Urban Layouts and Road Networks

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Course: Modeling 3D Urban Spaces using Procedural and Simulation-based Techniques

Challenge

- Design and model realistic/plausible road networks and urban layouts

  – Road network: a graph of streets, avenues, and highways

  – Urban layout: a road network plus its dual graph of parcels, with each parcel divided into blocks

Contents

- L-system modeling
  - Procedural Modeling of Cities, Parish et al. 2001
- Example-based modeling
  - Image Analogies, Hertzmann et al. 2001
  - Example-based Urban Layouts, Aliaga et al. 2008
- Tensor-based modeling
  - Procedural Modeling of Streets, Chen et al. 2008
- Shortest path based modeling
  - Galin et al. 2010
- Layer-based topology preserving/changing transformations based on graph cuts
  - Lipp et al. 2011

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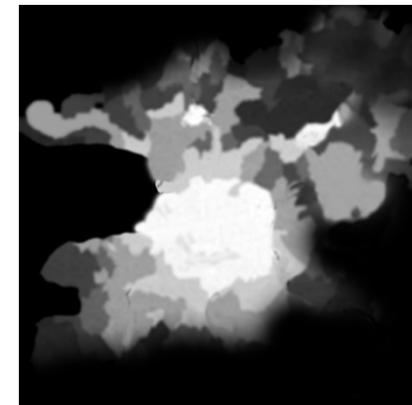
Urban Layouts and Road Networks

- **Procedural Modeling of Cities**
  - Parish and Müller
- SIGGRAPH 2001
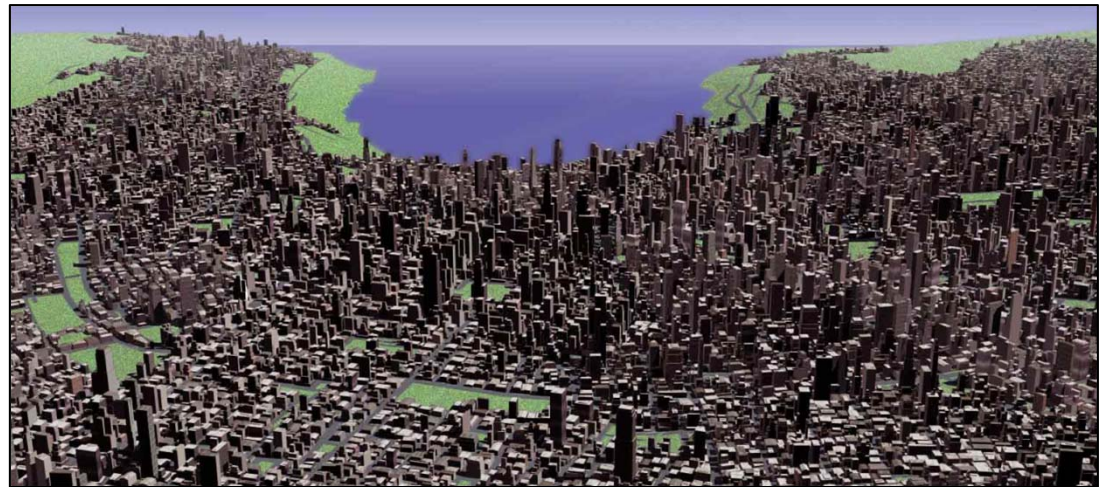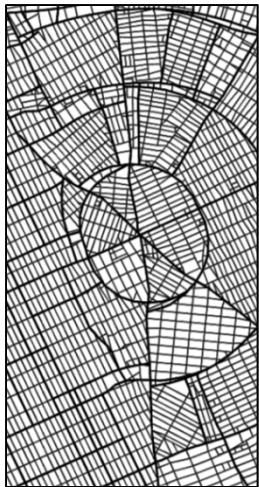
Procedural Modeling of Cities

- ## Input: Various image maps
  - Terrain elevation
  - Population density

- ## Output: Urban Model
  - System of highways and streets
  - Blocks and lots
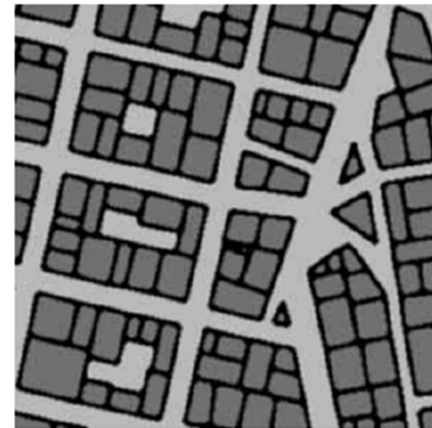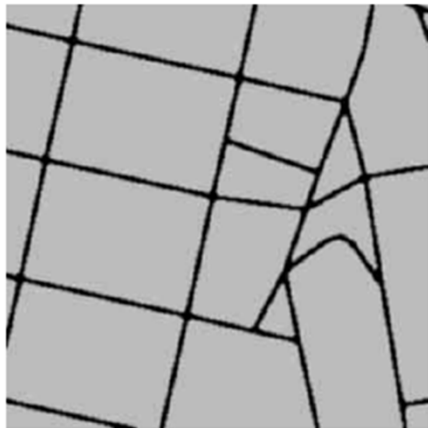 - Building geometry

Procedural Modeling of Cities

- ## Approach
  - **Road network**: Extended L-systems considering global goals and local constraints
    - Global: Street patterns and population density
    - Local: Land/Water/Park boundaries, elevation, crossing of streets

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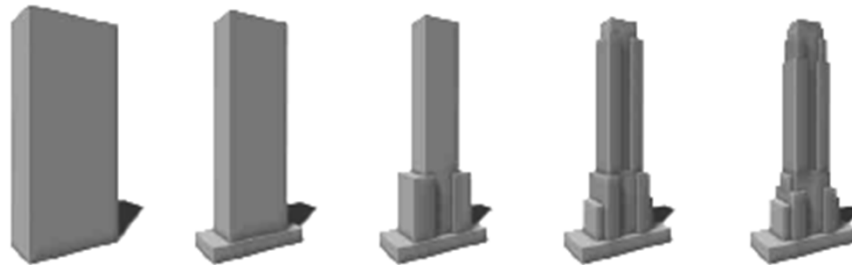# Procedural Modeling of Cities

- Approach
  - **Lots**: Recursive subdivision algorithm along longest edges of lots

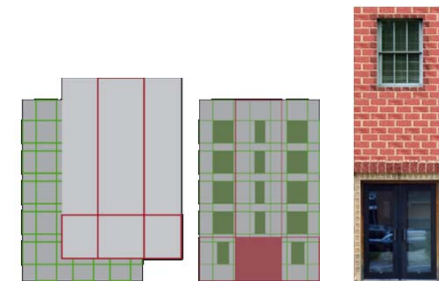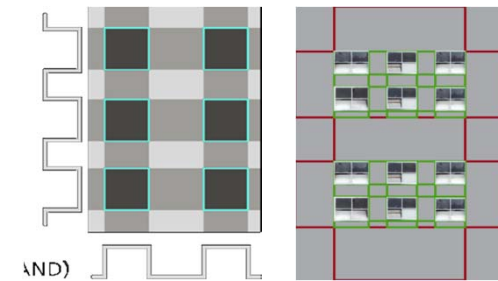# Procedural Modeling of Cities

- Approach
  - **Buildings**: Parametric stochastic L-system
    - One building generated per lot
    - Three types of buildings: Skyscrapers, commercial, residential
    - Several modules are used: Extrusion, branching, termination

Procedural Modeling of Cities

- ## Approach

  - **Facades**: Division into simple grid-like structures

    - A layer is formed by two base functions and every layer defines a facade element

    - Stacked layers are used to generate facade textures

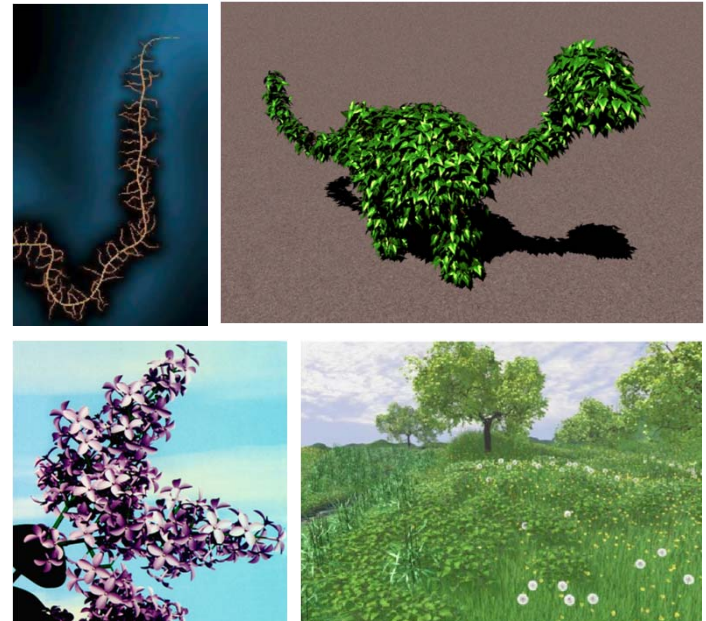   - Each style texture defined manually (no grammars)

Procedural Modeling of Cities

- ## L-systems

  – Generation of plants
    Prusinkiewicz, Lindenmayer; 1990

  – Environment-sensitive
    Prusinkiewicz, James, Mech; 1994

  – Interaction (Open L-System)
    Mech, Prusinkiewicz; 1996

  – Ecosystems
    Deussen, et al.; 1998

Urban Layouts and Road Networks

- **Image Analogies**
  - Hertzmann, Jacobs, Oliver, Curless, Salesin
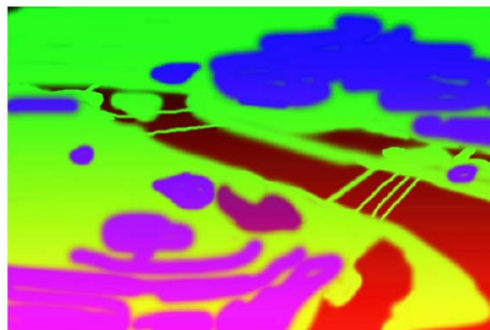- SIGGRAPH 2001

A : A' :: B : B'

