Cloud Removal in Image Time Series through Unmixing

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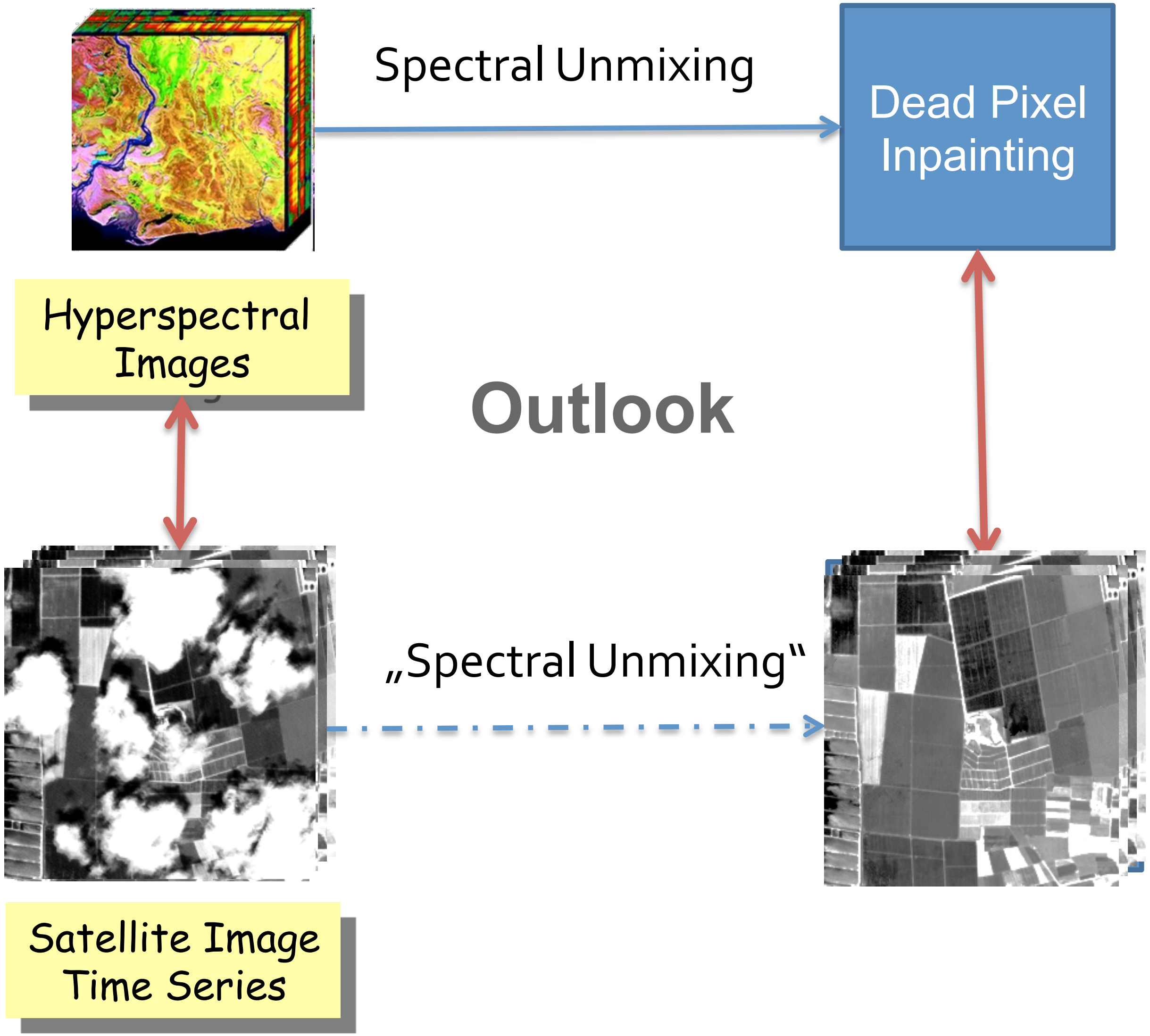
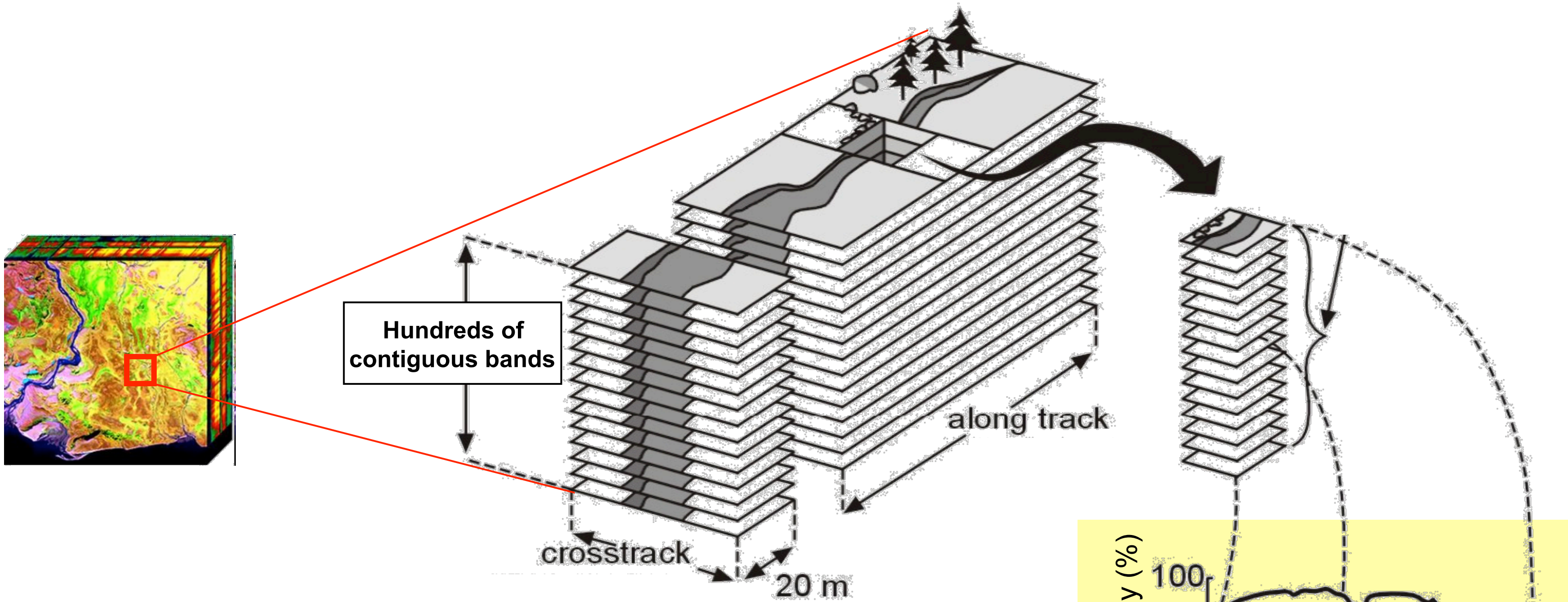
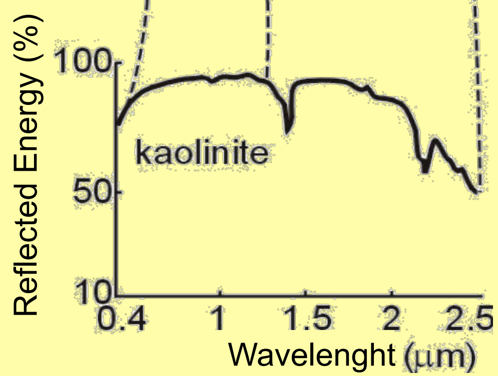
Outlook


