

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

YF005622

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Yokohama

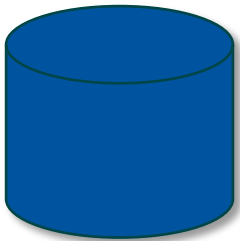
Japan

What is Laser Beam Melting (LBM)?

“3D printing” with metal powder

What is Laser Beam Melting (LBM)?

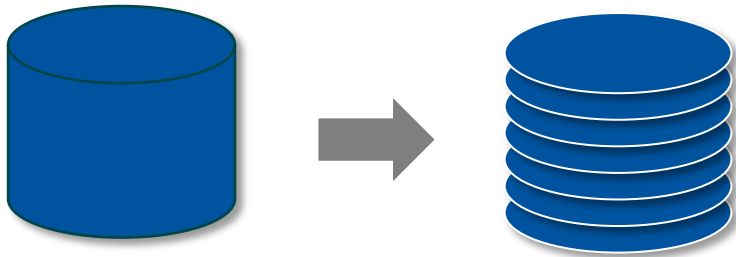
“3D printing” with metal powder



Design (3D)

What is Laser Beam Melting (LBM)?

“3D printing” with metal powder



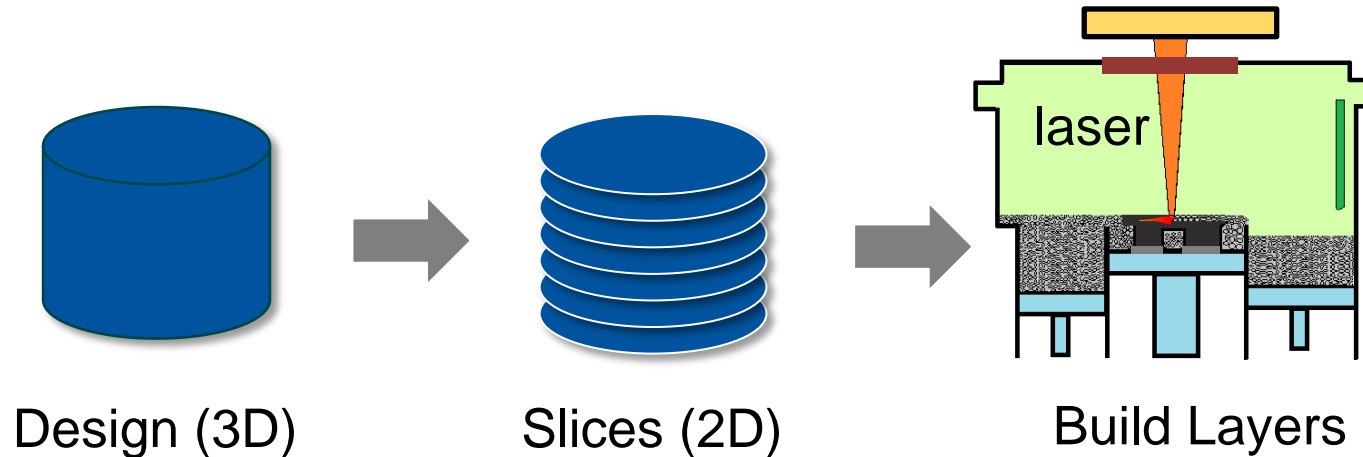
Design (3D)

Slices (2D)

- Layer-based, iterative

What is Laser Beam Melting (LBM)?

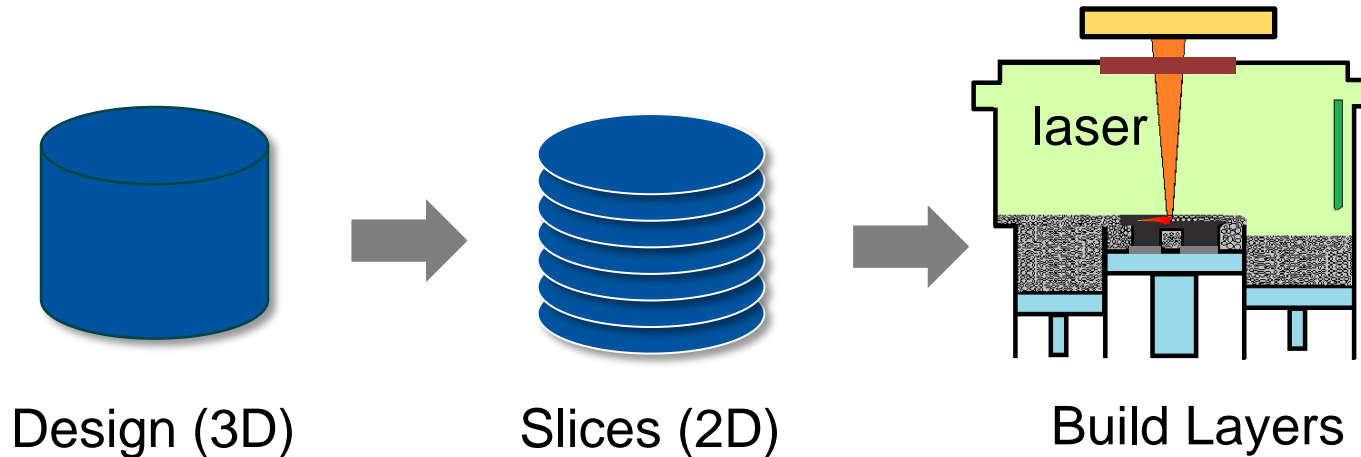
“3D printing” with metal powder



- Layer-based, iterative

What is Laser Beam Melting (LBM)?

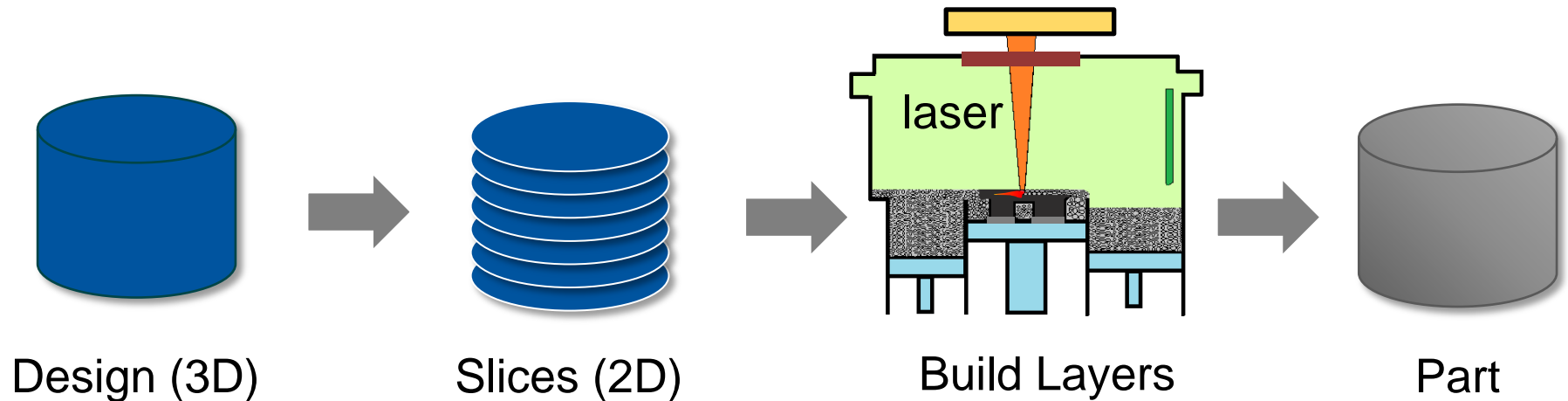
“3D printing” with metal powder



- Layer-based, iterative
- Laser melts metal powder according to layer geometry

What is Laser Beam Melting (LBM)?

“3D printing” with metal powder



- Layer-based, iterative
- Laser melts metal powder according to layer geometry

Laser Beam Melting – „3D Printing with Metal“



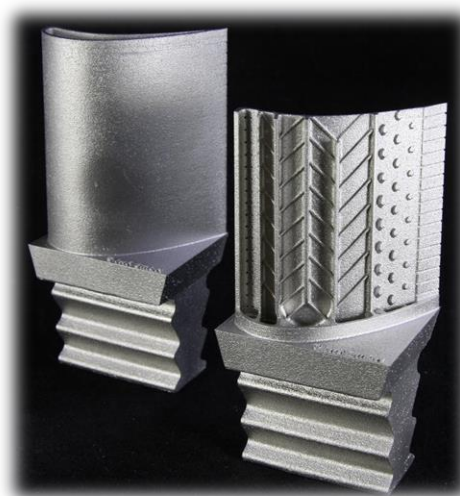
hip implant

[www.slm-solutions.com]



injection nozzle

[www.eos.info]



turbine blade (demo)

[RTC Duisburg]



spiders

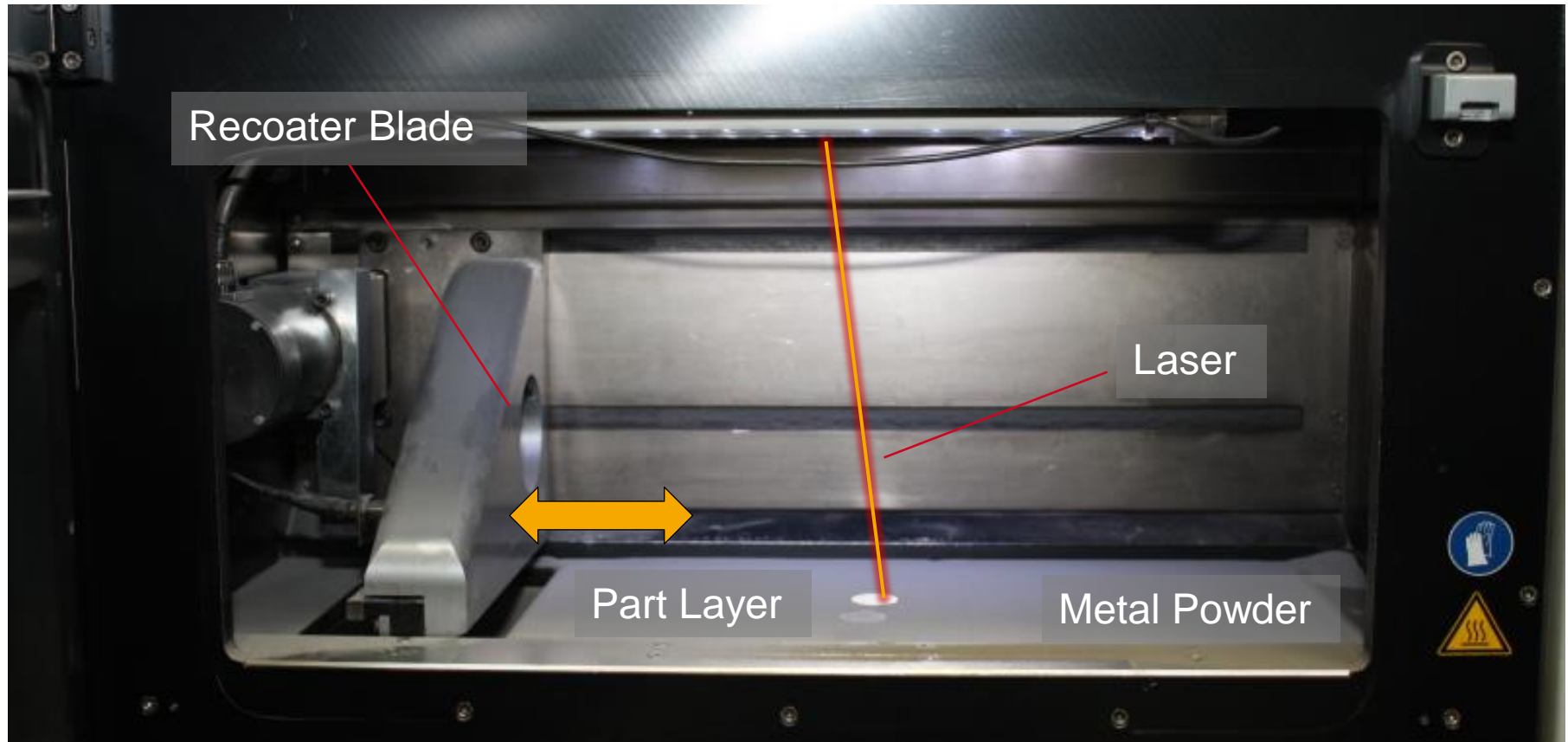
[RTC Duisburg]



