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Quality and Correlations Monitoring in Metal Additive Manufacturing through Efficient Streaming Machine Learning

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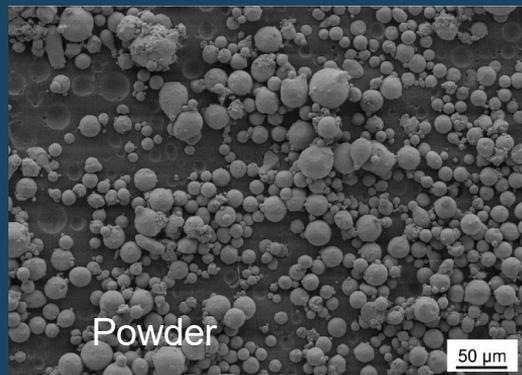
Chalmers University of Technology

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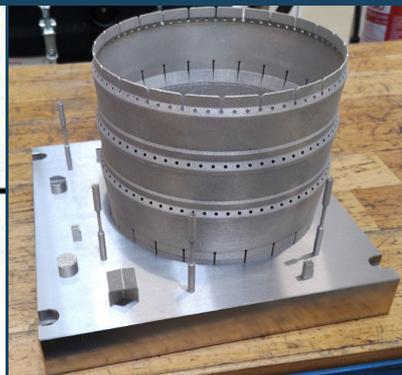
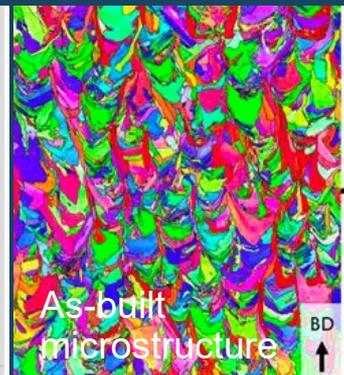
Höganäs AB

Powder bed fusion – laser beam (PBF-LB) : the perfect build?

Hastelloy X – single phase “easy-to-build” material



>99.95%
relative density



Y.S. (MPa)	UTS (MPa)	Elong. (%)
425	680	>30

But if not, how to detect defects/flaws in process?

How to finally tackle feed-back control?

Process development mapping- broader scope

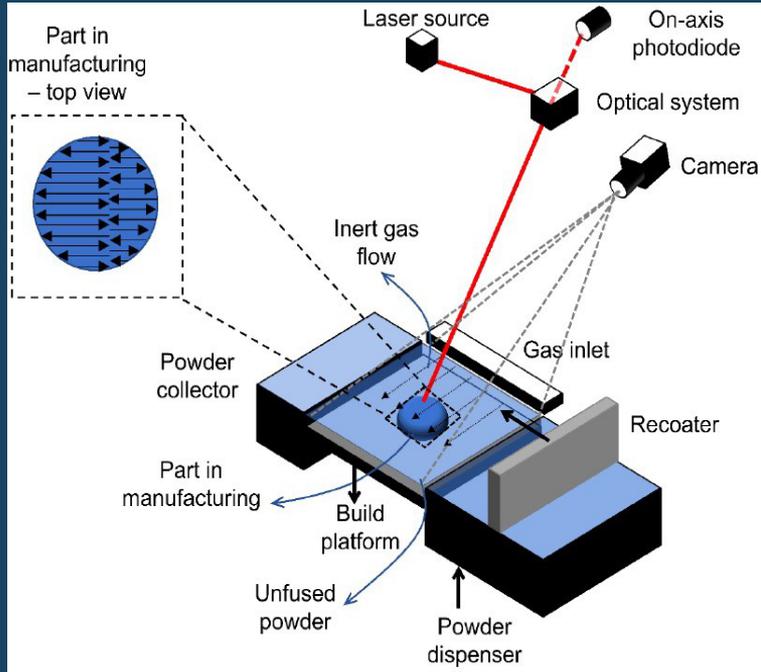
			Laser scan speed (mm/s)							
			200	400	600	800	1000	1200	1400	1600
Laser power: 100 W	Nominal layer	20	0.39	0.01	0.31	1.41	5.48	7.97	11.6	14.2
	thickness	40	0.14	0.76	0.78	5.95	14.3	19.4	27.3	32.1
	(μm)	80	5.61	11.7	16.5	26.8	35.1	45.4	N/A	N/A
Laser power: 200 W	Nominal layer	20	4.47	2.55	0.03	0.01	<0.01	0.19	0.63	1.27
	thickness	40	5.12	2.77	0.02	0.01	0.09	0.44	1.67	4.51
	(μm)	80	6.79	2.19	0.11	0.31	6.90	12.1	18.8	25.6
Laser power: 300 W	Nominal layer	20	N/A	2.34	0.44	<0.01	<0.01	0.02	0.10	0.14
	thickness	40	3.31	3.50	0.30	<0.01	0.01	0.04	0.12	0.26
	(μm)	80	4.50	3.19	0.35	0.01	0.03	0.06	0.39	2.53