Spectral Unmixing
Dead Pixel Inpainting
Hyperspectral Images
„Spectral Unmixing“
Satellite Image Time Series

Hyperspectral Images





The values of a pixel throughout all the spectral bands gives us the spectrum of the pixel

- Usually up to hundreds of bands in the range 0.4 – 2.5 micrometers
- Reduced spatial resolution
- State-of-the-art sensors are airborne (HySpex)
- Each image element contains a characteristic spectrum

Spectral Unmixing

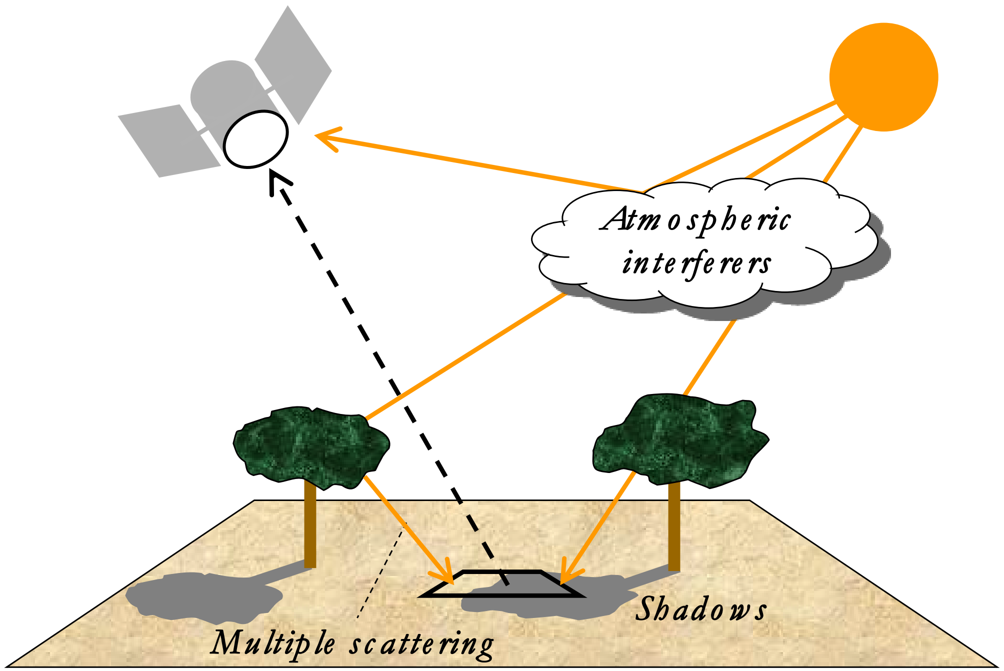
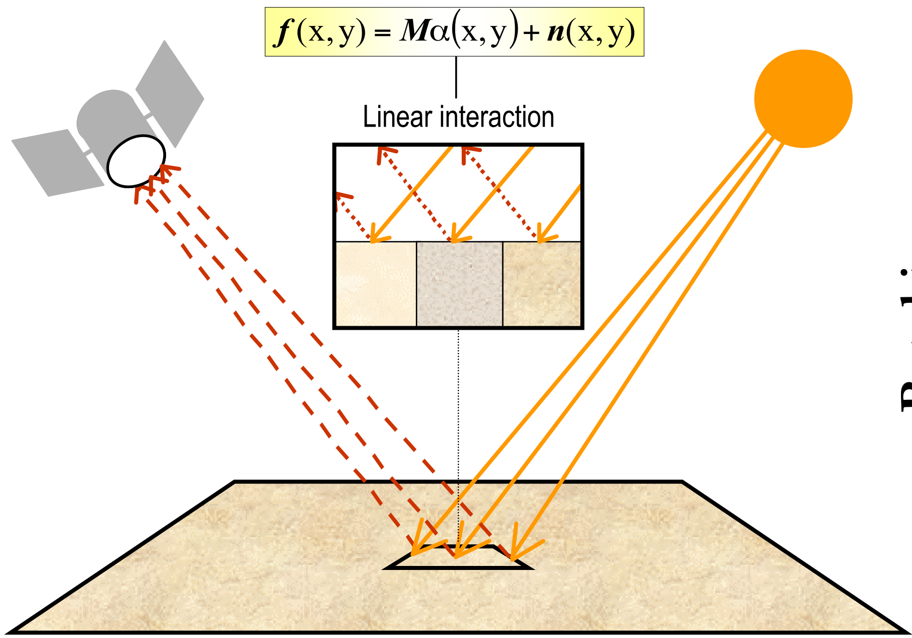
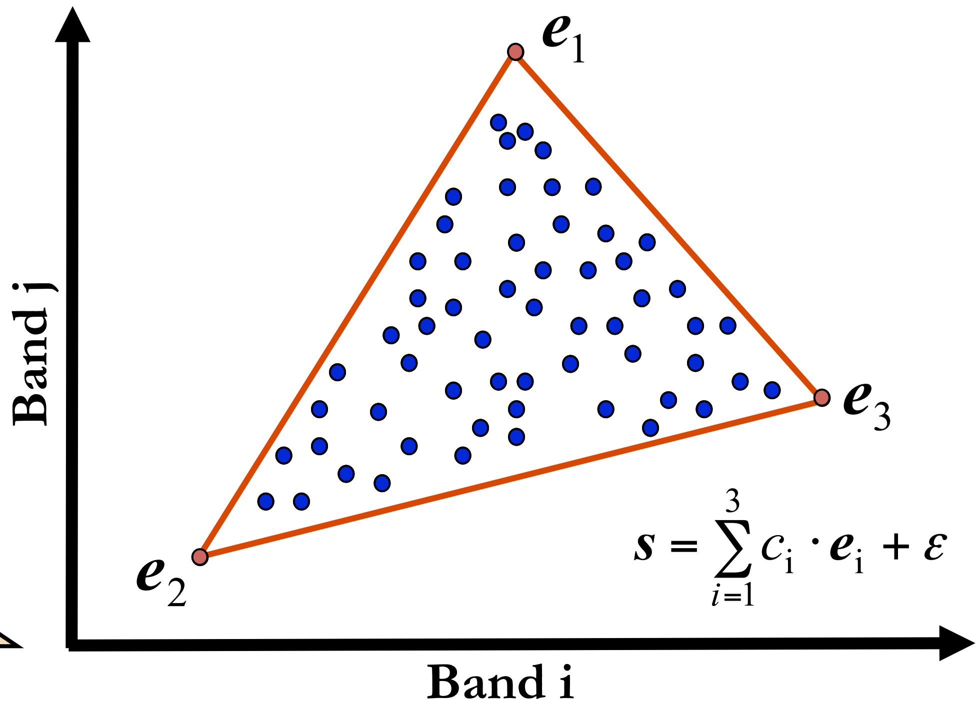


