Learning Diary - CASA0023

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Preface

Introduction

Welcome to my learning diary page of Remote Sensing Cities and Environment (CASA0023)! This diary is made for the content taught at 2022-2023.

I'm a current Master of Science student at Bartlett Centre for Advanced Spatial Analysis.

This is a learning diary of a Master of Science student at CASA Module CASA0023 (Remote Sensing City Environment).

This learning diary is presented as a Quarto book containing 9 weeks as chapters.

Each week, the content summarises that week's teaching content in section summary, sometimes it emphasises comprehensiveness and therefore appear in overwhelming length. This way, it is easy for a general reader to get lost in finding what's important. Therefore, I also added guides and highlighted what stood out in importance. Future development part can also assist in grasping the big picture of that week's topic.

Application addresses one (or multiple) literature recommended in the module micro-site. It elaborates on parts that interest me and mentions why they are interesting. Also, the contribution and future literature advancement are highlighted.

As for reflection, I try to relate the content in Summary and Application to wider discipline in regard of how those can be of use in future both from my personal perspective, and in how a spatial data scientist might strengthen their arsenal using the content in dealing with Earth Observation data. The selection of content is largely based on how interesting they are, and hopefully the reason why they appear interesting has been illustrated in the their usefulness.

Take a look at the module's micro-site, to better understand what I'm talking about! CASA0023 Remotely Sensing Cities and Environments (andrewmaclachlan.github.io)

There are two weeks that differ in the general structure of this quarto book: Week 2 Portfolio includes only a Xaringan-made and online-hosted slide, Week 4 Policy deals with a policy instead of papers.

1 Week 1 - Getting started with remote sensing

1.1 Summary

- Data types in remote sensing:
  - Passive data: Energy in electromagnetic form (e.g., human eyes)
  - Active data: Energy in addition to illumination (e.g., radar)
- Interaction of EM waves with Earth's surface and atmosphere:

Interaction Type	Components of Earth	Processes Considered	Difficulty
Single	Surface OR Atmosphere	Direct interaction with one component	Most straightforward to analyze
Dual	Surface AND Atmosphere	Absorption, scattering	Requires atmospheric correction for accurate results
Quad	Surface, Atmosphere, Features	Absorption, scattering, reflection, transmission	More challenging due to multiple components involved

1.1.1 Remote Sensing Data Formats

- Raster formats:
  - BIL
  - BSQ
  - BIP
  - GeoTIFF

1.1.2 Four Resolutions in Remote Sensing

1. Spatial resolution:
    - Ranges from 10 cm to several kilometers
2. Spectral resolution:
    - Number of different spectral bands captured
    - Unique spectral signatures for each feature on Earth
    - Atmospheric windows
    - Vegetation: Red edge - infrared bands
        - Application: Analyze infrared bands in cities to identify access to vegetation
3. Radiometric resolution:
    - Resolution of a cell's value
4. Temporal resolution:
    - Usually inversely related to pixel size (spatial resolution)

- Example satellite sensor: MODIS

1.1.3 Bands Explained

- In remote sensing, bands refer to the specific ranges of wavelengths captured by a sensor.
- Each band captures information about different features on Earth's surface.
- Understanding the properties of each band helps in the interpretation and analysis of remote sensing data.

1.1.4 Future Development

Area of Future Development	Description
Wireless communication	Faster and more secure data transmission using electromagnetic waves.
Medical imaging	New techniques using different types of waves for better diagnoses.
New uses for electromagnetic waves	Discovering new applications in energy, environment, and space exploration.
Remote sensing technology	More detailed data gathering using a wider range of wavelengths.

Area of Future Development	Description
Quantum computing	Developing new technologies that use the properties of particles at the quantum level, including electromagnetic waves.

1.2 Application

I explored Butcher (2016) for a better understanding of electromagnectic waves and the application in Remote Sensing.

