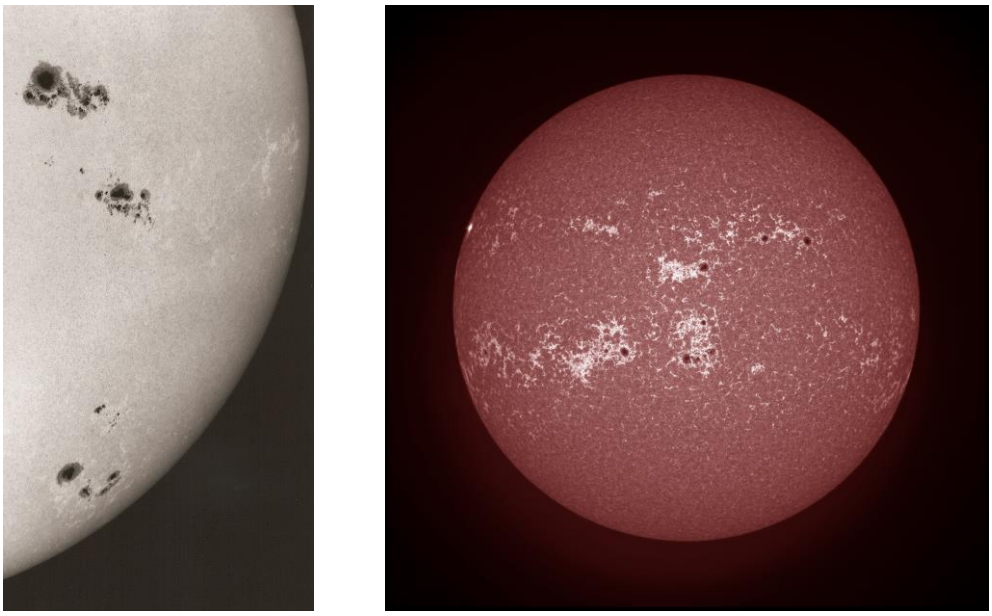

Figure 1: Sunspots visible in visual (left) [1] and ultraviolet spectre (right) [2]

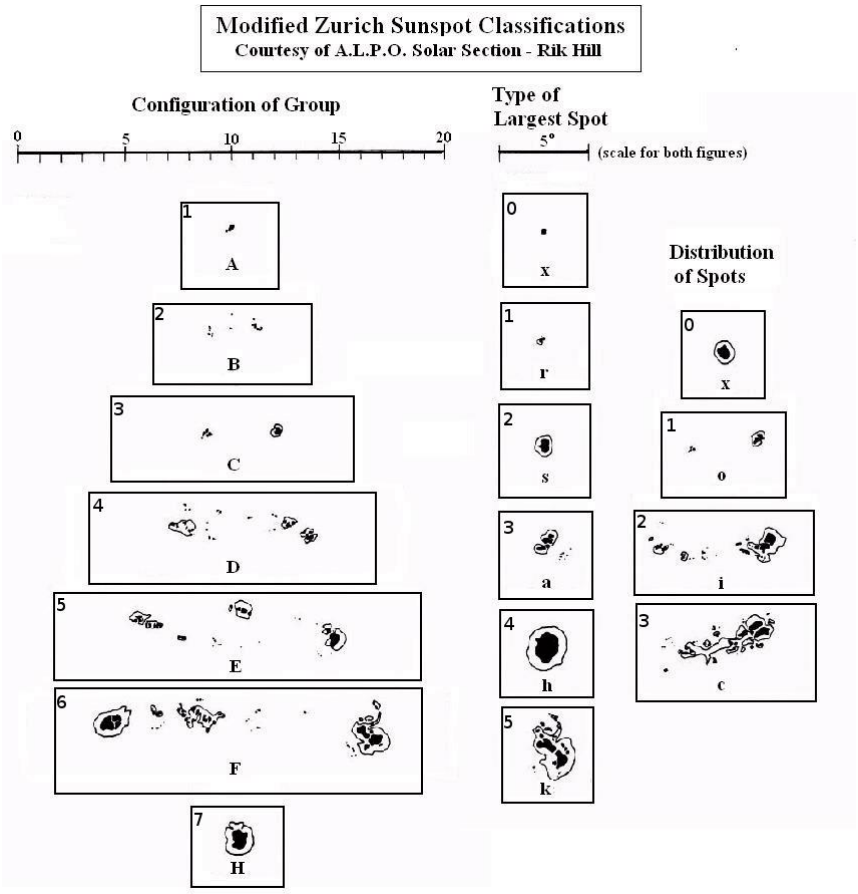

Figure 2: Summary image for the McIntosh classification [3]

A	unipolar group without penumbra
B	bipolar group without penumbra
C	bipolar group with one penumbra
D	bipolar group with multiple penumbrae size below 10°
E	bipolar group with multiple penumbrae size between 10° and 15°
F	bipolar group with multiple penumbrae size above 15°
H	unipolar group with penumbra

x	largest spot without penumbra compatible only with A and B
r	rudimentary penumbra incomplete and irregular penumbra
s	symmetrical penumbra size below 2.5° (equivalent to h)
a	asymmetrical penumbra size below 2.5° (equivalent to k)
h	symmetrical penumbra size above 2.5° (equivalent to s)
k	asymmetrical penumbra size above 2.5° (equivalent to a)

x	unipolar group compatible only with A and H
o	open, spots at poles but not in between
i	intermediate, spots lie between poles
c	compact, spots with penumbra in between

