Detection of Elevated Regions in Surface Images from Laser Beam Melting Processes

YF005622

Joschka zur Jacobsmühlen, Stefan Kleszczynski, Gerd Witt, Dorit Merhof

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Yokohama
Japan

Institute of Imaging and Computer Vision
RWTH AACHEN UNIVERSITY

What is Laser Beam Melting (LBM)?

“3D printing” with metal powder

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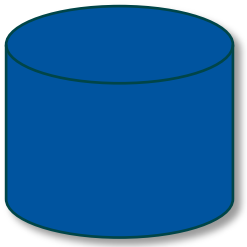
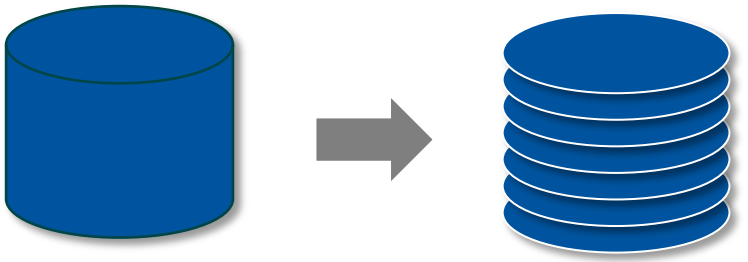


Design (3D)

What is Laser Beam Melting (LBM)?

“3D printing” with metal powder



Design (3D) Slices (2D)

- Layer-based, iterative

What is Laser Beam Melting (LBM)?

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Design (3D) Slices (2D) Build Layers

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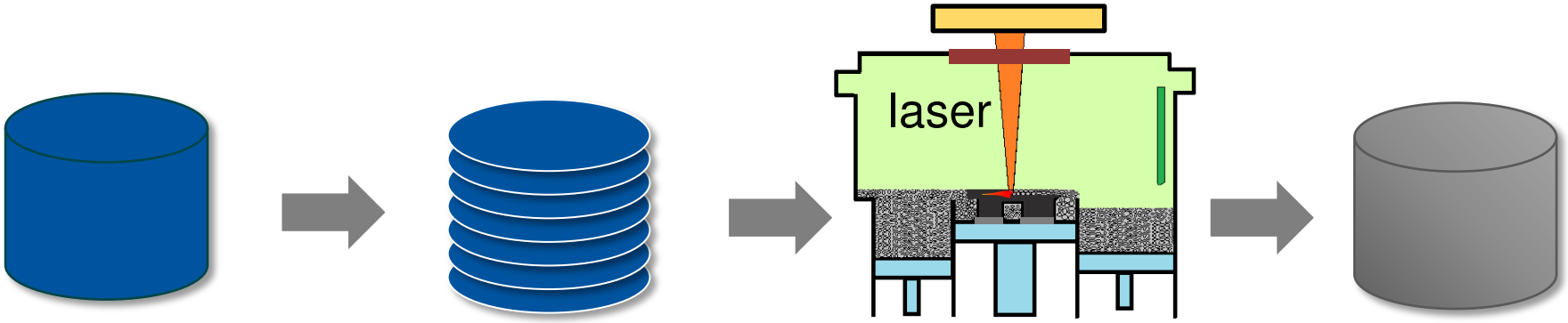
What is Laser Beam Melting (LBM)?

“3D printing” with metal powder



- Layer-based, iterative
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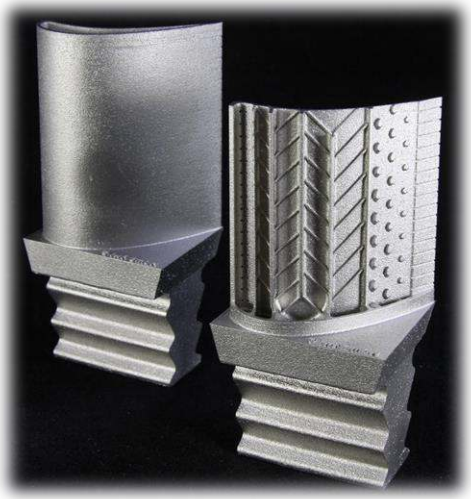
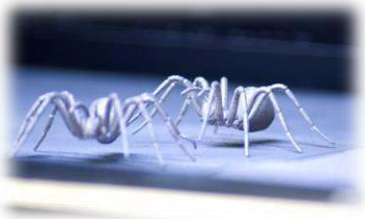
Laser Beam Melting – „3D Printing with Metal“

hip implant
[www.slm-solutions.com]

injection nozzle
[www.eos.info]



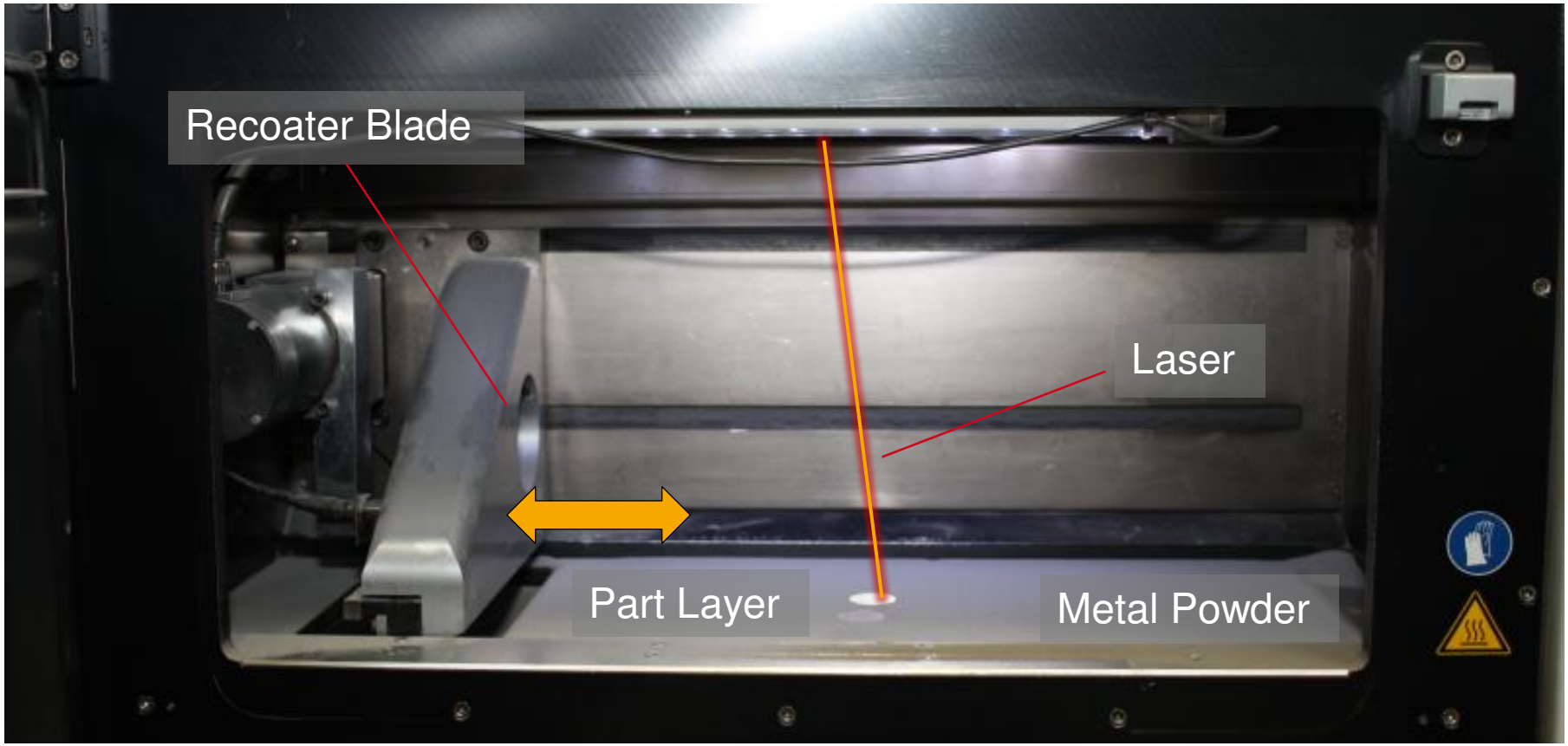
turbine blade (demo)
[RTC Duisburg]



spiders
[RTC Duisburg]

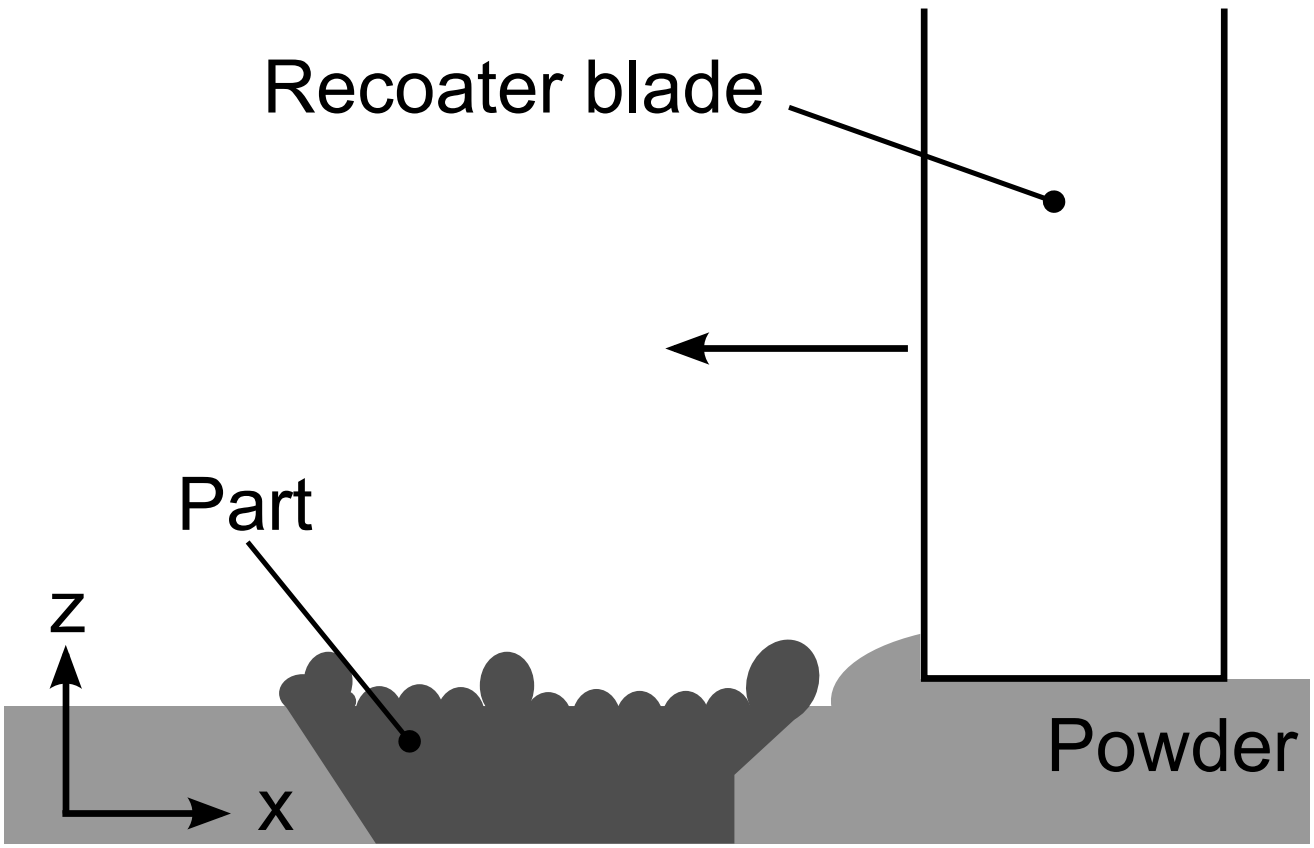
impeller
[RTC Duisburg]

Laser Beam Melting System – EOSINT M 270 (EOS GmbH, Germany)

