Dynamic Adaptive Disaster Simulation: Developing A Predictive Model of Emergency Behavior Using Cell Phone and GIS Data[1]

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Outline

- Introduction
  - Motivation
  - Previous Work
  - Contributions
- Our approach
  - Modeling Process
  - Calibration
- Validation, Results, and Discussion
- Conclusions and Future Work

Why Model Populations?

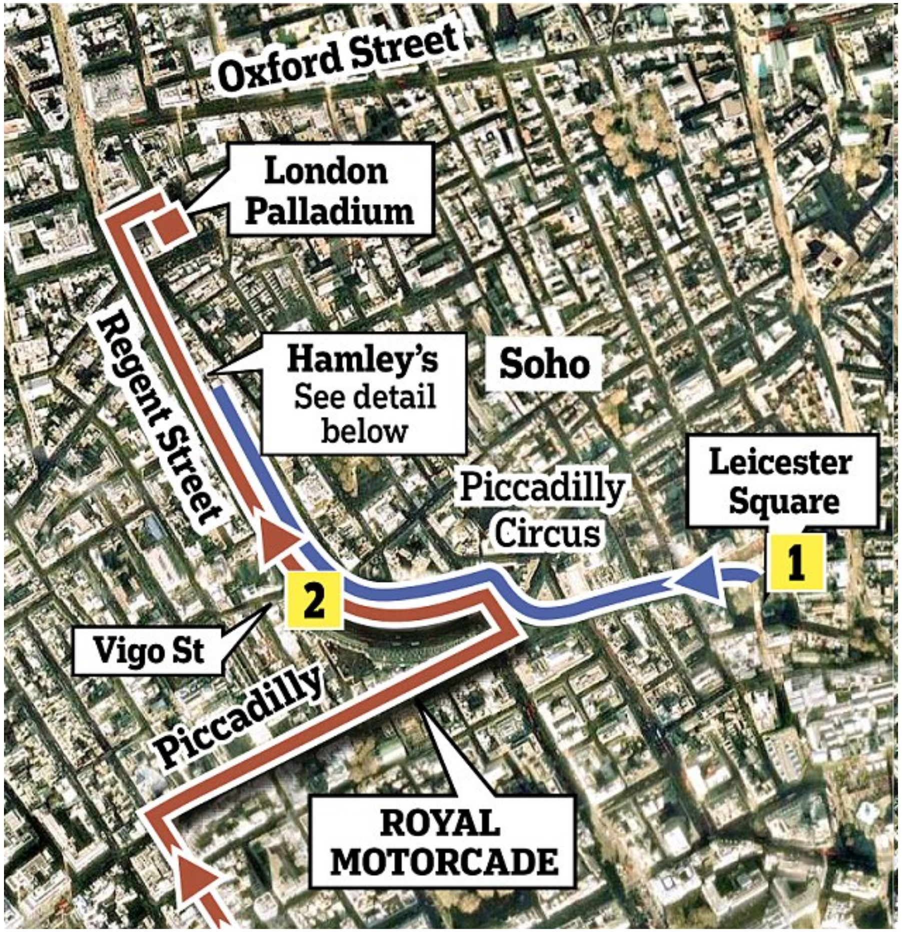
- **Hurricane Katrina**
  - **No comprehensive information on population movement**
    - **70,000 left in New Orleans**
  - **Resources distributed inefficiently**
    - **High ground areas (Superdome)**
    - **“fascinating phenomena”**

http://www.nerdylorrin.net/jerry/Katrina/KatrinaSuperdome.html

http://media.myfoxphilly.com/slideshows/katrina/1/lg/Fuel%20station %20damaged%20by%20Hurricane%20Katrina,%20Biloxi,%20Mississippi.htm

Why Model Populations? (cont.)

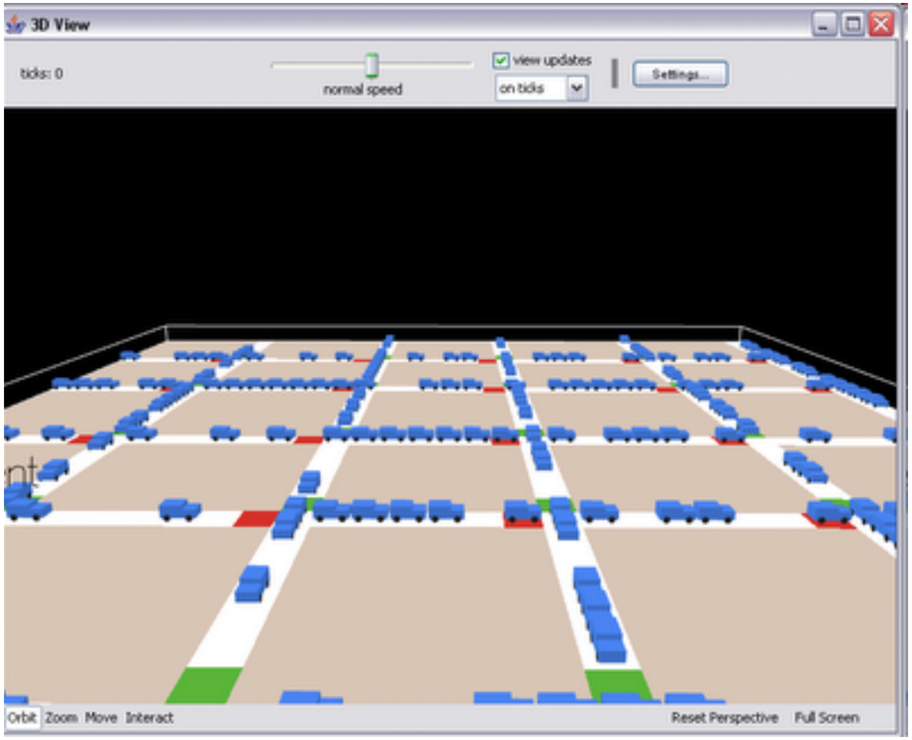
- London attacks on royal couple
  - Civil disorder was not reliably tracked
    - 100-person mob allowed to disrupt motorcade
    - Alternative routes were possible



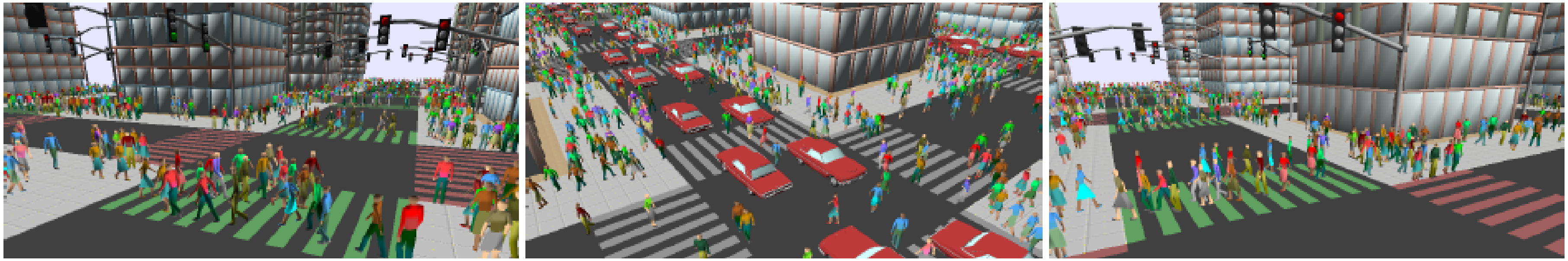
http://www.dailymail.co.uk/news/article-1337478/ROYAL-CAR-ATTACK-Blunder-left-Camilla-cowering-hit-ribs-protestors.html