Figure 3: An overview of the major differences between classes in the McIntosh classification system

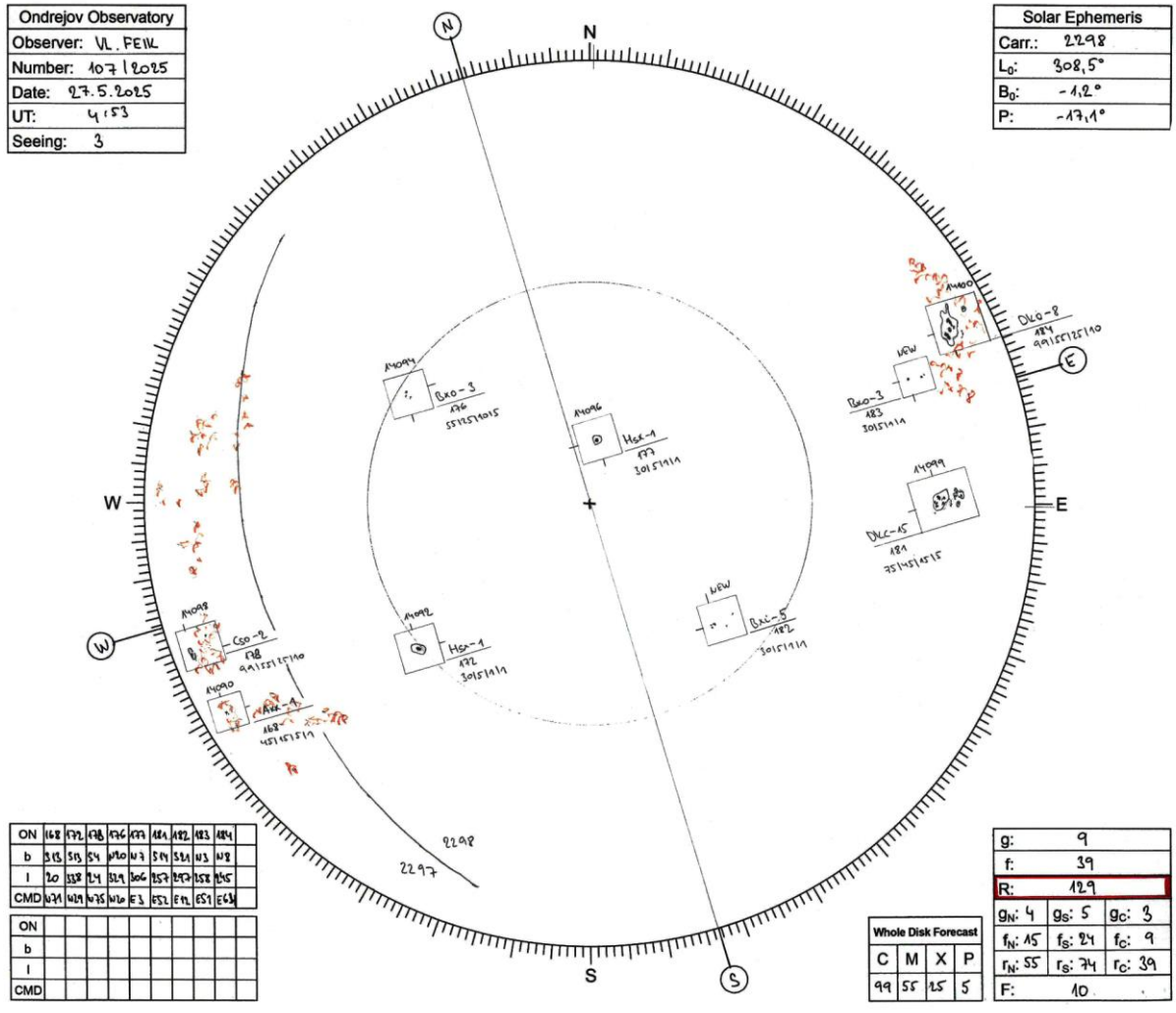

Figure 4: Example of drawing from the observatory of the Astronomical Institute in Ondřejov [4]

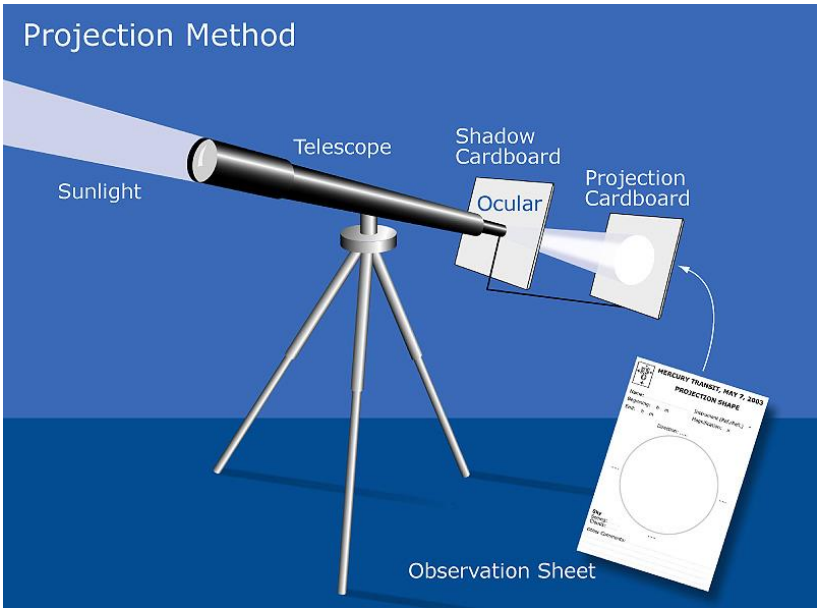

Figure 5: Telescope layout and orientation used for sunspot drawing [5]

