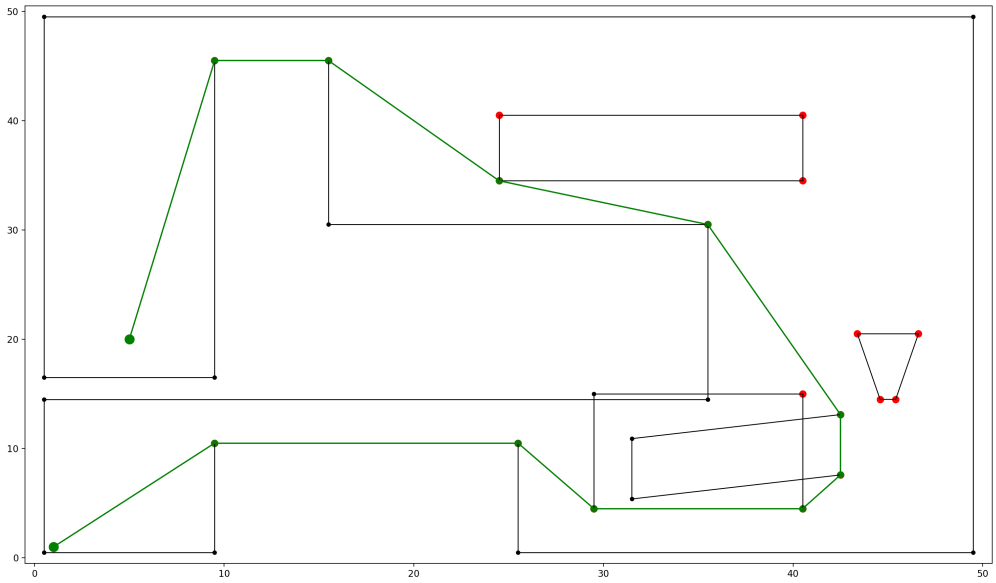
extremitypathfinder

Release 2.2.0

May 05, 2021

Contents:

python package for geometric shortest path computation in 2D multi-polygon or grid environments based on visibility graphs.



CHAPTER 1

Getting started

1.1 Installation

Installation with pip:

```
pip install extremitypathfinder
```

1.2 Dependencies

(`python3.6+`),‘‘numpy‘‘

1.3 Basics

```
from extremitypathfinder import PolygonEnvironment

environment = PolygonEnvironment()
# counter clockwise vertex numbering!
boundary_coordinates = [(0.0, 0.0), (10.0, 0.0), (9.0, 5.0), (10.0, 10.0), (0.0, 10.
↪0)]
# clockwise numbering!
list_of_holes = [
    [
        (3.0, 7.0),
        (5.0, 9.0),
        (4.5, 7.0),
        (5.0, 4.0),
    ],
]
environment.store(boundary_coordinates, list_of_holes, validate=False)
```

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```
environment.prepare()
start_coordinates = (4.5, 1.0)
goal_coordinates = (4.0, 8.5)
path, length = environment.find_shortest_path(start_coordinates, goal_coordinates)
```

All available features of this package are explained *HERE*.

CHAPTER 2

Usage

Note: Also check out the *API documentation* or the code.

2.1 Initialisation

Create a new instance of the *PolygonEnvironment class* to allow fast consequent timezone queries:

```
from extremitypathfinder import PolygonEnvironment

environment = PolygonEnvironment()
```

2.2 Store environment

Required data format: Ensure that all the following conditions on the polygons are fulfilled:

- numpy or python array of coordinate tuples: `[(x1,y1), (x2,y2,)...]`
- the first point is NOT repeated at the end
- must at least contain 3 vertices
- no consequent vertices with identical coordinates in the polygons (same coordinates in general are allowed)
- a polygon must NOT have self intersections
- different polygons may intersect each other
- **edge numbering has to follow this convention (for easier computations):**
  - outer boundary polygon: counter clockwise
  - holes: clockwise

```
# counter clockwise vertex numbering!
boundary_coordinates = [(0.0, 0.0), (10.0, 0.0), (9.0, 5.0), (10.0, 10.0), (0.0, 10.
↪0)]