impeller

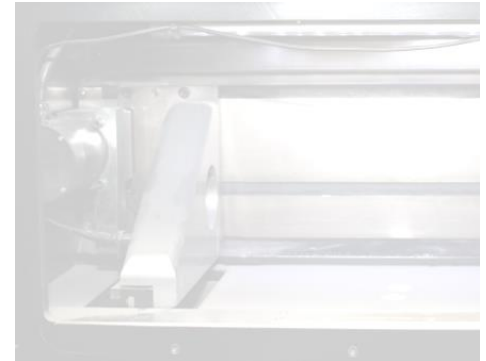
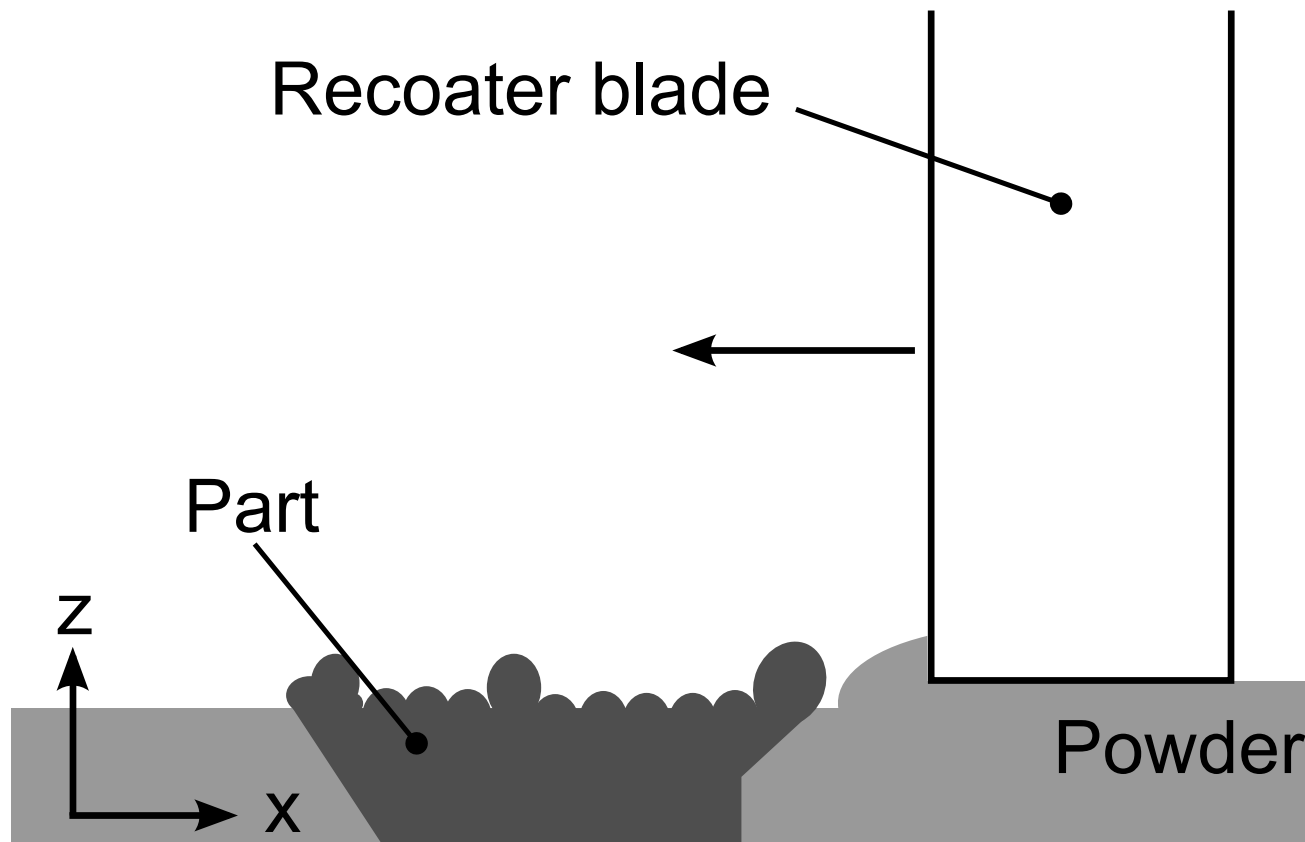
[RTC Duisburg]

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

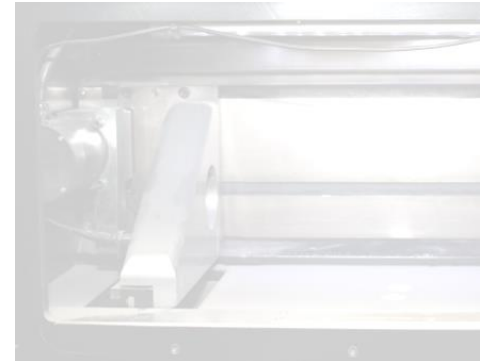
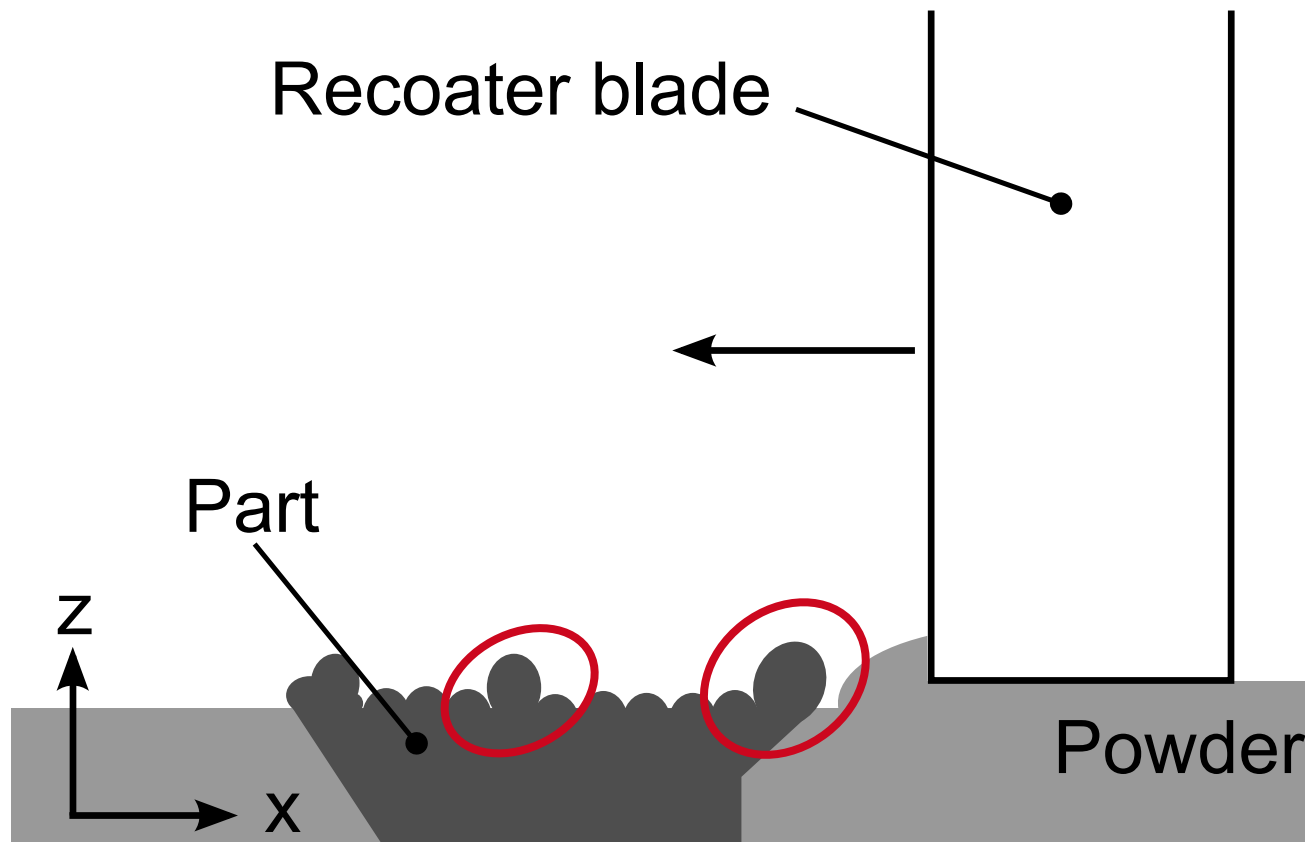


Process Chamber

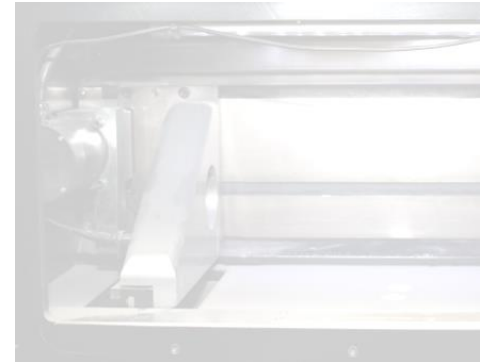
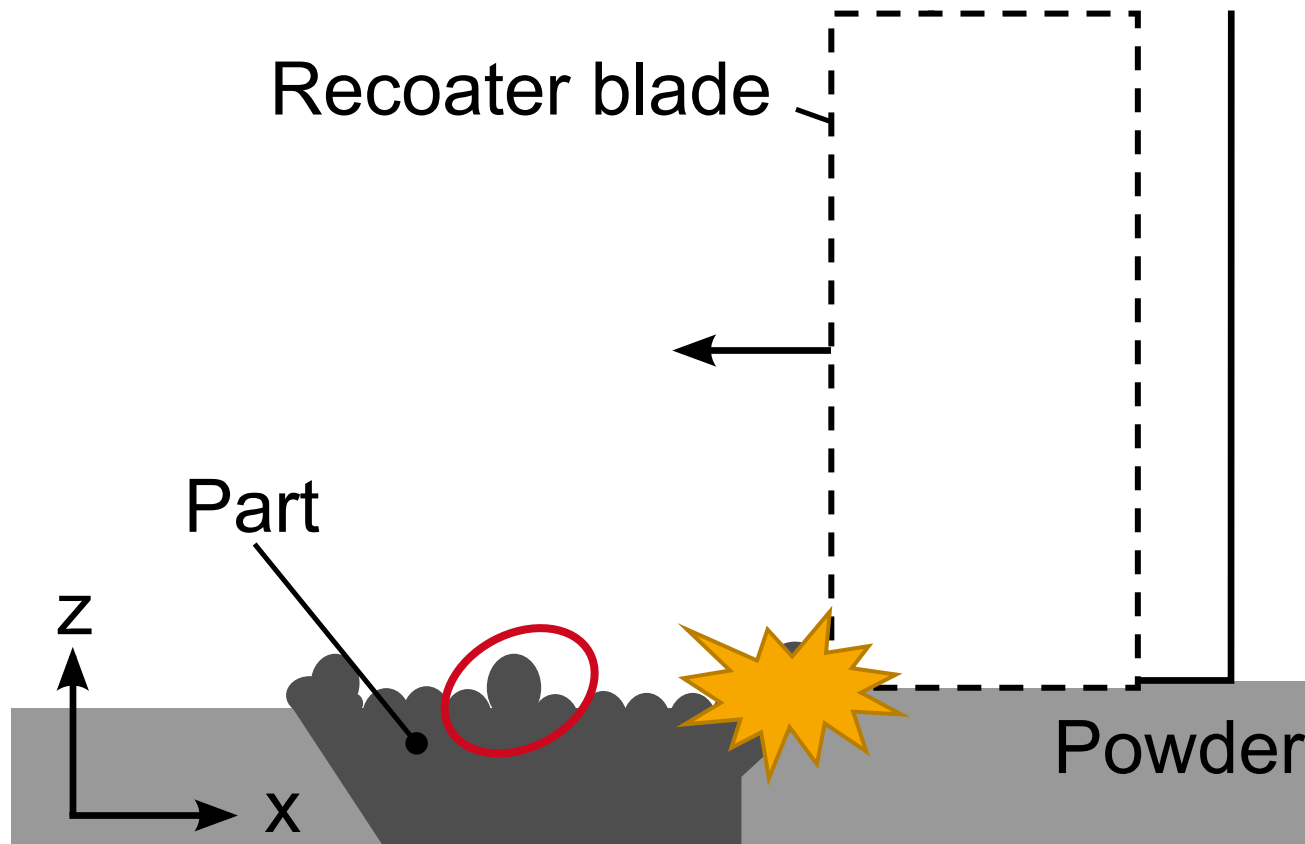
Elevated Part Regions



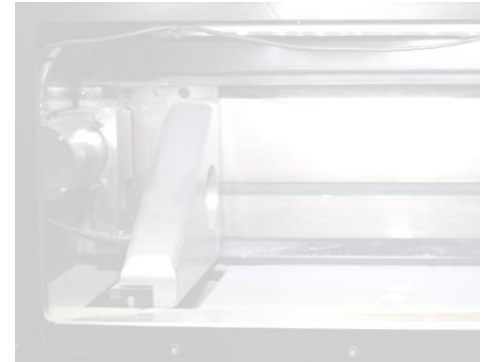
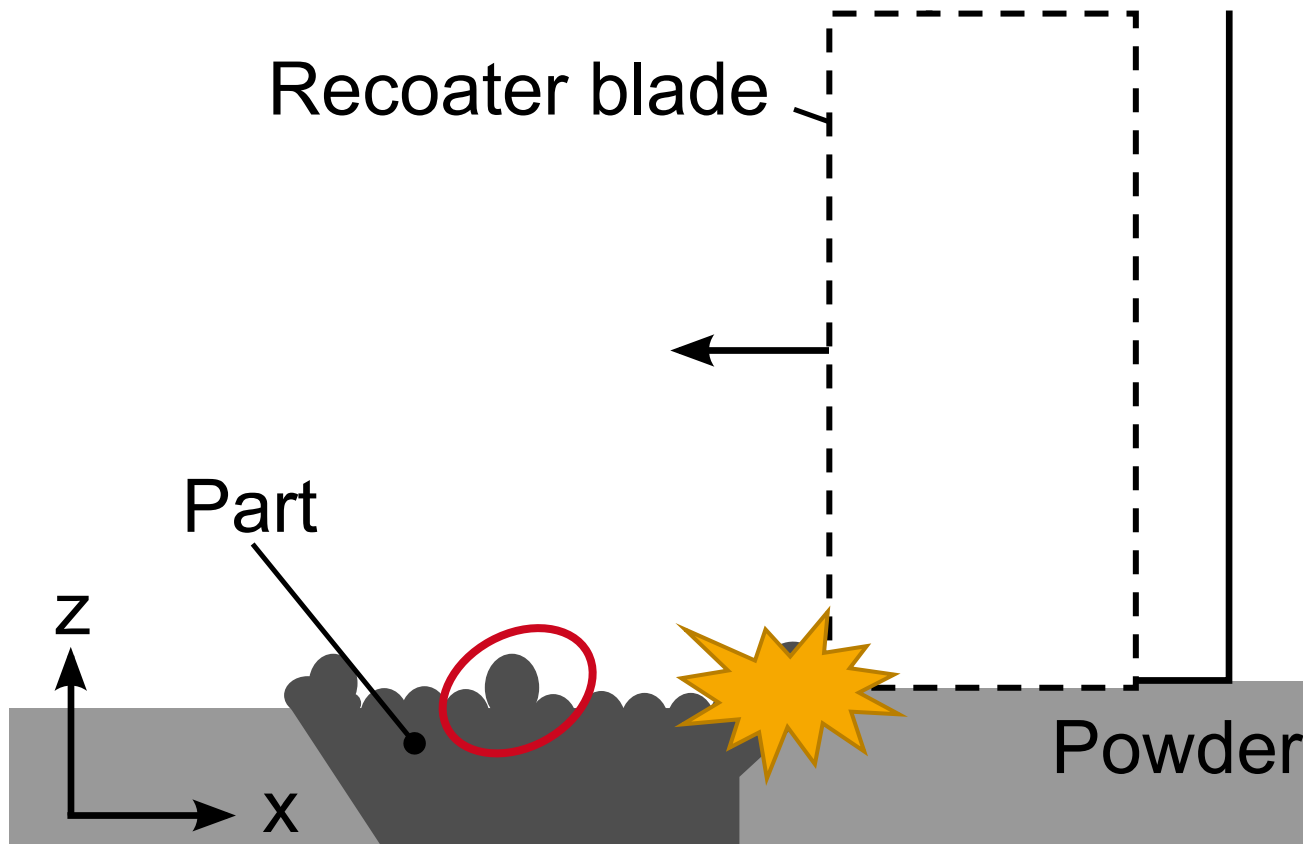
Elevated Part Regions



