Automatic detection of rail surface defects using video image: A case study in the Dutch railways

Lunch lecture series of Monitoring Community
10th May 2019

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Assistant Professor, TU Delft
Section of Railway Engineering

Outline

1) Video Image based Monitoring of Rail

2) Deep Neural Networks for Rail Monitoring

3) Making use of the data: Risk analysis

4) Conclusions

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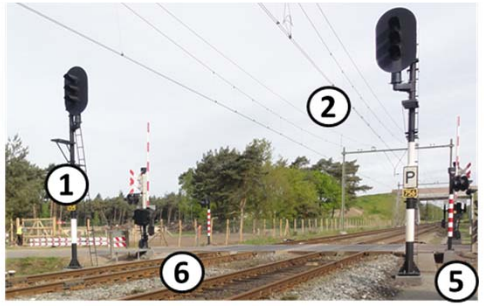
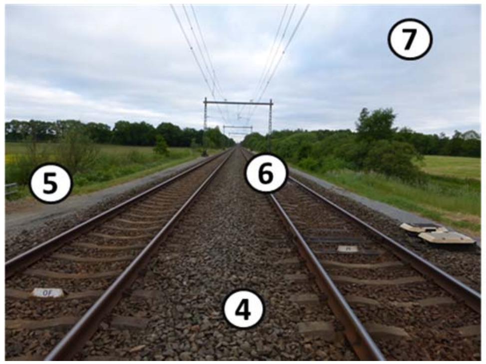
Railway Infrastructure

Railway Infrastructure

1. **Safety system:** signal, interlocking
2. **Energy System:** feeding power supply
3. **Communications:** Speakers, information board, applications
4. **Support:** subsoil, cables and wires
5. **Crossing:** Tunnels, level crossing, fences
6. **Guiding:** Rail, switches, joints
7. **Measurements:** Infradata from fixed and on-board sensors
8. **Rolling stock:** Passengers and freight
9. **Transfer:** Station, elevators





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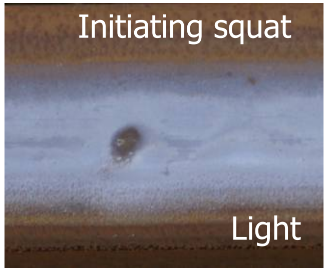
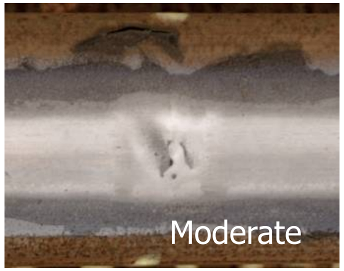
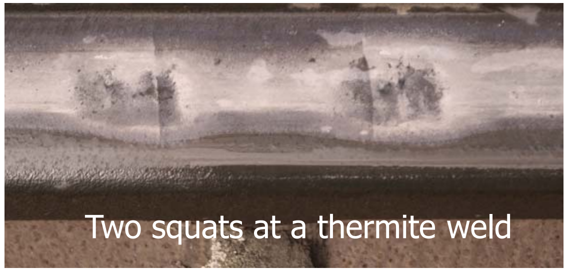
Defects in rails

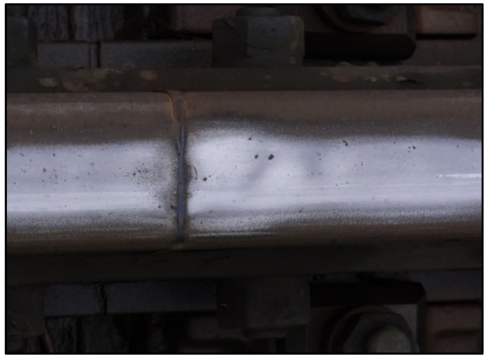






Squats

Corrugation



Insulated joint with plastic surface degradation

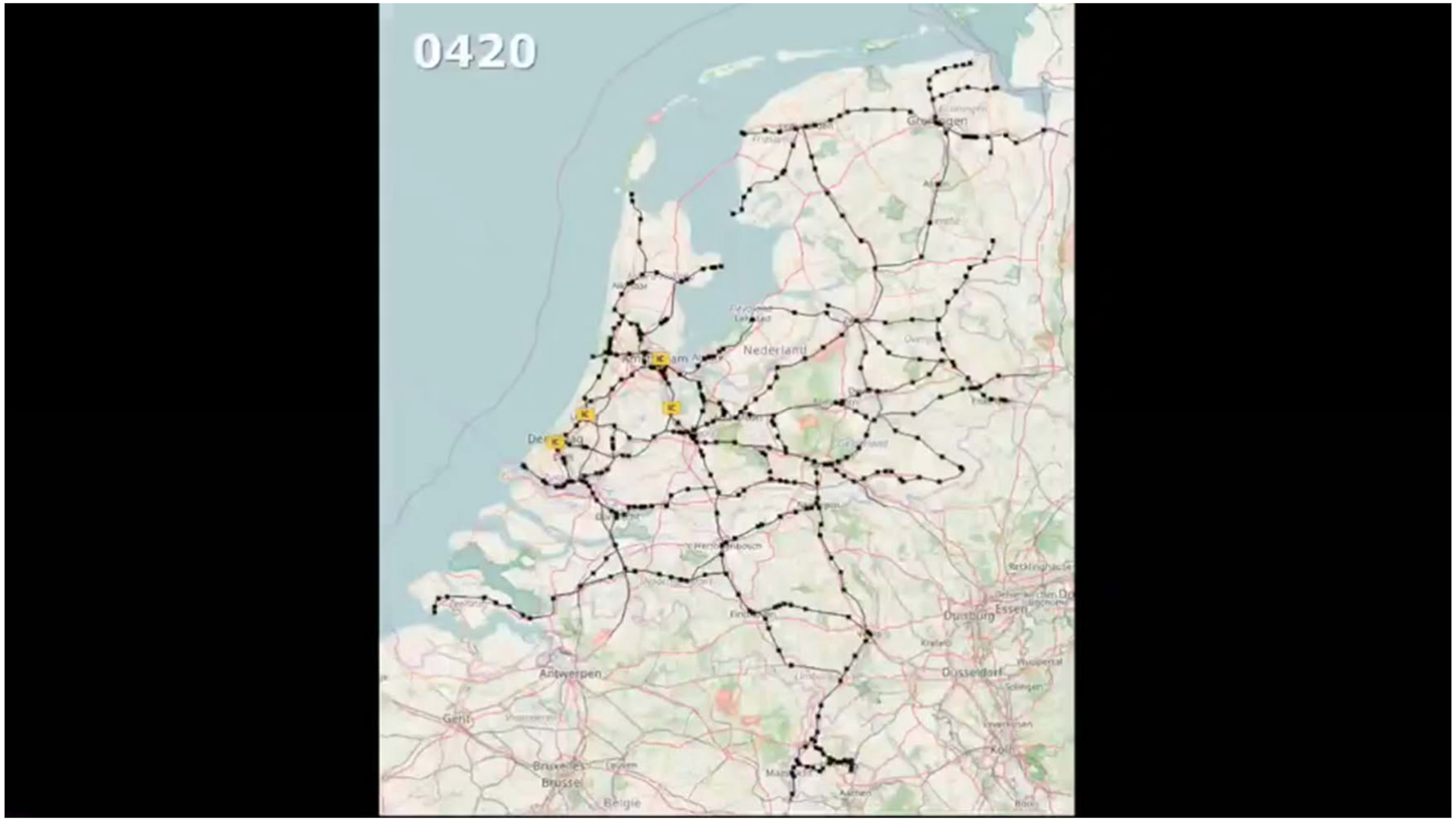
Wheel burns

Damaged welds

.....

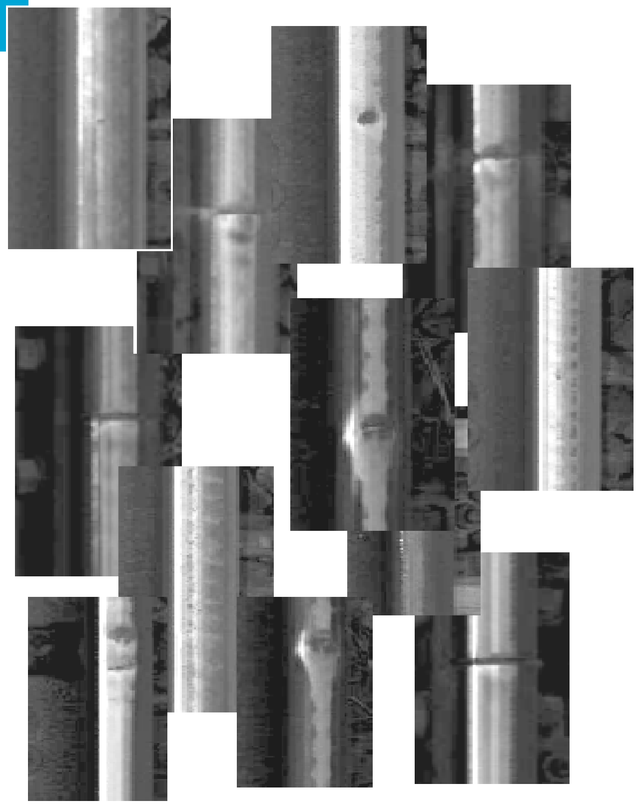
In The Netherlands (about 7000 km of tracks)

Almost no time for monitoring and maintenance ☹



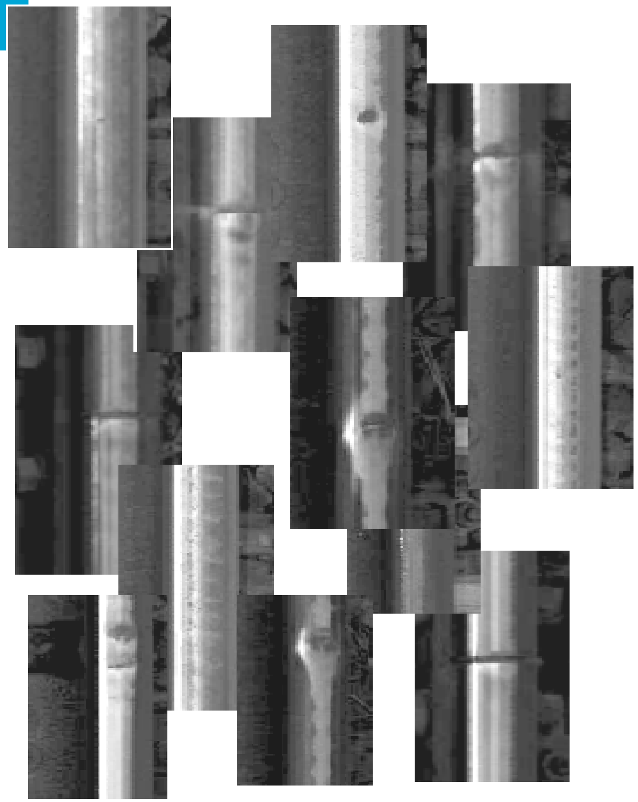
TU Delft

What do we need?



What do we need?