Existing Methods of Population Modeling

- ❑ **Agent-based modeling**
- ❑ **Flow/continuum-based modeling**

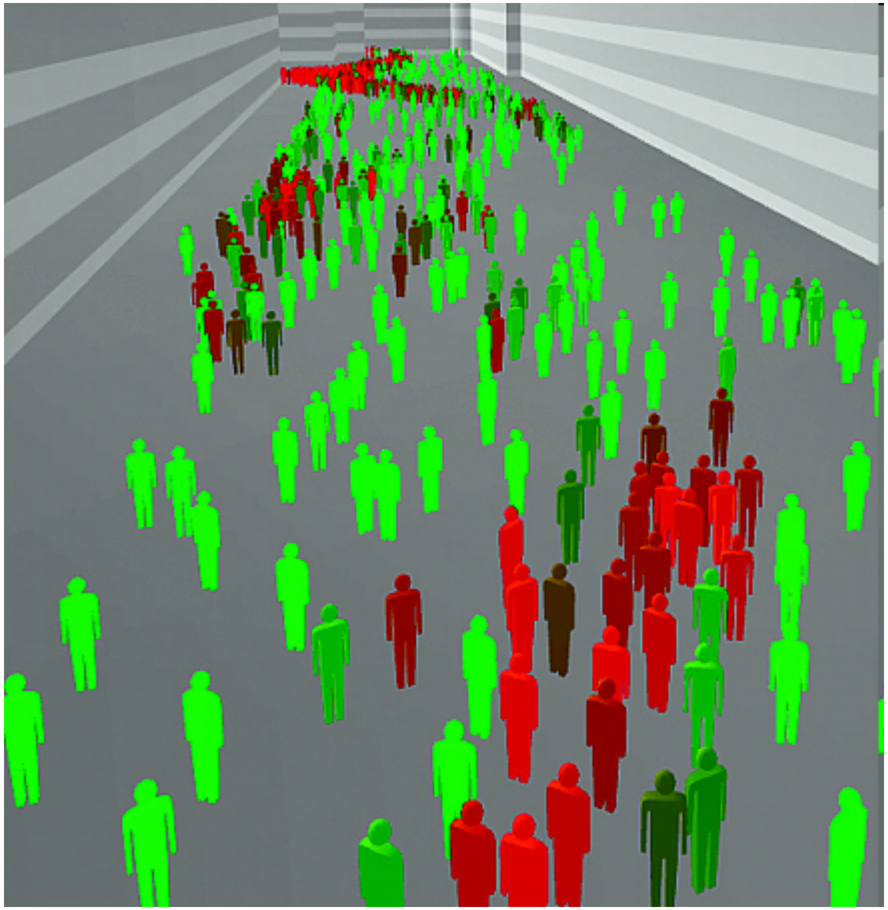


http://1.bp.blogspot.com/_pgrjV7xqqVY/R1mDQIMZqsI/AAAAAAAAAGM/MPBJzQl6DY4/s400/netlogo.gif



Treuille, A., Cooper, S., and Popovic, Z. (2006). Continuum crowds. ACM Transactions on Graphics, Vol. 25, Issue 3, pp. 1160-1168.

Challenges in Disaster Modeling

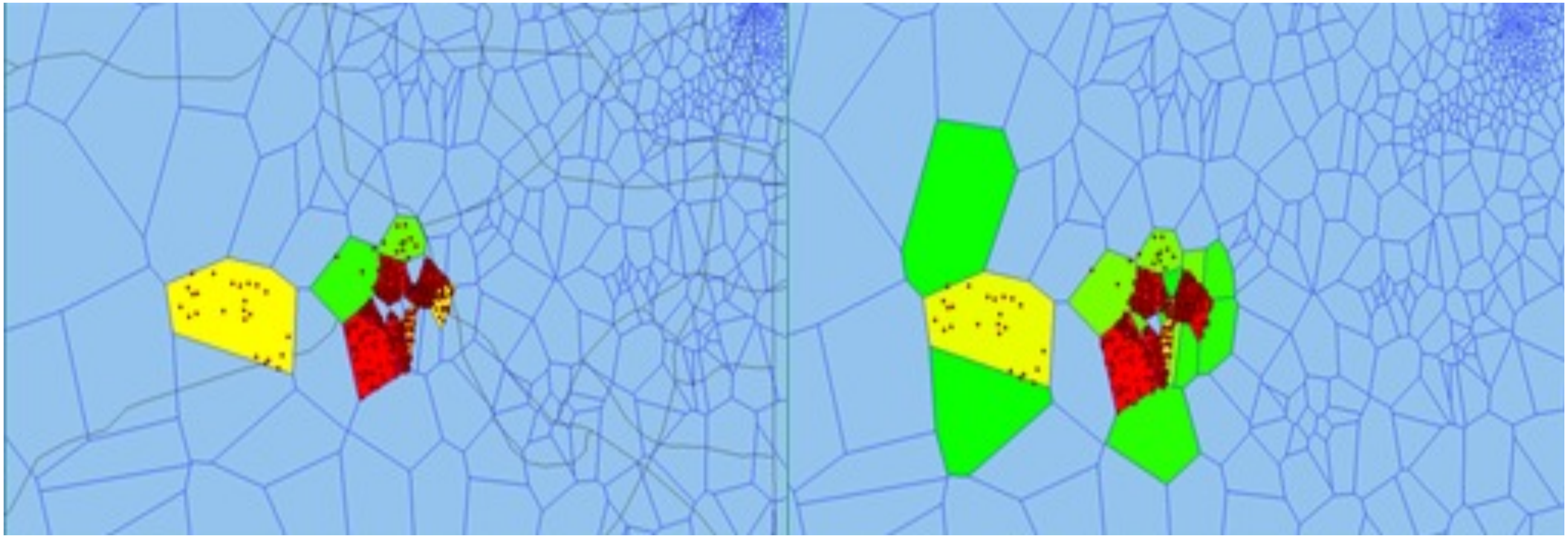


http://www.siemens.com/innovation/pool/de/Publikationen/Zeitschriften_pof/pof_herbst_2009/virt_real/personenstrom/pof209_virt_personen2.jpg

- Restricted to pre-programmed scenarios
- Based on speculations and assumptions
  - 25-40% difference in predicted evacuation times
- Online validation and data incorporation are difficult
- Dynamic Data-Driven Application Systems (DDDAS)
  - Better for real-time, adaptive predictions (Darema 2006)

The WIPER Project

- WIreless Phone-based Emergency Response System
  - Cell phones used as dynamic data source
- Simulation and Prediction
  - Pedestrian and vehicle agents
  - Basic movements: flee, flock, jam
- More work is needed (model complexity, adapt to scenarios)



Contributions

- Developed Dynamic Adaptive Disaster Simulation (DADS)
  - Proof-of-concept
  - DDDAS concepts
    - Adapts to specific scenarios
    - Continuously refines predictions
  - Can incorporate data
    - Geographic Information System (GIS)
    - Streaming real-time cell phone location data
    - Tested on synthetic cell phone data
  - Netlogo language and modeling environment, version 4.1.1
    - Used GIS extension

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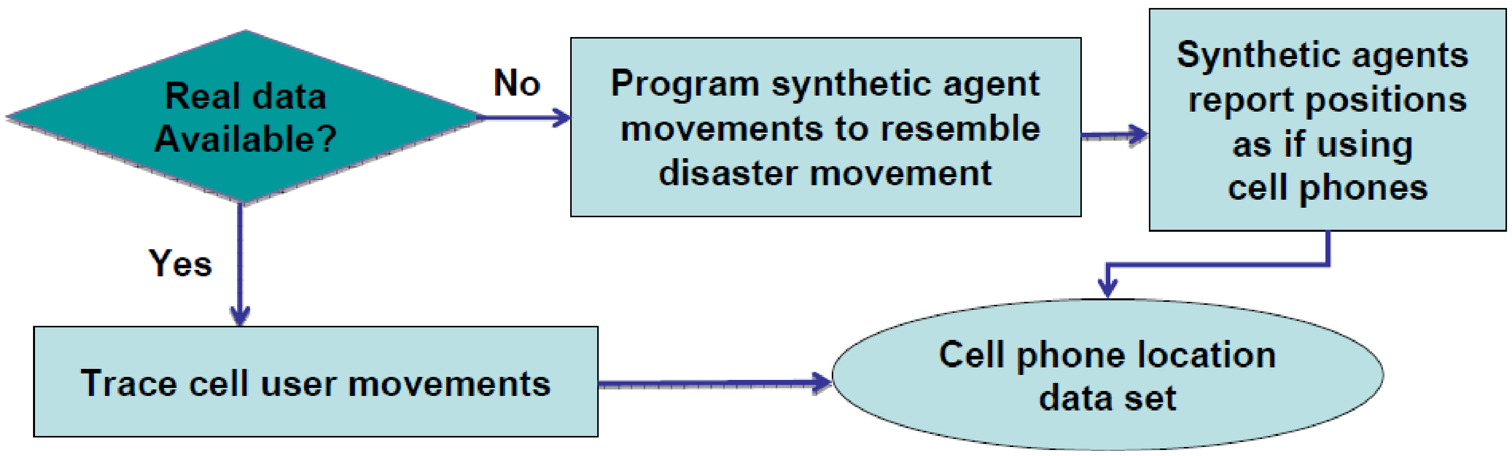
System Architecture