Elevated Part Regions

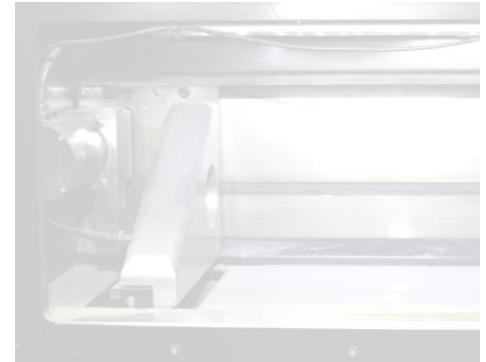
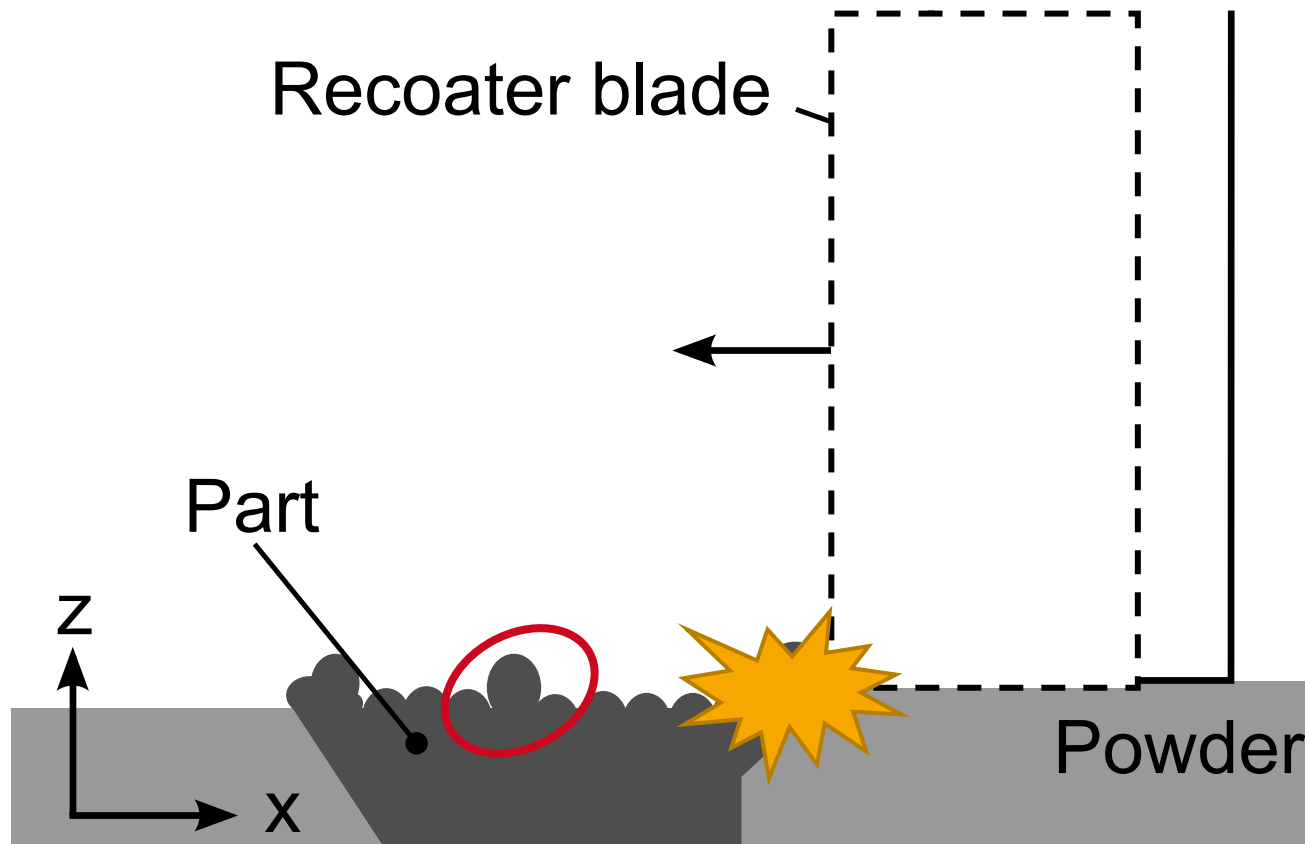


Elevated Part Regions



may damage part/recoater blade and cause jammings

Elevated Part Regions



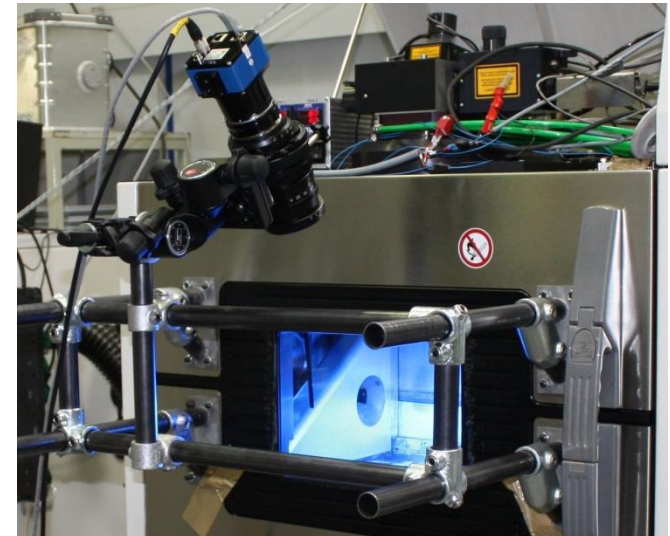
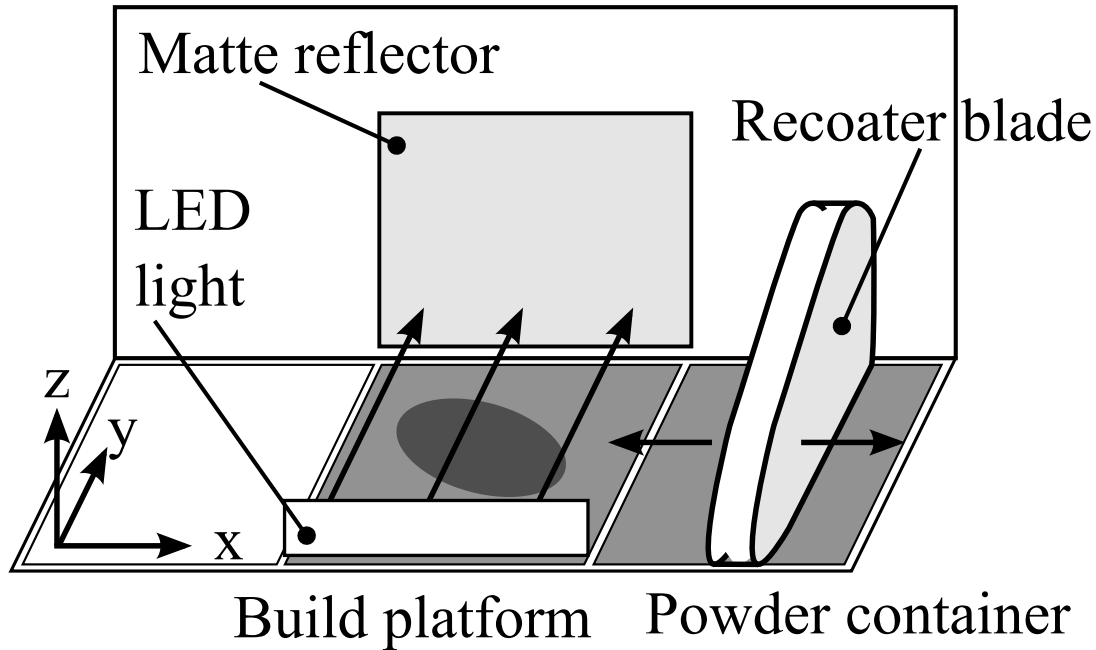
may damage part/recoater blade and cause jammings

➤ **major risk to process stability**

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**

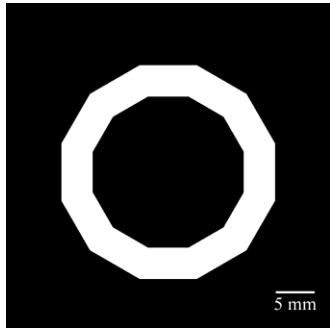
Powder Bed Imaging



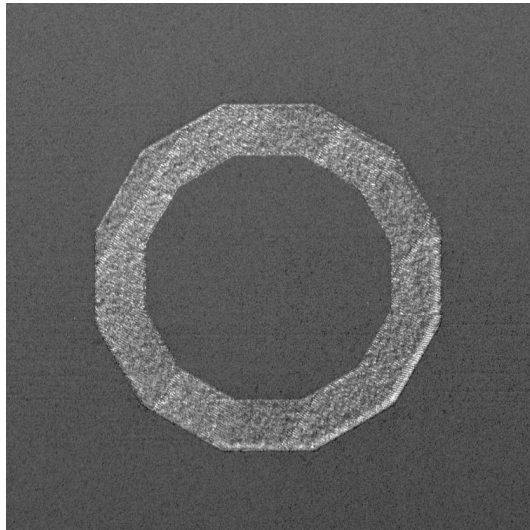
29 MPixel camera (SVS29050, SVS-VISTEK, Germany)
Hartblei 120 mm tilt and shift lens (Hartblei, Germany)

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

Image Data

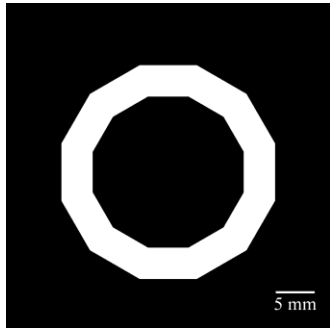


reference layer geometry
(from CAD)

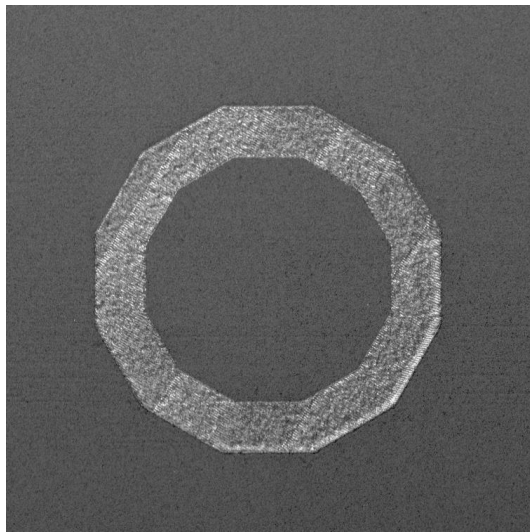


layer image (i)

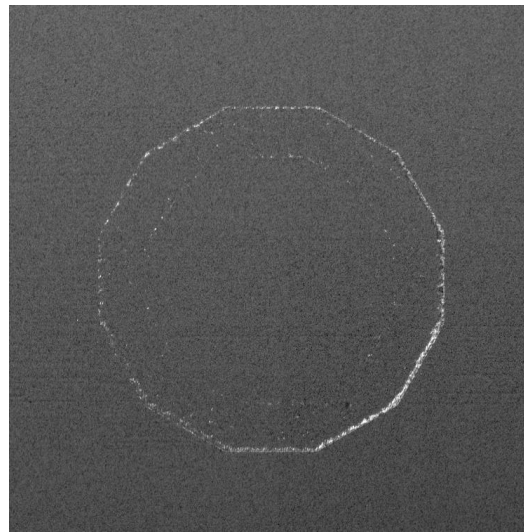
Image Data



reference layer geometry
(from CAD)

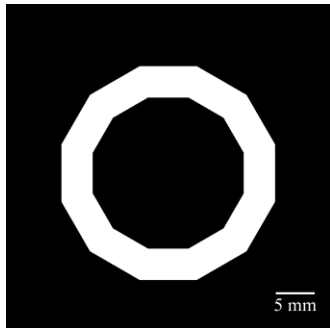


layer image (i)

