A semantic approach to patch-based procedural generation of urban road networks

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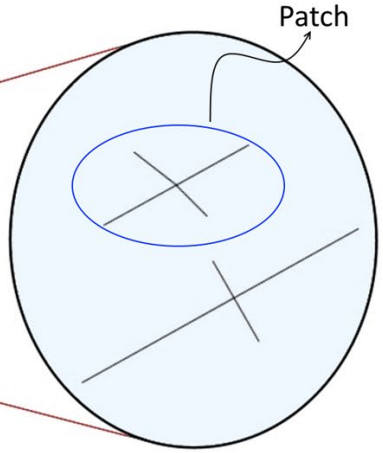
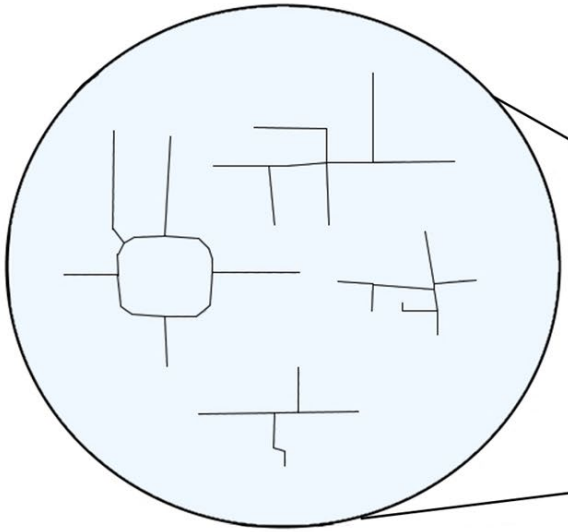
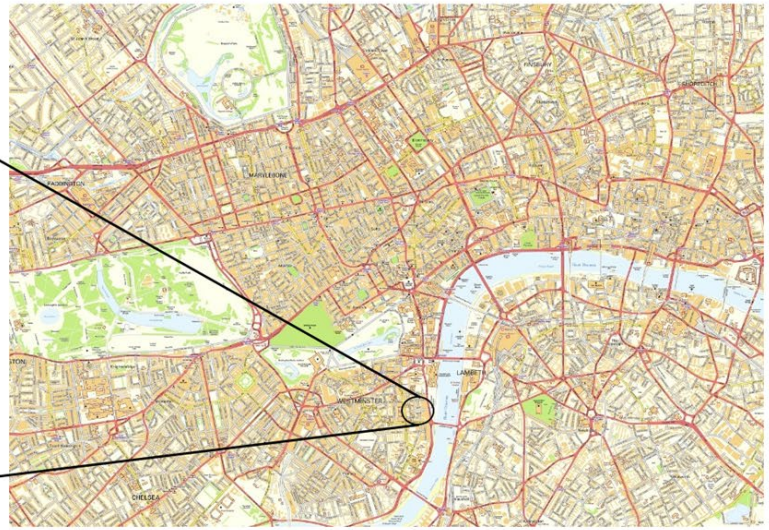
Manhattan



London





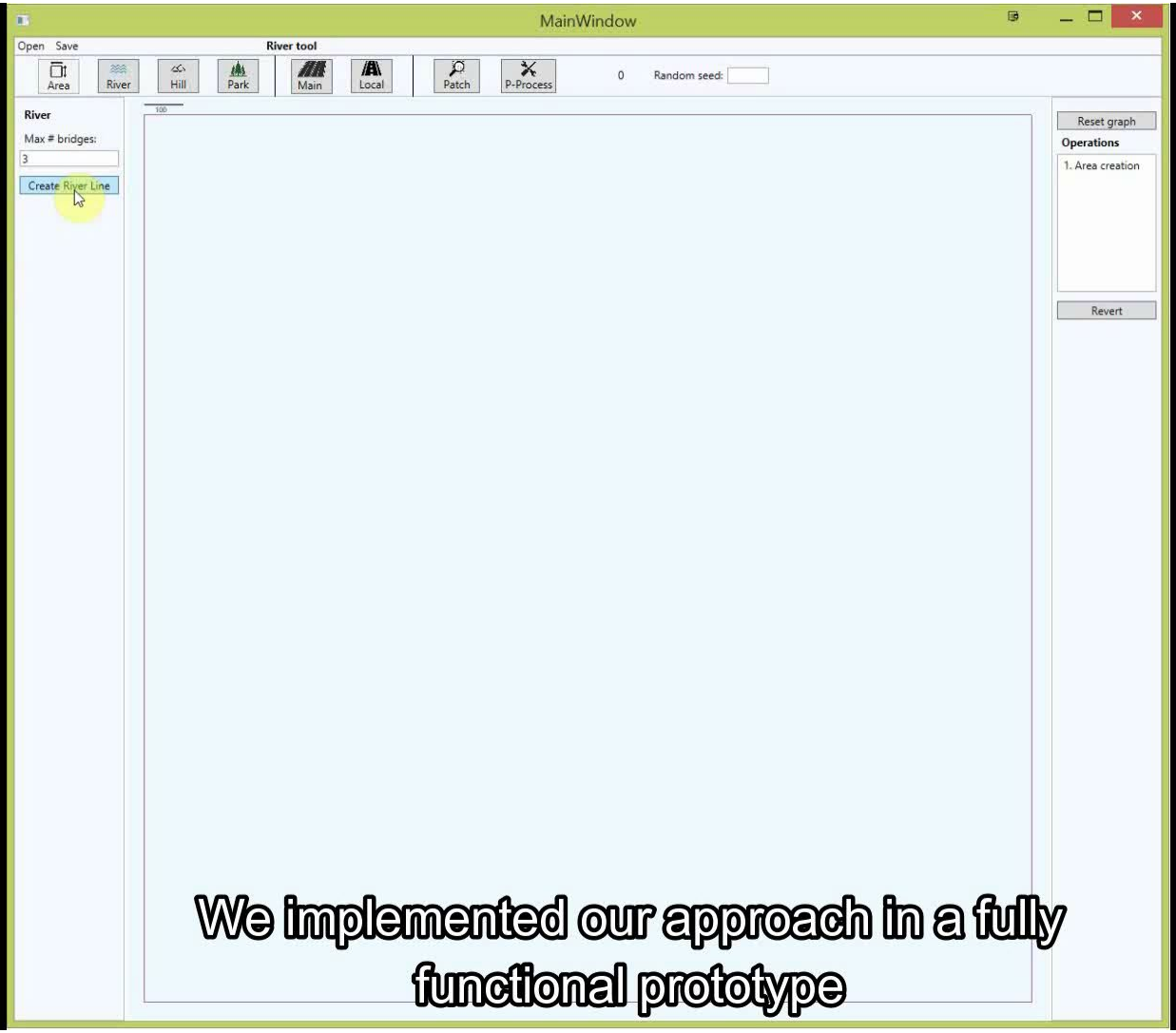
problem statement

- shortcomings of procedural road network generation methods
  - output looks often 'canned'
  - poor and non-intuitive control
  - hard to master for non-experts
- challenges
  - integration of patch-based and parametric-based methods
  - representation and utilization of patch semantics

contributions

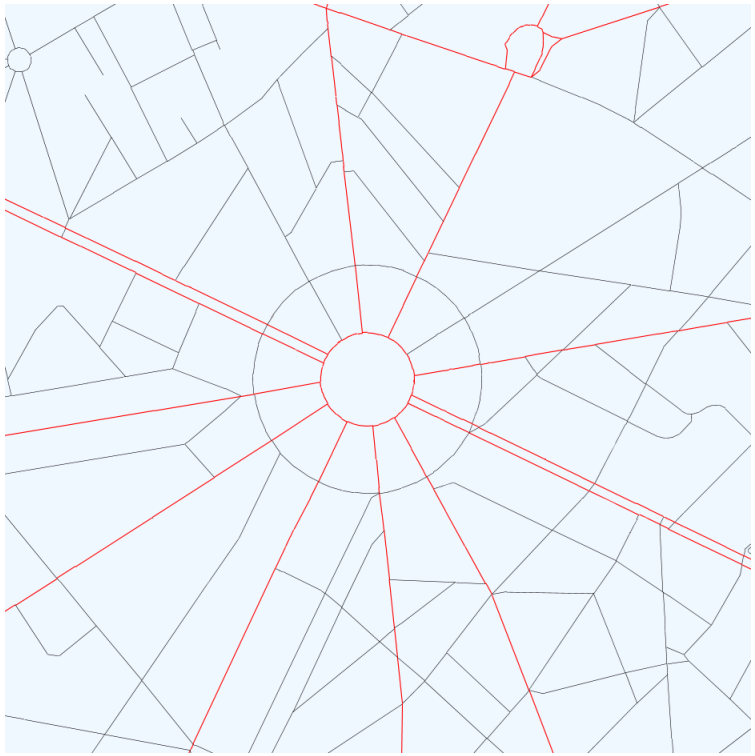
- use of patch semantics to guide the road generation
- intuitive configuration of road generator settings
- high expressive range parametric-based generation method

video


MainWindow
Open Save
River tool
Area
River
Hill
Park
Main
Local
Patch
P-Process
0
Random seed:
River
Max # bridges:
3
Create River Line
Reset graph
Operations
1. Area creation
Revert
We implemented our approach in a fully functional prototype

representation

road network as a geometric graph



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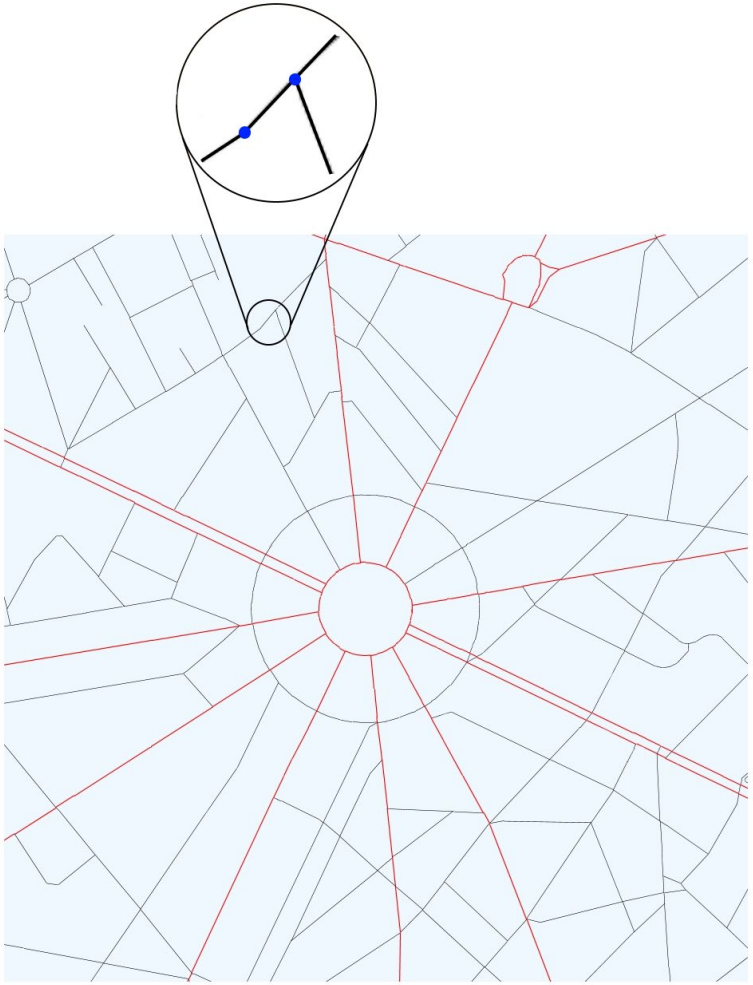

