Handguns and Hotspots
Cellular Automata: Models for Gun Crime in Chicago, IL

Shelby Scott
Department of Ecology and Evolutionary Biology
University of Tennessee, Knoxville

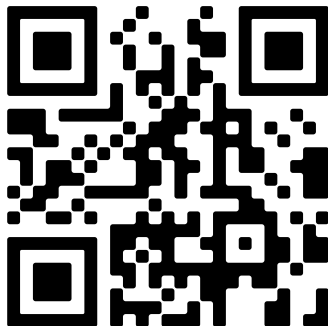15 January 2020

Acknowledgements

- Amanda, Christina, Heather, and Katie
- UTK Department of Ecology and Evolutionary Biology
- Dr. Louis J. Gross*, Dr. Nina Fefferman, Dr. Sergey Gavrilets, Dr. Suzanne Lenhart
- Funding: ASEE NDSEG Fellowship, NIH/NIGMS - IMSD #R25GM086761

shelbymscott.github.io

Overview

The Cost of Gun Violence in the United States

- Gun violence costs the United States $229 billion annually
- It leads to the death of 36,000 individuals and the non-fatal injury of 85,000 others
- Homicide is the leading cause of death in black males aged 10-24

- 75% of homicides involve the use of a firearm
- (Kellerman 1993) Having a gun in the home increases the risk for homicide occurring in the home
- (1996) Dickey Amendment removes CDC funding for gun violence research
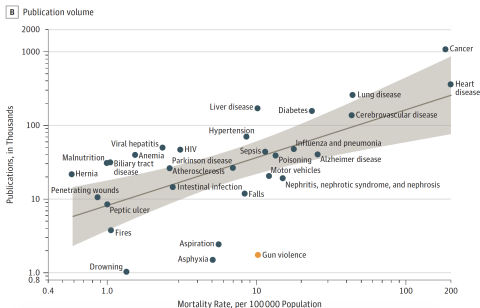
Individual Cost of Gun Violence

- Adults reporting exposure to gun violence as children showed an increased likelihood for chronic health conditions and risky behaviors

| Health Outcome	Risk Increase
Heart Disease	2.2
Stroke	2.4
Chronic obstructive lung disease (COPD)	3.9
Hepatitis	2.4
Ecstasy Use	9.2
Marijuana use	2.9
Poor mental health	2.7
Involvement in juvenile justice system	3.5
Use of substances during sex	6.5
Lack of condom use during sex	2.2

Byrdsong 2016 and Voisin 2016

The Impact of Gun Crime in Chicago

- Past studies have shown a diffusion of gun crime in both space and time
- Between 2015 and 2016 there was a 68% increase in gun crimes, disproportionately affecting disadvantaged neighborhoods
- Data used for this study:
  - Chicago city crime dataset, 2001 - 2017
  - Selected socio-economic indicators in Chicago, 2008 - 2012

Chicago Gun Crimes from 2001–2018
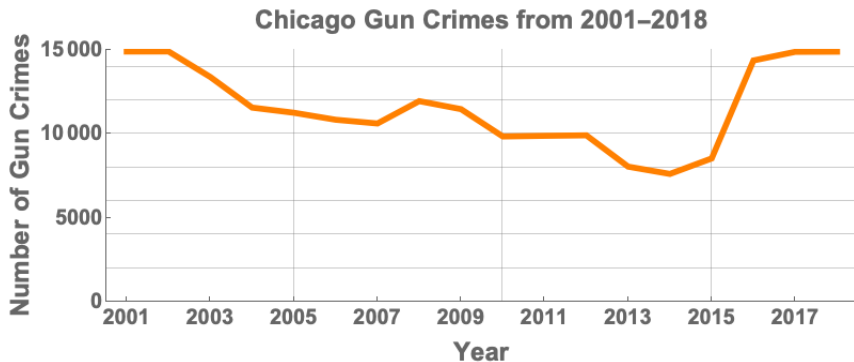
Cellular Automata

- *Cellular automata*: consist of a lattice of cells, each existing in a state. Simple local rules govern how these states change over time.
- Discrete in time and space
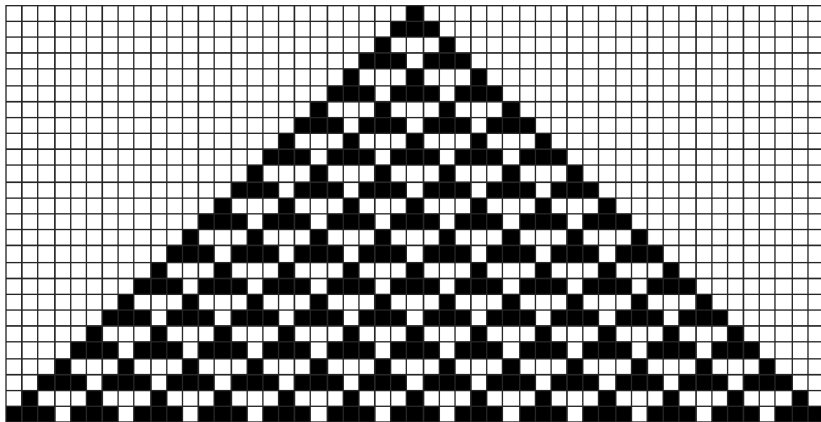- Simplest CA: one-dimensional with two states "on" and "off."

