GEOMIX

Geometry in the mix: geometric methods for non-linear spectral unmixing

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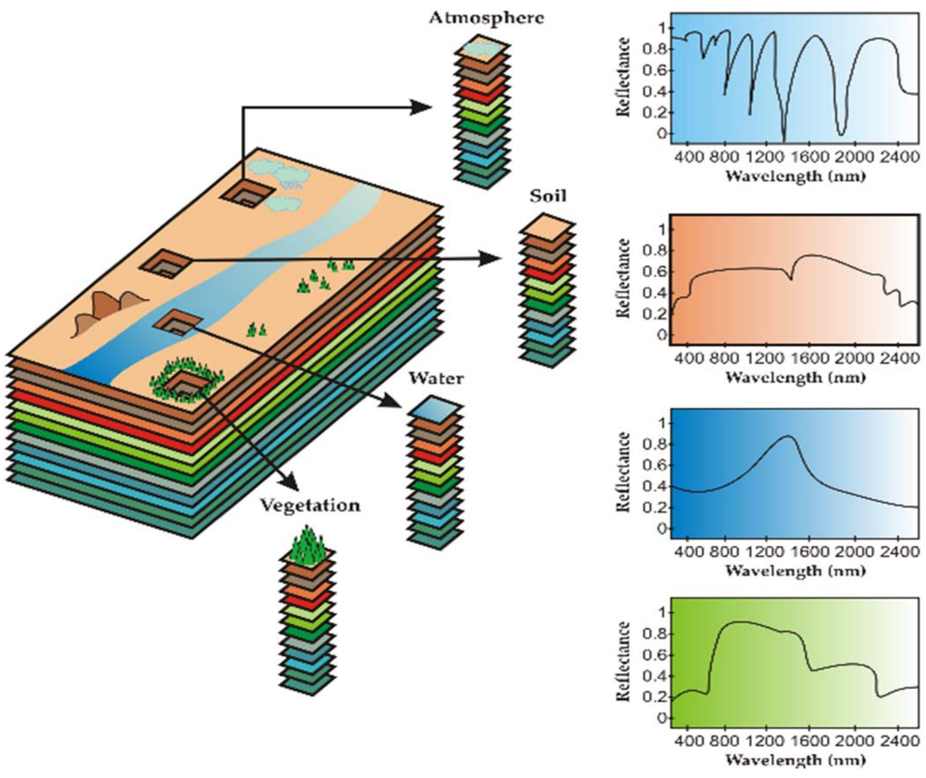
Hyperspectral imagery

Hyperspectral image:

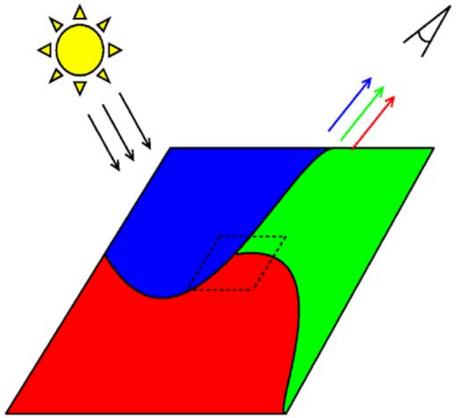
- High number of narrow spectral bands

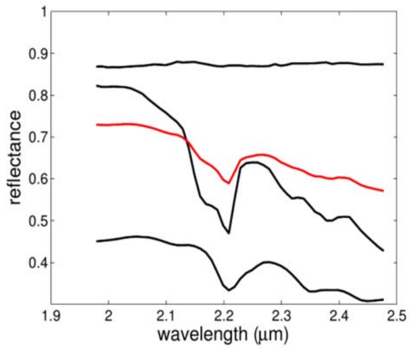


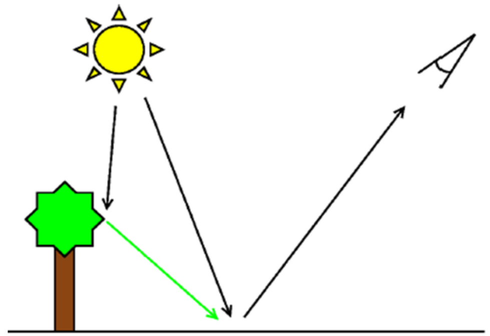
Source: "Hyperspectral Unmixing Overview: Geometrical, Statistical, and Sparse Regression-Based Approaches", J.M. Bioucas-Dias et al., IEEE J Sel Top Appl Earth Obs Remote Sens, vol.5, no.2, pp.354-379, 2012

