Shape-guided artistic route finding

Final presentation - 19.06.2023

Author: Leon Powałka, 5605822
1st supervisor: Dr. Liangliang Nan
2nd supervisor: Dr. Jantien Stoter
Co-reader: Dr. Michael Weinmann

Artistic routes (GPS Art)

GPS art example. [Source]

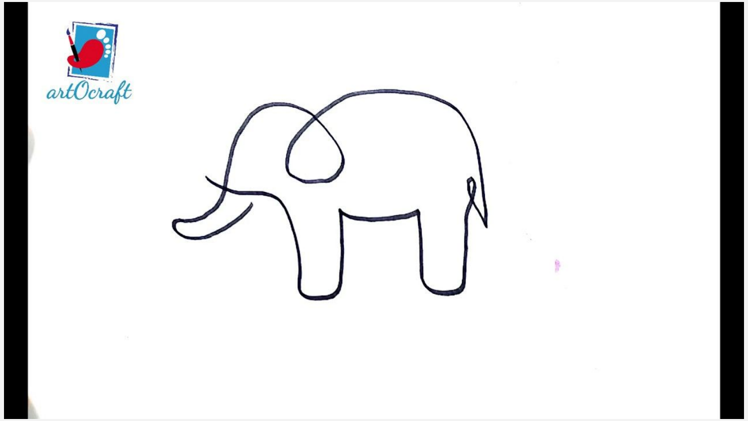
Many other interesting artworks:

https://www.strav.art/home

Darth vader GPS art
[Source]

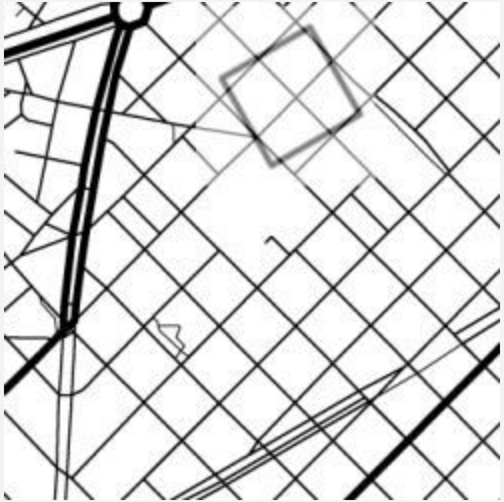
Problem statement

- **How to automatically generate artistic routes based on simple input drawings?**
  - How to quantitatively evaluate the quality of the obtained routes?
  - What priorities / compromises should be considered in order to produce optimal output, considering user's preferences?



Example input drawing that could be converted into an artistic route.
Source

Related work



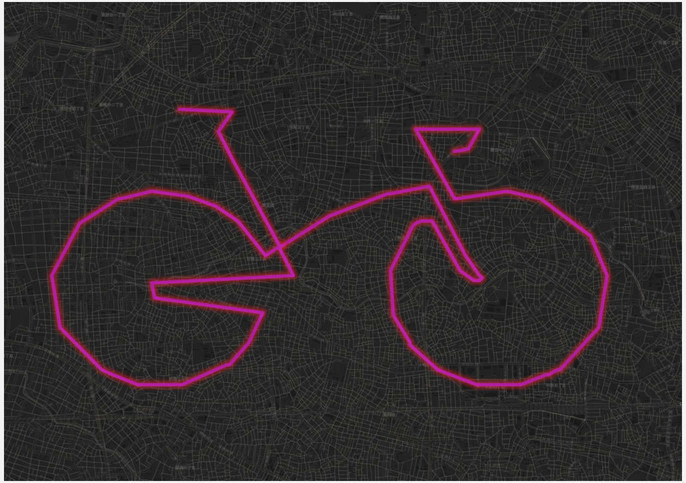
Balduz (2017) - rasterize and brute force approach
Source

Waschk and Krüger (2018) - Dijkstra algorithm with a custom cost function
Source

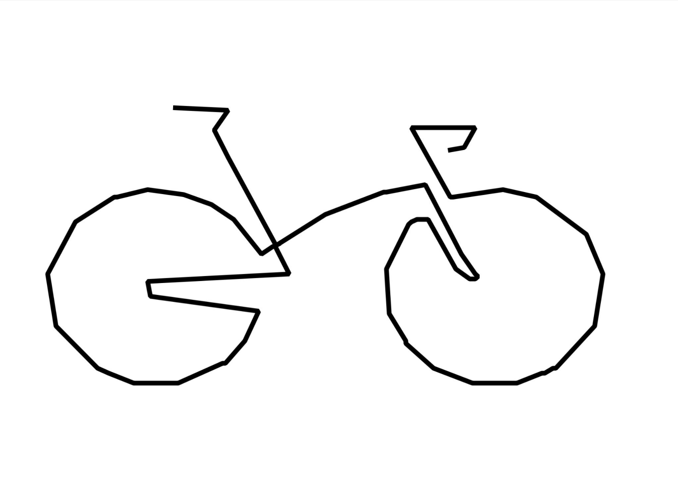
Problem approach

1. Transformation-fixed approach
2. Transformation-agnostic approach

Goal: Combine both approaches into a single workflow



Transformation-fixed drawing overlaid on top of a road network map.



Transformation-agnostic drawing. This kind of a drawing cannot be overlaid on a map, since it has no Coordinate Reference System.

Transformation-fixed problem approach

Solution:

- A* algorithm
- Route segment by segment
- Custom edge cost function (segment similarity)
- Result: valid, connected route

White - input drawing.
Red - shortest path
Green - path with optimized for similarity

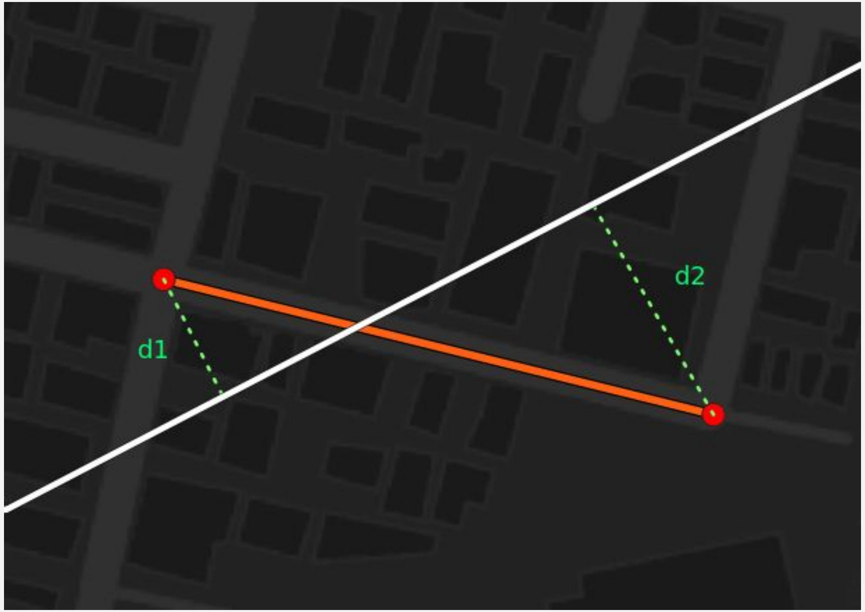
Cost function components

1. Distance(P, N)
2. Similarity_metric(P, N, S, E)

$C(P, N, S, E) = \alpha C1(P, N) + \beta C2(P, N,S,E)$

Where:

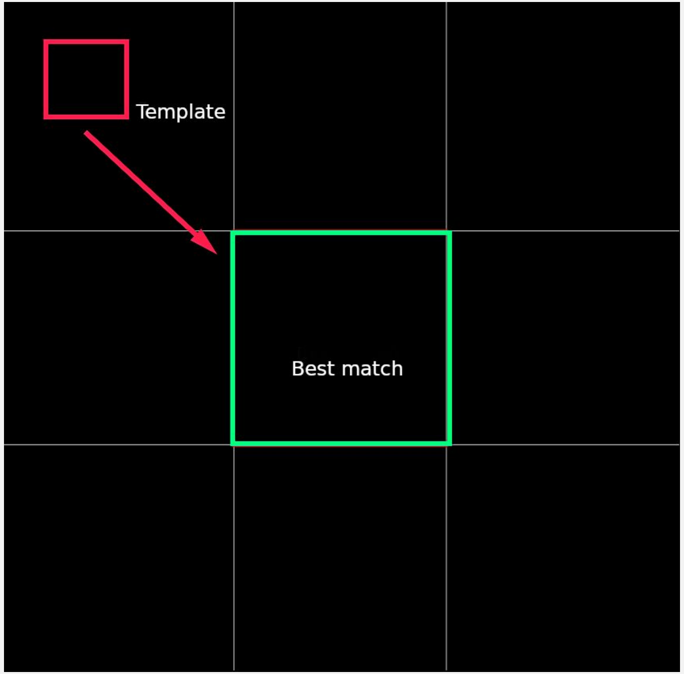
C - graph edge cost
P - graph edge start node
N - graph edge end node
S - drawing segment start point
E - drawing segment end point
α, β - weights given to the metrics



Metric C2 based on sum of distances from 2 endpoints of the street segment (orange) to the input drawing segment (white).