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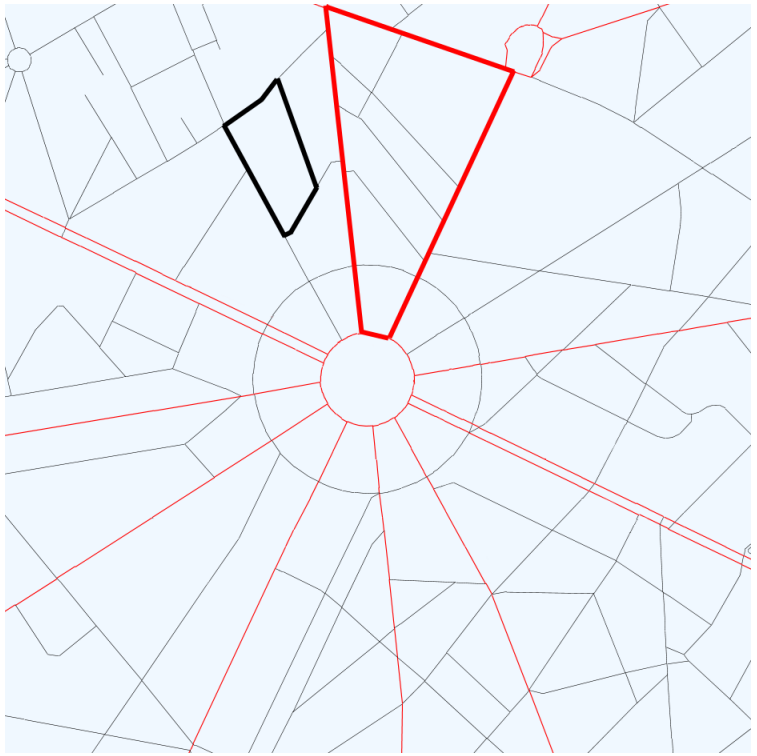
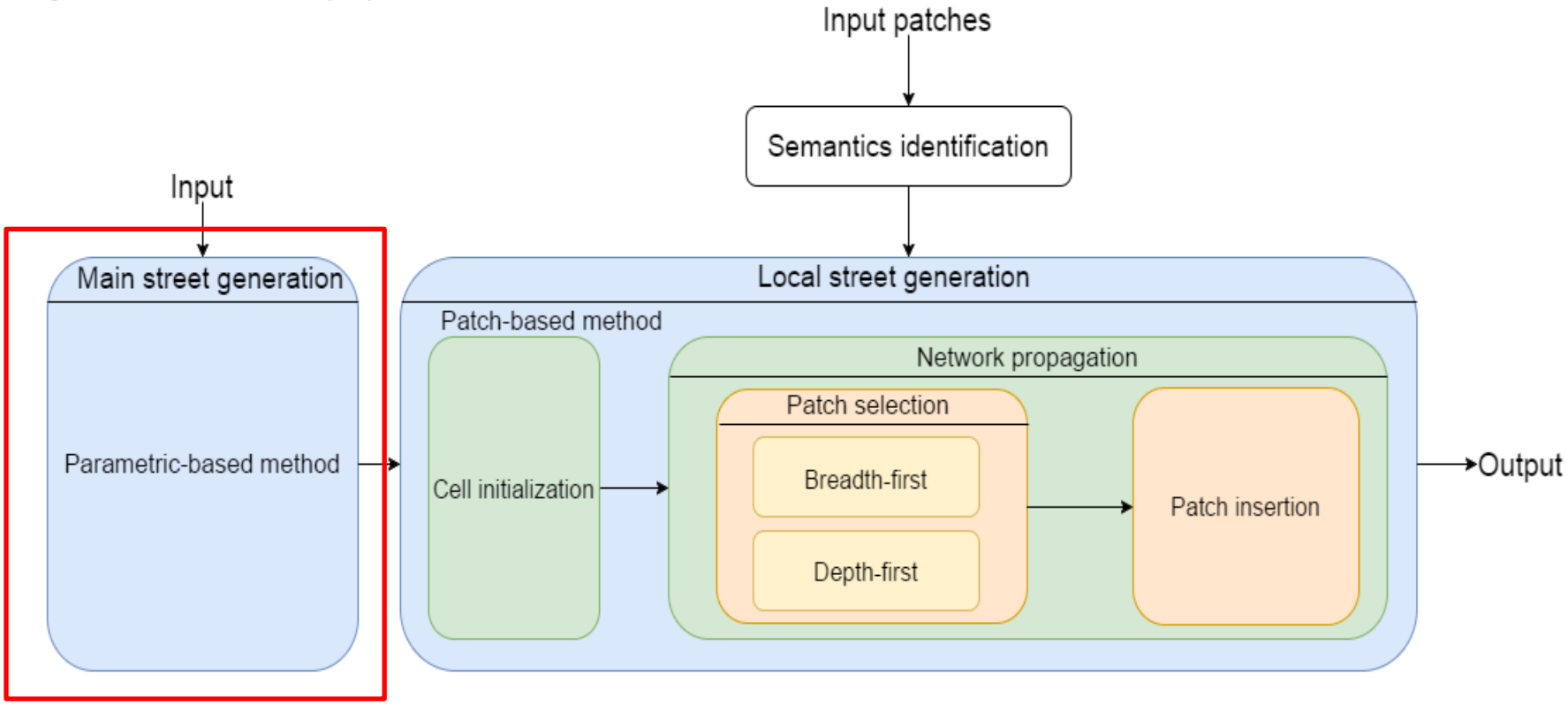
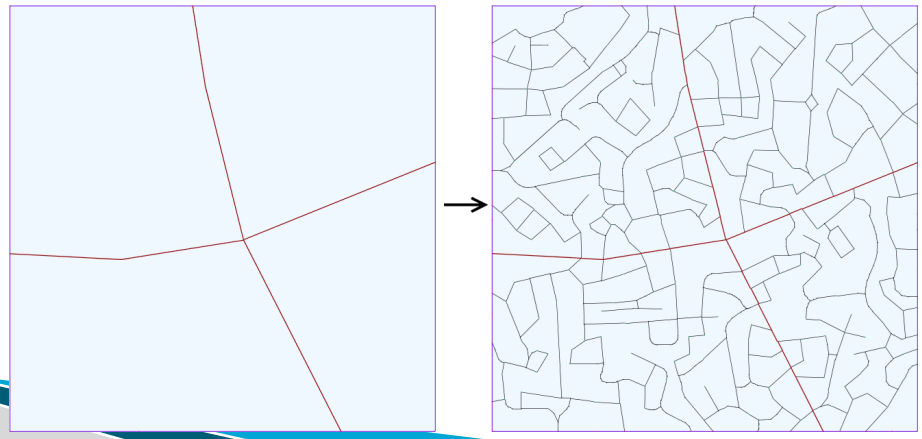


general approach



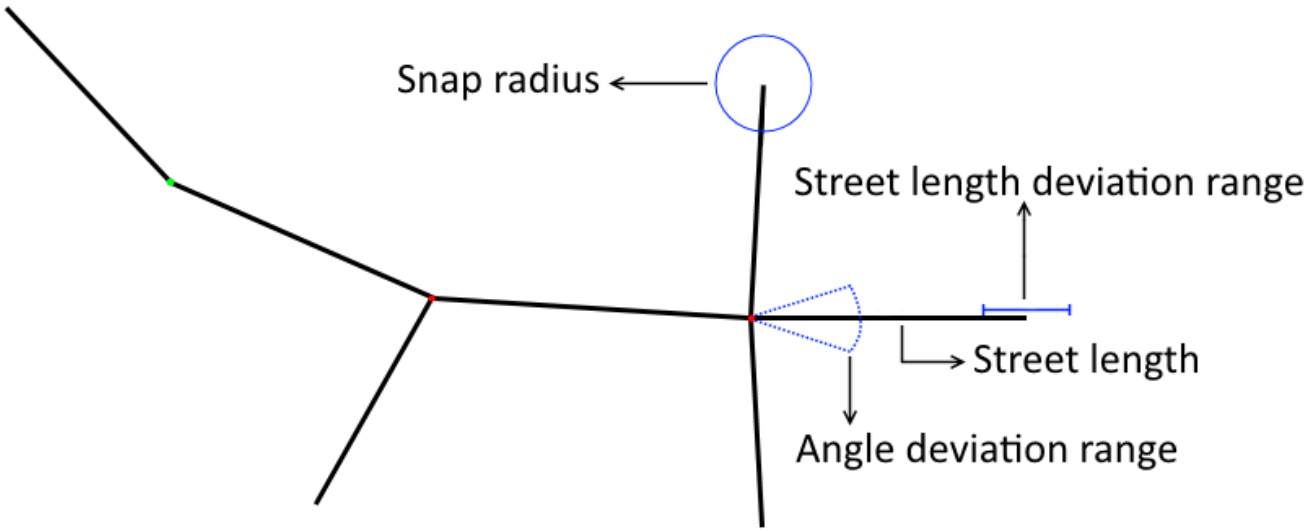


parametric-based method

parameters

- segment length
- segment length deviation range
- minimum street length
- minimum street angle
- vertex degree range
- angle deviation range
- snap radius

presets!