Image Analogies

- Two-stage design framework for image modeling:

  - *design phase*: a pair of images, with one image purported to be a "filtered" version of the other, is presented as "training data"

  - *application phase*: the learned filter is applied to some new target image in order to create an "analogous" filtered result
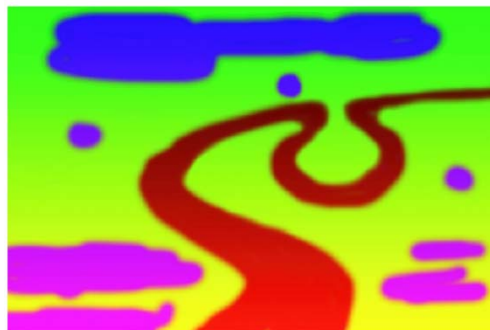
Image Analogies

- Application to synthesis of novel aerial views of urban spaces by example

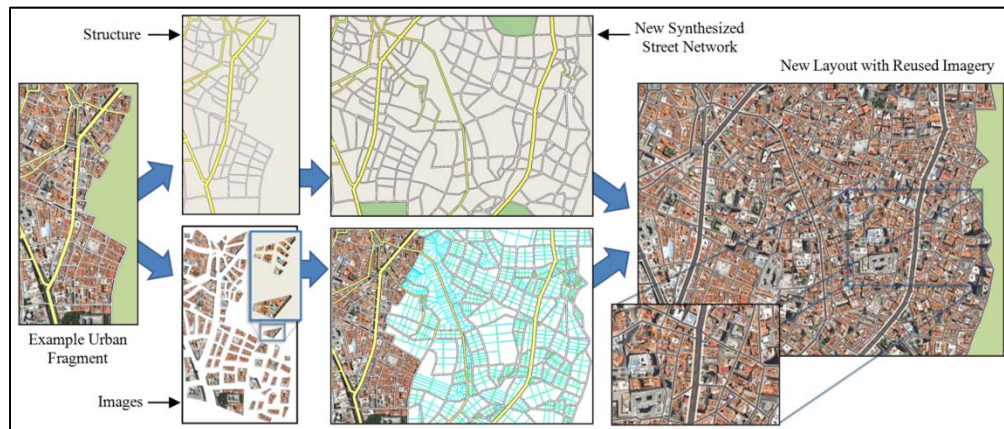Unfiltered source (A)

Filtered source (A')

Unfiltered (B)

Filtered (B')

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Urban Layouts and Road Networks

- **Example-based Urban Layout Synthesis**
  - Aliaga, Vanegas, Benes

- SIGGRAPH Asia 2008

Example-based Urban Layouts

- Input: Example urban layout
  - Images (aerial view)+ Structure (streets, parcels)

Example-based Urban Layouts

- Input: Example urban layout
- Output: New synthesized urban layout that looks like the example layout
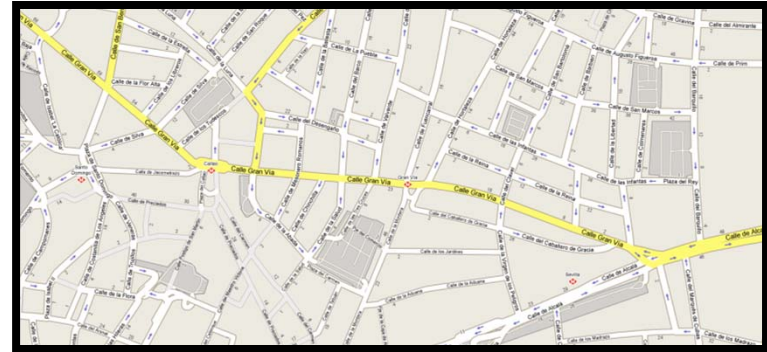
Example-based Urban Layouts

- Observation: Both image and structure information about the urban layout available
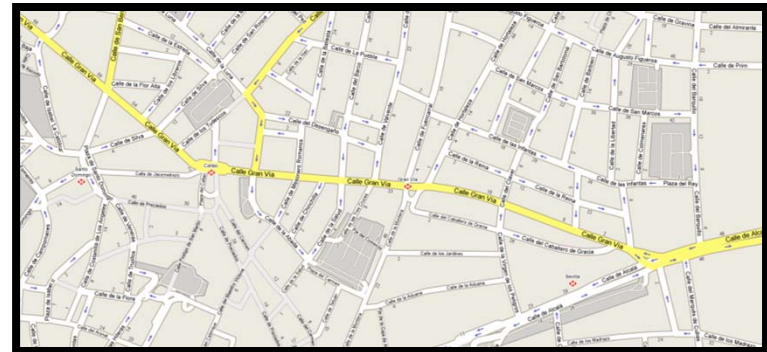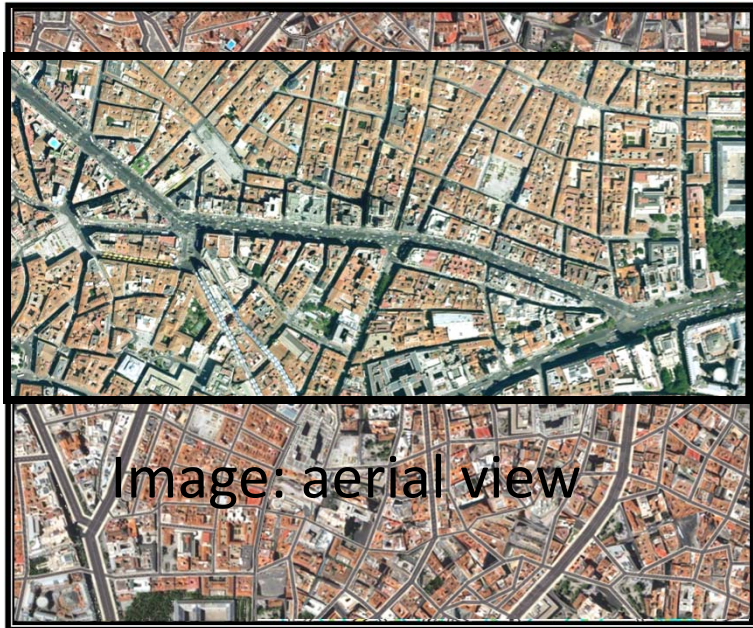
Courtesy of Google Maps

Image: aerial view

Structure: street + parcels
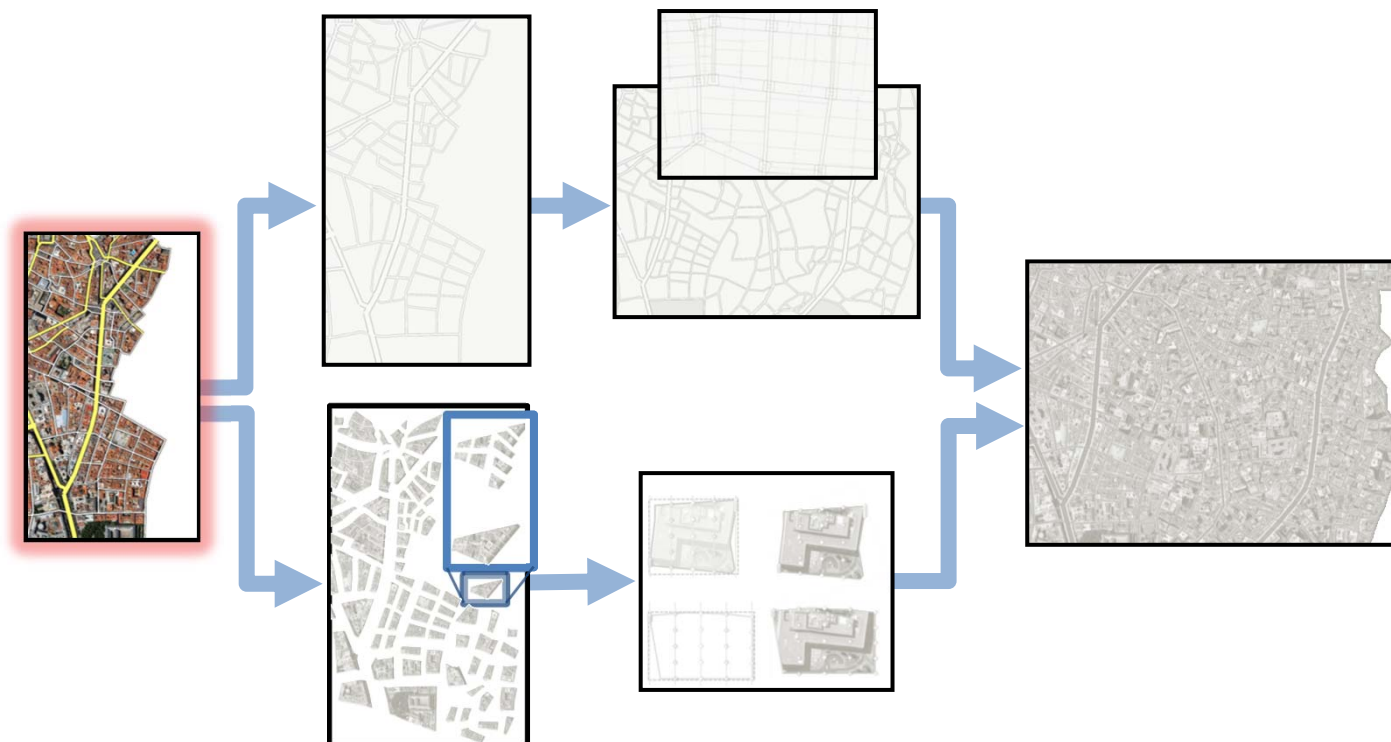
Example-based Urban Layouts

