Bridging the Gap between Urban Simulation and Urban Modeling

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Urban Modeling

Urban Simulation

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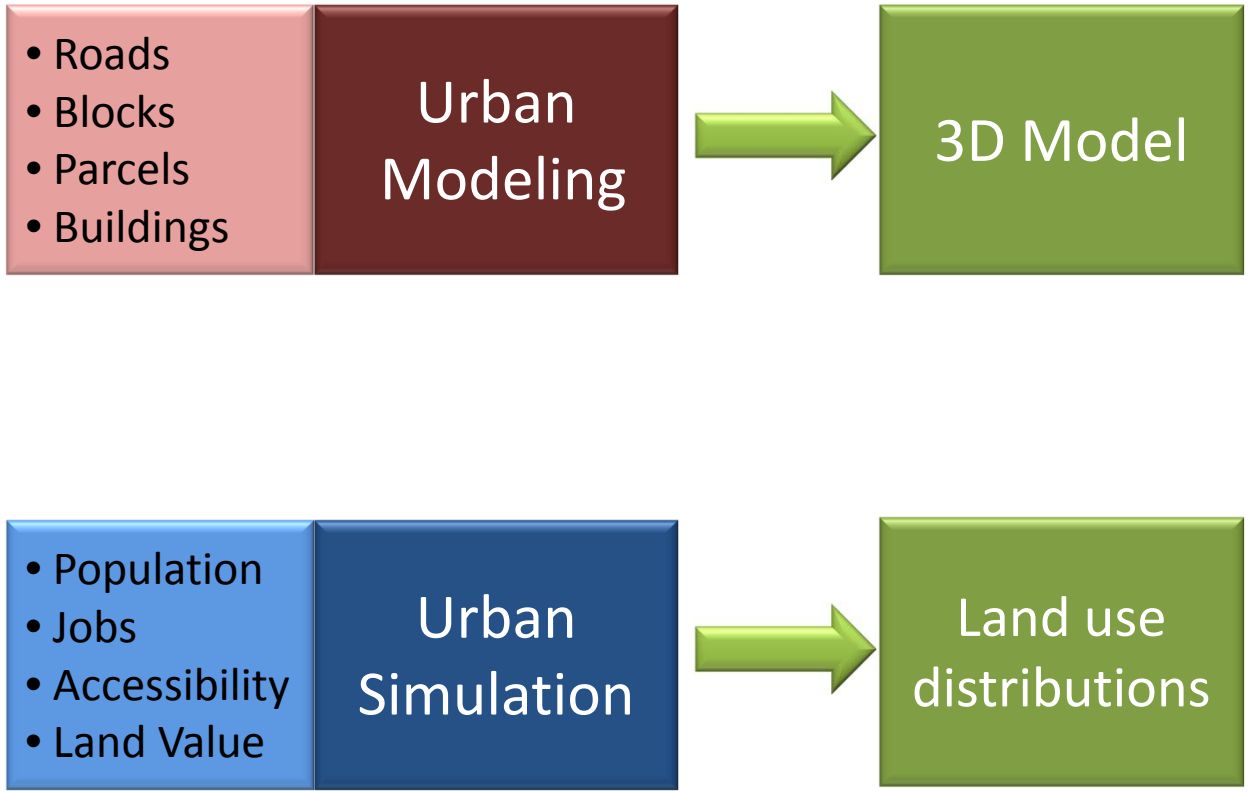

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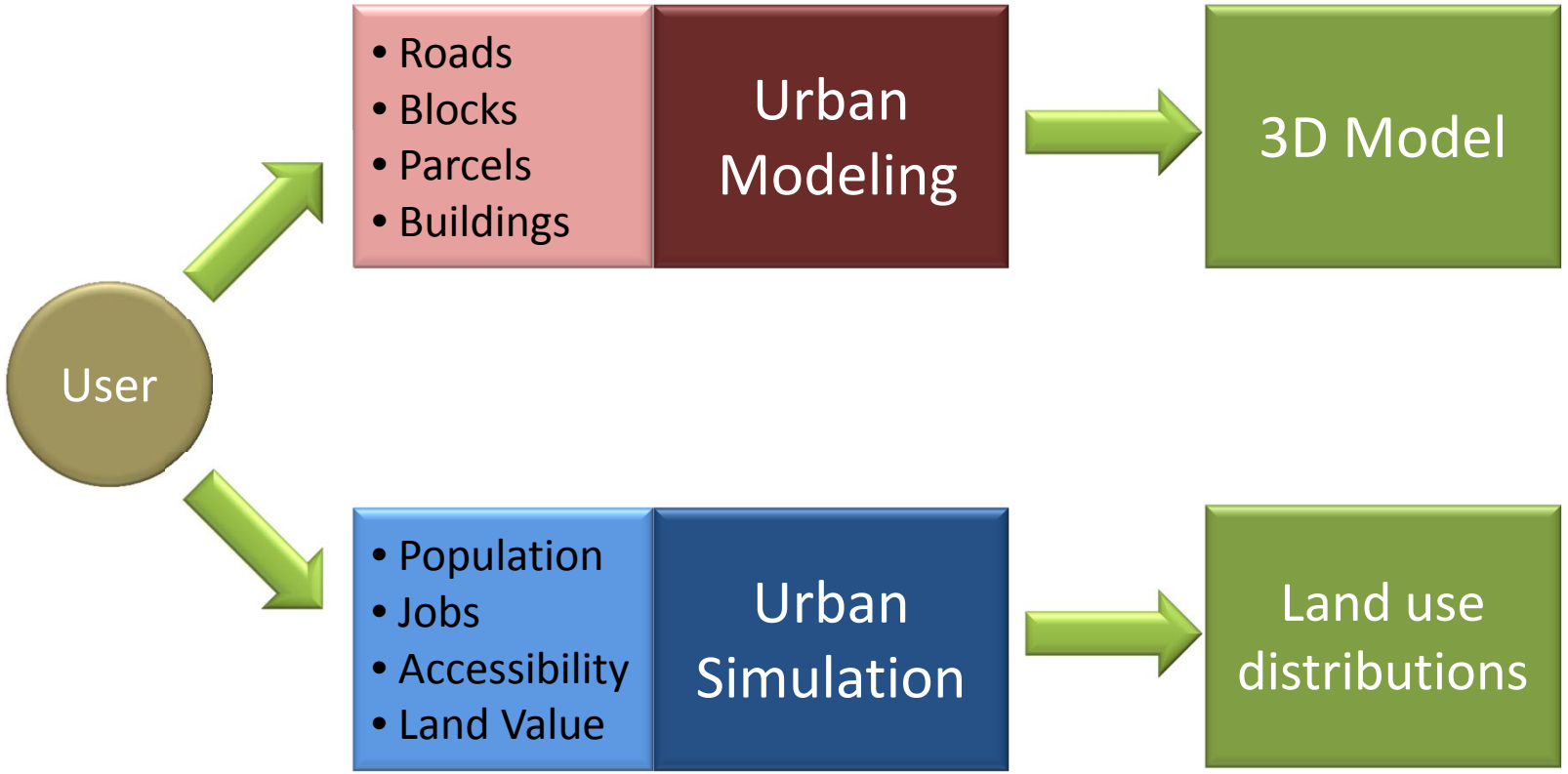

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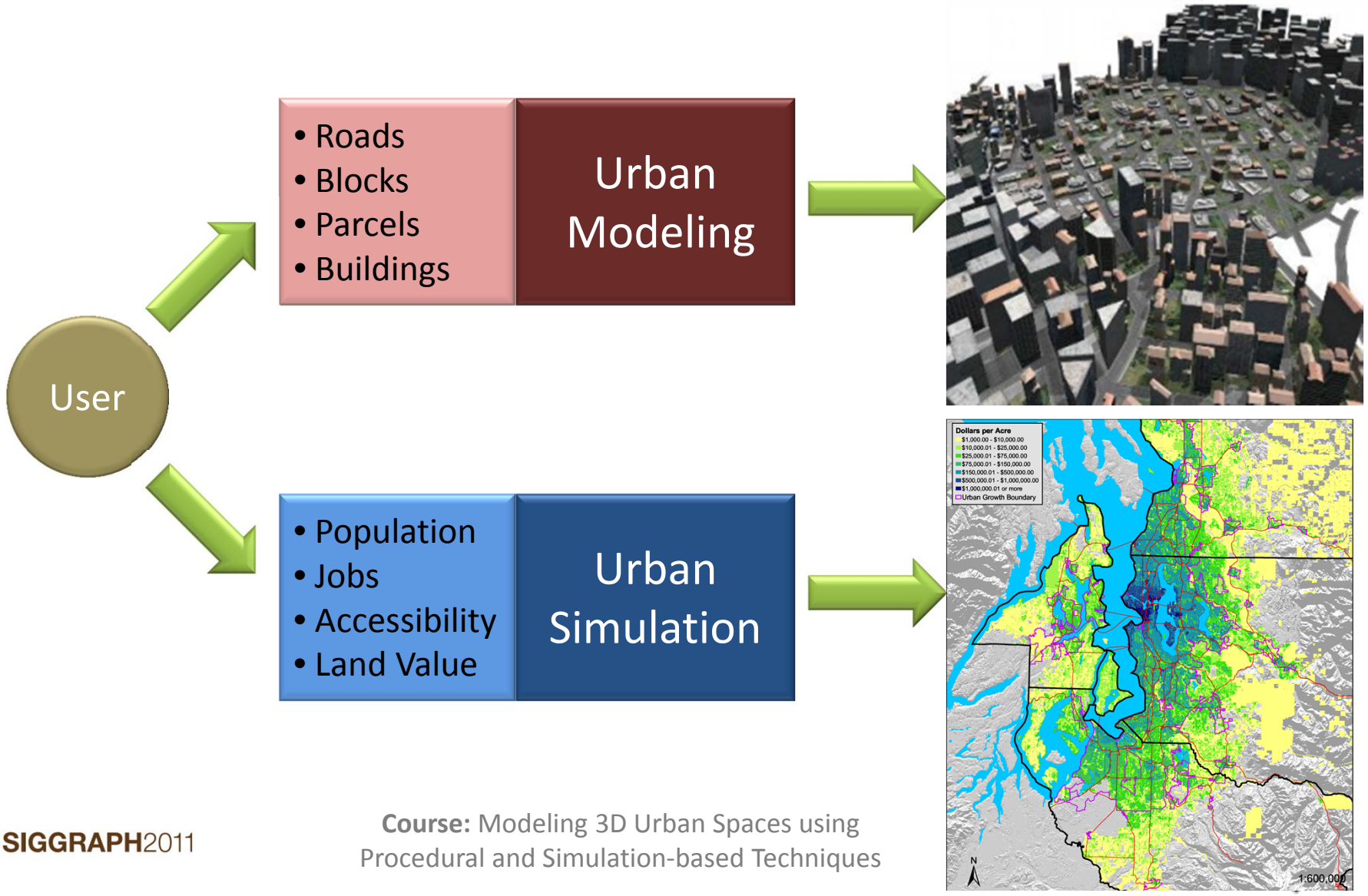

