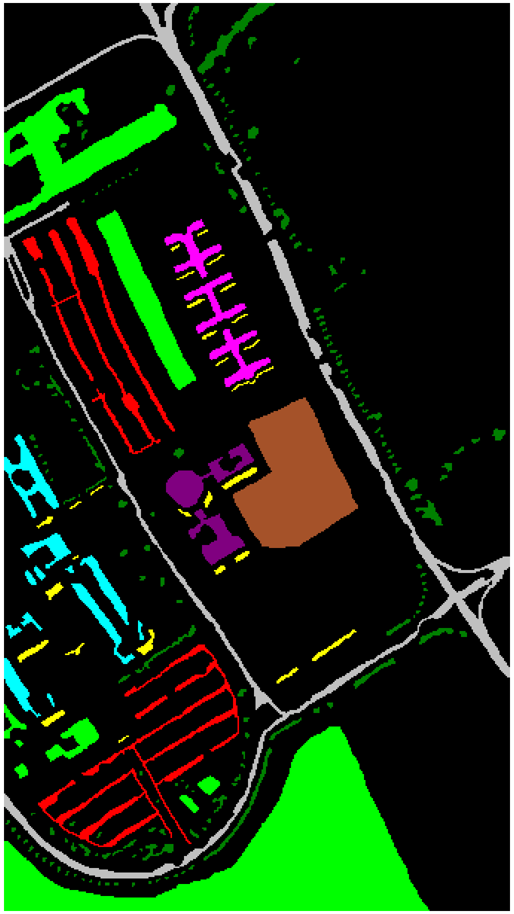
Remote sensing application 2:

Segmentation and classification of hyperspectral images using watershed

Classification problem

Input ROSIS image
610 x 340 pixels,
103 bands

Ground truth
reference



Task

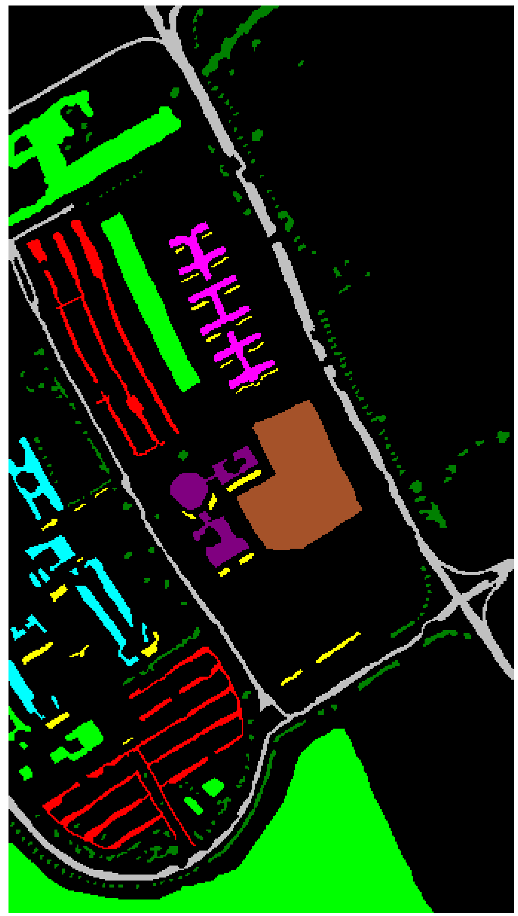
Assign ***every*** pixel to ***one*** of the ***nine*** information classes:

alphalt
meadows
gravel
trees
metal sheets
bare soil
bitumen
bricks
shadows

Classification problem (103-band ROSIS data)

Class	Training samples	Test samples
Asphalt	548	6641
Meadows	540	18649
Gravel	392	2099
Trees	524	3064
Metal sheets	265	1345
Bare soil	532	5029
Bitumen	375	1330
Bricks	514	3682
Shadows	231	947

Ground truth reference



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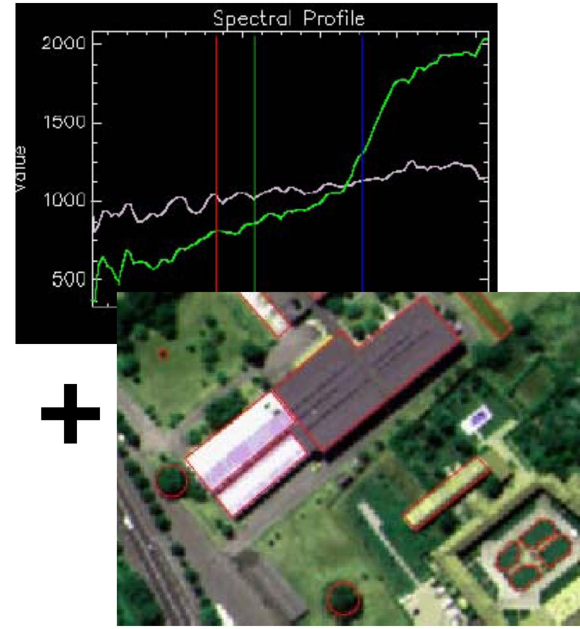
Spectral-spatial classification

- Spectral + spatial information for more accurate classification
- How to define spatial structures?
  - Closest neighborhood (e.g. morphological profiles) → done before
  - Adaptive neighborhood (segmentation map) → ***currently investigated***



Spectral-spatial classification

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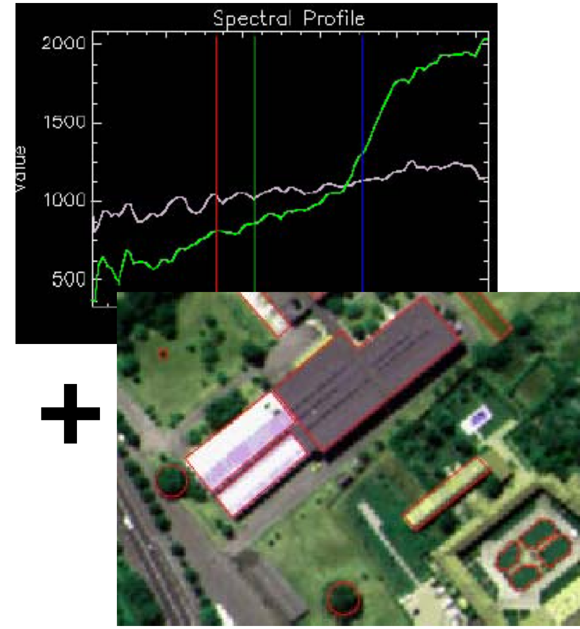
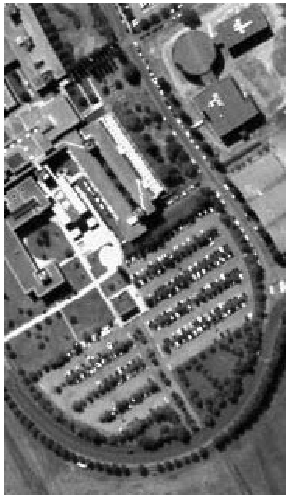