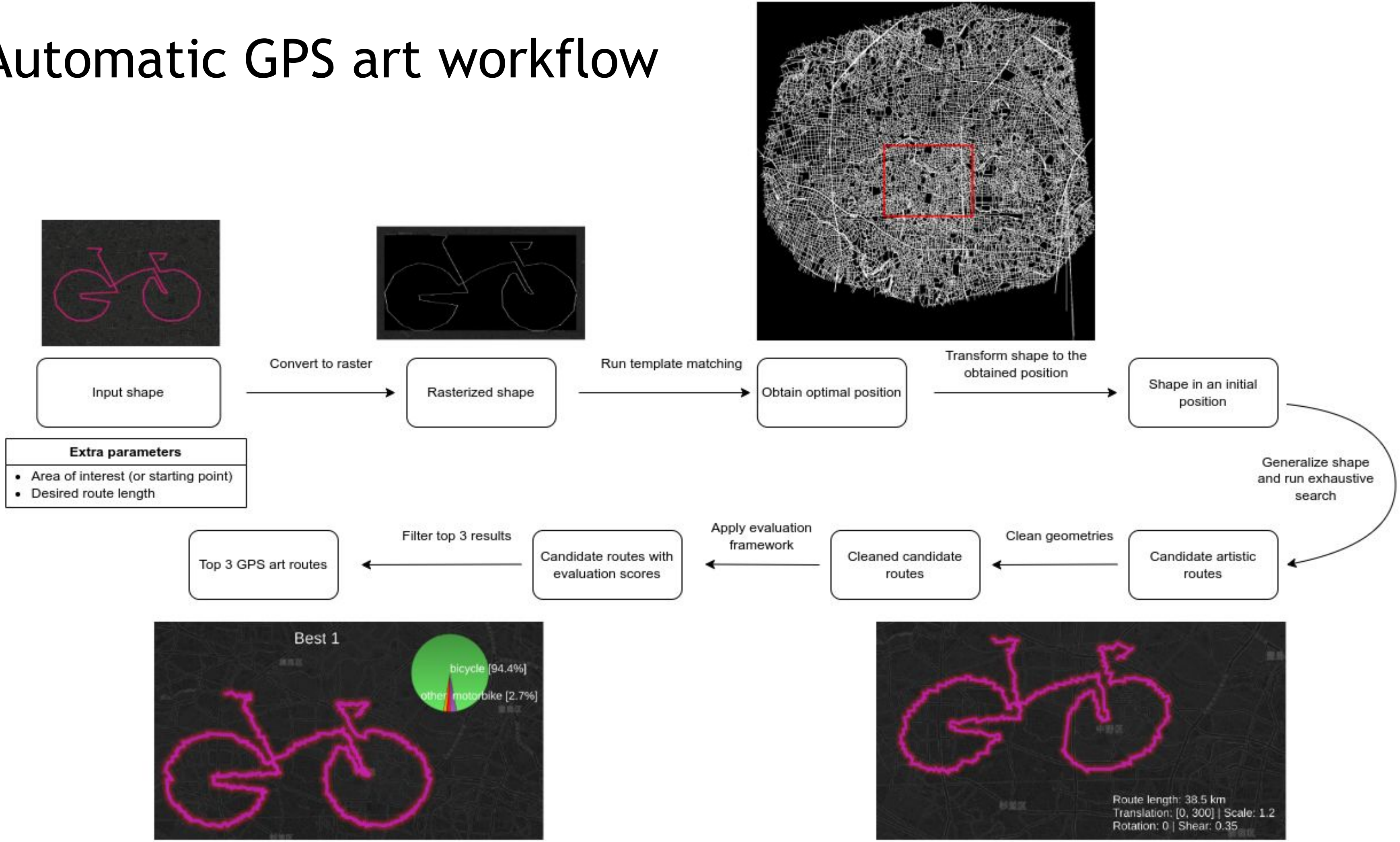
Transformation-agnostic problem approach

- Problem: almost guaranteed that no close match will be found.
- Template matching - find the location where the overlap between the input shape and the road network is the highest



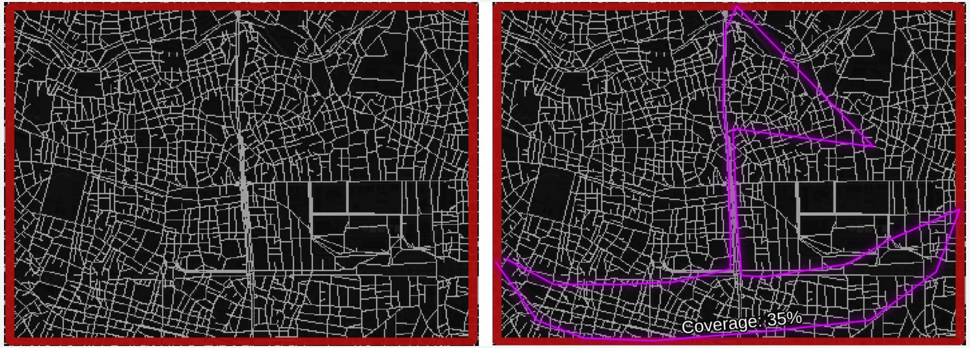
Basic template matching example with a square template and a tic-tac-toe board

Automatic GPS art workflow



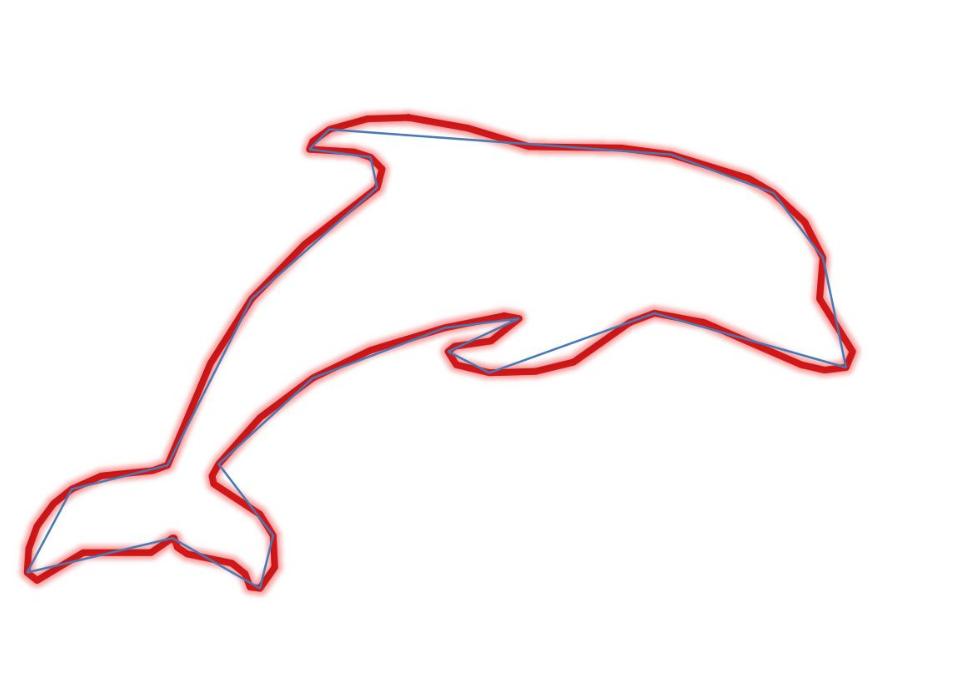
Template matching

Template matching result in the road network image



Template matching result in the road network image. Zoomed in. Coverage value is 35%

Shape simplification

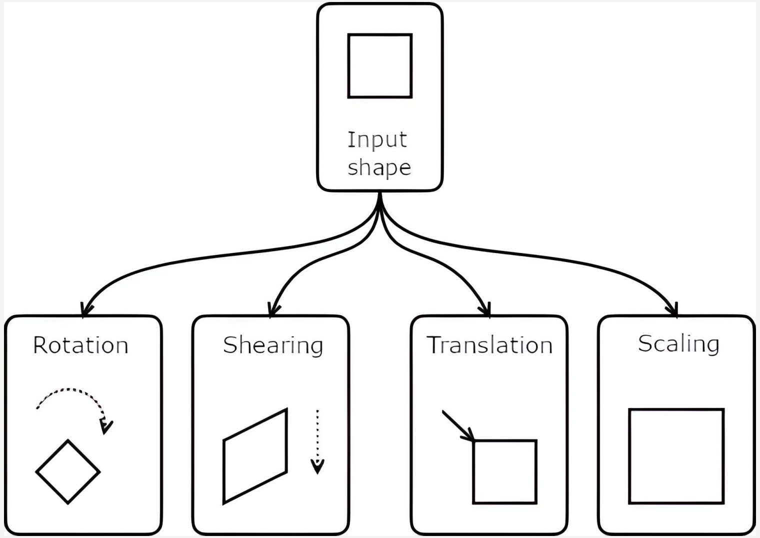


Original shape (red) and its simplified version (blue).