- Approach: Simultaneously synthesize structure and image

Image: aerial view

Structure: street + parcels

Example-based Urban Layouts

- Input: Example urban layout

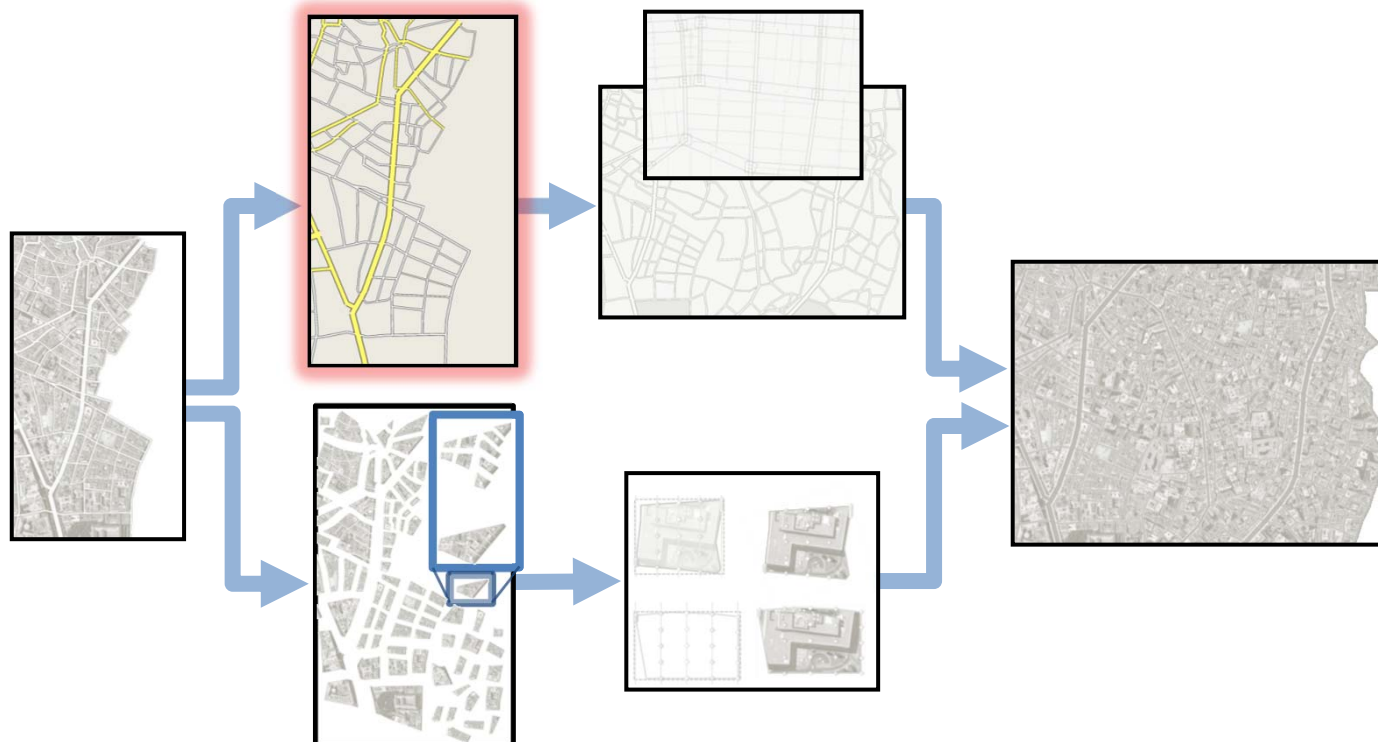Course: Modeling 3D Urban Spaces using Procedural and Simulation-based Techniques
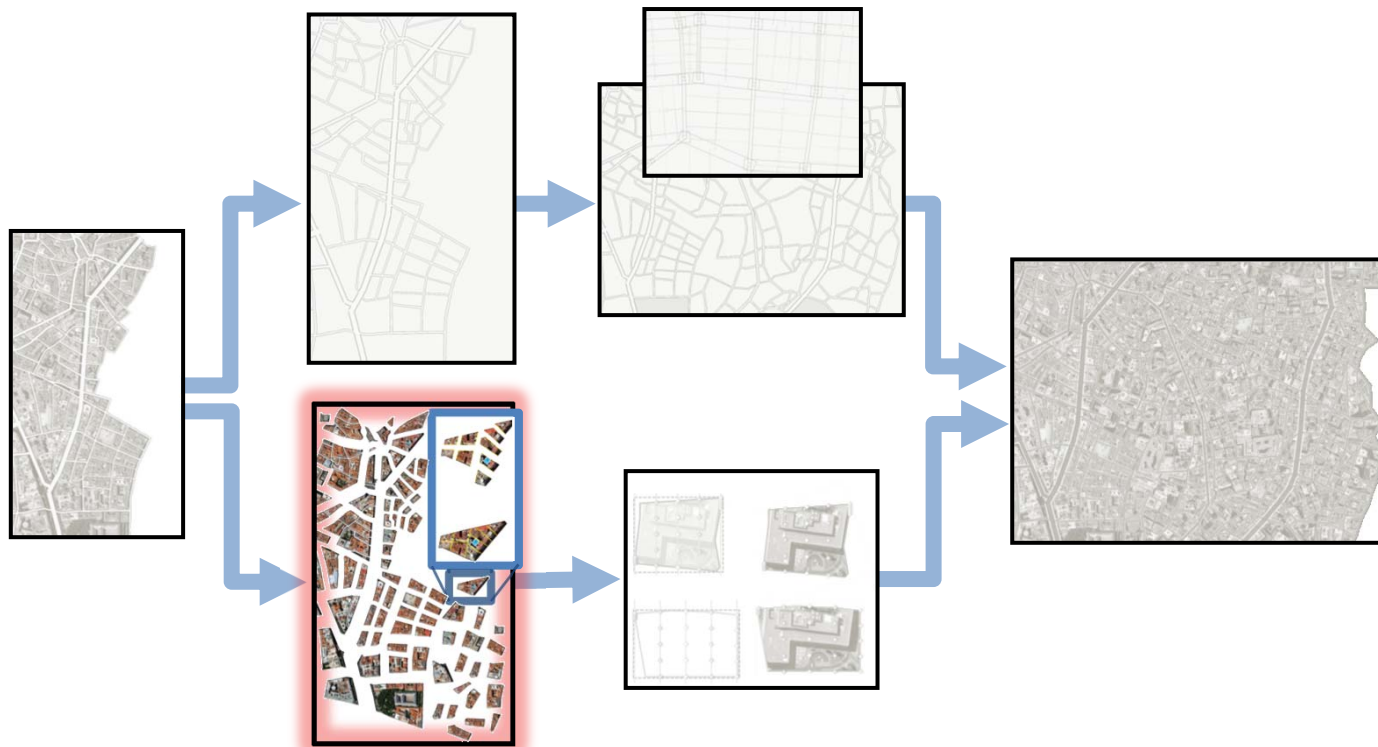
Example-based Urban Layouts

