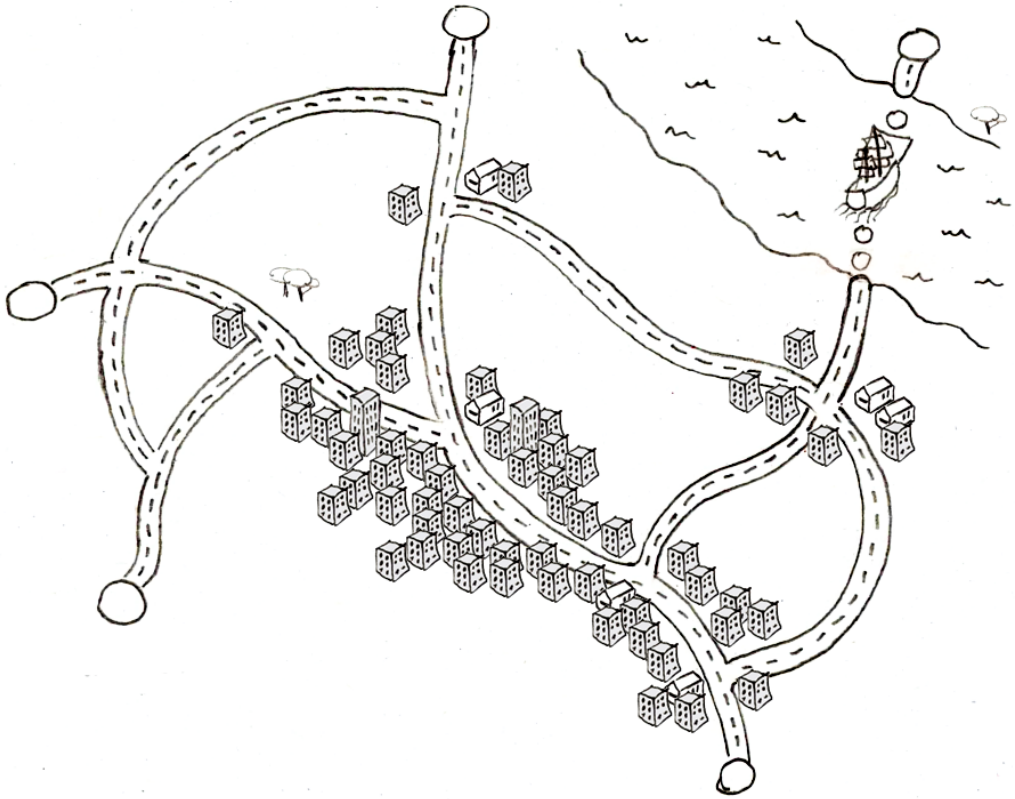
Procedural Modelling of Urban Road Networks

Jan Beneš, Alexander Wilkie, Jaroslav Křivánek

Computer Graphics Group at
Charles University in Prague

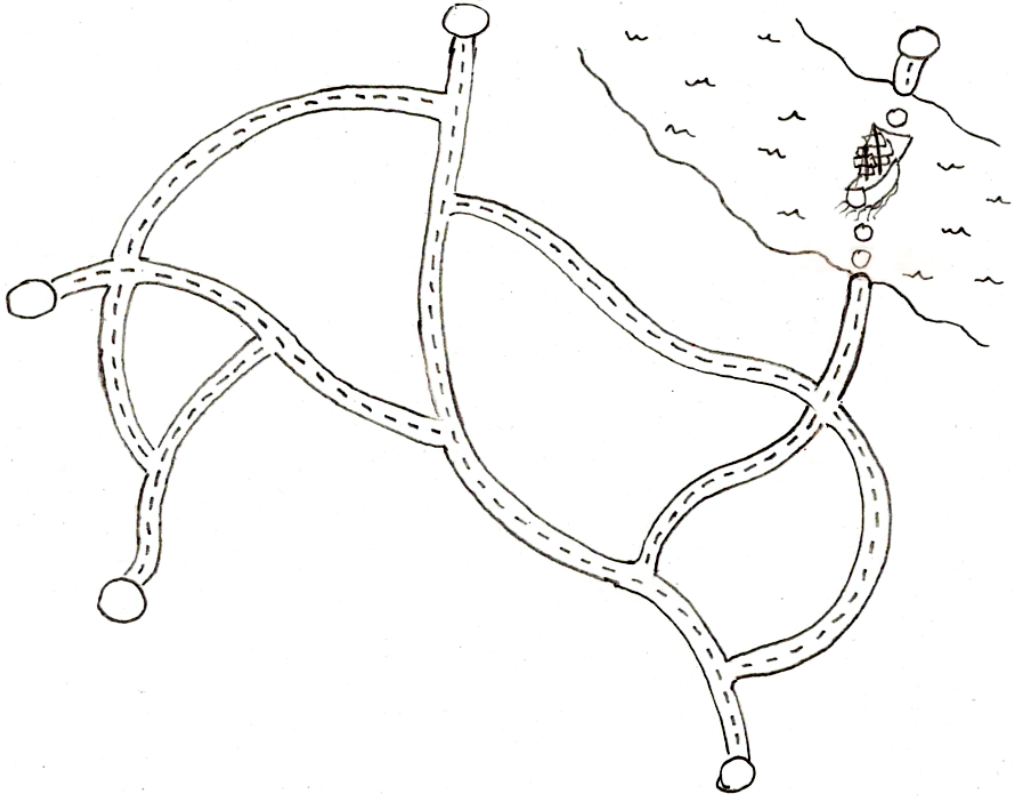
Context

- Growing Cities

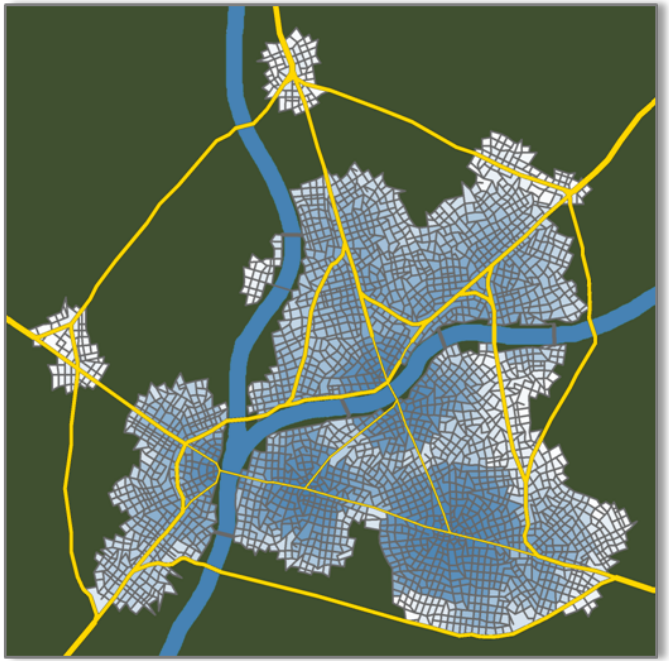


Context

- Growing Cities
- Really mean roads
- Even if we say cities



Cities with a realistic structure

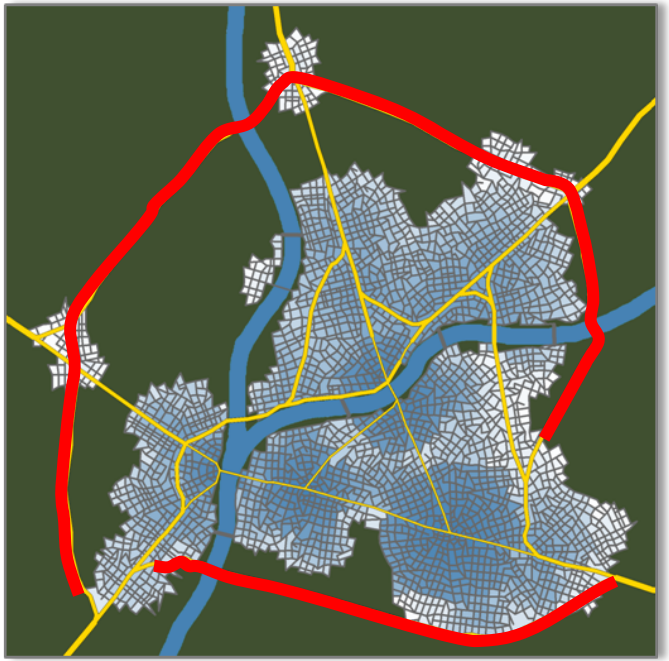


Cities with a realistic structure

- Suburbs

Goal #1

Cities with a realistic structure



- Suburbs
- Belt roads

Goal #1

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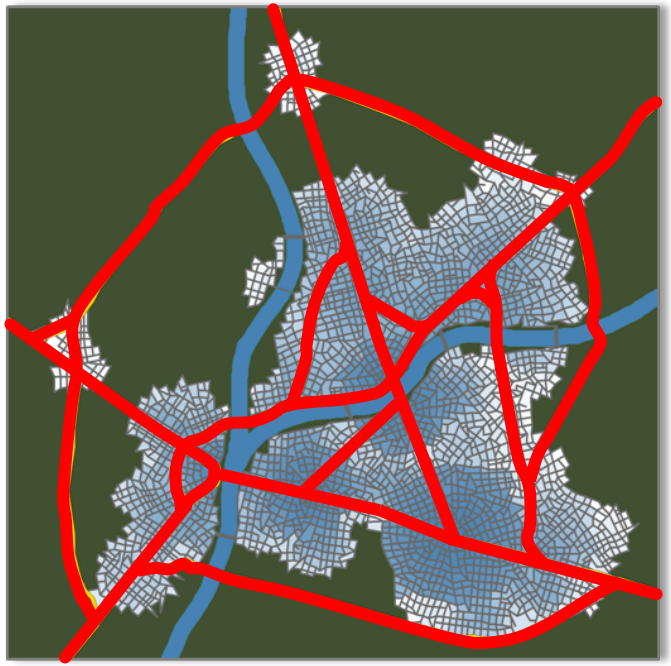
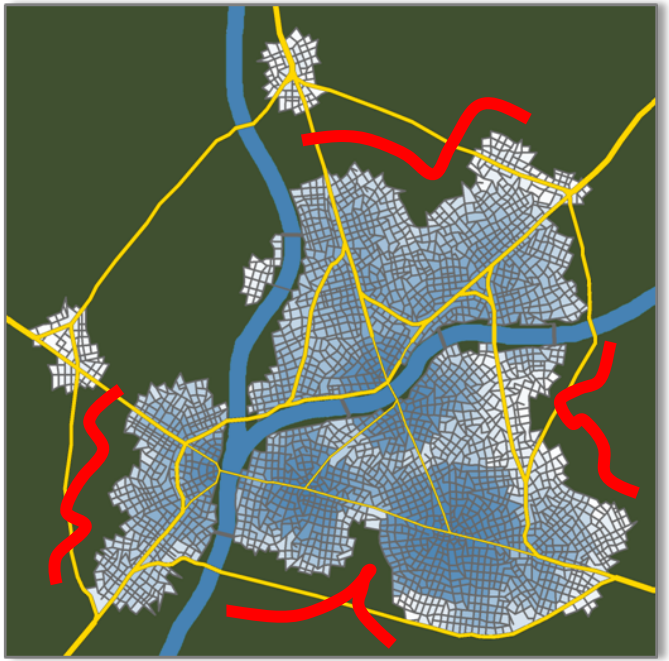


- Suburbs
- Belt roads
- Meaningful main roads

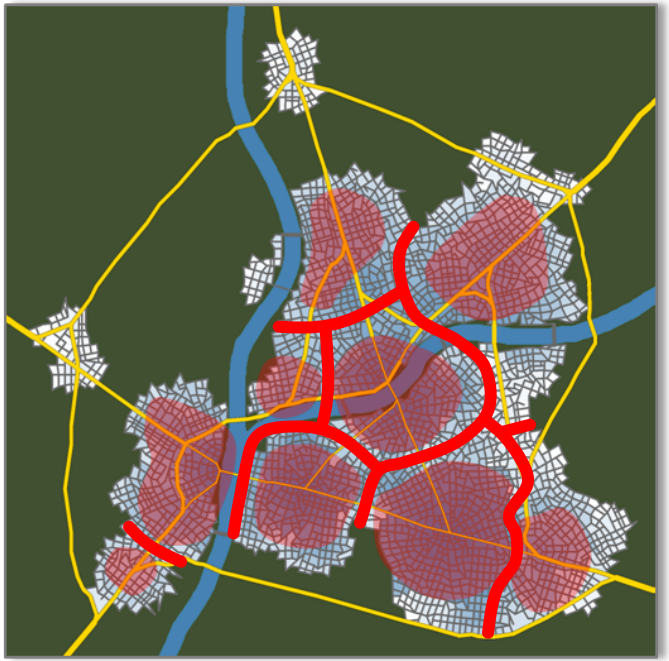
Goal #1

Cities with a realistic structure



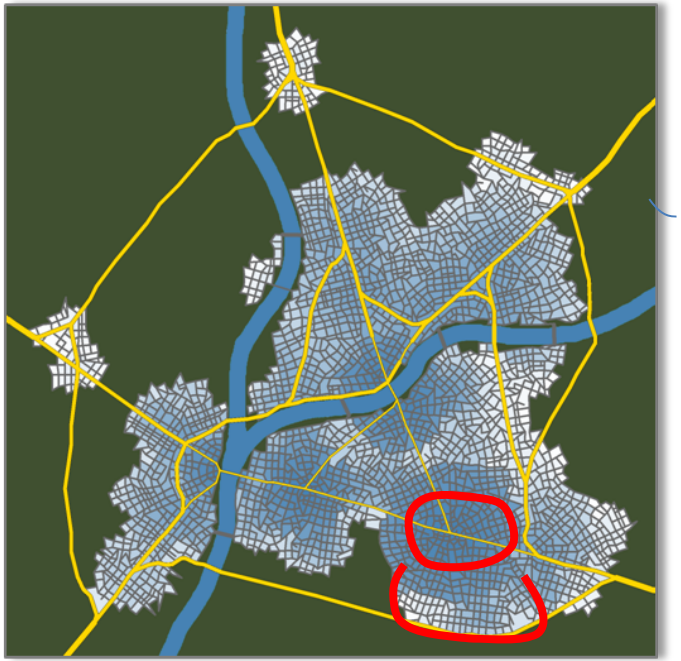
- Suburbs
- Belt roads
- Meaningful main roads
- Irregularities

Cities with a realistic structure



- Suburbs
- Belt roads
- Meaningful main roads
- Irregularities
- Agglomerations / Conurbations

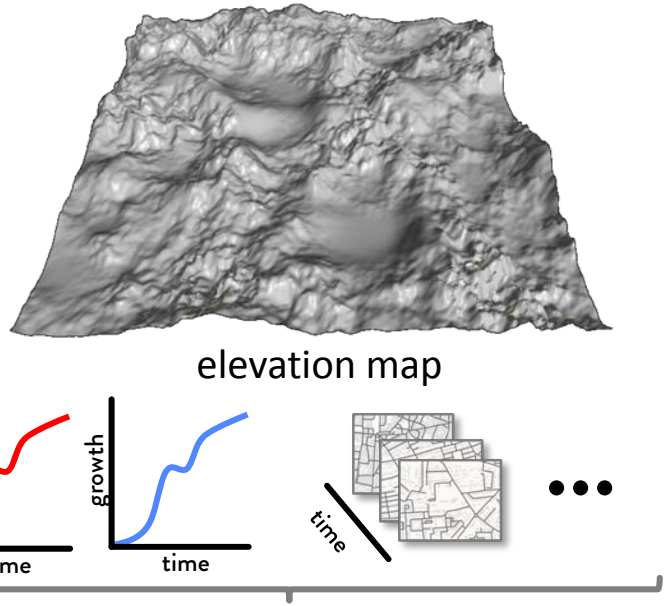
Cities with a realistic structure



- Suburbs
- Belt roads
- Meaningful main roads
- Irregularities
- Agglomerations / Conurbations
- Changing street patterns

Goal #2

Cities with minimal input



Goal #2

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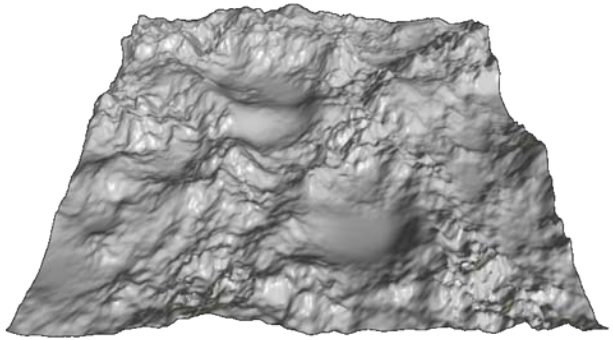
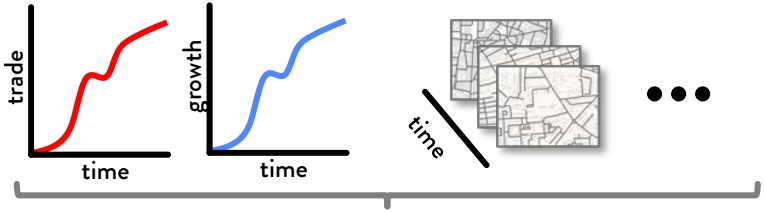
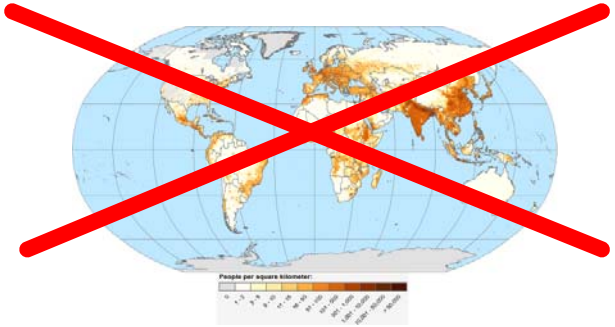


elevation map



"*Historical Context*"



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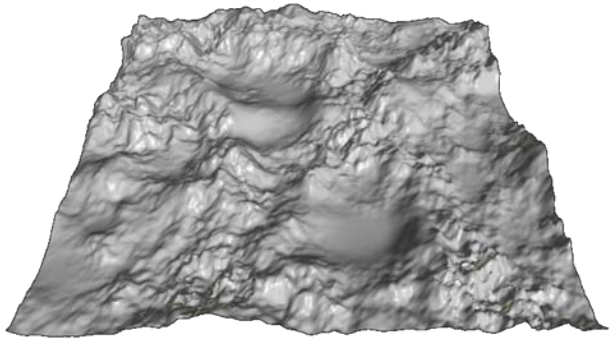


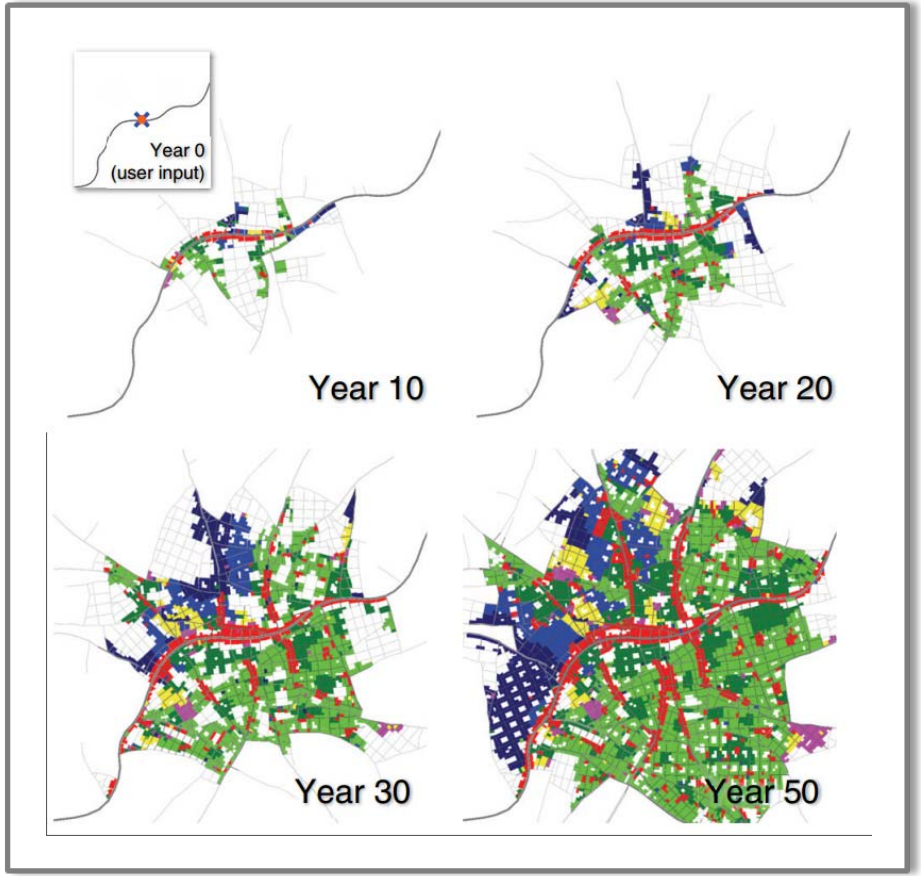
Previous Work

What we build on

Existing Methods

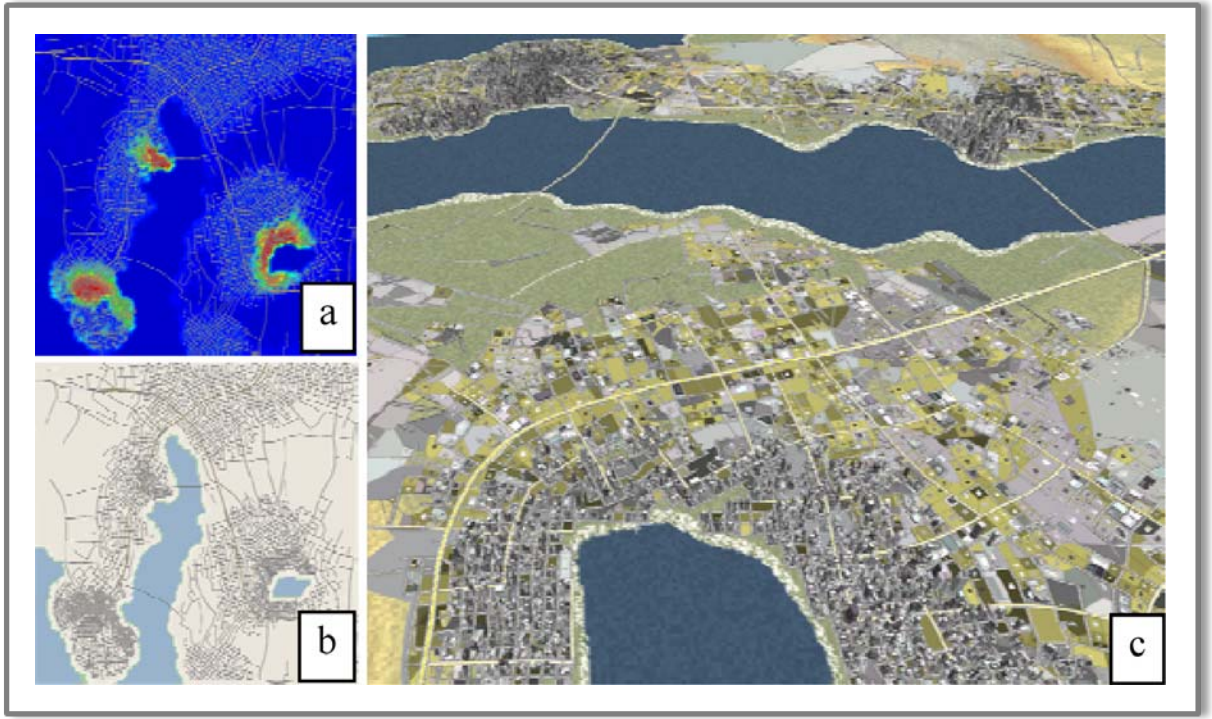
- Procedural cities [Muller01]
- User-guided
- Input maps
  - Population
  - Street patterns
- No growth

Existing Methods



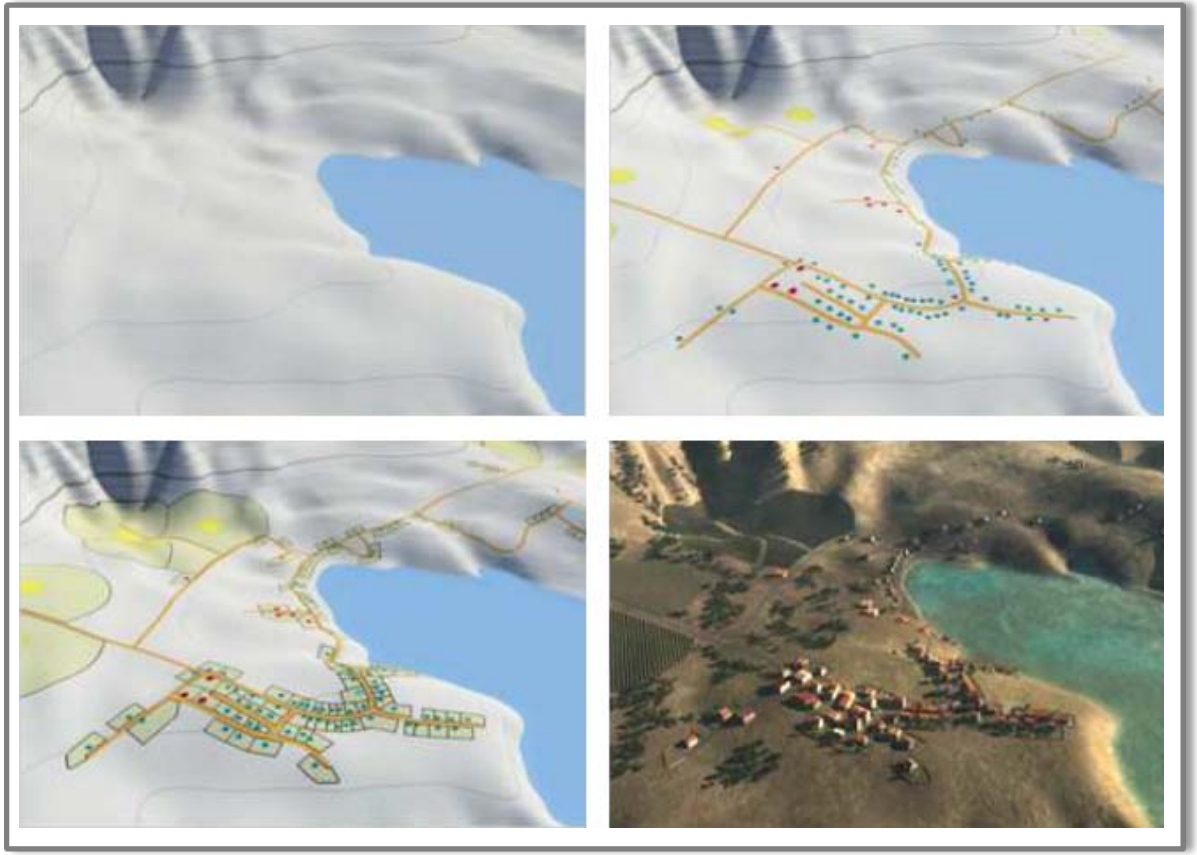
- [Weber09]
- City growth
- Local traffic simulation
- Controllable
- Automatic

Existing Methods



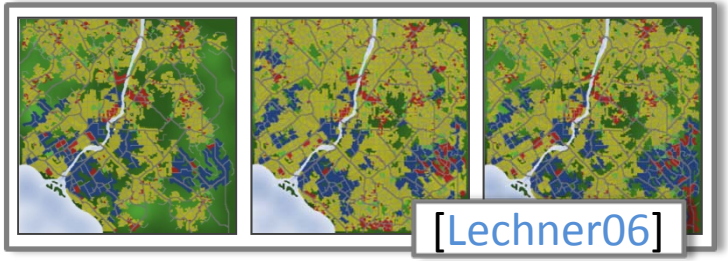
- [Vanegas09]
- Interactive
- Input
  - Highways
  - Demographic maps
  - Constraints
- Dynamical system

Existing Methods



- [Emilien12]
- Villages
- Settlement positioning
- Sparse road networks

Existing Methods



- Example based
  - [Aliaga08], [Yu12]
- Land use
  - [Lechner06]
  - [Gronewegen09]
- Interpolation
  - [Krecklau12]
- Other aspects
  - [Vanegas12], [Chen08], [Yang13], [Lipp11], [Galin11]

Our Contributions

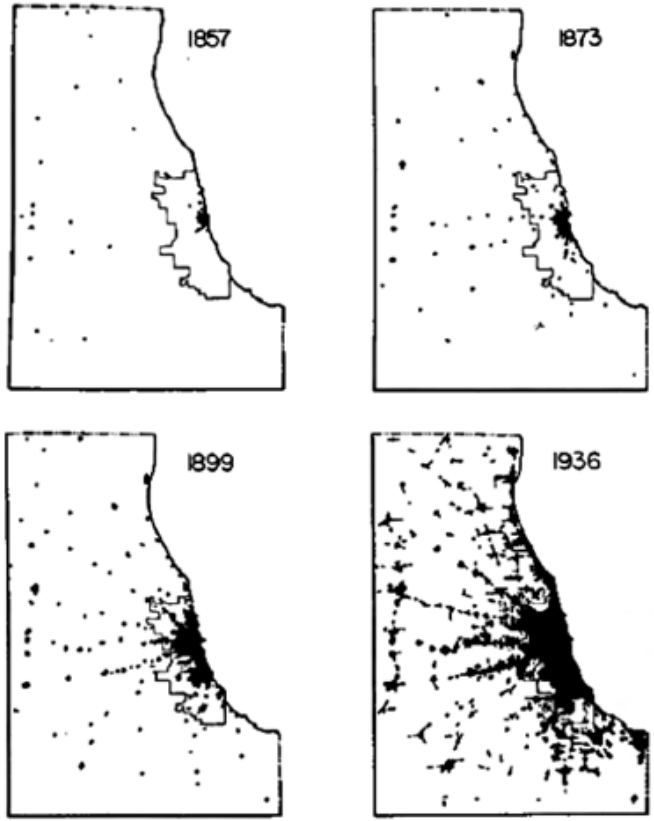
- More realistic city structure
  - Consider the neighbourhood
  - Trade driven major roads
  - Water and terrain
  - Settlement placement & city shape
  - Agglomerations/conurbations

Rationale

From first principles

City Shape

- What drives city shape?
  - Populated areas [Hoyt39]
  - Railways, stations
  - Similar for highways [TT95, Gar92]
- Where does growth happen?
  - Accessible, e.g. stations
  - Well suited for service, e.g. intersections & ports
- *"Nuclei of growth"*



Major Roads

- Nuclei of growth
  - Major road intersections
  - Ports
  - Both on major roads

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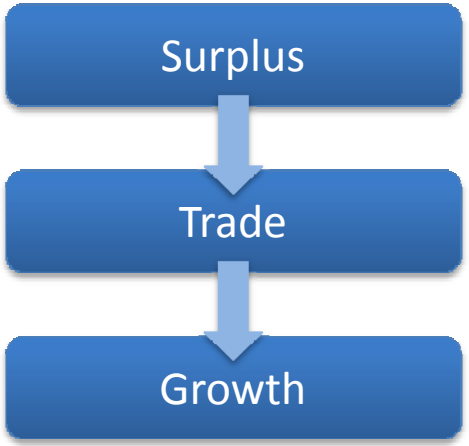
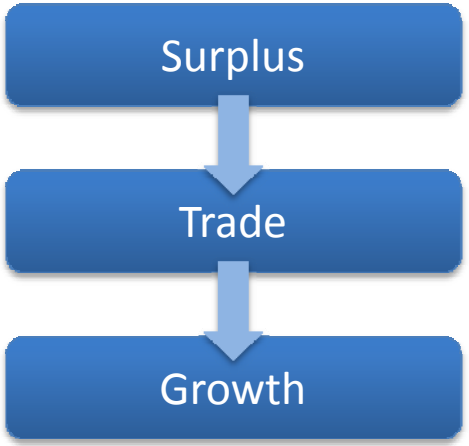


Trade is a consistent and key factor in city growth

Major Roads

- Nuclei of growth
  - Major road intersections
  - Ports
  - Both on major roads
- Major roads
  - Simulate trade
  - *between* cities
  - [Childe50]



Trade is a consistent and key factor in city growth

Minor Roads

Historic

Early 20th century

Late 20th century

Minor road pattern changes with time

- Simplifying assumption
- Also changes with:
  - Land use, terrain, etc.