Type of Wave	Wavelength Range	Frequency Range	Example Applications
Radio Waves	>1mm	<300 GHz	Broadcasting, communication, radar
Microwaves	1mm - 1m	300 MHz - 300 GHz	Cooking, communication, radar
Infrared Waves	700 nm - 1 mm	300 GHz - 430 THz	Thermal imaging, remote controls
Visible Light	400 nm - 700 nm	430 THz - 750 THz	Human vision, photography
Ultraviolet Waves	10 nm - 400 nm	750 THz -30 PHz	Sterilization, fluorescence microscopy
X-Rays	<10 nm	>30 PHz	Medical imaging, airport security
Gamma Rays	<0.01 nm	>30 EHz	Cancer treatment, nuclear medicine

One of the applications really attracted me was the spatial signature of vegetation on the terra, as we could assign features to each end of the spatial signature area see Figure **??**, such as bare land on the right end of the triangle-like area where red light captured are dense while near-infrared level is low. Heavy vegetation are witnessed at the upper end of the triangle-like area where red light low and near-infrared is high, indicating heavy biomass. As for the left-down corner where both red and near-infrared are low, we can identify wet lands. This is integrated in the NDVI (Normalized Difference Vegetation Index) to estimate vegetation cover.

Spatial signatures can also be used to monitor the health of vegetation by identifying patterns of quavariation in spectral reflectance that are indicative of stress or disease. For example, vegetation that is stressed or diseased may have a different spectral reflectance signature than healthy vegetation, which can be identified using spatial signatures.

In addition, spatial signatures can be used to monitor the growth and distribution of vegetation over time by comparing satellite imagery from different dates. This can be useful for

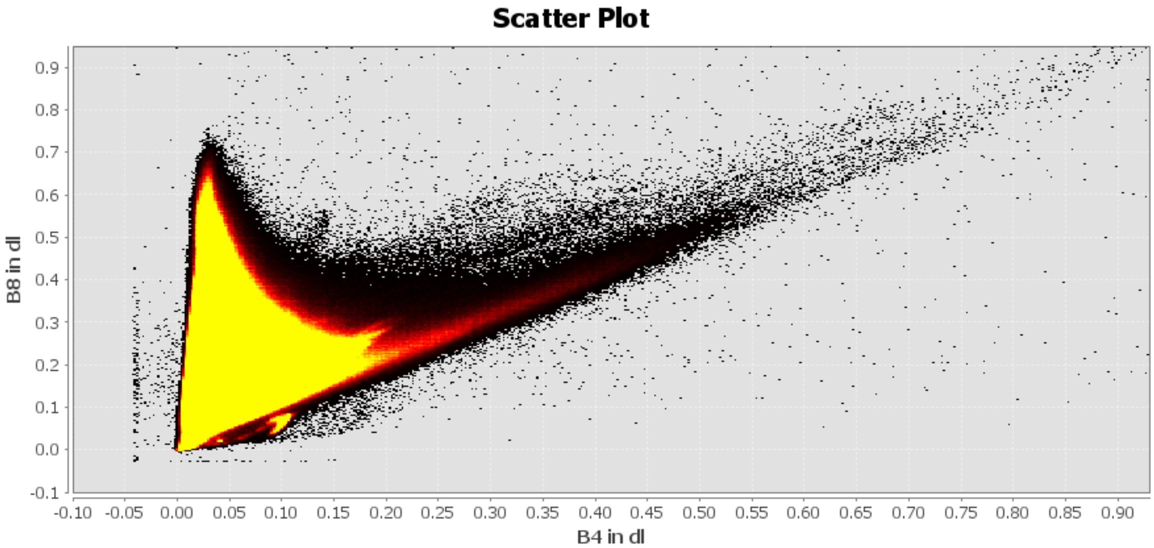


Figure 1.1: Spectral Feature Space, Vegetation On Bands B04 and B08

understanding the impacts of land use changes, climate change, and other factors on vegetation.

Overall, spatial signatures are a powerful tool for vegetation monitoring, as they can be used to identify and classify different types of vegetation, monitor vegetation health, and track vegetation changes over time.

1.3 Reflection

Having active sensing methods is inspiring as it reminds us that instead of struggling with improving image quality sensed passively using sunlight, we can try altering to artificial signals. Also that sunlight is but another form of electromagnetic wave. This implies a potential to cancel the boundary between natural phenomenon and artificial forms. I feel more encouraged to more actively explore relationships in nature with the devices at hand. I am considering implement active sensors to include SAR data for IoT-based data pipelines. With active sensing data like SAR monitoring forestry real-time, the machine learning model can acquire enough ground truth data from nature for constant adaptation. This could be incorporated into forestry monitoring systems and disaster monitoring systems to cover for both accuracy and rapidness.