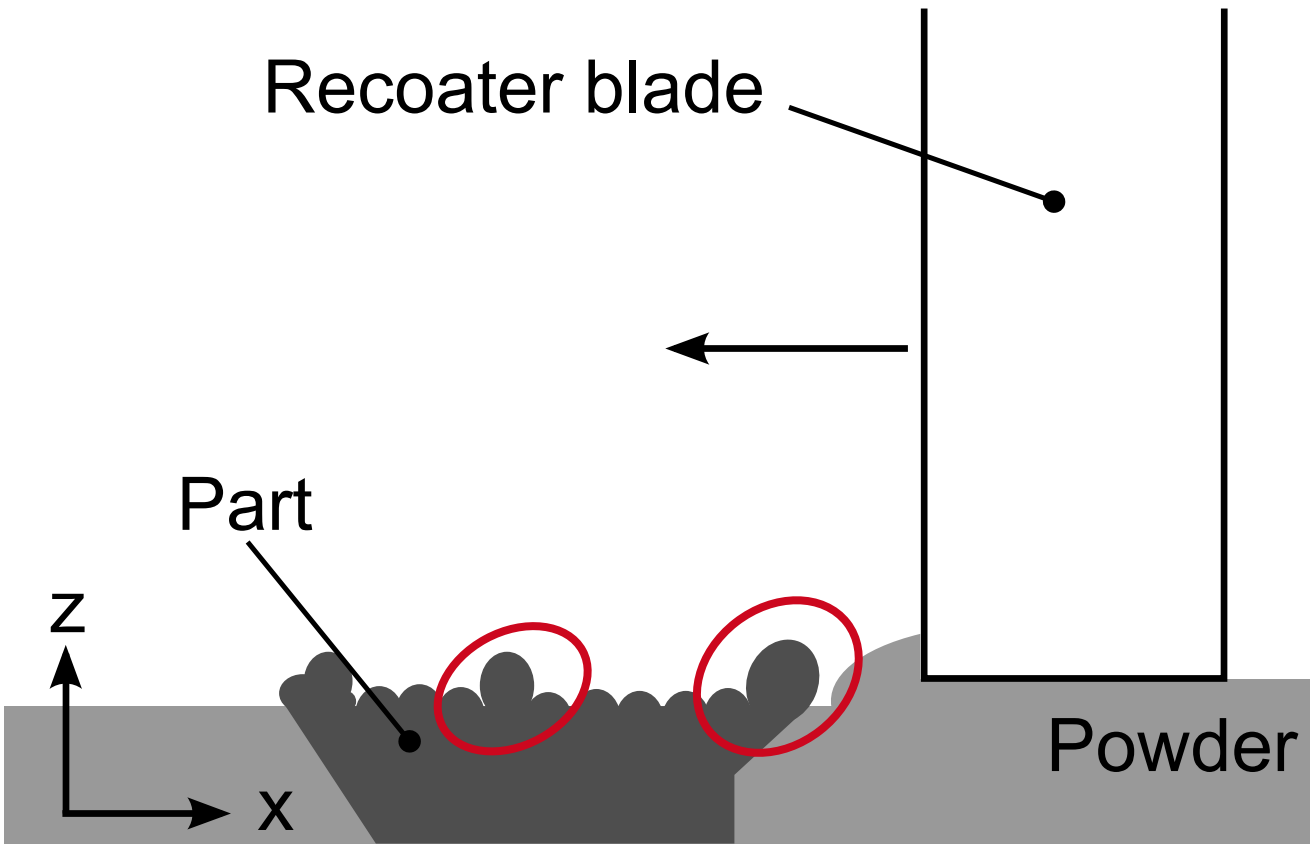


Process Chamber

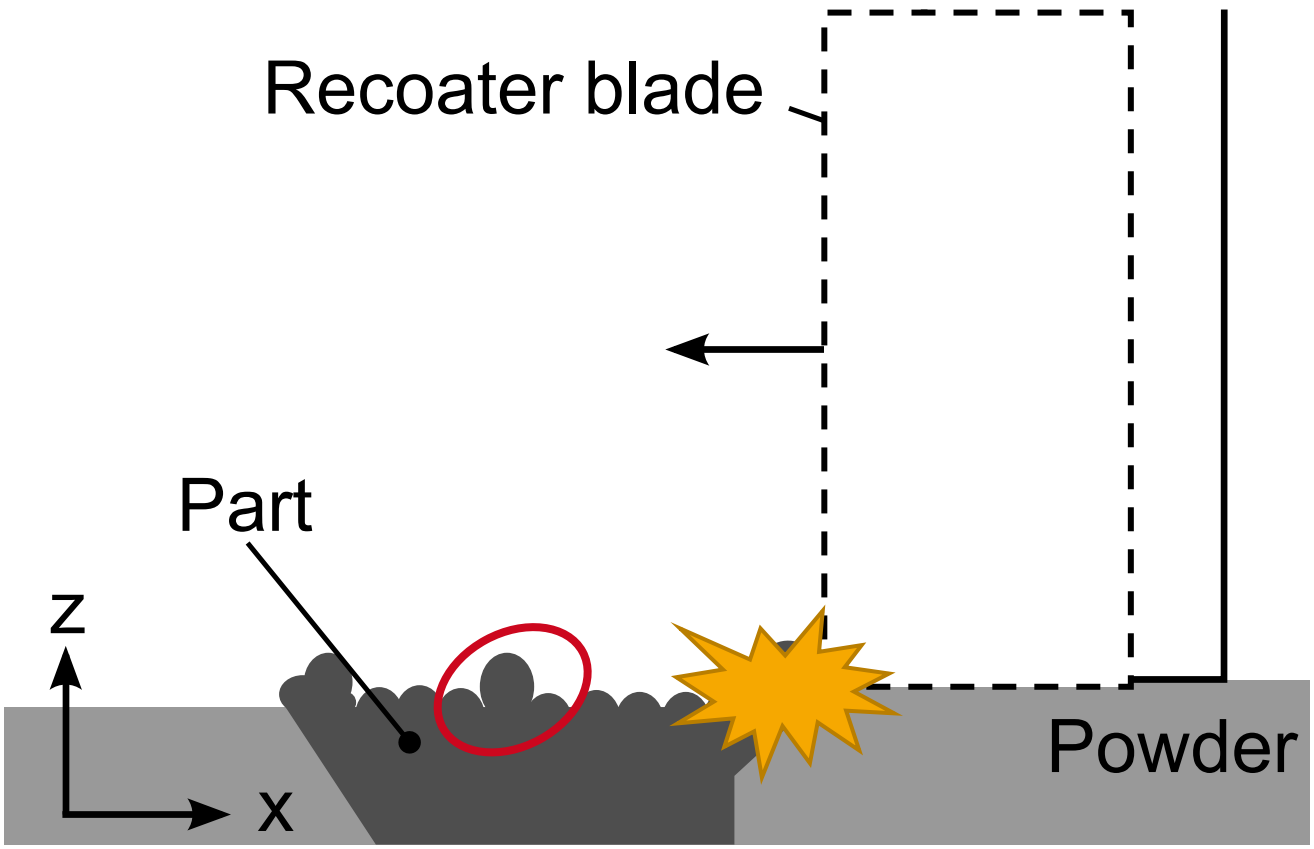
Elevated Part Regions



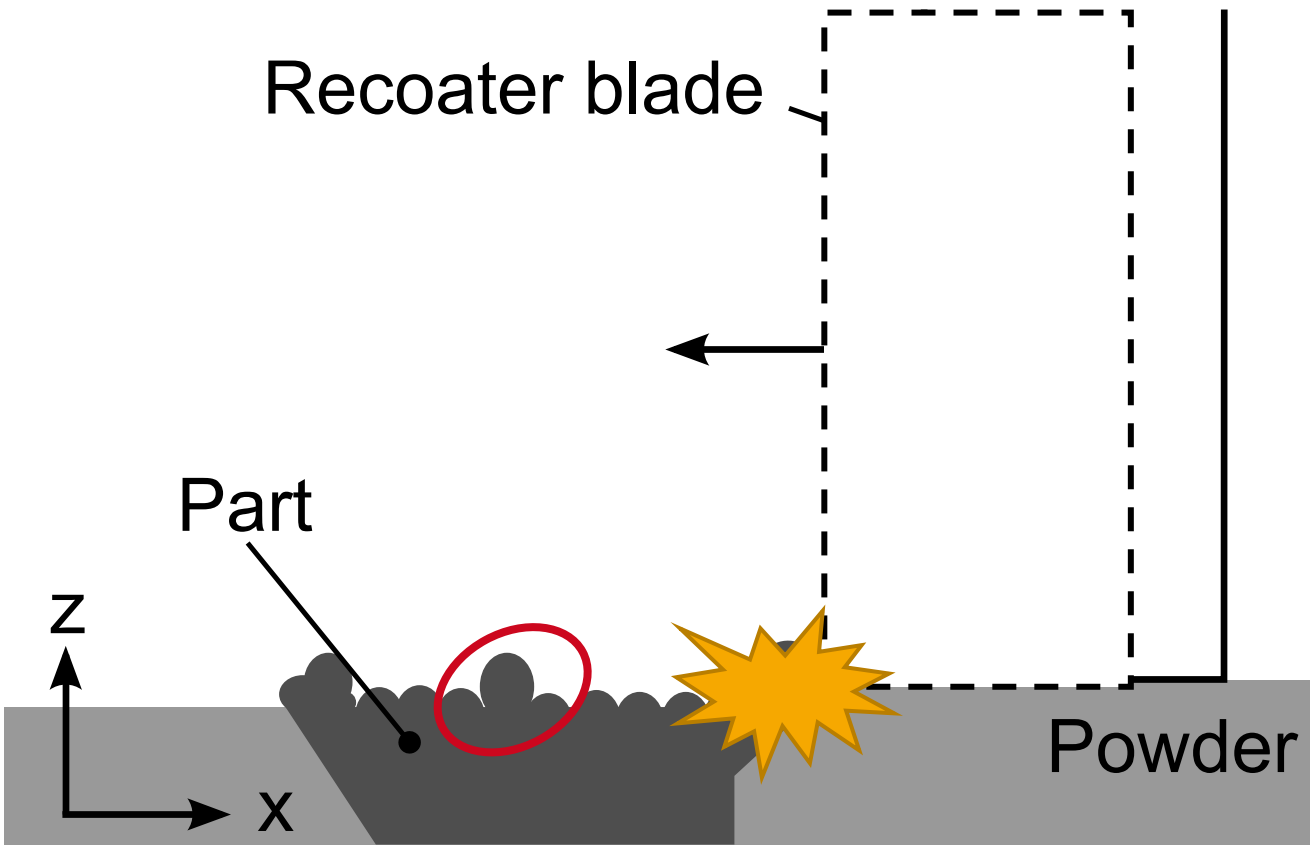
Elevated Part Regions



Elevated Part Regions

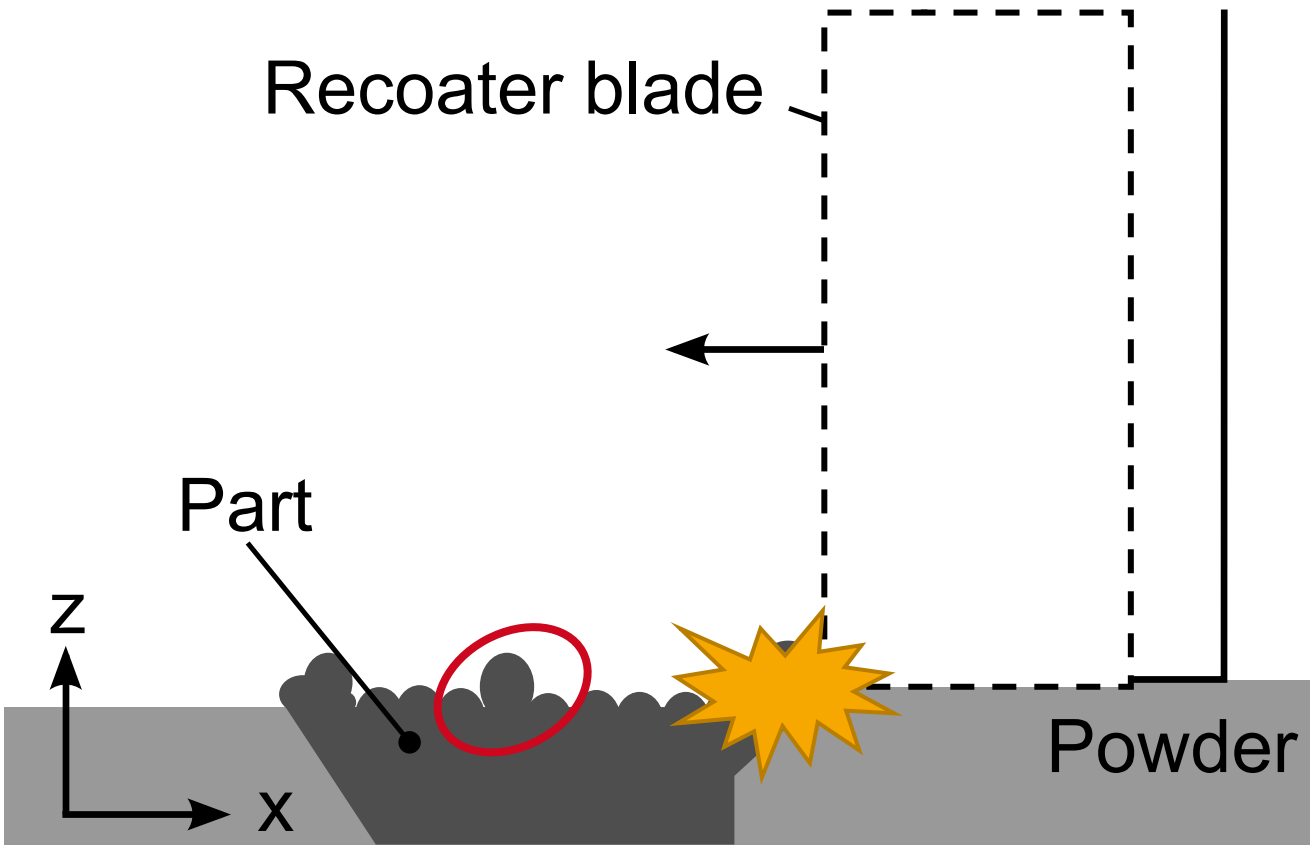


Elevated Part Regions



may damage part/recoater blade and cause jammings

Elevated Part Regions



may damage part/recoater blade and cause jammings

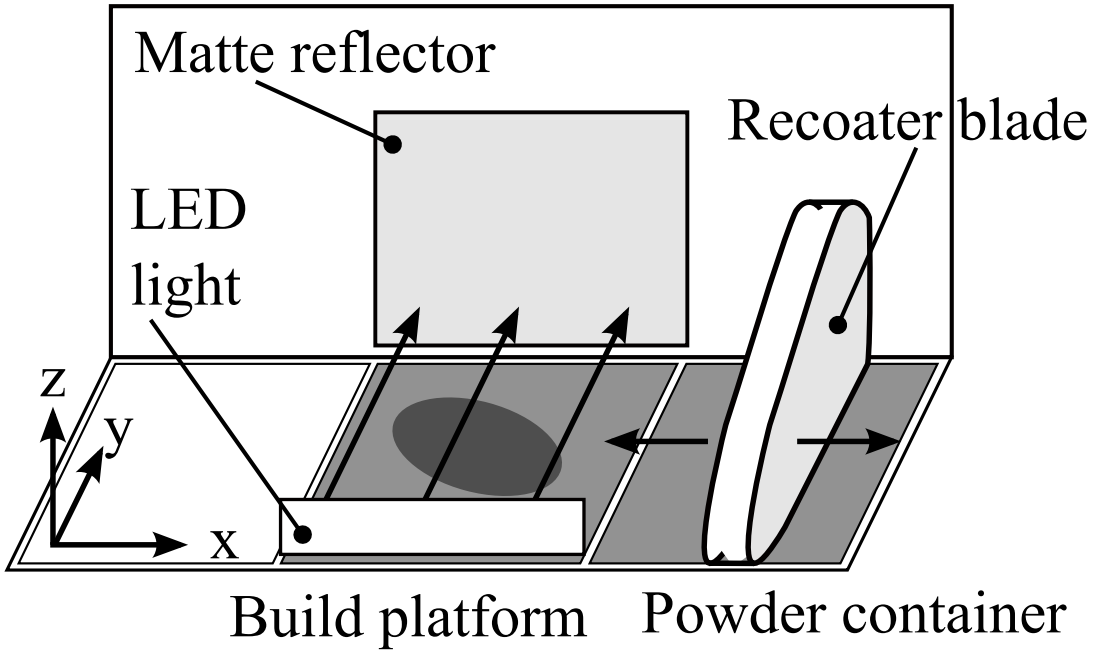
➢ **major risk to process stability**

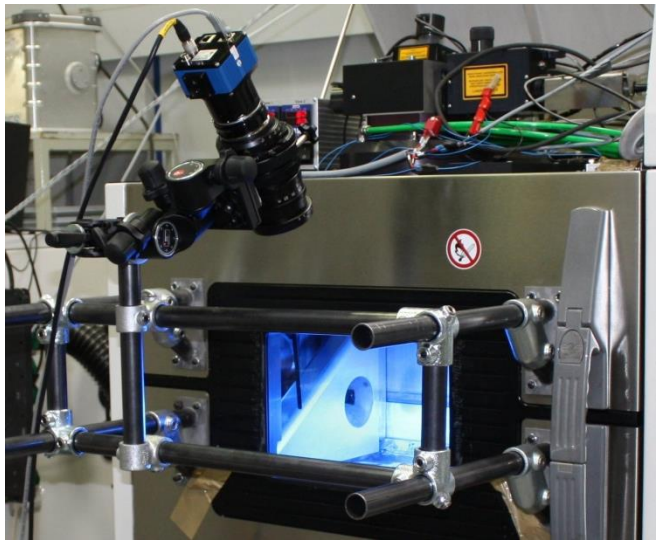
Outline

Detection of Elevated Regions in Surface Images from LBM Processes

- ✓ Laser beam melting
- ✓ Elevated regions and LBM process stability
- ➢ Methods
  - Powder bed imaging
  - Detection pipeline
  - Descriptor comparison
  - Classifier tuning
- Results

Powder Bed Imaging

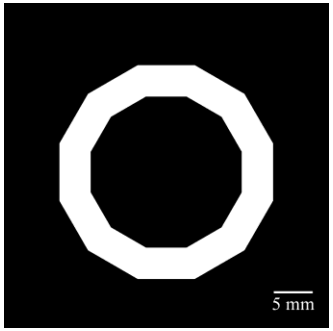




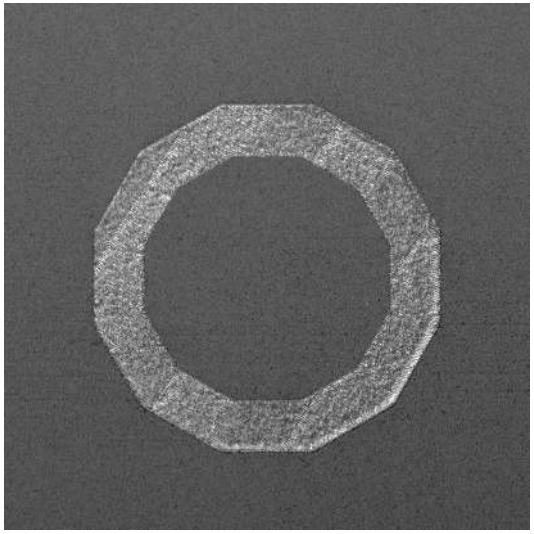
