

Disease Risk and Diffusion

Lecture #20 | GEOG 510
GIS & Spatial Analysis in Public Health
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Outline

- Disease Spread Diffusion
- Expansion vs. Relocation diffusion
- Network-based diffusion
- Herd Immunity
- Simulation model (demo)
- Spatial interaction
- Other diffusion approaches

Big Question(s)

- Diffusion and Spread
 - How does a disease move (or not) across space (and time)
 - Pattern
 - How are disease patterns different at different times?
 - Process
 - What drives **changes** in disease patterns?
 - 1st and 2nd order processes

Big Question(s)



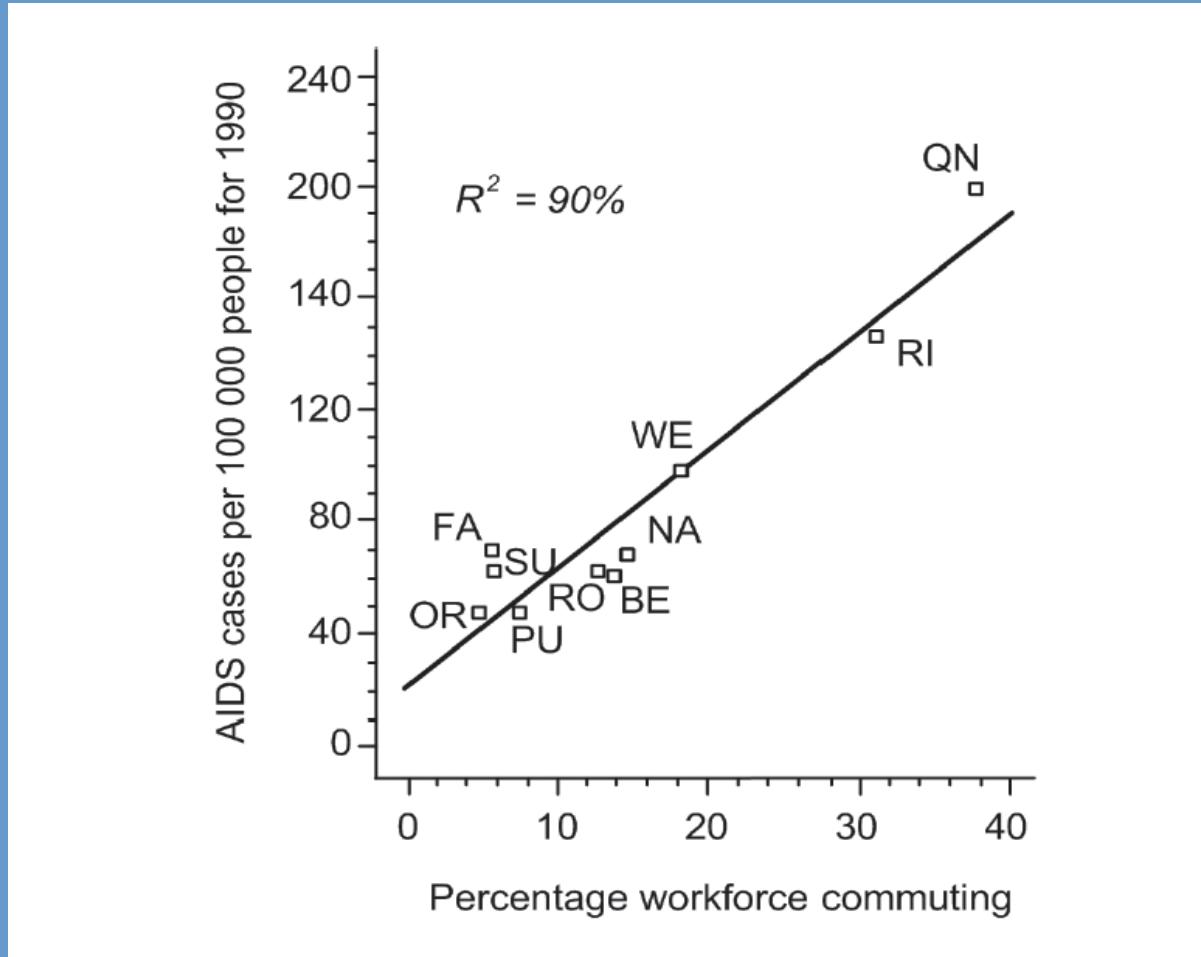
Can we predict/model disease spread?

Spatial Diffusion

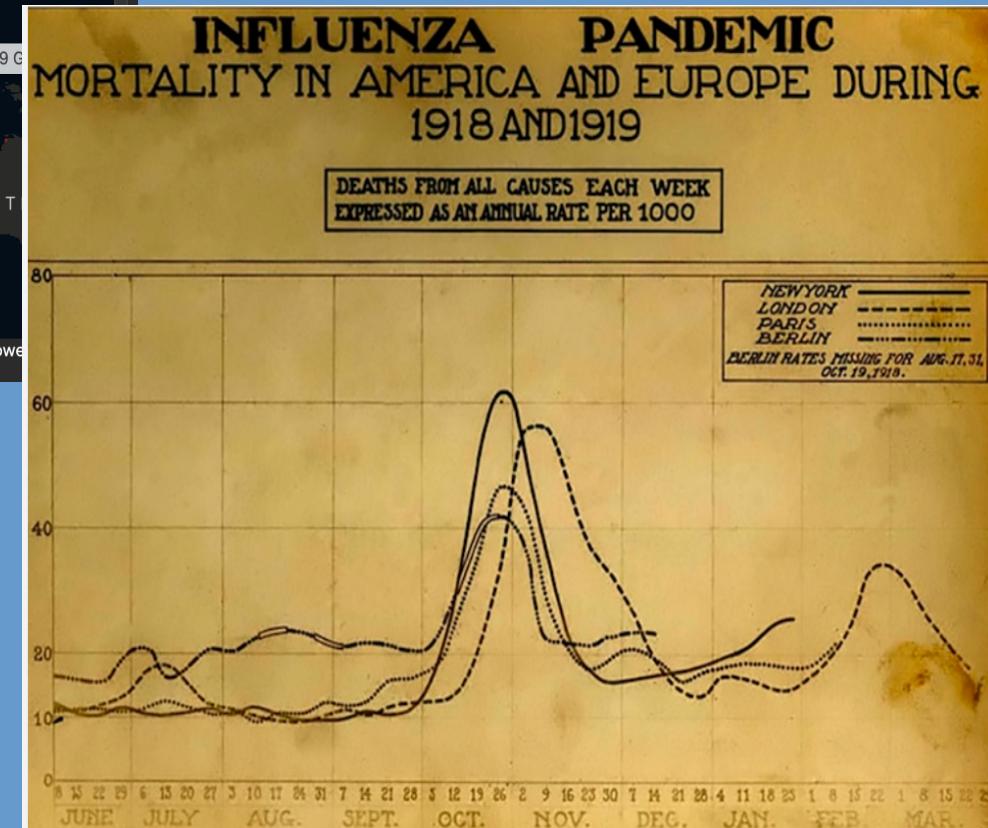
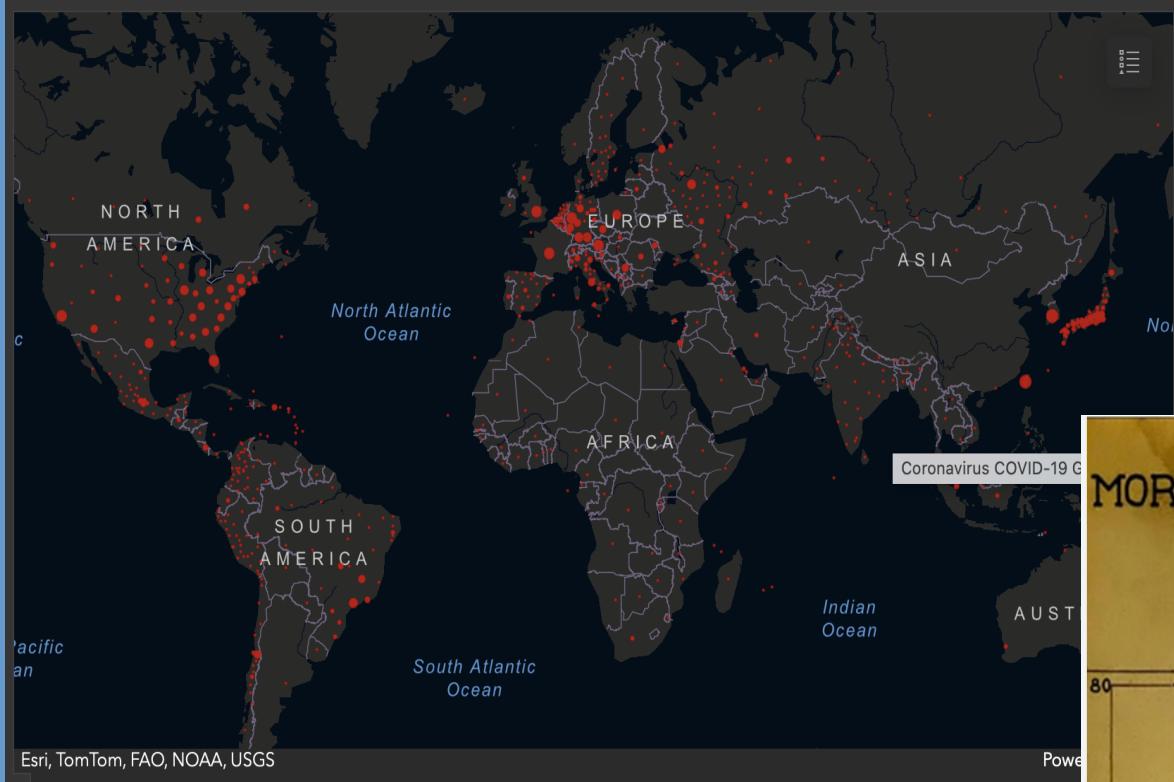
- Expansion
 - Disease remains in the source location over time
 - Often intensifies
- Relocation
 - Disease vacates the source location(s) over time
- Importance of Time
 - Cannot ascertain diffusion without time