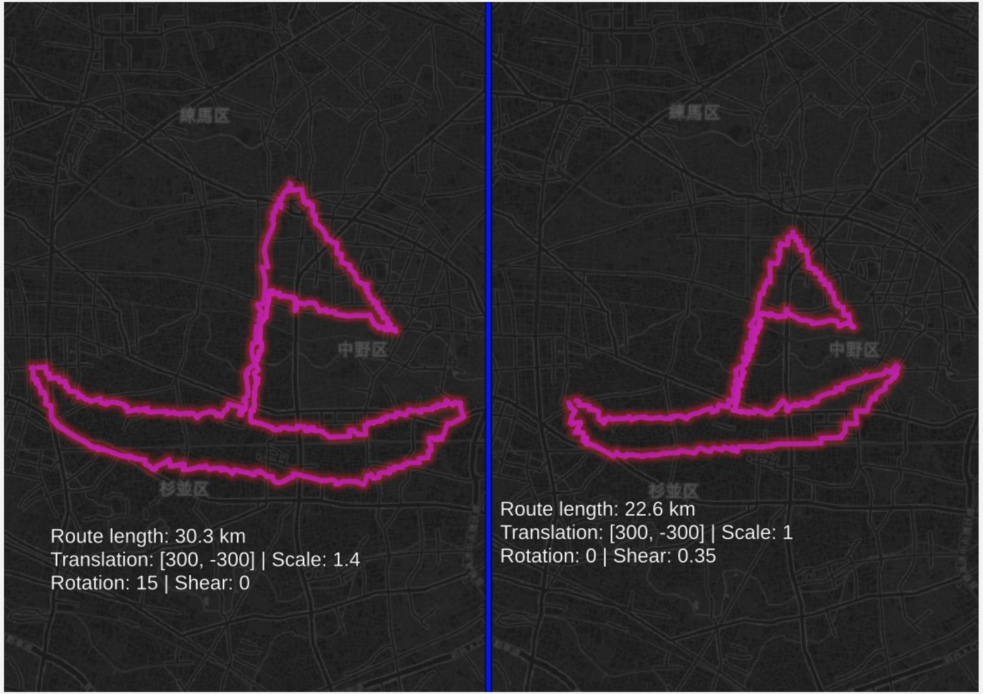
Shape simplification

Exhaustive search

- Uses transformation-fixed approach
- Generates many artistic route candidates

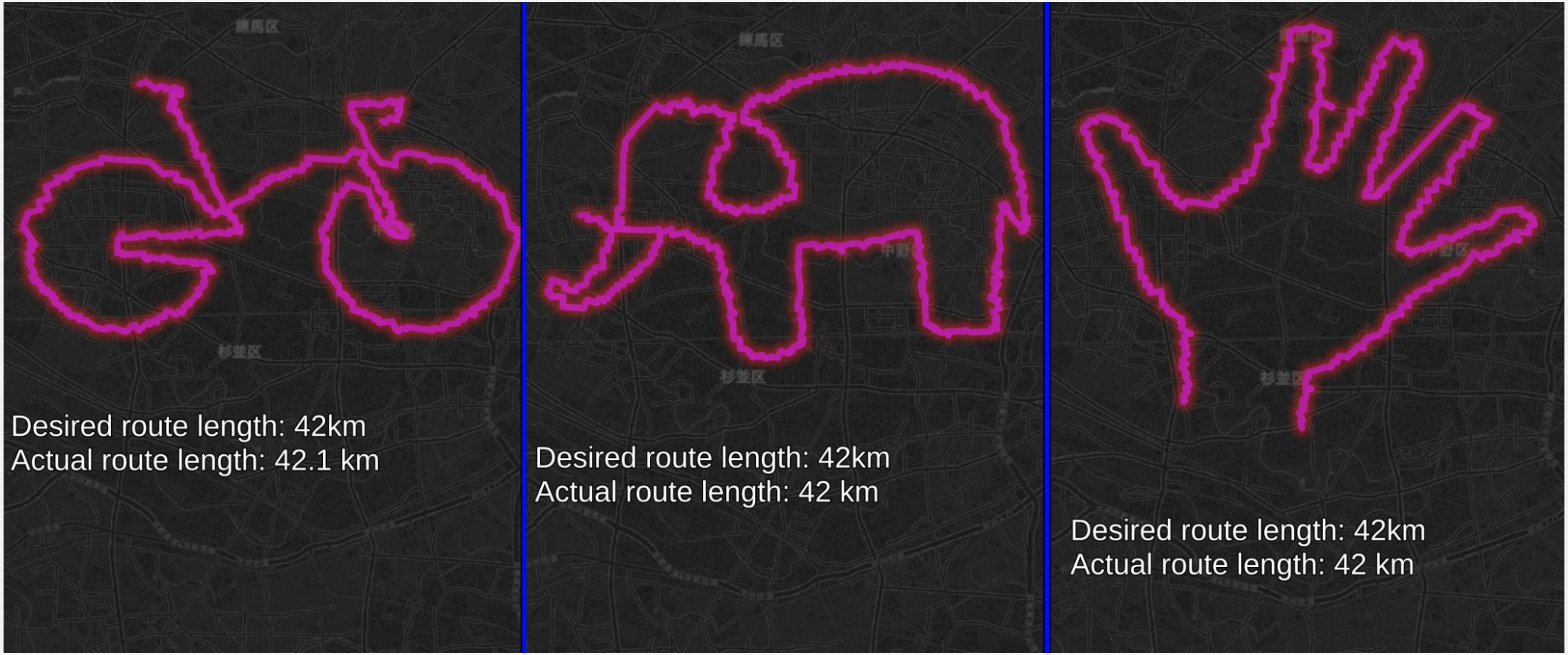


Kinds of transformations used in the exhaustive search



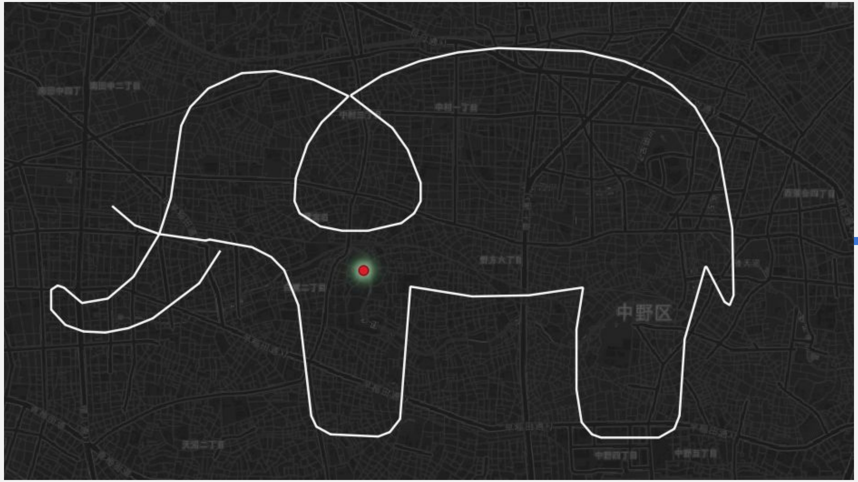
Examples of two different candidate routes for the same input shape

User parameter - desired route length



GPS art results for a desired route length of 42 kilometers

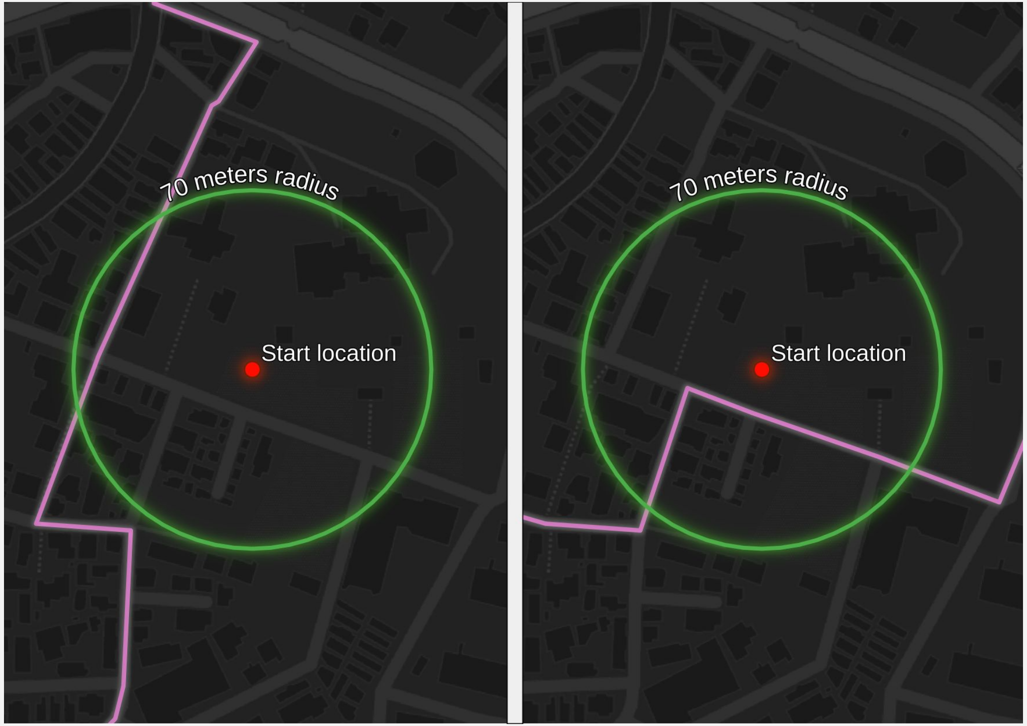
User parameter - start/end point



Input shape (white) and a desired starting point (red dot)

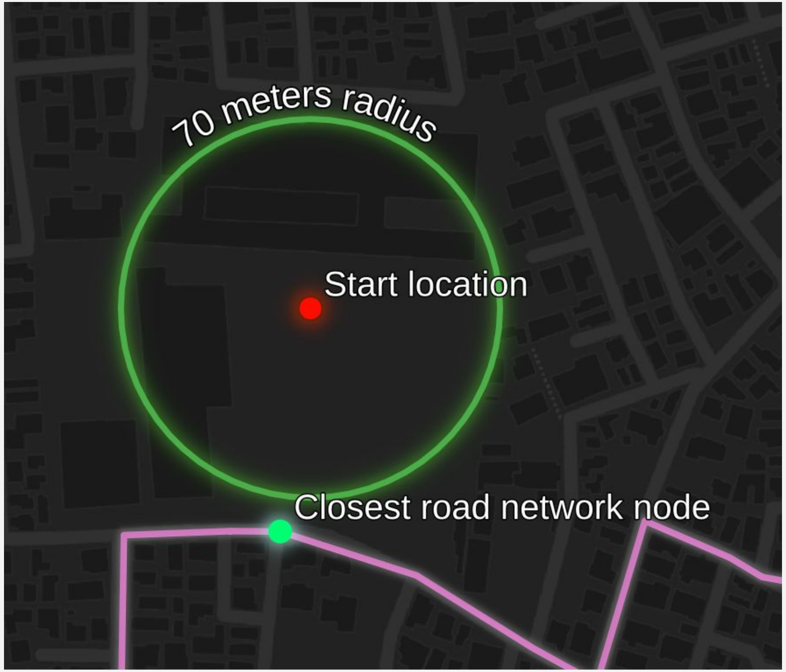
Result artistic route (pink) which starts in the desired location