Method Overview

Method Overview – First steps

- Preparing a city

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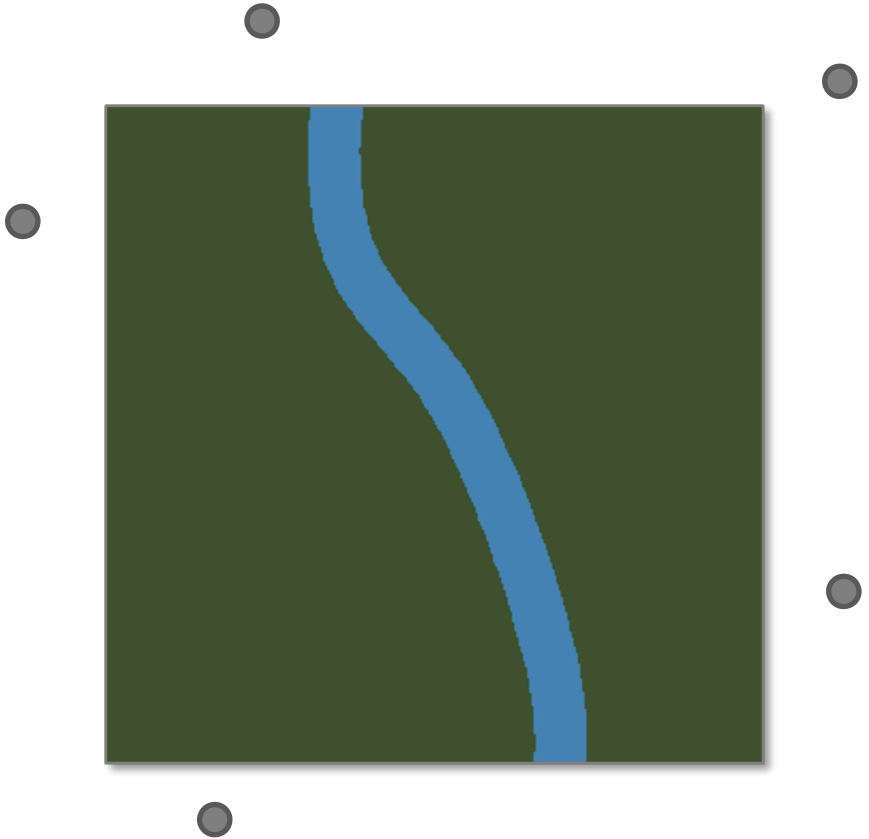
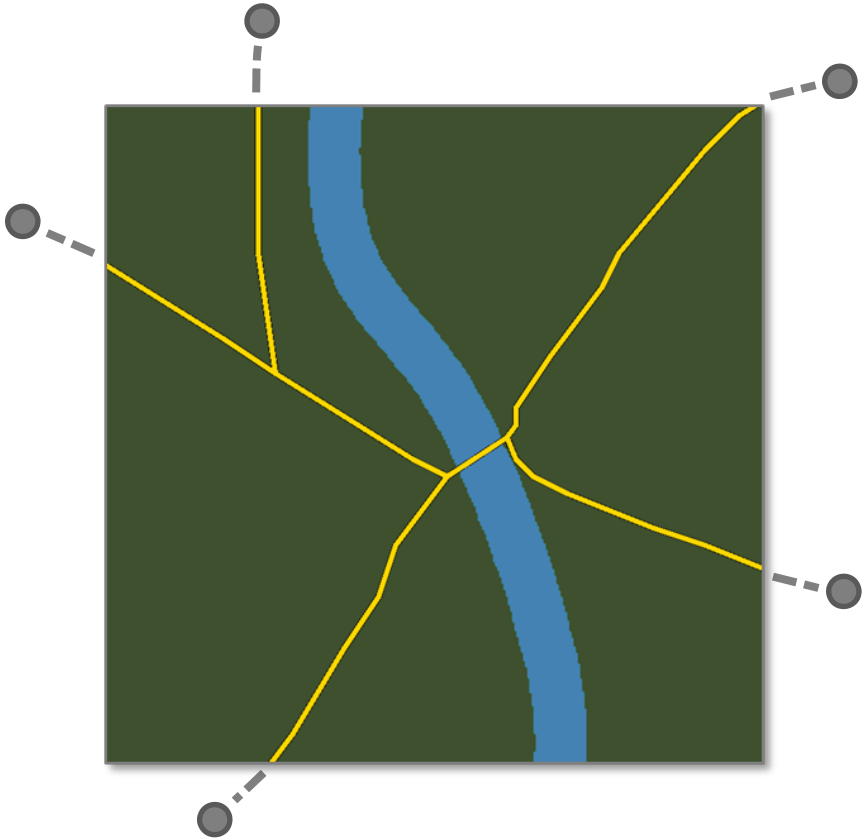
- Preparing a city
  - Neighbouring Cities



Method Overview – First steps

- Preparing a city
  - Neighbouring Cities
  - Connect by major roads
  - Initial Road network



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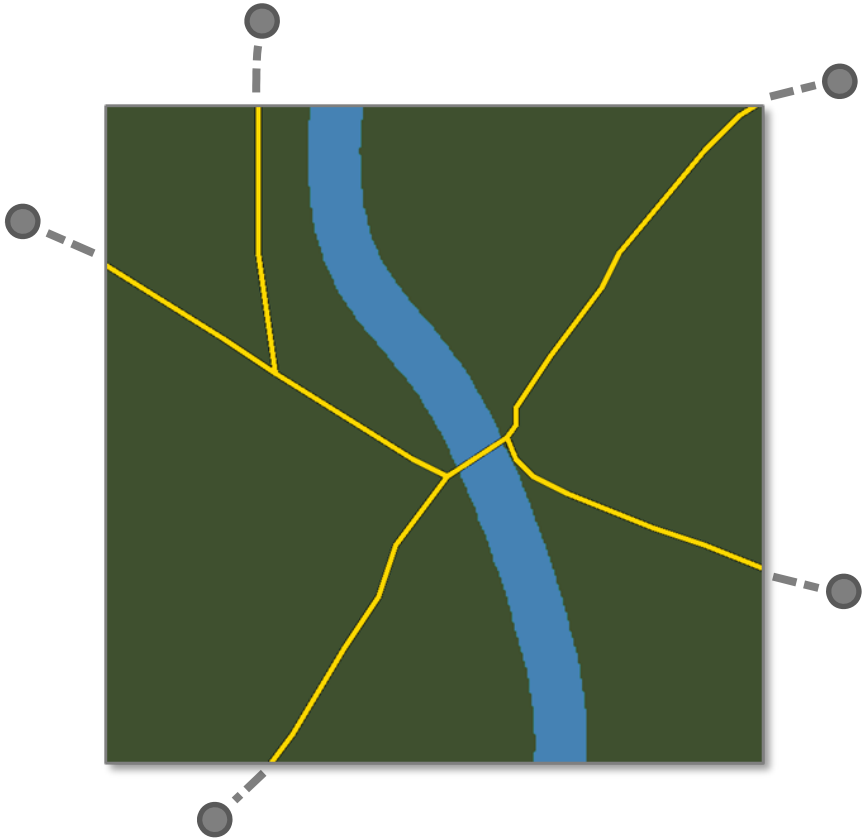

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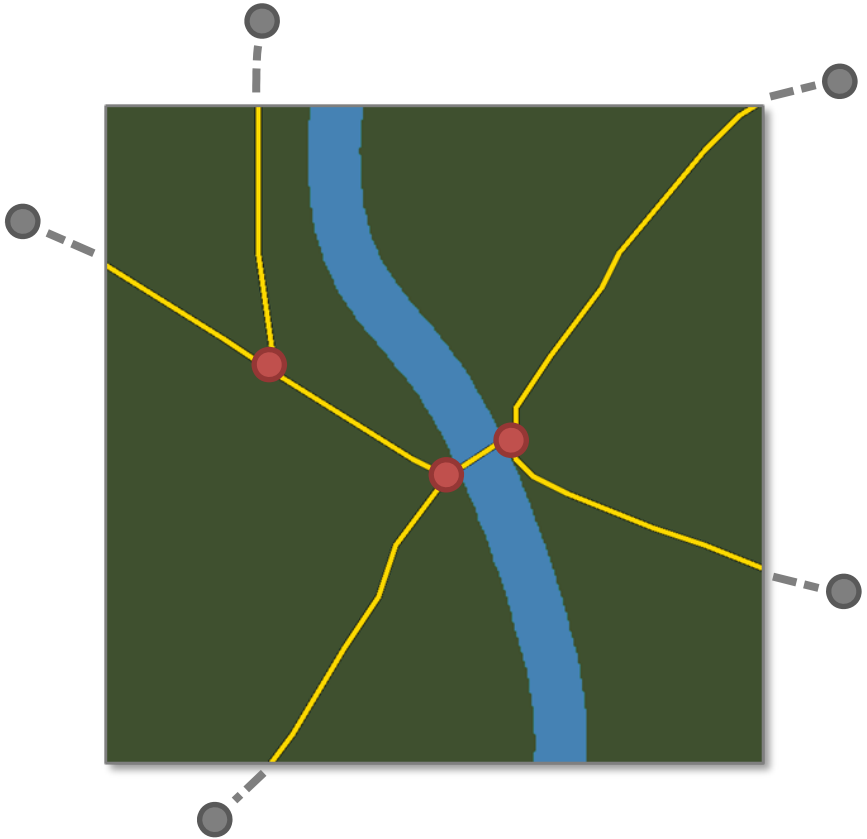
  1. (Re)generate



Method Overview – First steps

- Preparing a city
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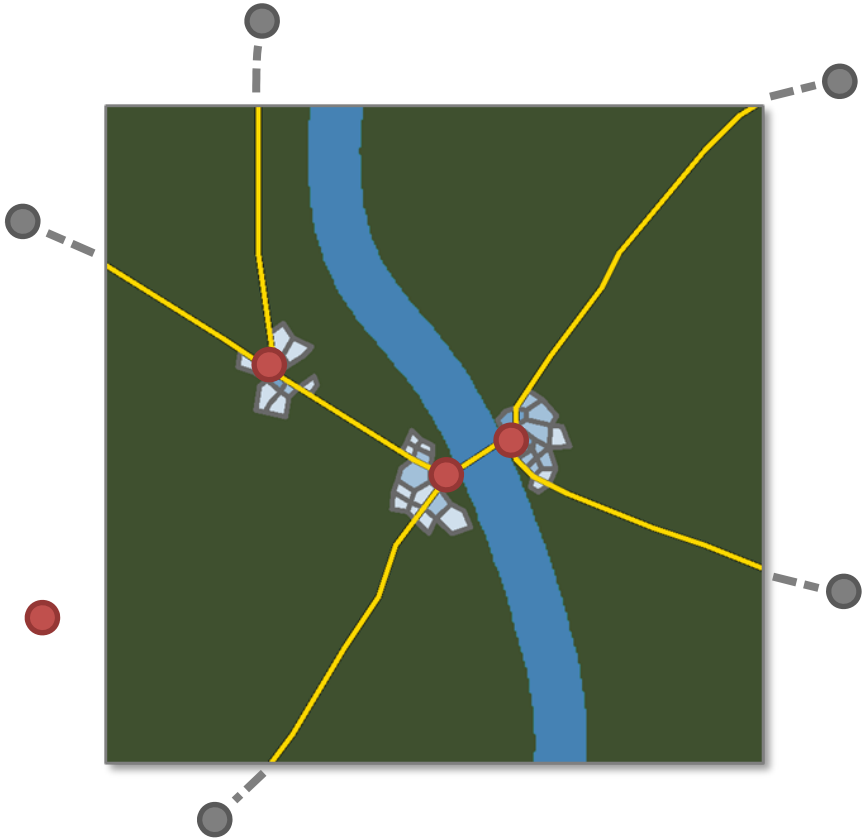
- Growing a city:
  1. (Re)generate ●
  2. Grow minor roads close to ●



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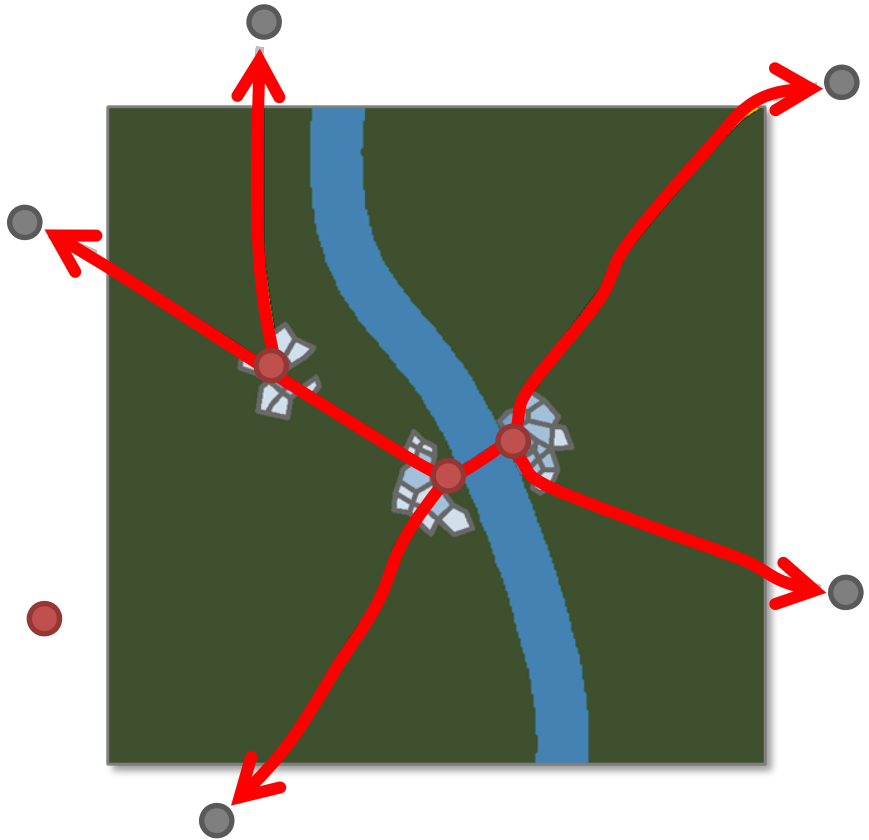
  3. Increase Trade



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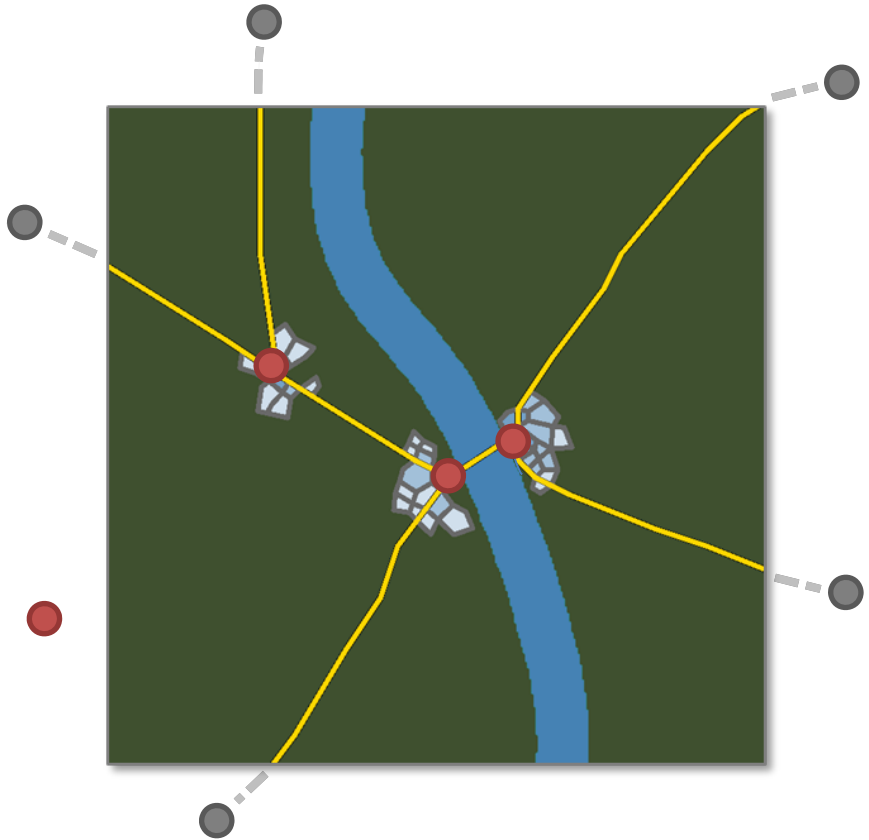

Method Overview – Major Roads

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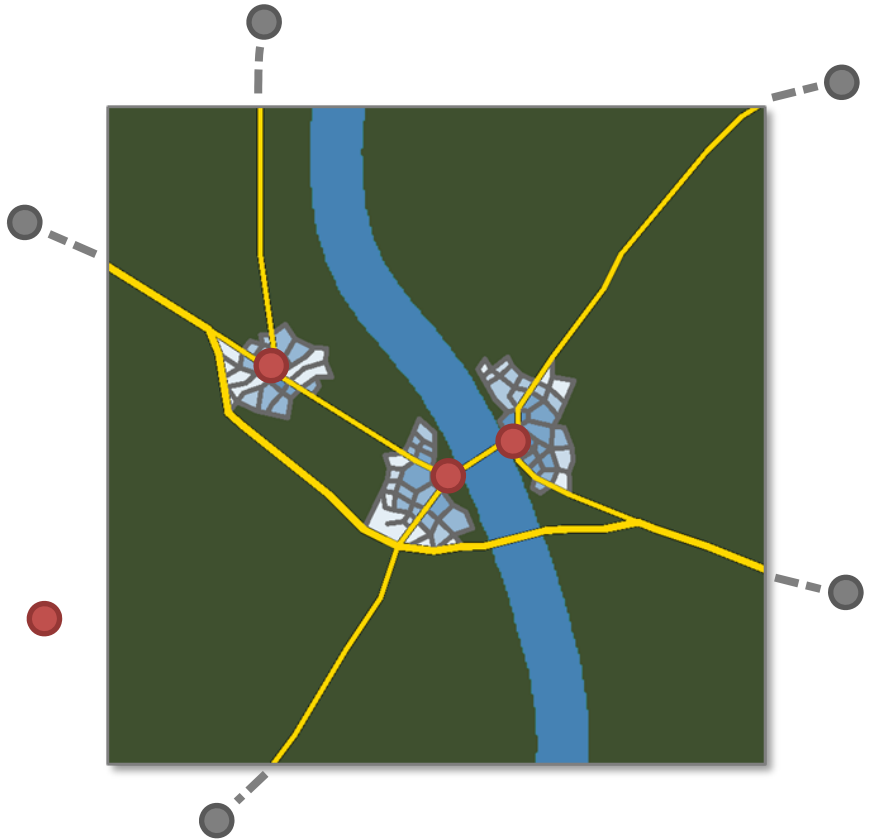
  4. Grow Major Roads



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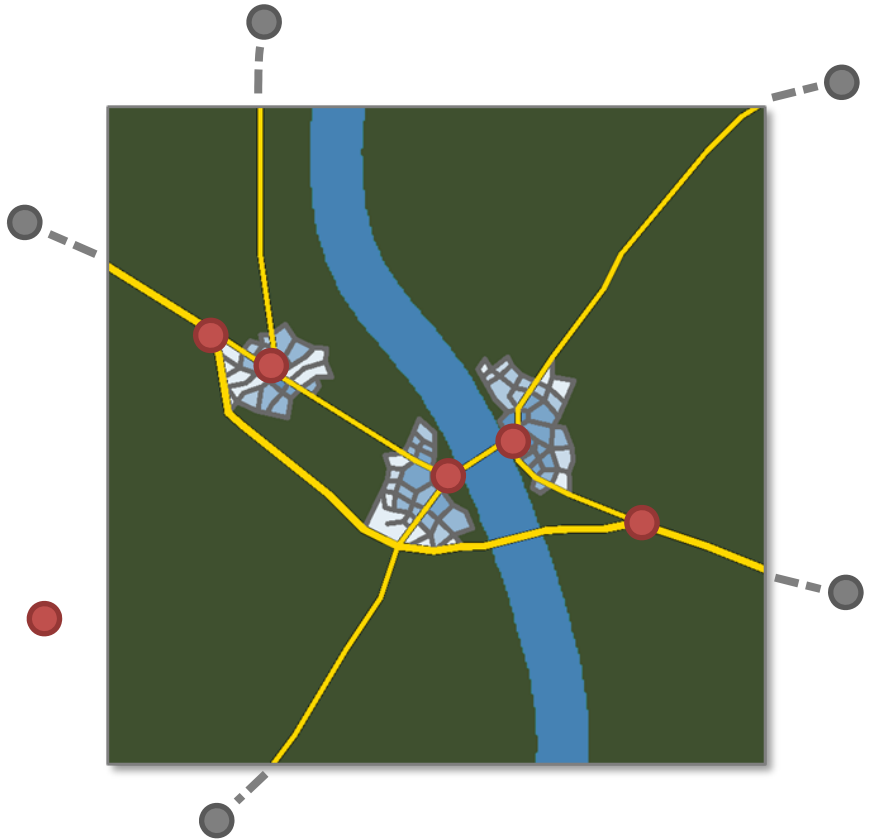
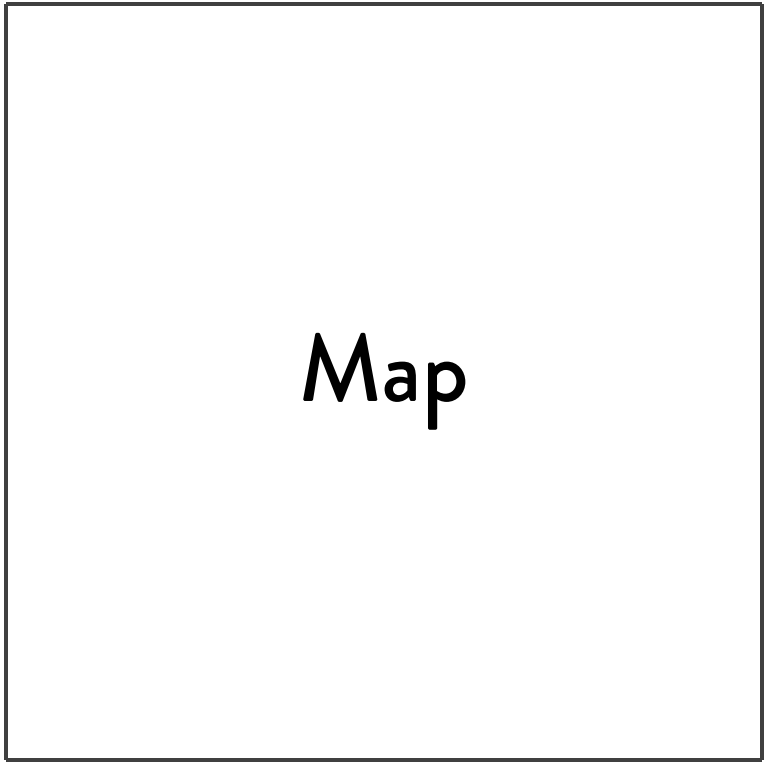


The Method

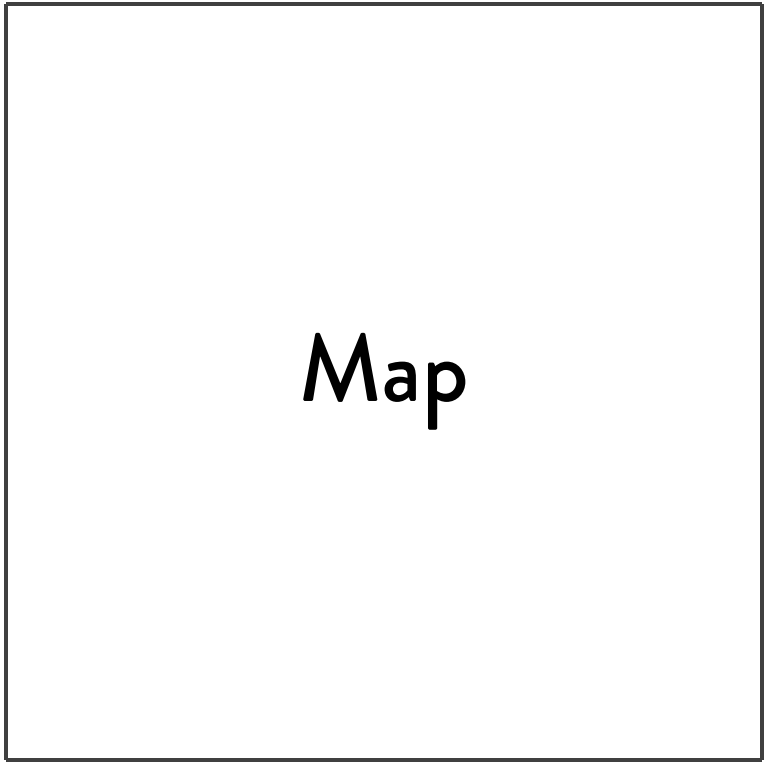
The above, more formally.

Neighbouring cities



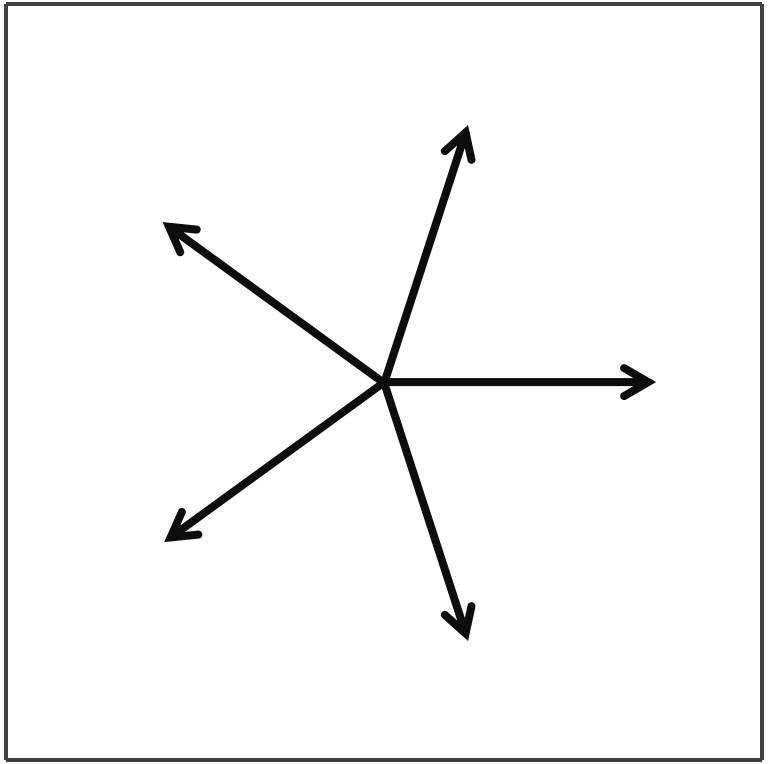
Neighbouring cities

- *N* = # Neighboring Cities



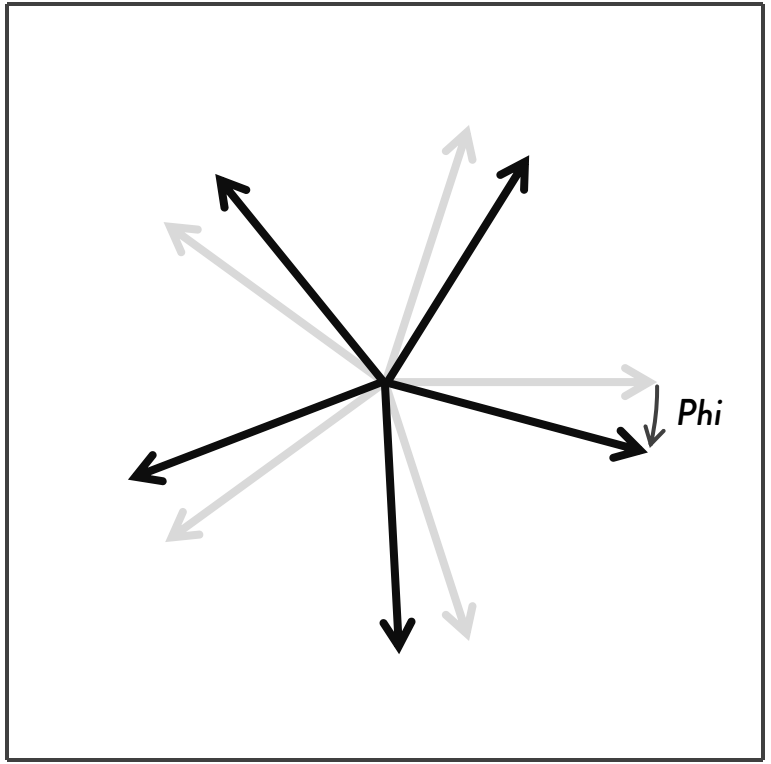
Neighbouring cities

- *N* = # Neighboring Cities
- *N* equally spaced rays



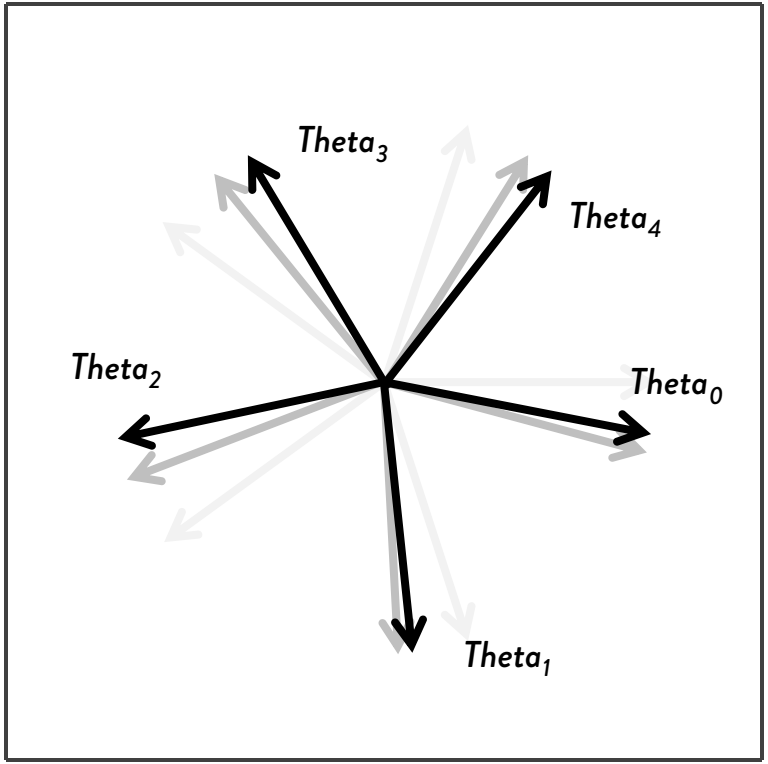
Neighbouring cities

- *N* = # Neighboring Cities
- *N* equally spaced rays
- Rotate all by *Phi*



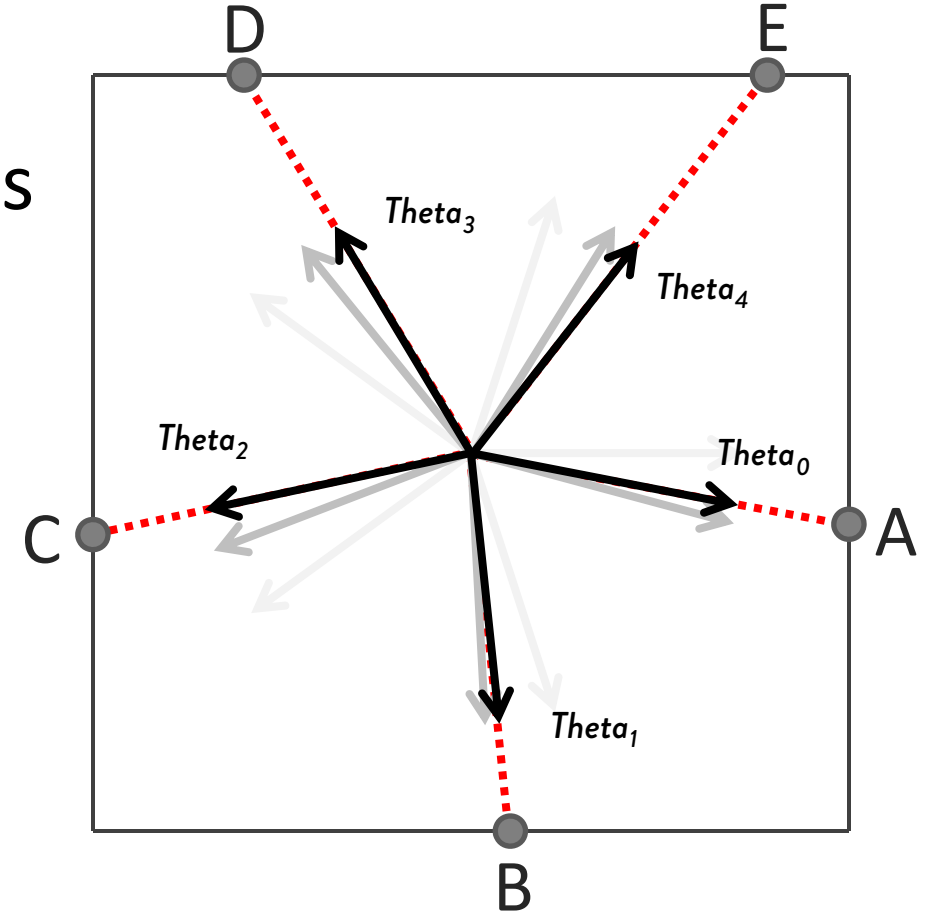
Neighbouring cities

- *N* = # Neighboring Cities
- *N* equally spaced rays
- Rotate all by *Phi*
- Perturb each by $Theta_i$