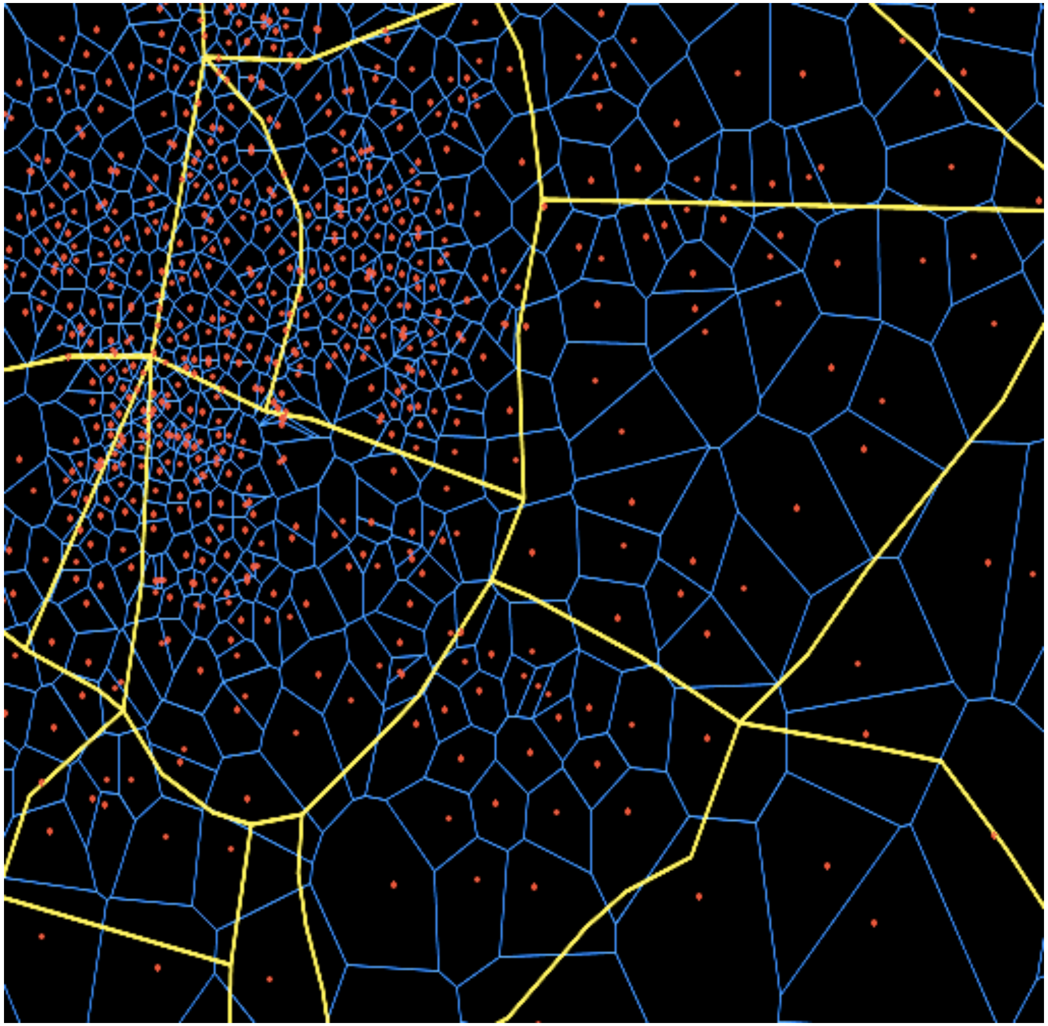


Agent Types

- Synthetic agents
  - Move as people would during a disaster
  - Represent real cell phone users
    - Movements generate synthetic cell phone data
    - Necessary because of nondisclosure agreements (NDA) with cell phone company—I am a minor
- Predictive agents
  - Move according to inferences drawn from cell phone data
  - Represent predictions of future population movement
    - Attempting to adaptively model disaster evacuation
    - Emergency management can be conducted based on agents' predictions

Modeling Environment: GIS Space

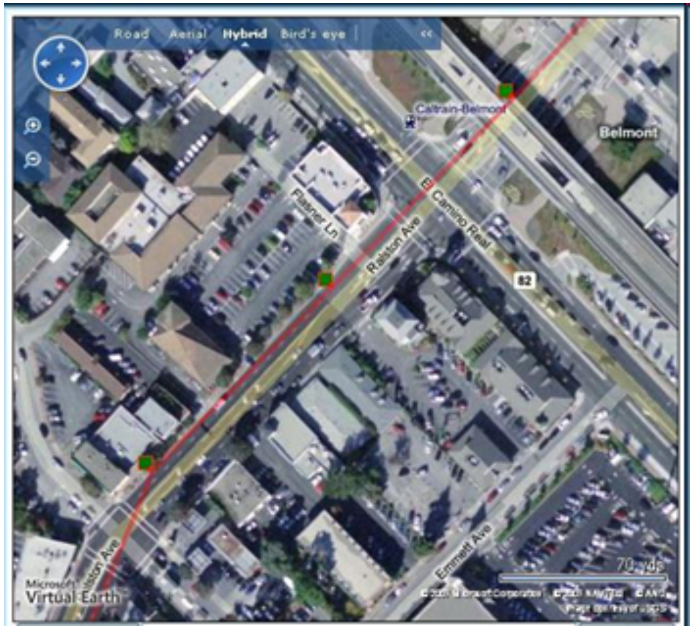
- Place names removed to maintain anonymity



Cell Phone Data

20070127	000400	@6f19d5	@fafd42	10004
20070127	000600	@69a50b	@fafd42	10004
20070127	000600	@31f919	@fafd42	10004
20070127	000700	@570f5c	@fafd42	10004
20070127	000700	@e940a6	@fafd42	10893
20070127	000800	@3e97cd	@fafd42	10343
20070127	000900	@a620f5	@fafd42	10005
20070127	000900	@687ae0	@fafd42	10011
20070127	001000	@2297d7	@fafd42	10011

- ❑ **Networks must be able to constantly track cell phones**
  - ➢ **Call Data Records (CDR)**
  - ➢ **Accuracy varies**
- ❑ **Phone-integrated GPS technology**



http://googlephonetracking.com/

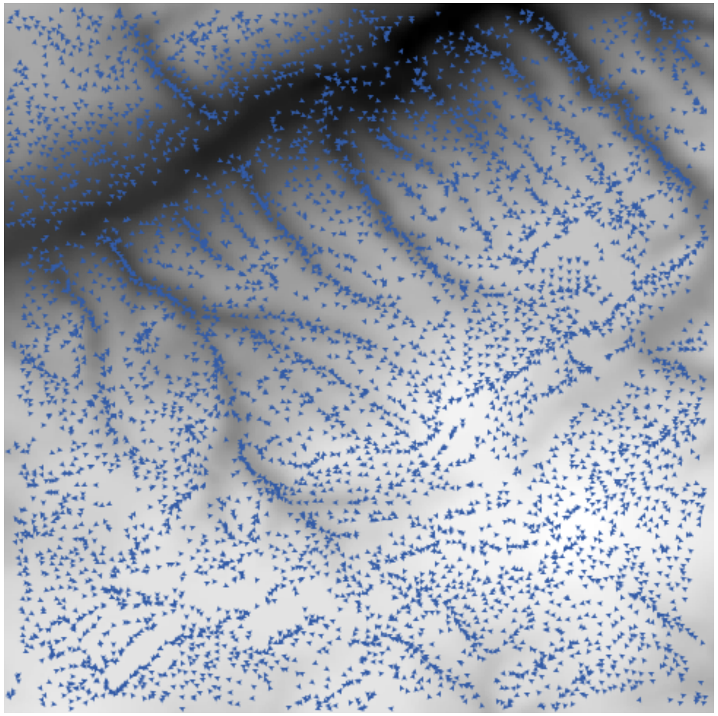
http://tuberose.com/Graphics/cell%20tower.jpeg

Modeling Approach

- Dynamic Potential Fields or elevation fields (Park 2009)
  - Agents move from high to low potential
  - Conceptually portrayed as a terrain of varying elevations
  - Used for both synthetic data and DADS itself