1	0	0	1	1	0	1	0	1	0	1	time T

⇓

0	1	0	1	0	0	0	1	0	1	1	time T+1
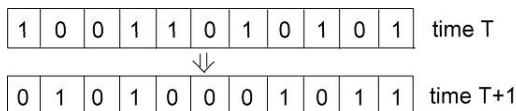
Sum	Example	New Value
5	11111	0
4	11101	1
3	01101	0
2	10001	1
1	01000	0
0	00000	0

http://eric_rollins.home.mindspring.com/introProgramming/hw5.html

Rule 54

Rule 30
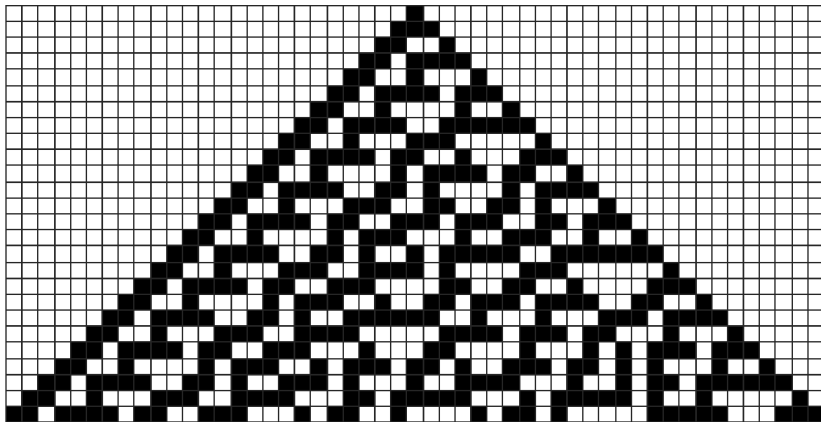
Applying Cellular Automata to Gun Crime in Chicago

- Spatial units $\rightarrow$ community areas of Chicago
- Temporal units $\rightarrow$ weeks
- Cell states $\rightarrow$ level of crime present
- Transition rules $\rightarrow$ depend on internal factors and on neighborhood influences
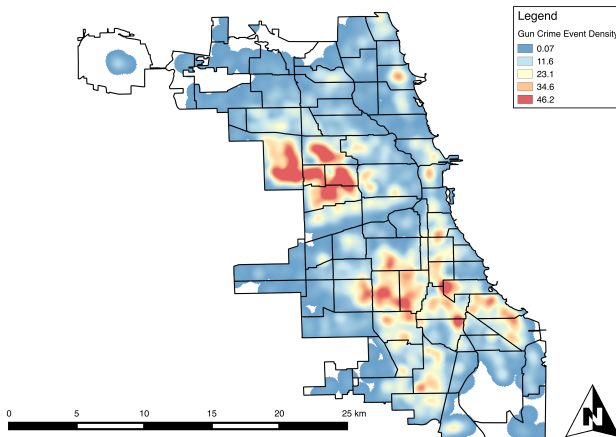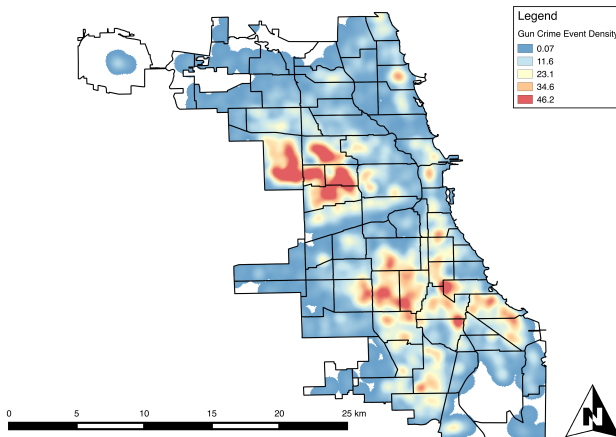
Applying Cellular Automata to Gun Crime in Chicago

- Spatial units → community areas of Chicago
- Temporal units → **weeks**
- Cell states → level of crime present
- Transition rules → depend on internal factors and on neighborhood influences

Temporal Patterns of Gun Crime in Chicago

Holidays are anecdotally associated with high gun crime and gun violence in Chicago, but these claims have not been tested.