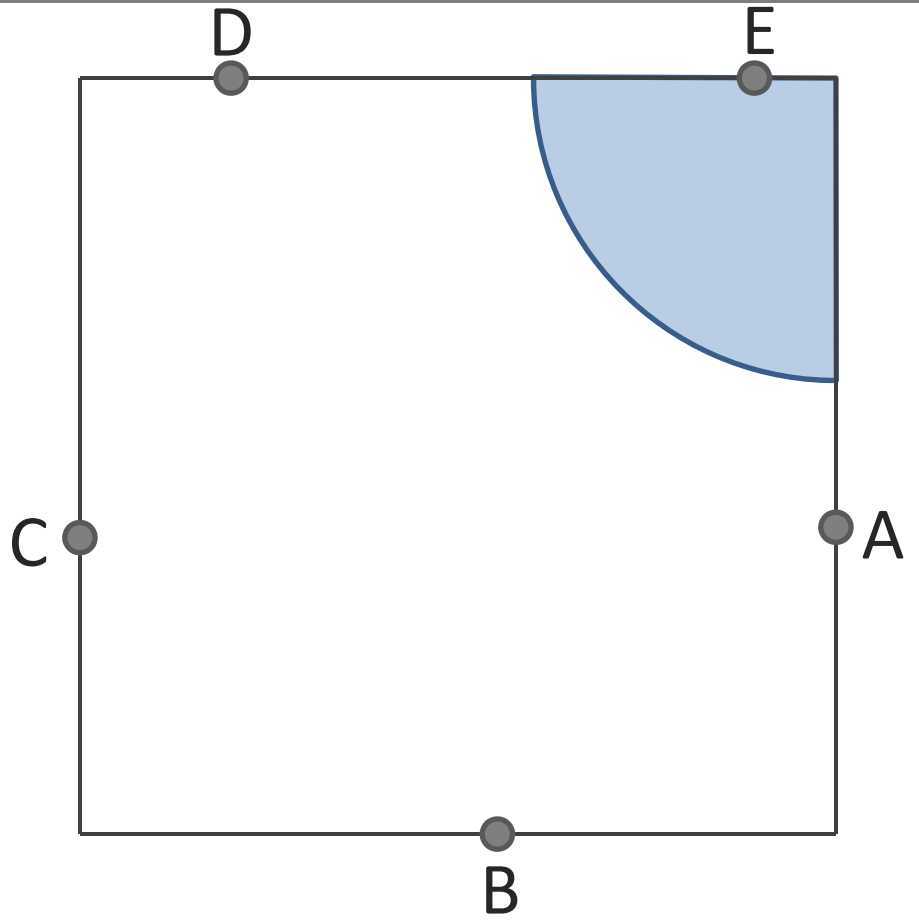


Neighbouring cities

- *N* = # Neighboring Cities
- *N* equally spaced rays
- Rotate all by *Phi*
- Perturb each by $Theta_i$
- Intersect the border

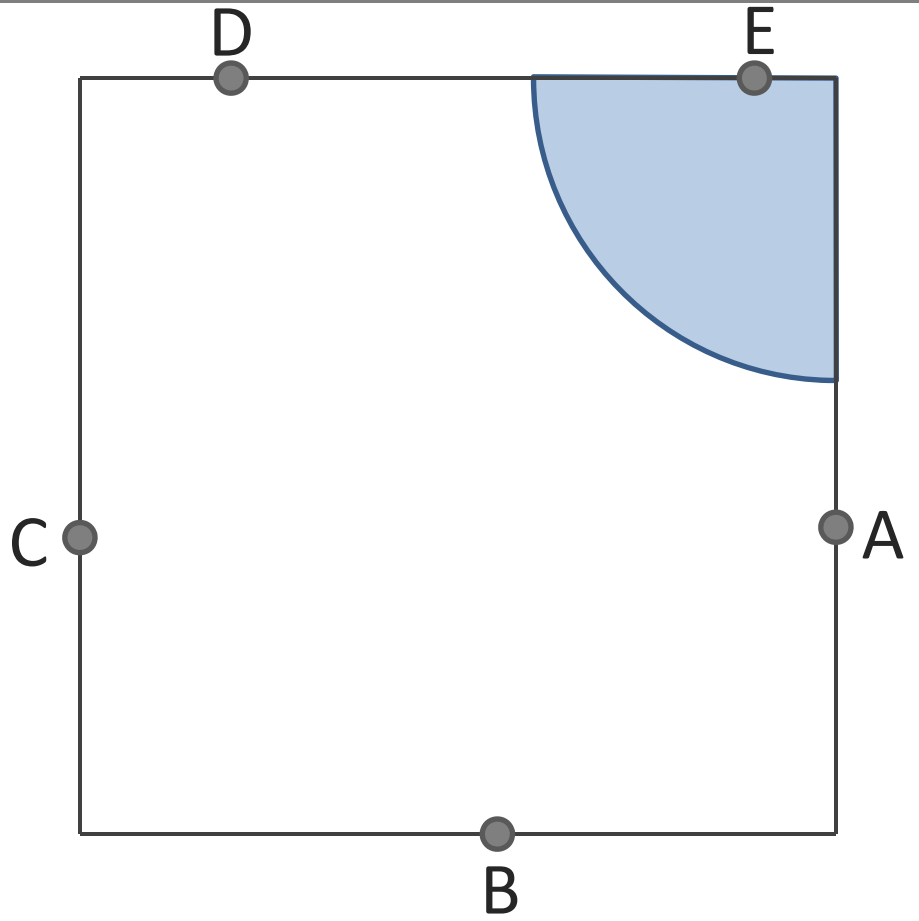


Initial Road Network



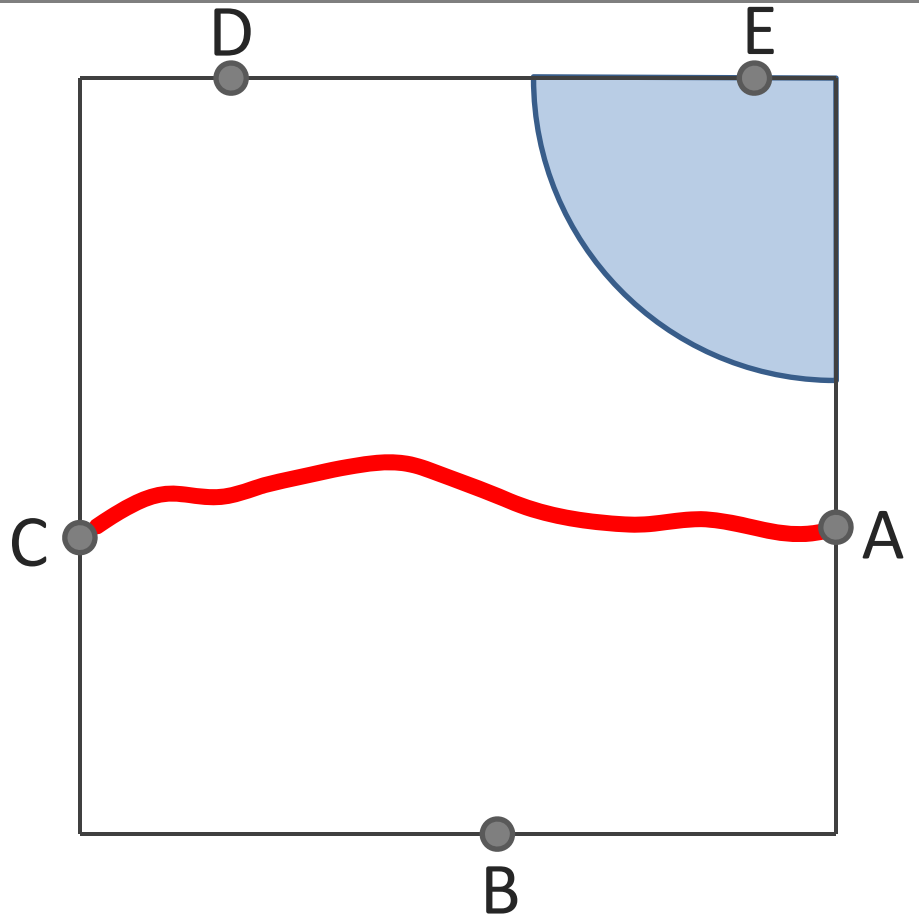
Initial Road Network

- Connect opposite cities



Initial Road Network

- Connect opposite cities
  1. AC



Initial Road Network

- Connect opposite cities
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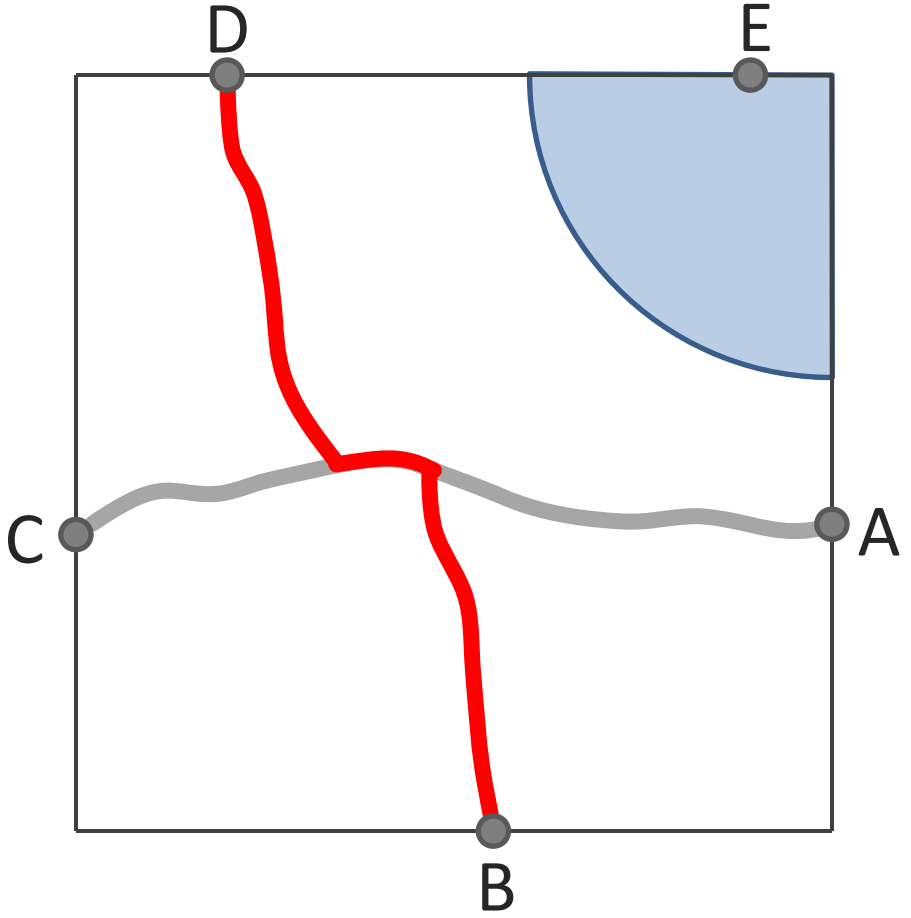
  2. BD



Initial Road Network

- Connect opposite cities
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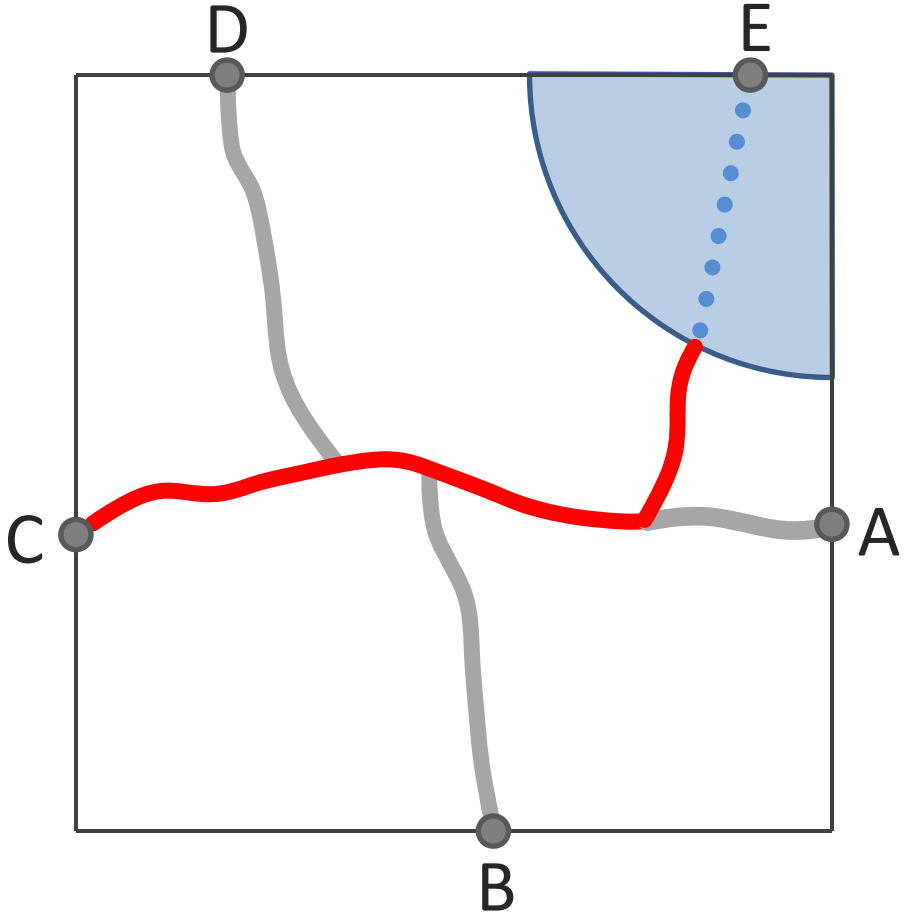
  2. BD
  3. CE



Initial Road Network

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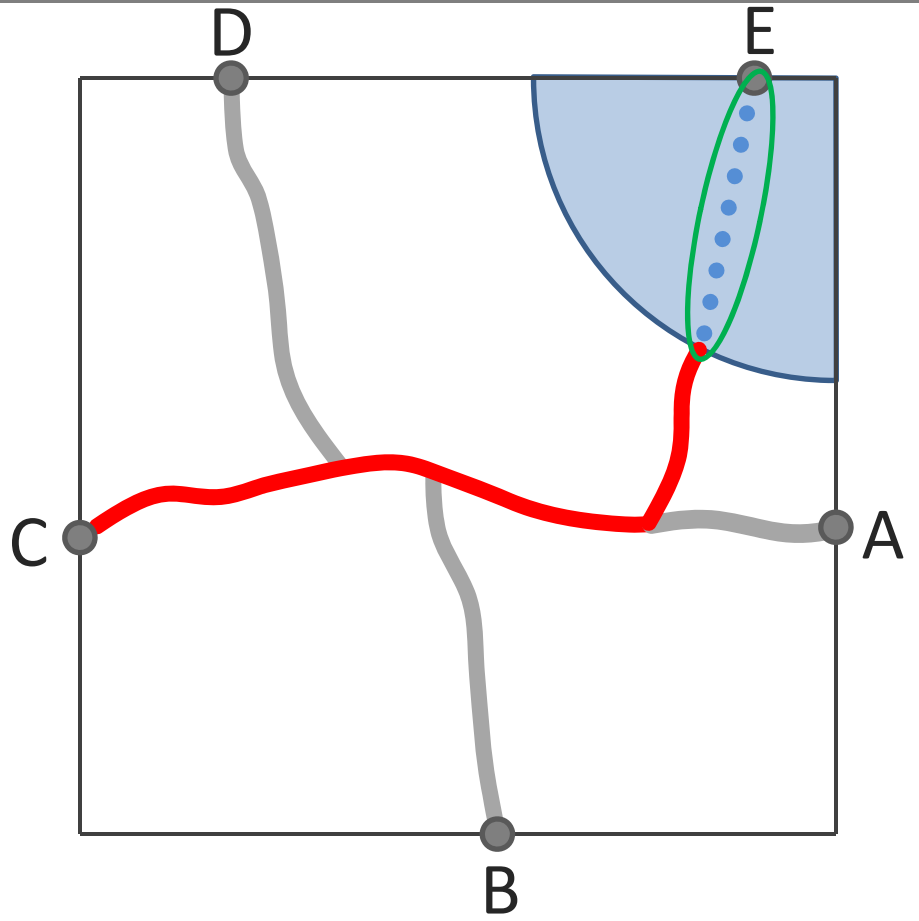
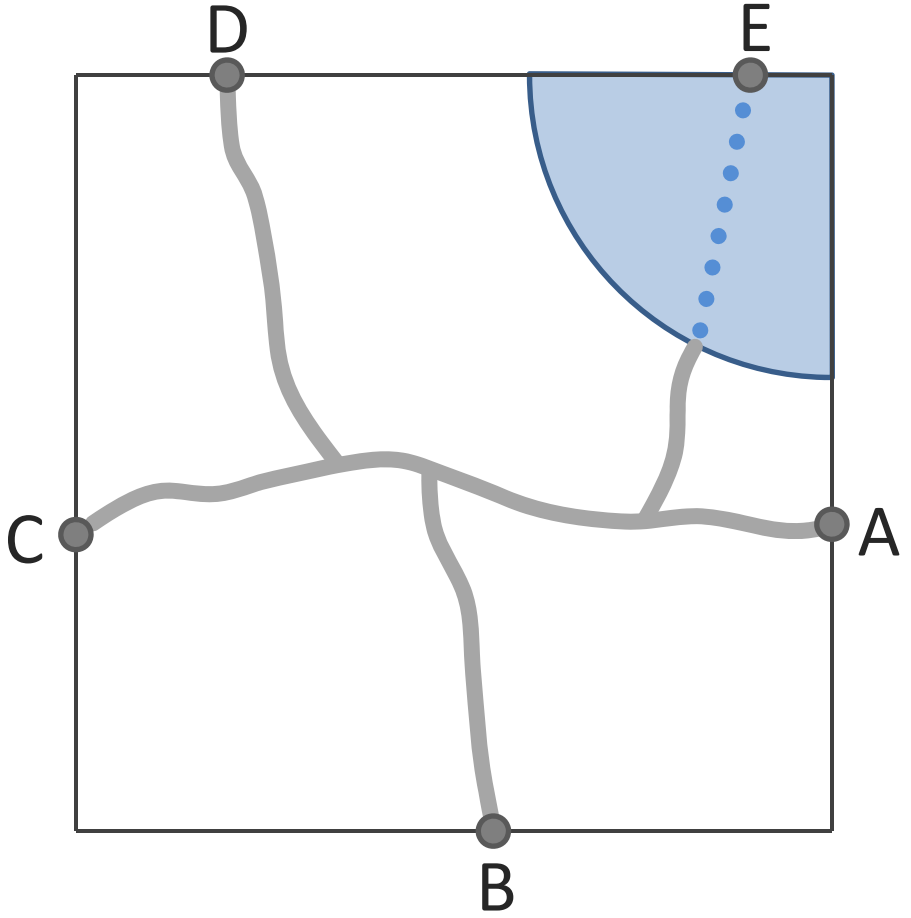


Initial Road Network

- Connect opposite cities
  1. AC
  2. BD
  3. CE
- Until all are connected



Initial Road Network

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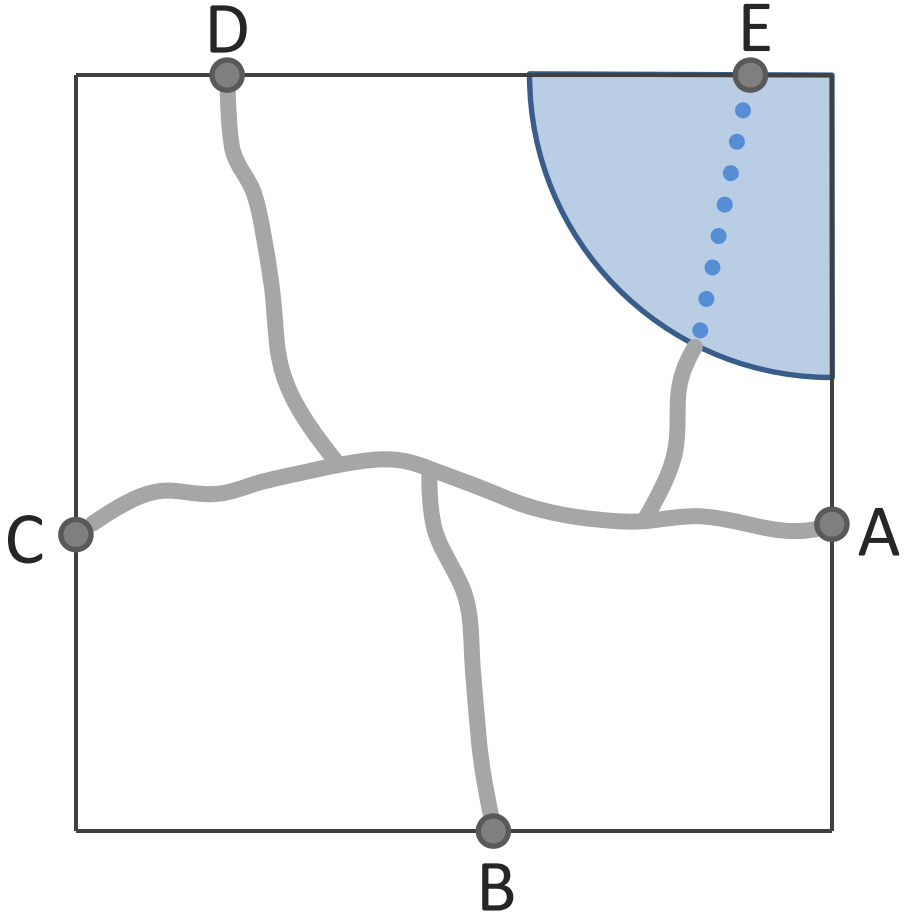
- Until all are connected
- Variations



Initial Road Network

- Connect opposite cities
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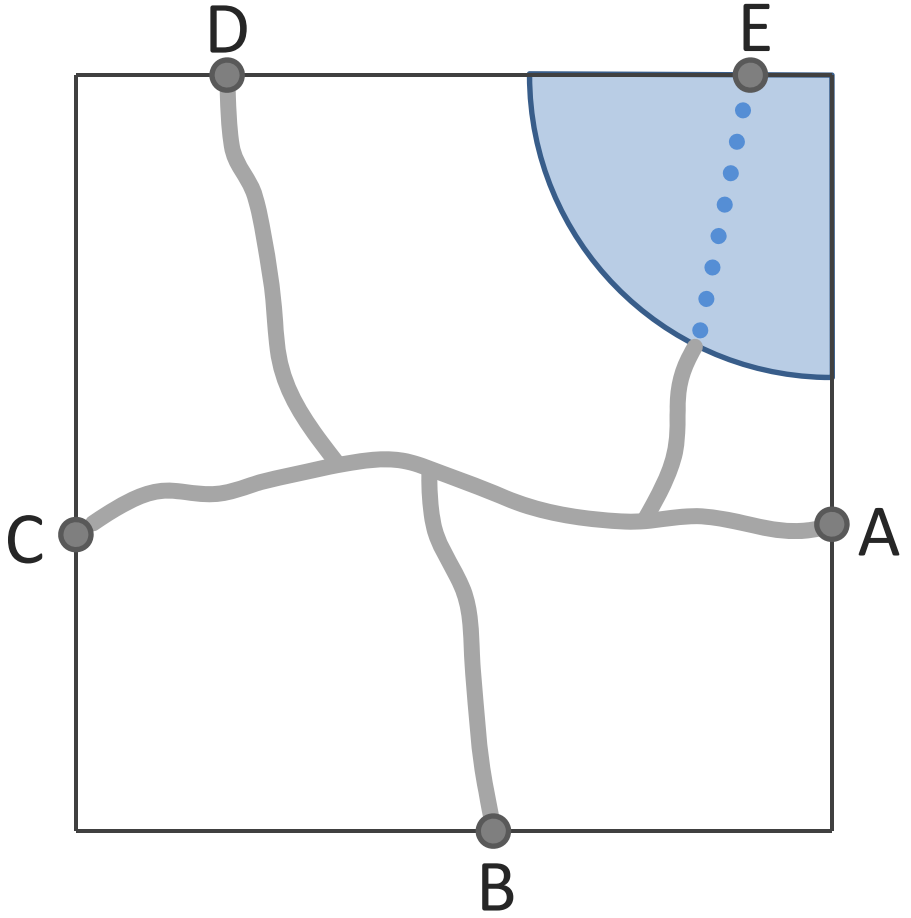
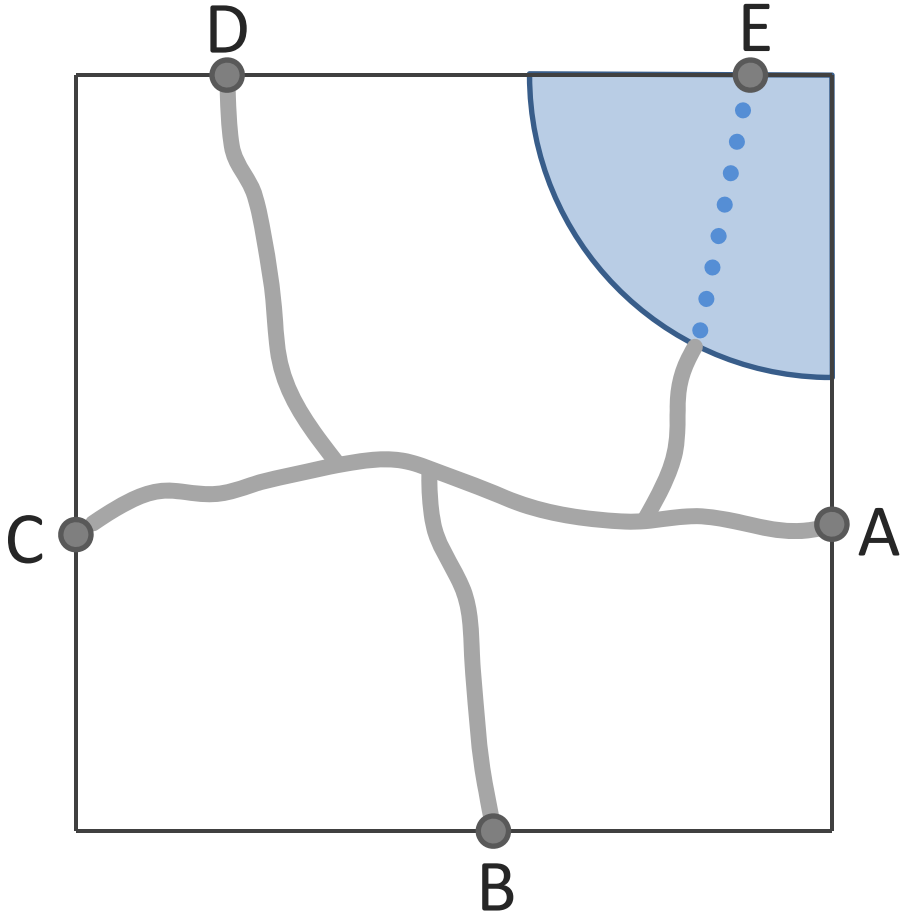
  3. CE
- Until all are connected
- Variations
  - Relax the term “opposite”