# clockwise numbering!
list_of_holes = [
    [
        (3.0, 7.0),
        (5.0, 9.0),
        (4.5, 7.0),
        (5.0, 4.0),
    ],
]
environment.store(boundary_coordinates, list_of_holes, validate=False)
```

Note: Pass `validate=True` in order to check the condition on the data. Raises `TypeError` if the input has the wrong type and `ValueError` if the input is invalid.

Note: If two Polygons have vertices with identical coordinates (this is allowed), paths through these vertices are theoretically possible! When the paths should be blocked, use a single polygon with multiple identical vertices instead (also allowed).

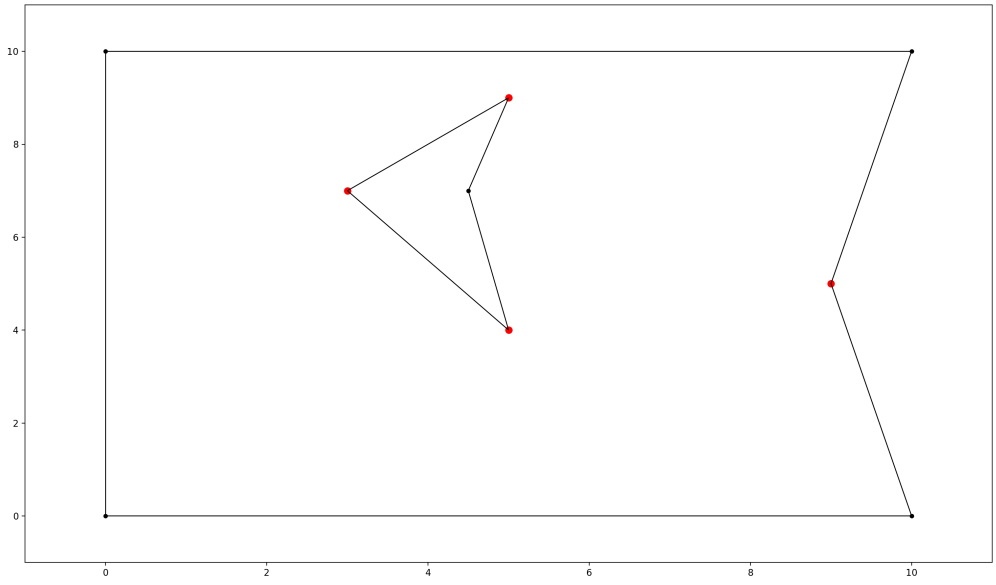


Fig. 1: polygon environment with extremities marked in red

2.3 Preprocessing

computes the *visibility graph* of the environment once.

```
environment.prepare()
```

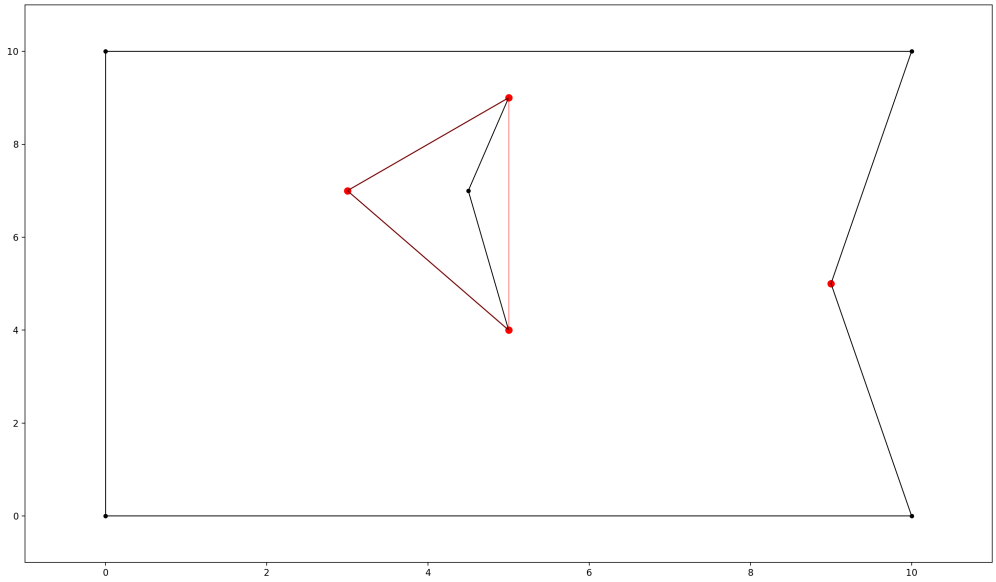


Fig. 2: polygon environment with optimised visibility graph overlay in red

2.4 Query

```
start_coordinates = (4.5, 1.0)
goal_coordinates = (4.0, 8.5)
path, length = environment.find_shortest_path(start_coordinates, goal_coordinates)
```

If any start and goal point should be accepted without checking if they lie within the map, set `verify=False`. This is required if points lie really close to polygon edges and "point in polygon" algorithms might return an unexpected result due to rounding errors.