> Labor Day violence: Shootings sharply up as fewer Chicago police officers deployed on streets than last year

> At least 43 people shot in Chicago over Memorial Day weekend. 'Unacceptable state of affairs,' new mayor says

> **6 Killed, 66 Hurt in July 4th Weekend Shootings in Chicago**

Assessing Holiday Influences

- Method: t-test comparing the average number of gun crimes on each holiday to the average number of daily crimes in the holiday's month
- Data: Chicago City Crime dataset
- Results:

| Holiday	Month	p-value	σ	t-stat	Result
New Year's Eve	December	0.43	8.83	0.80	0
New Year's Day	January	9.8523×10^{-5}	8.07	4.41	1
Memorial Day	May	0.33	11.17	1.00	0
July 4$^{\text{th}}$	July	0.58	10.11	0.56	0
Labor Day	September	0.69	9.28	0.40	0
Halloween	October	0.09	10.73	1.73	0
Thanksgiving	November	4.05×10^{-5}	7.41	-4.71	1
Christmas	December	3.04×10^{-7}	5.72	-6.35	1

Implications for Cellular Automata Model

- We can expect higher rates of gun crime on New Year's Day and lower levels on Thanksgiving and Christmas
- There are also seasonal variations in gun crime associated with temperature and precipitation
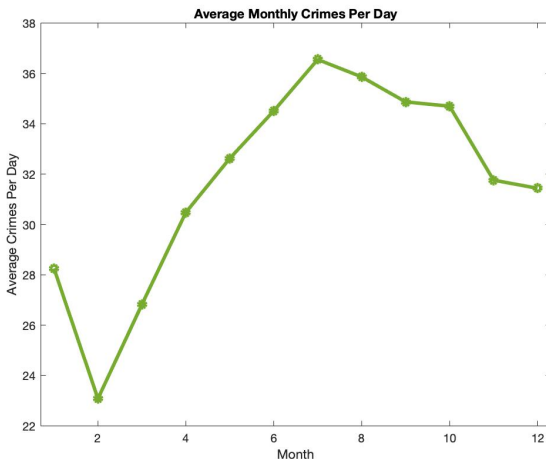
Average Monthly Crimes Per Day

Applying Cellular Automata to Gun Crime in Chicago

- Spatial units → community areas of Chicago
- Temporal units → weeks
- Cell states → **level of crime** present
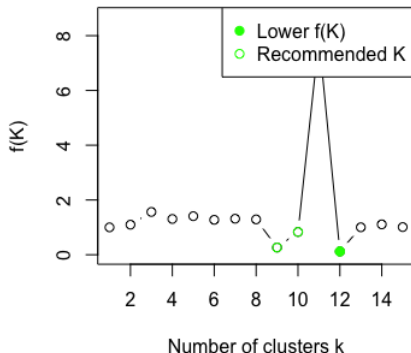- Transition rules → depend on internal factors and on neighborhood influences

Legend

Gun Crime Event Density
- 0.07
- 11.6
- 23.1
- 34.6
- 46.2
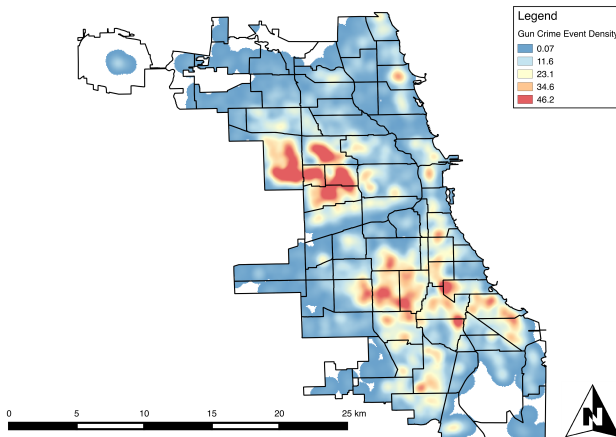
Determining Number of States

- Purpose: find the appropriate number of states based on clusters of average gun crime
- Method: k-selection algorithm
- Result: There are 12 different levels of gun crime, which can then be categorized into low, medium, and high categories.

f(k) finds 12 clusters

Applying Cellular Automata to Gun Crime in Chicago

- Spatial units $\rightarrow$ community areas of Chicago
- Temporal units $\rightarrow$ weeks
- Cell states $\rightarrow$ level of crime present
- Transition rules $\rightarrow$ depend on **internal factors** and on neighborhood influences
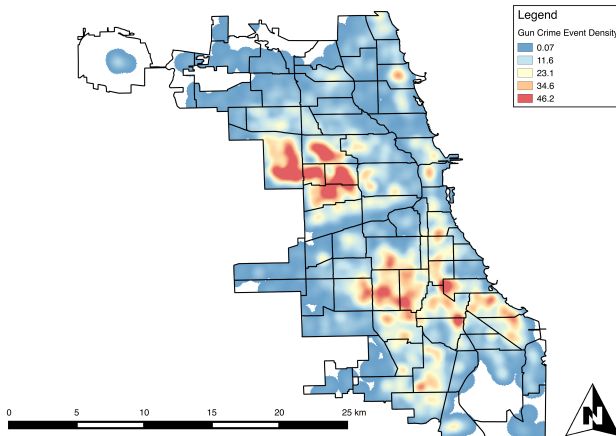
Which socio-economic conditions impact the number of gun crime events?