Figure by Antonio Plaza

Spectral Unmixing

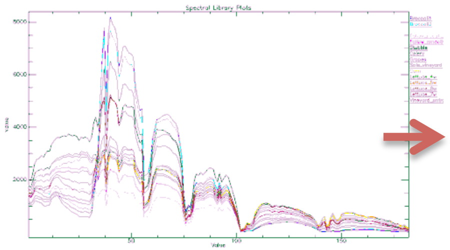
- In *linear* spectral unmixing, the goal is to find a set of macroscopically pure spectral components (called *endmembers*) that can be used to unmix all other pixels in the data.
- Unmixing amounts at finding the fractional coverage (*abundance*) of each endmember in each pixel of the scene, which can be approached as a *geometrical* problem:





Slide by Antonio Plaza

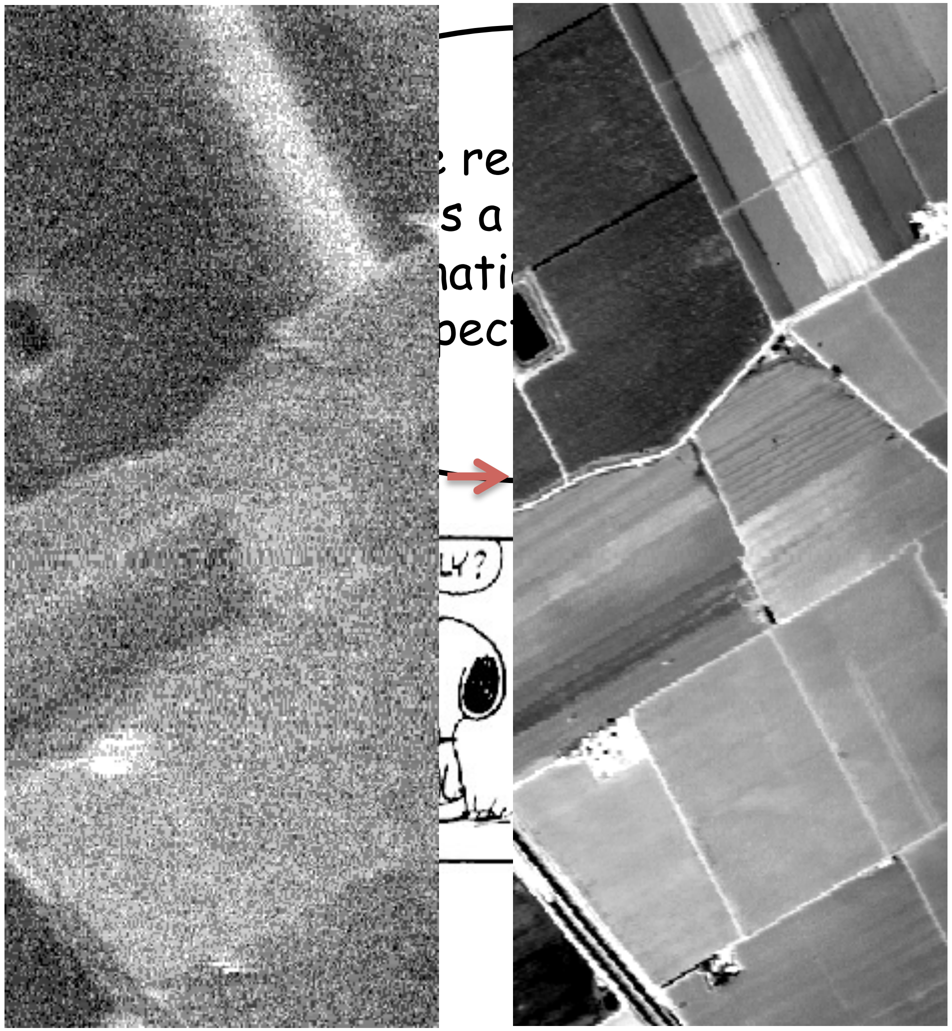
Unmixing-based Denoising (UBD)