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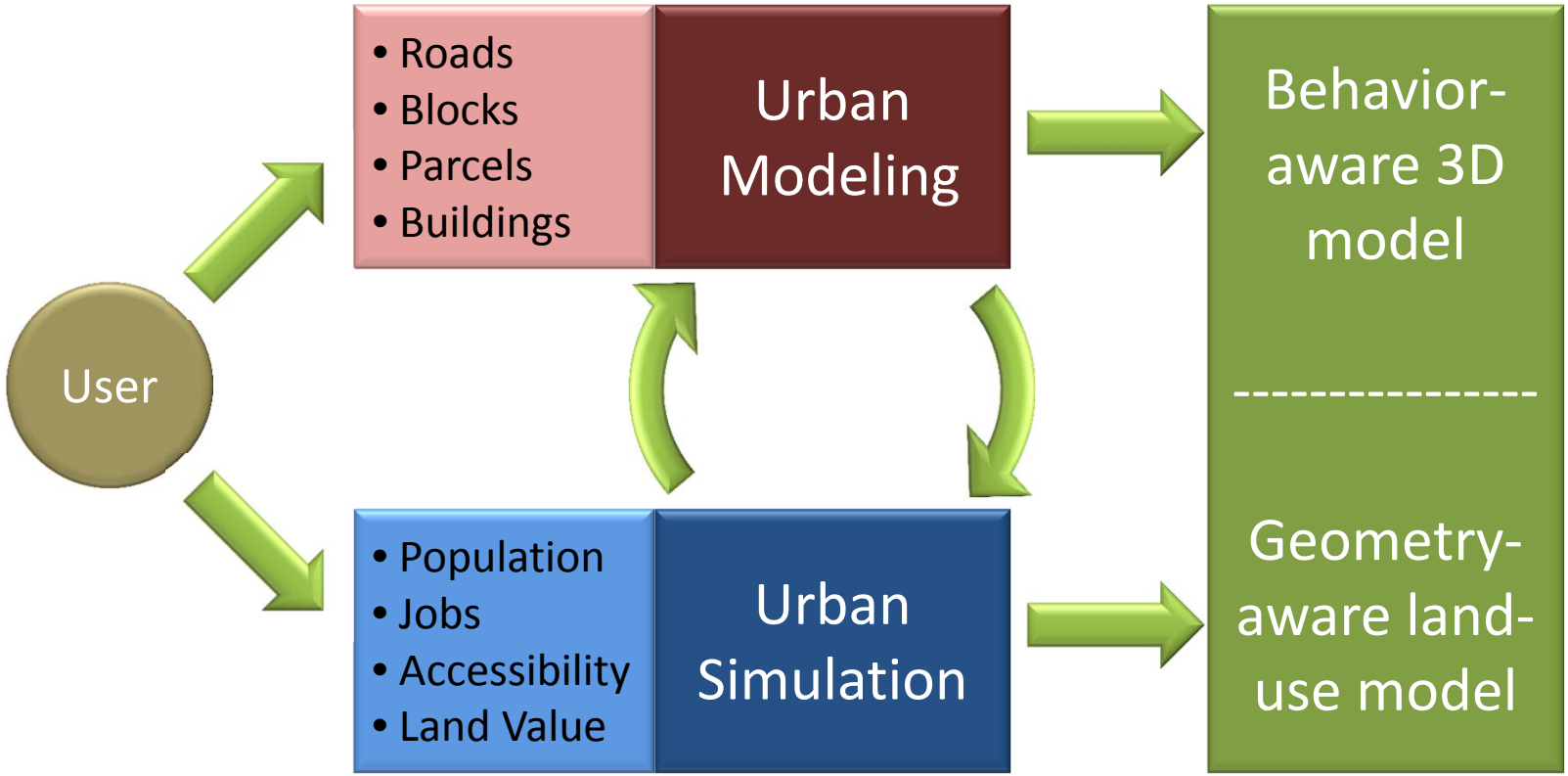

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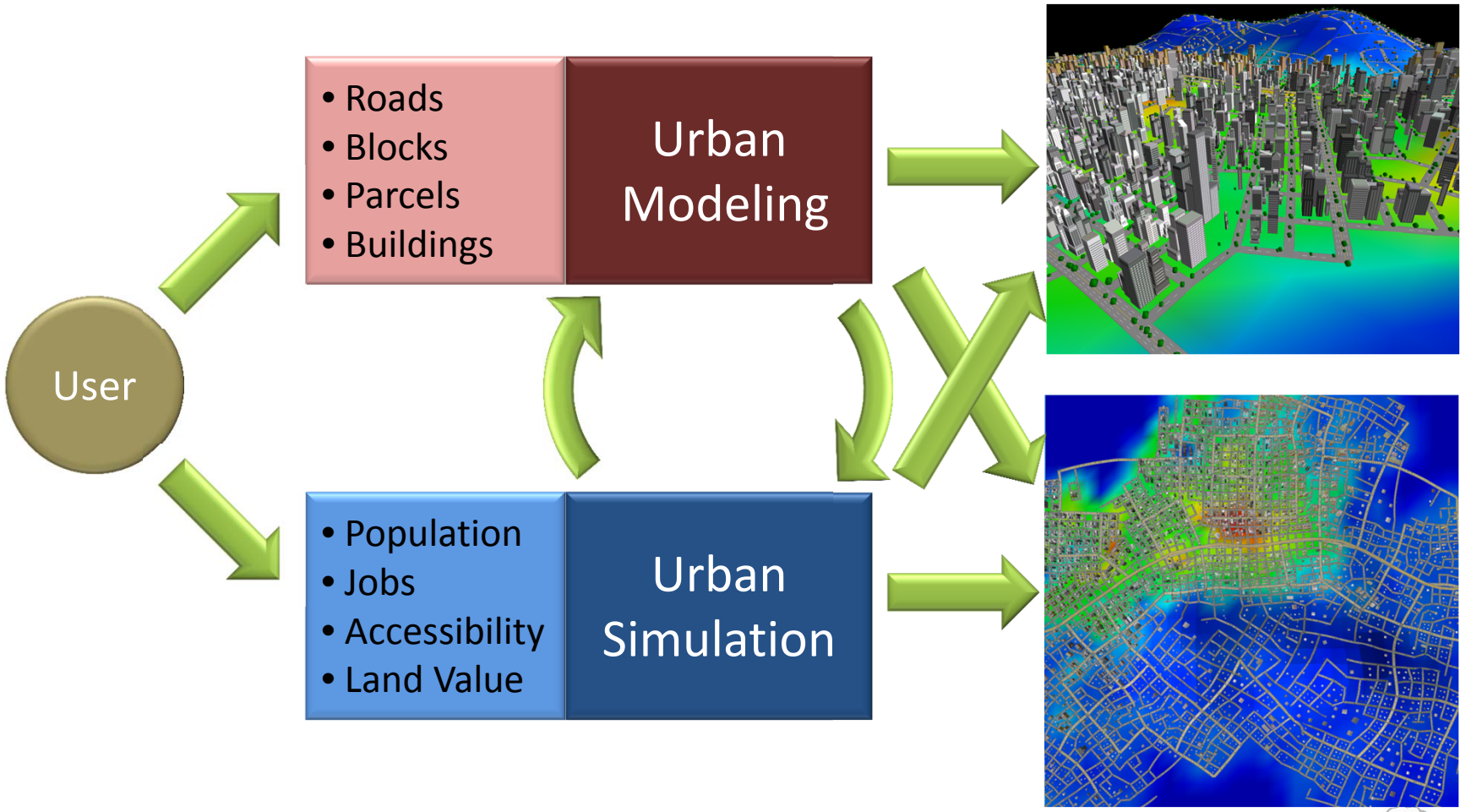


Urban Modeling

- Rest of this talk
  - Overview of approaches for urban simulation
  - Methods in Computer Graphics that integrate urban modeling, visualization and simulation
  - Integrated system for real-world urban planning

URBAN SIMULATION

Urban Modeling

- Covered in the previous sessions of this course

Urban Simulation

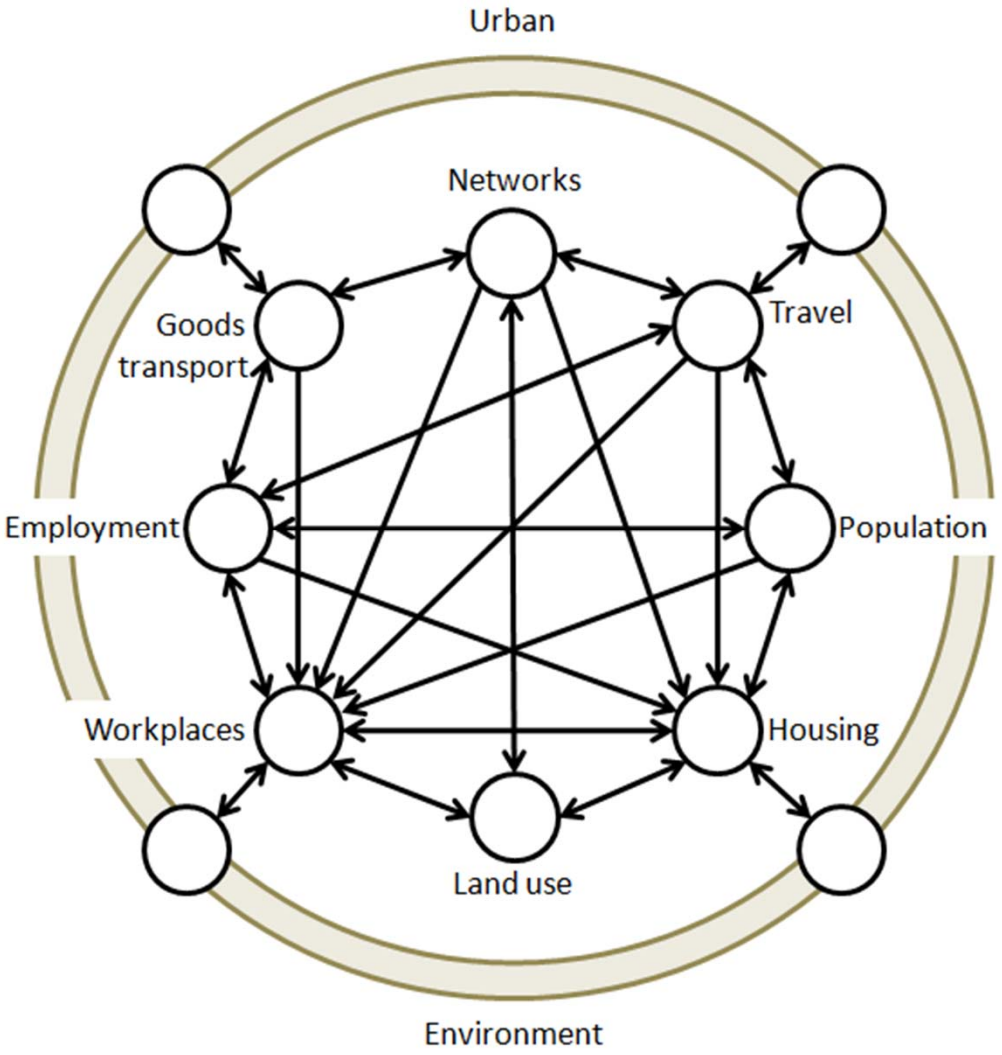
- Very brief overview

Urban Simulation

Urban Simulation

- Models the behavioral and spatial patterns of urban economic agents
  - Jobs
  - Population
  - Housing
  - Land use
- Aims to predict behavior of a city over time
- Outputs massive spatially distributed data

Urban Simulation



- General simulation model

Image recreated from:
Michael Wegener, “Operational urban models state of the art”, 1994.

Urban Simulation

- A brief overview of urban simulation paradigms:
  - Cellular automata
  - Agent-based models
  - Dynamic microsimulation
- Example system:
  - UrbanSim

Urban Simulation

- Cellular Automata
  - Simulate the conversion of non-urban land to urban use
  - City is represented as an arrangement of individual automata in a regular tessellated space

Urban Simulation

- Cellular Automata
  - Transition rules determine how automata states adapt over time
  - Information is exchanged between cells and spread through neighborhoods
  - Do not address changes to the built environment or is occupants, or the travel that connects agents

Urban Simulation

- Cellular Automata

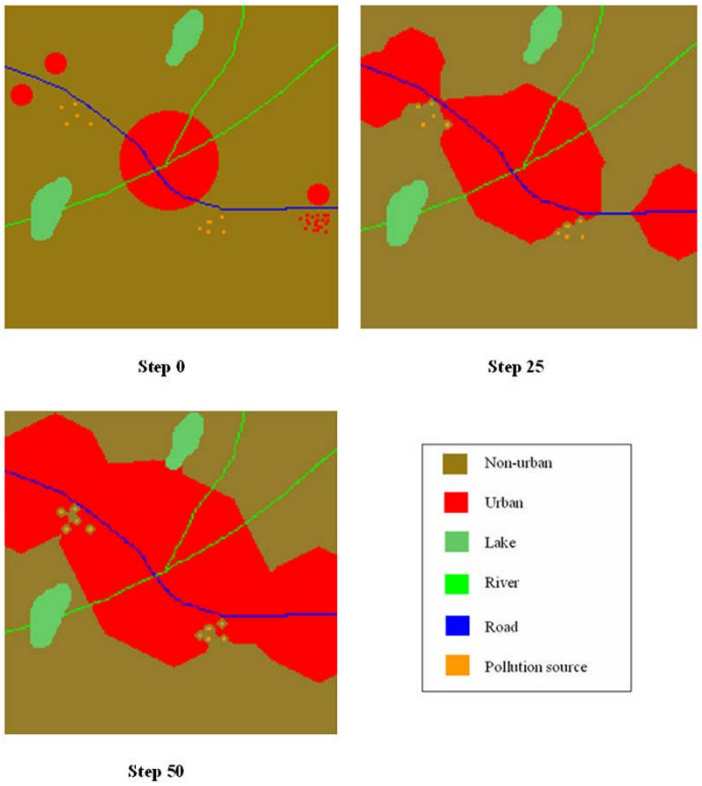
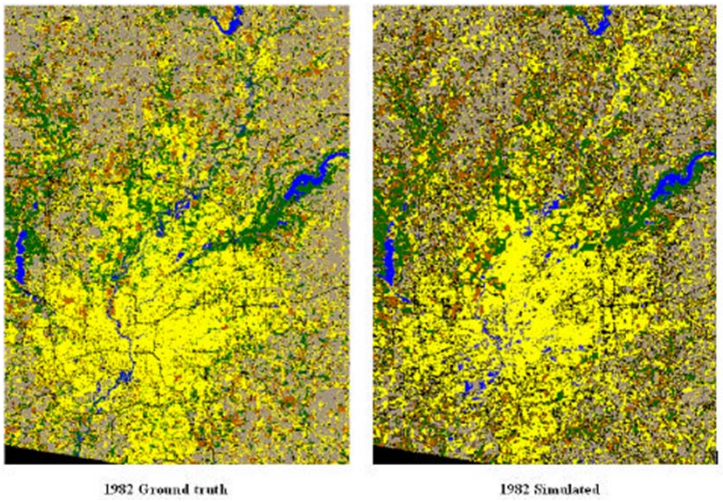