29 MPixel camera (SVS29050, SVS-VISTEK, Germany)
Hartblei 120 mm tilt and shift lens (Hartblei, Germany)

Kleszczynski, zur Jacobsmühlen et al..
Error Detection in Laser Beam Melting Systems by High Resolution Imaging
Solid Freeform Fabrication Symposium, **2012**

Image Data

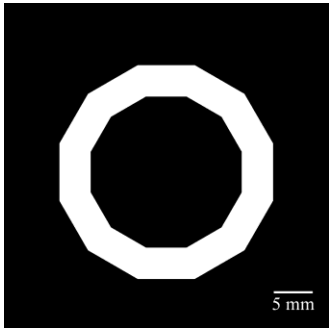


reference layer geometry
(from CAD)



layer image (i)

Image Data



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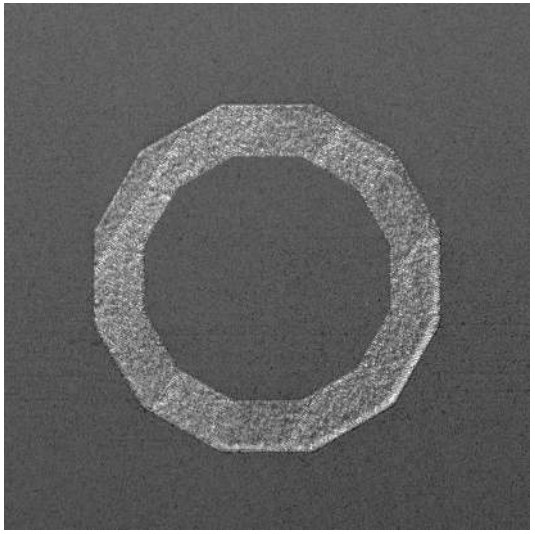

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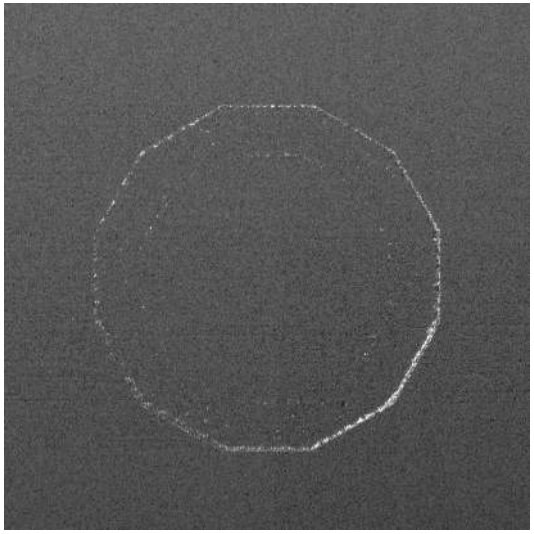
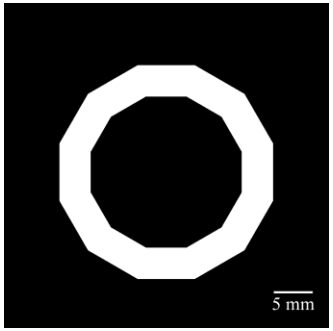


powder layer (i+1)

Image Data



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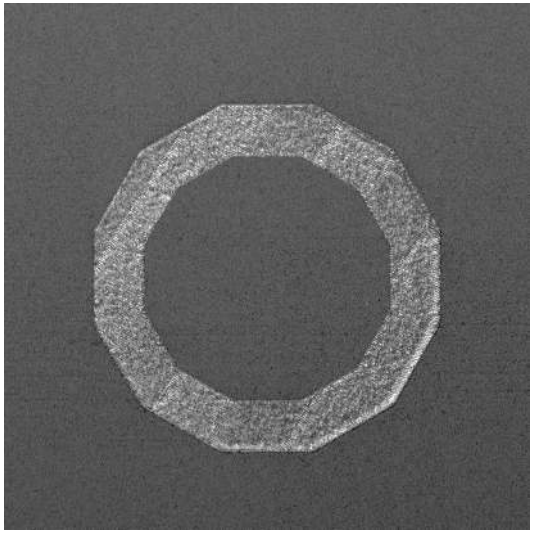

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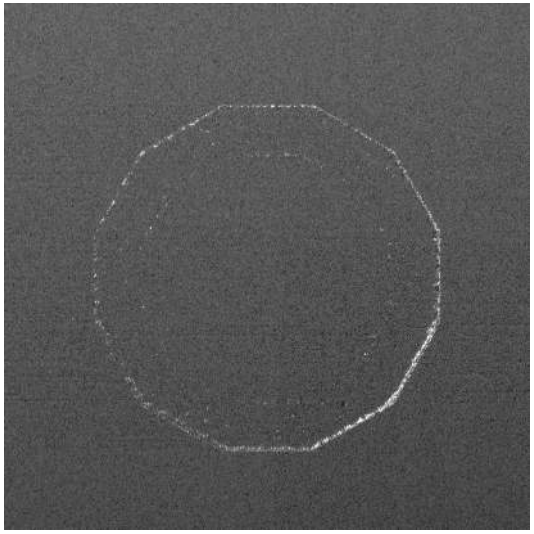
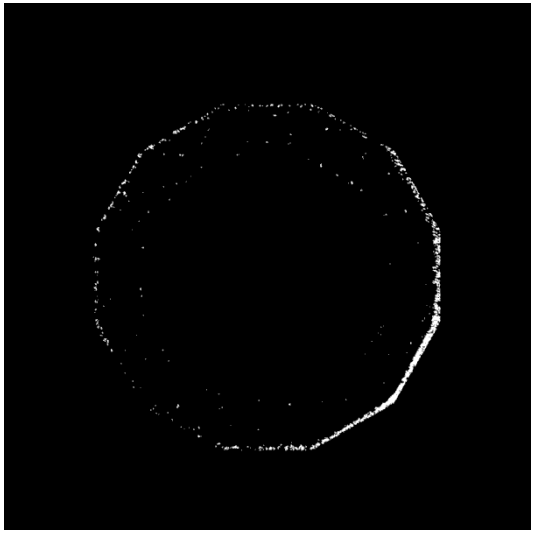
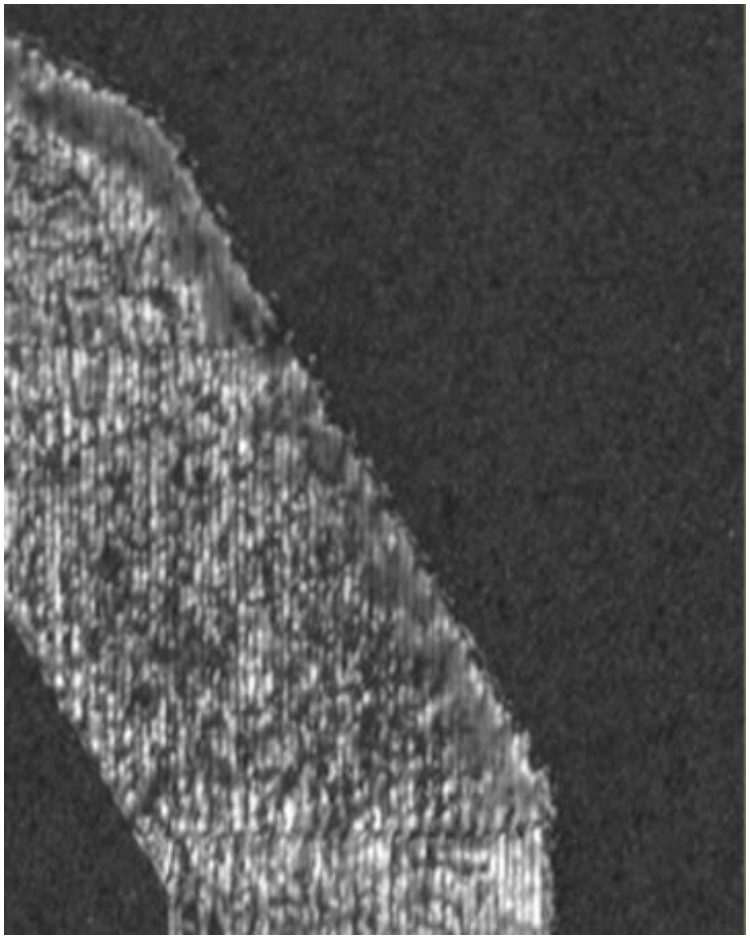