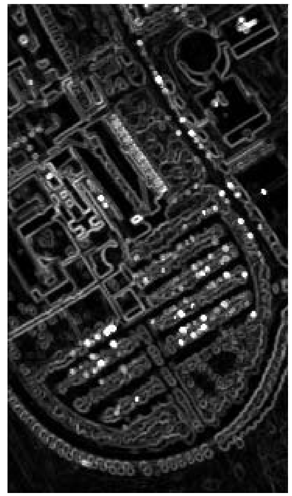
Objective:

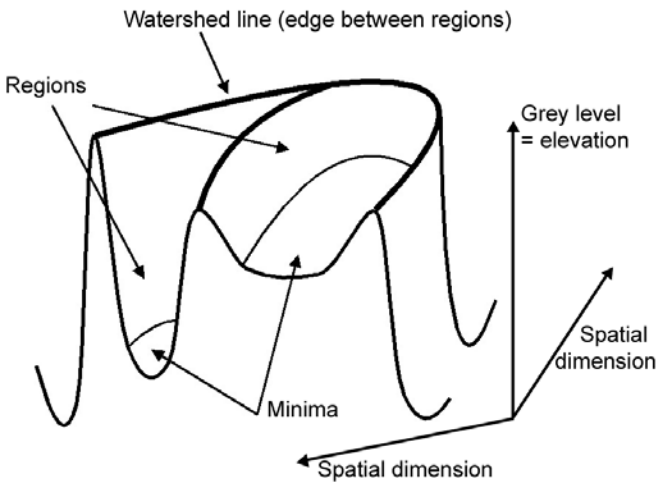
- ***Segment*** a hyperspectral image = find an exhaustive partitioning of the image into homogeneous regions
  - ➢ Use MM approach to segmentation: ***watershed transformation***
- ***Spectral*** info + ***spatial*** info → classify image

Watershed segmentation



gradient



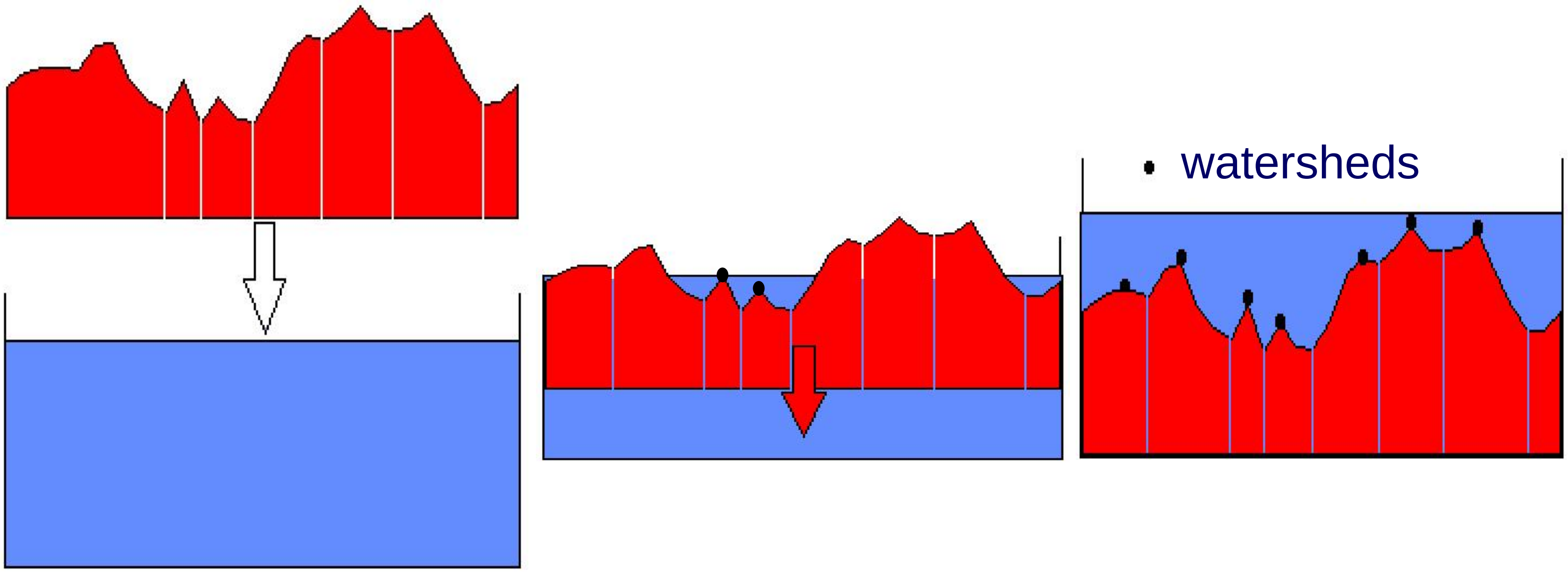


Region growing + edge detection method:

- ***Minimum*** of a gradient = core of a homogeneous region
- ***1 region*** = set of pixels connected to 1 local minimum of the gradient
- ***Watershed lines*** = edges between adjacent regions