- Use fluid-like agents (Helbing 2002)

- Example



Wilensky, U. (2006). NetLogo GIS Gradient Example. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Implementing Modeling Approach

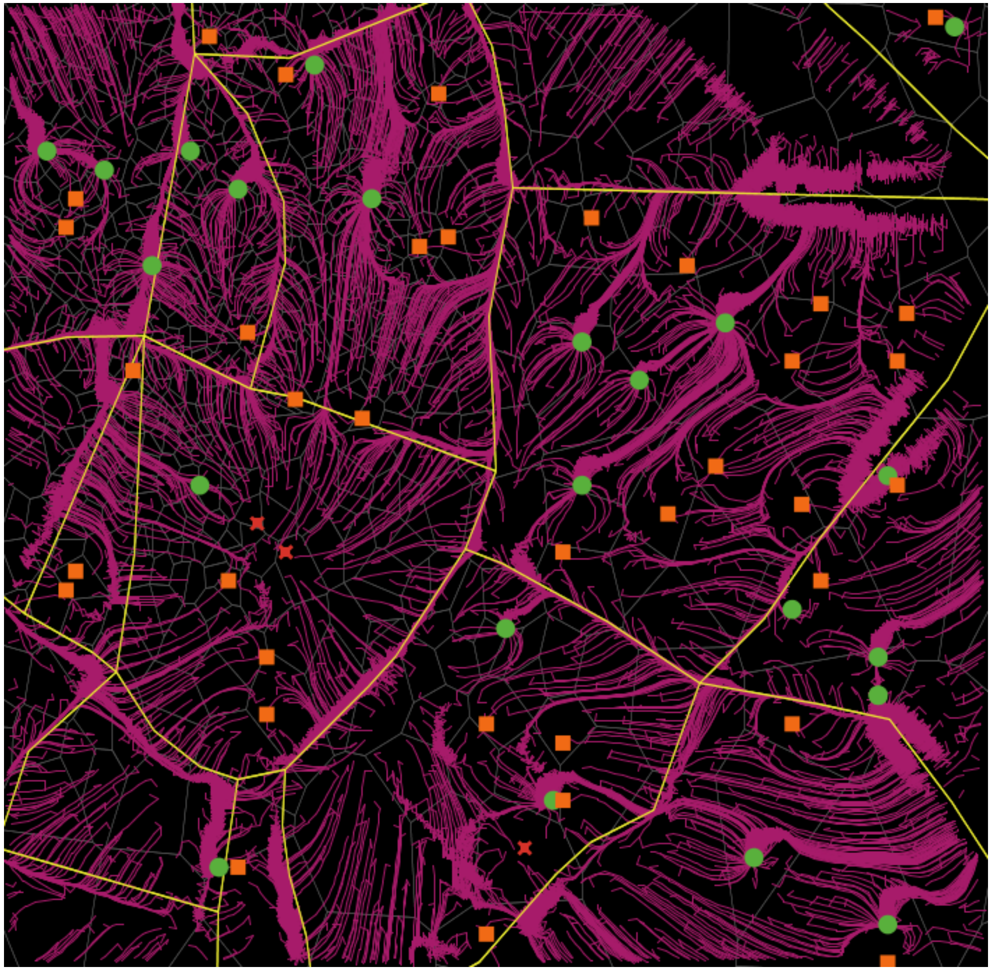
- Elevation field represented as matrix (Wilensky 2006)
  - Each element represents a patch of ground
  - Convolve the matrix with kernels:

$$\begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} \quad (1) \qquad \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \quad (2)$$

  - For each of two gradient matrices:
    - Calculate aspect: $a(x, y) = \arctan(y/x)$
  - Done in Netlogo, with GIS Extension
- Agents continuously set headings to match aspect of patch

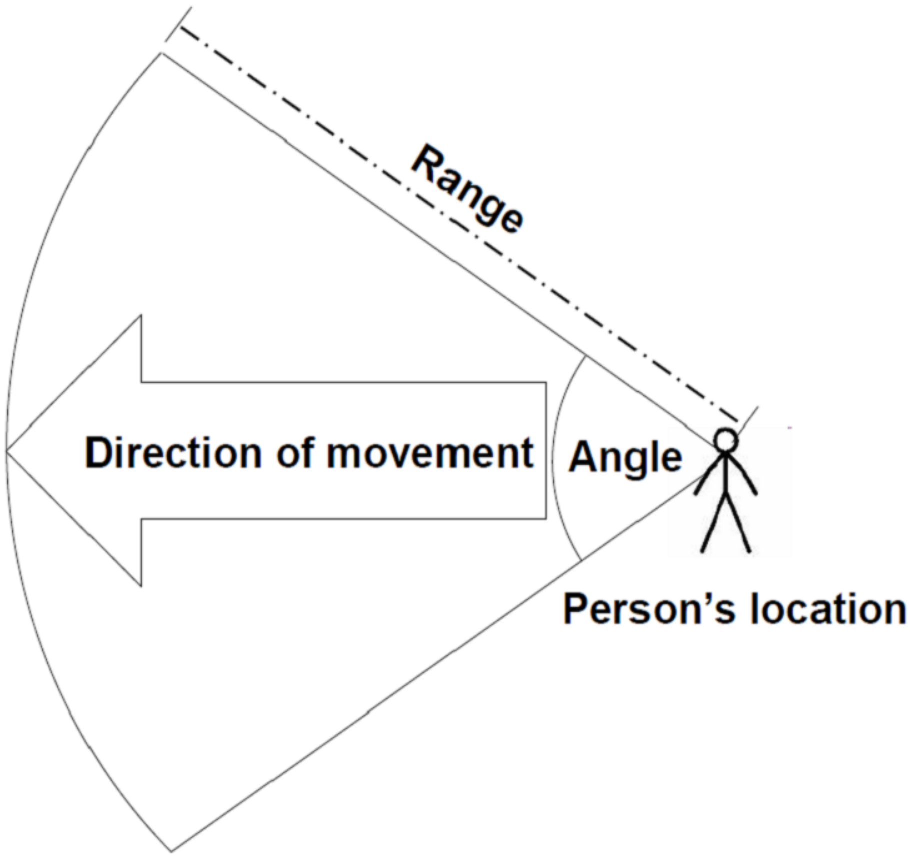
Generating Synthetic Data

- Synthetic elevation field
  - Types of regions in a scenario
    - Disaster (fixed)
    - Dangerous (random)
    - Safe (random)
    - Roads (fixed)
- 3200+ synthetic agents
  - Realistic pedestrian speeds
- Random scenarios
  - Example



