Leafmap: A Python package for interactive mapping and geospatial analysis with minimal coding in a Jupyter environment

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Summary

Leafmap is a Python package for interactive mapping and geospatial analysis with minimal coding in a Jupyter environment. It is a spin-off project of the geemap Python package (Wu, 2020), which was designed specifically to work with Google Earth Engine (GEE) (Gorelick et al., 2017). However, not everyone in the geospatial community has access to the GEE cloud computing platform. Leafmap is designed to fill this gap for non-GEE users. It is a free and open-source Python package that enables users to analyze and visualize geospatial data with minimal coding in a Jupyter environment, such as Google Colab, Jupyter Notebook, and JupyterLab. Leafmap is built upon several open-source packages, such as folium (Filipe et al., 2021) and ipyleaflet (Renou et al., 2021) (for creating interactive maps), WhiteboxTools (Lindsay, 2018) and whiteboxgui (for analyzing geospatial data), and ipywidgets (Grout & et al., 2021) (for designing interactive graphical user interface [GUI]). Leafmap has a toolset with various interactive tools that allow users to load vector and raster data onto the map without coding. In addition, users can use the powerful analytical backend (i.e., WhiteboxTools) to perform geospatial analysis directly within the leafmap user interface without writing a single line of code. The WhiteboxTools library currently contains 468 tools for advanced geospatial analysis, such as GIS Analysis, Geomorphometric Analysis, Hydrological Analysis, LiDAR Data Analysis, Mathematical and Statistical Analysis, and Stream Network Analysis.

Statement of Need

There is a plethora of Python packages for geospatial analysis, such as geopandas for vector data analysis (Jordahl et al., 2021) and xarray for raster data analysis (Hoyer & Hamman, 2017). However, few Python packages provide interactive GUIs for loading geospatial data in a Jupyter environment. It might take many lines to code to load and display geospatial data with various file formats on an interactive map, which can be a challenging task for novice users with limited coding skills. There are also some notable Python packages for visualizing geospatial data in a Jupyter environment, such as plotly (Mease & et al., 2021) and kepler.gl (He & et al., 2021). However, plotly is designed for displaying static data, which lacks bidirectional communication between the front-end and the backend. Kepler.gl provides unique 3D functionality for visualizing large-scale geospatial datasets, but it lacks tools for performing geospatial analysis, such as hydrological analysis and LiDAR data analysis. In contrast, leafmap provides many convenient functions for loading and visualizing geospatial datasets with only one line of code. Users can also use the interactive GUI to load geospatial datasets without coding. Leafmap is intended for anyone who would like to analyze and visualize geospatial data interactively in a Jupyter environment. It is particularly suited for novice users with limited programming skills. Advanced programmers can also find leafmap a useful tool for analyzing geospatial data and building interactive web apps.
Leafmap Plotting Backends

Leafmap has three plotting backends, including folium, ipyleaflet, and here-map-widget-for-jupyter (Kharude & Steenberg, 2021). An interactive map created using one of the plotting backends can be displayed in a Jupyter environment, such as Google Colab, Jupyter Notebook, and JupyterLab. By default, import leafmap in Jupyter Notebook and JupyterLab will use the ipyleaflet plotting backend, whereas import leafmap in Google Colab will use the folium plotting backend. Note that Google Colab does not yet support custom widgets, such as ipyleaflet and heremap widget (source). Therefore, interactive maps created using the ipyleaflet and heremap widget backends won’t show up in Google Colab, even though the code might run successfully without any errors.

The three plotting backends do not offer equal functionality. The ipyleaflet plotting backend provides the richest interactive functionality, including the custom toolset for loading, analyzing, and visualizing geospatial data interactively without coding. For example, users can add vector data (e.g., GeoJSON, Shapefile, KML, GeoDataFrame) and raster data (e.g., GeoTIFF, Cloud Optimized GeoTIFF [COG]) to the map with a few clicks (see Figure 1). Users can also perform geospatial analysis using the WhiteboxTools GUI with 468 geoprocessing tools directly within the map interface (see Figure 2). Other interactive functionality (e.g., split-panel map, linked map, time slider, time-series inspector) can also be useful for visualizing geospatial data. The ipyleaflet package is built upon ipywidgets and allows bidirectional communication between the front-end and the backend enabling the use of the map to capture user input (source). In contrast, folium has relatively limited interactive functionality. It is meant for displaying static data only. The folium plotting backend is included in this package to support using leafmap in Google Colab. Note that the aforementioned custom toolset and interactive functionality are not available for the folium plotting backend. Compared with ipyleaflet and folium, the heremap widget plotting backend provides some unique 3D functionality for visualizing geospatial data. An API key from the Here Developer Portal is required to use heremap.

Figure 1. The leafmap user interface built upon ipyleaflet and ipywidgets.
Figure 2. The WhiteboxTools graphical user interface integrated into leafmap.

**Leafmap Modules**

The key functionality of the leafmap Python package is organized into nine modules as shown in the table below.

| Module     | Description                                                                 |
|------------|------------------------------------------------------------------------------|
| basemaps   | A collection of XYZ and WMS tile layers to be used as basemaps               |
| colormaps  | Commonly used colormaps and palettes for visualizing geospatial data        |
| common     | Functions being used by multiple plotting backends to process geospatial data|
| foliumpack | A plotting backend built upon the folium Python package                     |
| heremap    | A plotting backend built upon the here-map-widget-for-jupyter               |
| leafmap    | The default plotting backend built upon the ipyleaflet Python package        |
| legends    | Built-in legends for commonly used geospatial datasets                      |
| osm        | Functions for extracting and downloading OpenStreetMap data                |
| toolbar    | A custom toolset with interactive tools built upon ipywidgets and ipyleaflet|

**Leafmap Tutorials**

Comprehensive documentation and API reference of the leafmap package is available at [https://geemap.org](https://geemap.org). A list of notebook examples and video tutorials for using leafmap can be found at [https://leafmap.org/tutorials](https://leafmap.org/tutorials). Users can also try out leafmap using Google Colab ([https://gishub.org/leafmap-colab](https://gishub.org/leafmap-colab)) and Binder ([https://gishub.org/leafmap-pangeo](https://gishub.org/leafmap-pangeo)) using an Internet browser without having to set up the Python environment and install leafmap on their computer.

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Sylvain Corlay. The authors would also like to express thanks to John Lindsay for developing the WhiteboxTools library, which serves as the geospatial analysis backend of leafmap. Special thanks go to all leafmap contributors, especially Sachin Kharude for contributing the heremap plotting backend to leafmap. Last but not least, the author would like to thank Tomas Beuzen and Martin Fleischmann for reviewing this paper and the leafmap package. Their constructive comments greatly improved the quality of the source code and documentation of the leafmap package as well as this paper.

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