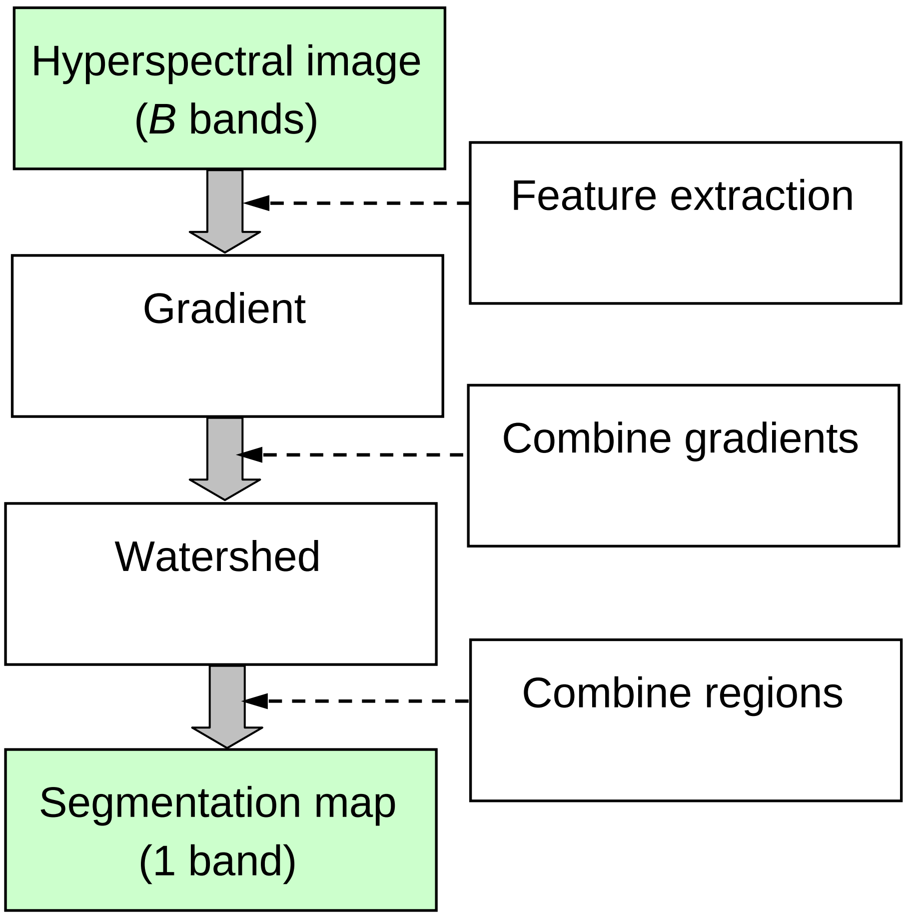
Watershed algorithm

- L. Vincent and P. Soille, "Watersheds in digital spaces: an ***efficient*** algorithm ***based on immersion simulations***," *IEEE Trans. Pattern Analysis and Machine Intel*., vol. 13, no. 6, pp. 583–598, June 1991.



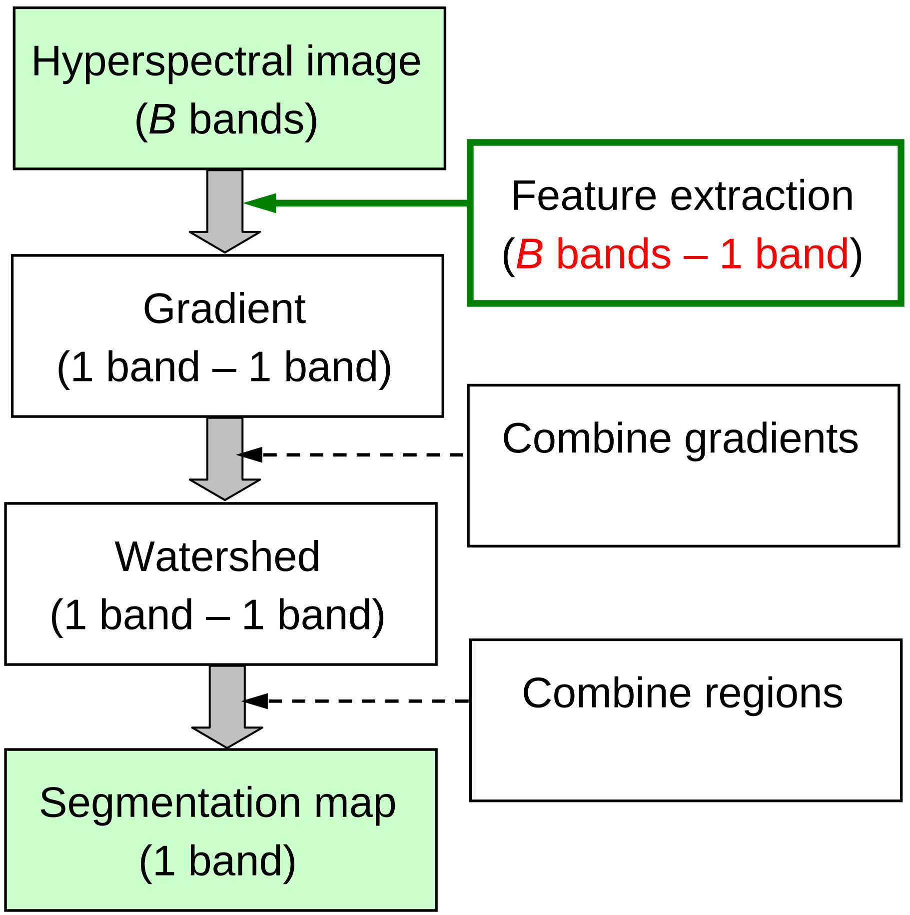
Watershed for a hyperspectral image

- From *B*-band image → 1-band segmentation map:



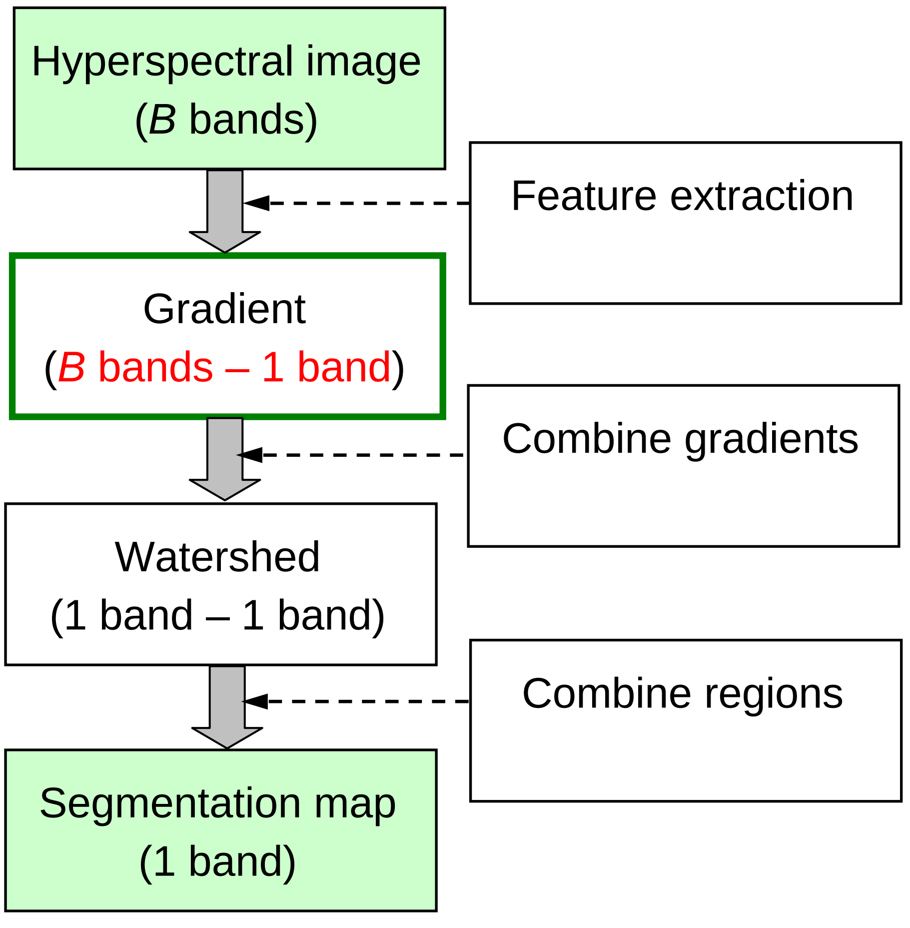
Watershed for a hyperspectral image

- From *B*-band image → 1-band segmentation map:
  - ➢ Feature extraction (PCA, ICA, …)?