User parameter - start/end point



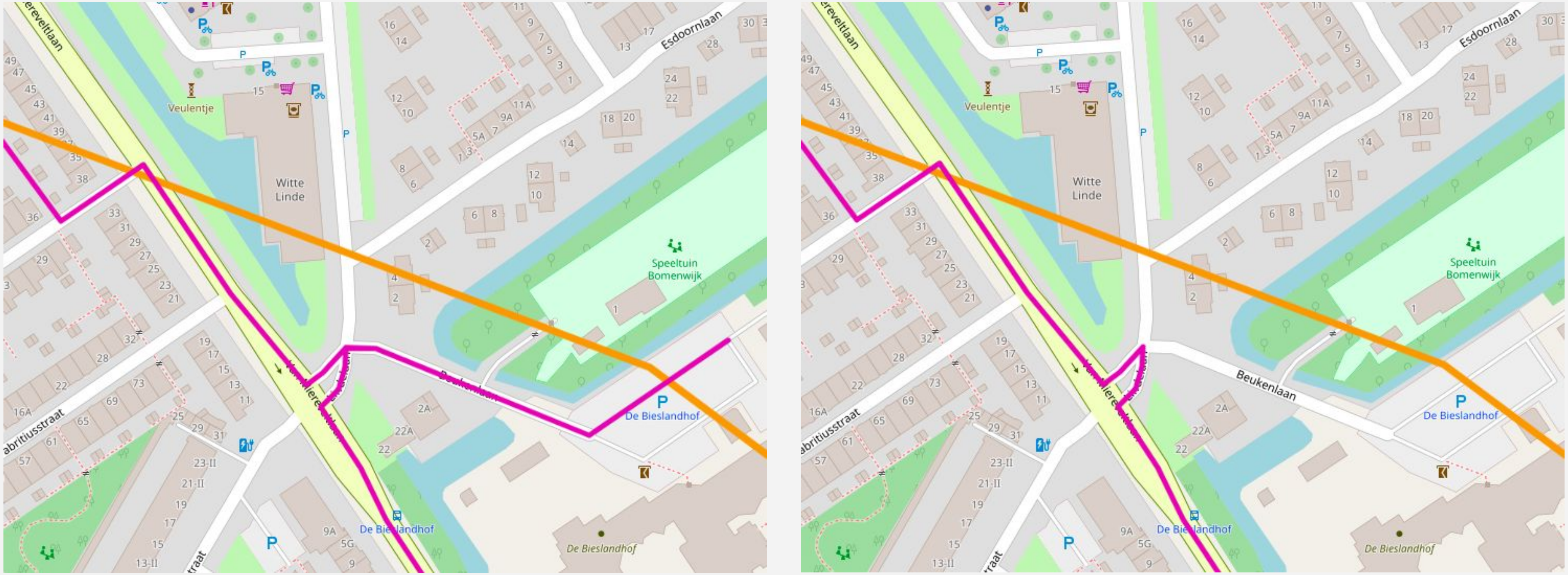
Two distinct routes which satisfy the constraint of a starting point (red marker) within a 70-meter threshold}

User parameter - start/end point



Start point with a threshold of 70m. No road network nodes are within 70m, so the closest one is chosen instead.

Postprocessing - removing U-turns



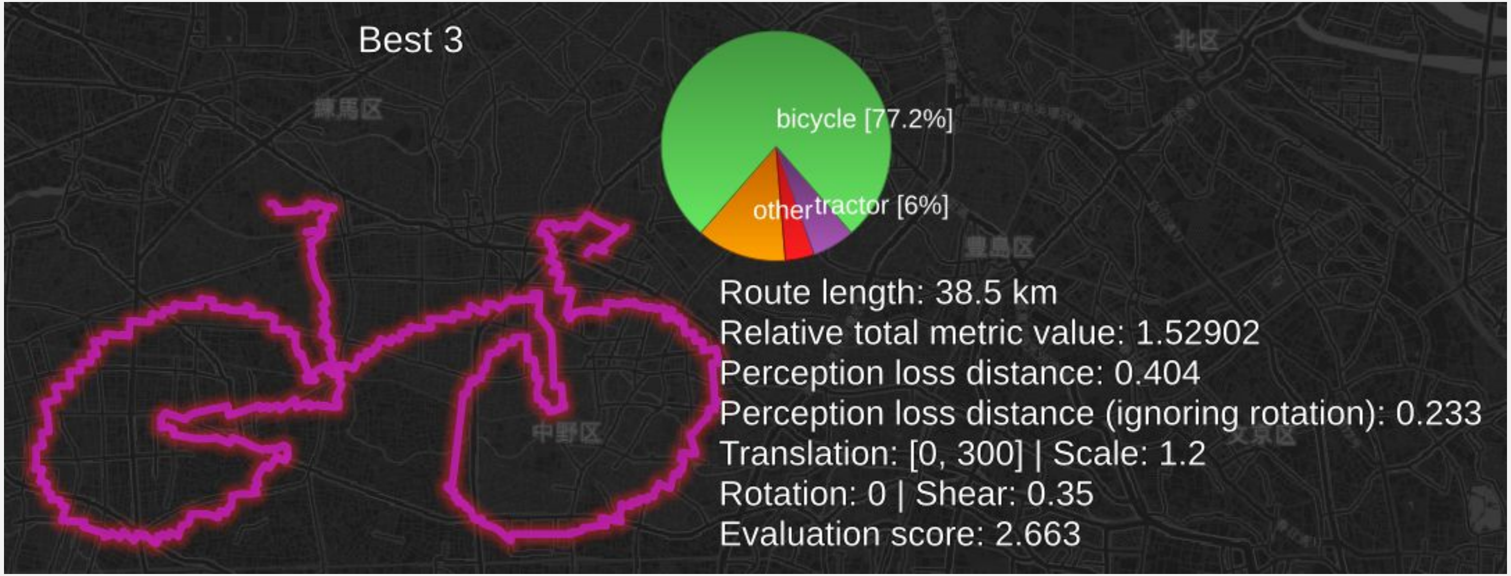
Routing scenario where a U-turn occurs before removing U-turns (left) and after removing U-turns (right).

Postprocessing - removing U-turns

Artistic route after removing U-turns. Removed segments are colored red.

Evaluation framework

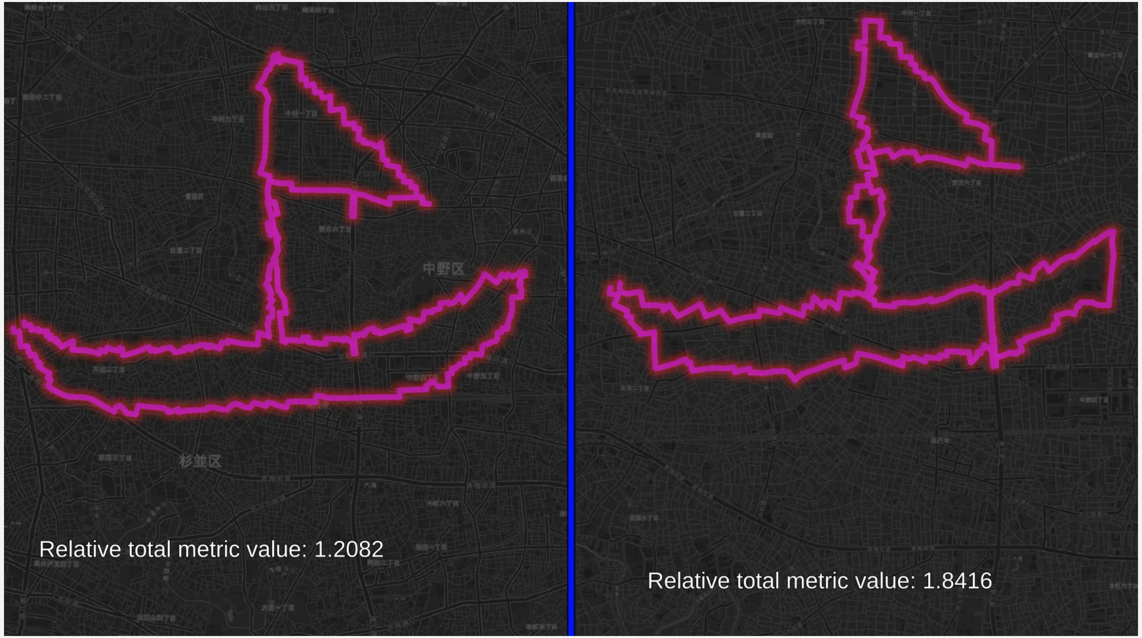
- Relative total metric value (derived from the cost function)
- Perceptual loss metric (ML)
- Object classification result (ML)
- **Total evaluation score** (based on weighted components)



Artistic route and its evaluation score components.

Evaluation framework - relative total metric value (RTMV)

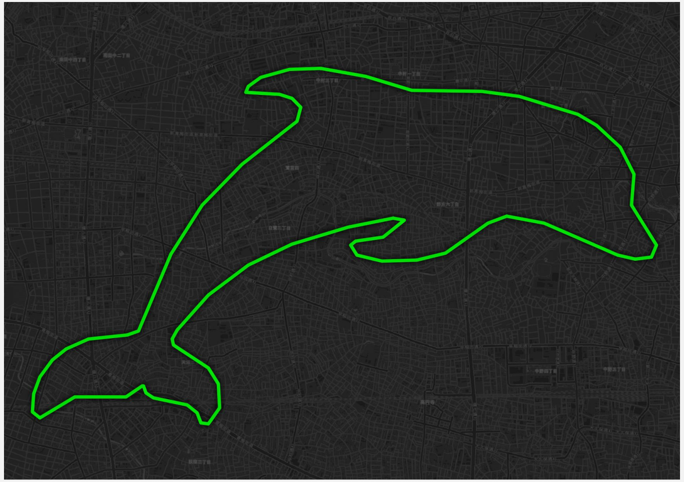
- Expresses geometric deviation from the input drawing



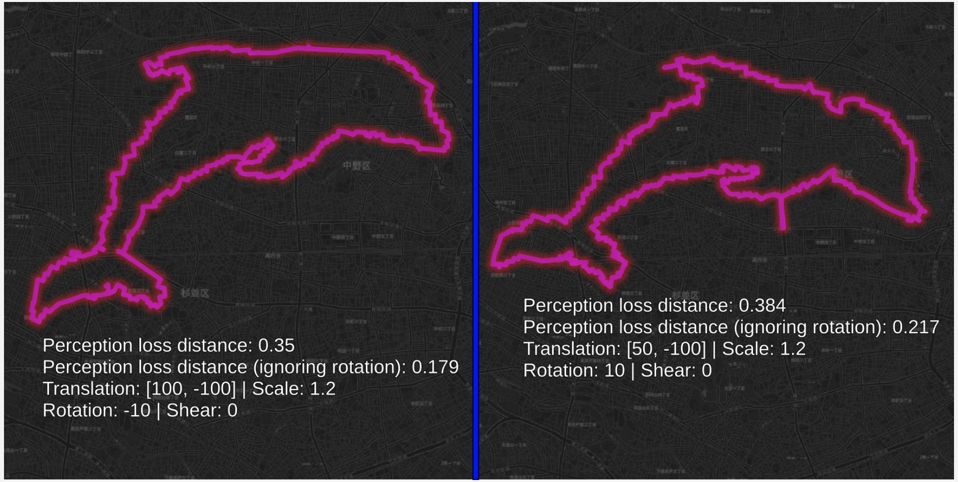
Comparison of low and high RTMV routes for the same source drawing