Disaster location | Dangerous location | Safe location | Road

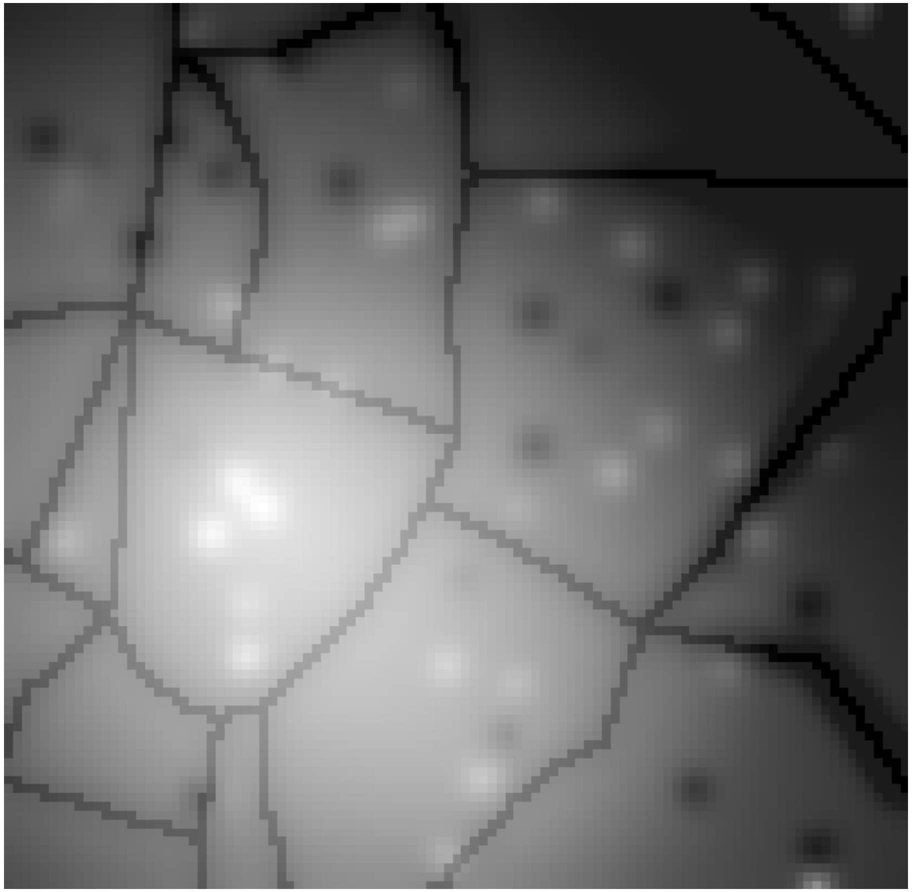
Conducting Inference on Data

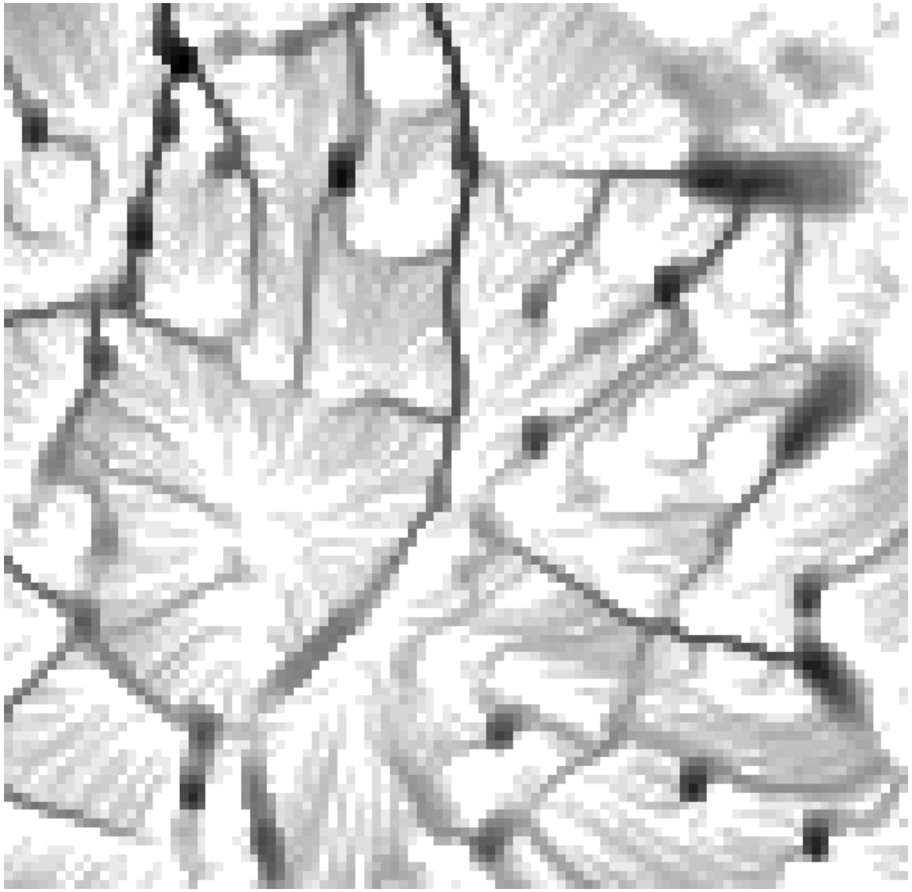


- Uses "vision cone" (Torrens 2007)
- Used as "cone of inference"
  - Patches inside the cone are inferred to be attractive
    - When a synthetic agent moves, decrease predictive elevation of patches
    - Generate a field of predictive elevations
  - DADS predictive agents move on predictive elevation field
    - Represent prediction of future locations of cell phone users
  - Example

Conducting Inference on Data (cont.)

- Problem becomes that of "reconstructing" a reasonable predictive elevation field
  - Must accurately capture factors influencing movement



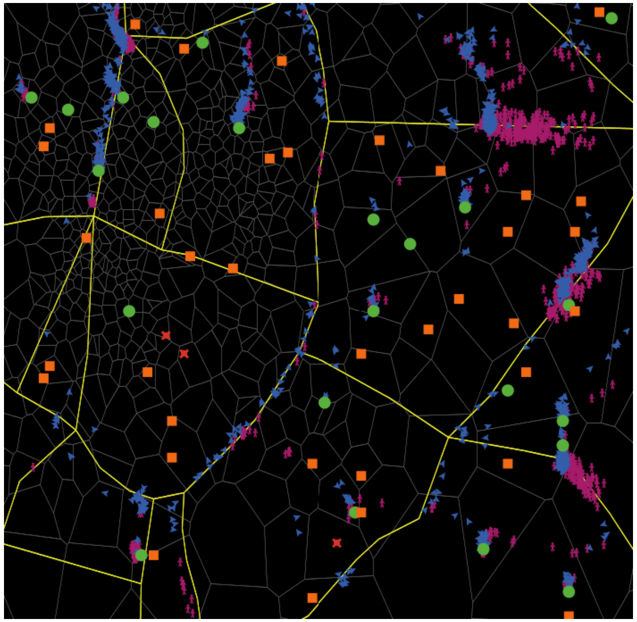


Summary of Methods

- Generate synthetic elevation field
  - Synthetic agents move on it to produce synthetic data
- Conduct inference as location data streams in
  - Generate predictive elevation field
- Predictive agents move on predictive field
  - Represent predictions of population movement
  - Example

Measuring Simulation Quality

- Manhattan distance metric (Schoenharl 2008)
  - Compare synthetic vs. predictive agents
    - p_i and q_i represent numbers of each agent type at each cell tower
- Smaller Manhattan distance = more accurate simulation

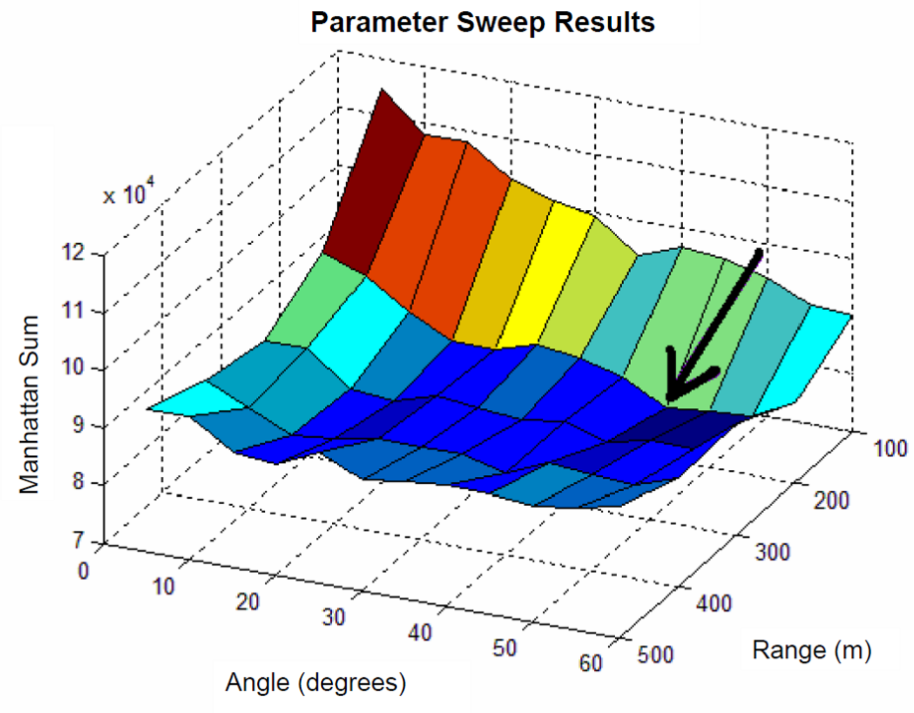


Experimental Setup and Results

- Identified optimal values for vision cone angle and range
- Multi-resolution approach
  - Coarse, then finer parameter sweeps
  - Compared predictions of all possible parameter pairs
    - Evaluated in three random scenarios