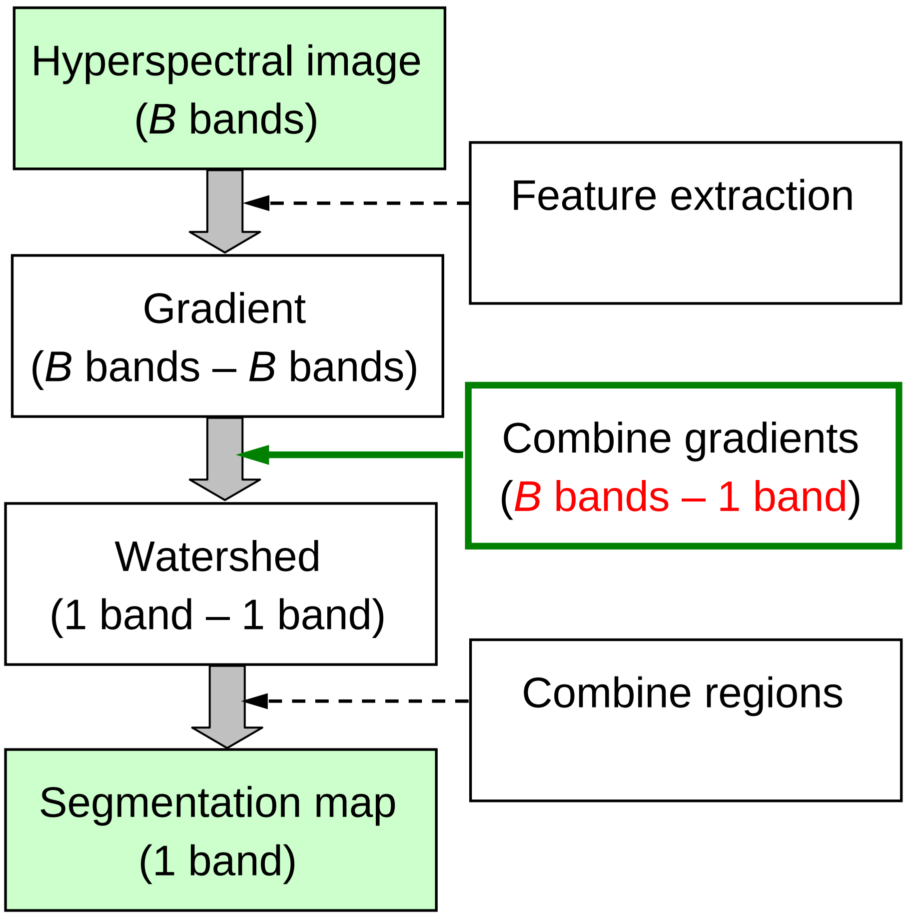
Watershed for a hyperspectral image

- From *B*-band image → 1-band segmentation map:
  - ➢ Feature extraction (PCA, ICA, …)?
  - ➢ Vectorial gradient?



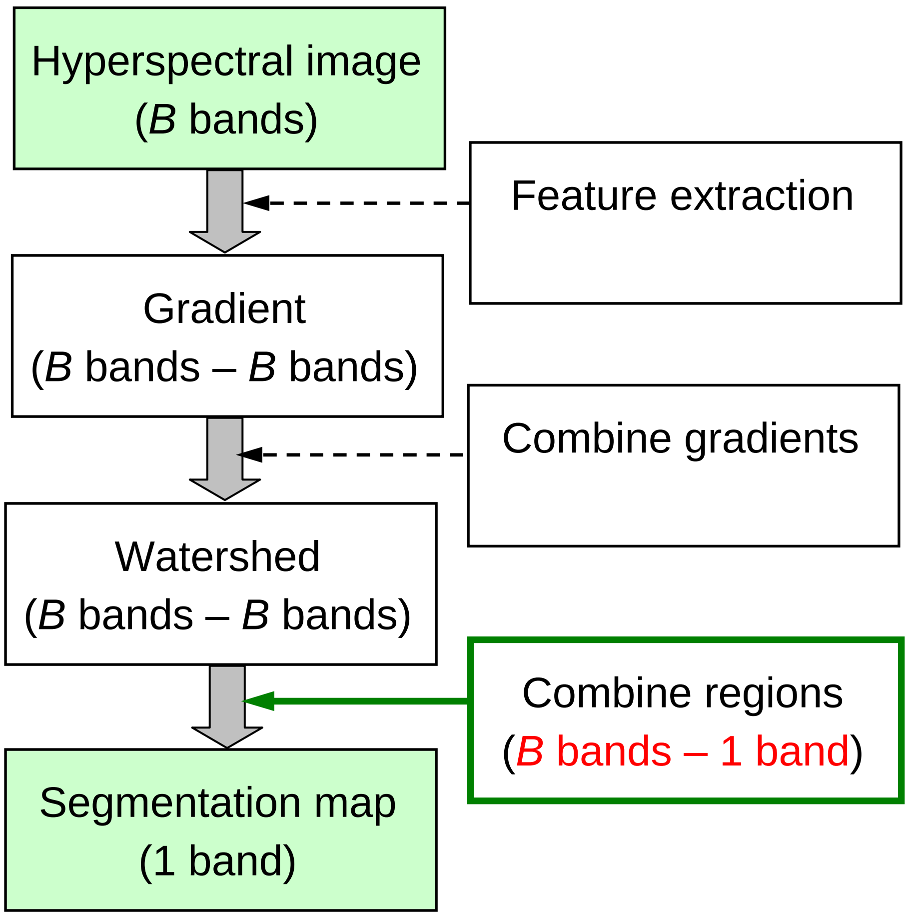
Watershed for a hyperspectral image

- From *B*-band image → 1-band segmentation map:
  - ➢ Feature extraction (PCA, ICA, …)?
  - ➢ Vectorial gradient?
  - ➢ Combine *B* gradients?