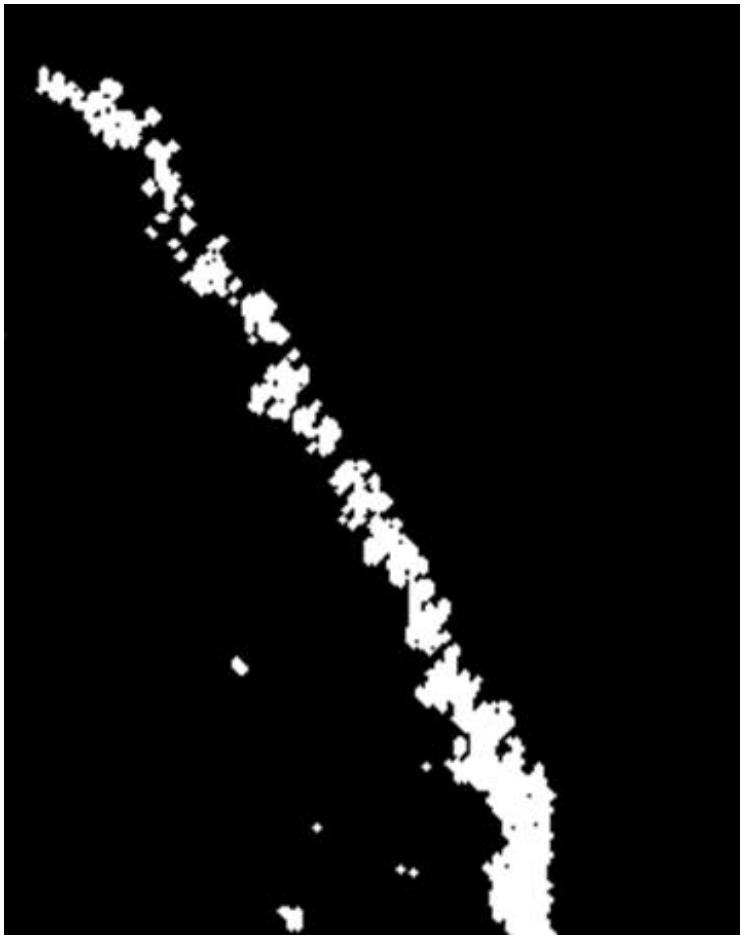
powder layer (i+1)



segmented elevated regions: **ground truth**

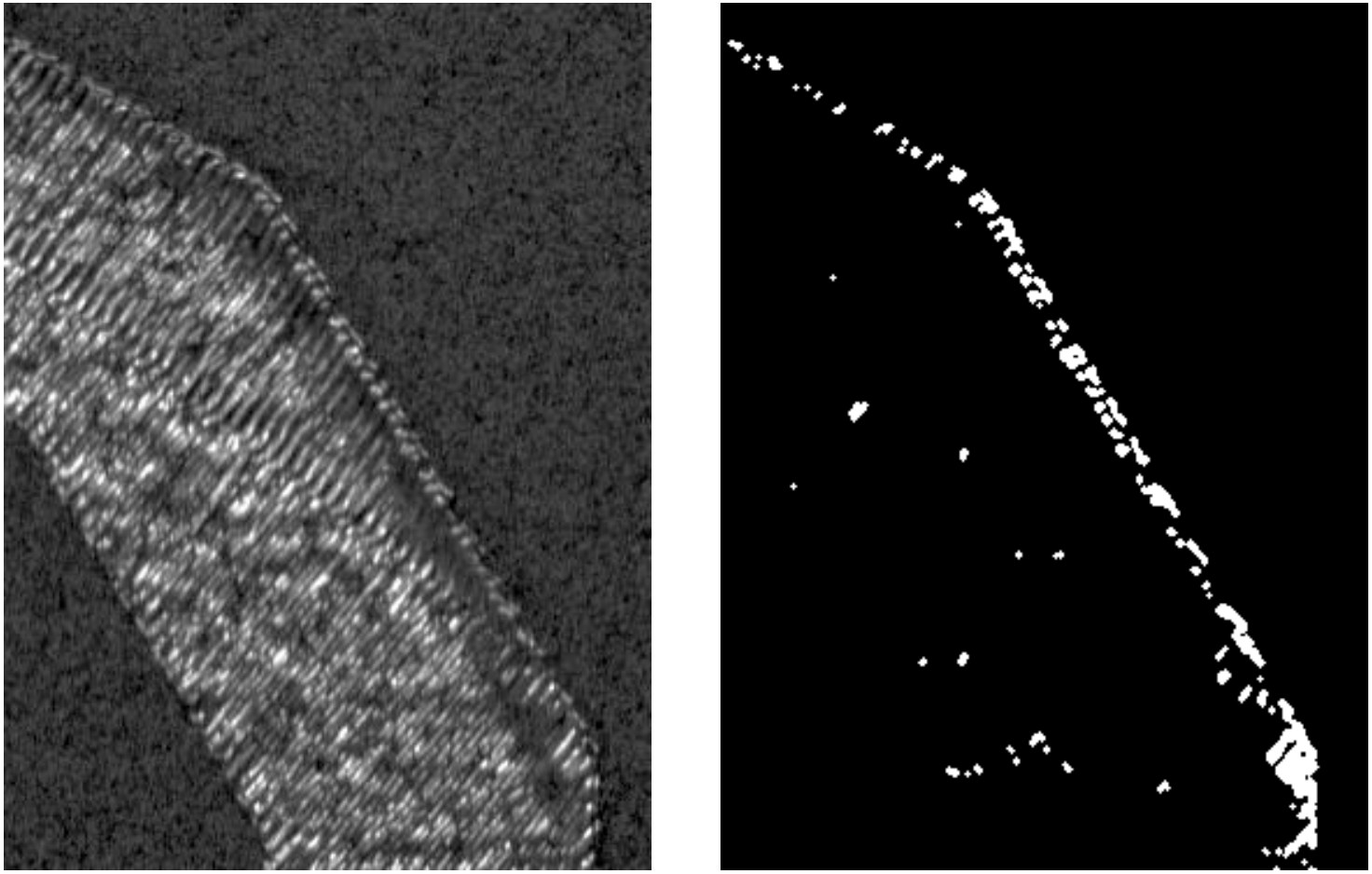
Sample Regions 1/3





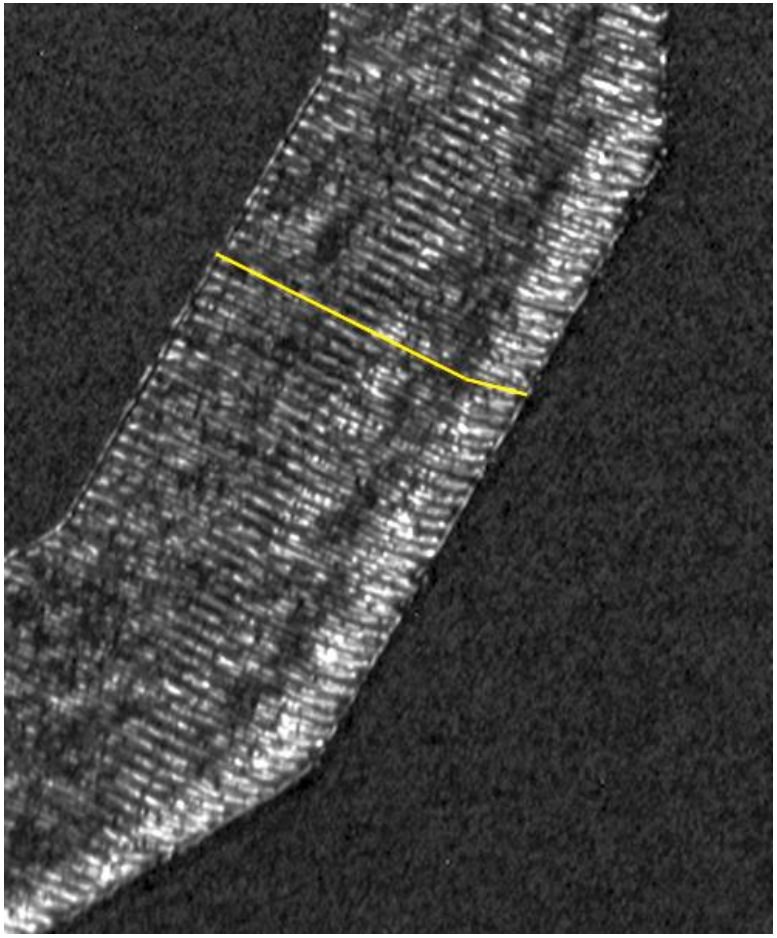
Fused laser scan lines at part edges

Sample Regions 2/3



Ragged contour

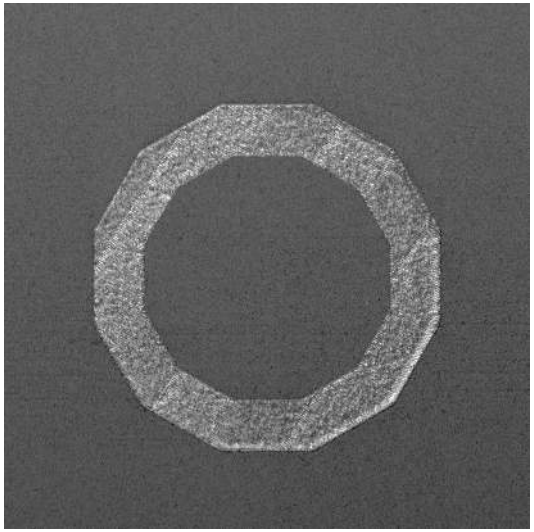
Sample Regions 3/3



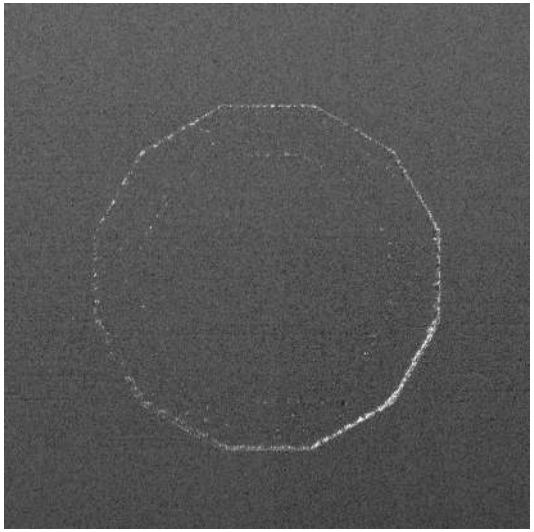
Bent laser scan lines due to elevated edge region

