

# Bridging the Gap between Urban Simulation and Urban Modeling

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Purdue University



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

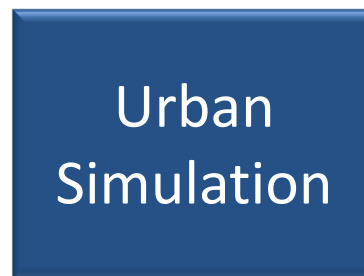


# Bridging the Gap between Urban Simulation and Urban Modeling

Urban  
Modeling

Urban  
Simulation

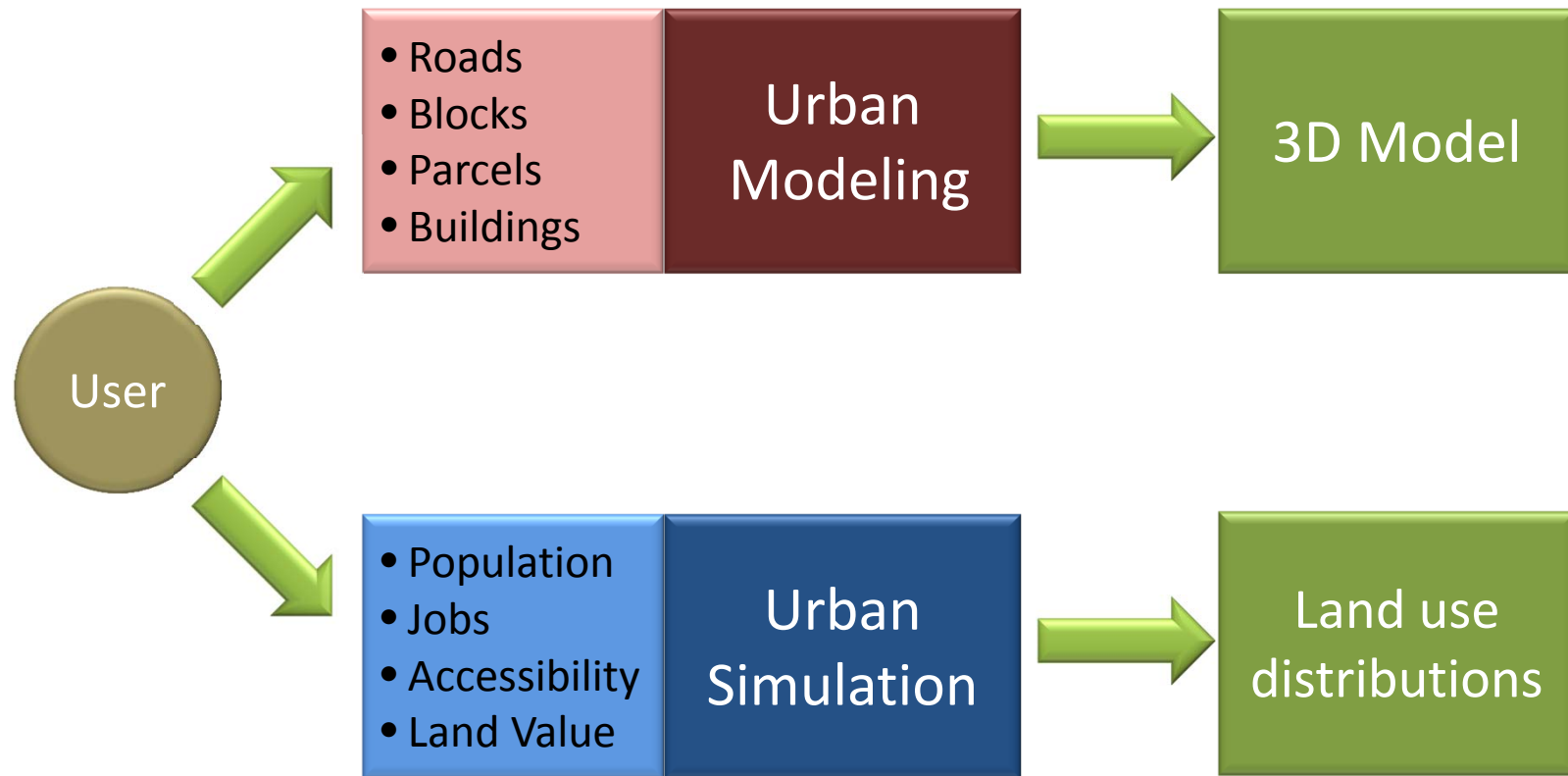
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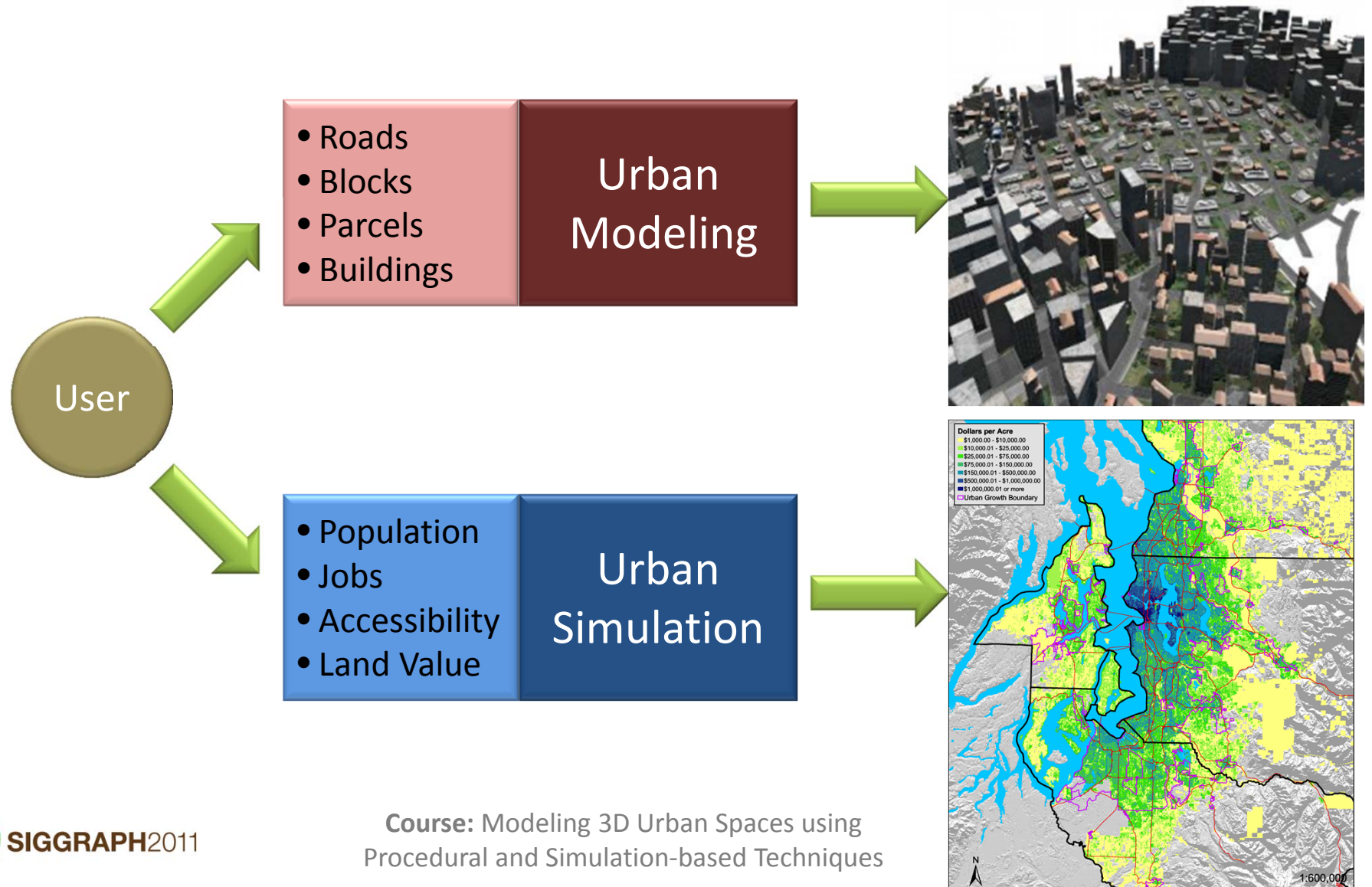
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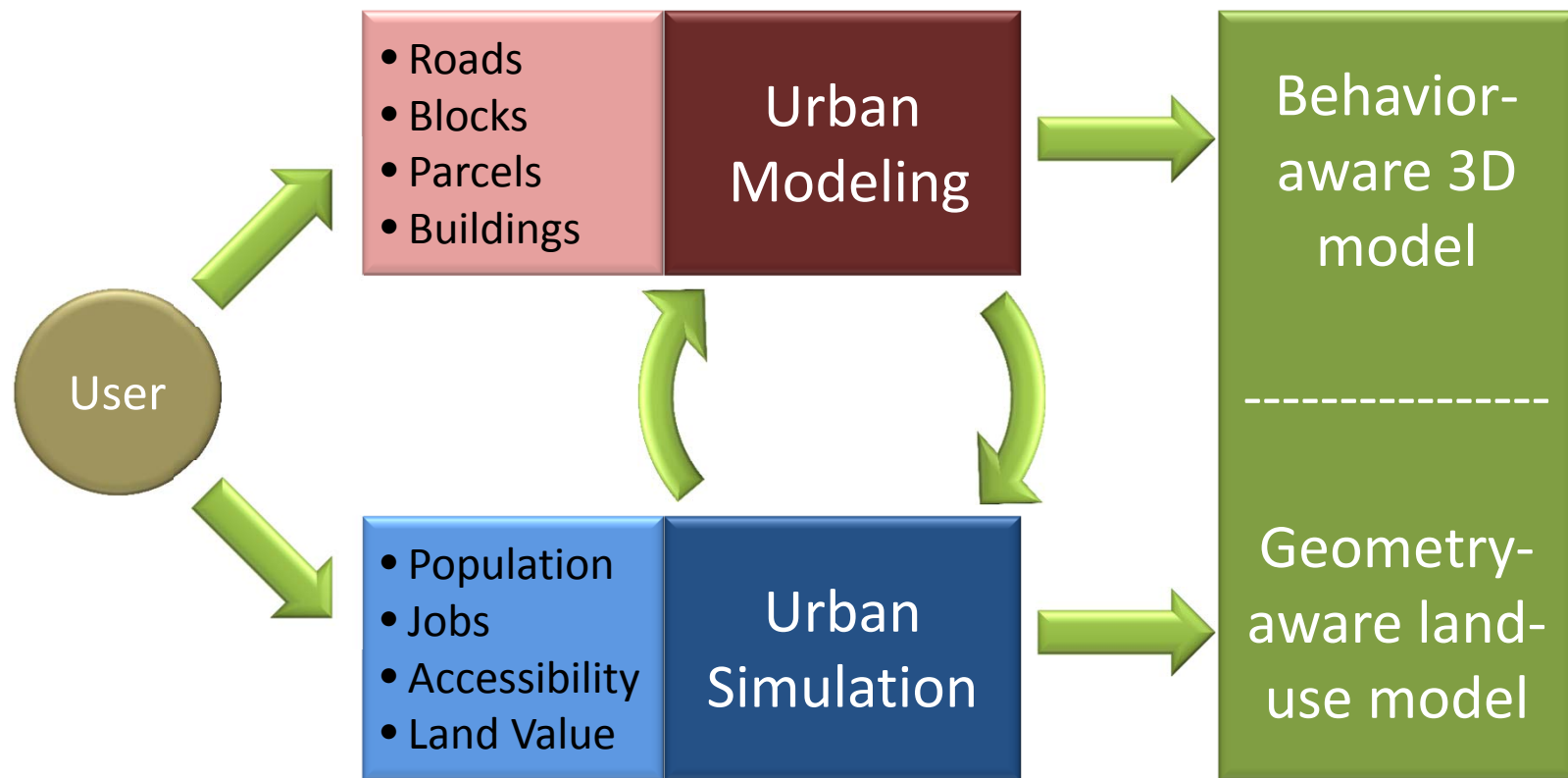
# Bridging the Gap between Urban Simulation and Urban Modeling