```
path, length = environment.find_shortest_path(
    start_coordinates, goal_coordinates, verify=False
)
```

2.5 Converting and storing a grid world

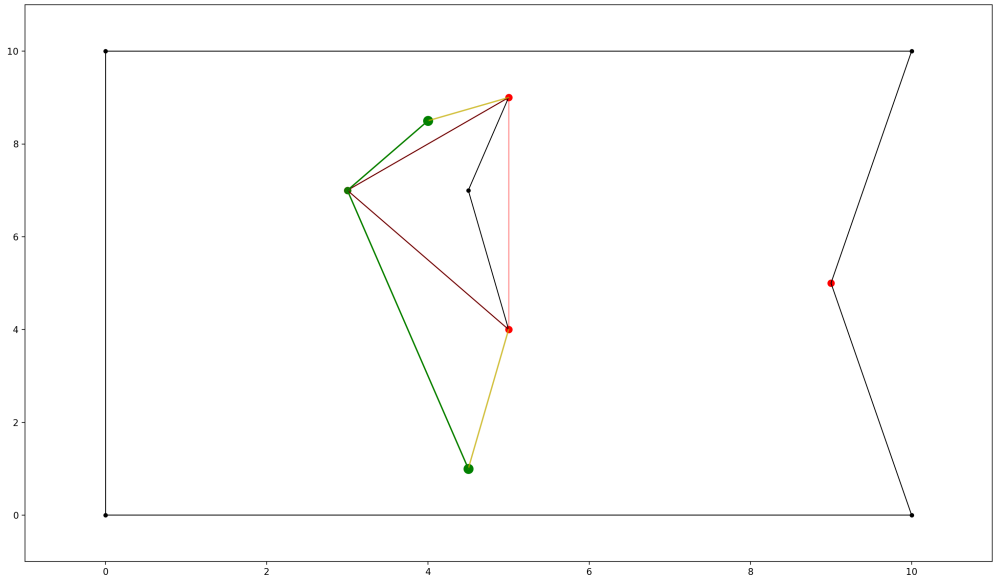


Fig. 3: polygon environment with optimised visibility graph overlay. visualised edges added to the visibility graph in yellow, found shortest path in green.

```
size_x, size_y = 19, 10
obstacle_iter = [  # (x,y),
    # obstacles changing boundary
    (0, 1),
    (1, 1),
    (2, 1),
    (3, 1),
    (17, 9),
    (17, 8),
    (17, 7),
    (17, 5),
    (17, 4),
    (17, 3),
    (17, 2),
    (17, 1),
    (17, 0),
    # hole 1
    (5, 5),
    (5, 6),
    (6, 6),
    (6, 7),
    (7, 7),
    # hole 2
    (7, 5),
]
environment.store_grid_world(
    size_x, size_y, obstacle_iter, simplify=False, validate=False
)
```

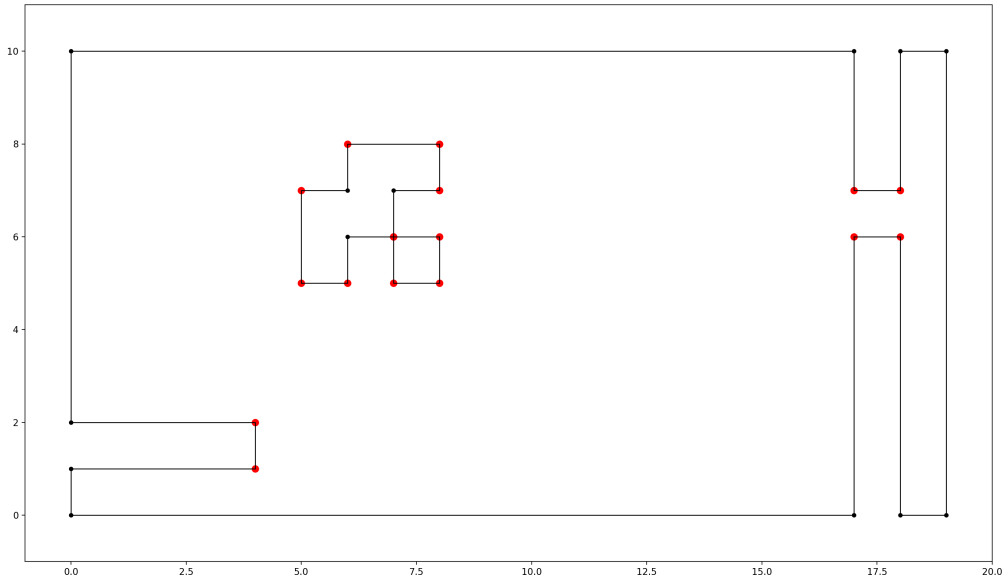


Fig. 4: grid-like environment converted to a polygon environment with "extremities" marked in red

Note: As mentioned in [1, Ch. III 6.3] in "chessboard-like grid worlds" (many small obstacles have a lot of extremities!) it can be better to use A* right away (implemented in `graph_search.py`).

2.6 Cache and import the environment

```
environment.export_pickle(path="./pickle_file.pickle")

from extremitypathfinder.extremitypathfinder import load_pickle

environment = load_pickle(path="./pickle_file.pickle")
```

2.7 Plotting

The class `PlottingEnvironment` automatically generates plots for every step in the path finding process:

```
from extremitypathfinder.plotting import PlottingEnvironment

environment = PlottingEnvironment(plotting_dir="path/to/plots")
environment.store(boundary_coordinates, list_of_holes, validate=True)
environment.prepare()
path, distance = environment.find_shortest_path(start, end)
```

Other functions in `plotting.py` can be utilised to plot specific parts of an environment (extremities, edges, ...)

2.8 Calling extremitypathfinder from the command line

A command line script is being installed as part of this package.

Command Line Syntax:

```
extremitypathfinder <path2json_file> -s <start> -g <goal>
```

The `<start>` and `<goal>` arguments must be passed as two separate float values.

Example:

```
extremitypathfinder ./example.json -s 2.5 3.2 -g 7.9 6.8
```

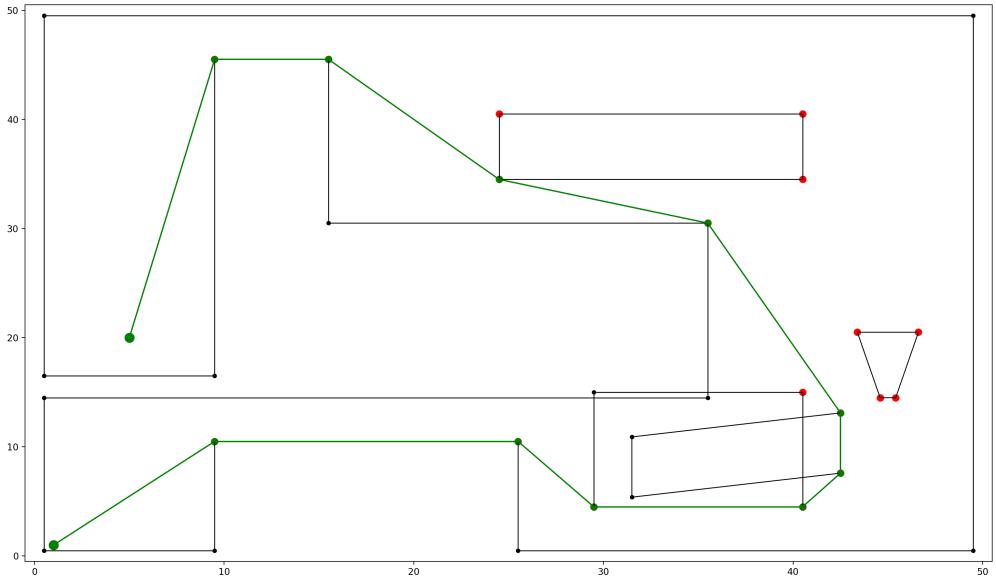
This returns `[(2.5, 3.2), (5.0, 4.0), (7.9, 6.8)] 6.656009823830612`

Please note that this might be significantly slower than using the package directly from within python.

CHAPTER 3

About

python package for fast geometric shortest path computation in 2D multi-polygon or grid environments based on visibility graphs.



Also see: GitHub, PyPI

3.1 License

`extremitypathfinder` is distributed under the terms of the MIT license (see LICENSE).

3.2 Basic Idea

Well described in [1, Ch. II 3.2]:

An environment ("world", "map") of a given shortest path problem can be represented by one boundary polygon with holes (themselves polygons).

IDEA: Two categories of vertices/corners can be distinguished in these kind of environments:

- protruding corners (hereafter called **"Extremities"**)
- all others

Extremities have an inner angle (facing towards the inside of the environment) of > 180 degree. As long as there are no obstacles between two points present, it is obviously always best (=shortest) to move to the goal point directly. When obstacles obstruct the direct path (goal is not directly 'visible' from the start) however, extremities (and only extremities!) have to be visited to reach the areas "behind" them until the goal is directly visible.

Improvement: As described in [1, Ch. II 4.4.2 "Property One"] during preprocessing time the visibility graph can be reduced further without the loss of guaranteed optimality of the algorithm: Starting from any point lying "in front of" an extremity `e`, such that both adjacent edges are visible, one will never visit `e`, because everything is reachable on a shorter path without `e` (except `e` itself). An extremity `e1` lying in the area "in front of" extremity `e` hence is never the next vertex in a shortest path coming from `e`. And also in reverse: when coming from `e1` everything else than `e` itself can be reached faster without visiting `e1`. -> `e` and `e1` do not have to be connected in the graph.

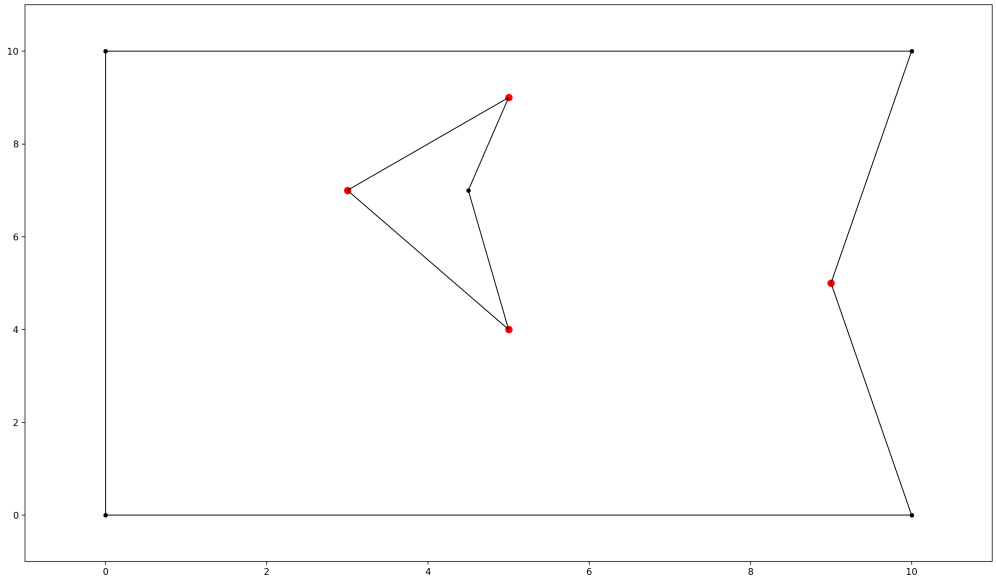


Fig. 1: polygon environment with extremities marked in red

3.2.1 Algorithm

This package pretty much implements the Visibility Graph Optimized (VGO) Algorithm described in [1, Ch. II 4.4.2], just with a few computational tweaks:

Rough Procedure:

- **1. Preprocessing the environment:** Independently of any query start and goal points the optimized visibility graph is being computed for the static environment once with `map.prepare()`. Later versions might include a faster approach to compute visibility on the fly, for use cases where the environment is changing dynamically. The edges of the precomputed graph between the extremities are shown in red in the following plots. Notice that the extremity on the right is not connected to any other extremity due to the above mentioned optimisation:
- **2. Including start and goal:** For each shortest path query the start and goal points are being connected to the internal graph depending on their visibility. Notice that the added edges are directed and also here the optimisation is being used to reduce the amount of edges:
- **3. A-star shortest path computation :** Finding the shortest path on graphs is a standard computer science problem. This package uses a modified version of the popular `A*-Algorithm` optimized for this special use case.

Tweaks (my contribution):

Visibility detection: my "Angle Range Elimination Algorithm" (AREA)

To the best of my knowledge there was no previous algorithm for computing the visibility of points (<-> visibility graph) that is visiting edges at most once without any trigonometric computations, without sorting and with that few

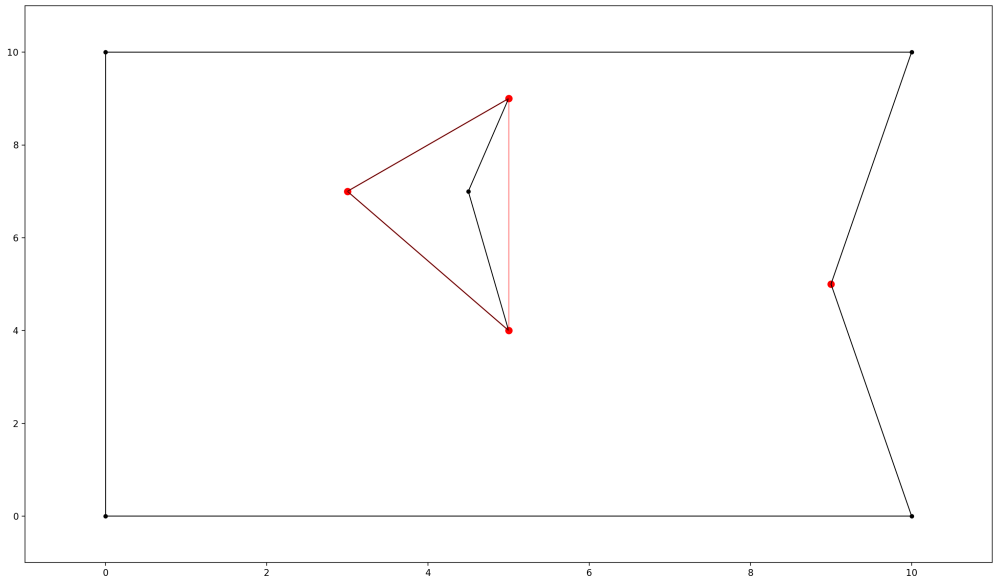


Fig. 2: polygon environment with optimised visibility graph overlay in red

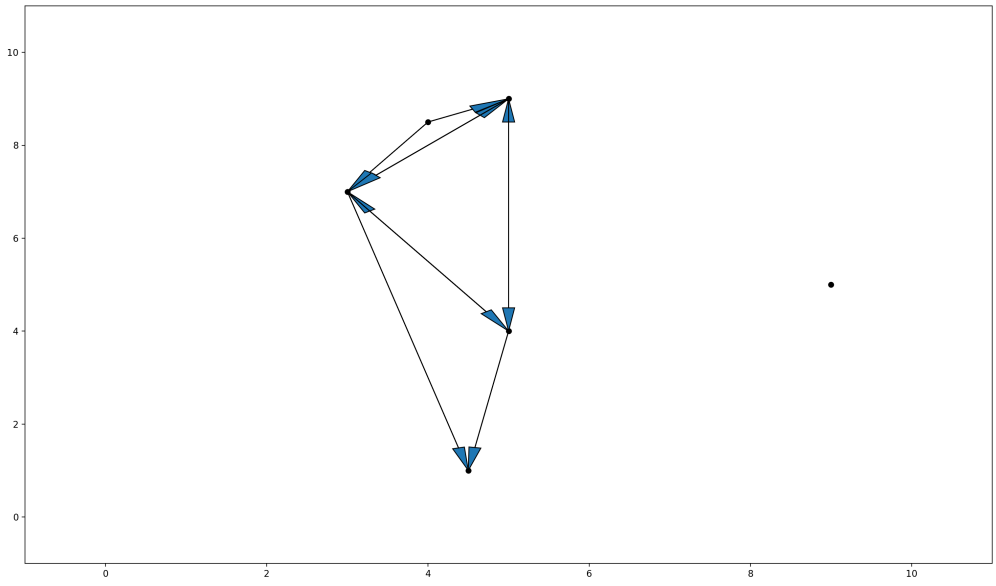


