

Mathematical Modeling of Early Detection of Infectious Disease Outbreaks

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MSR



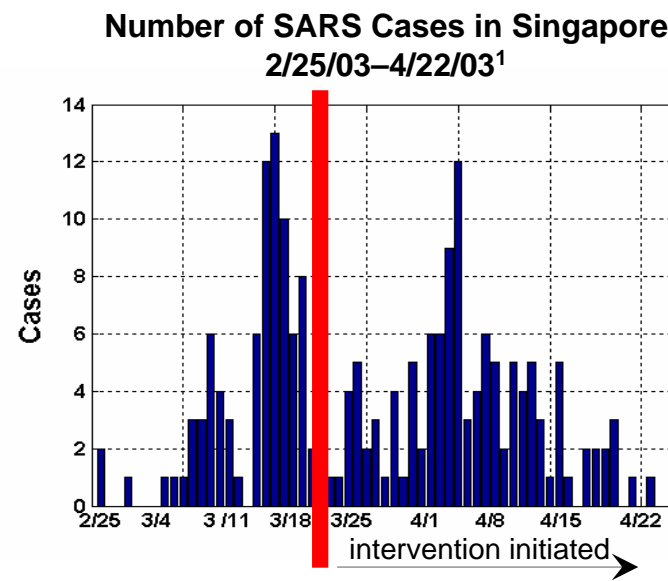
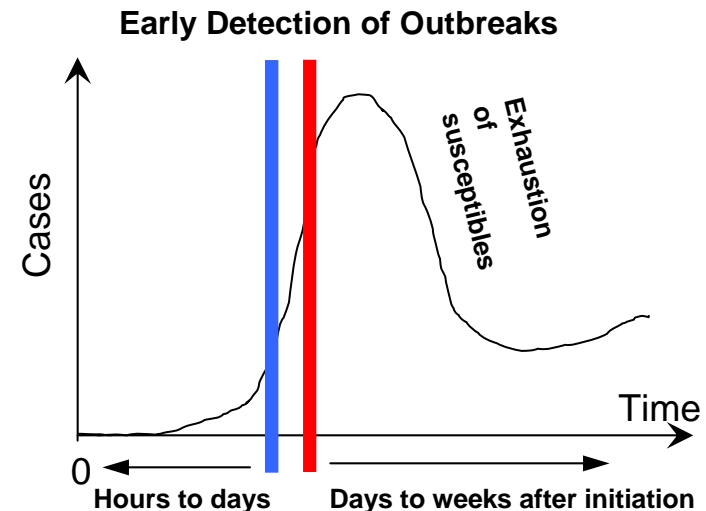
MITRE
Technology
Program

Problem

- **Current surveillance systems cannot detect new outbreaks in real time with low false positives**
 - Art of surveillance remains disconnected from the science of infectious disease dynamics
- **Goals of the technology**
 - Detect outbreaks in hours to days
 - Focus limited resources in critical areas
 - Mitigate deadly consequences of biothreats and naturally occurring outbreaks

Background

- CDC defines surveillance as “the ongoing, systematic collection, analysis, interpretation, and dissemination of health-related data to reduce morbidity, mortality and to improve health.”
 - Real-time data
 - Time lag of minutes
 - Real-time hospital admission data acquisition is in place in major cities
 - Real-time interpretation
 - Time lag of hours to days – communicable diseases
 - State of the art in detection is primitive – high false positives



¹Source: Science, May 2003

Objectives

- **Develop mathematical and computational models for early detection of infectious disease outbreaks**
- **Coordinate with the Harvard Medical School (HMS) and its affiliated hospitals to manage, integrate, and test models against HIPAA-compliant real datasets**
- **Transition models to real-time surveillance systems**
- **Transition new technology to MITRE's sponsors**

Activities

■ Transients in Time (FY 05)

- Develop temporal models of early detection, apply models to time series data, and validate

■ Transients in Time and Space

- Develop spatio-temporal models of early detection, apply to spatio-temporal data, and validate

■ Transients in Time, Space, and Social Networks

- Develop socio-spatio-temporal models of early detection, apply to social network data, and transition models to real-time surveillance systems

Highlight

Multi-Syndromic Analysis of Time Series: A New Concept for Outbreak Investigation

