A Data-Driven Framework for the Analysis of Geographic Patterns of Team Processes

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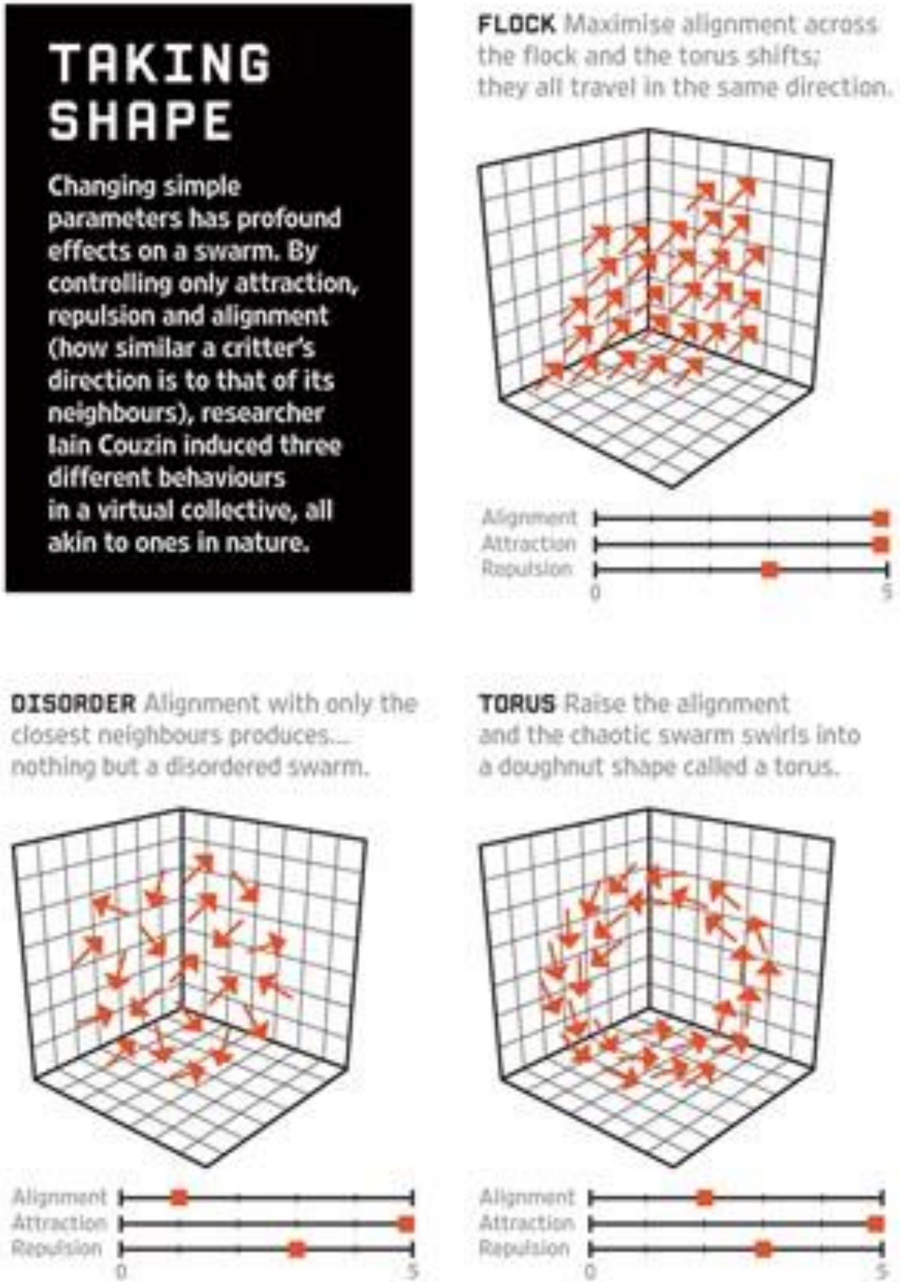
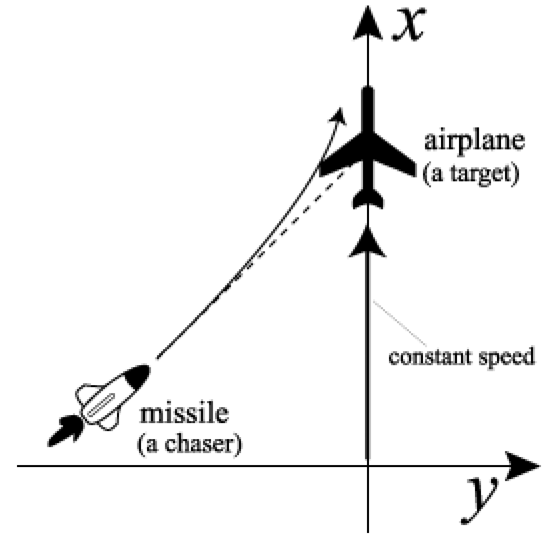
Introduction

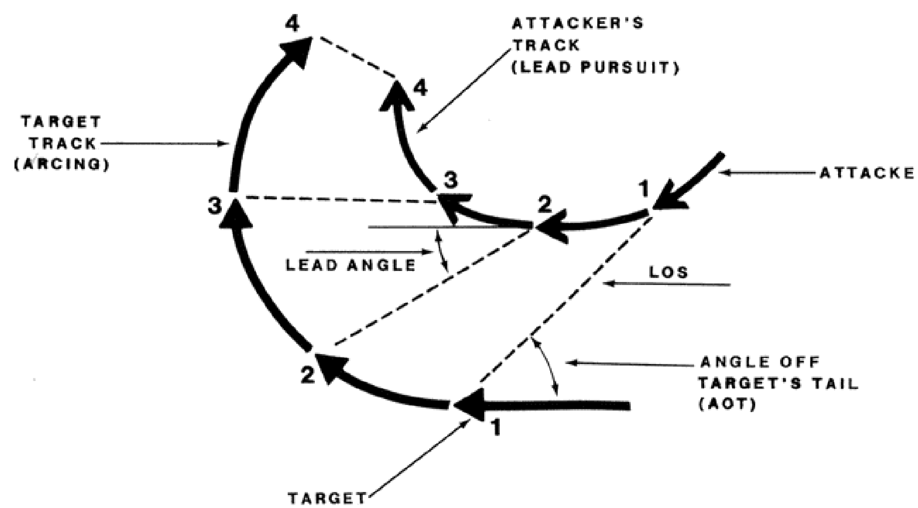
- Teams pursue many kinds of licit and illicit goals:
  - Law enforcement, emergency services, & disaster recovery
  - Smuggling, organized crime, & terrorism
- Goal-directed social behaviors:
  - May be modeled using games like hide-and-seek
  - Exhibit geographic patterns
- Owing to technology, there now exists unprecedented opportunity to understand licit & illicit team behaviors using:
  - Team games
  - Computer geosimulation
  - Smartphone-based tracking of movement and communication
  - The tools of geography and related disciplines
- Our goal is to determine how to anticipate, identify, and influence geographic attributes of team processes