A method that can tell us whether the image is:



Healthy rail

Insulated rail joint

Rail surface defect

TU Delft

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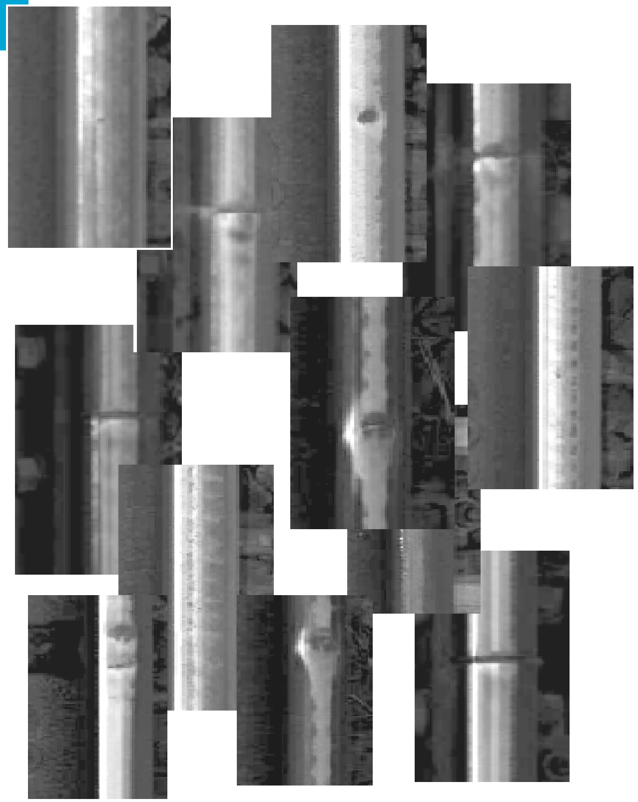

Healthy rail

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Rail surface defect

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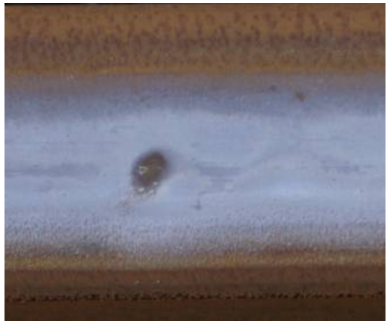
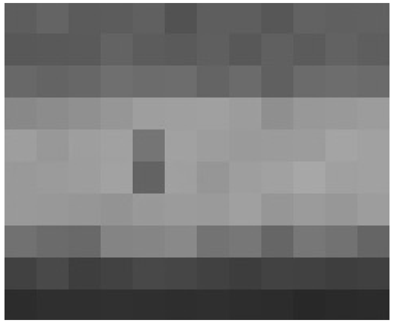
Images: dimensions

Dimensions
266 x 224



Dimensions
12 x 10



How many possible images
do we have?
Grey scale (265 levels)

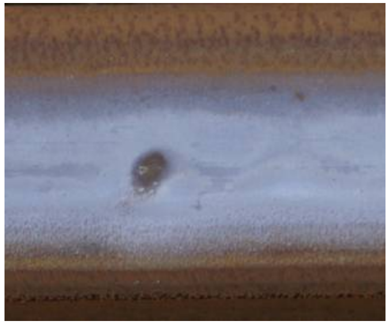
Answer: $(12 \times 10)^{265}$
Grey scale

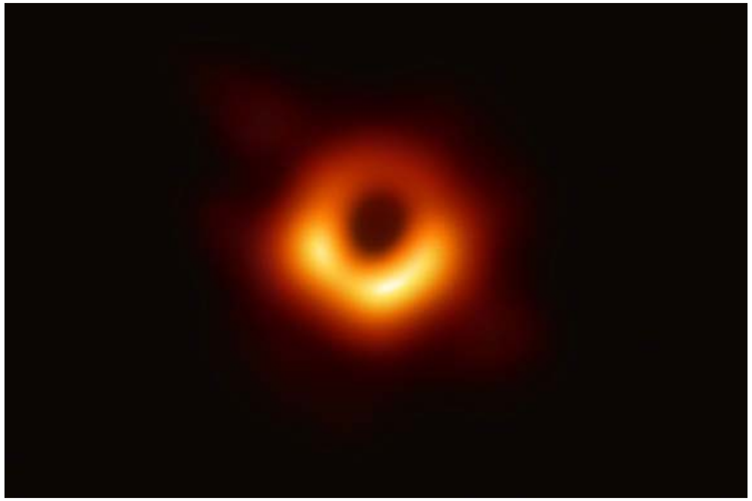
About 1.8×10^{532}
possible images

Imag

M87's black hole is 53.5 million light-years away (5.014×10^{26} millimeters)

Dimensions
266 x 224





The estimated number of atoms in the observable universe (10^{80})

5

How many possible images

do w

Grey scal

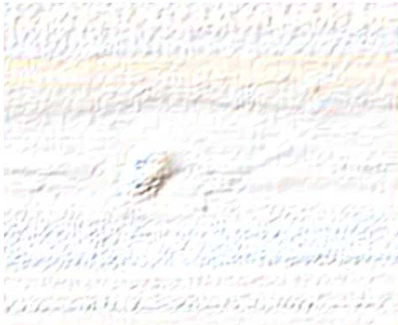
But don't worry, the Interesting features of the image lies in a lower dimension