Number of different settings nominally give high quality build!

For real component, how sure are we that local conditions are consistent in every part of the the part?

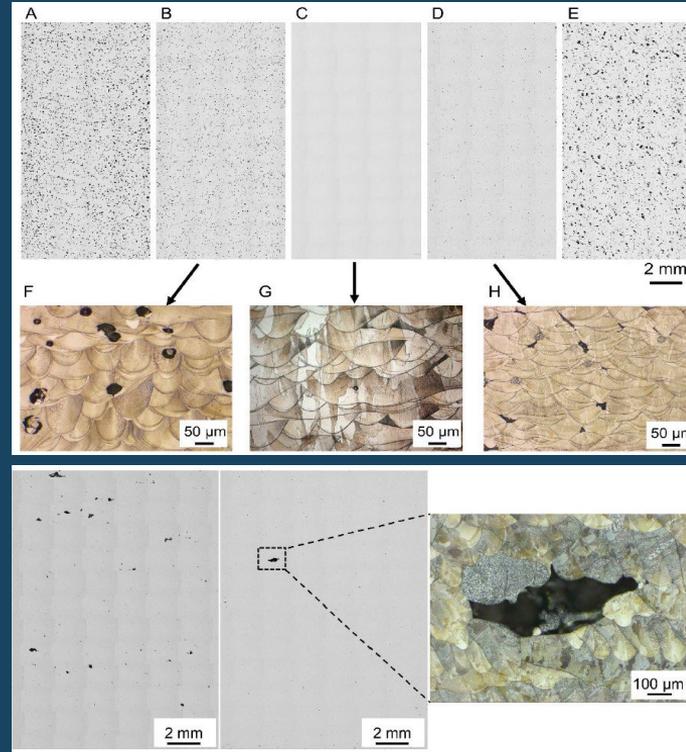
Most probably, we want to depict defects/flaws as they are created in the process, how?

On-line monitoring (EOSTATE system)



Hereafter: *near IR imaging using Optical tomography (OT) = integrated gray scale image across whole build including powder bed*