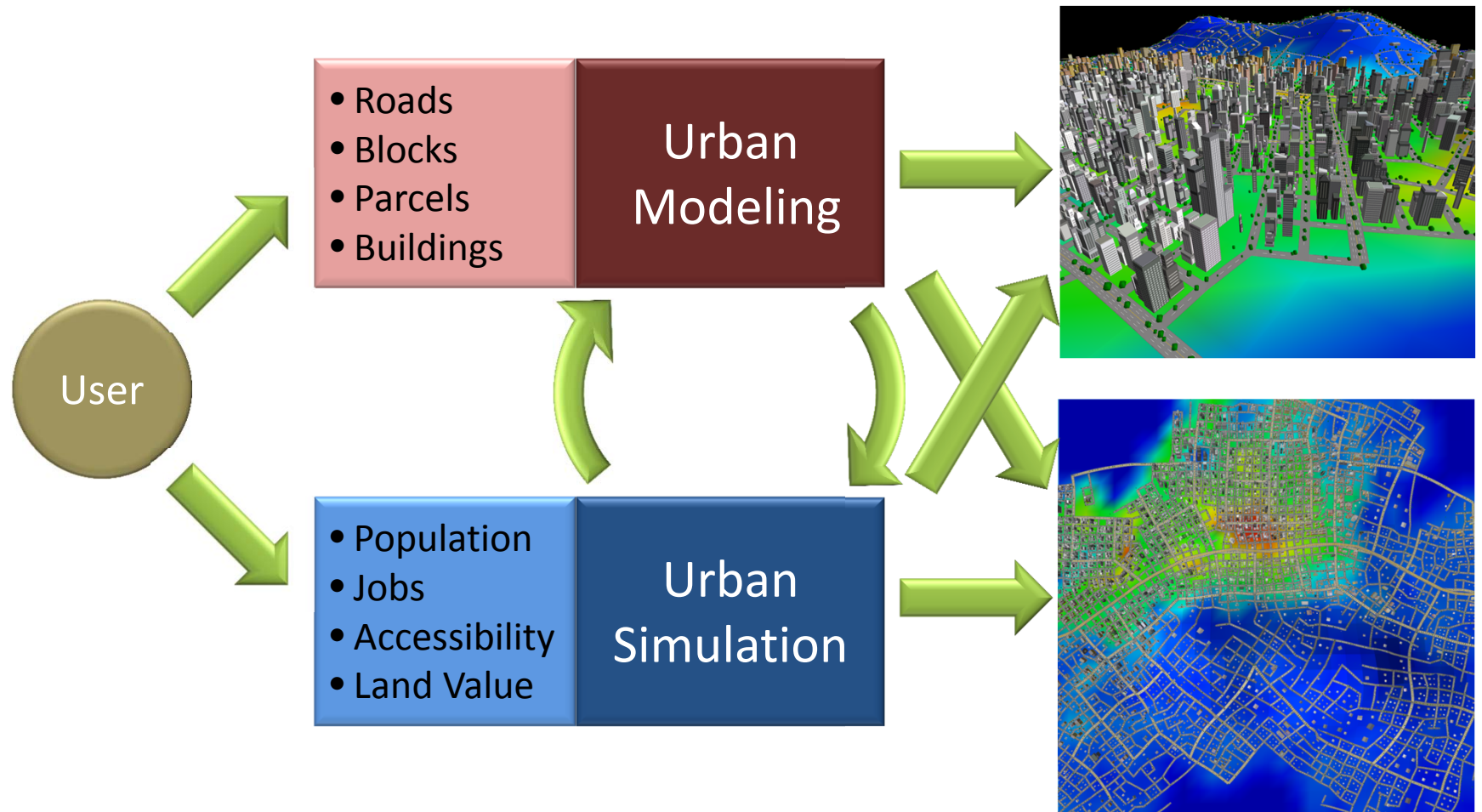
# Bridging the Gap between Urban Simulation and Urban Modeling



# Bridging the Gap between Urban Simulation and Urban Modeling



# Bridging the Gap between Urban Simulation and Urban Modeling





# 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



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



# Urban Modeling

- Covered in the previous sessions of this course

Urban  
Modeling

# 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

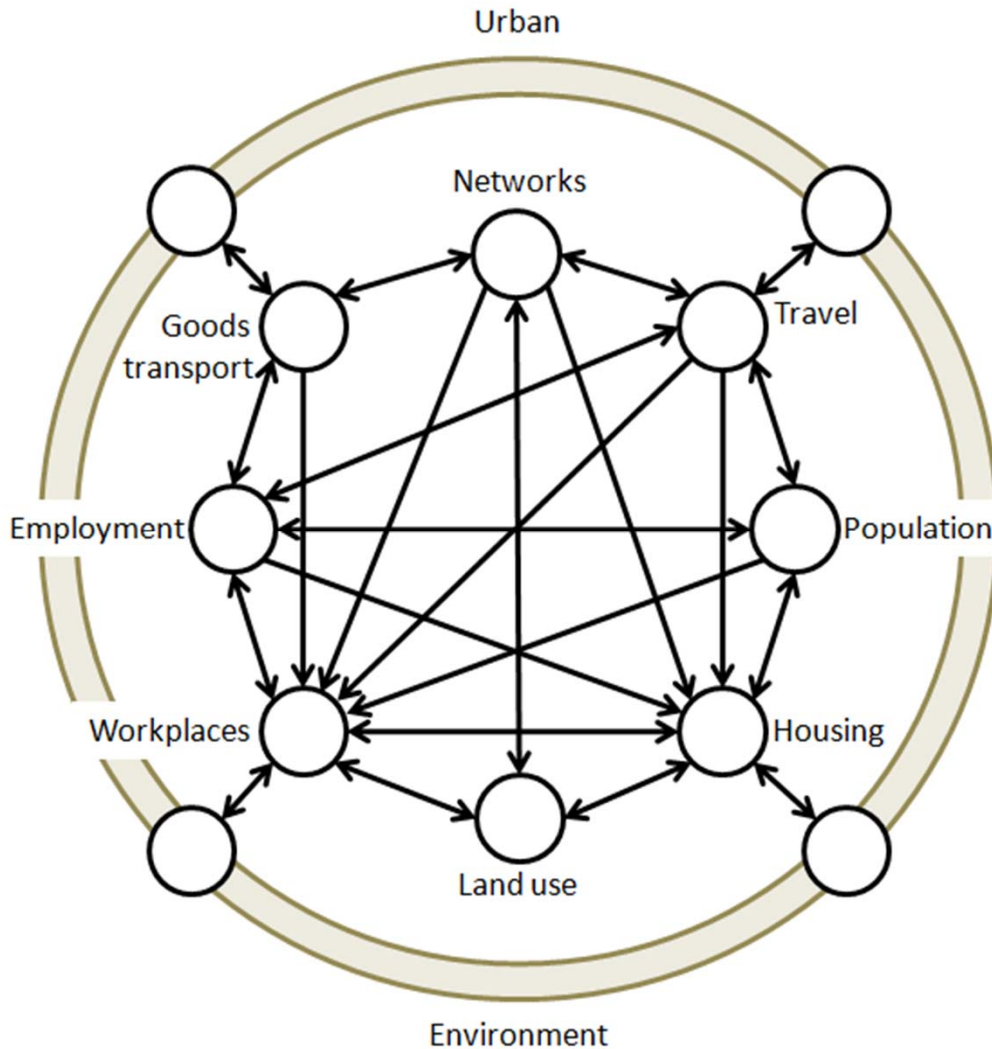


Image recreated from:  
Michael Wegener, "Operational urban models state of the art", 1994.

# 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

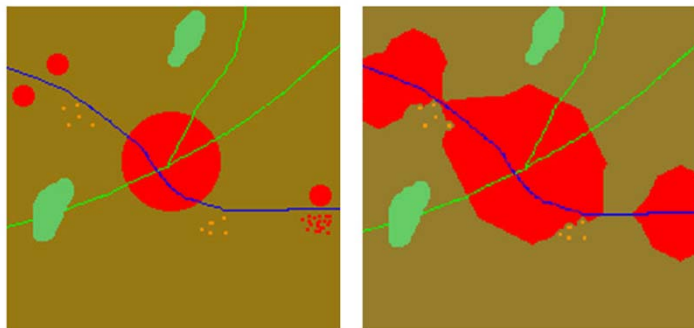


# Urban Simulation

- 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 its occupants, or the travel that connects agents

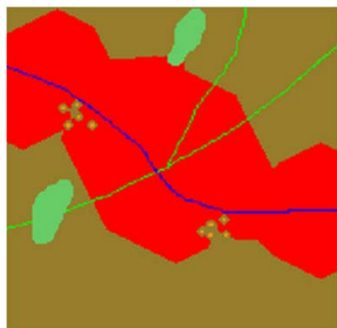
# Urban Simulation

- Cellular Automata



Step 0

Step 25



Step 50

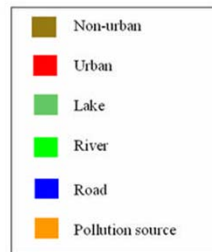
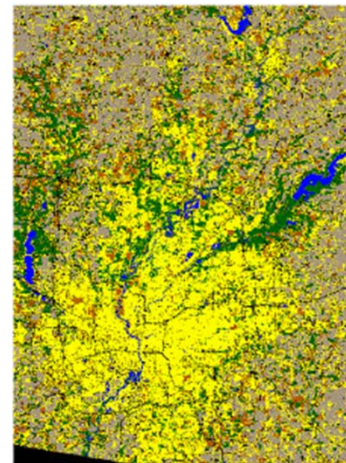
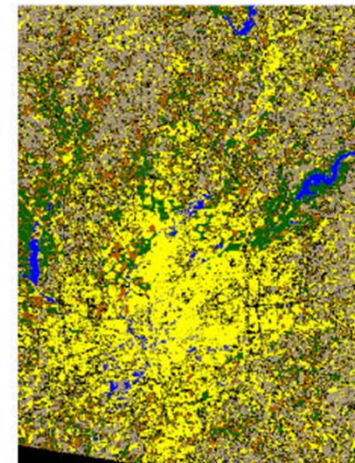


Image from:  
Sharaf Alkheder, Jie Shan, “Cellular Automata Urban Growth Simulation and Evaluation”, 2008