Reference Spectrum i

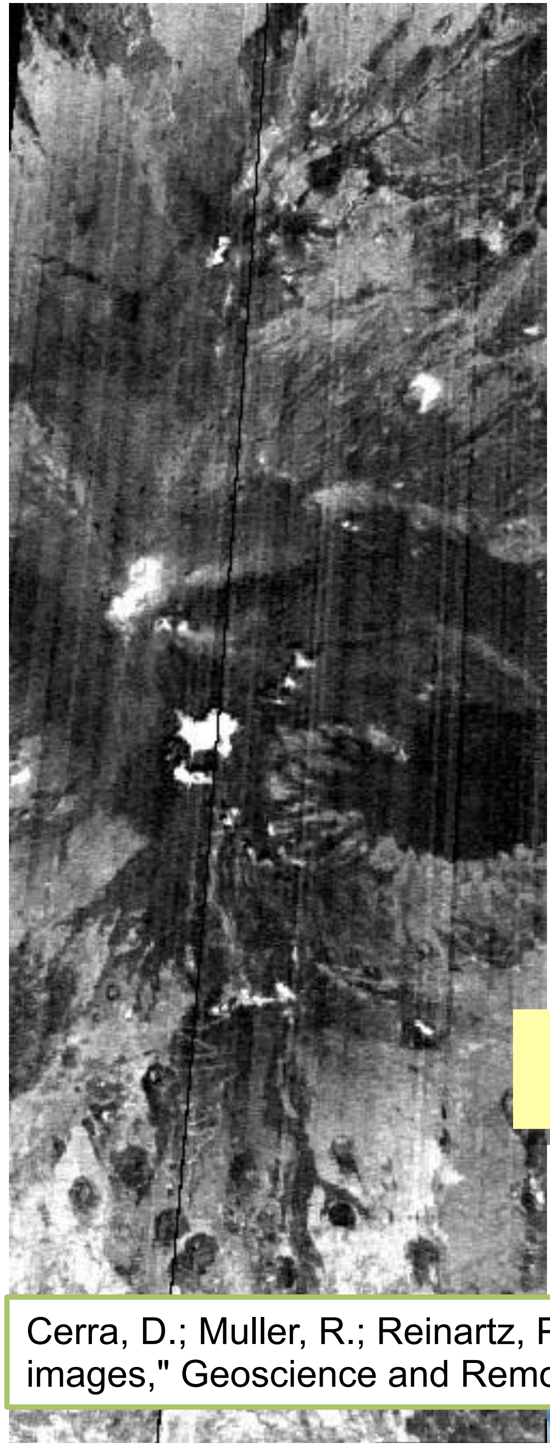
$$\hat{m} = \sum_{i=1}^{k} x_i s_i$$

Fractional Abundance



- Operates pixelwise
- Tuned for the retrieval of specific band(s) with low SNR

Cerra, D.; Muller, R.; Reinartz, P., "Noise Reduction in Hyperspectral Images Through Spectral Unmixing," *Geoscience and Remote Sensing Letters, IEEE* , vol.11, no.1, pp.109,113, Jan. 2014



Hyperion scene,
Etna Volcano, Italy

UBD & Inpainting

- We can use UBD to „predict“ missing values from a given band in a hyperspectral scene
- Results are more reliable than the ones obtained based on neighbouring pixels/bands, as the full spectral information of each pixel is exploited
- Details/edges are preserved

Cerra, D.; Muller, R.; Reinartz, P., "Unmixing-based denoising for destriping and inpainting of hyperspectral images," Geoscience and Remote Sensing Symposium (IGARSS), 2014

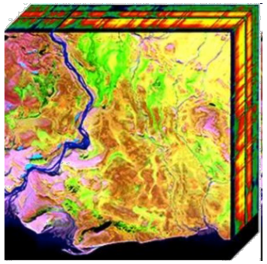
Inpainting Results
(comparison with noise-free values)

Method	RMSE
UBD + Sparse Rec.	**2.4344**
Spectral Interpolation (best)	9.2977
Spatial Interpolation (best)	5.3555
PDE	4.4295
DCT	7.9484

PDE
3D inpainting methods based on Partial Differential Equations

DCT
3D inpainting method based on Discrete Cosine Transform

From Hyperspectral Images to Multispectral Image Time Series



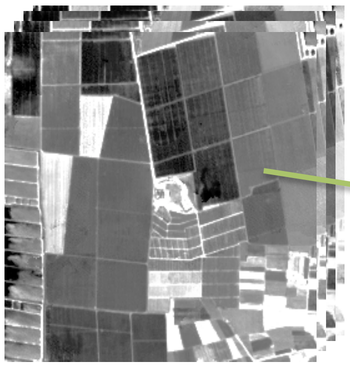
Hyperspectral Images

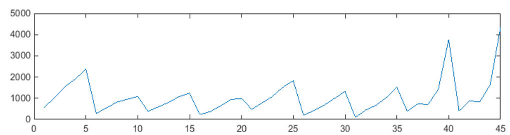
IN COMMON

High Dimensionality

DIFFERENCES

- „Spectra“ in TS are not continuous
- Spectral bands span a large frequency range
- Identification of materials in MS images limited
- Evolution in time in TS