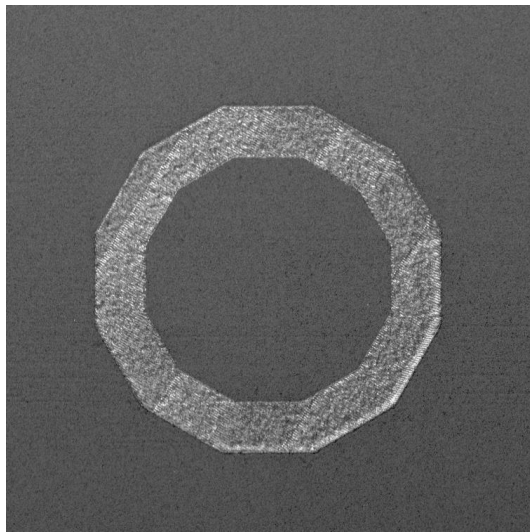


powder layer (i+1)

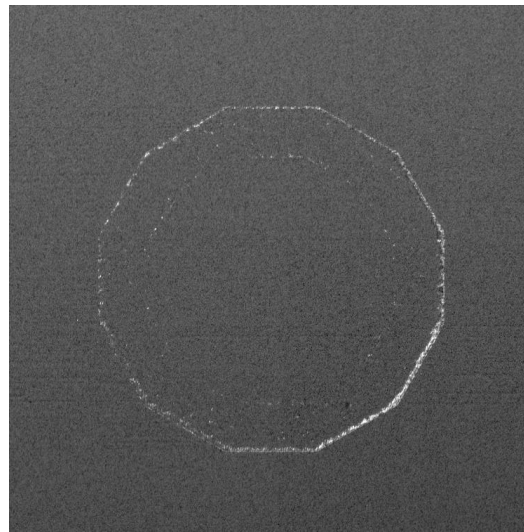
Image Data



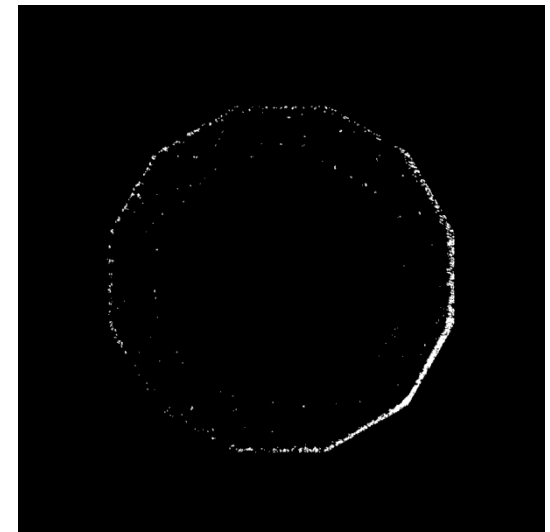
reference layer geometry
(from CAD)



layer image (i)

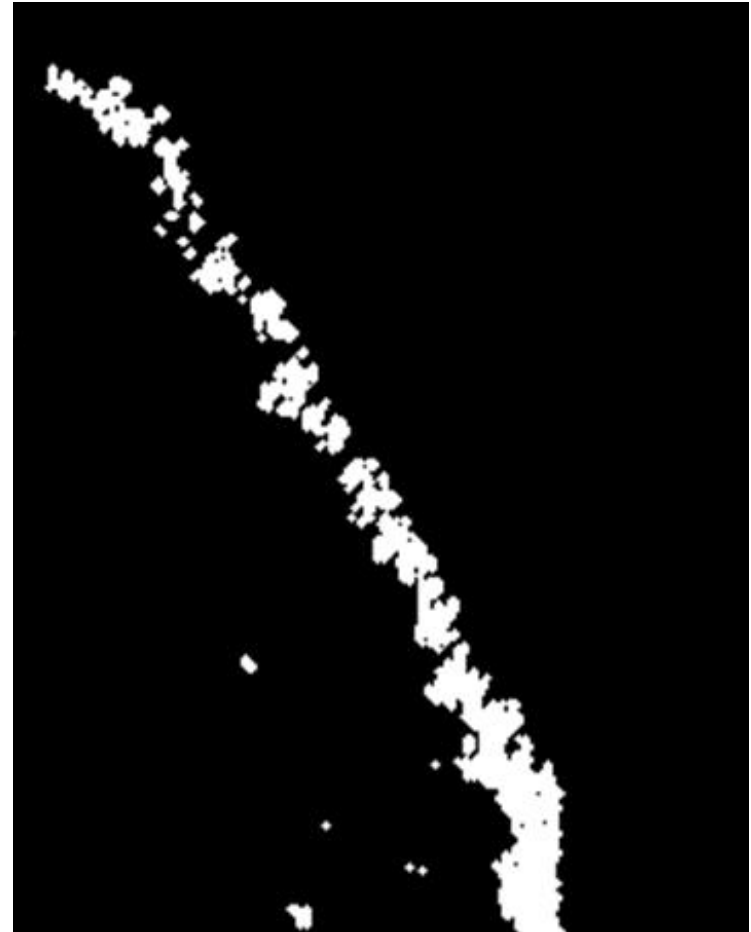
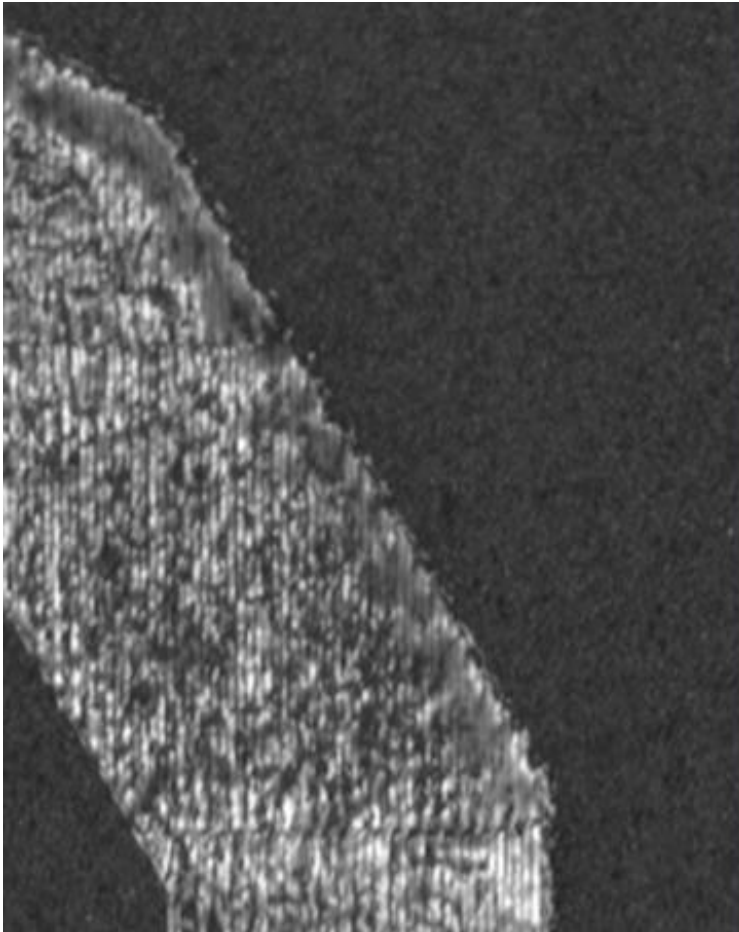


powder layer (i+1)



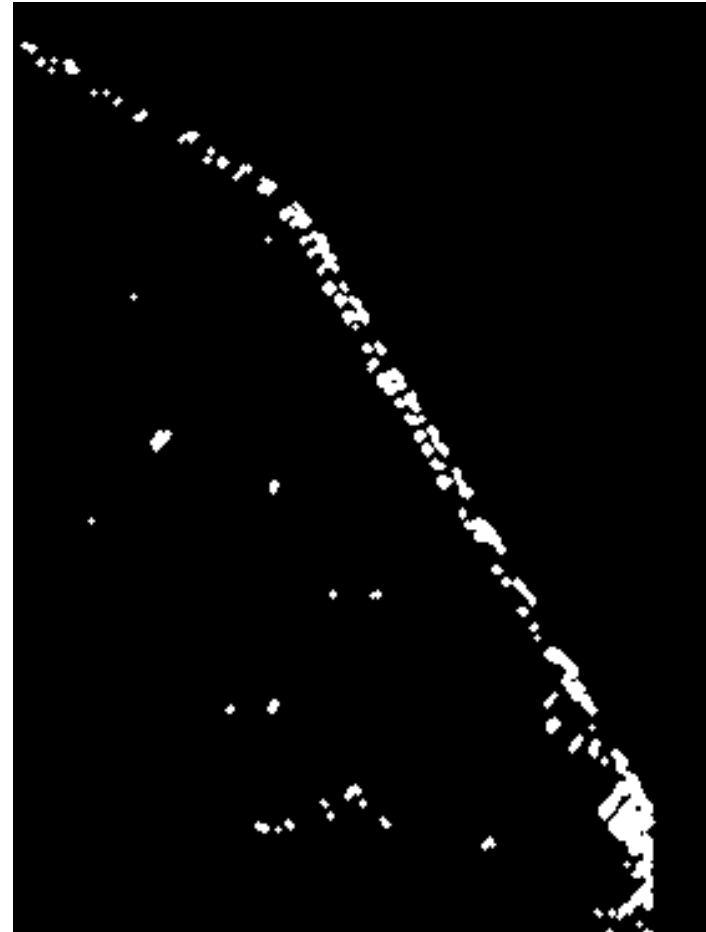
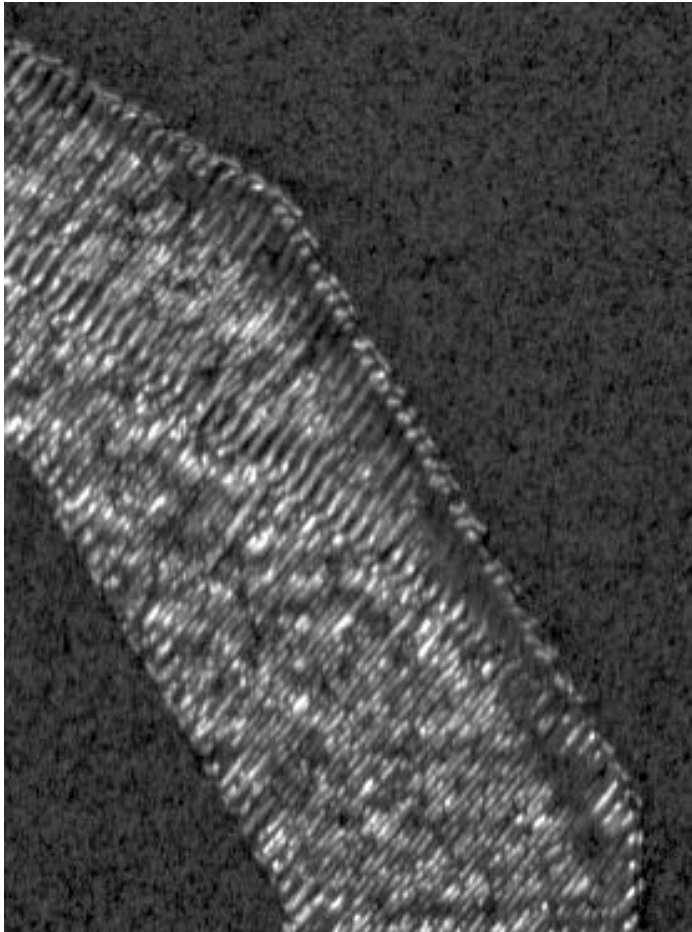
segmented elevated
regions: **ground truth**