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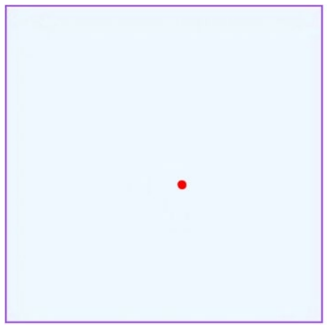

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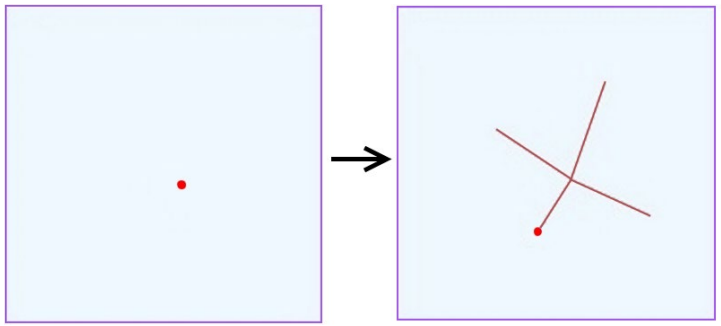

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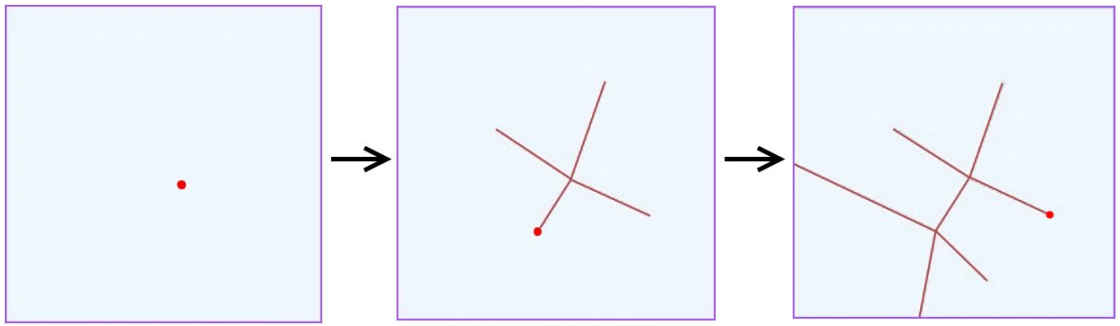

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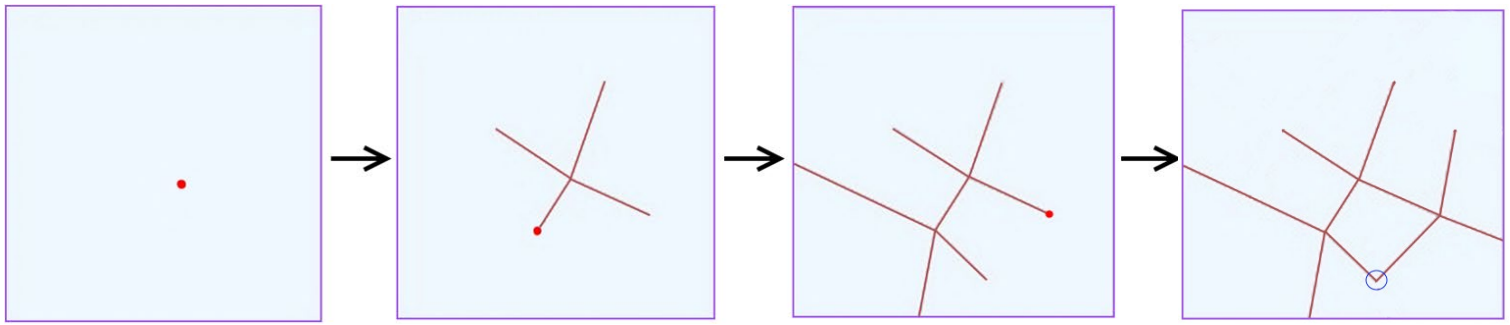

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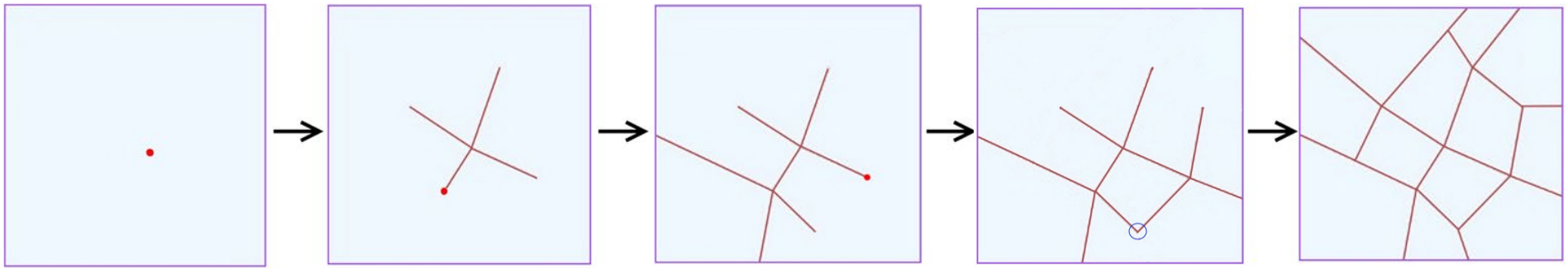
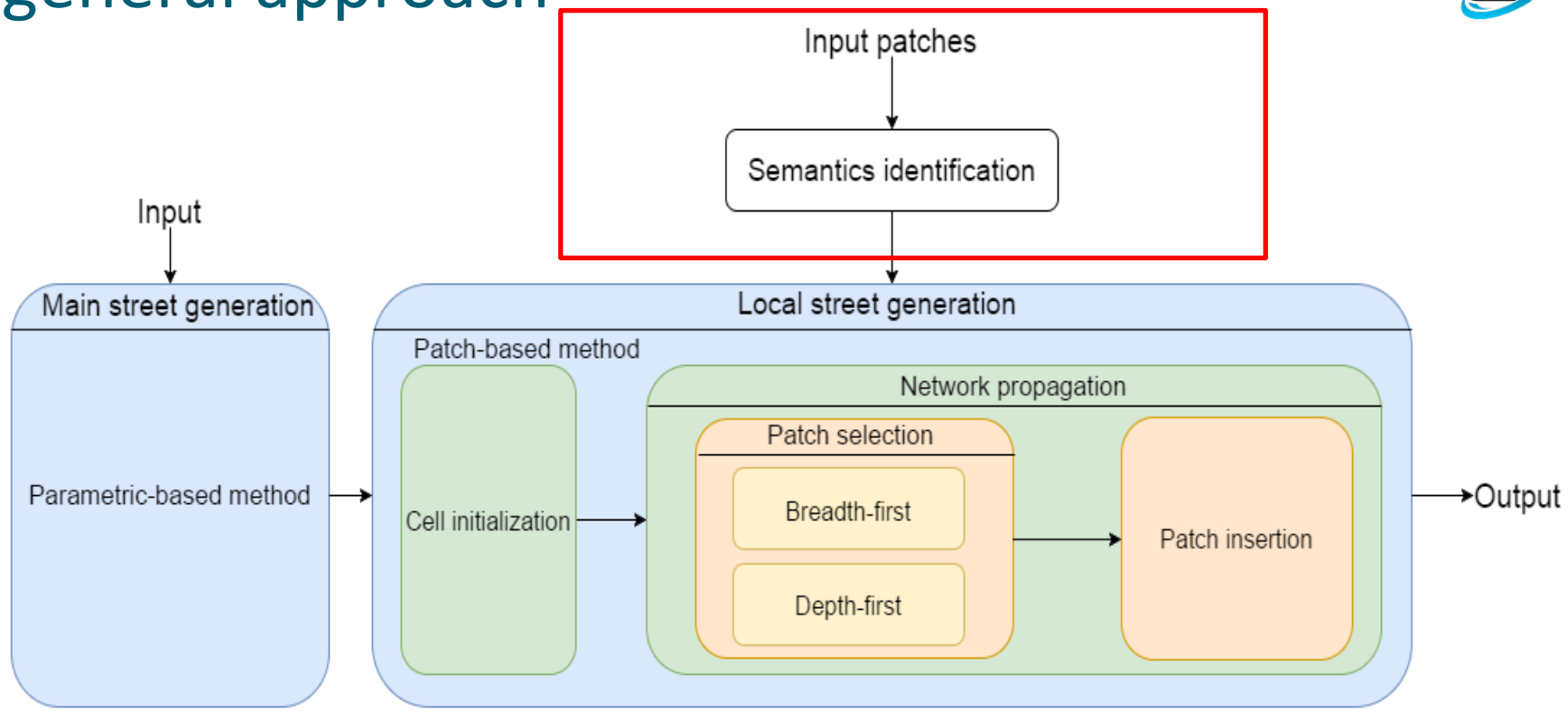
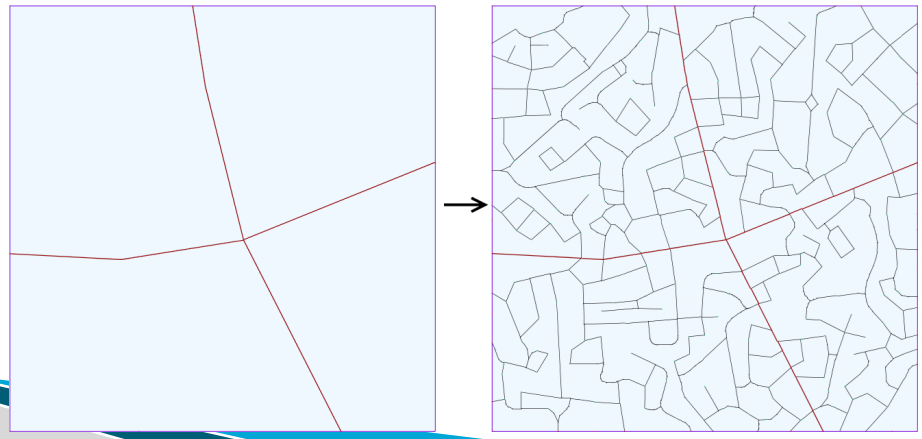


general approach

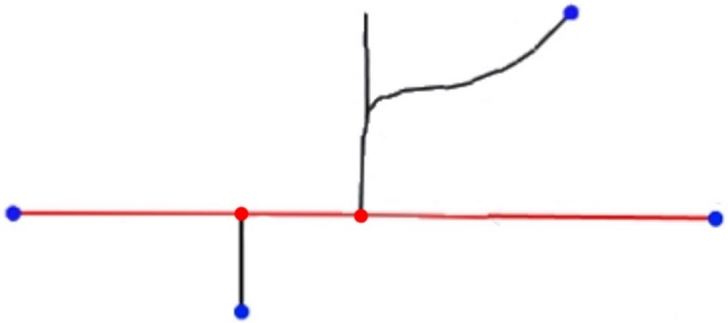




patch-based method - semantic identification

categories

- vertex
- edge
- patch



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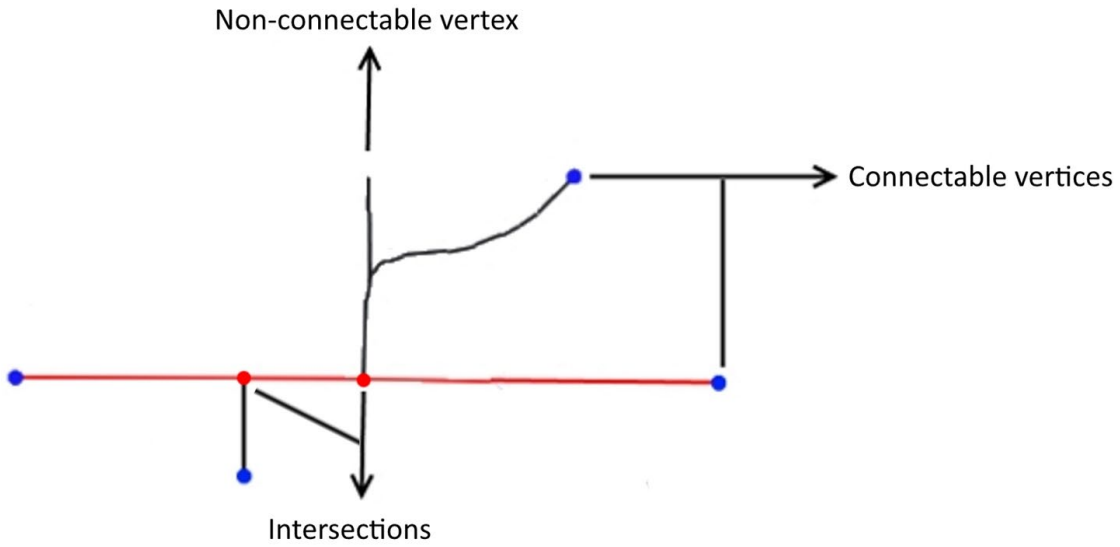