x 10^{532}

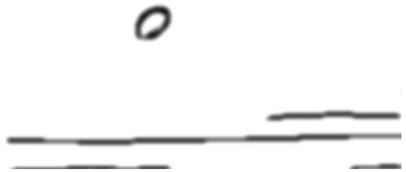
mages

Features hierarchy

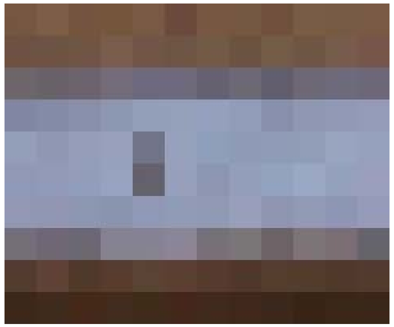
Image

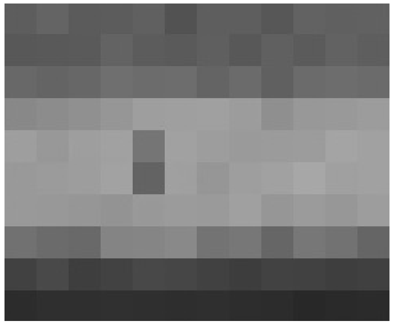


Contour



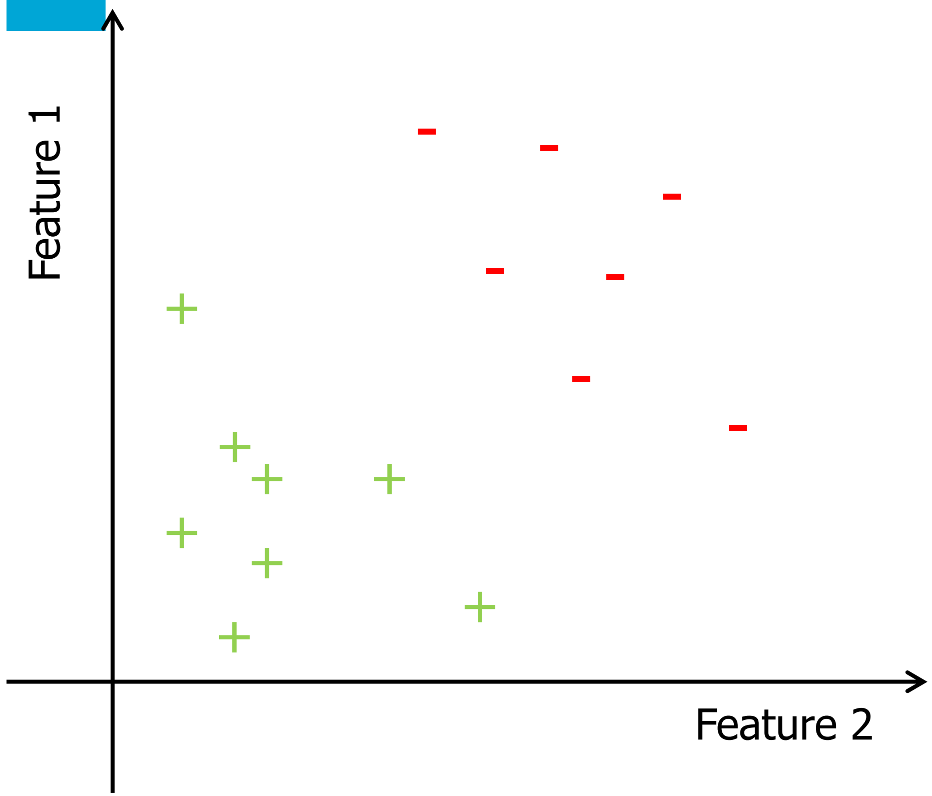
Edge → Shapes



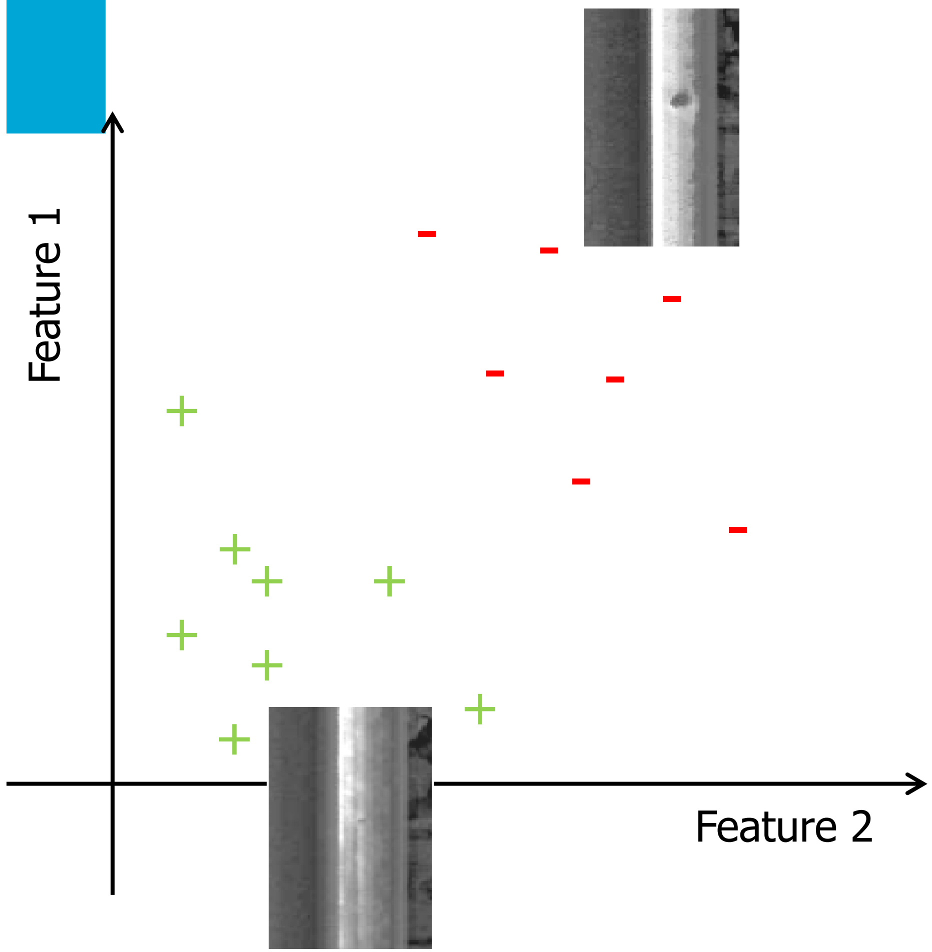


Smaller Dimensions

Classification methods



Classification methods



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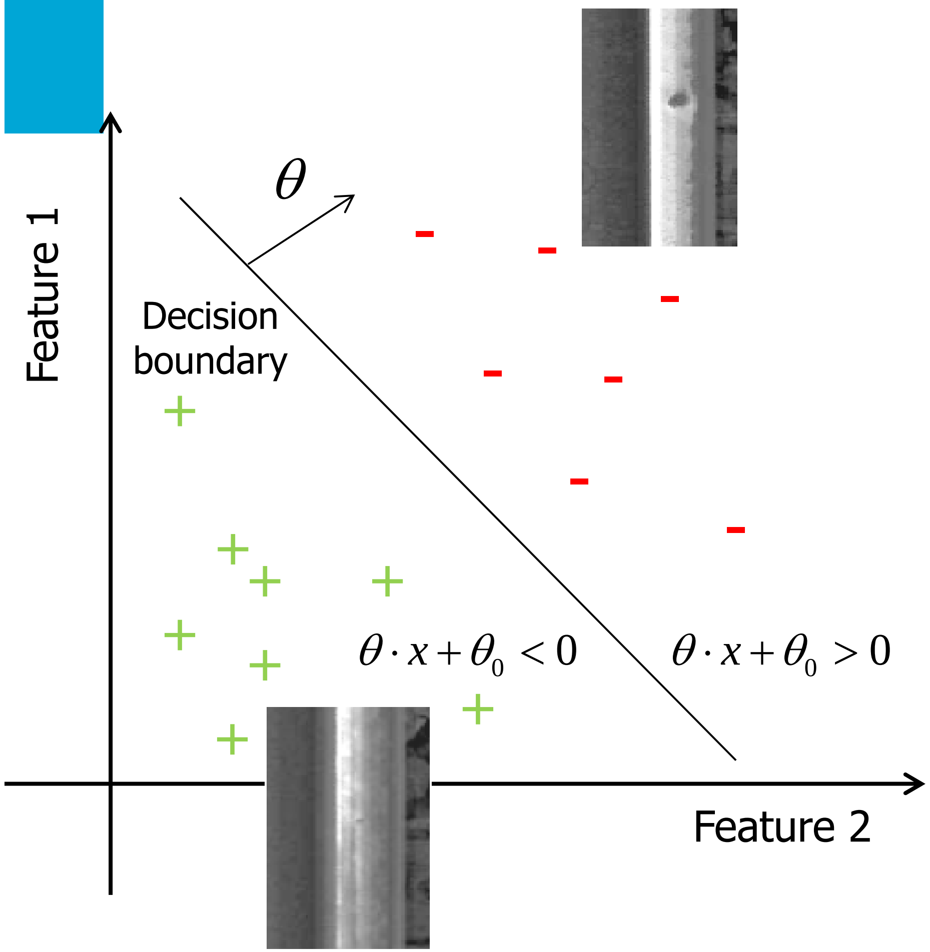

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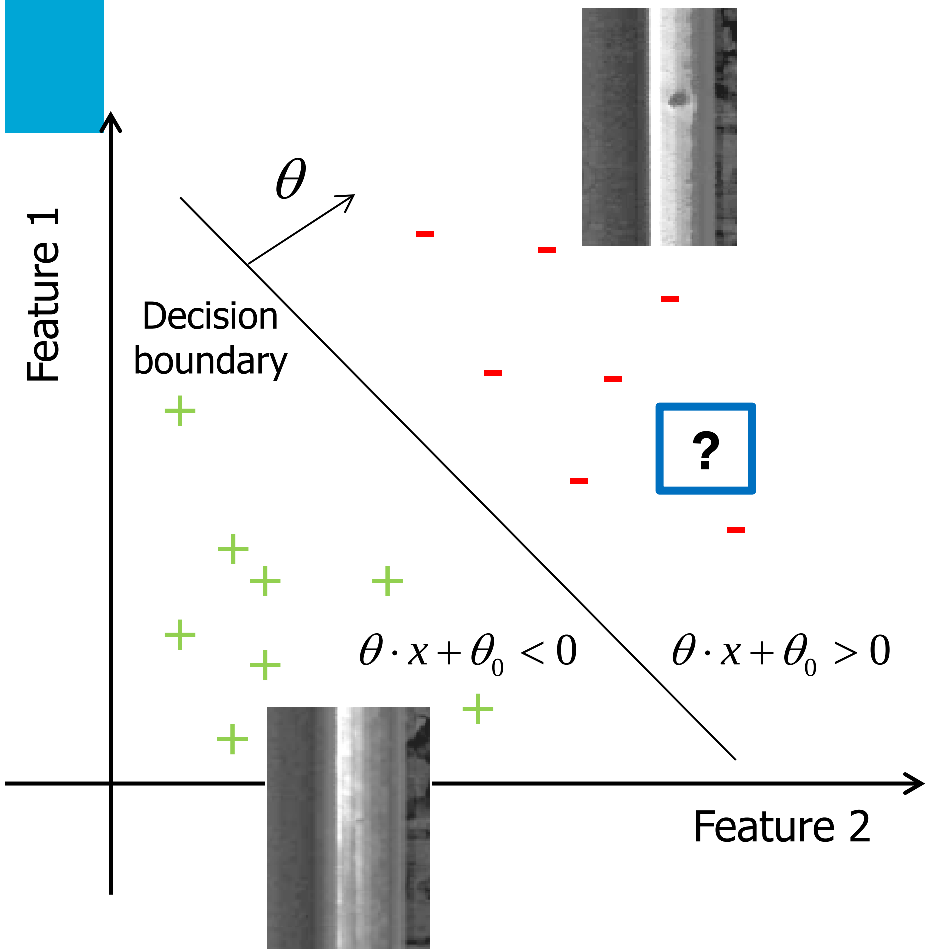
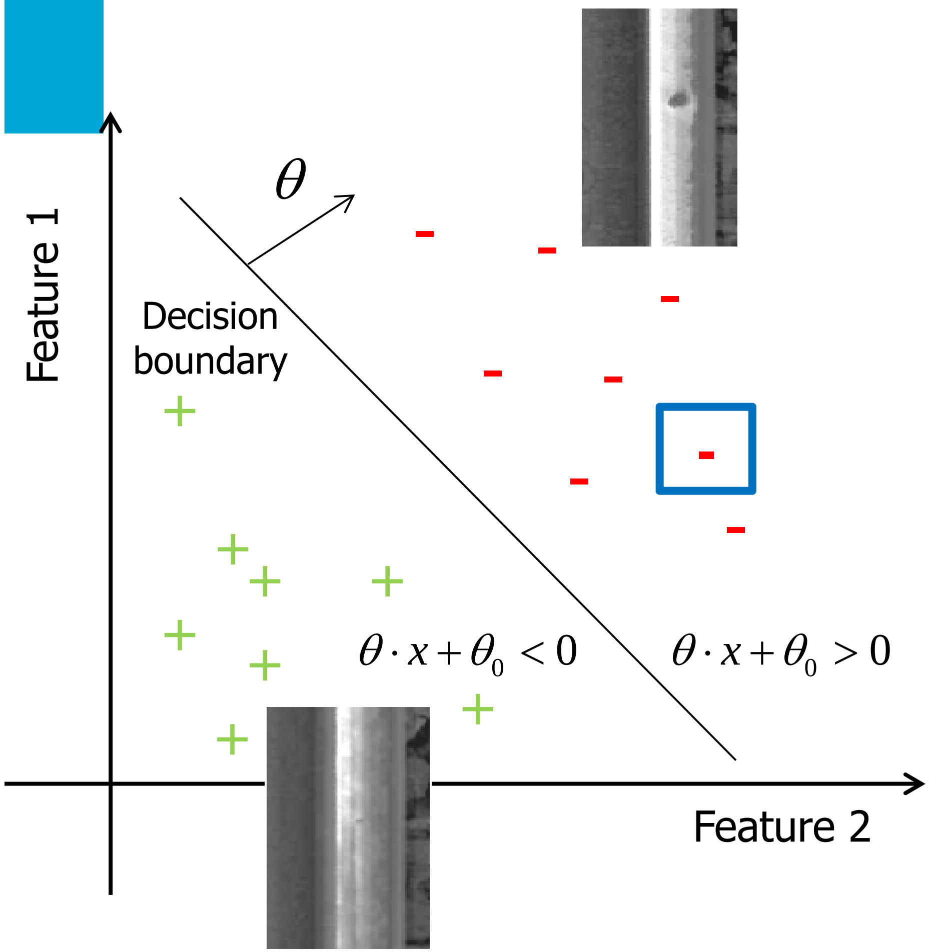
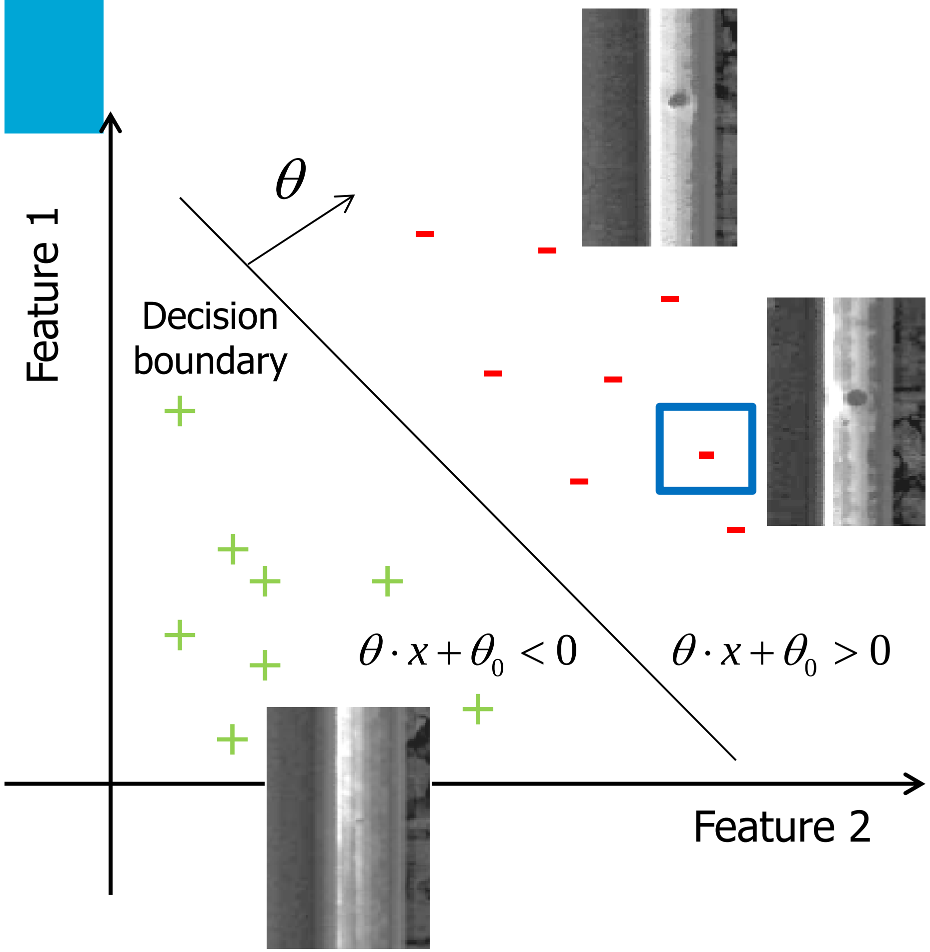


