simulation for complex urban systems

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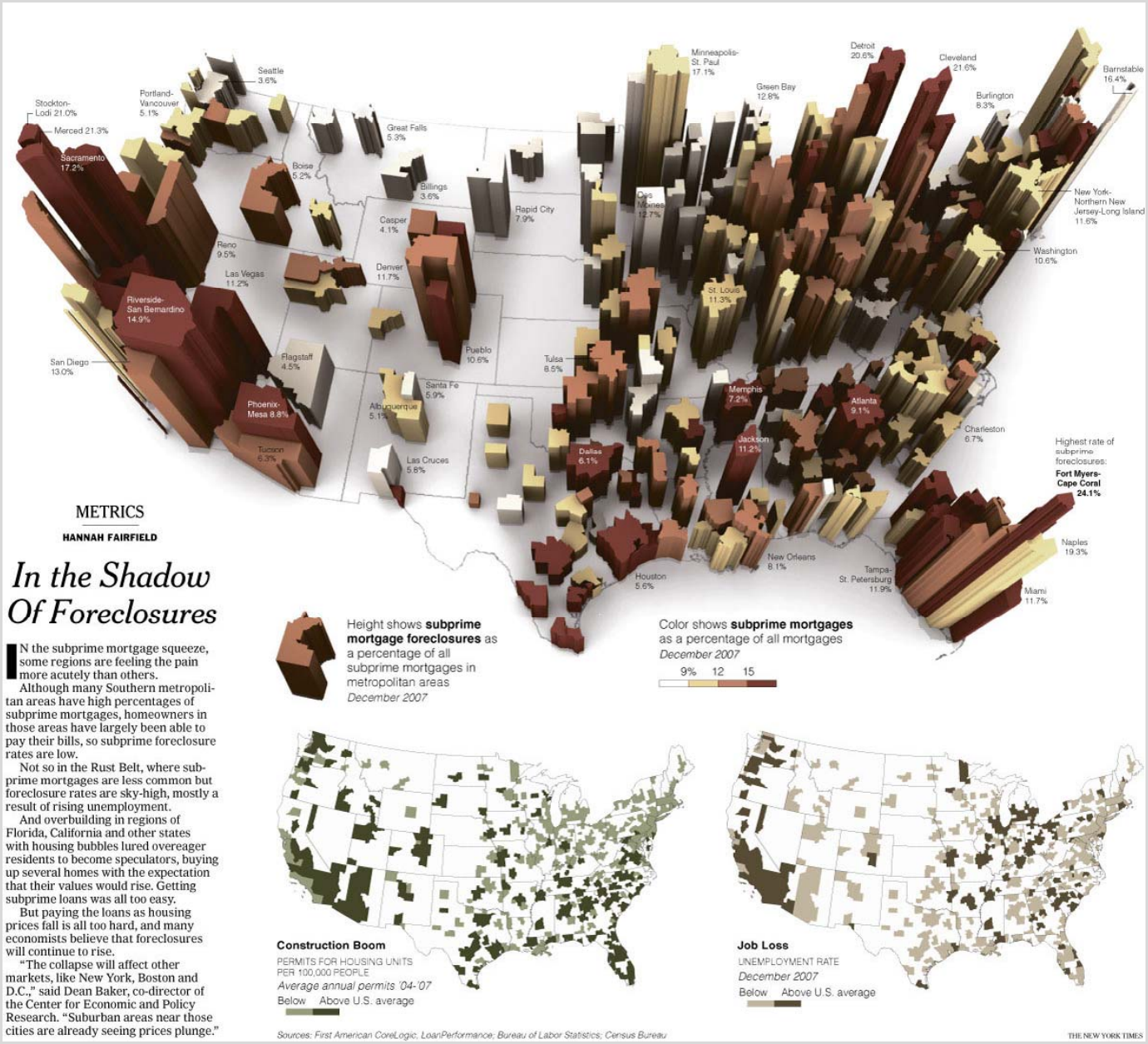
There exists a strong rationale for new approaches to modeling urban systems



"The impact of the subprime mortgage squeeze across the U.S."

Hannah Fairfield, *NY Times* (April 6, 2008)

(Some of) the grand challenges

- Representing system behavior realistically *
- Bottom-up modeling *
- New, extensible simulation methodologies *
- Uncertainty and system propagation
- Recognizing and capturing novelty
- Scaling within and across sub-systems *
- Data and dataware *
- Integrating diverse models (systems) massively
- High-performance computing

Much of the complexity and novelty that drives city systems is found at the urban microcosm

Behavioral geography underlies many urban dynamics

There may be no ground truth for prediction: we may need to build the model from theory, as a tool to think with

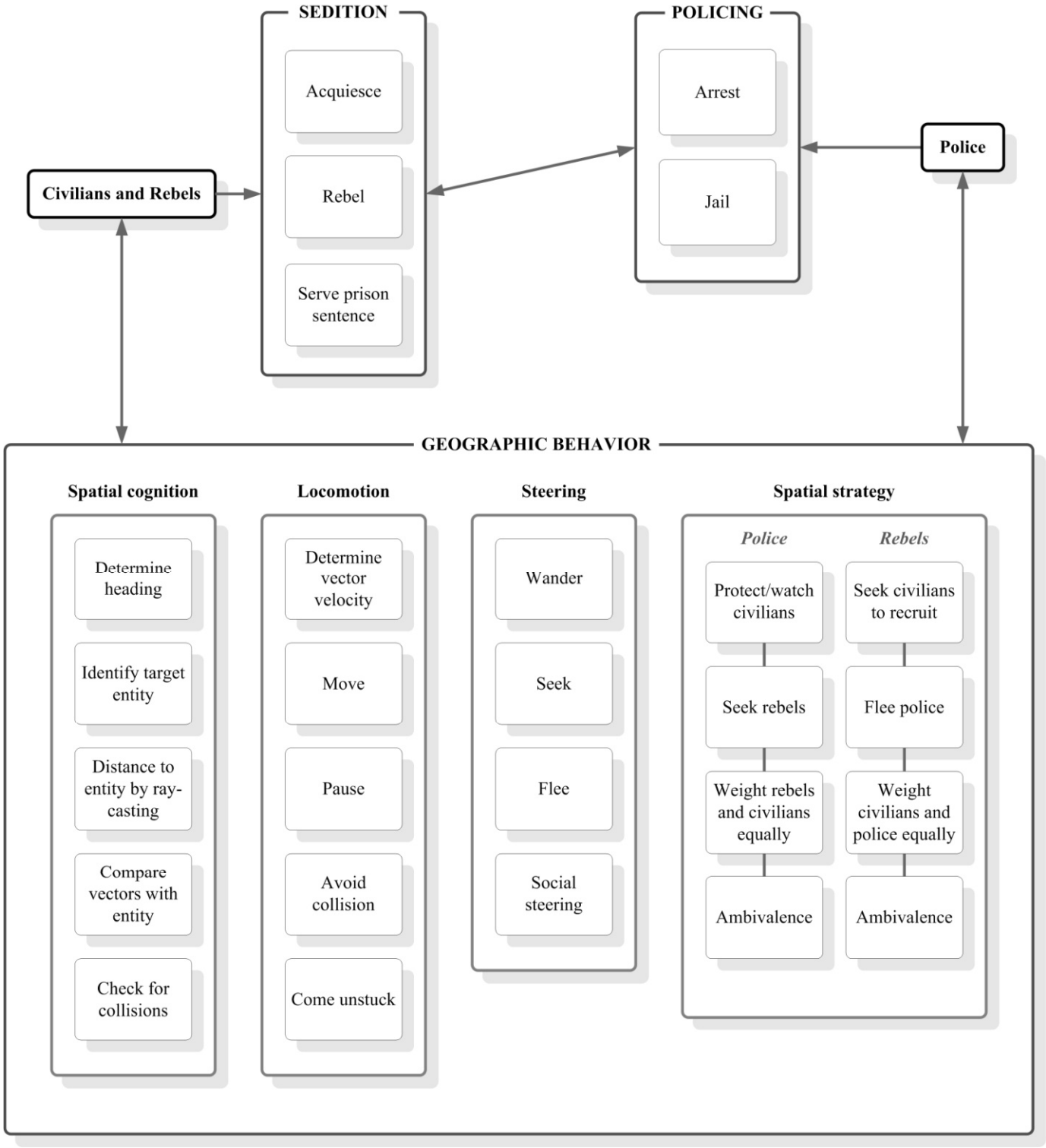
Chicago, 2006, immigration rally (Reuters)

Greece, 2008 (Reuters: John Kolesedis)

Minneapolis-St. Paul, 2008, RNC (Associated Press)

Simulating riot geography

Jailed Civilian Police Rebel



$A \sim (S, I, R_S)$, where R_S: $(S_t, I_t) \rightarrow S_{t+1}$

and where $S = \{S_t^1, S_t^2, \ldots, S_t^k\}$, $R_S = \{R_{S,t}^1, R_{S,t}^2, \ldots, R_{S,t}^k\}$, and $I = \{I_t^1, I_t^2, \ldots, I_t^k\}$

States

Rules

Inputs

Agents are modeled as finite-state automata

$$S_{socioemotional} = \{H, L, G, R, P, N\} \forall \text{ Civilian and Rebel agents,}$$

$$\text{where} \begin{cases} H = [0,1] \\ 0 \leq L \leq 1 \\ G = H(1 - L) \\ P = 1 - exp\left(-k\frac{C}{A}v\right) \\ N = RP \end{cases}$$

Agents possess inter-related socio-emotional states

$$S_{socioemotional} = \{H, L, G, R, P, N\} \forall \text{ Civilian and Rebel agents,}$$

where

$$H = [0,1]$$

$$0 \leq L \leq 1$$

$$G = H(1 - L)$$

$$P = 1 - exp\left(-k\frac{C}{A}v\right)$$

$$N = RP$$

Hardship

Legitmacy

Outward grievance

Number of nearby police

Likelihood of arrest

Number of nearby rebels

Cost of acting-out

Risk aversion

Agents possess inter-related socio-emotional states

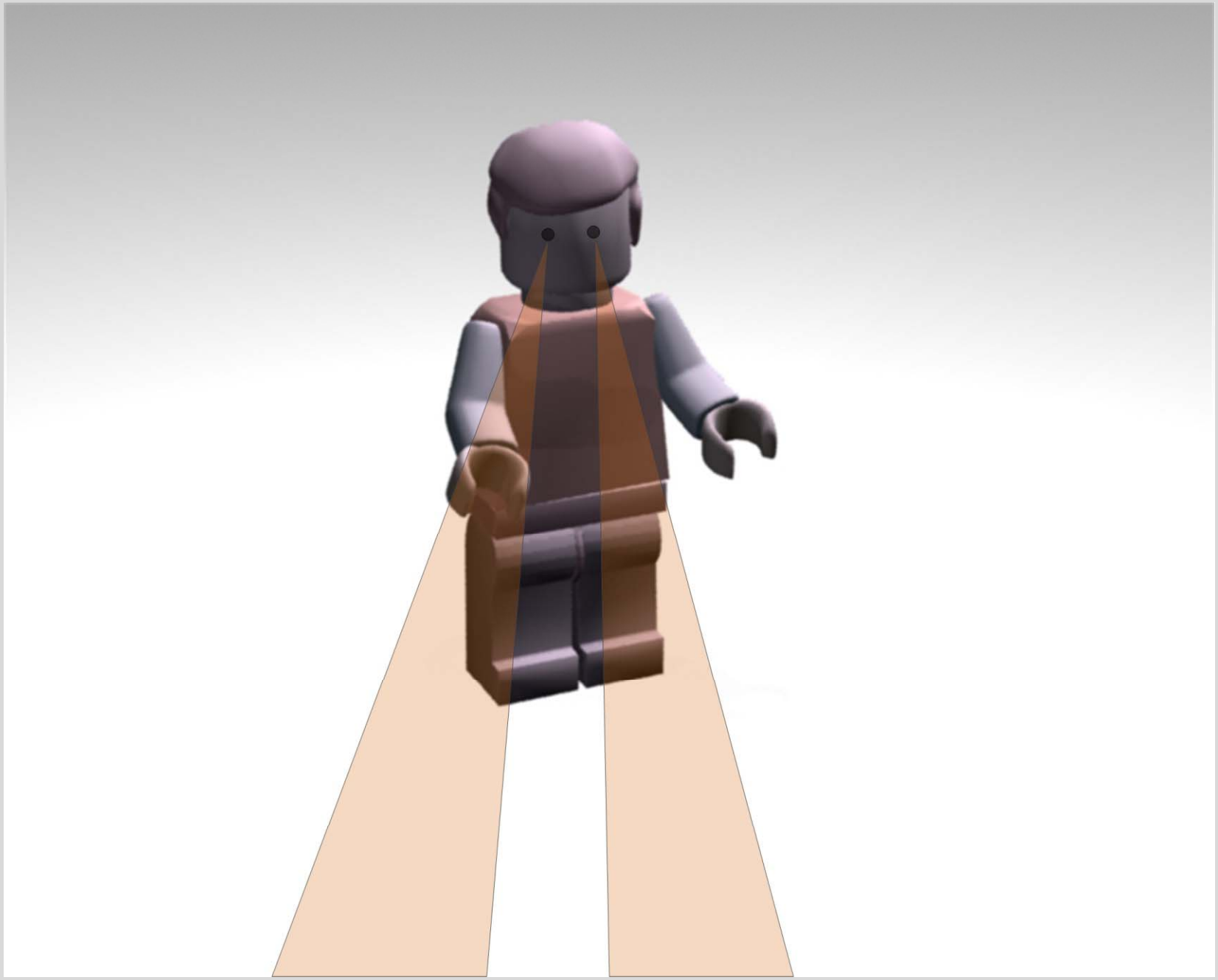
$$\boldsymbol{A} = \begin{cases} Civilian_t \rightarrow Rebel_{t+1} \; if \; its \; [H(1-L) - RP] > T \\ Civilian_t \rightarrow Civlian_{t+1} \; otherwise \end{cases} \quad (T = 0.1)$$

Civilian agents rebel if subjected to hardship and if they have safety in numbers

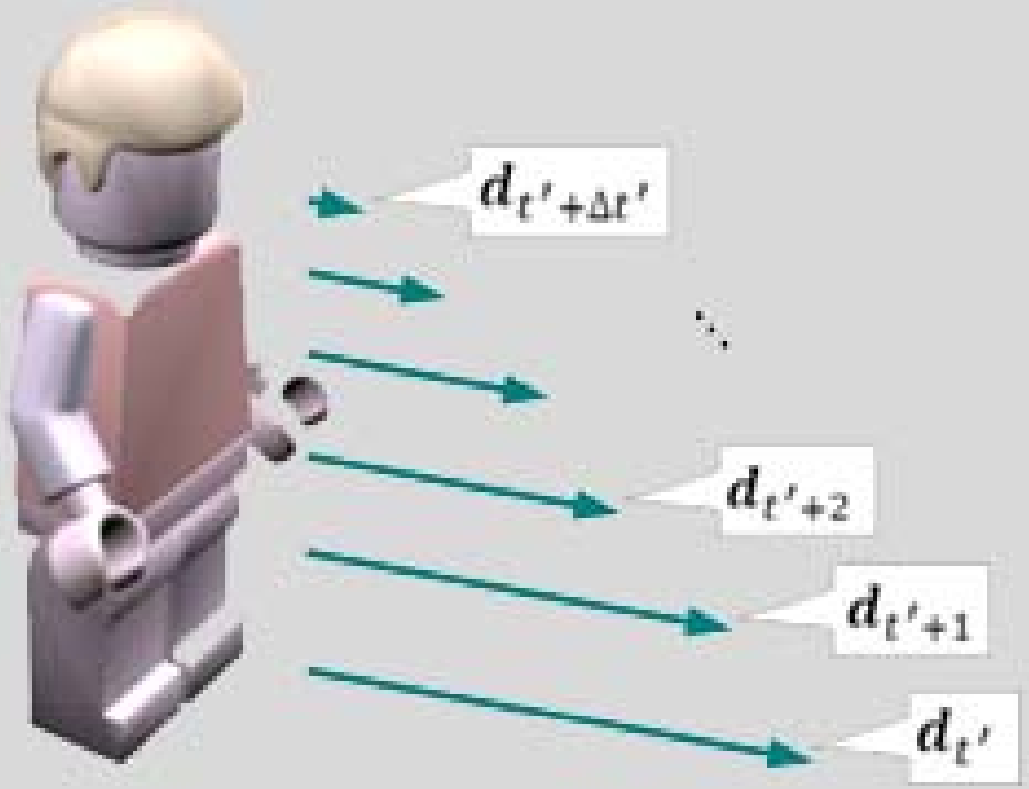
$$C = \begin{cases} Rebel_t \rightarrow Jailed_{t \rightarrow j_{max}} \; if \; Rebel_t \in V_t and \; is \; selected \\ Rebel_t \rightarrow Rebel_{t+1} \; otherwise \end{cases}$$