Spatial Diffusion

Spatial Diffusion



Expansion Diffusion



May also be called
“contagious diffusion”

Relocation Diffusion

In Haiti, Global Failures on a Cholera Epidemic

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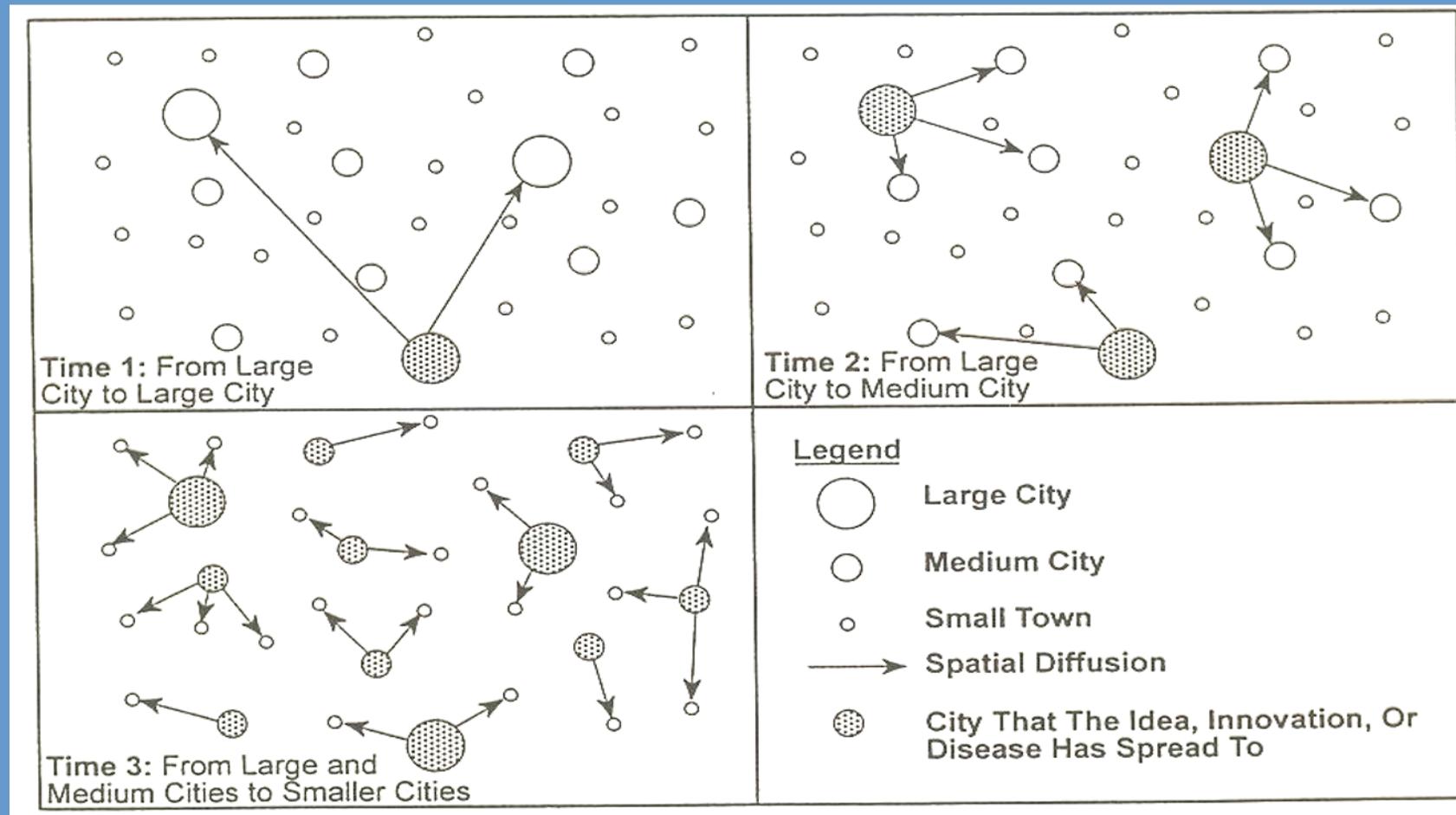


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Hierarchical Diffusion

Disease spreads through an ordered sequence of places (urban hierarchy)