Geography
Geopolitics
Strategic Studies
World History/I.R./Poli.Sci.
Heartland (Mackinder)
Rimland (Spykman)
Seapower (Mahan)
Spatial Analysis of Conflict (O'Laughlin, Flint)
Classical War Theory (Clausewitz, Paret)
Modern War Theory (Trinquier, Mao)
Realism (Morgenthau)
Liberalism (Kant)
Constructivism (Bull)
Neoclassicism (Keynes)
Dependency (Cardoso)
World Systems (Wallerstein)
Annales (Braudel)
Mercantilism (Colbert, Mun)
Industrialism (Smith, Ricardo)
Marxism (Marx)
Human Geography
Spatial Interaction (Ullman)
Central Place (Christaller)
Autocorrelation (Tobler)
Locational Inter-dependence (Hotelling)
Wayfinding (Golledge)
Spatial Choice (Rushton)
Volunteered Geographic Information (Goodchild)
Geography of Terrorism (Medina, Hepner)
Netwar (Arquilla, Ronfeldt)
Ind./Org. Psychology
Motivation (Lewin, Locke)
Hierarchy (Taylor, Weber)
Communication (Keyton)
Leadership (Katz, Kahn)
Teams (Cohen, Bailey)
Culture (Fine)
Spatial Statistics
Spatio-Temporal Analysis (Dutilleul, Knox)
Point Pattern Analysis (Diggle, Anselin, Getis, Ord)
Movement Analysis (Laube, Croitoru)
Geographic Dynamics of Goal-Directed Social Behaviors
Multiteam Systems (Marks, Zaccaro)
Geosimulation (Torrens, Crooks)
Social Network Analysis (White, Carley, Westaby)
Sociology
"New" Social Physics (Barabasi, Watts)
Classical Theory (Marx, Durkheim, Weber)
Geog. Info. Systems
GIS-T (Waters, Curtin)
Networks (Church, Cova)
Location Science (Curtin)
Network Optimization (Ahuja, Orlin)
Reality Mining (Eagle, Pentland)
Network Dynamics (Sniders, Carley)
"Old" Social Physics (Comte, Quetelet)
Main Topic
Proximal Topic
Distal Topic
Fundamental Topic
Operations Research
Computer Science
Linear Optimization (Dantzig)
Game Theory (Von Neumann)
Stochastic Processes (Doob, Lévy)
Point Processes (Ripley)
Mobile Networks (Bar-Noy)
Data Mining (Giannotti & Pedreschi, Fayyad et al.)
Homophily (Schelling)
Deviance (Merton, Hirschi)
Network Science
Agent-Based Modeling (Epstein, Axtell)
Sociometry (Moreno)
Graph Theory (Euler)