$\mathbf{X}_{n \times m}$: n observations (samples), m variables, $n > m$

$\mathbf{X} = \mathbf{t}_1 \mathbf{p}'_1 + \mathbf{t}_2 \mathbf{p}'_2 + \dots + \mathbf{t}_k \mathbf{p}'_k$, $k \leq \min\{m, n\}$

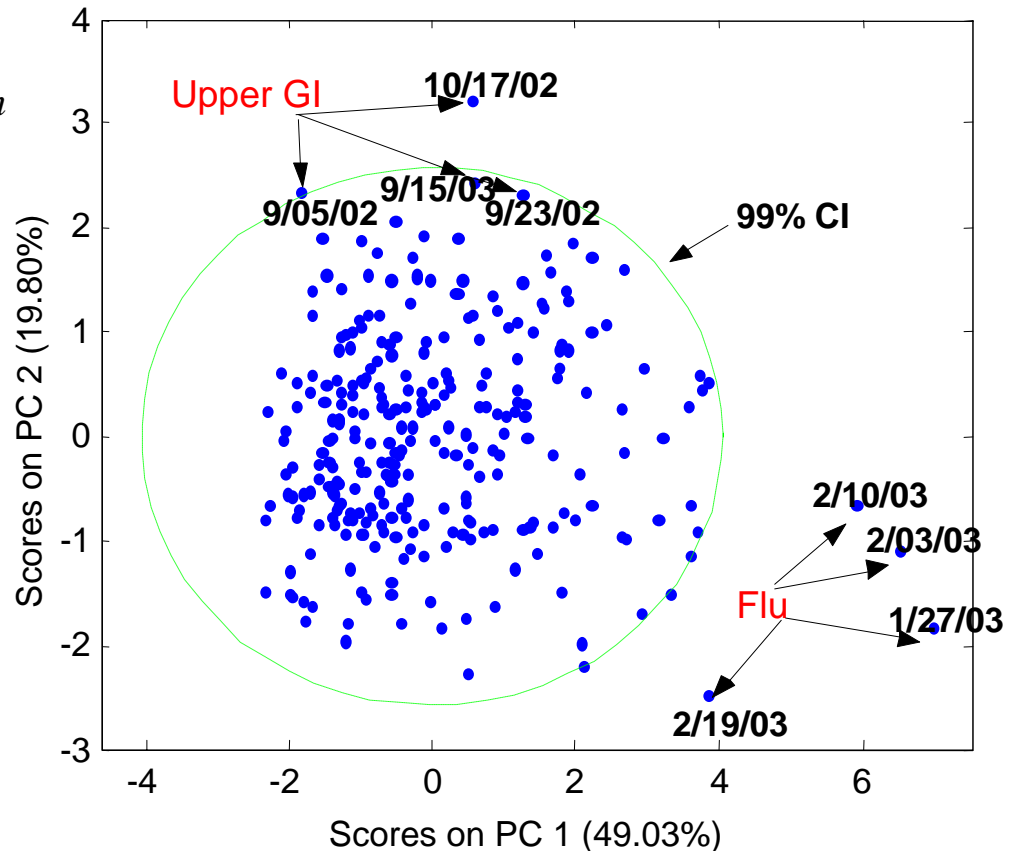
\mathbf{p}_i : eigenvectors of the covariance matrix

\mathbf{t}_i : vector of scores on principal component i

$\mathbf{X} \mathbf{p}_i = \mathbf{t}_i$ (projection of \mathbf{X} onto the \mathbf{p}_i)

$\mathbf{t}'_i \mathbf{t}_j = 0$, $i \neq j$ (orthogonal)