Evaluation framework - perceptual loss

- Visual distance between 2 given images (https://richzhang.github.io/PerceptualSimilarity/)
- Meant to resemble human perceptual judgement



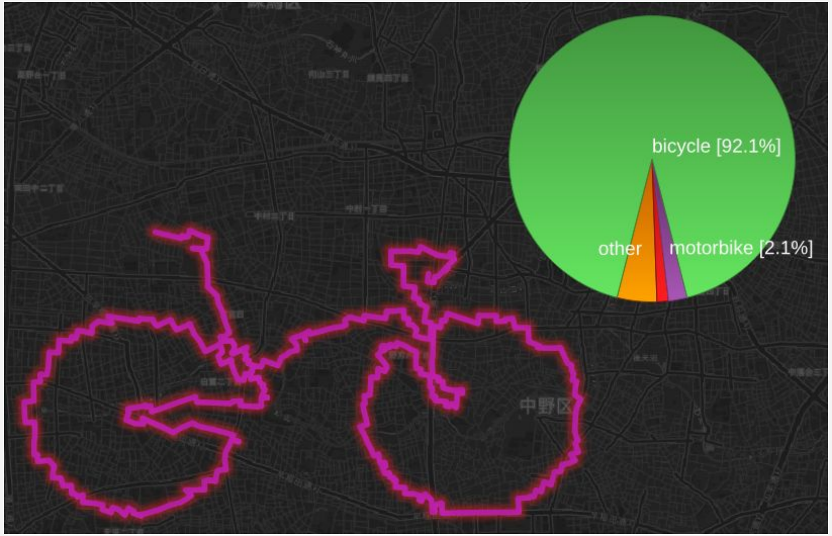
Input shape of a dolphin



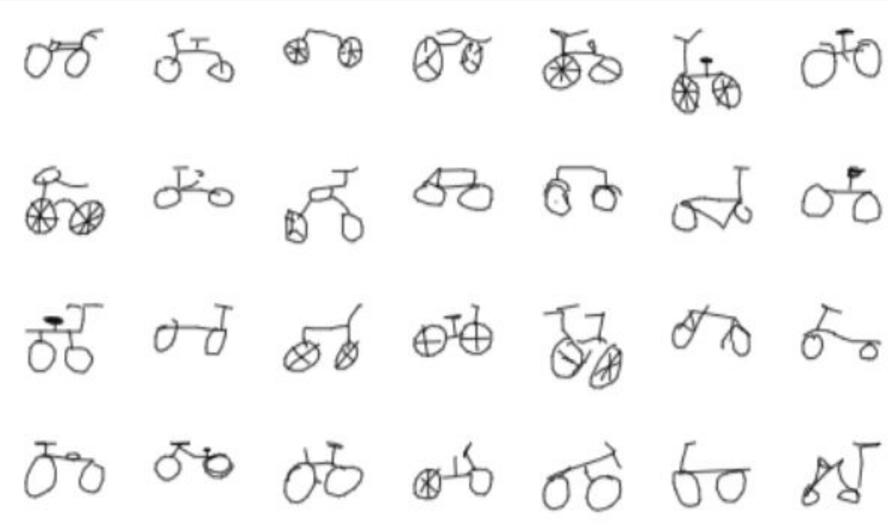
Perceptual loss distance for 2 GPS art candidates

Evaluation framework - object recognition

- Label certainty as given by the ML based object classifier
- Sensitive to different methods of drawing / significant route distortions