Image from:
Sharaf Alkheder, Jie Shan, "Cellular Automata Urban Growth Simulation and Evaluation", 2008



Urban Simulation

- Cellular Automata
  - **Cellular automata and urban simulation**
    Torrens, Sullivan, 2001
  - **Loose-coupling a cellular automaton model and GIS**
    Clarke, 1998
  - **Fuzzy inference guided cellular automata urban-growth modeling**
    Al-Kheder, Wang, Shan, 2008

Urban Simulation

- Agent-based Models
  - Extended cellular automata framework to include mobile, interacting agents
  - Examine cities as self-organizing complex systems

Urban Simulation

- Agent-based Models
  - Properties of agents explored with relatively simple behavioral rules
  - Most agent-based urban simulation models have behavior that is influenced only by localized context

Urban Simulation

- Dynamic Microsimulation
  - Combination of urban economic analysis with statistical modeling of choices made by agents in the urban environment
    - E.g., Households choosing residential location
  - Builds on:
    - Random Utility Theory (McFadden, 1974)
    - Discrete choice models

Urban Simulation

- Dynamic Microsimulation
  - **Integrated urban models**
    Putman, 1991
  - **General equilibrium models of polycentric urban land use**
    Anas, Kim, 1996
  - **A land use model for Santiago City**
    Martinez, 1996

Urban Simulation

- Example system: **UrbanSim**
  - **UrbanSim: Modeling urban development for land use, transportation, and environmental planning** Paul Waddell, 2002

Urban Simulation

- Example system: **UrbanSim**
  - Simulates the choices of
    - Individual households
    - Businesses
    - Parcel landowners
    - Developers

  interacting in real estate markets

Urban Simulation

- Example system: **UrbanSim**
  - Differs from Cellular Automata and agent-based models by integrating
    - Discrete choice methods
    - Explicit representation of real estate markets
    - Statistical methods to estimate model parameters and to calibrate uncertainty in the model system

URBAN VISUALIZATION

Urban Visualization

- Visualizations of computed datasets
  - Used by regional planning agencies to evaluate
    - Alternative transportation investments
    - Land use regulations
    - Environmental protection policies

Urban Visualization

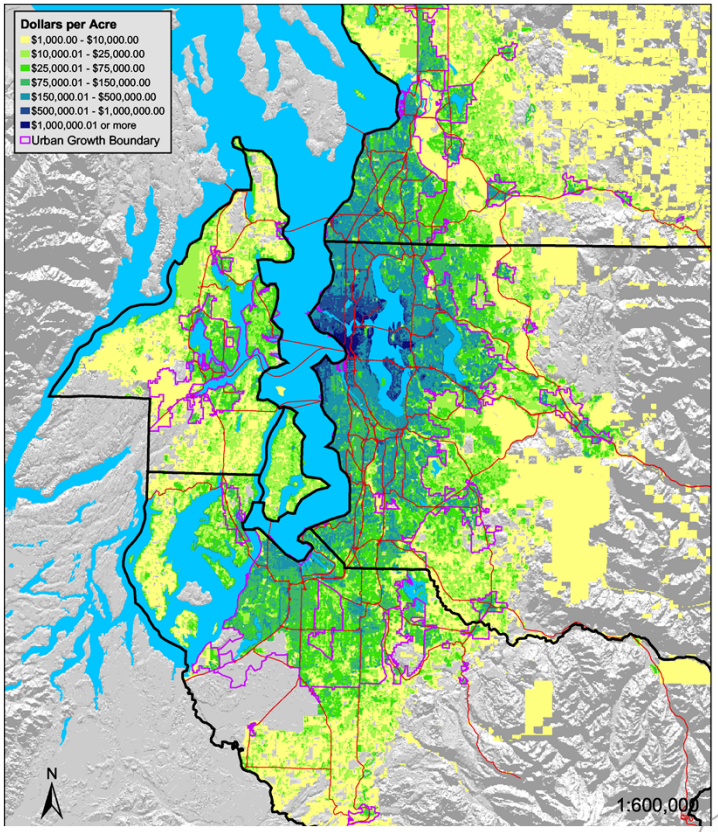
- Visualizations of computed datasets
  - Interest several groups of population with different levels of expertise in handling data
    - Policy makers
    - The public
    - Modelers running the simulation

Urban Visualization

- Traditional urban visualization techniques
  - Focused on handling large urban simulation datasets
  - Making their analysis more intuitive to urban planners
- In the following, we outline a few representative techniques

Urban Visualization

- Traditional urban visualization techniques
  - Choropleth maps:
    Areas **shaded** in proportion to the values of the displayed variables



Example simulation output:
Map-based indicator display for Puget Sound region
(Total land value per acre, 2000)
Image from: Alan Borning, University of Washington

Urban Visualization

- Traditional urban visualization techniques
  - Cartograms: Distort a map by **resizing** its regions according to the values of the displayed variable, but keeping the map recognizable

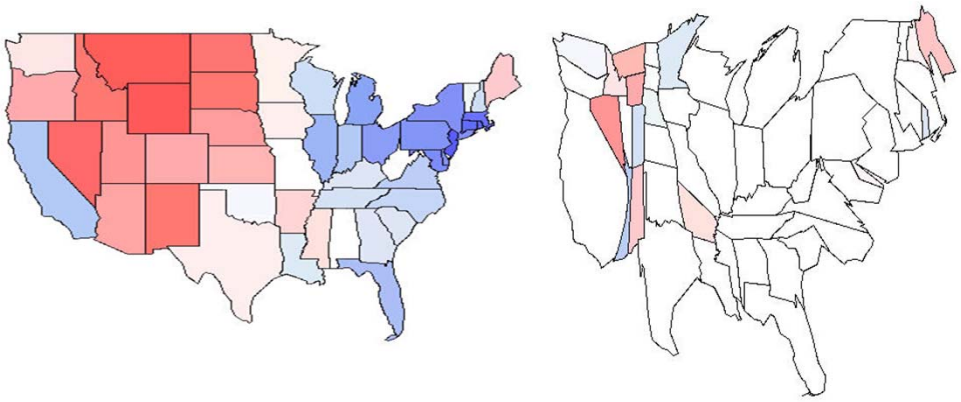
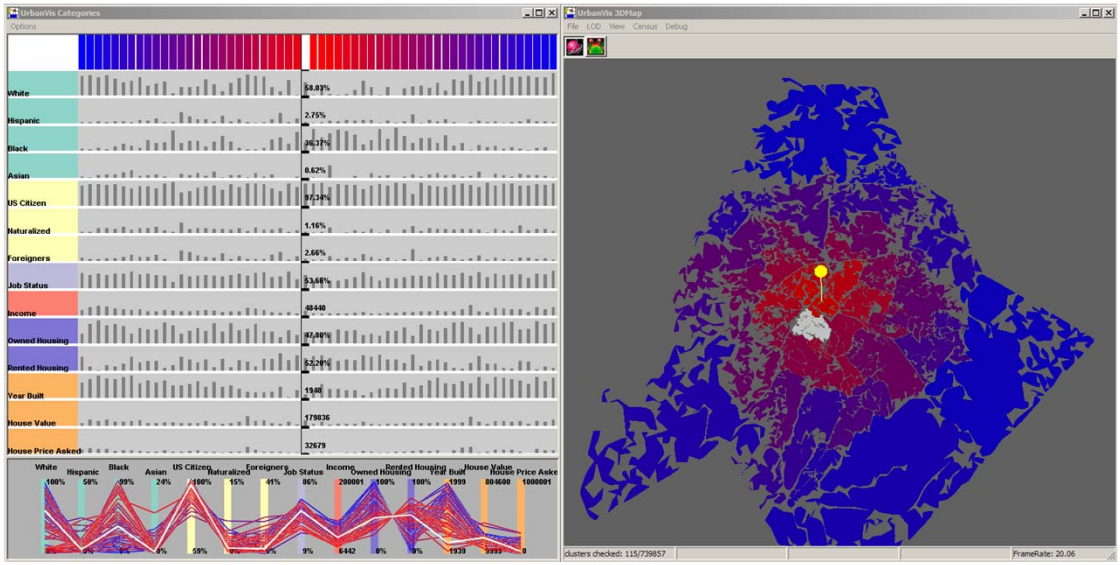


Image from:
Daniel Keim, Stephen North, Christian Panse, “CartoDraw: A Scanline based Cartogram Algorithm”, 2004.

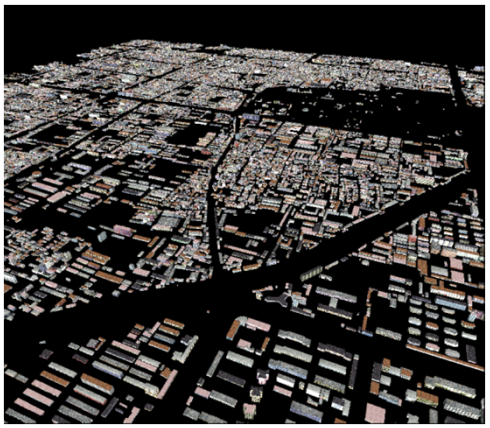
Urban Visualization

- **Legible Cities**
  Chang, Wessel, Kosara, Sauda, Ribarsky
- TVCG 2007

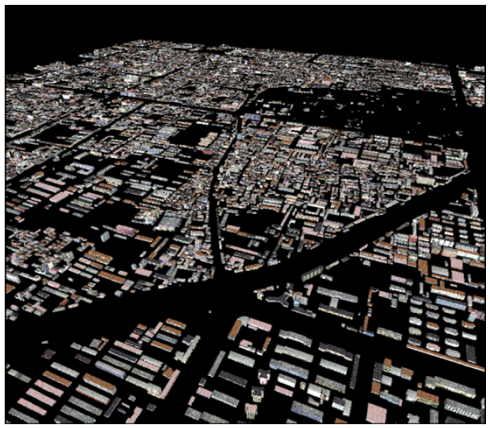


Urban Visualization

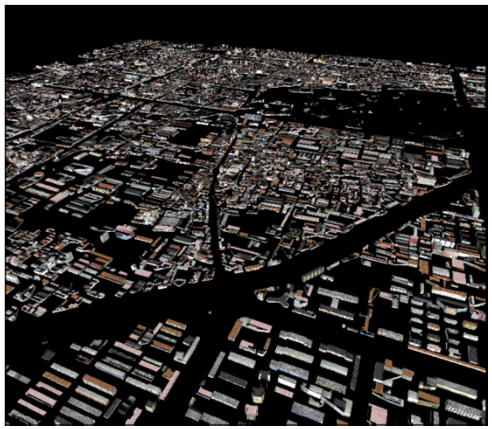
- Goal: Visualize an urban model in a focus-dependent, multi-resolution fashion, while retaining the legibility of the city



Original Model



45% polygons



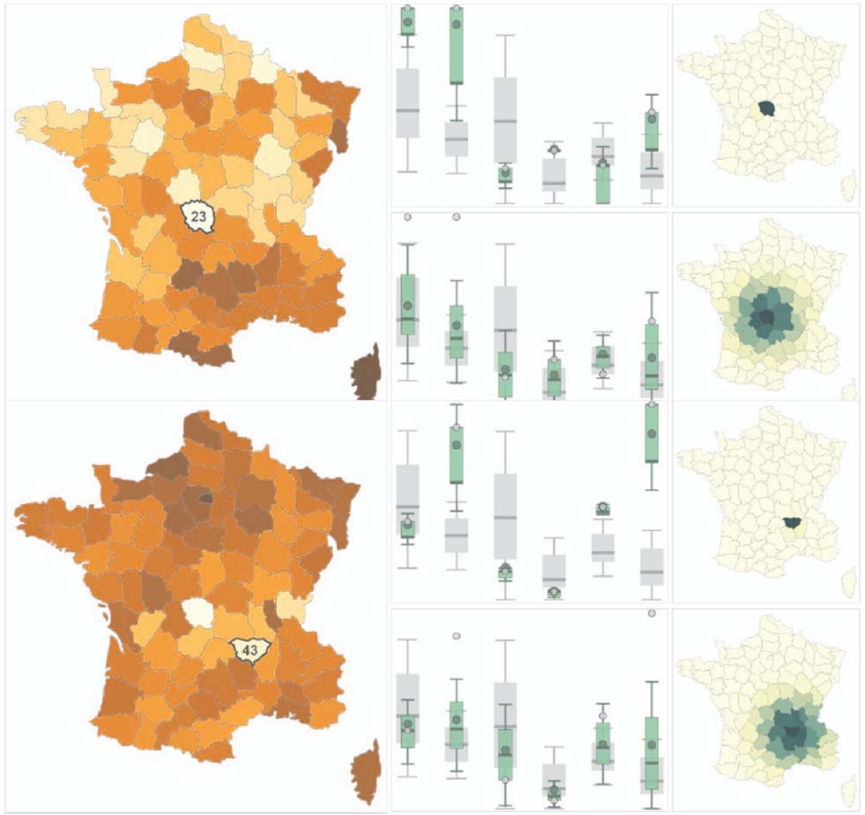
18% polygons

Urban Visualization

- Integrate 3D model view and data view
  - Relationships between the geospatial information of the urban model and the related urban data can be more intuitively identified