Classification methods



Classification methods



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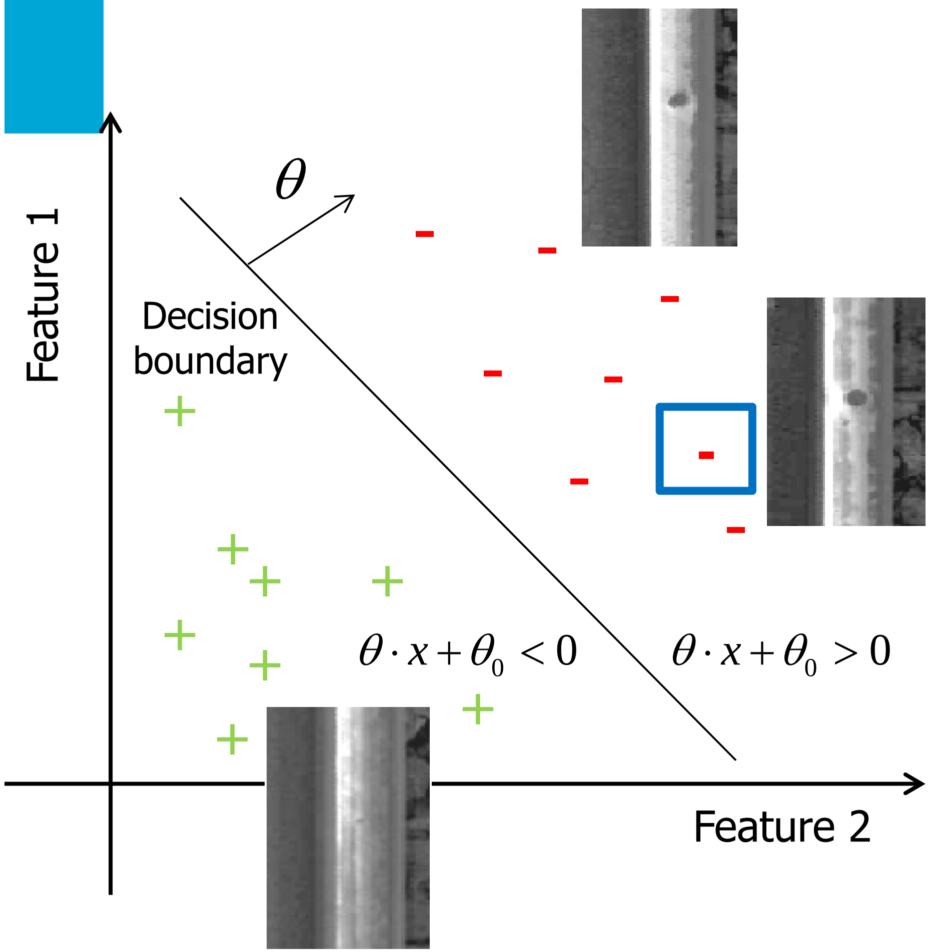

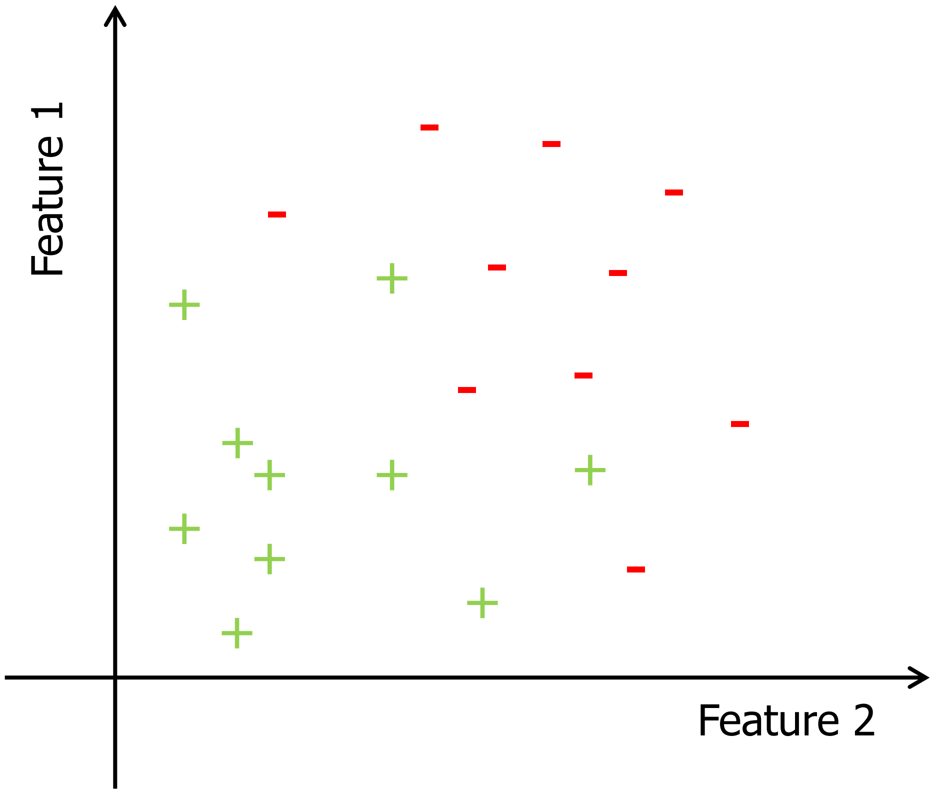

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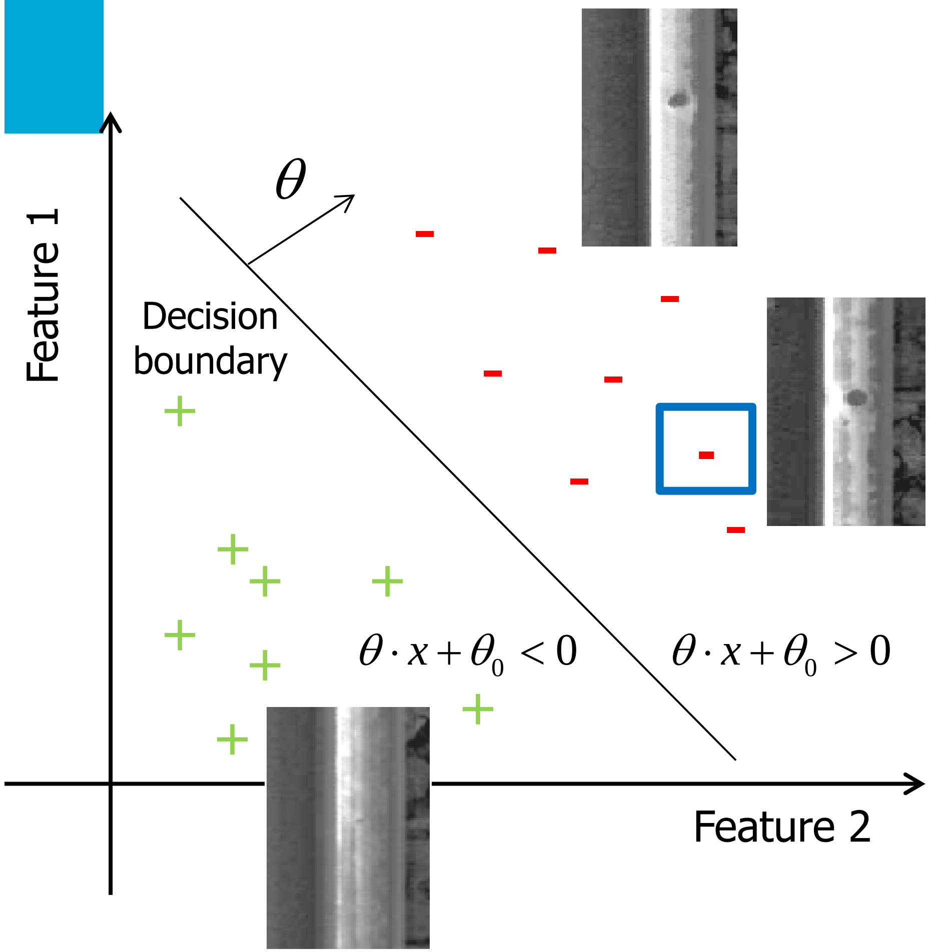
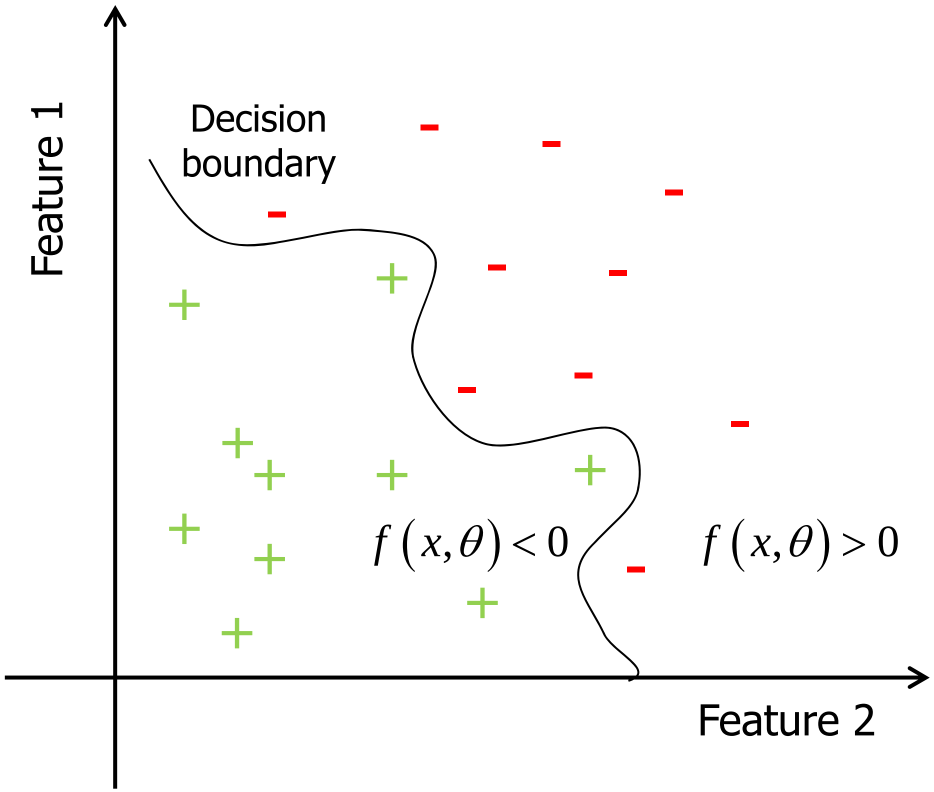
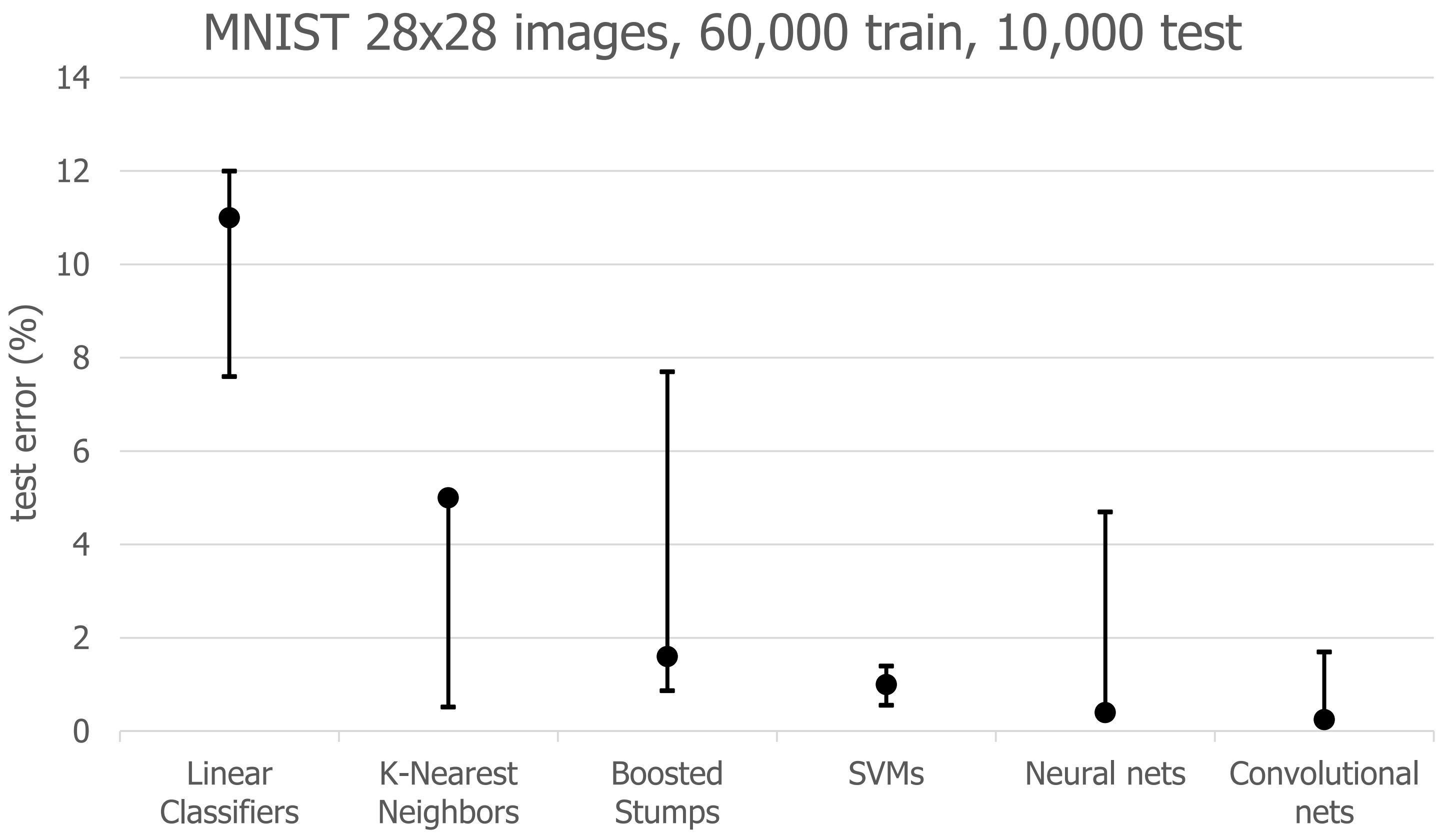