Best angle: 45°

Best range: 200m



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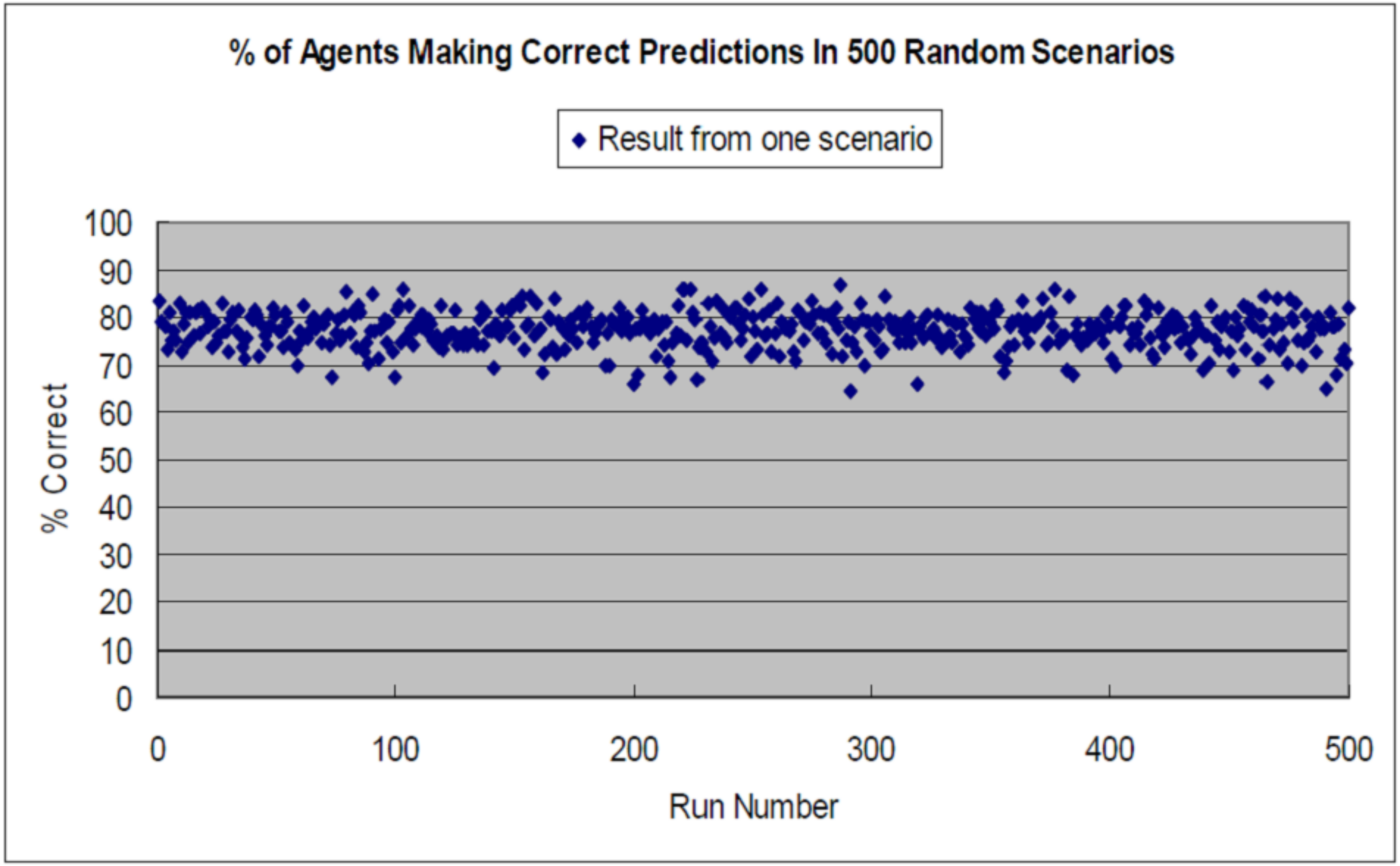
Validation

- Verifies that a model "is a reasonably accurate representation of the real world" (Xiang et al. 2005)
  - Internal Validation
    - Measures stability
  - Predictive Validation
    - Measures predictive accuracy
  - Other Validation Methods
    - Online validation is an "open research question" (Schoenharl 2007)

Internal Validation

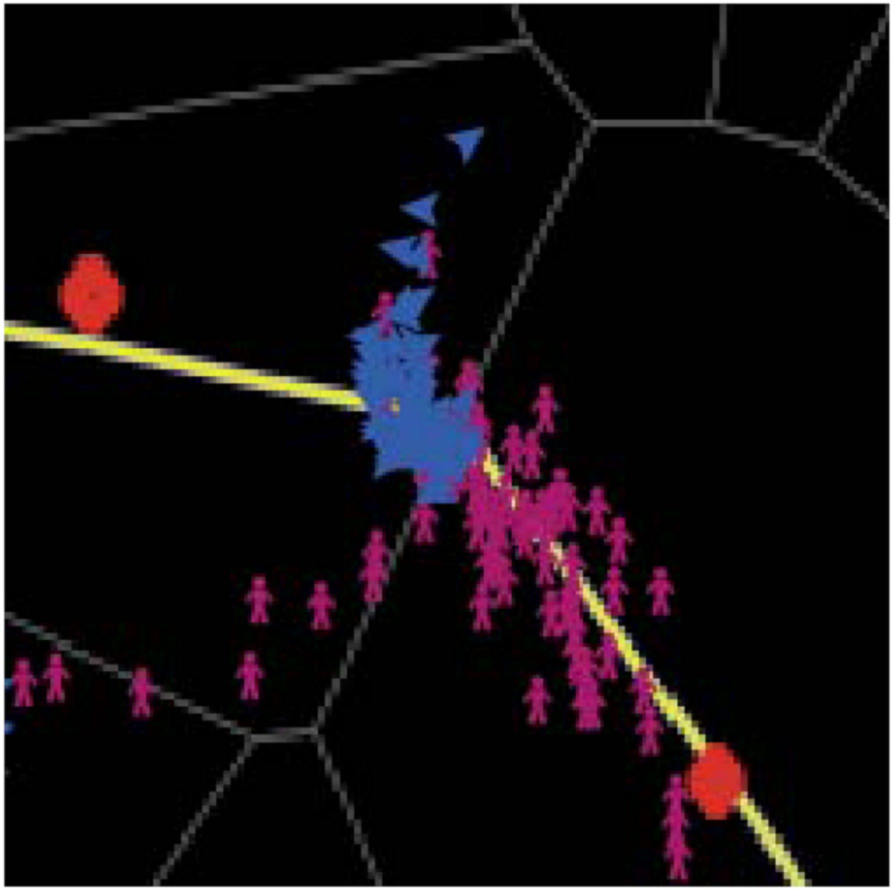
- ❑ **500 runs; measured final predictions (75 minutes in advance)**
  - ➢ **Different randomly generated scenario each time**



  - ➢ **Mean correct percentage: 77.30%; standard deviation: 3.87%**

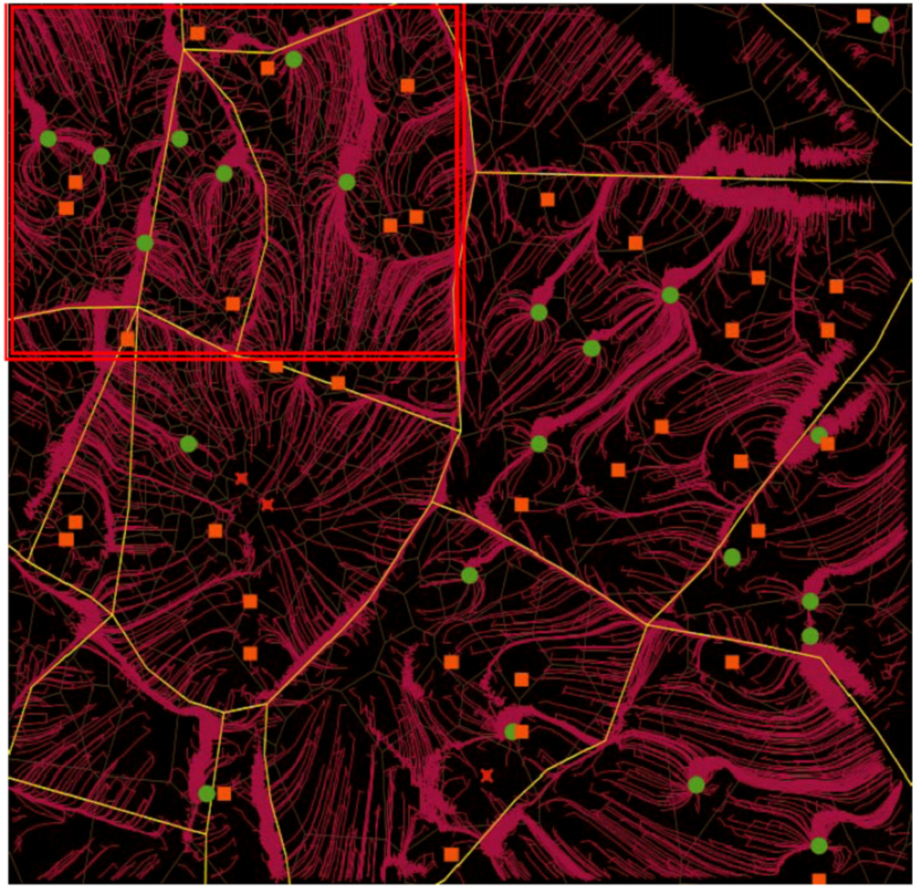
Predictive Validation

- An average of 77.30% of predictive agents made correct predictions, 75 minutes in advance
- Disadvantage of quantitative validation
  - Predictions are only correct if in the correct serving cell
- Qualitative validation is necessary

