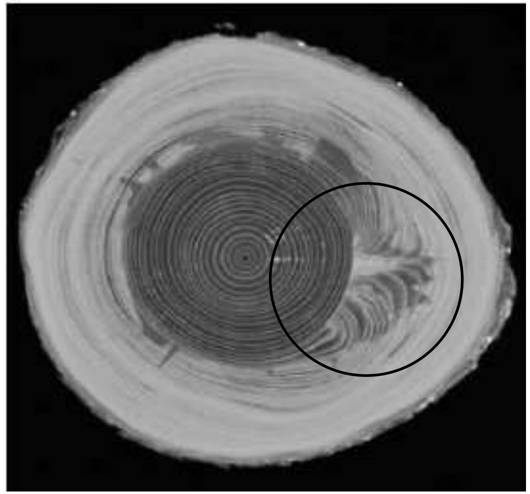
http://www.forestresearch.gov.uk - http://www.yukondendro.ca/

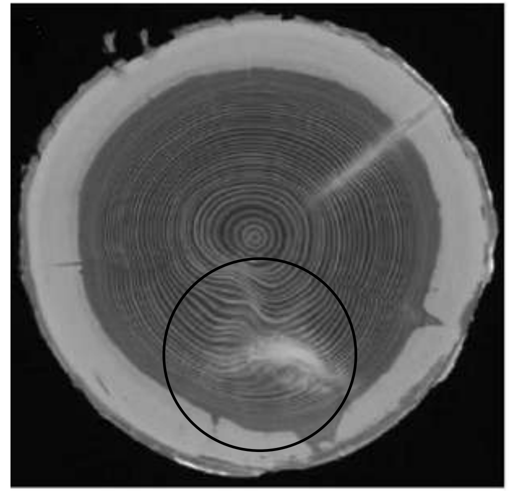
Wood Basics - Special Features

Longuetaud, F. et al. (2)



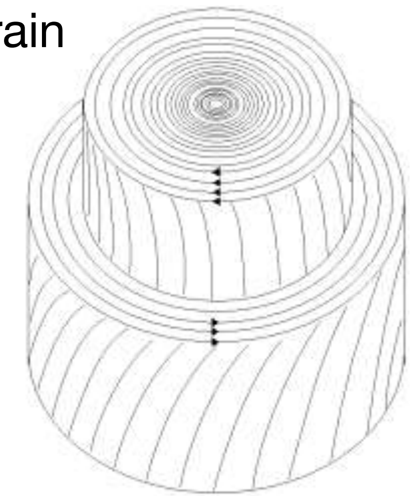
Resin pocket in sapwood



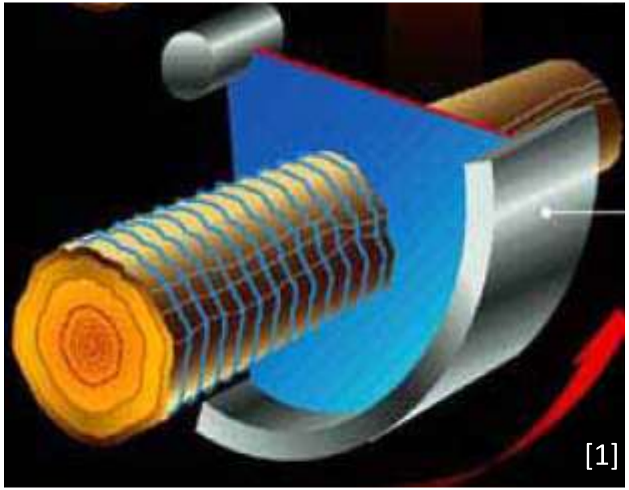


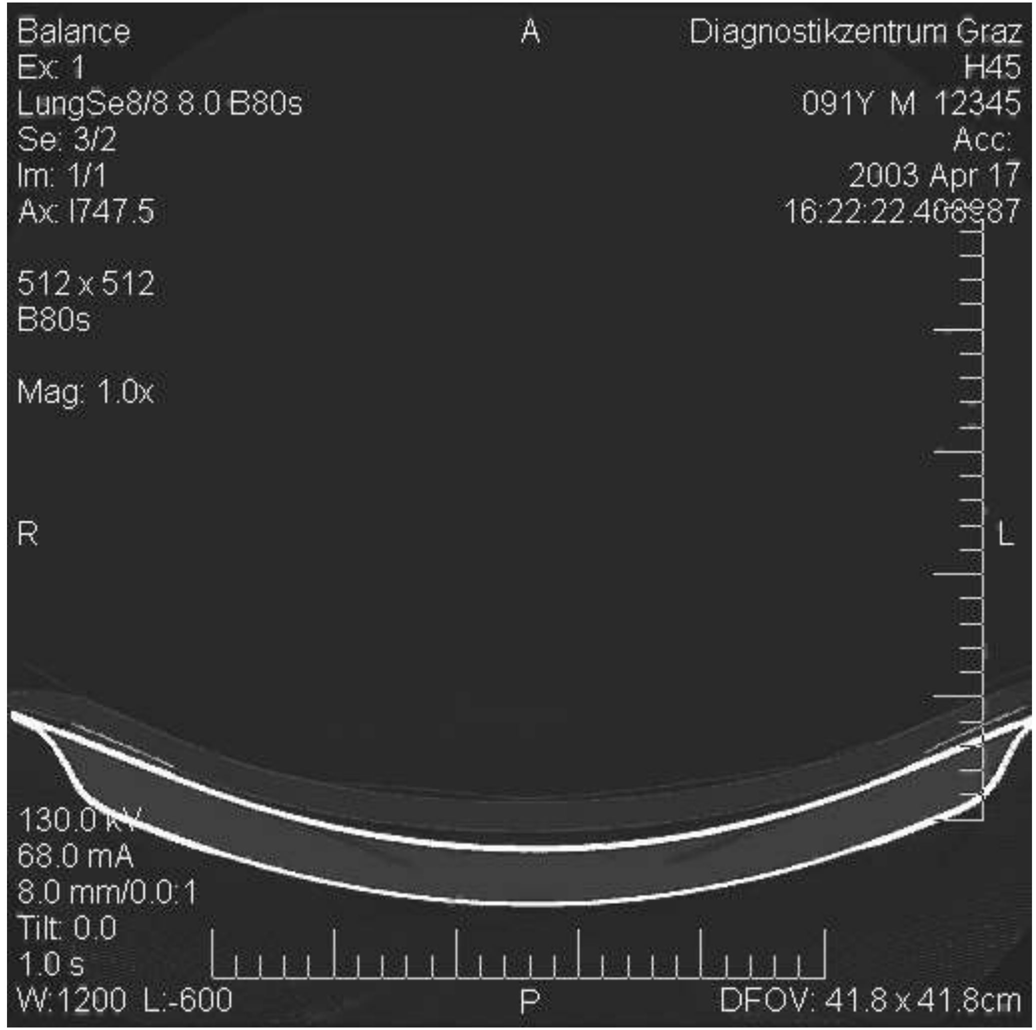
More particular defects probably resulting from wounds

Spiral Grain



Spiral Grain in CT-Images?





Ulrich Müller (3)

Pith Detection Techniques

- General Informations
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- Annual Ring Analysis
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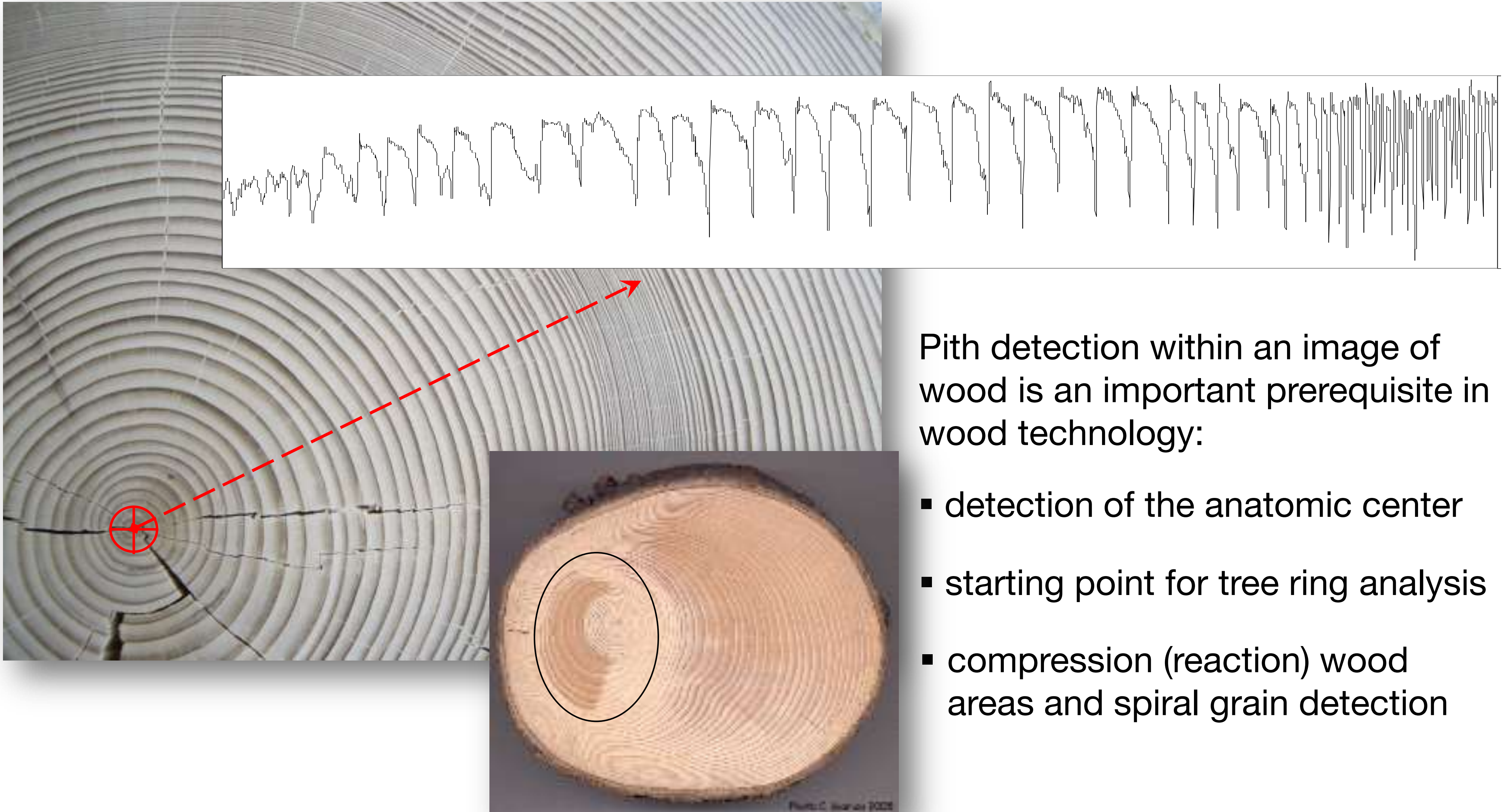
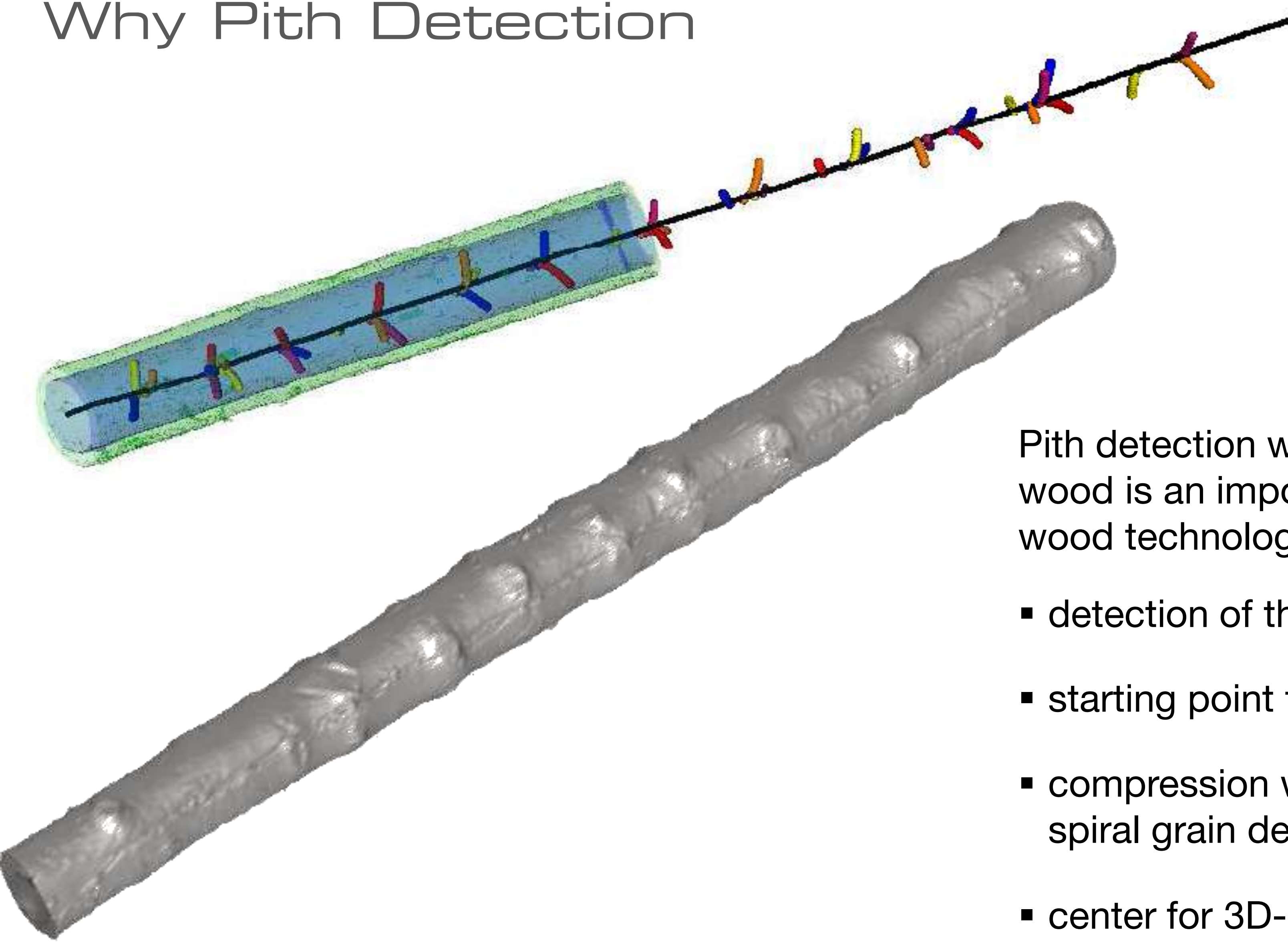
Why Pith Detection



Pith detection within an image of wood is an important prerequisite in wood technology:

- detection of the anatomic center
- starting point for tree ring analysis
- compression (reaction) wood areas and spiral grain detection