Metallography



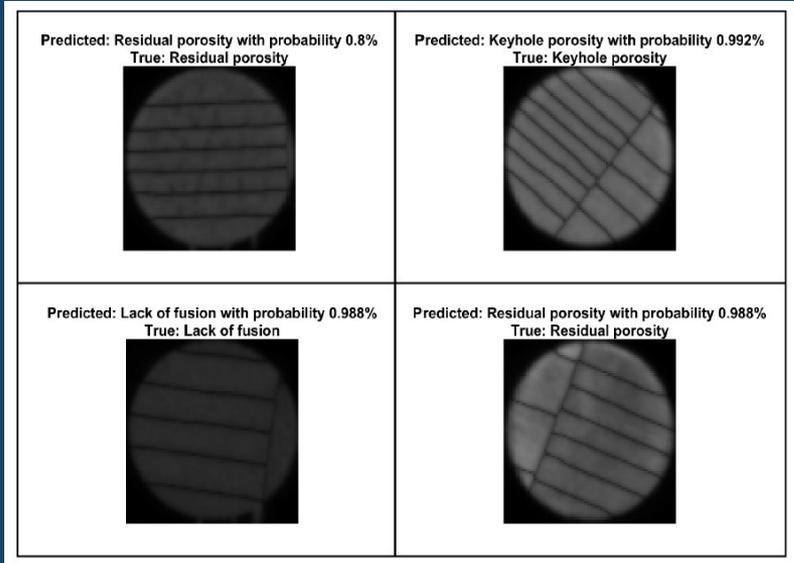
Systematic defects

Stochastic defects

Correlating OT with material characterisation using neural network approach



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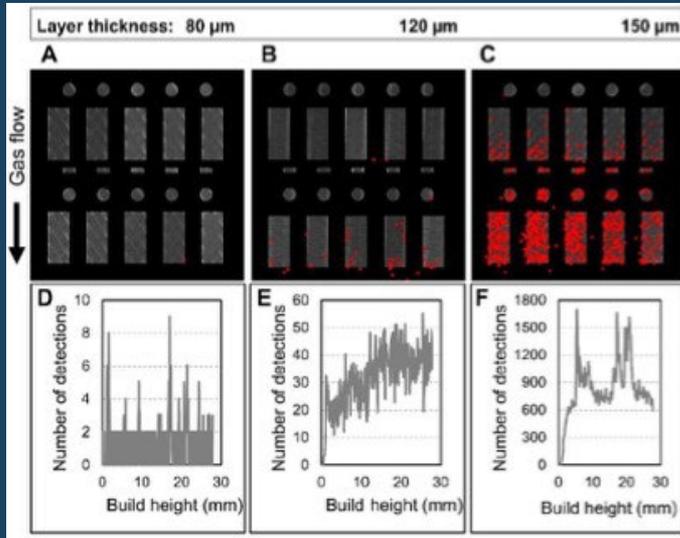
Predicted class	Keyhole porosity	378 33.7%	4 0.4%	6 0.5%	97.4% 2.6%	Precision False discovery rate
	Lack of fusion	0 0.0%	347 30.9%	6 0.5%	98.3% 1.7%	
	Residual porosity	1 0.1%	8 0.7%	372 33.2%	97.6% 2.4%	
		99.7% 0.3%	96.7% 3.3%	96.9% 3.1%	97.8% 2.2%	Recall False negative rate Overall accuracy
		Keyhole porosity	Lack of fusion	Residual porosity		
		True class				

Note: in-line monitoring does not depict defects, it only catches process deviation information!

Stochastic defects – in-situ process monitoring by OT to depict spatter



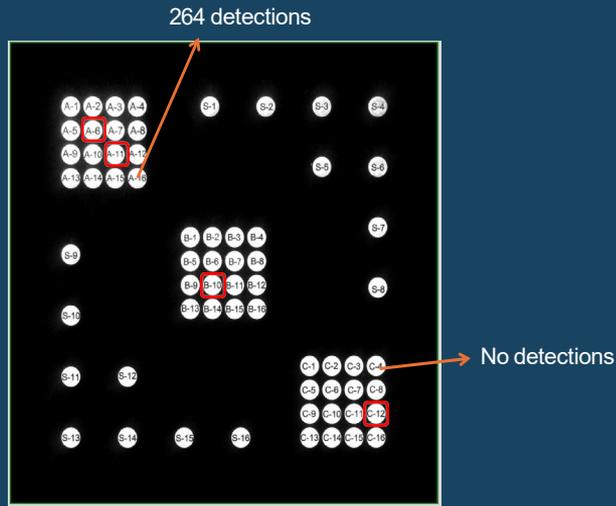
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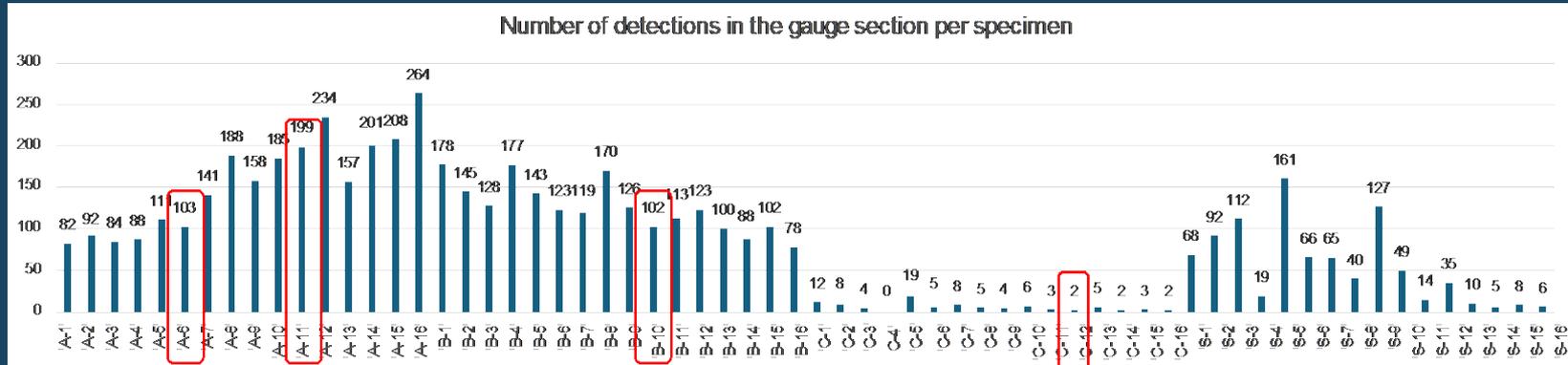
OT allows in-situ detection of spatter