Possible methods



Source: http://yann.lecun.com/exdb/mnist/
2015

Deep learning

Classic

Input
↓
Mapping (Hand designed)
↓
Output

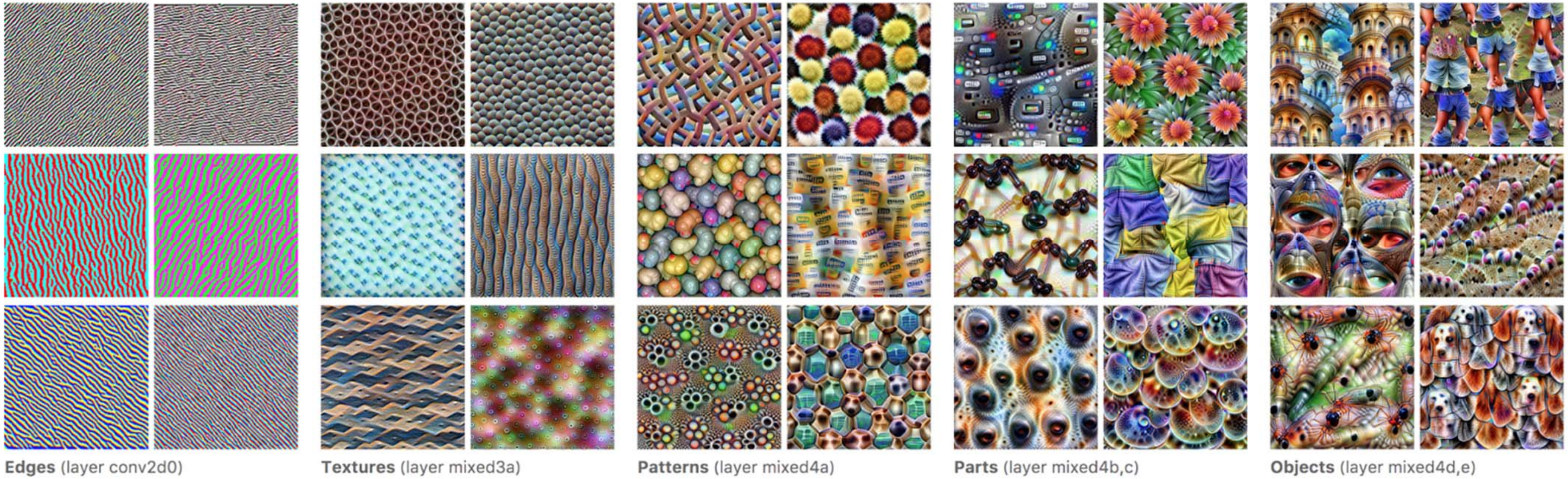
Classic Machine Learning

Input
↓
Mapping (Hand designed)
↓
Learned mapping
↓
Output

Deep Learning

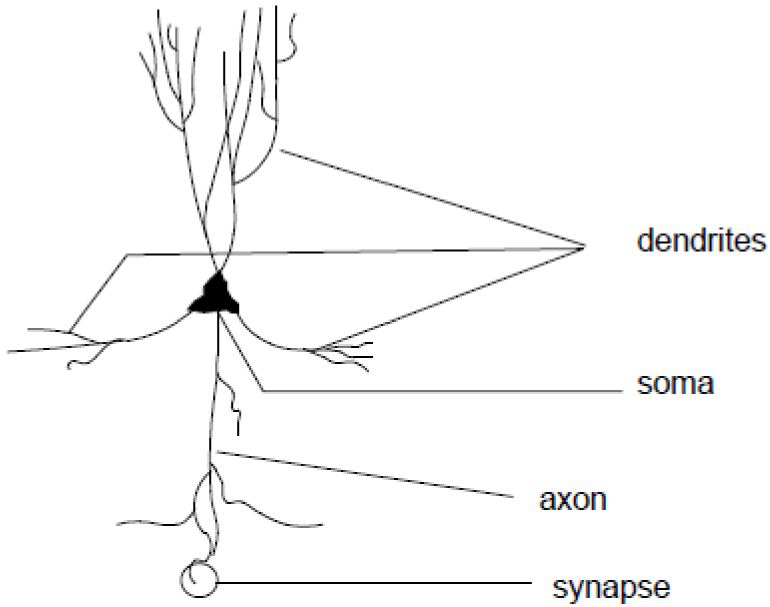
Input
↓
Learned features
↓
......
↓
Learned features
↓
Learned mapping
↓
Output

Deep learning: learned features

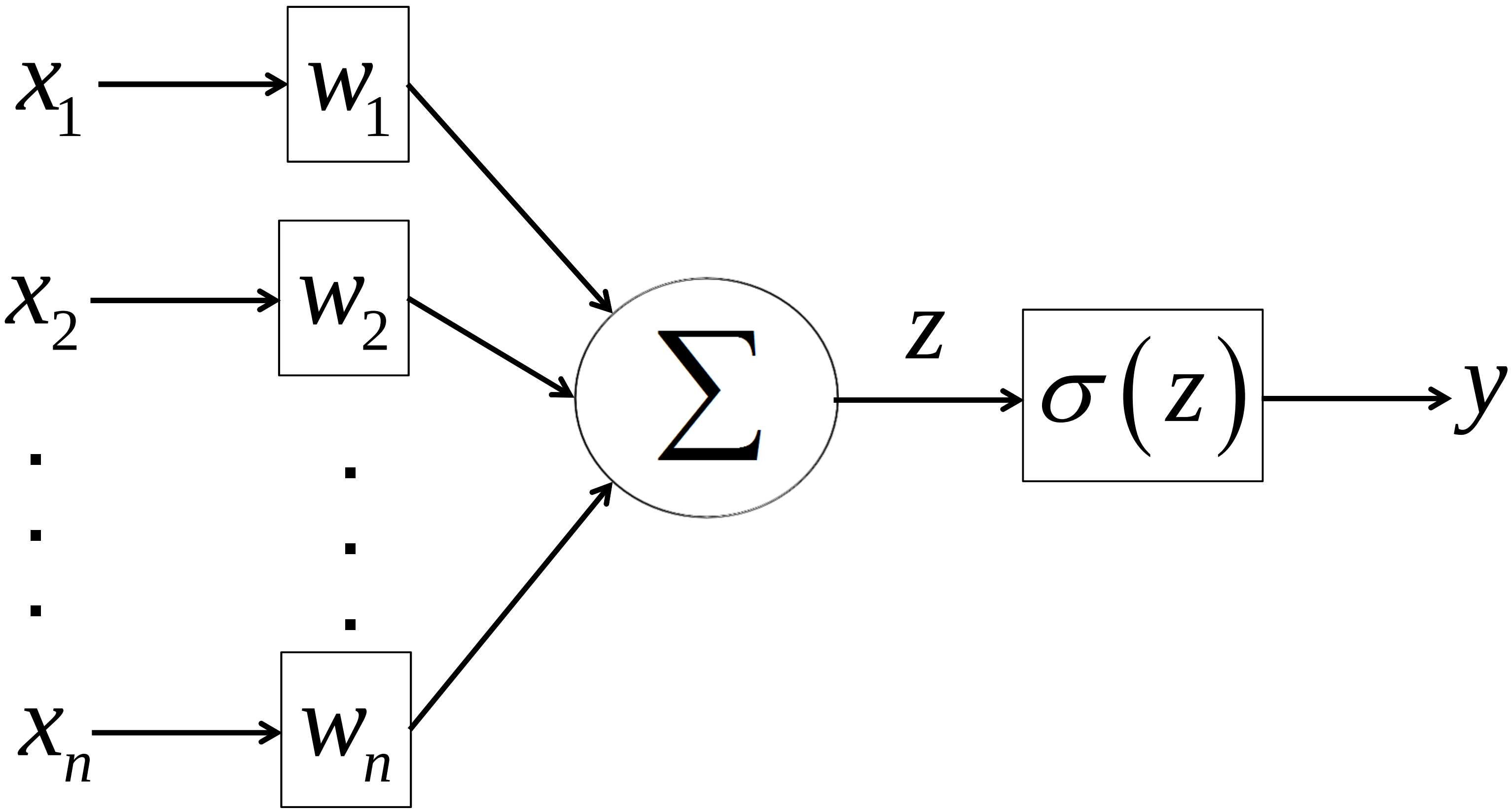


Deep learning: learned mapping

McCulloch and Pitts modelled the behavior of a single neuron in 1943. They called this mathematical model a Perceptron.