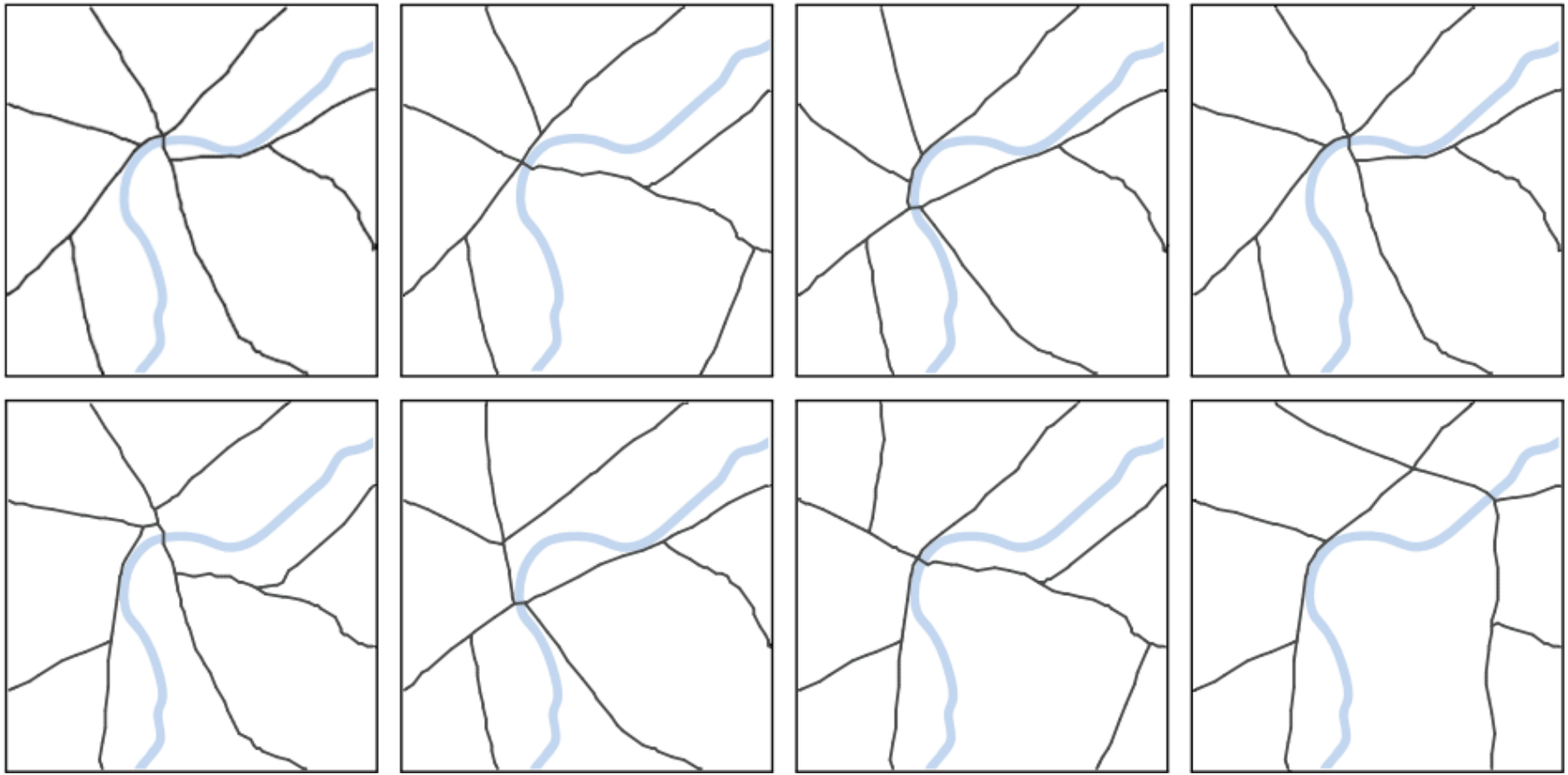


Initial Road Network

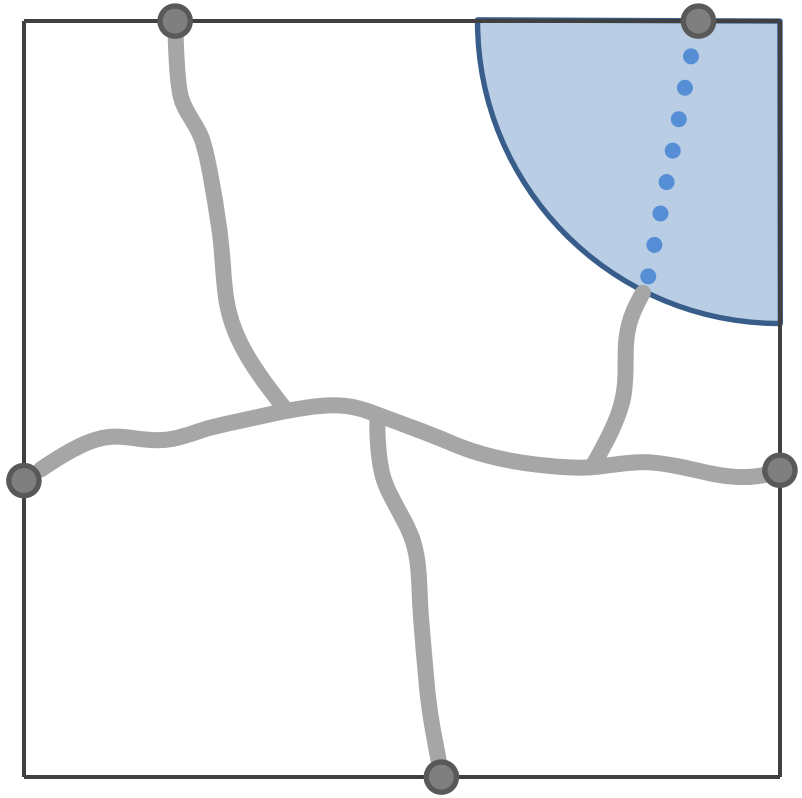
- Connect opposite cities
  1. AC
  2. BD
  3. CE
- Until all are connected
- Variations
  - Relax the term “opposite”
  - Shuffle the order



Initial Road Network

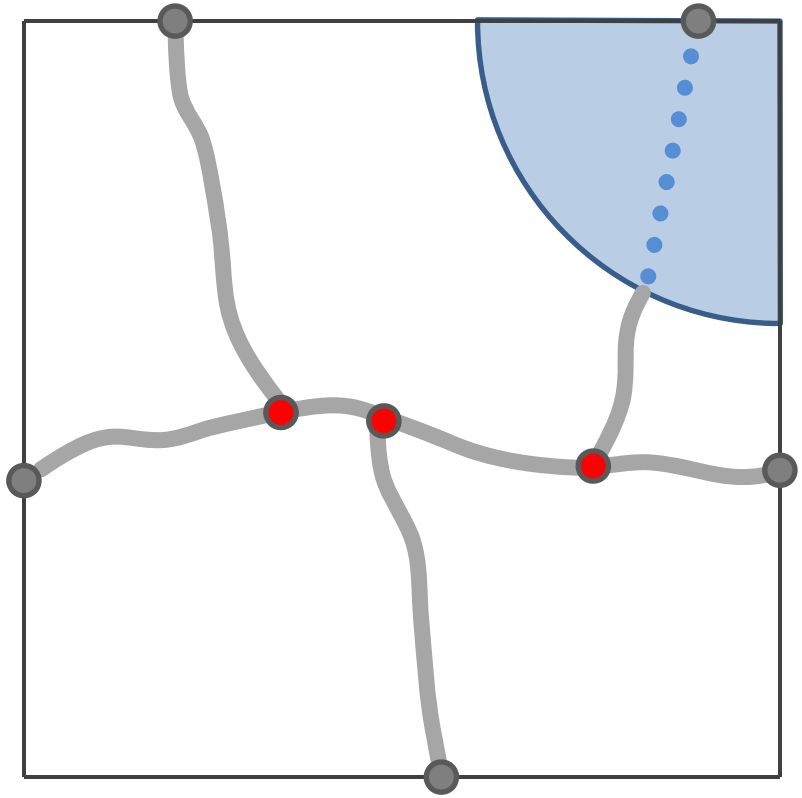


Nuclei of Growth



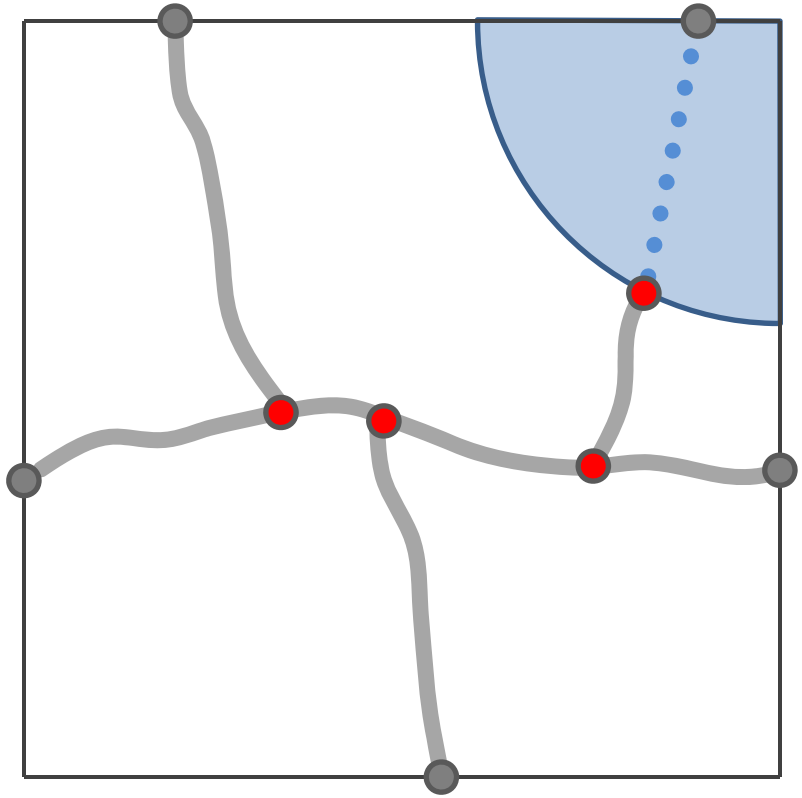
Nuclei of Growth

- Major road intersections



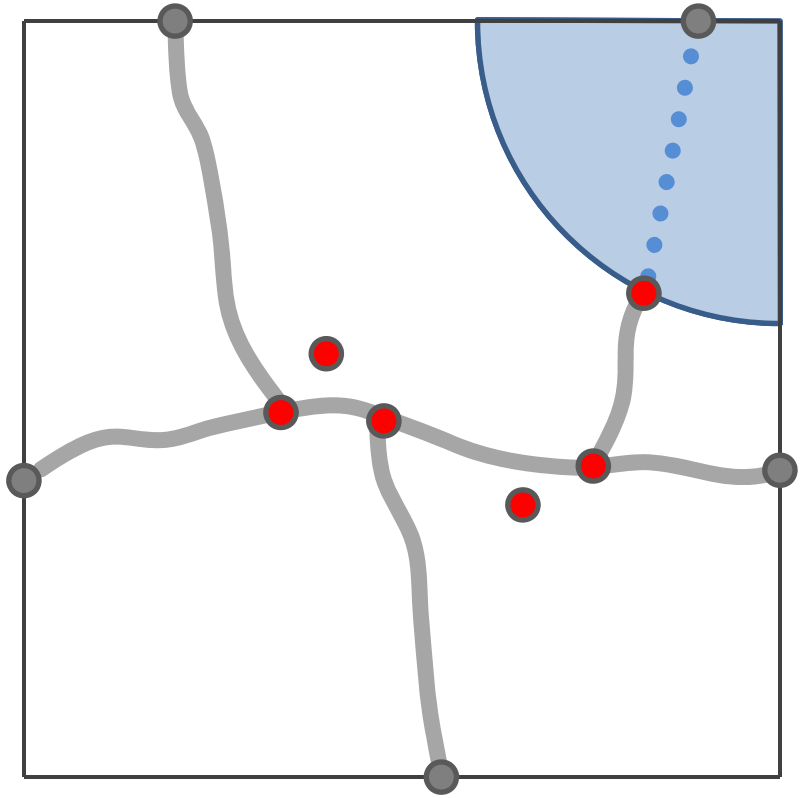
Nuclei of Growth

- Major road intersections
- Ports



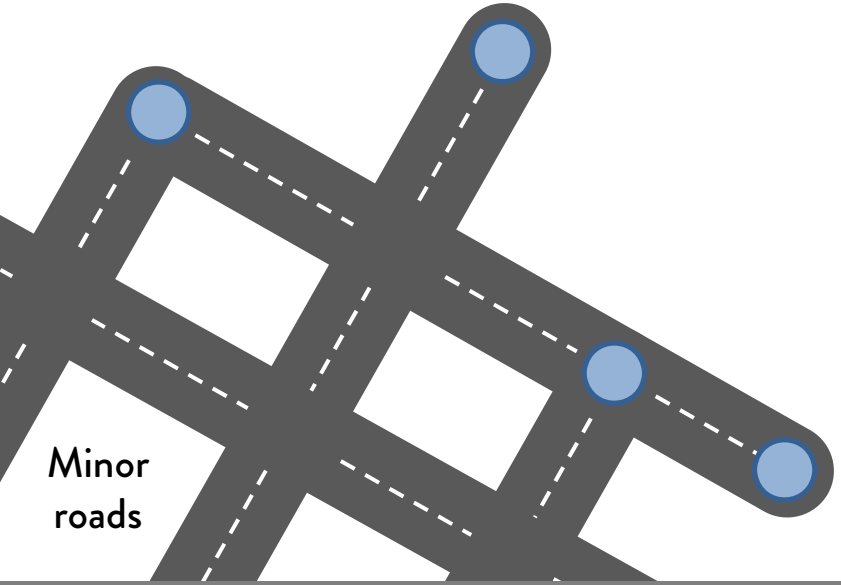
Nuclei of Growth

- Major road intersections
- Ports
- Near existing nuclei



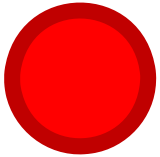
Minor Roads

- Intersections

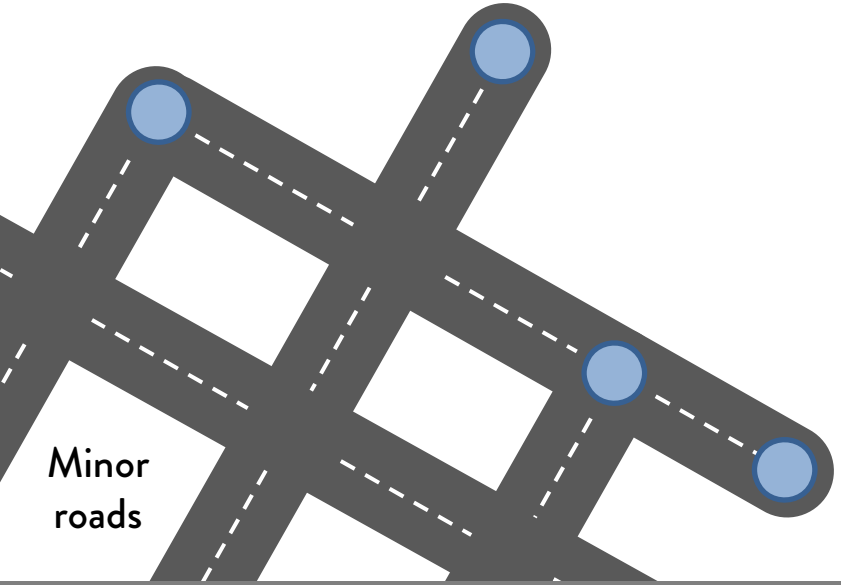


Minor Roads

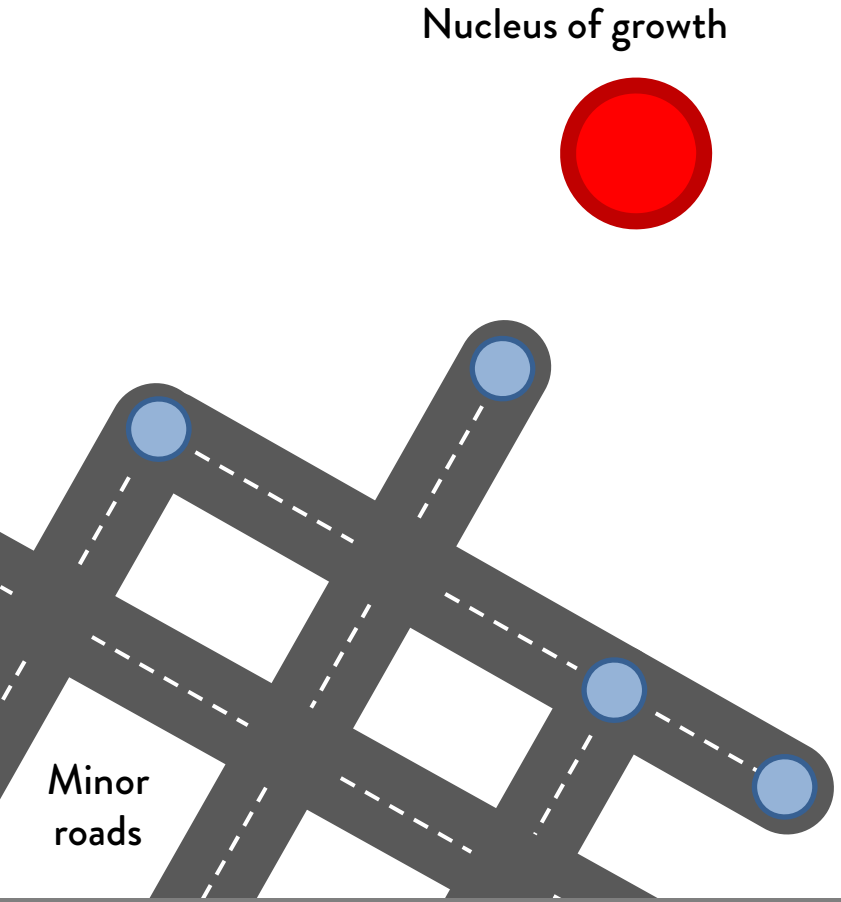
Nucleus of growth



- Intersections
- Nuclei of growth

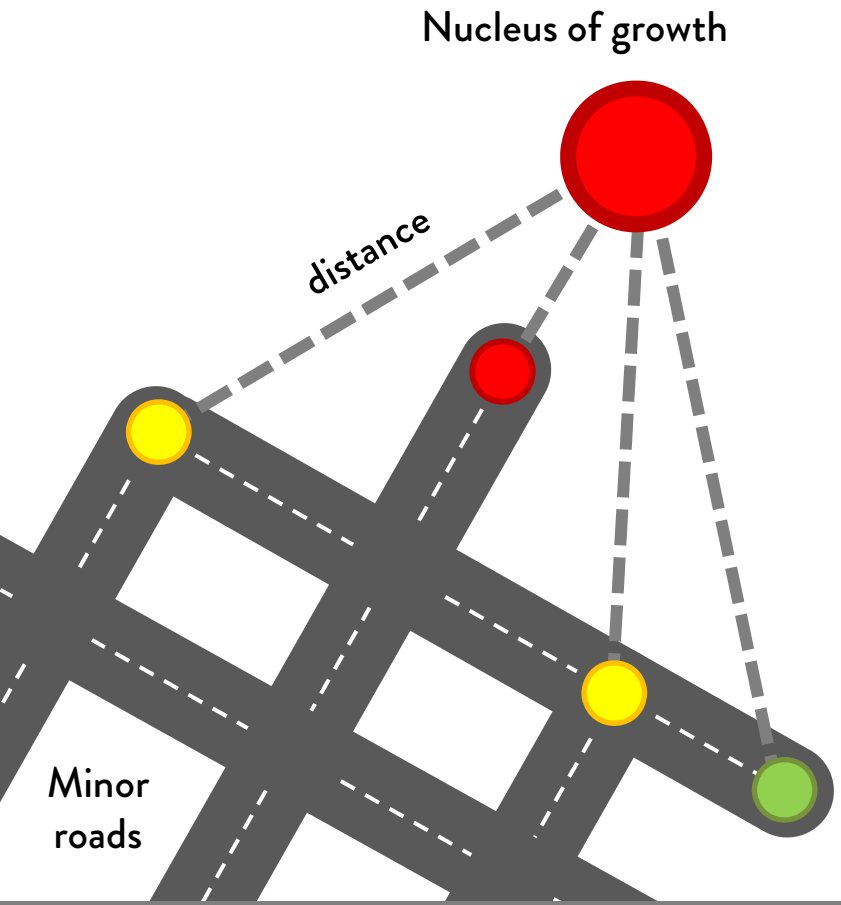


Minor Roads



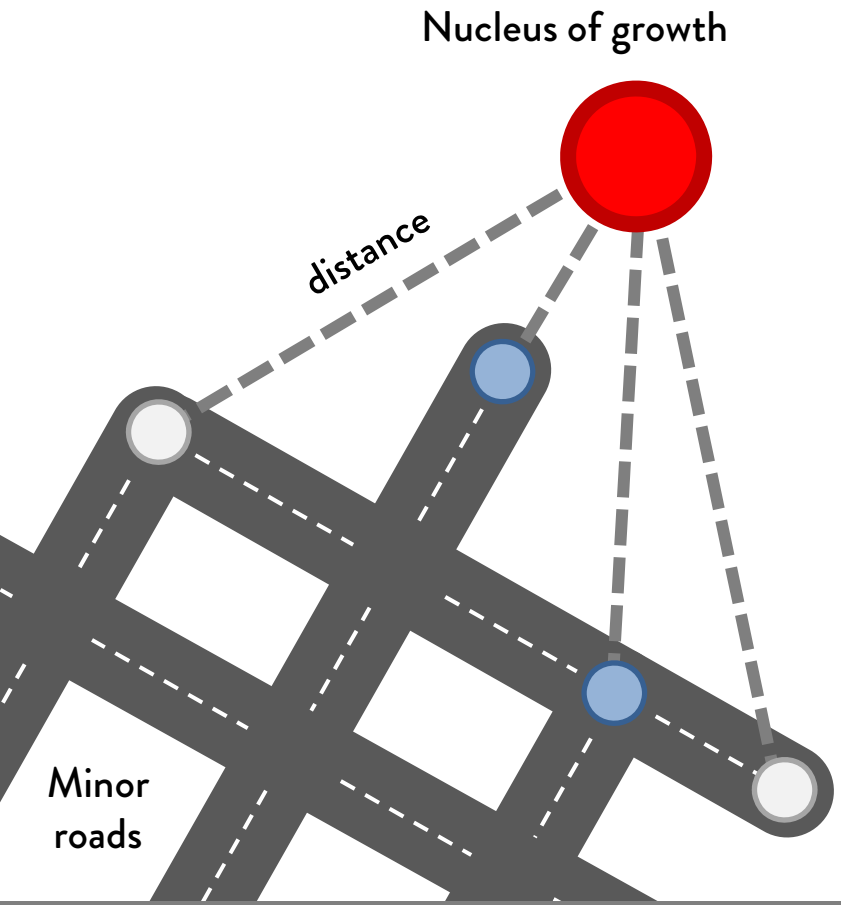
- Intersections
- Nuclei of growth
- Choose *N* intersections?
  - *N* ∈ "*Historical context*"

Minor Roads



- Intersections
- Nuclei of growth
- Choose *N* intersections?
  - *N* ∈ "*Historical context*"
- Closer = more probable

Minor Roads



- Intersections
- Nuclei of growth
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  - *N* ∈ "*Historical context*"
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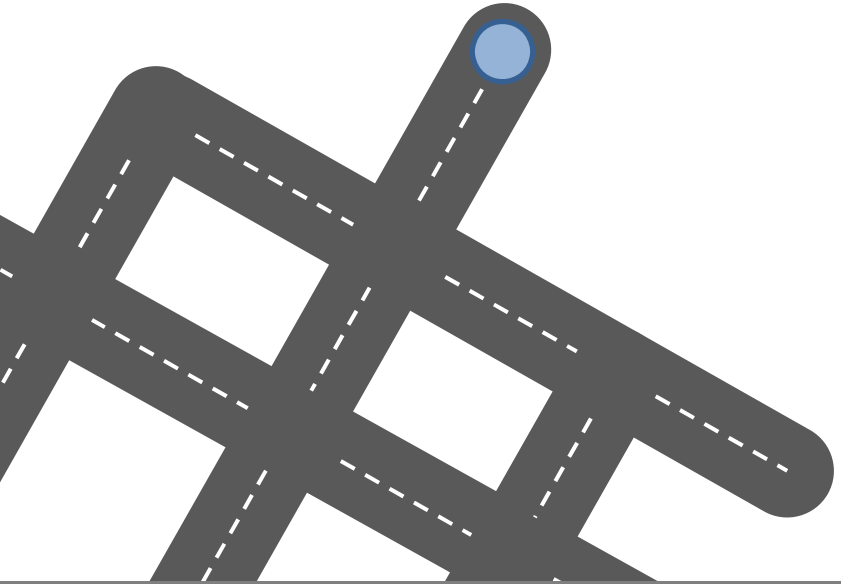
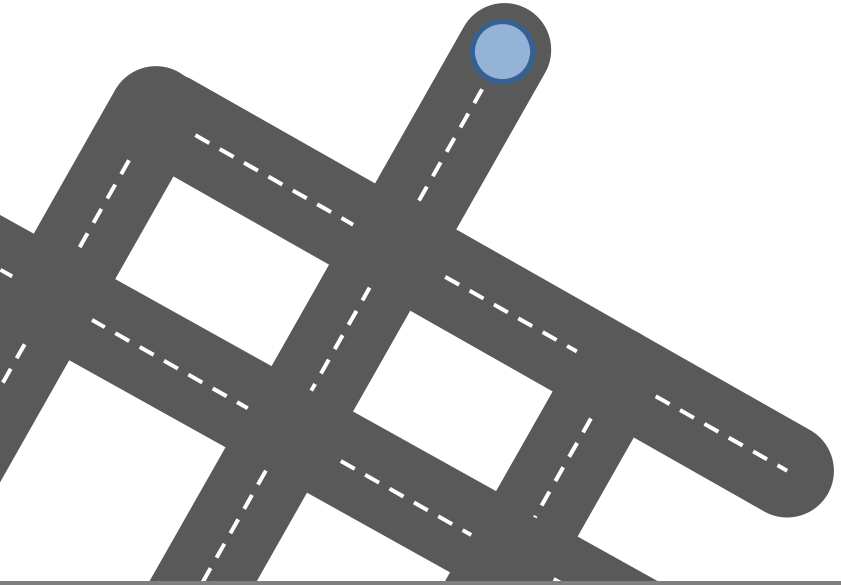
Minor Roads

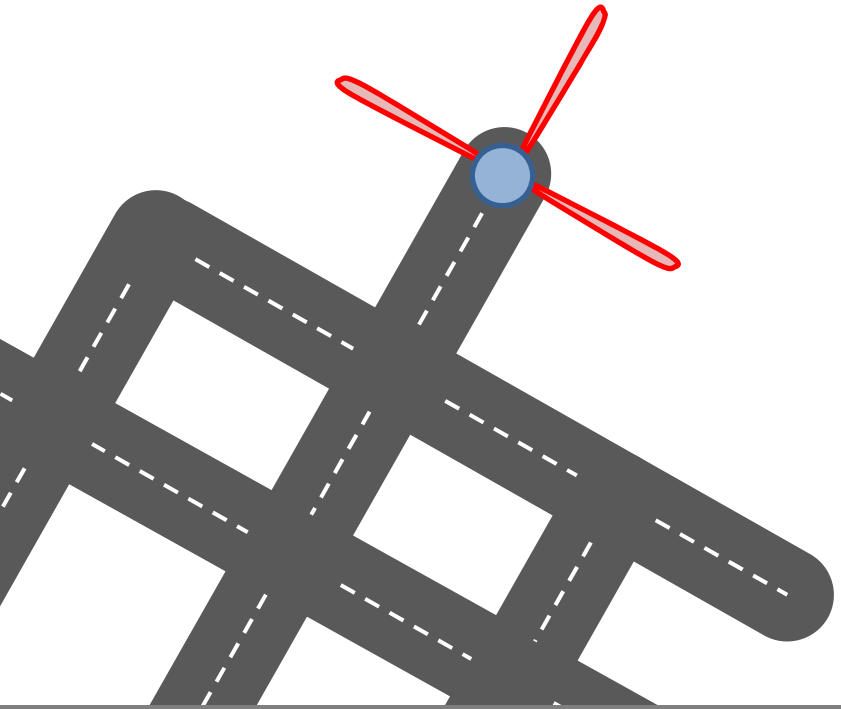


Minor Roads

- Similar to [Muller01] and [Weber09]



Minor Roads



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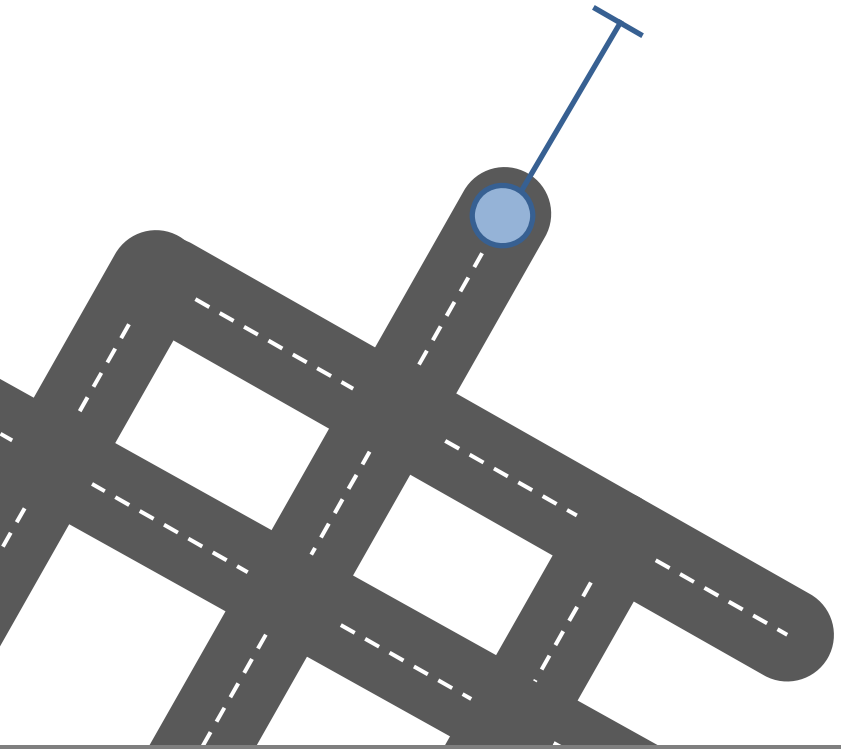

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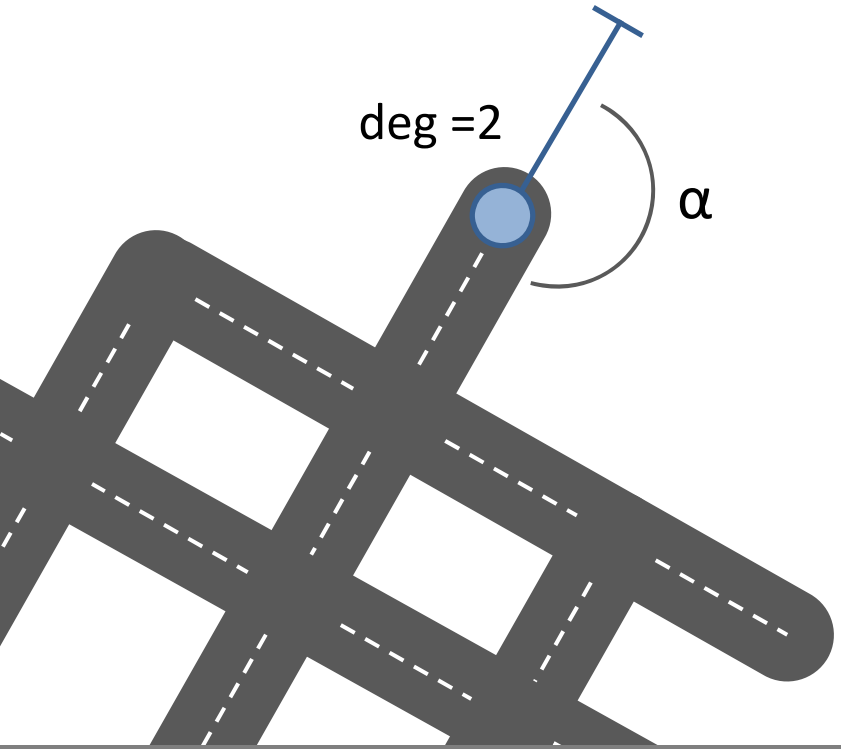
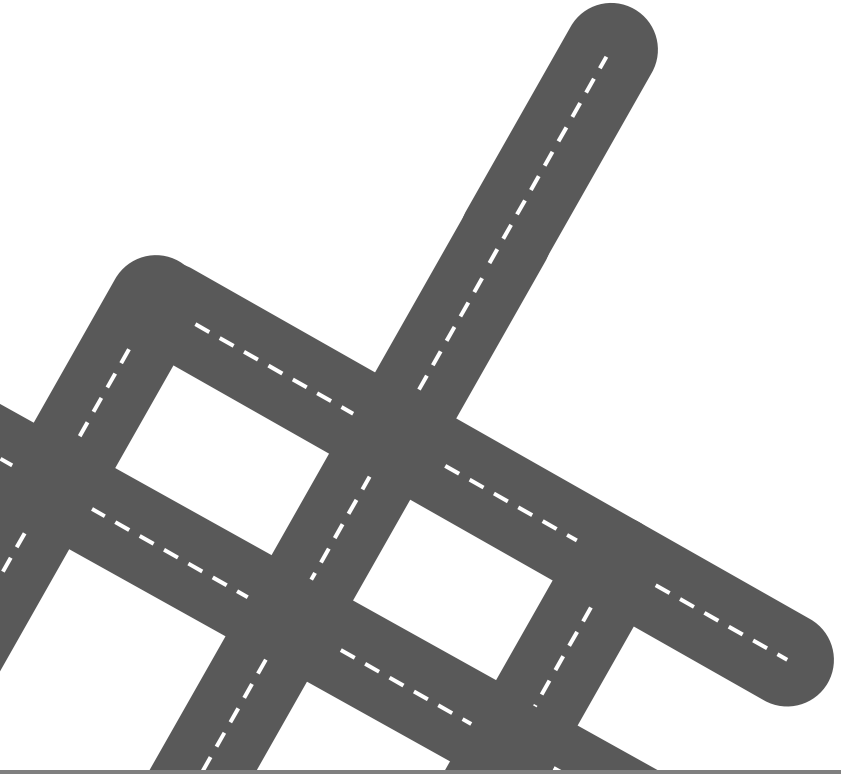