http://www.wired.co.uk/magazine/archive/2013/05/features/as-one





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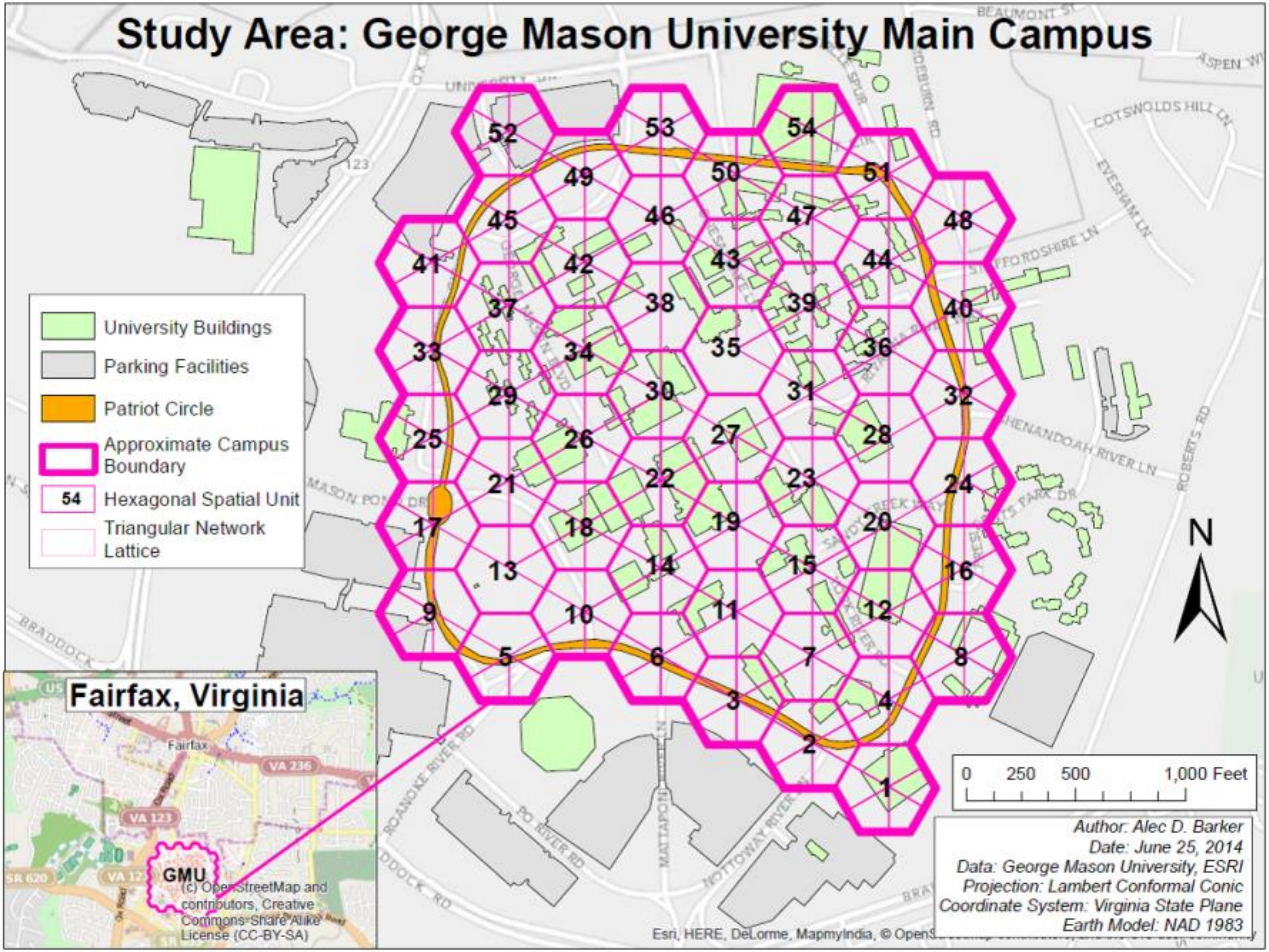
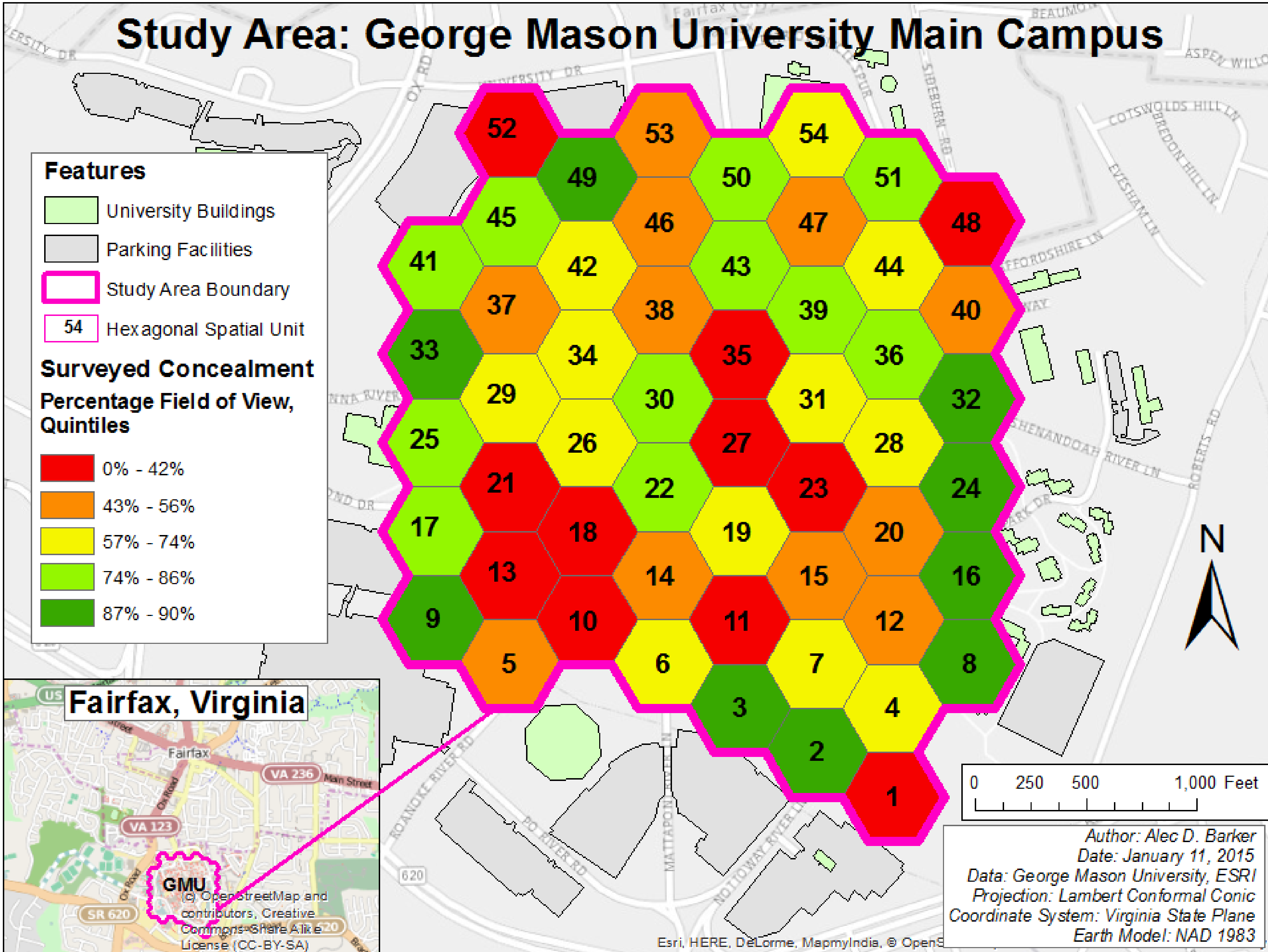
http://scilib.narod.ru/Avia/Shaw/images/image02-01.png

Methods

- The research design performed an experimental analysis of small team behaviors using:
  - simple games of team pursuit-and-evasion
  - network-based stochastic geosimulation
  - formal experimental design
  - measures including team success rates, “boundariness”
  - space-time permutation scan statistic given by Kulldorff et al., 2005
- We will compare these results to those of similar experiments involving human subjects, interactive games, and smartphone tracking to refine models, analyses, and conclusions



Study Area: George Mason University Main Campus
University Buildings
Parking Facilities
Patriot Circle
Approximate Campus Boundary
54
Hexagonal Spatial Unit
Triangular Network Lattice
Fairfax, Virginia
Fairfax
VA 236
VA 123
GMU
(c) OpenStreetMap and contributors, Creative Commons-Share Alike License (CC-BY-SA)
N
0
250
500
1,000 Feet
Author: Alec D. Barker
Date: June 25, 2014
Data: George Mason University, ESRI
Projection: Lambert Conformal Conic
Coordinate System: Virginia State Plane
Earth Model: NAD 1983
COTSWOLDS HILL LN
STAFFORDSHIRE LN
SHENANDOAH RIVER LN
ROBERTS RD
BEAUMONT ST
MASON POND DR
ROANOKE RIVER RD
PO RIVER RD
MATTAPONI
NOTTOWAY RIVER
BRADDOCK