Objective

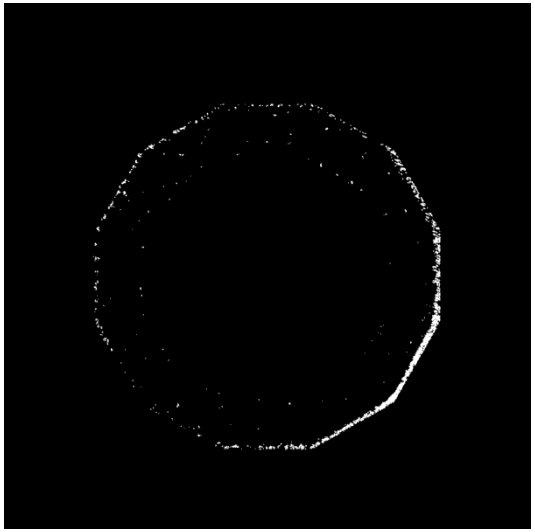
Detect elevated regions in layer image



layer image (i)



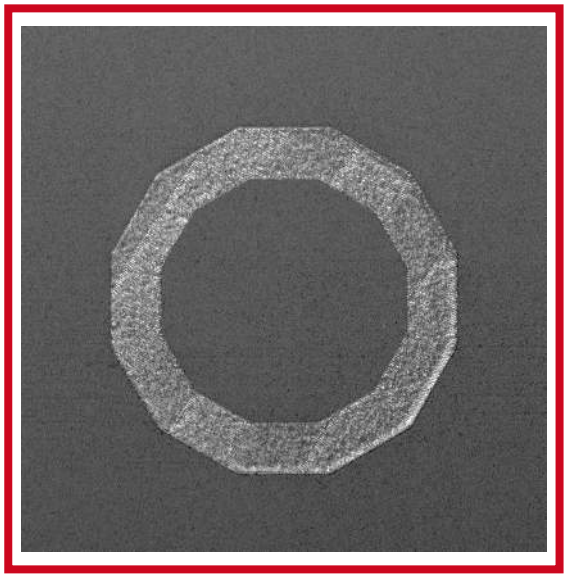
powder layer (i + 1)



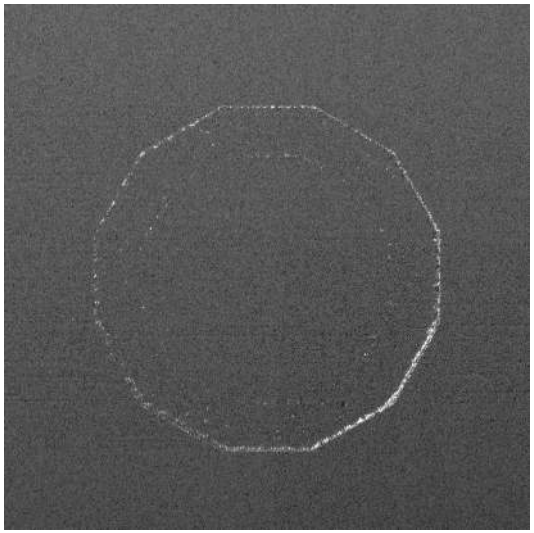
segmented elevated regions: **ground truth**

Objective

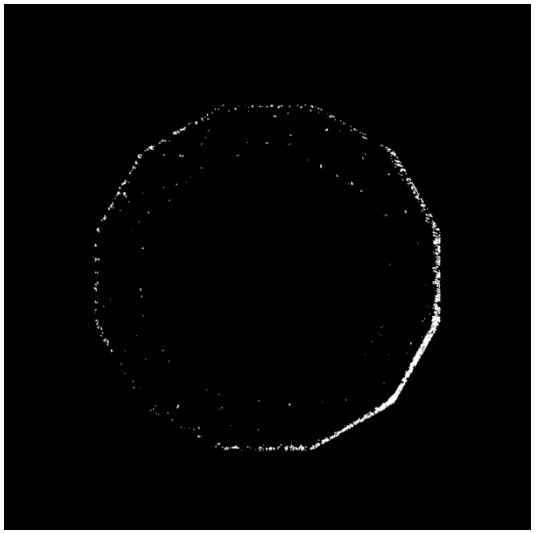
Detect elevated regions in layer image



layer image (i)



powder layer (i + 1)

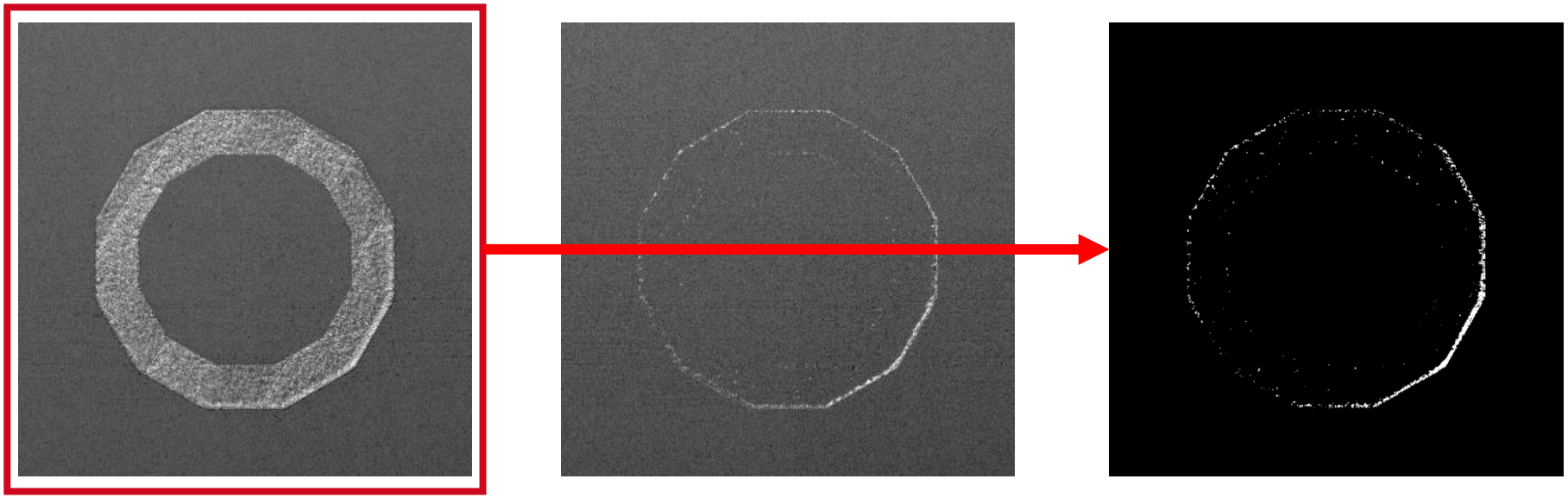


segmented elevated regions: **ground truth**

Objective

Detect elevated regions in layer image

- **Before** next powder layer is deposited



layer image (i)

powder layer (i + 1)

segmented elevated regions: **ground truth**

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Detect elevated regions in layer image

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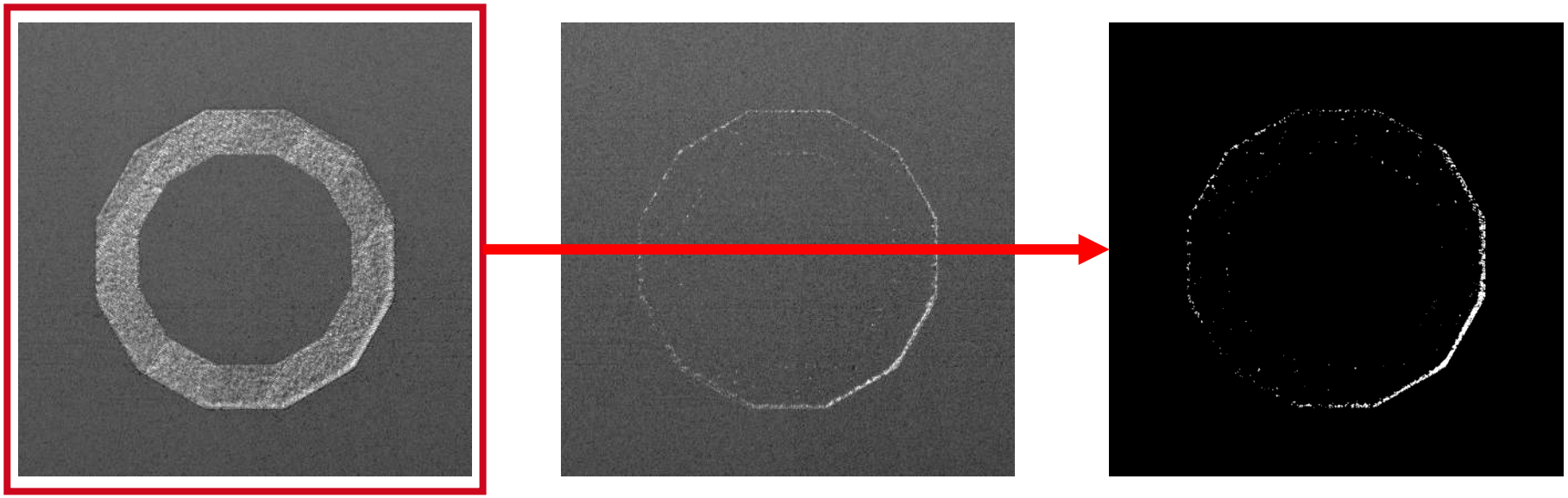


layer image (i)

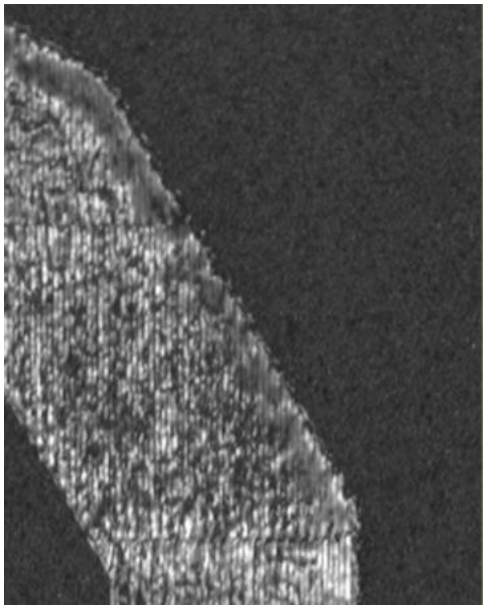
powder layer (i + 1)

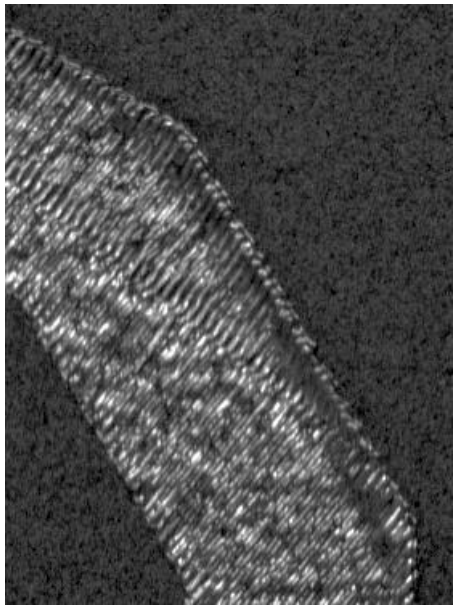
segmented elevated regions: **ground truth**

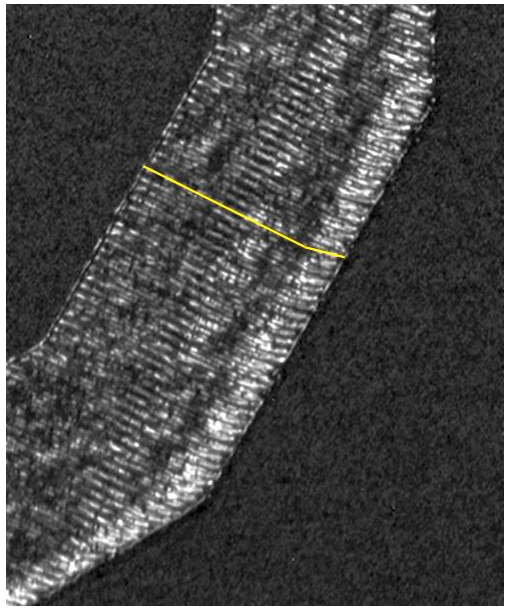
Method

Analyze local scan line shape

- distortions in elevated regions
- gradient operators for analysis of oriented image structures
- localization of elevated regions: **dense** description





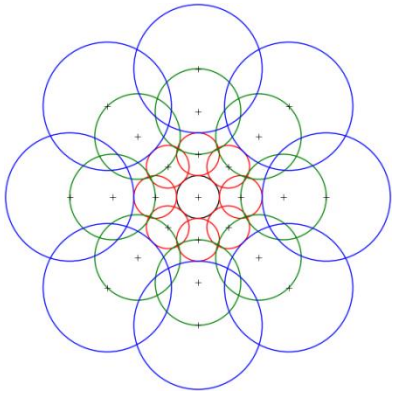


Method

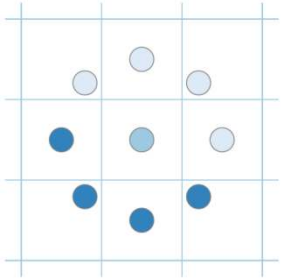
Descriptors

- Histogram of Oriented Gradients (HOG) [Dalal&Triggs, 2005]
- DAISY: log-polar sampling grid [Tola et al., 2010]
- Local Binary Patterns (LBP): “traditional” texture feature [Ojala et al., 2003]