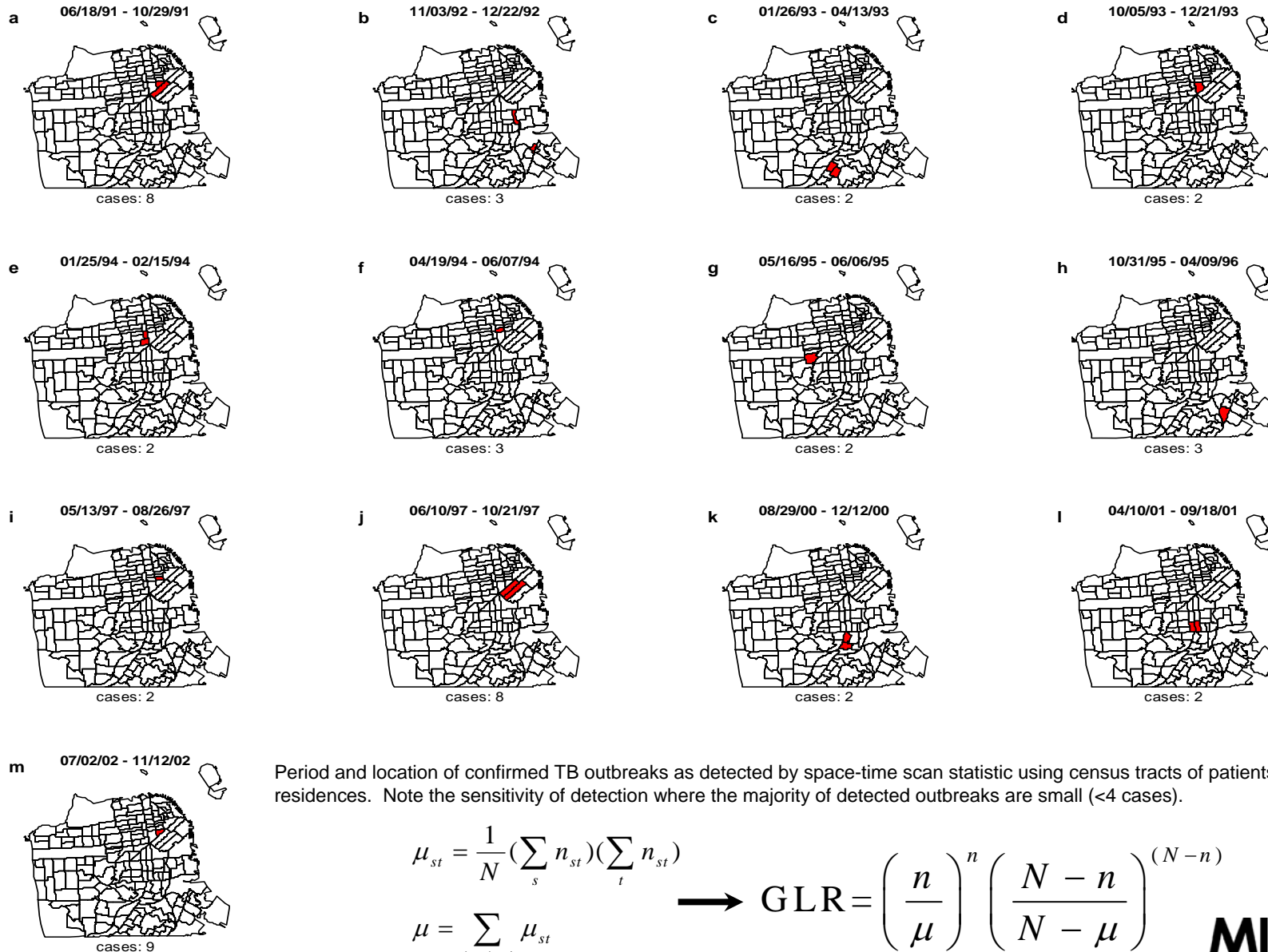
$\mathbf{p}'_i \mathbf{p}_j = 0$, $i \neq j$ (orthonormal)



Simultaneous Detection of Outbreaks of Influenza and Upper GI

Highlight

Space-Time Detection of Tuberculosis in SF



Period and location of confirmed TB outbreaks as detected by space-time scan statistic using census tracts of patients' residences. Note the sensitivity of detection where the majority of detected outbreaks are small (<4 cases).

$$\mu_{st} = \frac{1}{N} (\sum_s n_{st}) (\sum_t n_{st})$$

$$\mu = \sum_{(s,t) \in A} \mu_{st}$$

$$\longrightarrow \text{GLR} = \left(\frac{n}{\mu} \right)^n \left(\frac{N-n}{N-\mu} \right)^{(N-n)}$$