Hierarchical Diffusion

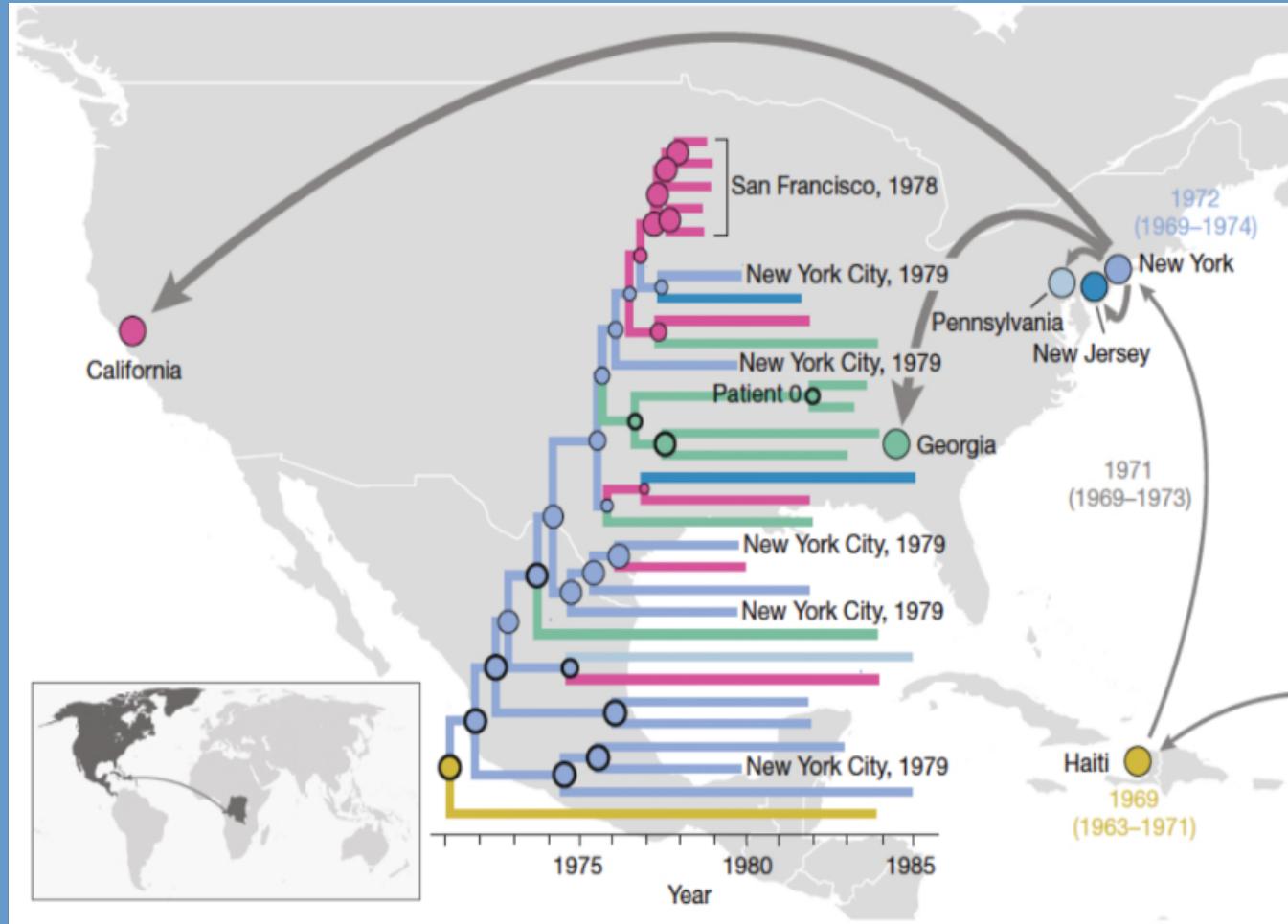
America's HIV outbreak started in this city, 10 years before anyone noticed

[Science](#) Oct 26, 2016 3:59 PM EDT

HIV arrived in New York City precisely 10 years before doctors first noticed the disease, a conclusion that's based on new research published [today in Nature](#). The finding solves a 35-year-old mystery surrounding the origins of America's outbreak, the first in the world to be noticed by doctors.

It indicates the virus passed from the Caribbean to New York in the early 1970s, where the disease gained a foothold for at least half a decade, before triggering outbreaks in places like San Francisco. The study also clears the name of Gaëtan Dugas, so-called "Patient Zero," who had been wrongly blamed for bringing the virus to U.S. shores.

Hierarchical Diffusion



Network Diffusion

Disease primarily spreads through networks (transport, social, food)