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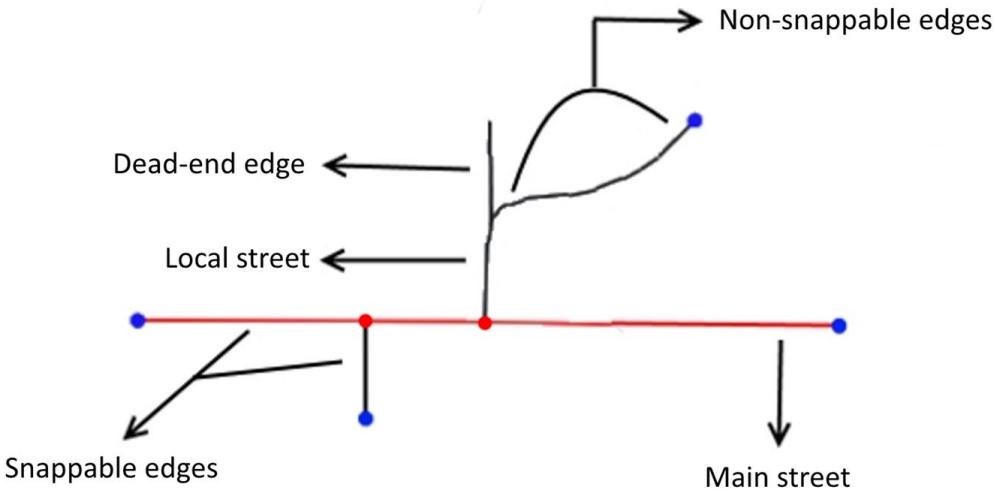

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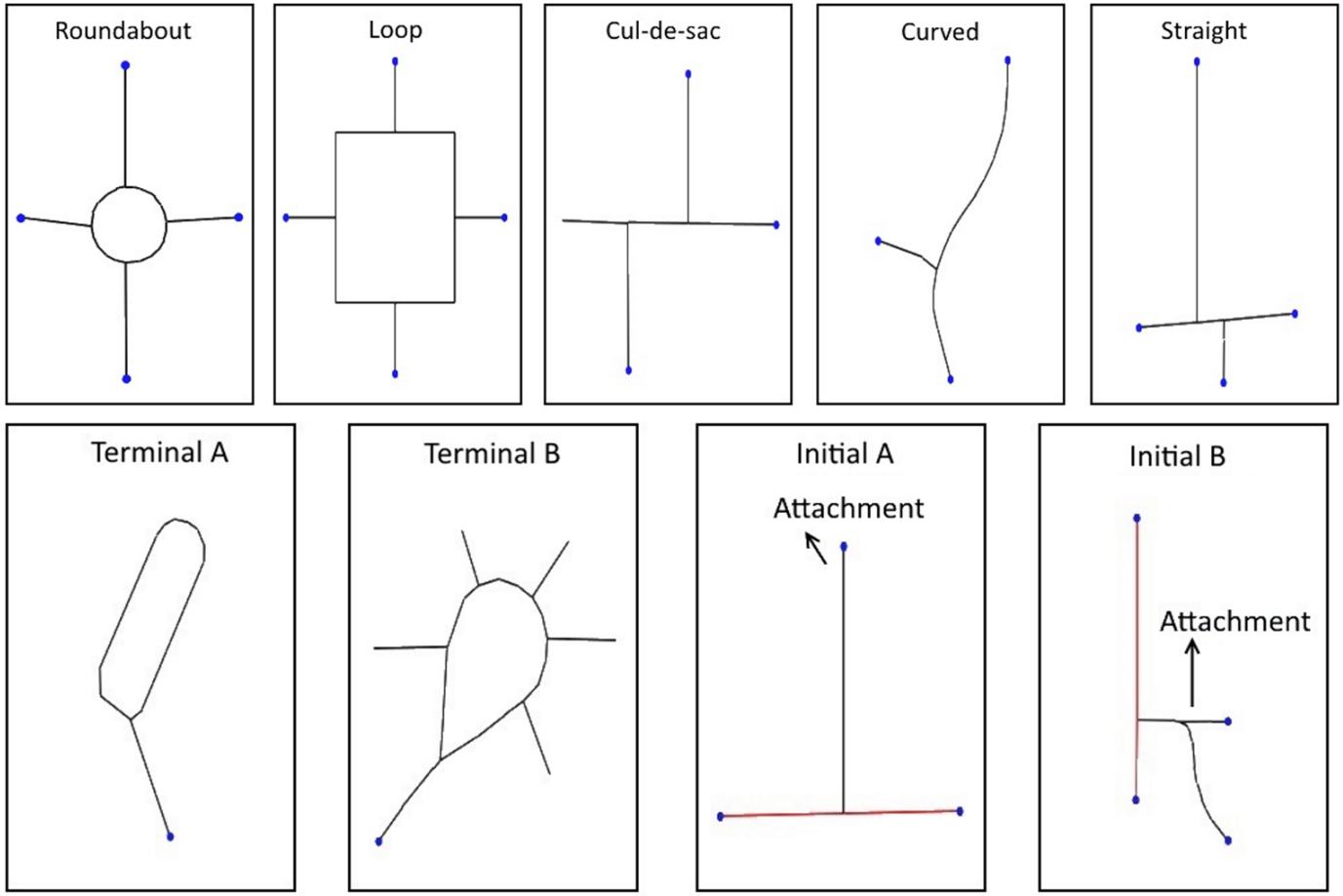
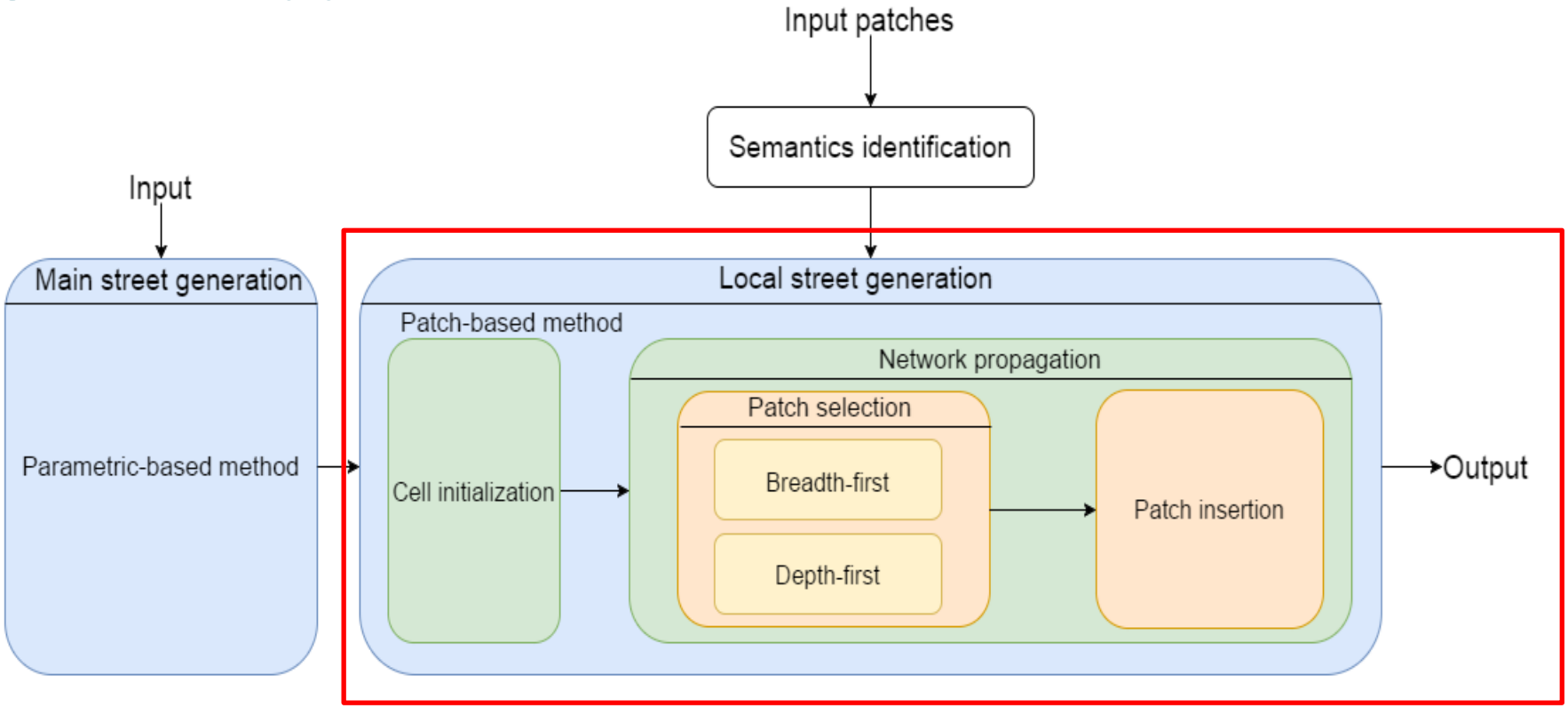
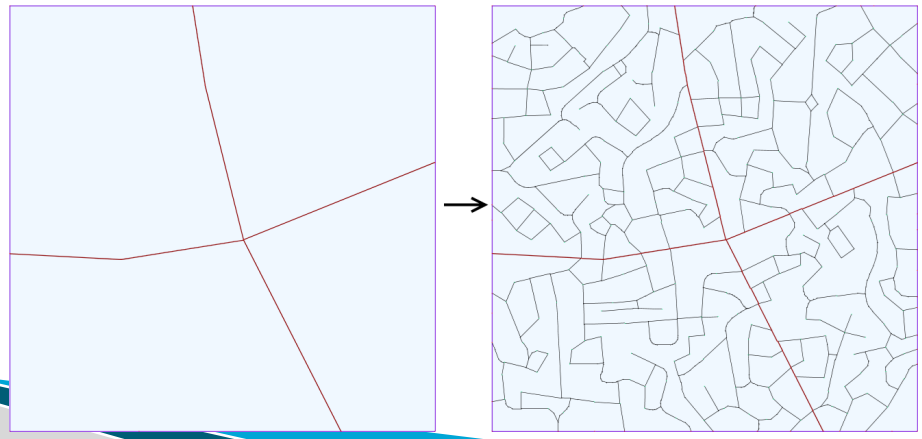
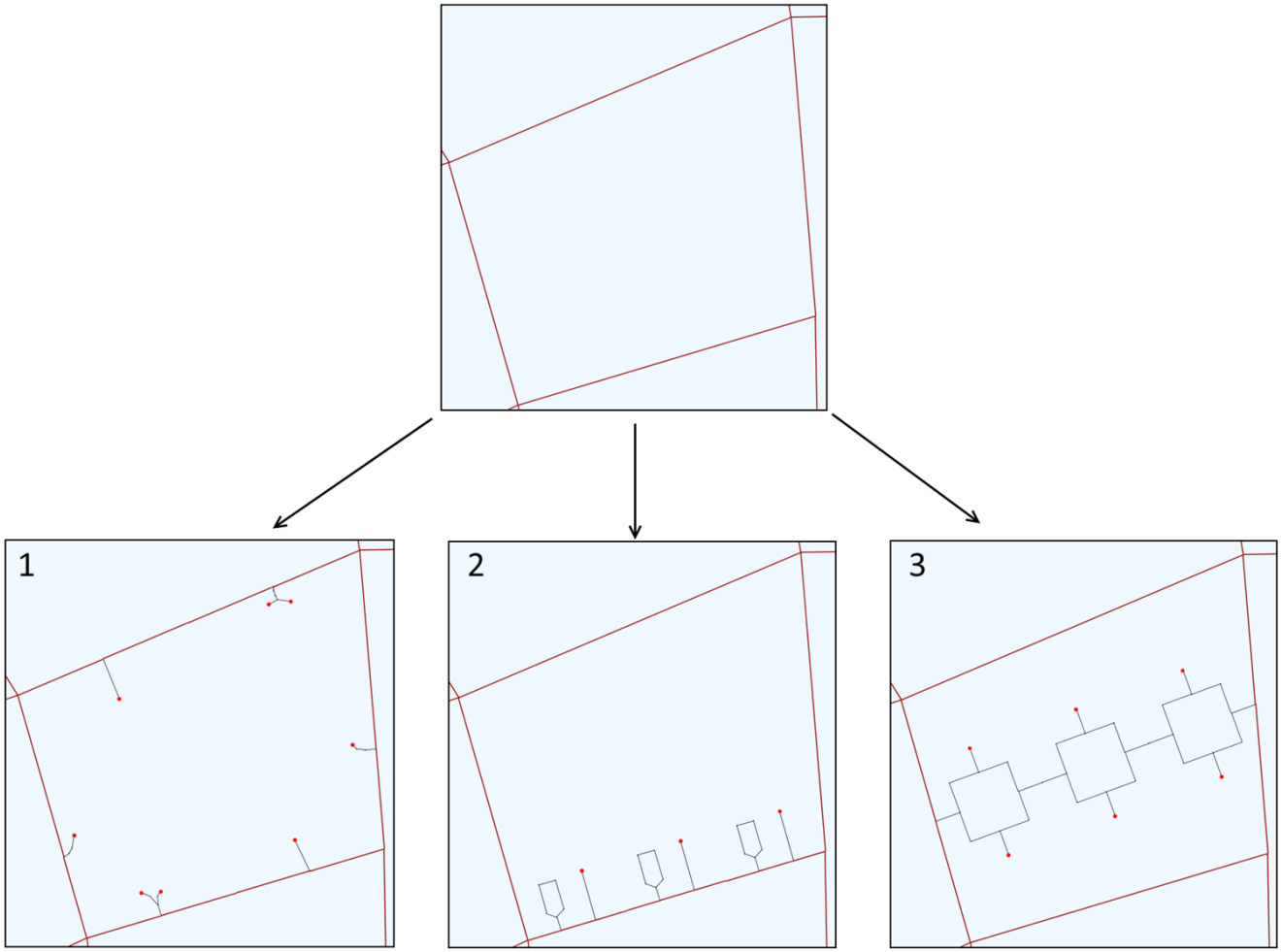