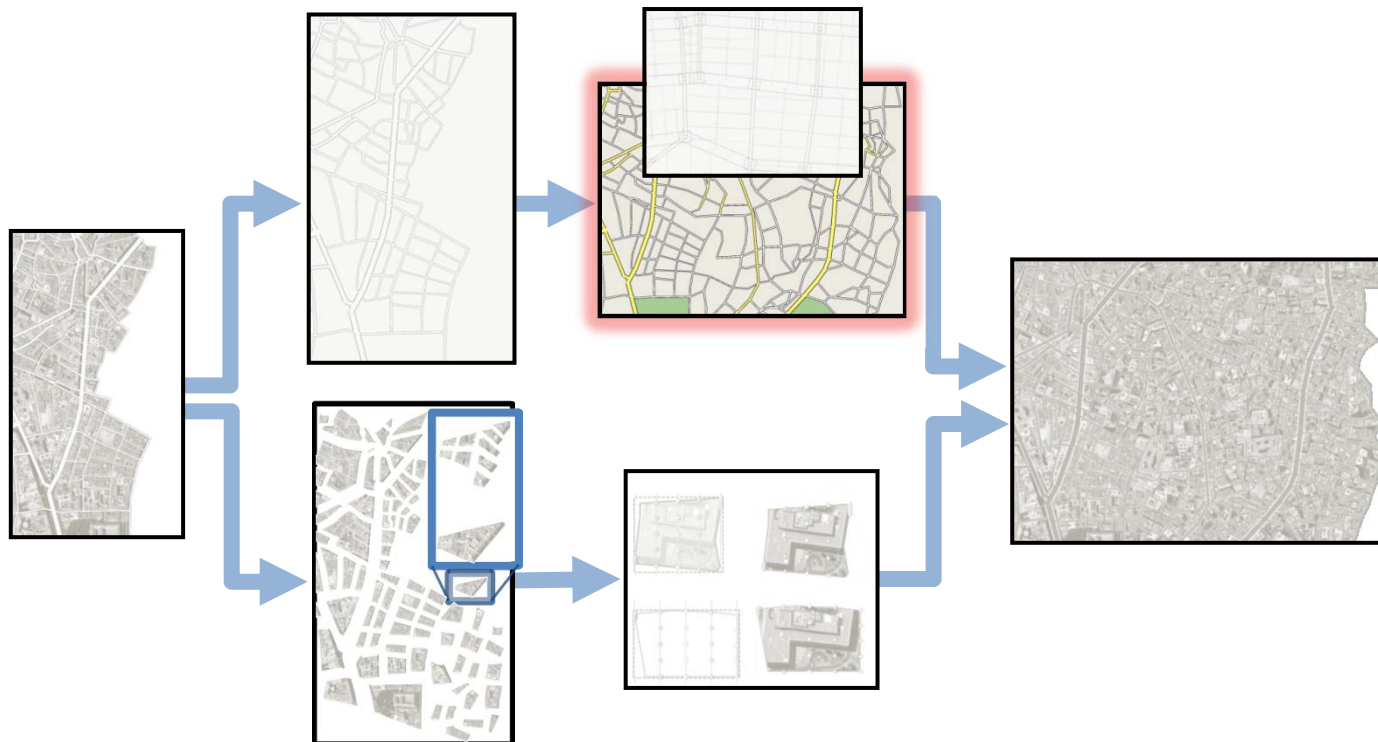- Characterize GIS vector data

Example-based Urban Layouts

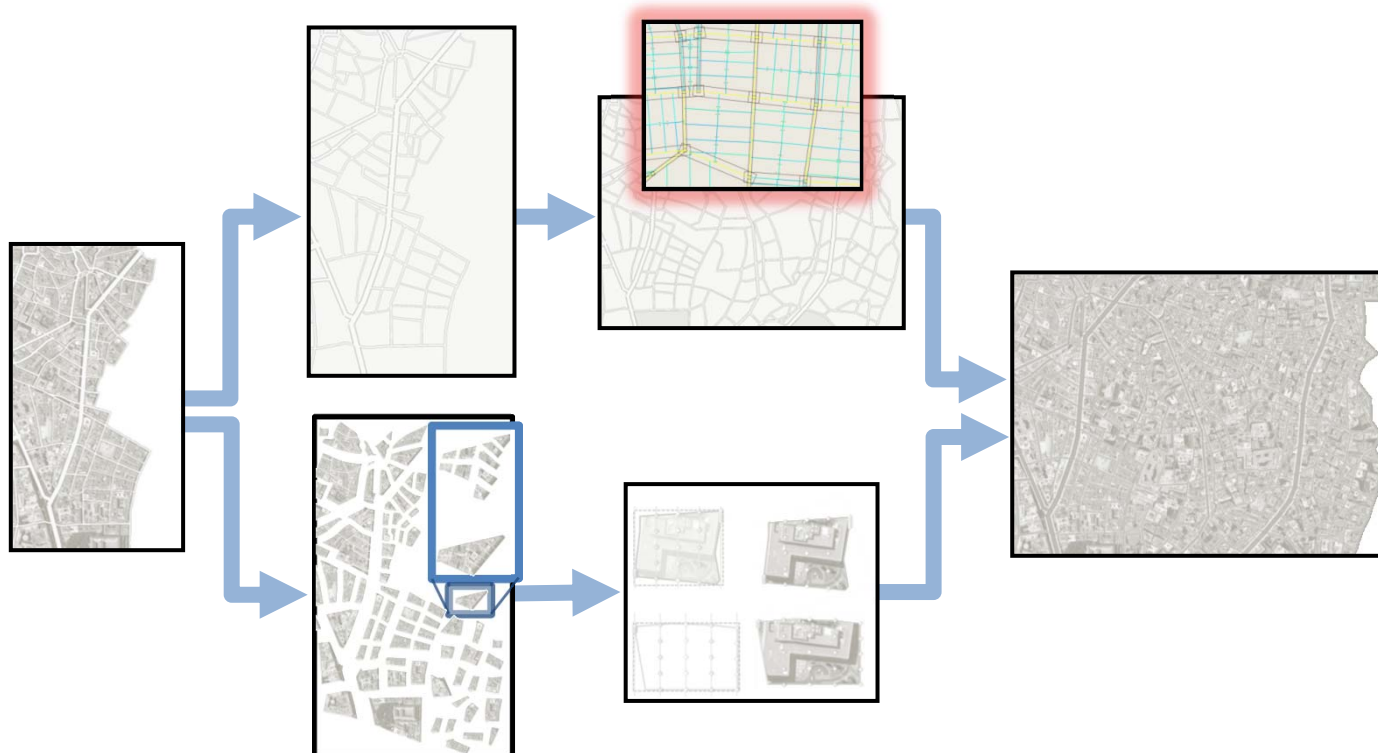- Compute per-parcel imagery

Example-based Urban Layouts

- Synthesize new streets
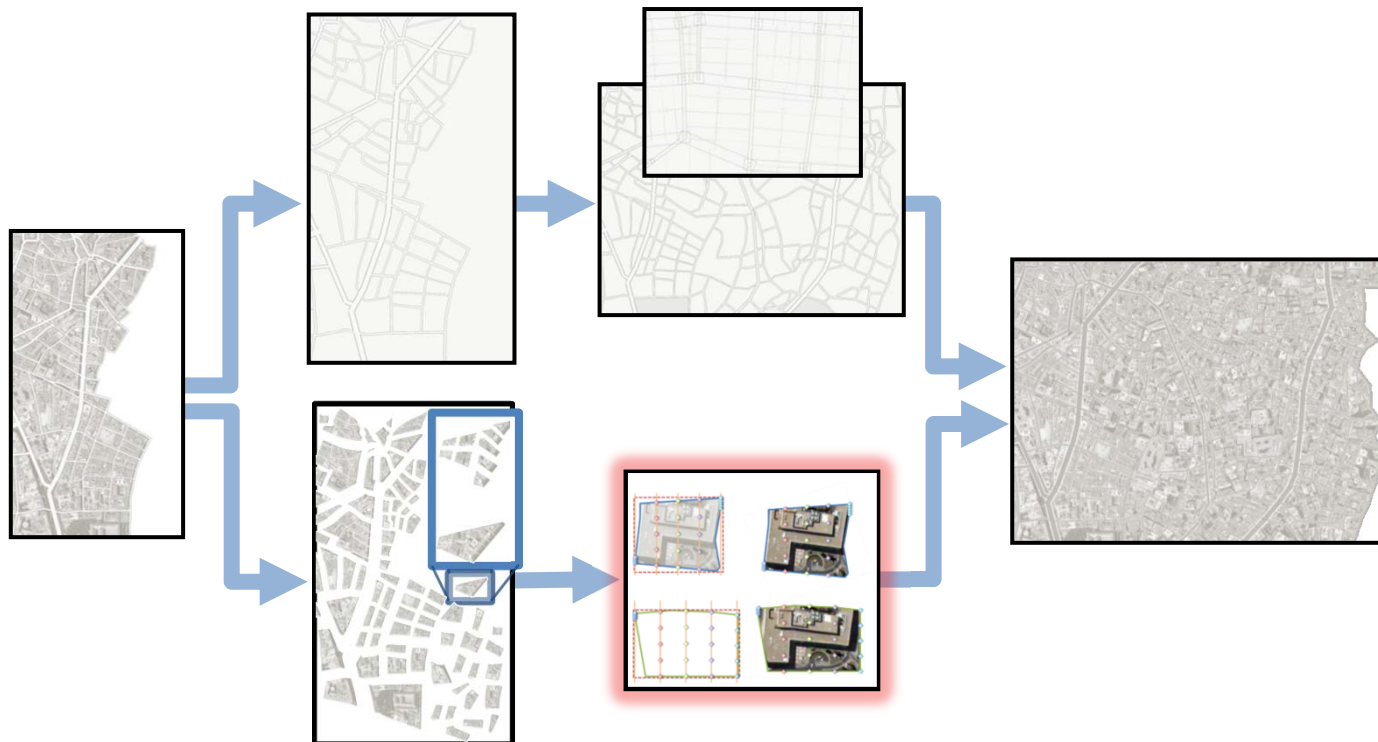
Example-based Urban Layouts

- Generate new blocks and parcels

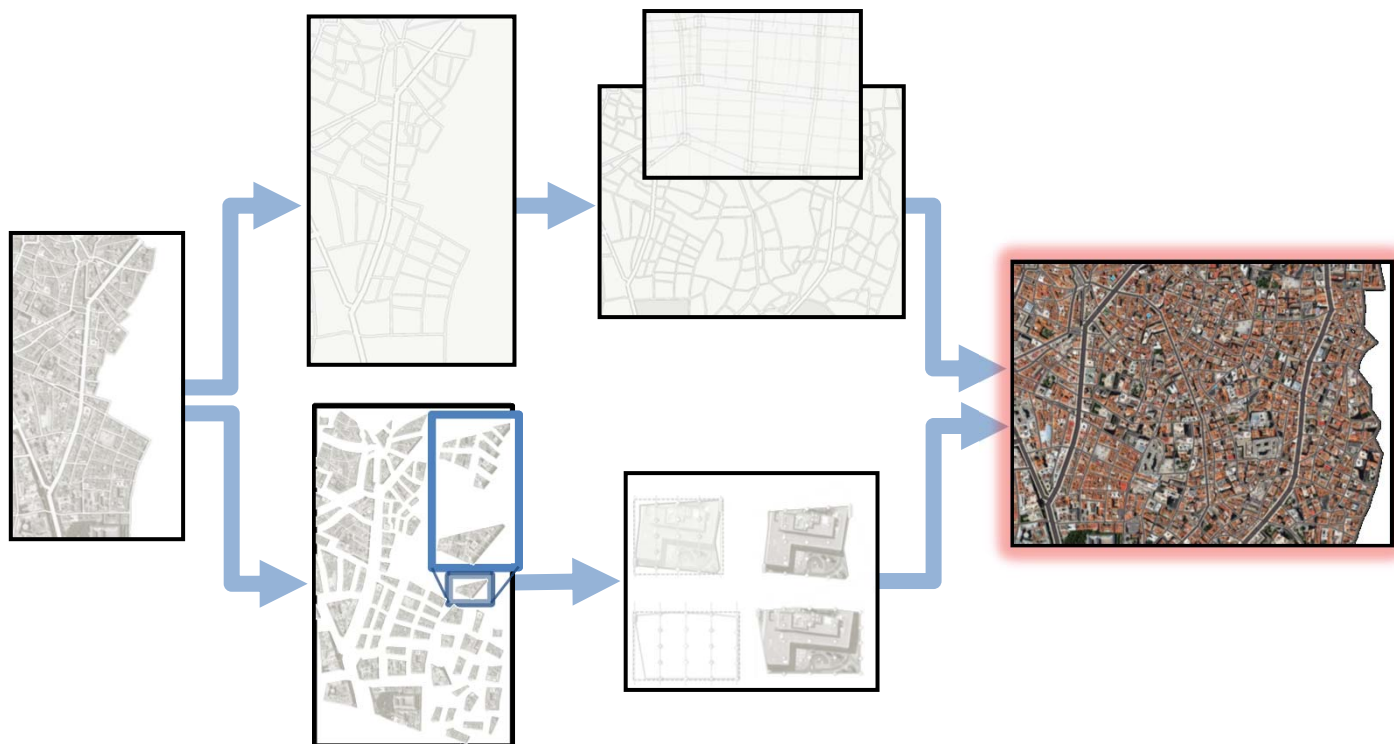Course: Modeling 3D Urban Spaces using Procedural and Simulation-based Techniques