MS Image Time Series

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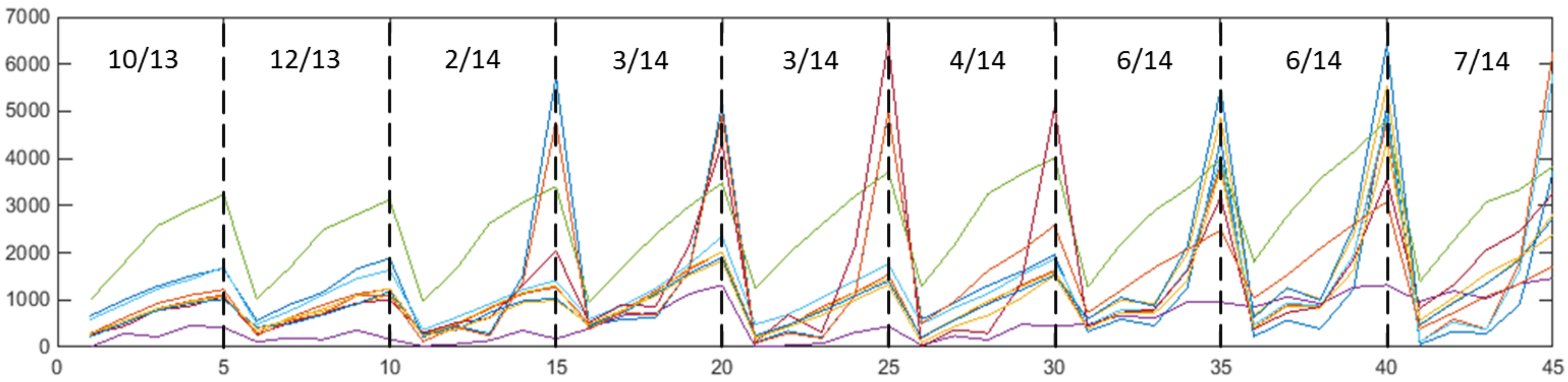
From Hyperspectral Images to Multispectral Image Time Series



What is an „Endmember“ or „pure material“ in a MSITS?

It is a class/object which presents a characteristic evolution in time

We assume that the number of such classes is limited and < tot bands

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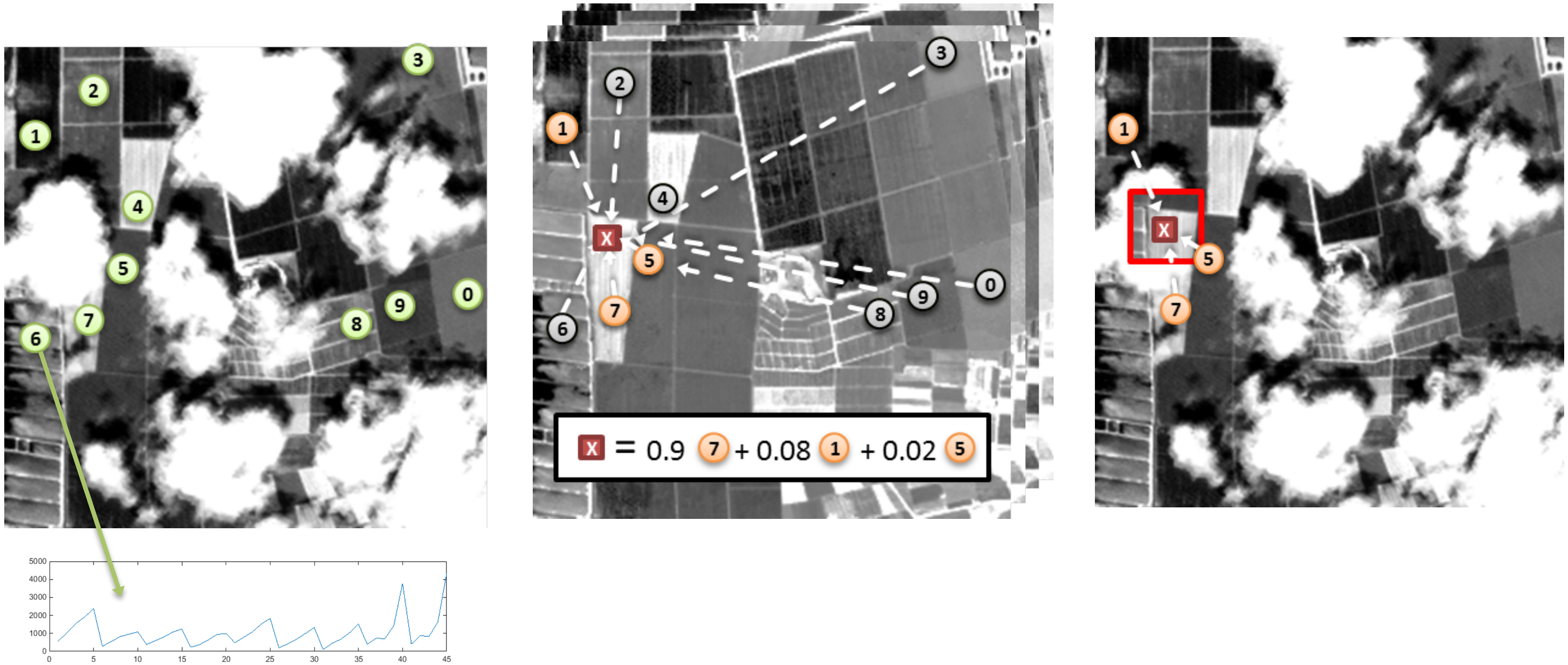
Now we can use Hyperspectral image processing tools for cloud removal