Why Pith Detection

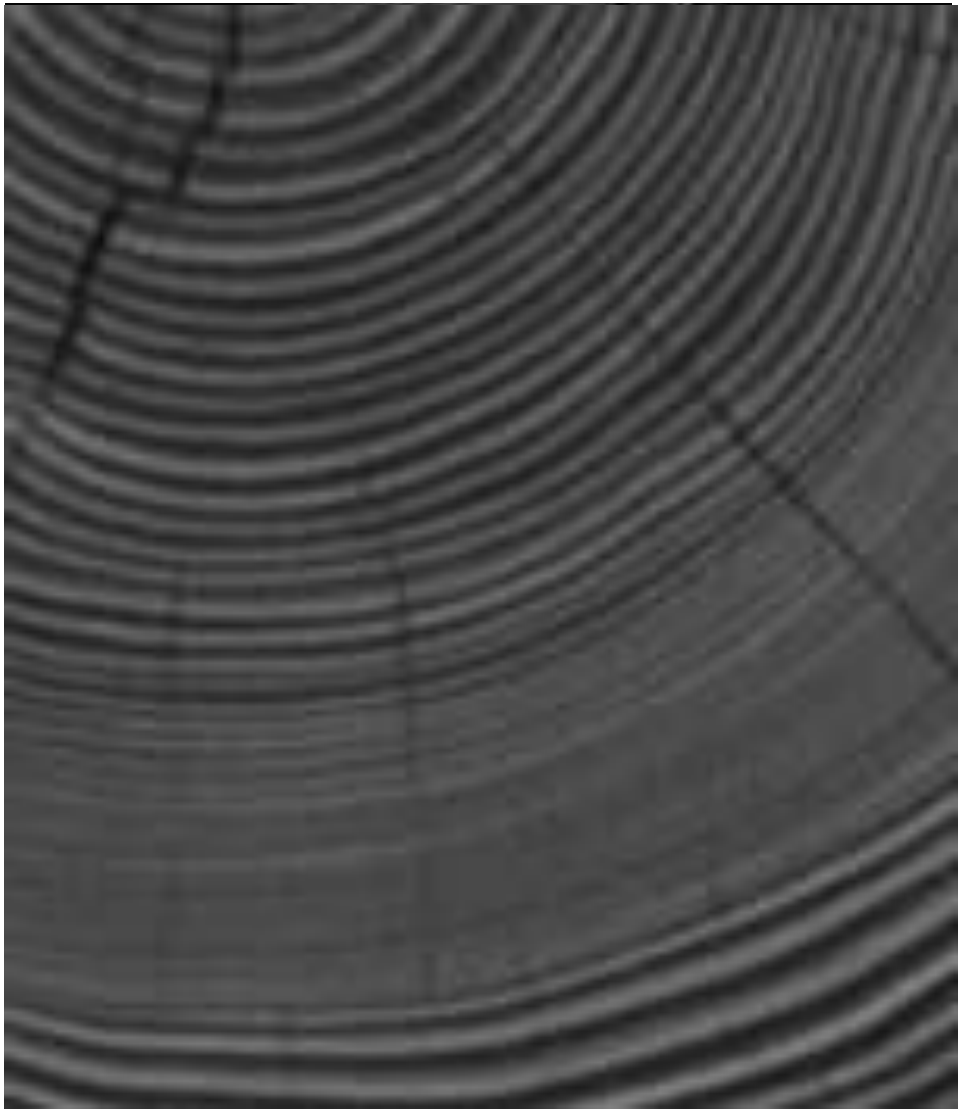


Longuetaud, F. et al. (2)

Pith detection within an image of wood is an important prerequisite in wood technology:

- detection of the anatomic center
- starting point for tree ring analysis
- compression wood areas and spiral grain detection
- center for 3D-modelling of logs

Problems: CT – Digital Images - Resolution



Problems: Rough – Clean Images – Anatomy

(0)

Cutting Pattern

Clean Cut

Rot

Resolution

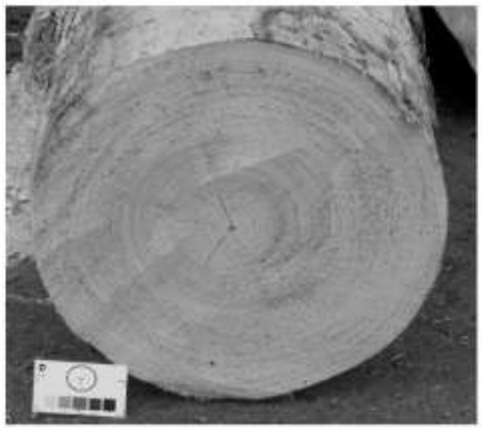
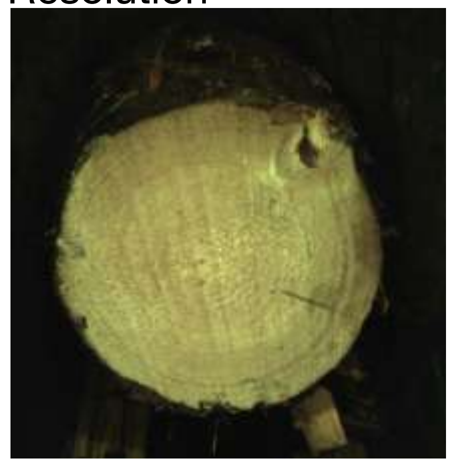
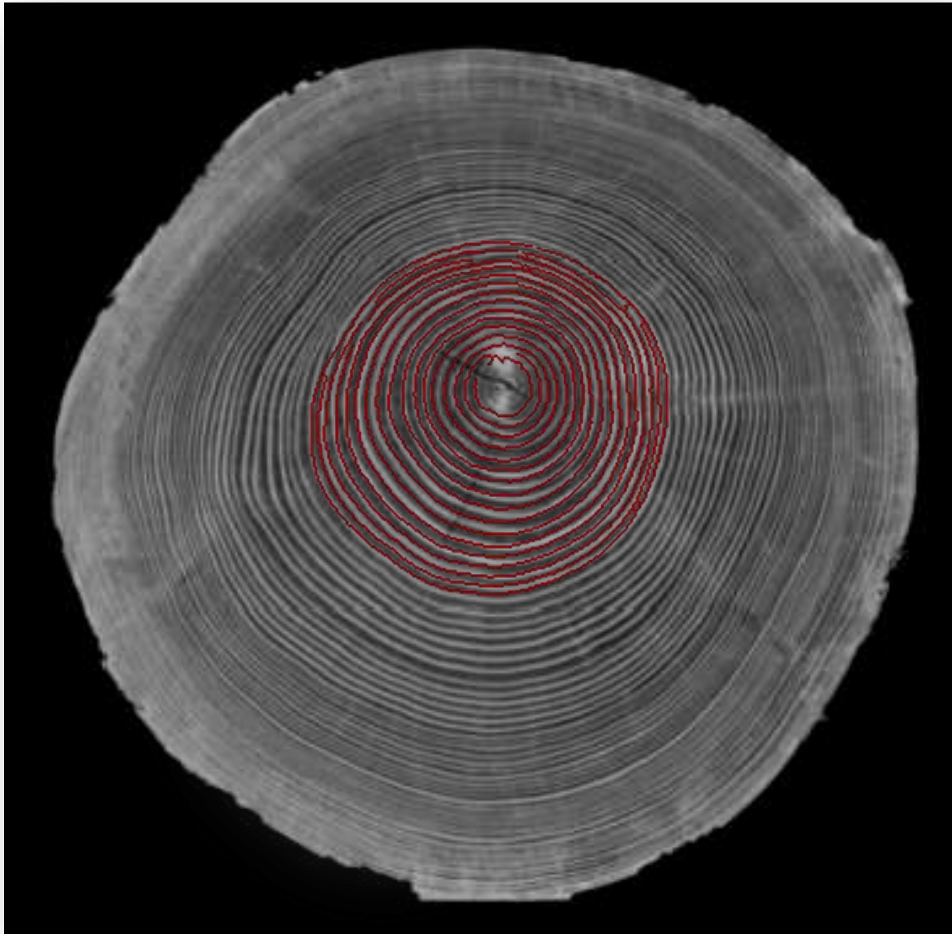


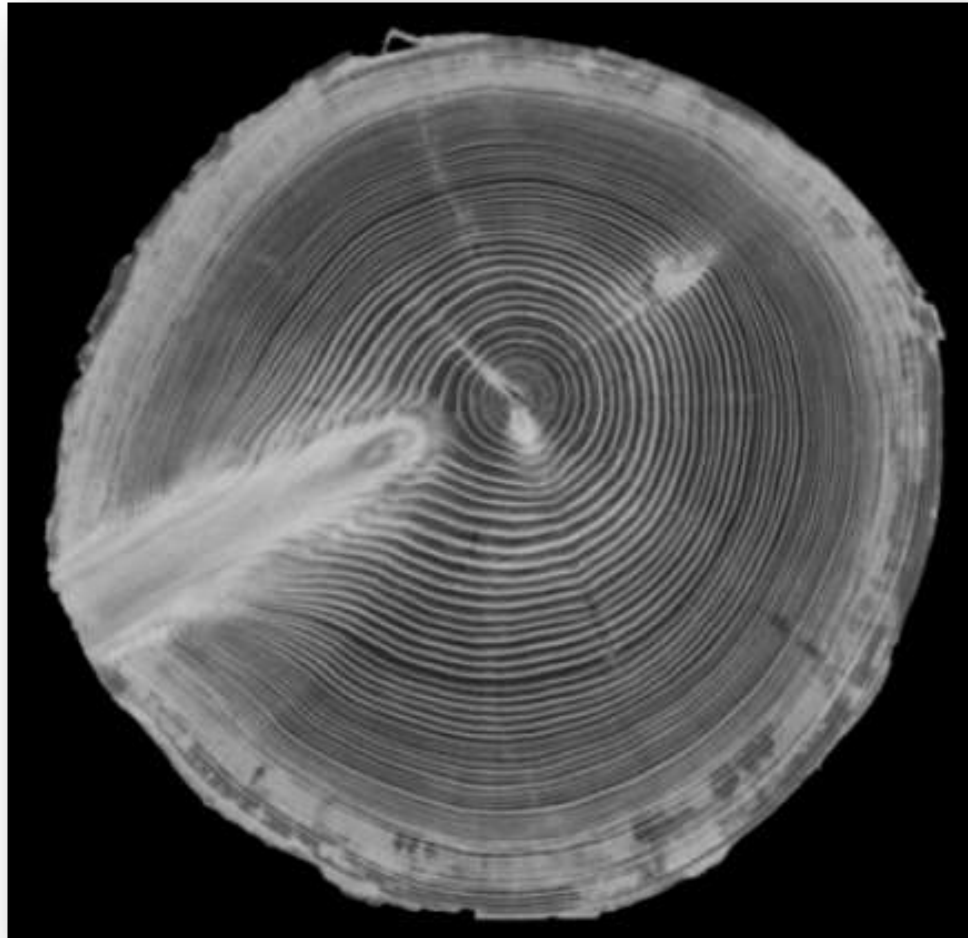
Figure 3: A pine end face imaged as found at the sawmill (upper) and shortly afterwards when newly sawn (lower).



(1)

Examples





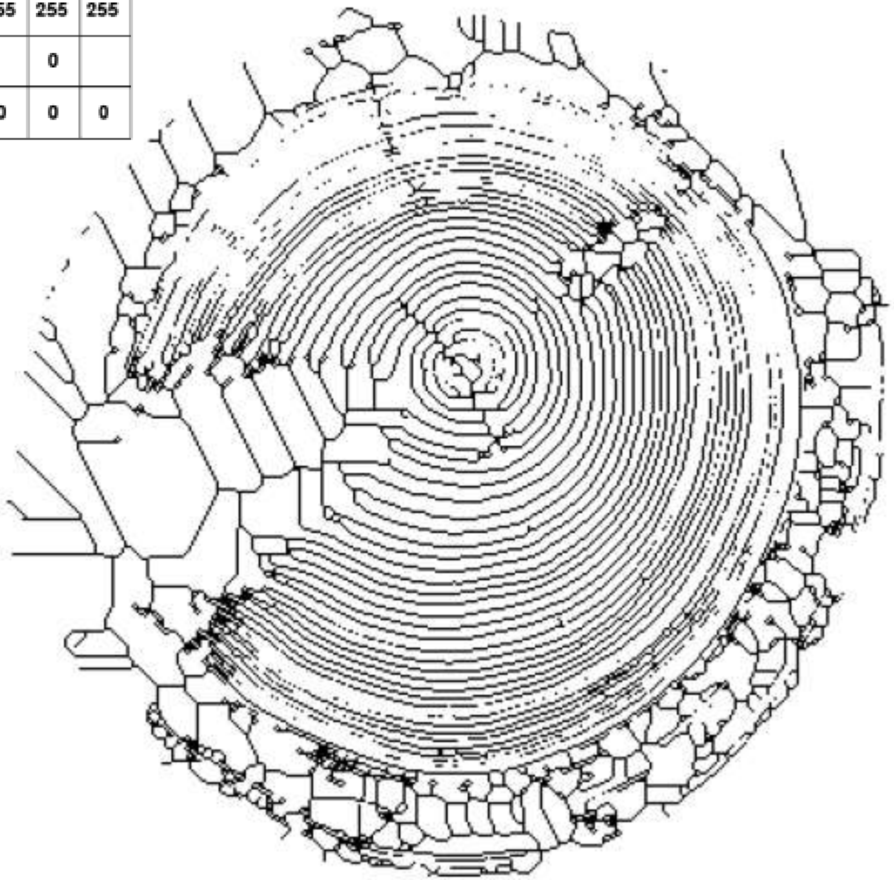
Two Samples from 36 CT-Slices

Preprocessing Exp. 1: Simple Preprocessing

Contrast Enhancement + Binarization + Inversion

Preprocessing Exp. 1: Simple Preprocessing

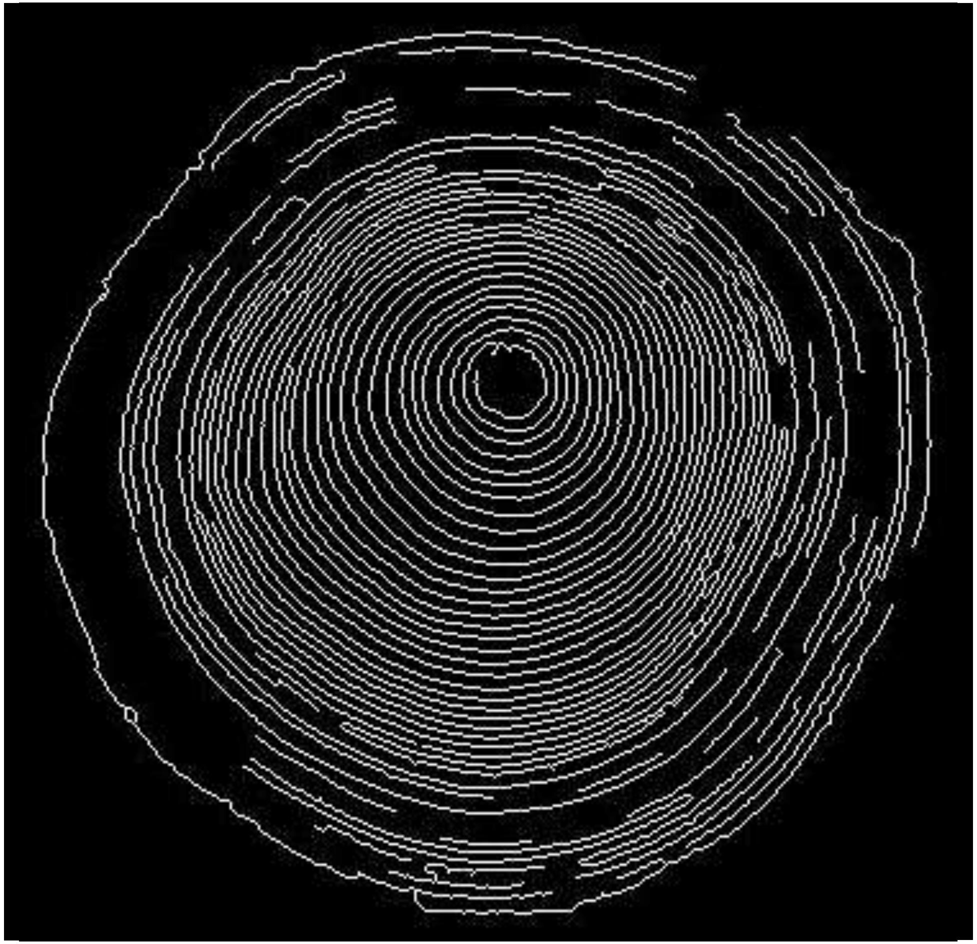
255	255	255
	0	
0	0	0



Morphological Thinning using a structuring element iteratively in all 45° rotations