- Similar to [Muller01] and [Weber09]
- Constraints

Minor Roads



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- Constraints

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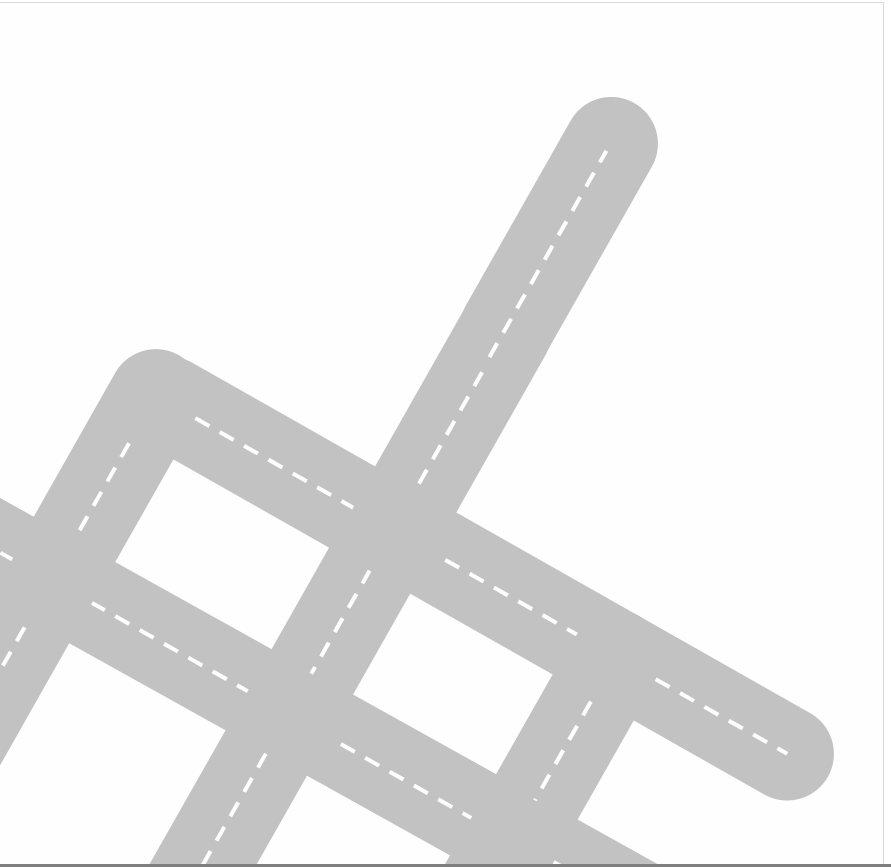

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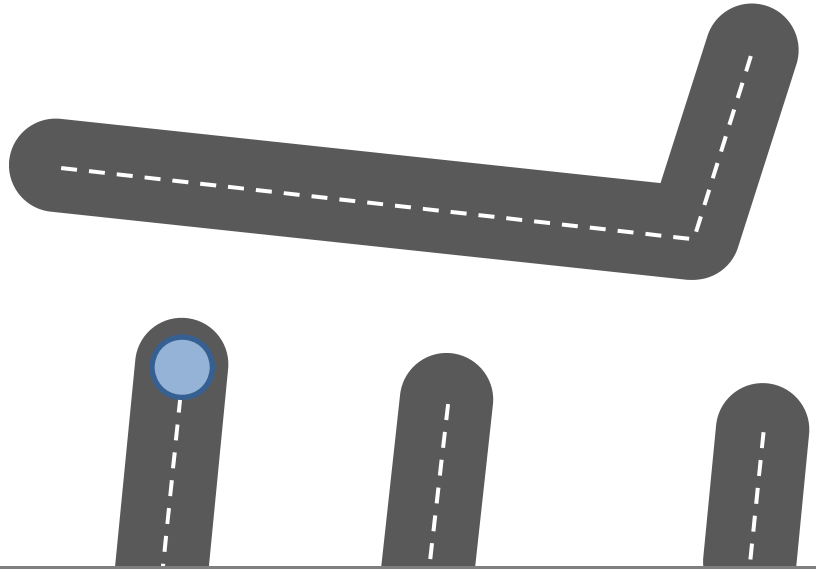
- Constraints
- Good fit



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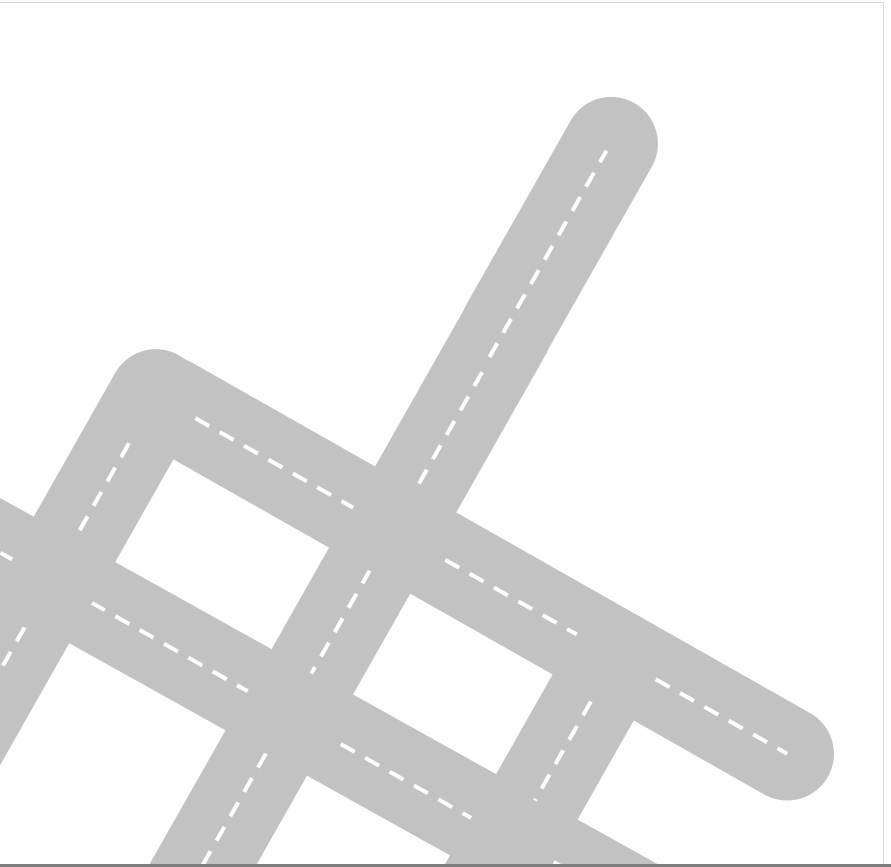

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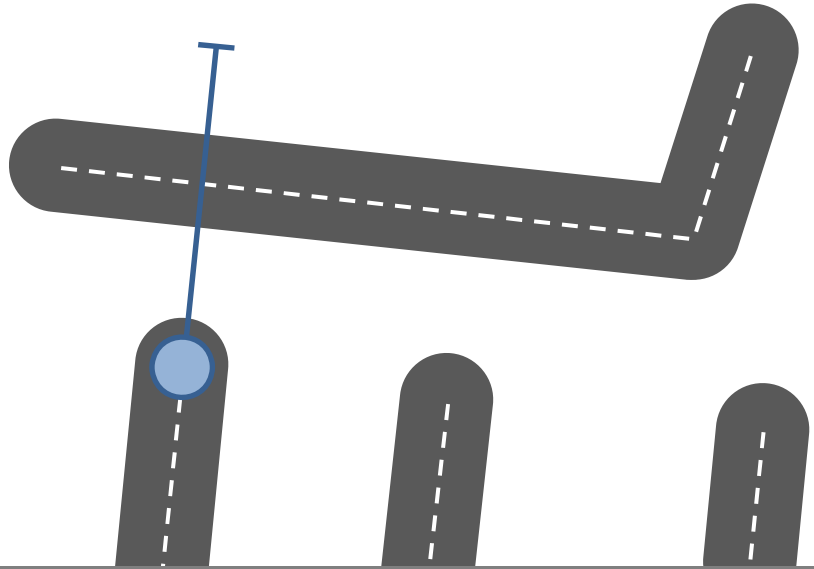

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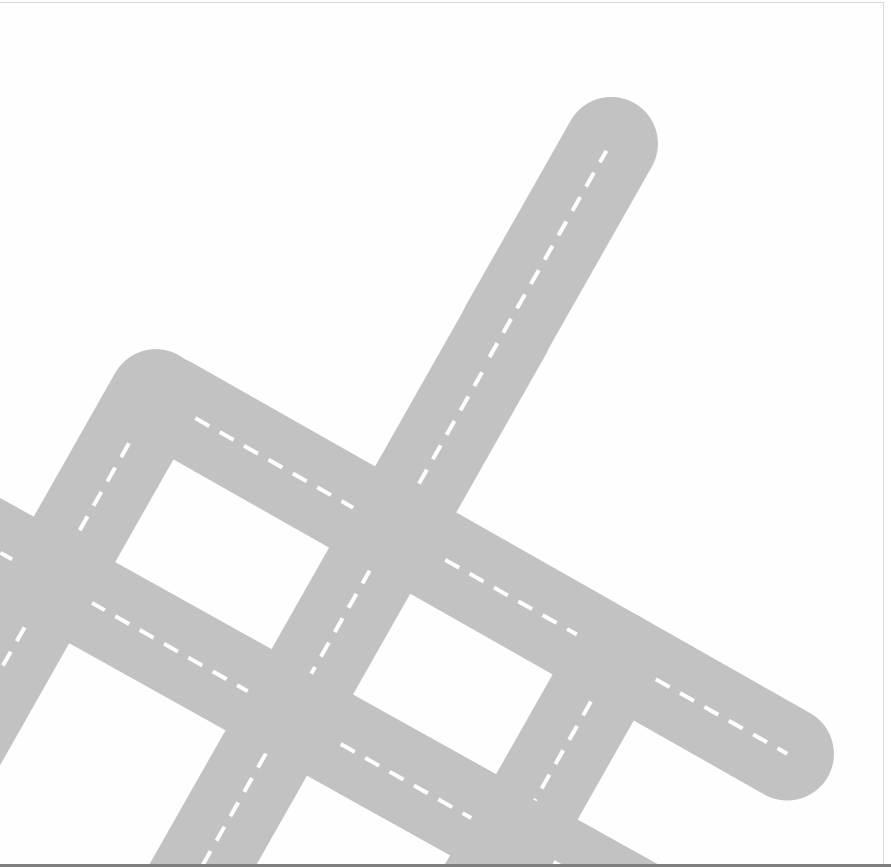

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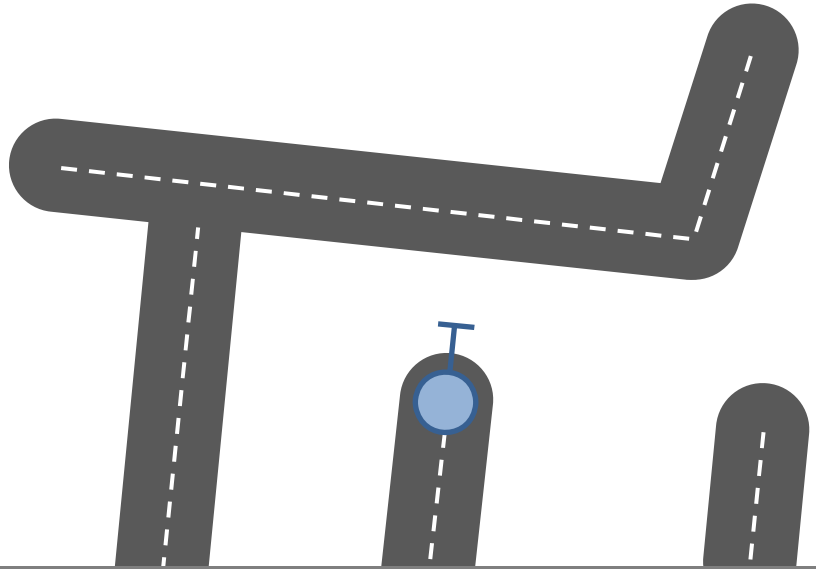

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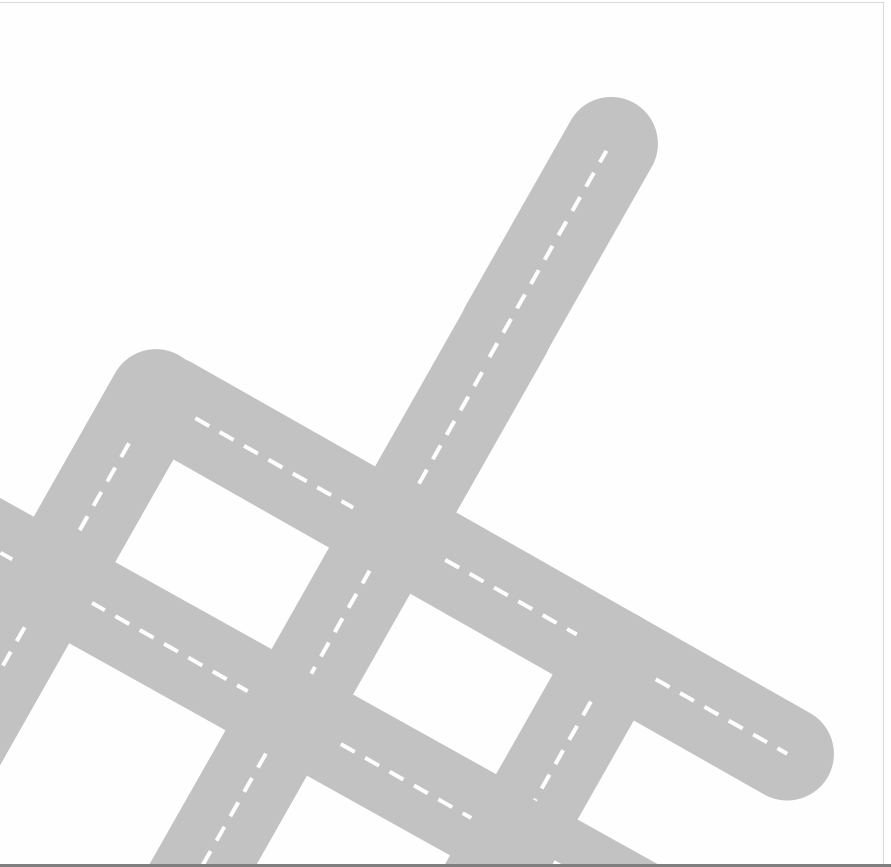

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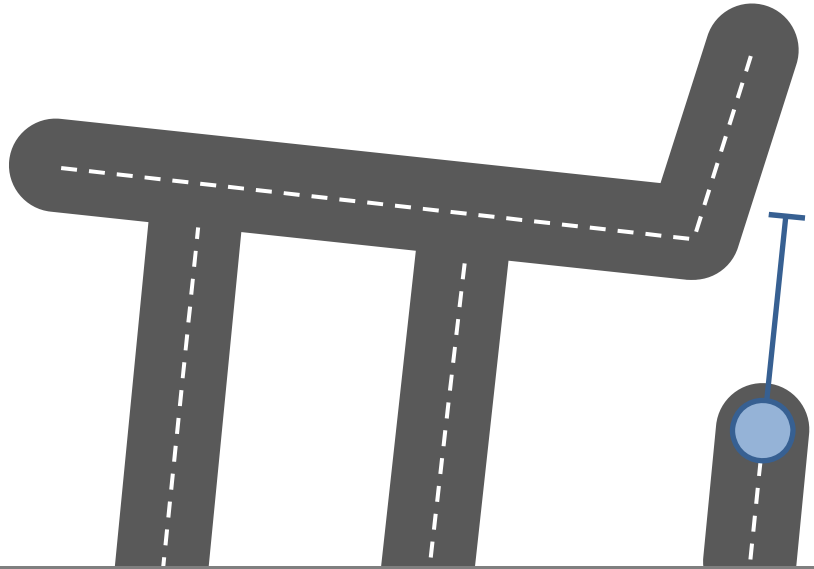

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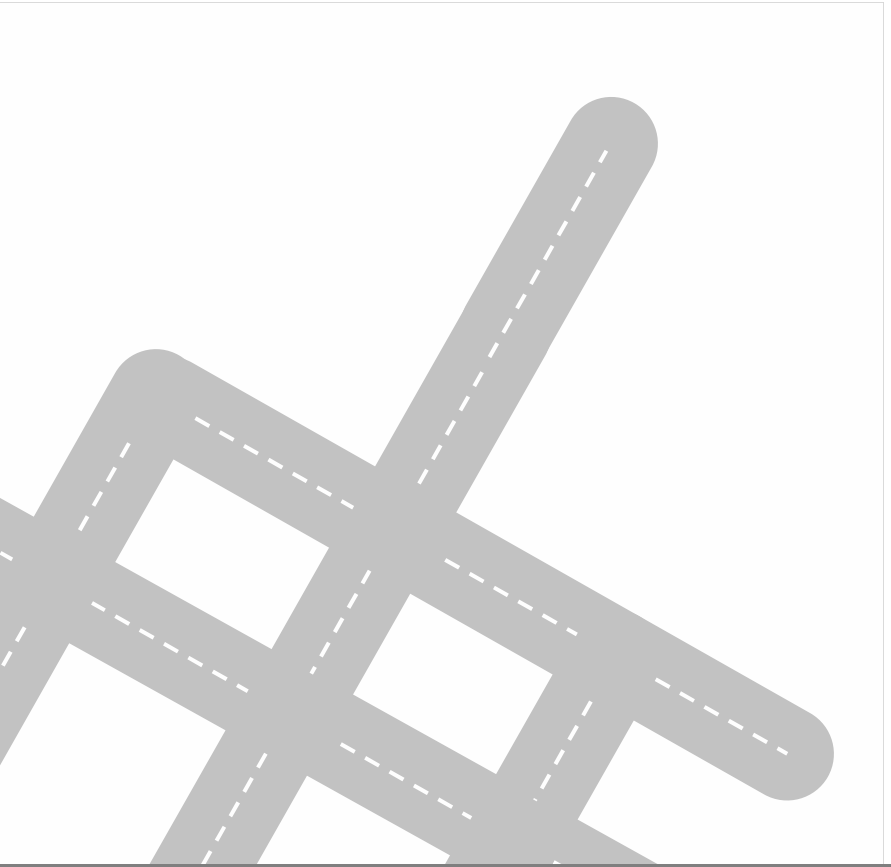

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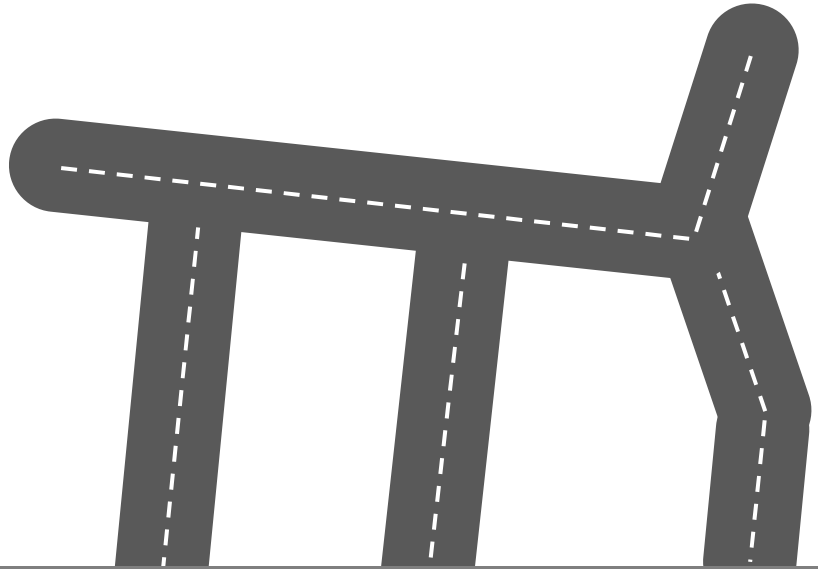
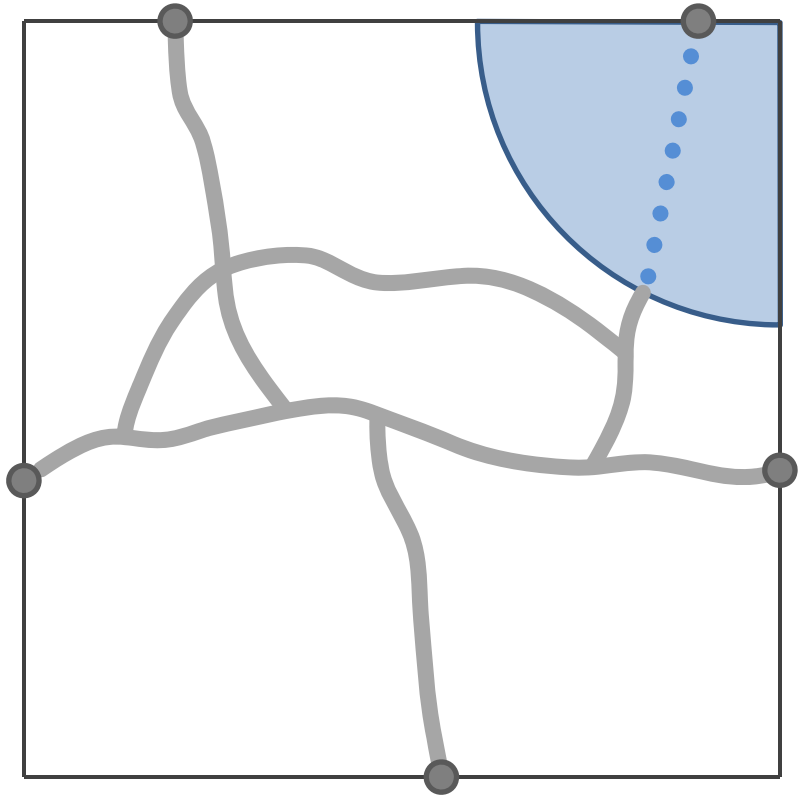


Trade Simulation

- **Simulate trade**
  - Neighbouring cities



Trade Simulation

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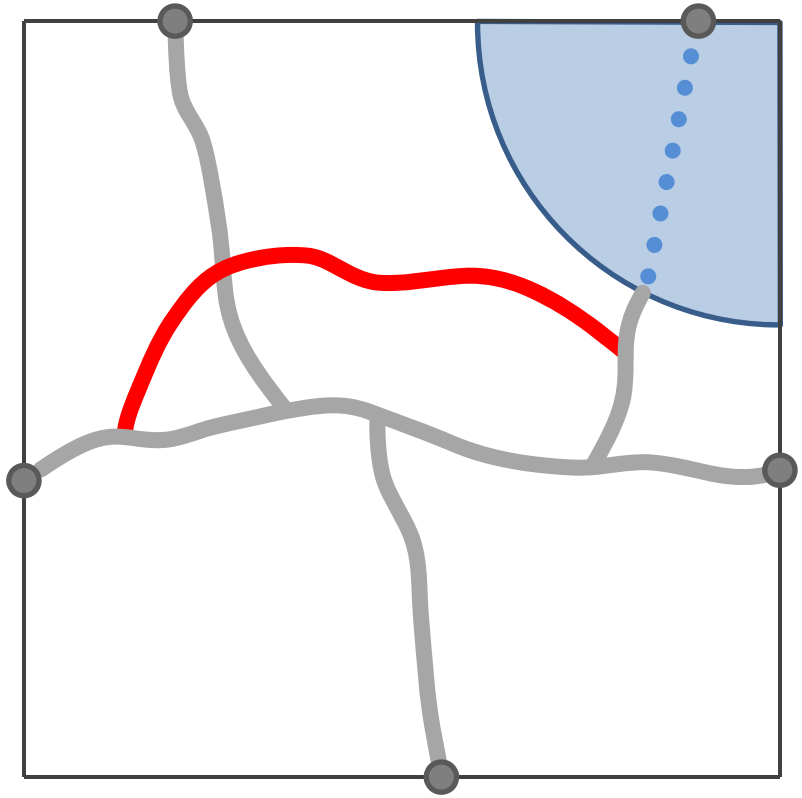

Trade Simulation

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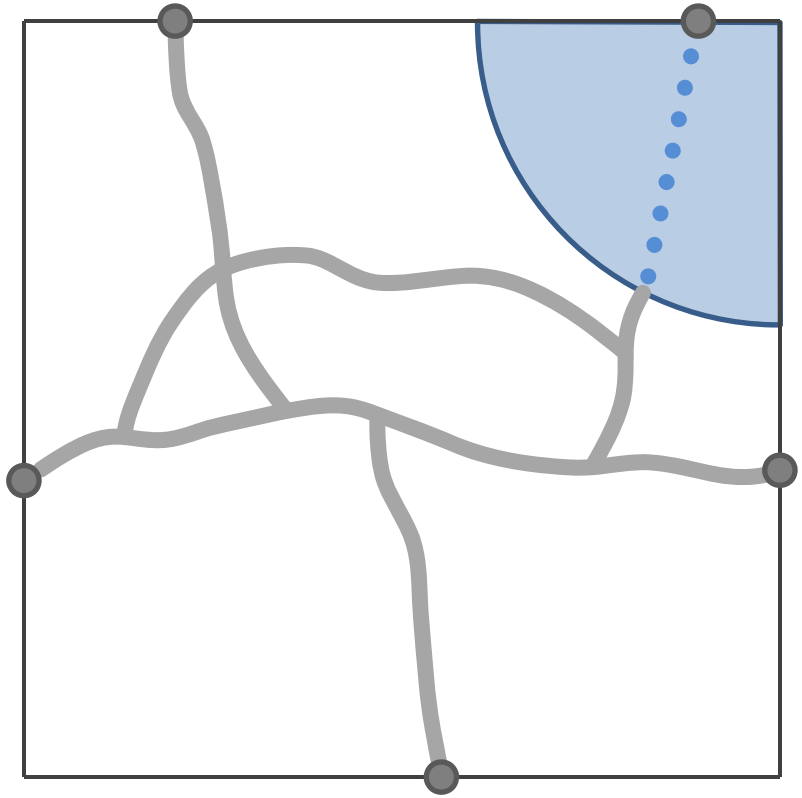

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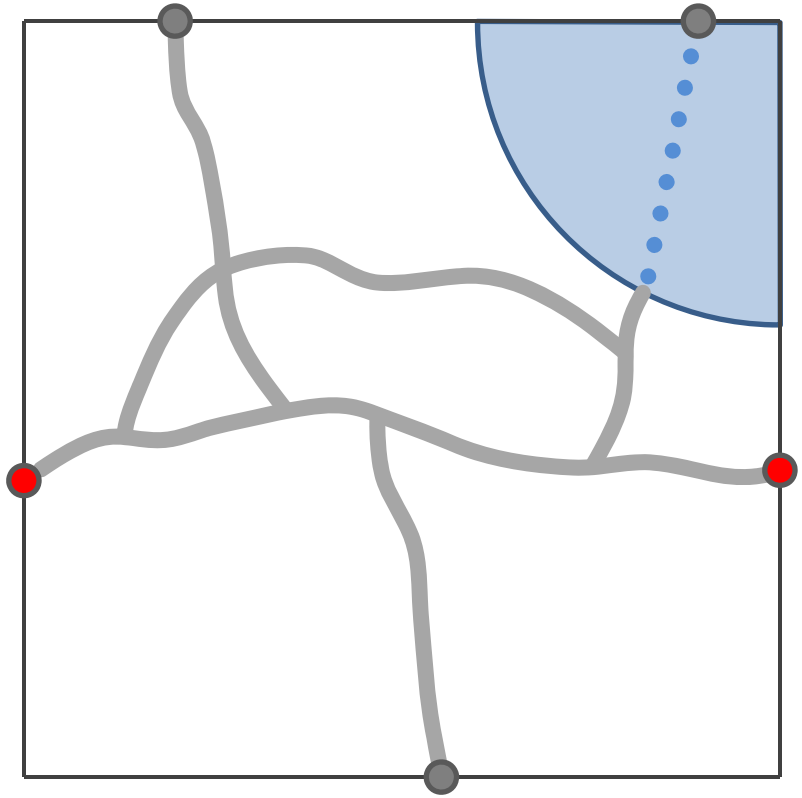
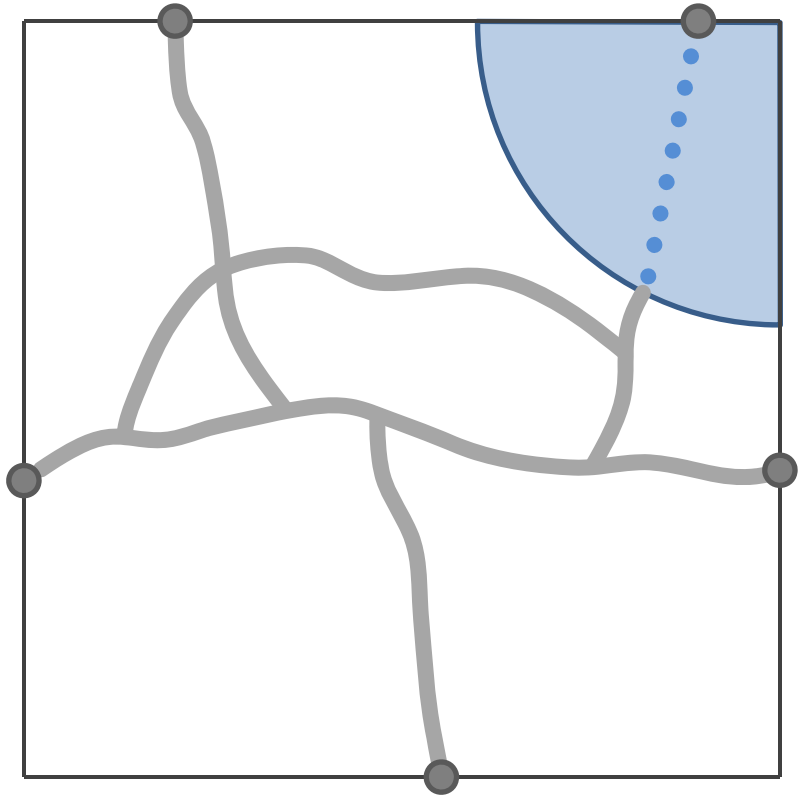
  - Neighbouring cities