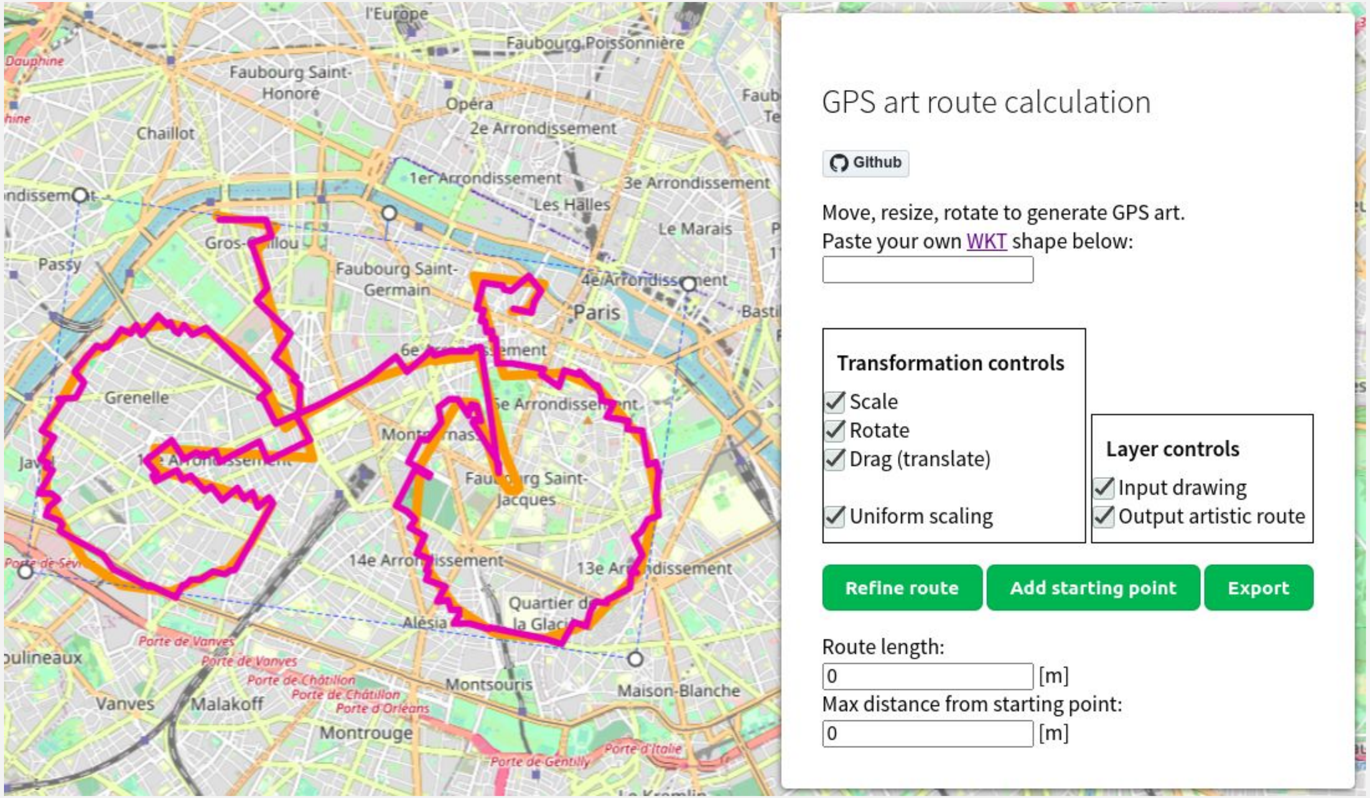


GPS art and the labels given by the object classifier

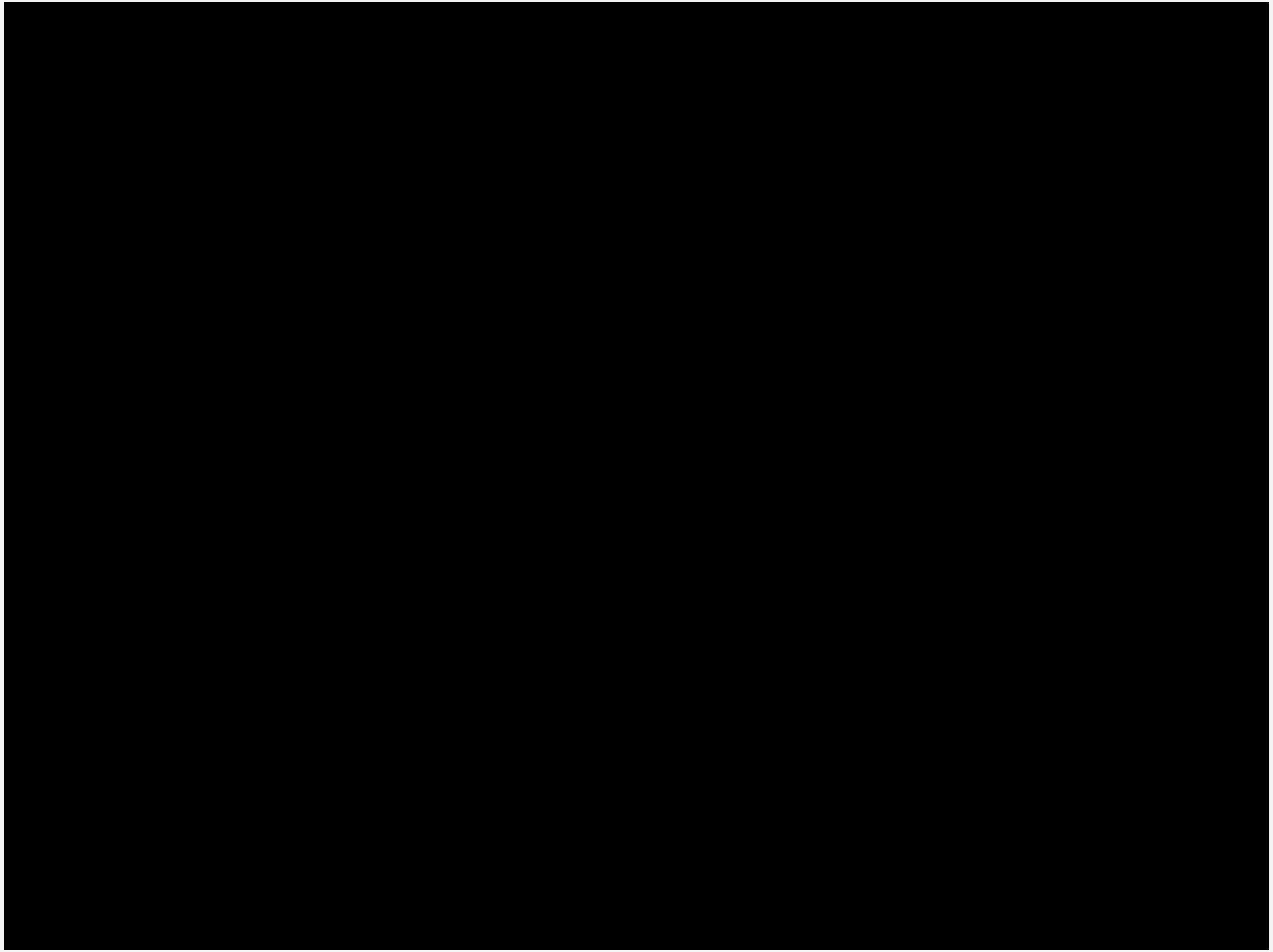


Some of the drawings used for training the object classifier. Source: link

Interactive application

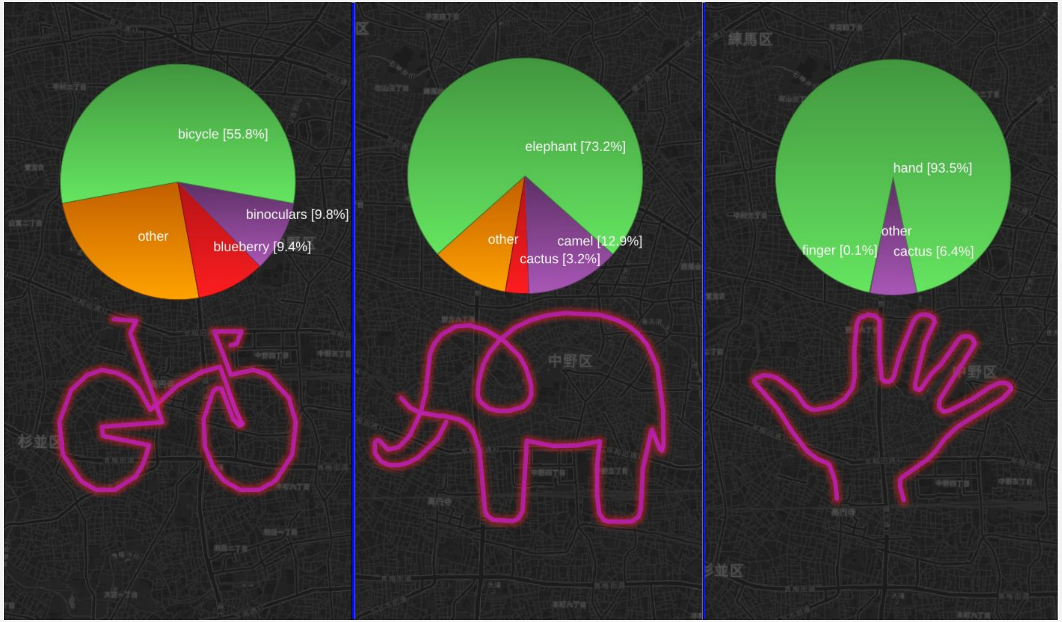


View of the interactive application. The map is visible on the left and the control panel on the right.



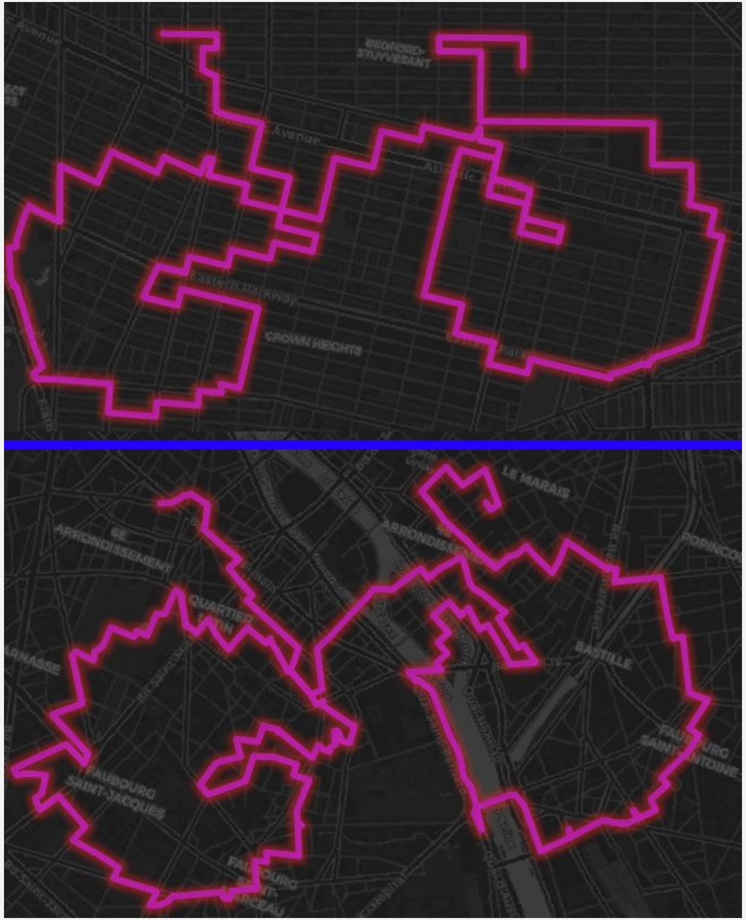
Tests

- Locations: Tokyo, New York, Paris, Delft, Amsterdam
- Drawings: bike, elephant, hand
- Route lengths: 10, 21, 42 [km]



Drawings used for the tests and the reference labels given by the object classifier.

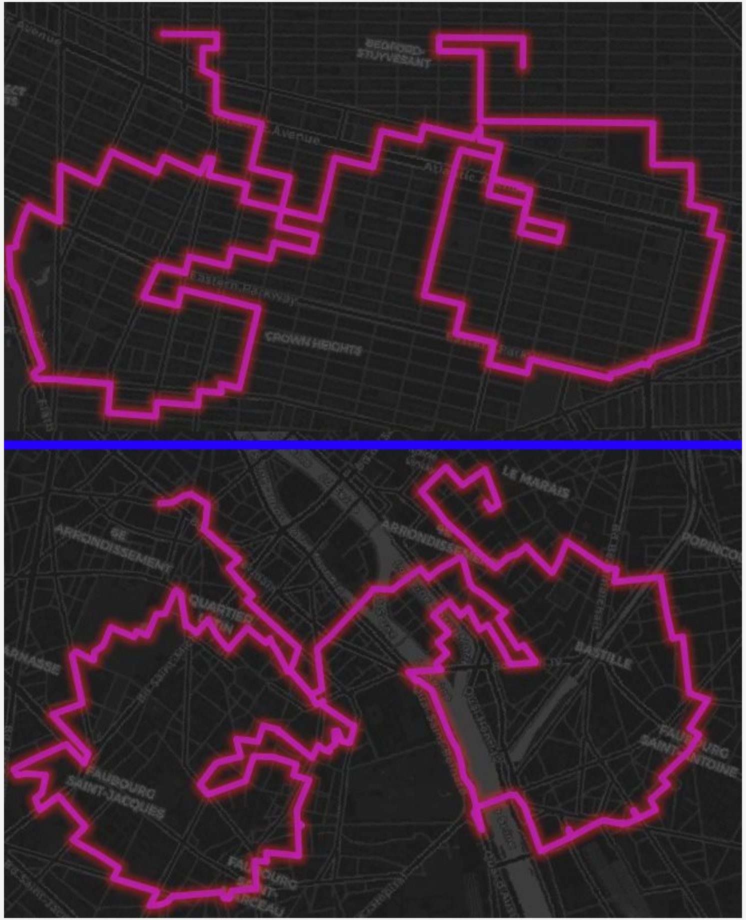
New York vs Paris (guess which is which)



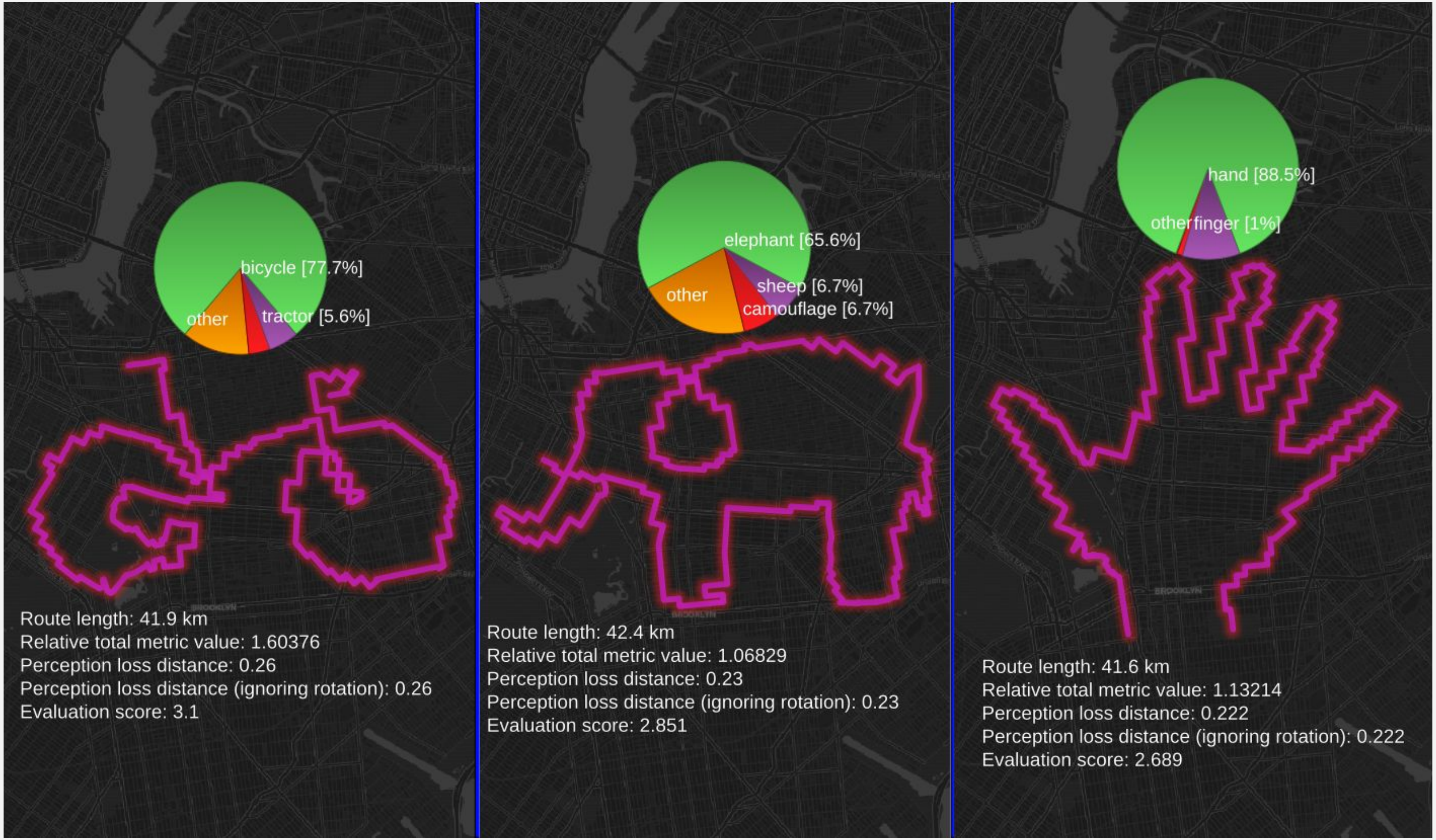
New York vs Paris (guess which is which)