Rebel agents are jailed if caught by police; otherwise, they rebel++

Agents are then wrapped in a geographic exoskeleton

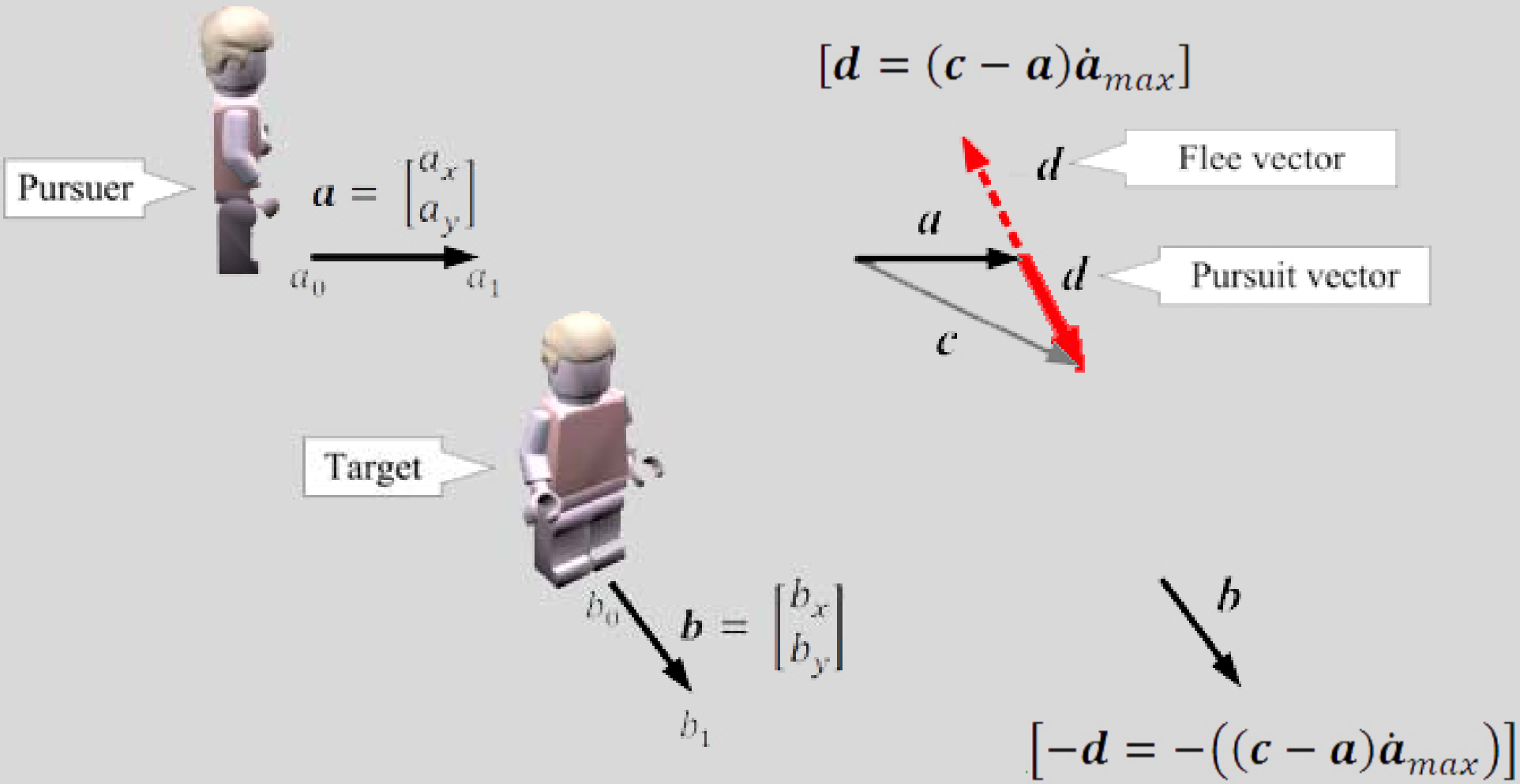


Watch out: they can fry you with their laser-beams

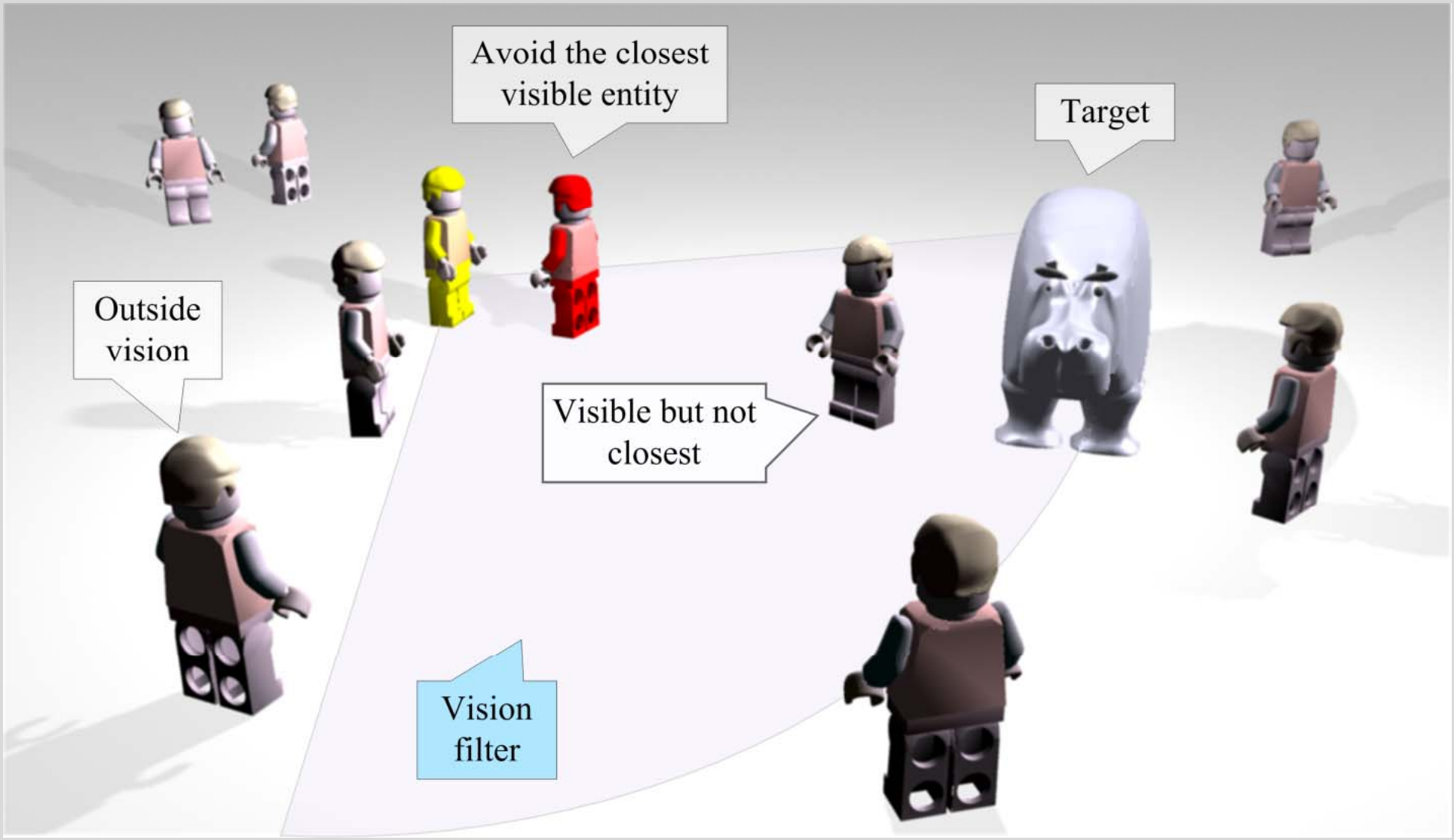


$$\boldsymbol{ray}\begin{cases} collision = true\ if\ \boldsymbol{d}_{t'\rightarrow\Delta t'} \cap (any\ other\ [relevant]\ object) \\ collision = false\ otherwise \end{cases}$$

Synthetic vision and depth perception is handled by ray-tracing



Physical steering (e.g., for pursuit and evasion)



Collision avoidance

$$\lambda = \frac{-W_{Police}}{W_{Civilian}}, \text{ given } (-W_{Police} + W_{Civilian} = 1) \text{ for Rebel agents}$$

$$\mu = \frac{W_{Rebel}}{W_{Civilian}}, \text{ given } (W_{Rebel} + W_{Civilian} = 1) \text{ for Police agents}$$

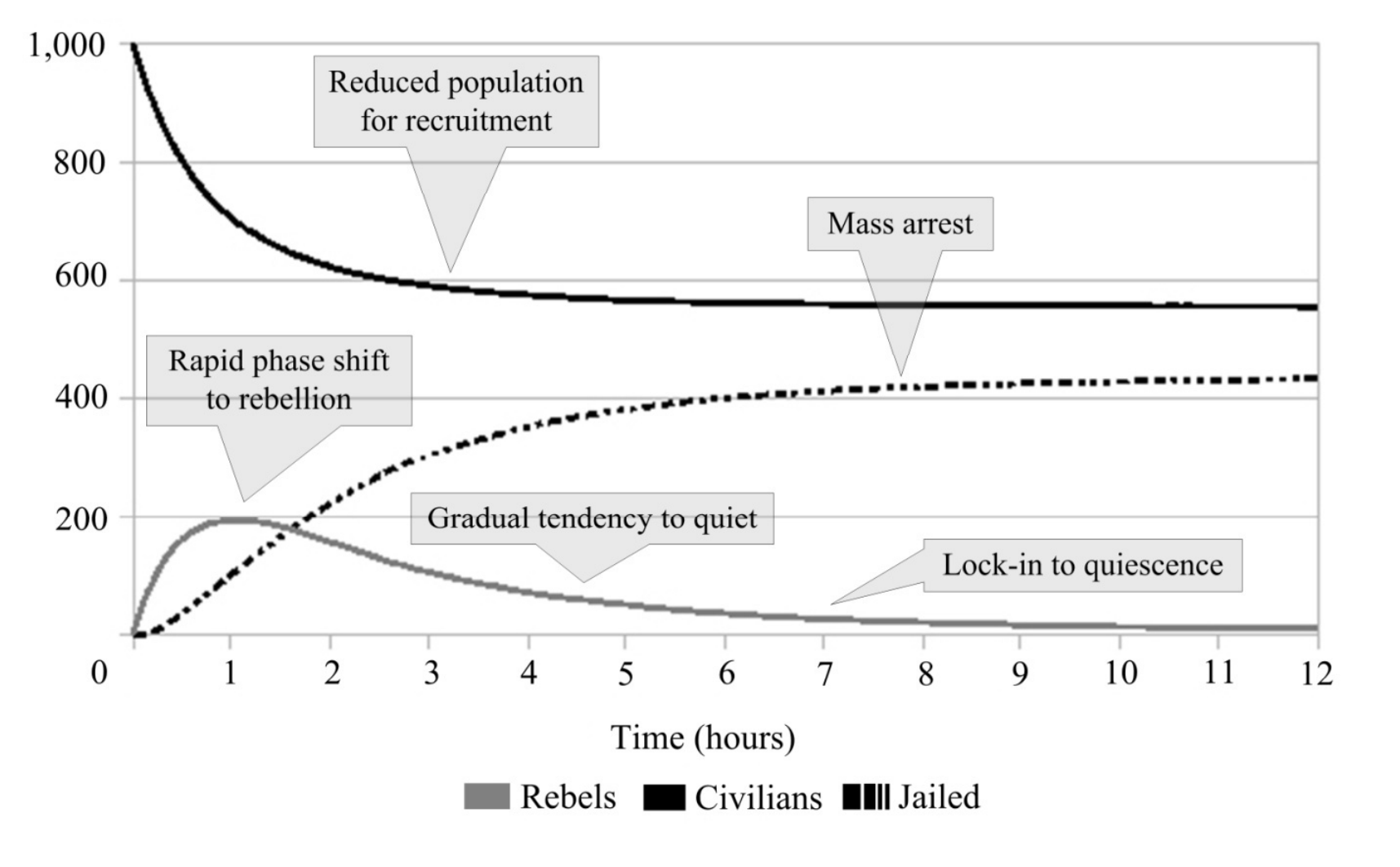
e.g., a rebel may avoid the police by: $|\boldsymbol{d}| = \left(\hat{\boldsymbol{d}} + (-W_{Police})\right)$

"Social" steering based on preferences and aversions

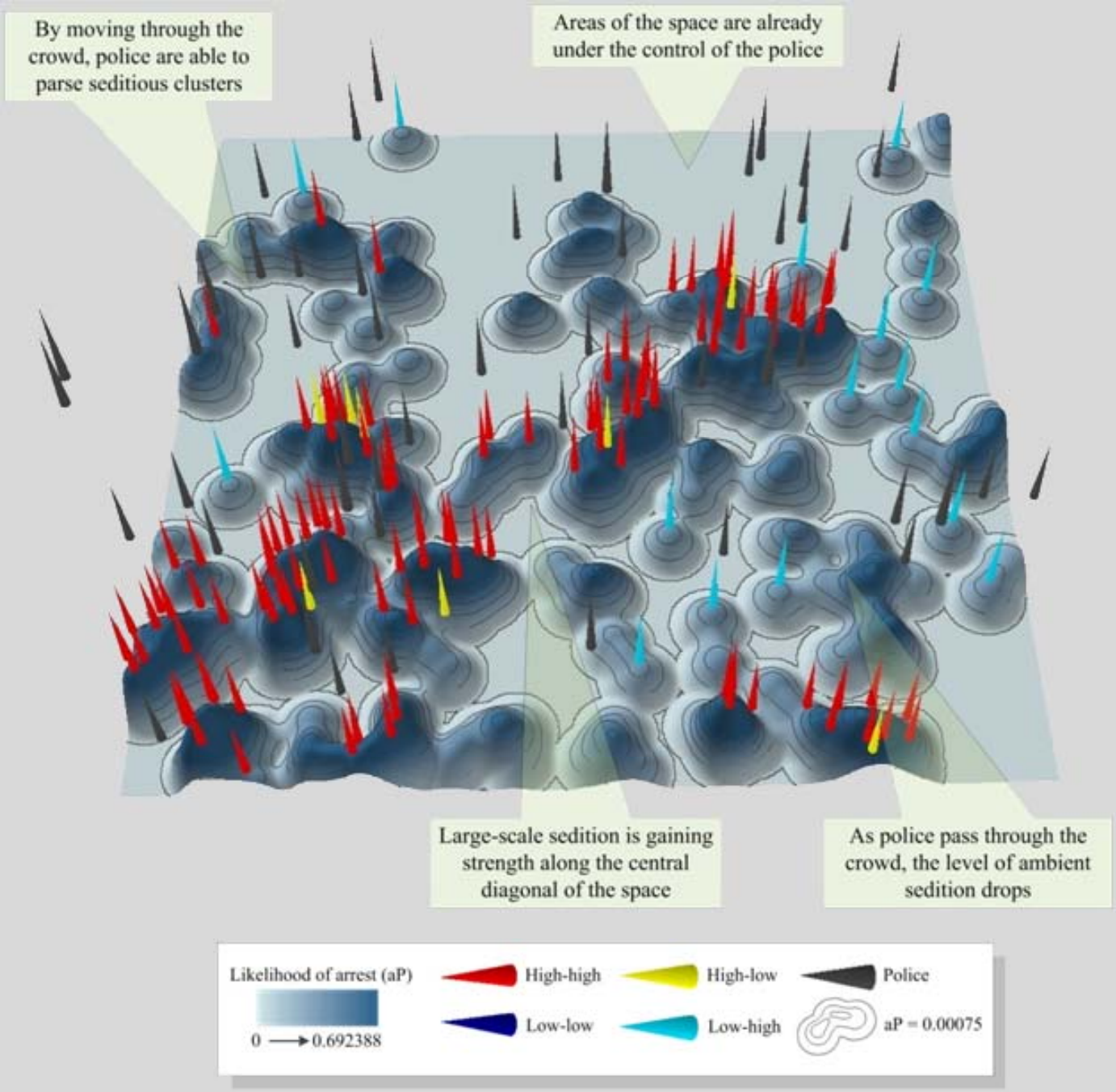
Table 1. Varying parameterization of the model to produce different simulation scenarios.						
Variable ↓	**Simulation scenario**					
	Base	*Built environment*	*Riot police*	*Mass protest*	*Angry mob*	*Show of force*
Simulation run-time	12 hrs.	12 hrs.	12 hrs.	12 hrs.	12 hrs.	12 hrs.
Legitimacy	0.82	0.82	0.82	0.82	0.25	0.82
Max jail term	24 hrs.	24 hrs.	24 hrs.	24 hrs.	24 hrs.	0 hrs.
Civilian and Rebel Vision (meters)	7	7	7	7	7	7
Police vision (meters)	7	7	7	7	7	7
Number of Police	50	15	200	50	50	50
Number of citizen agents	1,000	285	1,000	5,000	1,000	1,000
Rebel W_{Police}	–0.5	–0.5	–0.5	–0.5	–0.1	–0.5
Rebel $W_{Civilian}$	0.5	0.5	0.5	0.5	0.9	0.5
Rebel λ	0.5	0.5	0.5	0.5	0.11	0.5
Police W_{Rebel}	0.5	0.5	0.5	0.5	0.5	0.5
Police $W_{Civilian}$	0.5	0.5	0.5	0.5	0.5	0.5
Police μ	1	1	1	1	1	1
Arrest distance (meters)	2	2	2	2	2	2
Is jail a deterrent?	Yes	Yes	Yes	Yes	Yes	No
Agent field of vision	120°	120°	120°	120°	120°	120°
Patch length per agent step (meters)	0.25	0.25	0.25	0.25	0.25	0.25
Distance buffer (meters)	0.5	1.25	1.25	1.25	1.25	1.25
Infrastructure obstacles?	No	Yes	No	No	No	No

Table 2. Varying parameterization of the model to produce varying behavioral strategies for agents in simulation.

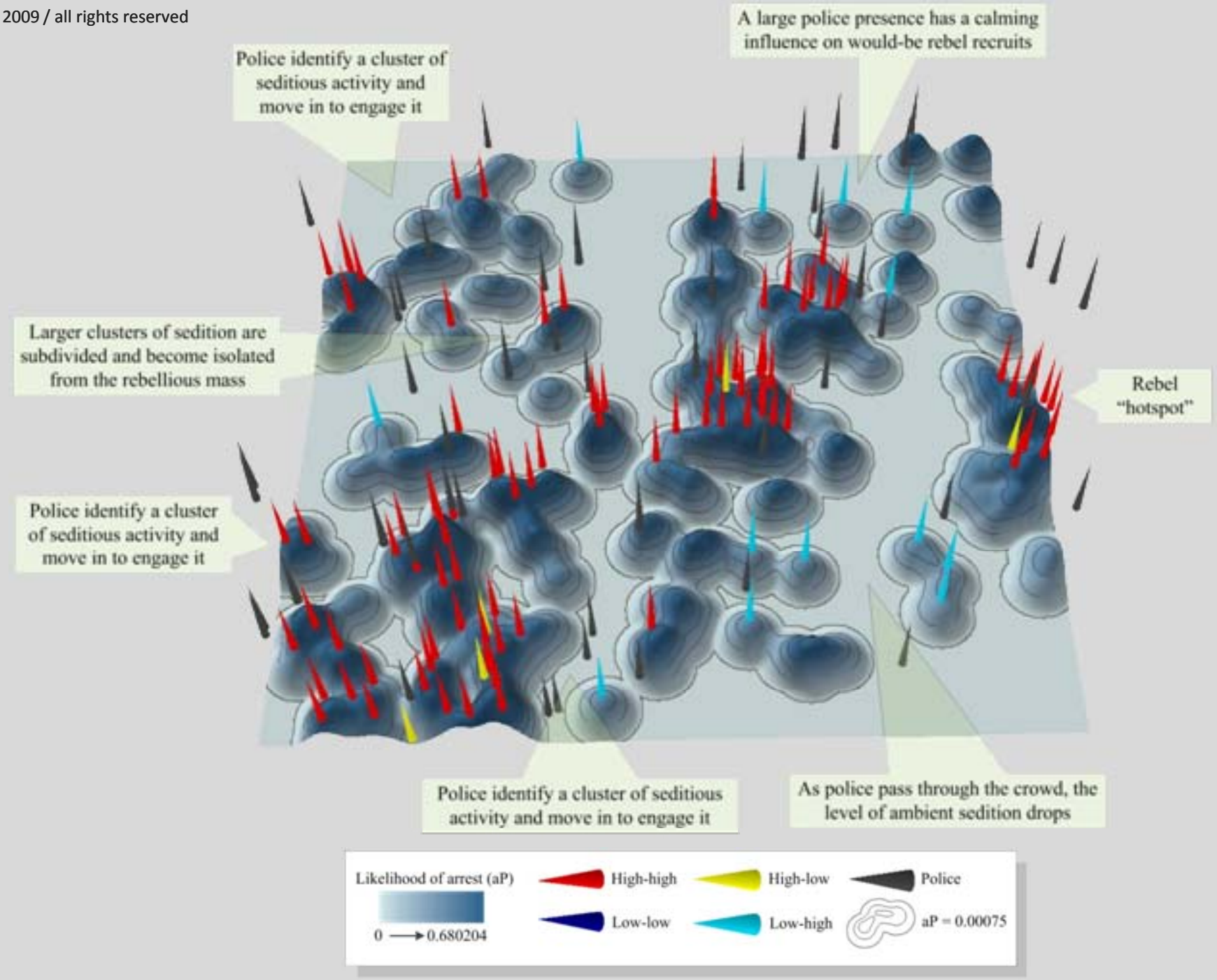
Variable ↓	**Strategies**						
	Equal treatment	*Police pursue rebels*	*Police protect civilians*	*Rebels recruit civilians*	*Rebels avoid police*	*Battle for civilians*	*Cat and mouse*
Simulation run-time	12 hrs.	12 hrs.	12 hrs.	12 hrs.	12 hrs.	12 hrs.	12 hrs.
Legitimacy	0.82	0.82	0.82	0.82	0.82	0.82	0.82
Max jail term	24 hrs.	24 hrs.	24 hrs.	24 hrs.	24 hrs.	24 hrs.	24 hrs.
Civilian and Rebel Vision (meters)	7	7	7	7	7	7	7
Police vision (cells/meters)	7	7	7	7	7	7	7
Number of Police	50	50	50	50	50	50	50
Number of citizen agents	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Rebel W_{Police}	–0.5	–0.5	–0.5	–0.3	–0.7	–0.3	–0.7
Rebel $W_{Civilain}$	0.5	0.5	0.5	0.7	0.3	0.7	0.3
Rebel λ	1	1	1	0.43	2.33	0.43	2.33
Police W_{Rebel}	0.5	0.7	0.3	0.5	0.5	0.3	0.7
Police $W_{Civilian}$	0.5	0.3	0.7	0.5	0.5	0.7	0.3
Police μ	1	2.33	0.43	1	1	0.43	2.33
Arrest distance (meters)	2	2	2	2	2	2	2
Is jail a deterrent?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Agent field of vision	120°	120°	120°	120°	120°	120°	120°
Patch length per agent step (meters)	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Distance buffer (meters)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Infrastructure obstacles?	No	No	No	No	No	No	No



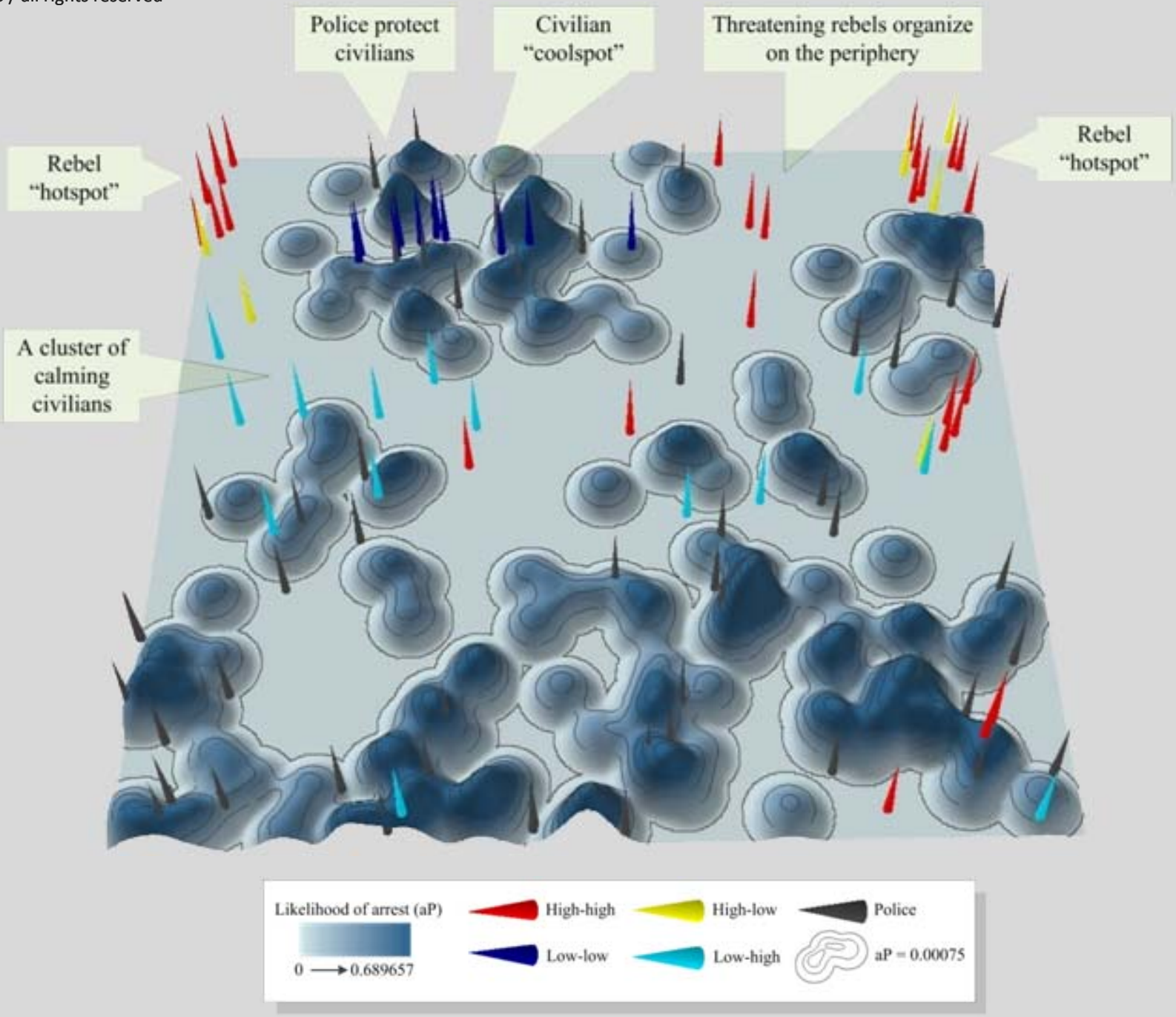
Base scenario: rapid rise to rebellion; mass arrest needed to contain rioting