Network Diffusion

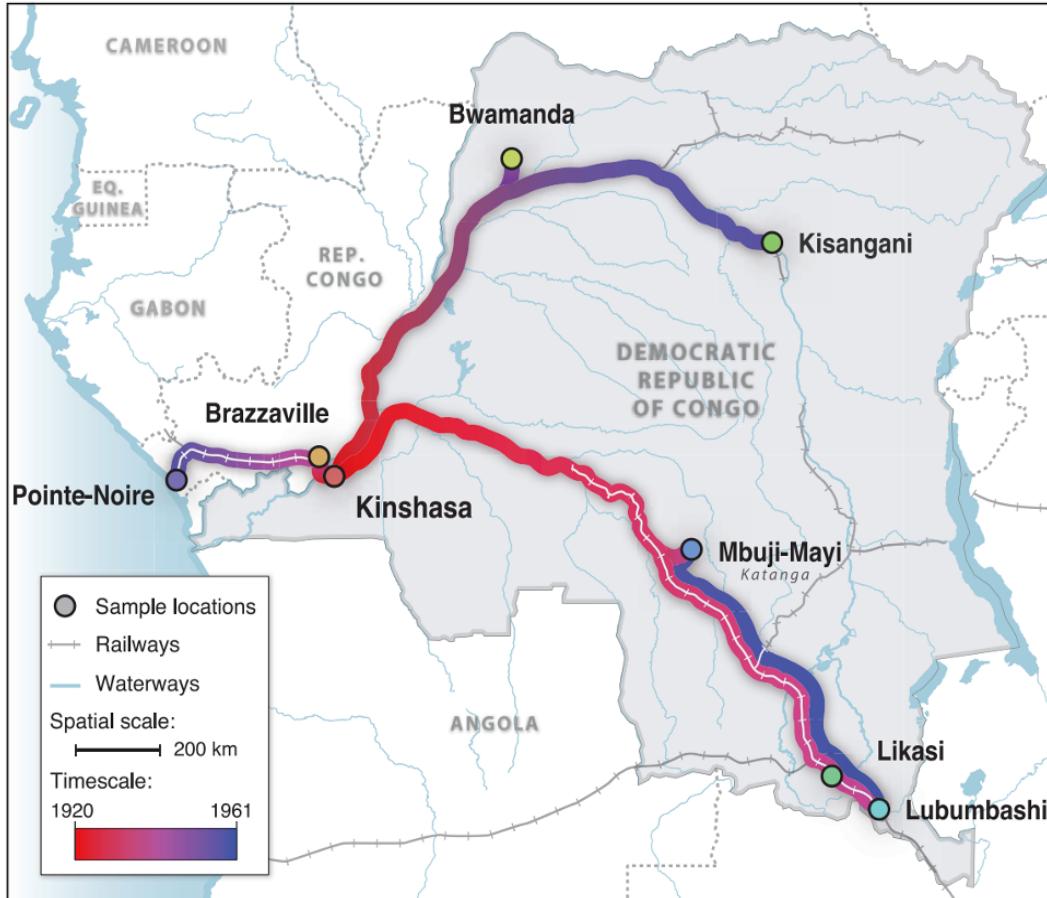
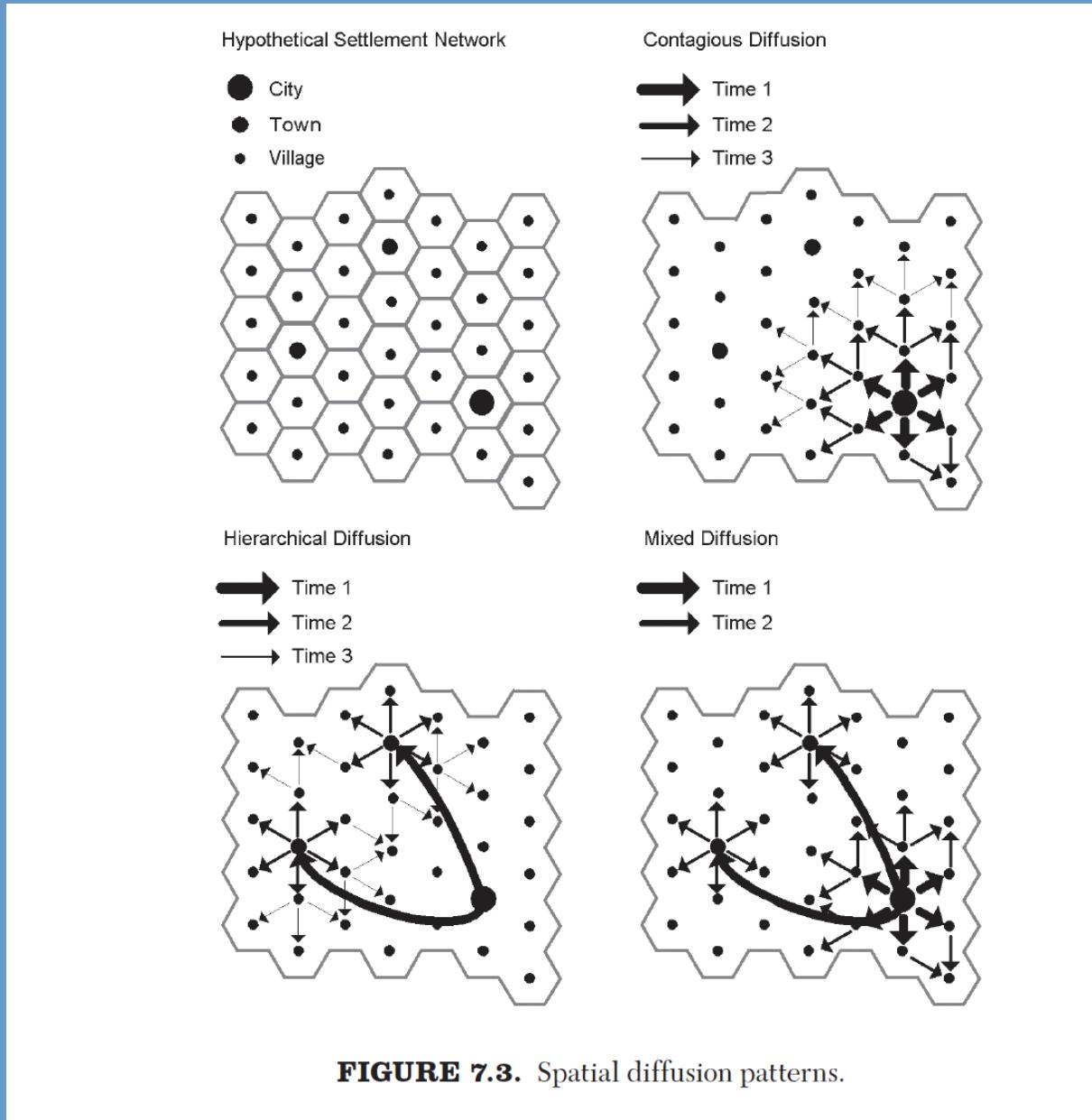


Fig. 2. Spatial dynamics of HIV-1 group M spread. Circles represent sampled locations and are colored according to the estimated time of introduction of HIV-1 group M from Kinshasa. Strongly supported rates of virus spatial movement (table S6) are projected along the transportation network for the DRC (railways and waterways), which was fully operational until 1960 (38). Gradient colors depict the time scale of spatial movements (bottom left).

The hidden history of the HIV pandemic

Rail and river transport in 1960s Congo, combined with the sexual revolution and changes in health care practices, primed the HIV pandemic. Faria *et al.* unpick the circumstances surrounding the ascendancy of HIV from its origins before 1920 in chimpanzee hunters in the Cameroon to amplification in Kinshasa. Around 1960, rail links promoted the spread of the virus to mining areas in southeastern Congo and beyond. Ultimately, HIV crossed the Atlantic in Haitian teachers returning home. From those early events, a pandemic was born.

Mixed Diffusion



Modeling Diffusion

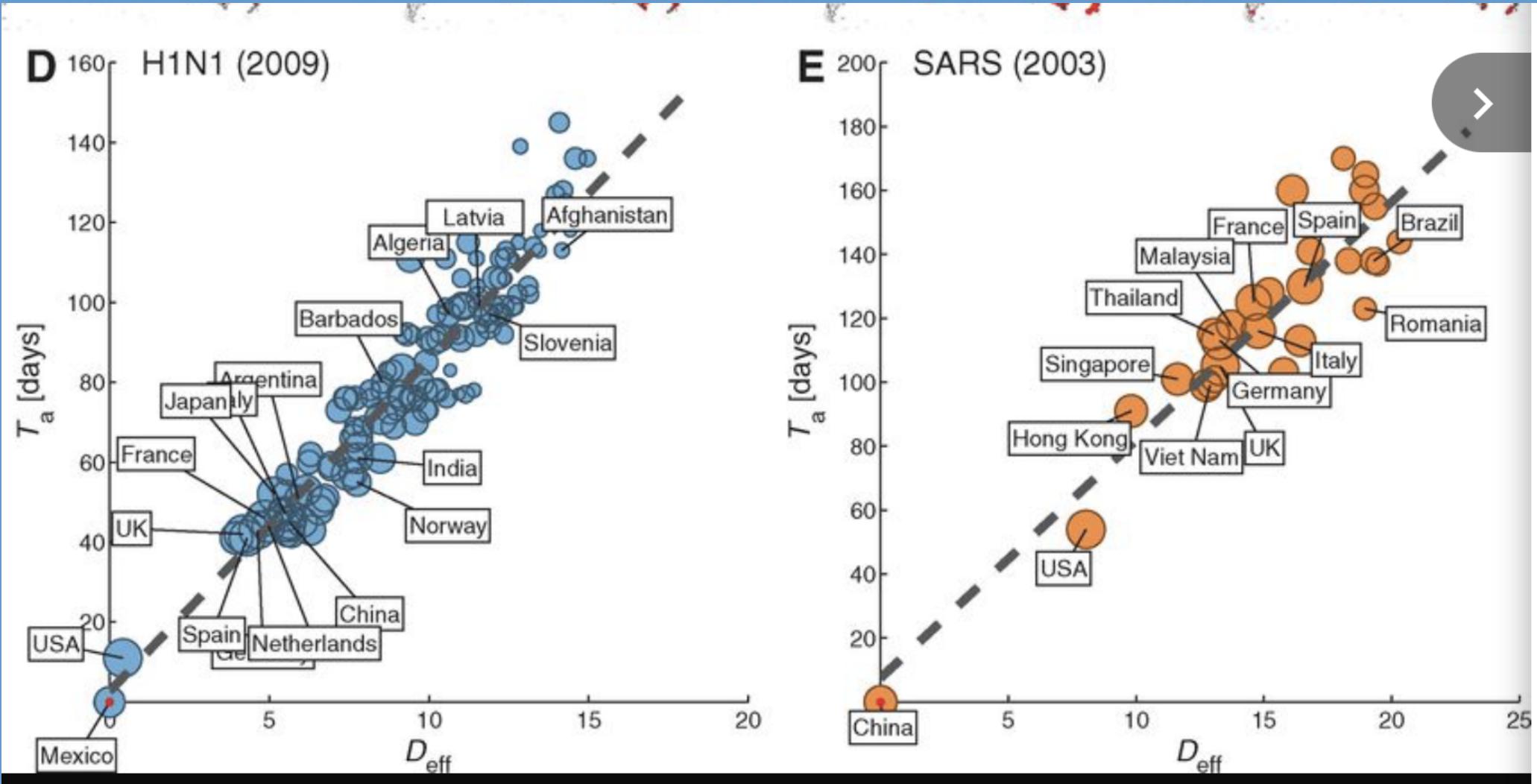
- Simulation models
 - Agent-based, spatially aware models
 - Agents are independent actors
 - Generally, local in scale
 - Simulate individuals movement through space and time
 - Chance of interaction and disease transmission
 - Supplemental Slide
 - Fred (<https://fred.publichealth.pitt.edu>)