Watershed for a hyperspectral image

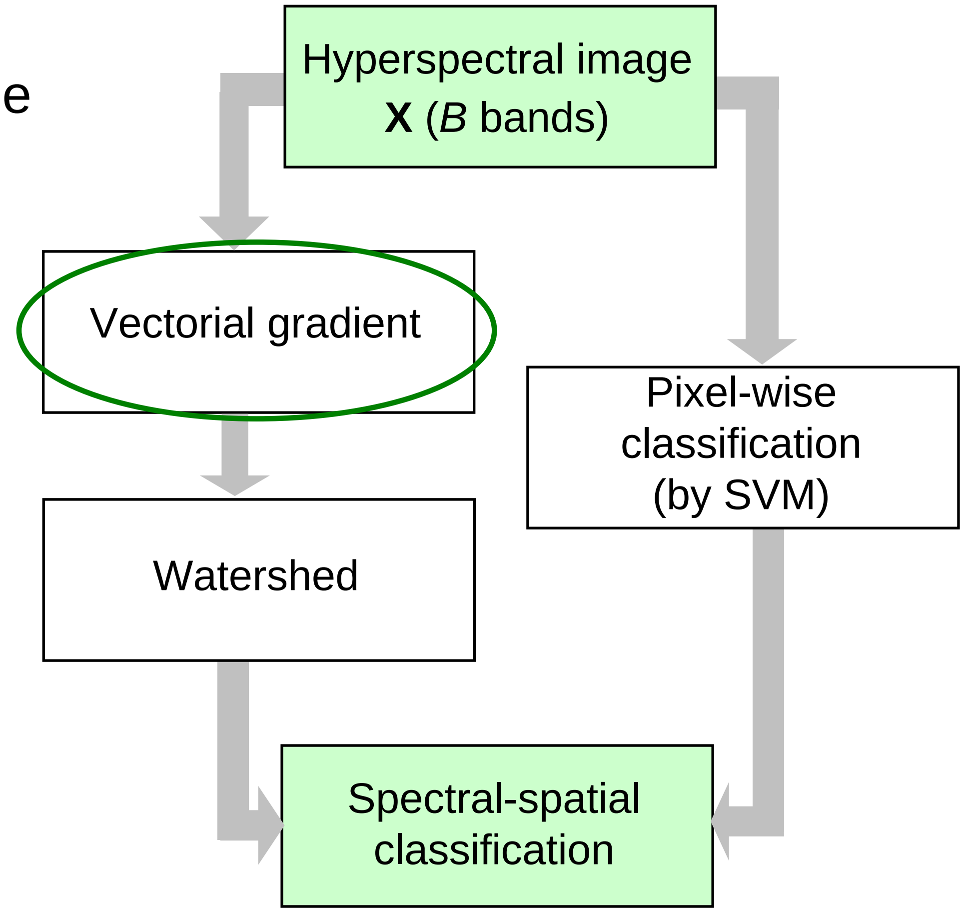
- From *B*-band image → 1-band segmentation map:
  - ➢ Feature extraction (PCA, ICA, …)?
  - ➢ Vectorial gradient?
  - ➢ Combine *B* gradients?
  - ➢ Combine *B* watershed regions?



Segmentation and classification of data

- Input
  - *B*-band hyperspectral image $\mathbf{X} = \{x_j \in R^B, j = 1, 2, \ldots, n\}$
  - B ~ 100

- Vectorial gradient



Robust Color Morphological Gradient

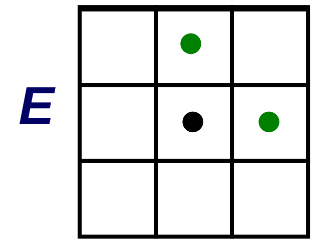
- For each pixel $\mathbf{x}_p$, $\chi = [\mathbf{x}_{p1}, \mathbf{x}_{p2}, \ldots, \mathbf{x}_{pe}]$ is a set of *e* vectors within *E*

- Color Morphological Gradient (CMG):

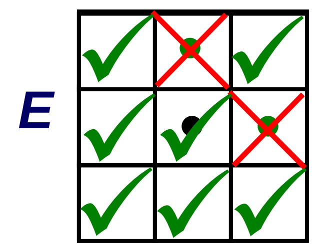
$$CMG_E(\mathbf{x}_p) = \max_{i,\, j \in \chi}\{\|\, \mathbf{x}_{pi} - \mathbf{x}_{pj} \,\|_2\}$$

- Robust Color Morphological Gradient (RCMG):
  - $\mathbf{x}_{pi\_max}, \mathbf{x}_{pj\_max}$ – pixels that define the CMG of $\mathbf{x}_p$
  - $$RCMG_E(\mathbf{x}_p) = \max_{i,\, j \in \{\chi - [\mathbf{x}_{pi\_max},\, \mathbf{x}p_{j\_max}]\}}\{\|\, \mathbf{x}_{pi} - \mathbf{x}_{pj} \,\|_2\}$$

If two pixels marked by green define the CMG:



The RCMG is computed using all the pixels except these two:

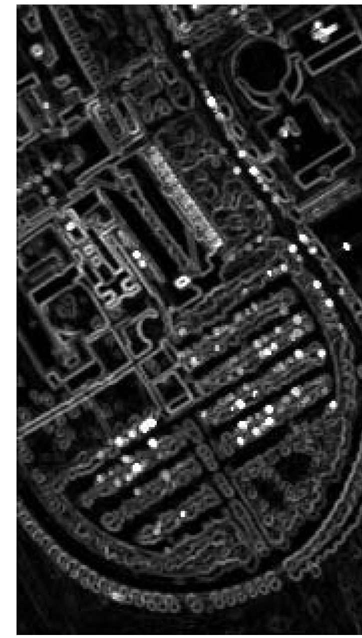


RCMG of the University of Pavia image

- *B*-band image → one-band gradient
- Principal borders are defined
- Presence of “noisy” edges
  - Filter image → “noisy” borders reduced, but info about details lost