Study Area: George Mason University Main Campus
Features
University Buildings
Parking Facilities
Study Area Boundary
54 Hexagonal Spatial Unit
Surveyed Concealment
Percentage Field of View, Quintiles
0% - 42%
43% - 56%
57% - 74%
74% - 86%
87% - 90%
Fairfax, Virginia
GMU
(c) OpenStreetMap and contributors, Creative Commons-Share Alike License (CC-BY-SA)
N
0 250 500 1,000 Feet
Author: Alec D. Barker
Date: January 11, 2015
Data: George Mason University, ESRI
Projection: Lambert Conformal Conic
Coordinate System: Virginia State Plane
Earth Model: NAD 1983

Data

- Geosimulation of a multi-agent system
- 1.11 million runs, June-November 2014

	Does Not Have Actionable Information	***Has Actionable Information***
Evader	CONCEALMENT MAXIMIZATION Maximizes concealment available at any of the seven nodes in the immediate area	RISK MINIMIZATION Minimizes risk by evaluating cumulative concealment, pursuer proximities, and information quality at each of the seven nodes in the immediate area
Pursuer	RANDOM SEARCH Applies random draws to movement preferences to determine if and where to move	COST MINIMIZATION Minimizes cost by evaluating cumulative distance required to move to a node where an evader(s) was observed and information quality

Data

Data Table	Data Fields
Game Outcomes	game serial number, game end time, number of evaders, number of evaders engaged
Player Movements	game serial number, turn, player, start cell, end cell, start latitude, start longitude, end latitude, end longitude
Player Communications	game serial number, turn, sender, message type, receiver, message cell, sender cell, receiver cell, message latitude, message longitude, sender latitude, sender longitude, receiver latitude, receiver longitude
Detections and Engagements	game serial number, turn, observer, target, result, observer cell, target cell, observer latitude, observer longitude, target latitude, target longitude
Cell Occupancies	game serial number, cell, number of occupants, turn, team

- The computer simulation models produced
  - .csv tables for analysis in R and SaTScan (5 per batch run)
  - .kml files for visualization in Google Earth (1 per batch run)
- These tables recorded game outcomes, player movements, player communications, detection and engagement events, and cell occupancies

Results

- Correlates of Team Success
  - The outcomes of a game of pursuit and evasion correlated most strongly with the basic probability that a pursuer would decide to move if the pursuer did not possess actionable information (P_Pmove).
  - The outcomes of a game of pursuit and evasion are also correlated with the interaction of the basic probabilities that a pursuer would decide to move and communicate (P_Pmove:P_Pcomm).