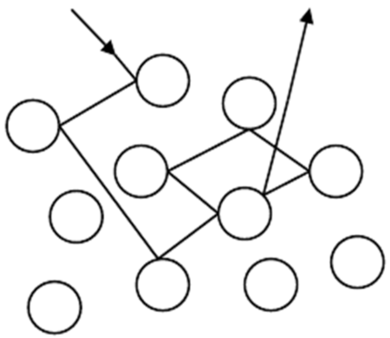
Spectral mixing

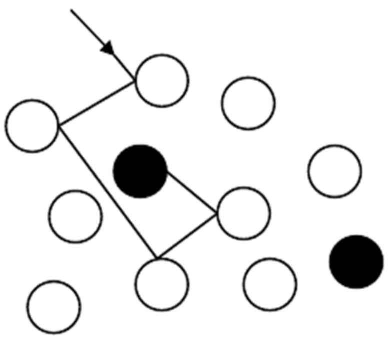
- Low spatial resolution, multiple reflections, intimate mixtures
- Observed spectrum is complex mixture of components within and near pixel’s field of view
- Unmixing: inverts this process





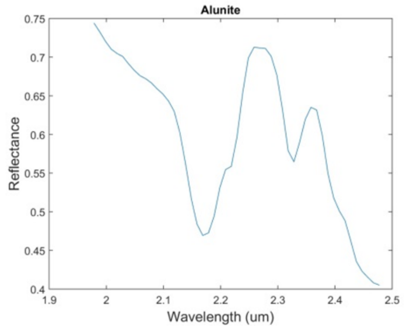


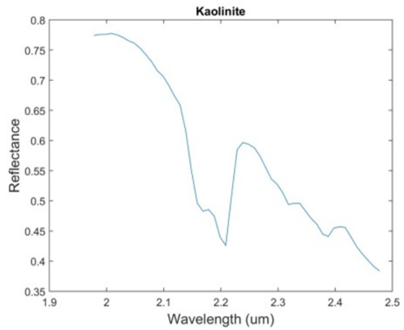




Unmixing delivers:

- Endmember spectra





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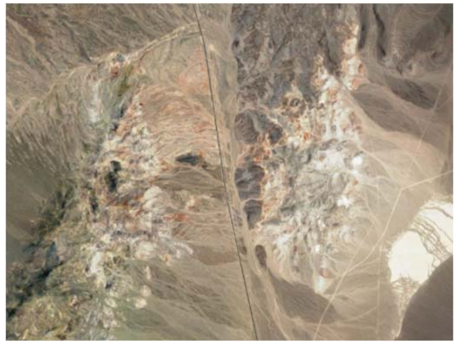
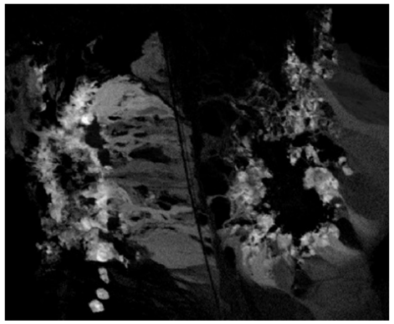
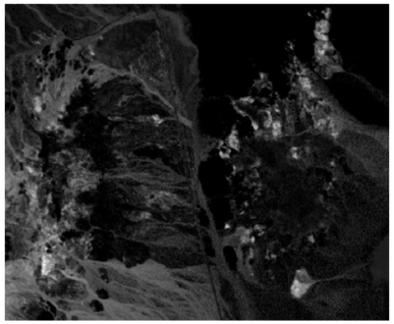


- Abundance maps





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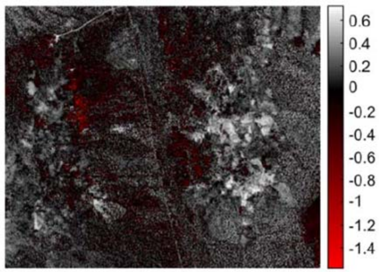
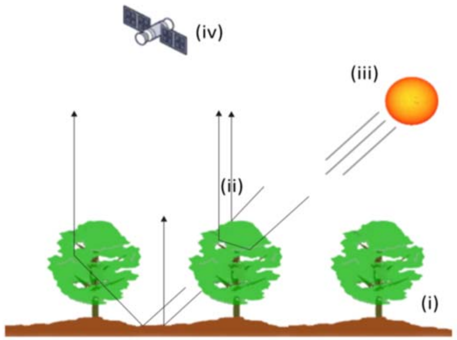
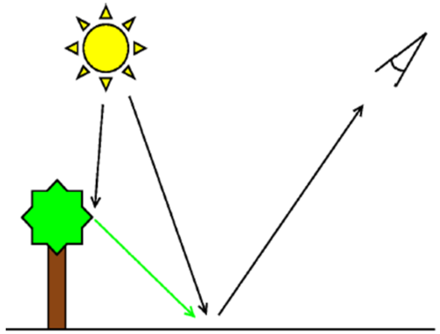
- Possible metadata:



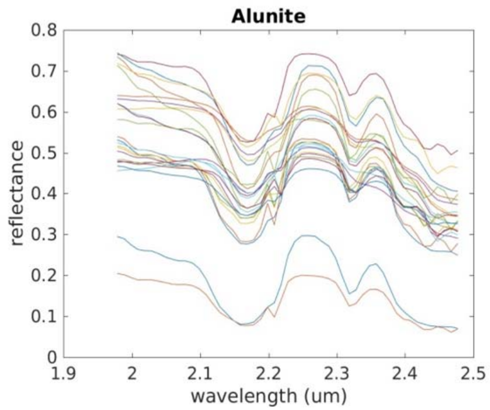
Many problems

Nonlinear effects

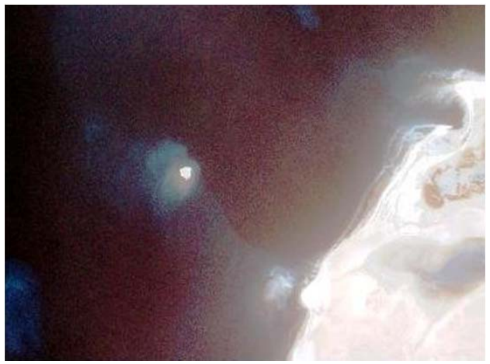


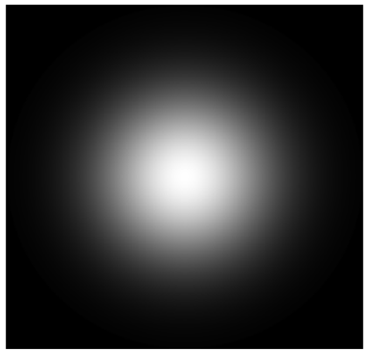


Variability



Neighbor effects





Validation

Many models

- Linear mixing model
  - (+) Fast, easy, popular, clear physical interpretation
  - (-) Only for simplest of scenes

- Bilinear mixing models
  - (+) Secondary scattering
  - (-) Physics lacking, hard optimization, interpretation

- Intimate mixing, Radiative Transfer models
  - (+) Powerful for intimate mixtures, physics based
  - (-) Forward model, restricted applicability

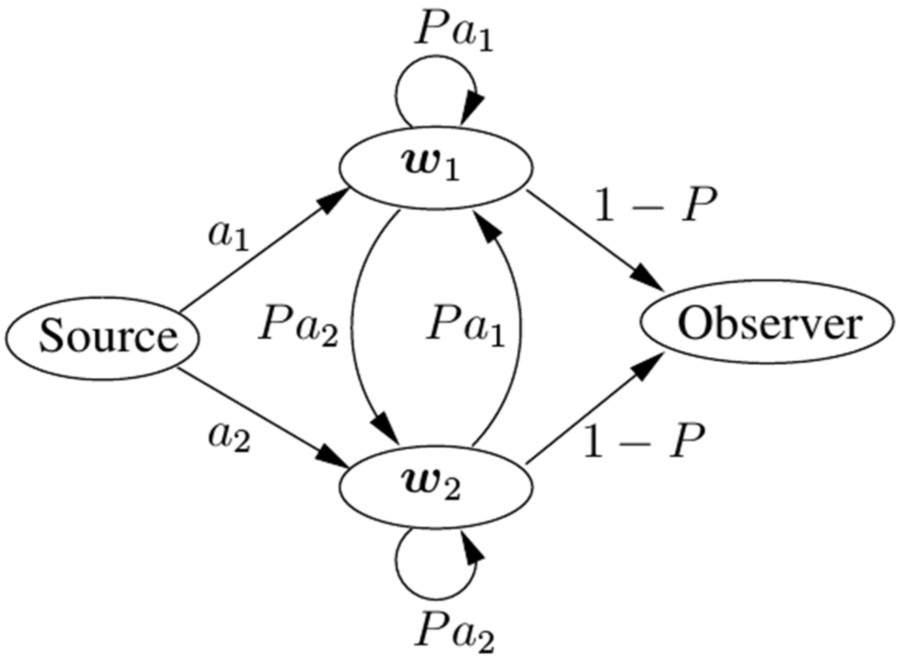
Goals

- Physics-based nonlinear models and data-drive methods
  - Easy to use:
    - Model easy to invert and fit to data
    - Parameters have clear physical meaning
  - Allow spectral variability, shadows, neighbor effects
  - Reasonable computational times

- An unmixing validation framework

Multilinear mixing model

- Ray-based approximation of light
- Markov-chain description of interactions
- Assumptions:
  - After each interaction, probability P for further interactions
  - Probability of interacting with a material = abundance
  - Light intensity changes according to endmember reflectance