Sample Regions 1/3



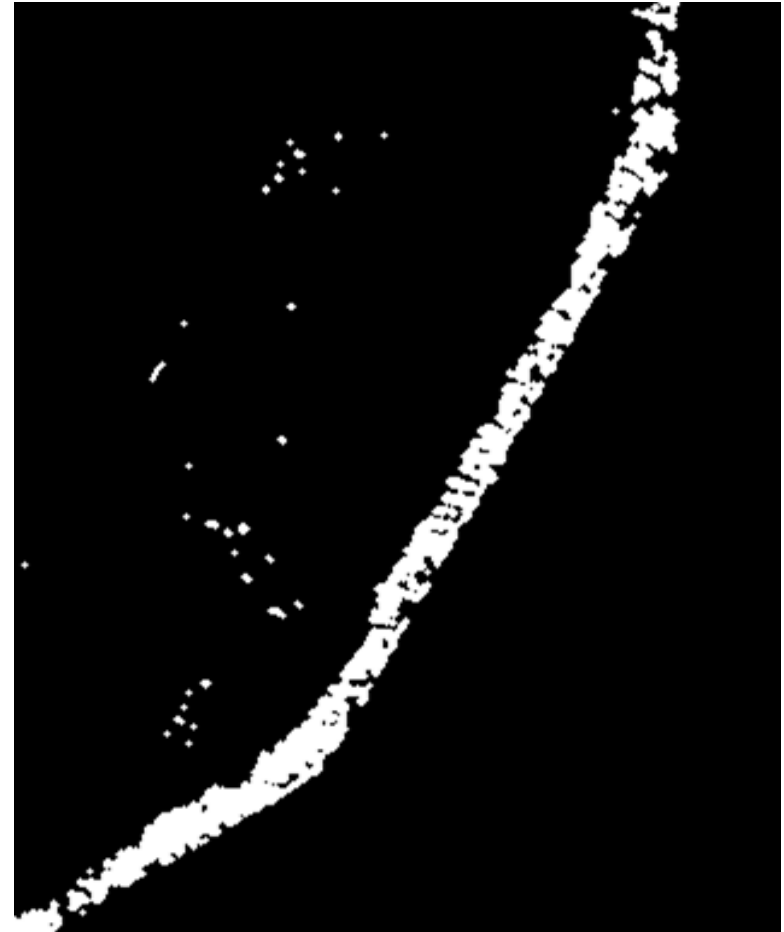
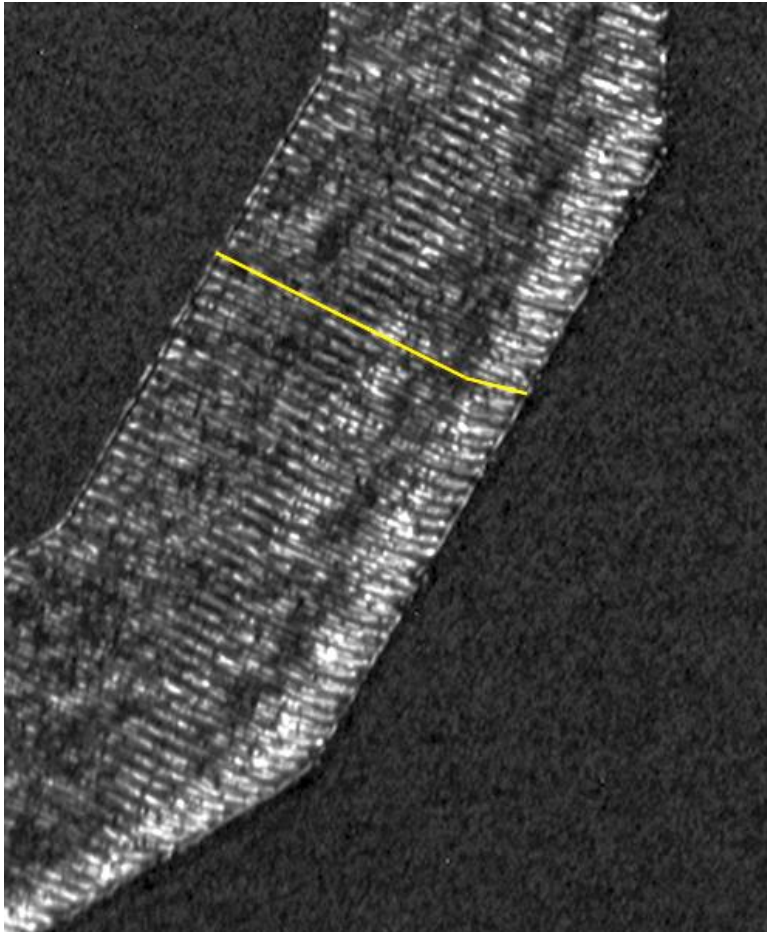
Fused laser scan lines at part edges

Sample Regions 2/3



Ragged contour

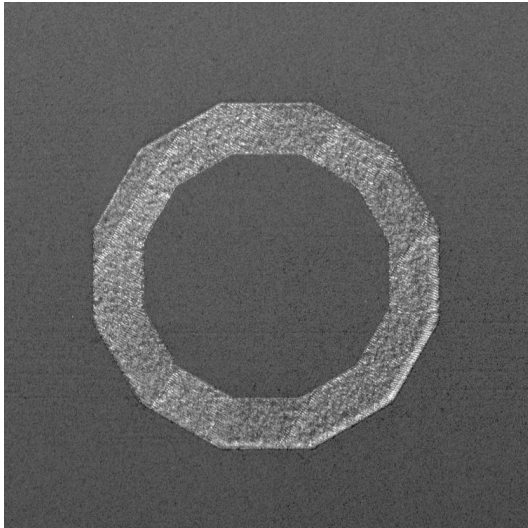
Sample Regions 3/3



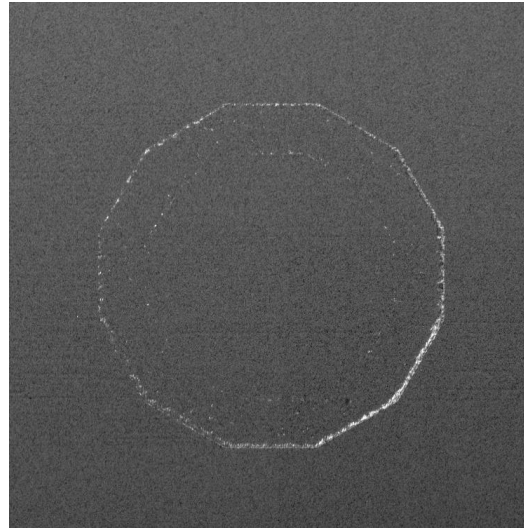
Bent laser scan lines due to elevated edge region

Objective

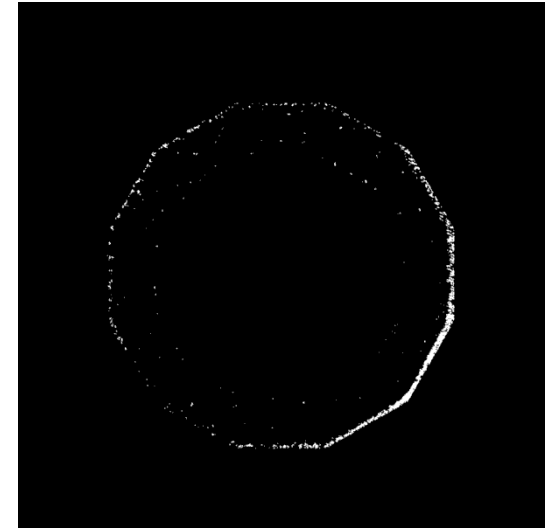
Detect elevated regions in layer image



layer image (i)



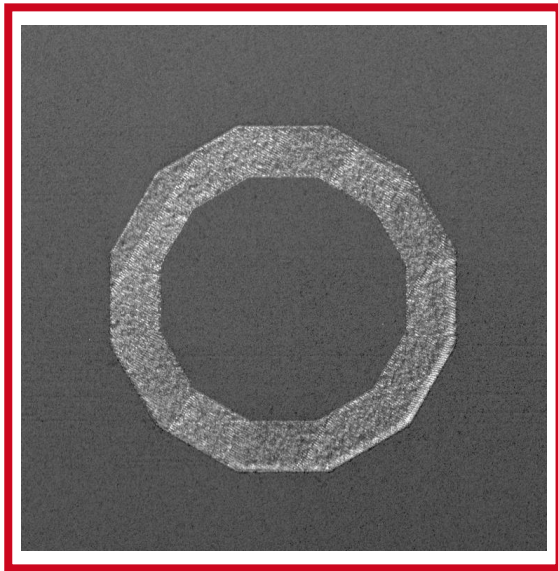
powder layer (i + 1)



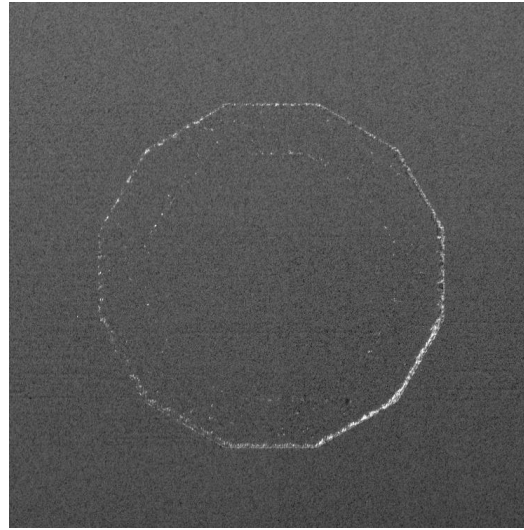
segmented elevated regions: **ground truth**

Objective

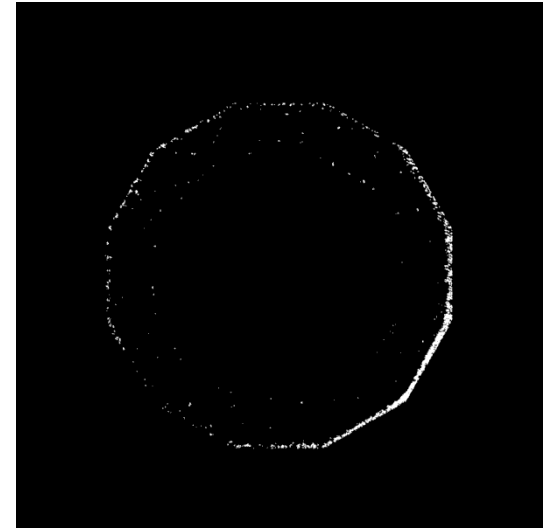
Detect elevated regions in layer image



layer image (i)



powder layer (i + 1)

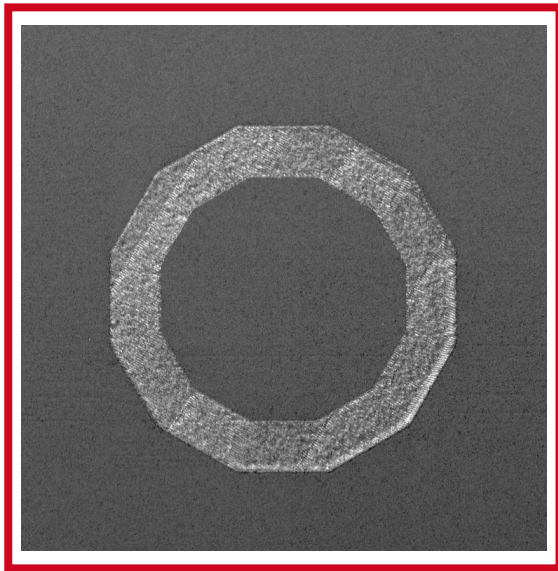


segmented elevated regions: **ground truth**

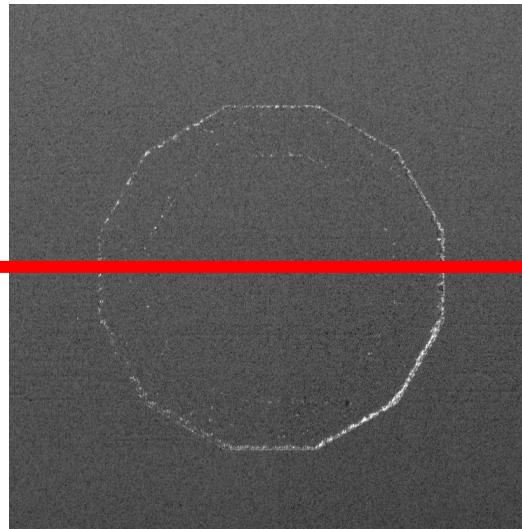
Objective

Detect elevated regions in layer image

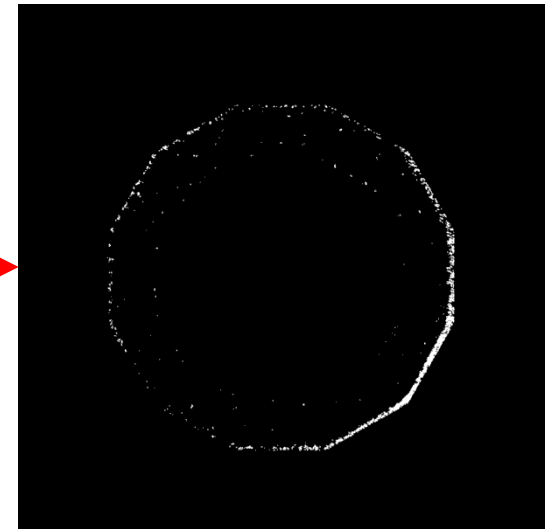
- **Before** next powder layer is deposited



layer image (i)



powder layer (i + 1)

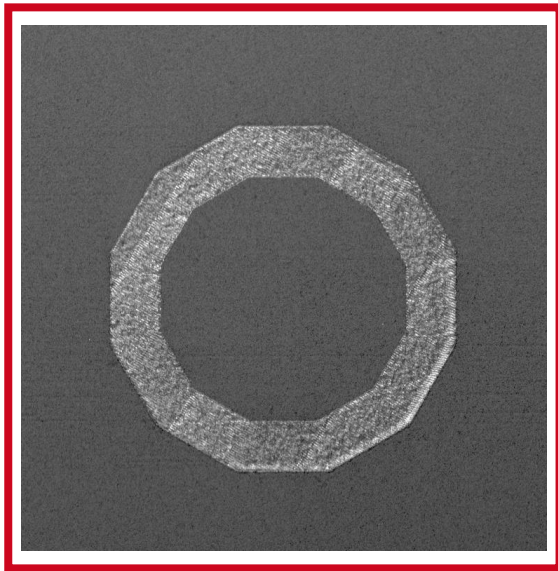


segmented elevated regions: **ground truth**

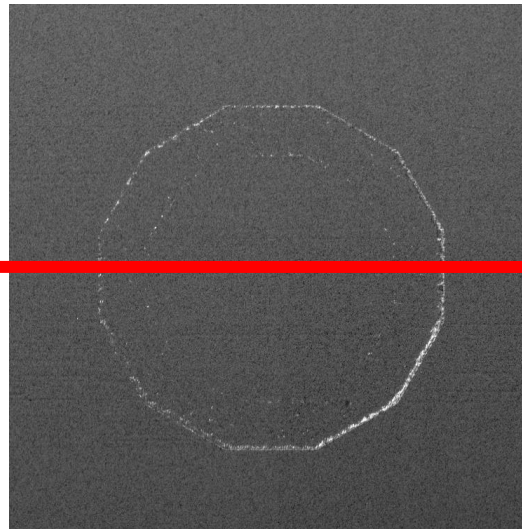
Objective

Detect elevated regions in layer image

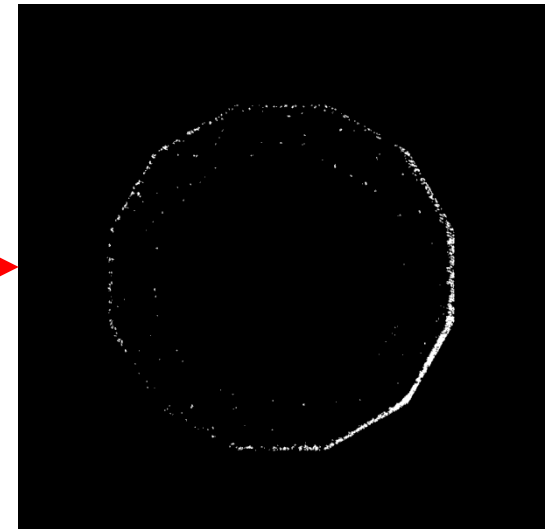
- **Before** next powder layer is deposited



layer image (i)