MITRE

Impact

Biodefense

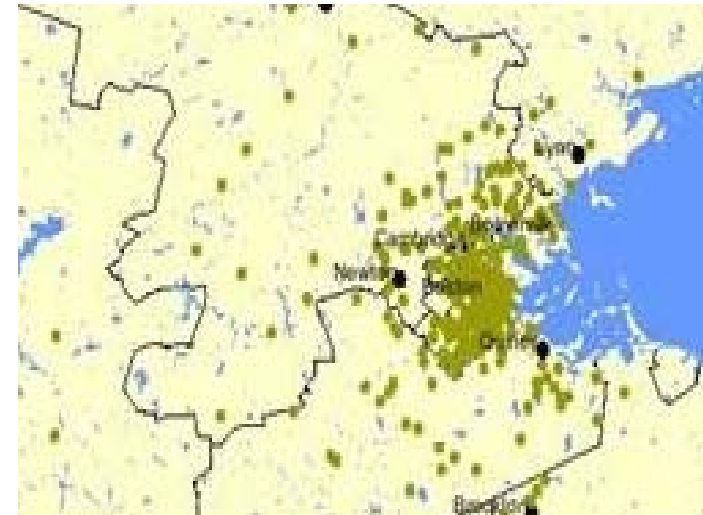
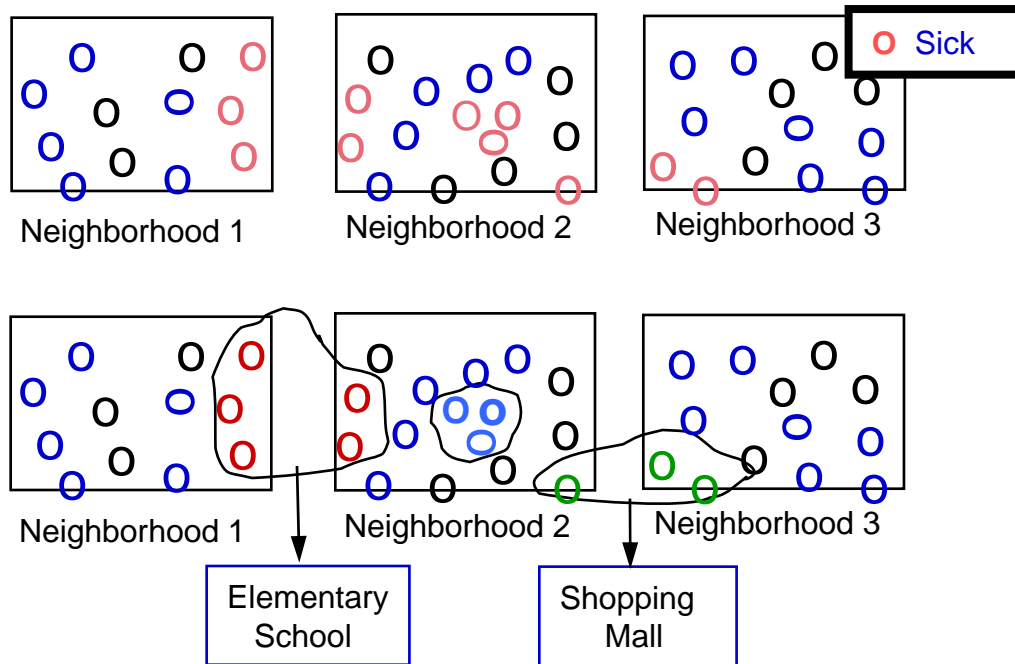
- Strengthens biosecurity
- Saves lives (military and civilian)
- Reduces cost of post-epidemic management
- Reduces economic loss in productivity
- Improves public health surveillance both in the short term and long term

MITRE

- Relevant to MITRE sponsors
- Opportunity to model real data and validate models against real data
- Collaboration with leading academic and medical institutions
- Enhances MITRE expertise and leadership in disease modeling and surveillance

Future Plans

Signatures of social contacts are embedded in spatial data!



Source: Children's Hospital, Boston

Transients in Time, Space, and Social Networks

Develop social network models of spread of disease, apply to HIPAA-compliant contact data from public health communities, and transition to real-time surveillance systems

Transients in Time and Space

Develop spatio-temporal models of early detection, apply to HIPAA-compliant data, validate, and transition to real-time surveillance systems