Urban Visualization

- **Geographically Weighted Visualization**
  Dykes, Brunsdon
- TVCG 2007



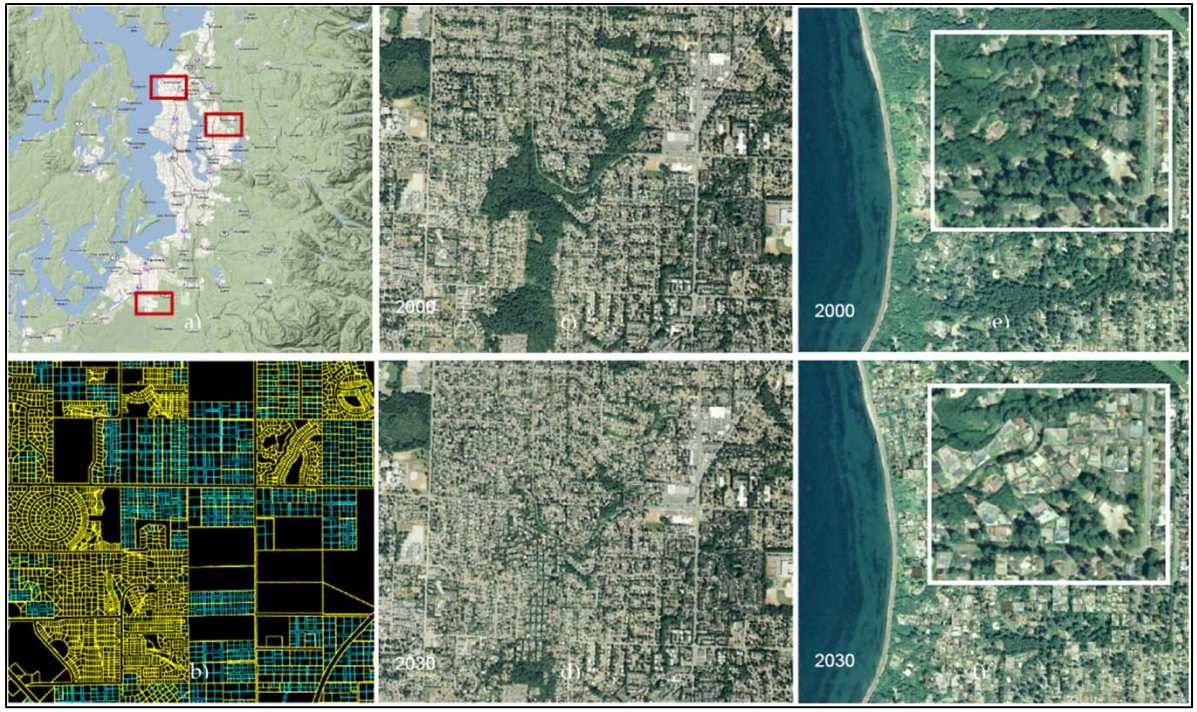
Urban Visualization

- Visually encode information about geographic and statistical proximity and variation through
  - geographically weighted (GW)-choropleth maps
  - multivariate GW-boxplots
  - GW-shading and scalograms
- New graphic types reveal information about GW statistics at several scales concurrently

BRIDGING THE GAP BETWEEN URBAN SIMULATION, VISUALIZATION AND MODELING

Bridging the gap between urban simulation, visualization and modeling

- **Visualization of Simulated Urban Spaces**
  Vanegas, Aliaga, Benes, Waddell
- TVCG 2009



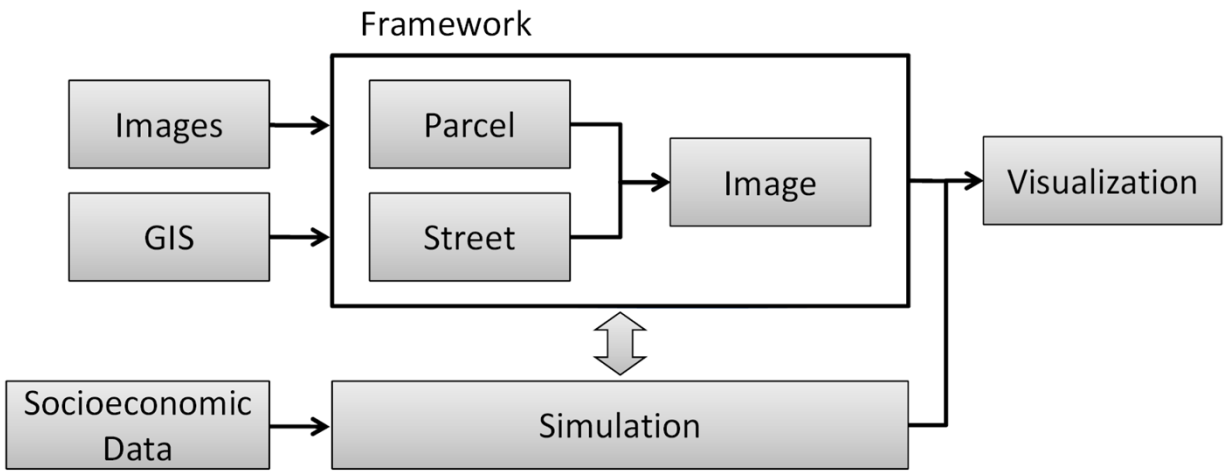
Visualization of Simulated Urban Spaces

- Infer an urban layout
  - Images (aerial view) + Structure (streets, parcels)

  from the values of a set of simulation variables at any given time step

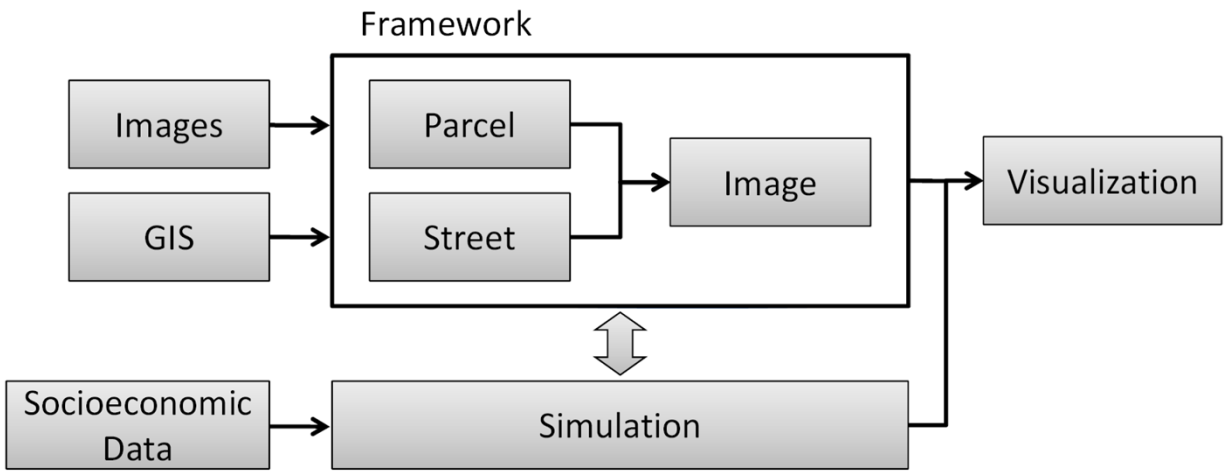
Visualization of Simulated Urban Spaces

- Approach
  - Spatially match socioeconomic data set with input aerial images and structure of the urban space



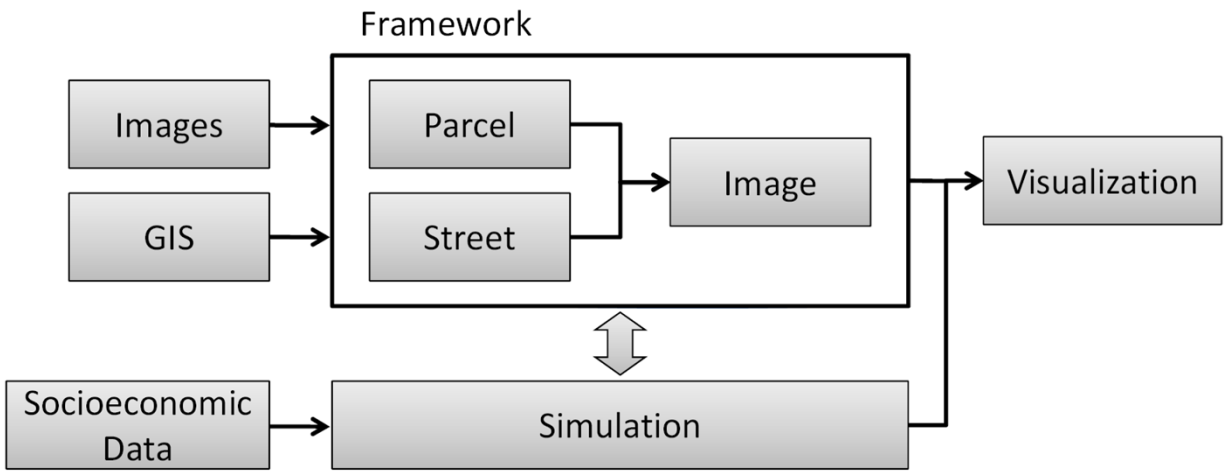
Visualization of Simulated Urban Spaces

- Approach
  - Create new structure that matches a set of attributes inferred from the simulation variables
  - New blank lots are created



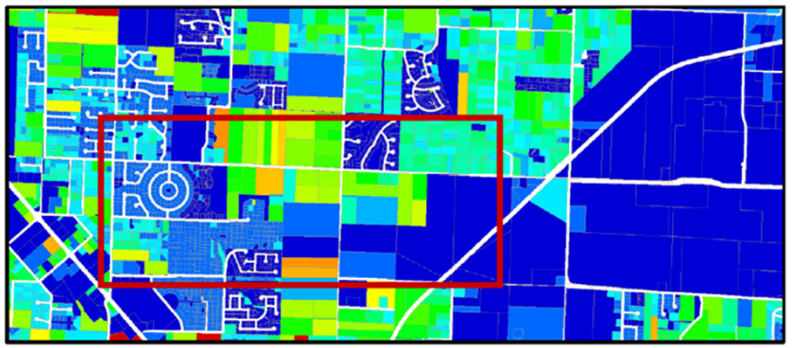
Visualization of Simulated Urban Spaces

- Approach
  - Aerial view imagery is “borrowed” from existing lots of the city with similar socioeconomic attributes as the new blank lot



Visualization of Simulated Urban Spaces

- Example result

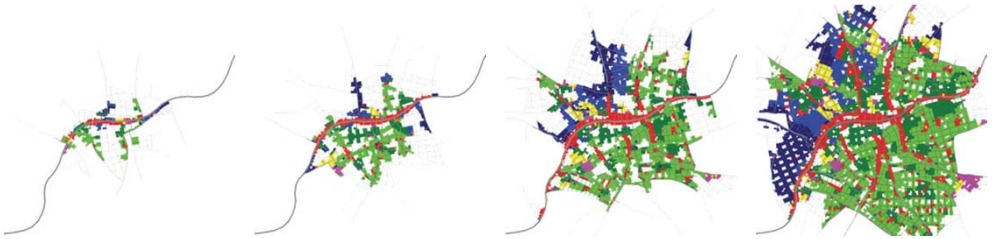


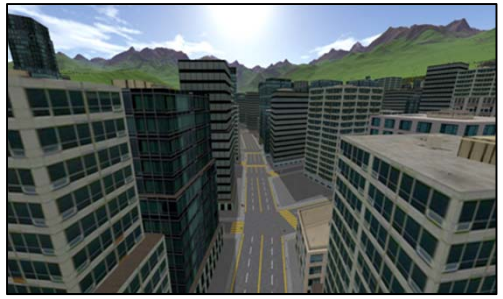
Visualization of Simulated Urban Spaces

- Example result

Bridging the gap between urban simulation, visualization and modeling

- **Interactive Geometric Simulation of 4D Cities**
  Weber, Müller, Wonka, Gross
- Eurographics 2009