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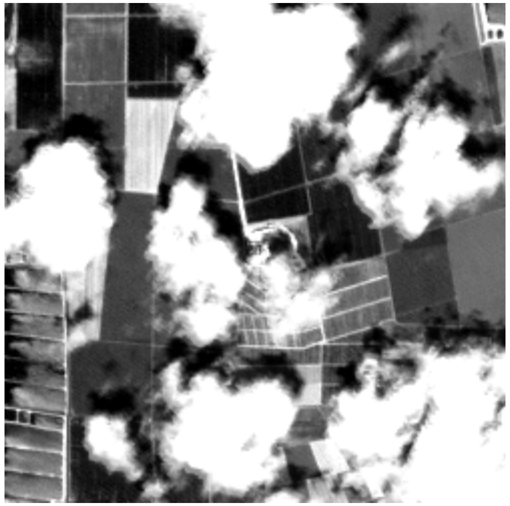
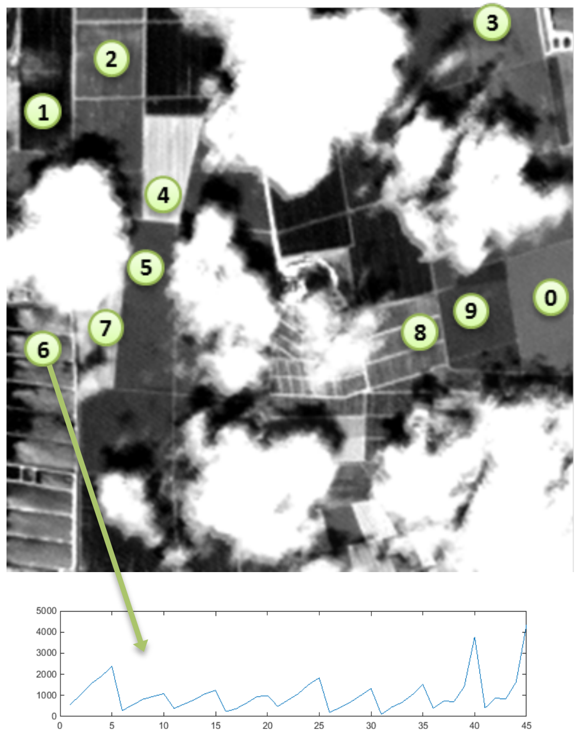
1. Estimate the number of „endmembers“ outside the clouds



HySime (hyperspectral signal subspace identification by minimum error)
J. Bioucas-Dias and J. Nascimento "Hyperspectral subspace identification", *IEEE Transactions on Geoscience and Remote Sensing,* vol. 46, no. 8, *pp. 2435-2445, 2008*

2. Extract the „endmembers“



N-FINDR, Vertex Components Analysis (VCA), methods based on pixel purity..

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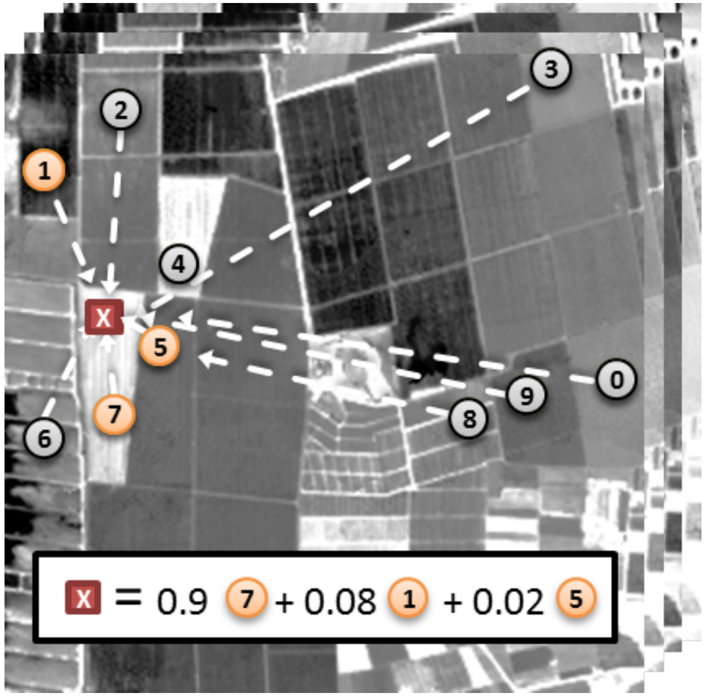
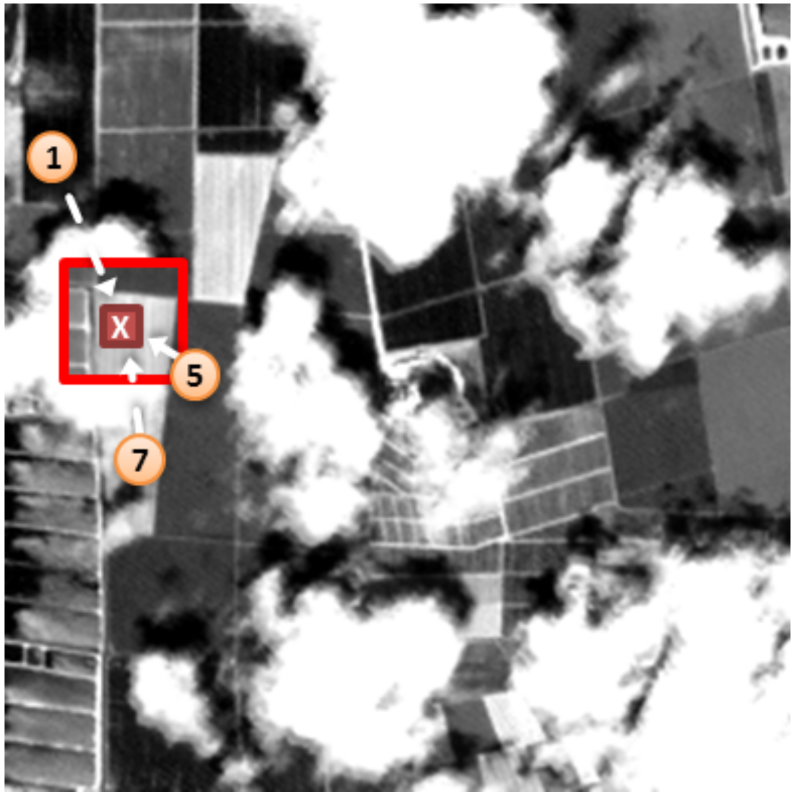
3. Characterize a cloudy pixel from estimating ist abundances in non-cloudy images