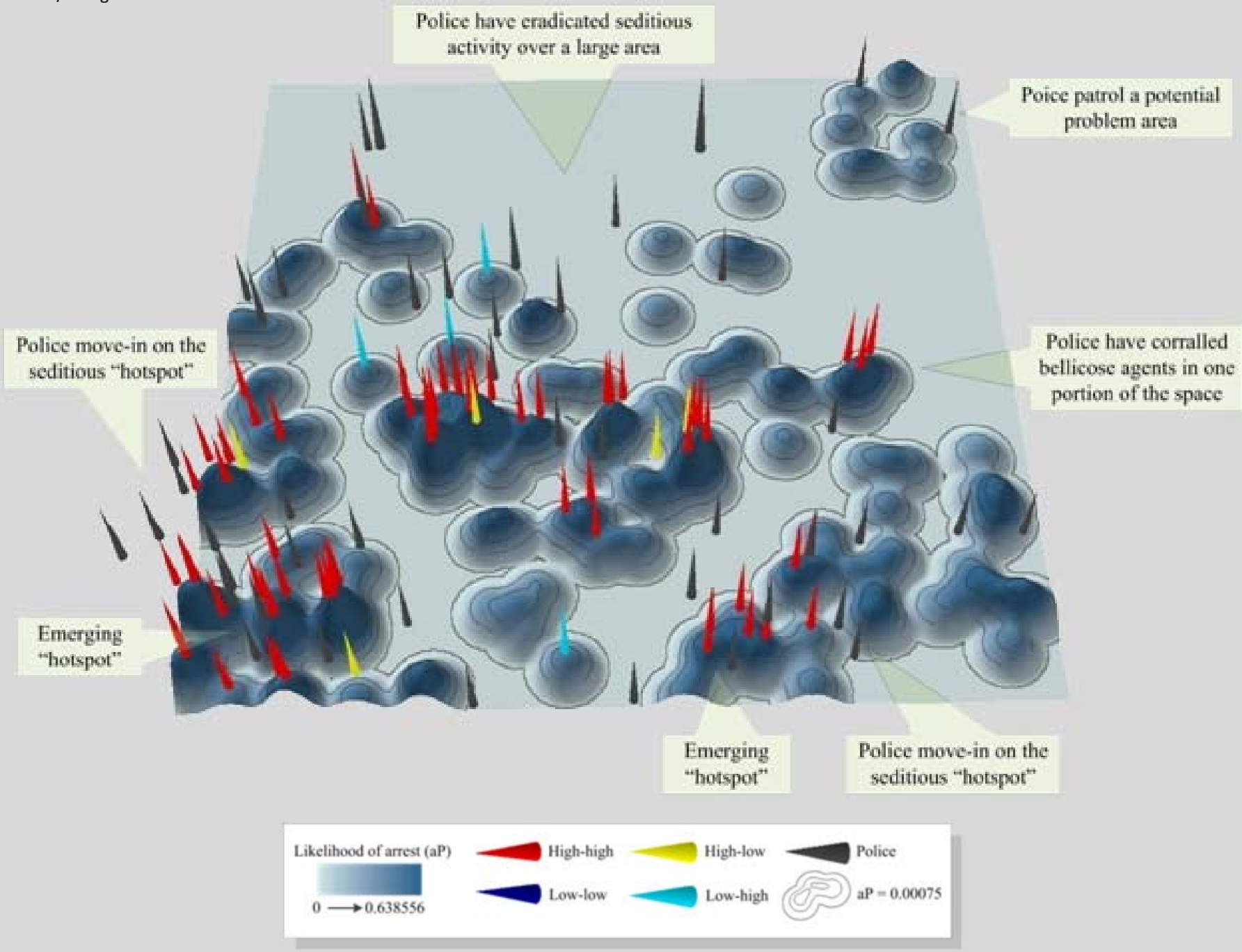
Hour 1: hotspot clusters of rioting form; the police move to address them