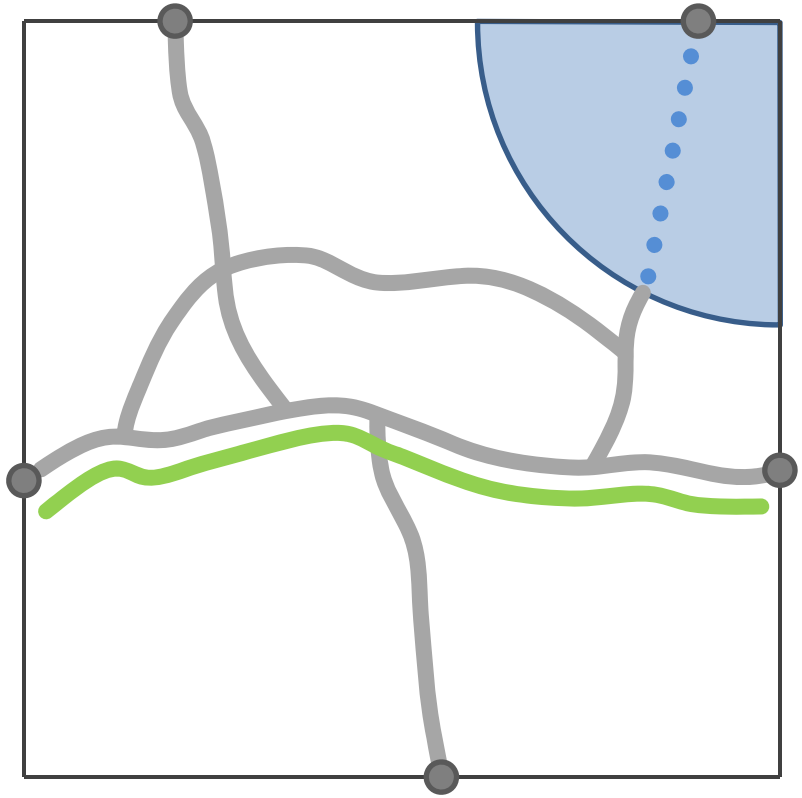
Trade Simulation

- **Simulate trade**
  - Neighbouring cities
- Trade routes



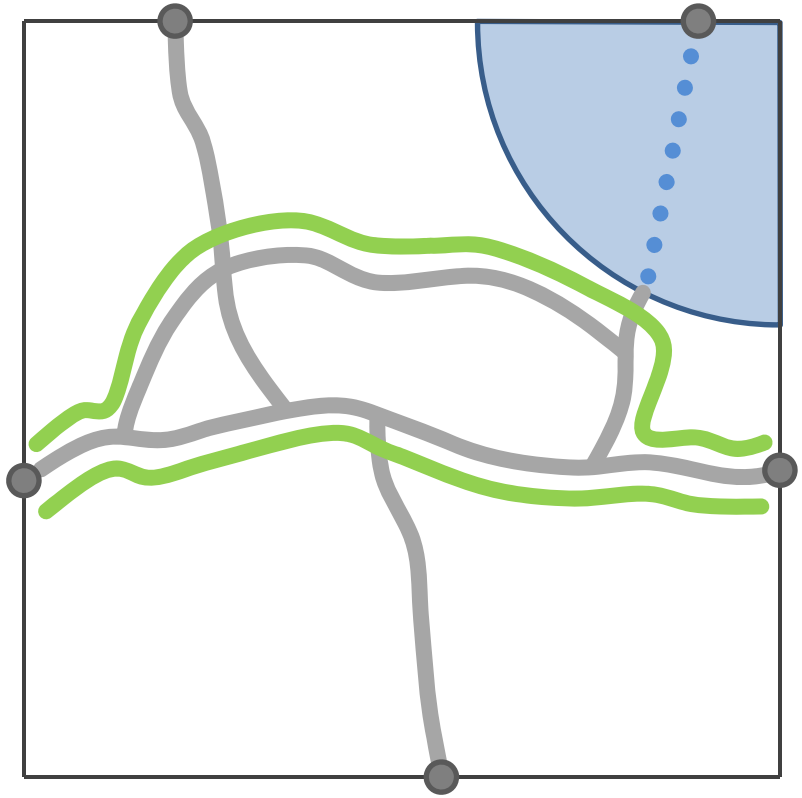
Trade Simulation

- **Simulate trade**
  - Neighbouring cities
- Trade routes
  - One



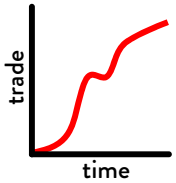
Trade Simulation

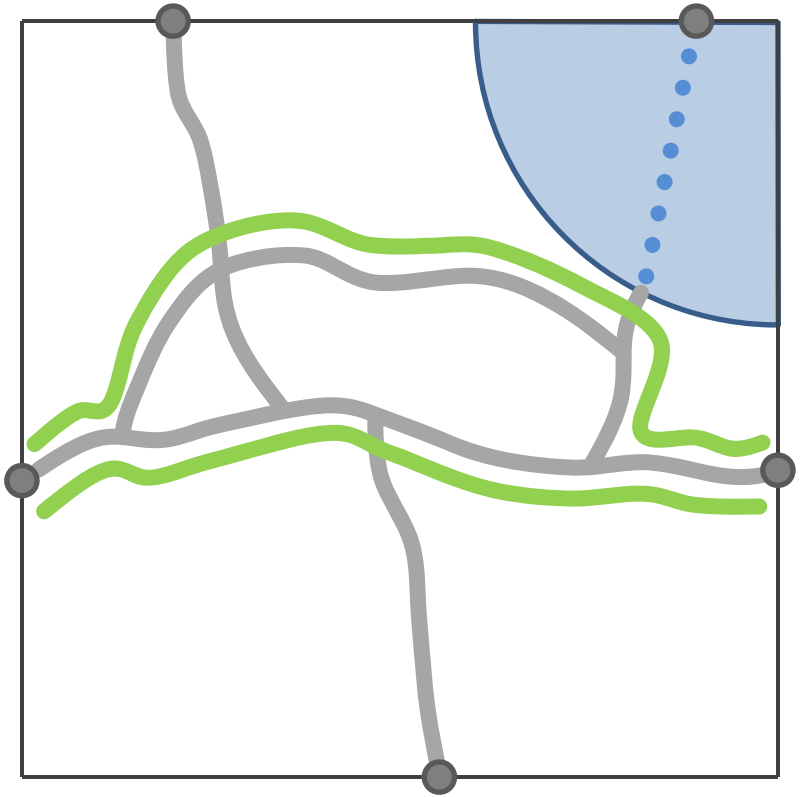
- **Simulate trade**
  - Neighbouring cities
- Trade routes
  - One
  - Or more



Trade Simulation

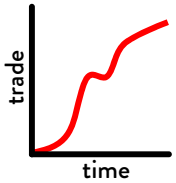
- **Simulate trade**
  - Neighbouring cities
- Trade routes
  - One
  - Or more
- Amount of trade
  - *"Historical context"*

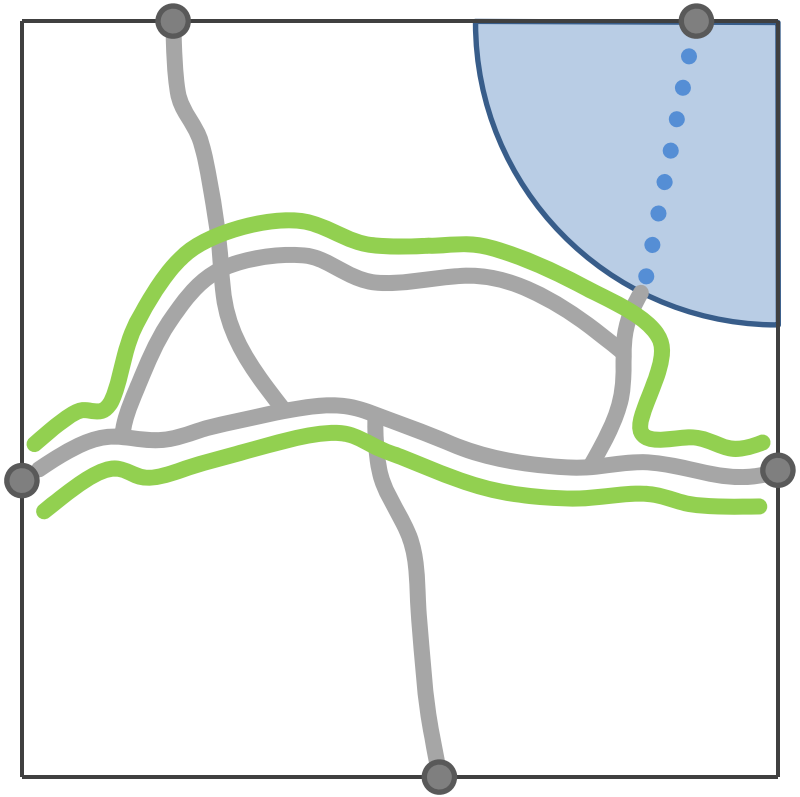




Trade Simulation

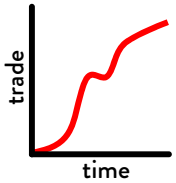
- **Simulate trade**
  - Neighbouring cities
- Trade routes
  - One
  - Or more
- Amount of trade
  - *"Historical context"*
- Trade routes full?

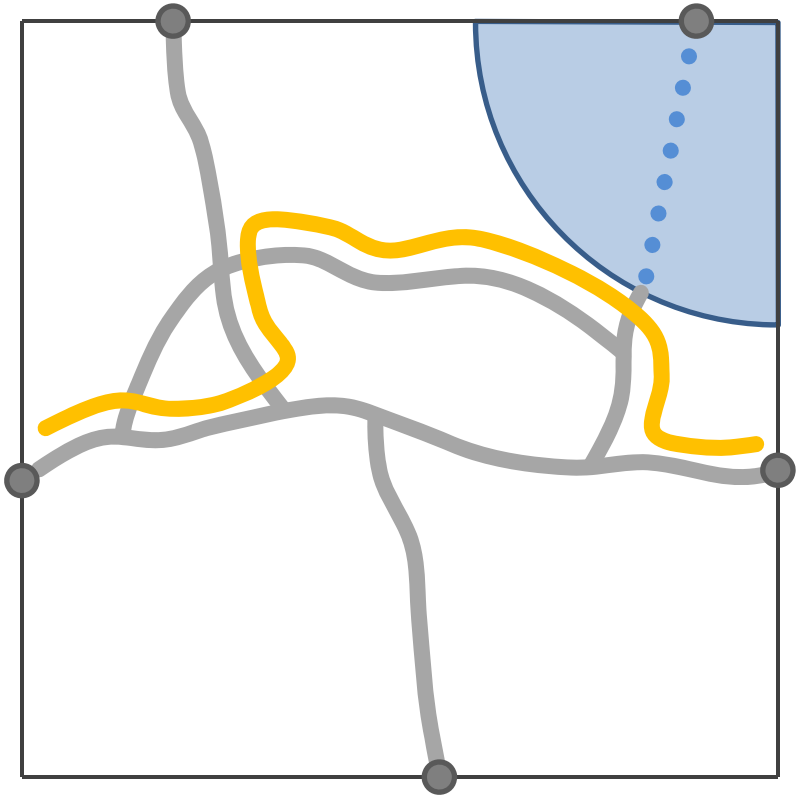




Trade Simulation

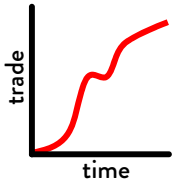
- **Simulate trade**
  - Neighbouring cities
- Trade routes
  - One
  - Or more
- Amount of trade
  - *"Historical context"*
- Trade routes full?
  - New trade route

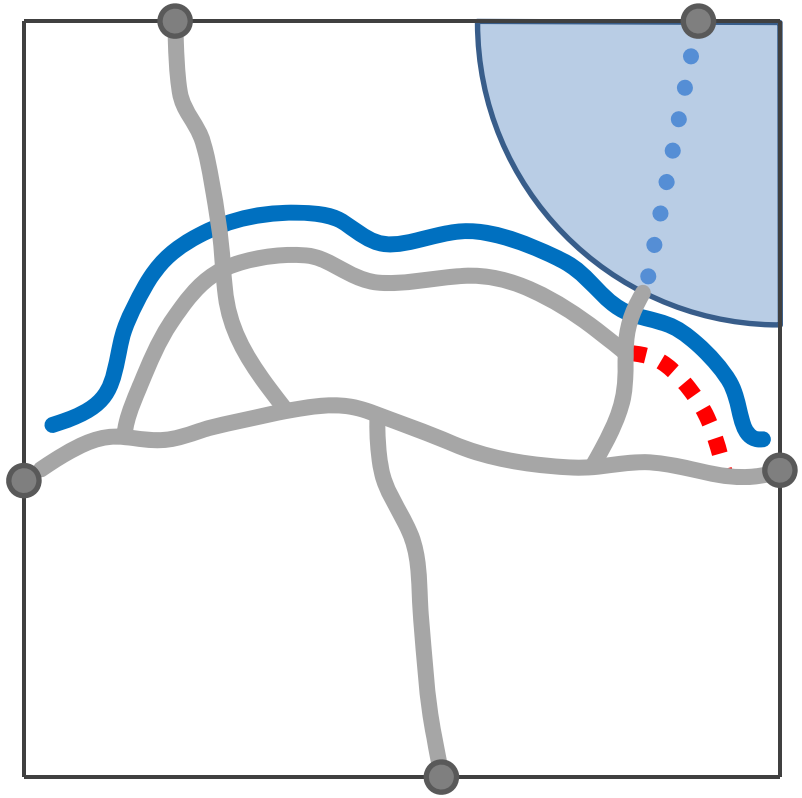




Trade Simulation

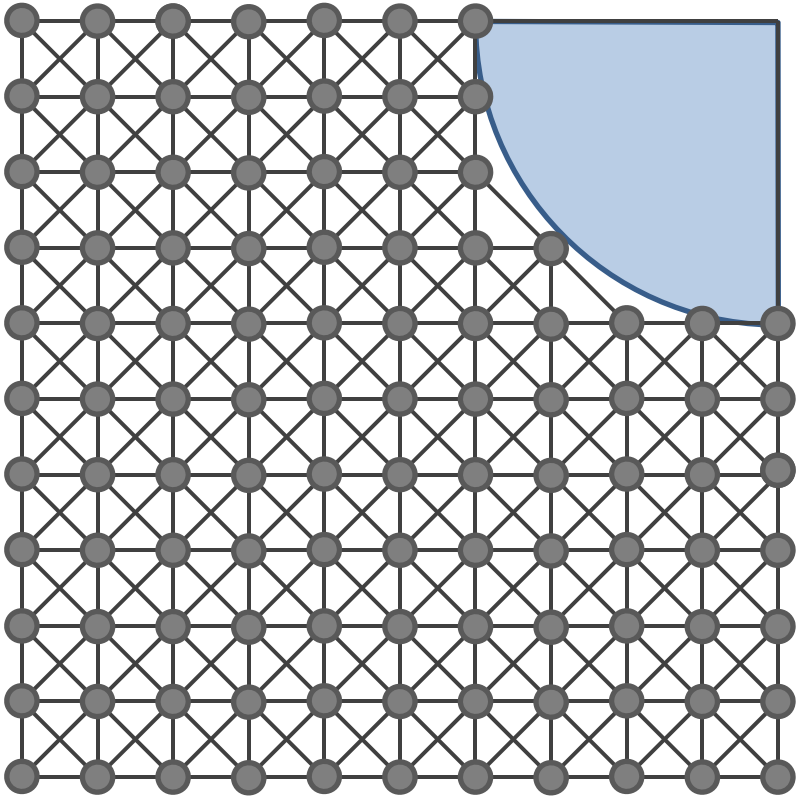
- **Simulate trade**
  - Neighbouring cities
- Trade routes
  - One
  - Or more
- Amount of trade
  - *"Historical context"*
- Trade routes full?
  - New trade route
  - New major road & route





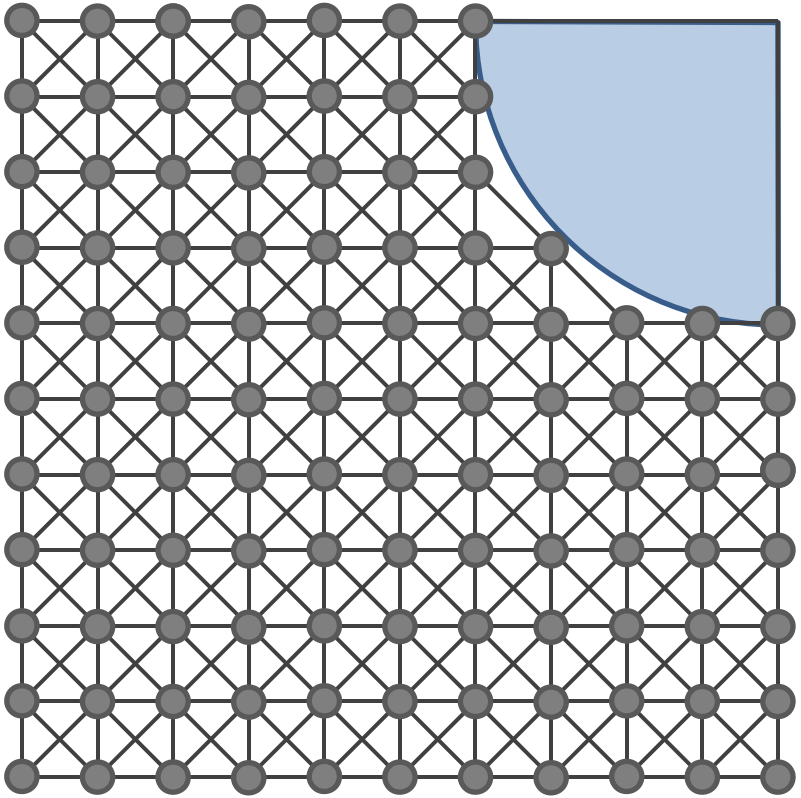
Major Roads

- [Galin10]
  - Overlay terrain with a graph



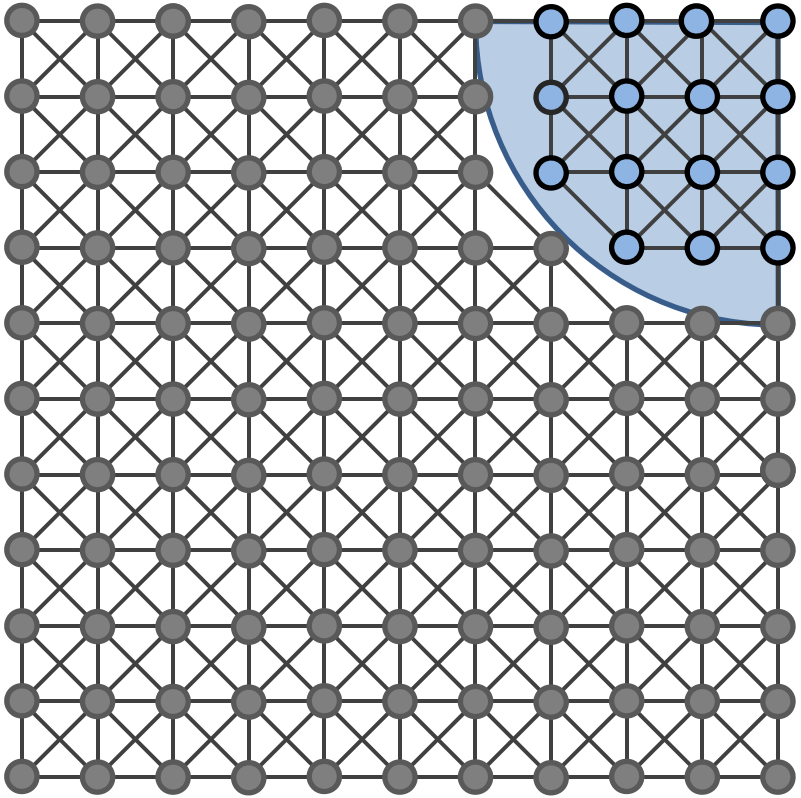
Major Roads

- [Galin10]
  - Overlay terrain with a graph
  - Curvature & elevation aware shortest path



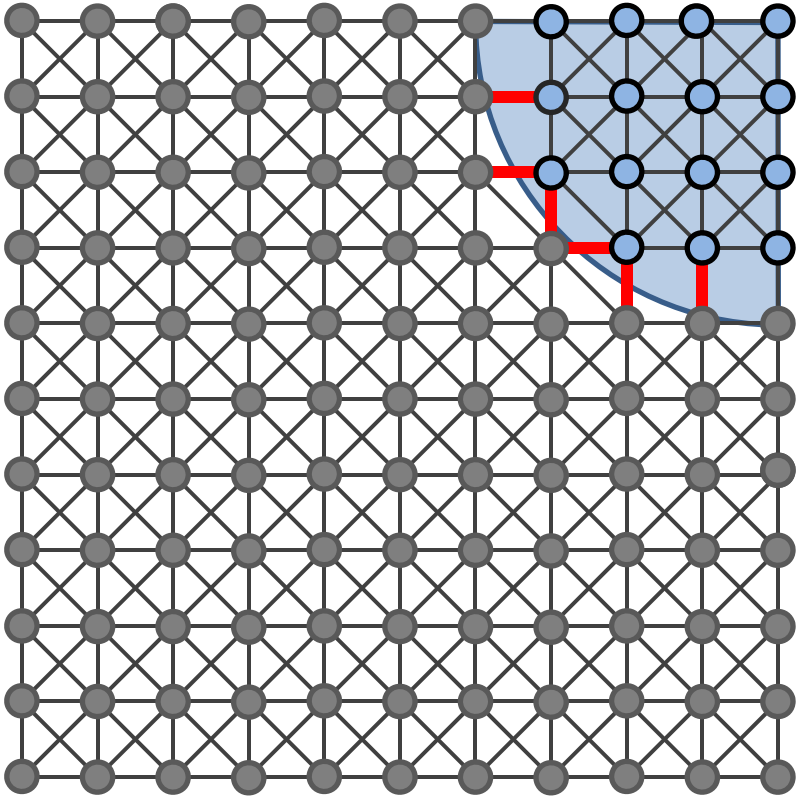
Major Roads

- [Galin10]
  - Overlay terrain with a graph
  - Curvature & elevation aware shortest path
- Extend
  - Water graph



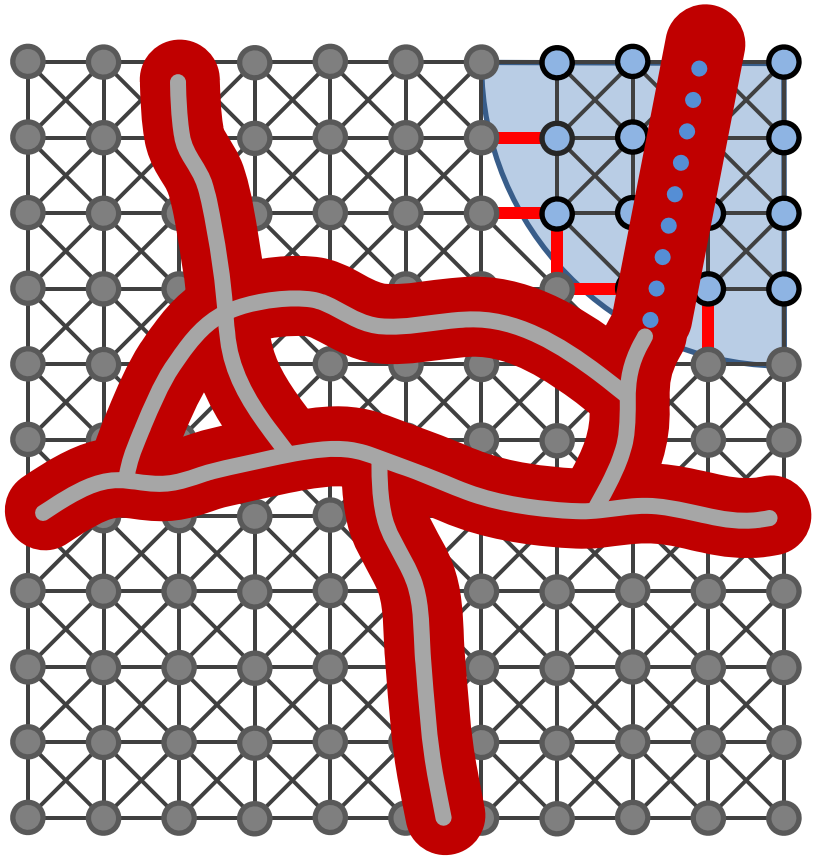
Major Roads

- [Galin10]
  - Overlay terrain with a graph
  - Curvature & elevation aware shortest path
- Extend
  - Water graph
  - Harbour edges



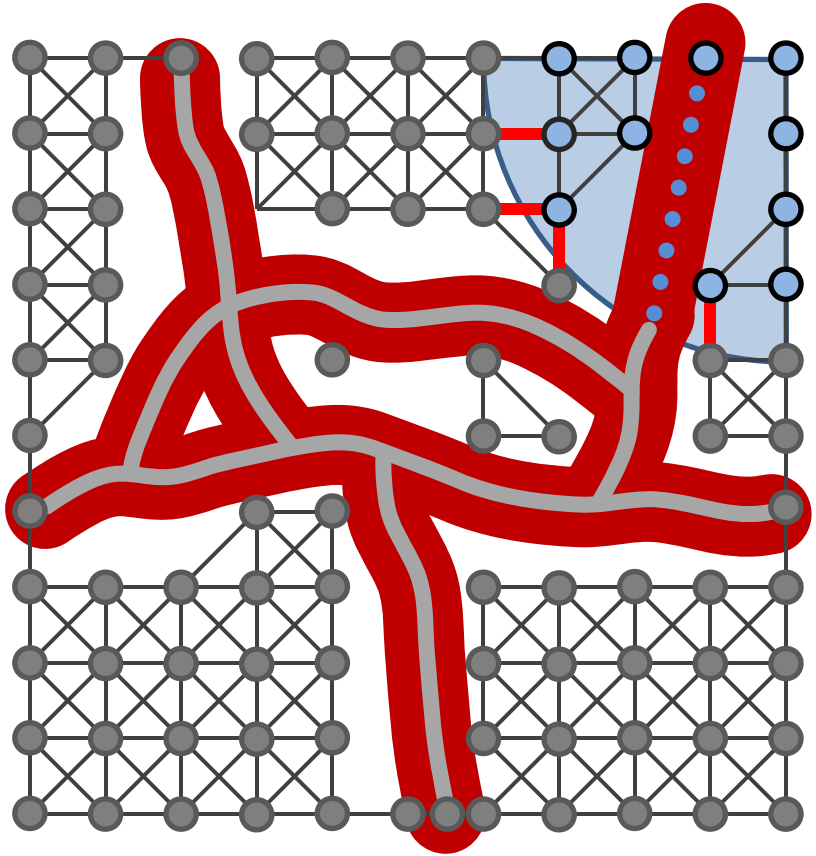
Major Roads

- [Galin10]
  - Overlay terrain with a graph
  - Curvature & elevation aware shortest path
- Extend
  - Water graph
  - Harbour edges
- Existing road network



Major Roads

- [Galin10]
  - Overlay terrain with a graph
  - Curvature & elevation aware shortest path
- Extend
  - Water graph
  - Harbour edges
- Existing road network
  - Remove collisions



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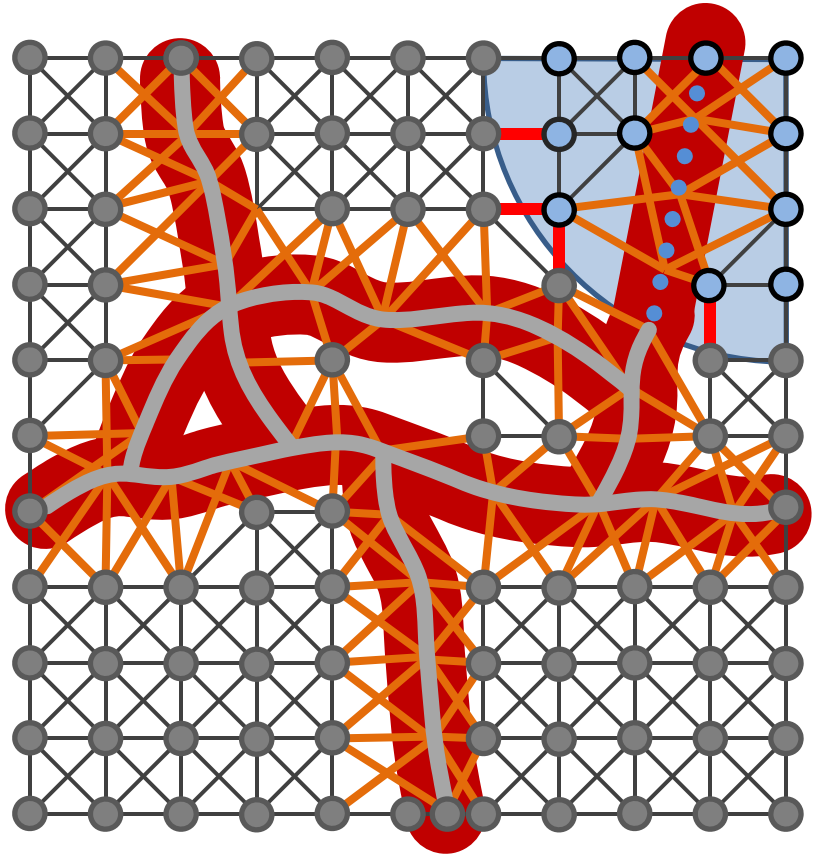
  - Stitch together



Major Roads

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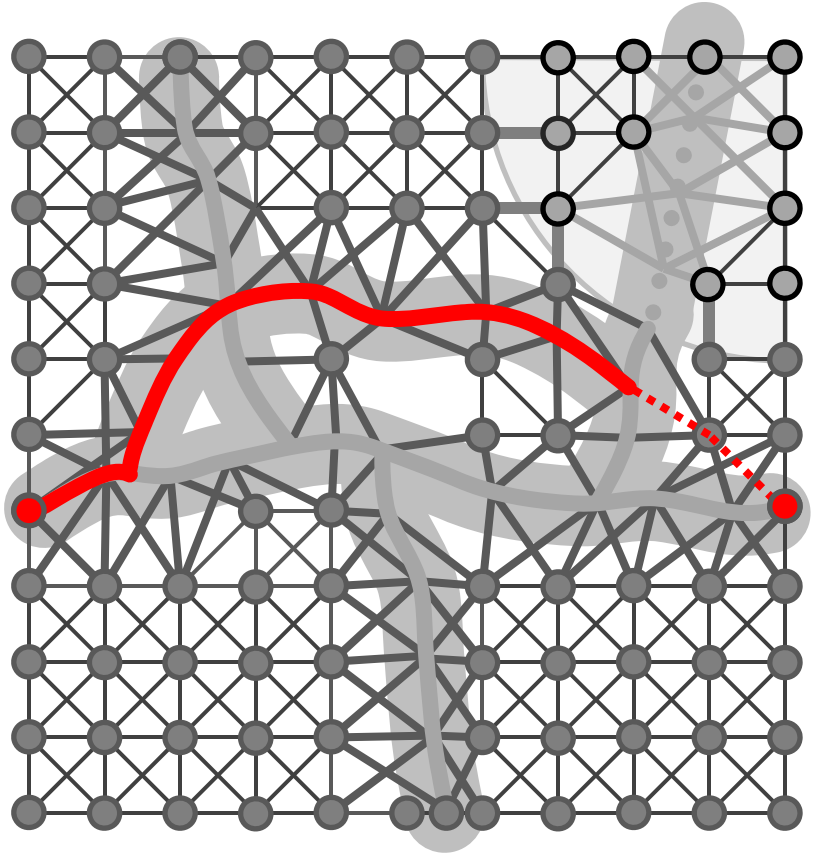

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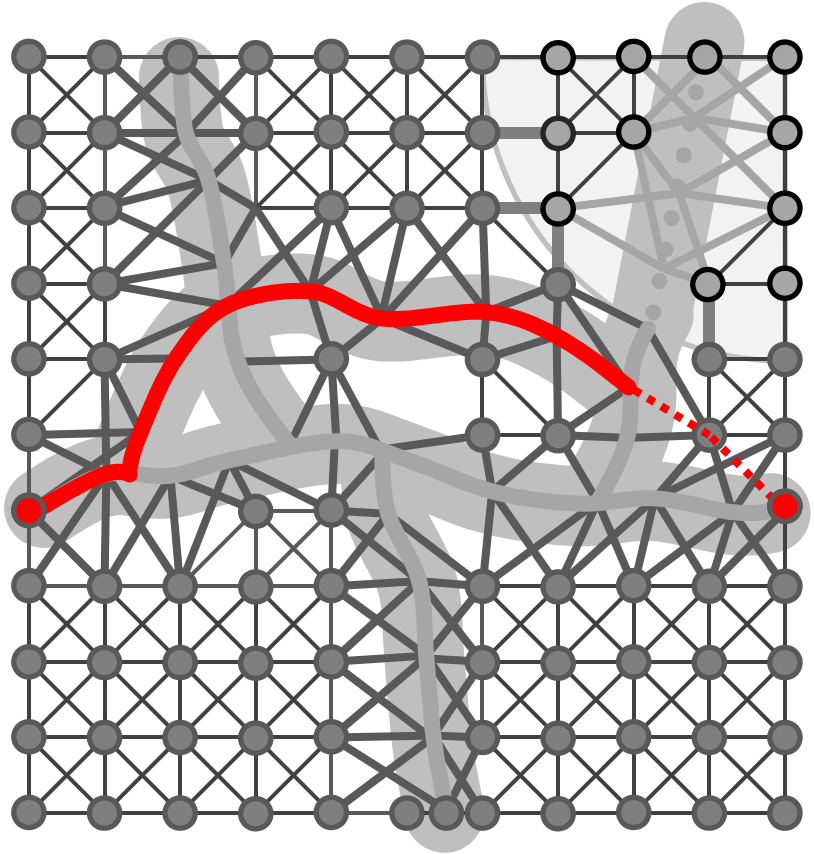
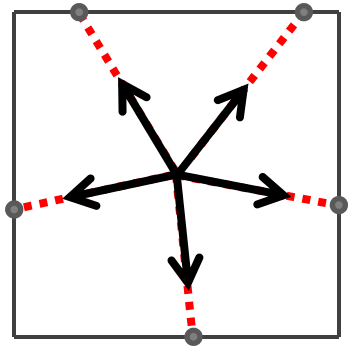