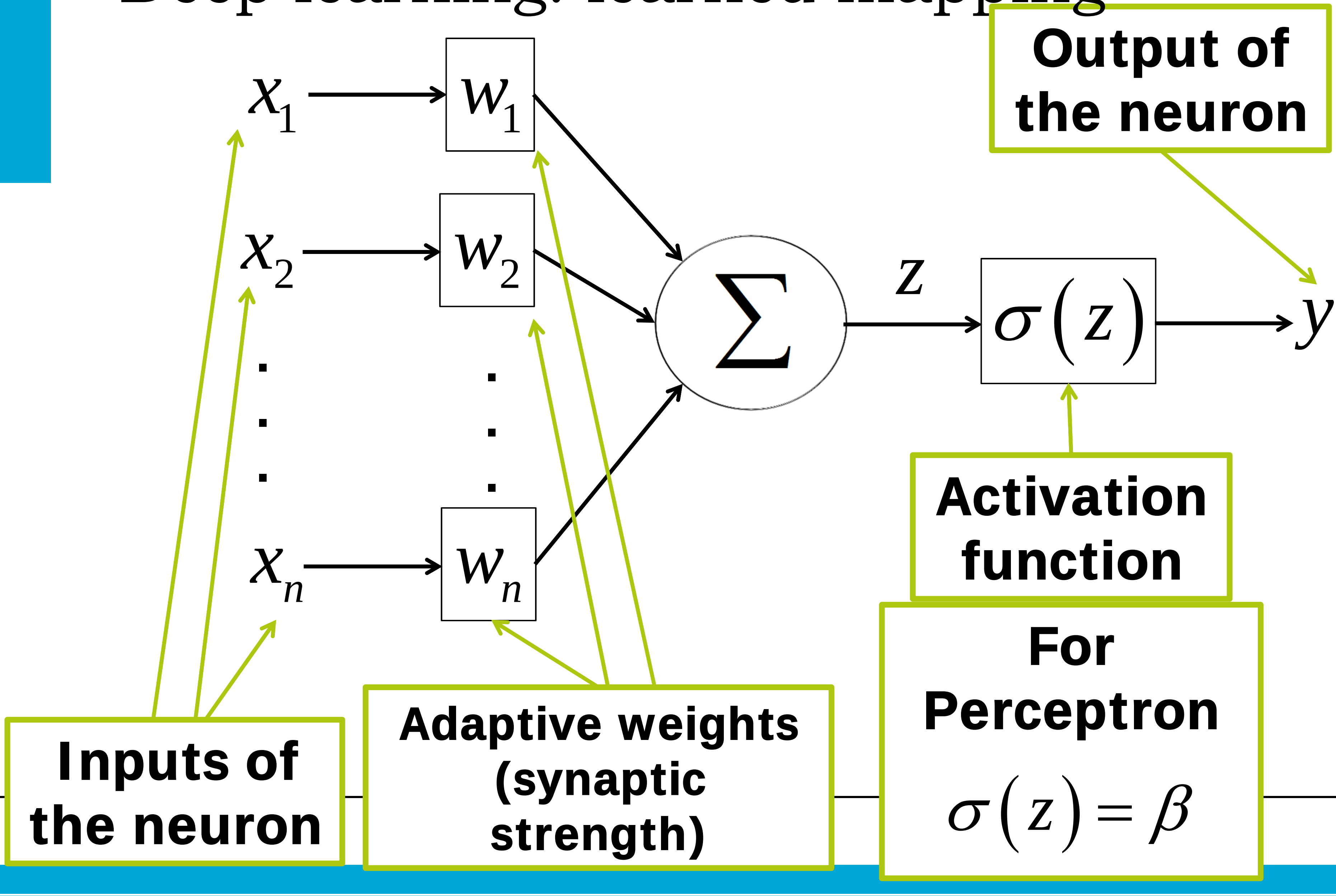


Deep learning: learned mapping



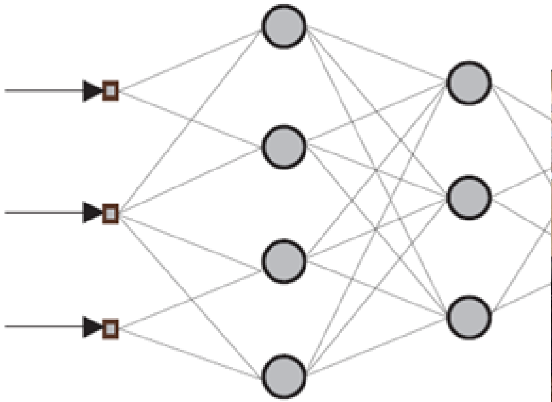
Artificial neuron

Deep learning: learned mapping



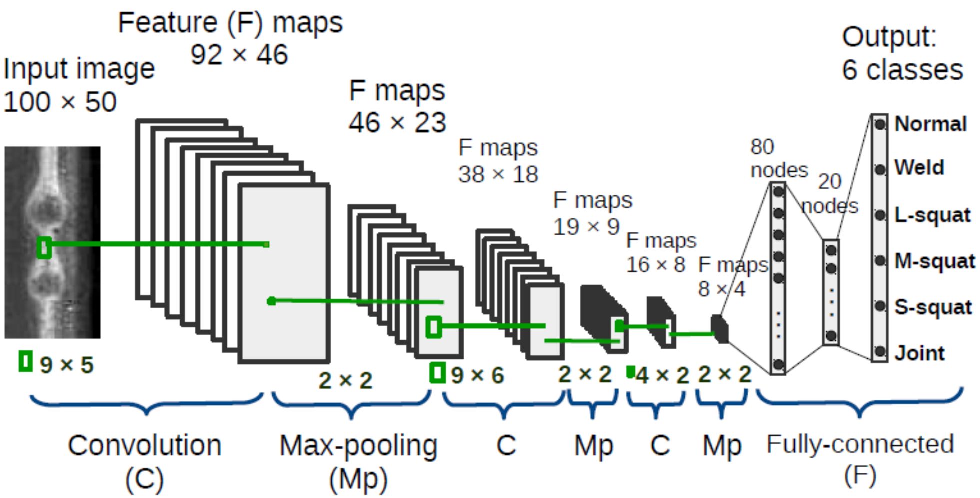
Deep learning: learned mapping

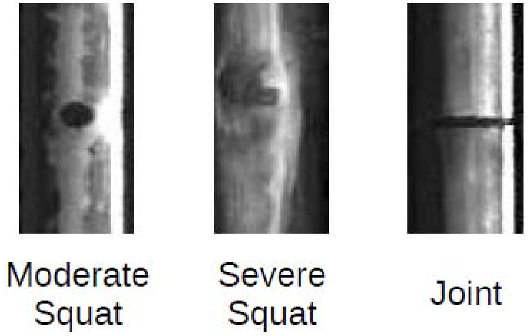
Multi-layer ANN

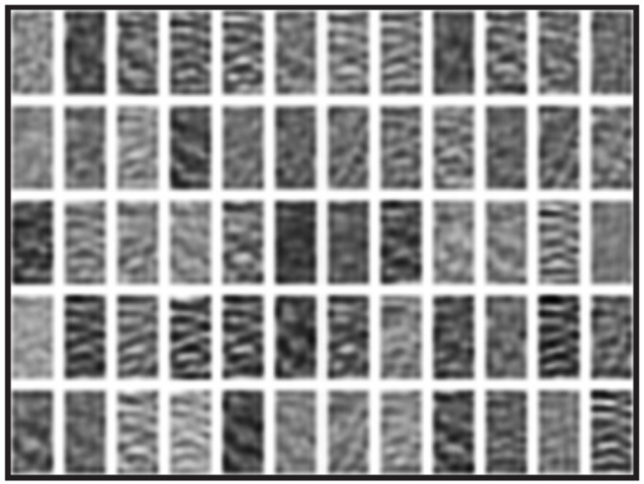


Paul Werbos, the father of backpropagation, since 1974 we can train neural networks

Detection of rail defects







S. Faghih-Roohi, S. Hajizadeh, A. Núñez, R. Babuska, and B. De Schutter, "A deep learning approach for detection of rail defects". Proceedings of the IEEE World Congress on Computational Intelligence, IEEE WCCI 2016, 2016 International Joint Conference on Neural Networks (IJCNN), Vancouver, Canada, 25-29 July, 2016, pp. 2584-2589.

Image data

- The dataset consists of 4220 samples, of which 3170 are normal, and roughly 1000 are defects.