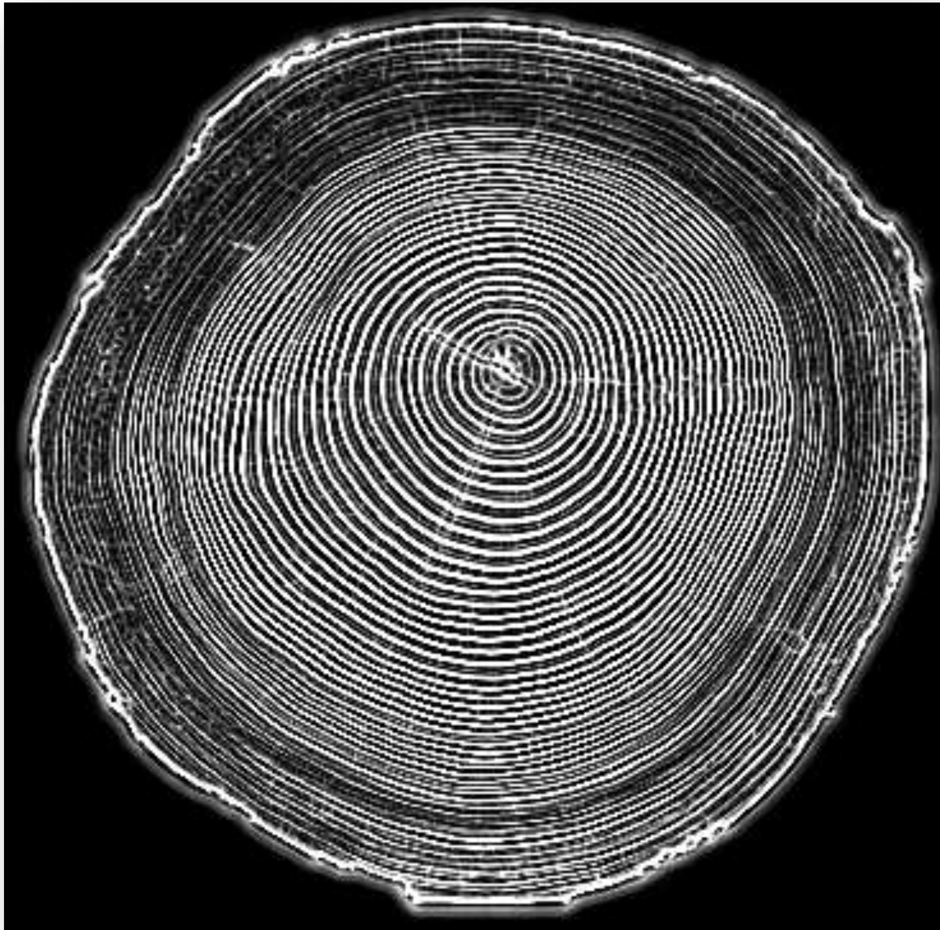
Iterative T- and X – Junction Removement in 8 - neighbourhoods

Preprocessing Exp. 2: Mexican Hat

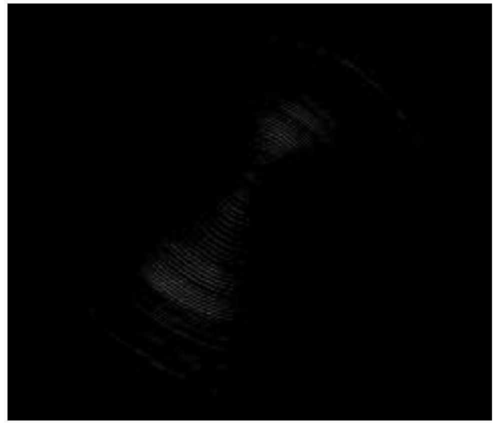


- Noise removal with a 3x3 Gauss filter
- Local contrast enhancement
  Yu & Bajaj, 2004
- Isolation of anual rings with a
  5x5 Mexican Hat filter
- Thresholding
- Skeletonization
- Cleaning

Preprocessing Exp. 3: Gabor Filtering



- Creation of gabor filters with different frequencies and orientations
- Convolution operations with filters



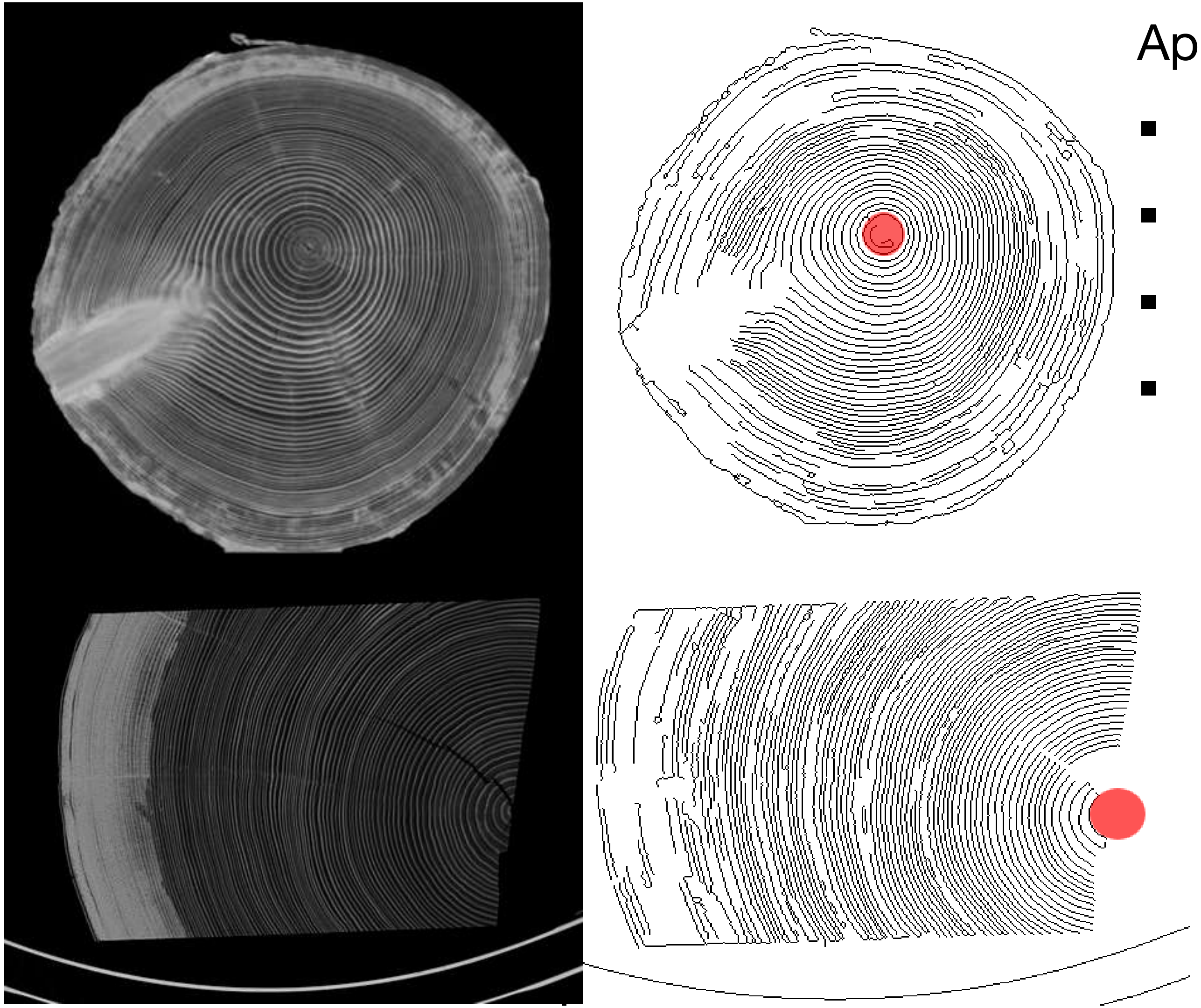
- Rotation from 0 to 180 degrees
- Postprocessing as for Mexican Hat Preprocessing

Preprocessing: Sample Image with Knots

Mexican Hat Preprocessing

Gabor Preprocessing

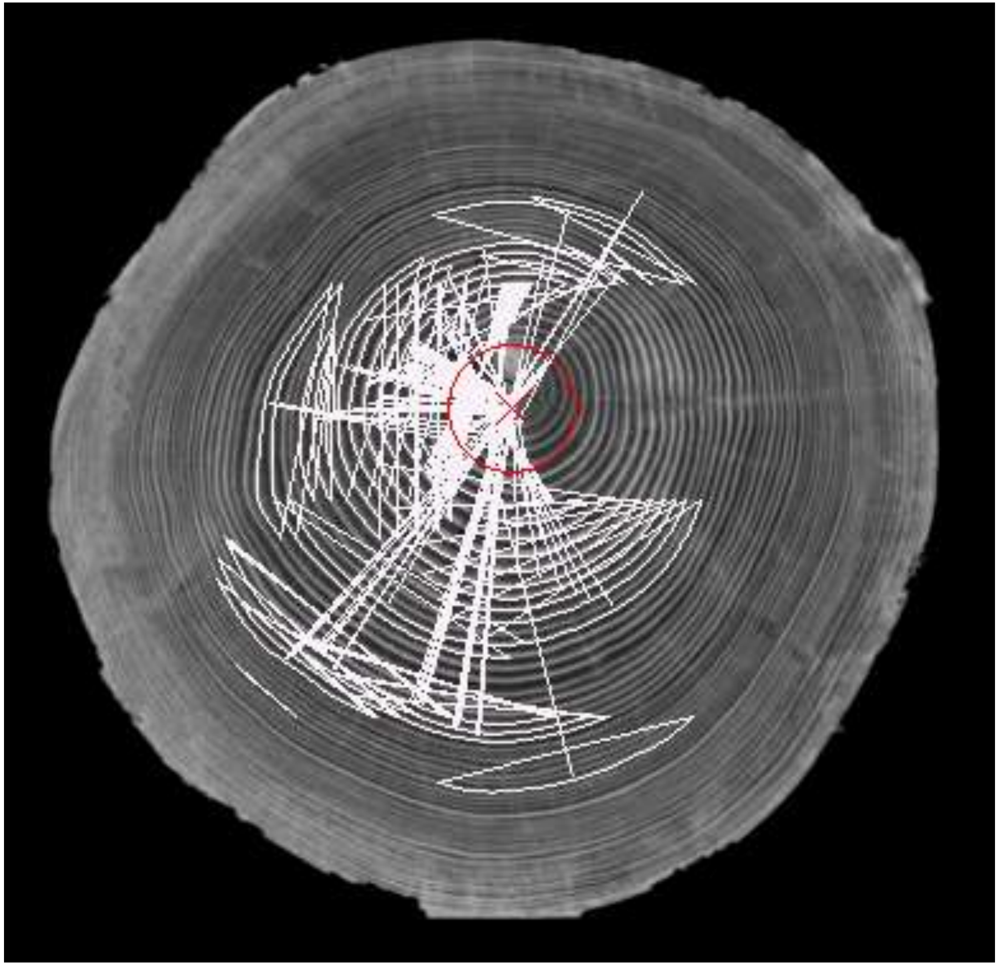
Pith (Center) Detection Techniques



Application of different methods:

- Gradient Based Methods
- Segment Curvature
- Poincaré Index
- Utilisation of the Circle Equation

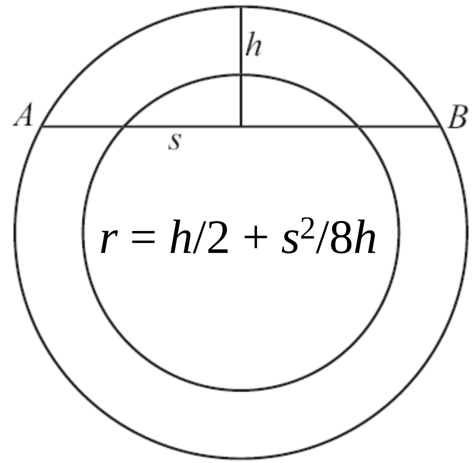
Gradient Based Methods



Visualization of the procedure

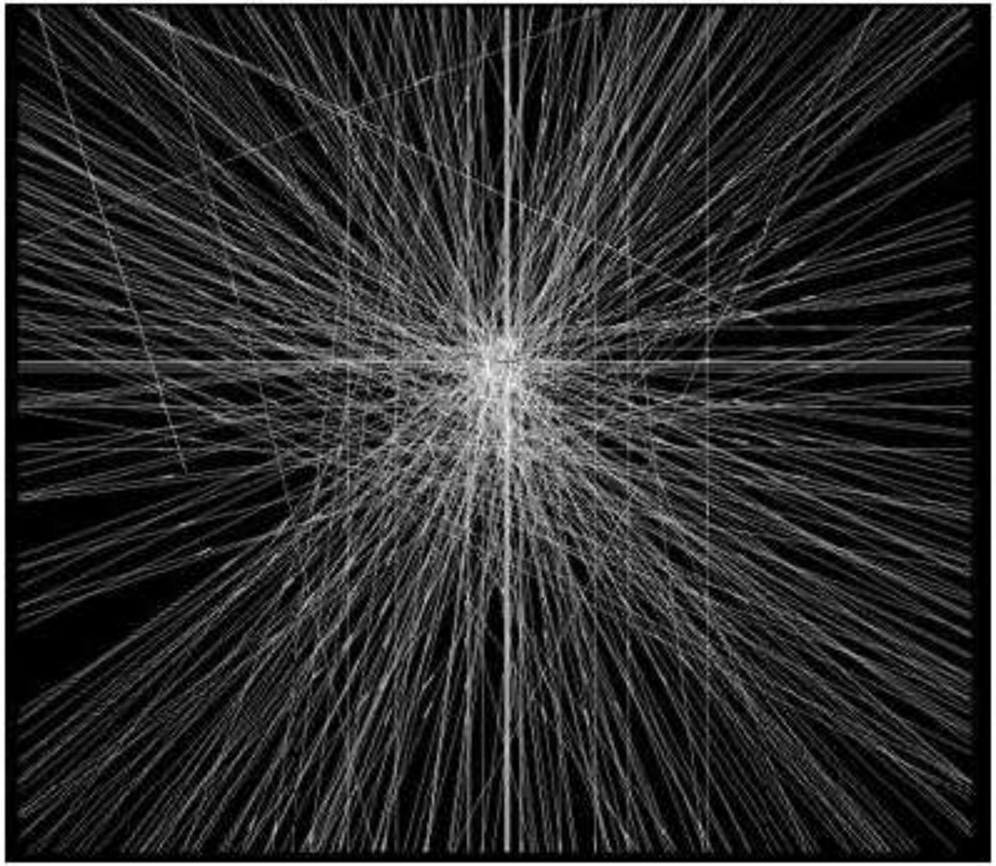
Applied two pith detection techniques:

- Using the intersection of gradient directions
- Gradient direction and radial length estimation



Both techniques rely on a connection of end points of circular arcs, where the estimated gradient direction is the normal vector to the connecting line.