Example-based Urban Layouts

- Produce new aerial view imagery

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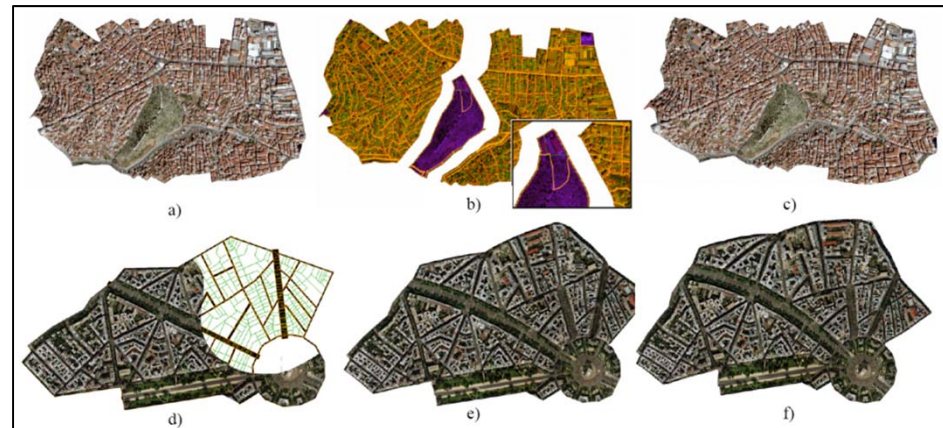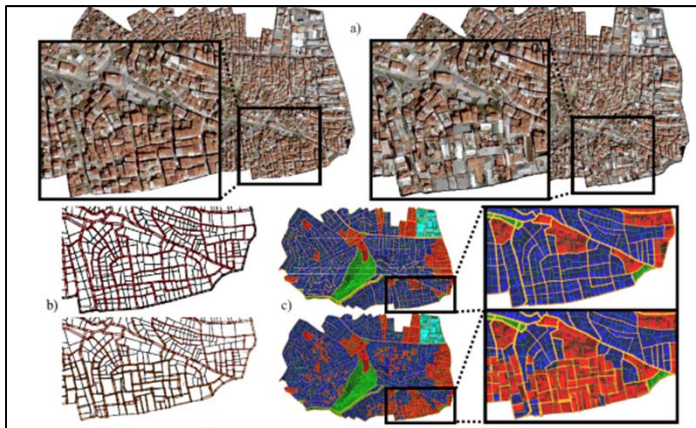
Example-based Urban Layouts

- Output: A new synthesized urban layout

Urban Layouts and Road Networks

- **Interactive Reconfiguration of Urban Layouts**
  Aliaga, Benes, Vanegas, Andrysco

- IEEE CG&A 2008

Interactive Reconfiguration of Urban Layouts

- An editor providing tools to
    - expand, scale, replace and move

  parcels and blocks of existing layouts

- Exploits connectivity and zoning of parcels

Interactive Reconfiguration of Urban Layouts

- Uses a solver to find a planar transformation for each tile that best accommodates the changes caused by the editing operations

- Two types of error:

  – Gap error + Deformation error

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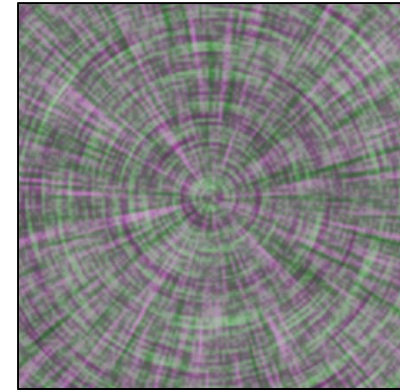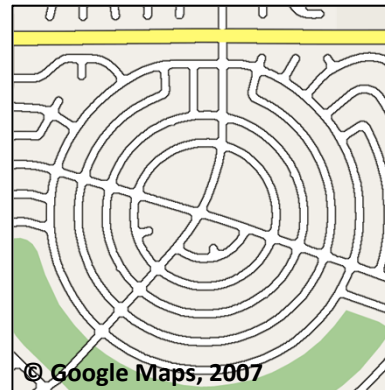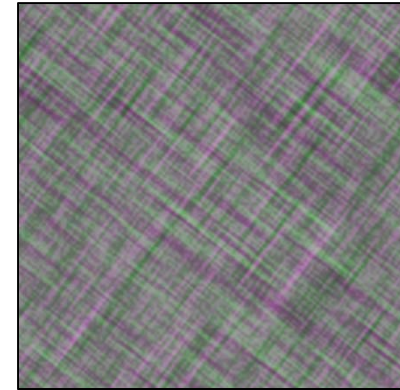
Urban Layouts and Road Networks

- **Procedural Modeling of Streets**
  - Chen, Esch, Wonka, Müller, Zhang

- SIGGRAPH 2008
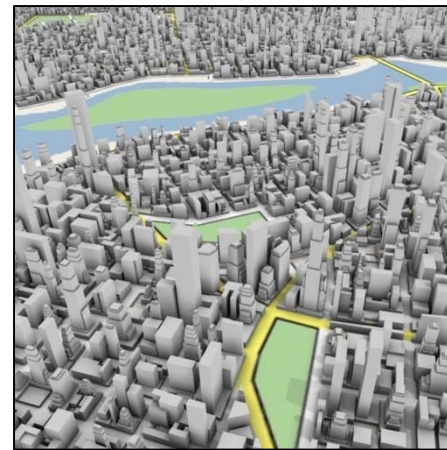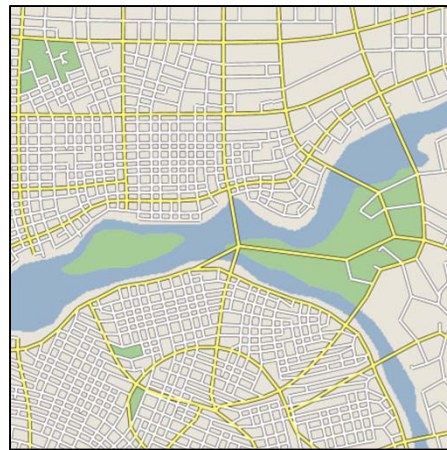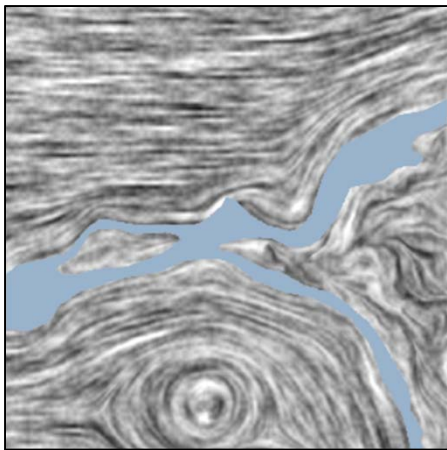
Procedural Modeling of Streets

- Observation
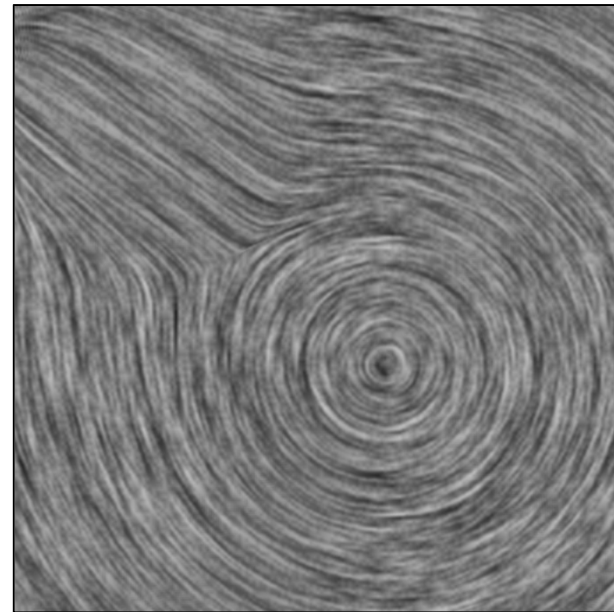 - Relation between street patterns and tensor field

Real street patterns   **Tensor field patterns**
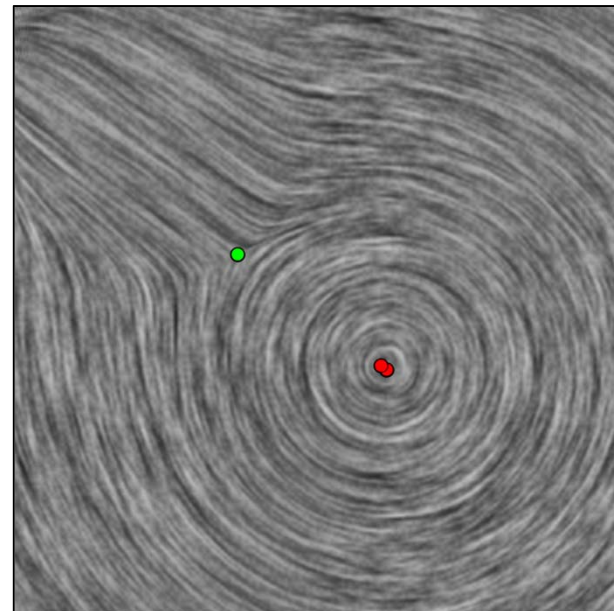
Procedural Modeling of Streets

- Tensor fields
  - Second order symmetric tensor fields
    - Eigenvectors of tensor values for two orthogonal families
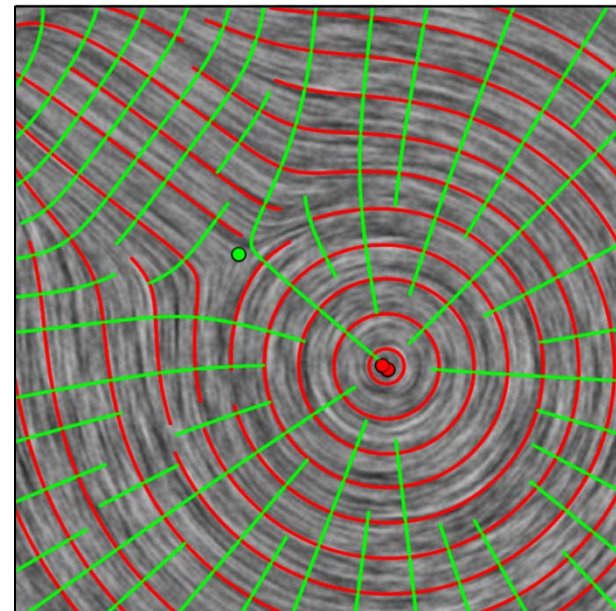
Procedural Modeling of Streets