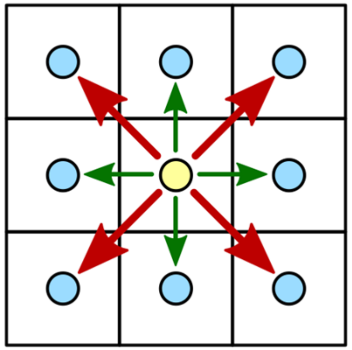
$$\boldsymbol{x} = \frac{(1-P)\boldsymbol{y}}{1-P\boldsymbol{y}} = \frac{(1-P)\sum_{i=1}^{p} a_i \boldsymbol{w}_i}{1-P\sum_{i=1}^{p} a_i \boldsymbol{w}_i}$$

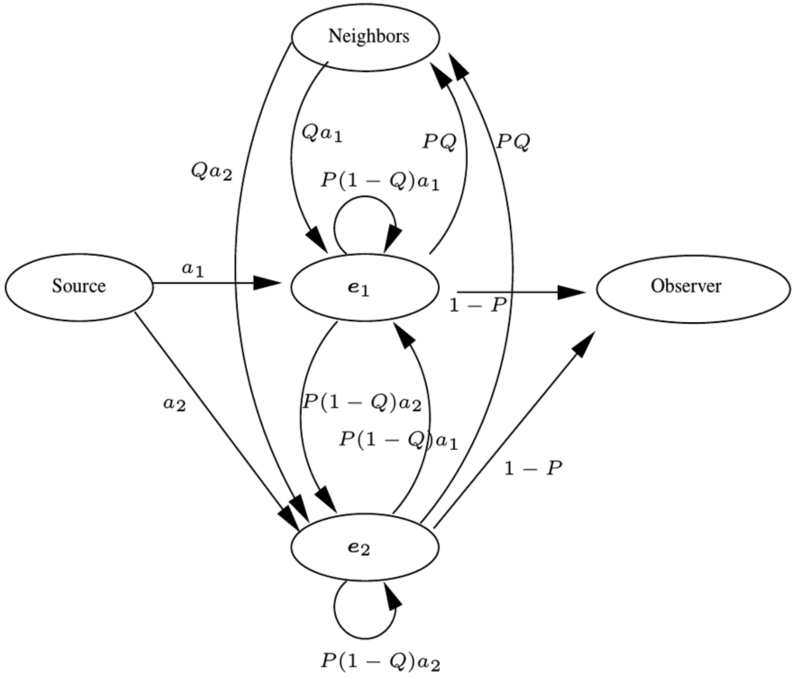
R. Heylen, P. Scheunders, "A multilinear mixing model for nonlinear spectral unmixing," IEEE Tran. Geosci. Remote Sens., vol. 54, no. 1., pp. 240-251, Jan 2016.

Multilinear mixing model: neighbor effects

Inclusion of neighbor effects

- Pixel-dependent “neighbor endmember”:
- Secondary illumination: Additional light source
- Adjacency: Additional linear term





$$\boldsymbol{x} = \frac{(1-P)(\vec{1}+Q\boldsymbol{n}_n)\boldsymbol{y}}{1-P\left((1-Q)\vec{1}+Q^2\boldsymbol{n}_n\right)\boldsymbol{y}}$$

Multilinear mixing model: shadow

- Shadow = no direct illumination. Include by scaling linear term with a shadow parameter in [0,1].
- Ambient light: Include additional light term

Multilinear mixing model: spectral variability

- Variability: Library based approach (e.g. MESMA). Allow endmembers to vary per pixel. Select best combination.

- Preliminary results are promising (master thesis)

- Geometrical methods for speeding up search strategy

R. Heylen, A. Zare, P. Gader and P. Scheunders, "Hyperspectral unmixing with endmember variability via alternating angle minimization," IEEE Tran. Geosci. Remote Sens., vol. 54, no. 8, pp. 4983-4993, Aug. 2016

Validation of spectral unmixing

Validation on several levels:

- Modeled data obtained by using mixing models
- Standard data sets with several levels of ground truth available (e.g. AVIRIS and APEX data)
- New data sets (CRISM data)
- Existing simulated hyperspectral scenes using ray-tracing technology (e.g. Somers et al.)
- New simulated hyperspectral scenes using our own ray-tracer

Unmixing validation initiative:

- Set up by PI and international partner
- Collect, generate (raytracer) and distribute unmixing data sets
- Develop best practices for validation: “How” to validate.
- (Will be) presented at IEEE conferences (past and future), IEEE GRS Magazine (special issue, edited by R. Heylen, M. Parente and J. Kerekes)