general approach





patch-based method - cell initialization

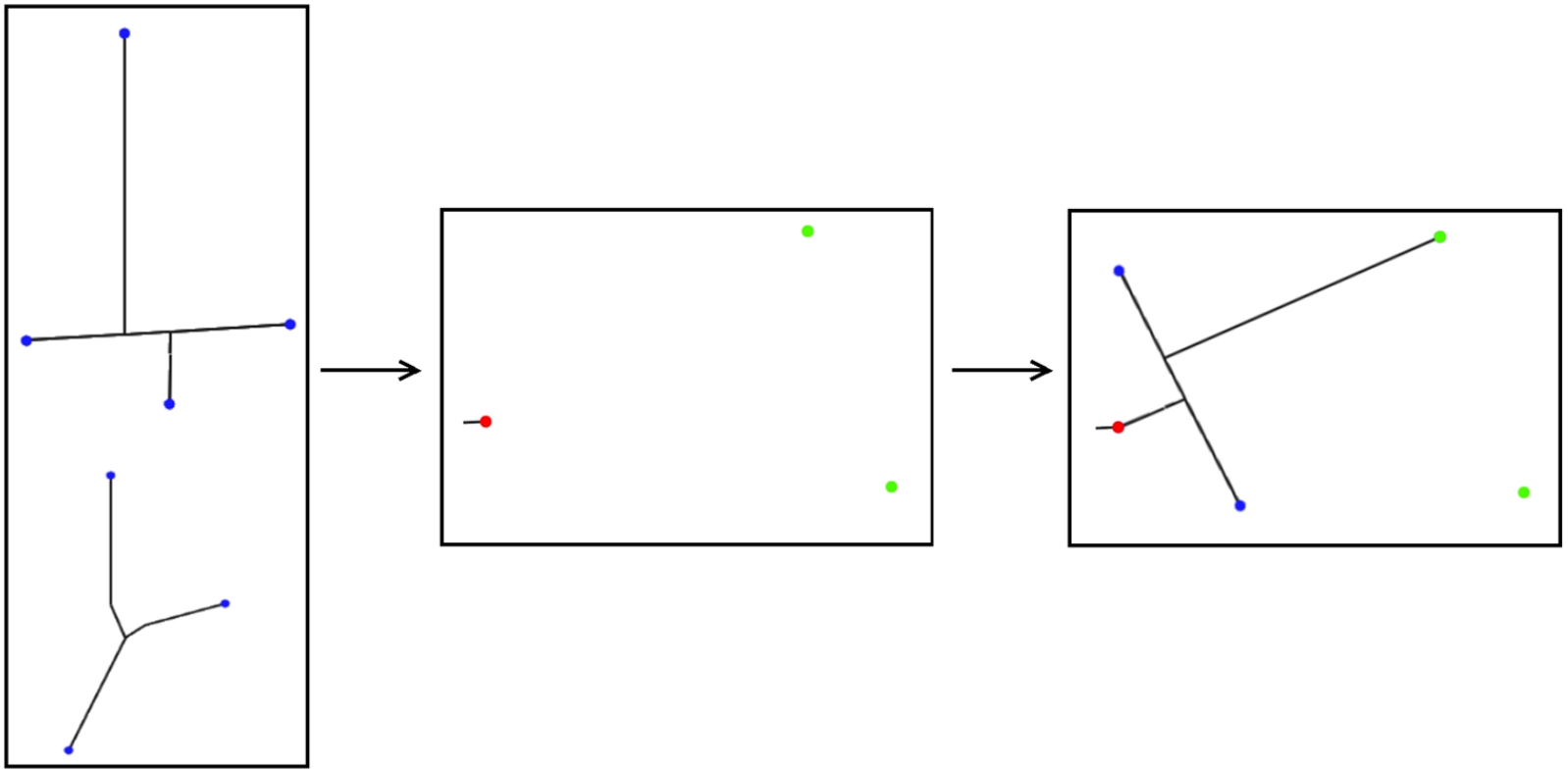


patch-based method - network propagation

Algorithm 1 Network propagation

```
1:  Input: graph, patches, cell
2:  Output: graph
3:  while graph.candidateVertices.Count >0 do
4:      currentVertex ← graph.candidateVertices.pop()
5:      propagationDirection ← calculate the propagation direction for currentVertex
6:      if propagationDirection is valid then
7:          filteredPatches ← filter available patches
8:          if filteredPatches.isEmpty() then
9:              apply parametric-based growth on currentVertex
10:         else
11:             suitablePatch ← apply Breadth-First to find a suitable patch
12:             if suitablePatch == null then
13:                 suitablePatch ← apply Depth-First to find a suitable patch
14:             if suitablePatch != null then
15:                 attach suitablePatch on currentVertex
16:             else
17:                 apply parameteric-based growth on currentVertex
```

network propagation - breadth-first



network propagation - breadth-first

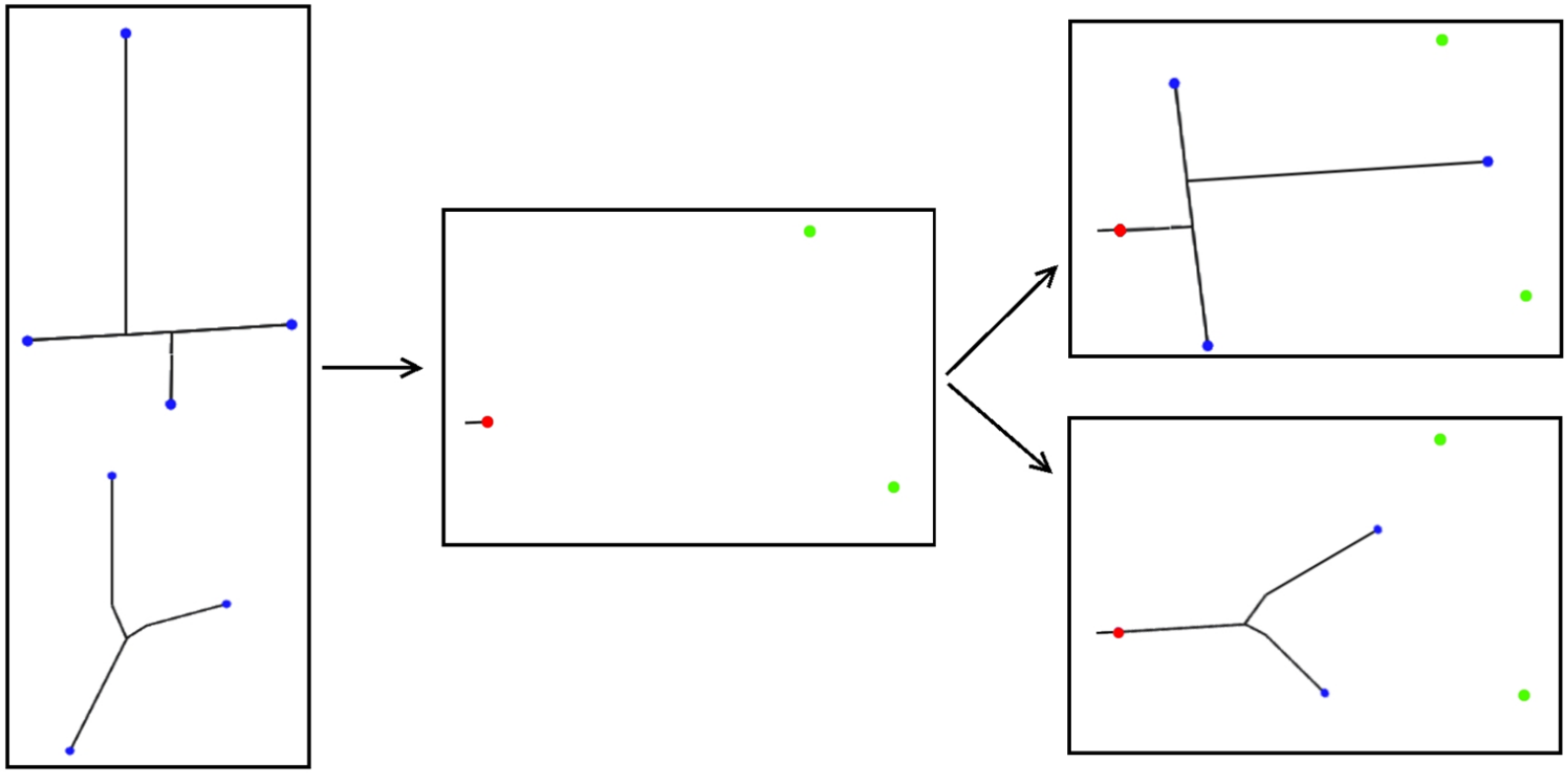
rating formula:

$$1 - \frac{|distancePatchPair - distanceGraphPair|}{distanceGraphPair}$$

patch fitting:

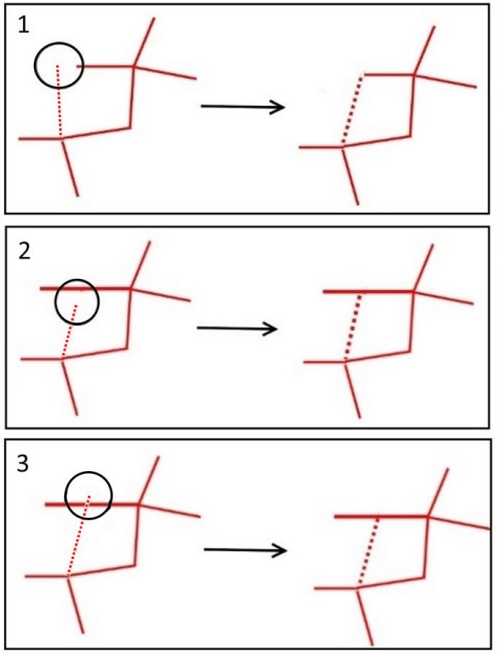
- extend or shorten an edge
- calculate the rotation

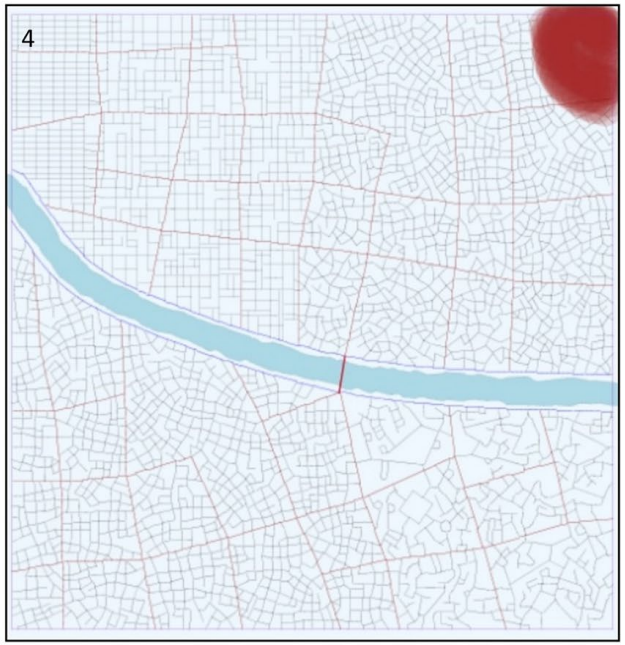
network propagation - depth-first



method - adaptation

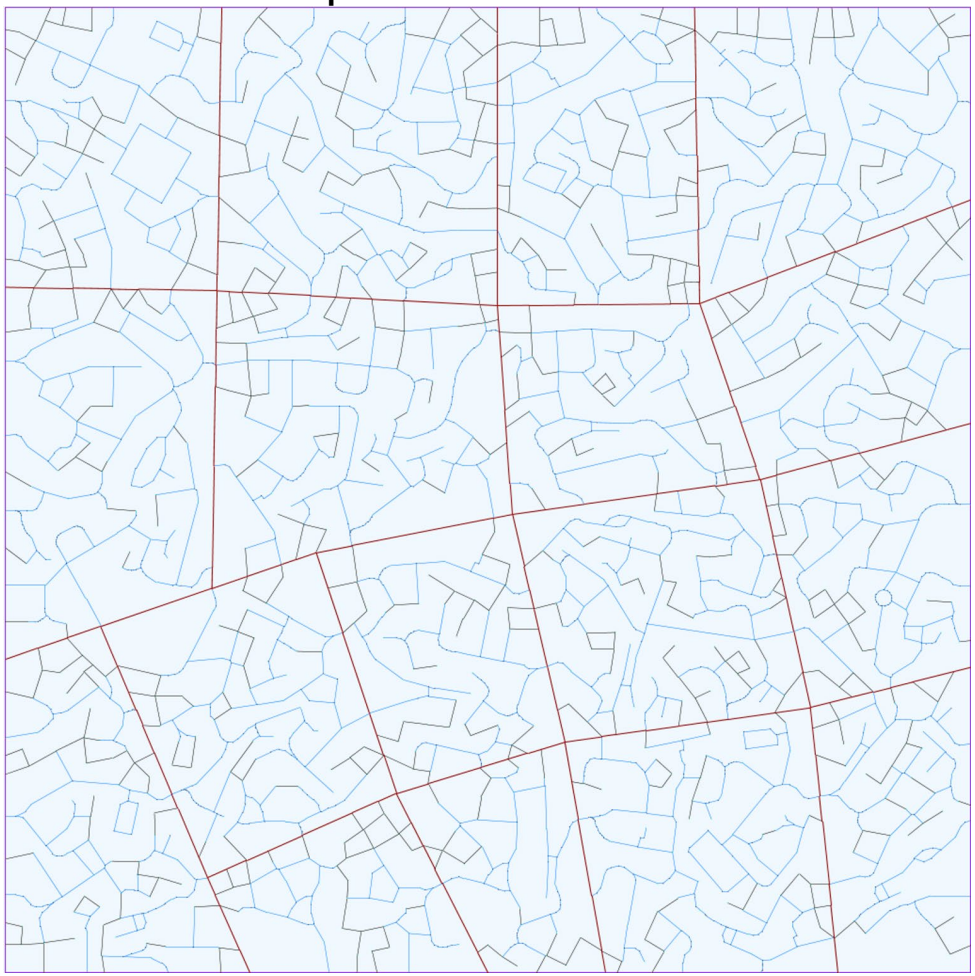
- **connect** road segment to nearby vertex (1) /edge (2). Discard:
  - angle lower than minimum angle
  - length road segment lower than minimum length
  - maximum vertex degree reached
- **clip** intersecting road segments (3)
- **create** bridge to cross river (4)
- **discard** steep road segment (4)