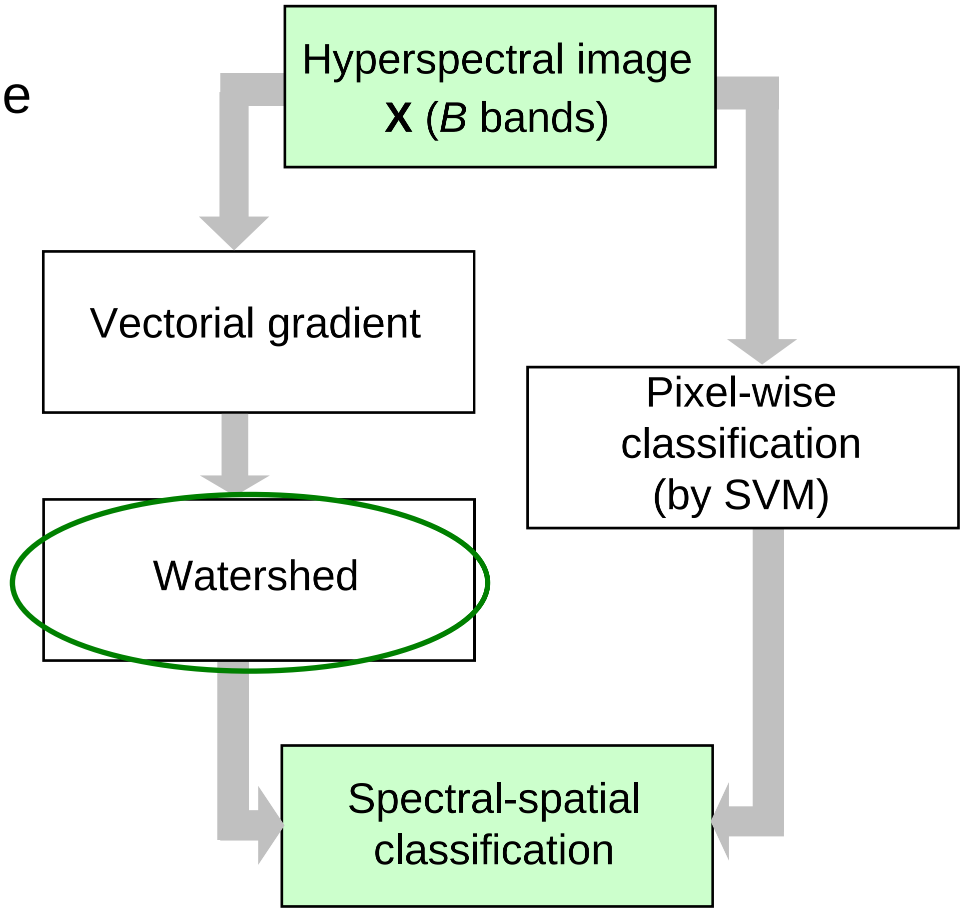
Input image

RCMG



Segmentation and classification of data

- Input
  - *B*-band hyperspectral image
    $\mathbf{X} = \{x_j \in R^B, j = 1, 2, \ldots, n\}$
  - B ~ 100
- Vectorial gradient
- ***Watershed***

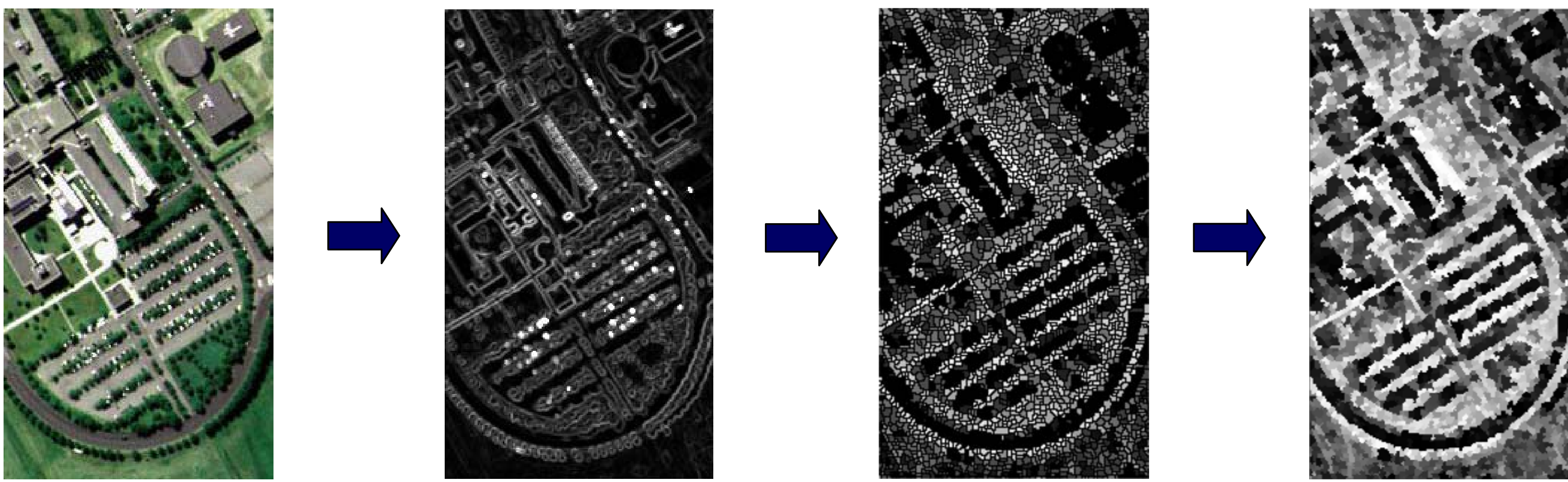


Watershed

- Algorithm of Vincent and Soille (1991)
- For every region **S** Standard Vector Median:

$$\mathbf{s}_{VM} = argmin_{\mathbf{s}\in\mathbf{S}} \left\{ \sum_{j=1}^{m} \|\mathbf{s} - \mathbf{s}_j\|_1 \right\}$$

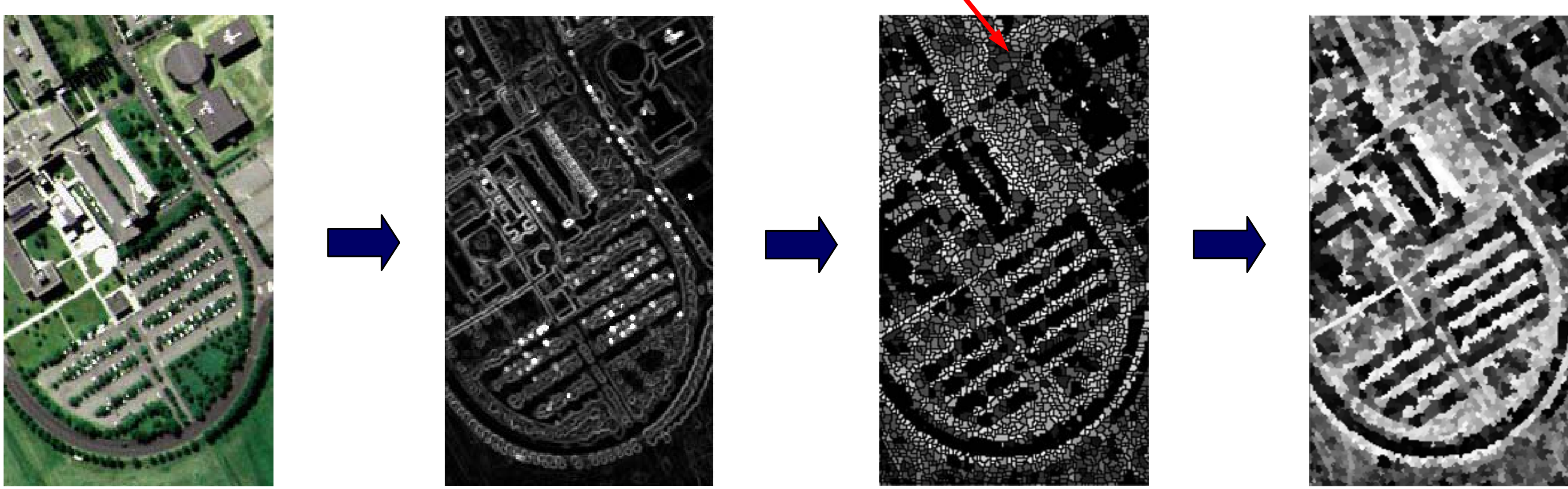
- Every watershed pixel → to the neighboring region with the “closest” median