- Method: Negative Binomial Regression with Subset Selection
- Factors tested:
  - Crowding
  - Poverty
  - Unemployment
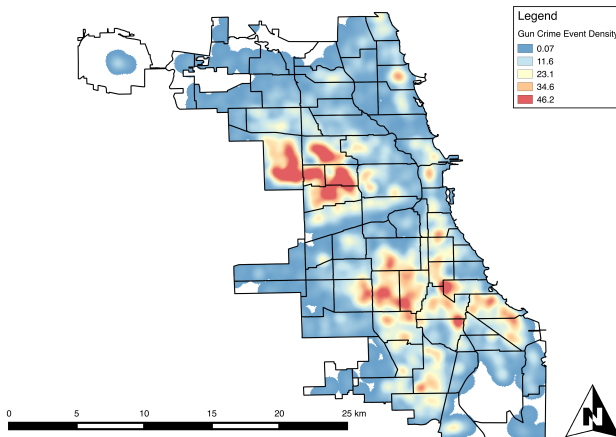 - Education level
  - Dependents
  - Per capita income

Predictor	Coefficient
Poverty	1.0344
Unemployment	1.1123
Dependents	- 0.9477

Regression Results

$log(\text{\# Gun Crimes}) = 4.1258 + 0.0338 * \text{poverty} + 0.1064 * \text{unemployment} - 0.0537 * \text{dependents}$

Applying Cellular Automata to Gun Crime in Chicago

- Spatial units → community areas of Chicago
- Temporal units → weeks
- Cell states → level of crime present
- Transition rules → depend on internal factors and on **neighborhood influences**

Does gun crime spread in both space and time?

- Method: Bayesian spatio-temporal point process (Loeffler and Flaxman 2017)
- Goal: Distinguish between clustered but non-diffusing gun crime and clustered gun crime resulting from diffusion
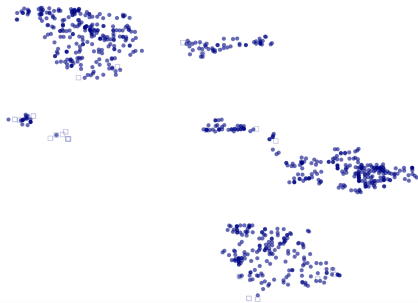
Conditional Intensity

$$\lambda(x,y,t) = m_0 \mu(x,y,t) + \theta \sum_{i:t_i<t} \omega \exp(-\omega(t-t_i)) \frac{1}{2\pi\sigma^2} \exp(-((x-x_i)^2) + (y-y_i)^2/(2\sigma^2))$$

- Triggering kernels for both time (t) and space (x,y)
- $\mu(x,y,t)$: background intensity, weighted by m_0
- θ: the average number of shootings triggered by any particular shooting
- σ: spatial length scale
- ω: temporal length scale

Subset of Chicago data

Community Areas 20–25 2008

- Overall question: Do gun crimes "trigger" one another in space and time?
- Answer: **yes**
- For every 100 crimes observed at a given location, we expect the next 93 crimes that occur to be caused by the initial 100 crimes
- We expect them to happen very soon after ($\sim$12 hours) and within a close geographic radius ($\sim$1.6 km).

Conclusions

- Are there temporal patterns of gun crime in Chicago?
  - Yes.
  - New Year's Day, Thanksgiving, and Christmas are associated with significantly different numbers of gun crime compared to the rest of the months
  - There are also influences of temperature and precipitation
- Which socio-economic conditions impact the number of gun crime events?
  - Poverty $(+)$
  - Unemployment $(+)$
  - Dependents $(-)$
- Does crime diffuse in both space and time?
  - Yes
  - A majority of crimes (93%) are triggered by past crimes and future crimes occur relatively close to past crimes

Future Work

- Incorporate statistical results into cellular automata model

- Apply methods of control to cellular automata - accepting ideas!

- Create evidence-based policy recommendations of how to best combat gun crime in Chicago

- Extend these ideas to other cities and countries to reduce the burden of firearm-induced violence

NIMBioS
National Institute for Mathematical and Biological Synthesis

Questions?