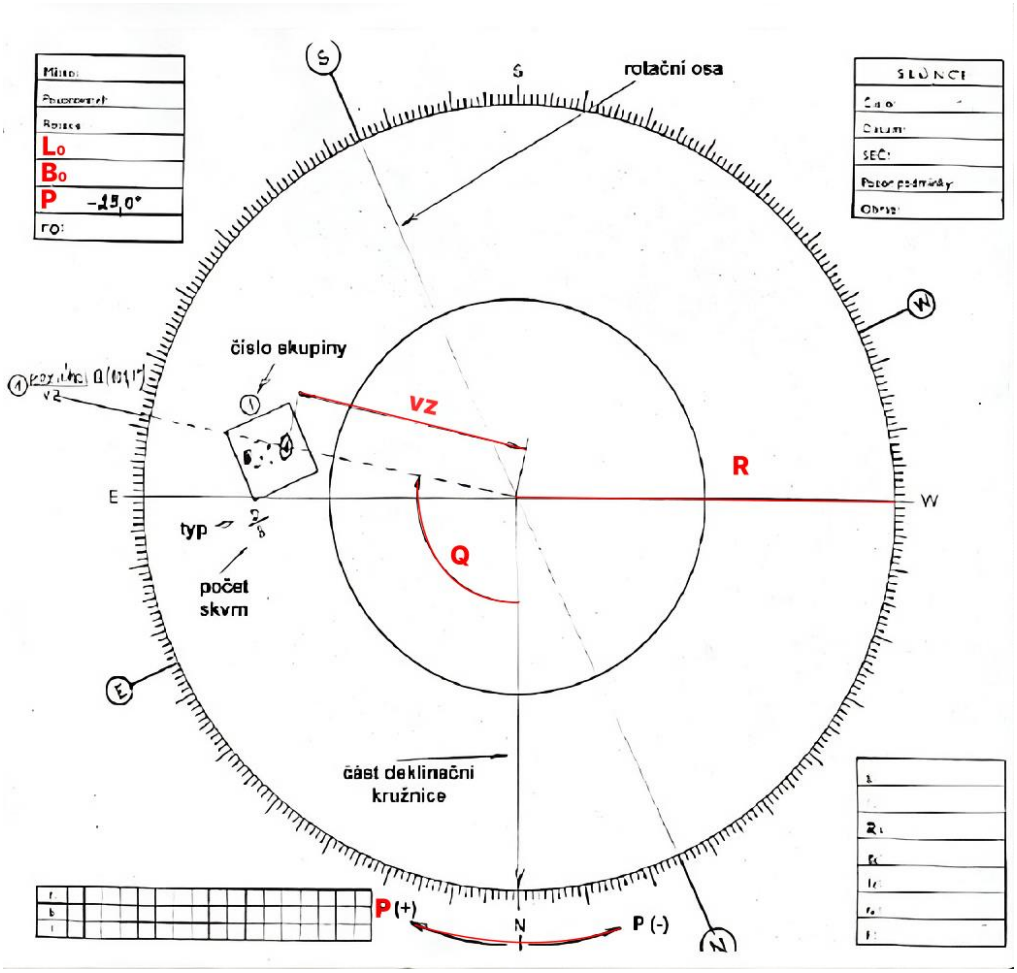

Figure 6: Occurrence of data in the drawing [6],

where *vz* is the distance from the center of the spot to the center of the drawing, *R* is the size of the solar disk in the drawing, *B0* is the heliographic latitude of the center of the drawing, *L0* is the heliographic longitude of the center of the drawing, *P* is the positional angle of the Sun's rotational axis, and *Q* is the positional angle of the group measured on the drawing from north through east

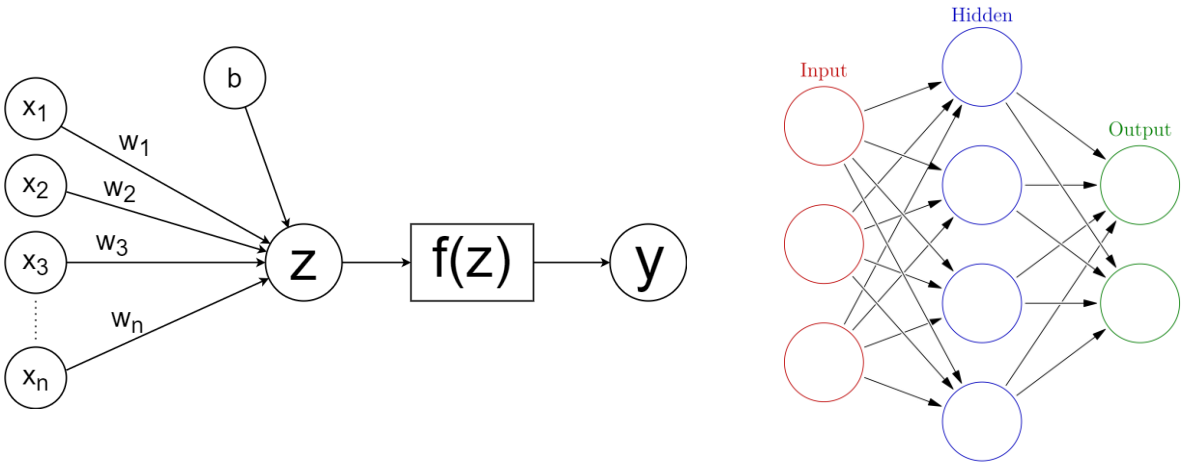

Figure 7: The process of calculating the value of a neuron (left) and an example of a feedforward neural network (right) [7]