- ## Tensor fields
  - – Second order symmetric tensor fields
    - Eigenvectors of tensor values for two orthogonal families
  - – Topology Singularities
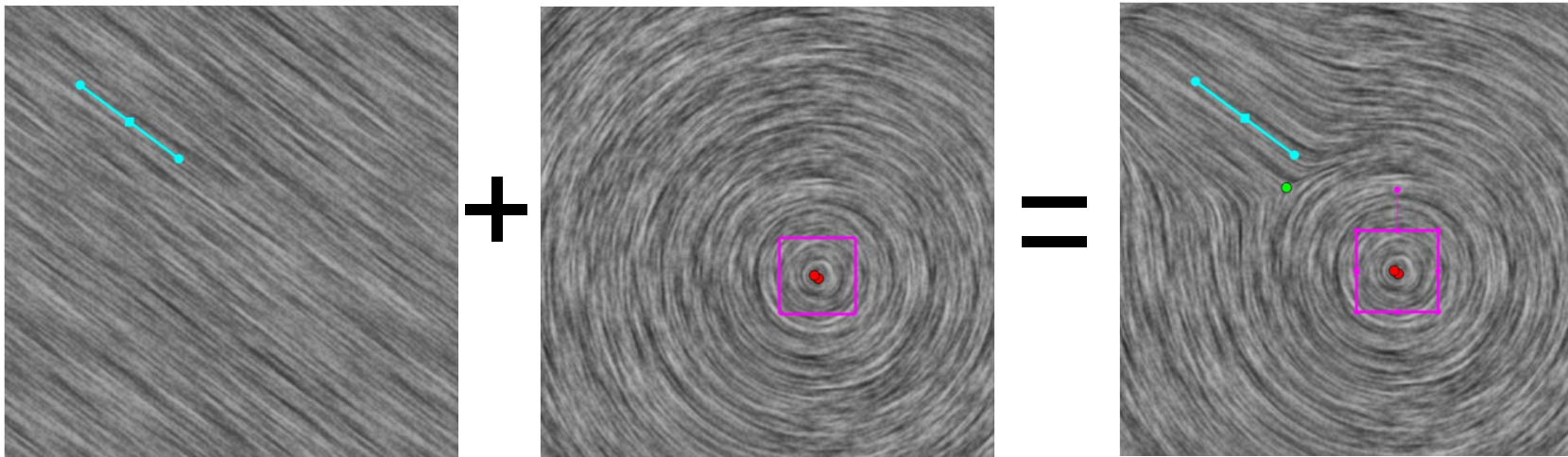
Procedural Modeling of Streets

- Tensor fields
  - Second order symmetric tensor fields
    - Eigenvectors of tensor values for two orthogonal families
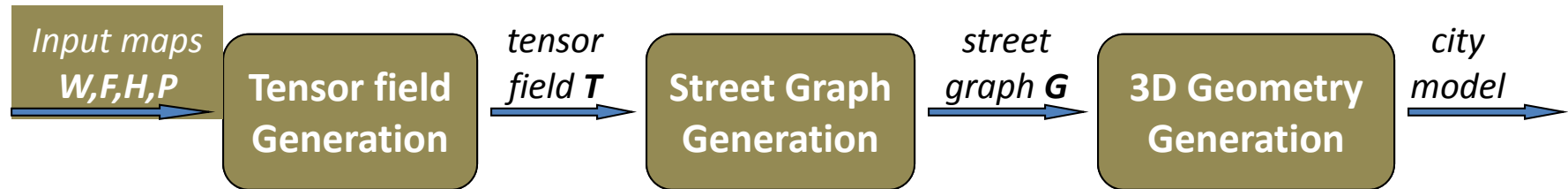 - Topology Singularities
  - Hyperstreamlines

Procedural Modeling of Streets

- Tensor field design
  - Define basis fields *Ti*
  - Combine using radial basis functions

Procedural Modeling of Streets

Input maps **W,F,H,P** → **Tensor field Generation** → *tensor field **T*** → **Street Graph Generation** → *street graph **G*** → **3D Geometry Generation** → *city model*
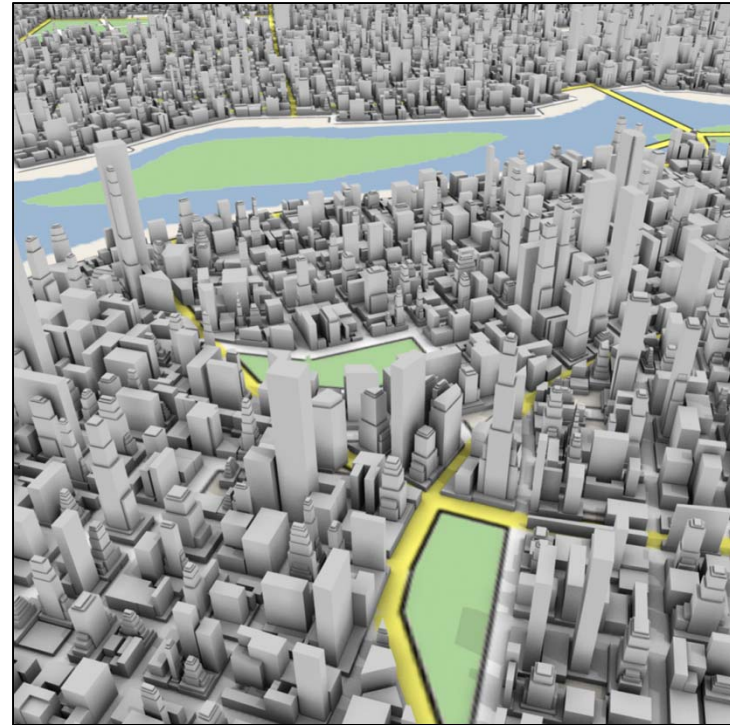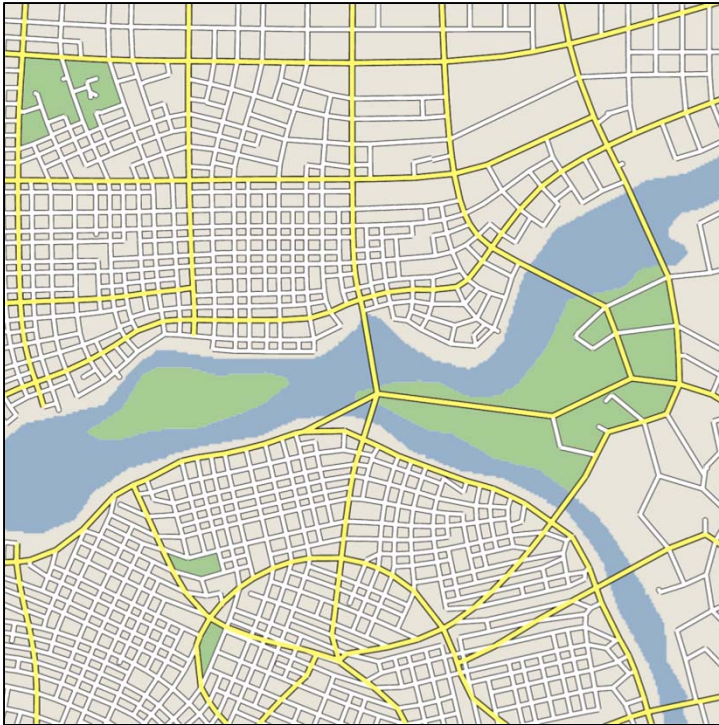
- System Pipeline

Procedural Modeling of Streets

- Example result

Urban Layouts and Road Networks

- **Procedural Generation of Roads**
  - Galin, Peytavie, Marechal, Guerin

- Eurographics 2010

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Procedural Generation of Roads

- Overall goal is an interactive algorithm for generating a road connecting an initial and a final point that adapts to the characteristics of an input scene.
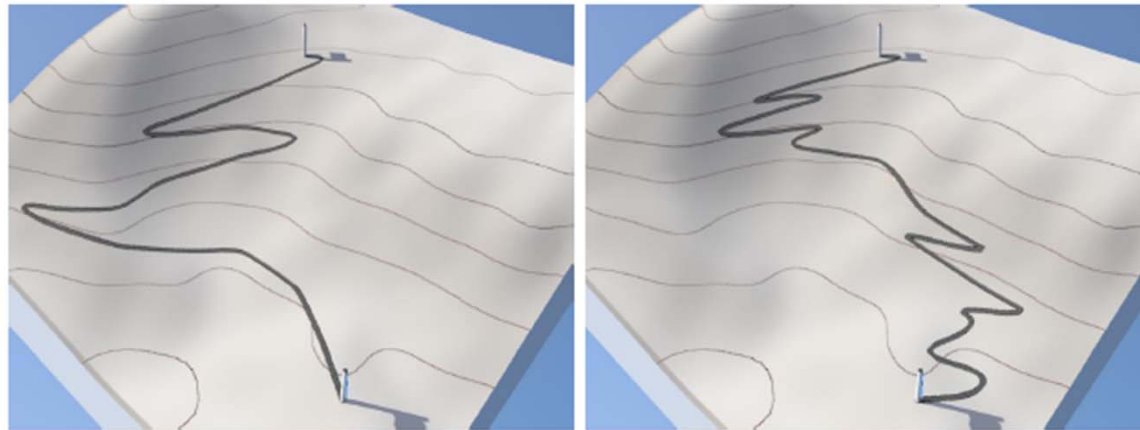
Smoother path   Sharper path

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Procedural Generation of Roads

- Contributions
  - a class of parameterized and controllable cost functions that takes into account the different parameters/characteristics of the terrain
  - an efficient method to compute a weighted anisotropic shortest path problem using an optimization over an implicit finite graph
  - compact procedural models for representing roads, tunnels and bridges with a few parameters describing their geometrical characteristics