Gradient Based Methods



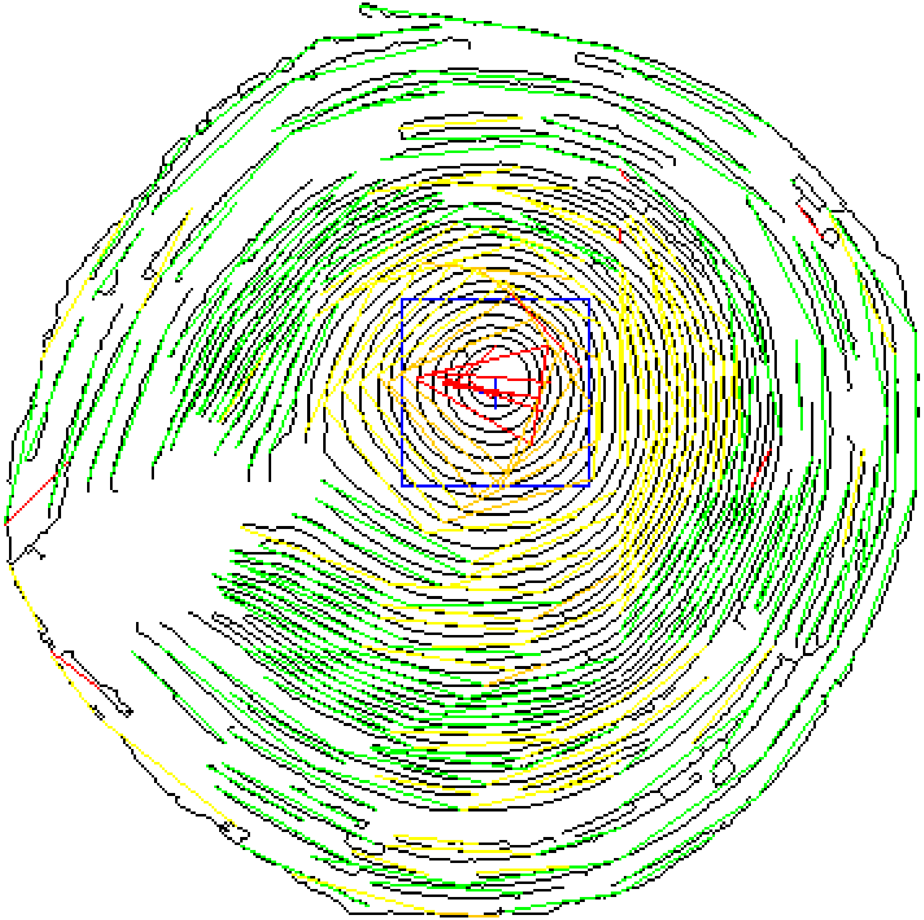
Evaluation of the Gradient Direction:

- Follow Gradient Orientation in either direction and accumulate each hit pixel in an array.
- Usage of the maximum value inside the accumulator to identify the center
- Alternatively calculate barycenter of accumulator or use box filtering

Summary:

- Simple and fast
- Insensitive to twigs and distortions
- Finding the center inside the accumulator can be tricky

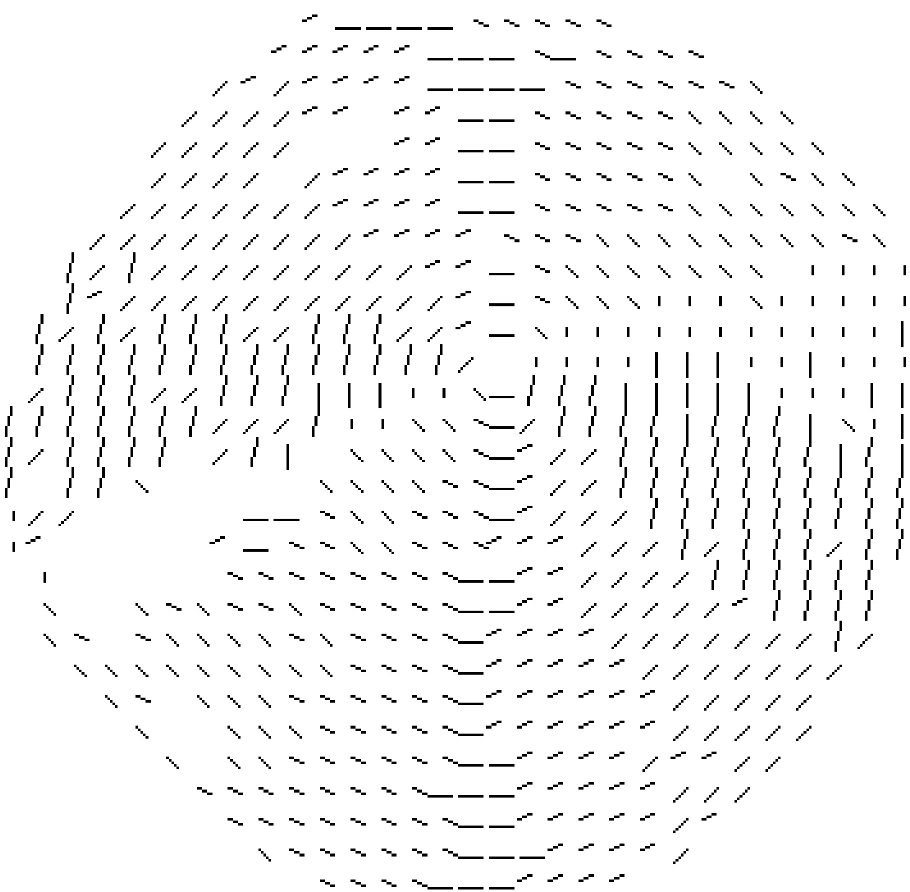
Segment Curvature



This technique is based on the idea that arc curvature increases towards the pith

- Tresholding on curvature to identify segments close to the center.
- Use statistical methods to throw away „bad“ segments.
- Average segment‘s center points to estimate center.
- Use Hough transform on a 64 x 64 pixel window around estimated center to find the „real“ center point.
- works best combined with Hough-Transf.
- works best with cirular images
- sensitive to twigs and leeks

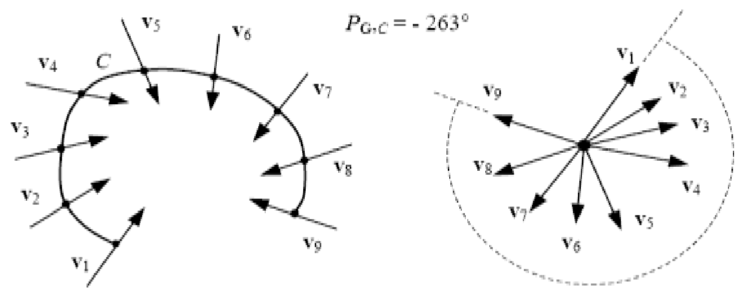
Poincaré Index



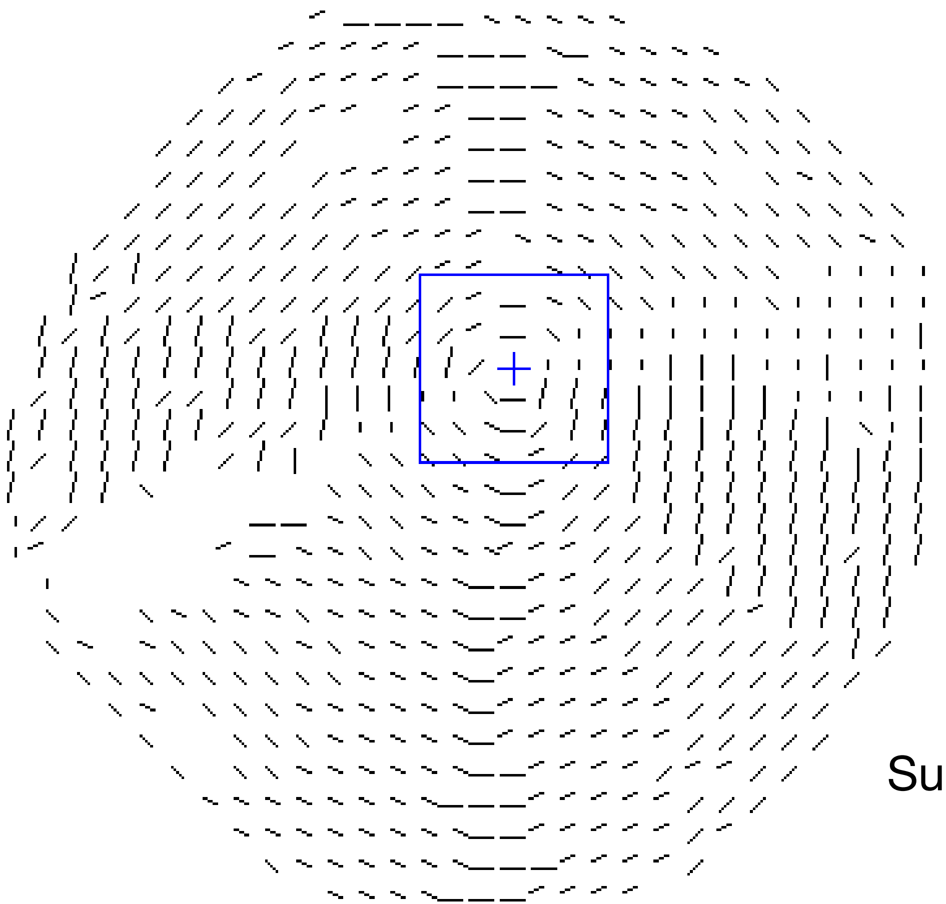
The Poincaré method is a well known technique to detect singularities in fingerprint images. It can also be used to find only the core singularity (i.e. in our case the position of the pith).

The idea of using it for pith detection is based on the fact that cross-section images contain at least one closed curve, in general many more of such curves exist (the tree rings of course).

The Poincaré index method relies on the fact that the total rotation of the vectors in a direction field along a closed curve equals 360 degrees.



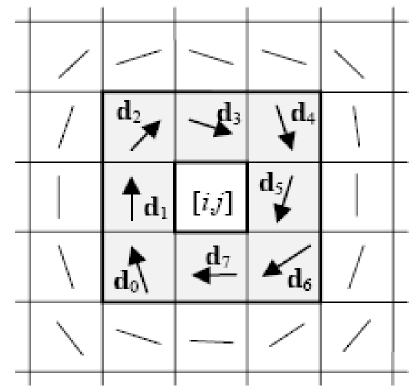
Poincaré Index



To generate the so called „orientation image“ a Sobel operator is applied to the images after preprocessing.

The Poincaré index can be computed as:

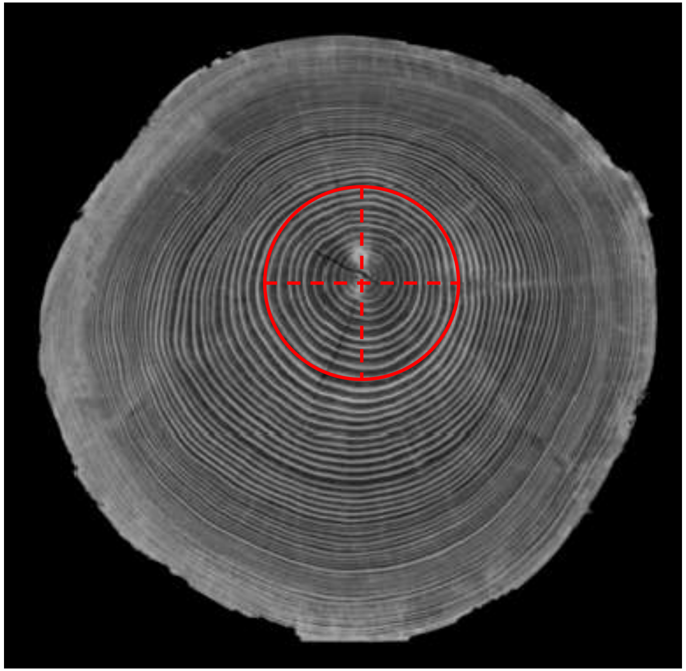
$$P_{G,C}(i,j) = \sum_{k=0}^{7} angle(d_k, d_{(k+1) mod 8})$$



Summary:

- Tricky to implement
- Many practical problems
- Center point – and Orientation accuracy depend on the size of the averaging window

Utilisation of the Circle Equation



All points (i.e. pixels) of a circular arc fulfil the circular equation $(x - x_0)^2 + (y - y_0)^2 = r^2$ (with (x_0, y_0) the coordinates of the circle centre), therefore for each pair of points (x_i, y_i), (x_j, y_j) on a circular arc we get:

$$x_i^2 - 2x_i x_0 + x_0^2 + y_i^2 - 2y_i y_0 + y_0^2 = r^2 \quad (1)$$

$$x_j^2 - 2x_j x_0 + x_0^2 + y_j^2 - 2y_j y_0 + y_0^2 = r^2 \quad (2)$$

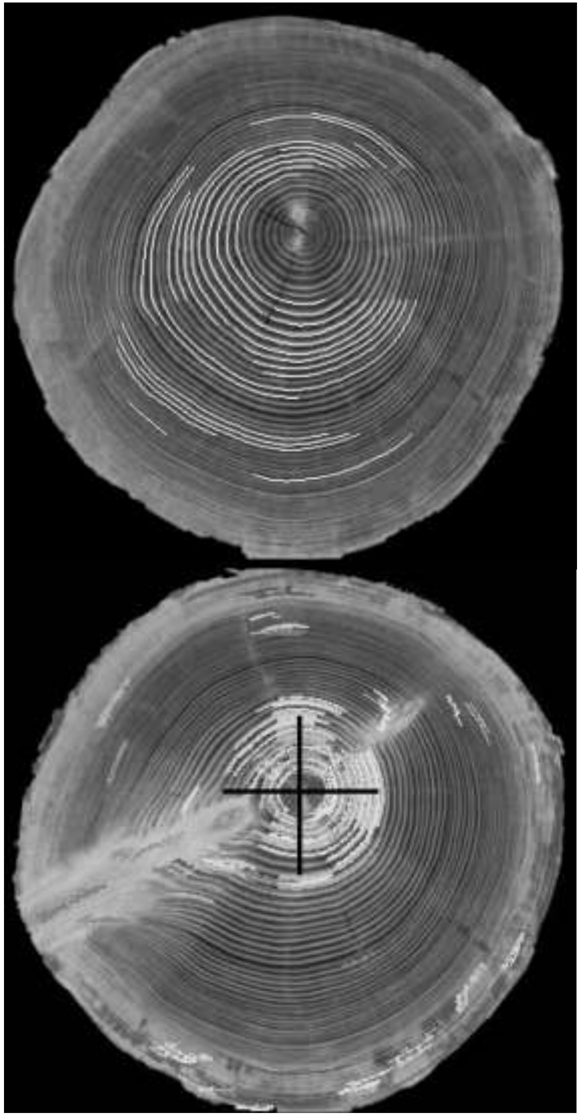
From (1) and (2) we get:

$$\underbrace{2\,(x_j - x_i)}_{\mathbf{A}_{k1}}\, x_0 + \underbrace{2\,(y_j - y_i)}_{\mathbf{A}_{k2}}\, y_0 = \underbrace{x_j^2 - x_i^2 + y_j^2 - y_i^2}_{b_k} \quad (3)$$

which can be written as a over-determined linear equation:

$$\mathbf{A}\vec{x}_0 = \vec{b} \quad (4)$$

Utilisation of the Circle Equation



To solve a linear least square problem in order to estimate $\vec{x}_0$, we apply the QR decomposition: $\mathbf{A} = \mathbf{QR}$, where $\mathbf{Q}$ is an orthogonal matrix ($\mathbf{Q}^T\mathbf{Q} = \mathbf{I}$) and $\mathbf{R}$ is an upper triangular matrix. Now we get:

$$\vec{x}_0 = \mathbf{R}^{-1}\mathbf{Q}^T\vec{b} \tag{5}$$

For error estimation one can use:

$$\epsilon = \| \mathbf{A}\vec{x}_0 - \vec{b} \| \tag{6}$$

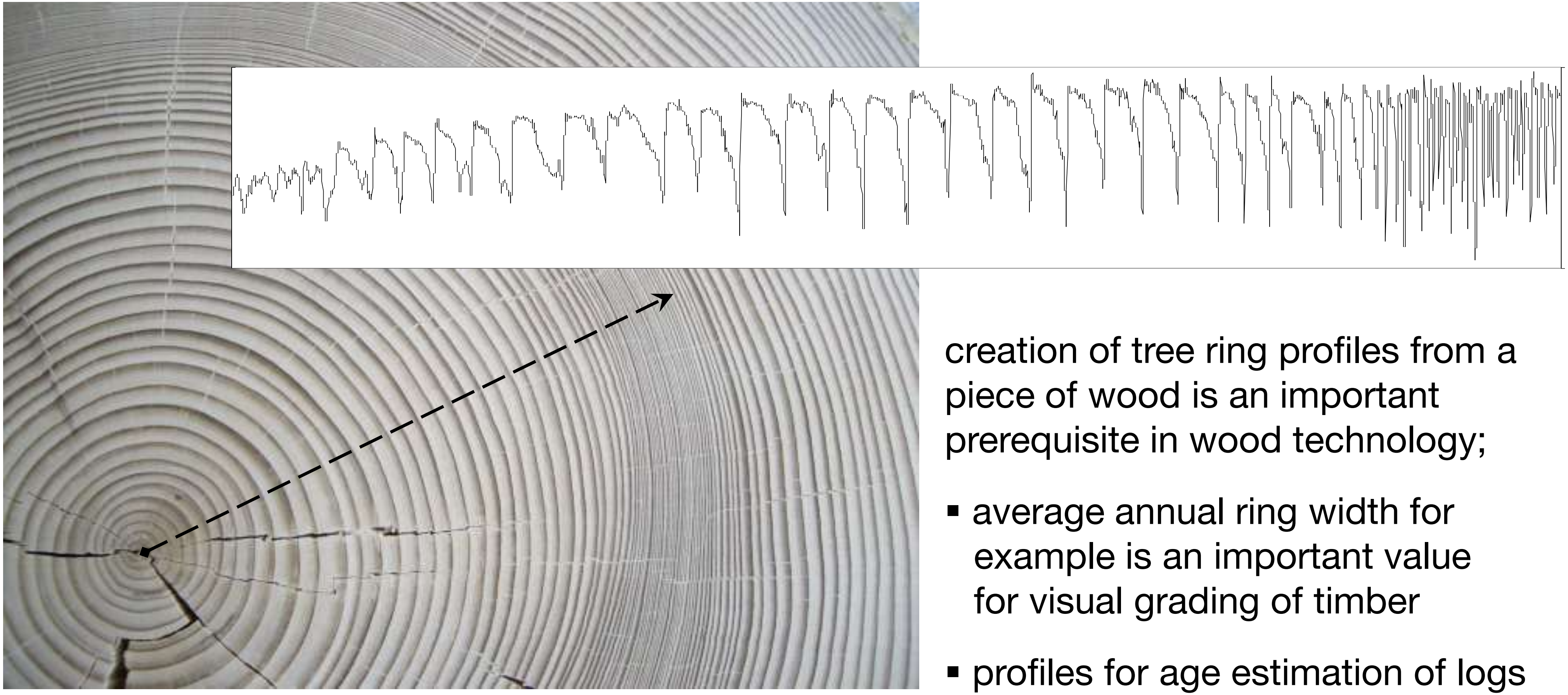
In order to apply this technique, we need to determine pixels situated on circular arcs (i.e. tree rings) which is done in two modes.