HOG



DAISY



LBP

Image Data

Layer images from 3 build jobs

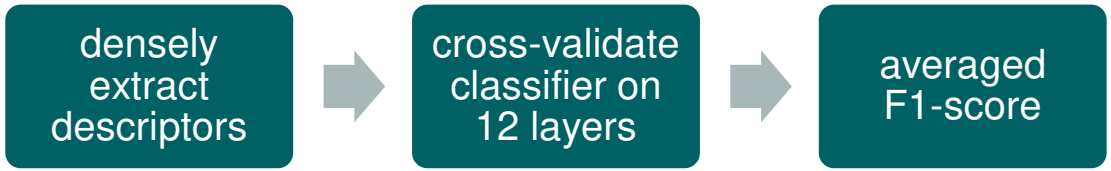
Job	# Images	Image Size	Resolution [µm/px]
A	94	2134 px × 1982 px	32.9
B	93	2539 px × 2357 px	27.7
C	93	3142 px × 2917 px	22.3

- 280 layer images
- $N = 6 \times 10^6 \ldots 17 \times 10^6$ blocks (depending on descriptor size)

Method

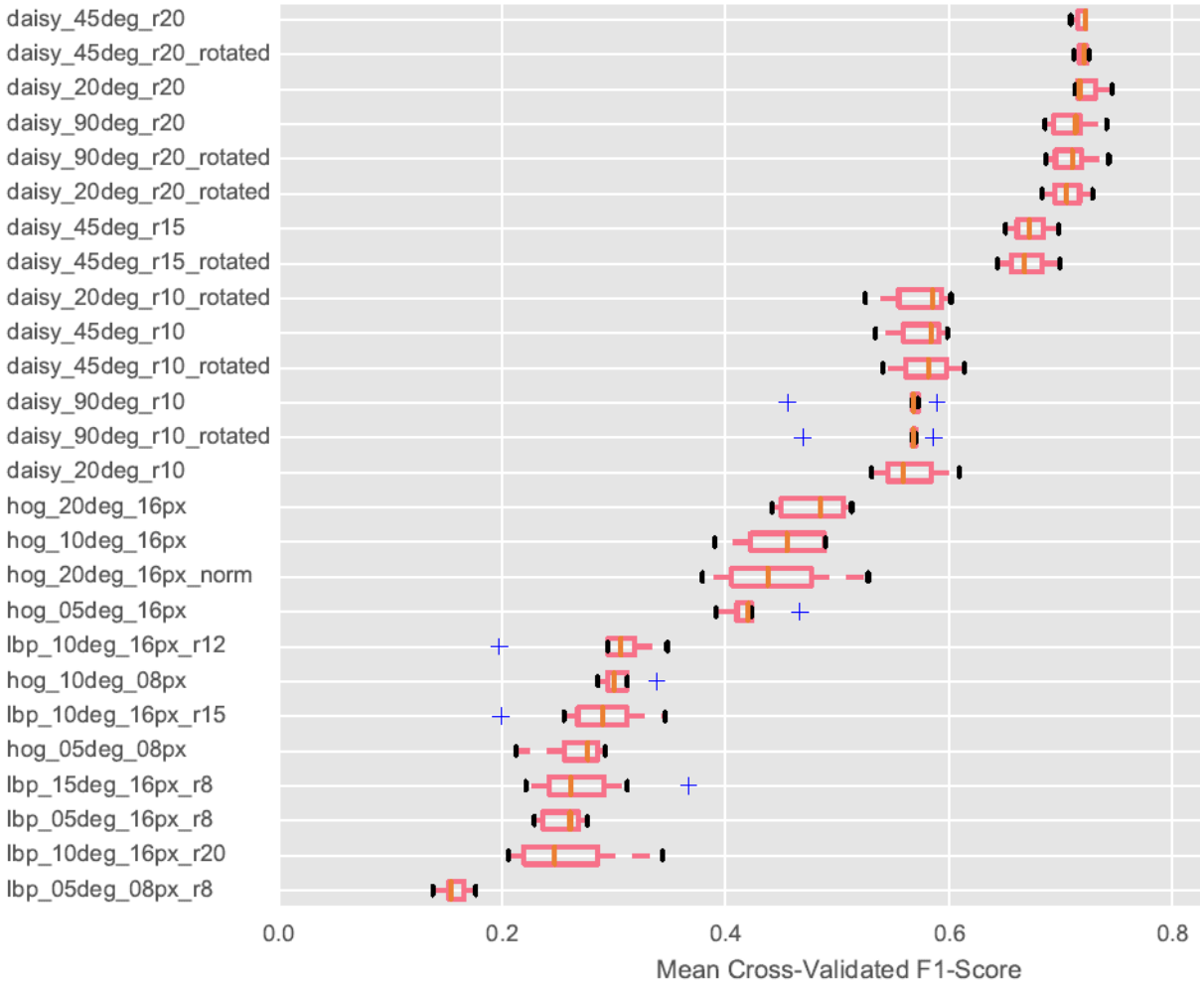
Training of Descriptor Configuration and Classifier

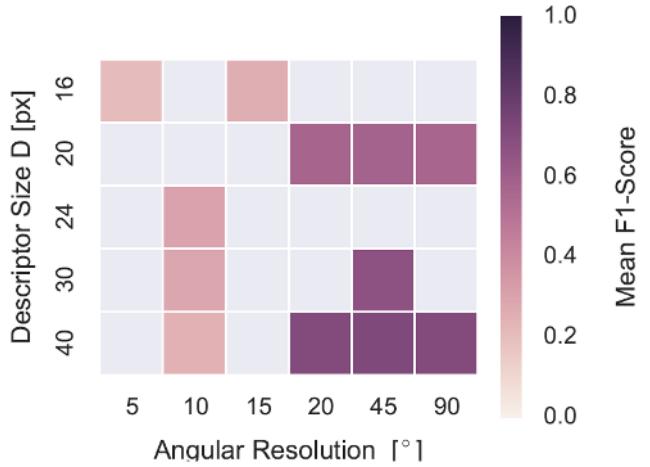
For each configuration:



- Parameters
  - descriptor region sizes: {16, 20, 24, 30, 40} pixels
  - angular resolution (# bins in histogram): 5, 10, 20, 45, 90°
- Gradient Tree Boosting classifier for fast evaluation

Results – Descriptor Comparison





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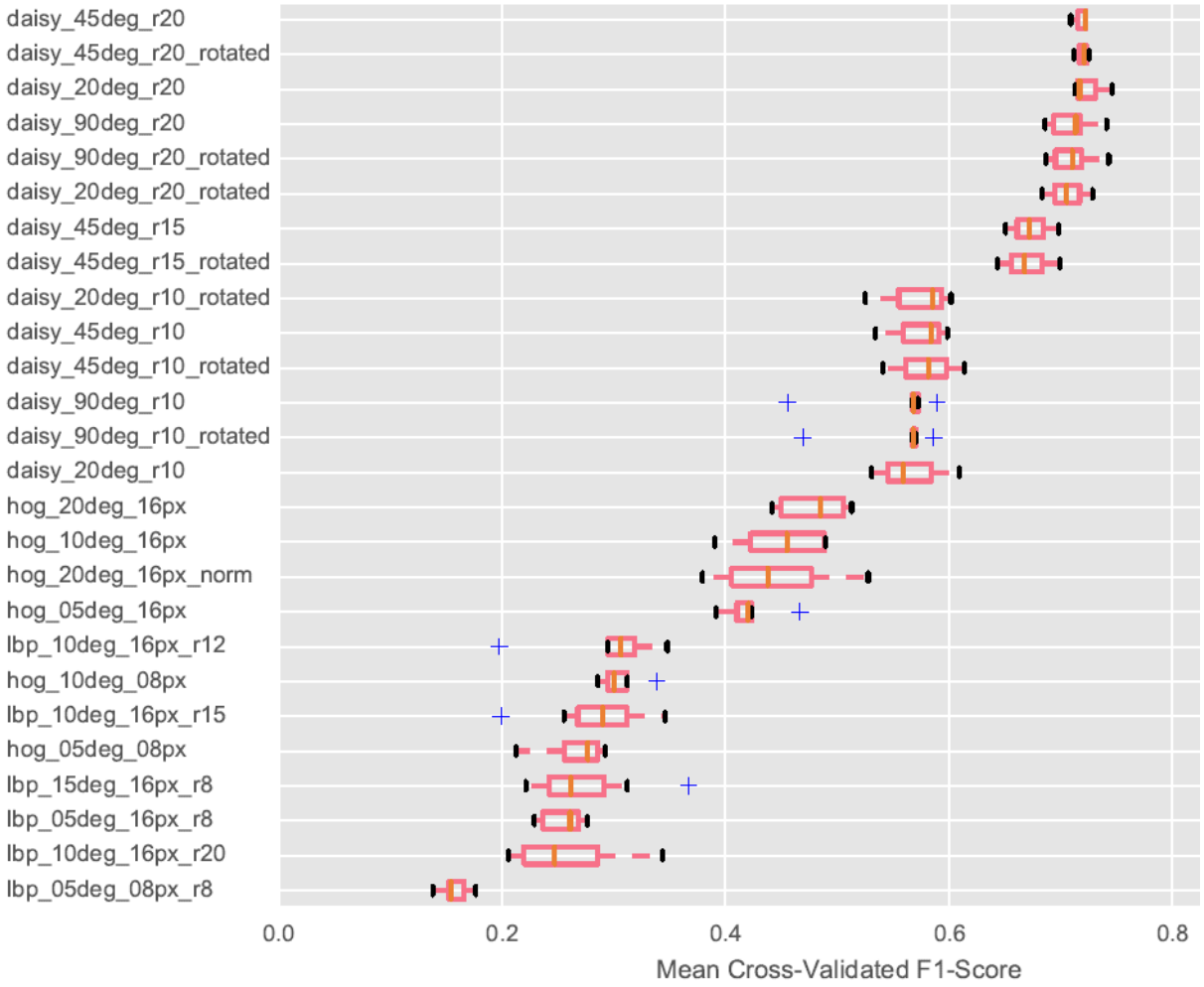
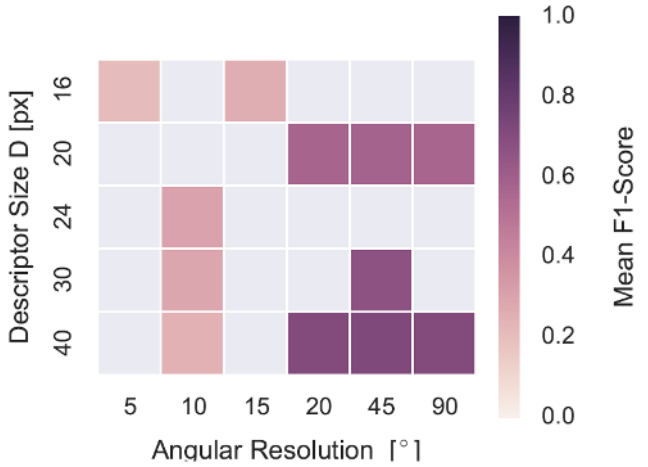