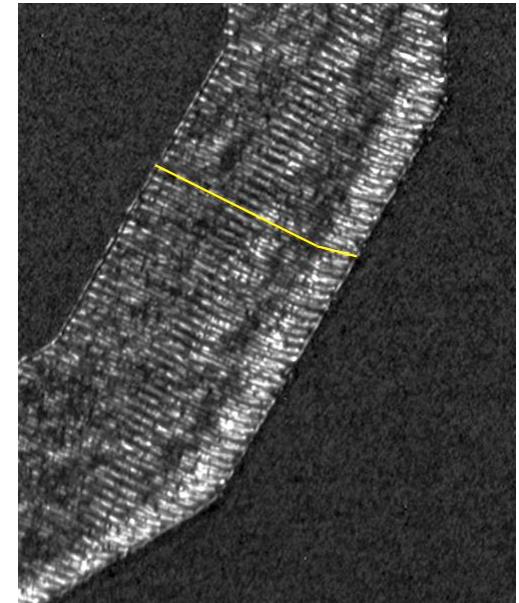
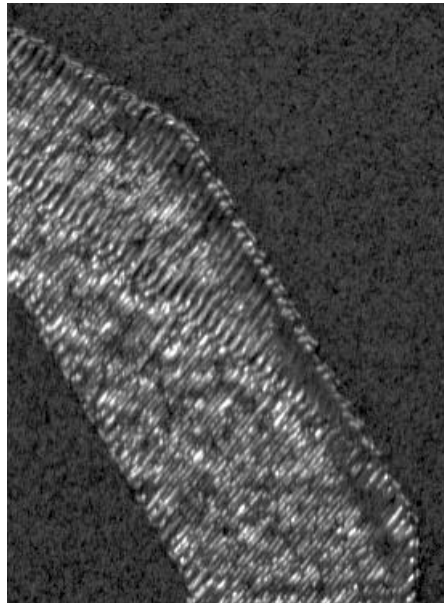
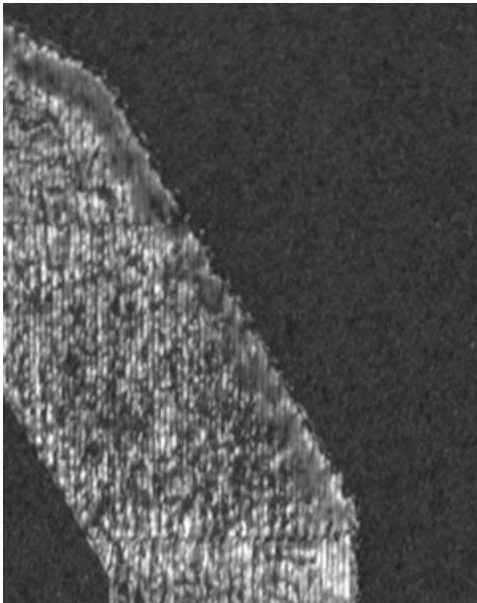
powder layer (i + 1)



segmented elevated regions: **ground truth**

Analyze local scan line shape

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

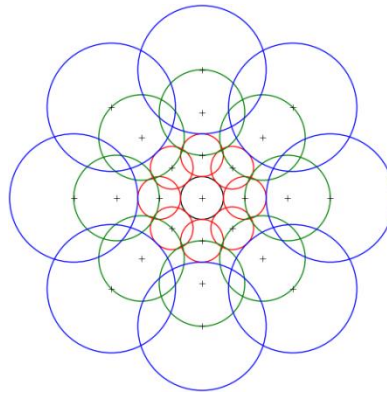


Descriptors

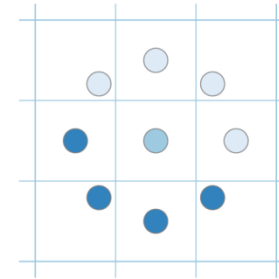
- Histogram of Oriented Gradients (HOG) [Dalal&Triggs, 2005]
- DAISY: log-polar sampling grid [Tola et al., 2010]
- Local Binary Patterns (LBP): “traditional” texture feature [Ojala et al., 2003]



HOG



DAISY



LBP

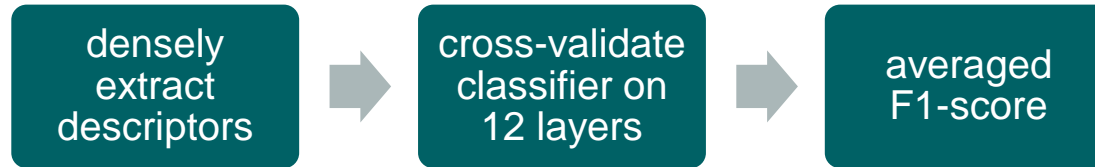
Layer images from 3 build jobs

| Job | # Images | Image Size | Resolution [$\mu\text{m}/\text{px}$] |
|-----|----------|--------------------------|--|
| A | 94 | 2134 px \times 1982 px | 32.9 |
| B | 93 | 2539 px \times 2357 px | 27.7 |
| C | 93 | 3142 px \times 2917 px | 22.3 |

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

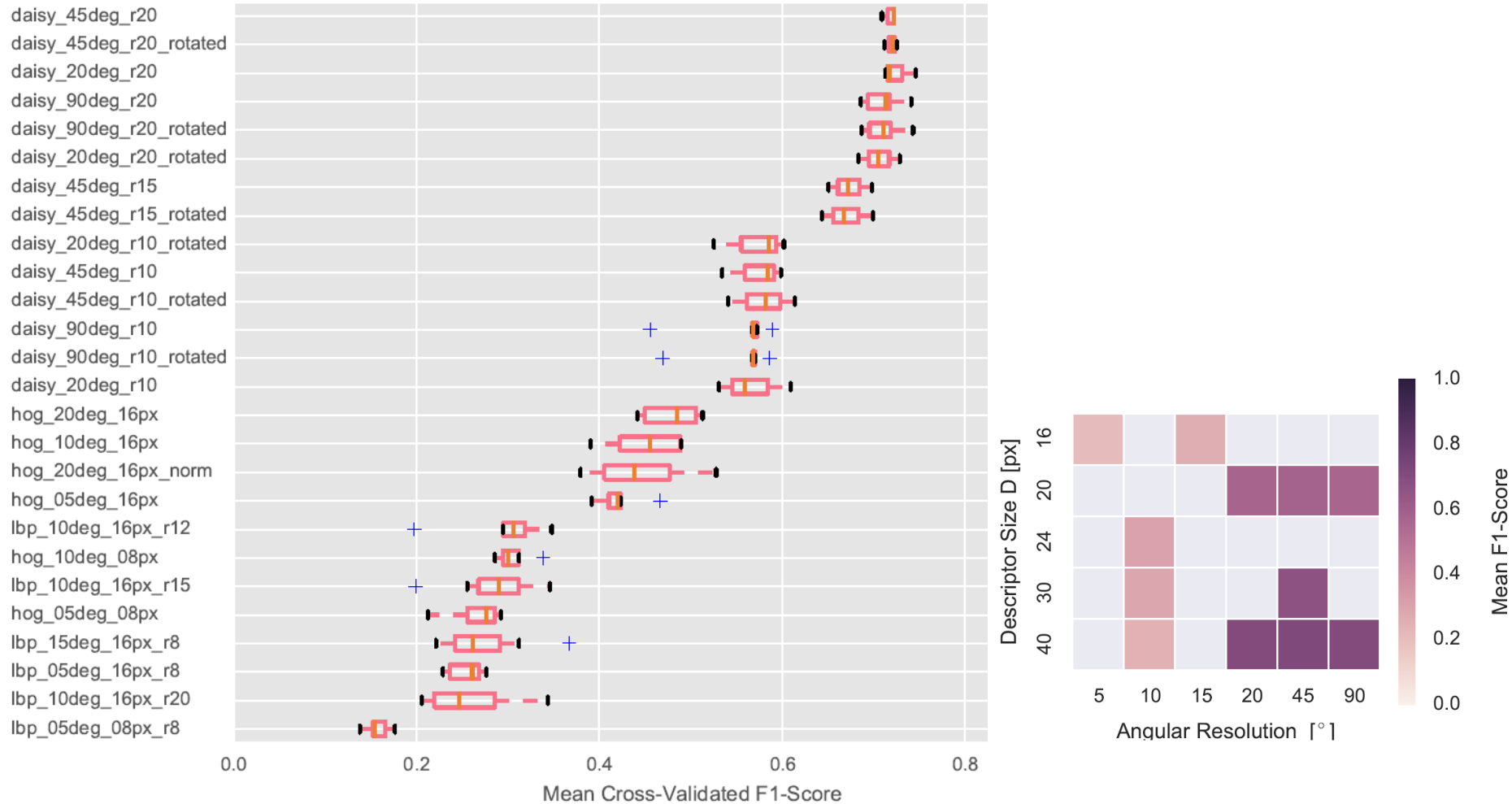
Training of Descriptor Configuration and Classifier

For each
configuration:

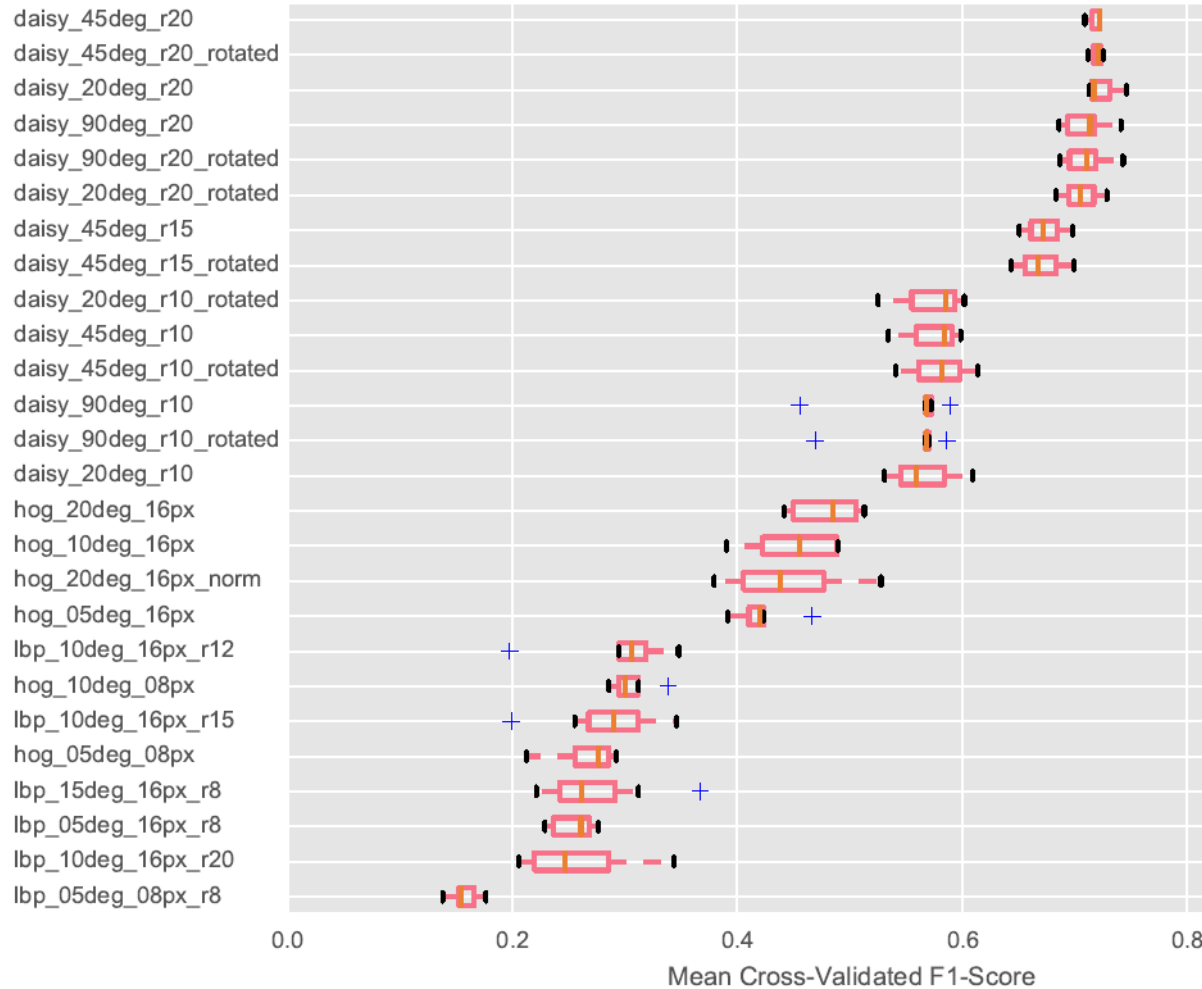


- Parameters
 - descriptor region sizes: {16, 20, 24, 30, 40} pixels
 - angular resolution (# bins in histogram): 5, 10, 20, 45, 90°
- Gradient Tree Boosting classifier for fast evaluation