Watershed

- Oversegmentation
  - ➢ Merging of regions

- Obtained regions → to improve classification



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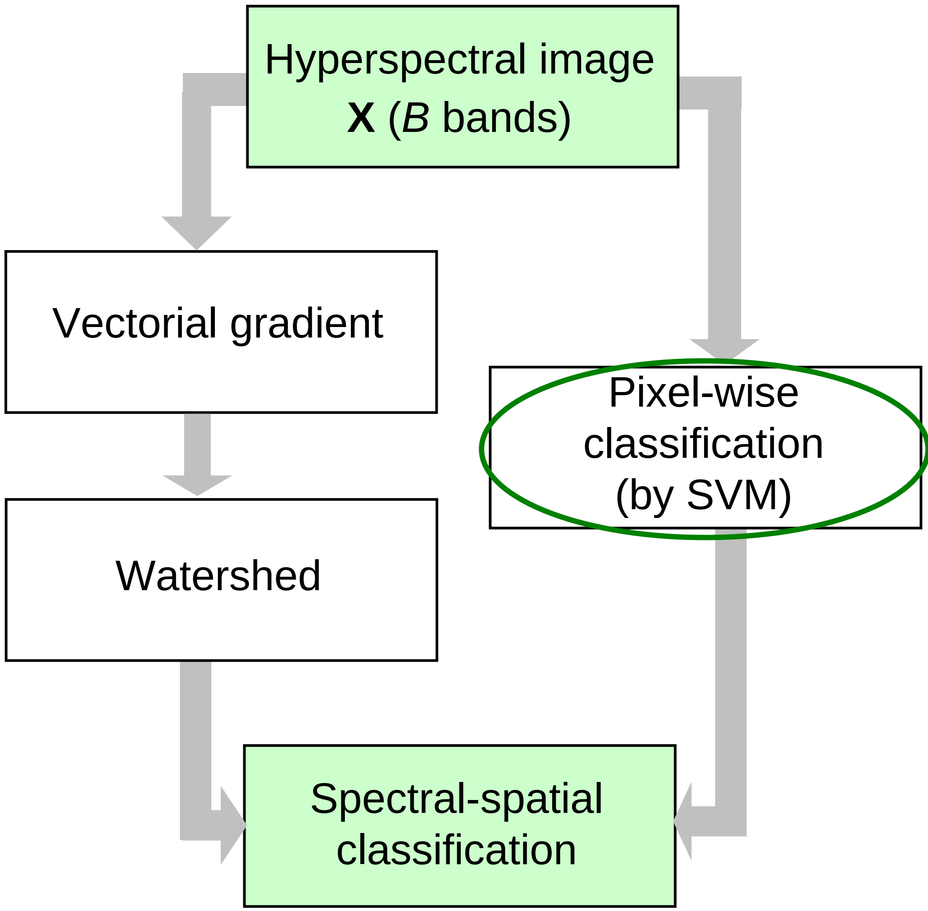
Mathematical morphology

Segmentation and classification of data

- Input
  - *B*-band hyperspectral image
    $\mathbf{X} = \{x_j \in R^B, j = 1, 2, \ldots, n\}$
  - B ~ 100
- Vectorial gradient
- Watershed
- ***Pixel-wise classification (by SVM)***

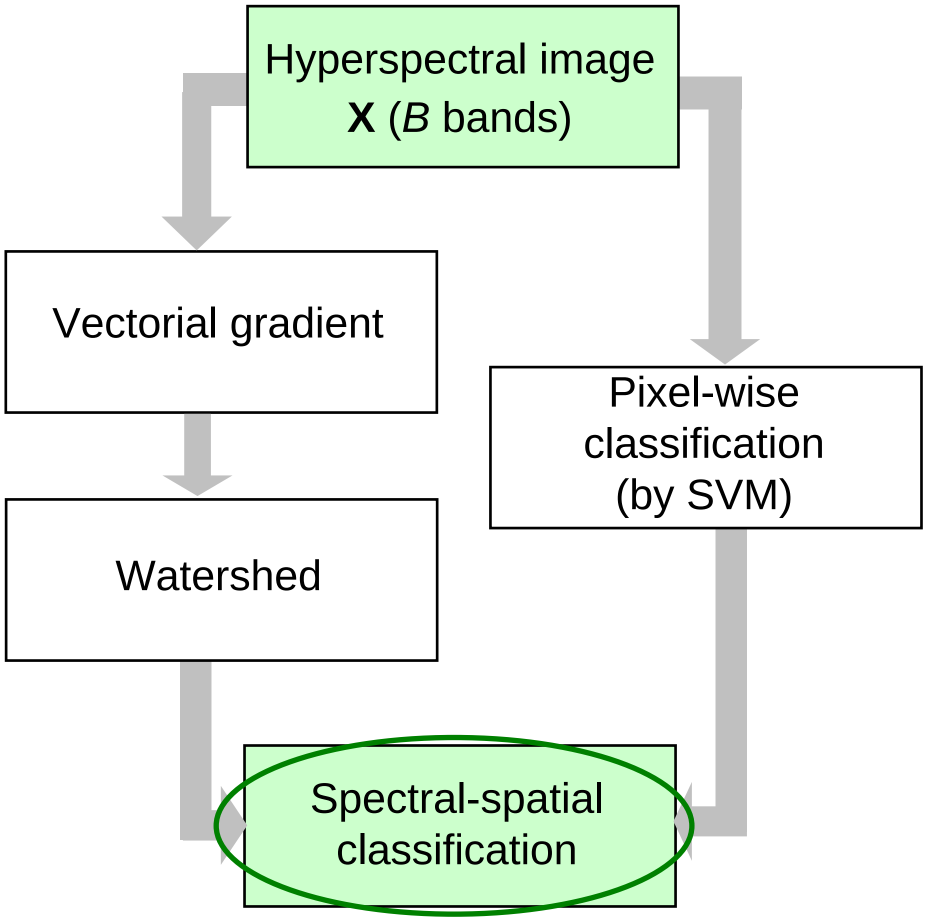


Pixel-wise SVM classification

- Milti-class pairwise (one *versus* one) classification, with Gaussian Radial Basis Function was performed
- Optimal parameters were determined by 5-fold cross-validation: C = 128, γ = 0.125
- Overall test accuracy: ***82.1%***

Segmentation and classification of data

- Input
  - *B*-band hyperspectral image $\mathbf{X} = \{x_j \in R^B, j = 1, 2, \ldots, n\}$
  - B ~ 100
- Vectorial gradient
- Watershed
- Pixel-wise classification (by SVM)
- ***Spectral-spatial classification***



