High Resolution Cities: Connecting Research with Practice

Presented at TCMA 2019 Spring Conference

Budhendra Bhaduri (@budhubhaduri)

April 05, 2019
Overview of presentation

• Urban Dynamics Institute (UDI)

• R&D Themes and example projects
  – Population and land use
  – Sustainable mobility
  – Energy and water
  – Urban resiliency

• City Partnerships
Urban Dynamics Institute
Understanding and optimizing the impact of future technologies, policies, and populations

Mission

Provide a data-driven understanding of complex urban systems, governed by both physical and behavioral sciences, by pursuing novel science and technology to observe, measure, analyze, and model urban dynamics from city to global scales.

Population and land use
Distribution/dynamics, land use change, citizen science

Sustainable mobility
Connected vehicles, driver assistance systems, safety

Water and energy
Efficiency, pollution, sustainability

Urban resiliency
Cybersecurity, communication, disaster management
Scientific Advisory Board

Michael Batty
Chairman
UCL Center for Advanced Spatial Analysis

Luis Bettencourt
Director
Mansueto Institute for Urban Innovation, University of Chicago

Jack Dangermond
President
ESRI

Nigel Davis
Head Platforms & Delivery
Willis Limited

Erin Gill
Director of Sustainability
City of Knoxville

Michael Goodchild
Professor Emeritus
UC Santa Barbara

Jonathan Harbor
Professor
Purdue University

Burkhard Huhnke
Product Innovation
Volkswagen of America

Zachary Lemnios
VP, Physical Sciences and Government Programs
IBM

Jonathan Levine
Professor
University of Michigan

Huei Peng
Director
Mcity, University of Michigan

Karen Seto
Professor
Yale University

Luc Vincent
VP Engineering
Lyft
Cities Advisory Council

Bruce Applegate
Assistant to the City Manager
City of Oak Ridge

Erin Gill
Director of Sustainability
City of Knoxville

Robert Phocas
Energy and Sustainability Manager
City of Charlotte

Biju George
Chief Operating Officer
DC Water

Erin Hafkenschiel
Director of Transportation and Sustainability
City of Nashville

Erik Schmidt
Director of Sustainability
City of Chattanooga

Nancy Gassman
Assistant Public Works Director
City of Fort Lauderdale

Megan O’Neil
Building Performance Program Manager
City of Atlanta

Greg Thomas
MPO Coordinator
City of Cleveland
Population and Land Use
ORNL has been a pioneer in global population distribution and dynamics research

**LandScan Global**
- Spatial resolution of 30 arc seconds (~1km)
- Ambient population (average of 24 hours)
- Remote sensing based global data modeling and mapping

**LandScan USA**
- Spatial resolution of 3 arc seconds (~90m) coverage for the US
- Nighttime and daytime population
- Integration of infrastructure and activity databases

**LandScan HD (ongoing development)**
- Spatial resolution of 3 arc seconds (~90m) global coverage
- Residential and ambient population
- Settlement mapping from very high resolution imagery (1m or less)
- Integration of population density and activity databases
LandScan: improving knowledge of population dynamics

**LandScan Global**
- Resolution: 30 arc seconds (~1 km)
- Ambient population (average of 24 hours)
- Remote sensing–based global data modeling and mapping

**LandScan USA**
- Resolution: 3 arc seconds (~90 m), US coverage
- Nighttime and daytime population
- Integration of infrastructure and activity databases

**LandScan HD (ongoing development)**
- Resolution: 3 arc seconds (~90 m), global coverage
- Residential/ambient population
- Settlement mapping from very high resolution imagery (1 m or less)
- Integration of population density and activity databases
High-resolution imagery (multi-spectral, panchromatic)

Settlement area (feature extraction)

Building footprint (deep learning)

Neighborhood mapping/Settlement density (automated building counts,)

Building heights (DEM/LiDAR, Google StreetView)

Land use via open source data/VGI (Wikimapia, zoning data)

Population density (DHS, PDT, Census, Micro-Census)
Mapping human settlements from high resolution images

Addis Ababa, Ethiopia

Yaoundé, Cameroon
United States: high resolution building map

- **220,005** NAIP images
- 1 meter multispectral 2012-2014
- ~5.8 TB compressed
- 9.8 trillion pixels
Infrastructure data can be developed from image mining

Mobile Home Parks (NAIP 1m)

Rooftop Solar Panels (WV3 0.3m)

- Database point
- Detected point
Detecting swimming pools at scale

- 4106 WV 2 and 3 images for TX
- 40TB (2.0 GB – 12 GB each)
- 10 minutes on ~4000 nodes on Titan
- 20TB of output data
UrbanPop: American Population Simulator

Downscales Census data to block group resolution with unprecedented demographic detail

- High resolution nighttime and daytime demographics with uncertainty quantification.
- Simulates individual home, work, and commute patterns by fusing rich demographic detail with business, transportation, and flow data using penalized maximum entropy dasymetric modeling.
- Energy, health, transportation mode and distance are tightly connected to demography and now become far more spatially explicit and locally understood.

Wendy
- White
- 16+ Years Old
- $75,000+
- Scientific Administrative
- Waste Management
- Greater Knoxville Area, TN

Where Wendy likely Lives

How Wendy likely Commutes

Where Wendy likely Works
LandCast

Locally Adaptive, Spatially Explicit Projection of U.S. Population

- Understanding future population distributions is critical for developing sustainable infrastructure based on last 30+ years of land use and population changes
- The first ever large scale, adaptive spatial algorithm for addressing local characteristics of unique geographic areas
- Spatially explicit 1km population distribution in 2030 and 2050 (One of many potential population futures)
PlanetSense: Explore and exploit open-source data in real-time

- Curate Points of Interest (POI) and relevant information (open/close, website and more)
- Transient population estimates and land-use
- Crowd-sourced ground photo imagery for conflict zone mapping
- Gather real-time geo-spatial intelligence from open-source multi-data fusion
- Linked data for knowledge discovery through graph analysis
Temporal Signatures for Points of Interests’ Hours of Operation

By studying the hours of operation for various facilities (e.g. restaurants, museums, retail, etc.) around the world, we can improve our understanding of the fundamental cultural and regional effects that shape the dynamics of human societies at an aggregate scale.