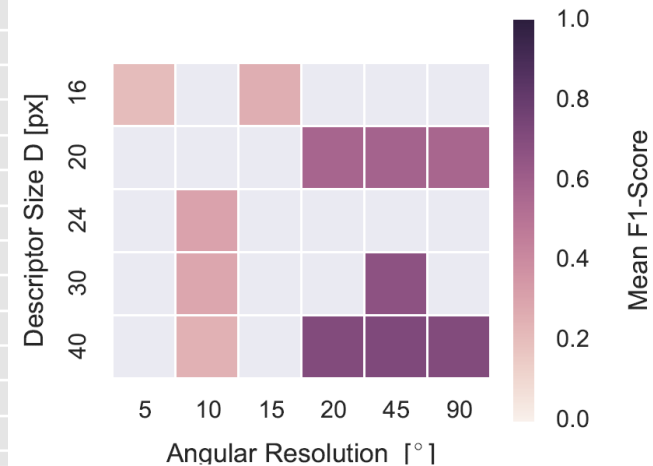
Results – Descriptor Comparison



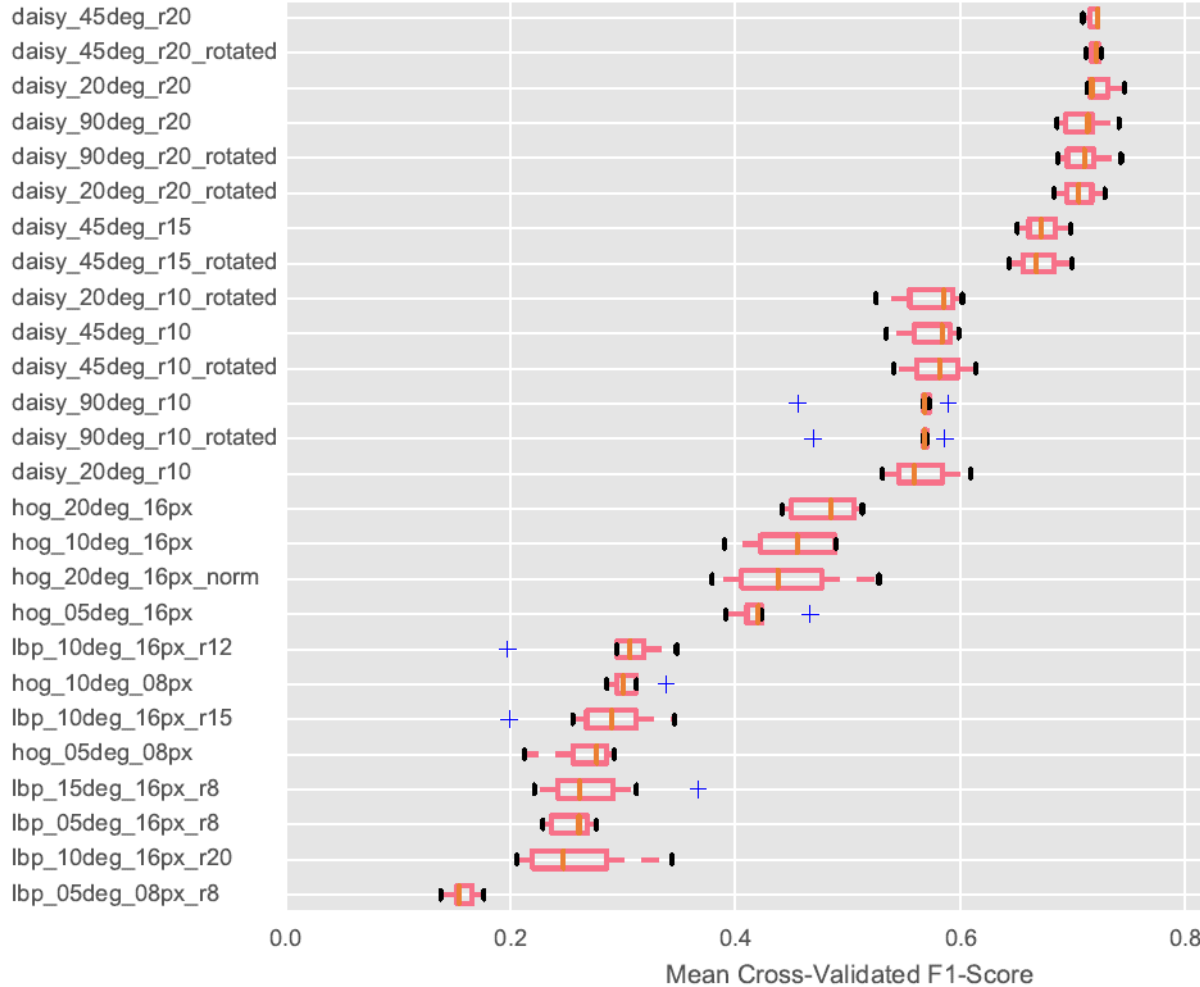
Results – Descriptor Comparison



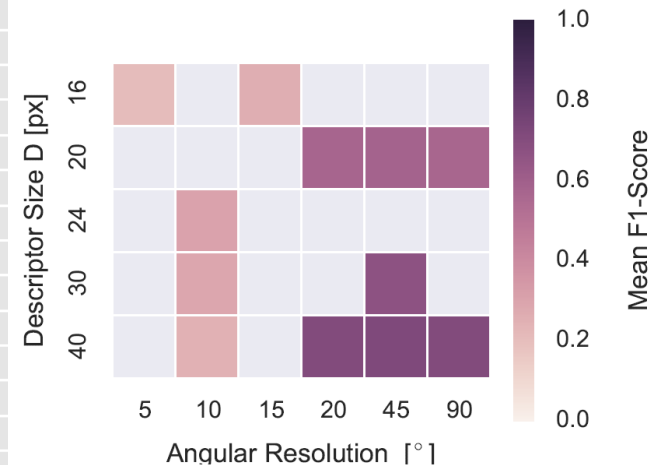
- DAISY best descriptor



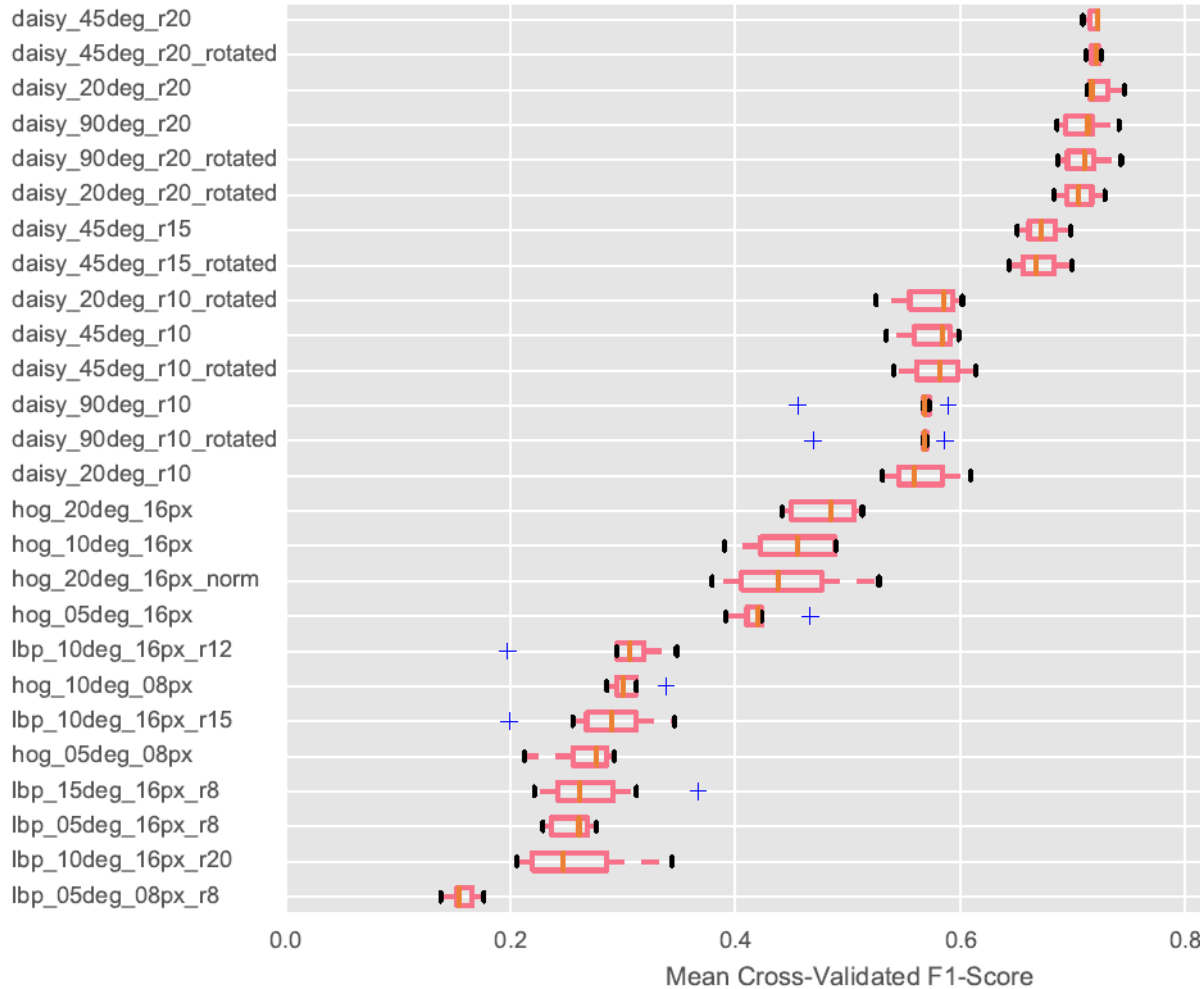
Results – Descriptor Comparison



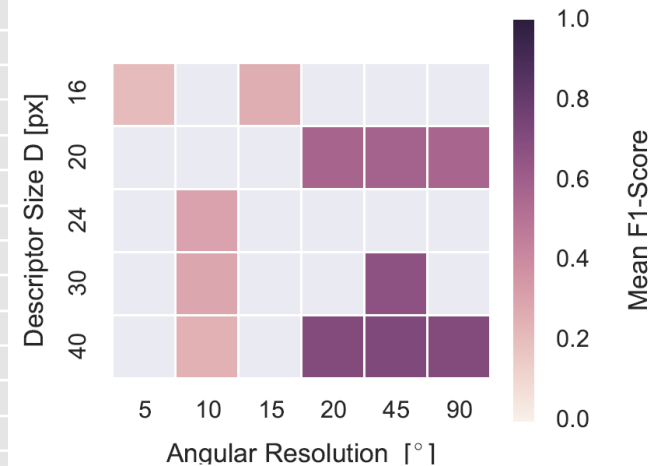
- DAISY best descriptor
- large descriptors yield better performance



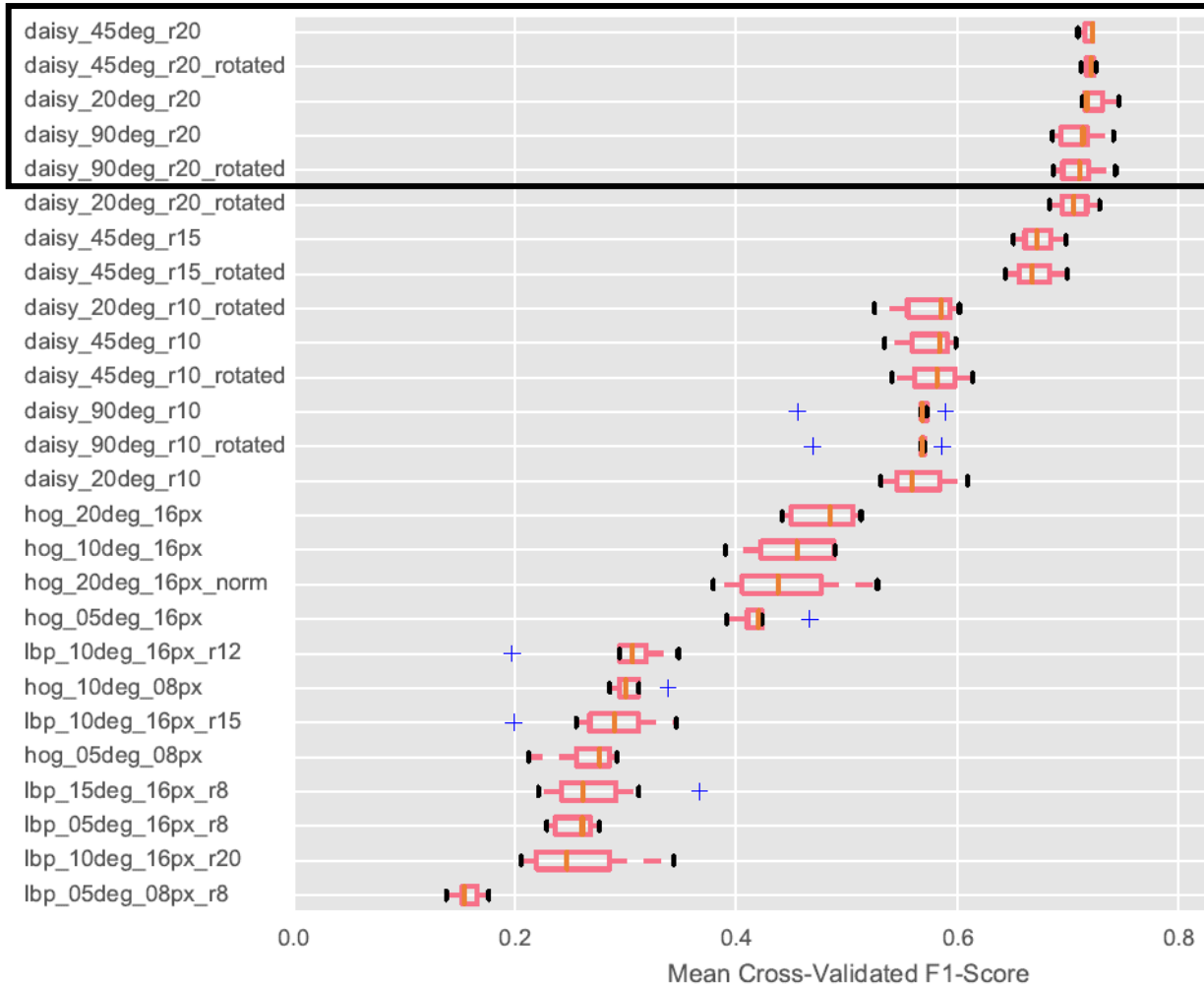
Results – Descriptor Comparison



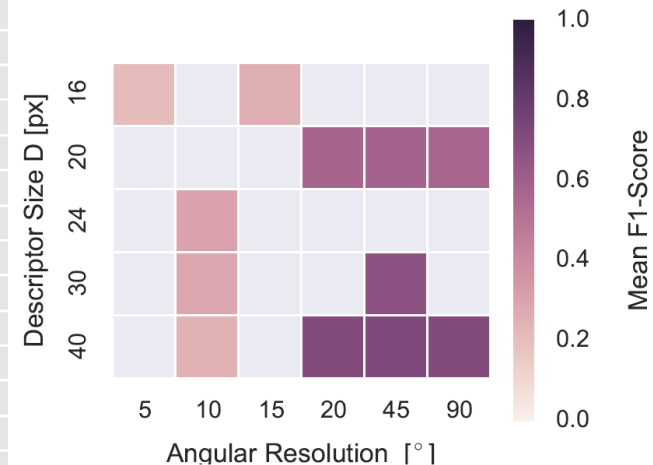
- DAISY best descriptor
- large descriptors yield better performance
- select top 5 configurations