1982 Ground truth



1982 Simulated

# 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



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# Urban Visualization

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

# Urban Visualization

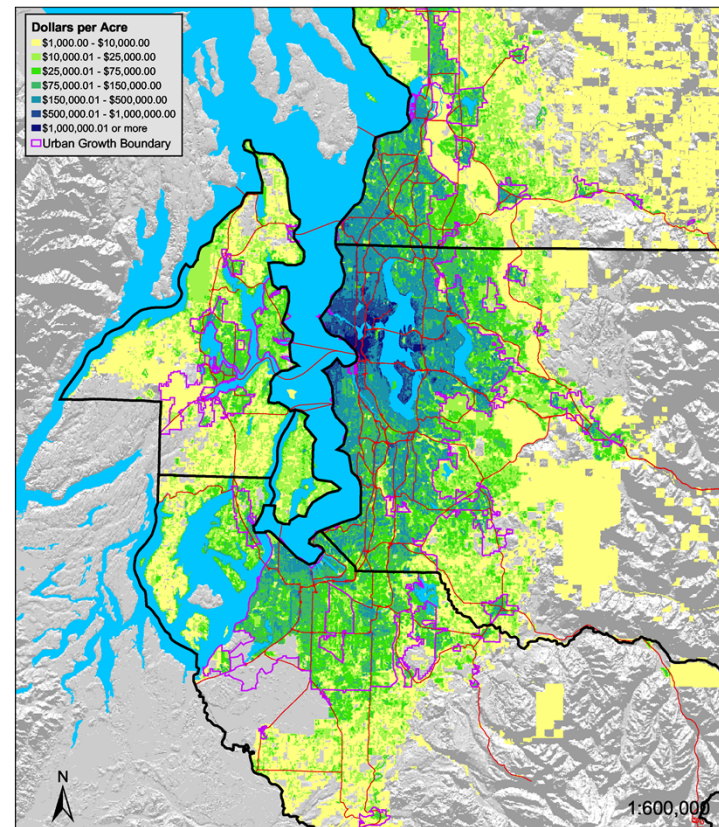
- Visualizations of computed datasets
  - Interest several groups of population with different levels of expertise in handling data
    - Policy makers
    - The public
    - Modelers running the simulation

# 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

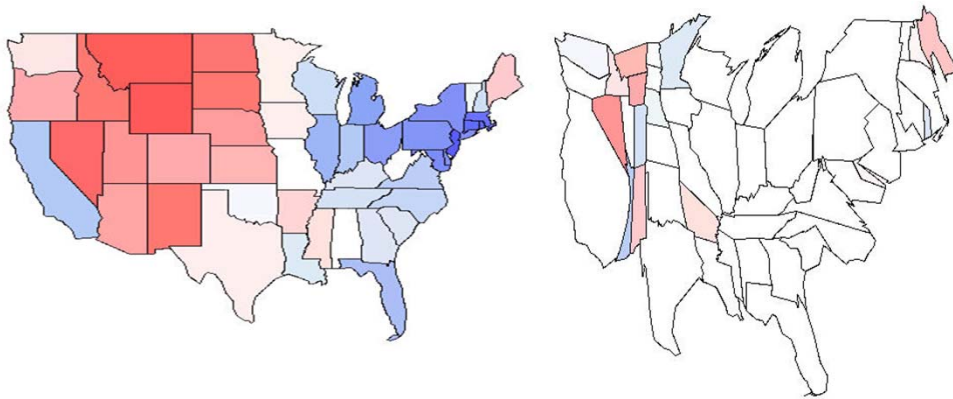
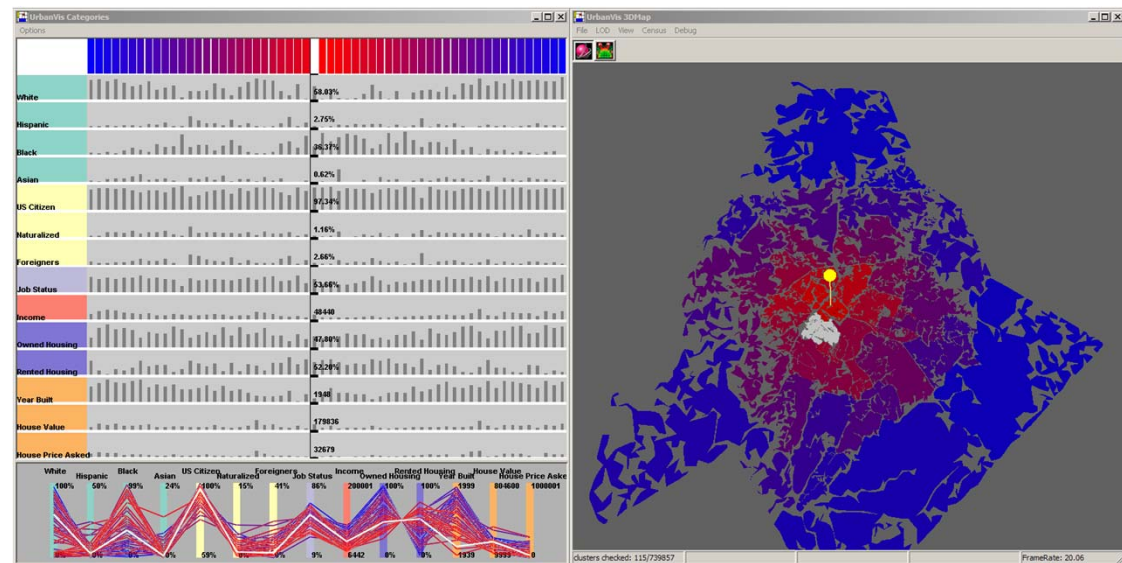


Image from:  
Daniel Keim, Stephen North, Christian Panse, "CartoDraw: A Scanline based Cartogram Algorithm", 2004.



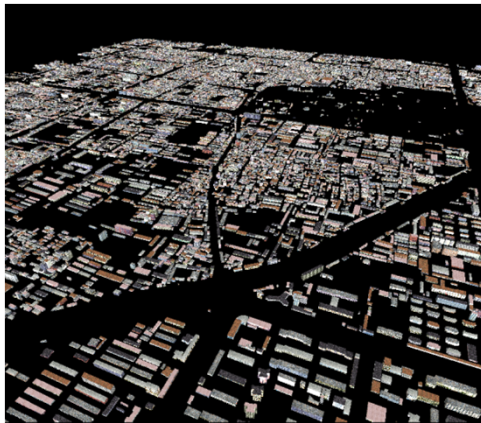
# Urban Visualization

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

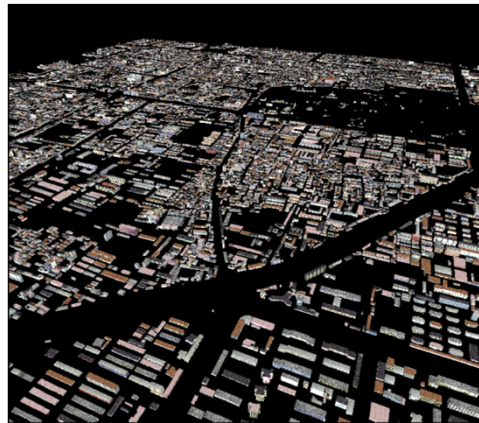


# Urban Visualization

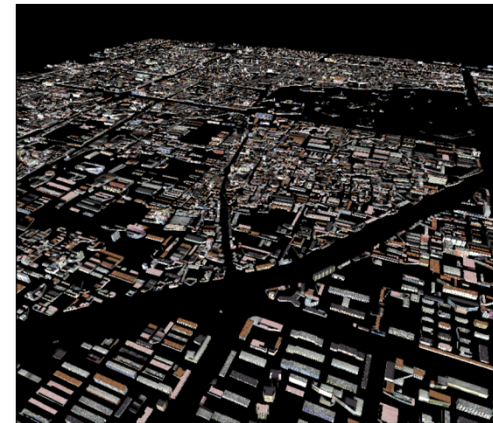
- Goal: Visualize an urban model in a focus-dependent, multi-resolution fashion, while retaining the legibility of the city



Original Model



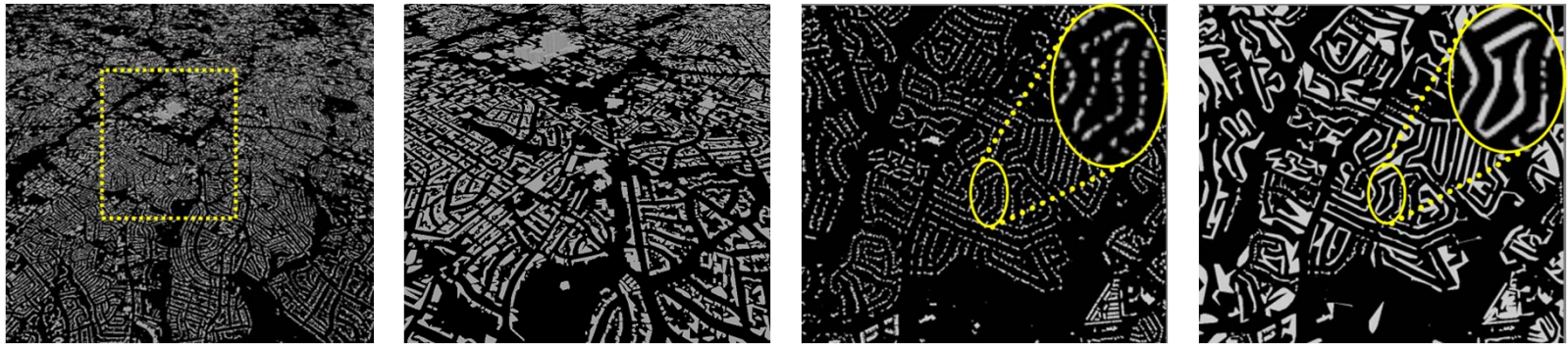
45% polygons



18% polygons

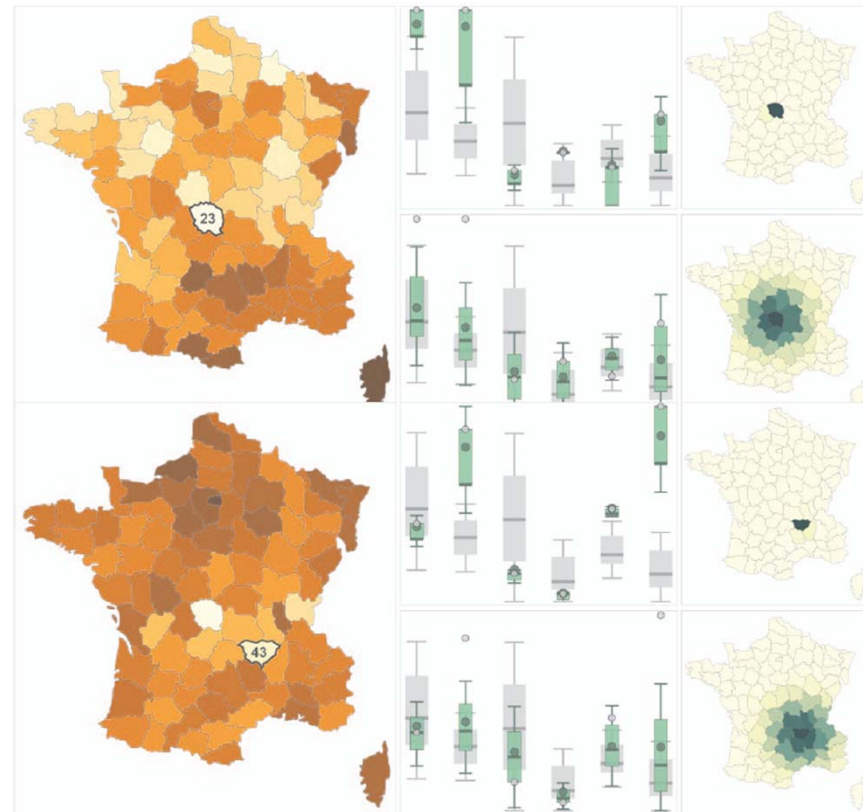
# Urban Visualization

- 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



Course: Modeling 3D Urban Spaces using  
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# Bridging the gap between urban simulation, visualization and modeling