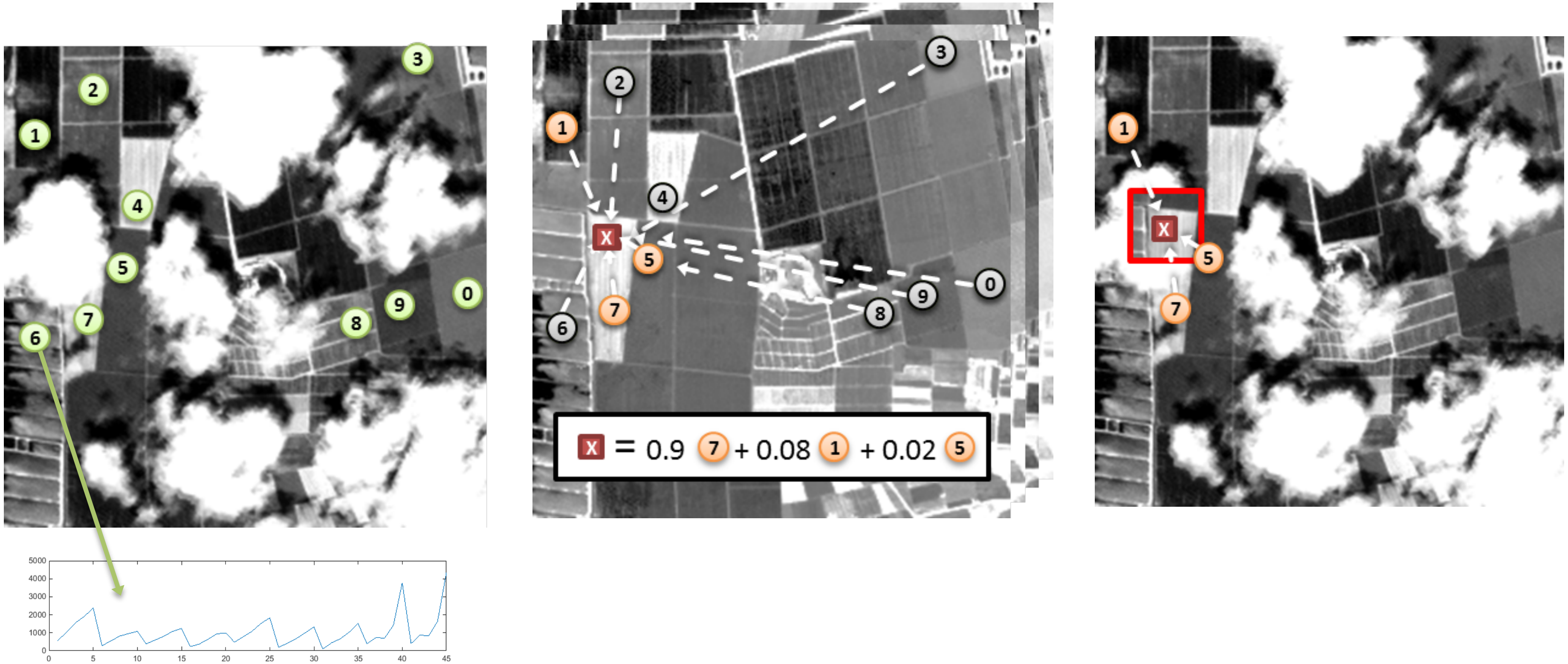


Non-Negative Least Squares

4. Retrieve the cloudy pixel in the contaminated image



Workflow



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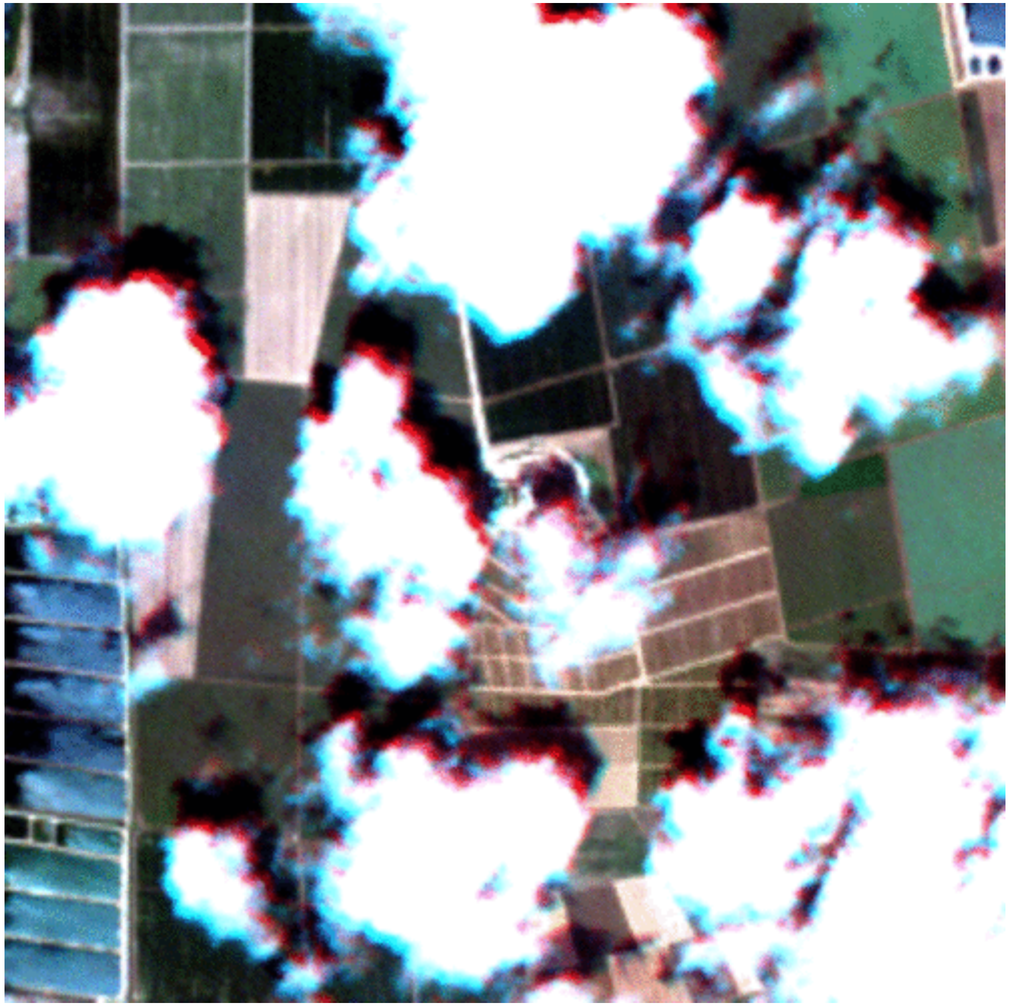
Experimental Results