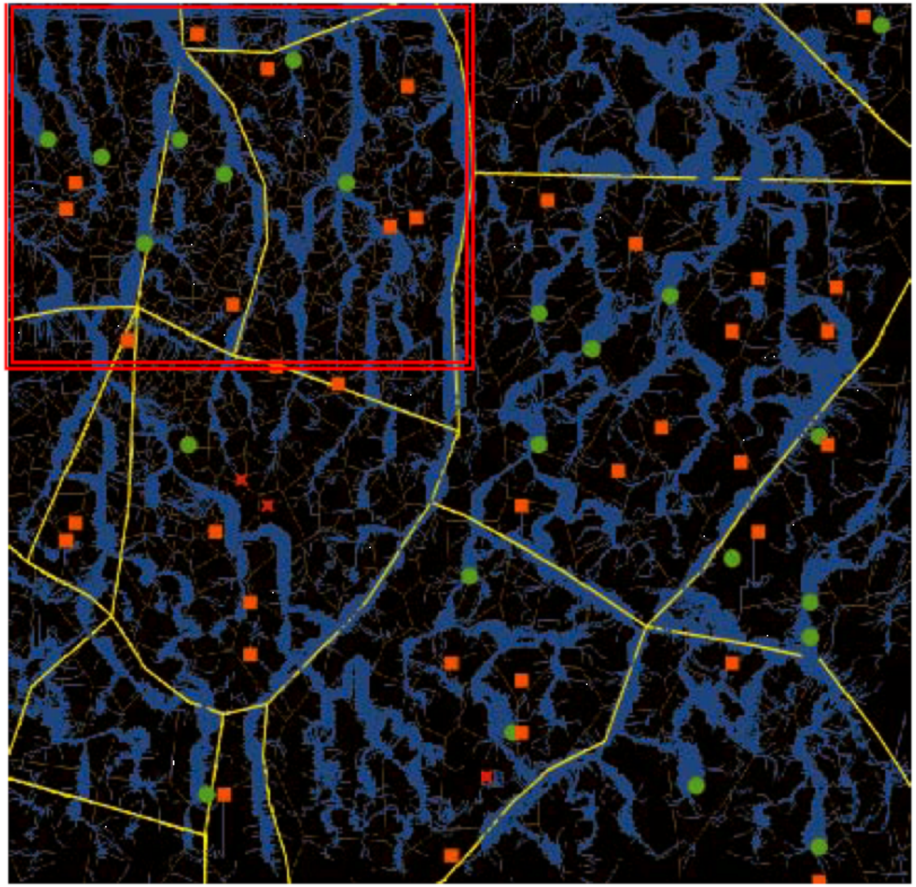


Qualitative Predictive Validation

- Compare paths taken by synthetic/predictive agents

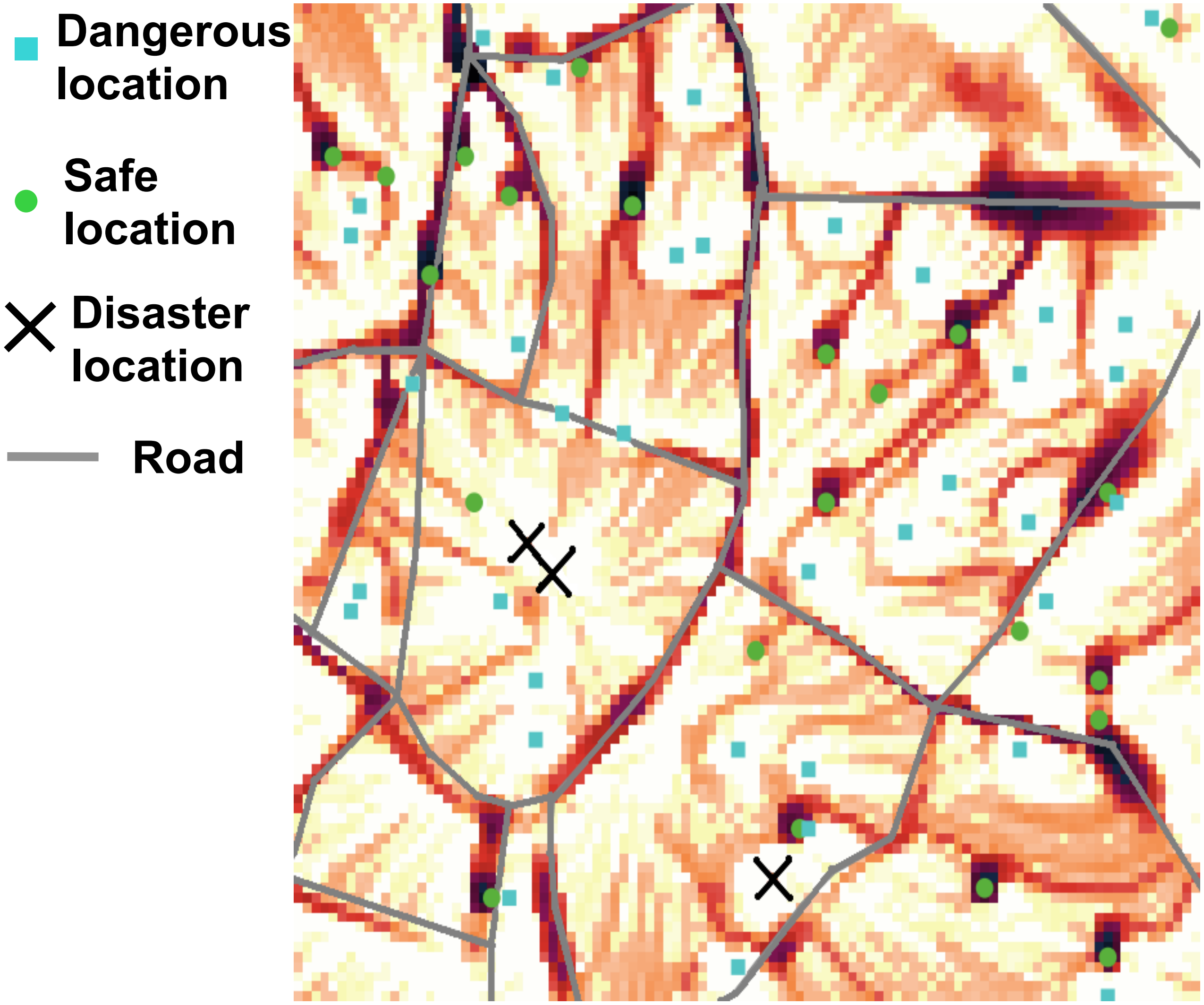


Synthetic



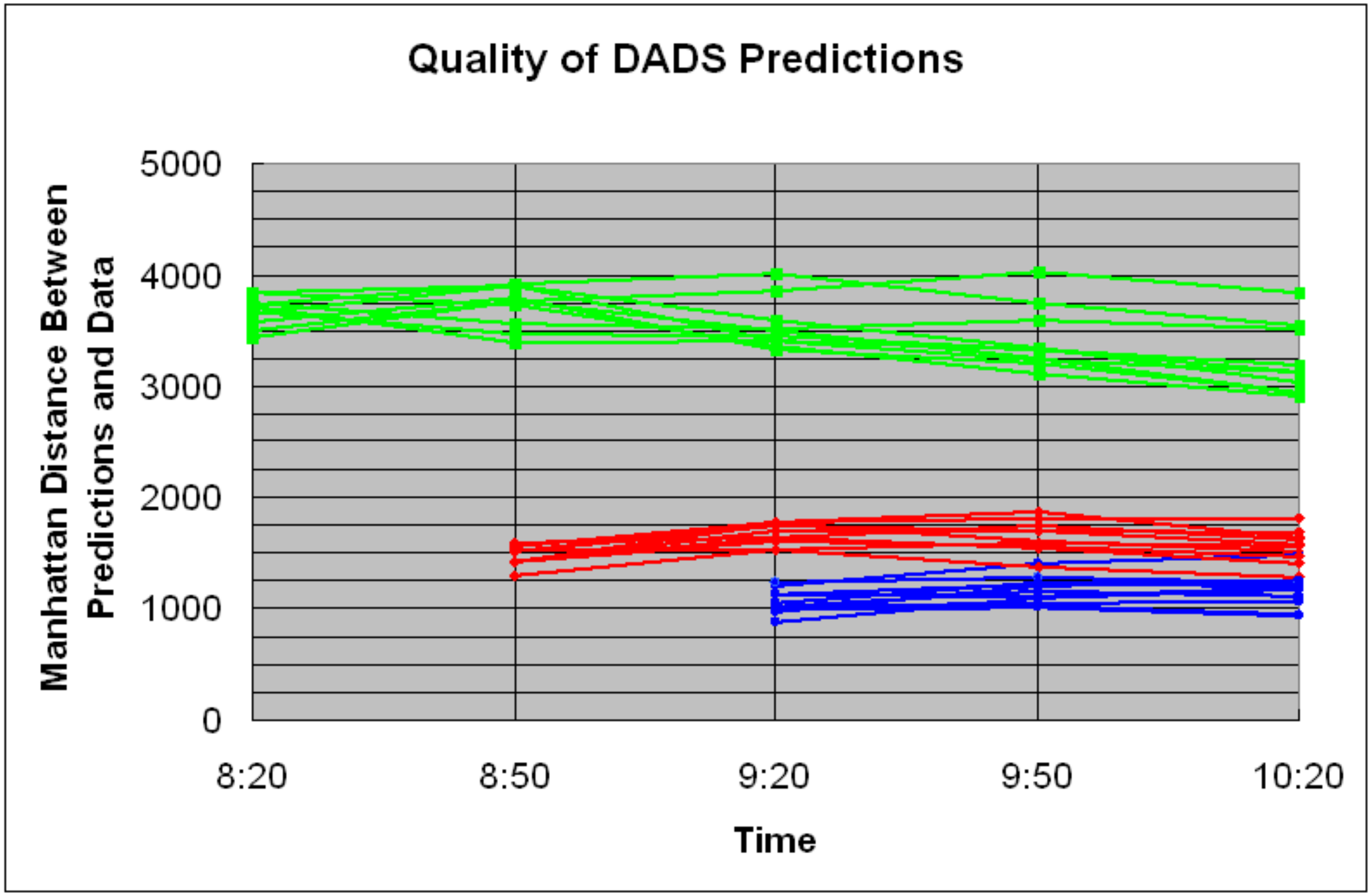
Predictive

Qualitative Predictive Validation



- Shapes of attractive and repulsive regions
  - Can indicate disaster type
    - Can use to refine simulation
    - Future Work
- Road networks
  - Usable for traffic simulations

Ability to Improve Predictions



- ❑ **Predictions of population locations at 10:20 a.m.**
  - ➢ **Green lines: at 8:05, red lines: at 8:35, blue lines: at 9:05**

- ❑ **Reflects the DDDAS concept of dynamically updating simulations**

Discussion

- Assumptions— "a model is only as good as the assumptions on which it is based"
  - Homogeneous agents
  - No crowd dynamics
  - Synthetic data
  - No restrictions on agent vision or movement

http://blog.creativecurator.com/wp-content/uploads/2010/05/cctv-fire.jpg

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Summary

- DADS uses streaming cell phone location data to simulate and predict population movement in disasters
  - Makes use of emergent intelligence
  - Can analyze historical data
    - Study tool for past disasters
  - GPS will further increase utility
- Demonstrates DDDAS
  - Adapts to specific scenarios and constantly improves
- Validated on synthetic data
  - Predictively and internally valid
  - Provides useful inferences in situations like Katrina
    - Helpful in evacuations, even if disaster disables cell service

Important Considerations

- Distinguish evacuees from responders
  - Potentially misleading data
  - Heterogeneous agents?
- Cell phones as a data source
  - Limited power supply
    - Could be problematic in the long term
  - Cell towers vulnerable
    - Earthquakes
    - Volcanic ash
  - GPS technology
  - How quickly can we draw accurate inferences?