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



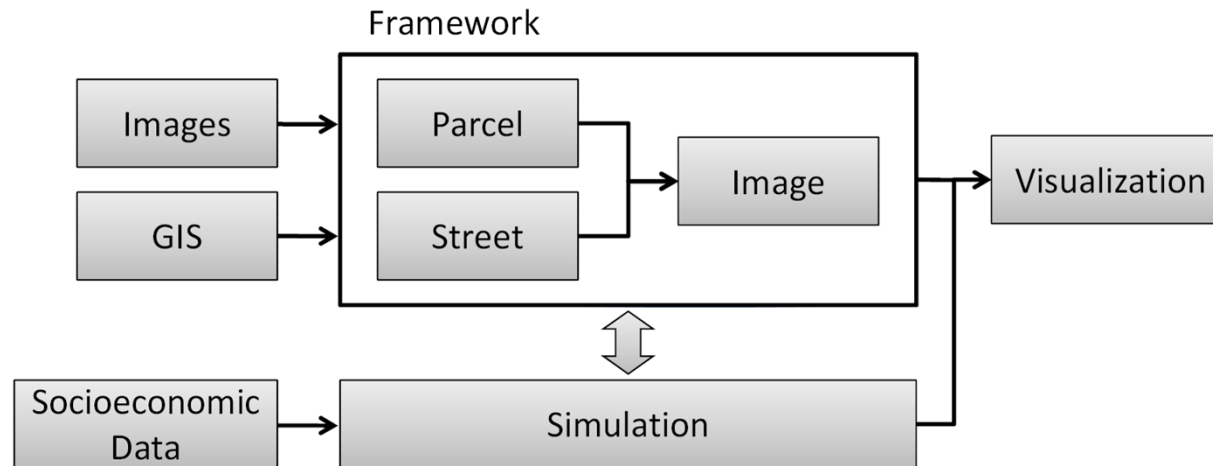
# Visualization of Simulated Urban Spaces

- Infer an urban layout
  - Images (aerial view) + Structure (streets, parcels)  
from the values of a set of simulation  
variables at any given time step



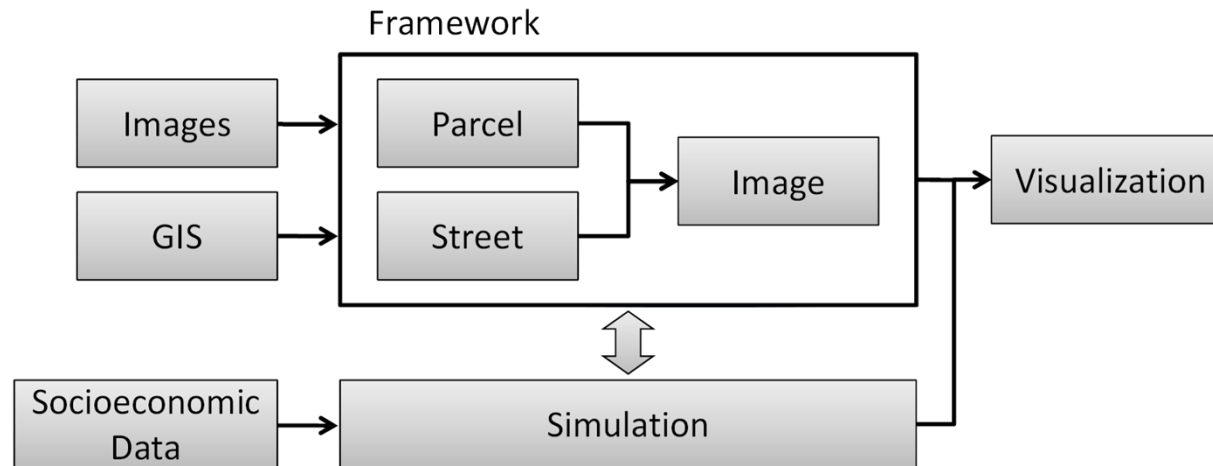
# Visualization of Simulated Urban Spaces

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



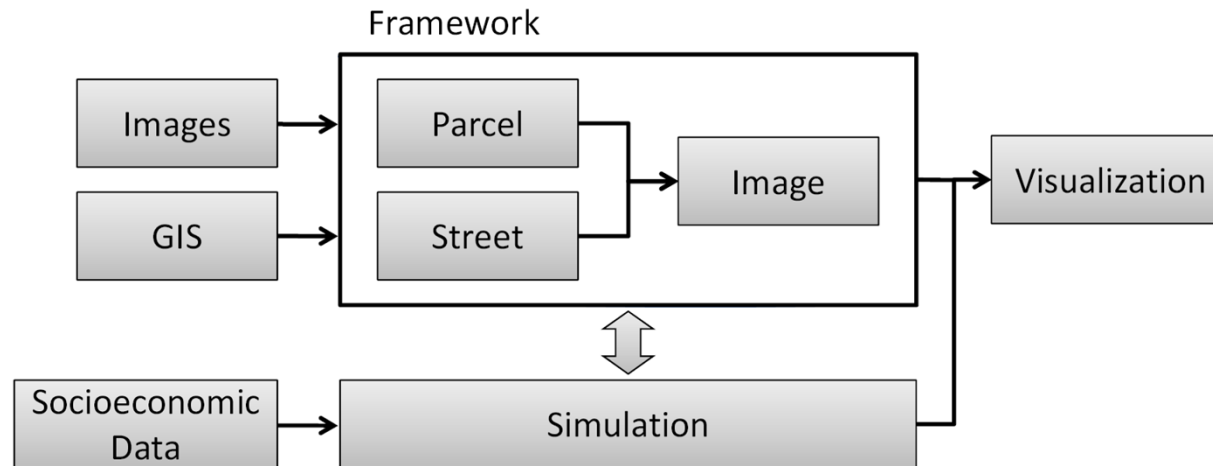
# Visualization of Simulated Urban Spaces

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



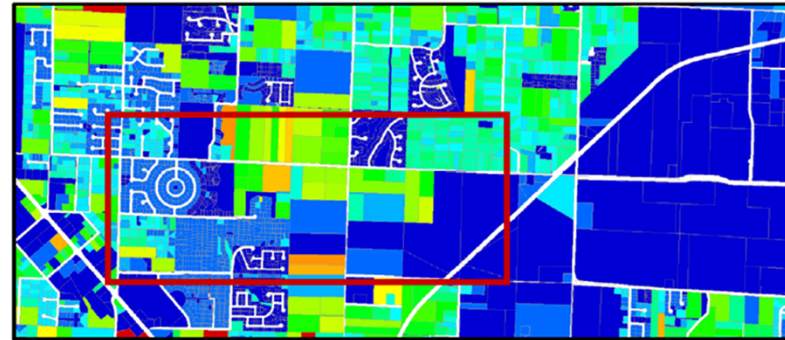
# Visualization of Simulated Urban Spaces

- 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



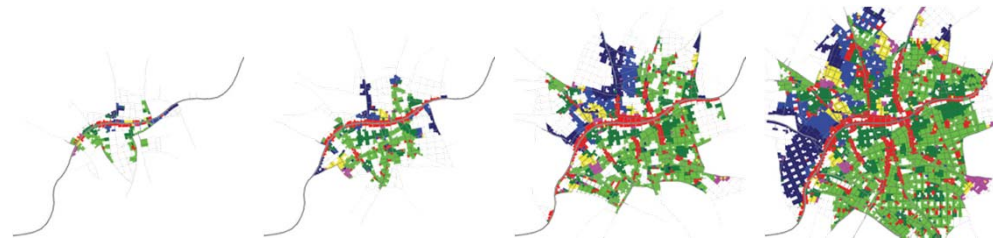
# Visualization of Simulated Urban Spaces

- Example result



# Bridging the gap between urban simulation, visualization and modeling

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



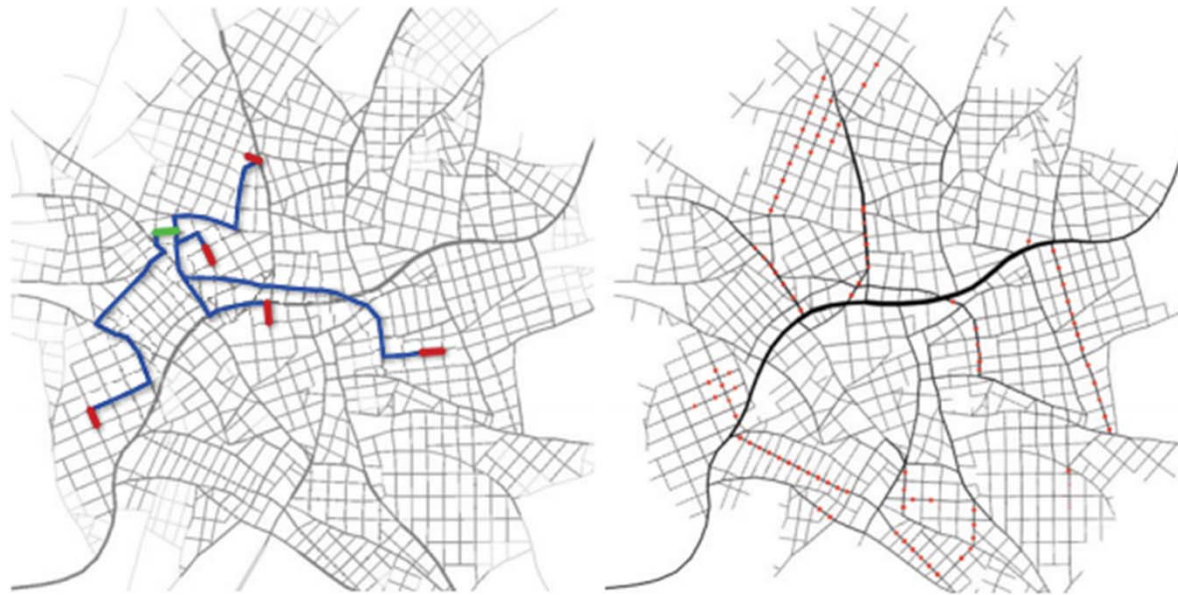
# Interactive Geometric Simulation of 4D Cities