Can we correlate this in some way with for example X-ray Computer Tomography (XCT)?

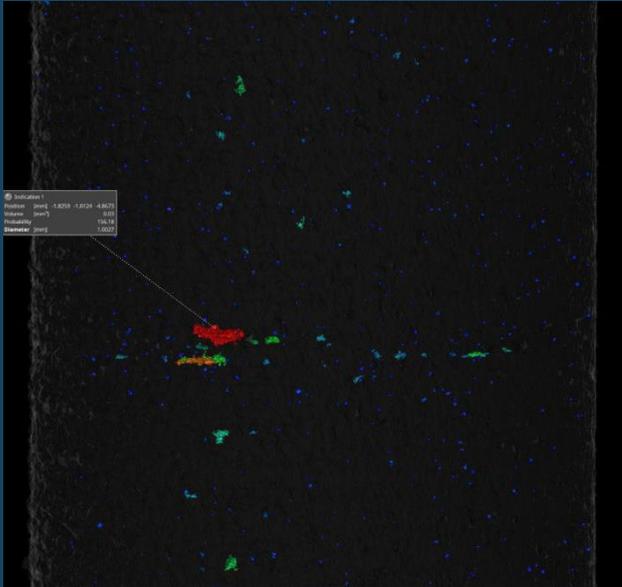
Yes, next slide!



Specimens selected for XCT: marked in red

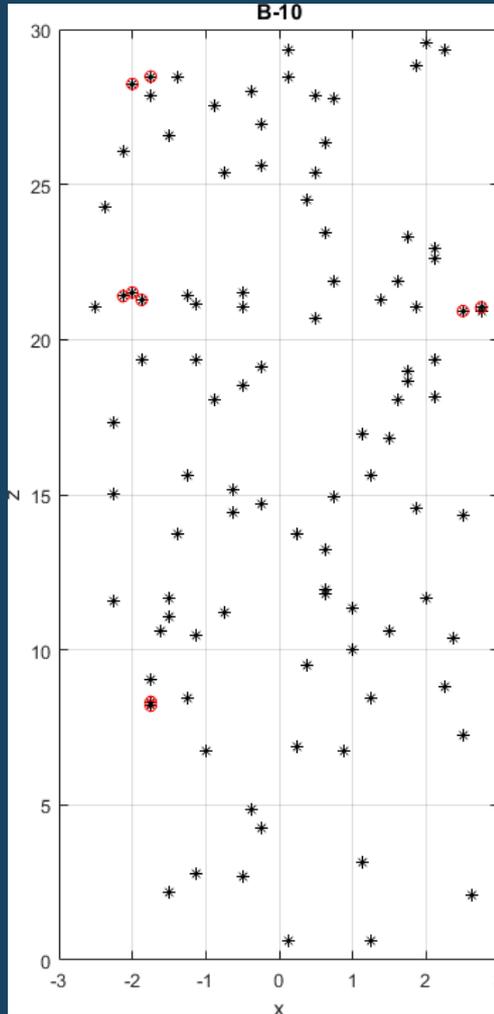


B-10



XCT:

- Numerous defects grouped at the same z coordinate
- Further large defects present along z



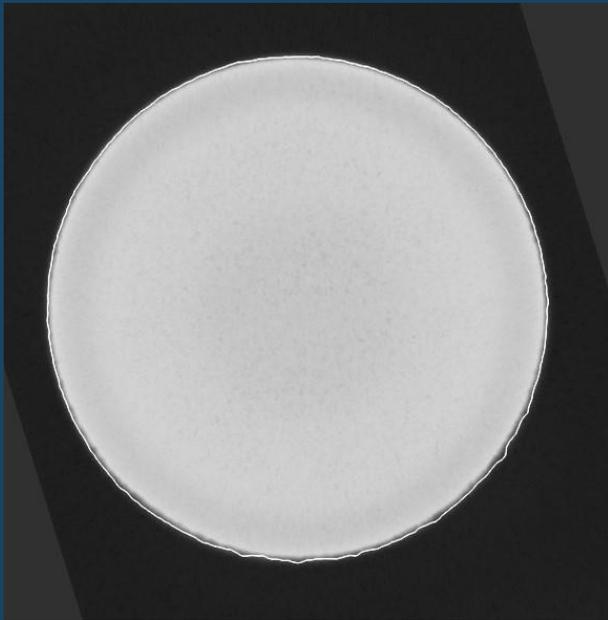
OT

- 102 detections in the gauge section
- Well distributed along z
- Clusters (in red) → high chances of large defects