Results

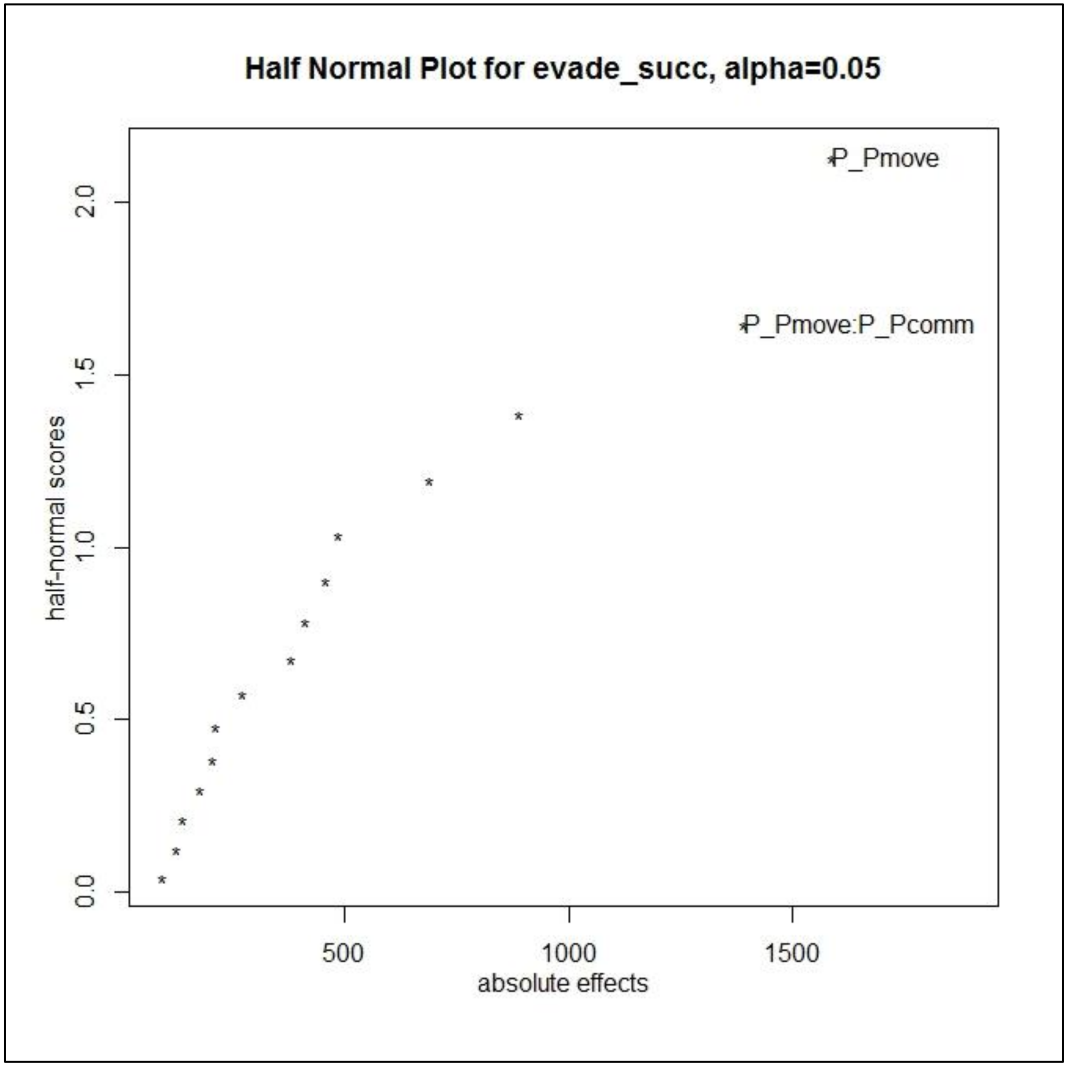


Figure 13: Half Normal Plot for Evader Success, Experiment Five, α= 0.05

Results

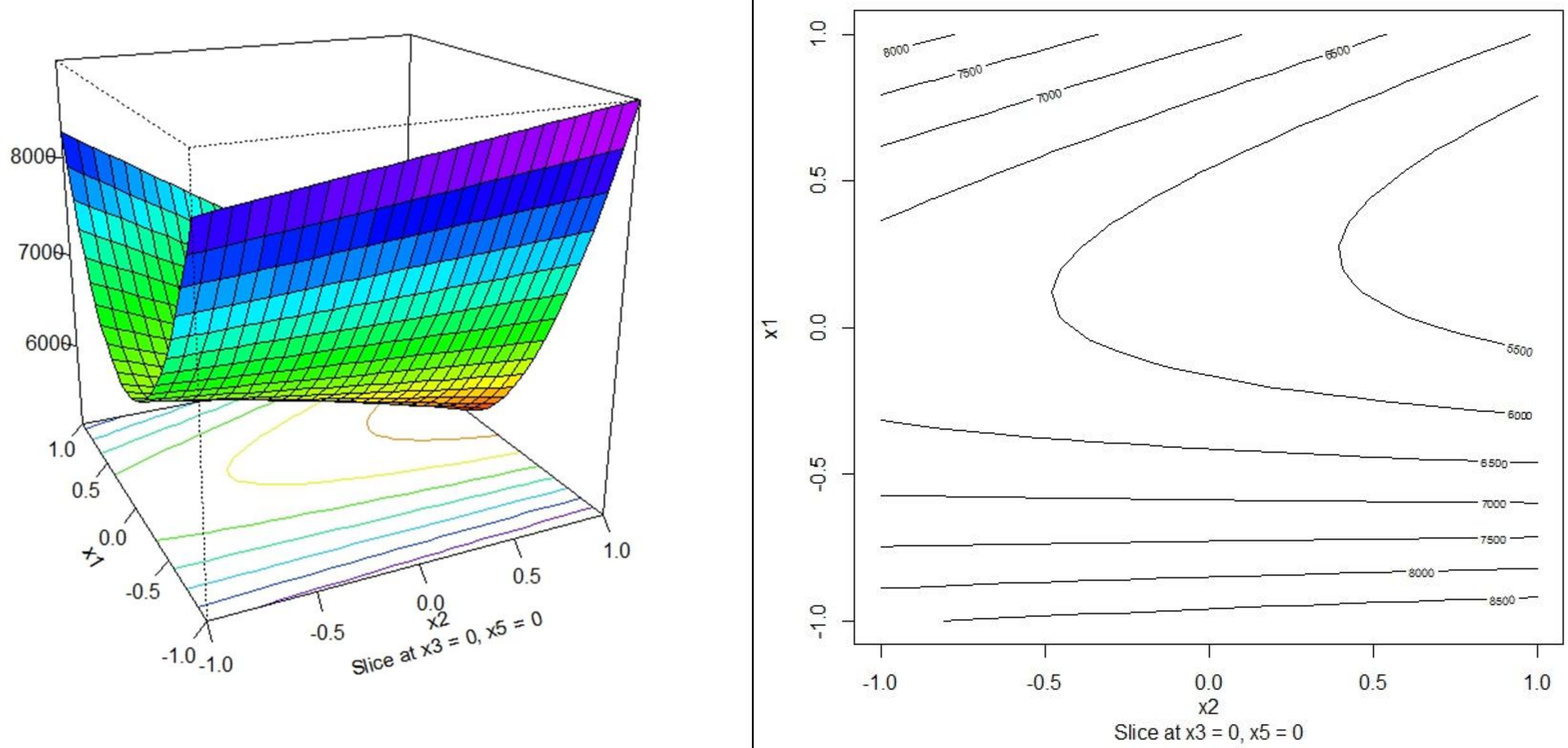
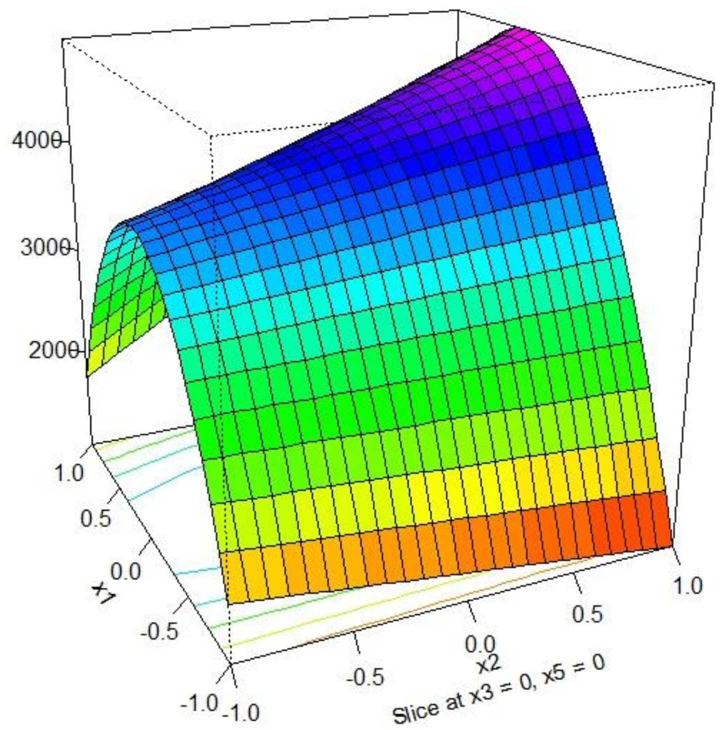


Figure 14: Response Surface Plot (3D) for Evader Success, Experiment Five, x1=P_Pmove, x2=P_Pcomm
Figure 15: Response Surface Plot (2D) for Evader Success, Experiment Five, x1=P_Pmove, x2=P_Pcomm