Modeling Diffusion

- Spatial interaction models
 - Gravity model
 - Interaction (F) among places modeled as a function of:
 - Size (population, p)
 - Distance (d)

$$F = G \frac{p_1 p_2}{d^x}$$

Modeling Diffusion



Source: Brockmann et al., 2013

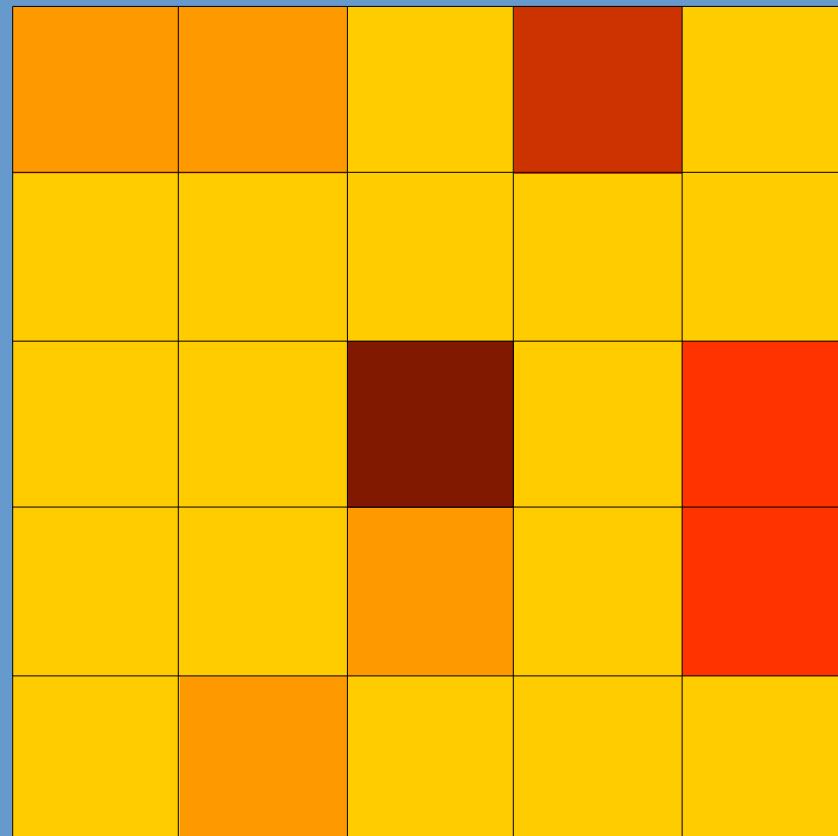
Approaches

- Cohen and Tita (1999)
 - LISA analysis on cross sectional crime data
 - Evaluate the transitions between LISA categories (time $t-1$ to time t)
 - HH, HL, LL, LH
 - High-high, High outlier, Low-low, Low outlier

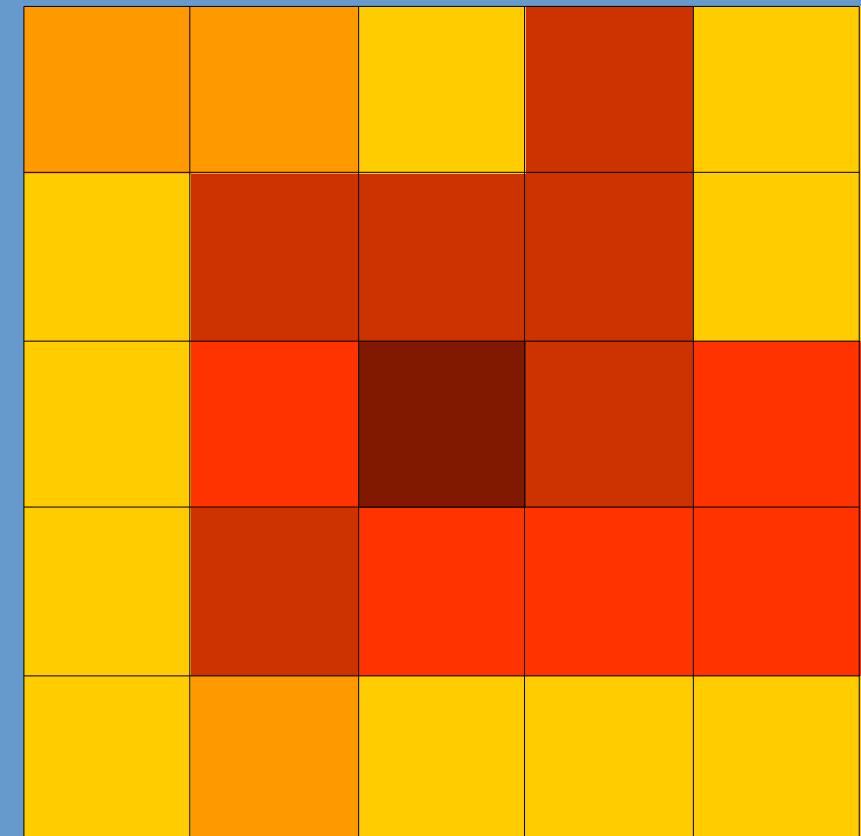
Table II. Dynamics of Change in Spatial Distribution of Homicide Rates Over Successive Observations

Direction of change	Type of diffusion	Mechanism of change	Year-to-year change in <i>local-neighbor</i> pairs	
			Local is diffusion outcome	Local is diffusion source
From low to high levels	Contagious	Expansion among Neighbors Relocation among neighbors Isolated increase Global increase	LH to HH LH to HL LL to HL LL to HH	HL to HH HL to LH LL to LH LL to HH
	Hierarchical			
From high to low levels	Contagious	Expansion among neighbors Relocation among neighbors Isolated decrease Global decrease	HL to LL HL to LH HH to LH HH to LL	LH to LL LH to HL HH to HL HH to LL
	Hierarchical			
No change	None	Stationary		