New York

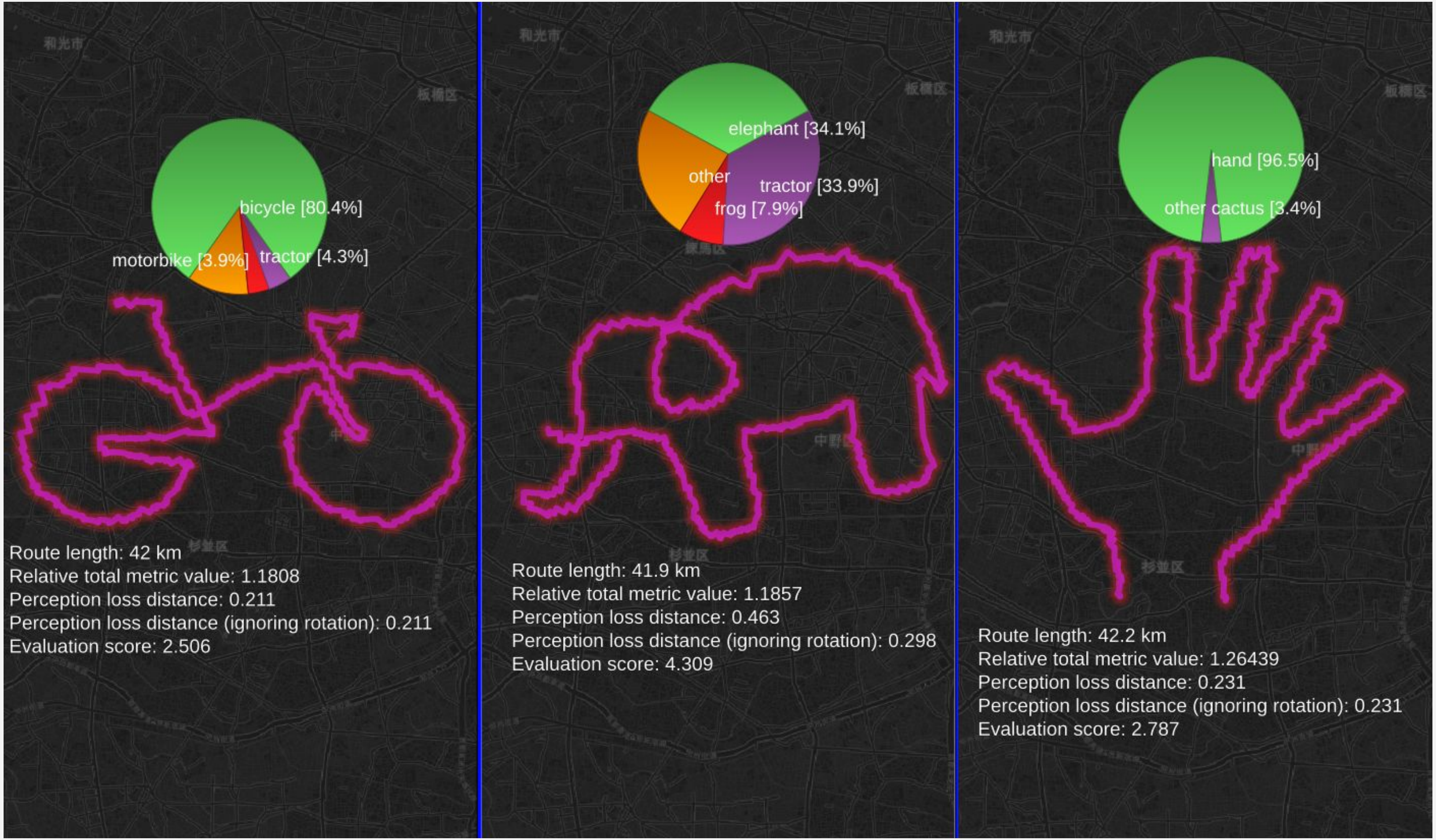
Paris



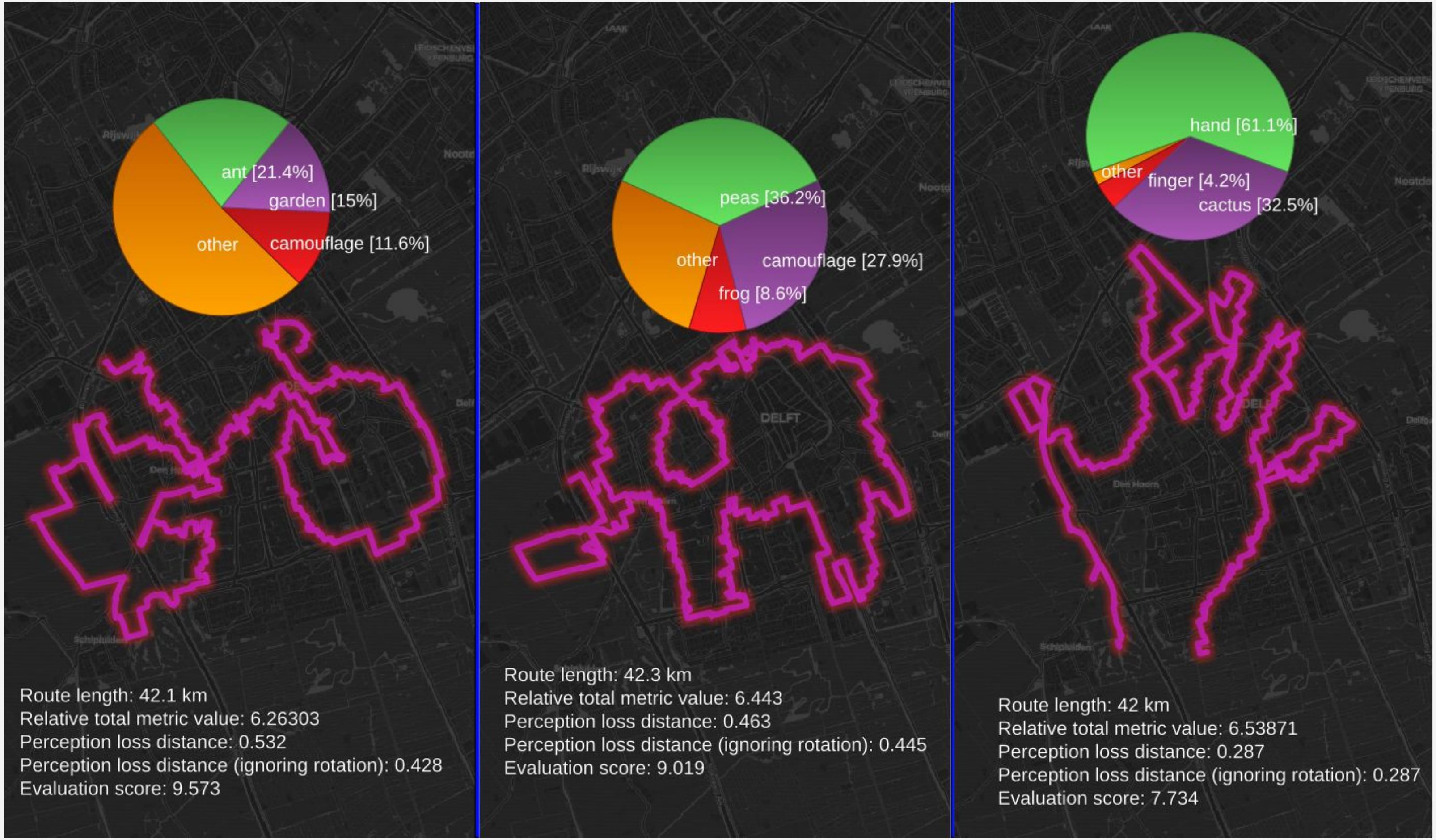
New York City - 42 km



Tokyo - 42 km


bicycle [80.4%]
motorbike [3.9%]
tractor [4.3%]
Route length: 42 km
Relative total metric value: 1.1808
Perception loss distance: 0.211
Perception loss distance (ignoring rotation): 0.211
Evaluation score: 2.506
elephant [34.1%]
other
tractor [33.9%]
frog [7.9%]
Route length: 41.9 km
Relative total metric value: 1.1857
Perception loss distance: 0.463
Perception loss distance (ignoring rotation): 0.298
Evaluation score: 4.309
hand [96.5%]
other cactus [3.4%]
Route length: 42.2 km
Relative total metric value: 1.26439
Perception loss distance: 0.231
Perception loss distance (ignoring rotation): 0.231
Evaluation score: 2.787

Delft - 42 km


ant [21.4%]
garden [15%]
other
camouflage [11.6%]
Route length: 42.1 km
Relative total metric value: 6.26303
Perception loss distance: 0.532
Perception loss distance (ignoring rotation): 0.428
Evaluation score: 9.573
peas [36.2%]
other
camouflage [27.9%]
frog [8.6%]
DELFT
Route length: 42.3 km
Relative total metric value: 6.443
Perception loss distance: 0.463
Perception loss distance (ignoring rotation): 0.445
Evaluation score: 9.019
hand [61.1%]
other
finger [4.2%]
cactus [32.5%]
Route length: 42 km
Relative total metric value: 6.53871
Perception loss distance: 0.287
Perception loss distance (ignoring rotation): 0.287
Evaluation score: 7.734