Fig. 3: optimised directed heuristic graph for shortest path computation with added start and goal nodes

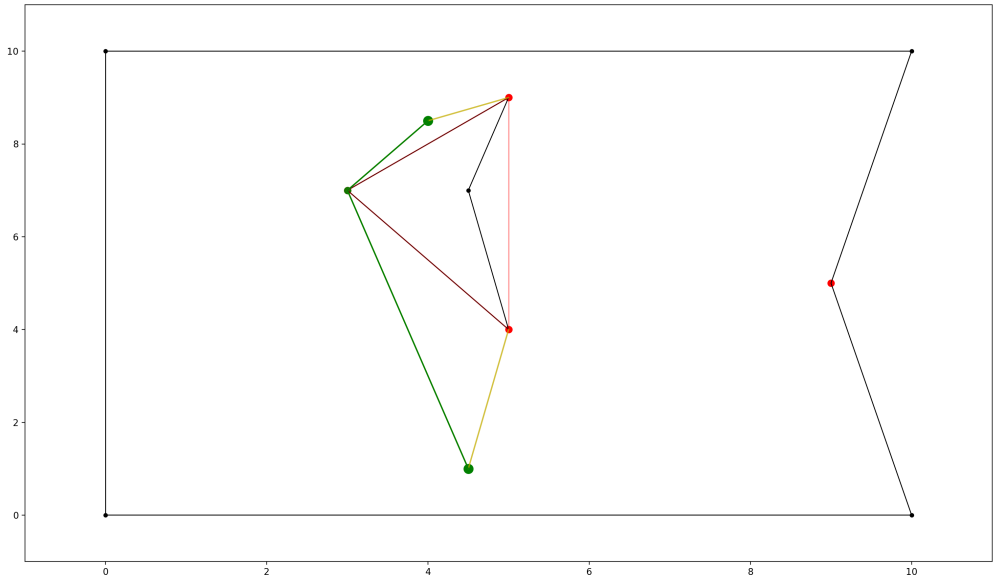


Fig. 4: polygon environment with optimised visibility graph overlay. visualised edges added to the visibility graph in yellow, found shortest path in green.

distance/intersection checks.

Simple fundamental idea: points (extremities) are visible when there is no edge running in front "blocking the view".

Rough procedure: For all edges delete the points lying behind them. Points that remain at the end are visible.

In this use case we are not interested in the full visibility graph, but the visibility of just some points (extremities, start and goal). Additionally deciding if a point lies behind an edge can often be done without computing intersections by just comparing distances. This can be used to reduce the needed computations.

Further speed up can be accomplished by trying to prioritize closer edges, because they have a bigger chance to eliminate candidates.

The basic runtime complexity of this algorithm should be $O(m^2 n)$, where m is the amount of extremities (candidates) and n is the amount of edges (= #vertices). This is fast, because of a few tweaks and usually $m << n$.

Implemented in `PolygonEnvironment.find_visible()` in `extremitypathfinder.py`

Comparison:

Lee's visibility graph algorithm:

complexity: $O(n^2 log_2 n)$ (cf. these slides)

- Initially all edges are being checked for intersection
- Necessarily checking the visibility of all points (instead of just some)
- Always checking all points in every run
- One intersection computation for most points (always when T is not empty)

- Sorting: all points according to degree on startup, edges in binary tree T
- Can work with just lines (not restricted to polygons)

My Algorithm:

- Checking all edges
- Not considering all points (just a few candidates)
- Decreasing number of candidates with every run (visibility is a symmetric relation -> only need to check once for every point pair!)
- Minimal intersection comp. (fraction of candidates)
- No sorting needed
- Could theoretically also work with just lines (this package however currently just allows polygons)
- More simple and clear approach

Angle representation: Instead of computing with angles in degree or radians, it is much more efficient and still sufficient to use a representation that is mapping an angle to a range $a \in [0.0; 4.0[$ ($[0.0; 1.0[$ in all 4 quadrants). This can be done without computationally expensive trigonometric functions! Check the implementation in class `AngleRepresentation` in `helper_classes.py`.

Modifications to A-star: The basic algorithm has been modified to exploit the following geometrical property of this specific task (and hence also the extracted graph):

> It is always shortest to directly reach a node instead of visiting other nodes first (there is never an advantage through reduced edge weight).

This can be exploited in a lot of cases to make A* terminate earlier than for general graphs:

- no need to revisit nodes (path only gets longer)
- when the goal is directly reachable, there can be no other shorter path to it -> terminate.
- not all neighbours of the current node have to be checked like in vanilla A* before continuing to the next node.

Implemented in `graph_search.py`

Laziness: Angle representations of points are being computed only on demand.

3.3 Comparison to pyvisgraph

This package is similar to pyvisgraph which uses Lee's algorithm.

Pros:

- very reduced visibility graph (time and memory!)
- algorithms optimized for path finding
- possibility to convert and use grid worlds

Cons:

- parallel computing not supported so far
- no existing speed comparison

3.4 Contact

Tell me if and how your are using this package. This encourages me to develop and test it further.