Results



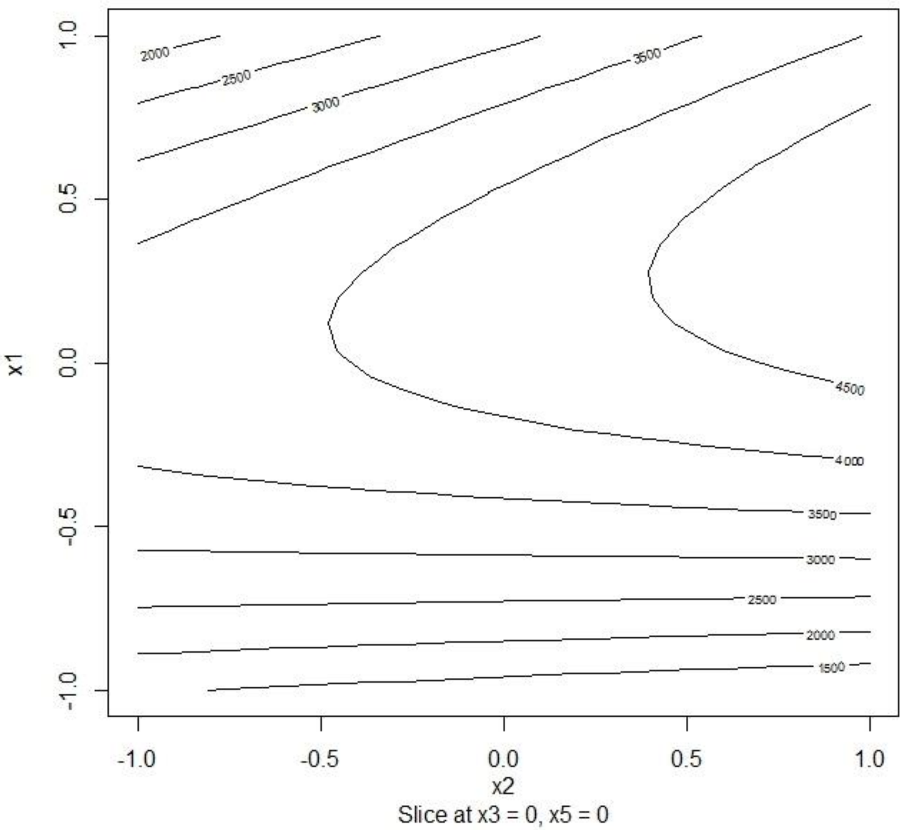


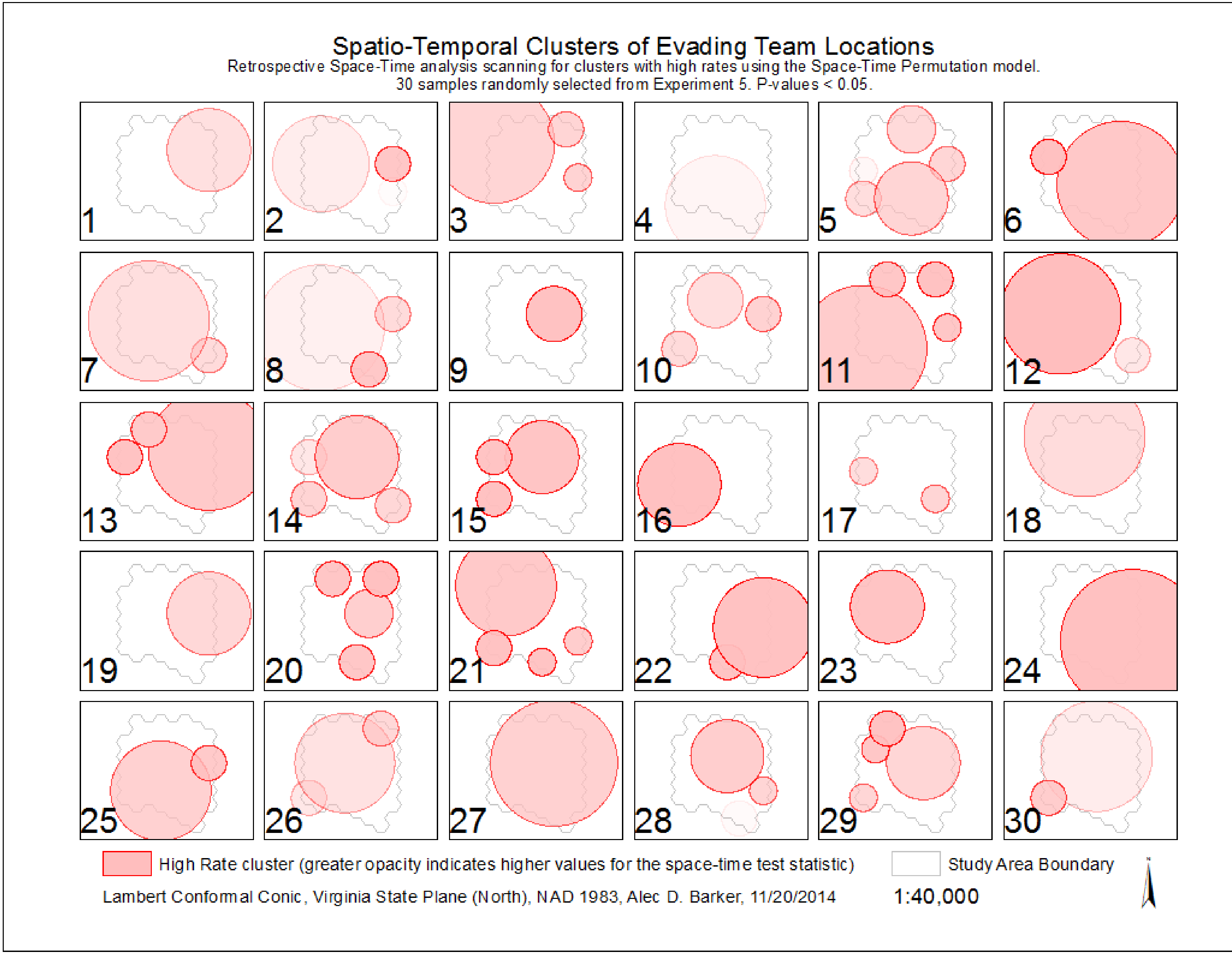
Figure 16: Response Surface Plot (3D) for Pursuer Success, Experiment Five, x1=P_Pmove, x2=P_Pcomm
Figure 17: Response Surface Plot (2D) for Pursuer Success, Experiment Five, x1=P_Pmove, x2=P_Pcomm

Results

- Spatiotemporal Clustering Behaviors
  - Evidence of spatiotemporal clustering in team movement behaviors is observable in thirty game repetitions randomly sampled from Experiment Five.
  - Spatiotemporal clustering behaviors were more strongly represented in the movements of the pursuing team; there were twice as many clusters observed in pursuit behaviors than there were in evasion behaviors, on average.

Table 15: Space-Time Clusters Observed in 30 Randomly Sampled Observations of Experiment Five.