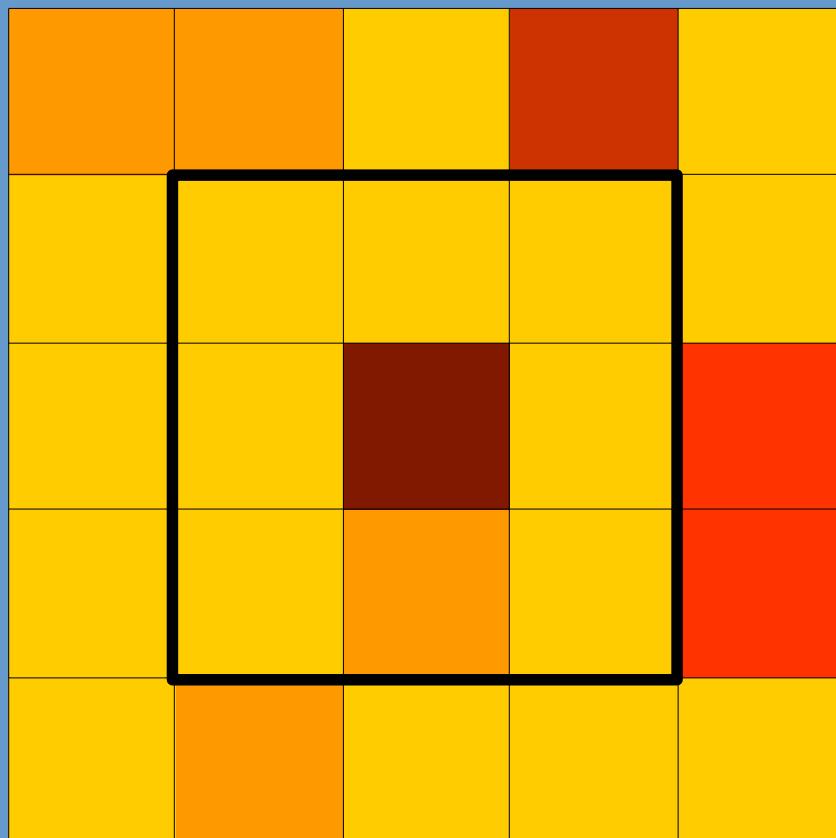
time $t-1$



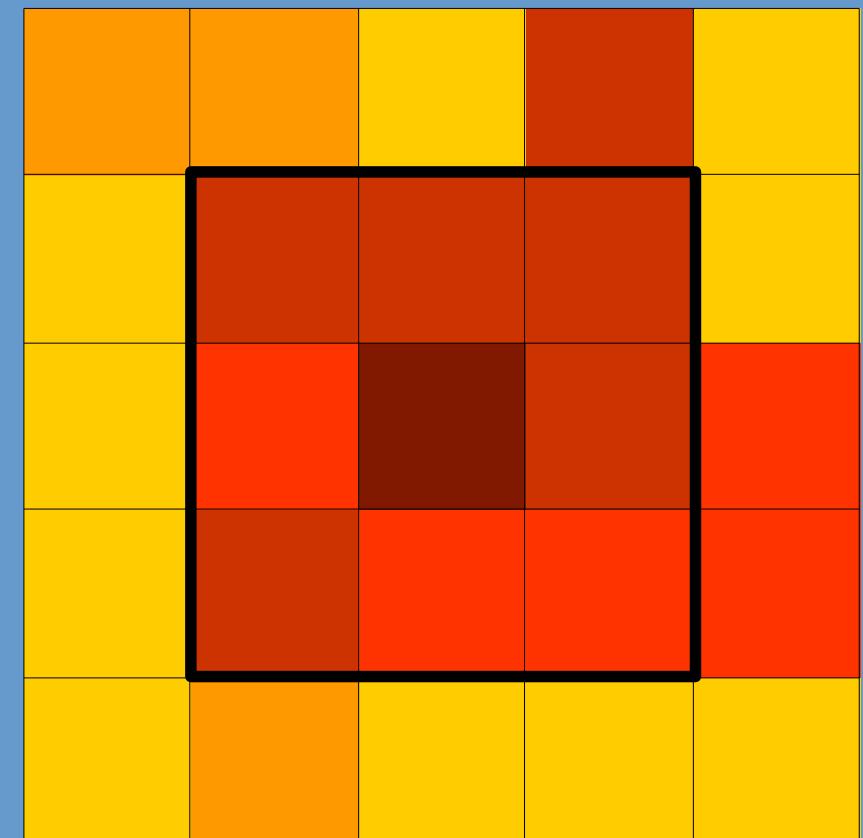
time t



time $t-1$



time t



Expansion

time $t-1$

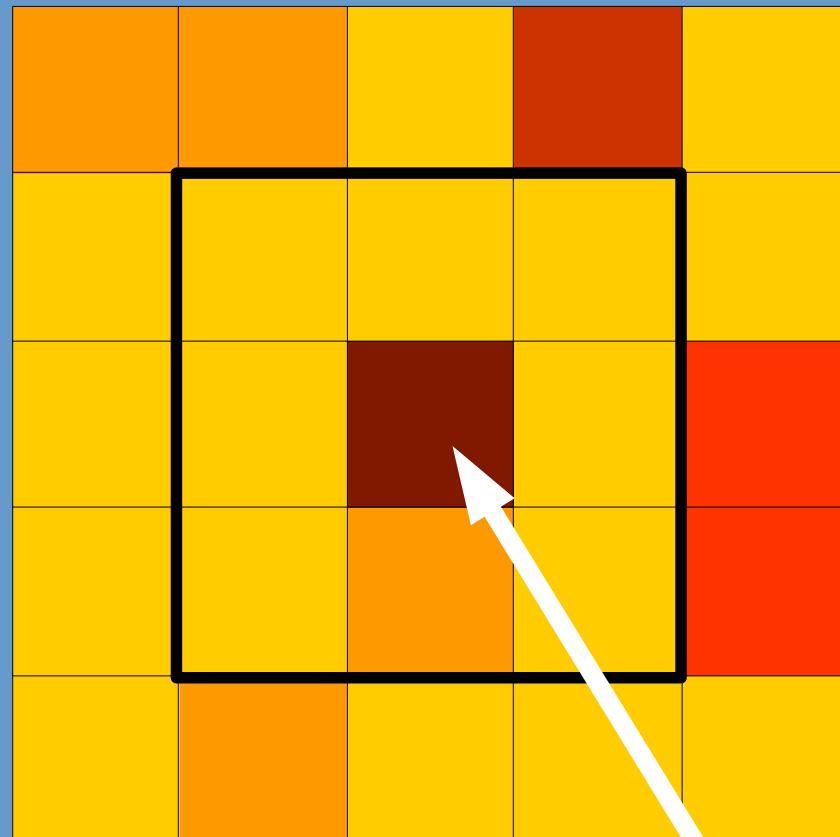
		HL		

time t

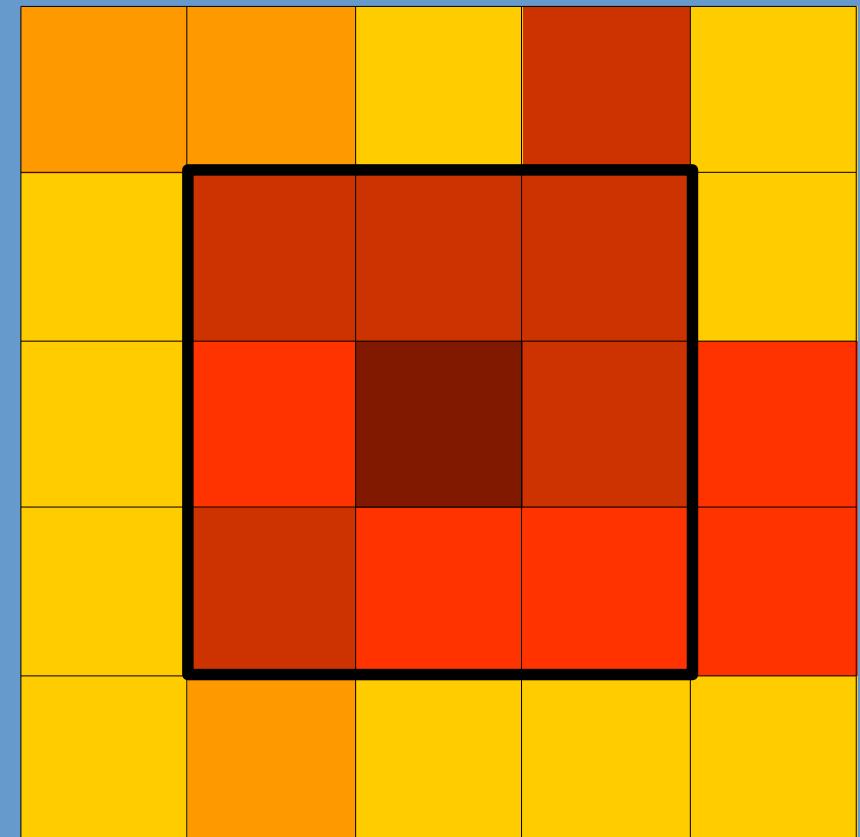
		HH		

Expansion

time $t-1$

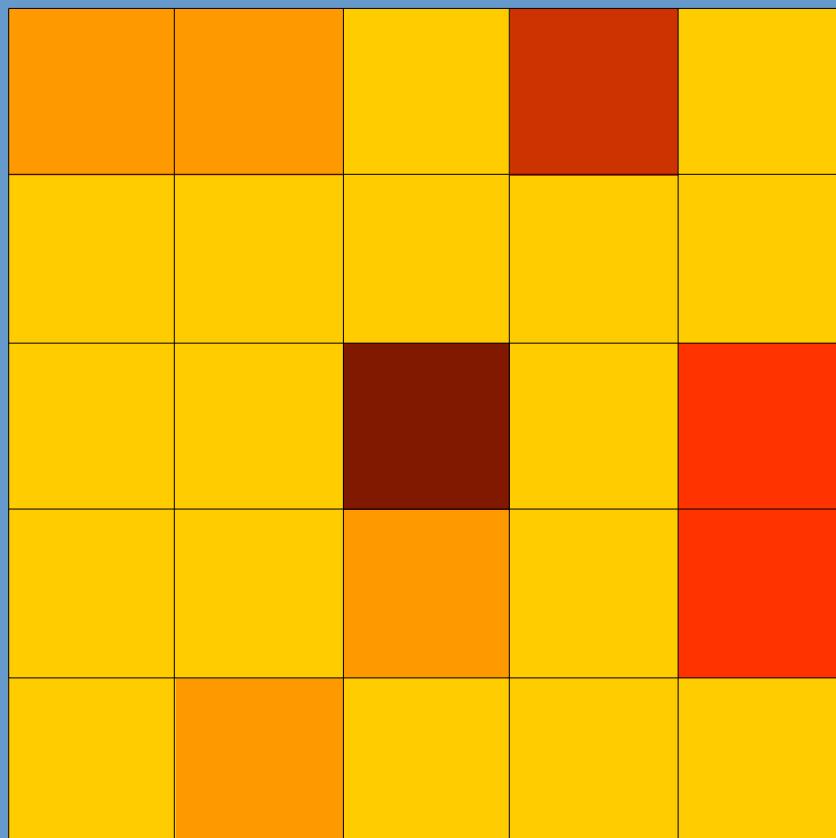


time t

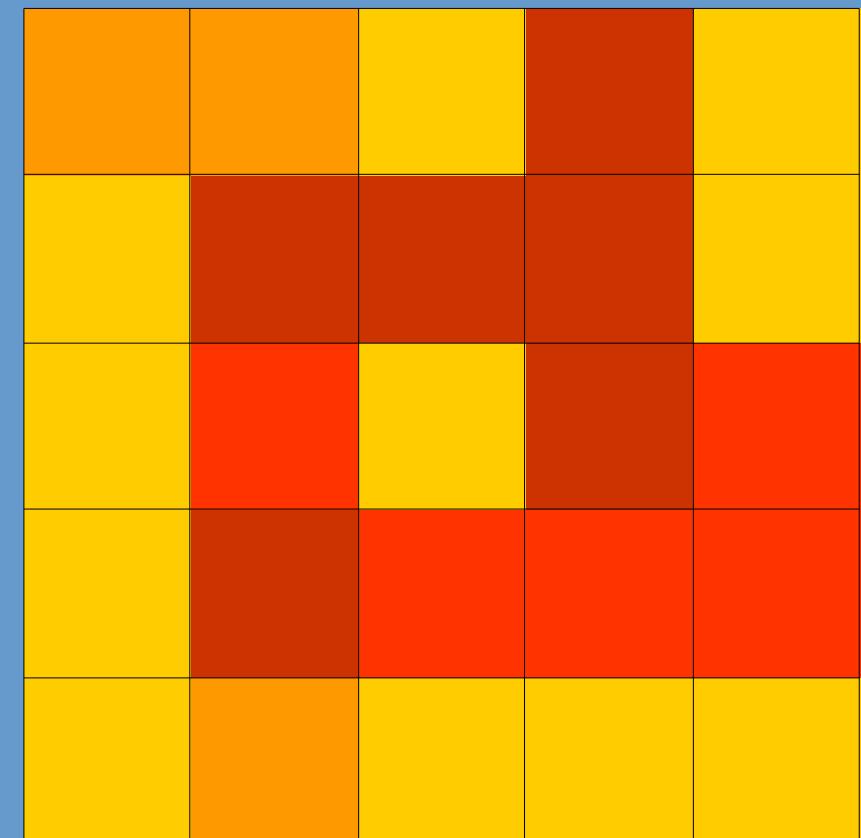


Source

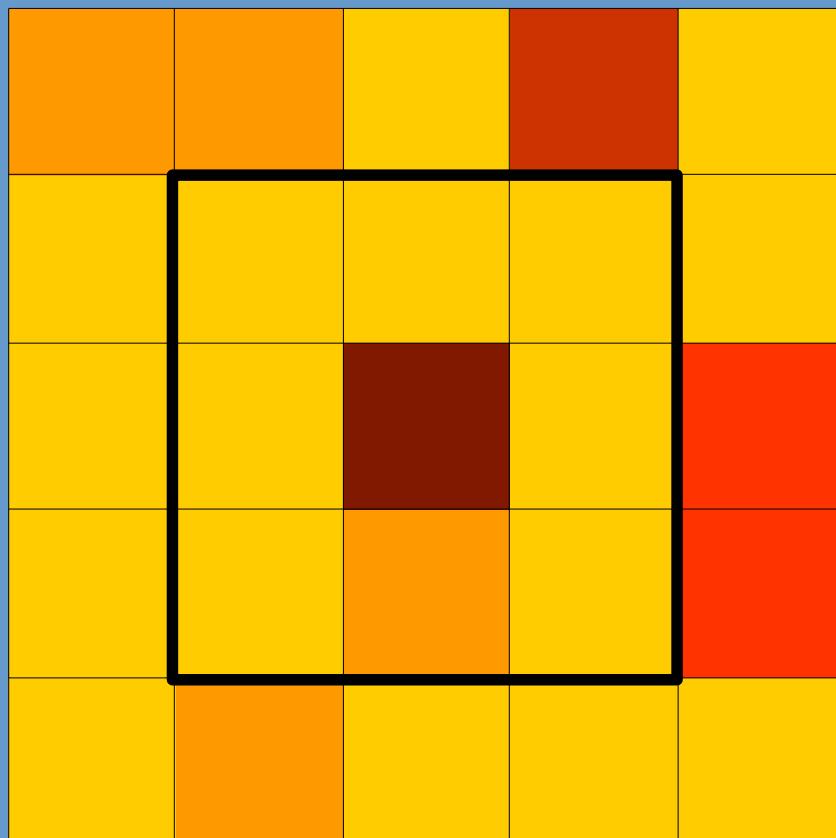
time $t-1$



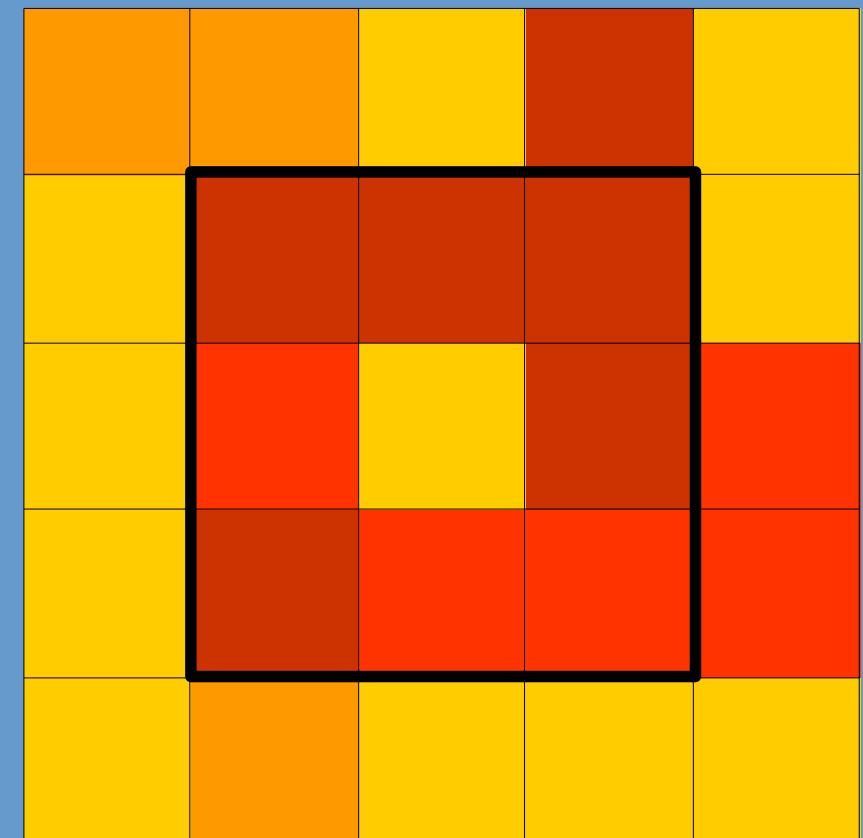
time t



time $t-1$



time t



Relocation

time $t-1$

		HL		

time t

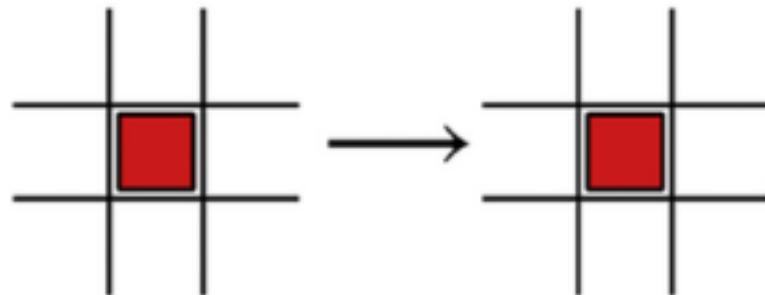
		LH		

Relocation