Hour 2: police begin to dissolve the clusters

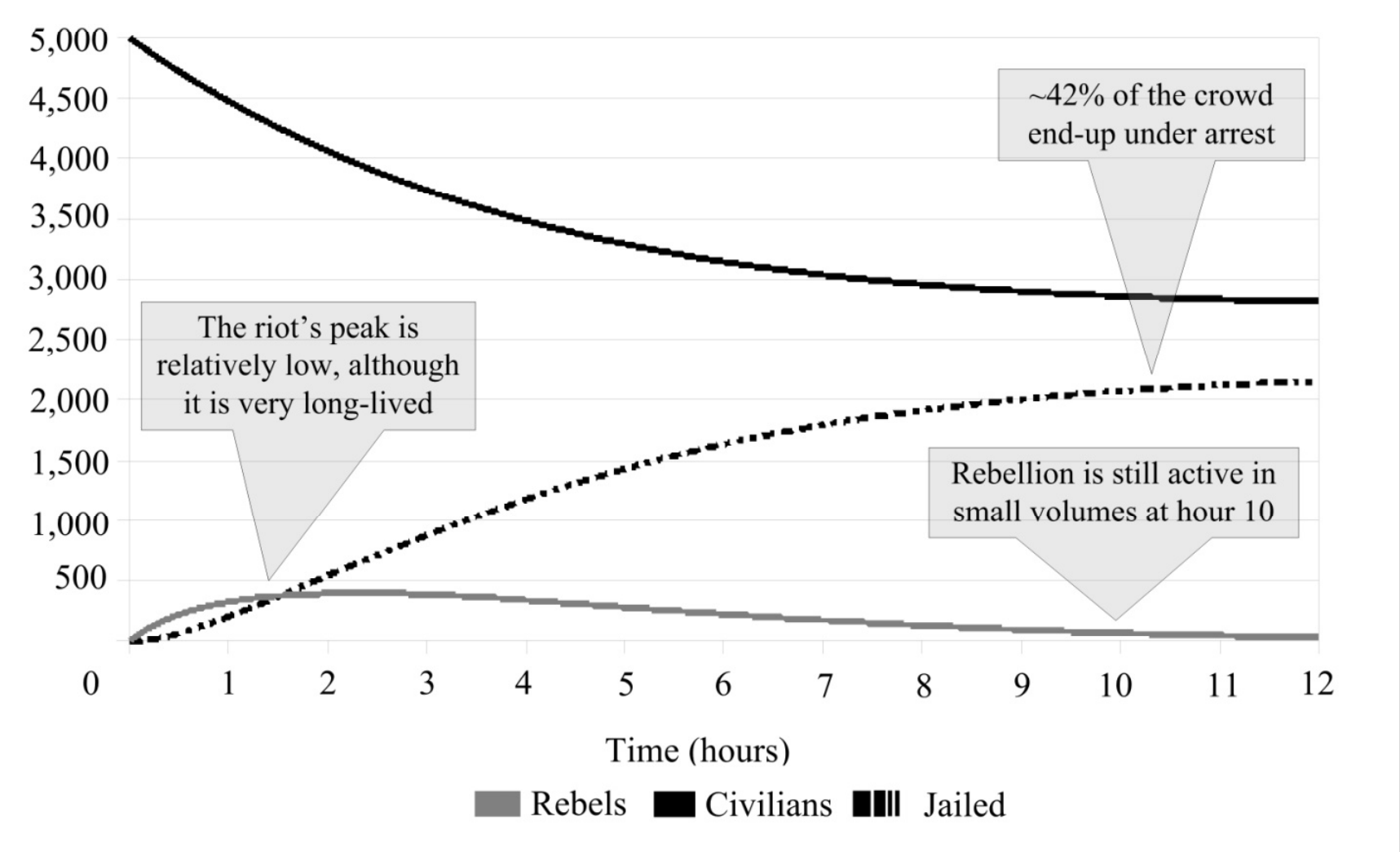


Hour 4: enveloped by police, quiescent coolspots begin to emerge

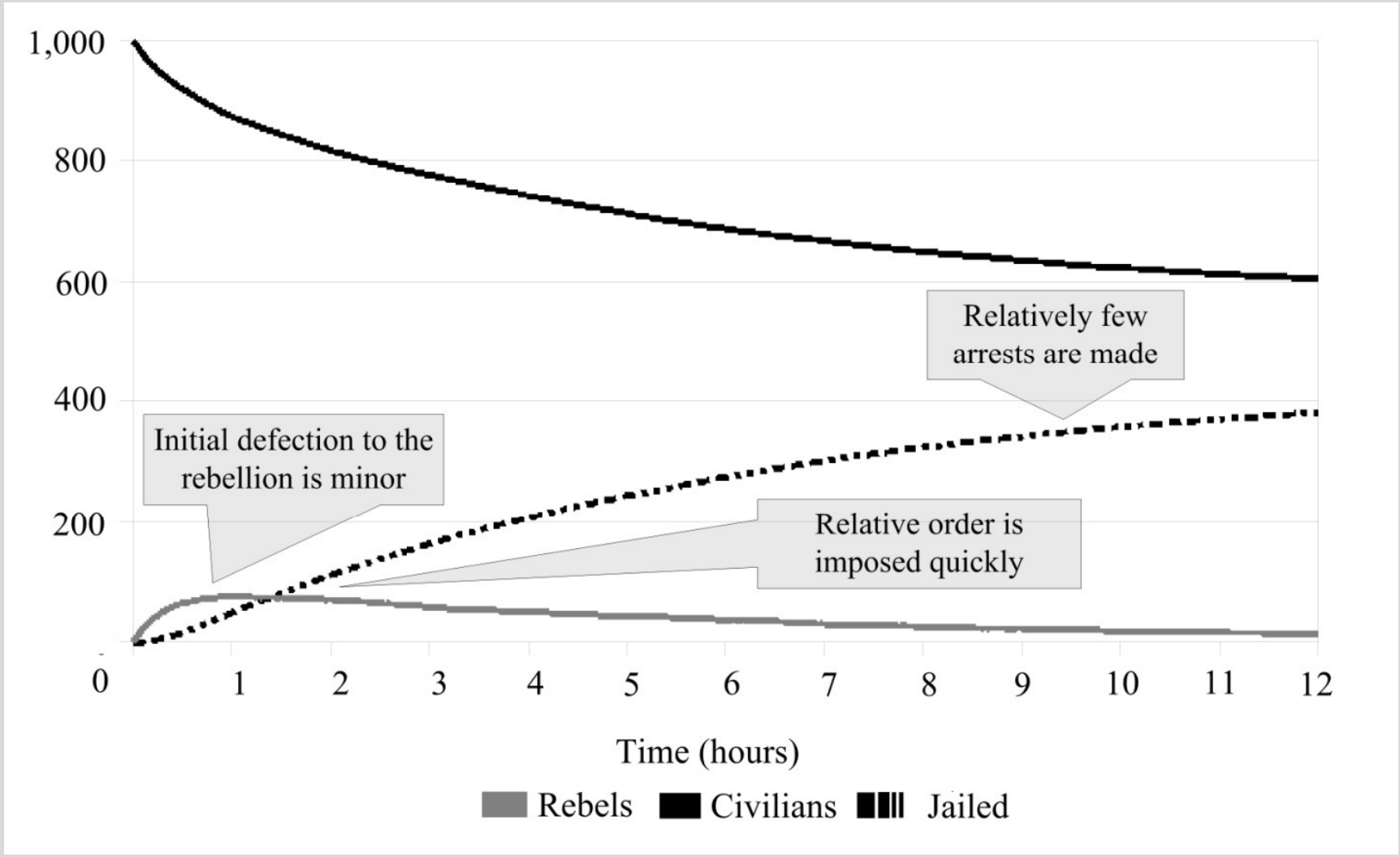


Hour 11: ~75% of the space is cleared of rioting, although hotspots remain

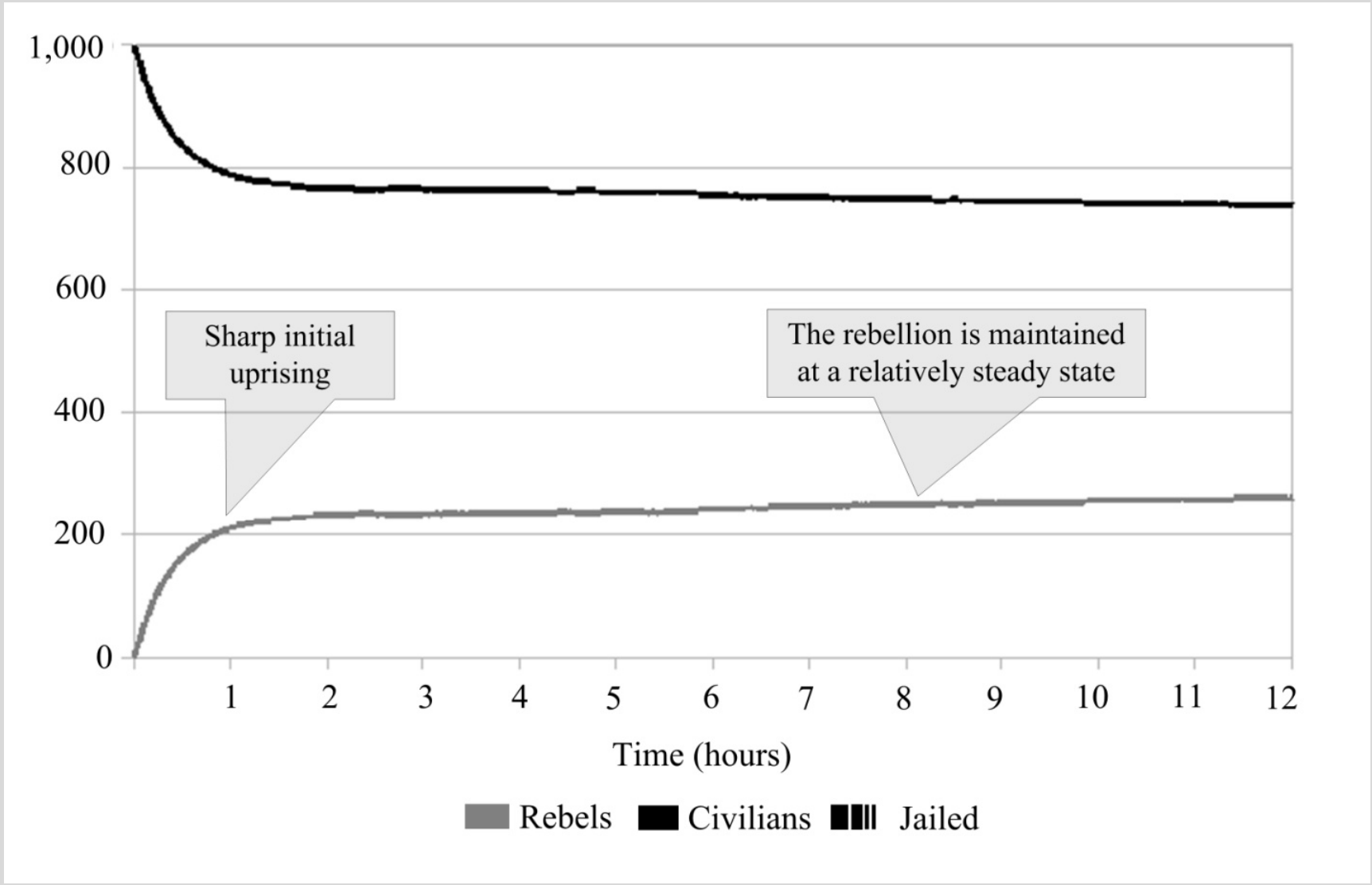
Uh-oh



The "Mass protest" scenario: ambient quiescence dampens sedition



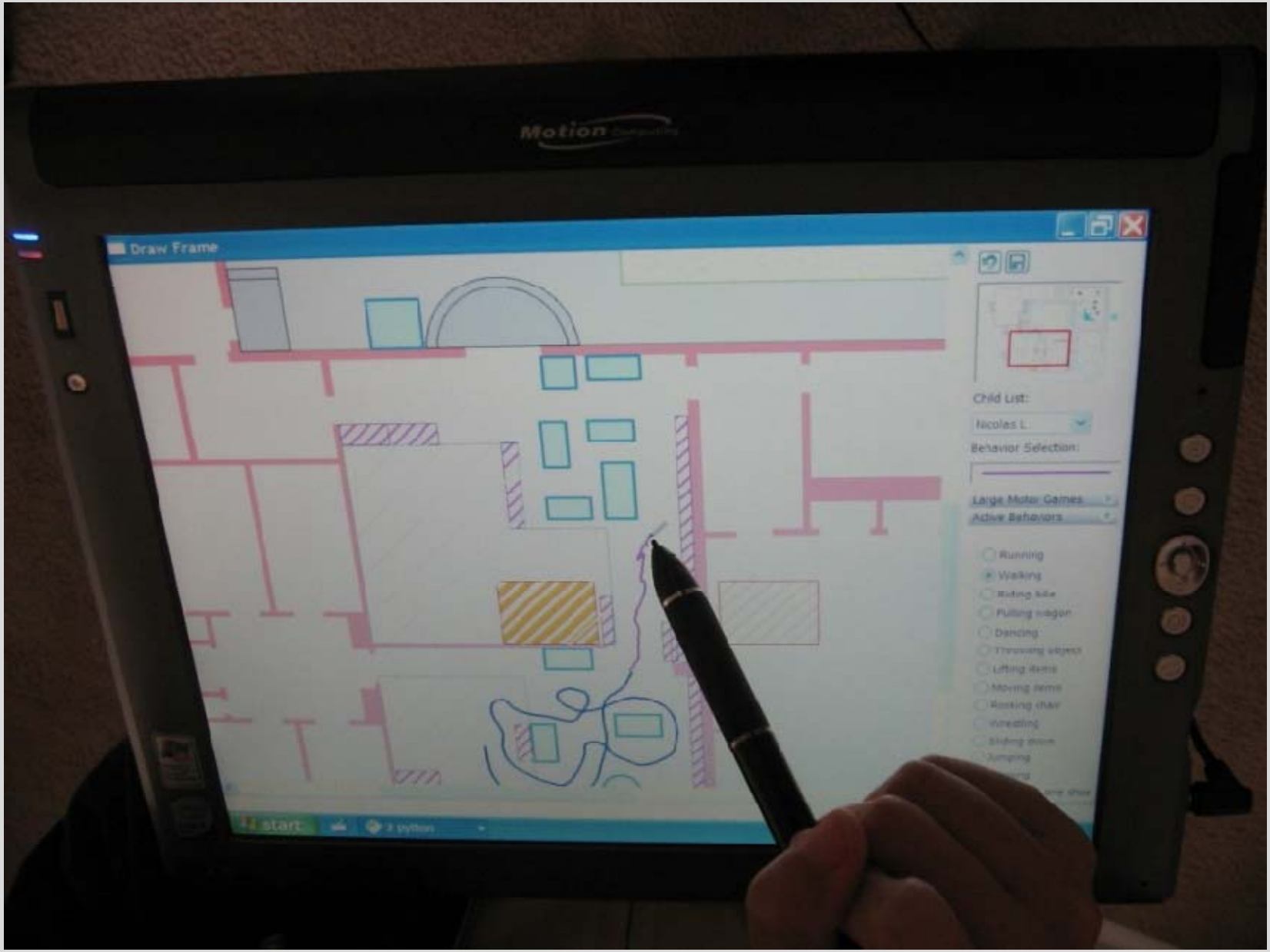
“Riot police” scenario

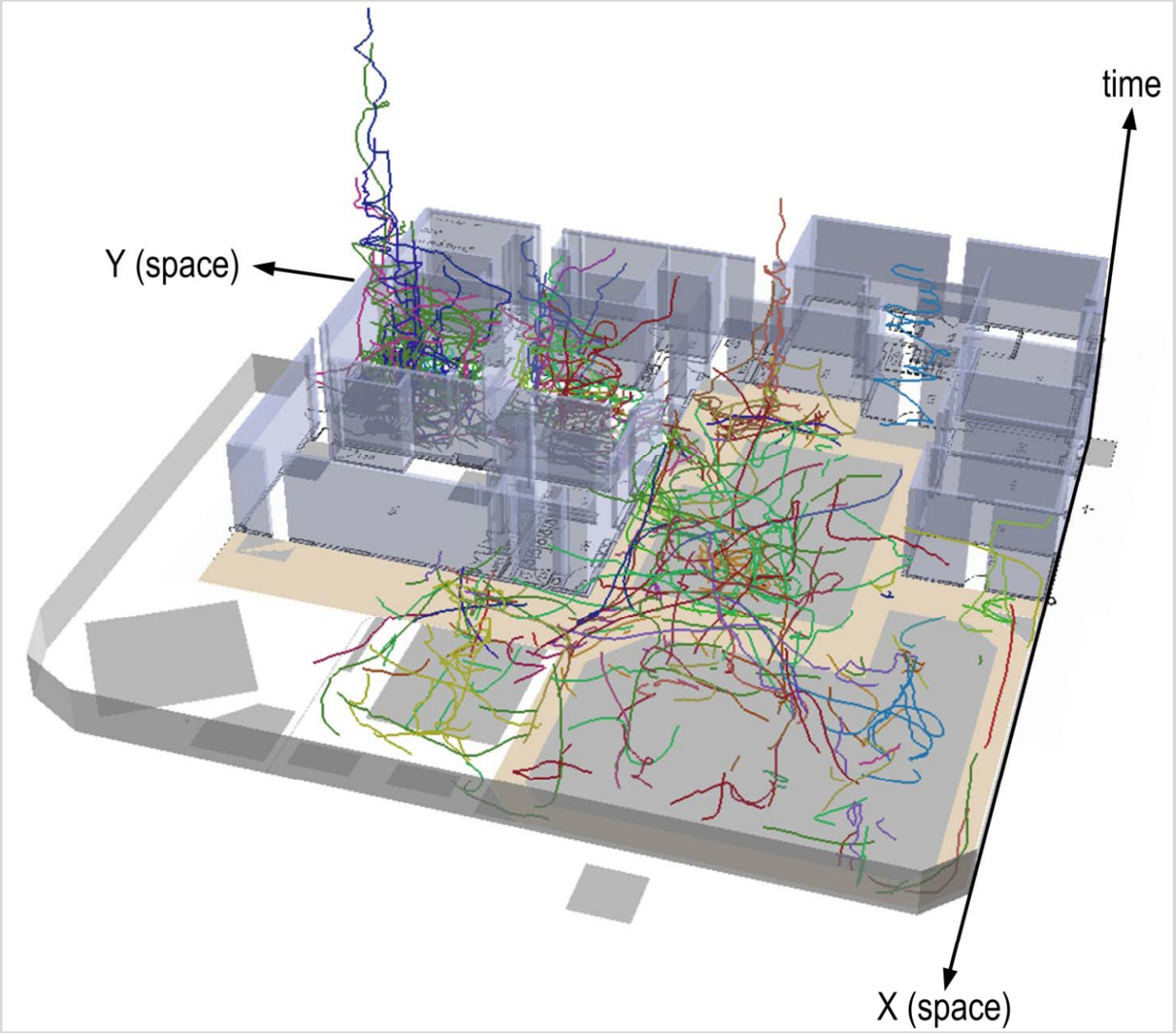


From a police perspective: the “non-engagement” scenario

We may lack sufficient theory upon which to build a model

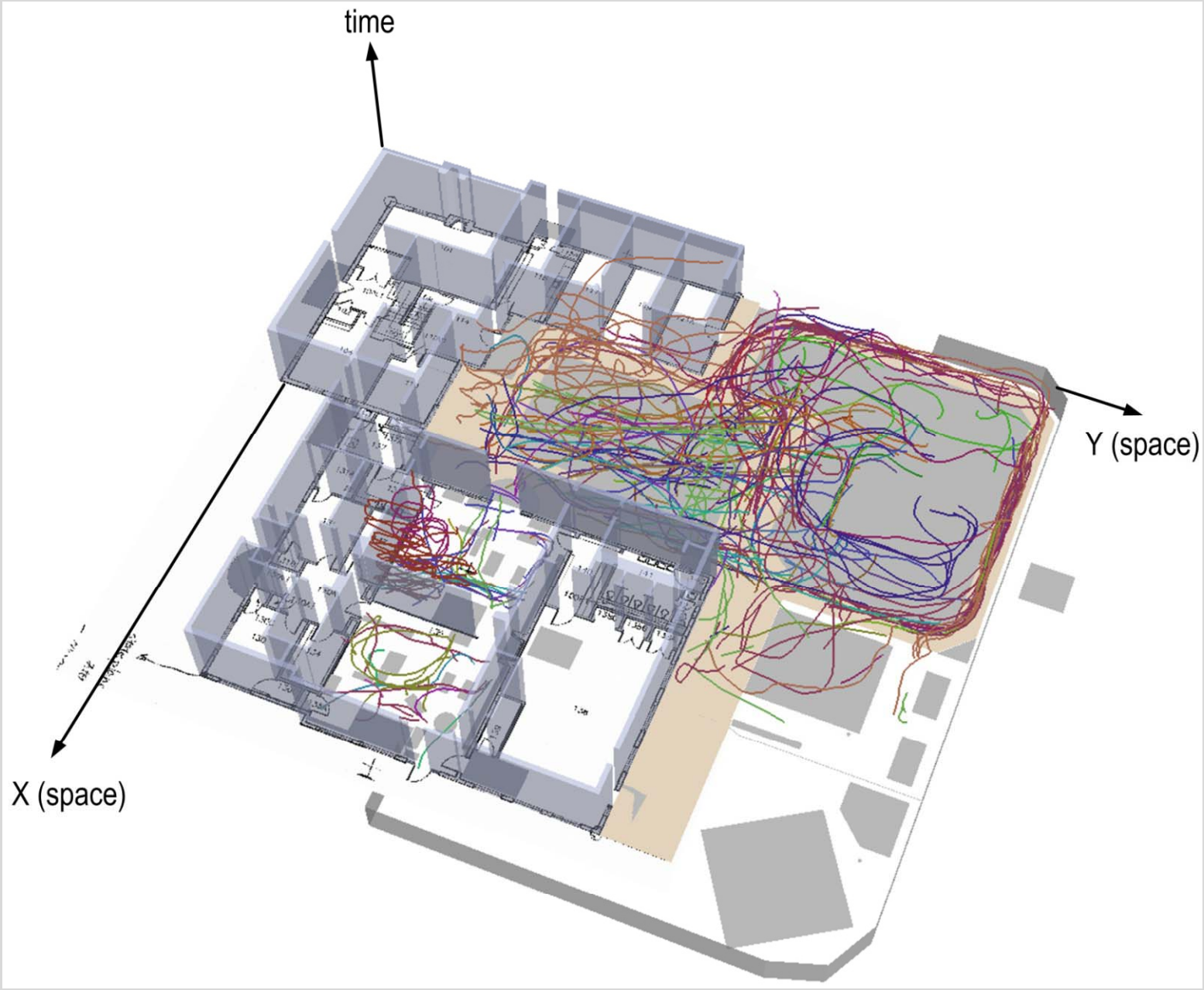
Deriving behaviors by machine-learning





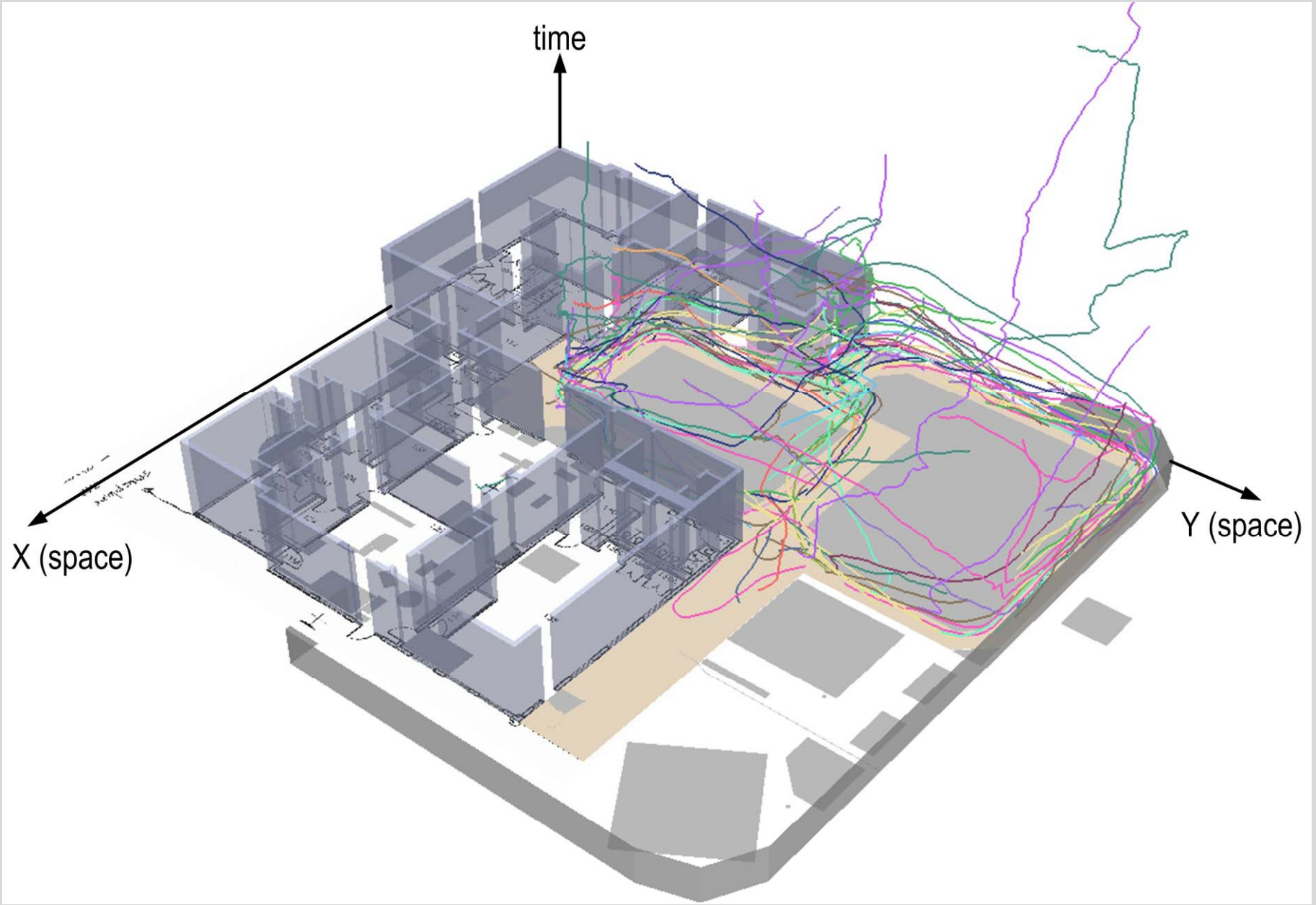
Machine-learned behaviors

Walking



Machine-learned behaviors

Running



Machine-learned behaviors

Riding a bicycle

Machine-learned behaviors

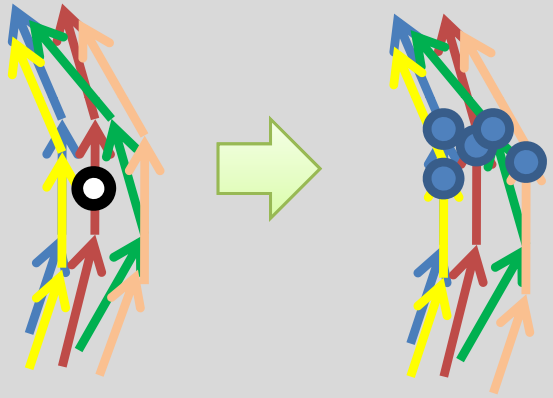
Playing baseball

1

Original data

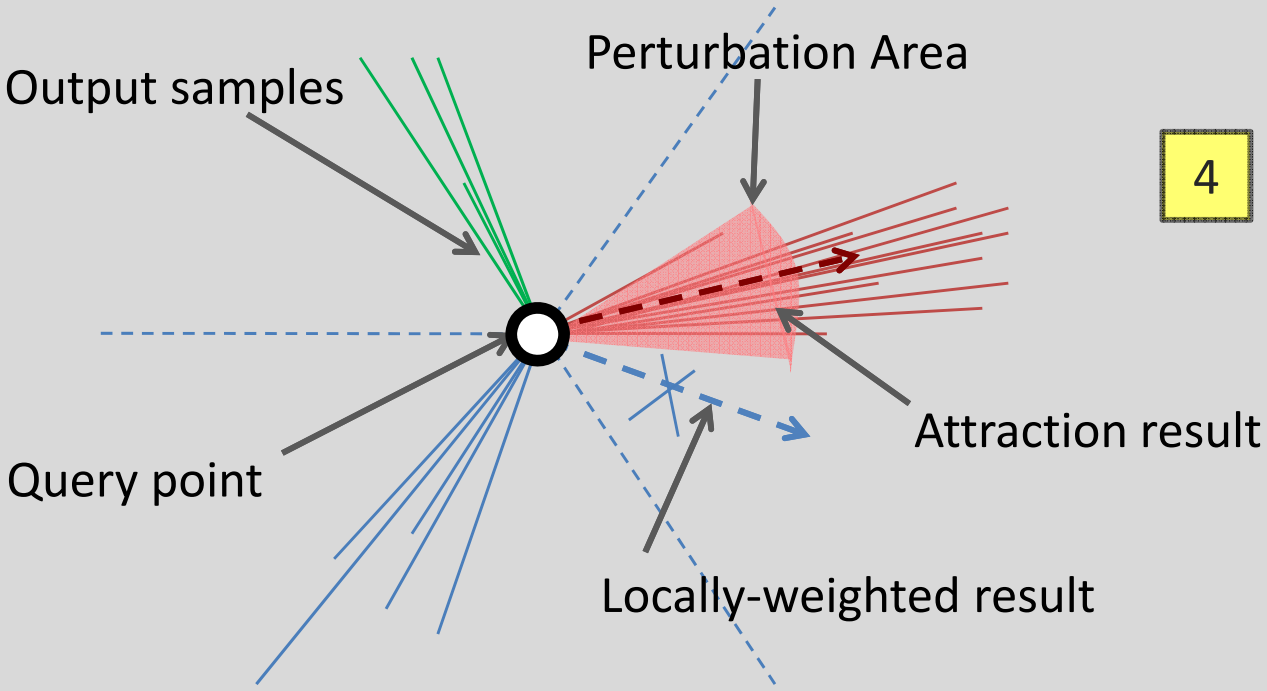
2

Build samples



3

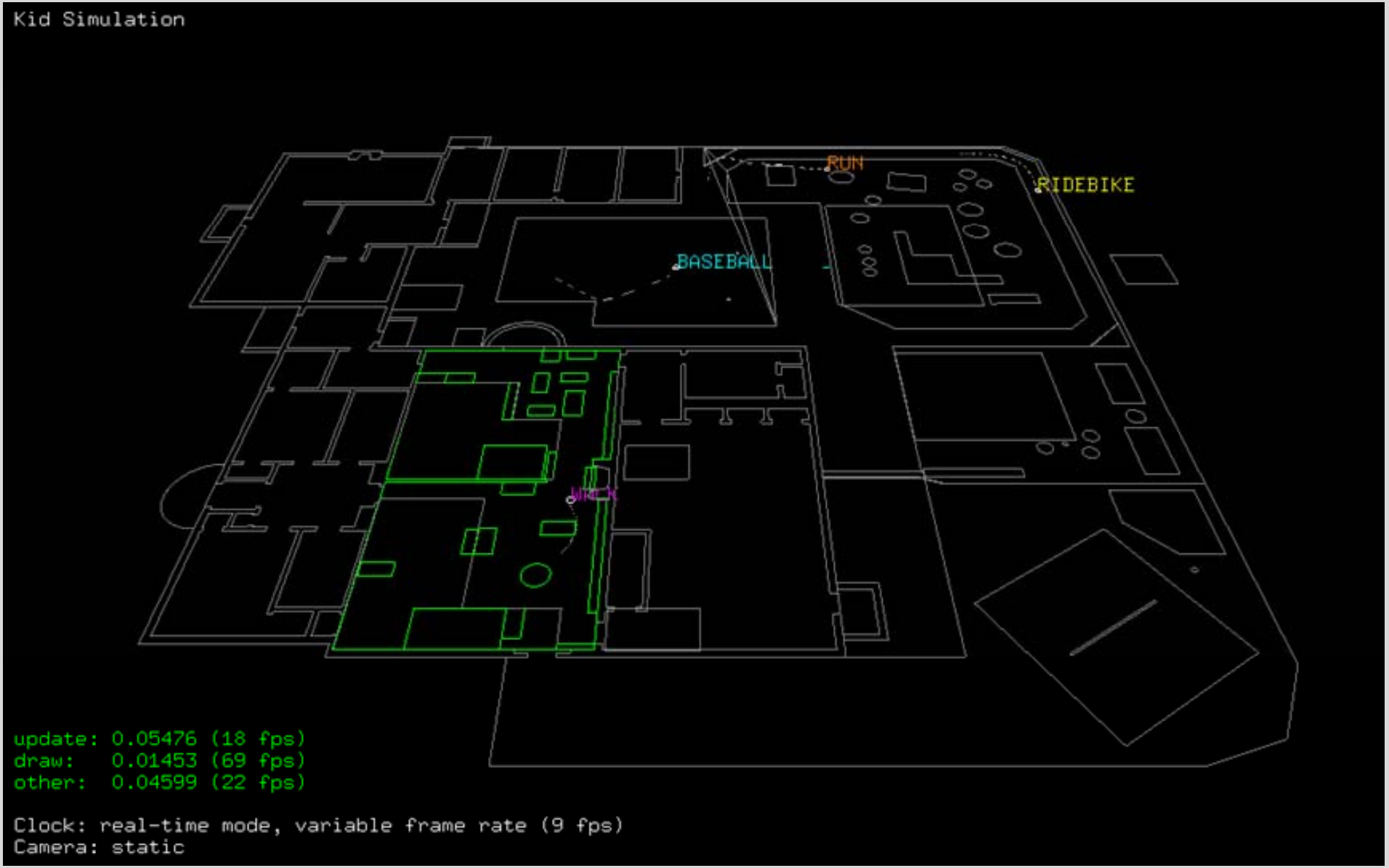
Find similar action points



4

Using these points, build a model to predict speed and direction

(Work with Xun Li)

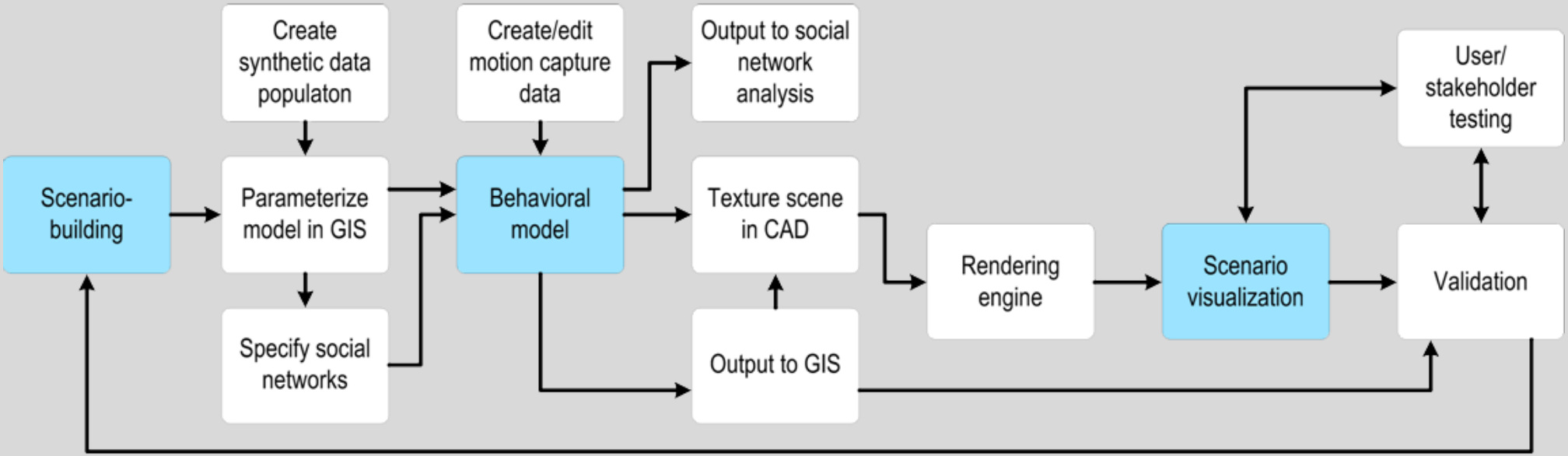


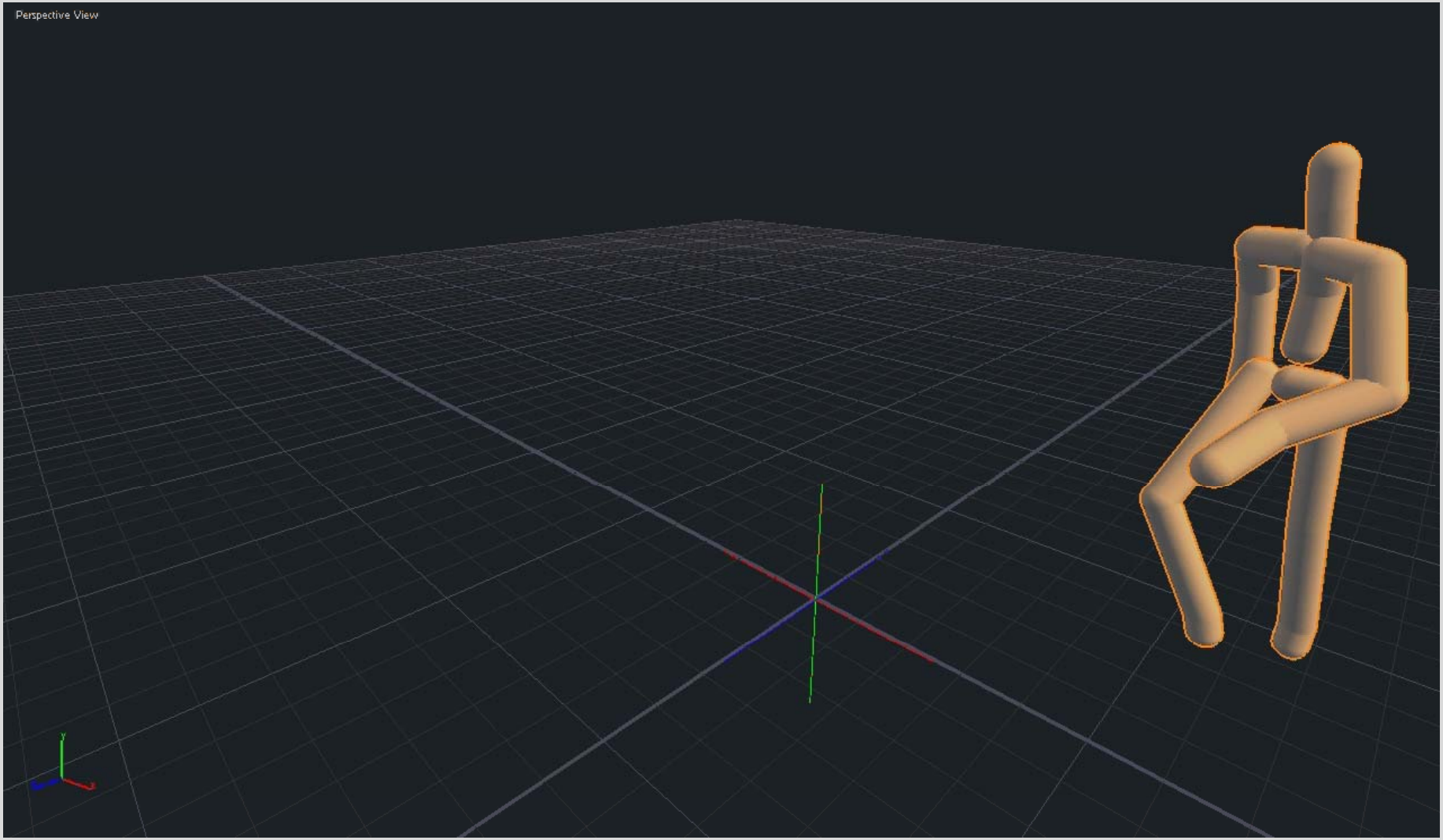
(Work with Xun Li)