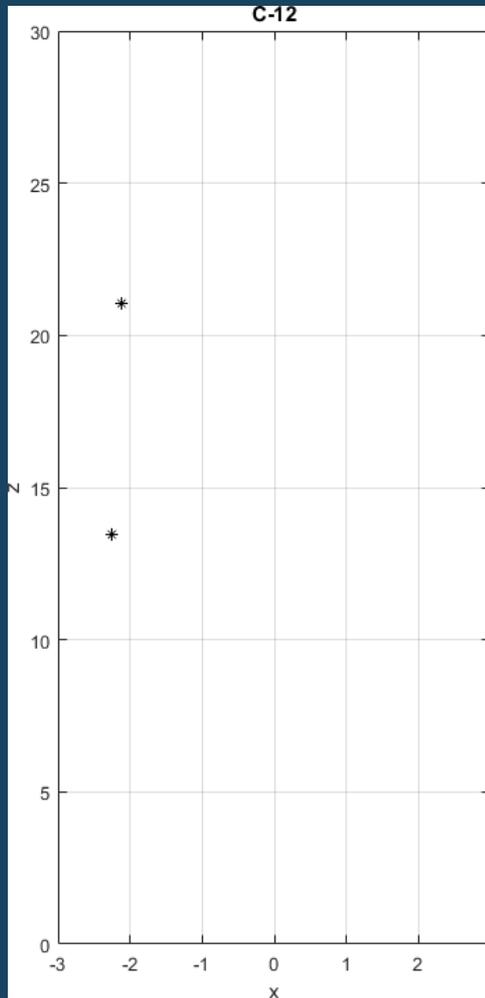


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C-12



XCT: no apparent defects

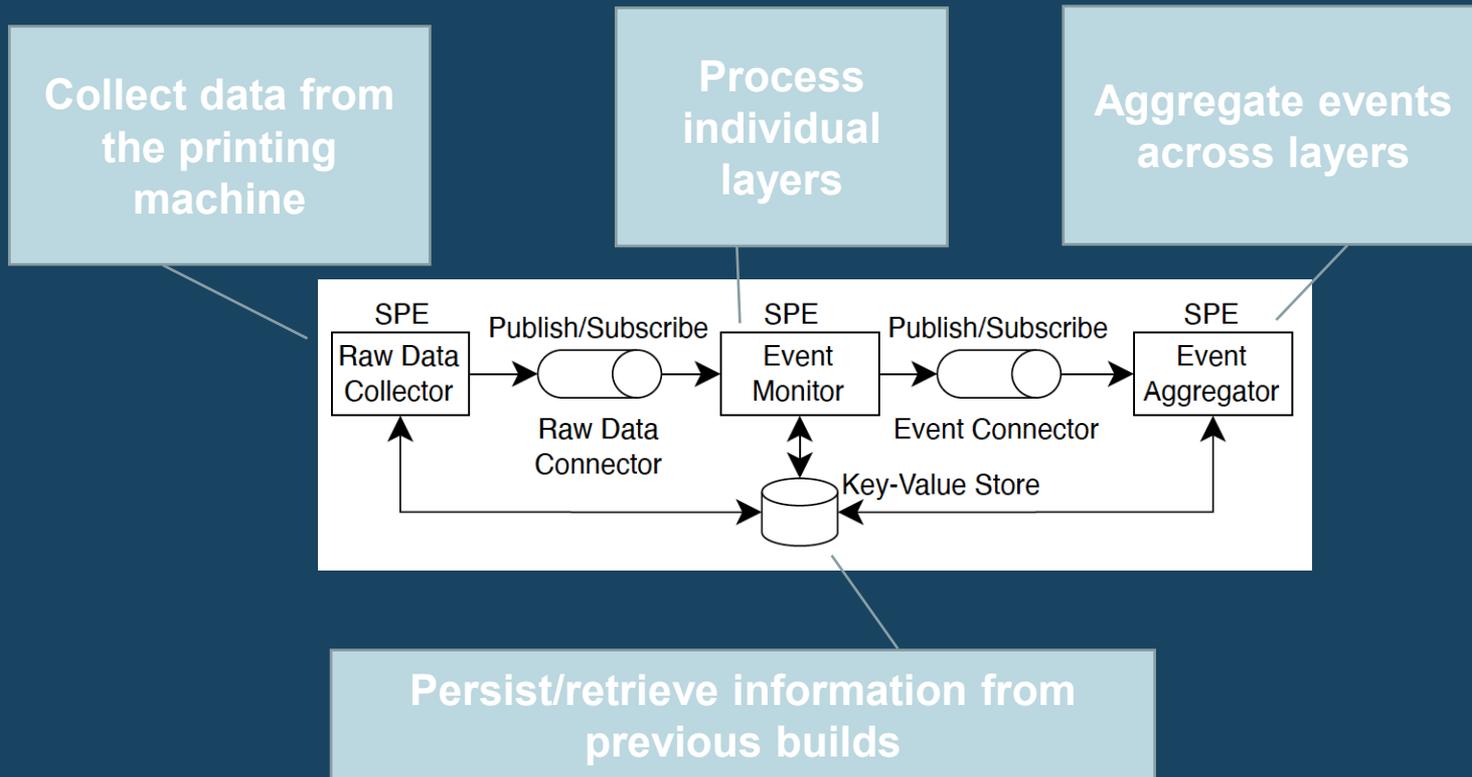


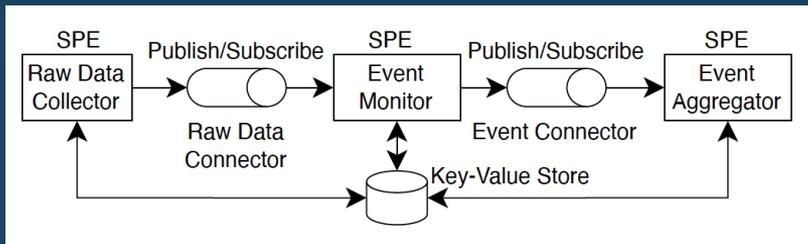
OT

- 2 detections in the gauge section
- No clusters



The STRATA framework





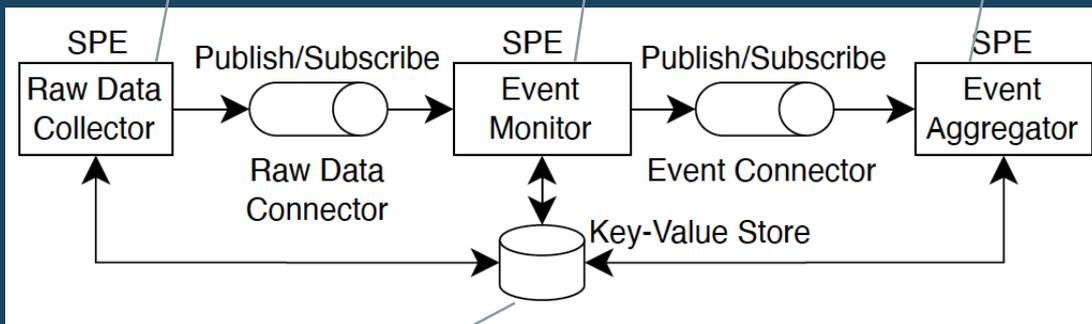
- Make timely decisions.
 - A printing process shows signs of defects? Re-configure or terminate as soon as possible → save energy, material, time, and be more sustainable.