- DAISY best descriptor



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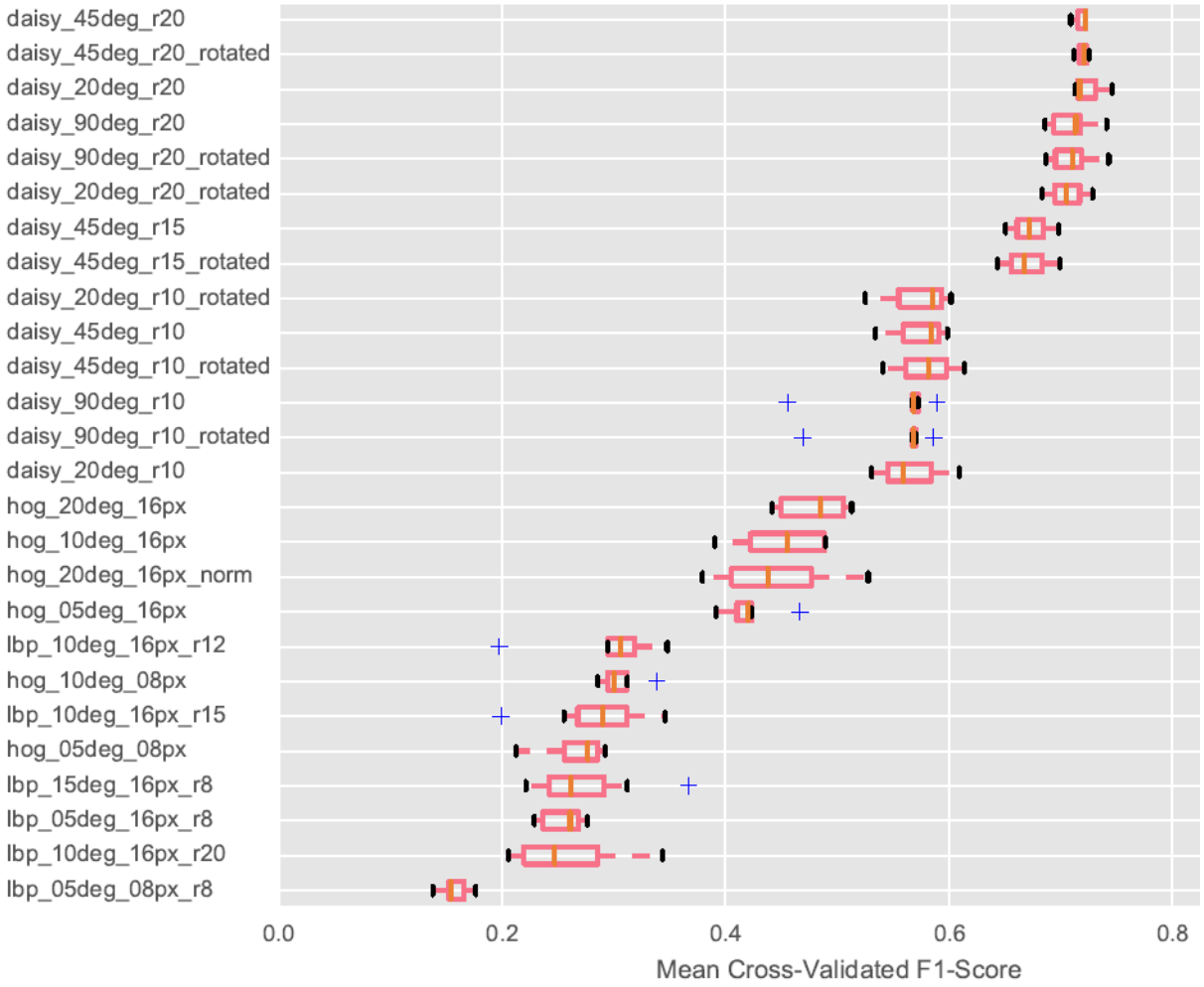
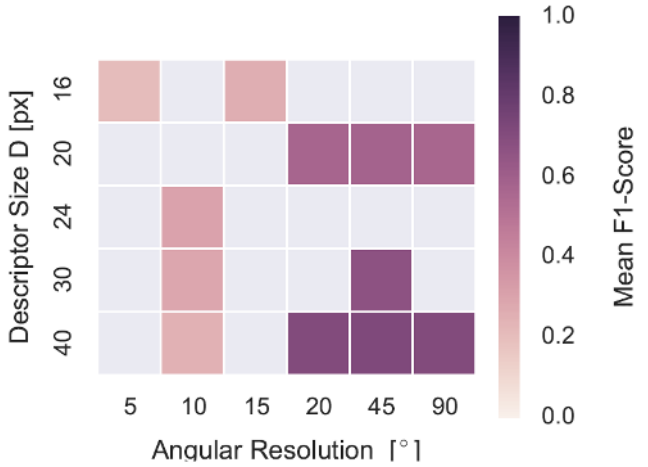


- DAISY best descriptor
- large descriptors yield better performance



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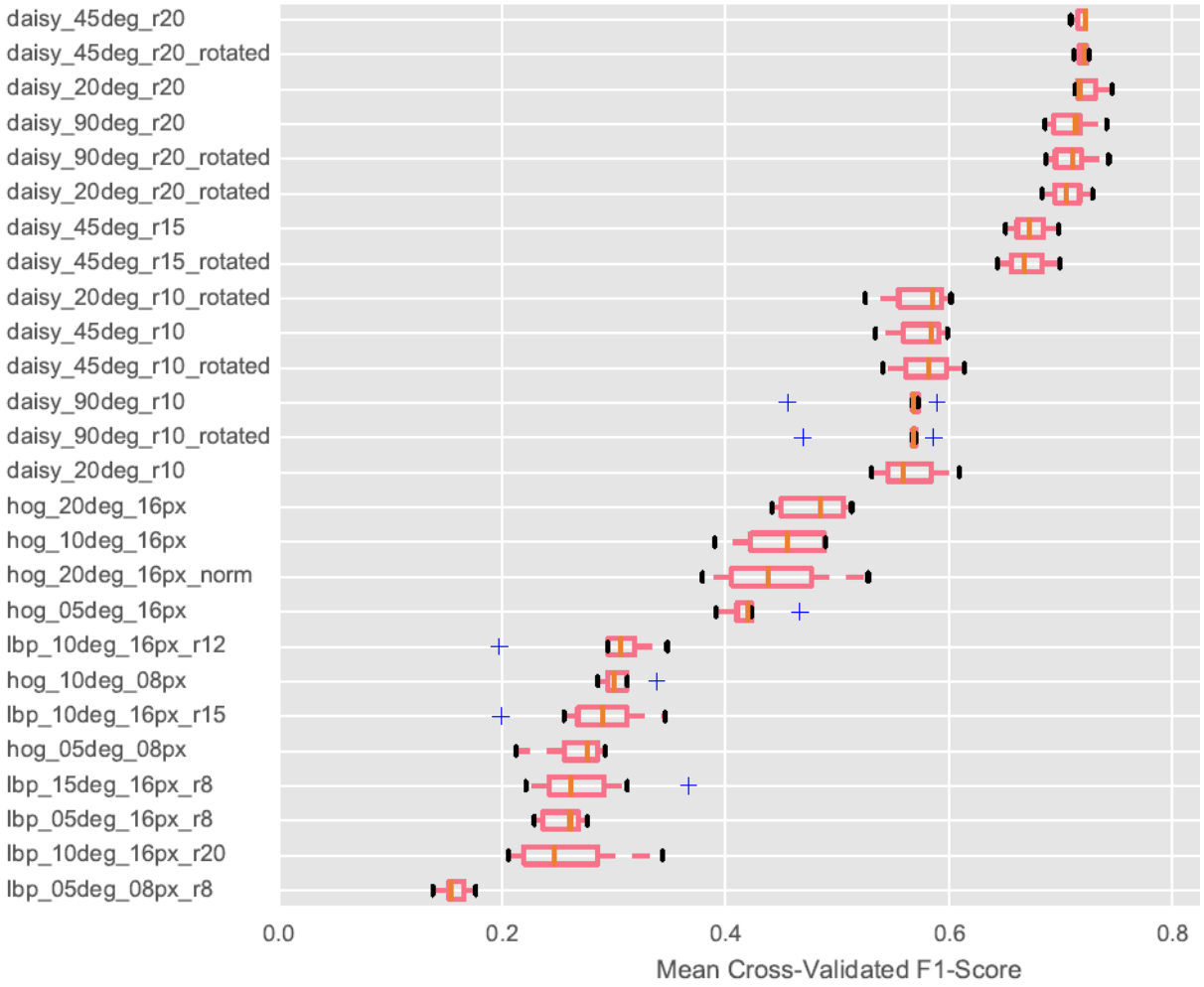
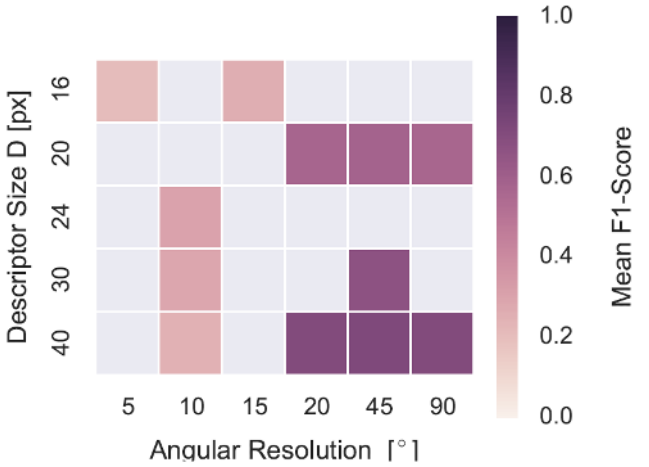


- DAISY best descriptor
- large descriptors yield better performance
- select top 5 configurations



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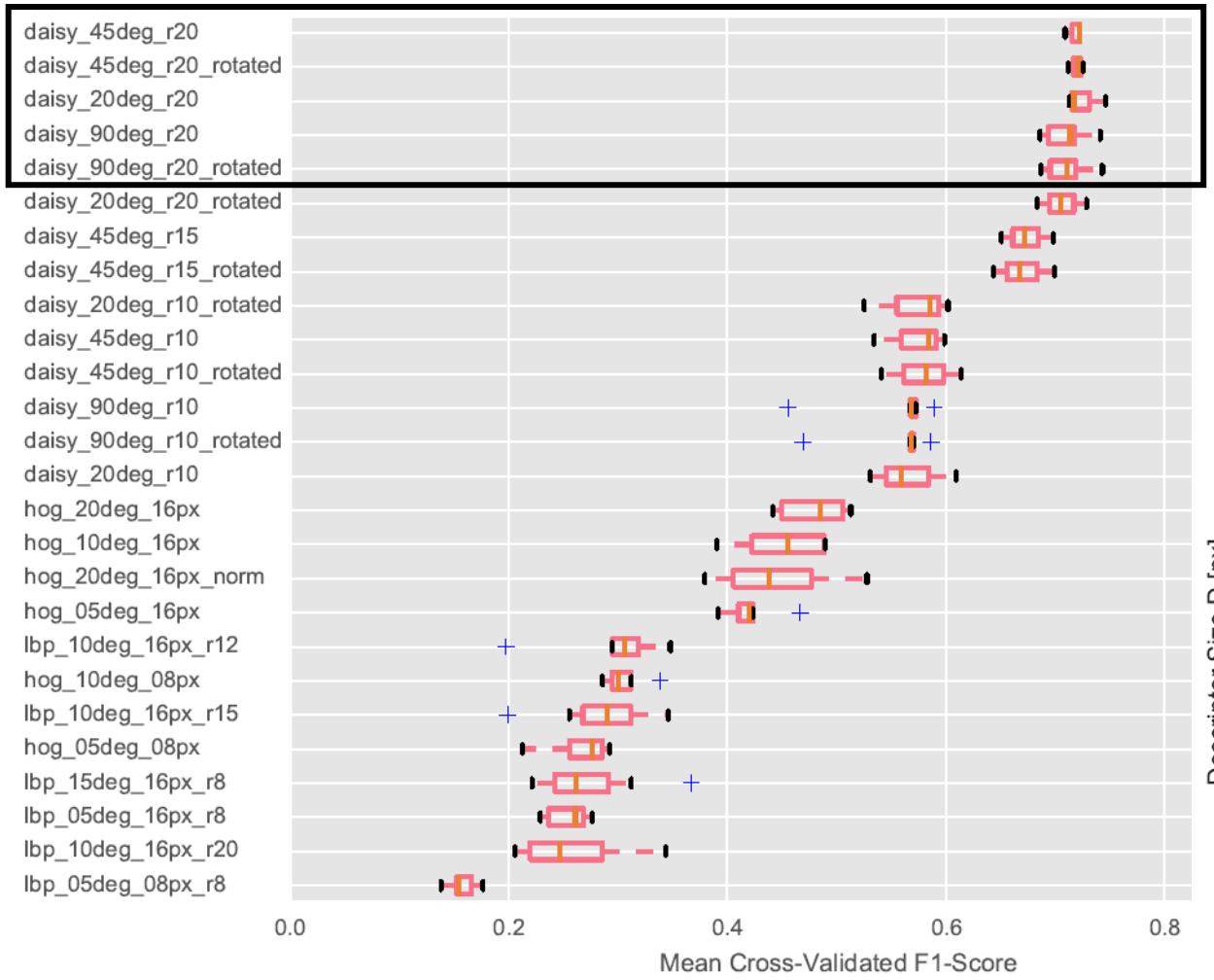