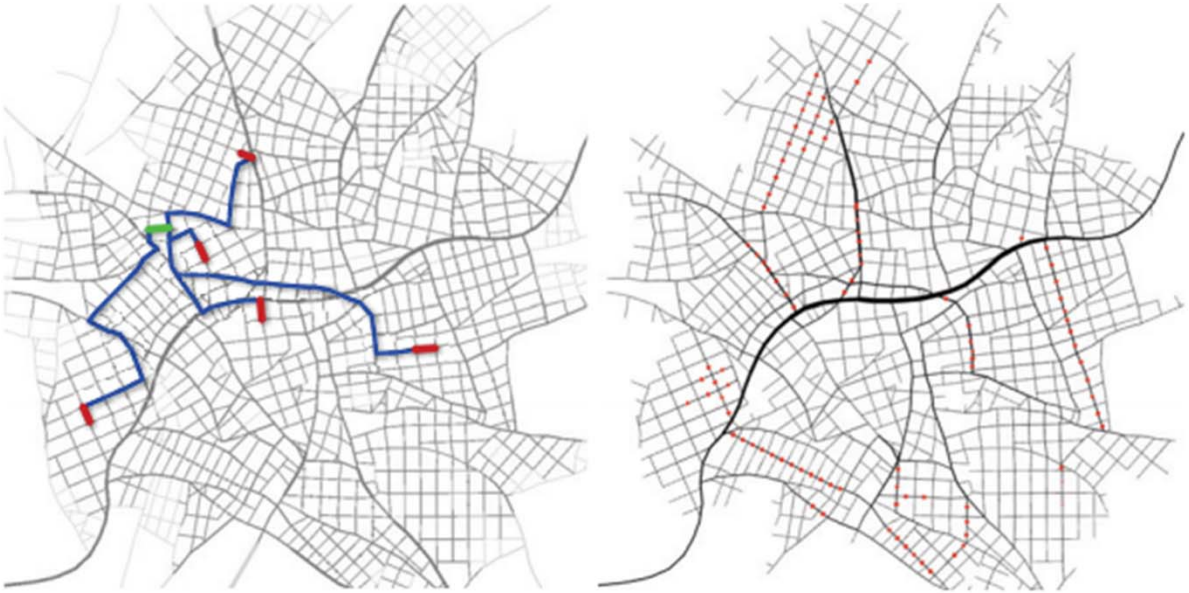


Interactive Geometric Simulation of 4D Cities

- Problem:
  - How to model cities that are changing over time?
  - How to use the urban simulation data to infer the geometry of the city (roads, lots, buildings)?

Interactive Geometric Simulation of 4D Cities

- Traffic simulation for street generation

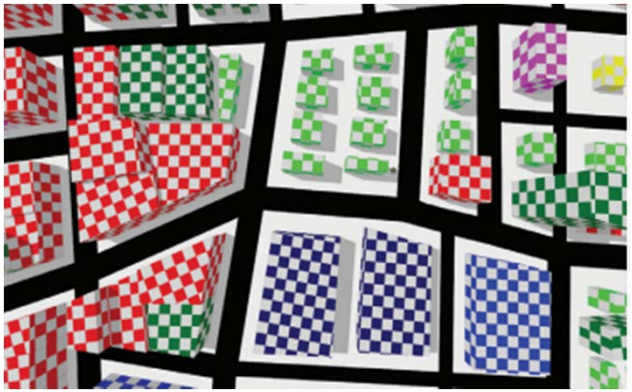


Interactive Geometric Simulation of 4D Cities

- Land use simulation
  - Optimization of a land use value function

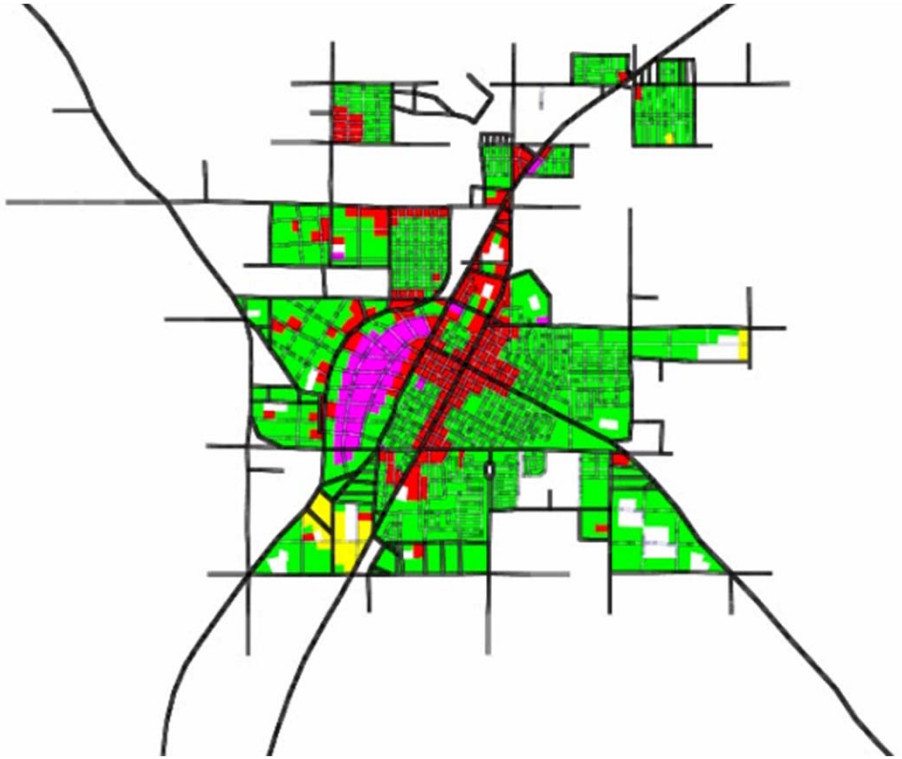
$$luv = \lambda_{global} \cdot luv_{global} + \lambda_{local} \frac{\sum_{\forall i} lot[i].area \cdot lot[i].luv}{\sum_{\forall i} lot[i].area}$$

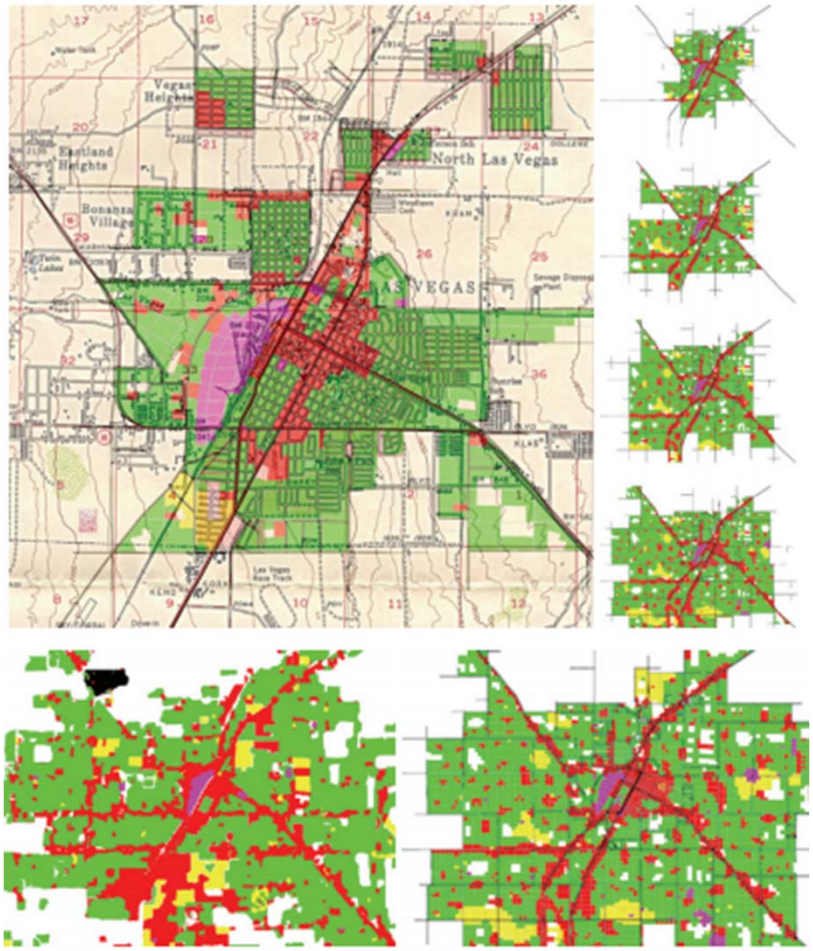
  - Global and Local land use goals



Interactive Geometric Simulation of 4D Cities

- Validation

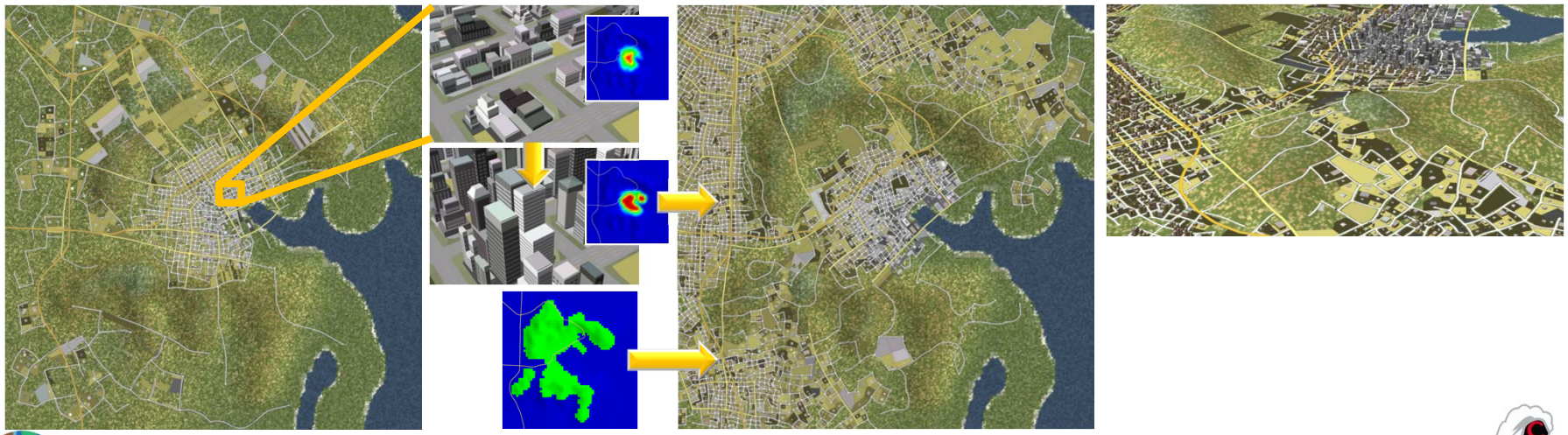




Interactive Geometric Simulation of 4D Cities

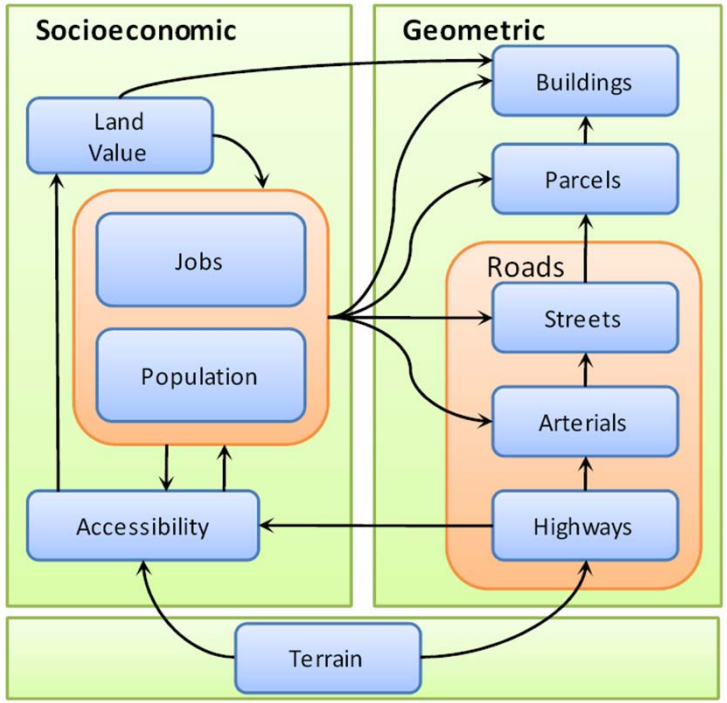
Bridging the gap between urban simulation, visualization and modeling

- **Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling**
  Vanegas, Aliaga, Benes, Waddell
- SIGGRAPH Asia 2009



Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling

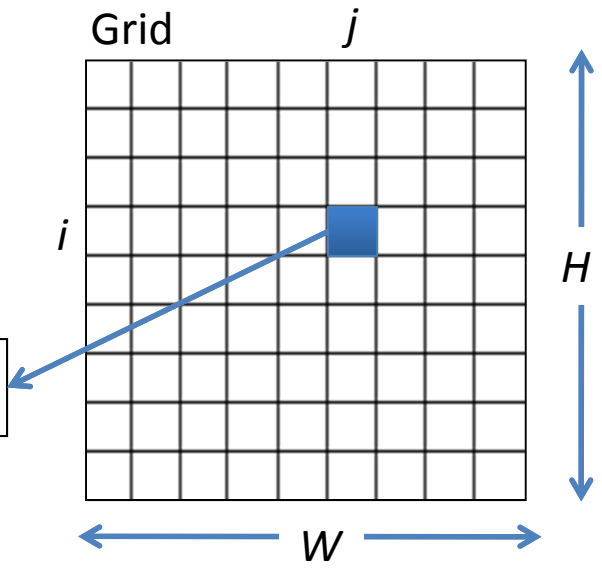
- Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling



Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling

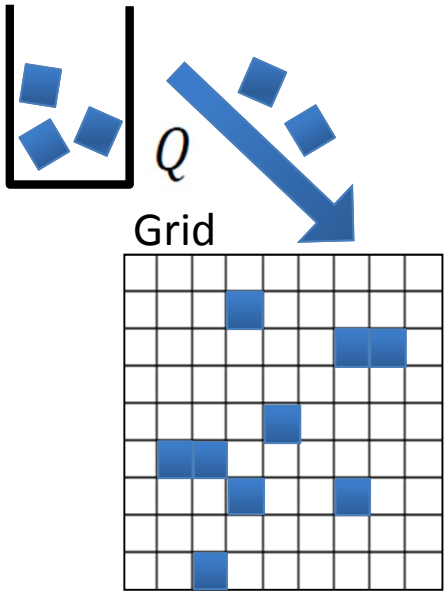
- System
  - Consists of N variables defined over a spatial domain
  - Each variable sampled over a 2D spatial grid $\boldsymbol{G}$ of size W x H
  - $v_k(i,j)$ denotes the value of k-th variable at grid cell (i,j)

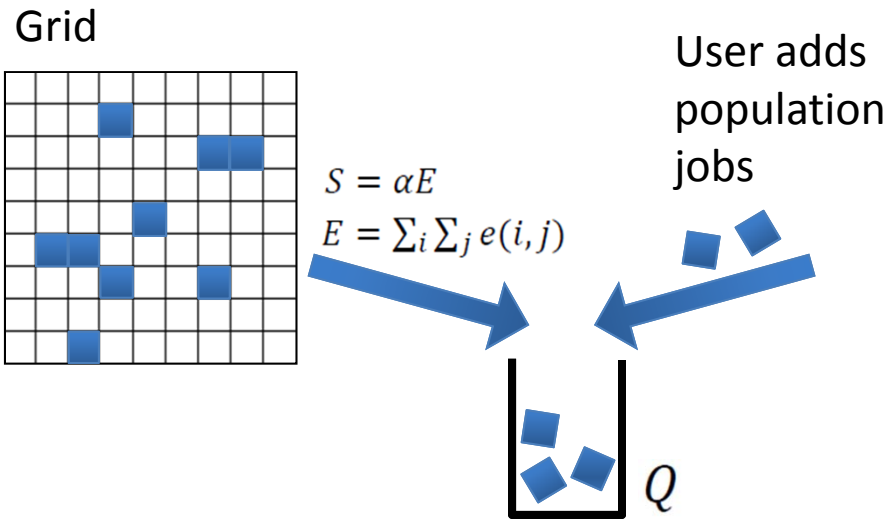
$$v_0(i,j),\ v_1(i,j),\ \ldots\ ,\ v_N(i,j)$$



Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling

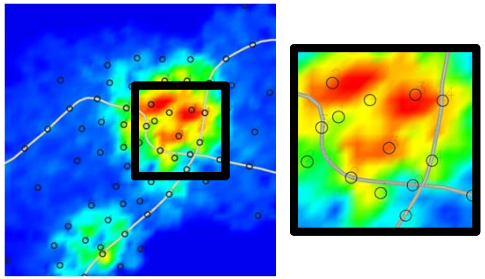
- Operations
  - Location and de-location of behavioral variables using location choice and mobility algorithms





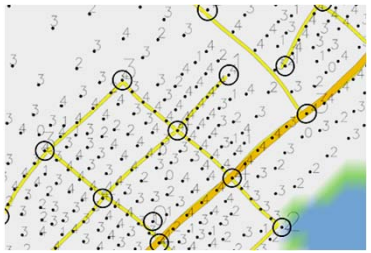
Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling

- Arterials and Streets
  - Seeds

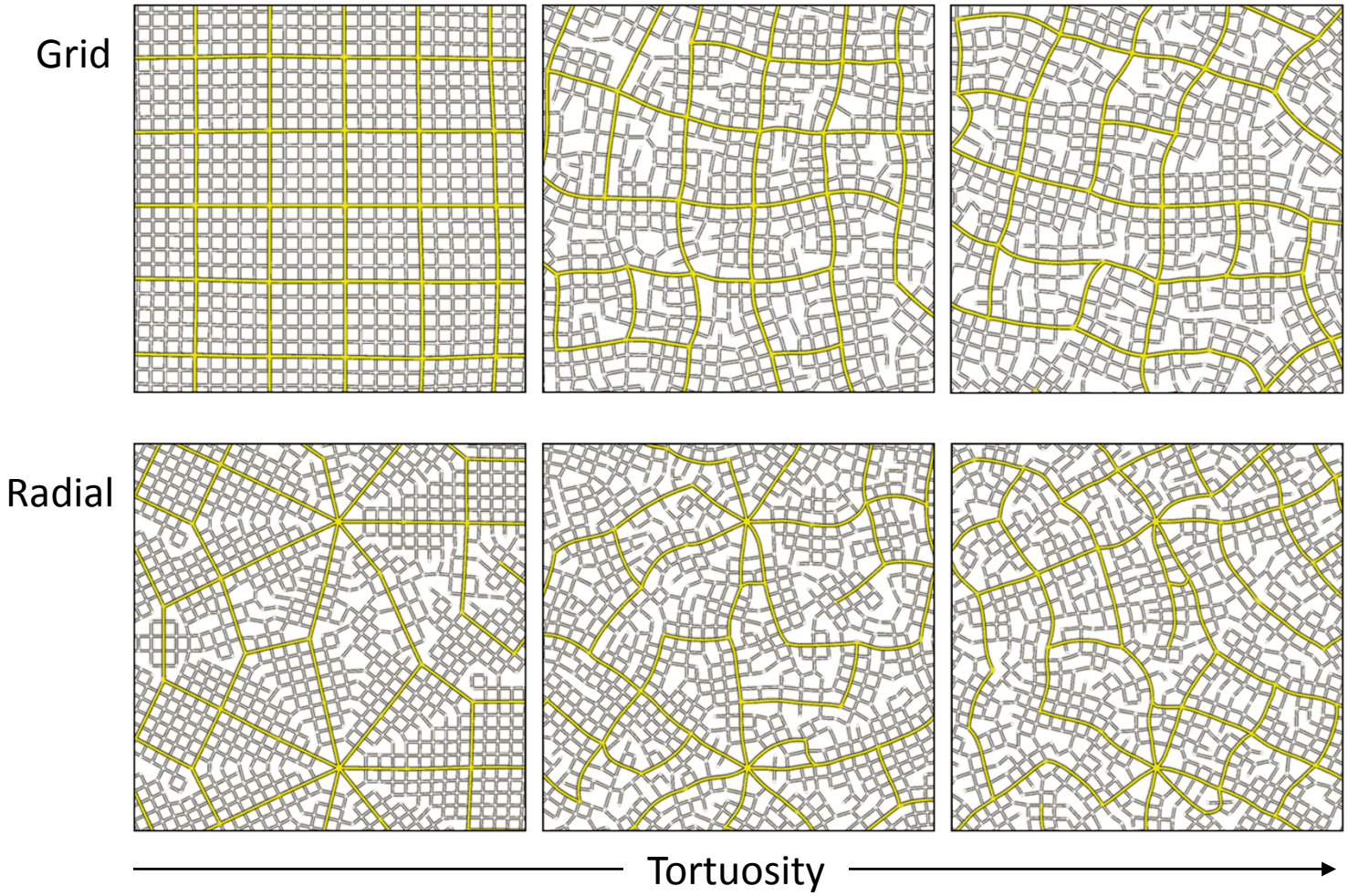


  - Expansion of Arterials

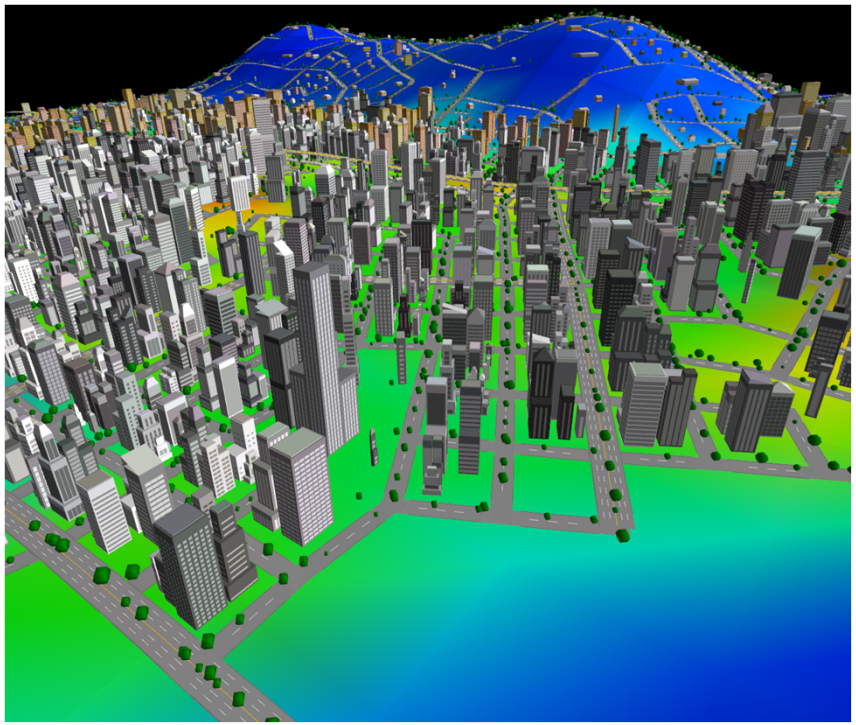
  - Expansion of Streets

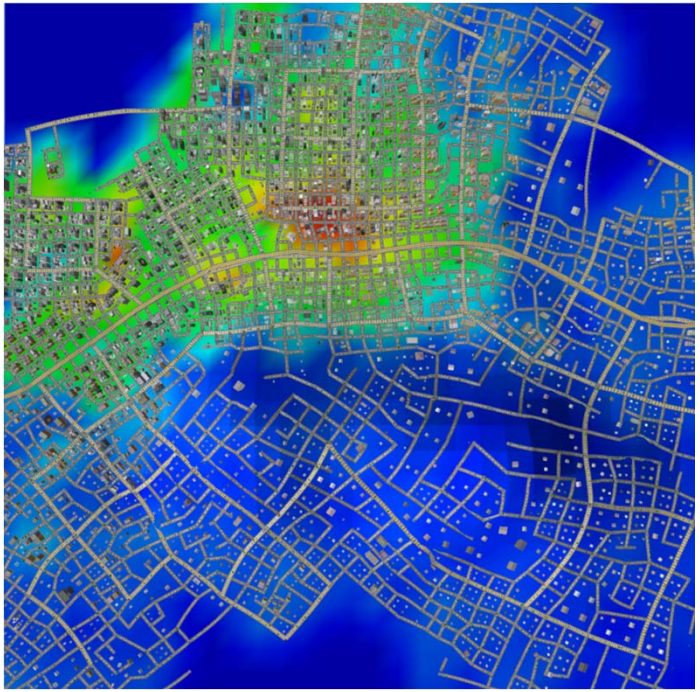


Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling



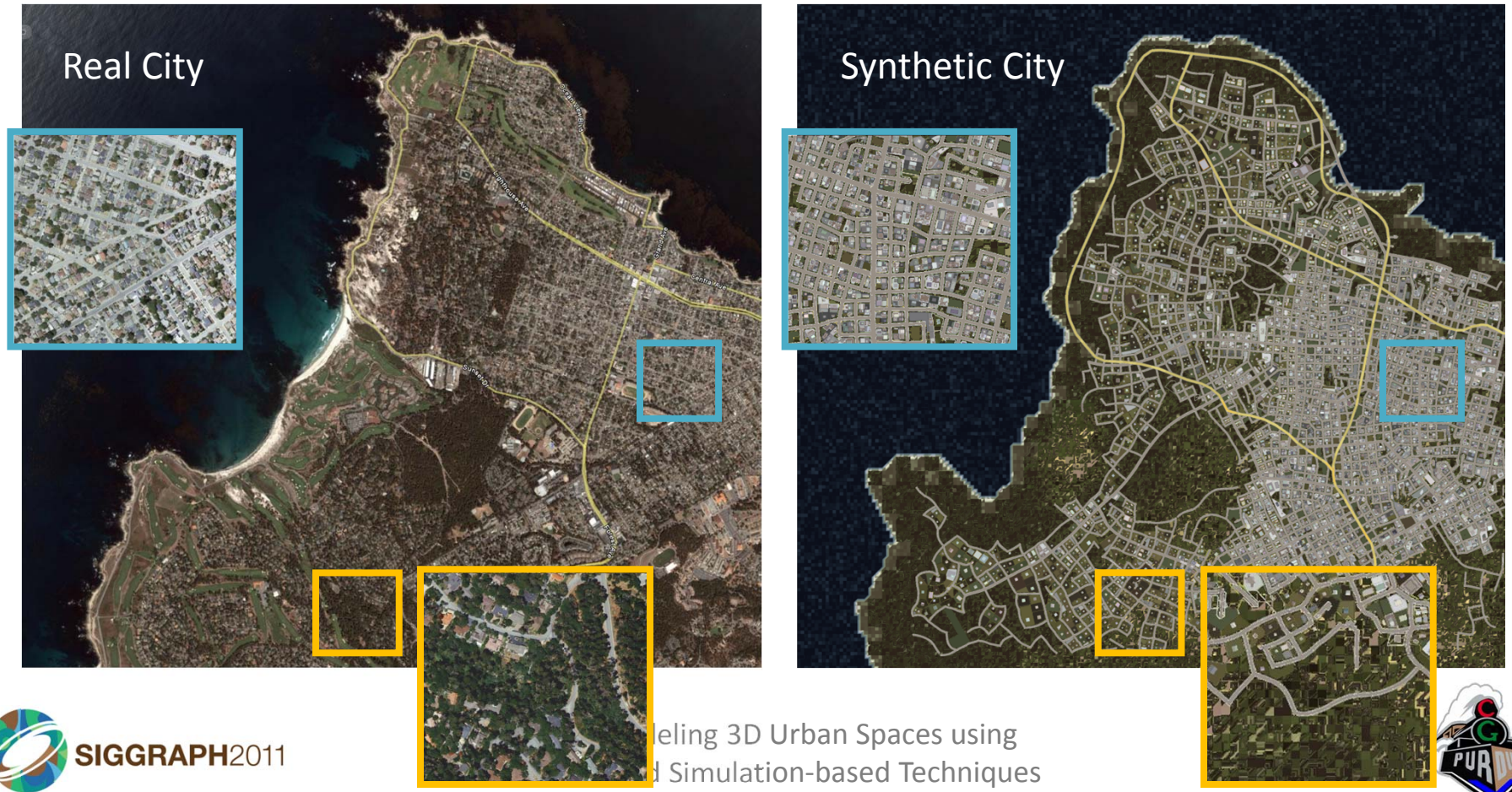
Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling





Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling

- Validation of urban simulation model



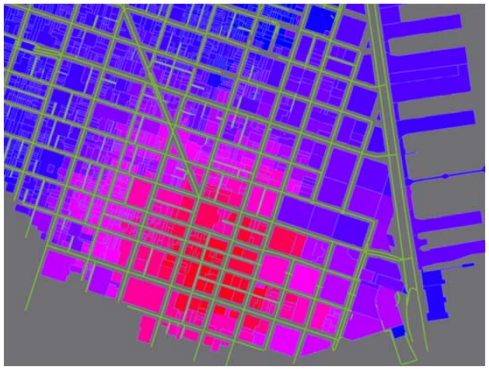
Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling

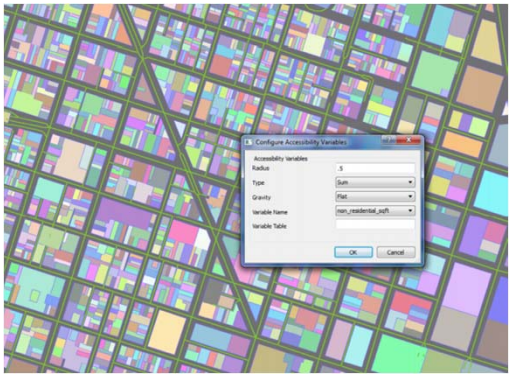
- Video

APPLICATION: URBAN VISION

Application: **UrbanVision**

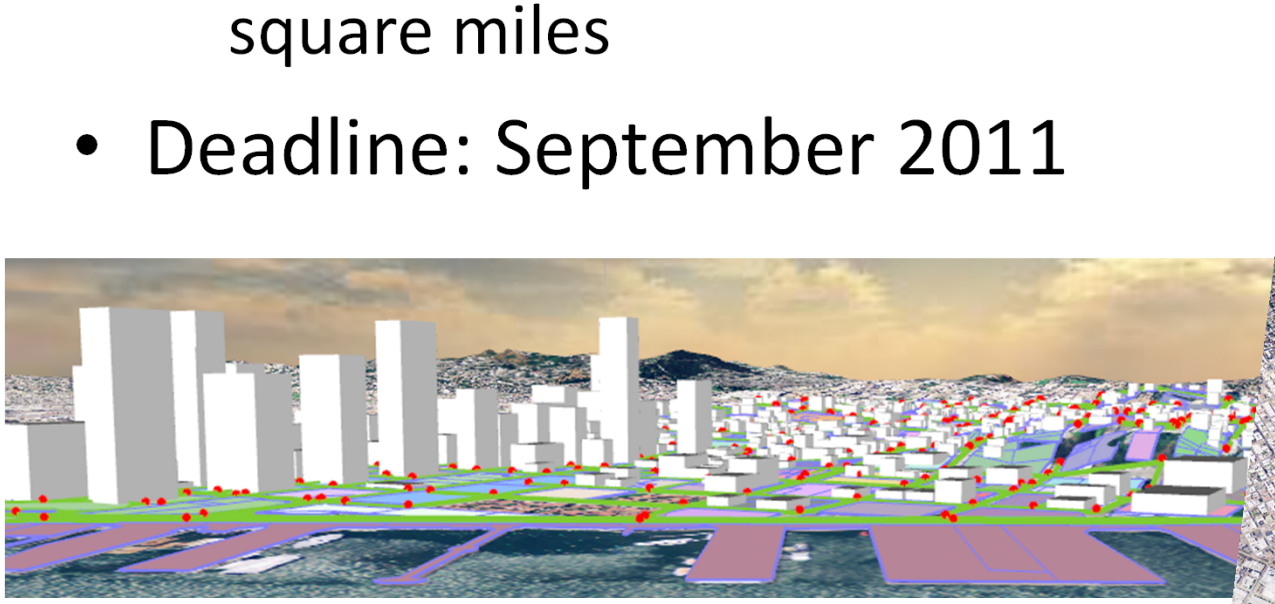
- Goal: develop an open-source extension to UrbanSim to include geometric modeling and behavioral modeling for use in urban planning scenarios





Application: **UrbanVision**

- Deployment: San Francisco Bay Area
  - 7+ million people, 1.5 million parcels, 7000 square miles
- Deadline: September 2011

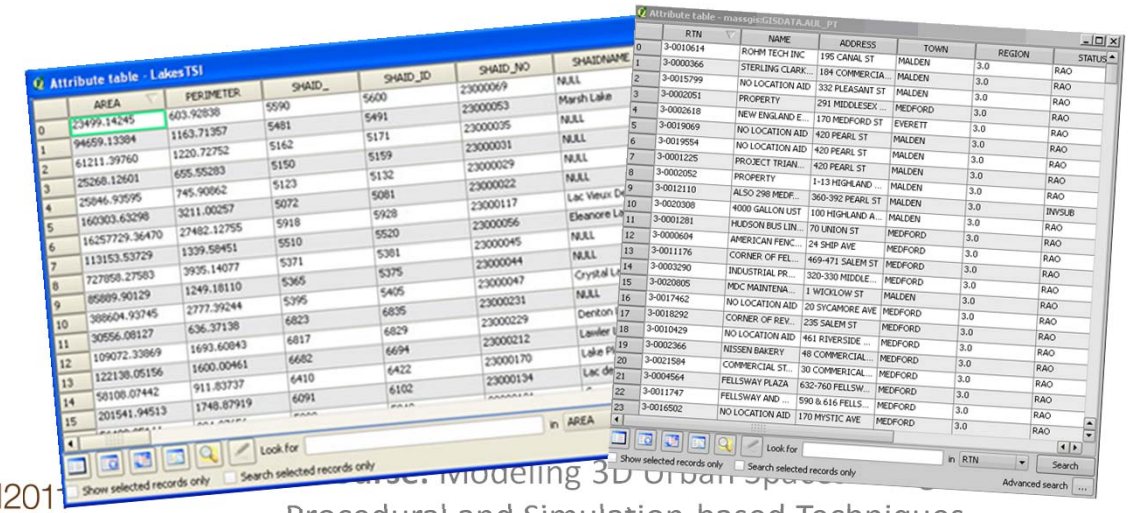


Application: **UrbanVision**

- Workforce:
  - PI – Berkeley (lead): Paul Waddell
  - Ian Carlton , Federico Fernandez, Fletcher Foti, Hyungkyoo Kim, Pedro Peterson, Liming Wang, and others
  - PIs – Purdue: Daniel Aliaga, Bedrich Benes
  - Michel Abdul, Ilke Demir, Ignacio Garcia-Dorado, Carlos Vanegas, Innfarn Yoo, and others

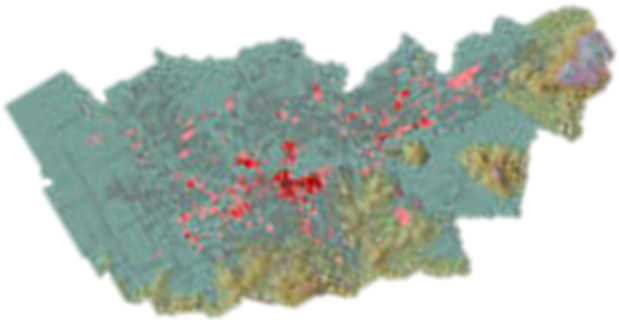
Why is this system useful?

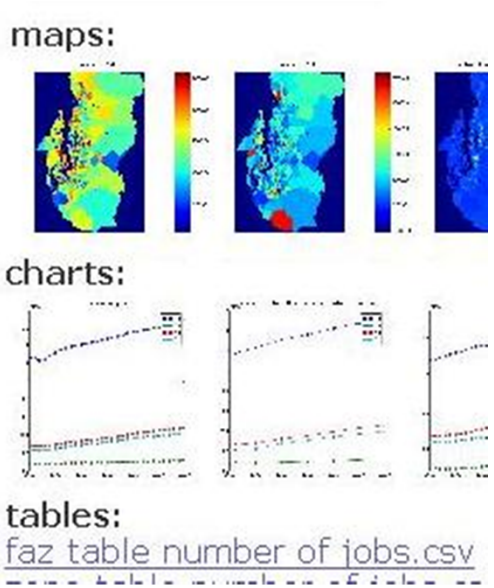
- Limitations of existing urban simulation systems
  - Difficult to specify what is to be simulated
    - Simulation scenario (time)
    - Area of interest (space) – Example: Real Estate



Why is this system useful?

- Limitations of existing urban simulation systems
  - Difficult to specify what is to be simulated
  - Visualization of results
    - Offline
    - Lacks 3D content





Why is this system useful?

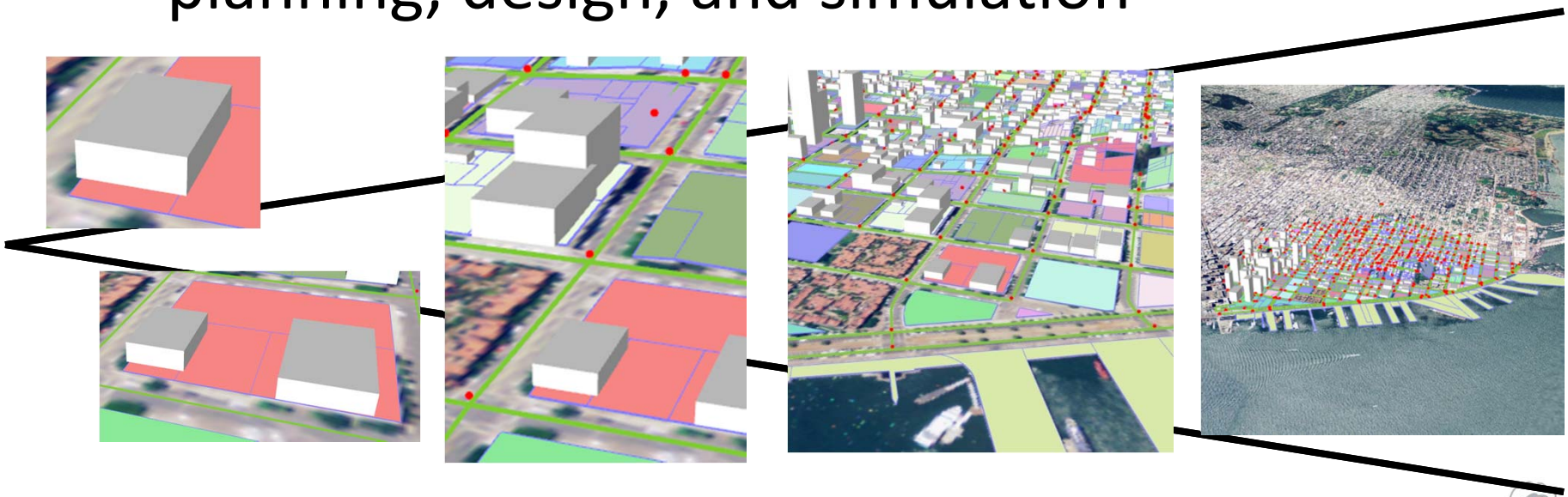
- Limitations of existing urban simulation systems
  - Difficult to specify what is to be simulated
  - Visualization of results
  - User interaction
    - Limited to tables in databases
    - Lacks “immersive” navigation

Why is this system useful?