- WorldView-2 Dataset
  - 9 images
  - 8 spectral bands per image
  - Total: 72 „bands“ (64 used to model the data)
  - Acquired over agricultural fields in Israel
    - From October 2013 to July 2014
  - The last image (July 2014) is reconstructed
  - This is the only image available for that month
- Cloud mask and cloud shadow mask manually produced
- Spectra initialized through VCA and refined through IEA
  - IEA: Iterative Error Analysis
- Abundances computed with Non-negative Least Squares

Experimental Results (RGB Composite)



Conclusions

- Hyperspectral remote sensing algorithms have been tested on MS image time series to estimate the content of cloud-covered pixels

  - **Hyperspectral** images: Characterization, identifications & interactions between pure material

  - Time series: Characteristic evolutions in time of classes of interest

- The pixelwise cloud removal algorithm based on unmixing gives promising first results

-Strong assumption: any object of interest in the scene must be detectable in a cloud-free portion of the image

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Future Work

-Quantitative analysis through simulated cloud masks

-Analysis of longer time series

-Automatic workflow using cloud and cloud shadow detection algorithms

-Comparisons to the state of the art

Thanks a lot for your attention ☺

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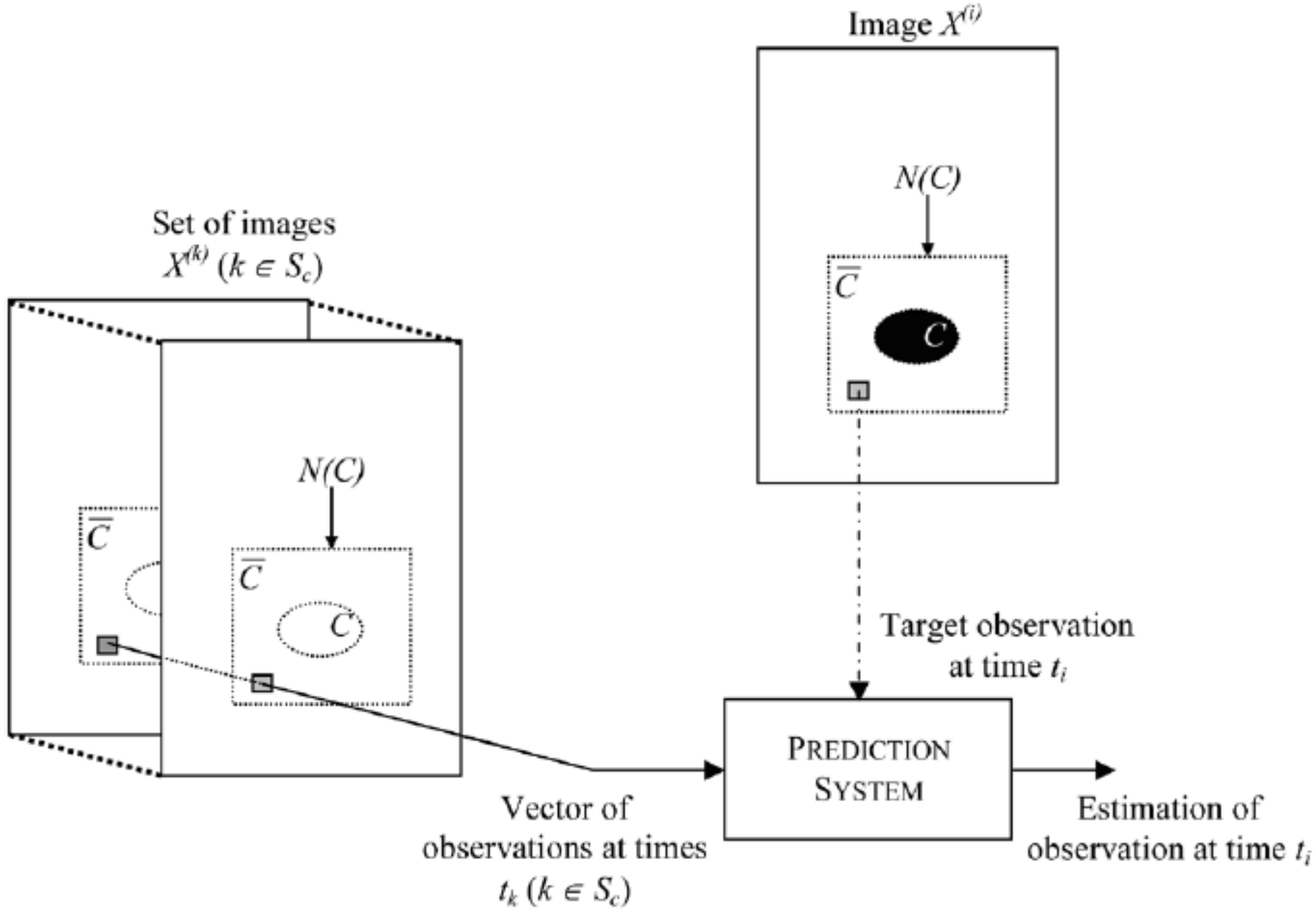
Image $X^{(i)}$
N(C)
$\overline{C}$
C
Set of images
$X^{(k)}$ $(k \in S_c)$
N(C)
$\overline{C}$
C
$\overline{C}$
Target observation
at time t_i
PREDICTION
SYSTEM
Vector of
observations at times
t_k $(k \in S_c)$
Estimation of
observation at time t_i

What is different?