Data Source			Pursuer		Evader	
Sample	Run	Game	Number of clusters	Maximum p-value	Number of clusters	Maximum p-value
1	13	9958	5	1E-17	1	1E-17
2	11	7182	4	1E-17	3	1E-17
3	5	9791	5	1E-17	3	1E-17
4	16	5404	5	4.7E-15	1	1E-17
5	10	6087	5	1E-17	5	1E-17
6	5	8185	3	1E-17	2	0.041
7	11	2367	4	1E-17	2	1E-17
8	4	4704	6	1.2E-15	3	0.0000013
9	3	4072	2	0.0000086	1	0.00074
10	16	1120	5	1E-17	3	1.7E-14
11	13	2999	3	1E-17	4	0.017
12	13	186	4	1E-17	2	1E-17
13	3	7178	5	0.028	3	0.0012
14	7	2915	4	3.2E-12	4	2.2E-16
15	9	3143	3	1E-17	3	0.017
16	9	5945	5	0.038	1	0.0033
17	9	2947	2	1E-17	2	1E-17
18	10	1364	5	0.000017	1	1E-17
19	4	6071	6	1E-17	1	1E-17
20	8	107	4	1E-17	4	0.033
21	17	4286	10	0.0083	4	0.00088
22	15	5314	3	0.0000011	2	0.0059
23	11	5716	7	1E-17	1	1E-17
24	8	9228	5	0.00031	1	0.0012
25	3	5874	4	0.00013	2	7.4E-11
26	17	8051	4	1E-17	3	1E-17
27	5	7666	5	1E-17	1	3.3E-16
28	4	227	12	0.0000023	3	1.4E-13
29	14	2015	4	0.018	4	0.0013
30	16	9306	5	1E-17	2	2.7E-10
		Mean	4.8	Mean	2.4	
		St. Dev.	2.007	St. Dev.	1.172	


Spatio-Temporal Clusters of Evading Team Locations
Retrospective Space-Time analysis scanning for clusters with high rates using the Space-Time Permutation model.
30 samples randomly selected from Experiment 5. P-values < 0.05.
1
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30
High Rate cluster (greater opacity indicates higher values for the space-time test statistic)
Study Area Boundary
Lambert Conformal Conic, Virginia State Plane (North), NAD 1983, Alec D. Barker, 11/20/2014
1:40,000

Results

- Boundary-Seeking Behaviors
  - There is very strong evidence for the primacy of boundaries and borders in the location decisions of teams engaged in pursuit and evasion.
  - Comparison of the “boundariness” values generated by team pursuit and evasion behaviors with different terrain models and random walk models support the idea that evading teams seek locations on areal boundaries, whether or not concealment is available in interior areas.
  - Consequentially, pursuing teams also occupy boundary locations more frequently than in random walk models.

Results

Two-sample means T-test

- Two-tailed:
  - H_0: $\mu_{observed} = \mu_{random}$, "A team's preference for boundary locations is not differentiable from random."
  - H_A: $\mu_{observed} \neq \mu_{random}$, "A team's preference for boundary locations is differentiable from random."
- One-tailed:
  - H_0: $\mu_{observed} = \mu_{random}$, "A team's preference for boundary locations is not differentiable from random."
  - H_A: $\mu_{observed} > \mu_{random}$, "A team's preference for boundary locations both is differentiable from and higher than random."

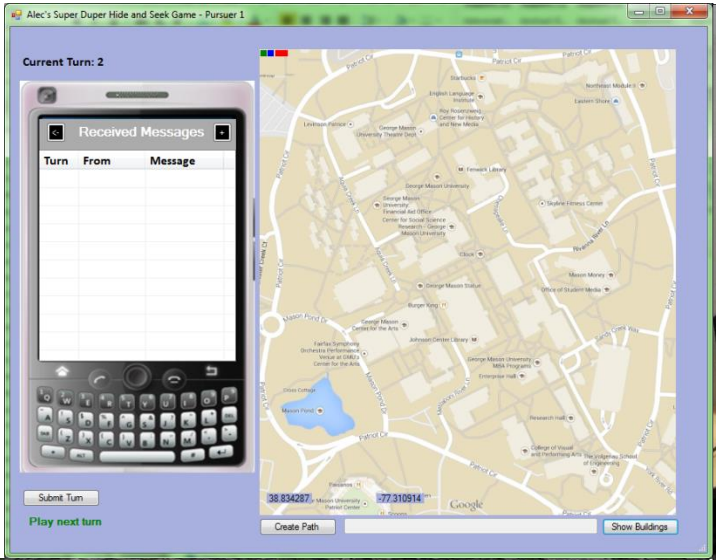
	Experiment 2		Experiment 3		Experiment 5		Experiment 6		Experiment 7
Run	Evader	Pursuer	Evader	Pursuer	Evader	Pursuer	Evader	Pursuer	Random
1	0.745243	0.437785	0.747625	0.473693	0.427666	0.41072	0.557908	0.436546	0.3617195
2	0.716672	0.435616	0.731902	0.473082	0.379184	0.423246	0.523888	0.440672	0.3616914
3	0.718161	0.467971	0.740573	0.510539	0.431903	0.385001	0.509368	0.42902	0.3615570
4	0.757495	0.40434	0.749876	0.424862	0.37989	0.385739	0.58365	0.403029	0.3621451
5	0.706365	0.410647	0.693366	0.44947	0.409219	0.385395	0.554271	0.416335	0.3613460
6	0.714624	0.362571	0.68063	0.393282	0.482891	0.391856	0.516605	0.4235	0.3615560
7	0.619595	0.372221	0.502997	0.400789	0.467643	0.384978	0.471066	0.405611	0.3616221
8	0.601929	0.361069	0.426233	0.3575	0.363661	0.401757	0.577876	0.455626	0.3617681
9	0.682364	0.372156	0.636885	0.390206	0.510204	0.412654	0.507393	0.438567	0.3621159
10	0.742302	0.436982	0.747625	0.473693	0.427666	0.41072	0.557908	0.436546	0.3613275
11	0.698811	0.388055	0.640571	0.402561	0.367475	0.384794	0.492543	0.403252	0.3622756
12	0.658497	0.424791	0.444116	0.39109	0.543561	0.391737	0.493704	0.379481	0.3628125
13	0.723792	0.438443	0.736214	0.462884	0.410428	0.425522	0.574341	0.41044	0.3615151
14	0.728494	0.419683	0.743341	0.44366	0.524338	0.383842	0.496282	0.40623	0.3611688
15	0.716022	0.469493	0.669375	0.427942	0.382647	0.410059	0.591107	0.443881	0.3615015
16	0.731489	0.419389	0.618321	0.403805	0.405783	0.388175	0.585851	0.413283	0.3617325
17	0.636518	0.384479	0.479059	0.380971	0.397534	0.405959	0.575319	0.423974	0.3632115
18	0.771624	0.393543	0.764216	0.429962	0.545204	0.386733	0.575508	0.381981	0.3616566
19	0.746039	0.437359	0.74868	0.475293	0.427666	0.41072	0.557908	0.436546	0.3608473
Mean	0.706107	0.412452	0.657979	0.429752	0.43603	0.398927	0.542237	0.420238	0.3617668
Std.Dev.	0.046738	0.033199	0.112895	0.04102	0.05619	0.013462	0.036524	0.019677	0.0005264
t Stat	31.93491	6.616392	11.40215	7.168108	5.464802	11.3746	20.41046	12.18945	
P(T<=t) one-tail	1.33E-17	1.64E-06	5.72E-10	5.64E-07	1.72E-05	5.94E-10	3.39E-14	1.96E-10	
t Critical one-tail	1.734064	1.734064	1.734064	1.734064	1.734064	1.734064	1.734064	1.734064	
P(T<=t) two-tail	2.65E-17	3.27E-06	1.14E-09	1.13E-06	3.43E-05	1.19E-09	6.78E-14	3.92E-10	
t Critical two-tail	2.100922	2.100922	2.100922	2.100922	2.100922	2.100922	2.100922	2.100922	