Spectral-spatial classification

Pixel-wise classification map

Pixel-wise classification map + segmentation map

Majority vote within the watershed regions

No WHEDs (watershed pixels not processed)

With WHEDs (watershed pixels assigned to neighboring regions)

Spectral-spatial classification

Classification accuracies (%):

Accuracy	Pixel-wise SVM	SVM + Majority vote	
		No WHEDs	*With WHEDs*
Overall accuracy	82.08	84.41	**86.64**
Average accuracy	89.11	90.70	**92.13**
Kappa coefficient κ	77.49	80.32	**83.05**
Asphalt	85.48	89.82	**94.28**
Meadows	71.56	74.03	**76.41**
Gravel	**70.70**	69.99	69.89
Trees	97.88	98.04	**98.30**
Metal sheets	99.55	**99.78**	**99.78**
Bare soil	93.46	95.37	**97.51**
Bitumen	91.95	94.74	**97.14**
Bricks	92.97	96.31	**98.29**
Shadows	**98.42**	98.20	97.57

Spectral-spatial classification

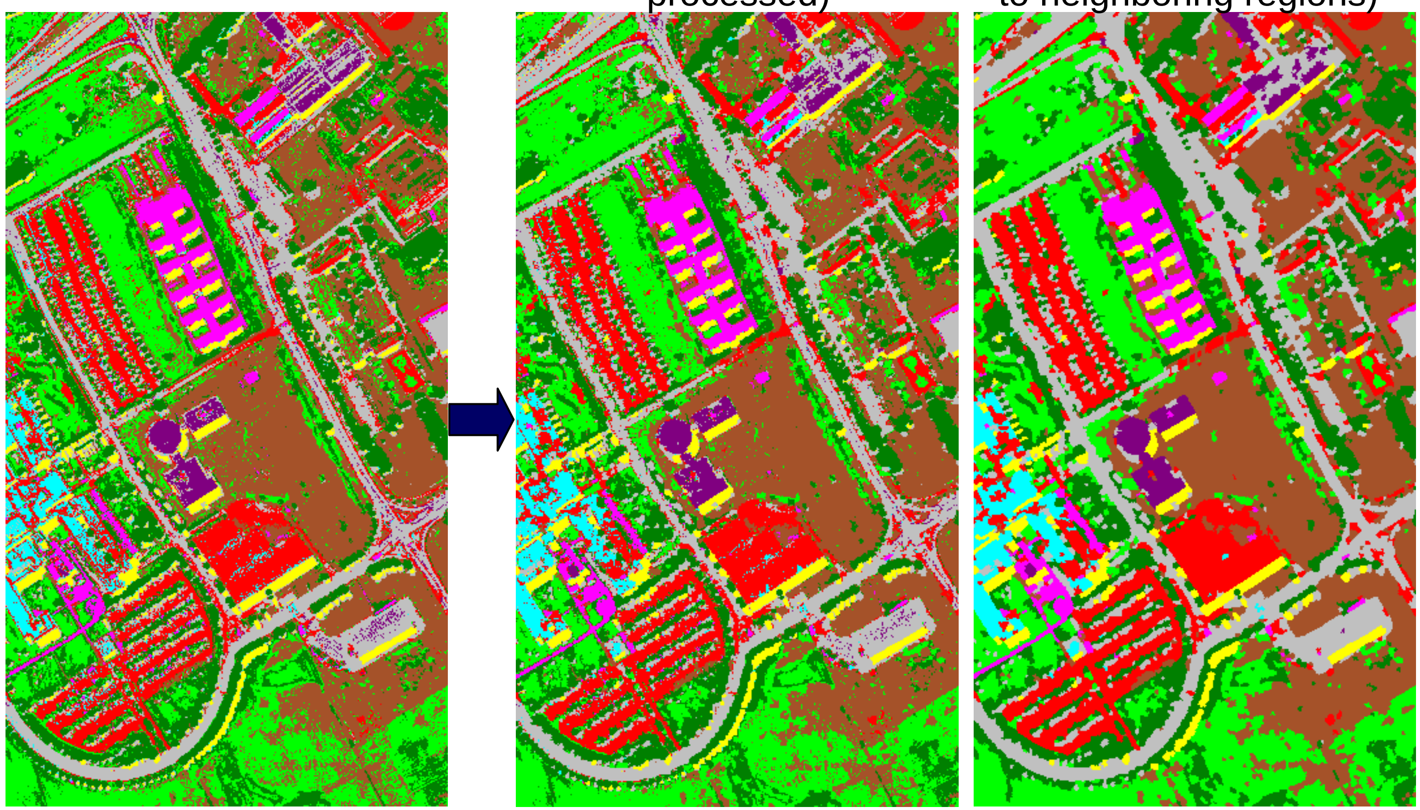
- Noise reduced
- Rough borders

Pixel-wise classification map

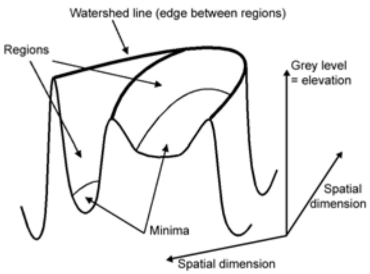
Majority vote within the watershed regions

No WHEDs (watershed pixels not processed)

With WHEDs (watershed pixels assigned to neighboring regions)

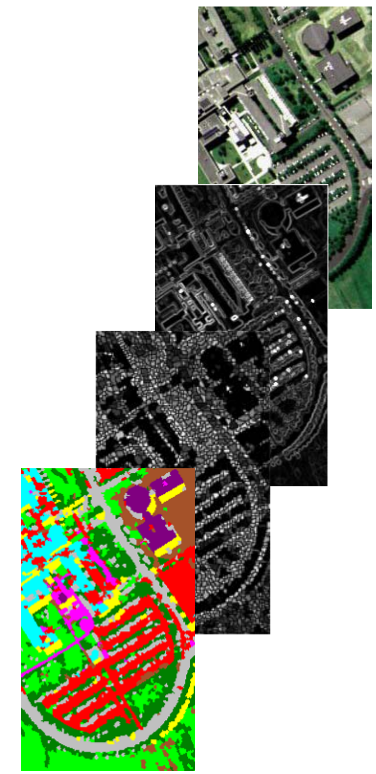


Summary: segmentation and classification using watershed



- Segmentation by morphological watershed combines region growing and edge detection techniques
  - ➢ Extension of a watershed to hyperspectral data is feasible

- A further step forward towards the integration of spatial and spectral information for the classification of hyperspectral data:
  use of ***adaptive neighborhoods*** (***segmentation map***)
  - ➢ Results are promising



- ***Perspectives:***
  Reduce oversegmentation 🡐 incorporate *a priori* knowledge into segmentation
  - ➢ Marker-controlled watershed segmentation