Delft - 10 km


camouflage [39.1%]
peas [22.3%]
other
garden [7.3%]
Route length: 10.5 km
Relative total metric value: 3.93403
Perception loss distance: 0.541
Perception loss distance (ignoring rotation): 0.498
Evaluation score: 8.592
ant [58.8%]
grapes [9.3%]
other
camouflage [6%]
Route length: 10.4 km
Relative total metric value: 3.61471
Perception loss distance: 0.548
Perception loss distance (ignoring rotation): 0.534
Evaluation score: 7.81
cactus [97%]
other
hand [0.9%]
Route length: 9.9 km
Relative total metric value: 3.0343
Perception loss distance: 0.318
Perception loss distance (ignoring rotation): 0.318
Evaluation score: 4.842

Test results

- Overall average route length difference: **1.7%**
- Different metrics capture distinct characteristics

city	RTMV (geometric error)	perceptual distance	accurate labels [%]	label certainty[%]
Tokyo	1.23	0.3	89	72
Paris	1.68	0.37	33	81
New York	1.16	0.33	44	73
Delft	4.77	0.4	33	62
Amsterdam	3.96	0.34	78	61

Summary of results. Metric values are average per city

Test results

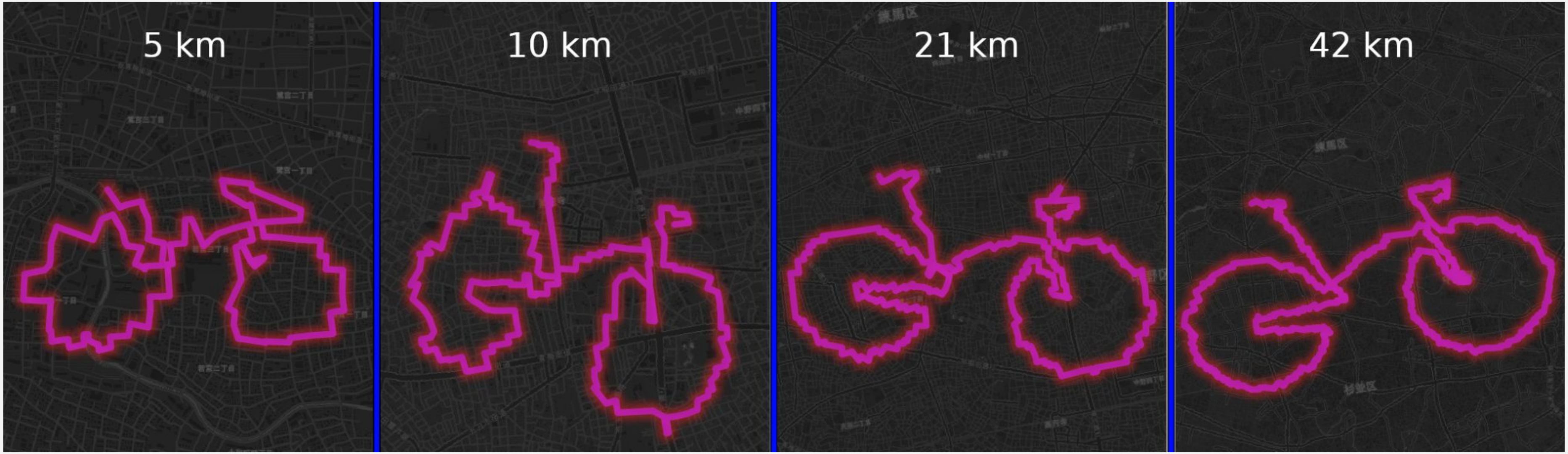
desired length [km]	RTMV	perceptual distance	accurate labels [%]	label certainty[%]
10	2.23	0.41	20	35
21	2.45	0.32	60	66
42	3	0.31	87	79

Summary of results. Metric values are average per desired route length

desired length [km]	RTMV	perceptual distance	accurate labels [%]	label certainty[%]
10	1.34	0.4	13	38
21	1.32	0.32	27	76
42	1.41	0.28	60	81

Summary of results, without the Dutch cities (Delft, Amsterdam)

Tokyo - 4 different scales



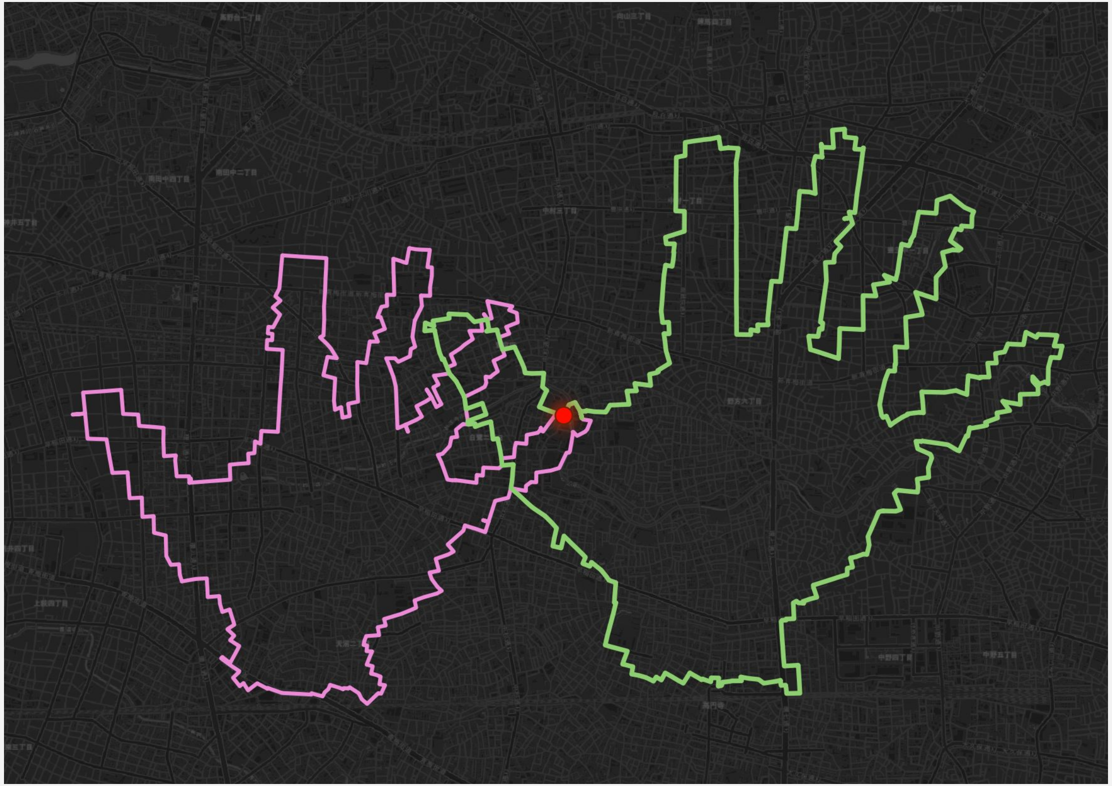
Automatic workflow vs interactive app

- Efficiency
- Number of explored options
- Quality evaluation method
- Dealing with difficult cases

Example result achieved in the interactive application

Advantages

- Evaluation framework is well integrated
- Extra requirements (route length, starting point)
- Template matching for initial placement
- Postprocessing improves quality



Two different candidate routes which both satisfy the starting point (red dot) requirement.

Limitations

- Input data requirements (single connected component)
- Efficiency
- Street network layout/density
- User requirements (short routes)
- How do we know if we obtained the best solution?

An artistic route result for desired length below 8 kilometers.

Conclusions

- Automatic generation (single-stroke drawings)
- Automatic quality evaluation
- Recommendations
    - Longer routes are better
    - Dense urban networks preferred
- Future work, points to improve
    - smart way to preserve semantic meaning
    - improve performance by using more advanced methods for image matching

Tools and datasets

- Datasets
  - OSM (https://www.openstreetmap.org/)
  - Urban Road Network data (https://figshare.com/articles/dataset/Urban_Road_Network_Data/2061897)
- Software tools:
  - Routing algorithm - C++ (Boost, CGAL, CROW)
  - Postprocessing, filtering, evaluation - Python (Pandas, Tensorflow)
  - Visualizations - QGIS
  - Interactive app - Javascript (Leaflet)

References

- Balduz, P. (2017). Walk line drawing.
- Bradski, G. (2000). The OpenCV Library. Dr. Dobb's Journal of Software Tools.
- Brunelli, R. (2008). Template matching techniques in computer vision: Theory and practice.
- Igarashi, T., Moscovich, T., and Hughes, J. F. (2005). As-rigid-as-possible shape manipulation. ACM Trans. Graph., 24(3):1134–1141.
- Networks, U. R. (2016). Urban road network data. https://figshare.com/articles/dataset/Urban_Road_Network_Data/2061897.
- Rachmawati, D. and Gustin, L. (2020). Analysis of dijkstra's algorithm and a* algorithm in
- shortest path problem. Journal of Physics: Conference Series, 1566(1):012061.
- Santoso, L. W., Setiawan, A., and Prajogo, A. K. (2010). Performance analysis of dijkstra, a* and ant algorithm for finding optimal path case study : Surabaya city map.
- Waschk, A. and Kr ¨uger, J. (2018). Automatic route planning for gps art generation. In SIG-GRAPH Asia 2018 Technical Briefs, SA '18, New York, NY, USA. Association for Computing Machinery.
- Wiki, O. (2022). About — openstreetmap wiki,. https://wiki.openstreetmap.org/w/index.php?title=About&oldid=2368272. [Online; accessed 15-January-2023].
- Zhang, L. (2021). Hand-drawn sketch recognition with a double-channel convolutional neural network. EURASIP Journal on Advances in Signal Processing, 2021.
- Zhang, R., Isola, P., Efros, A., Shechtman, E., and Wang, O. (2018). The unreasonable effectiveness of deep features as a perceptual metric.

57