One of the challenges I encountered is to navigate the complexities of the interface of SNAP and QGIS. It becomes clear to me that yes implementing several functions in code can be challenging, but a software with collective functions as a whole can be mindblowing even when with decent GUIs. Specifically, finding which function falling under which menu consumes a

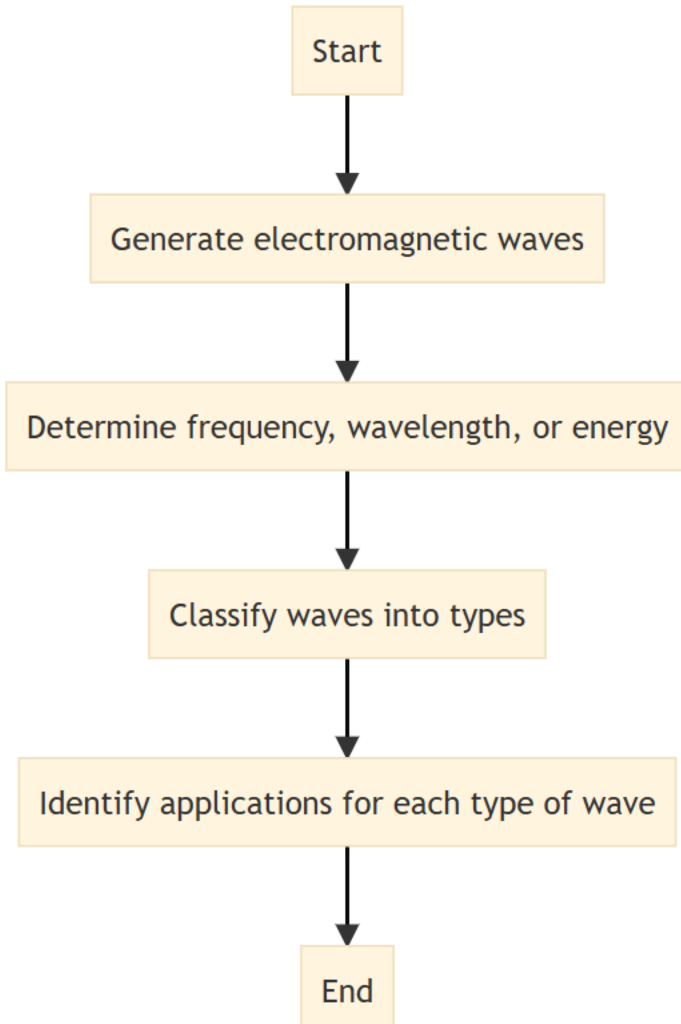


Figure 1.2: workflow of the Electromagnetic Spectrum

lot of time, and figuring out filling parameters to carry the analysis also took some efforts of iterative validation. Anyway, it's nice to have attempts of designing GUIs for EO data manipulation. Hopefully, with Large Language Model simplifying GIS software designing, we can more easily translate code workflows into user-friendly interfaces and apply our design ideas.

2 Week 2 - Portfolio

Slide about flood prediction and monitoring is here: https://tongmengxie.github.io/Xaringan_slides

2.1 Available instructions

- Introducing Xaringan

3 Week 3 - Remote sensing data

In this week's learning diary, we try to deal with an essential task of remote sensing data workflow, correction

3.1 Summary:

3.1.1 Different Sensors

Across track scanners: Mirror reflects light onto 1 detector. For example, Landsat dataset are captured by this sort

Along track scanners: Basically several detectors pushed along. E.g., Quickbird, SPOT

3.1.2 Geometric Correction

RS data could include image distortions introduced by: View angle, topography, wind and rotation of the earth

We identify Ground Control Points (GCP) in distorted data to match them with local map, correct image, or GPS data from handheld device, but these reference images could also contain distortions and imprecisions.

RMSE is adopted here to measure fitness between images. Use GCPs to minimise RMSE.

Doing geometric correction can shift the original image, so we want to re-sample the final raster by using Nearest Neighbour, Linear, Cubic, Cubic spline re-samplers

3.1.3 Atmosphric Correction

According to Jensen (1986), two factors contribute to environmental attenuation: Atmospheric scattering, topographic attenuation.