- Ring Tracing
- Sets with equal Gradients

Annual Ring Analysis

- General Informations
- Image & Signal Processing in Wood Technology – Selected Examples
- Some Basics in Wood Anatomy
- Pith Detection Techniques
- **Annual Ring Analysis**
- Kristin‘s Thesis
  - Overview
  - Solutions
- Questions for the Discussion

Why Tree Ring Profiles



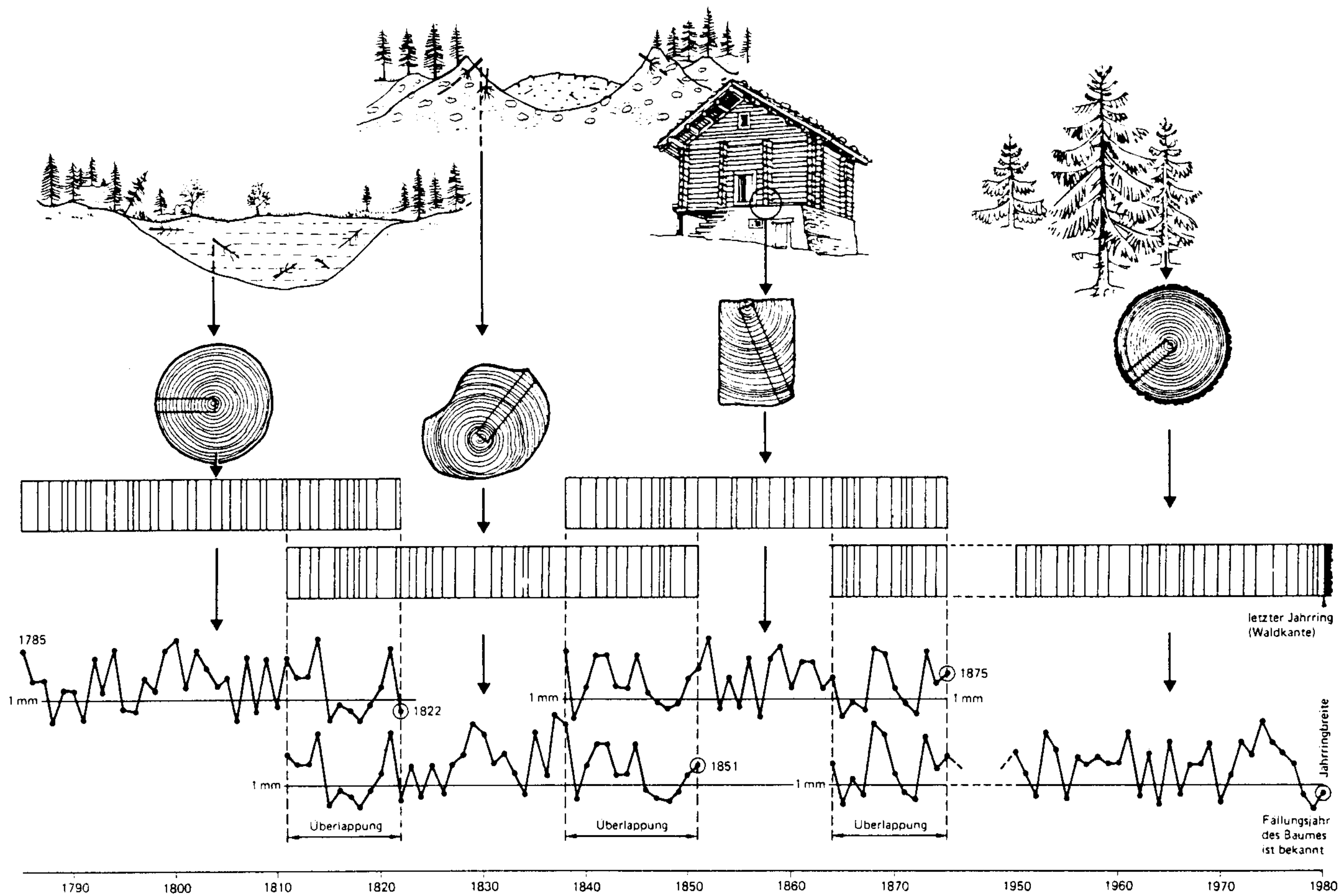
creation of tree ring profiles from a piece of wood is an important prerequisite in wood technology;

- average annual ring width for example is an important value for visual grading of timber
- profiles for age estimation of logs
- Tree ring profiles are used in the scientific field of dendrochronology

Dendrochronology

Leonardo da Vinci (1452 - 1519): annual rings can give prediction about rainfall.

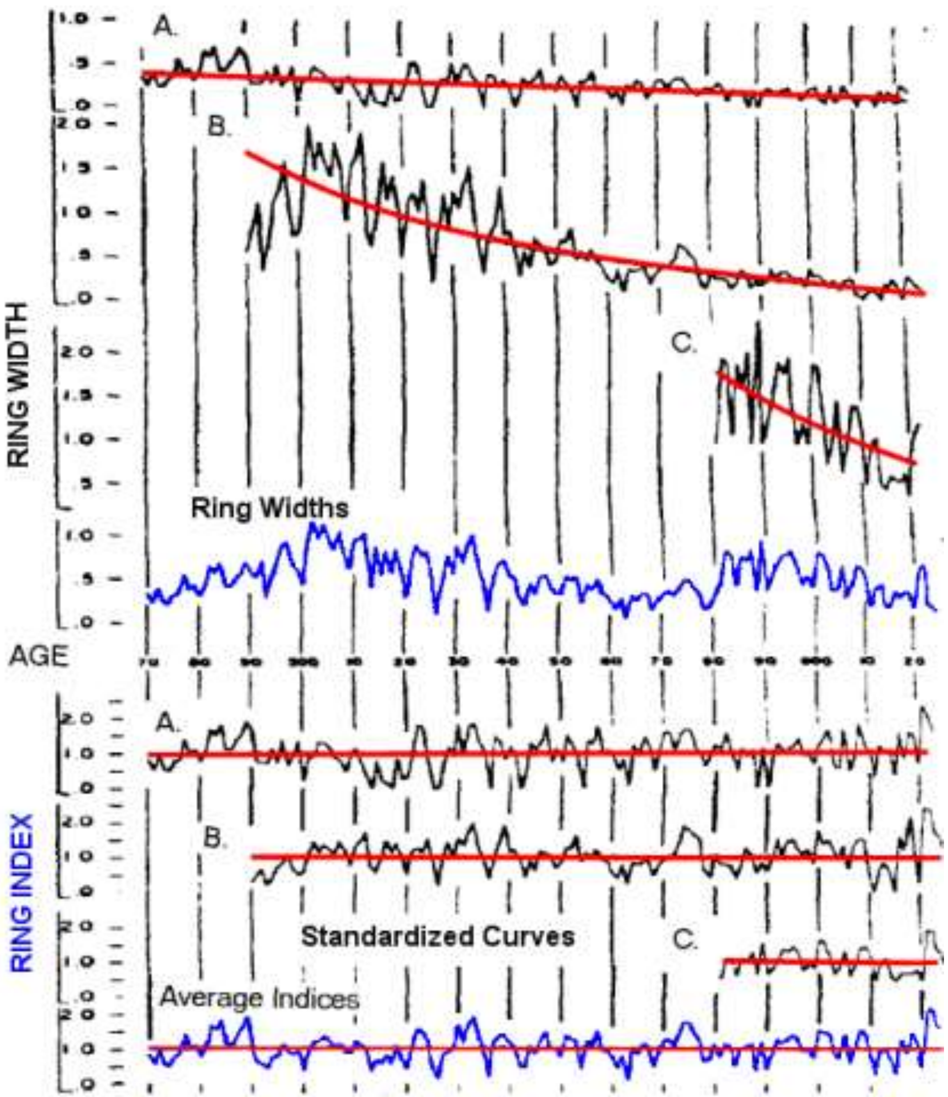
Eliott Douglass (1867 - 1962) searched for dependencies between sun activities and climate (1929), therefore he measured the distances of annual rings of an old pine and wrote them into a table. He also measured the rings of other pines of the same region and drew them all, with an overlap, on a timescale → Crossdating technique (he could cover a timespan of 585 years of annual growth) [4]



Profile Generation

Living Trees

Dendrochronology



Different Ways for
Profile Generation and Standardization

Each ring's width is divided by the series' standard deviation

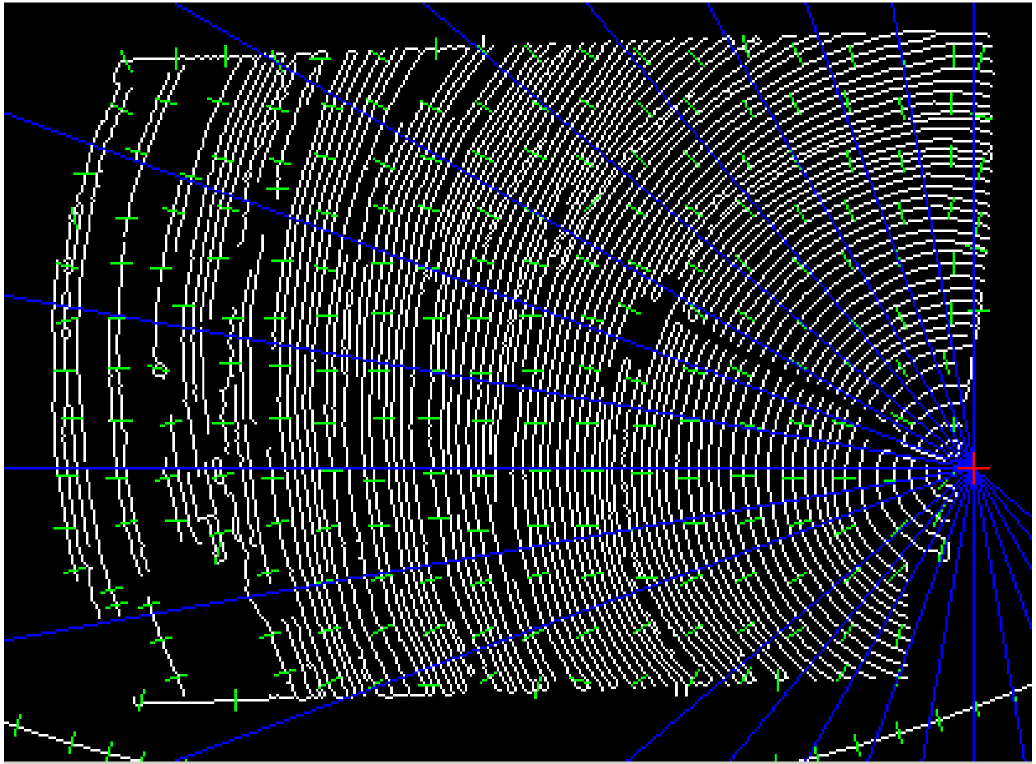
Each tree has its own Biological Growth Curve which is subtracted;

Combined record shows influence of individual trees

The individual growth curves are subtracted by subtracting a curve fit to the series.

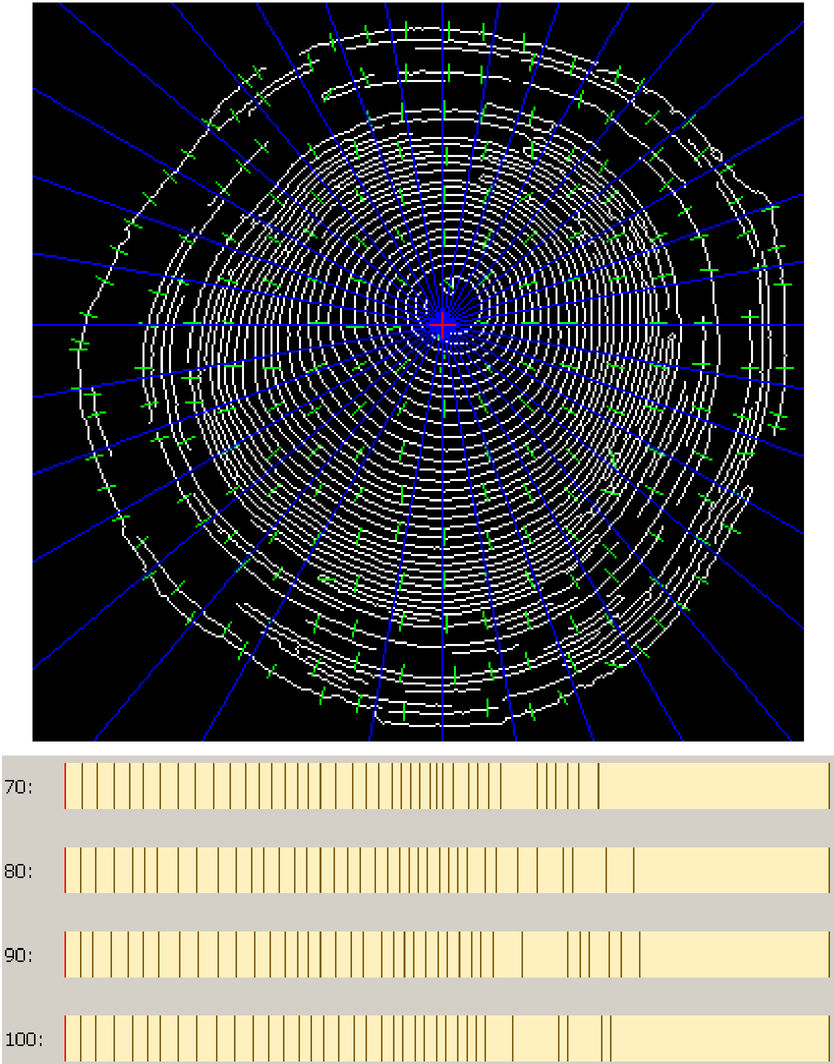
The combined series does not show the influence of individual trees' growth patterns