- 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



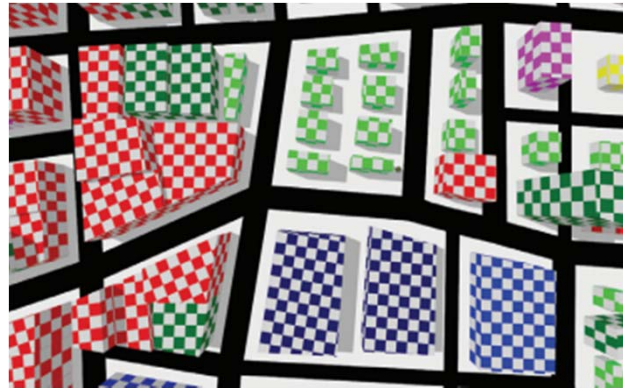


# Interactive Geometric Simulation of 4D Cities

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

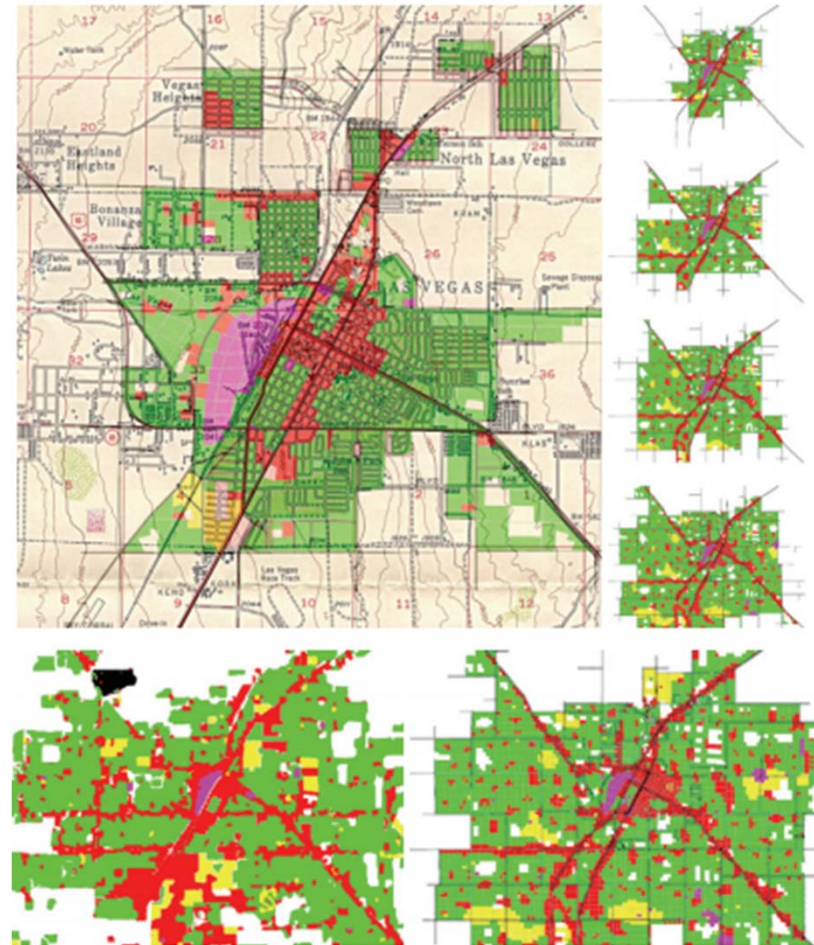
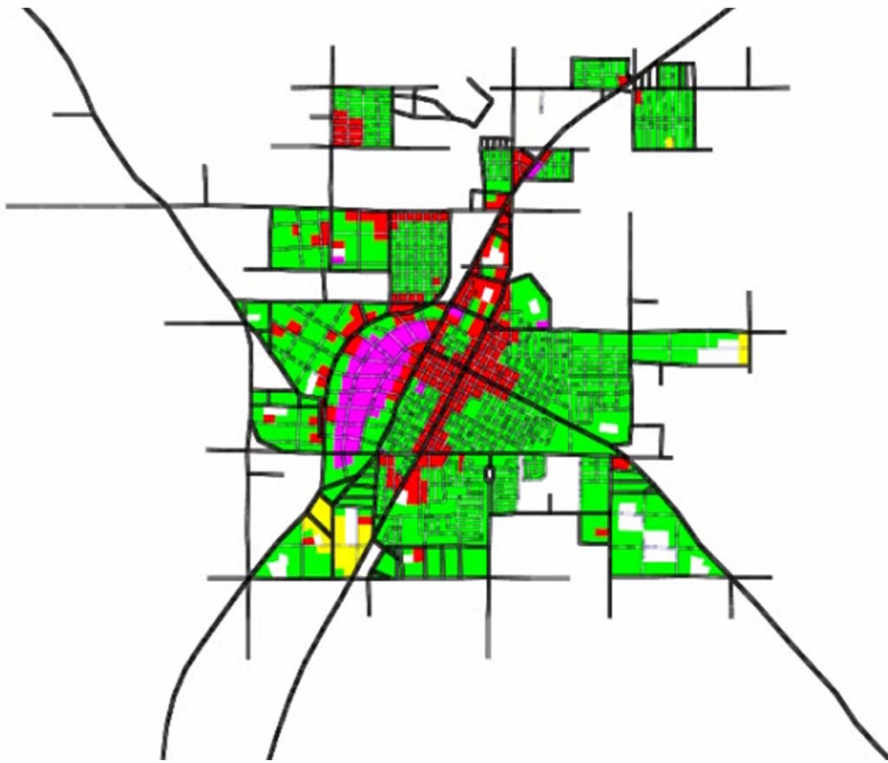
$$luv = \lambda_{global} \cdot luv_{global} + \lambda_{local} \frac{\sum_{\forall i} lot[i].area \cdot lot[i].luv}{\sum_{\forall i} lot[i].area}$$

- Global and Local land use goals



# Interactive Geometric Simulation of 4D Cities

- Validation

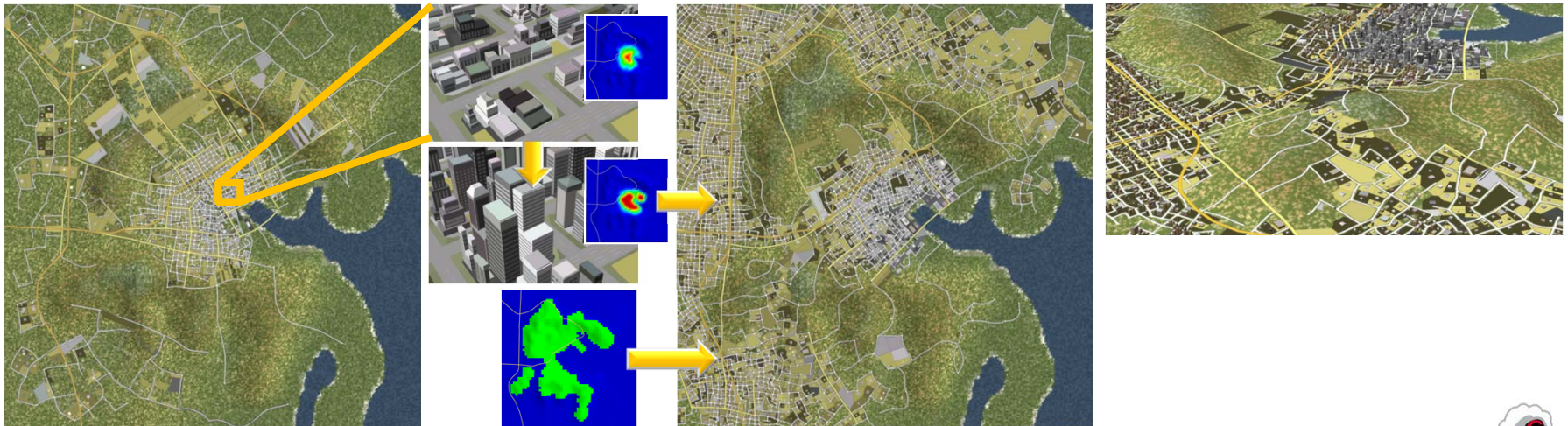


# Interactive Geometric Simulation of 4D Cities



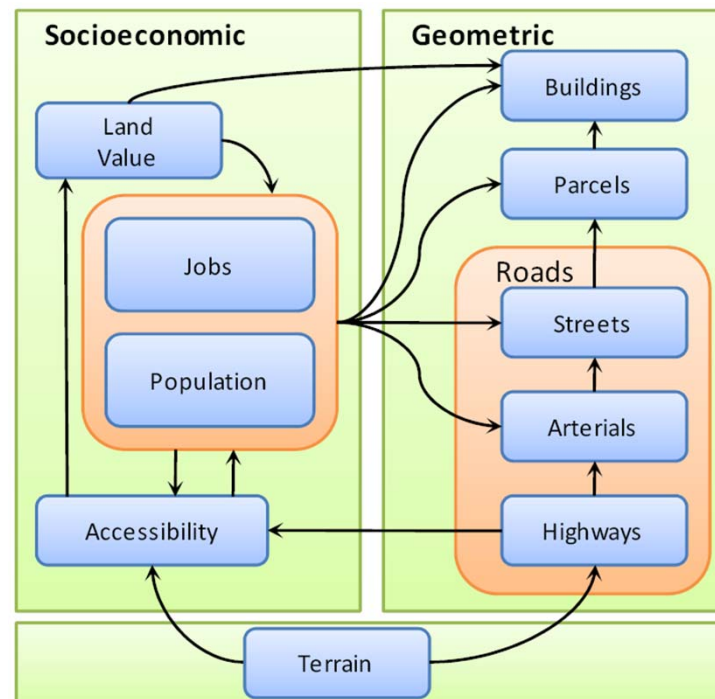
# Bridging the gap between urban simulation, visualization and modeling