Procedural Generation of Roads

- Continuous Cost Function

$$C(\rho) = \int_0^T c(\mathbf{p}(t), \dot{\mathbf{p}}(t), \ddot{\mathbf{p}}(t)) \, \mathrm{d}t$$
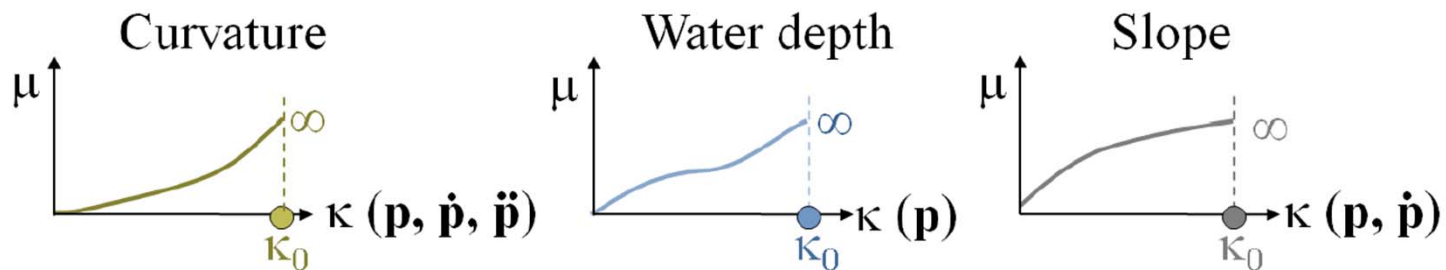
$$C(\rho^*) = \min_{\rho \in \mathcal{P}} C(\rho)$$

Procedural Generation of Roads
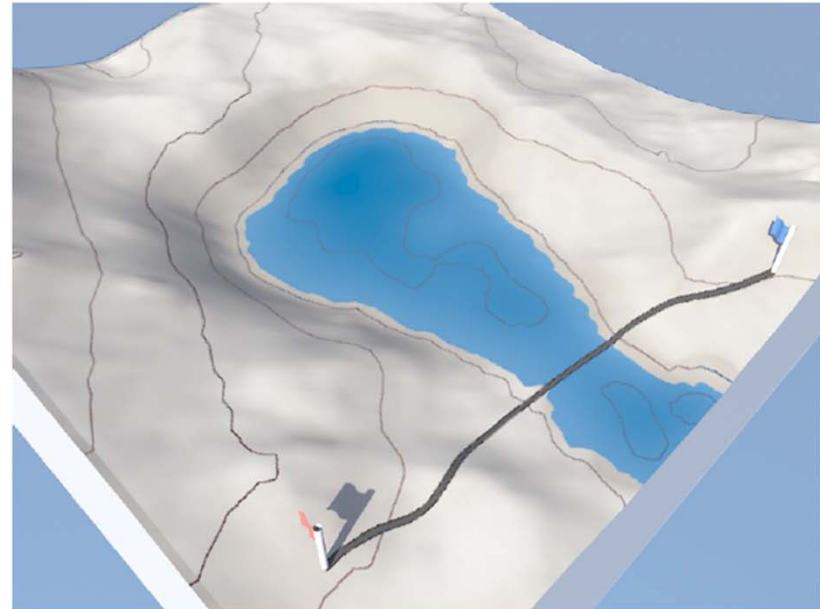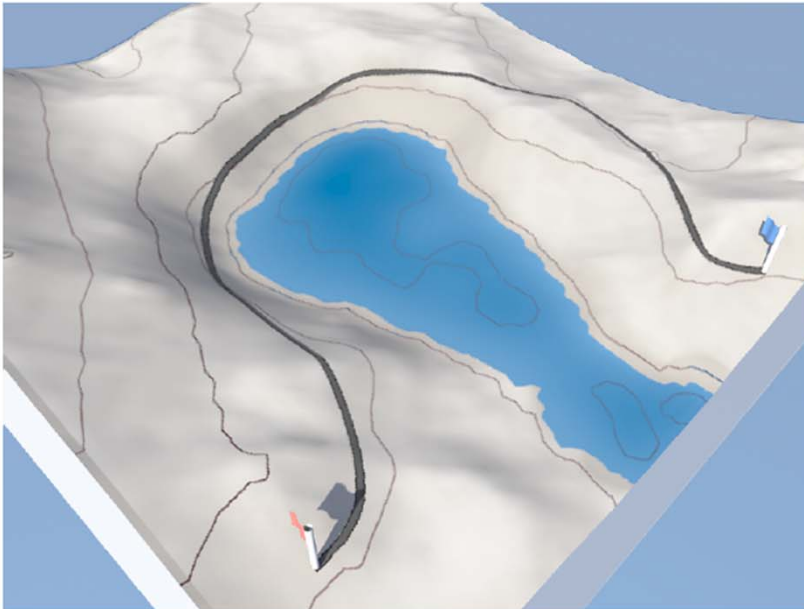
- Discretization of the Cost Function

$$c(\mathbf{p}, \dot{\mathbf{p}}, \ddot{\mathbf{p}}) = \sum_{i=0}^{i=n-1} \mu_i \circ \kappa_i(\mathbf{p}, \dot{\mathbf{p}}, \ddot{\mathbf{p}})$$

Procedural Generation of Roads

- Results:
  - Without or with bridges…
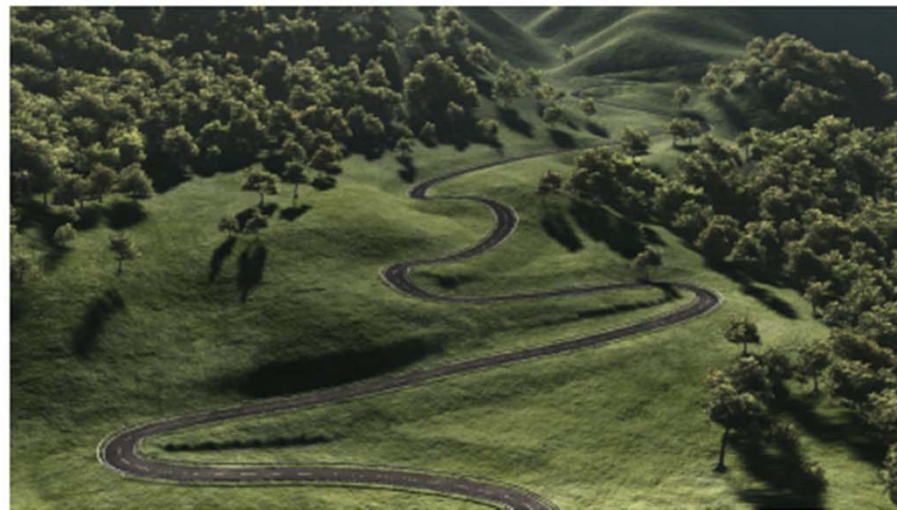
Procedural Generation of Roads

- Results:
  - Altering cost function parameters…

Procedural Generation of Roads

- Results:

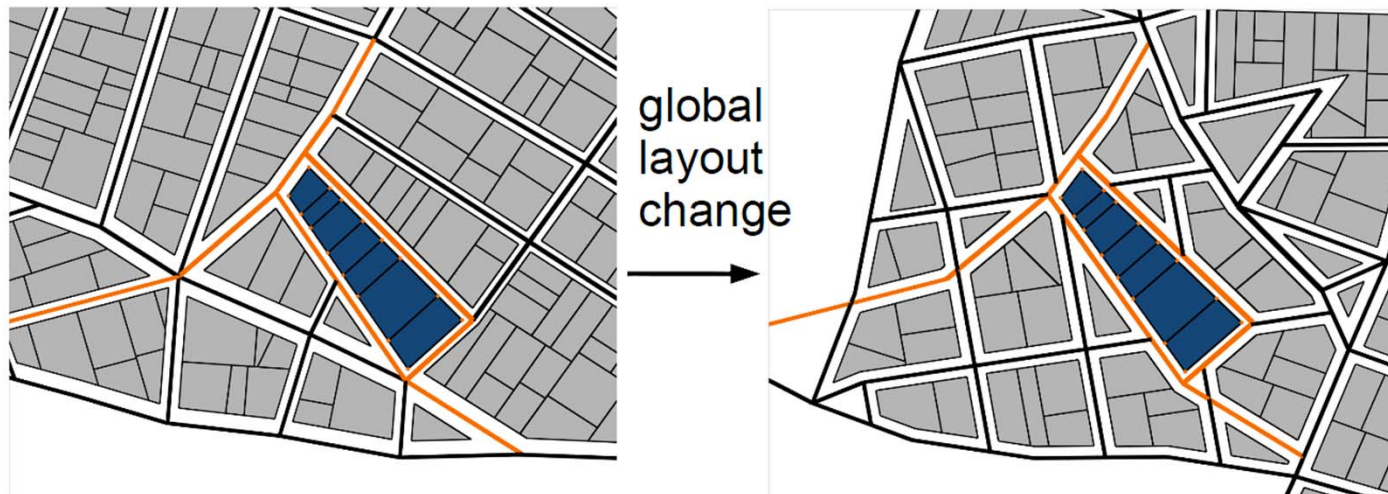Course: Modeling 3D Urban Spaces using Procedural and Simulation-based Techniques

Urban Layouts and Road Networks

- **Interactive Modeling of City Layouts using Layers of Procedural Content**
  - Lipp, Scherzer, Wonka, and Wimmer
- Eurographics 2011

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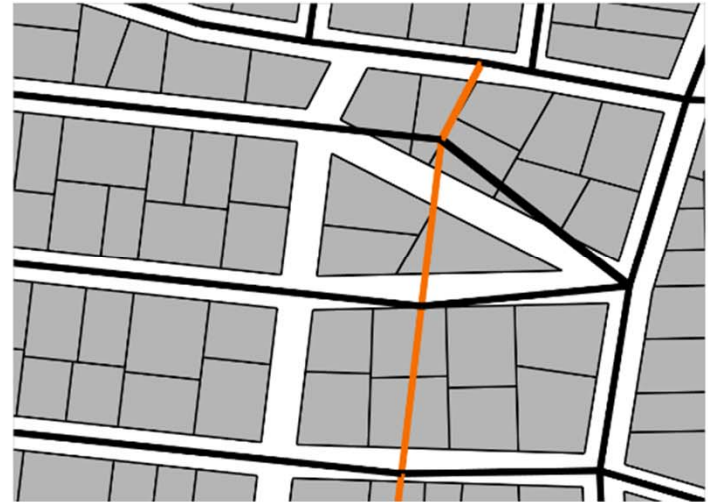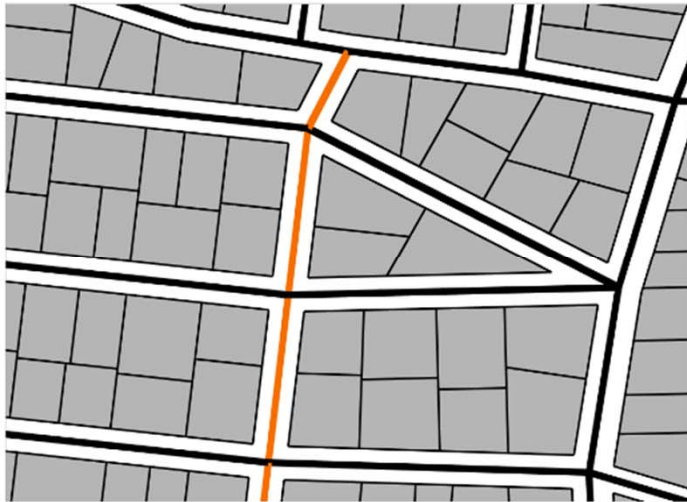# Interactive Modeling of City Layouts

- Overall goal is an interactive city modeling system that is built on persistent editing operations that remain in the space of valid urban layouts.