Most certainly there is stuff I missed, things I could have optimized even further or explained more clearly, etc. I would be really glad to get some feedback.

If you encounter any bugs, have suggestions etc. do not hesitate to **open an Issue** or **add a Pull Requests** on Git. Please refer to the *contribution guidelines*

3.5 References

[1] Vinther, Anders Strand-Holm, Magnus Strand-Holm Vinther, and Peyman Afshani. "Pathfinding in Two-dimensional Worlds". no. June (2015).

3.6 Further Reading

Open source C++ library for 2D floating-point visibility algorithms, path planning: https://karlobermeyer.github.io/VisiLibity1/

Python binding of VisiLibity: https://github.com/tsaoyu/PyVisiLibity

Paper about Lee's algorithm: http://www.dav.ee/papers/Visibility_Graph_Algorithm.pdf

C implementation of Lee's algorithm: https://github.com/davetcoleman/visibility_graph

3.7 Acknowledgements

Thanks to:

Georg Hess for improving the package in order to allow intersecting polygons. **'Ivan Doria <https://github.com/idoria75 >'__** for adding the command line interface.

CHAPTER 4

API documentation

4.1 PolygonEnvironment

class extremitypathfinder.**PolygonEnvironment**

Bases: object

Class allowing to use polygons to represent "2D environments" and use them for path finding.

Keeps a "loaded" and prepared environment for consecutive path queries. Internally uses a visibility graph optimised for shortest path finding. General approach and some optimisations theoretically described in: [1] Vinther, Anders Strand-Holm, Magnus Strand-Holm Vinther, and Peyman Afshani. "Pathfinding in Two-dimensional Worlds"

__init__

Initialize self. See help(type(self)) for accurate signature.

all_edges

all_extremities

all_vertices

boundary_polygon = None

export_pickle(*path: str = 'environment.pickle'*)

find_shortest_path(*start_coordinates: Tuple[Union[float, int], Union[float, int]], goal_coordinates: Tuple[Union[float, int], Union[float, int]], free_space_after: bool = True, verify: bool = True*) → Tuple[List[Tuple[float, float]], Optional[float]]

computes the shortest path and its length between start and goal node

Parameters

- **start_coordinates** – a (x,y) coordinate tuple representing the start node
- **goal_coordinates** – a (x,y) coordinate tuple representing the goal node

- **free_space_after** – whether the created temporary search graph self.temp_graph should be deleted after the query
- **verify** – whether it should be checked if start and goal points really lie inside the environment. if points close to or on polygon edges should be accepted as valid input, set this to `False`.

Returns a tuple of shortest path and its length. ([], None) if there is no possible path.

graph = None

holes = None

polygons

prepare()

Computes a visibility graph optimized (=reduced) for path planning and stores it

Computes all directly reachable extremities based on visibility and their distance to each other

---

Note: Multiple polygon vertices might have identical coordinates. They must be treated as distinct vertices here, since their attached edges determine visibility. In the created graph however, these nodes must be merged at the end to avoid ambiguities!

Note: Pre computing the shortest paths between all directly reachable extremities and storing them in the graph would not be an advantage, because then the graph is fully connected. A star would visit every node in the graph at least once (-> disadvantage!).

---

prepared = False

store(*boundary_coordinates: Union[numpy.ndarray, List[T]], list_of_hole_coordinates: Union[numpy.ndarray, List[T]], validate: bool = False*)

saves the passed input polygons in the environment

Note: the passed polygons must meet these requirements:

- given as numpy or python array of coordinate tuples: `[(x1,y1), (x2,y2,)...]`
- no repetition of the first point at the end
- at least 3 vertices (no single points or lines allowed)