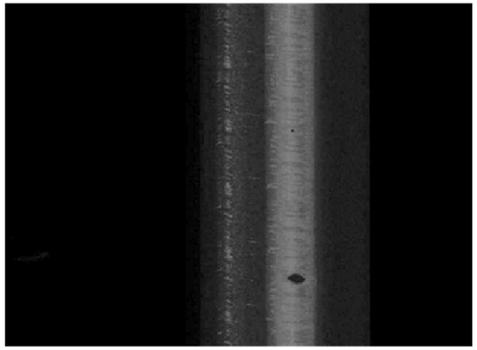
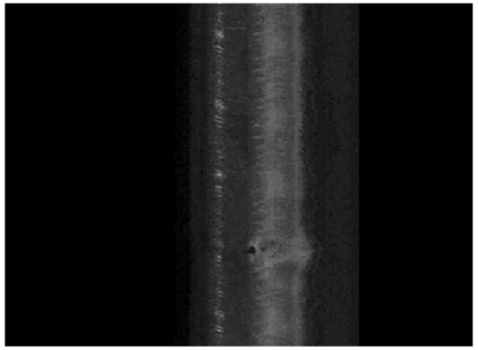
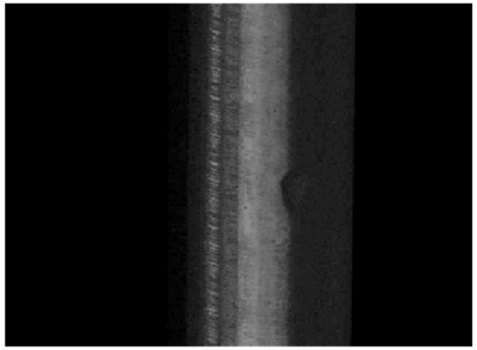
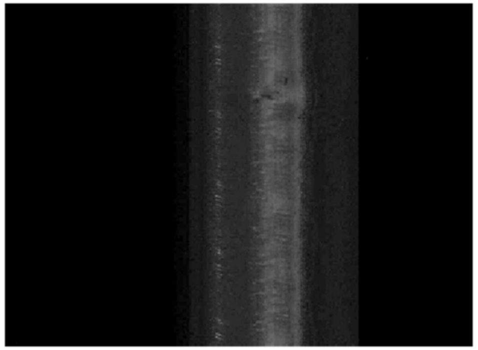
- We train a **convolutional neural network** model with 80% of the data, and test with the remaining 20% (in 5 folds). Here is the averaged result of the test:

	Predicted normal	Predicted defect
Normal samples	635	1
Defects	10	197

Accuracy = 0.9870

False detections (image data)

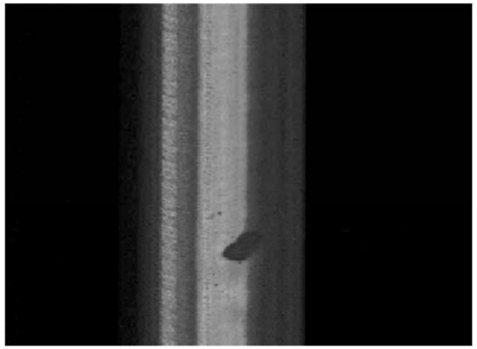
Defects not detected

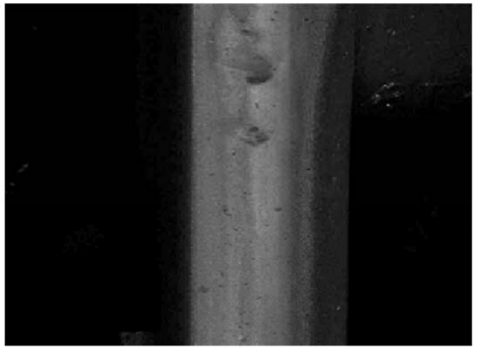





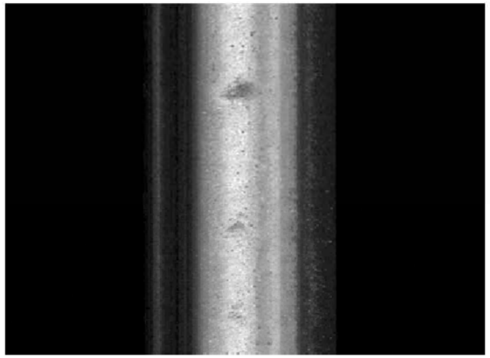
Images from INSPECTATION

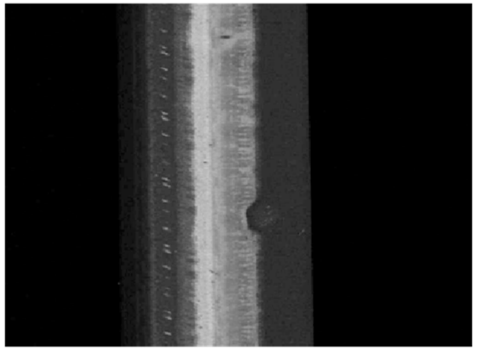
Hits 1 (image data)

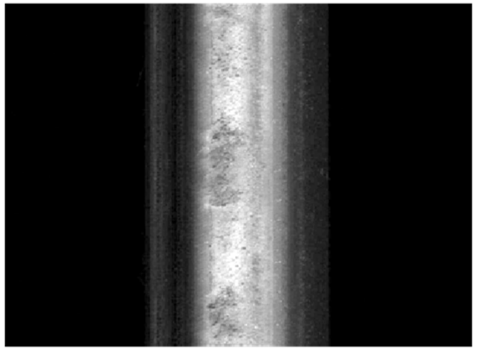
True Positive







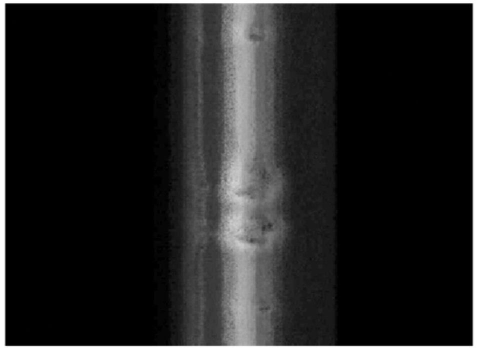


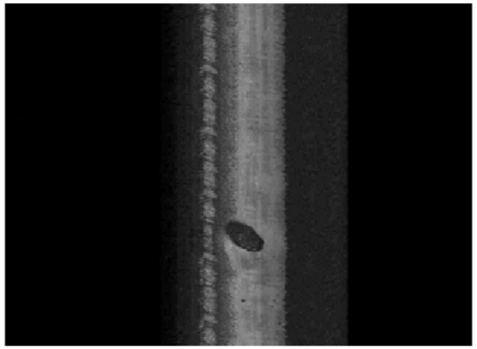


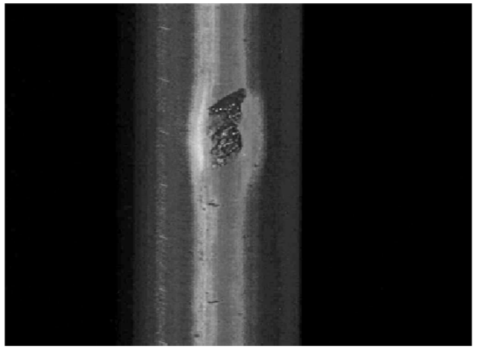
Images from INSPECTATION

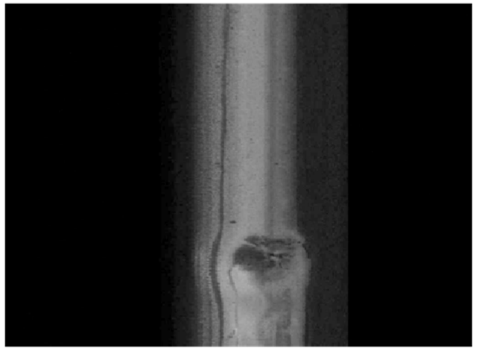
Hits 2 (image data)

True Positive





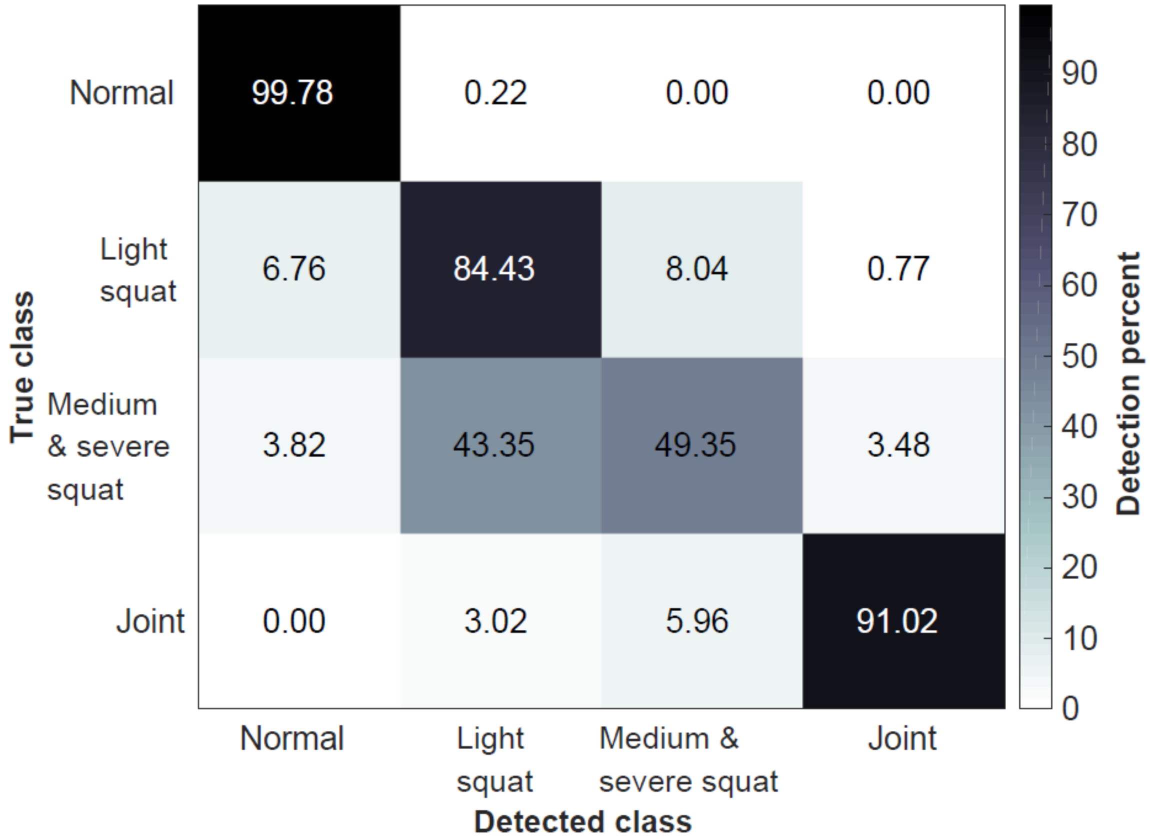




Images from INSPECTATION

Classification of types

- We also tried to classify the defects into 2 categories of spots/light vs. medium/severe.