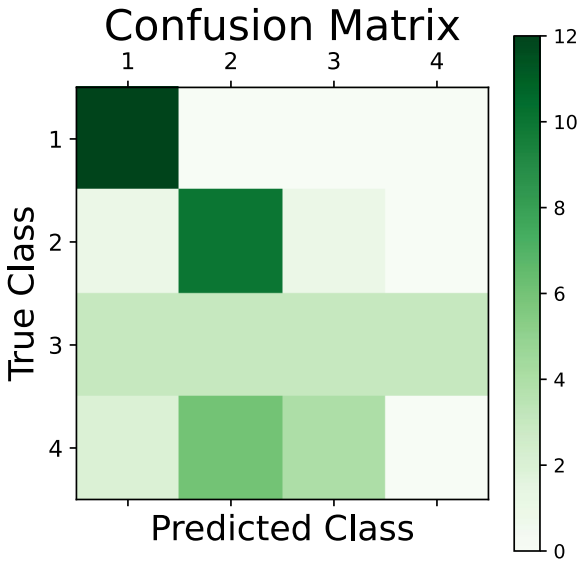

Figure 8: A an example of a confusion matrix,
the first class was predicted perfectly, the second with minor errors, the samples of the third class were often misclassified as samples of all classes, and the fourth class was never correctly predicted, being most often confused with the second class

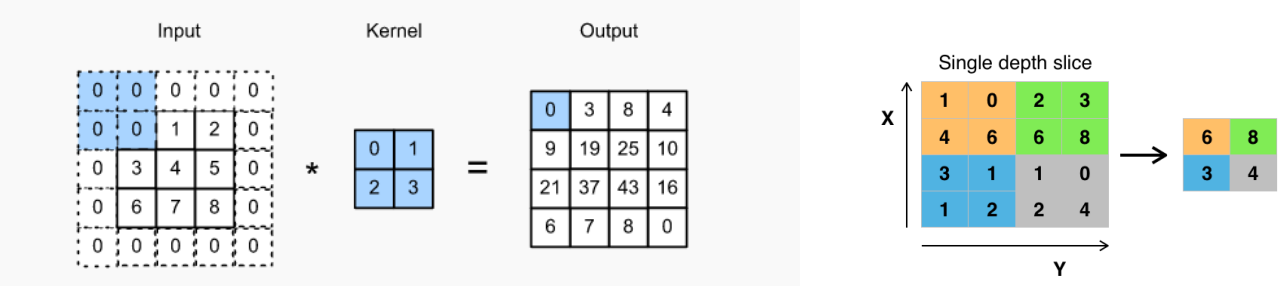

Figure 9: Calculation of neuron values in a convolutional network (left) [8] and an example of max-pooling (right) [9]

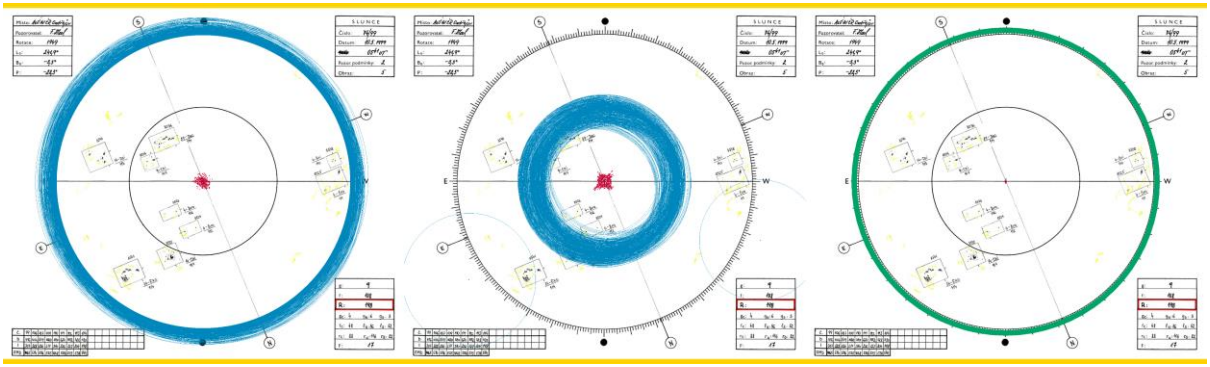

Figure 10: An example of automated detection of large (left) and small auxiliary circles (middle), with detected circles shown in blue and their centers marked in red; and the machine-estimated position and center of the large circle (right)