Profile Generation

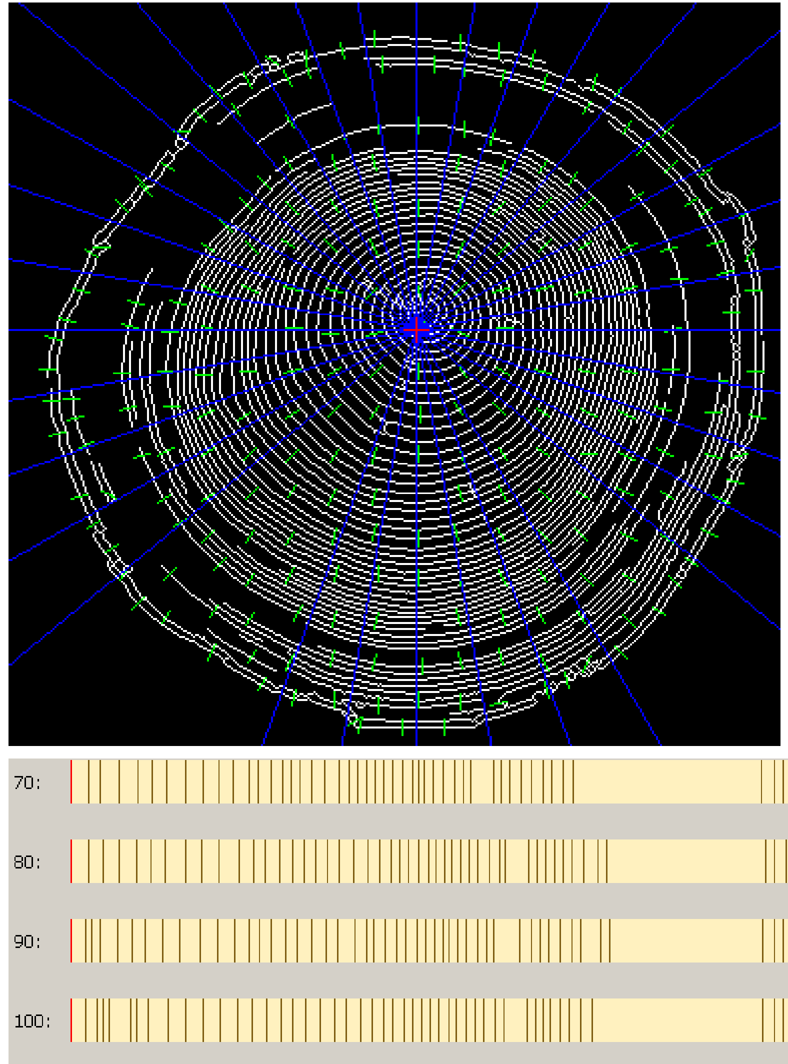


- Preprocessing
- End face is scanned from the outside to the inside
- Strictly along a straight line
- Generating multiple profiles by going counter clockwise around the trunk
- Scanning year rings along a straight line using the Bresenham algorithm
- Scan window must be 2x1, otherwise a year ring might be missed
- Profile records the distance between year rings
- Profile data is normalized in the end

Application Examples

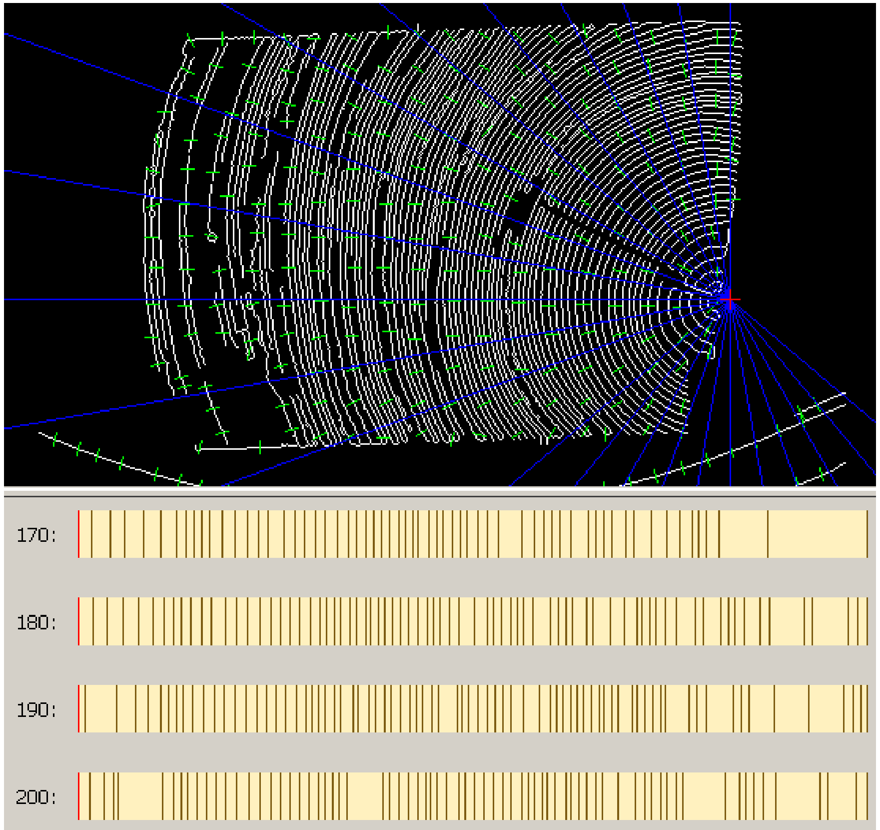


Standard Preprocessing

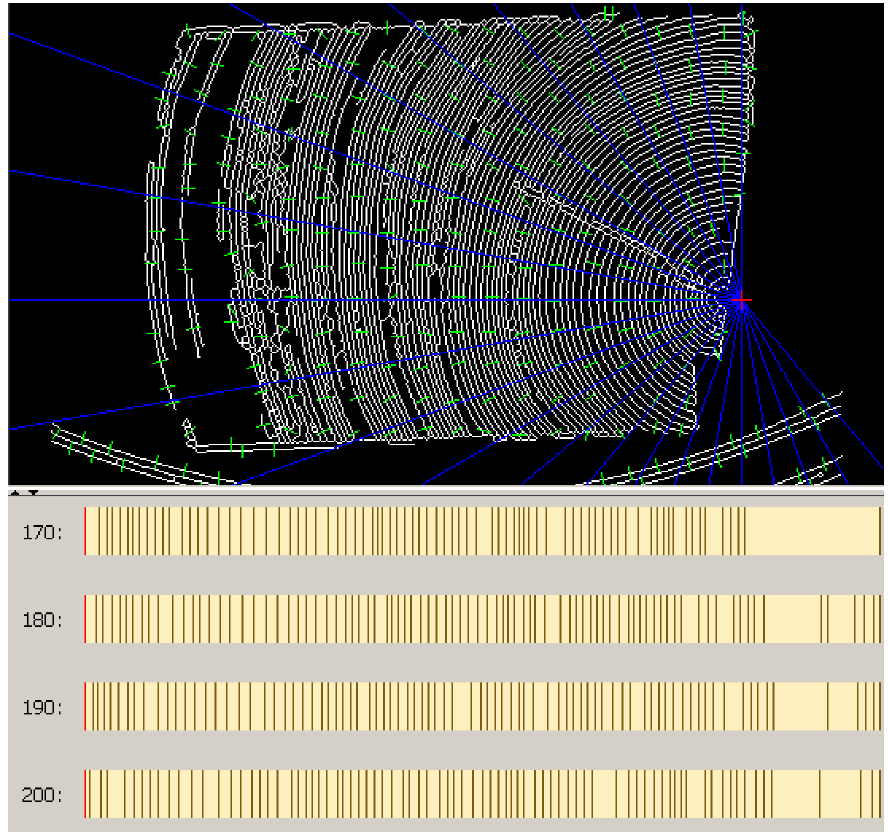


Variant: Gabor Preprocessing

Application Examples



Standard Preprocessing



Variant: Gabor Preprocessing

Kristin‘s Thesis

- General Informations
- Image & Signal Processing in Wood Technology – Selected Examples
- Some Basics in Wood Anatomy
- Pith Detection Techniques
- Annual Ring Analysis
- Kristin‘s Thesis
  - Overview
  - Solutions
- Questions for the Discussion

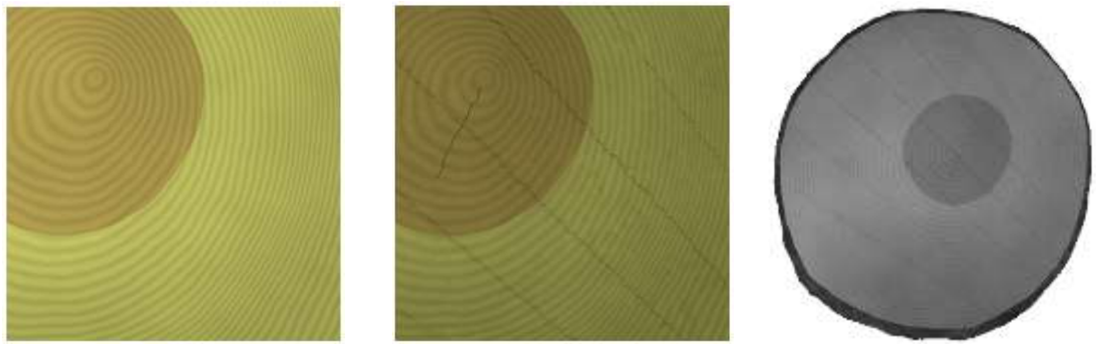
Kristin's Thesis

What makes the Thesis of Kristin unique?

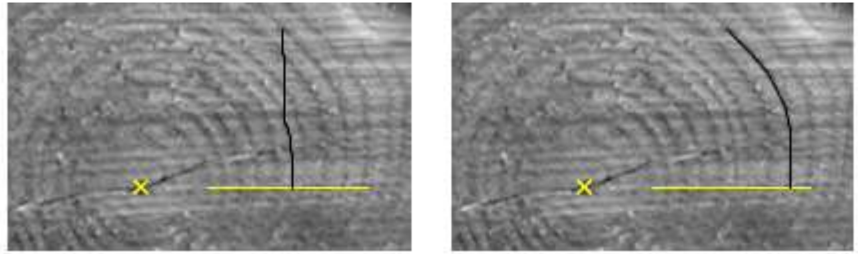
1. The introduction and application of polar gray weigthed distance transforms

2. Analysis of untreated, rough end faces

3. Creation of synthetic end face images



4. Large Data Set of Images (Industry)



Kristin's Thesis - Overview

II K. Norell, J. Lindblad, and S. Svensson, *Grey weighted polar distance transform for outlining circular and approximately circular objects*, In Proceedings of the 14th Internat. Conference on Image Analysis and Processing, Modena, Italy, pp. 647-652, 2007, IEEE.

III R. Strand and K. Norell, *The polar distance transform by fast-marching.*

IV K. Norell and J. Lindblad, *Spatially-variant morphological operations on binary images based on the polar distance transform.*

Proceedings of the 19th Int. Conference on Pattern Recognition, Tampa, FL, 2008, IEEE.

V K. Norell and G. Borgefors, Estimation of pith position in untreated log ends in sawmill environments, ***Computers and Electronics in Agriculture***, 63 (2):155–167, 2008.

VI K. Norell, *An automatic method for counting annual rings in noisy sawmill images*, In Proceedings of the 15th Int. Conference on Image Analysis and Processing, Salerno, Italy, pp. 307-316, Lecture Notes in Computer Science 5716, Springer Verlag, 2009.

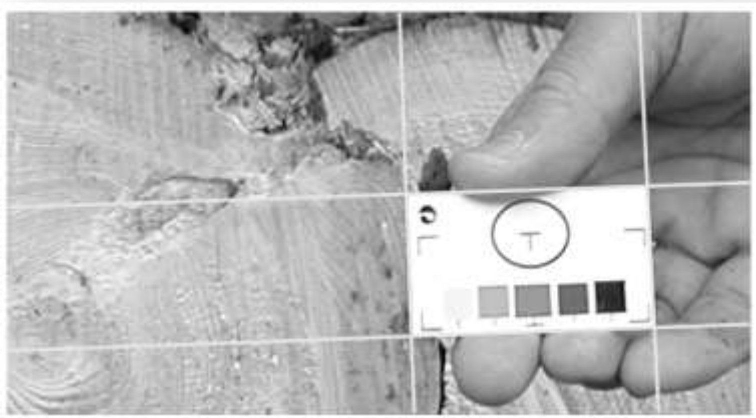
VII K. Norell, Counting annual rings on Pinus sylvestris end faces in sawmill industry. Subm.

I K. Norell, *Creating synthetic log end face images*, In Proceedings of the 6th Int. Symp. on Image and Signal Processing and Analysis, Salzburg, Austria, pp. 353 - 358, 2009, IEEE.

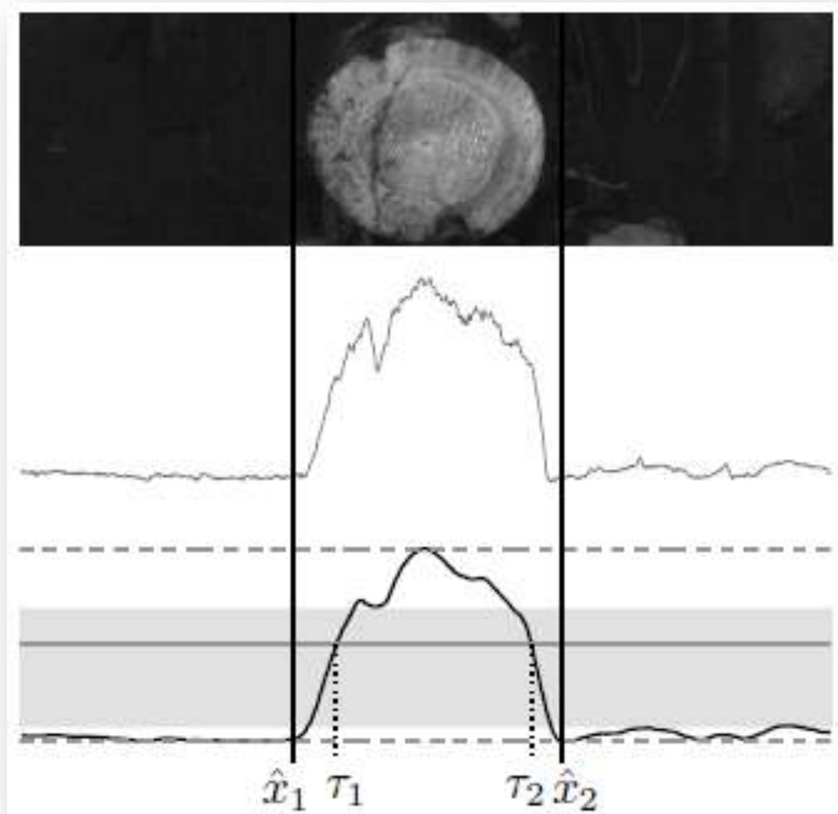
Kristin's Thesis - Solutions

Preprocessing Procedures

- Determination of pixel size and calibration using reference objects



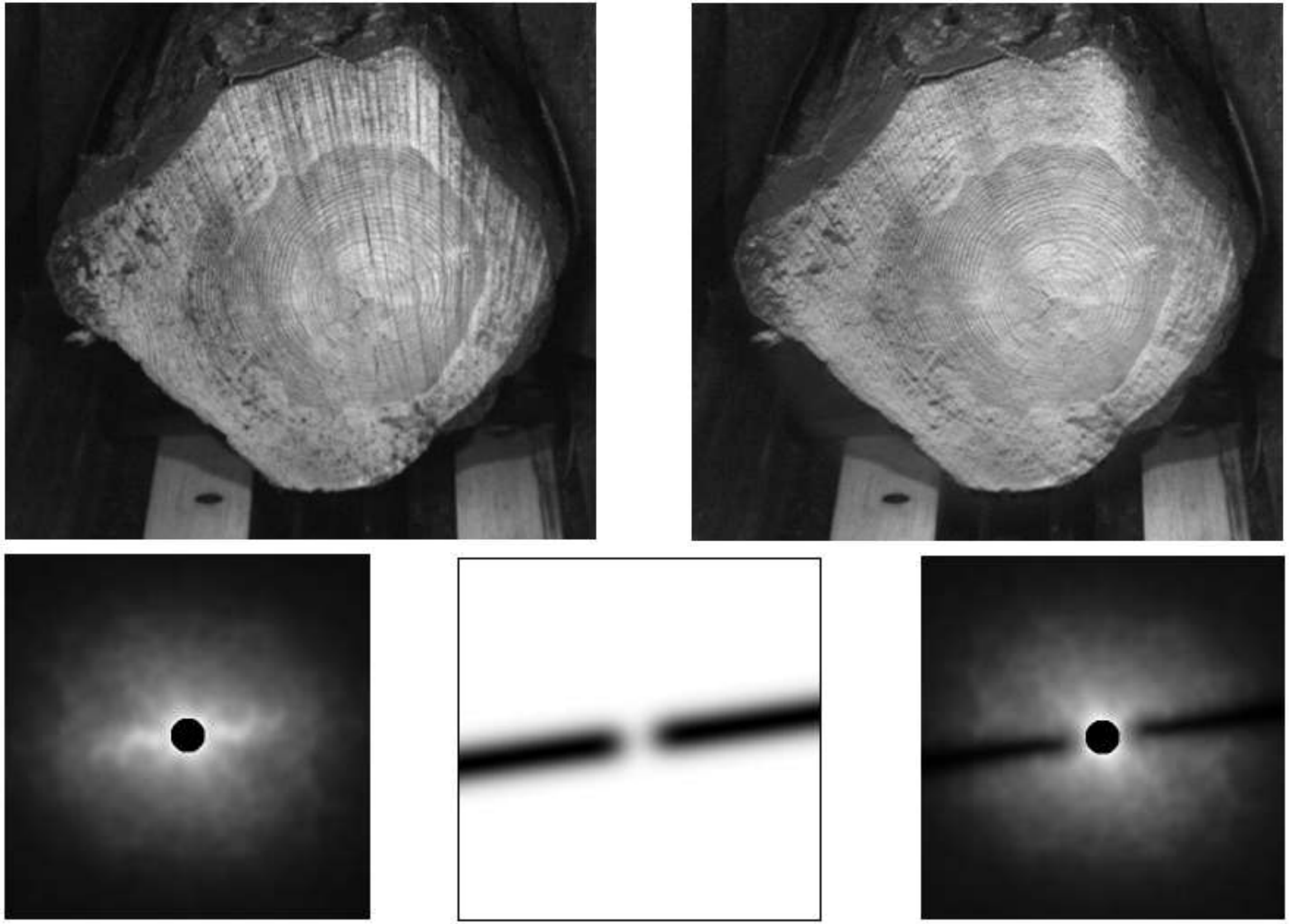
- Automatic vertical and horizontal cropping