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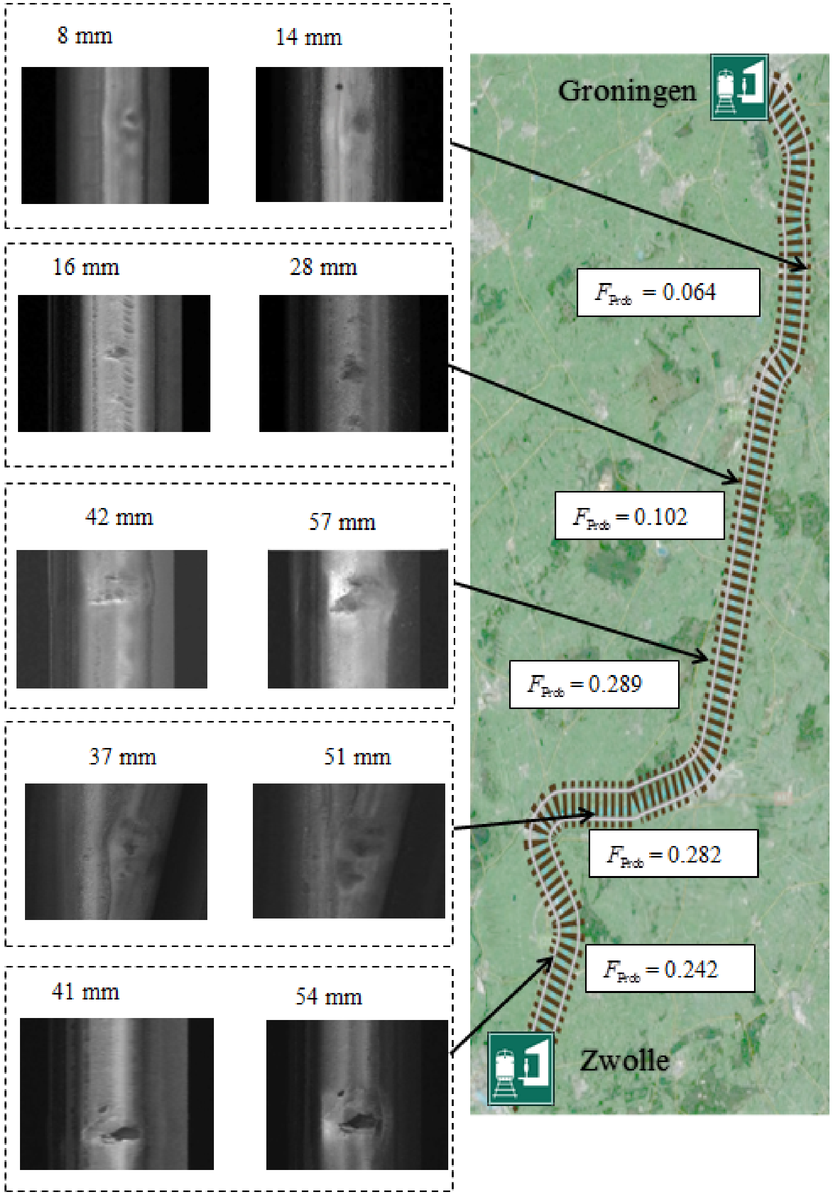
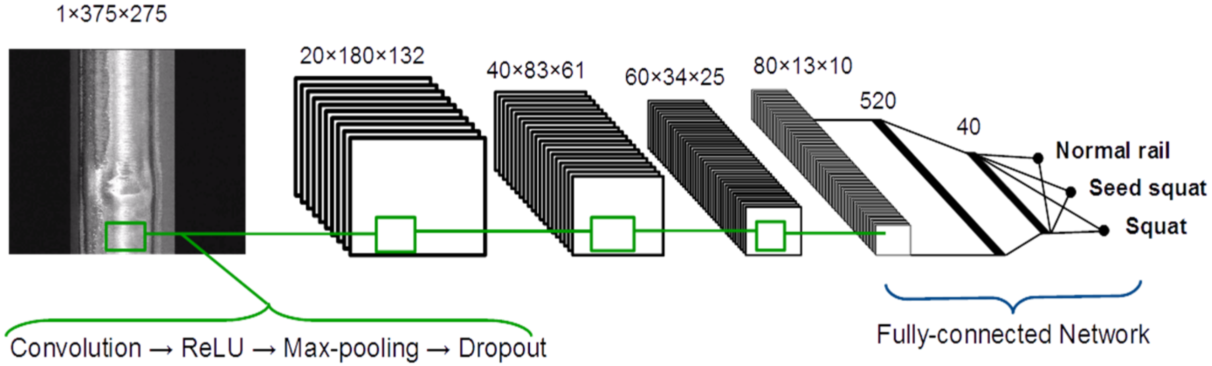
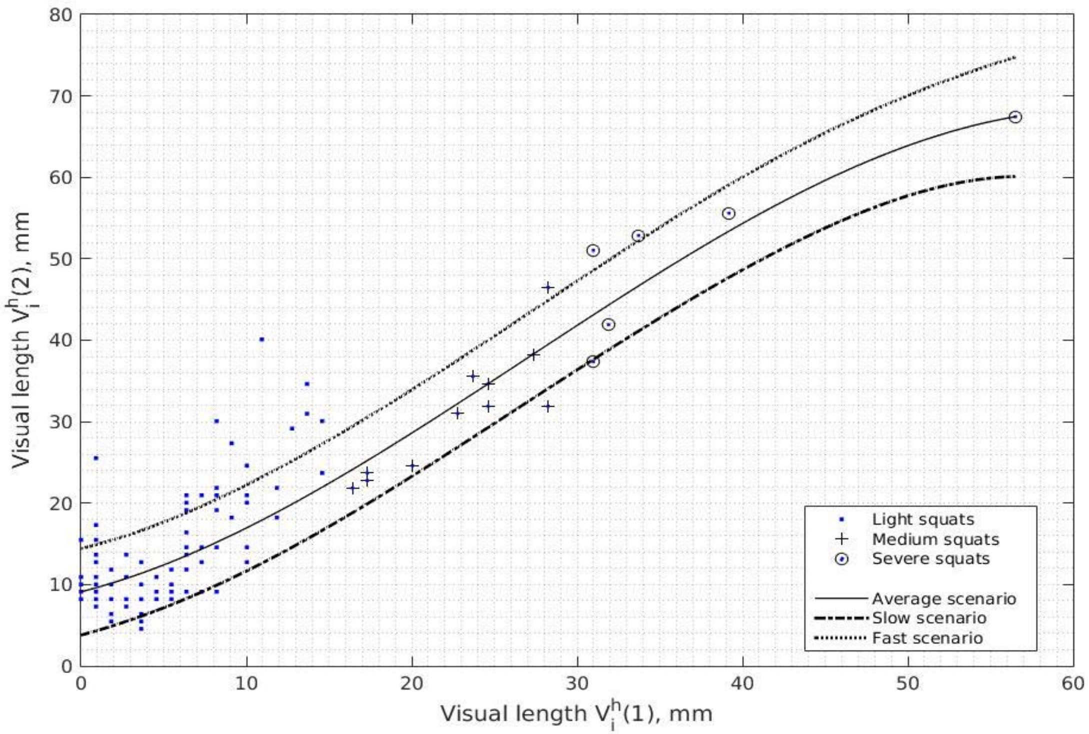


- ❖ A big data analysis approach is used to automatically detect squats from rail images.
- ❖ A Bayesian model is employed to estimate the failure probability.

A. Jamshidi, S. Faghih-Roohi, S. Hajizadeh, A. Núñez, R. Babuška, R. Dollevoet, Z. Li and B. De Schutter, "A big data analysis approach for rail failure risk assessment". Risk Analysis, Volume 37, Issue 8, August 2017, Pages: 1495-1507.



Architecture of the proposed DCNN model



A. Jamshidi, S. Faghih-Roohi, S. Hajizadeh, A. Núñez, R. Babuška, R. Dollevoet, Z. Li and B. De Schutter, "A big data analysis approach for rail failure risk assessment". Risk Analysis, Volume 37, Issue 8, August 2017, Pages: 1495-1507.

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Conclusions

- "Fancy" algorithms will not perform 100% if the knowledge of the railway system is not included explicitly.

- Purely data-based methods do not guarantee physical meaning. A combined approach, data-based with physical modelling would be preferred.

- There is a great potential for using Deep Learning to facilitate maintenance decisions on Dutch railways. Further research: head-checks, corrugation, wheel-burns, indentations.

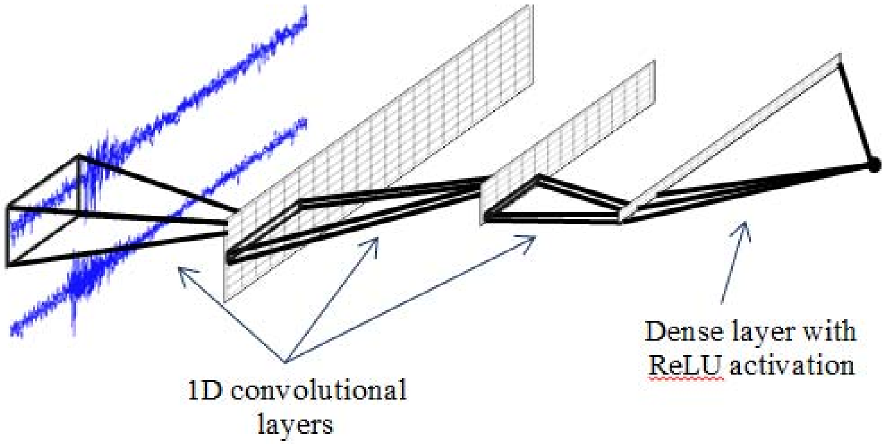
Conclusions

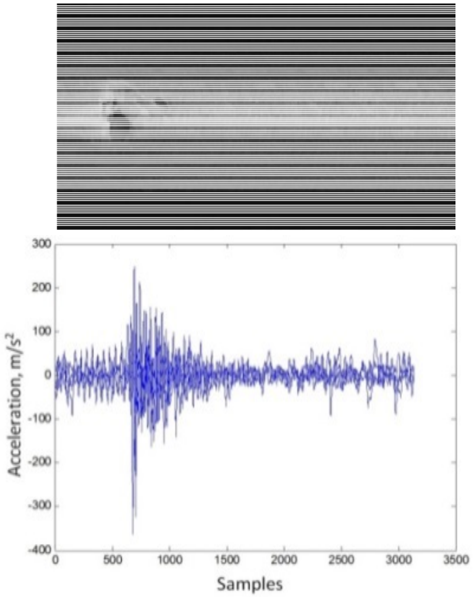
- Self-learning, transfer learning and new architectures could be tested.

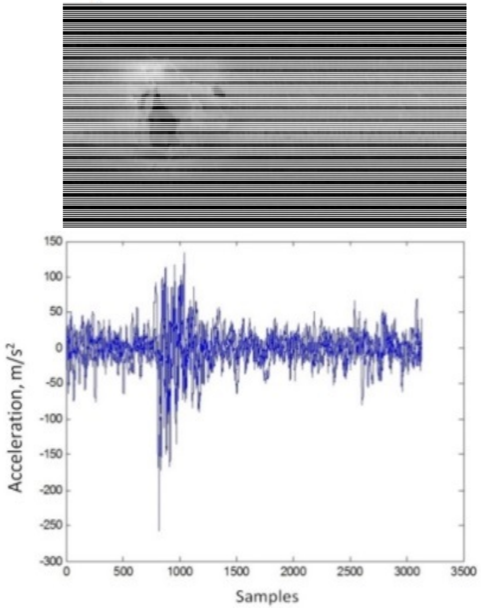
- Higher resolutions cameras, including 3D measurements, can allow a complete digitalization of the railways assets.

- Many open challenges: Fusion of data, velocity, etc.

How to keep improving?







- ❖ Video and ABA to detect squats.
- ❖ Other signals for influential factors used for modelling.

A. Jamshidi, S. Hajizadeh, Z. Su, M. Naeimi, A. Núñez, R. Dollevoet, B. De Schutter and Z. Li, “A decision support approach for condition-based maintenance of rails based on big data analysis”. Transportation Research Part C: Emerging Technologies, Volume 95, October 2018, Pages: 185-206.

Deep learning: learned features

Just for fun:

https://affinelayer.com/pixsrv/index.html

https://playground.tensorflow.org/

Automatic detection of rail surface defects using video image: A case study in the Dutch railways

Lunch lecture series of Monitoring Community
10th May 2019

Dr. Alfredo Núñez Vicencio
Assistant Professor, TU Delft
Section of Railway Engineering