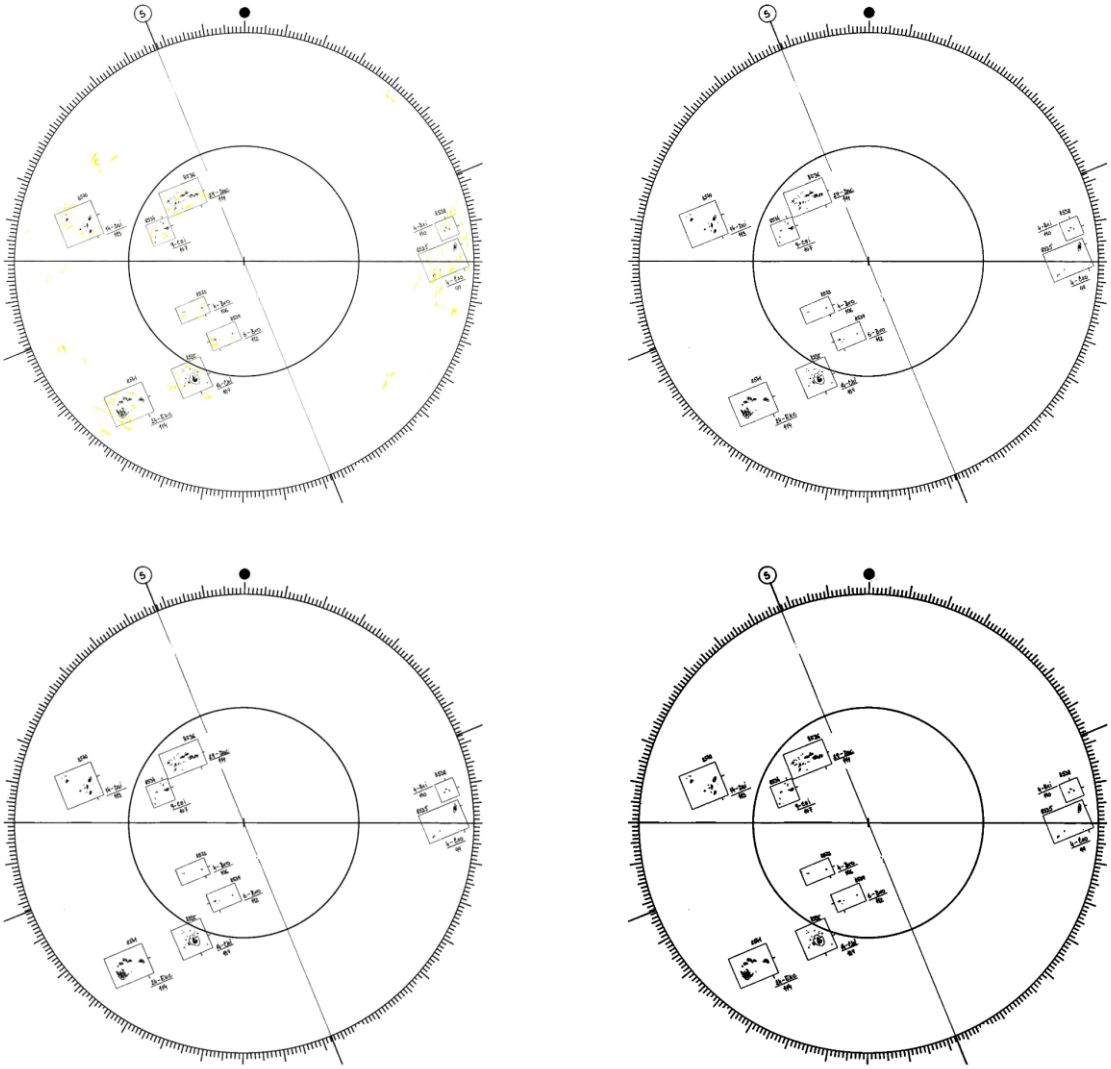

Figure 11: The process of modifying a copy of the drawing to improve detection quality: the original drawing with tables removed (upper left), the result after the first pixel replacement (upper right), the blurred version of the drawing (lower left), and the final version after the second pixel replacement (lower right)