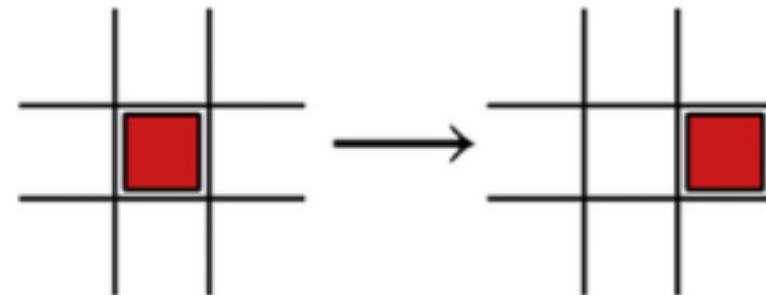
Approaches

- Baudain et al. (2013)
 - Presence/absence analysis of riot data from London
 - Evaluate the binary transitions (time $t-1$ to time t) of observations and neighbors
 - Simulate randomness, evaluate number of observed transitions
 - Compare to observed

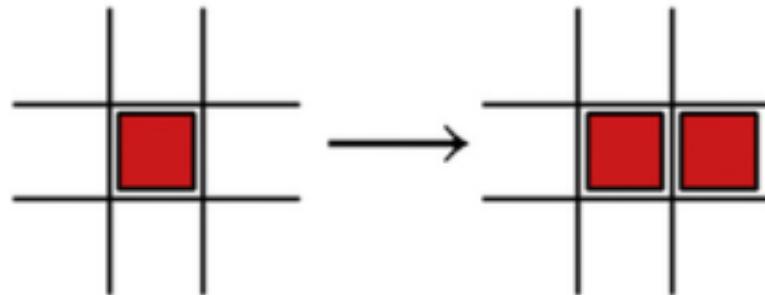
Containment



Relocation



Escalation



Flashpoint

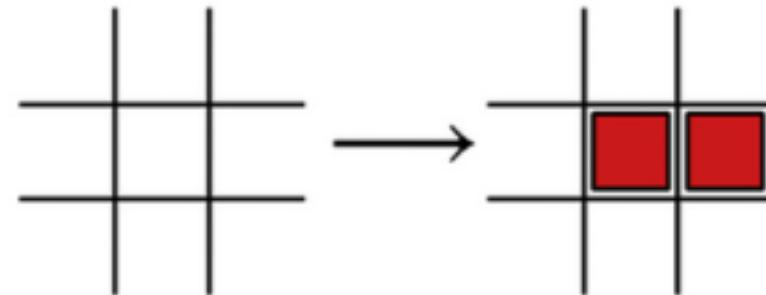


Fig. 4. Geographic patterns of diffusion. An illustration of the simplest examples of each of the diffusion patterns of interest occurring in a spatio-temporal grid.

Approaches

- Regression-based approach
 - Case rate (current) at location i is a function of 1) case rate at previous time and 2) case rate of neighbors at previous time

$$p_{i,t} = p_{i,t-1} + \sum_{j=1}^n w_{ij} p_{j,t-1}$$

Approaches

- Regression-based approach
 - Case rate (current) at location i is a function of 1) case rate at previous time, 2) case rate of neighbors at previous time, and 3) case rate of neighbors at current time

$$p_{i,t} = p_{i,t-1} + \sum_{j=1}^n w_{ij} p_{j,t-1} + \sum_{j=1}^n w_{ij} p_{j,t}$$

Keywords

- Expansion
- Relocation
- Agent based model
- Spatial interaction model