- **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

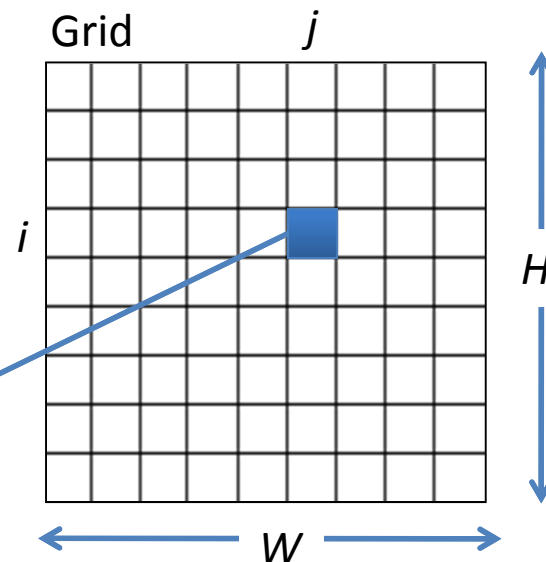


# Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling

- System

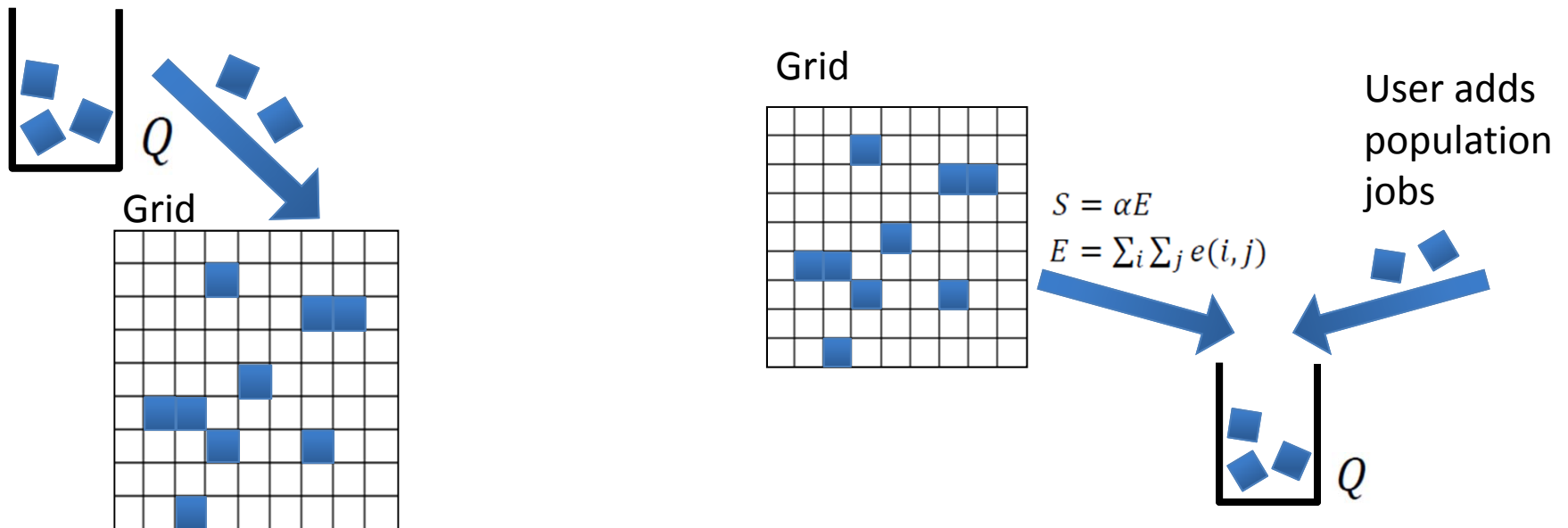
- Consists of  $N$  variables defined over a spatial domain
- Each variable sampled over a 2D spatial grid  $G$  of size  $W \times H$
- $v_k(i,j)$  denotes the value of  $k$ -th variable at grid cell  $(i,j)$

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



# Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling

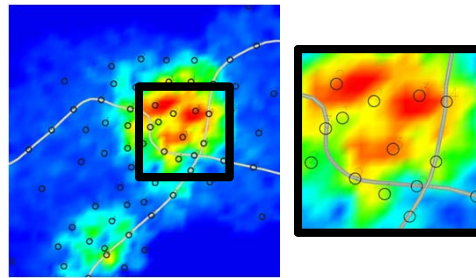
- Operations
  - Location and de-location of behavioral variables using location choice and mobility algorithms



# Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling

- Arterials and Streets

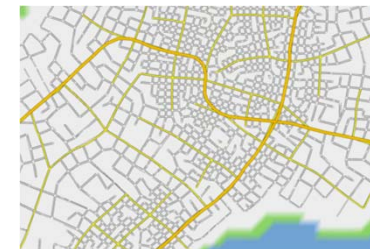
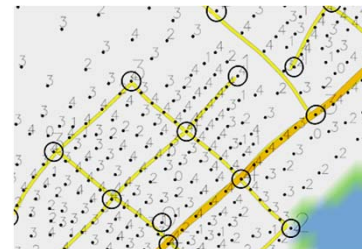
- Seeds



- Expansion of Arterials

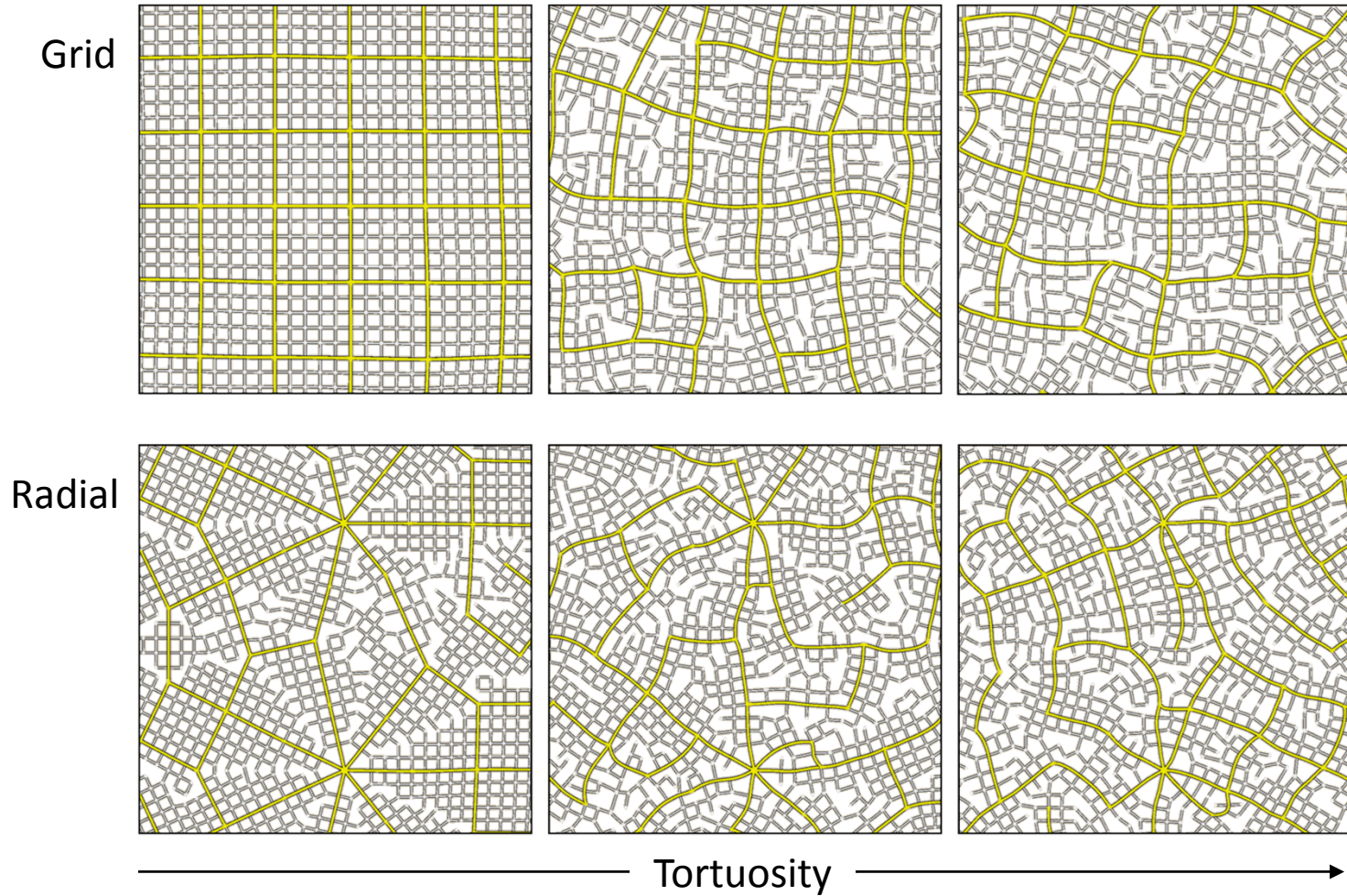


- Expansion of Streets

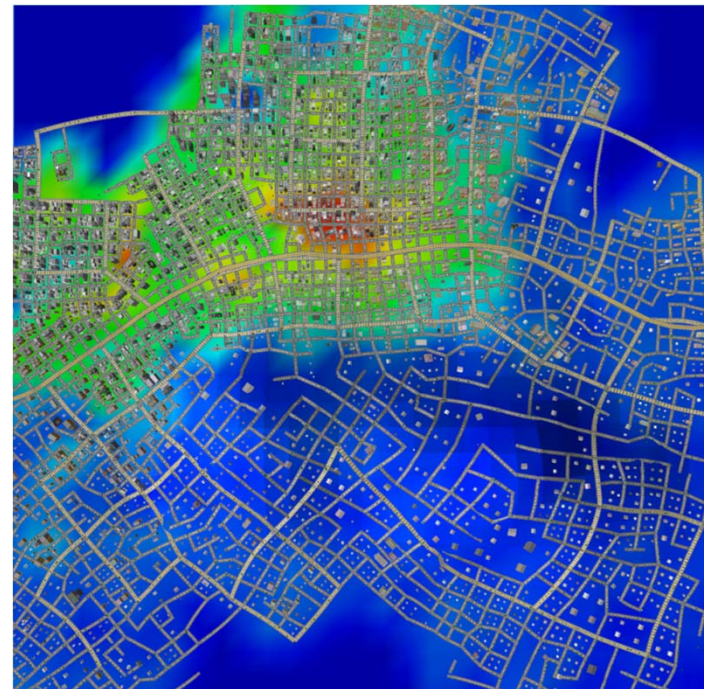
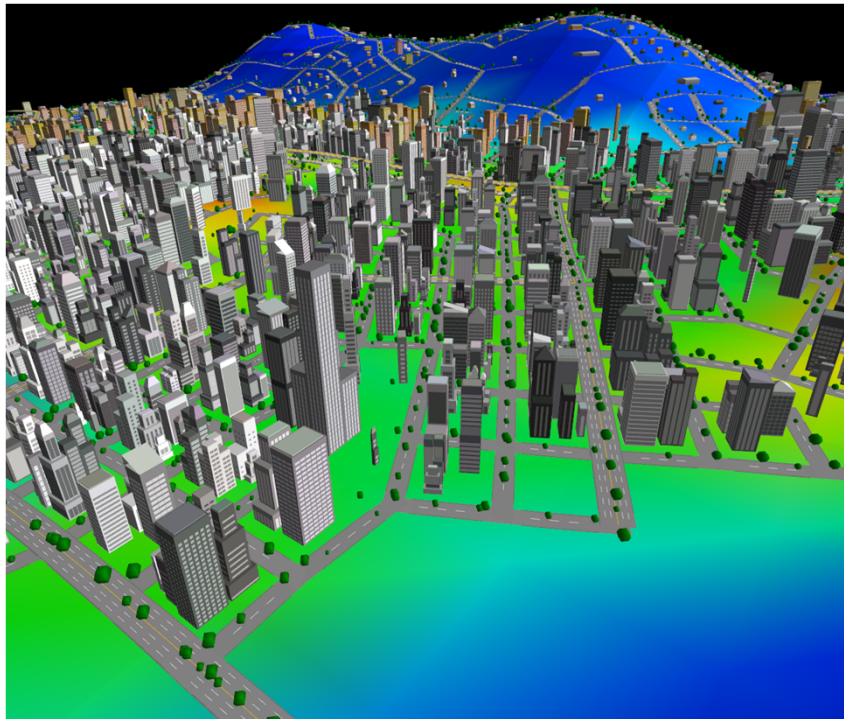




# Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling

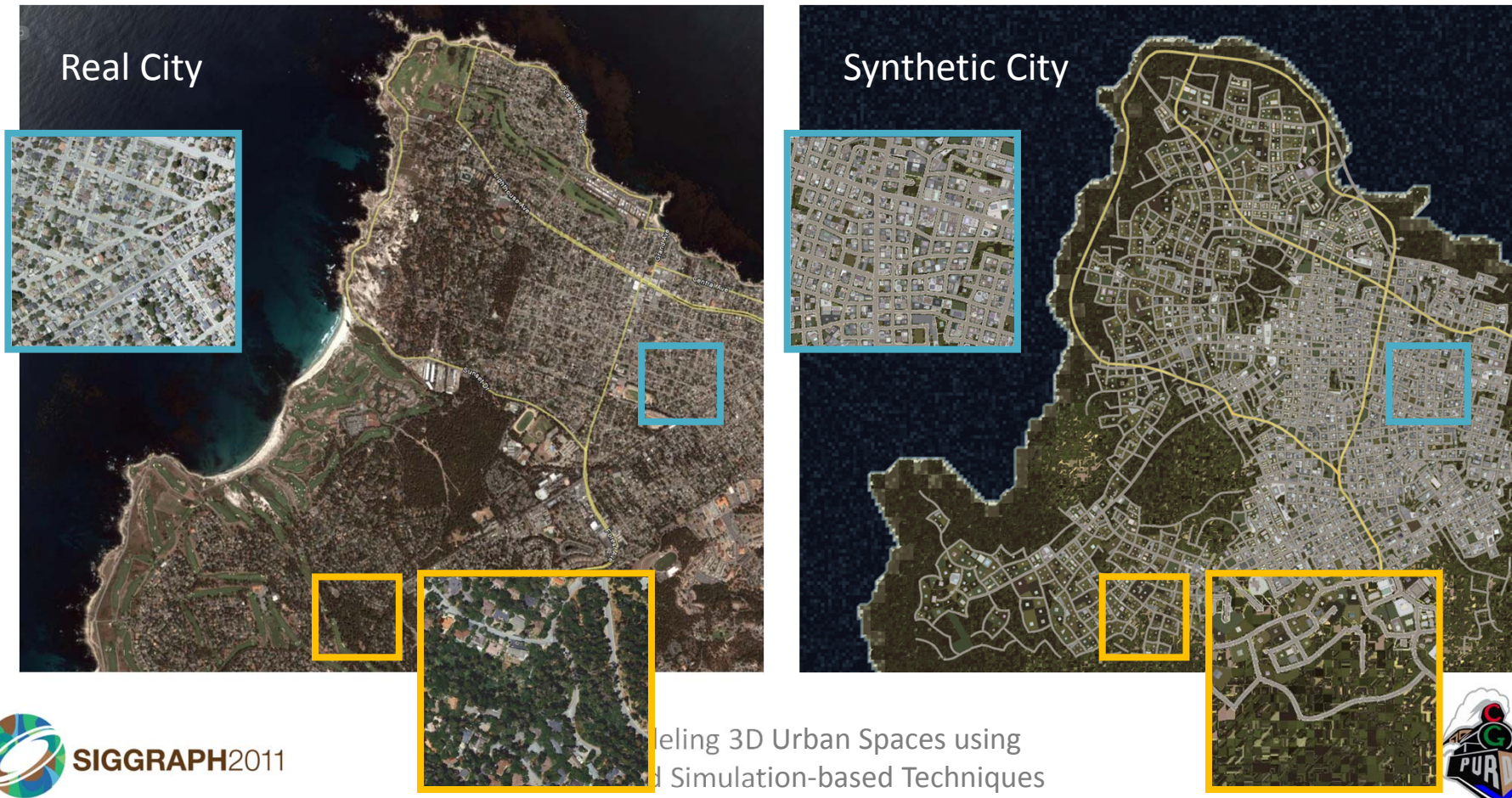


# Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling



# 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

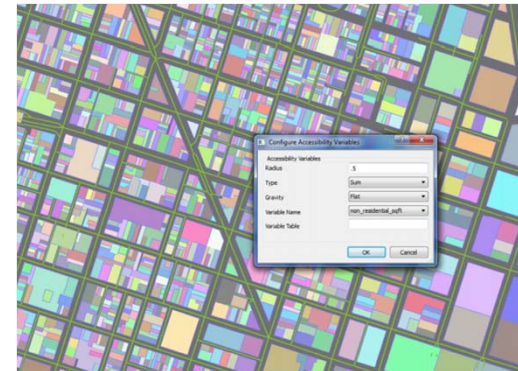
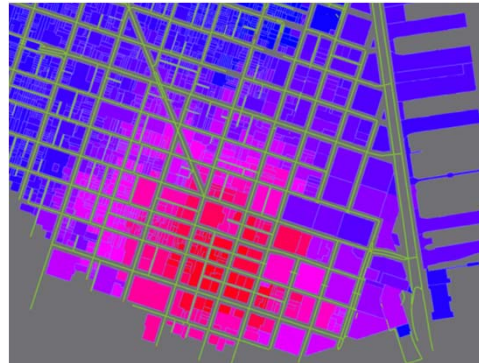


Course: Modeling 3D Urban Spaces using  
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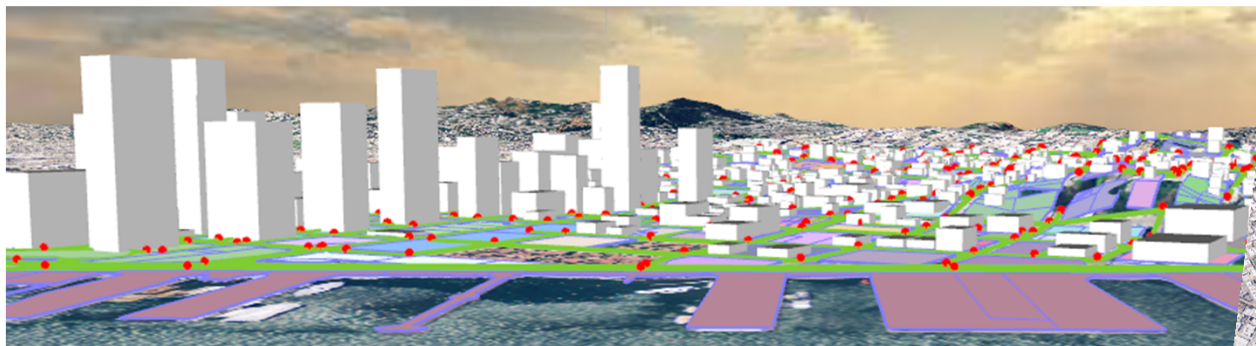
# Application: UrbanVision

- 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

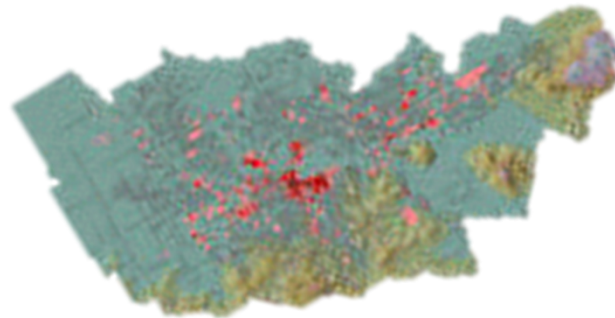
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2	61211.39760	1220.72752	5162	23000035	NULL
3	25268.12601	695.55283	5150	23000031	NULL
4	25846.93595	745.90862	5123	23000029	NULL
5	160303.63298	3211.00257	5072	23000117	Lac Vieux C...
6	16257729.36470	27482.12755	5918	23000117	Eleanor L...
7	113153.53729	1339.58451	5371	23000056	NULL
8	727858.27583	3935.14077	5371	23000045	NULL
9	85889.90129	1249.18110	5365	23000047	Crystal L...
10	388604.93745	2777.39244	5395	23000231	Denkon
11	30556.08127	636.37138	6823	23000229	Lanier
12	109072.33869	1693.60843	6817	23000212	Lake Pl...
13	122138.05156	1600.00461	6682	23000170	Lac de
14	50108.07442	911.83737	6410	23000134	...
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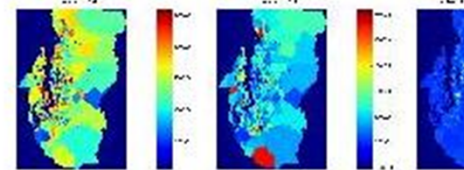
RTN	NAME	ADDRESS	TOWN	REGION	STATUS
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1	3-0000366	STERLING CLARK	154 COMMERCIA	MALDEN	3.0
2	3-0015799	NO LOCATION AID	332 PLEASANT ST	MALDEN	3.0
3	3-0002051	PROPERTY	291 MEDFORD ST	MALDEN	3.0
4	3-0002618	NEW ENGLAND E.	170 MEDFORD ST	MEDFORD	3.0
5	3-0019069	NO LOCATION AID	430 PEARL ST	EVERETT	3.0
6	3-0019854	NO LOCATION AID	430 PEARL ST	MALDEN	3.0
7	3-0001225	PROJECT TRIAN	430 PEARL ST	MALDEN	3.0
8	3-0002052	PROPERTY	1-13 HIGHLAND ...	MALDEN	3.0
9	3-0012110	ALSO 298 MEDF...	360-392 PEARL ST	MALDEN	3.0
10	3-0020308	4000 GALLON LST	100 HIGHLAND A.	MALDEN	3.0
11	3-0001281	HUDSON BUS LIN	170 LINCOLN ST	MALDEN	3.0
12	3-0000604	AMERICAN FENC...	24 SHIP AVE	MEDFORD	3.0
13	3-0011176	CORNER OF FELL...	469-471 SALEM ST	MEDFORD	3.0
14	3-0003290	INDUSTRIAL PR...	320-330 MIDDLE	MEDFORD	3.0
15	3-0020805	MDC MAINTENA...	1 WICKLOW ST	MALDEN	3.0
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17	3-0018292	CORNER OF REY...	235 SALEM ST	MEDFORD	3.0
18	3-0010429	NO LOCATION AID	461 RIVERSIDE	MEDFORD	3.0
19	3-0002366	NESSEN BAKERY	48 COMMERCIAL	MEDFORD	3.0
20	3-0021594	COMMERCIAL ST.	30 COMMERCIAL	MEDFORD	3.0
21	3-0004954	FELLSWAY PLAZA	632-760 FELLSW.	MEDFORD	3.0
22	3-0011747	FELLSWAY AND ...	590 & 616 FELLS.	MEDFORD	3.0
23	3-0016502	NO LOCATION AID	170 MYSTIC AVE	MEDFORD	3.0