Recapitulation



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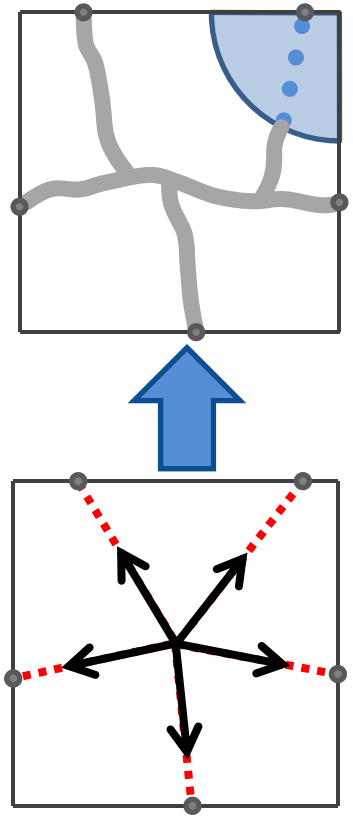

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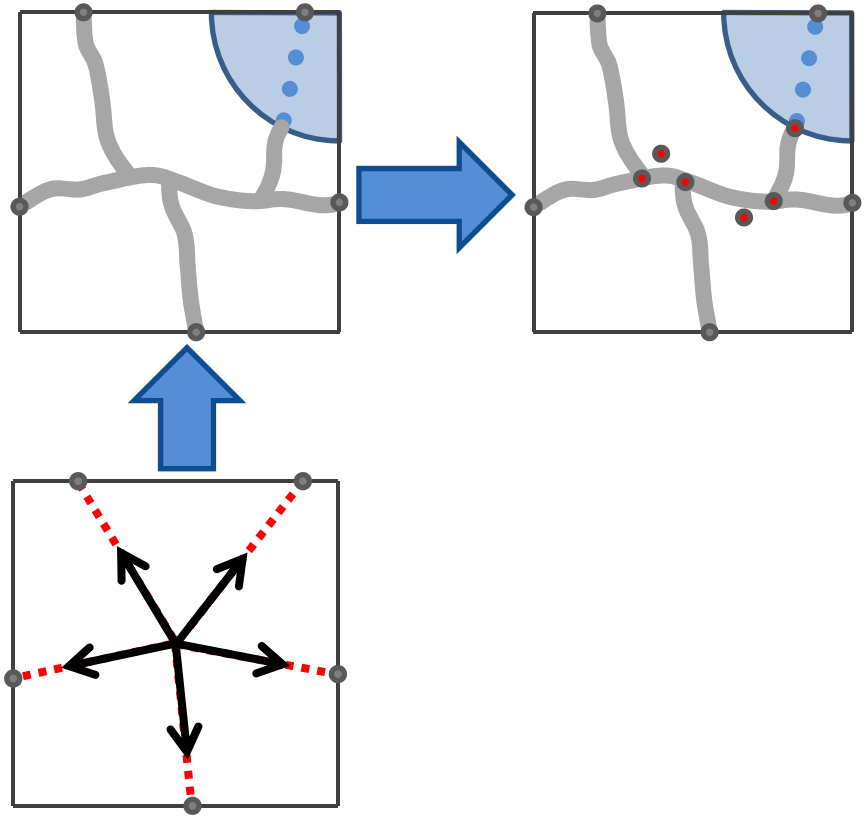

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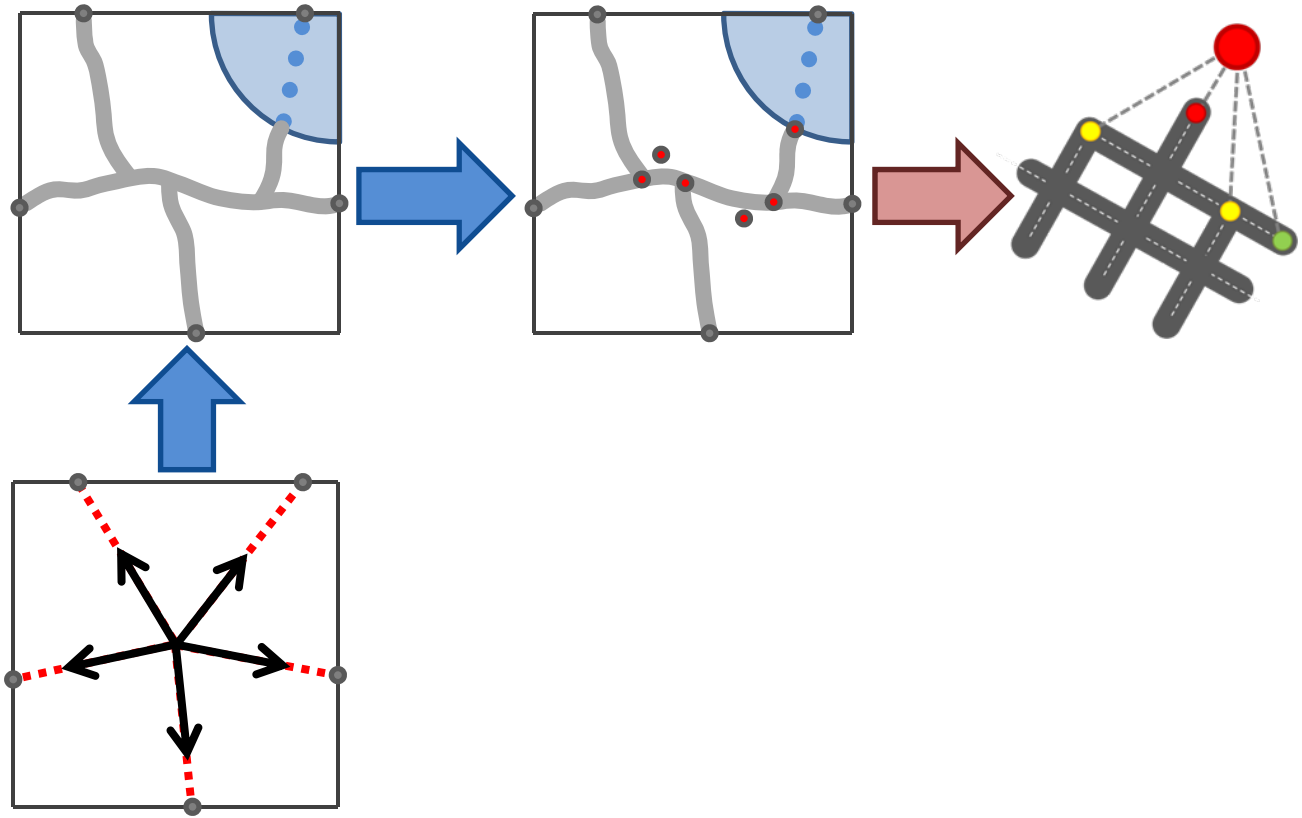

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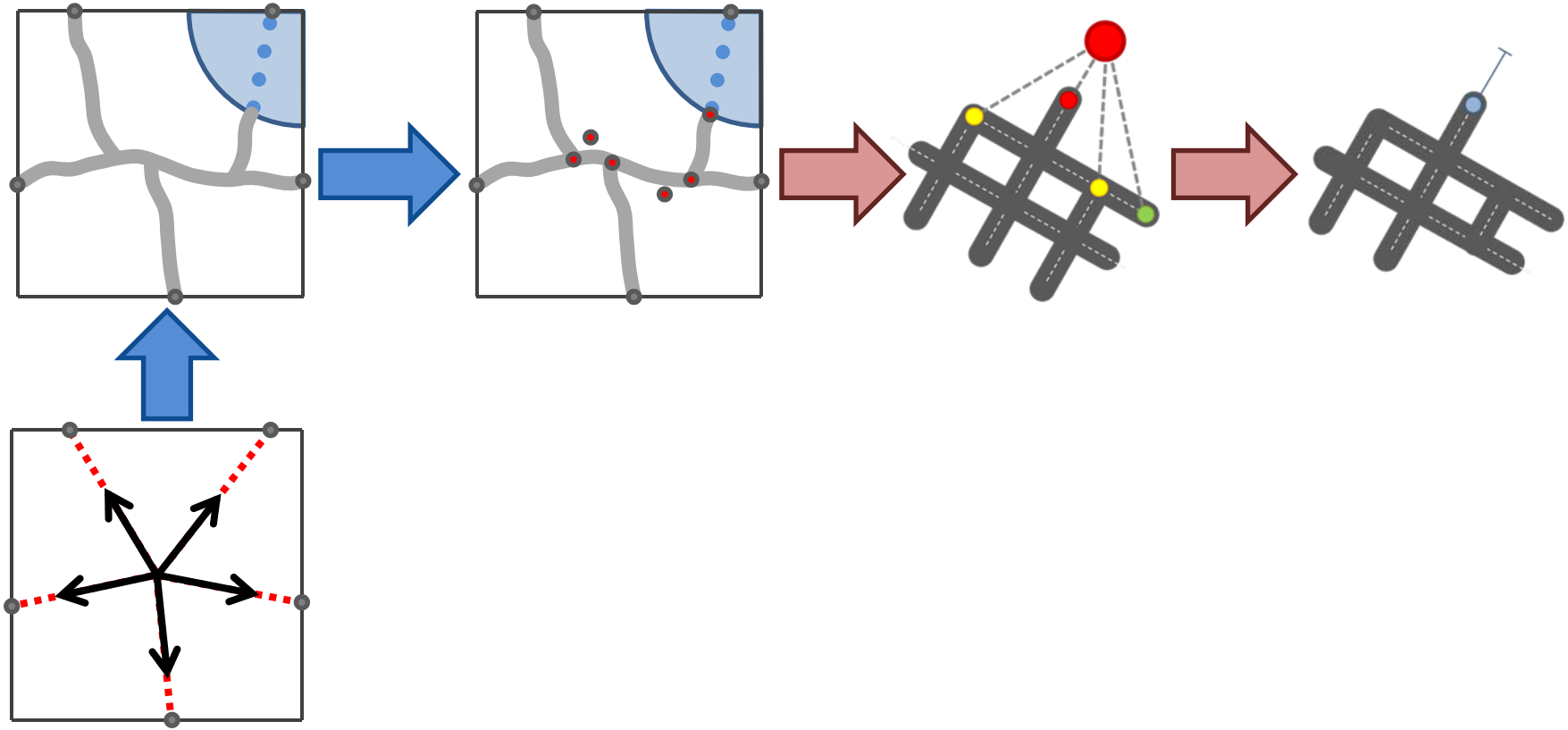

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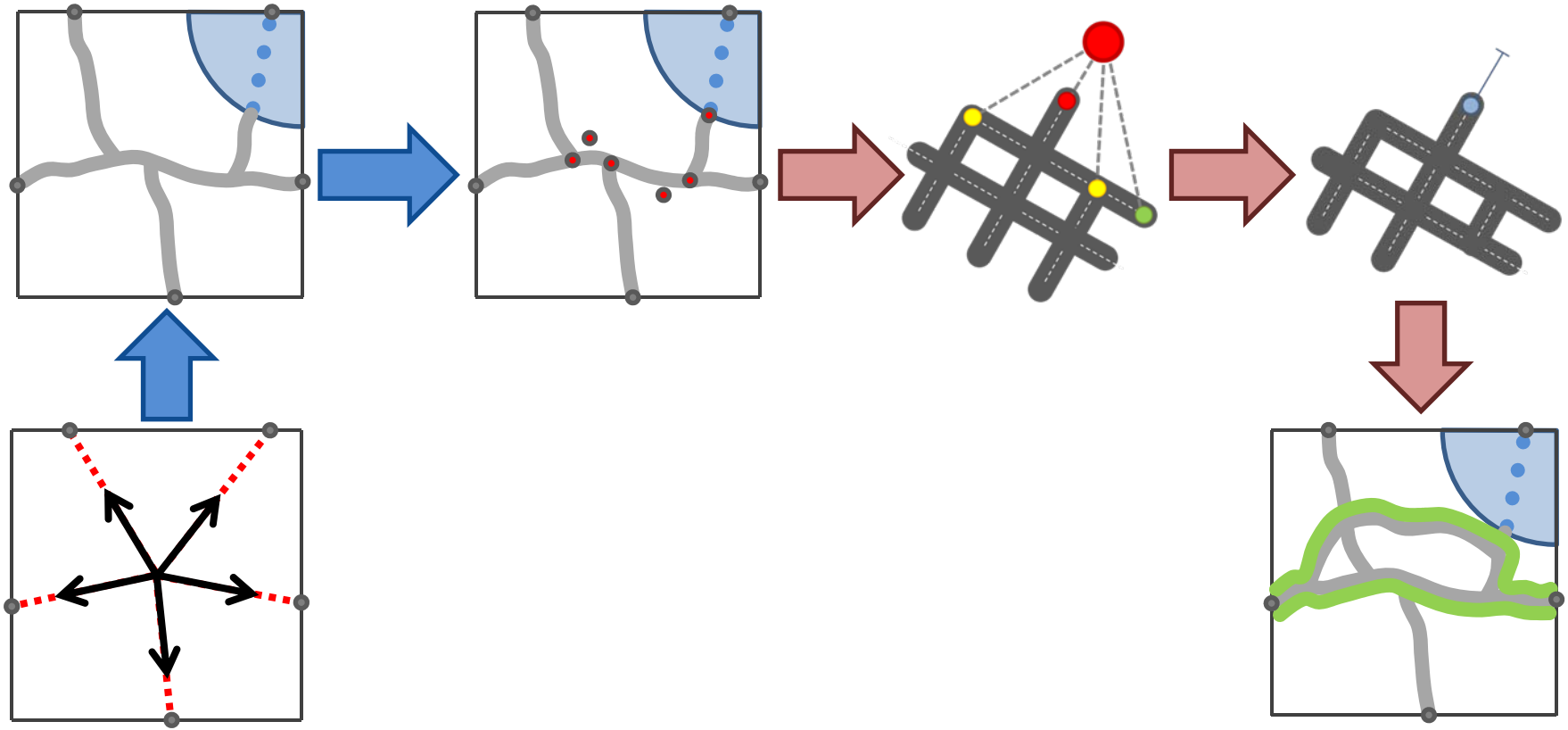

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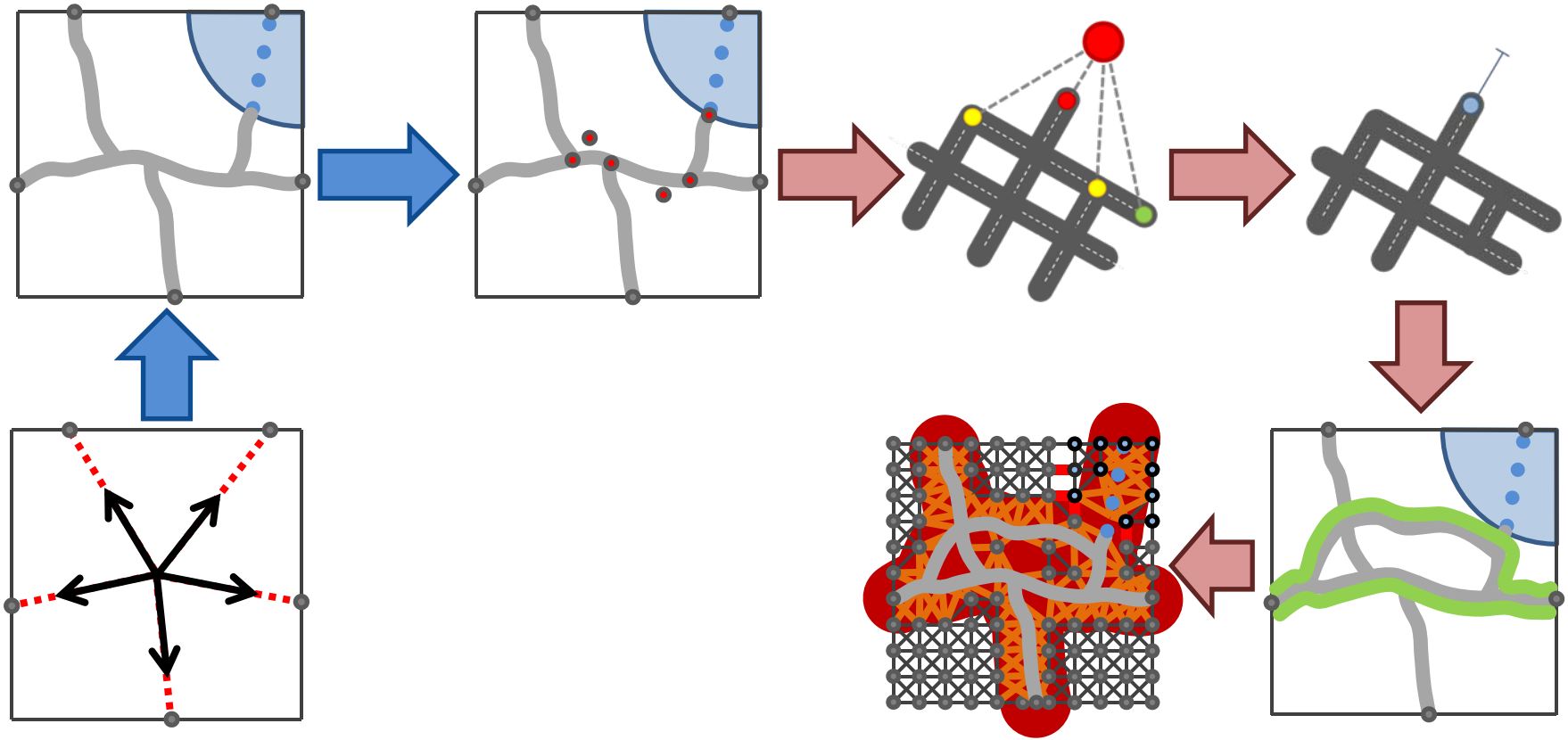

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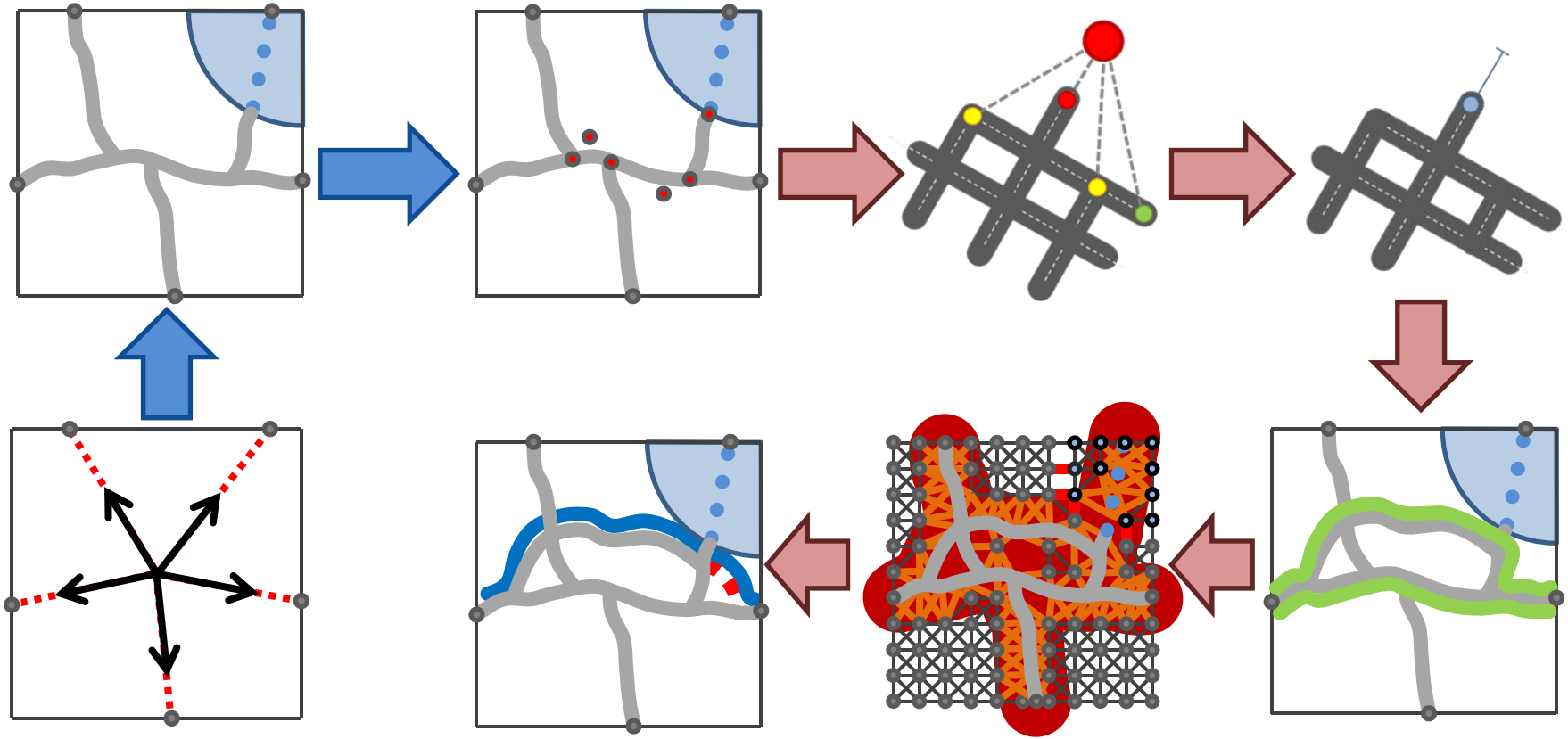

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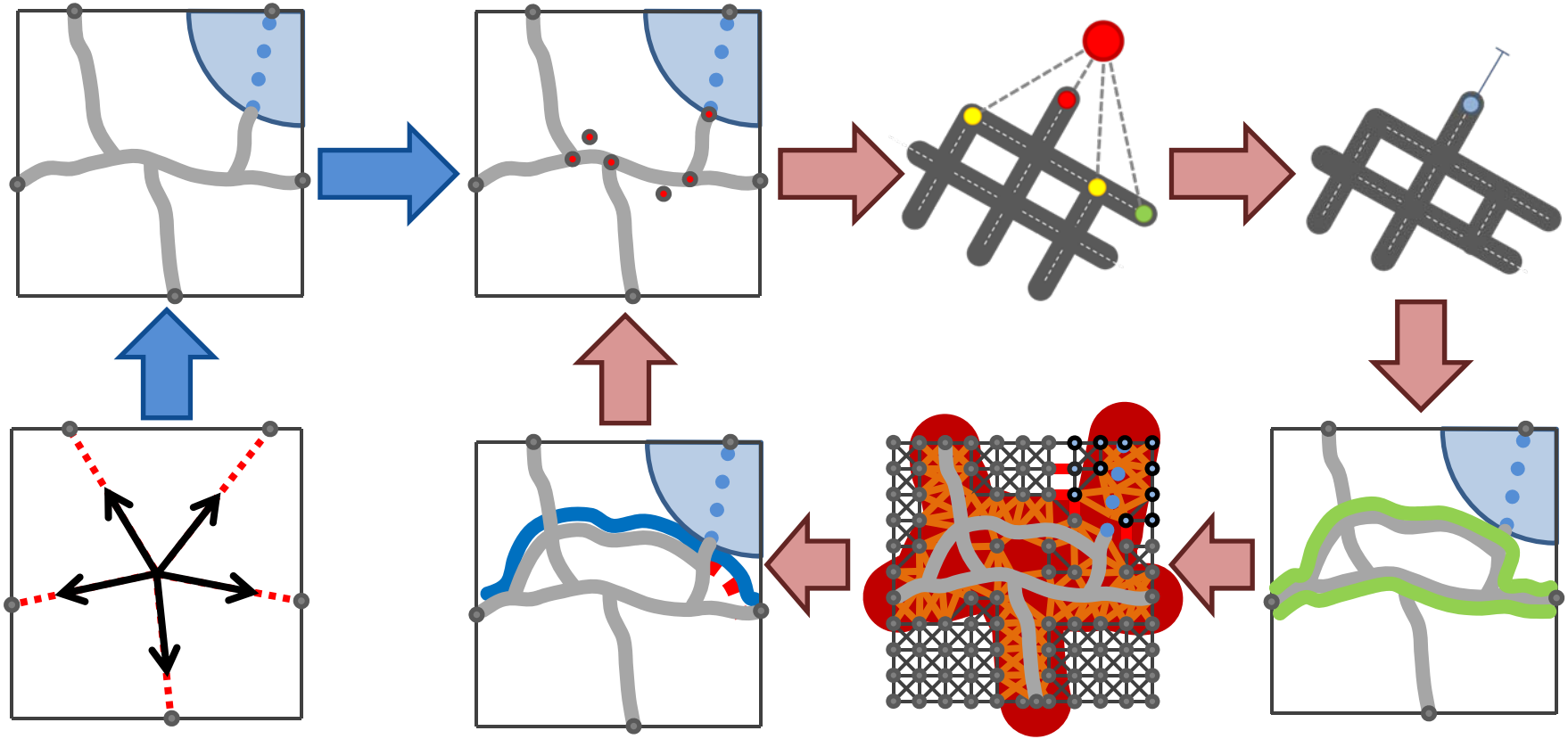
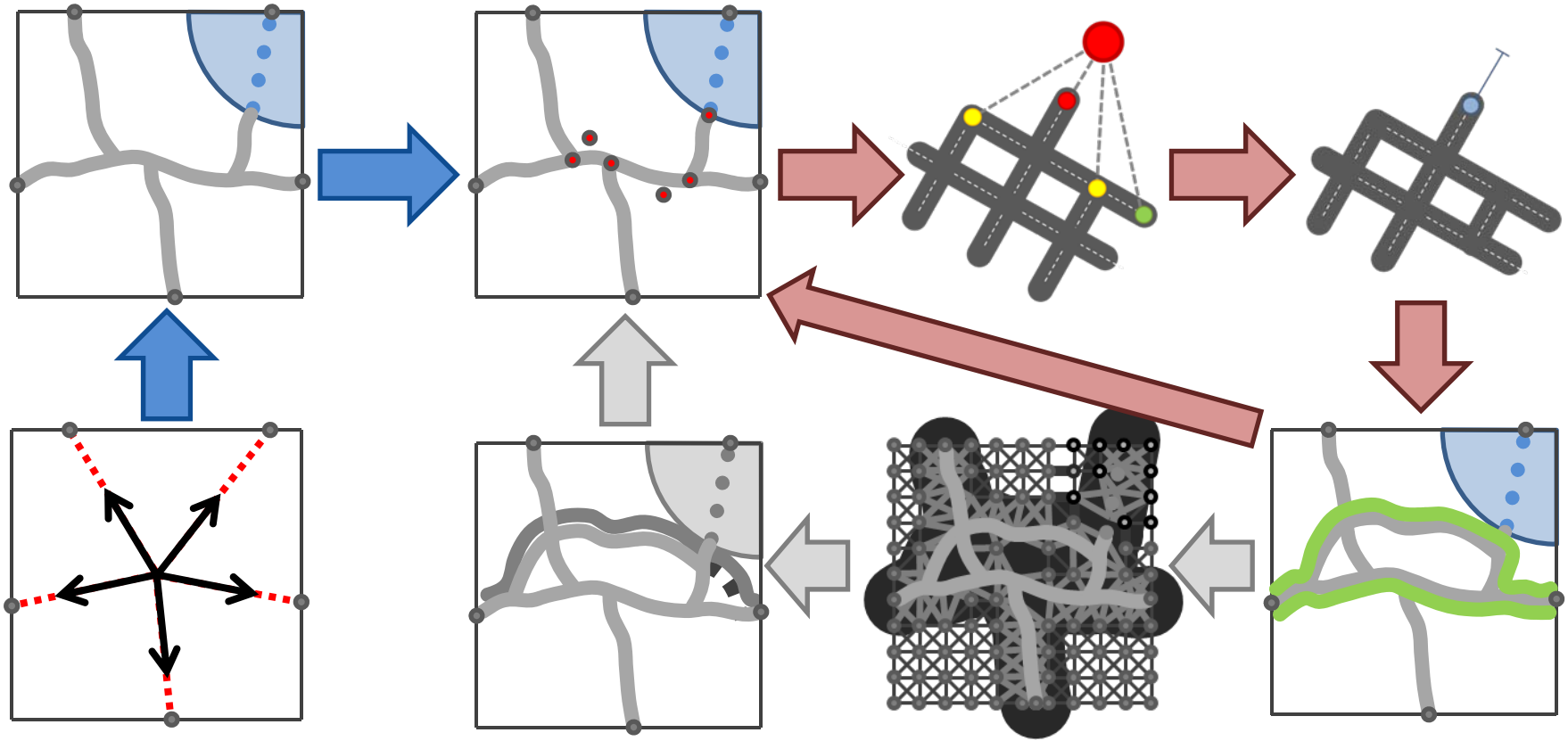
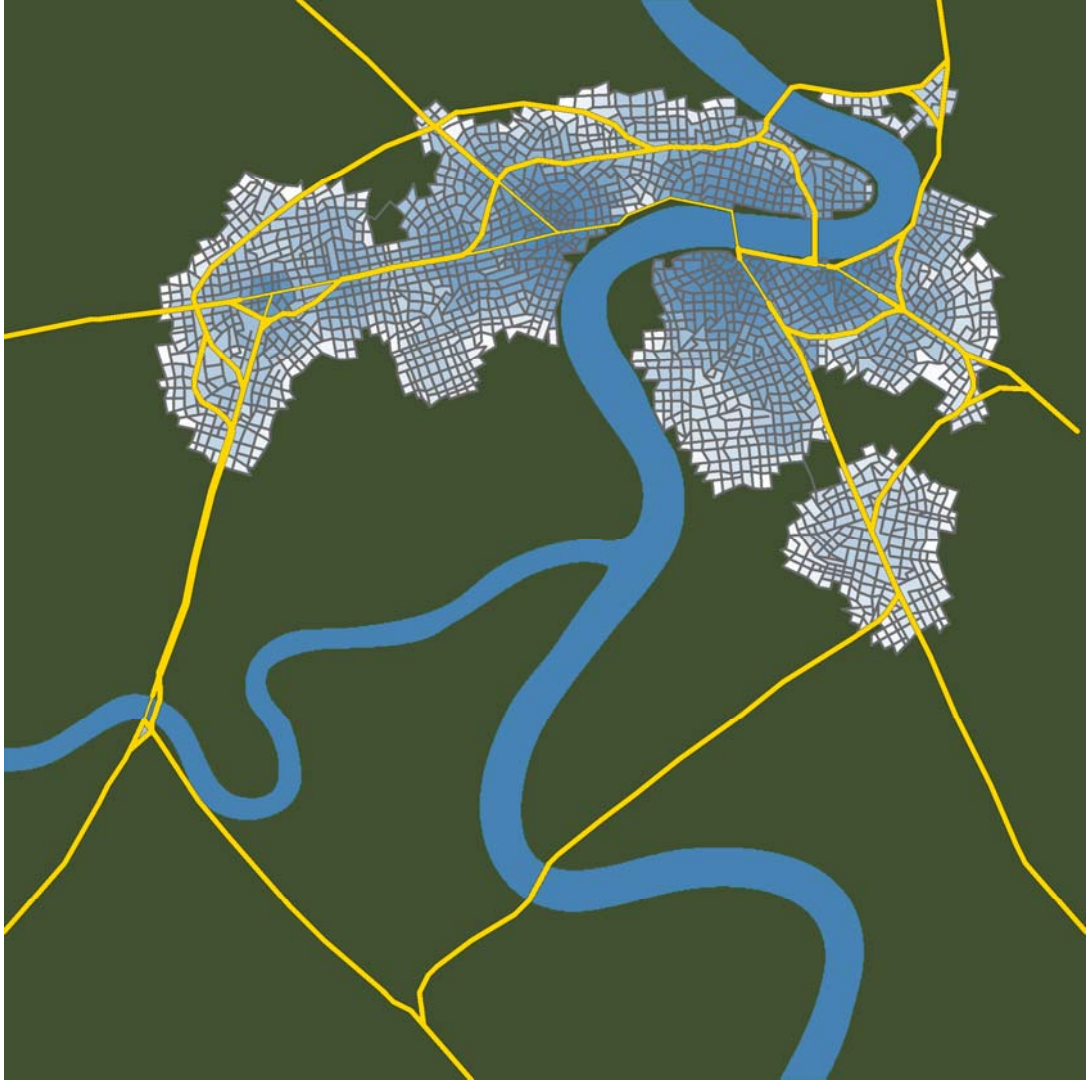
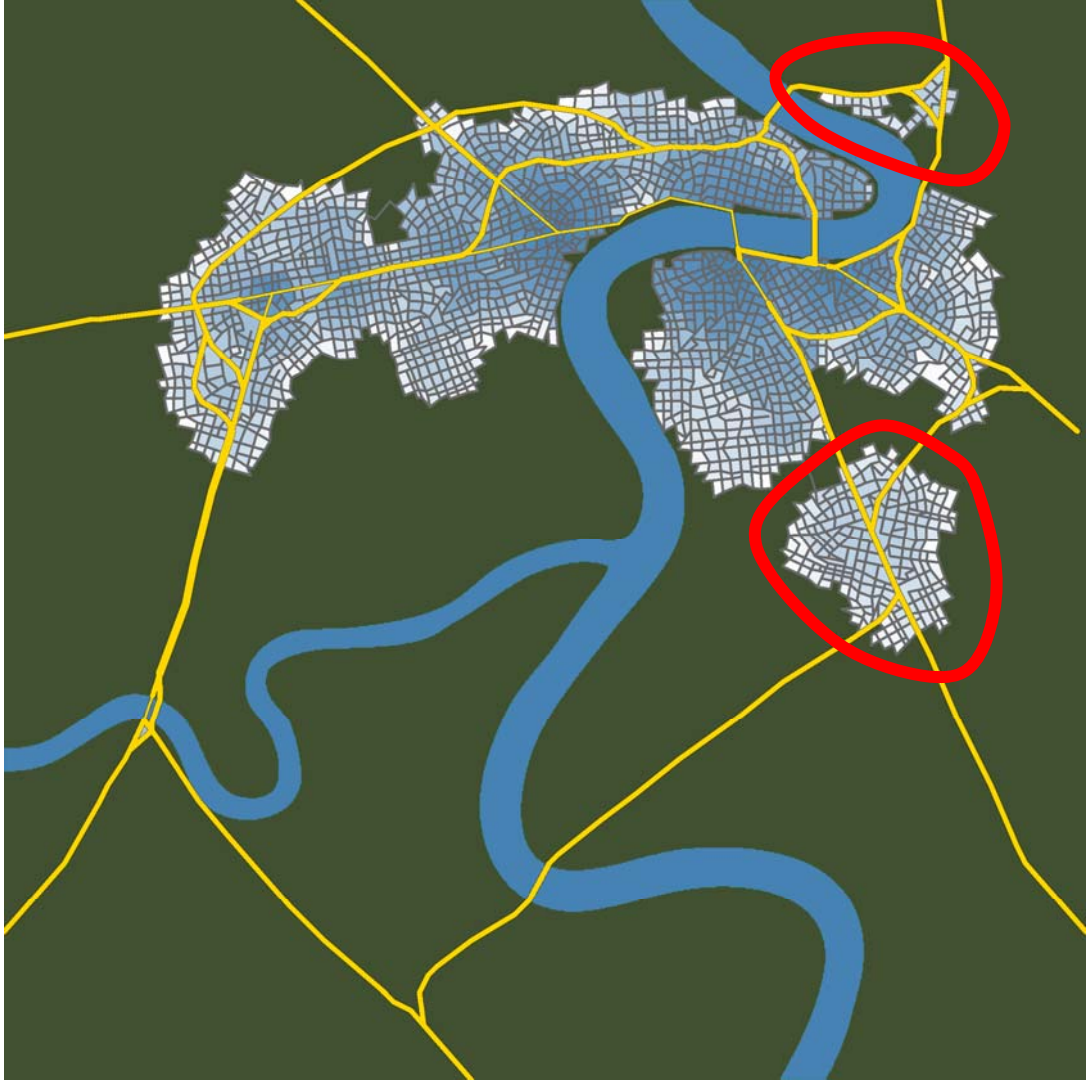