OUTPUT

Understand the external processes that drive the patterns we see in signatures

Automatically generate temporal population transition periods

Differences across space within facility category (e.g. retail)

Differences across facility categories within space (global)

country A

country B

country C

school

museum

restaurant

Honduras 97% Catholic

Kuwait 76% Muslim

Religion

Temperature

Colonialism

...
Sustainable Mobility
Vehicle coordination to optimize traffic flow and alleviate congestion

**Increasing efficiency, saving energy, reducing emissions**

- Vehicle-based, decentralized control algorithms
- Each car is an independent, intelligent agent that will maximize efficiency through strategic interactions
  - Vehicle to vehicle communication
  - Vehicle to infrastructure communication
CommuterSim: Travel mode choice New York City

Neighborhood level decision support in energy consumption, transportation, mobility, and public health

- Commuter Sim is an HPC Agent based model to predict travel mode choice.
- About **3.5 million agents** are simulated where commuters work, interact, and influence each other’s choices.
- How many more people might walk if sidewalks were widened?

### Anticipated Benefits of Wider Sidewalks and Longer Bike Lanes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Borough</th>
<th>Percent Increase in Mode Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>WALK</td>
<td>Bronx</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>Brooklyn</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>Manhattan</td>
<td>15.2</td>
</tr>
<tr>
<td>BIKE</td>
<td>Bronx</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td>Brooklyn</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td>Manhattan</td>
<td>19.6</td>
</tr>
</tbody>
</table>

- **WorkerSimulated Flow:** Work locations of agents
- **Synthetic agent generation:** Socio-demographic attributes (e.g., age, income, home location)
- **Built environment attributes:** (e.g., land use patterns, activity locations)
- **Regen-HPC ABM Simulation**
- **GIS Map to Analyze Scenarios:** Which block groups will have the most impact from infrastructure improvement?
Energy and Water
Detecting the influence of urbanization on regional water resources

- US Cities Can Manage National Hydrology and Biodiversity Using Local Infrastructure Policy
- Disparate policy sectors need a common framework for communication
- Holistic assessment identifying predominant alterations to the water cycle
- Urban land transformation and electricity production have large impacts to distal ecosystems

McManamay et al., PNAS 2017 114: 9581-9586.
Energyshed Delineation for Cities

Assessing City Impact & Energy Competition in Distal Geographies

- Energyshed = a region of locally dense energy consumption balanced by production in the surrounding landscape
- Use network market share optimization to balance energy production-consumption along the electric grid
- Quantify city-to-city energy competition and city carbon-water footprints
- Isolate power plants balancing the most load and vulnerabilities in the grid
- Examine scenarios of future energy portfolios
Urban Resiliency
Over 7 million impacted electric customers who were out of power in the morning of 9/11/17 during Hurricane Irma after landfall.

Majority of the ~7 million impacted electric customers were from Florida, Georgia, and South Carolina.

EAGLE-I system updates every 15 minutes with the number of electrical outages reported by utilities.

Increase the coverage of electricity customers: 84.05% of TX and 93.34% for FL.
Digital Twin of a Utility (Virtual EPB)

- DOE’s Building Technologies Office and Office of Electricity
  - Goal: create a digital twin of every building in the service area for the Electric Power Board of Chattanooga, TN (15-min energy data for 169,000 buildings)
  - Final Deliverable: Simulation-informed data and valuation report for energy, demand, emissions, and $ impact to EPB for each building in EPB’s service area for 5 prioritized use cases covering 9 monetization scenarios

Results:
- $11-35 million/year potential savings

- BldgID, Area (m²), #floors
- Color: Energy Use Intensity (kWh/m²) by building type
- Min, Avg, Max, Percentile EUI
ORNL Signs CRADA with Southern Company

Demonstrates neighborhood-level, buildings-to-grid integration with VOLTTRON™

- State-of-the-art community of 62 homes in Alabama will aggregate renewable generation and distributed energy storage at the neighborhood level through community scale storage, solar photovoltaic (PV), and emergency distributed generation.

- Demonstrates grid integration, scalable distributed control and end-use energy management.

- VOLTTRON™-based, building-level control of HVAC and water heating to deliver virtual storage capacity to offset electrical storage requirements.

- Near-term Outcomes – New VOLTTRON™ agents for HVAC, water heating and system self-discovery implemented in homes.

- Intermediate Outcomes – Assess the transactive control in neighborhood.

- Long-term Outcomes – Large scale implementation by utilities (Southern Company)

First-of-its-kind, transactive residential microgrid in the Southern United States.

Understanding urban activity requires knowing the population density and how it changes over time.

Transportation monitoring including directional counters.

Radio frequency (RF) antenna used for monitoring location beacons sent by cellular handsets.

Environmental sensors - air quality (pollutants), water quality, temperature, relative humidity, and vibration.

Prototypic demonstration of non-intrusive technology in real-time with high spatial and temporal resolution.

Collect data over time to understand trends:

How many people are traveling in Oak Ridge?

Where are they spending their time?
Smart data applications for cities: precision deicing
Acknowledgement
Questions?