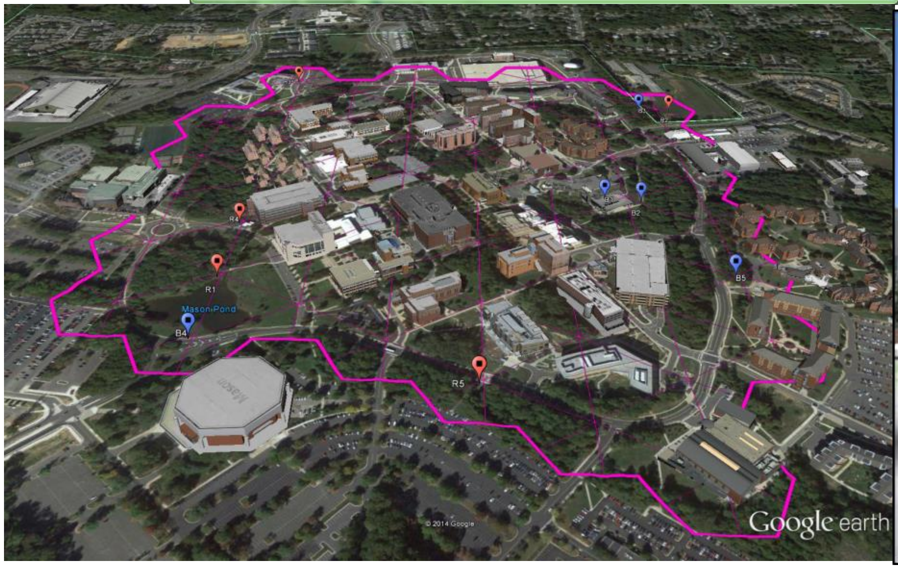
Table 16: Analysis of Boundary-Seeking Behaviors (α=0.05, 18 DF)

Conclusions

- This project began with three fundamental lines of inquiry to produce a basis for a much larger analytical framework that will be useful for understanding how groups of people move and communicate in pursuit of their collective goals.
- This project provides evidence for several conclusions and hypotheses resulting from those three lines of inquiry:
  - Correlates of team success
  - Spatiotemporal clustering behaviors
  - Boundary-seeking behaviors
- These conclusions pertain exclusively to the computer simulation model and comparative empirical research remains necessary to understand real-world implications thereof.
  - Lab-based interactive computer games and human subjects
  - Full-scale games with smartphone tracking in the real world

Future Research





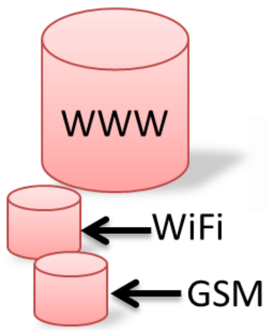
Future Research

Smartphone-based Reality Mining for Geographic Dynamics of Goal-Directed Social Behaviors

Analysis Platform	Data Relay	Sensor Hardware	Sensor Software	Human Behaviors

Research Metrics
Geographic
Social
Σ=

- -Researcher PC
- -Custom analysis package built in R
- -Commercial GIS, spatial statistics, social network, and statistics software
- -Imports .xml to analysis interface from secure server



- -Secure remote server
- -Receives data via the mobile network and/or the wireless network using HTTPS and SSL security
- -Stores .xml in a single-use directory
- -Also receives and stores Redpin IPS queries

- -12x ZTE Concord
- -Owned, registered, and configured by the researcher
- -Android 2.3 OS
- -GPS, Camera
- -64GB Memory
- -1700 mAh
- -Unlimited data plan
- -$60 each + $3 per day

RM Beacon
Reports location, time, calls, text, web, and email via .xml

Call Recorder
Locally stores a voice record of all calls

Redpin IPS
Captures indoor location (room-level)

Other
Gmail
Internet browser

- -Owned, installed, registered, and configured by the researcher
- -Autorun in background
- -Custom-developed, open-source, and/or low-cost software

- swarm
- disperse
- join
- leave
- lead
- follow

et cetera...

Future Research

- Applied Research and Development
  - Transportation and Urban Planning
  - Disaster Response and Recovery
  - Criminology and Law Enforcement
  - Targeting and Decision Support in Irregular Warfare
  - Migration, Trade, and Trans-border Communication
  - Cohesion and Culture
  - Art, Taste, and Influence Networks
  - Economics and Society

Future Research

- Sustained Basic Research
  - Exploring variables of demographics, culture, terrain, goal type, leadership, affiliation, cohesion, and diurnal rhythm
  - Repeating the series of computer-simulated, table-top, and full-scale experiments in various locations, such as urban, suburban, or rural settings in domestic and foreign environments
  - Recruiting experiment participants from a demographically varied subject pool, thereby assessing the influence of age, place of origin, or terrain familiarity
  - Investigating leadership, cohesion, and affiliation via controlled interventions in team organization
  - Understanding different combinations of competitive behaviors like smuggling-and-interdiction or security-and-infiltration

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