http://www.wirelessestimator.com/t_content.cfm?pagename=Hurricane%20Ike%20telecom

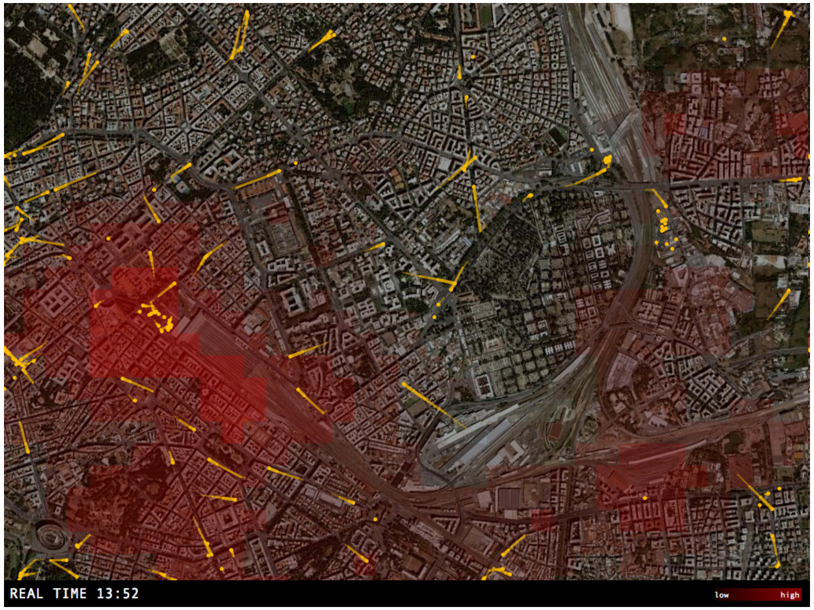
http://chicagoist.com/2006/10/25/south_loop_building_fire.php

Future Work—DADS Itself

- Test on real cell phone location data
  - Allow for adjustment of data reception
    - DDDAS concept—sensor adjustment
- Further assess modeling techniques
  - Increased realism
    - Agent heterogeneity
    - Crowd dynamics
- More sophisticated methods of parameterization
- Explore more ways to use cell phone data
  - Examine call volume, distribution, location, etc.

Future Work—Population Simulation

- Large-scale
  - Modeling citywide or global movement patterns in other situations
- Small-scale
  - Modeling individual behavior
  - Depicting movement and/or evacuation in a building
- Tool for study as well as prediction



http://thecityfix.com/files/2010/06/public_transport_rome.jpg

http://cdn.wn.com/pd/cd/97/038669f9ba7cf8fcc73da99f5699_grande.jpg

Future Work—Adaptive Simulation

http://globalvoicesonline.org/2010/08/09/china-zhouqu-landslide-a-man-made-disaster/

- Simulations designed to adapt to streaming data
- Modeling landslides in China
  - Caused by dams, mining, and deforestation
- Better sensor networks enable this sort of technology
  - DADS is an example

Ethical Concerns

- "The Tradeoff of Confidentiality and Access" (NRC 2007)
  - Must sacrifice precision for privacy
    - WIPER—aggregated by voronoi cell
  - How much precision is needed?
    - DADS appears to require precision
    - "Naïve realism"
- Possible solutions
  - Opt-out (Johnston 2010) or opt-in?
    - How many cell phones are needed?
  - Aggregation and other tactics
  - "Data enclaves" and legal or licensing systems

Thank you!

Questions?

A paper describing this research has been accepted for SpringSim/ADS 2011, and can be found at the following URL: http://www.nd.edu/~dddas/Papers/papers.html