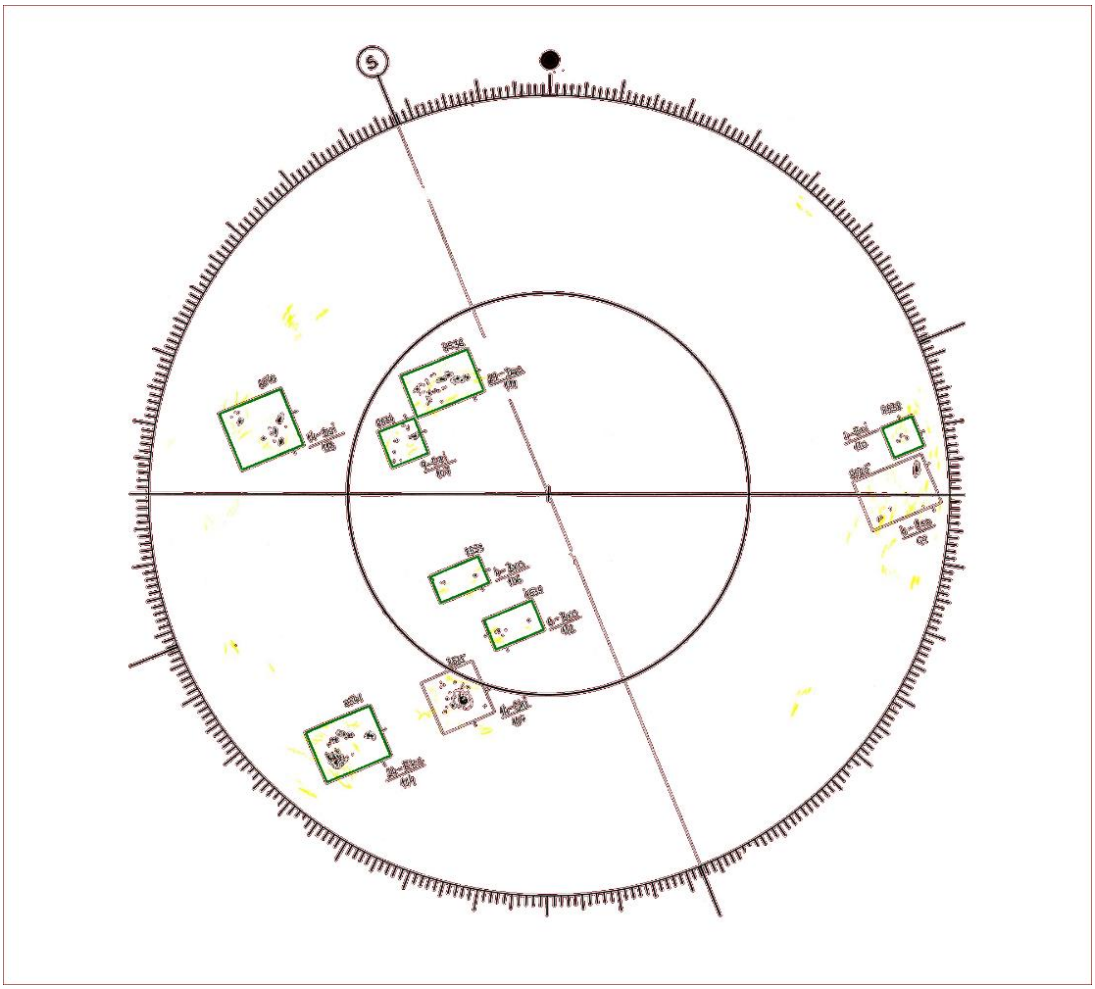

Figure 12: Example of group detection; green - detected groups of spots, brown - detected other shapes

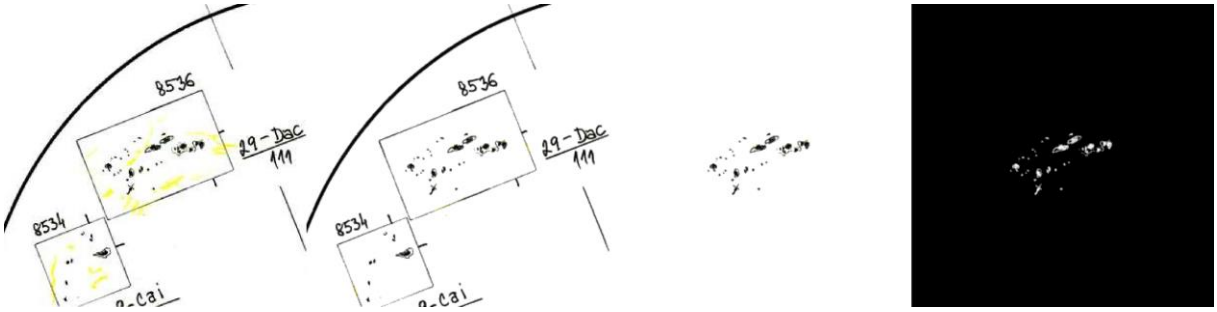

Figure 13: Adjustment of individual spot groups to their final form: the extracted 300×300 px section of the drawing around the detected group (far left), the group after removing faculae areas (middle left), the group with the surrounding area covered (middle right), and the final form of the group (far right)

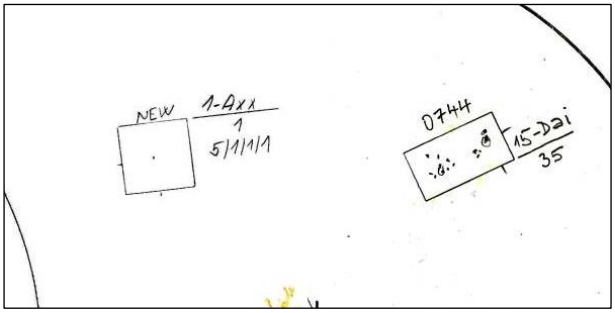

Figure 14: Classes of the model Axx-Dai

Layer	Layer Type	Number of Neurons	Matrix Size	Activation Function
1	Convolutional	32	3×3	ReLU
2	Maxpooling		2×2	
3	Convolutional	16	3×3	ReLU
4	Maxpooling		2×2	
5	Flatten			
6	Fully Connected	24		ReLU
7	Fully Connected	2		Softmax

Figure 15: Structure of CNN model Axx-Dai

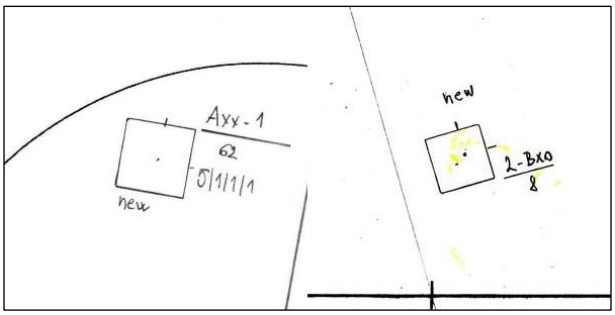

Figure 16: Classes of the model Axx-Bxo

Layer	Layer Type	Number of Neurons	Matrix Size	Activation Function
1	Convolutional	16	3×3	ReLU
2	Maxpooling		2×2	
3	Flatten			
4	Fully Connected	16		ReLU
5	Fully Connected	2		Softmax