There are unnecessary and necessary atmospheric corrections:

necessary ones are:

- Biophysical parameters needed (e.g. temperature, leaf area index, NDVI)
- E.g. .. .NDVI is used in the Africa Famine Early Warning System and Livestock Early Warning System
- Using spectral signatures through time and space

Absorption and scattering can create the haze, i.e. reduces contrast of image.

Scattering can create the "adjacency effect", radiance from pixels nearby mixed into pixel of interest.

3.1.4 Orthorectification Correction

This is a subset of georectification, i.e. giving coords to an image. Particularly Orthorectification means removing distortion so pixels can appear being viewed at nadir (straight down). This requires the support of an Elevation Model to calculate the nadir view for each pixel on a sensor geometry.

To do this: cosine correction, Minnaert correction, Statistical Empirical correction, C Correction (advancing the Cosine). Need radiance (DN to TOA) from sloped terrain, Sun's zenith angle, Sun's incidence angle - cosine of the angle between the solar zenith and the normal line of the slope. Latter two found in angle coefficient files (e.g. Landsat data ANG.txt).

3.1.5 Rdiometric Correction

Corrections to raw satellite imagery can be performed using a method called Dark Object Subtraction (DOS). The logic is that the darkest pixel in the image should be 0 and any value it has is due to the atmosphere. To remove the atmospheric effect, the value from the darkest pixel is subtracted from the rest of the pixels in the image. The calculation involves converting the Digital Number (DN) to radiance, computing the haze value for each band (but not beyond NIR), and subtracting the 1% reflectance value from the radiance. The calculation requires values such as mean exoatmospheric irradiance, solar azimuth, Earth-sun distance, and others, which can be found in sources such as Landsat user manuals.

3.1.6 Joining data sets

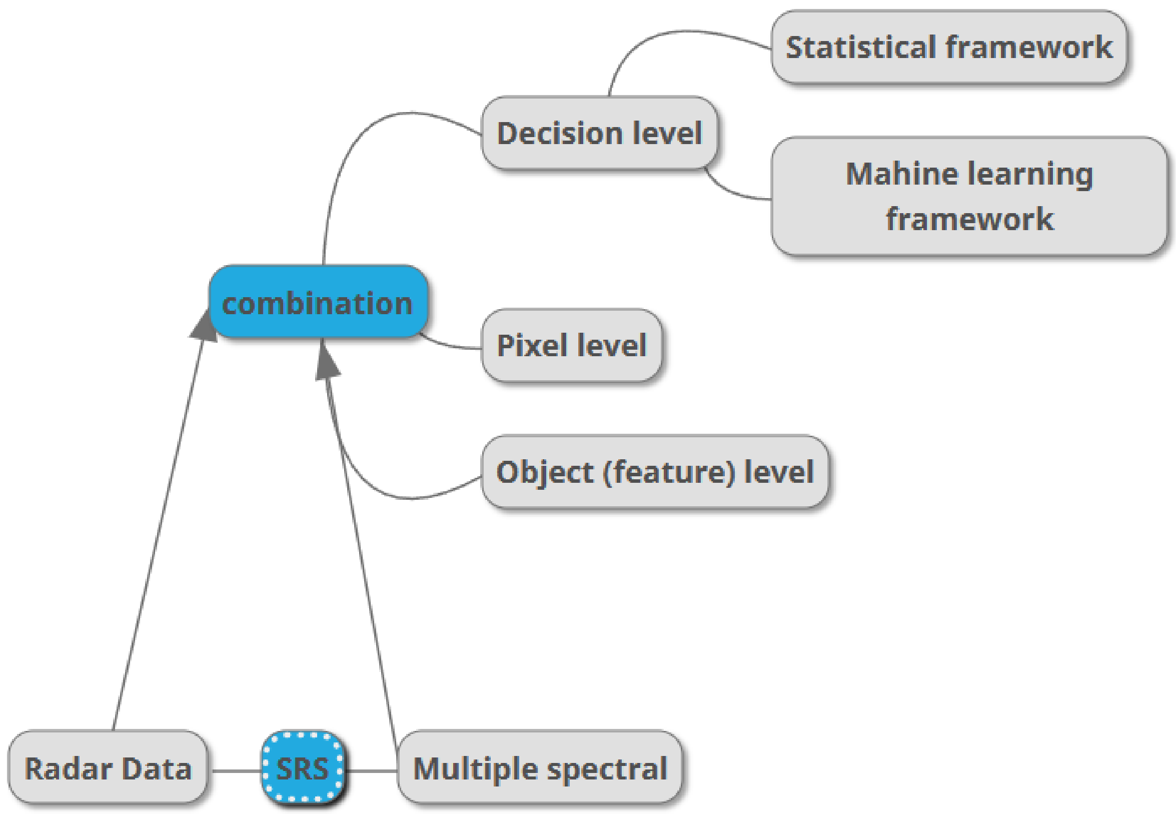
Also known as Mosaicking: We feather two images, creating a seamless mosaic, where the diving lien is called seamline.