- no consequent vertices with identical coordinates in the polygons (same coordinates allowed)
- no self intersections
- edge numbering has to follow these conventions: boundary polygon counter clockwise, holes clockwise

---

Parameters

- **boundary_coordinates** – array of coordinates with counter clockwise edge numbering
- **list_of_hole_coordinates** – array of coordinates with clockwise edge numbering
- **validate** – whether the requirements of the data should be tested

Raises **AssertionError** – when validate=True and the input is invalid.

store_grid_world(*size_x: int, size_y: int, obstacle_iter: Iterable[Tuple[Union[float, int], Union[float, int]]], simplify: bool = True, validate: bool = False*)
Convert a grid-like into a polygon environment and save it

Prerequisites: grid world must not have single non-obstacle cells which are surrounded by obstacles ("white cells in black surrounding" = useless for path planning)

Parameters

- **size_x** – the horizontal grid world size
- **size_y** – the vertical grid world size
- **obstacle_iter** – an iterable of coordinate pairs (x,y) representing blocked grid cells (obstacles)
- **validate** – whether the input should be validated
- **simplify** – whether the polygons should be simplified or not. reduces edge amount, allow diagonal edges

temp_graph = None

translate(*new_origin: extremitypathfinder.helper_classes.Vertex*)
shifts the coordinate system to a new origin

computing the angle representations, shifted coordinates and distances for all vertices respective to the query point (lazy!)

Parameters **new_origin** – the origin of the coordinate system to be shifted to

within_map(*coords: Tuple[Union[float, int], Union[float, int]]*)
checks if the given coordinates lie within the boundary polygon and outside of all holes

Parameters **coords** – numerical tuple representing coordinates

Returns whether the given coordinate is a valid query point

CHAPTER 5

Contribution Guidelines

Contributions are welcome, and they are greatly appreciated! Every little bit helps, and credit will always be given.

You can contribute in many ways:

5.1 Types of Contributions

5.1.1 Report Bugs

Report bugs via Github Issues.

If you are reporting a bug, please include:

- Your version of this package, python and Numba (if you use it)
- Any other details about your local setup that might be helpful in troubleshooting, e.g. operating system.
- Detailed steps to reproduce the bug.
- Detailed description of the bug (error log etc.).

5.1.2 Fix Bugs

Look through the GitHub issues for bugs. Anything tagged with “bug” is open to whoever wants to implement it.

5.1.3 Implement Features

Look through the GitHub issues for features. Anything tagged with “help wanted” and not assigned to anyone is open to whoever wants to implement it - please leave a comment to say you have started working on it, and open a pull request as soon as you have something working, so that Travis starts building it.

Issues without "help wanted" generally already have some code ready in the background (maybe it's not yet open source), but you can still contribute to them by saying how you'd find the fix useful, linking to known prior art, or other such help.

5.1.4 Write Documentation

Probably for some features the documentation is missing or unclear. You can help with that!

5.1.5 Submit Feedback

The best way to send feedback is to file an issue via Github Issues.

If you are proposing a feature:

- Explain in detail how it would work.
- Keep the scope as narrow as possible, to make it easier to implement. Create multiple issues if necessary.
- Remember that this is a volunteer-driven project, and that contributions are welcome :)

5.2 Get Started!

Ready to contribute? Here's how to set up this package for local development.

- Fork this repo on GitHub.
- Clone your fork locally
- To make changes, create a branch for local development:

```
$ git checkout -b name-of-your-bugfix-or-feature
```

- Check out the instructions and notes in `publish.py`
- Install `tox` and run the tests:

```
$ pip install tox
$ tox
```

  The `tox.ini` file defines a large number of test environments, for different Python etc., plus for checking codestyle. During development of a feature/fix, you'll probably want to run just one plus the relevant codestyle:

```
$ tox -e codestyle
```

- Commit your changes and push your branch to GitHub:

```
$ git add .
$ git commit -m "Your detailed description of your changes."
$ git push origin name-of-your-bugfix-or-feature
```

- Submit a pull request through the GitHub website. This will trigger the Travis CI build which runs the tests against all supported versions of Python.

CHAPTER 6

Changelog

TODO python 3.6 support. tests not passing so far only for this python version

6.1 2.2.0 (2021-01-25)

- Included a command line interface
- Improved testing routines and codestyle

6.2 2.1.0 (2021-01-07)

IMPORTANT BUGFIX: in some cases the visibility computation was faulty (fix #23)

- added new test case

6.3 2.0.0 (2020-12-22)

- IMPROVEMENT: Different polygons may now intersect each other. Thanks to Georg Hess!
- BUGFIX: Fixed a bug that caused "dangling" extremities in the graph to be left out
- `TypeError` and `ValueError` are being raised instead of `AssertionError` in case of invalid input parameters with `validate=True`. Thanks to Andrew Costello!

6.4 1.5.0 (2020-06-18)

- BUGFIX: fix #16. introduce unique ordering of A* search heap queue with custom class `SearchState` (internal)

6.5 1.4.0 (2020-05-25)

- BUGFIX: fix clockwise polygon numbering test (for input data validation, mentioned in #12)

6.6 1.3.0 (2020-05-19)

- FIX #11: added option `verify` to `find_shortest_path()` for skipping the 'within map' test for goal and start points

6.7 1.2.0 (2020-05-18)

- supporting only python 3.7+
- fix #10: Memory leak in DirectedHeuristicGraph
- fix BUG where "dangling" extremities in the visibility graph would be deleted
- using generators to refer to the polygon properties (vertices,...) of an environment (save memory and remove redundancy)
- enabled plotting the test results, at the same time this is testing the plotting functionality
- added typing

internal:

- added sphinx documentation, included auto api documentation, improved docstrings
- added contribution guidelines
- add sponsor button
- updated publishing routine
- split up requirement files (basic, tests)
- specific tags for supported python versions in wheel
- testing all different python versions with tox
- added coverage tests
- added editorconfig
- specify version in VERSION file
- added new tests

6.8 1.1.0 (2018-10-17)

- optimised A*-algorithm to not visit all neighbours of the current node before continuing

6.9 1.0.0 (2018-10-07)

- first stable public version

6.10 0.0.1 (2018-09-27)

- birth of this package

CHAPTER 7

Indices and tables

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