Kristin's Thesis - Solutions

Preprocessing Procedures

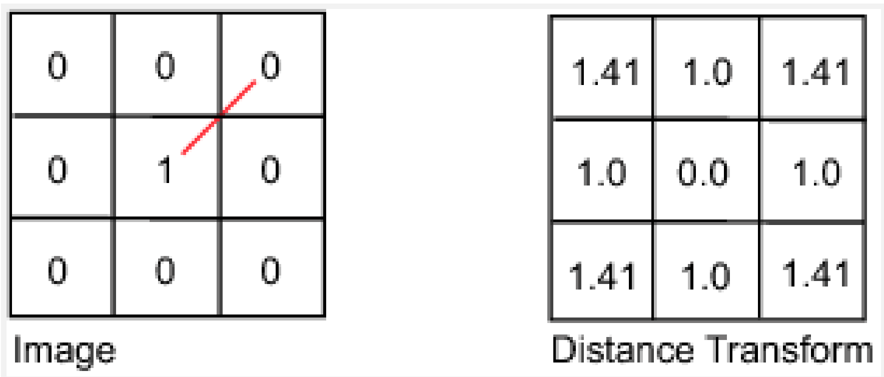
- Automatic removal of marks from uneven sawing



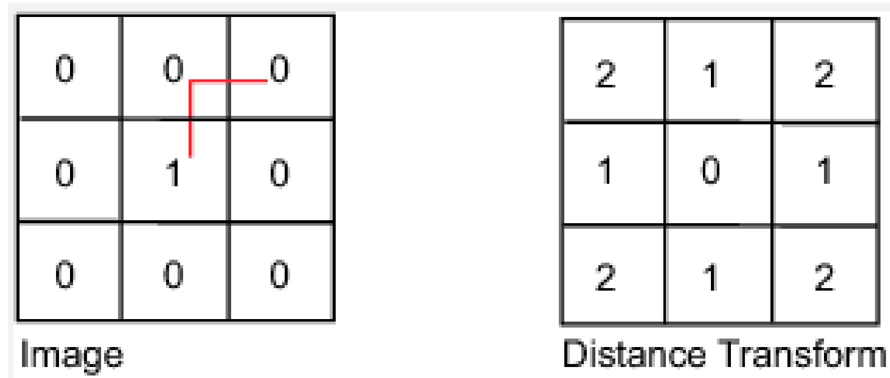
Kristin's Thesis - Solutions

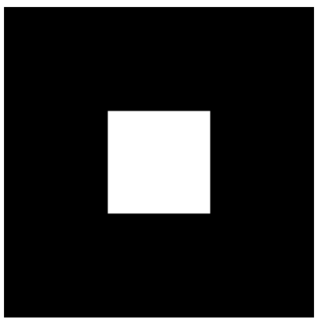
Polar, Grey Weighted Distance Transform (II, III, IV)

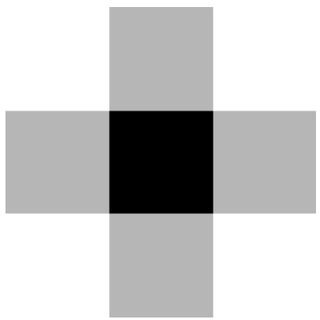
Euclidean



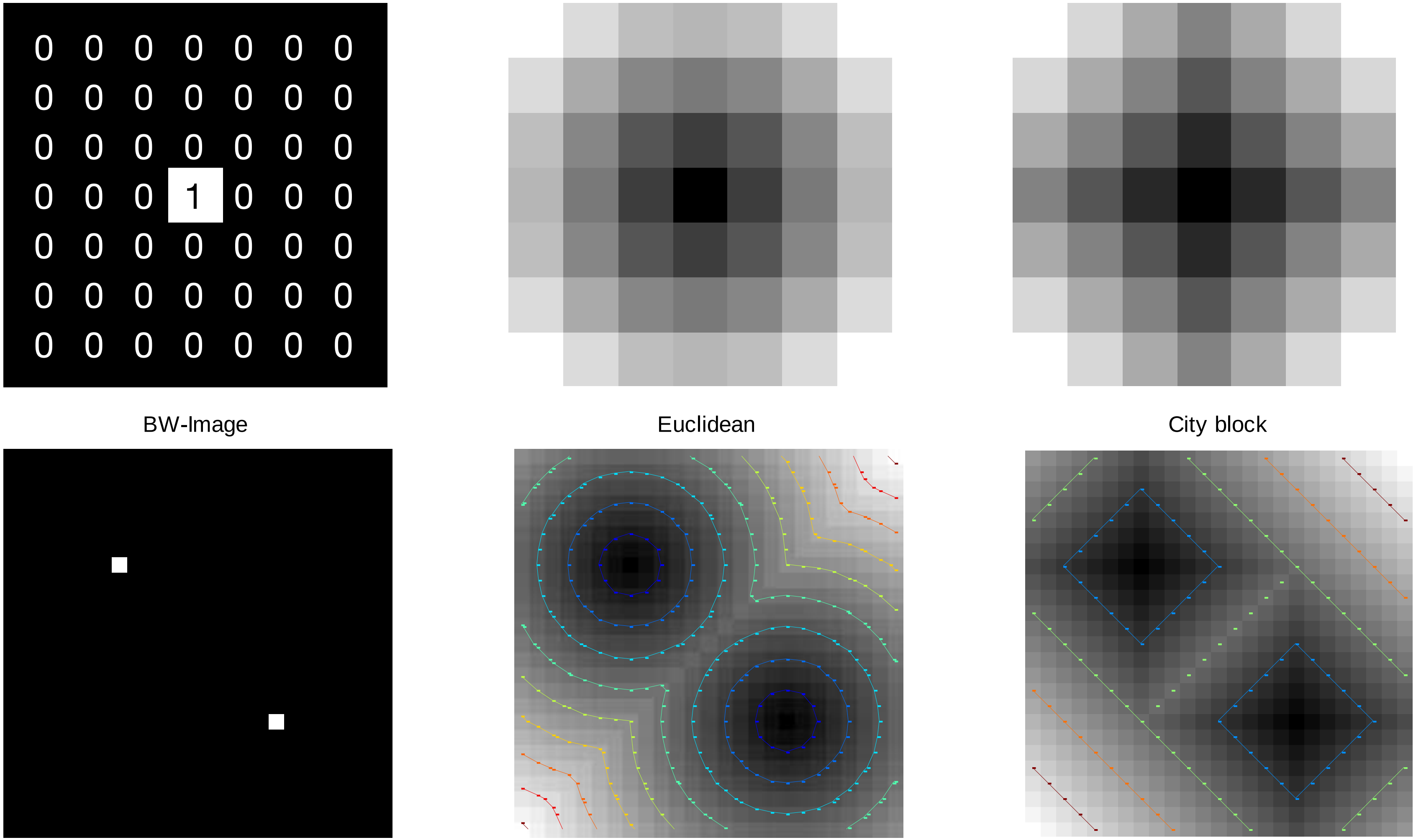
City Block





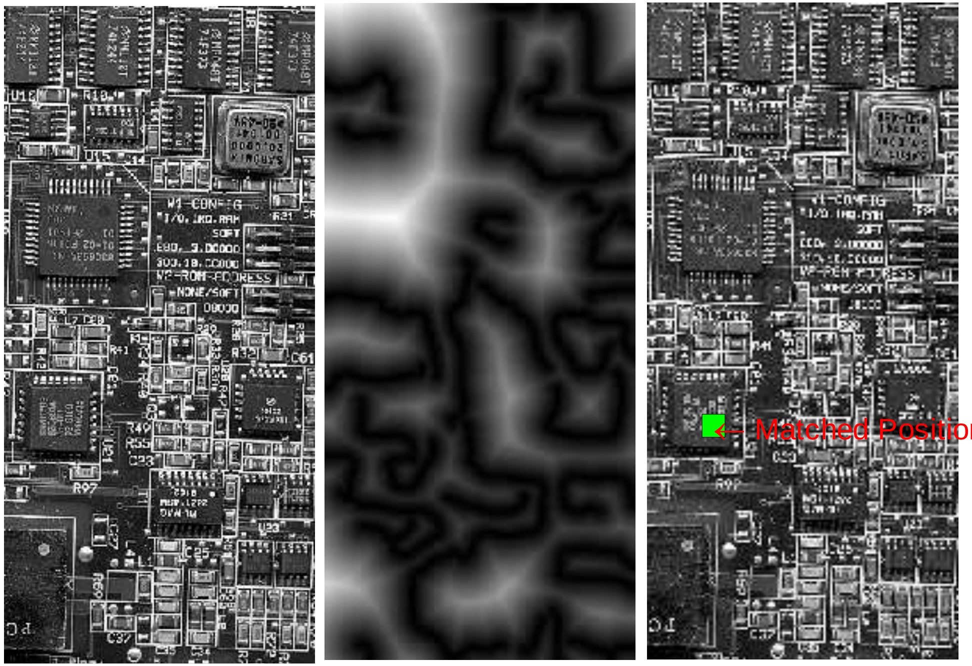


Kristin's Thesis - Distance Transforms

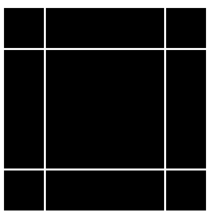


Distance Transforms

Distance Transform matching results



template



Grey weighted Distance Transform Example

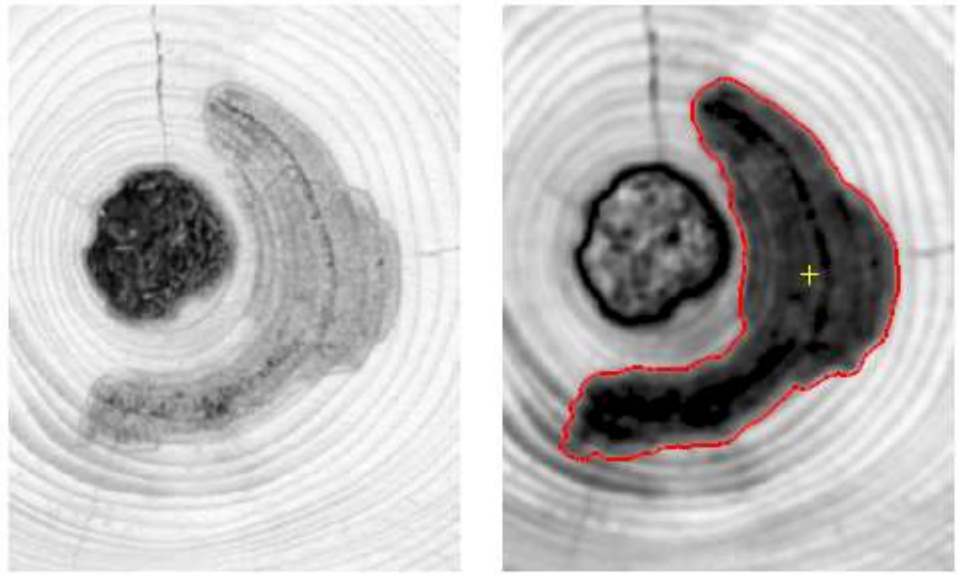


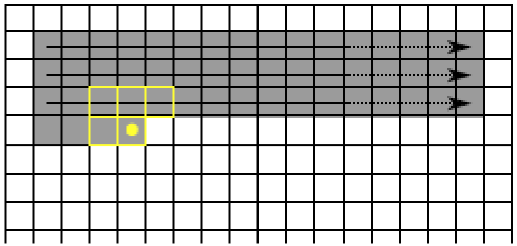
Figure 37: Original image (left) and the cost image with segmented rot area outlined in red (right). The pixel from which the distance was computed is marked with +.

Kristin's Thesis - Solutions

Polar, Grey Weighted Distance Transform (II, III, IV)

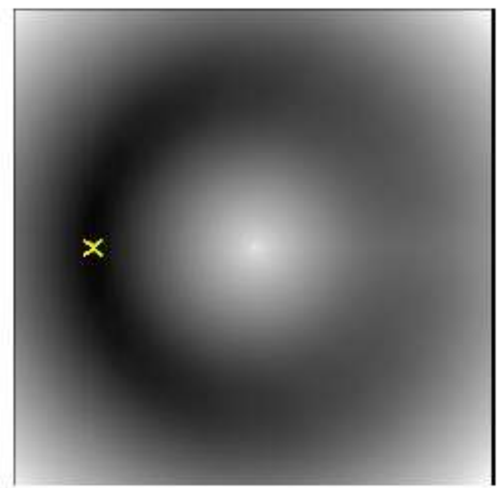
Distance Transforms may be calculated with different approaches

- Chamfering



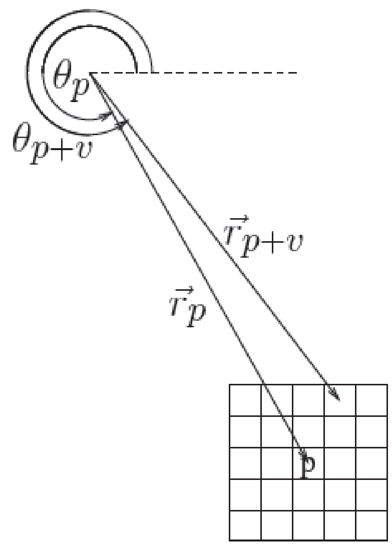
$$D(p) = \min_{v \in \text{upper}} \left(D(p+v) + w(v) \right)$$

- Fast Marching



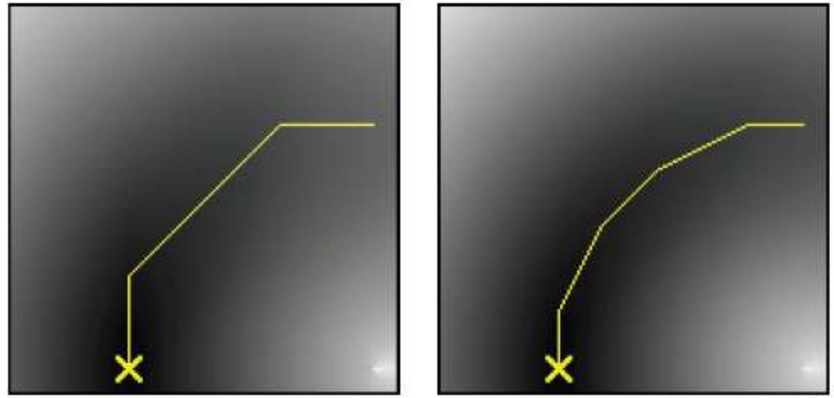
(b) $\gamma = 0.10$

Polar (grey weighted) Distance Transform



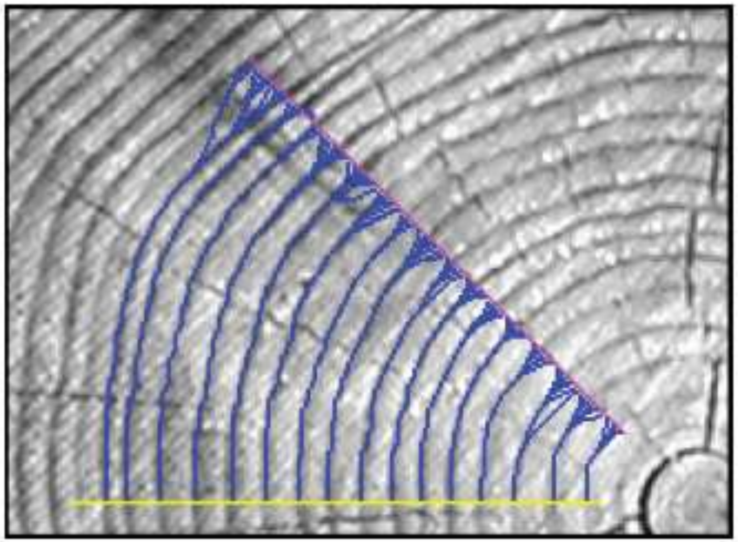
Kristin‘s Thesis - Solutions

Polar, Grey Weighted Distance Transform (II, III, IV)

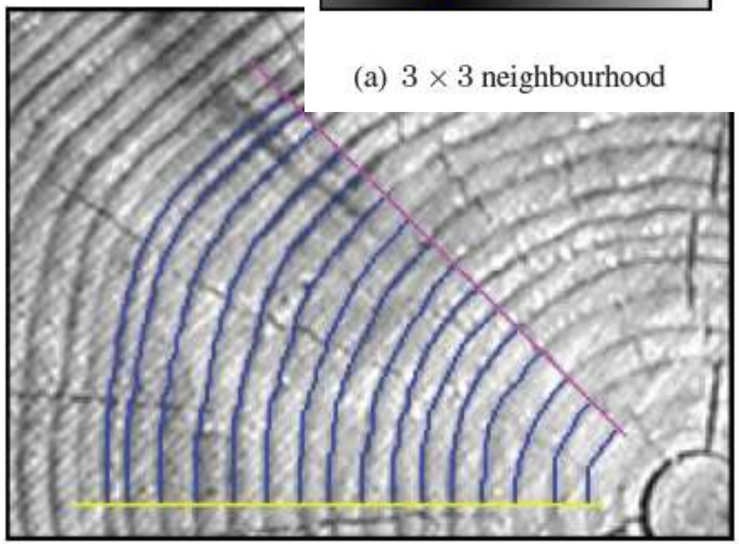


(a) 3×3 neighbourhood

(b) 5×5 neighbourhood



(b) Shortest paths to the object from pixels marked out on the diagonal line from the origin to the upper left of the image.