- Editing system supports
  - Direct control and editing of procedural layouts
  - Combining urban layouts
  - Persistent changes
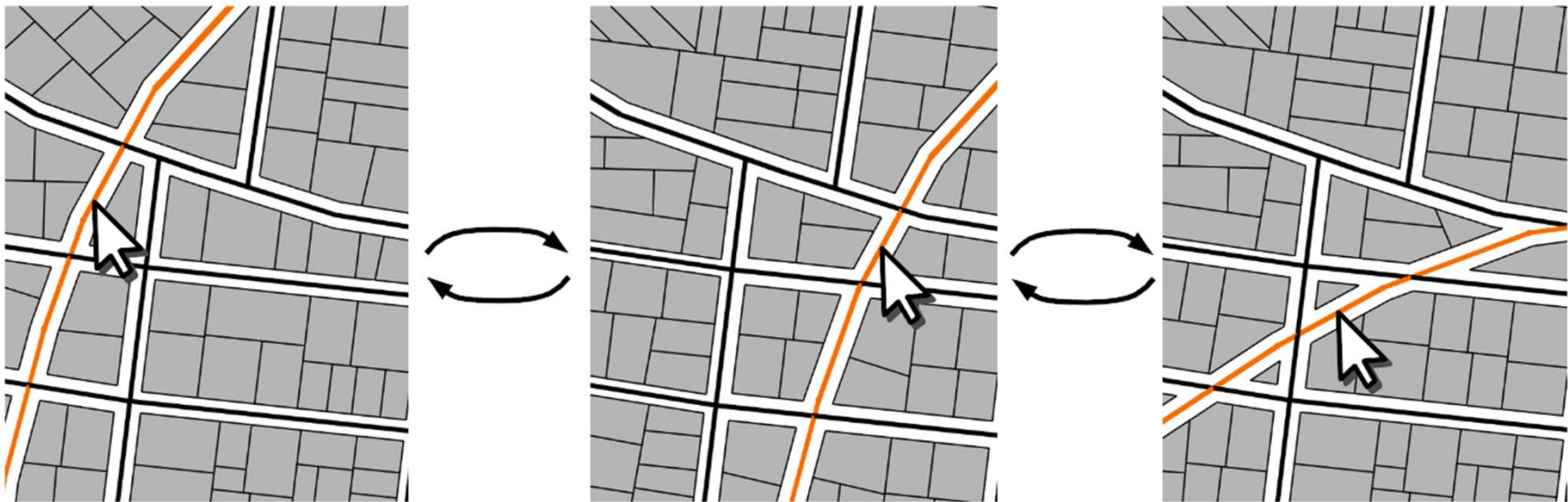
Interactive Modeling of City Layouts

- Result of "moving a street" using a naïve approach

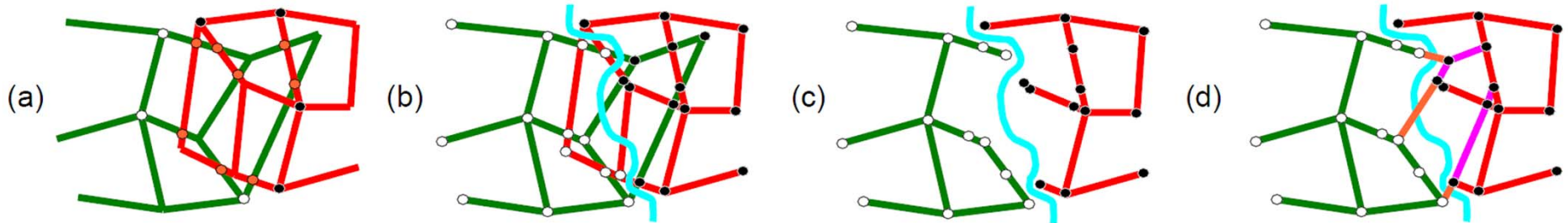# Interactive Modeling of City Layouts

- Result of "moving a street" using the proposed approach

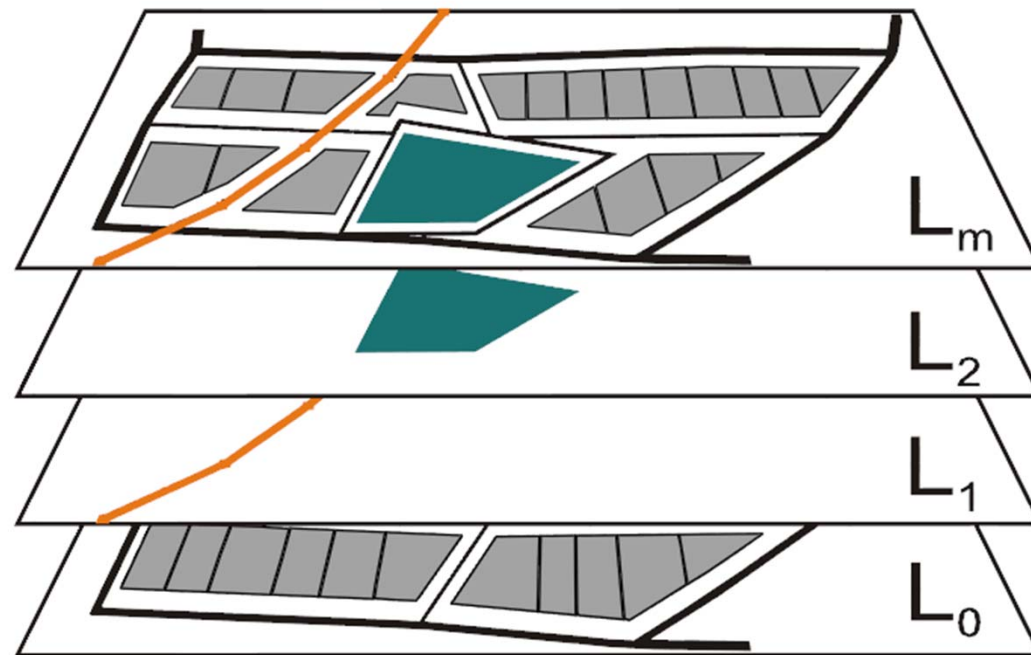# Interactive Modeling of City Layouts

- Use graph-cut analogy to change the street topology by merging two different urban layouts
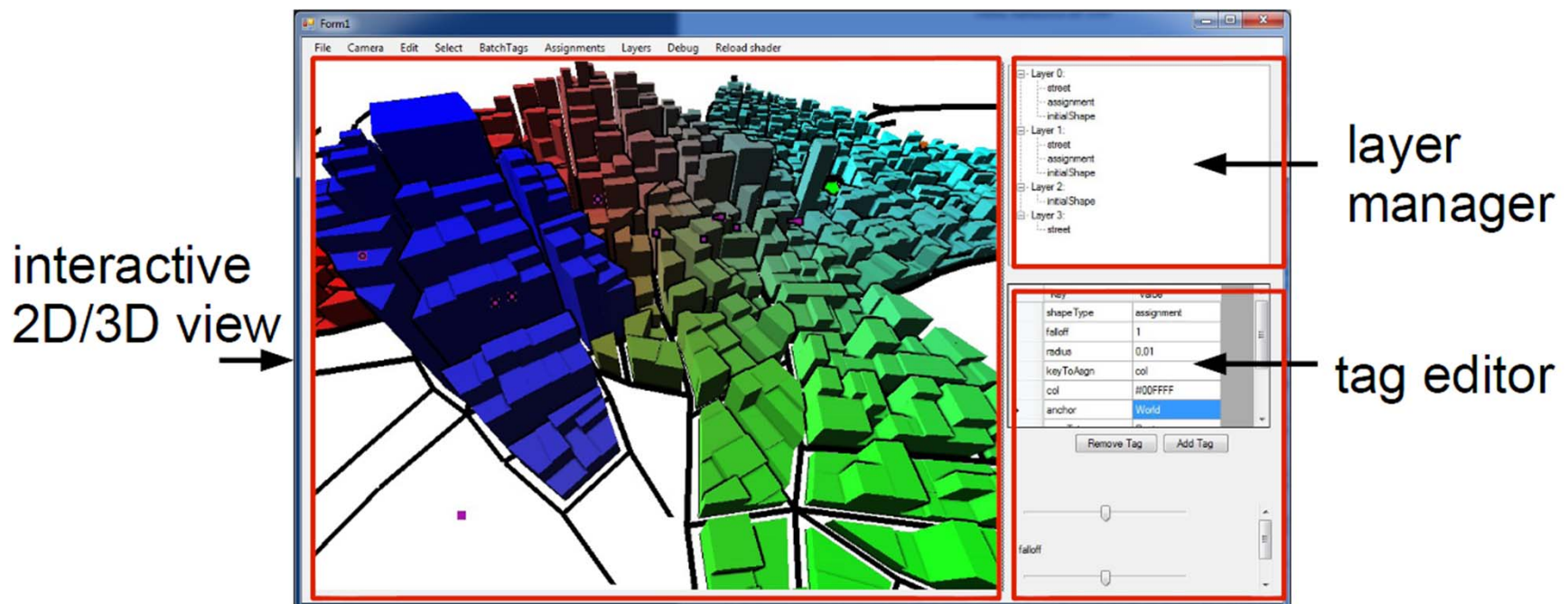
Interactive Modeling of City Layouts

- Support multiple layers and use their merging to combine edits and obtain persistent changes

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Interactive Modeling of City Layouts

- Results
  - Interactive system

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Interactive Modeling of City Layouts

- Results
  - Various editing stages of an example layout