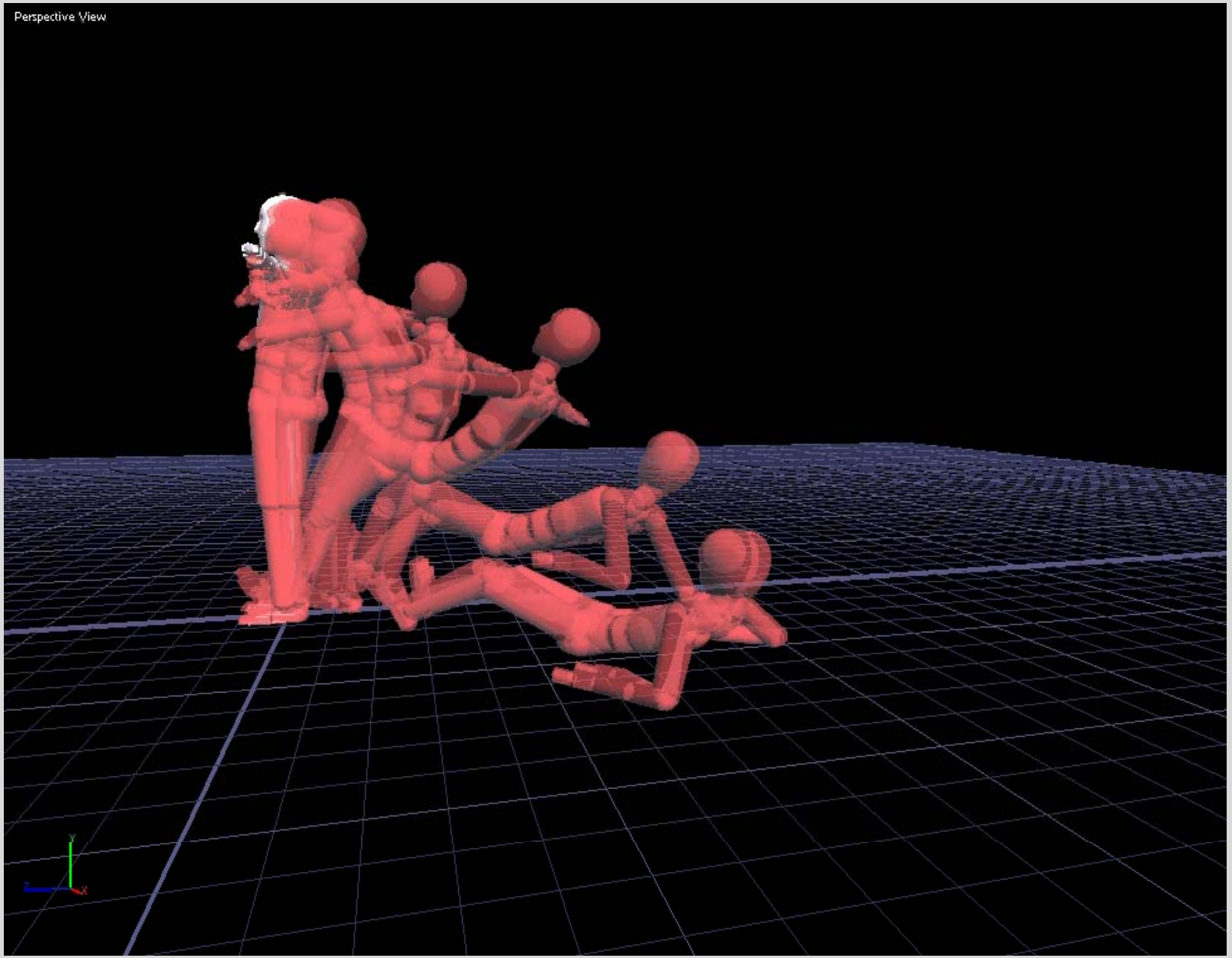
Mixing disjointed theory and data

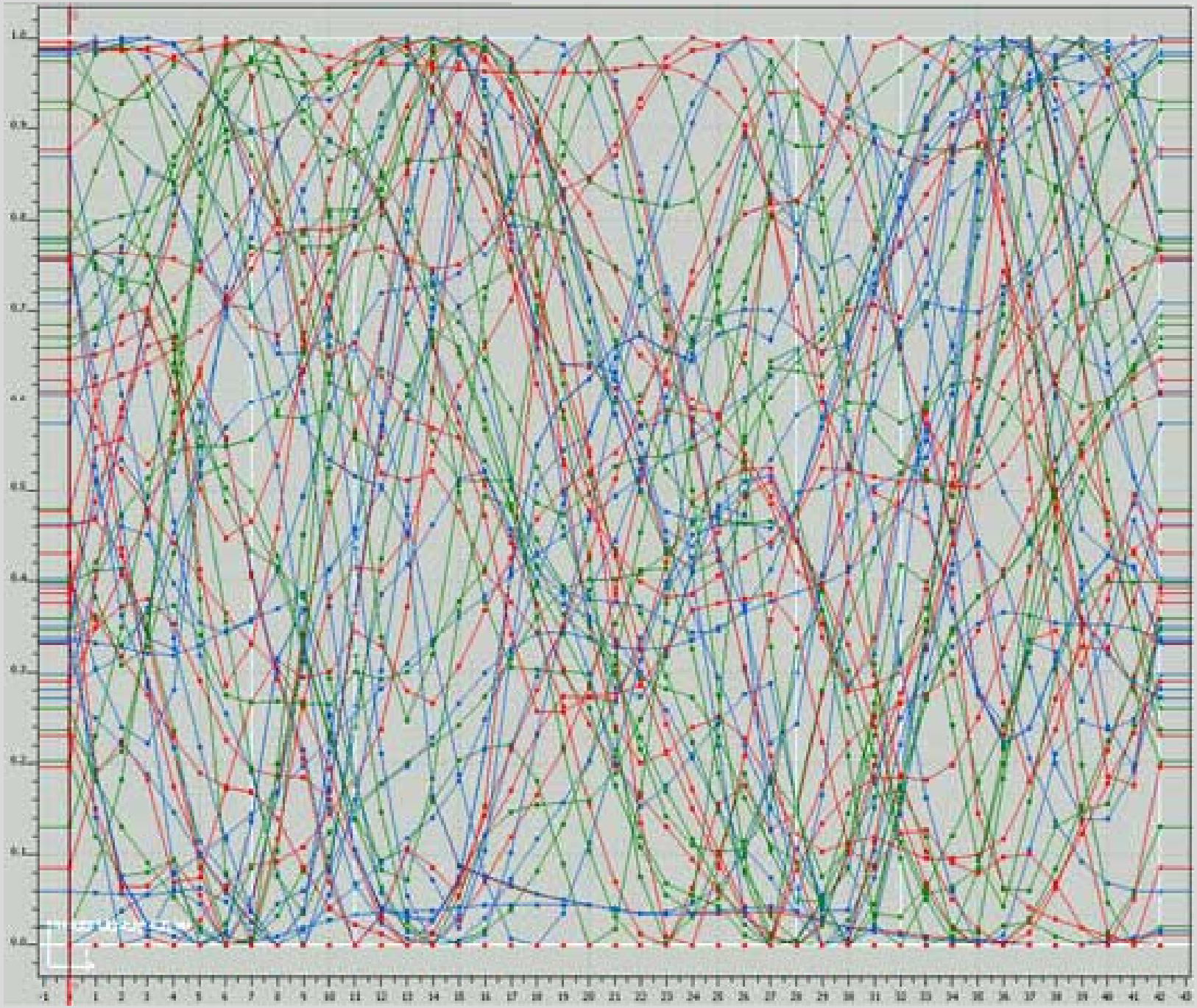
Modeling urban dynamics at small geographies

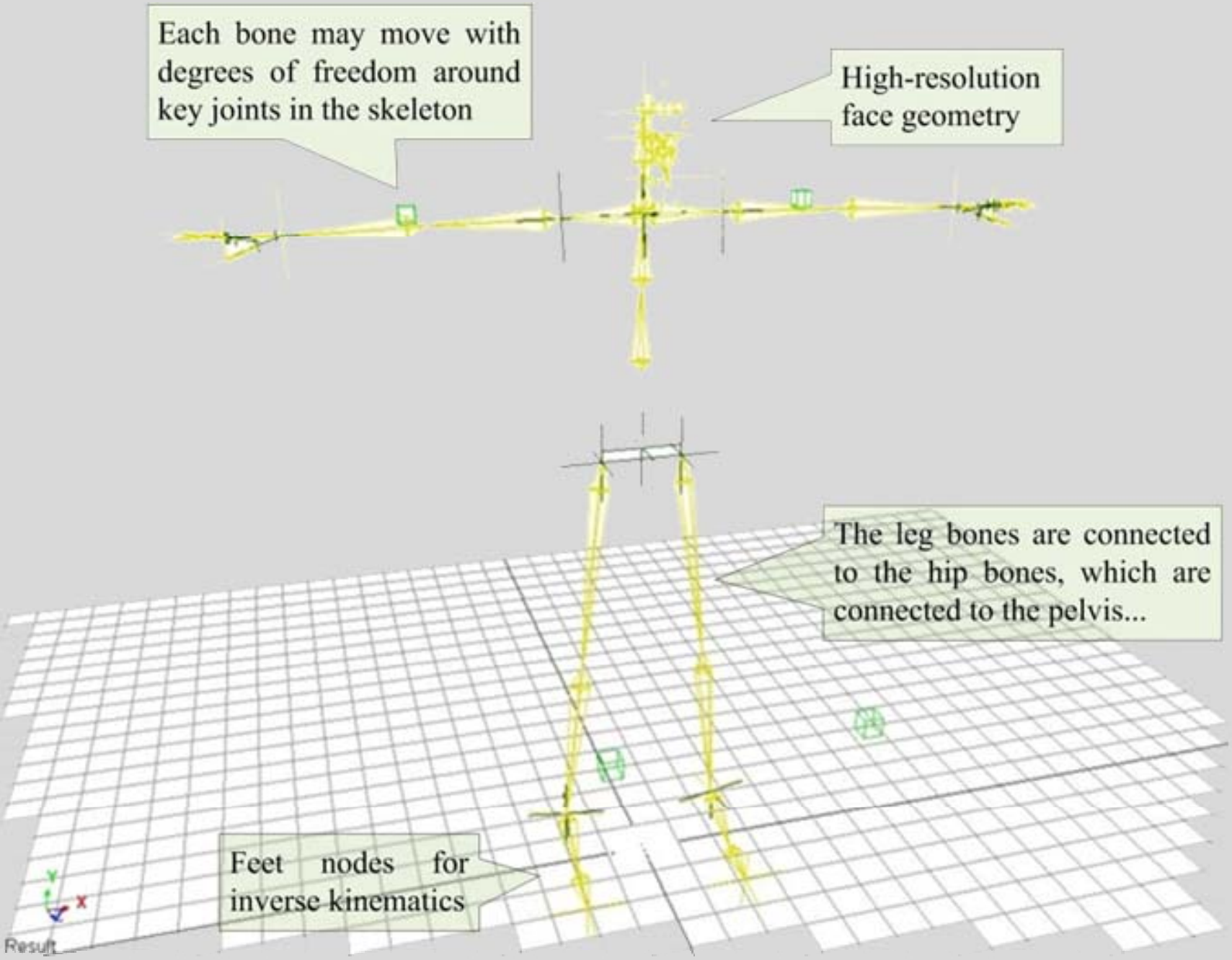
The data relate to the choreography of movement; we need to simulate behaviors