# Why is this system useful?

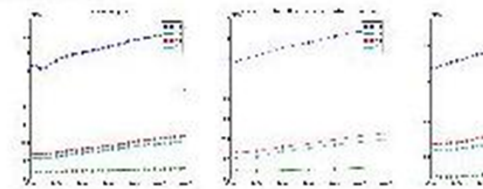
- Limitations of existing urban simulation systems
  - Difficult to specify what is to be simulated
  - Visualization of results
    - Offline
    - Lacks 3D content



maps:



charts:



tables:

faz table number of jobs.csv  
----- table number of jobs.csv -----

# Why is this system useful?

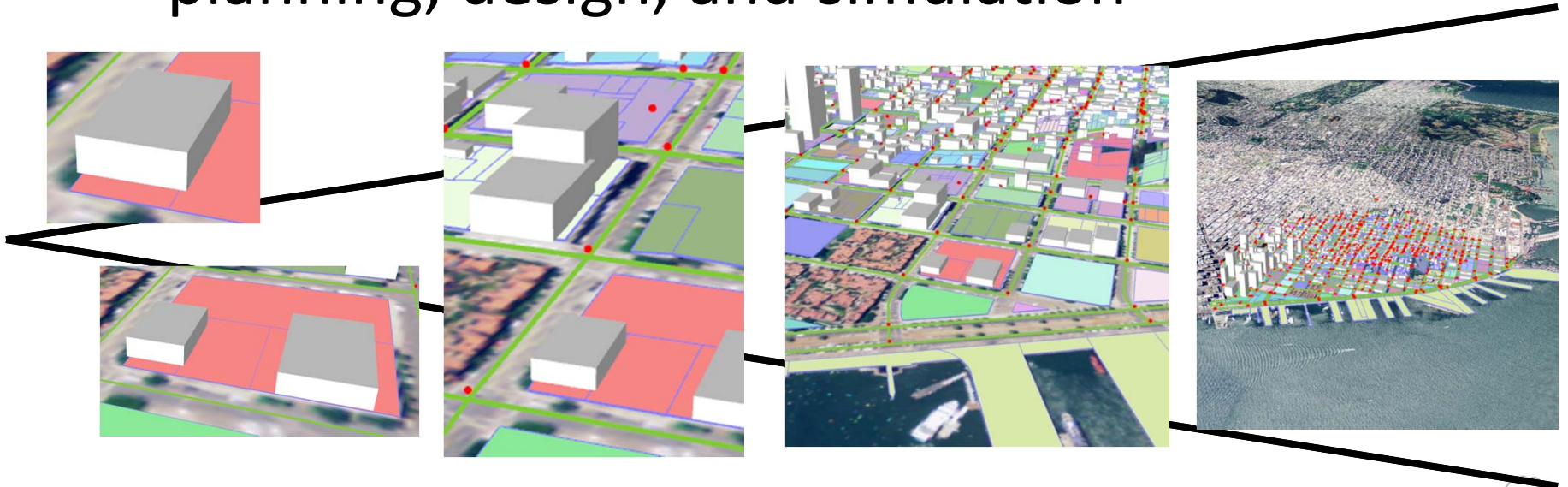
- Limitations of existing urban simulation systems
  - Difficult to specify what is to be simulated
  - Visualization of results
  - User interaction
    - Limited to tables in databases
    - Lacks “immersive” navigation

# 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

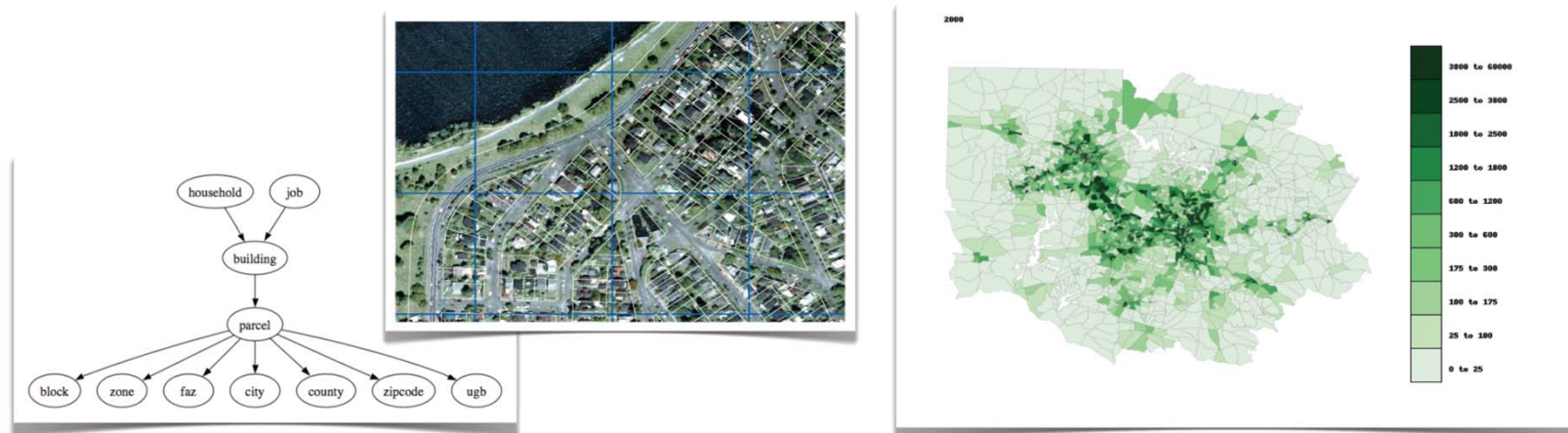
# Goals (1) – Open Source

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



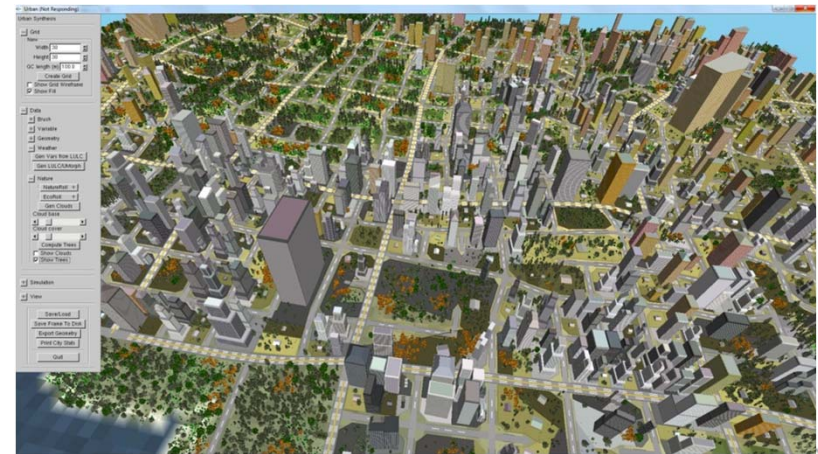
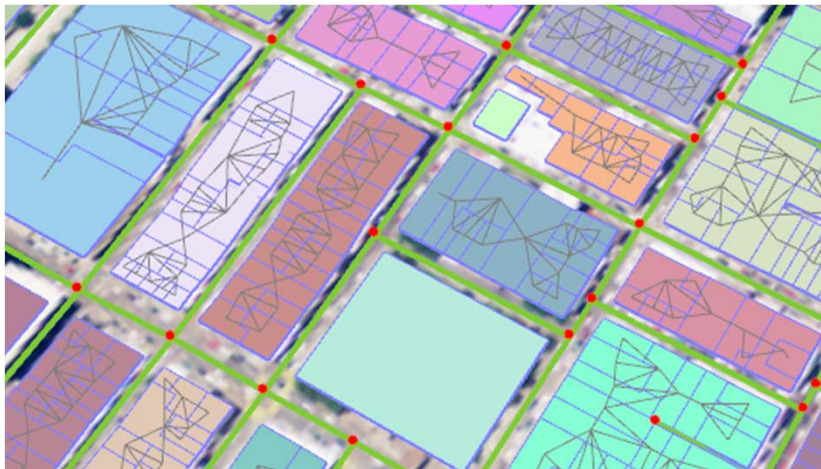
# Goals (2) – Behavioral Simulation

- **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.

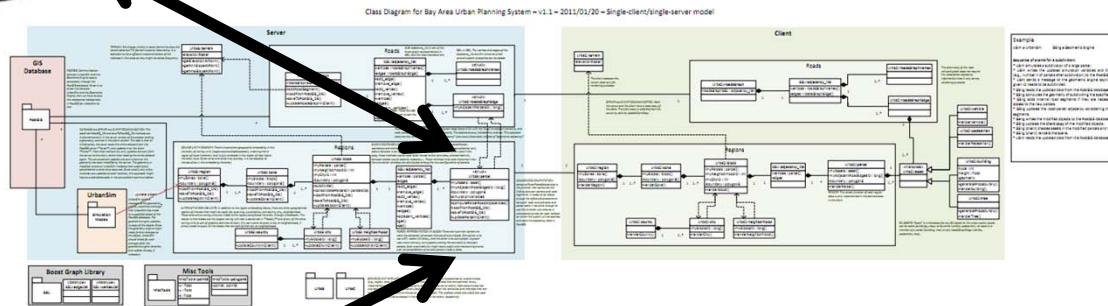


# Goals (4) - Robust Integration

- 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



now



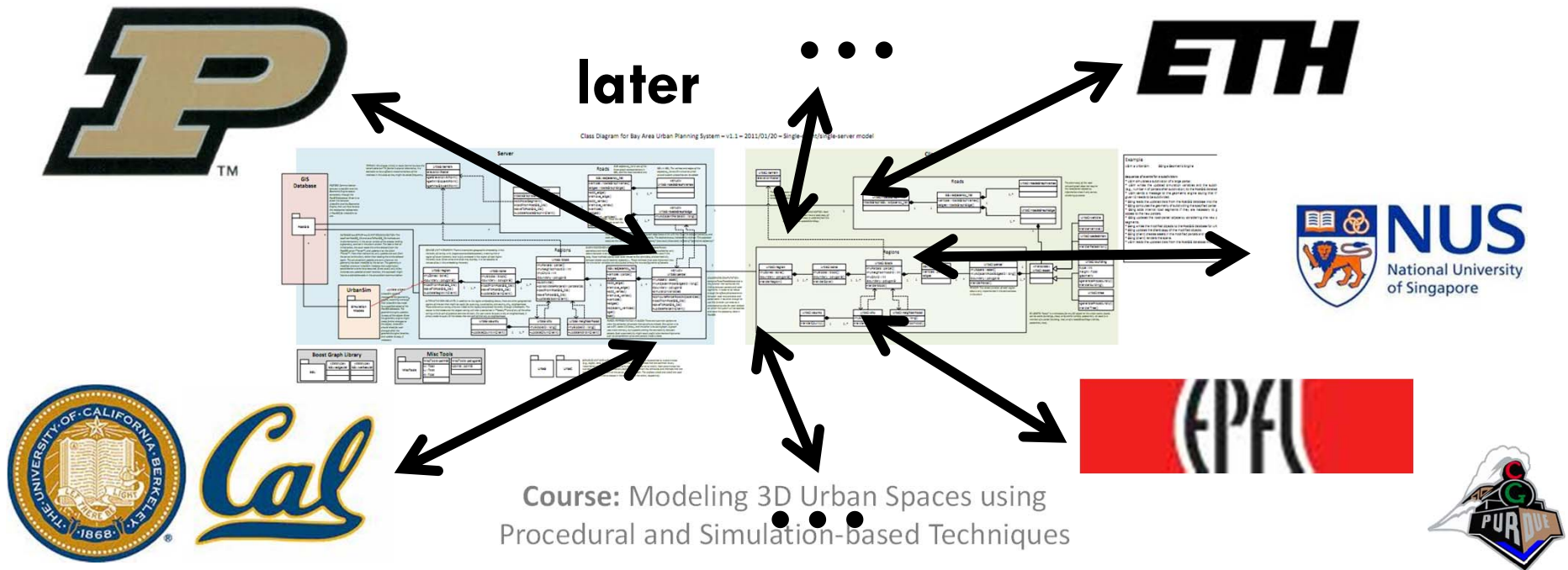
Course: Modeling 3D Urban Spaces using  
Procedural and Simulation-based Techniques





# 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



# 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