- Limitations of existing urban simulation systems
  - Difficult to specify what is to be simulated
  - Visualization of results
  - User interaction
  - Isolation
    - No common framework for integration of different behavioral and geometric simulation models

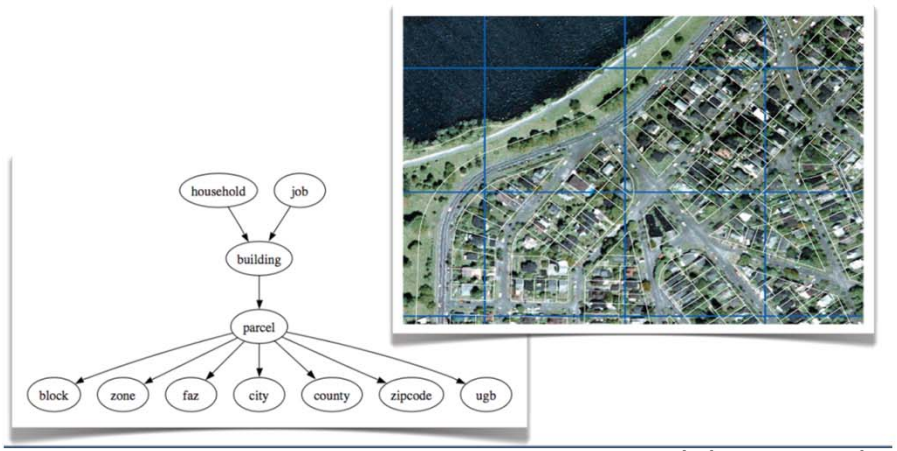
Goals (1) – Open Source

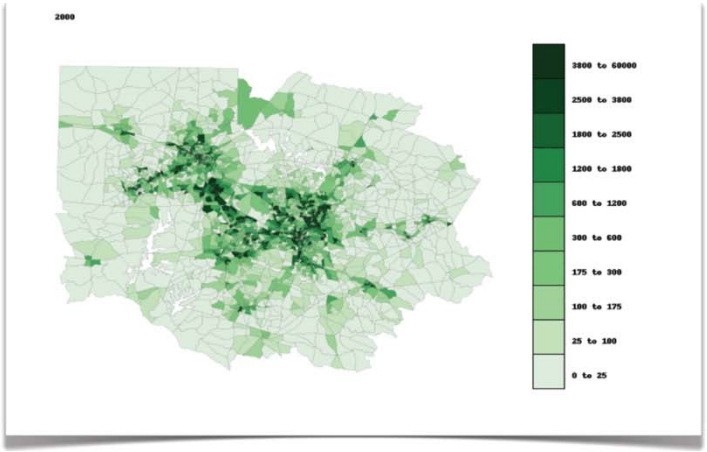
- Develop an **open-source platform** for a high-resolution representation and simulation of future urban landscapes for use in urban planning, design, and simulation



Goals (2) – Behavioral Simulation

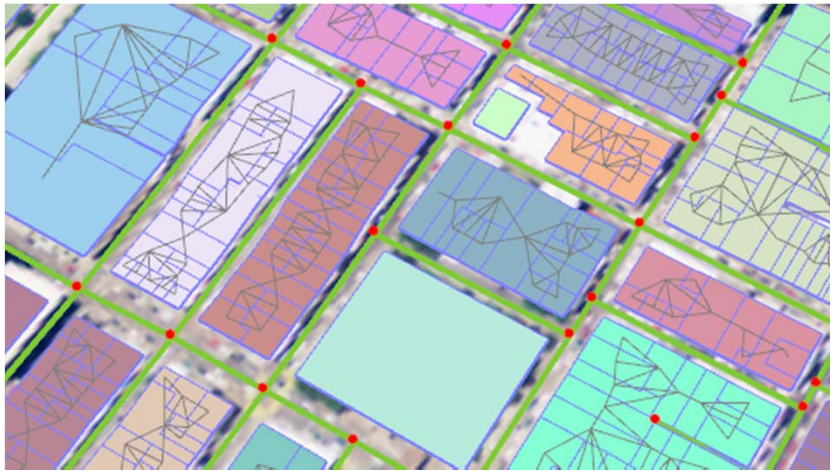
- **Read, write, and simulate changes** to buildings, streets, and patterns of urban development and transportation and environmental conditions over time.
- Based on extension to "**UrbanSim**"

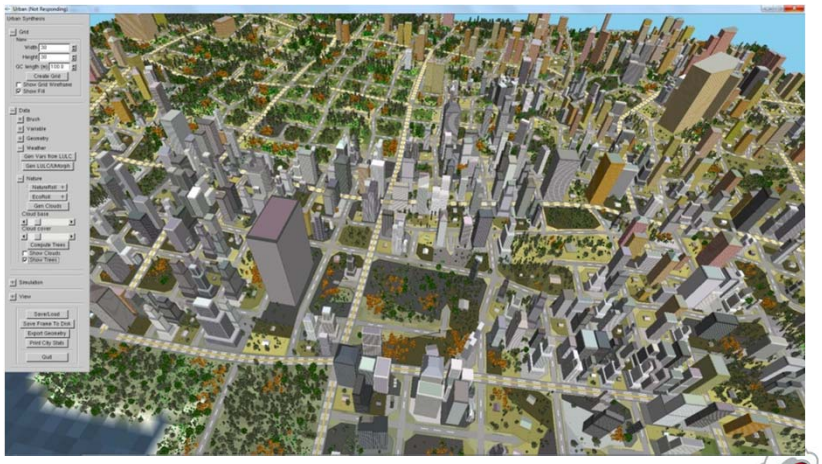




Goals (3) - Geometric Simulation

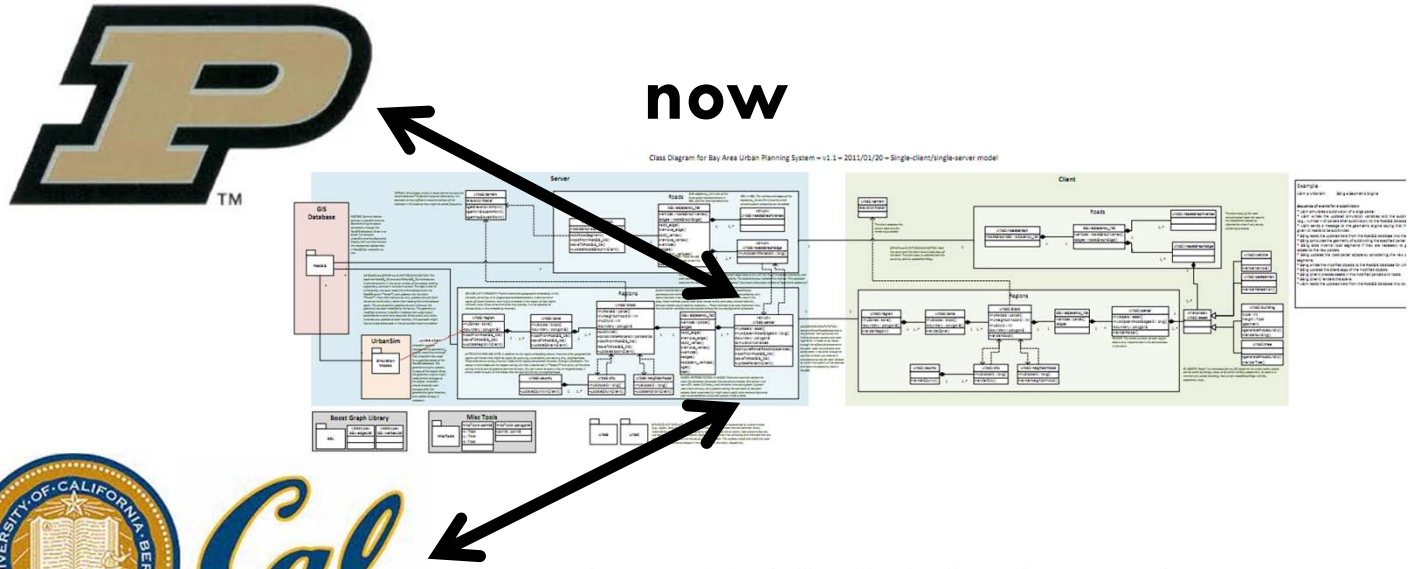
- **Model current and future simulated scenarios with geometric structures** including streets, buildings, vegetation, pedestrians, and vehicles.





Goals (4) - Robust Integration

- Develop a **common API** to make it easy to **interface current and future models** and visualization functionality in ways that are efficient (fast) and modular



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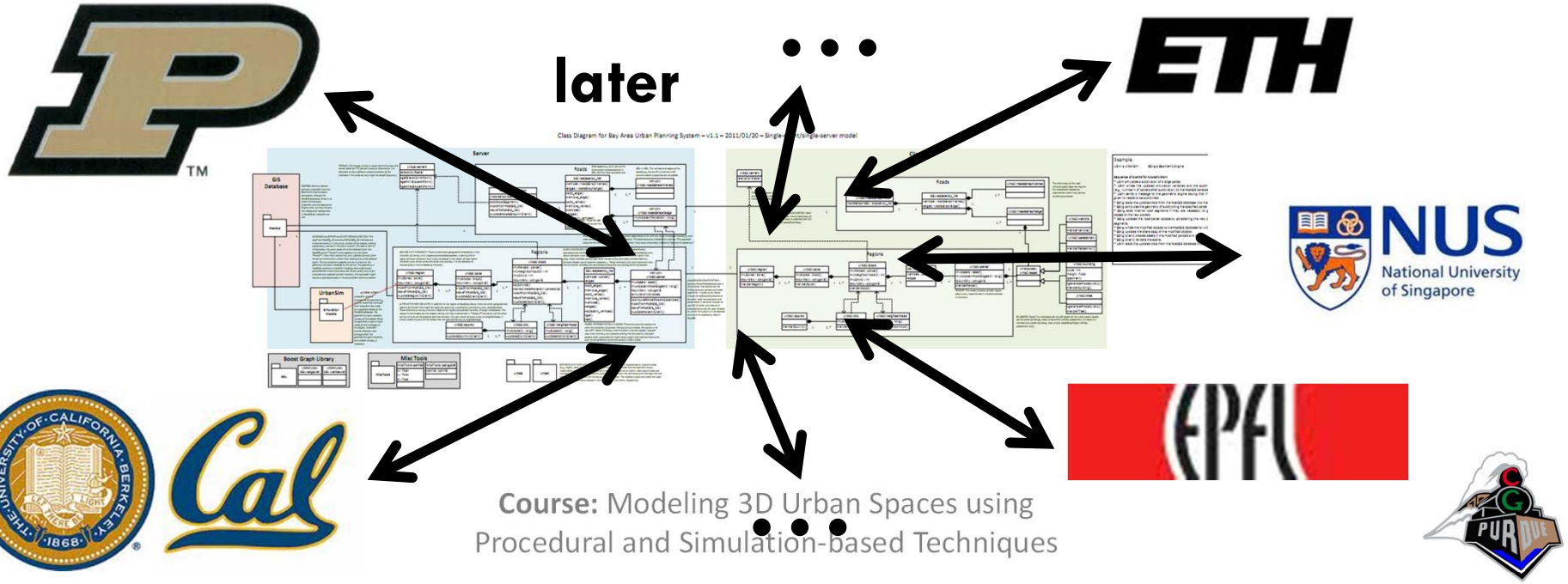

Application: **UrbanVision**

- Video

Who will use this system?

- Initially
  - Metropolitan Transportation Commission (MTC)
  - Association of Bay Area Governments (ABAG),
  - Bay Area local governments
  - Other stakeholders
- What for?
  - To support public engagement in the Sustainable Communities Strategies planning process

Who will use this system?

- Later (hopefully!)
  - City Governments and planning agencies
  - Community
  - Other research projects in urban simulation/modeling