Figure 17: Structure of CNN model Axx-Bxo

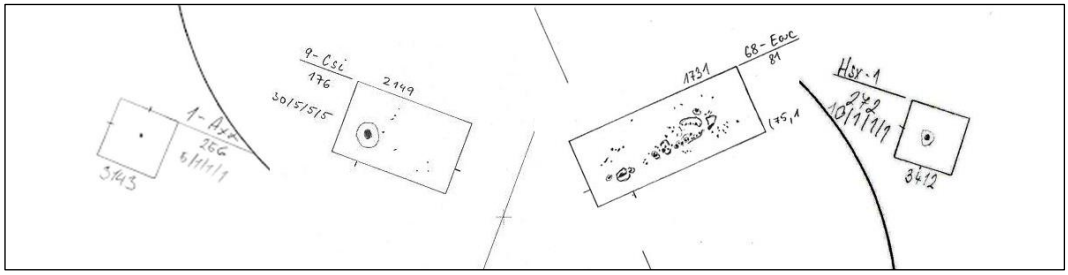

Figure 18: Classes of the model Axx-Csi-Eac-Hsx

Layer	Layer Type	Number of Neurons	Matrix Size	Activation Function
1	Convolutional	32	4×4	ReLU
2	Maxpooling		3×3	
3	Convolutional	16	3×3	ReLU
4	Maxpooling		2×2	
5	Flatten			
6	Fully Connected	32		ReLU
7	Fully Connected	4		Softmax

Figure 19: Structure of CNN model Axx-Csi-Eac-Hsx

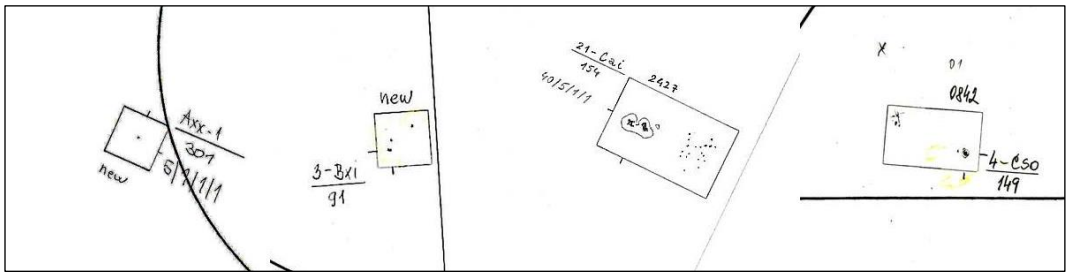

Figure 20: Classes of the model Axx-Bxi-Cai-Cso

Layer	Layer Type	Number of Neurons	Matrix Size	Activation Function
1	Convolutional	16	4×4	ReLU
2	Maxpooling		3×3	
3	Convolutional	8	3×3	ReLU
4	Maxpooling		2×2	
5	Flatten			
6	Fully Connected	32		ReLU
7	Fully Connected	4		Softmax

Figure 21: Structure of CNN model Axx-Bxi-Cai-Cso

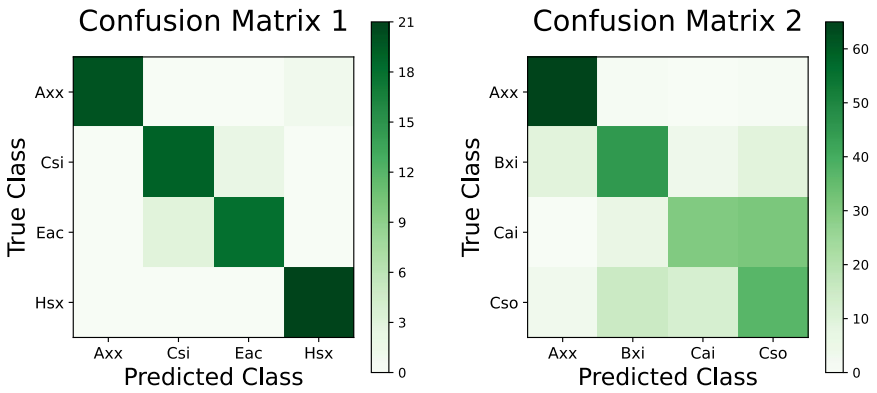

Figure 22: An example of confusion matrices for the four-class models: the matrix for the Axx-Csi-Eac-Hsx model (left) and the matrix for the Axx-Bxi-Cai-Cso model (right).

Layer	Layer Type	Number of Neurons	Matrix Size	Activation Function
1	Convolutional	32	3×3	ReLU
2	Maxpooling		3×3	
3	Convolutional	16	2×2	ReLU
4	Maxpooling		2×2	
5	Convolutional	8	2×2	ReLU
6	Maxpooling		2×2	
7	Flatten			
8	Fully Connected	32		ReLU
9	Fully Connected	7		Softmax

Figure 23: Structure of CNN model A-B-C-D-E-F-H

Layer	Layer Type	Number of Neurons	Matrix Size	Activation Function
1	Convolutional	32	3×3	ReLU
2	Maxpooling		3×3	
3	Convolutional	16	2×2	ReLU
4	Maxpooling		2×2	
5	Flatten			
6	Fully Connected	32		ReLU
7	Fully Connected	6		Softmax