(c) The shortest path to each of the 16 end pixels in the object.

Kristin‘s Thesis - Solutions

Counting Annual Rings in Noisy Images

- The circular shape of polar distance transforms was combined with the intenisity of annual ring patterns
- Completely automatic method including cropping, filtering, removement of marks and pith position estimation.
- Evaluation on a pine image data set from sawmill production.
- Performance as well as manual grading
- Exact estimation of the ring number often not possible (resolution) but grading was successfull

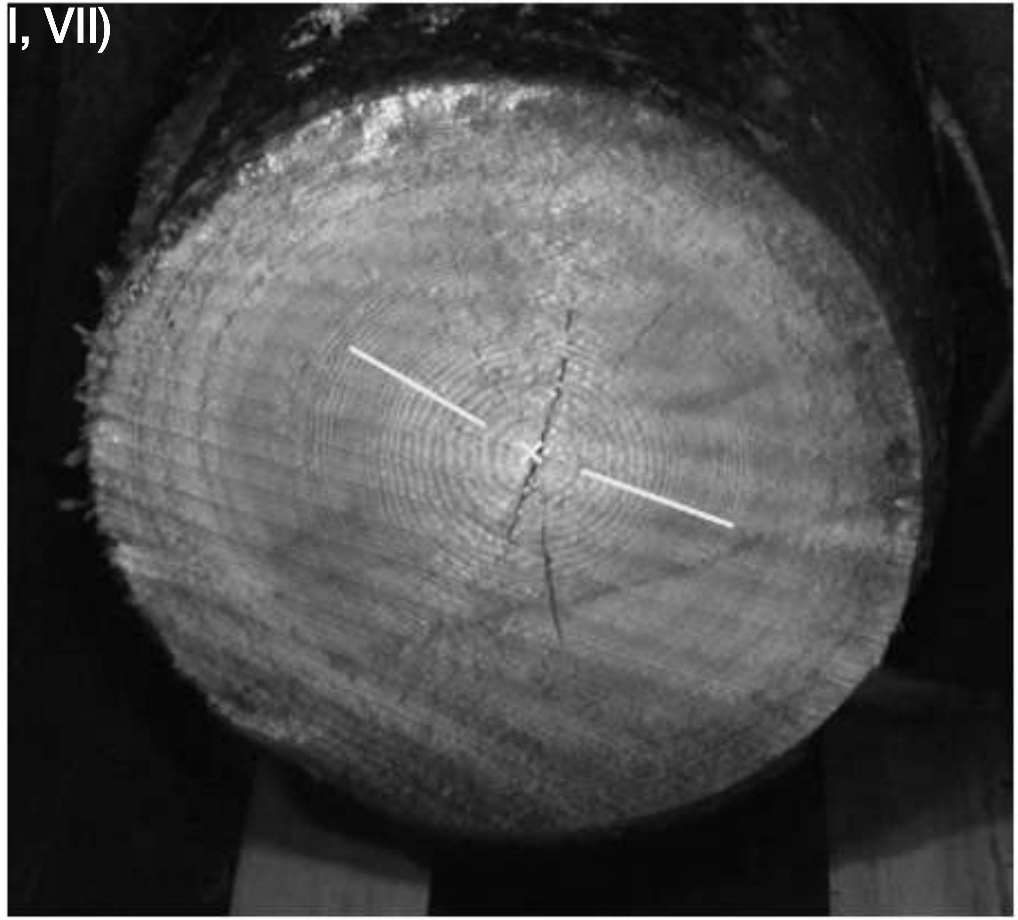


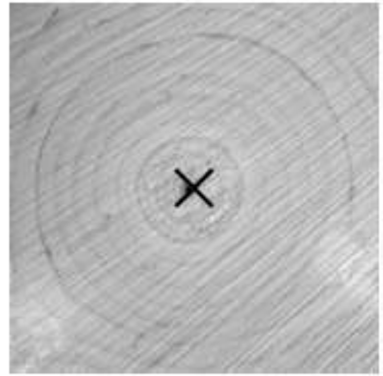
Figure 68: Automatically detected orientations for measuring the number of annual rings along two rays from 20 to 80 mm from the automatically detected pith (×).

Kristin's Thesis - Solutions

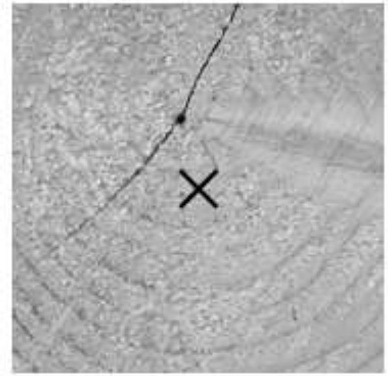
Estimation of pith position in untreated end faces (V)

- Two different methods applied (V)
- Mainly differing in the method of local orientation estimation:
  - Quadrature Filtering
  - Laplacian Pyramid (main method - faster)
- Robust for rough surfaces, but obviously cases occur when the method performs bad!
- Robust to knots, cracks, dirt, snow, …

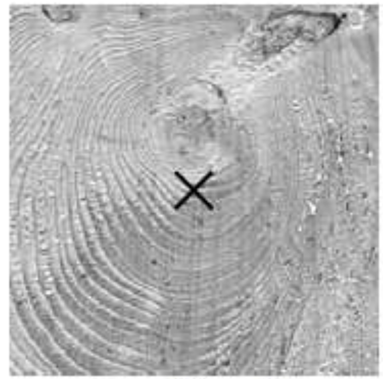
- Ground truth by choosing one pixel in the image manually.
- Evaluated on over 500 images of spruce and pine



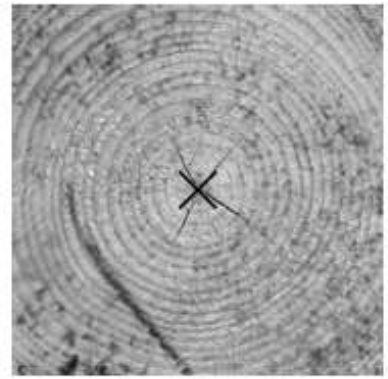
(a) $e = 1.6, v = 2.2$



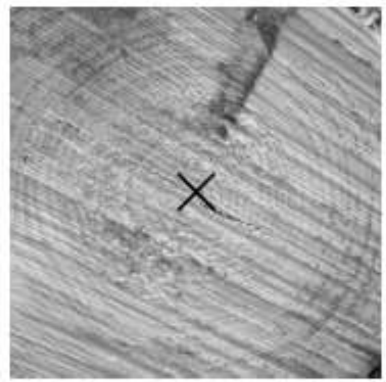
(b) $e = 19.5, v = 23.6$



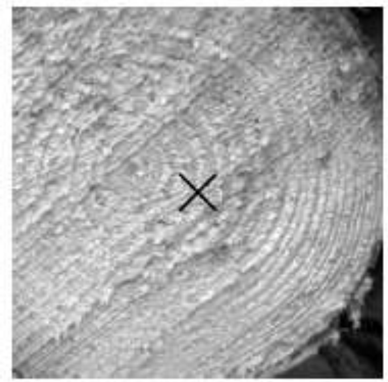
(c) $e = 12.3, v = 51.2$



(d) $e = 0.4, v = 1.4$



(e) $e = 1.4, v = 8.3$

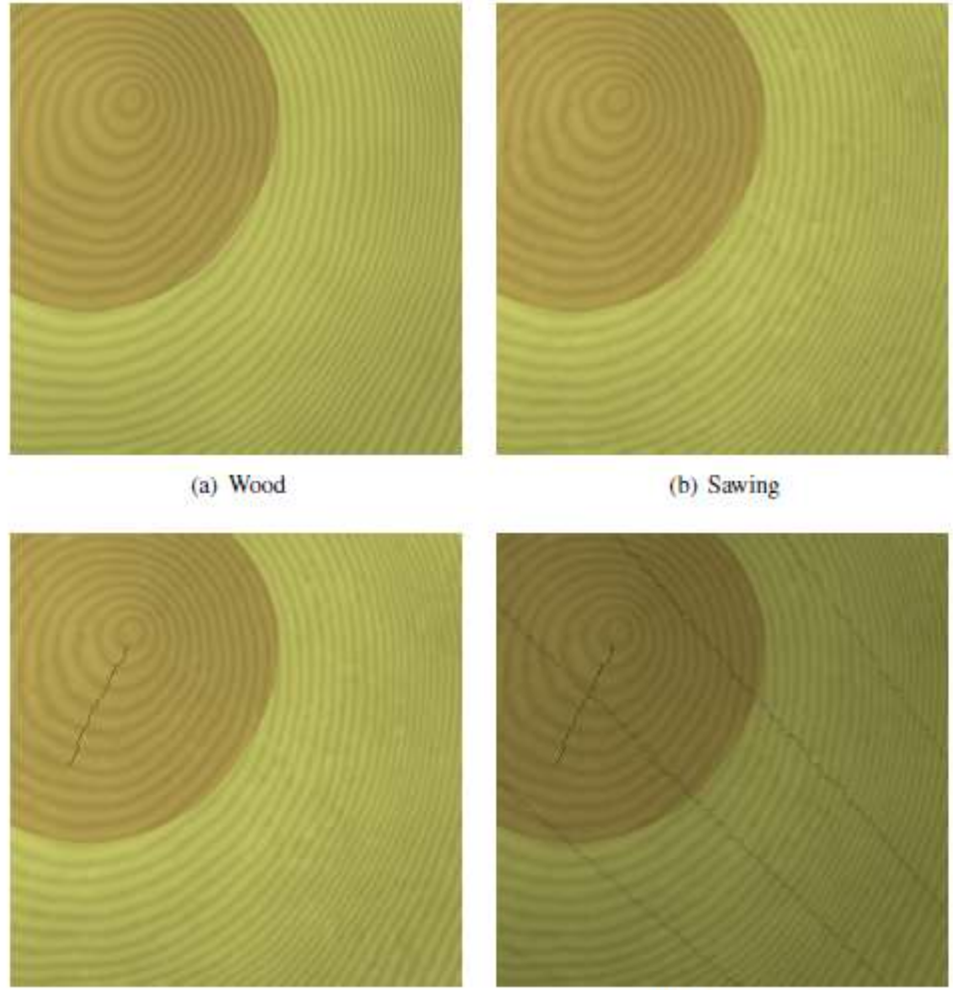


(f) $e = 19.0, v = 35.2$

Kristin's Thesis - Solutions

Generation of Synthetic Images (I)

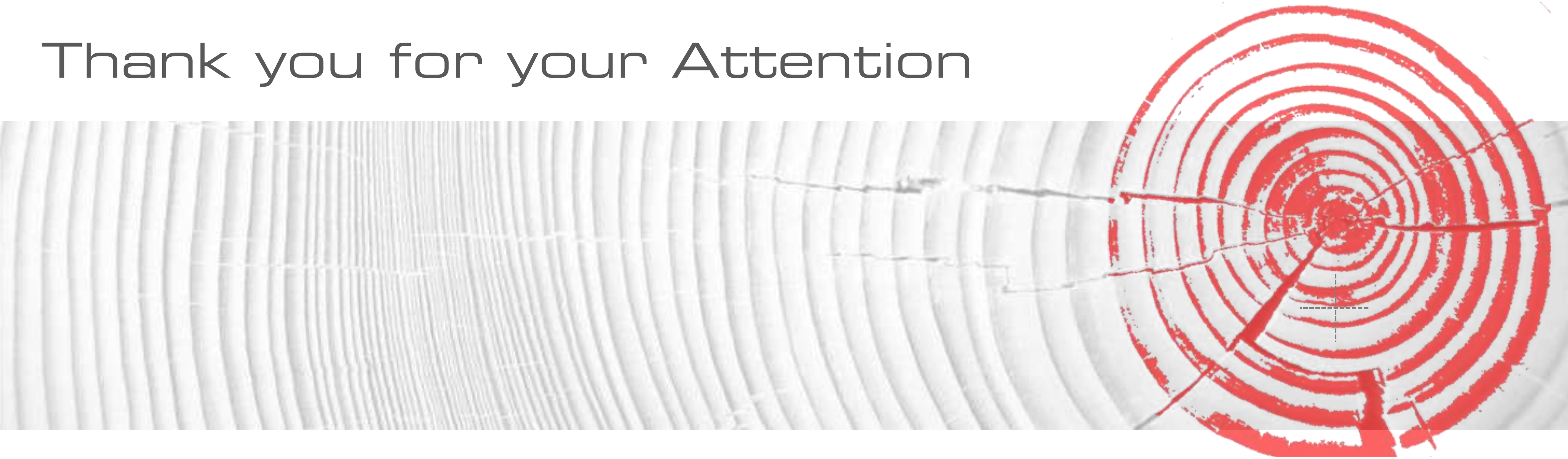
- Wood (Anatomy)
- Sawing Patterns
- Storage (Cracks)
- Camera setup
- Image acquisition



(a) Wood (b) Sawing (c) Storage (d) Camera setup

Figure 17: Result after different steps in the simulation.

Thank you for your Attention



Literature:

(1) Norell, K. *Automatic Analysis of Log End Face Images in the Sawmill Industry*. Doctoral Thesis, Faculty of Forest Sciences, Centre for Image Analysis, Uppsala, Sweden, 2010.

(2) F. Longuetaud, J.-M. Leban, F. Mothe, E. Kerrien, and M.-O. Berger, Automatic detection of pith on ct images of spruce logs. *Comput. Electron. Agric*., 44 (2), pp. 107–119, 2005.

(3) A. Teischinger, Ch. Buksnowitz, and U. Müller. *Wood properties of old growth´spruce and their technological potential*. In S. Kurjatko, J. Kudela, and R. Lagaˇna, editors, Proceedings of the 5th Symposium "Wood Structure and Properties 06", pages 413–416, Arbora Publishers, Zvolen, Slovakia, 2006.

(4) M. A. Stokes and T.L. Smiley. *An introduction to tree-ring dating.* University of Arizona Press, 1996.