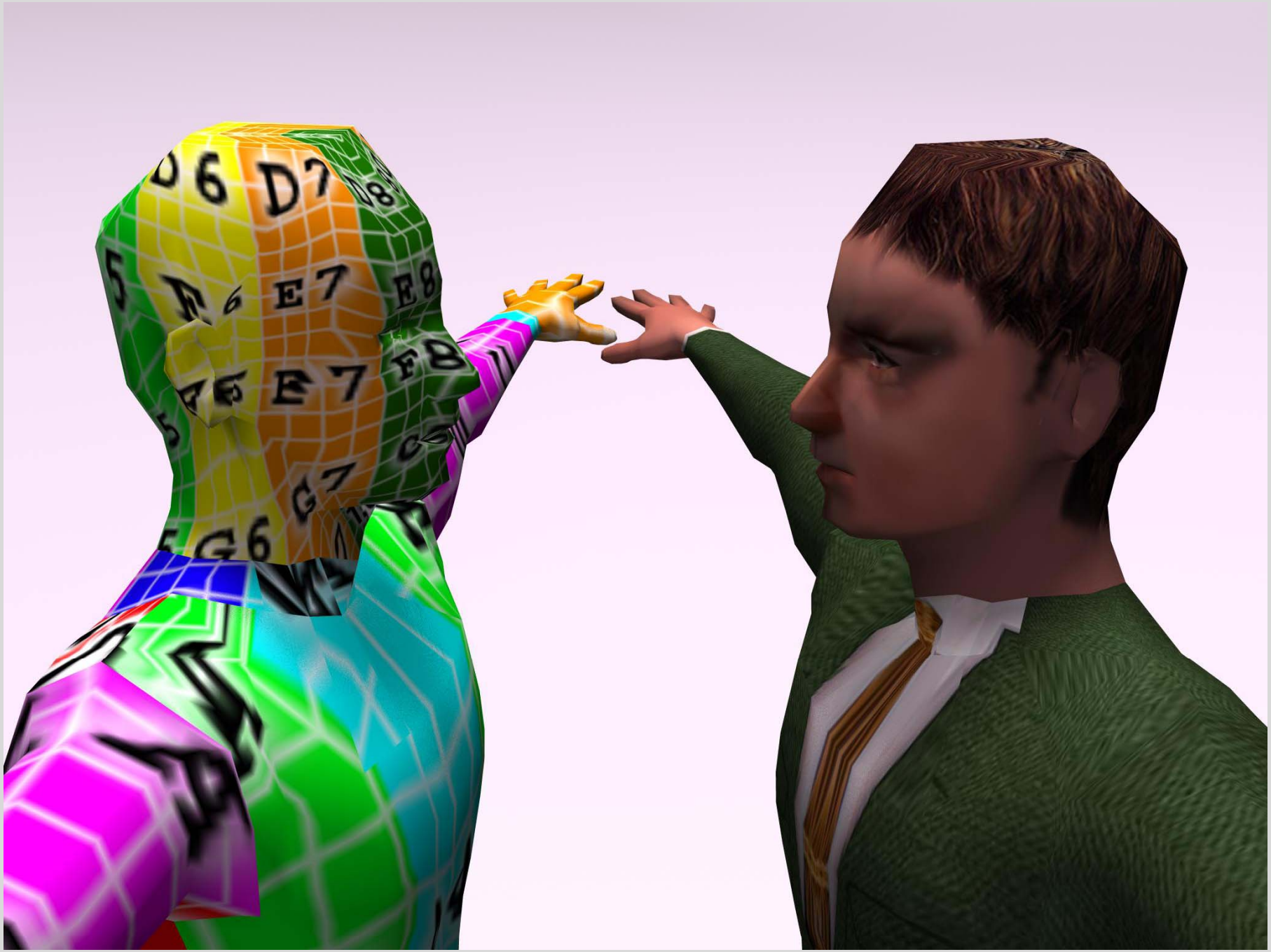


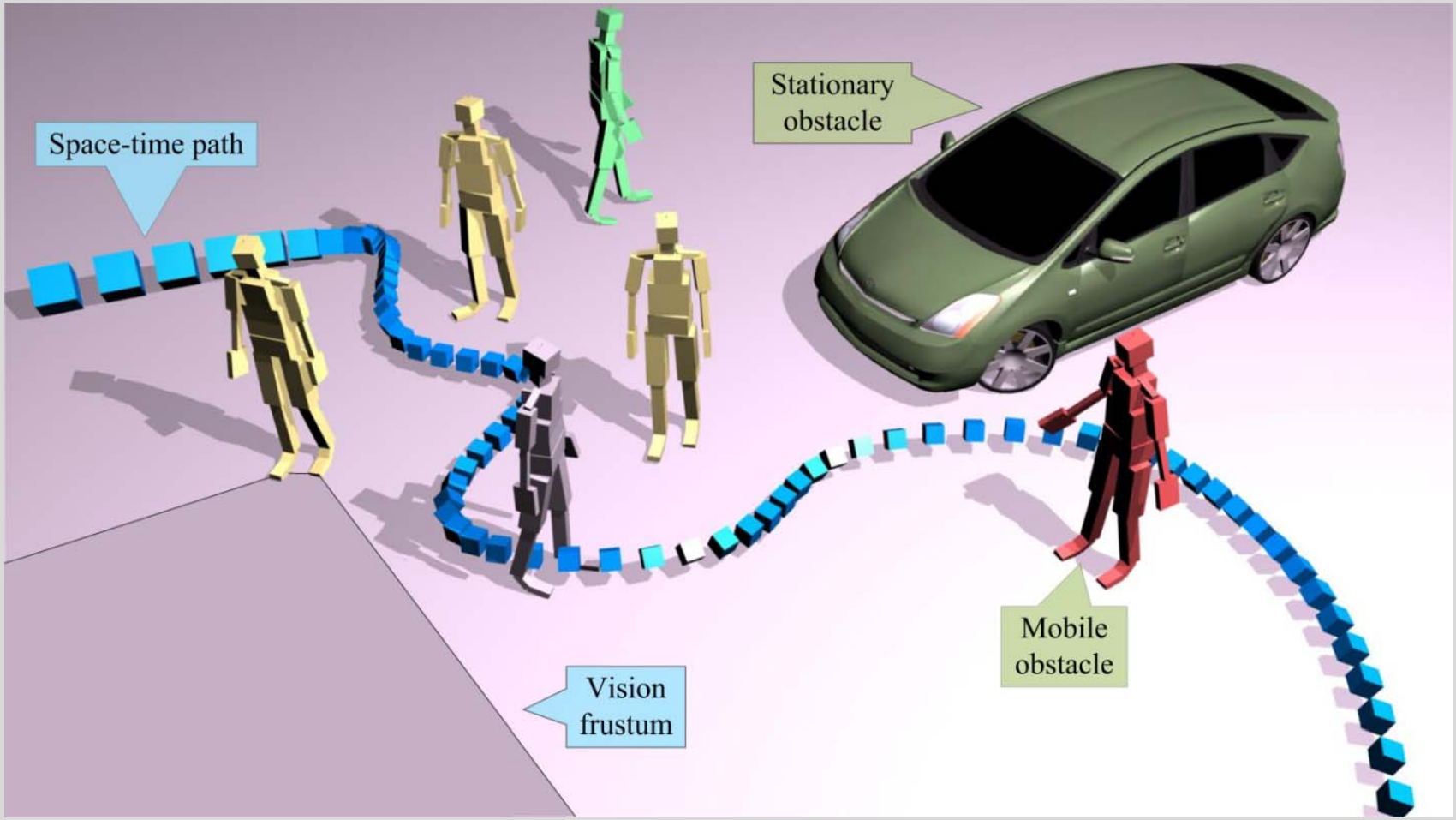








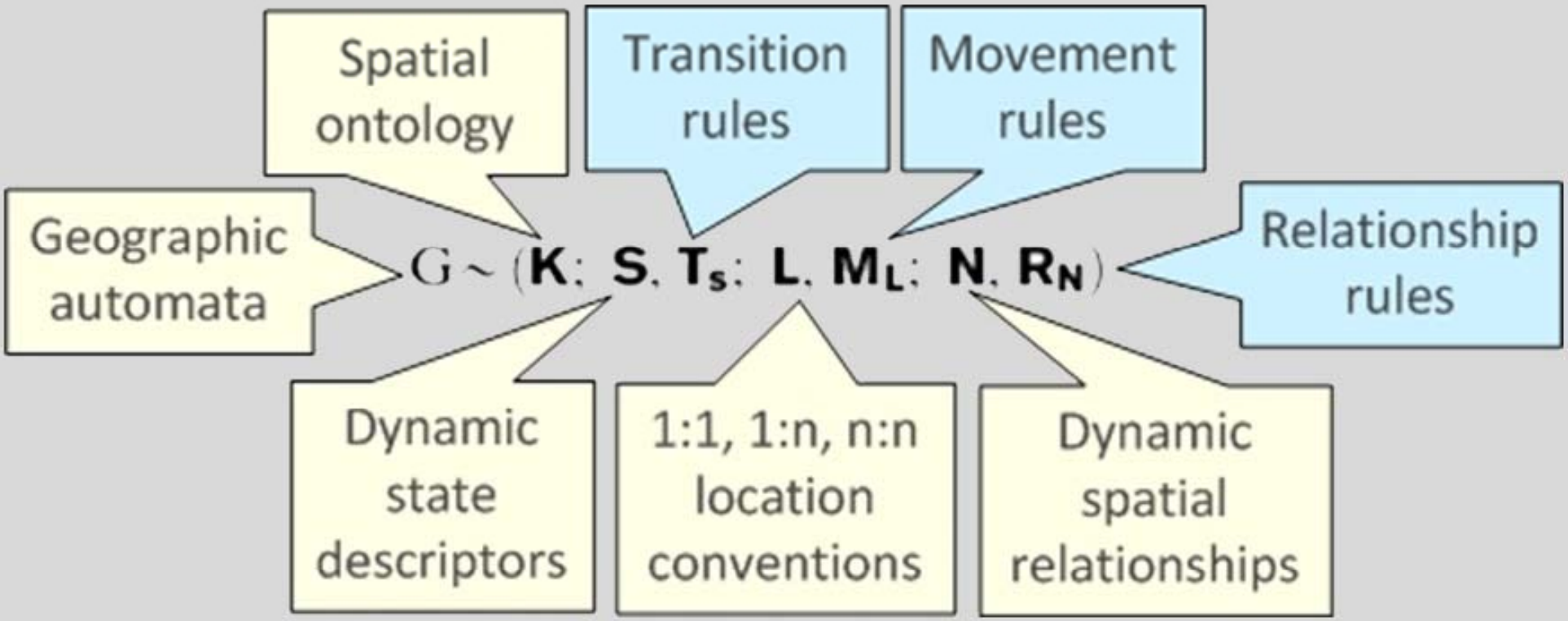




Vision frustum, ray-tracing, physical steering

Higher-level behavior is simulated (≠scripted) using computable brains

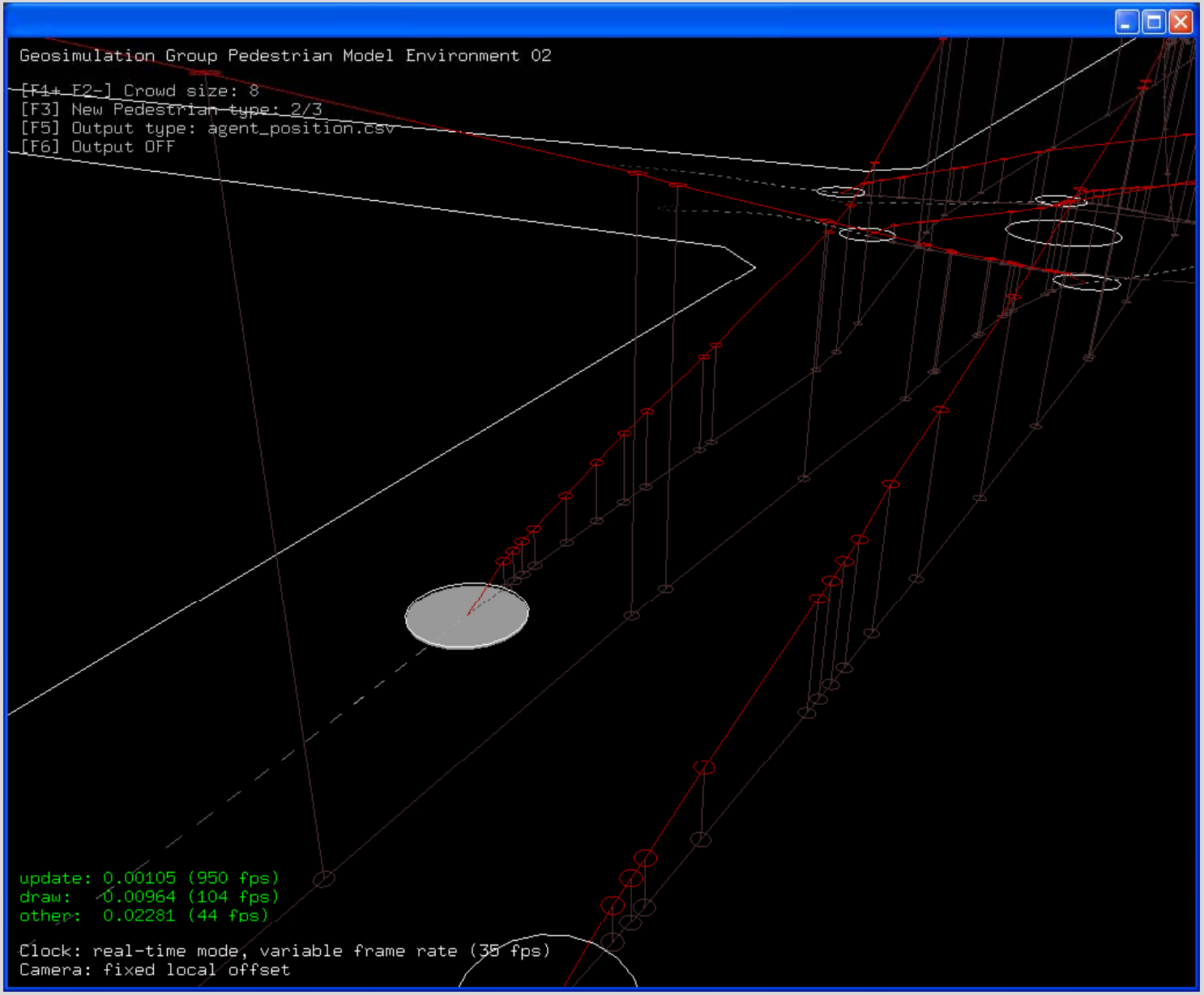
$$A \approx (\mathbf{S}_t, \mathbf{T}_s)$$
$$\mathbf{T}_s: (S_t, I_N) \rightarrow S_{t+1}$$



$\mathbf{T_S}$: $(S_t, L_t, N_t) \rightarrow S_{t+1}$

$\mathbf{M_L}$: $(S_t, L_t, N_t) \rightarrow L_{t+1}$

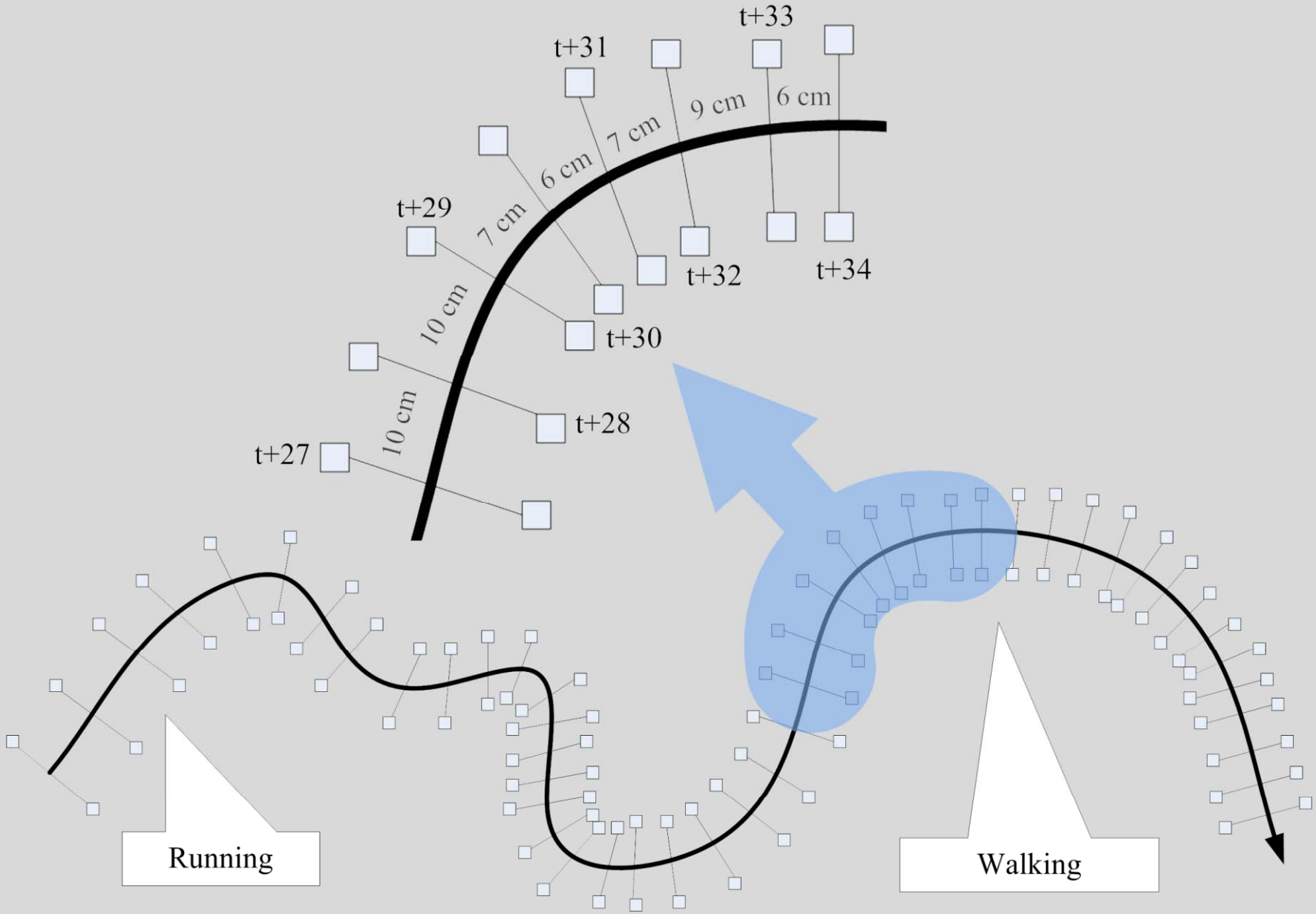
$\mathbf{R_N}$: $(S_t, L_t, N_t) \rightarrow N_{t+1}$



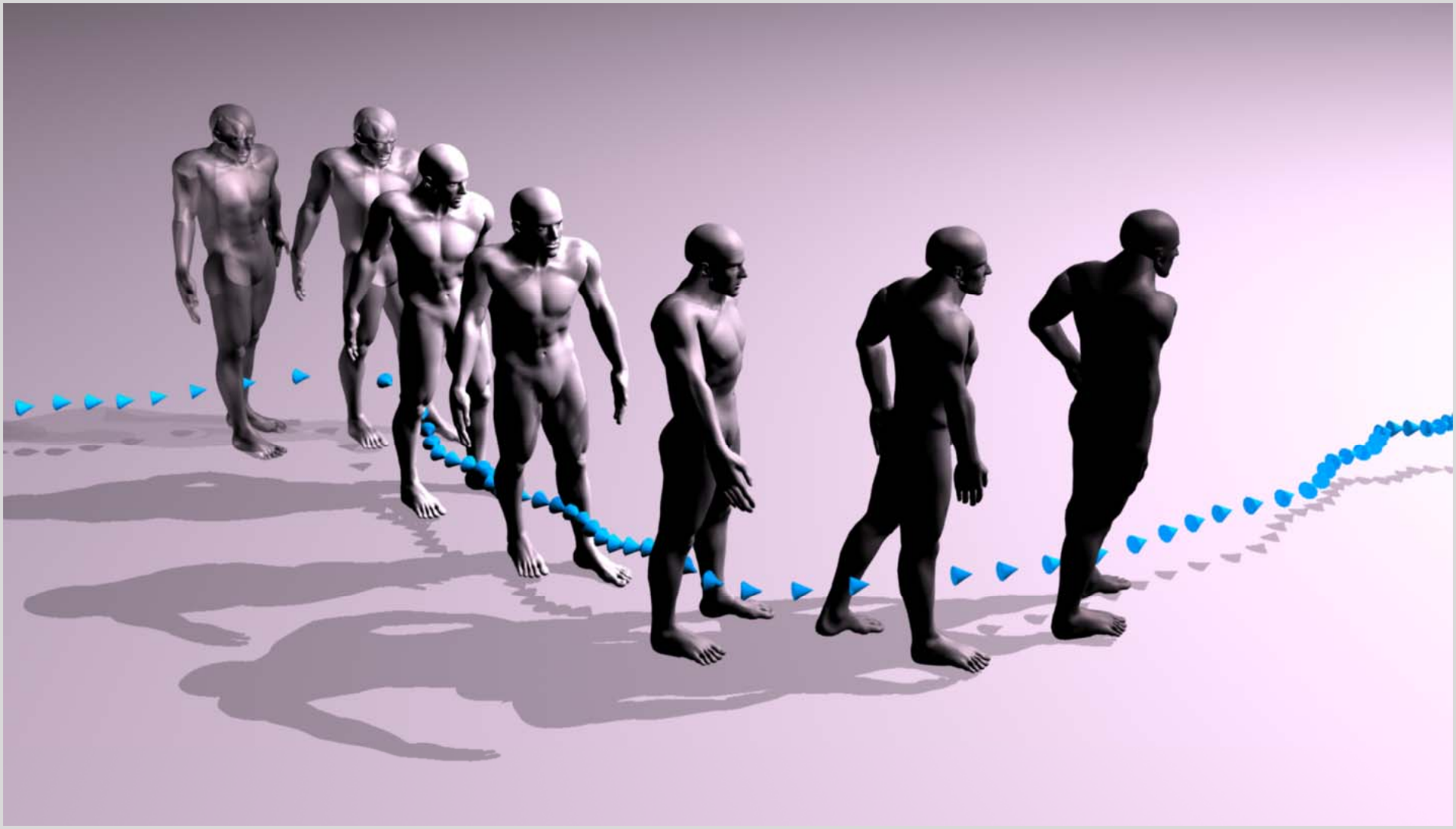
Uh-oh

Wayfinding using time geography

(Work with Scott Brown)



Discrete bundles of space and time as “footsteps”

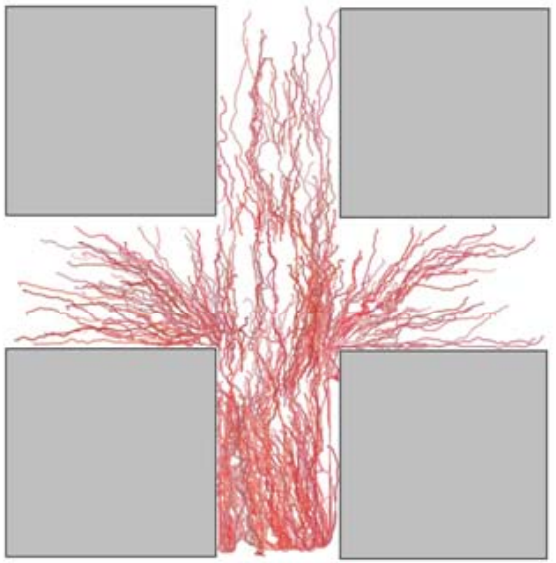


Inverse kinematics to resolve body locomotion

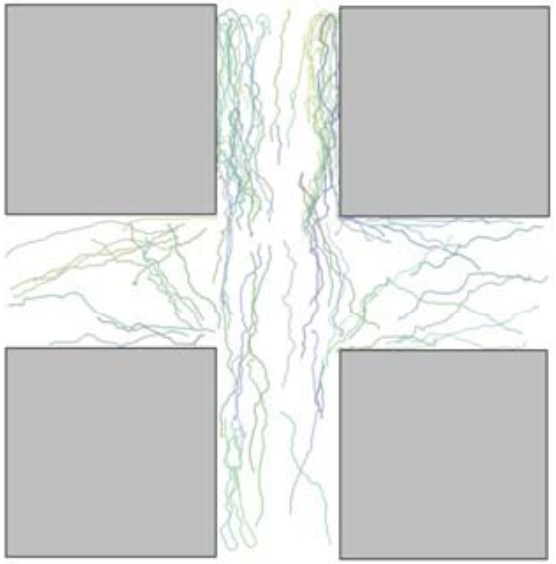
Street crowd, New York City blackout (August 15, 2003)

(Photo: John Wehr)