Figure 24: Structure of CNN model a-h-k-r-s-x

Layer	Layer Type	Number of Neurons	Matrix Size	Activation Function
1	Convolutional	16	3×3	ReLU
2	Maxpooling		3×3	
3	Convolutional	8	2×2	ReLU
4	Maxpooling		2×2	
5	Flatten			
6	Fully Connected	32		ReLU
7	Fully Connected	4		Softmax

Figure 25: Structure of CNN model c-i-o-x

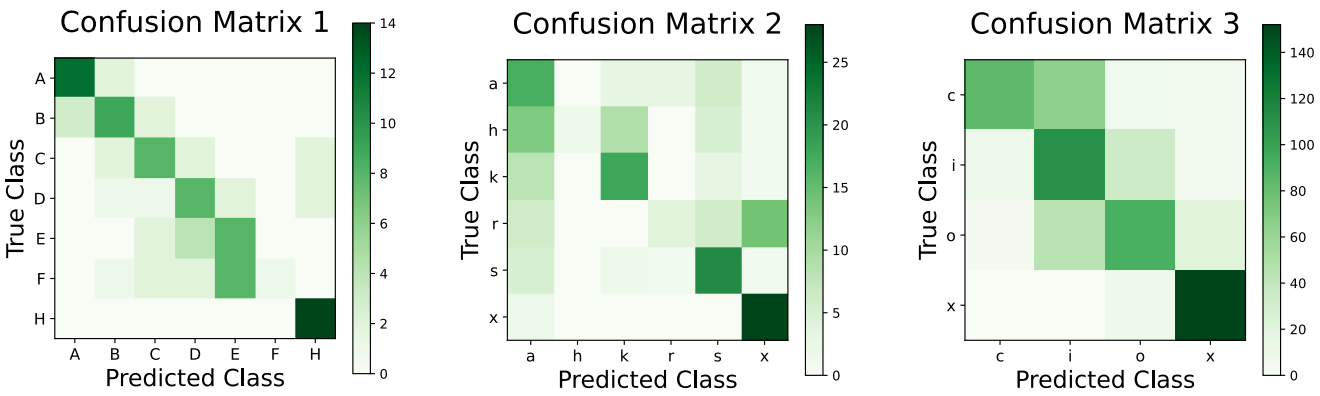

Figure 26: An example of confusion matrices for the letter-based models: the matrix for the A-B-C-D-E-F-H model (left), the a-h-k-r-s-x model (middle), and the c-i-o-x model (right)

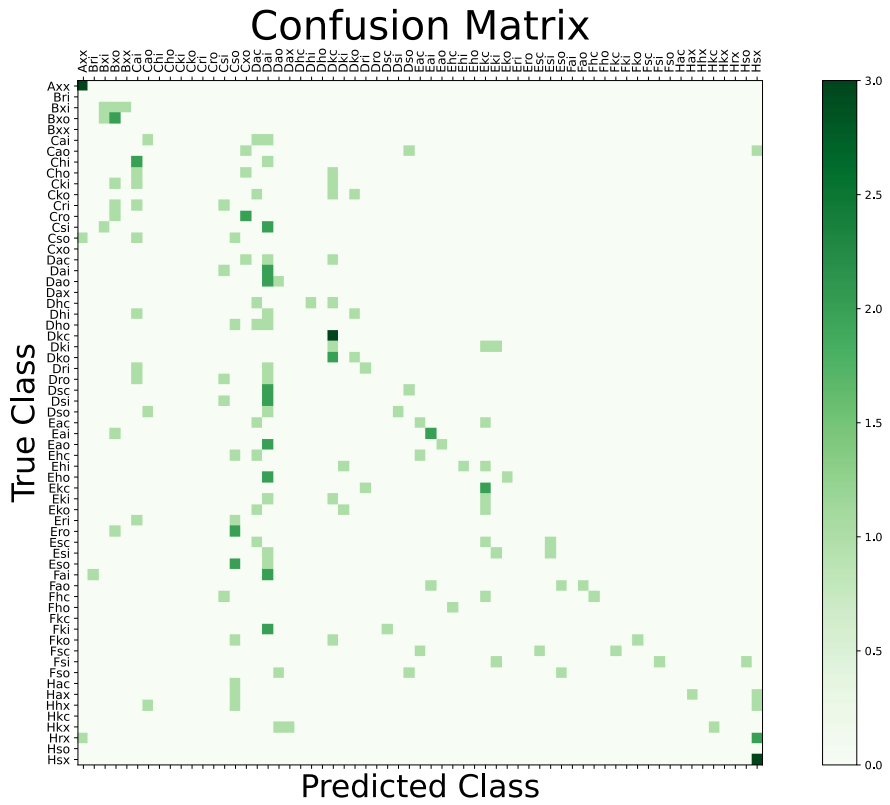

Figure 27: Confusion matrix of the final letter model

[1] Hans Bernhard (2000) *Sunspots* [online image]. Wikipedia. Available at: https://de.wikipedia.org/wiki/Sonnenfleck#/media/Datei:Sunspots.JPG (Accessed: 14 March 2024).
[2] Unknown author (n.d.) *Faculae and Sunspots at Solar Maximum* [online image]. Wikipedia. Available at: https://en.wikipedia.org/wiki/Solar_facula#/media/File:Faculae_and_Sunspots_at_Solar_Maximum.tif (Accessed: 14 March 2024).
[3] Astronomický ústav AV ČR (n.d.) *McIntoshova klasifikace* [online image]. Available at: https://www.asu.cas.cz/~sunwatch/public/files/other/clanky/zonnevlekclassificatie-1.jpg (Accessed: 14 March 2024).
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