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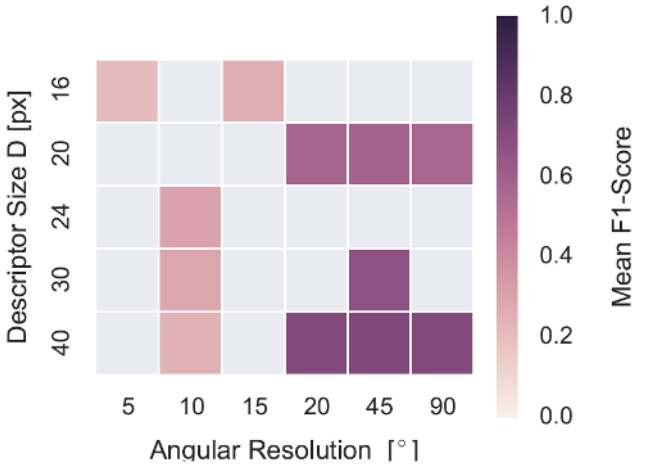

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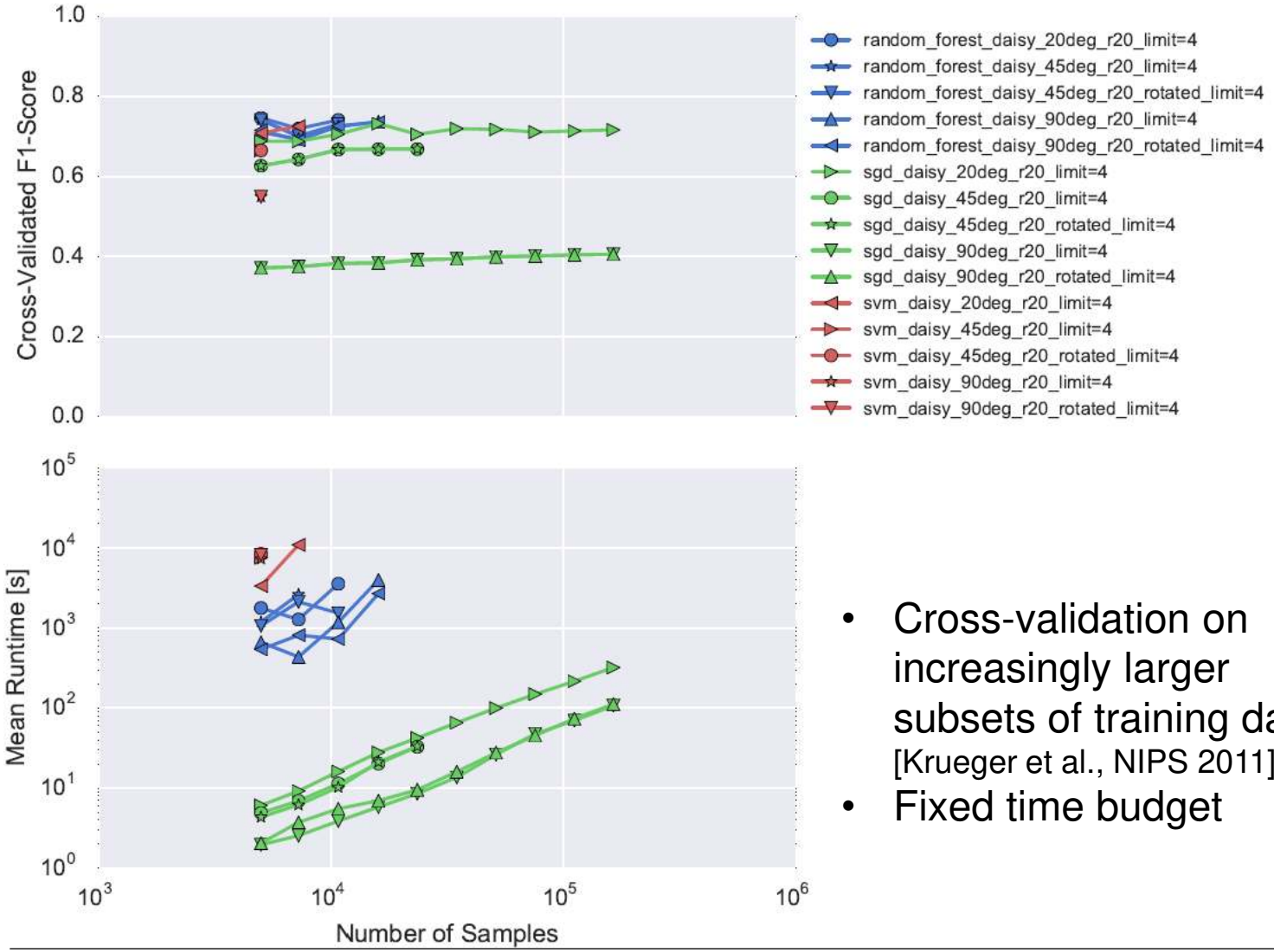
Training of Descriptor/Classifier Pairs

- Classifiers:
  - support vector machine (SVM)
  - random forest (RF)
  - linear SVM trained with stochastic gradient descent (SGD)

Classifier Parameter Tuning and Learning Curves

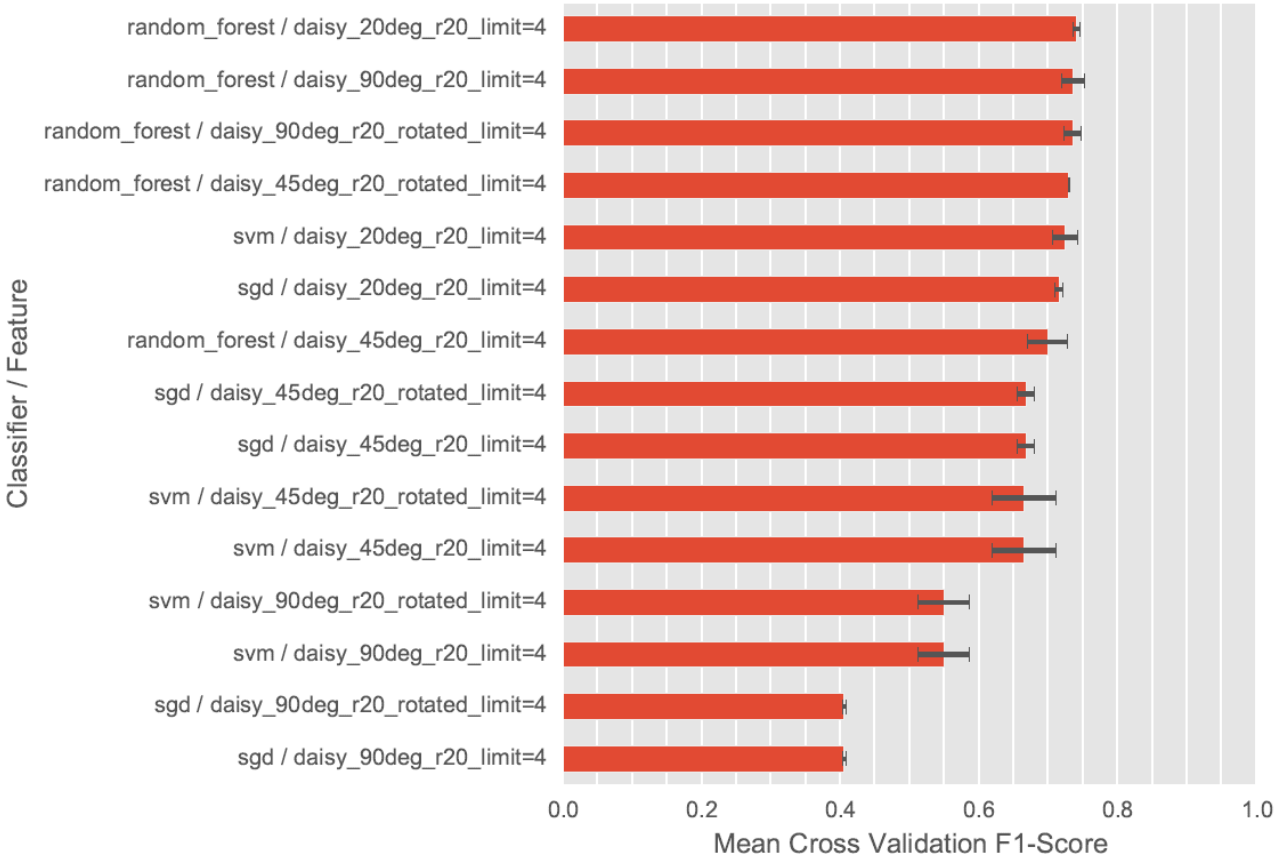


Top 5 descriptor configurations

- Cross-validation on increasingly larger subsets of training data
  [Krueger et al., NIPS 2011]
- Fixed time budget

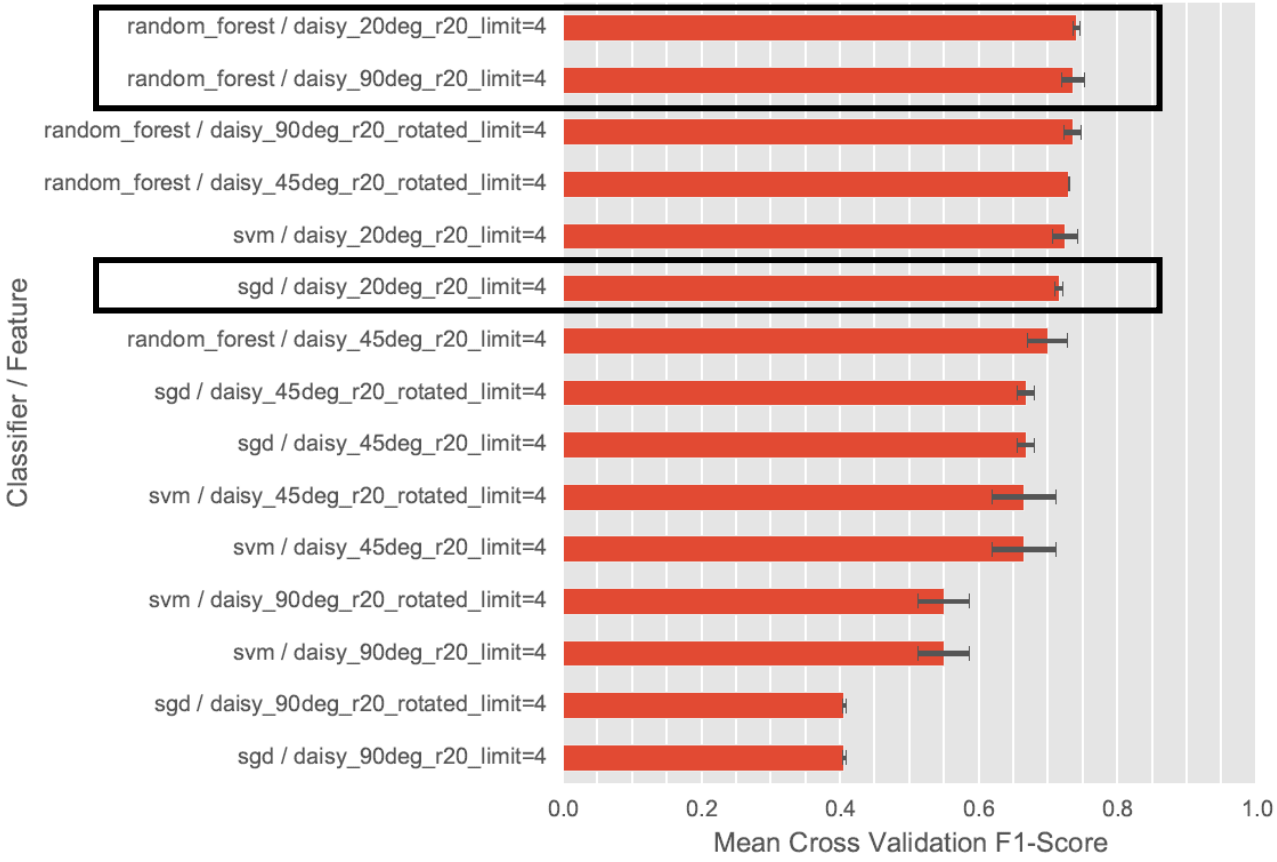
Classifier Parameter Tuning

Sorted Results



Classifier Parameter Tuning

Sorted Results



Validation Results

- Best 3 configurations from sorted results of classifier tuning
- Trained on 4.8×10^6 samples, tested on 2.4×10^6 Samples
- cross-validation, split by build job (train on two jobs, test on remaining)

Configuration	Training Speed [samples/s]	Prediction Speed [samples/s]	F_1-Score
SGD + DAISY $A = 20° D = 40$	11675	519825	0.670
RF + DAISY $A = 20° D = 40$	12	2340	0.667
RF + DAISY $A = 90° D = 40$	25	1506	0.650

Conclusion

- Descriptors are good features for surface classification
- Comparison:
  - DAISY performs best
  - Large descriptor regions are better
  - High angular resolution not required for elevation detection
- Classification
  - training on increasingly larger subsets of data yields quick insight

- Outlook
  - test performance of larger regions
  - use ensemble classifiers to increase classification accuracy