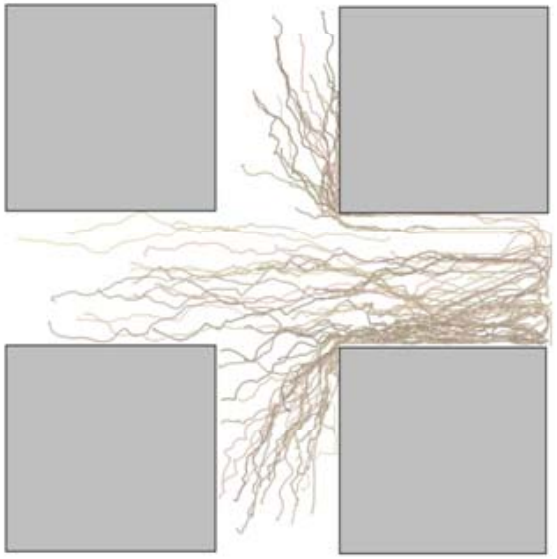
Uh-oh



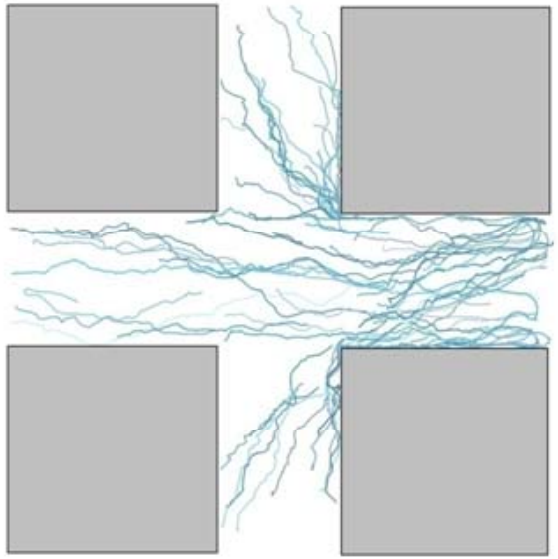
Male, walking



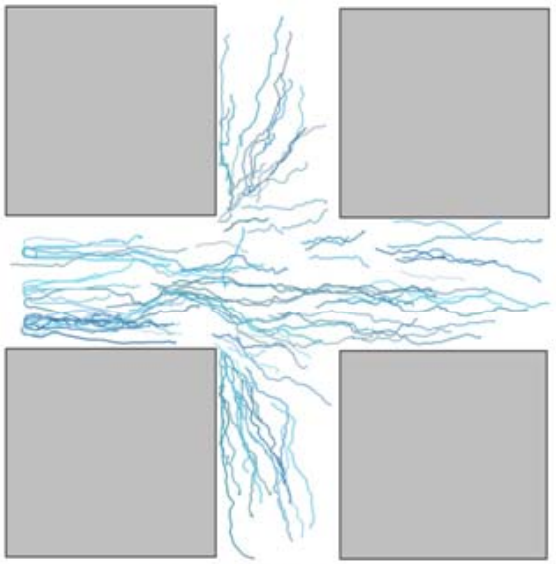
Female, walking



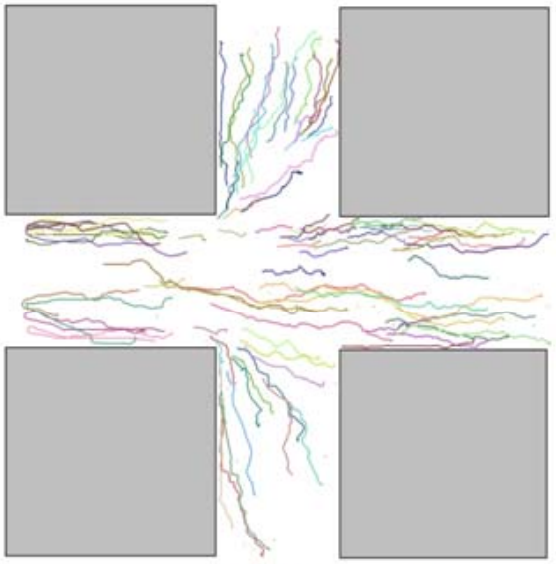
Male, running



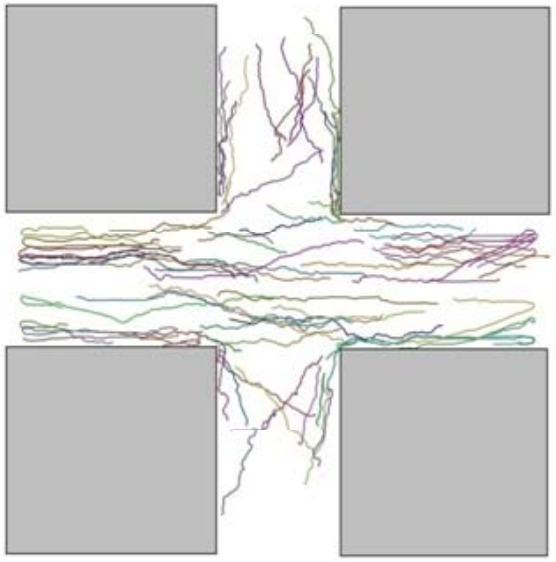
Female, running



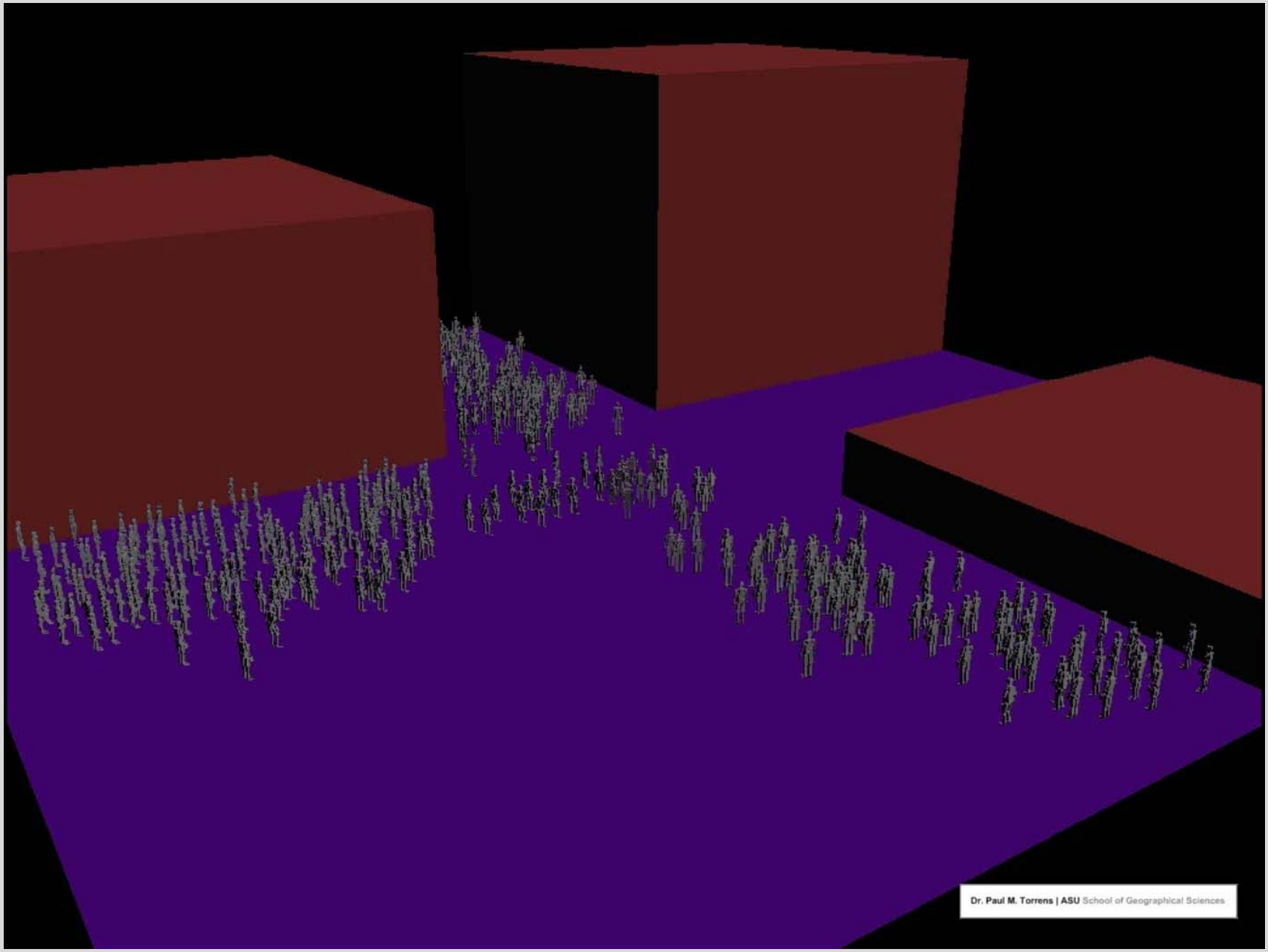
Male, ambulatory difficulty



Female, walking leisurely

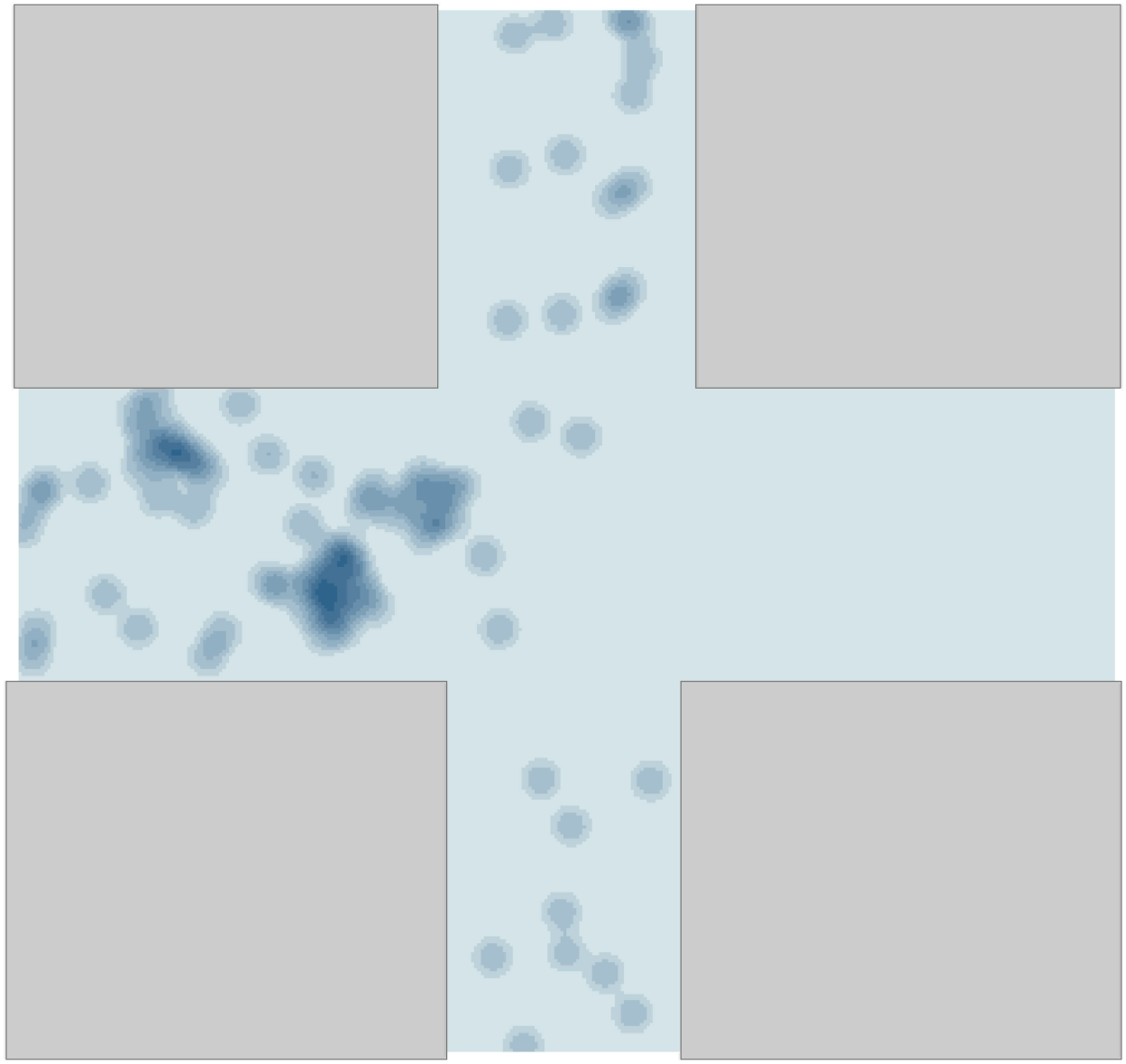


Child walking

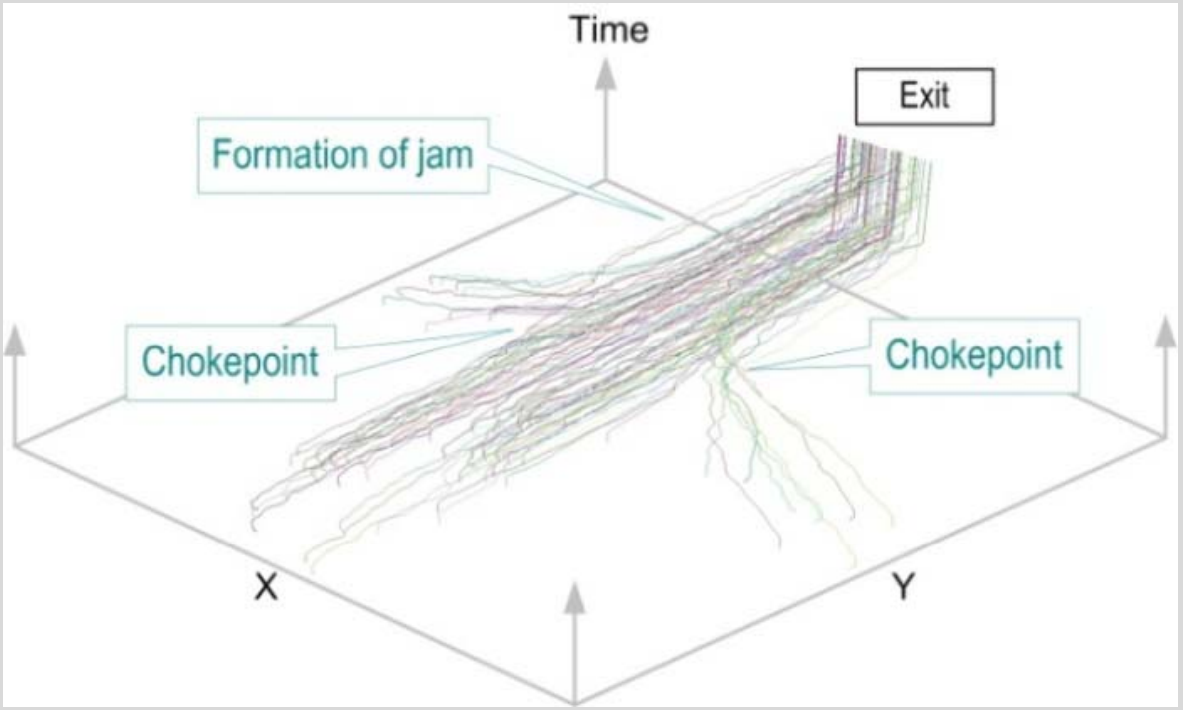


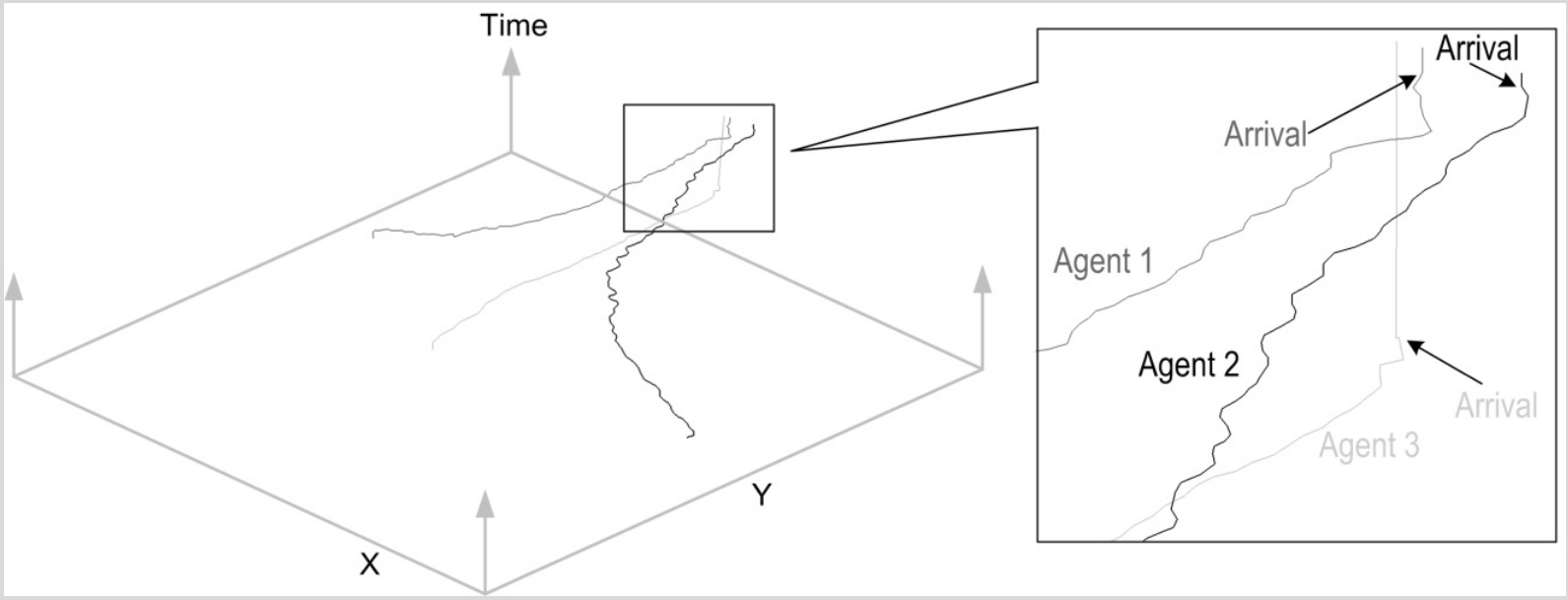
Uh-oh

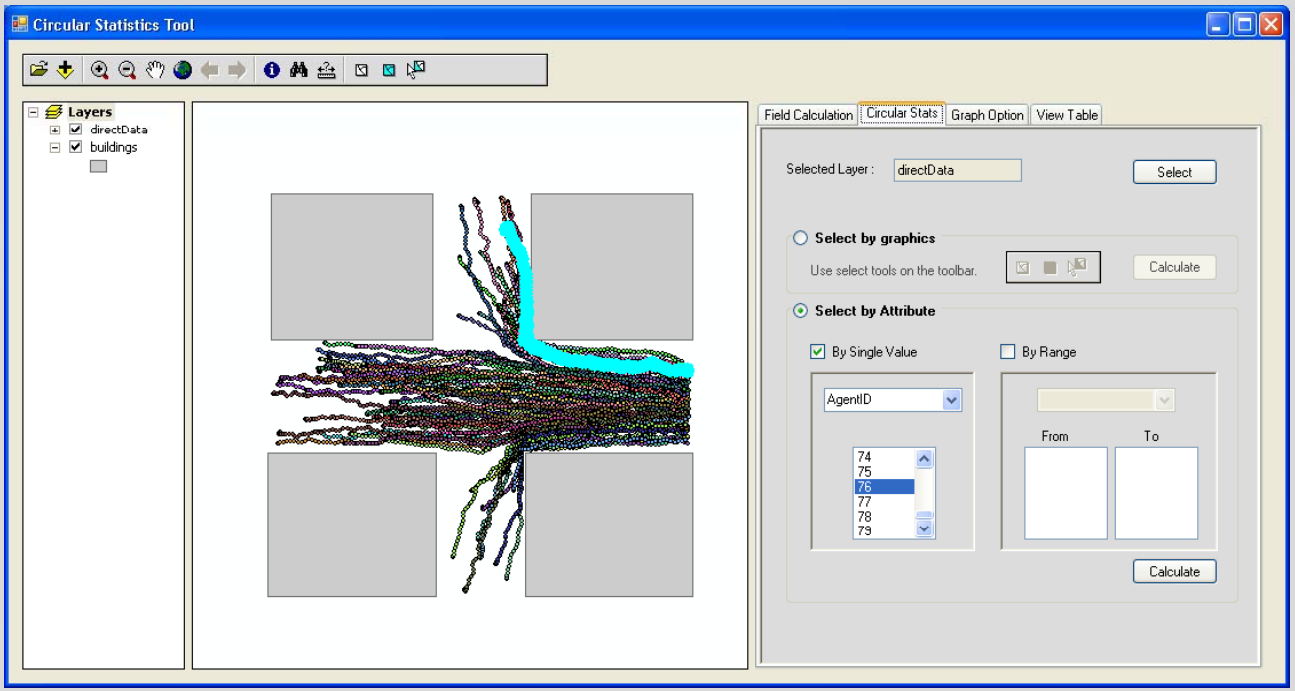
Image borrowed from ABC: http://i177.photobucket.com/albums/w234/JoeLostHeroes1/monster.jpg