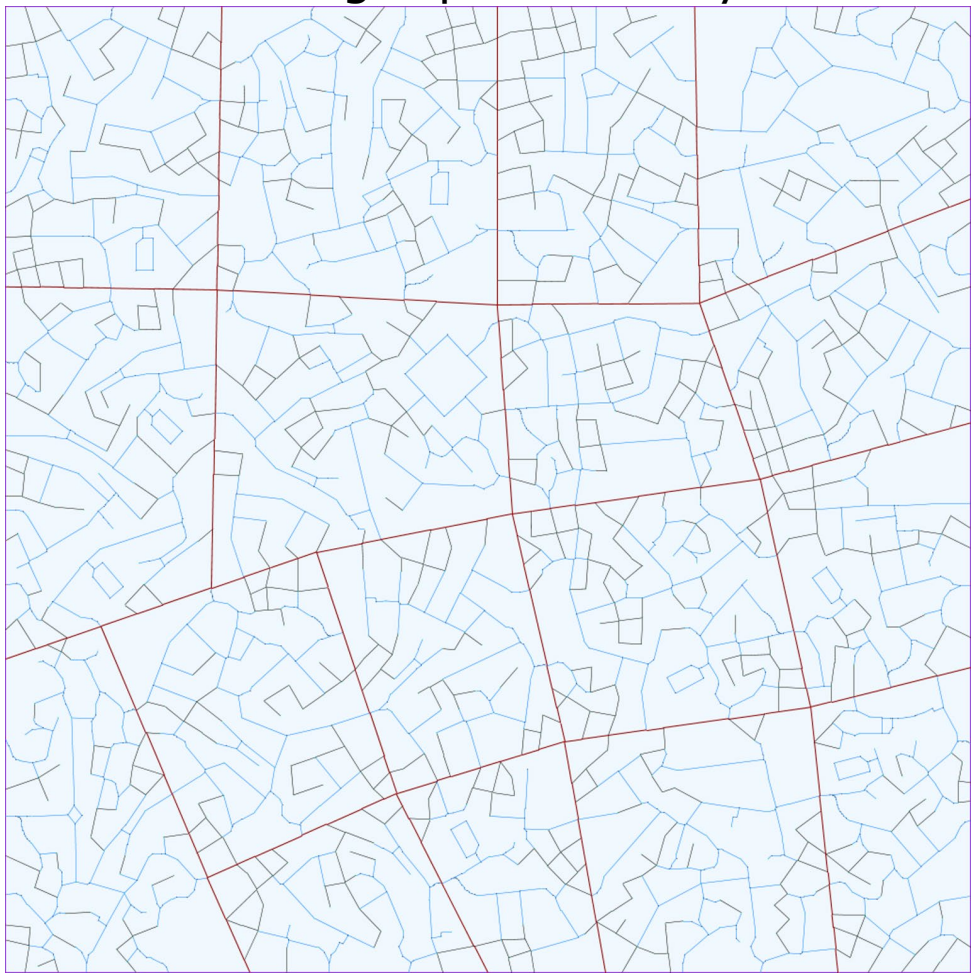
results - patch-based method

All patches included



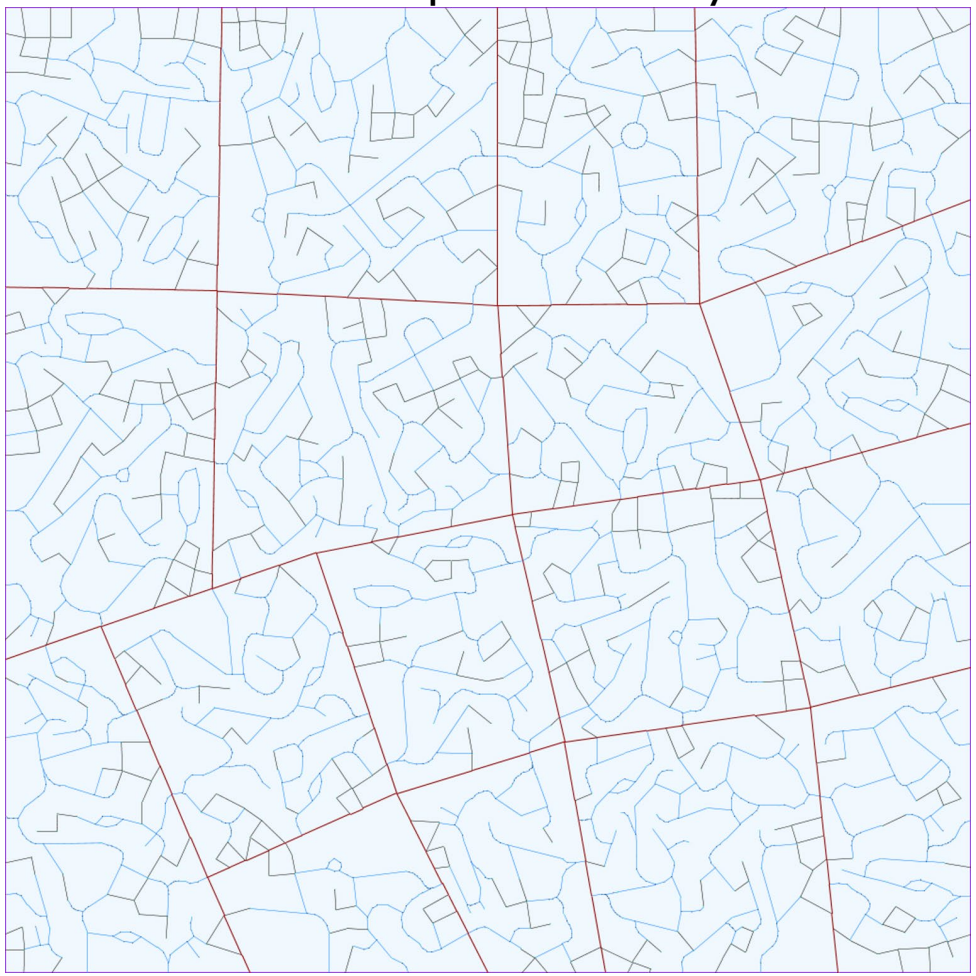
results - patch-based method

straight patches only



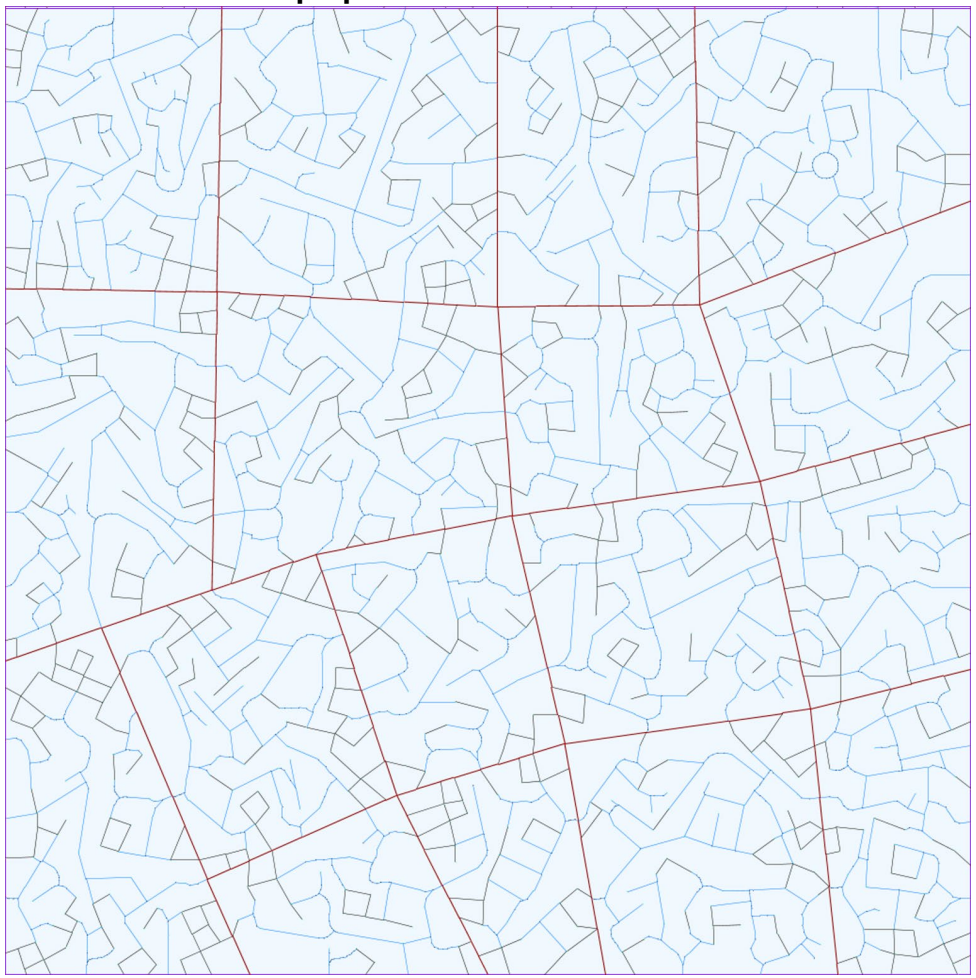
results - patch-based method

curved patches only



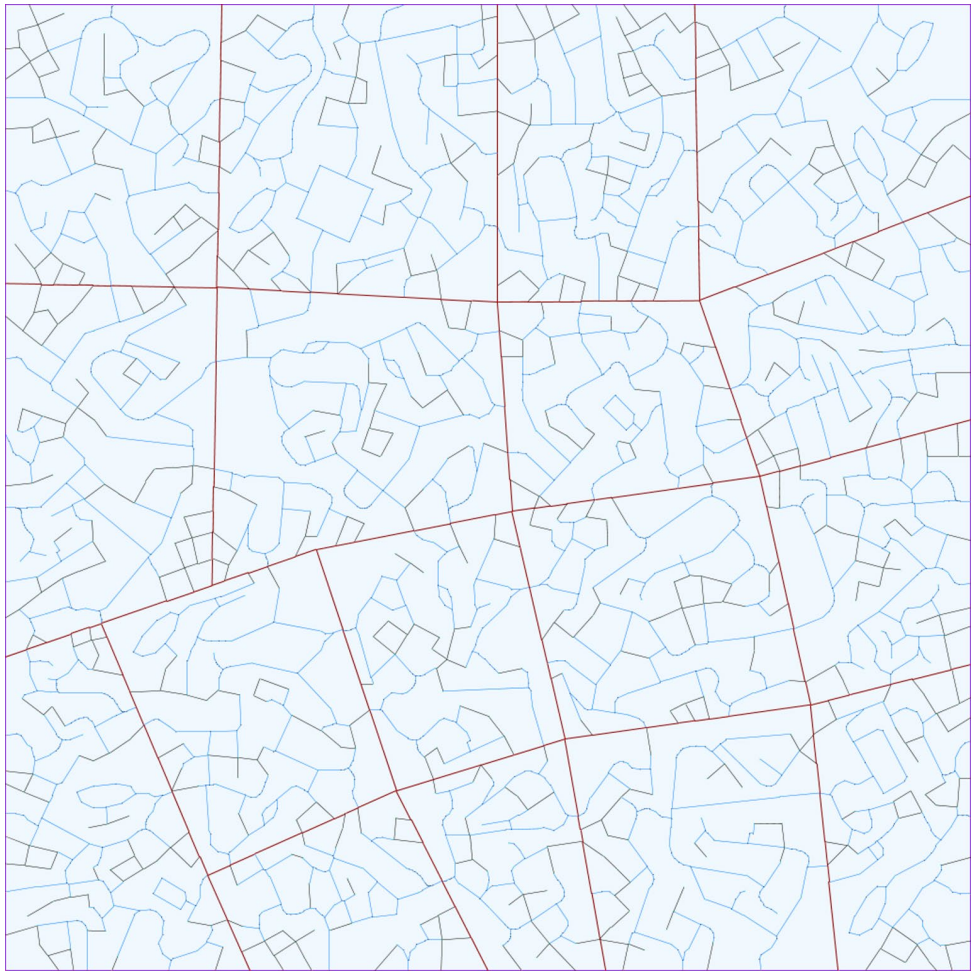
results - patch-based method

loop patches excluded



results - patch-based method

cul-de-sac patches excluded



results - patch-based method

results:

Tags exclusion	P. available	P. total used	P. unique used	Time
None	98	381	58	25
Curved	39	354	29	13
Straight	59	335	38	16
Loop	75	362	44	21
Cul-de-sac	84	345	52	22

findings:

- differences in generation time
- #unique patches used significantly lower than #available patches

results - analysis parametric-based method

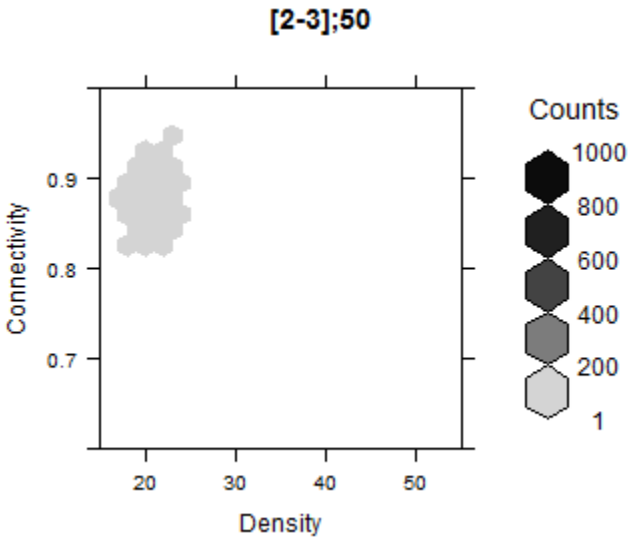
expressive range

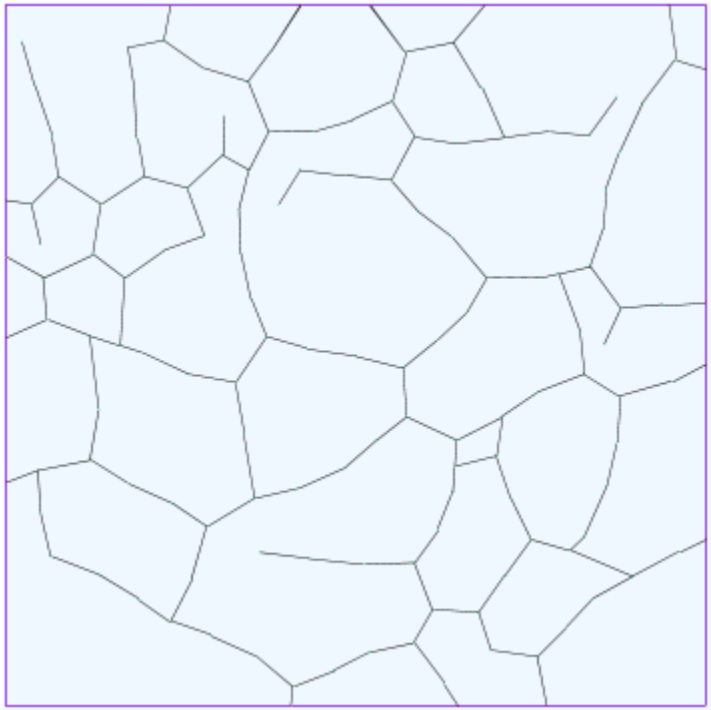
- **street connectivity** and **street density** as metrics
  - Connected Node Ratio: $\frac{\#intersections}{\#intersections + \#deadends}$
  - Total street length per area unit