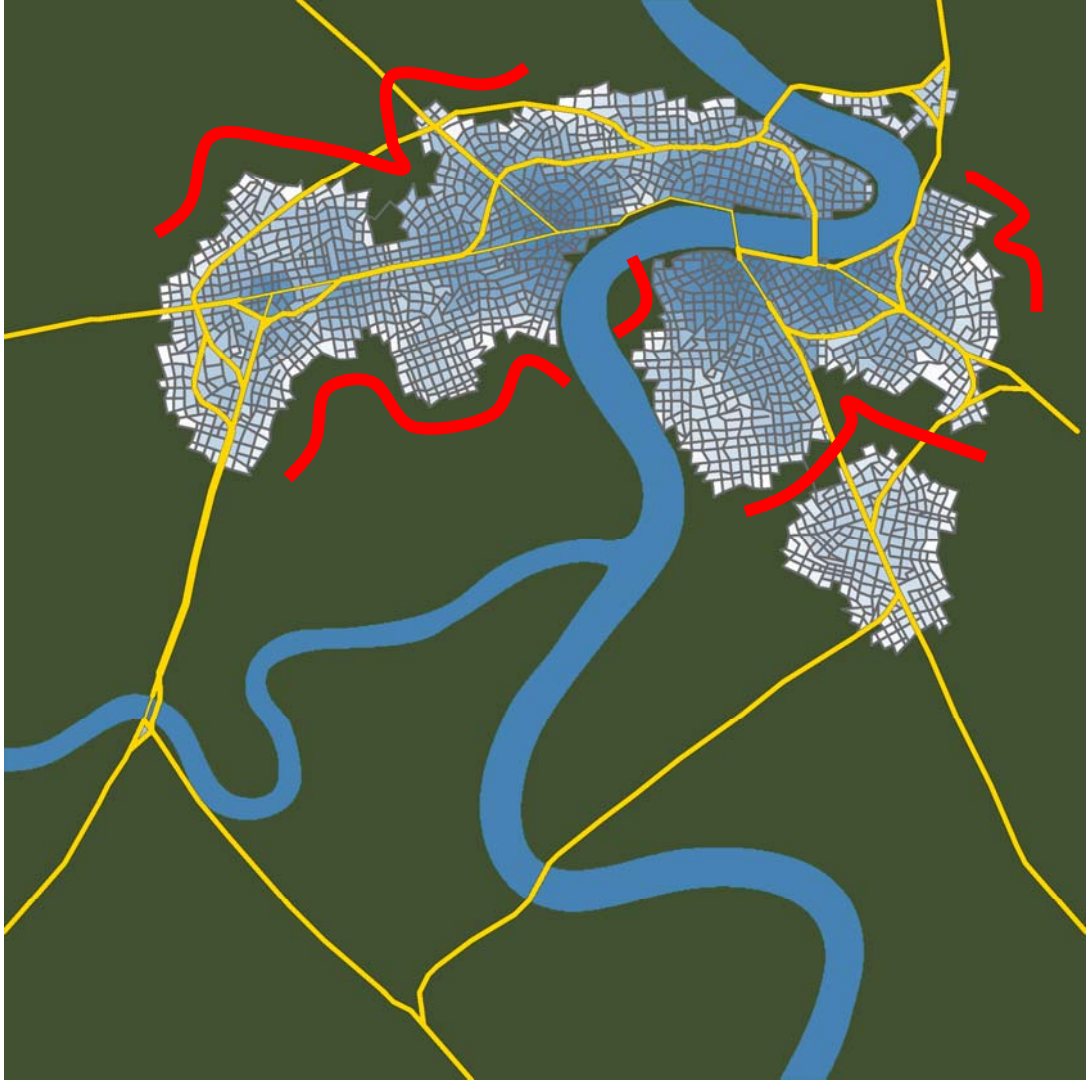
Recapitulation

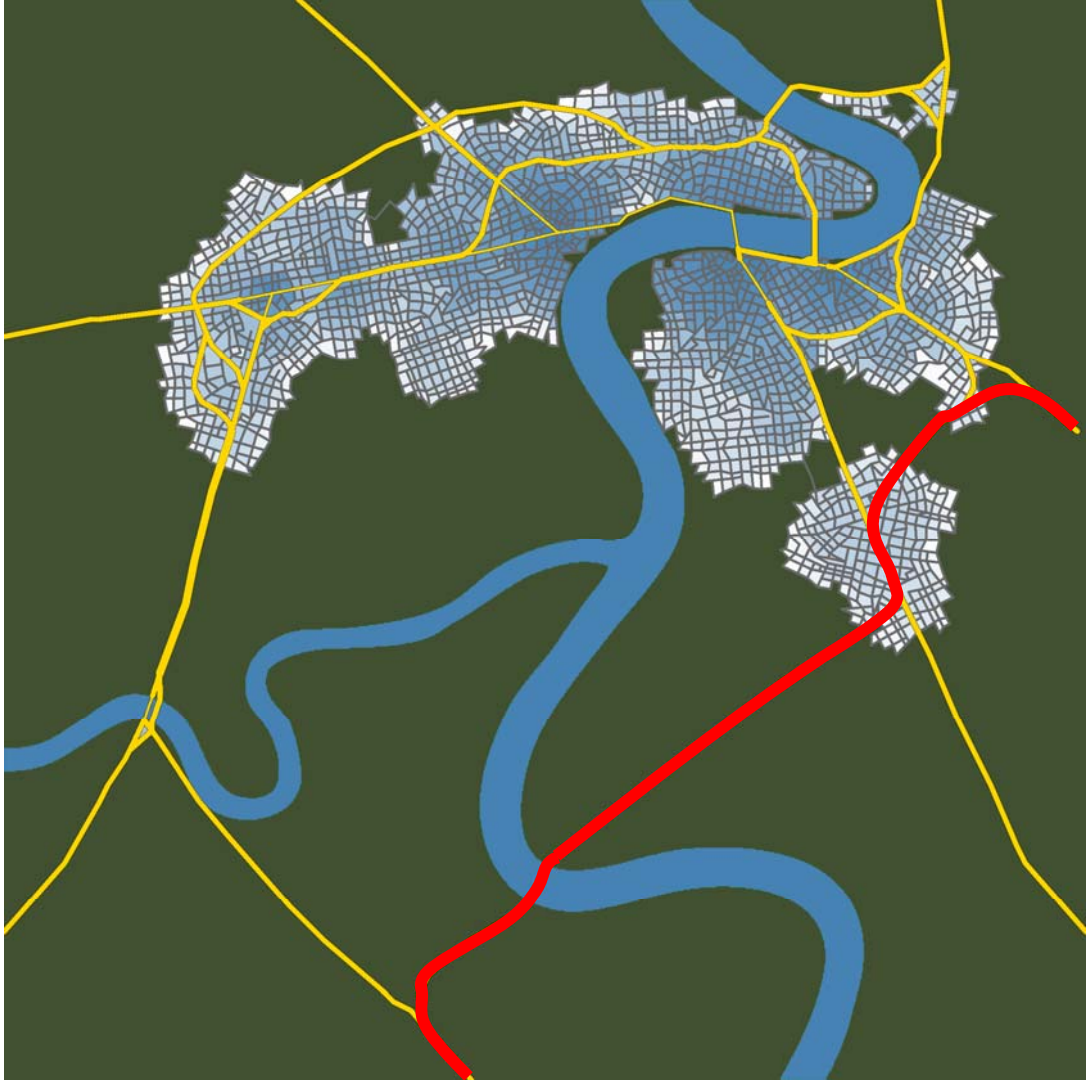


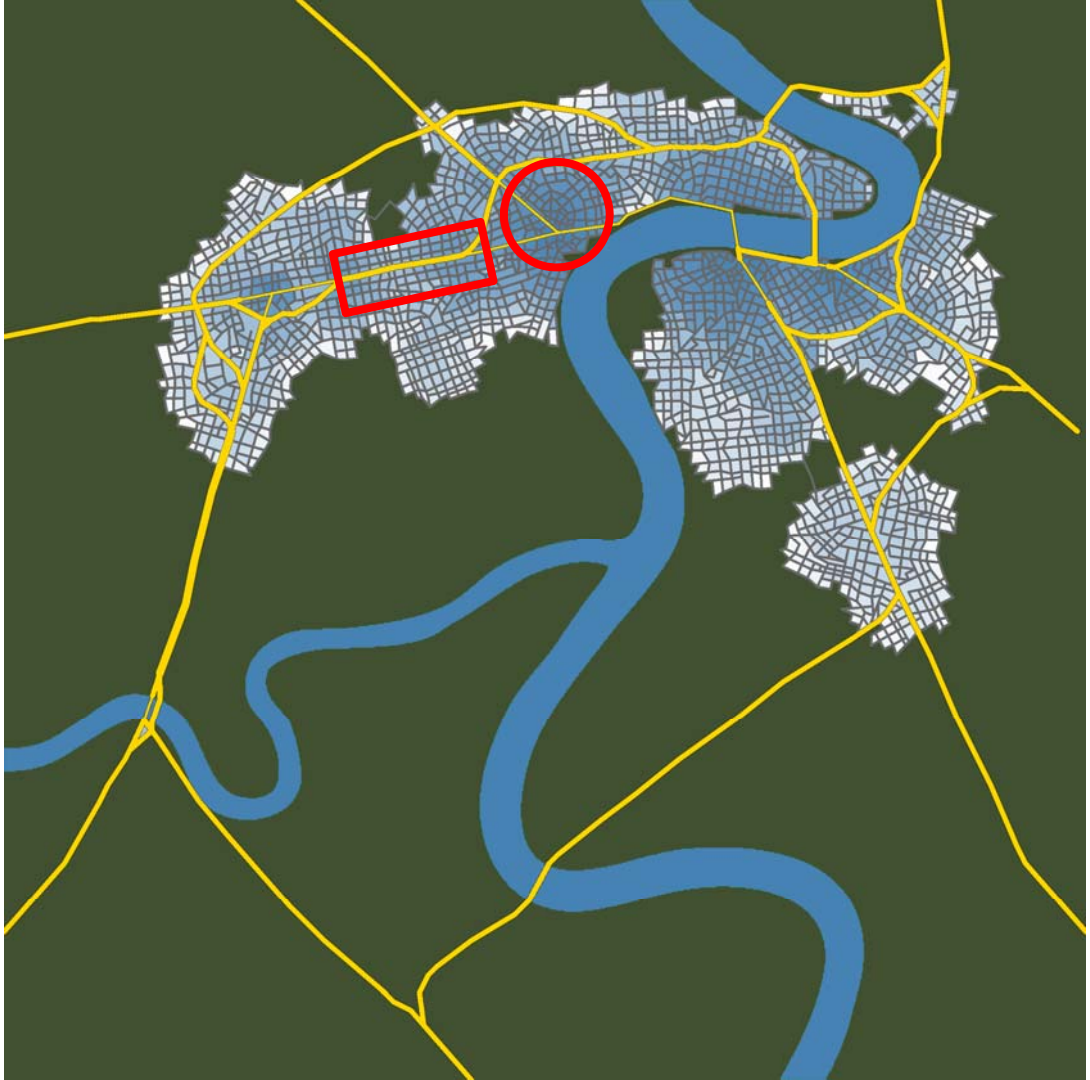
Results & Conclusions

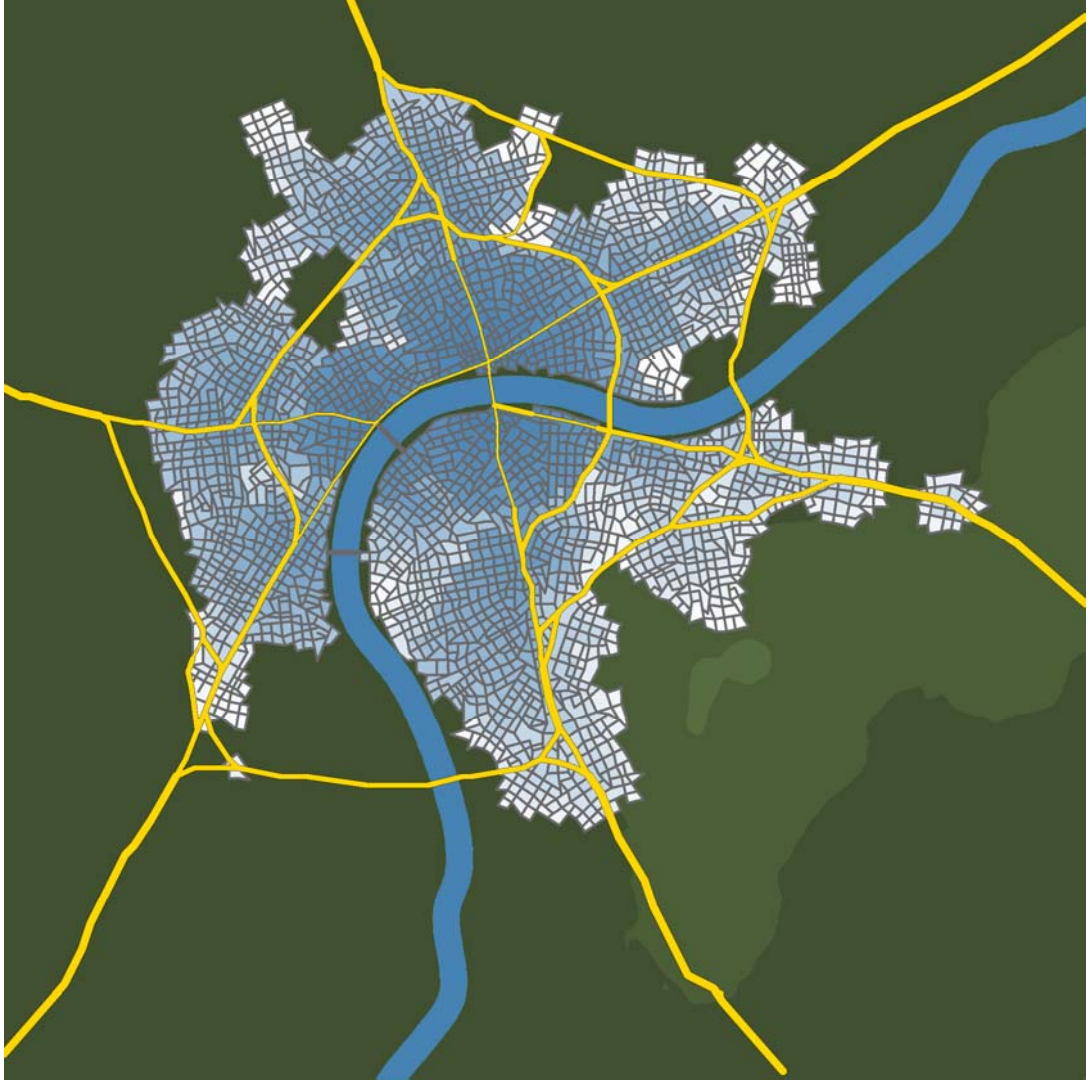


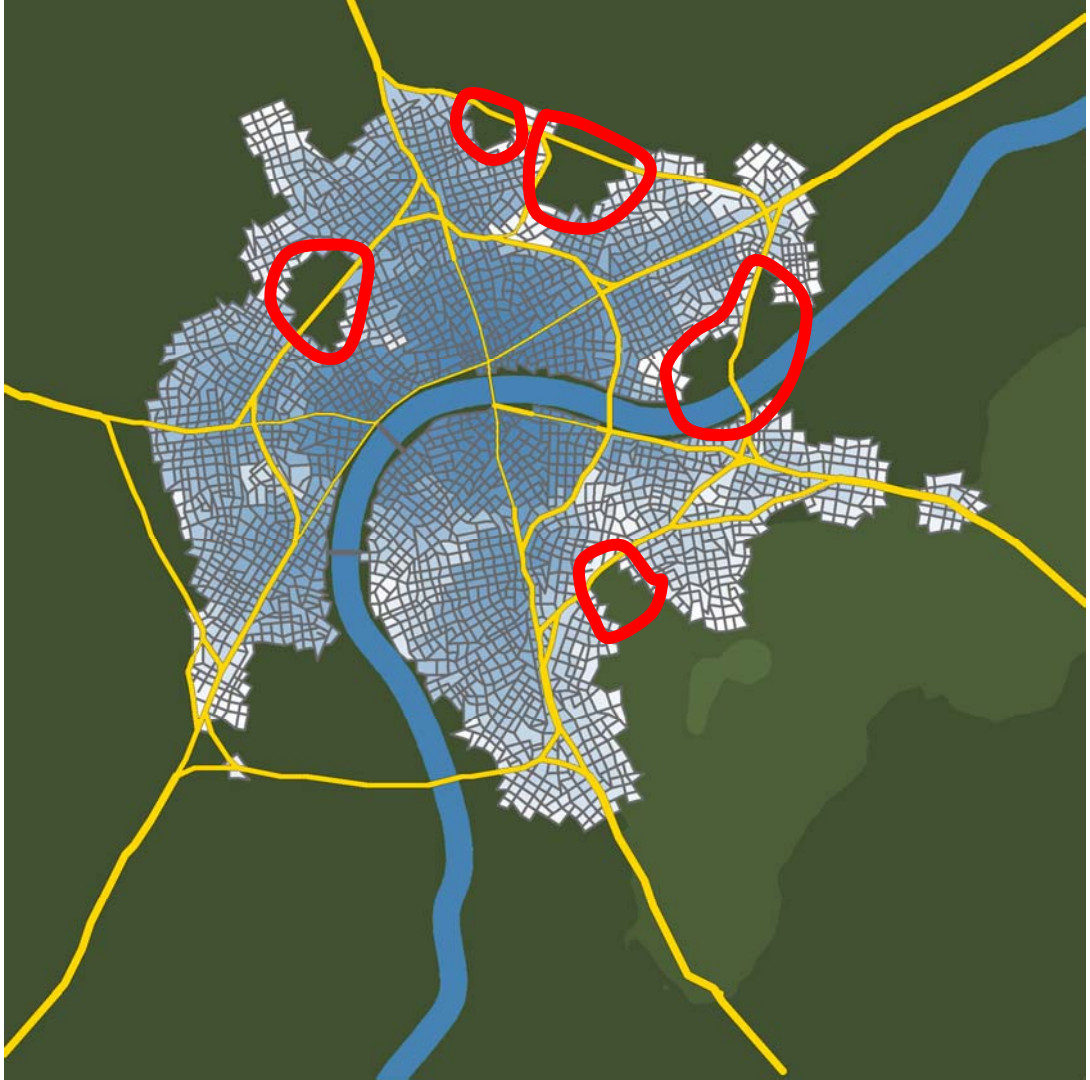









Elevation
+0m
+60m
+120m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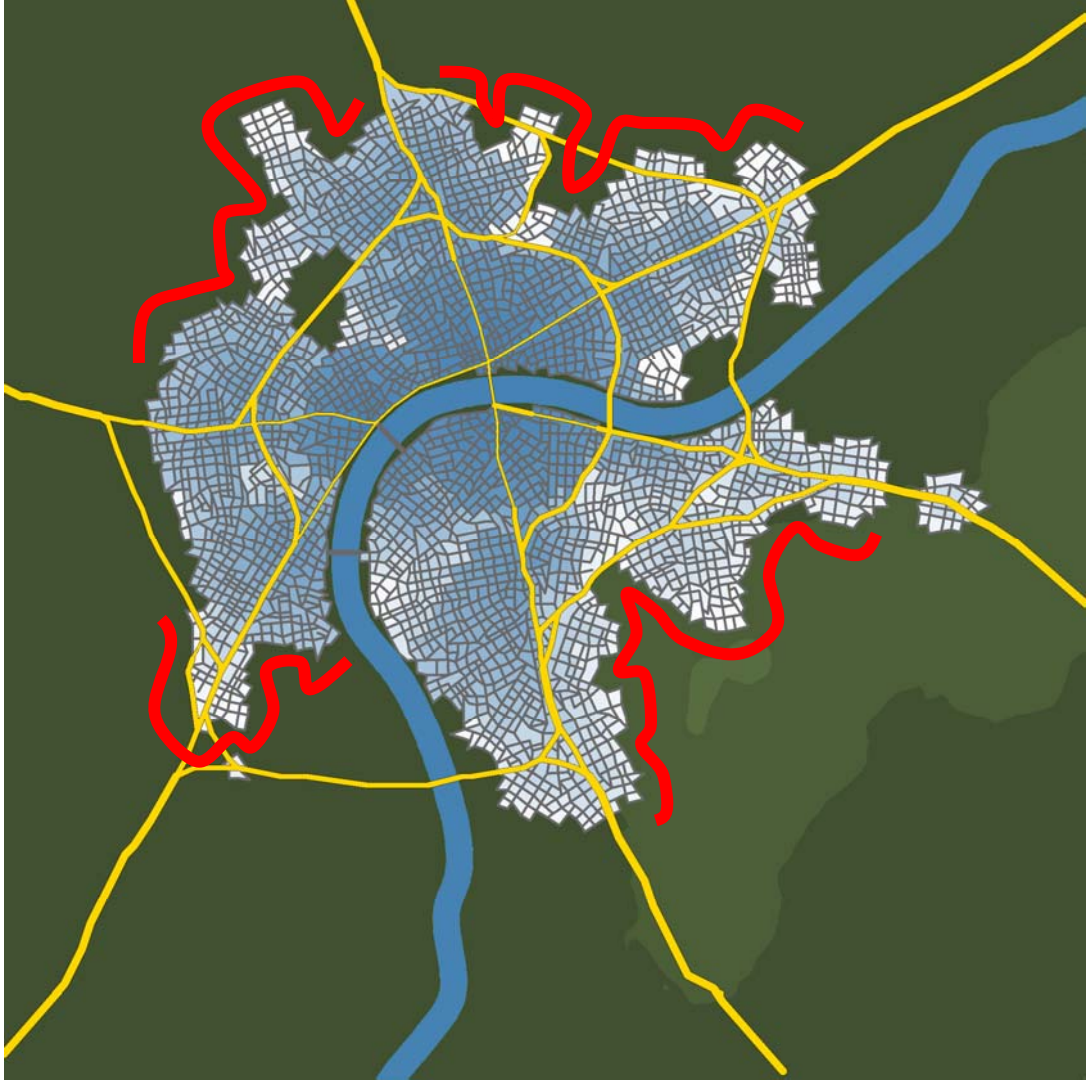
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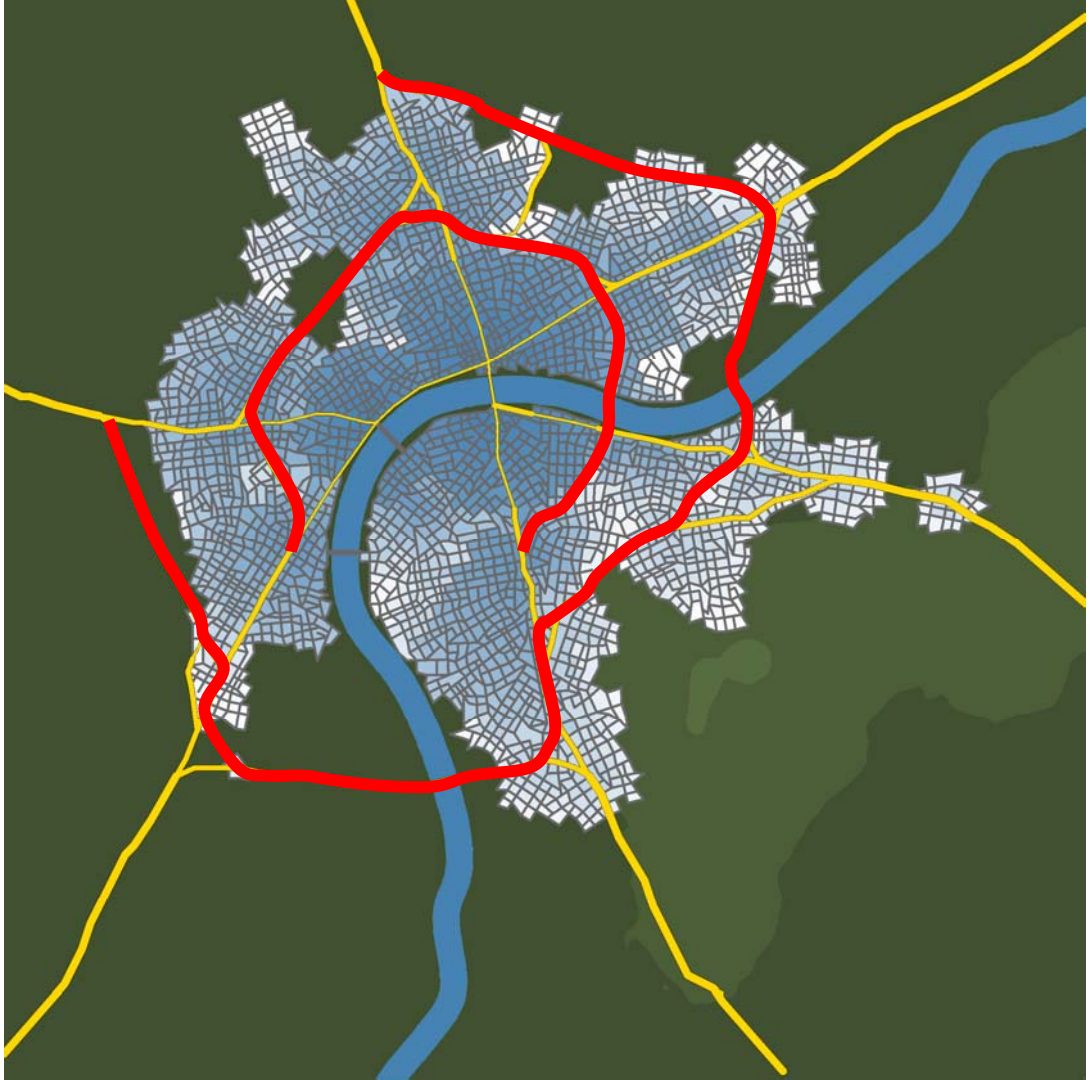
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+120m

Elevation
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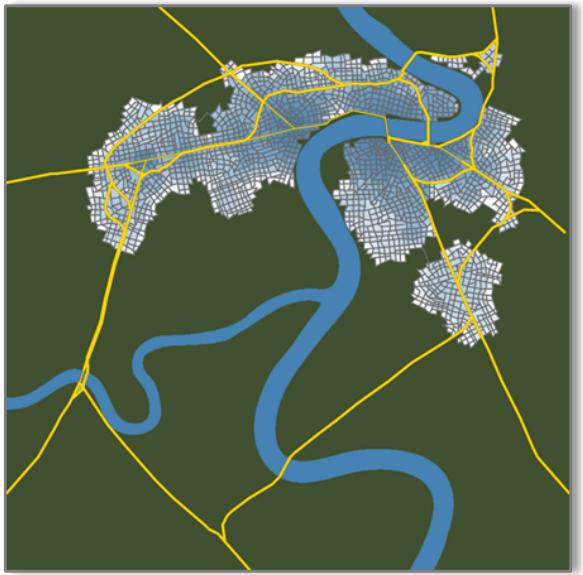
+60m
+120m

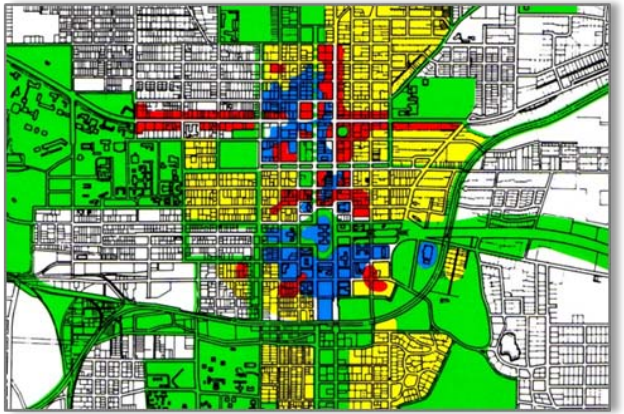
Conclusions

- More realistic cities
  - Assumes trade is key
  - Trade driven major roads
  - Water and terrain
  - Settlement placement
  - City as a set of settlements
- Requires minimal input



Future Work

- Other modes of transportation
- Incorporate Land Use
- In-city transportation
- Redevelopment



Thank you!

Paper, video, supplemental materials:

JanBenes.net

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