3.1.7 Image Enhancements

Image stretch, Band ratioing, Normalised Burn Ratio, Edge enhancement, Filtering, PCA, Image fusion (see application) etc.

3.1.8 Future development

3.2 Application - Discussing image fusion in one literature



From literature we delve in the nuances of levels on which we perform image fusion to acquire better results. The integration methods vary as the levels vary (Schulte to Bühne and Pettorelli 2018).

Satellite remote sensing (SRS) can be derived from Multispectral sensors and radar sensors.

Multispectral sensors are passive, merely receiving electromagnetic waves reflected from surface, usually used to reflect chemical properties (such as nitrogen or carbon content and moisture). Usually produces data with comparatively low spatial resolution

Radar ones emit electromagnetic radiation and measure the returning signal, responding to the three-dimensional structure of objects, being sensitive to their orientation, volume and surface roughness. Usually produces data with comparatively high spatial resolution

3.2.1 Image fusion:

1. **decision-level** (SRS integration), where separate predictors are used to estimate a parameter of interest.

2. **object-level (feature-level).** unit: multi-pixel objects. (1) using radar and multispectral imagery is input into an object-based image segmentation algorithm, or (2) segmenting each type of imagery separately before combining them. multi-pixel objects

3. **pixel-level (Observation-level)**, where pixel values are combined to derive a fused image with new pixel values, either in the spatial or the temporal domain.

(2. and 3. derive entirely new predictors.)

Schematic overview of multispectral-radar SRS data fusion techniques. The parameter of interest can be a categorical variable, like land cover, or a continuous variable, like species richness. In pixel-level fusion, the original pixel values of radar and multispectral imagery are combined to yield new, derived pixel values. Object-based fusion refers to (1) using radar and multispectral imagery is input into an object-based image segmentation algorithm, or (2) segmenting each type of imagery separately before combining them. Finally, decision-level fusion corresponds to the process of quantitatively combining multispectral and radar imagery to derive the parameter of interest (by e.g. combining them in a regression model, or classification algorithm)

3.2.2 Implementation Approaches

pixel-level

1. Component substitution techniques: such as principal component analysis (PCA), Intensity-hue-saturation (IHS).

2. PCA is the only pixel-level image fusion technique that cannot be applied to imagery with different spatial resolutions, and the only that allows unlimited image numbers.