- Monitor a process by integrating/fusing information from the current process as well as past ones.
- Offer experts with complex/rich analysis semantics that scale.

Evaluation – Temperature monitoring

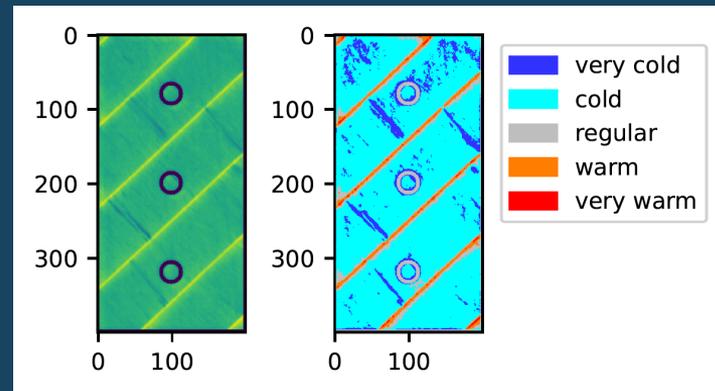
Collect Optical Tomography (OT) images

Cluster/label specimens' portions

Cluster too-cold/too-warm specimens' portions across layes

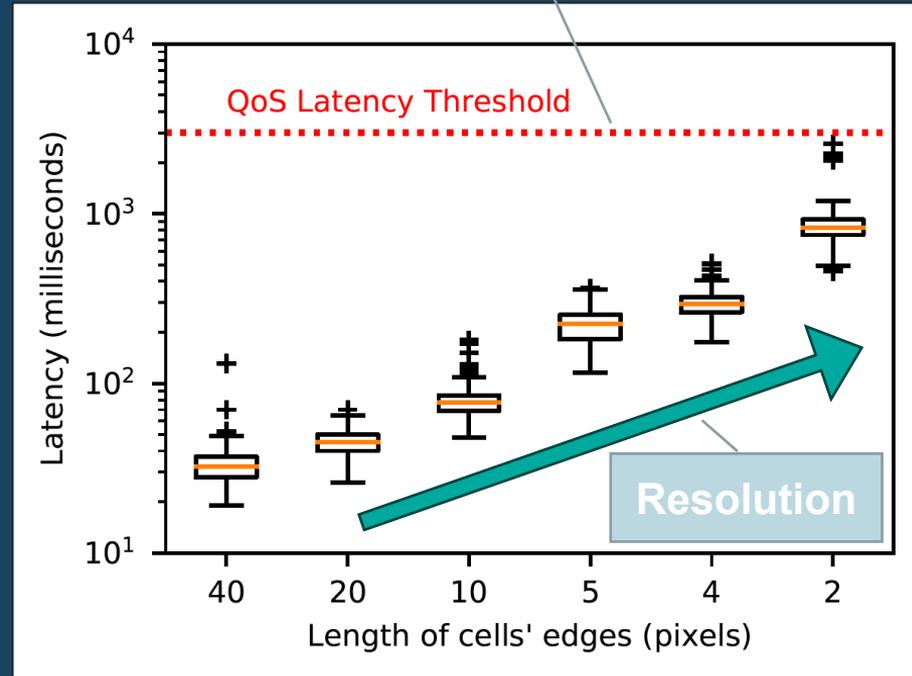
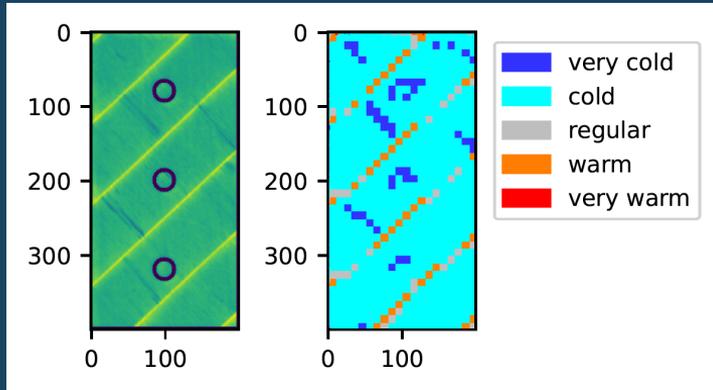