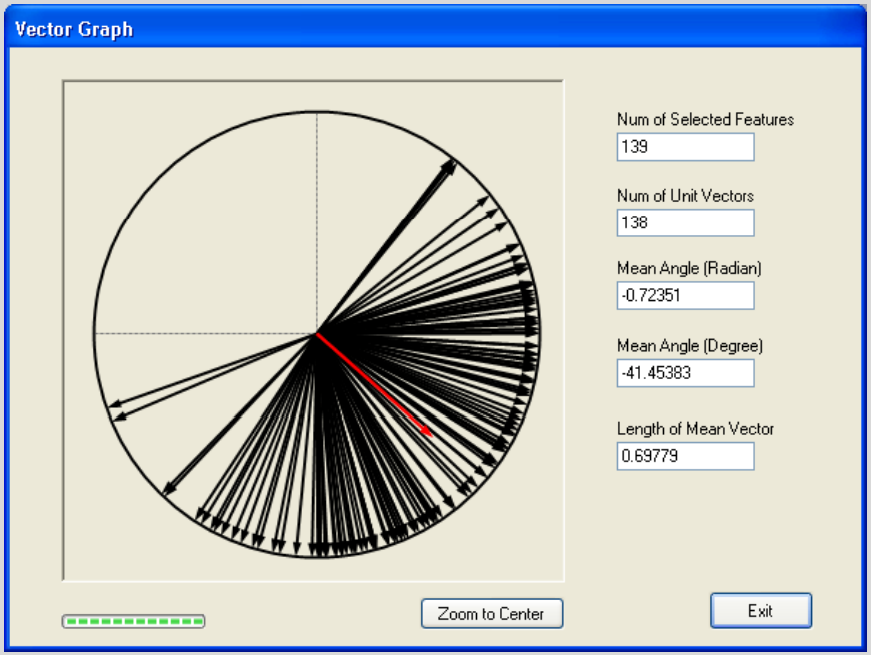


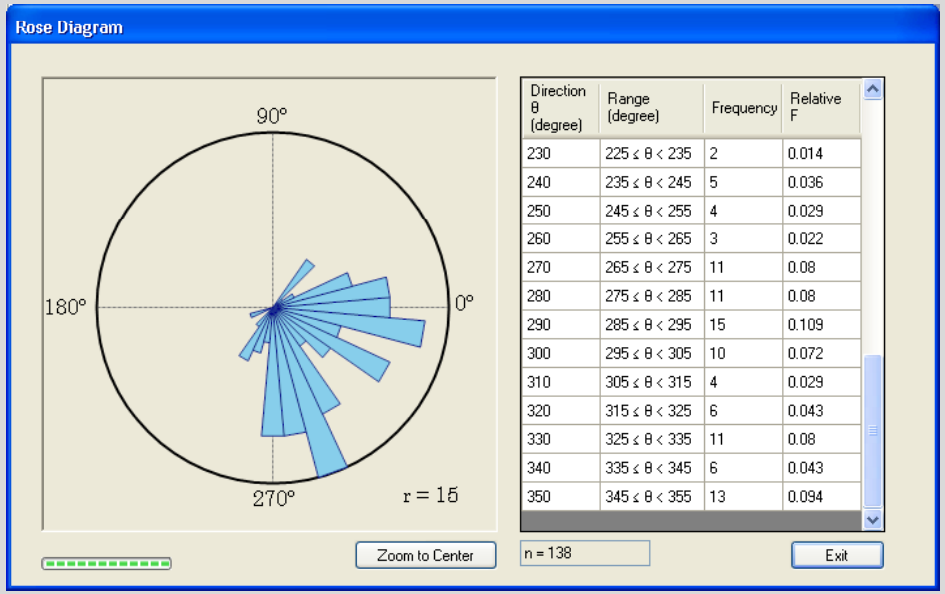
Uh-oh





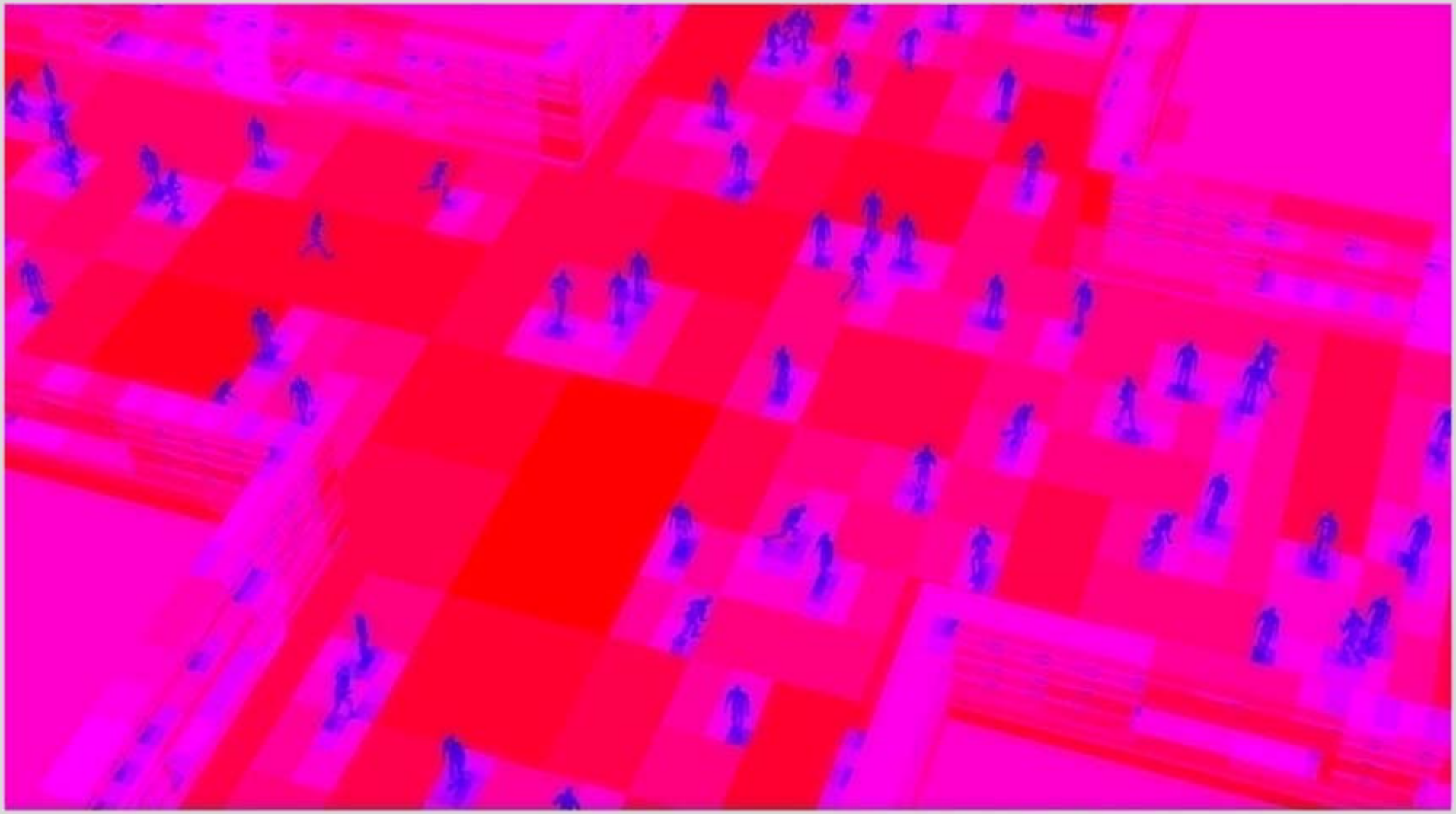


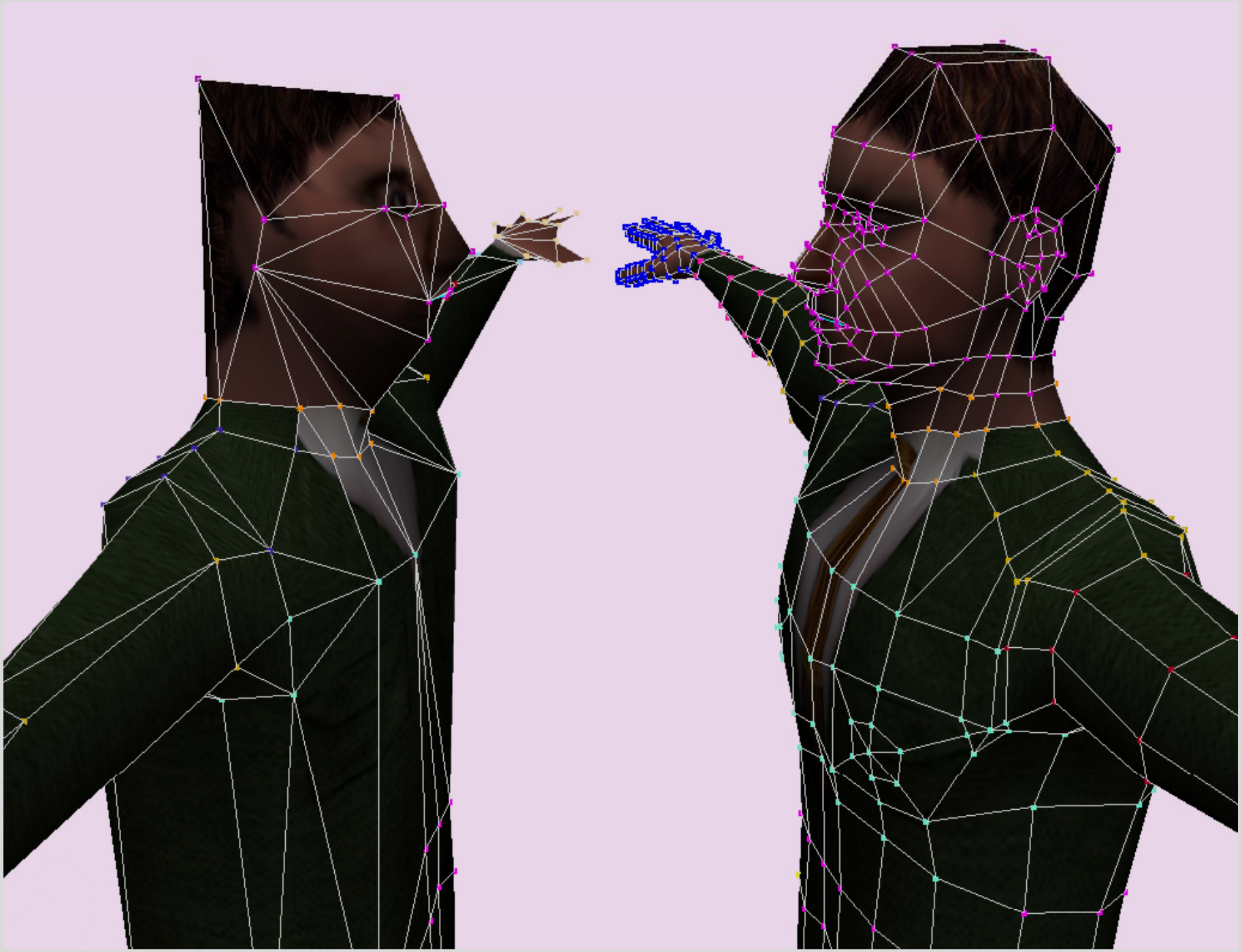




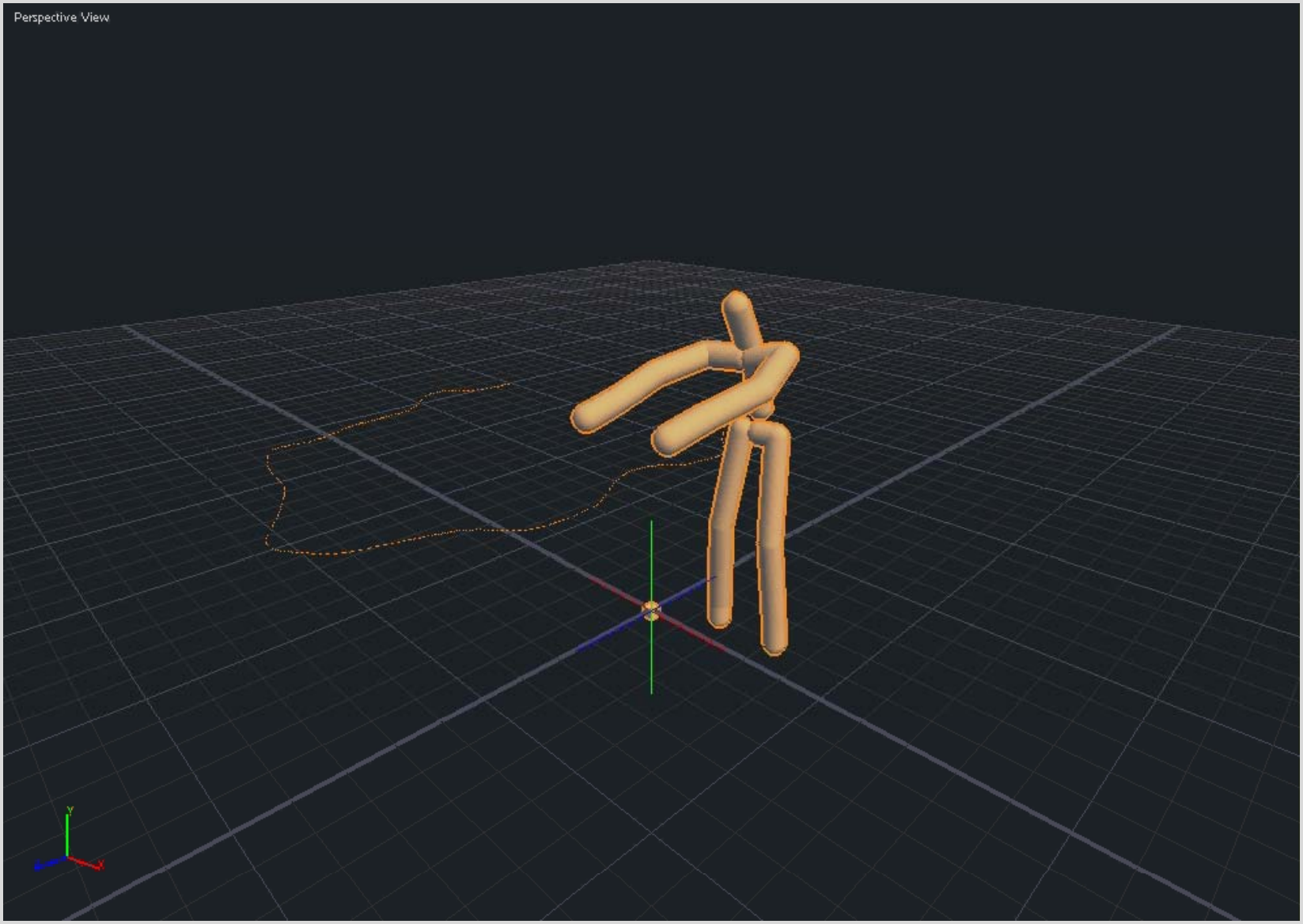
(Work with Atsushi Nara)

Building this much behavior into agents is computationally intensive

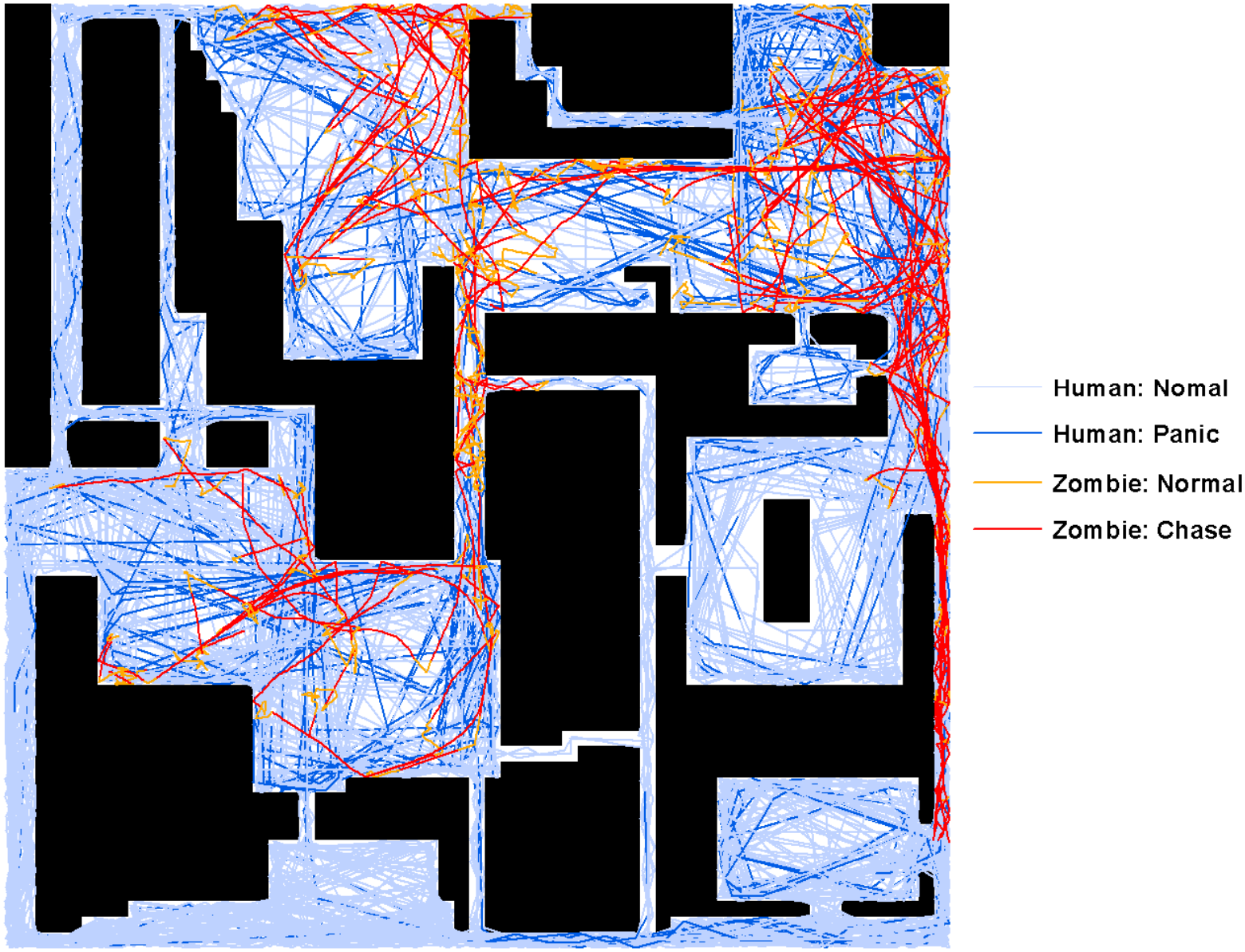




Future work



Uh-oh



Uh-oh

Presidential Early Career Award for Scientists and Engineers

NSF CAREER Award

NSF Geography & Regional Science

NSF Methodology, Measurement, and Statistics

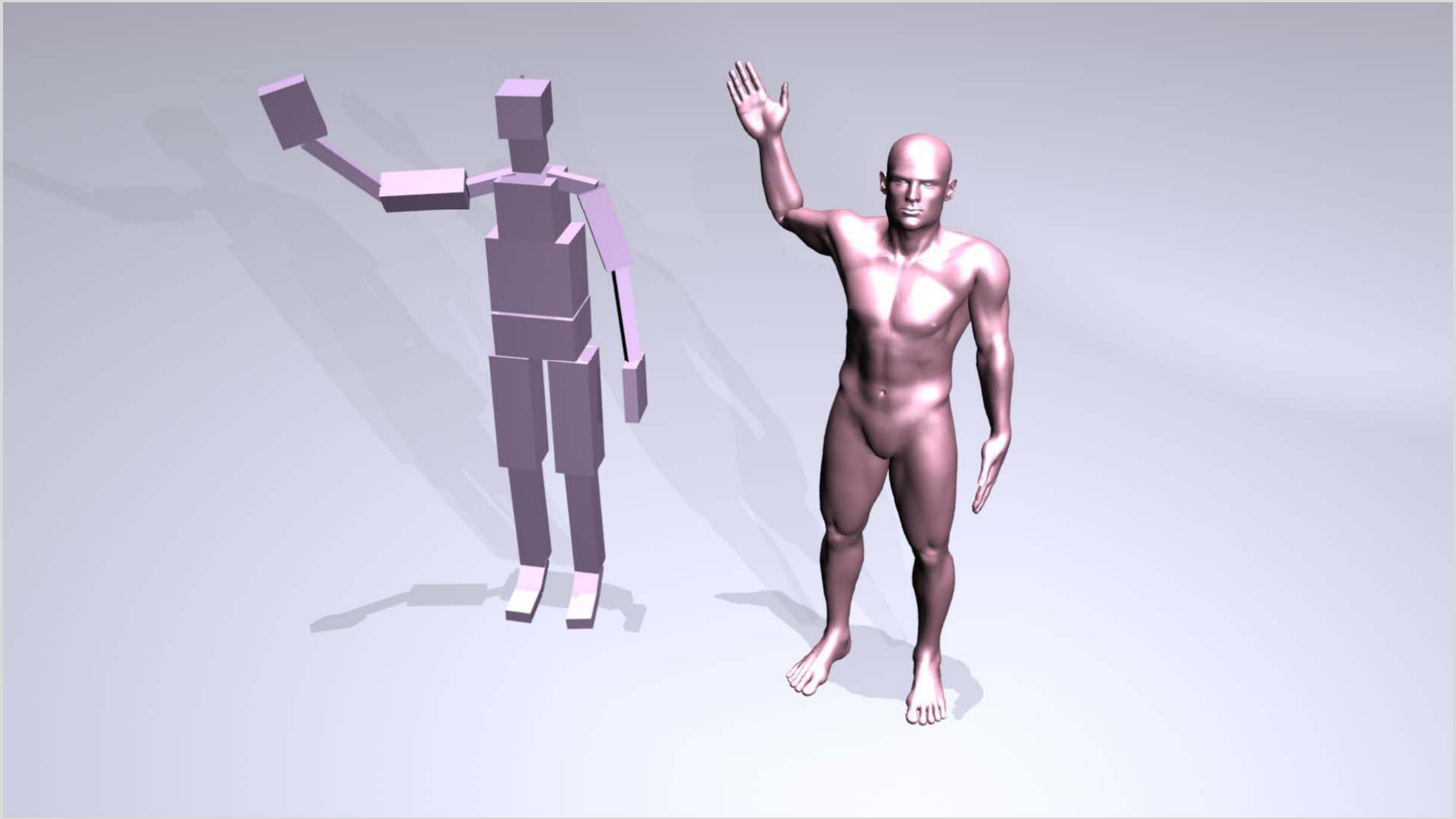
NSF Human Dynamics of Social Change

Science Foundation Arizona

Herberger Foundation

Autodesk, Inc.

Alias, Inc.



Thanks!

Geosimulation

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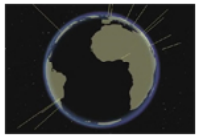
Dr. Paul M. Torrens, ASU School of Geographical Sciences, torrens at geosimulation dot com

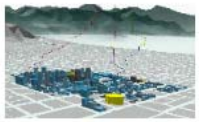
News | New publications | New grants | Contact details

New projects >>

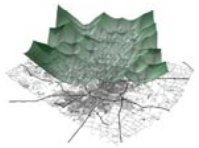


Megacity futures

Immersive modeling



Space-time GIS and analysis



A toolkit for measuring sprawl

Presidential Early Career Award >>

I was awarded the *Presidential Early Career Award for Scientists and Engineers* by President Bush in a ceremony at the White House on December 19, 2008. The award was for my work on computer models of human behavior in critical situations. Press releases: White House; Executive Office of the President, Office of Science and Technology Policy; National Science Foundation; Arizona State University; The Association of American Geographers. (Photo by Chris Greenberg.)

News >> (older news is here)

BBC Focus magazine, "the world's best science and technology monthly", featured my research on crowd behavior in thier April issue (with a mention on the front page), with a story entitled, "The trouble with crowds: The scientists working to prevent another Hillsborough", that discusses crowd behavior and critical events on the twentieth anniversary of the Hillsborough diasaster (Edward Chipperfield) (March 10, 2009)

LiveScience's Research in Action section has featured my work on crowd and riot modeling, with a piece entitled, "Riot dynamics modeled". Currently, the story is featured on the front page (Diane Banegas) (March 8, 2009)

My work (and my photograph!) is featured on the front page of *Engineering News Record*: "Researchers in 'early career' lauded for work to revolutionize engineering and industry" (Debra K. Rubin) (February 22, 2009)

The Association of American Geographers newsletter has a feature on my Presidential Award in this month's issue (February 16, 2009)

Popular Mechanics interviewed me for a feature on crowds at today's presidential inauguration: "How officials will control the crowds at obama's inauguration" (Philip Taylor) (January 20, 2009)

http://geosimulation.org