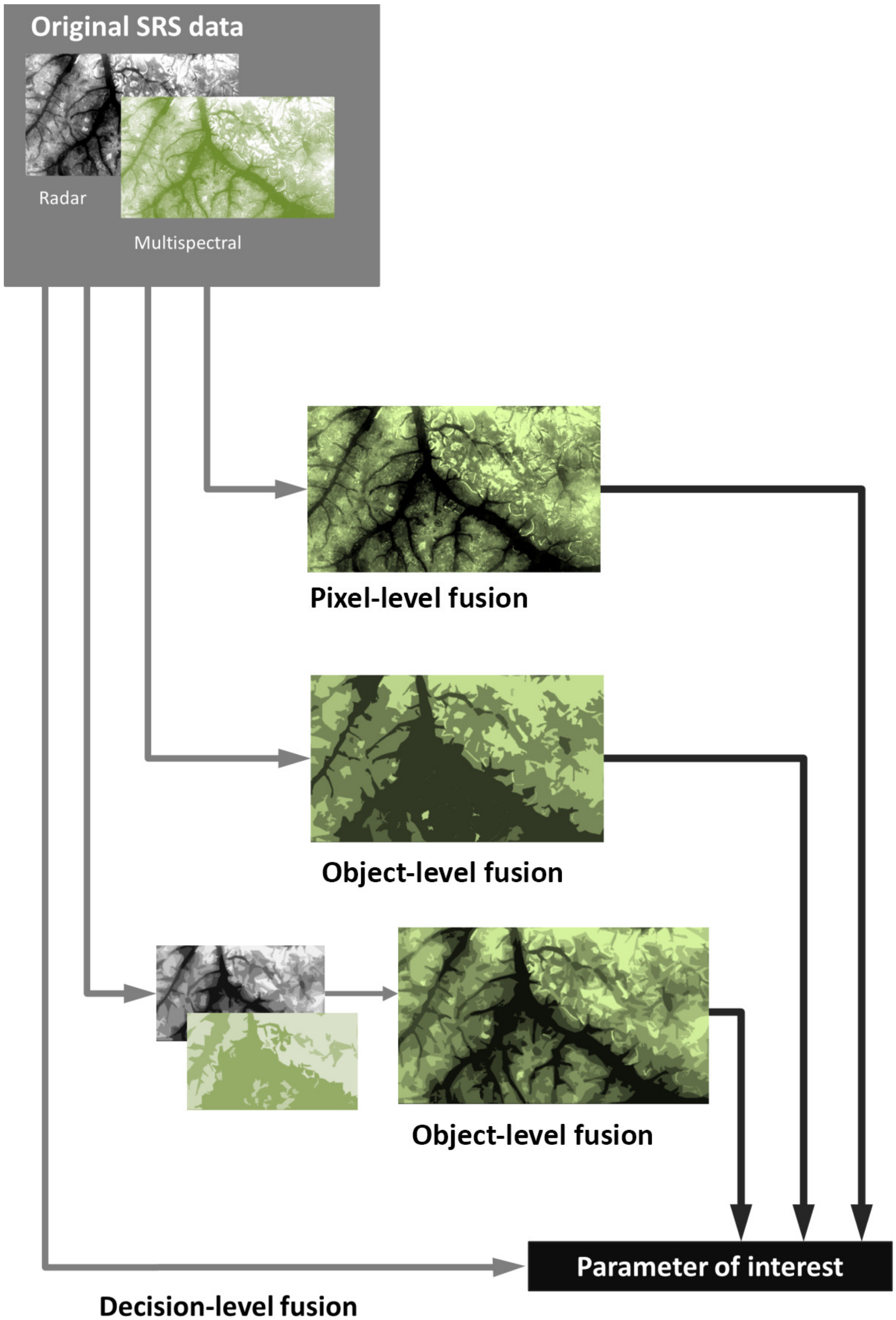


Figure 3.1: Credit: Schulte to Bühne and Pettorelli (2018)