- variations on **minimum street angle** and **vertex degree range**
- all other parameters fixed:
  - segment length (50m)
  - segment length deviation range (10m)
  - minimum street length (20m)
  - street angle deviation range (10%)
  - snap radius (20m)

- hexagonal bin plots to visualize
  - connectivity ranging between 0.6 and 1
  - density ranging between 15 and 55

results - parametric-based method





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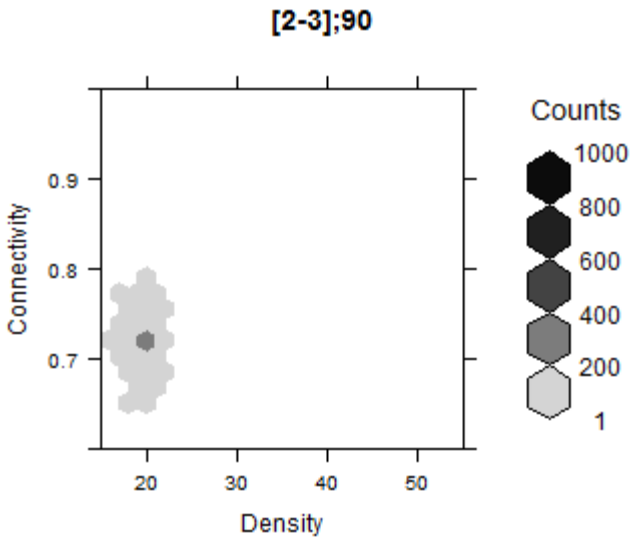

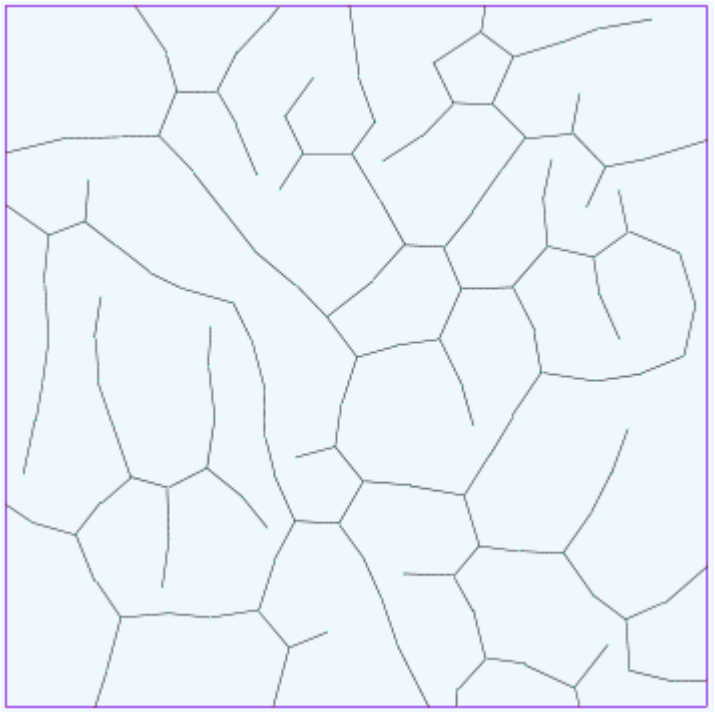

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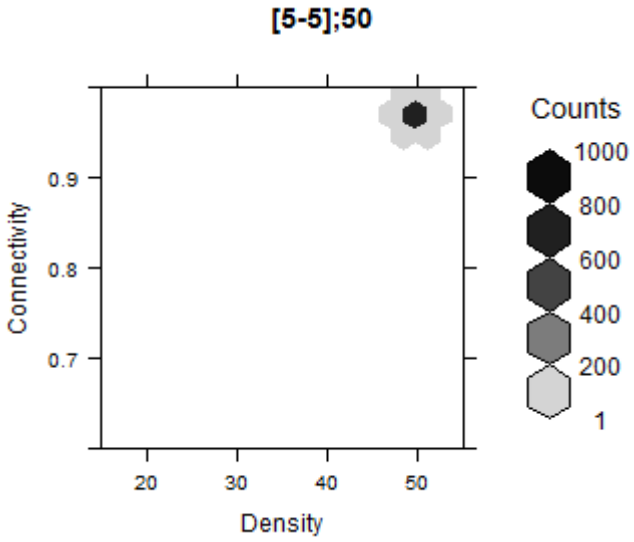

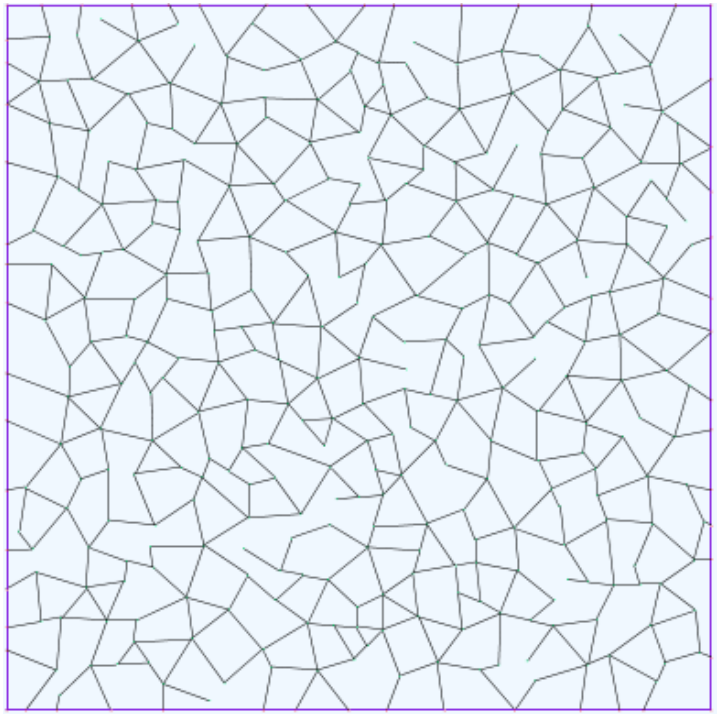

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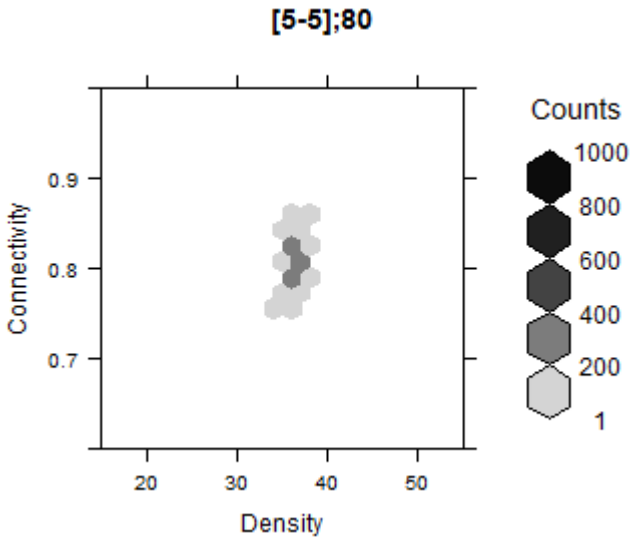

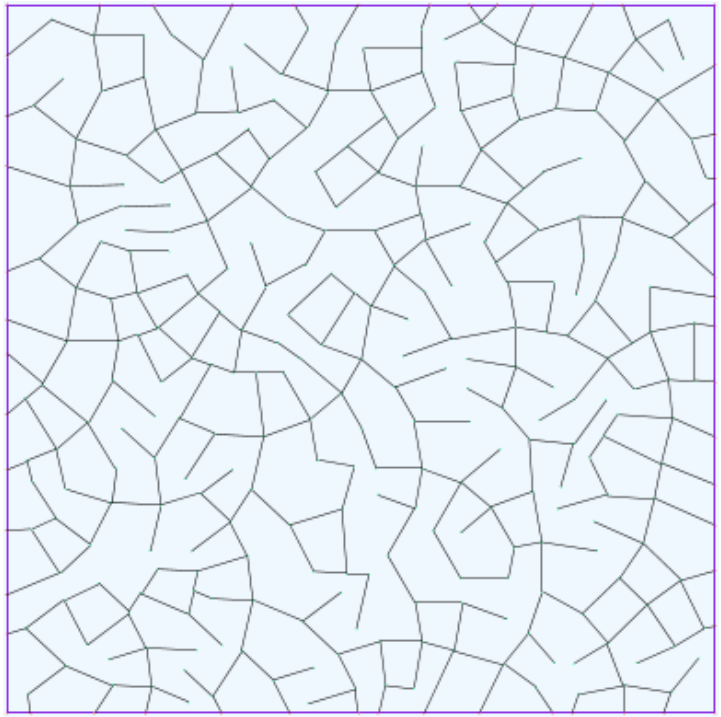

results - parametric-based method

- high connectivity and density -> high vertex degree range and low minimum angle
- high connectivity and low density -> low vertex degree range and low minimum angle
- low connectivity and density -> low vertex degree range and high minimum angle

- low connectivity and high density not covered
- conclusion: wide expressive range

conclusion

novel road network generation

- use of patch semantics to help guiding patch-based road network generation
- controllable parametric-based road generation with a broad expressive range
- integration of patch-based and parametric-based methods
- high level settings scheme that allows non-experts to easily create and modify road networks

future work

- use patterns during propagation
- patch selection to connect more than two vertices
- expressive range analysis for the patch-based generator