Results – Descriptor Comparison

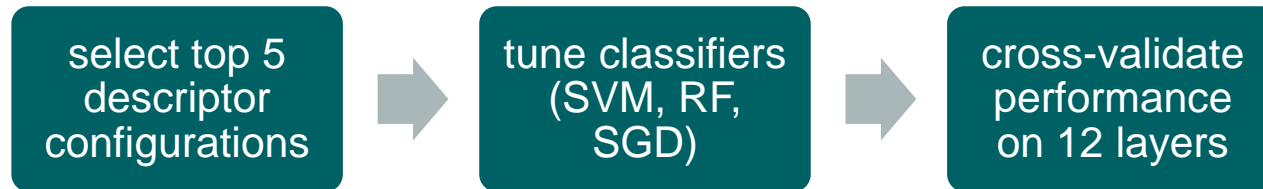


- DAISY best descriptor
- large descriptors yield better performance
- select top 5 configurations

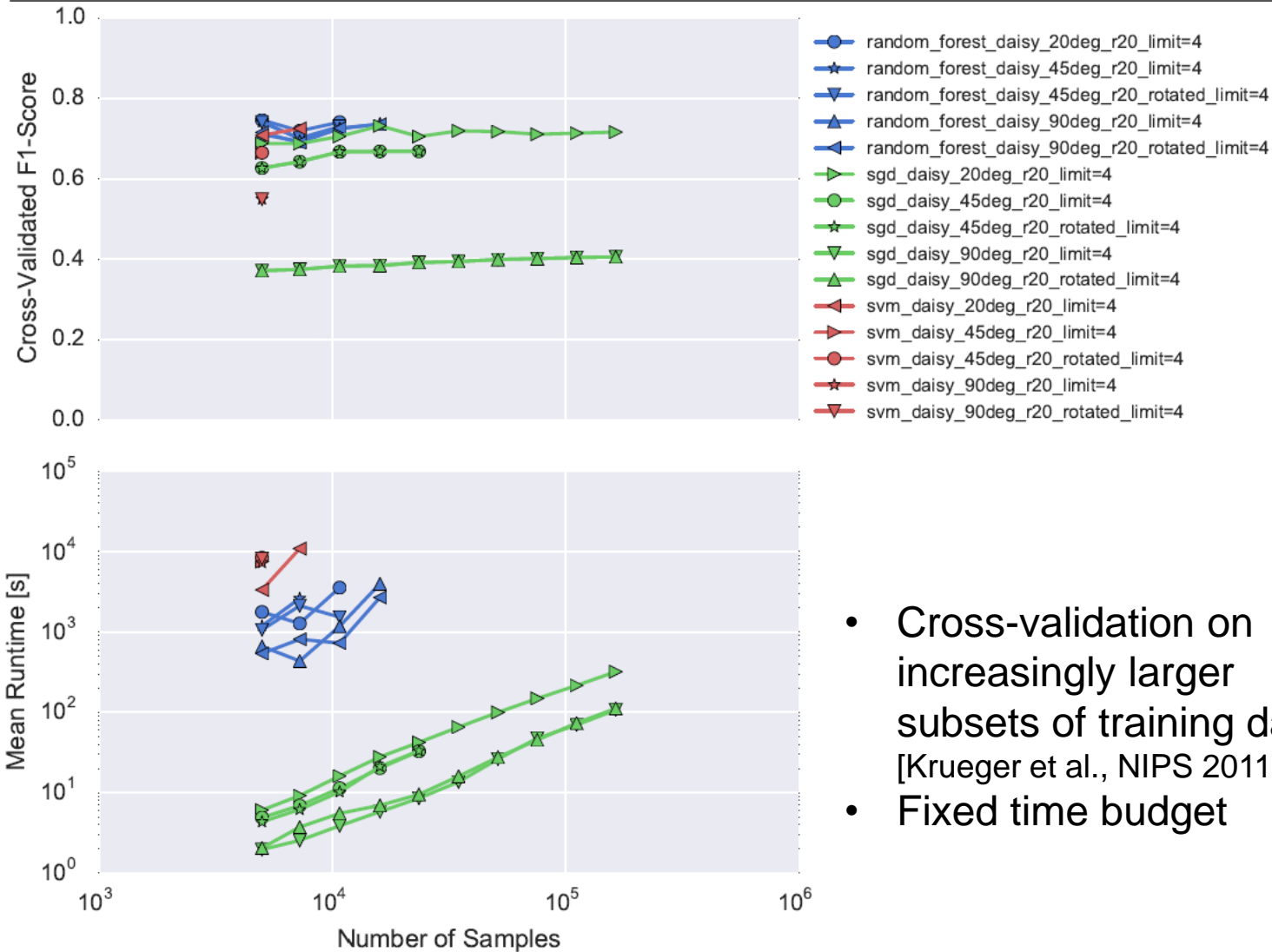


Training of Descriptor/Classifier Pairs

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

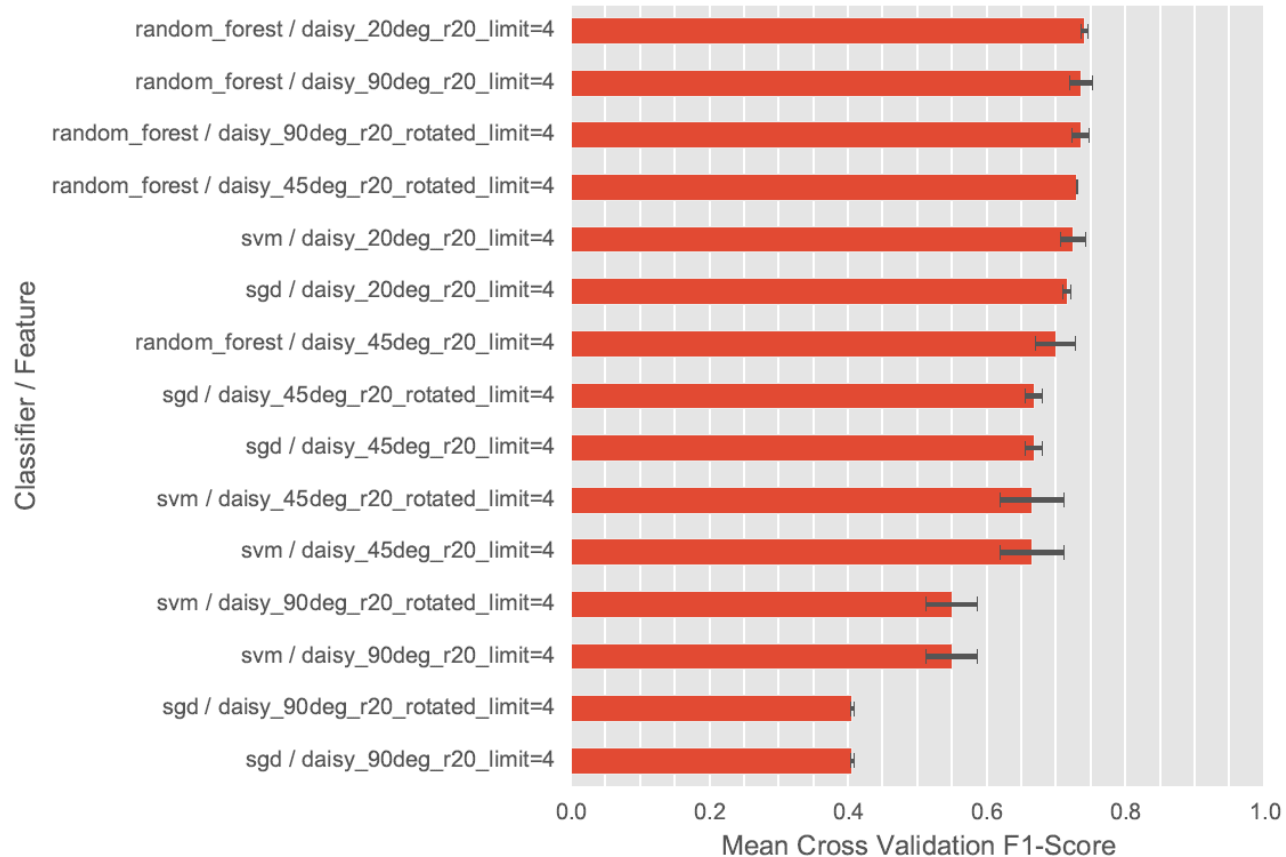


Classifier Parameter Tuning and Learning Curves



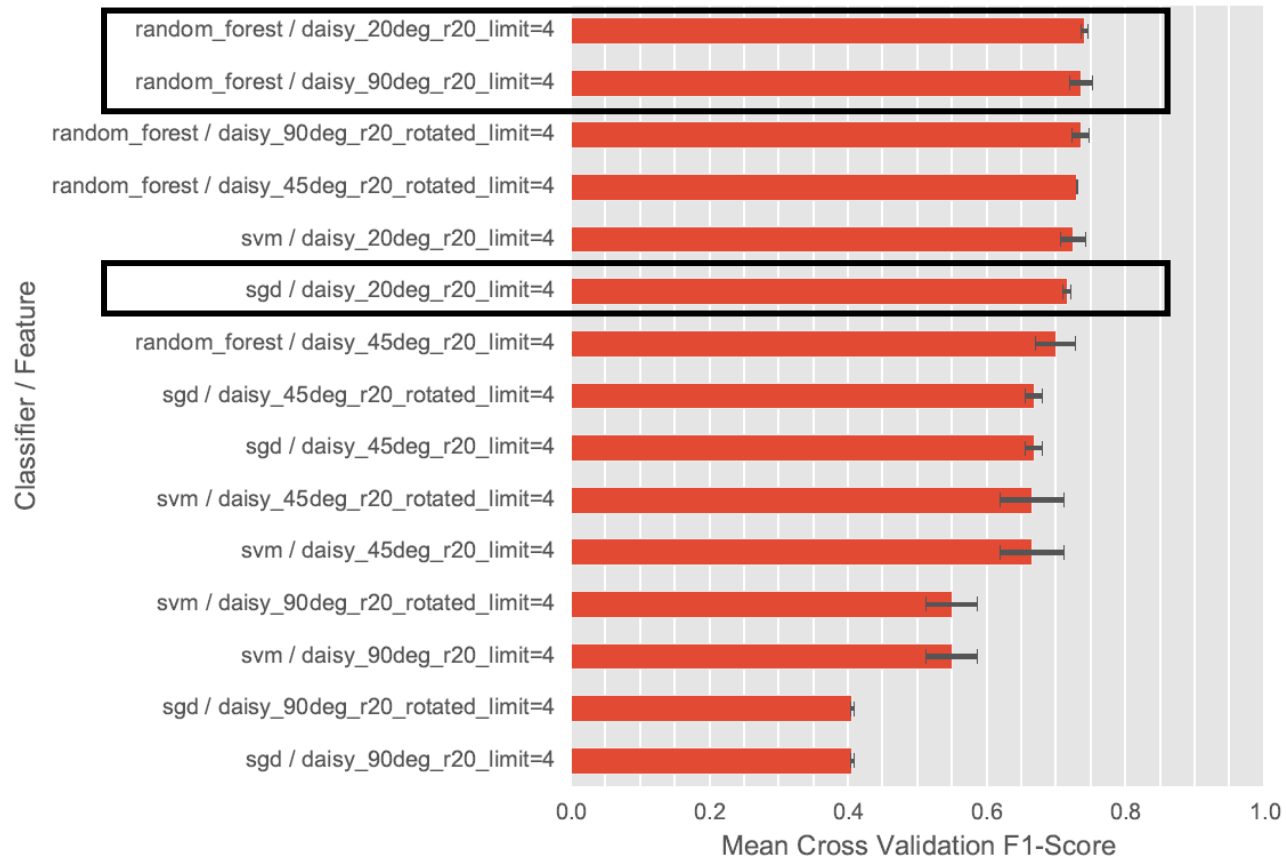
Classifier Parameter Tuning

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 $A = 20^\circ D = 40$ | 11675 | 519825 | 0.670 |
| RF + DAISY $A = 20^\circ D = 40$ | 12 | 2340 | 0.667 |
| RF + DAISY $A = 90^\circ D = 40$ | 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