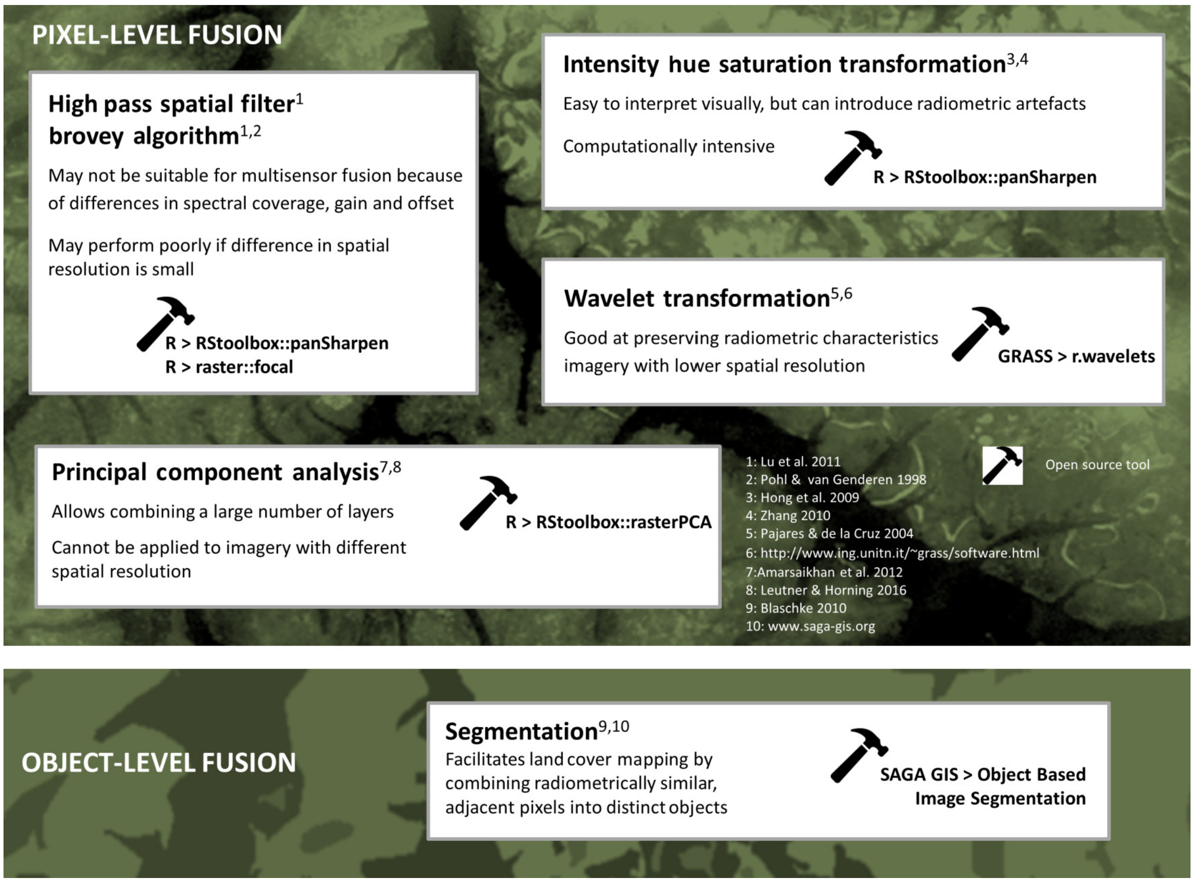


Figure 3.2: Credit: Schulte to Bühne and Pettorelli (2018)

3. IHS fusion. Three images with lower spatial resolution (typically multispectral data) are integrated with a single image with high spatial resolution (typically radar) to retain the radiometry but increase the spatial resolution of the former. Facilitate visual interpretation by combining resulting images into a single RGB image.

4. Multi-resolution analysis, such as **Wavelet transformation. Decompose multispectral and radar imagery into their respective low- and high-frequency components

5. Arithmetic fusion techniques: such as the Brovey transform algorithm. Unlikely to be appropriate for multispectral-radar SRS image fusion.

Object-level: Based on brightness and intensity values of each pixel, as well as its spatial context, objects such as lines, shapes or textures are extracted.

1. **image segmentation:** Demands that multispectral and radar SRS images are with the same spatial resolution

2. *extracting objects separately and combining in a feature map*

Object-based fusion reduces all multispectral and radar information into a single layer of discrete objects, which are often relatively easy to relate to ecological features.

Decision-level fusion: Quantitative decision-making frameworks—such as a regression, a quantitative model or a classification algorithm.

3.3 Reflection

Data correction, Data fusion and Image enhancement SRS data fusion can increase the quality of SRS (Satellite Remote sensing)-derived parameters for application in terrain detection, urban analysis, ecology and conservation (Schulte to Bühne and Pettorelli 2018). It is thus important to explore how best to capitalise on recent technological developments and changes in SRS data availability. It is exctiing to apply solid machine learning methods to this area and it is marvelous to see the progress reflected by the increasing number of software supporting this application. The improvement of image quality enables new research designs in ecology and conservation areas and reignite previously greyed-out options.

The application of data correction, data fusion, and image enhancement techniques to SRS data can greatly improve the accuracy and reliability of SRS-derived parameters, which can then be used in various fields, including terrain detection, urban analysis, ecology, and conservation. With the rapid advancements in technology and the increasing availability of SRS data, there is a growing opportunity to leverage the latest machine learning techniques in this area. The development of new software tools to support these applications is a testament to the progress being made in this field. By enhancing the quality of the SRS data, researchers are able to design more robust and informative studies, unlocking new insights and avenues for exploration in ecology and conservation. This, in turn, has the potential to lead to breakthroughs and innovations in these fields, making a significant impact on the world around us.