Maintain thresholds used to cluster specimen from historical data

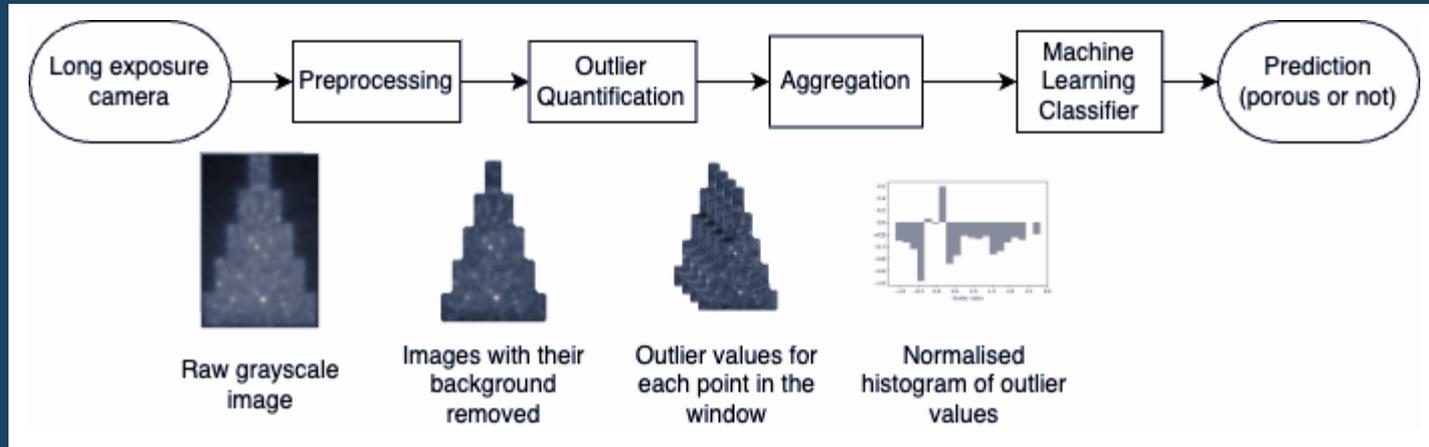
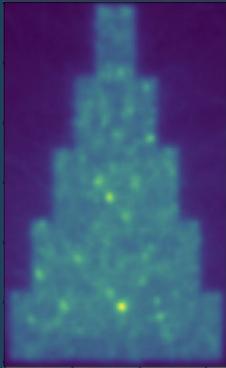


Evaluation – Temperature monitoring

Threshold to take decisions before the next layer printing starts



Porosity Prediction





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