FRED: Overview & Case Studies

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Outline

- Why model?
- FRED – A Framework for Reconstructing Epidemiological Dynamics
- Case studies
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Modeling in Public Health Policy

Scientific Literature

Expert Opinion

Decision Maker

Modeling & Simulation

Public Health Data
Simulations Enable a New Level of "What-if" Analysis

- Preparedness Planning
- Vaccine Policy
- Paid Sick Leave Policy
- Risk Communication
- Chronic Disease Planning
- School closures
Types of Modeling

- Mathematical Modeling
  - Differential Equation
- Statistical Modeling
  - Regression
  - Clustering
- Network Modeling
- Agent-Based Modeling
- Etc.
Agent-based Models

• Study the effects of heterogeneous populations on spatiotemporal epidemic dynamics

• Include each person in the model, along with social contacts and interactions with the environment

• Include individual responses and behaviors in the model

• Investigate interactions between agents and spatially distributed resources such as school and hospitals
Agent-based Models

Purposes

• Study how interactions among individuals and their environment can result in patterns of population behavior

• Study the impact of policy and programs on public health
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What is FRED?

- **FRED** is a **Framework for Reconstructing Epidemiological Dynamics**
- **Framework**: FRED is not a model. FRED is a tool for building models
- **Epidemiology**: the study and analysis of the patterns, causes, and effects of health and disease conditions in defined populations (Wikipedia)
  - Infectious and noninfectious diseases
  - Health-related conditions such as obesity, drug use, violence, vaccine acceptance, etc
- **Dynamics**: FRED is designed to study how patterns of health conditions in defined populations vary over time and space

*FRED is designed to build agent-based (individual-based) models*
Foundational Concepts in FRED

• Space
  – Three-dimensional geography based on actual locations

• Time
  – Time step = 1 day (agents have multiple serial activities per day, encoded by hour)
  – Duration = 1 day to 100 years

• Agent = individual person

• Places (mixing groups for agents)
  – Households, neighborhoods, workplaces, schools
  – Flexibly create places and assign agents

• Population
  – Based on census data and other sources
  – Agents are associated with specific places
• Synthetic population for selected countries
  – Group quarters: college dorms, prisons, military bases, nursing homes

• Simulates daily activities of individual:
  – Household, neighborhood, school, workplaces, healthcare facilities

• Intercity Travel

• Flexible Disease Models:
  – Natural History
  – Transmission Models
  – Importation schedule
  – Daily tracking: counts by location, who infects whom, etc.

• Intervention Models
  – Vaccines, Antivirals
  – Social Distancing
Census-matched Synthetic Population

Person = Agent

Each agent is assigned to household, school and workplaces with other agents

U.S. Population (112,595,578 households with 289,390,247 people)

US Census Data
CLUS 2010 Data
DoE School Data
BLS Business Data

Extract Pennsylvania
FRED: Key Features

Agent Model

Demographics:
- Age
- Sex

Health:
- Immune Status
- Exposure Status
- Symptoms

Activity Profile:
- Pre-schooler
- Student
- Worker
- Retired

Behavior:
- Vaccine Acceptance
- Social Distancing
- Hand Washing

Models of Health Behavior Change:
- Stochastic
- Social norms / influence
- Health Belief Model
- Segmented populations

Agents can age, give birth, die

Maintain health history over lifetime of agents

Activity Profiles can change over lifetime of agents
Synthetic Population Matches Real Demographics

Pittsburgh, PA
Location and size of each school

Location and size of each workplace

Household size, ethnicity, ages, income
Location and size of each school

Household size, ethnicity, ages, income

Location and size of each workplace
FRED Daily Dynamics

Location and size of each school

Location and size of each workplace

Household size, ethnicity, ages, income
FRED: Key Features

Individual Disease Model

Susceptible → Exposed → Infectious → Recovered

- Susceptible (S)
- Exposed (E)
- Infectious (I)
- Recovered (R)

I subcategories:
- Symptomatic
- Asymptomatic

Distributions for influenza:
Longini et al, Science 2005
FRED Outputs

Daily Summary Statistics of Population Health Status
- Incidence
- Prevalance, etc

Plots of user-selectable variables

Individual transmission events
- Who infects whom, and where infection occurs

Data for producing maps and movies

FRED: Key Features
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Measles vaccinations

- 47 US states allow religious and/or personal exemptions to allow unvaccinated children to attend schools.
- In some states, vaccination exemptions are increasing
- Some argue that exemptions should not be allowed
Two simulations of measles outbreaks

Scenarios:

- **95%** of children 6 months to 15 years old are **immunized** against measles

- **80%** of children 6 months to 15 years old are **immunized** against measles
Measles in Allegheny County, PA
Coverage = 95%
Day 30

Red Dot = Infectious Case
Blue Dot = Recovered Case
Measles in Allegheny County, PA
Coverage = 80%
Day 30

Red Dot = Infectious Case  Blue Dot = Recovered Case
"... Sen. Marty Block, a San Diego Democrat, said he was convinced to vote “yes” after Pan showed him a computer modeling program [Link to FRED] from the University of Pittsburgh that simulates how quickly a measles outbreak could spread depending on a community's vaccination rate."
Paid sick leave

- US is the only industrialized country without universal access to paid sick leave (Heymann et al. 2009)
- Employees sometimes turn up at work when sick and infect others
- Would paid sick leave help?
Baseline Attack Rate among employed adults due to workplace transmission: 11.5%

Simulated epidemic: $R_0=1.4$

Conclusion: ~71% of infections at work occur due to presenteeism
Lessons Learned

• Universal access to paid sick days reduces influenza infections due to workplace transmission by about 6%

• Flu Days have a larger impact on infection reduction:
  – 25% (1 Flu day)
  – 39% (2 Flu days)

• Combination of universal paid sick days and interventions to increase the number of days spent at home may have a large as well as an equitable impact

• Donora PA
  – 24 miles SE of Pittsburgh
  – 14,000 residents in 1948
• Temperature inversion Oct. 27-31, 1948
• Combined with heavy emission of air pollution from nearby mills
• More than one-third of population affected with respiratory distress
  – 15.5% mild symptoms
  – 16.8% moderate symptoms
  – 10.4% severe symptoms
• 70 excess deaths within 1 month
  – Elevated mortality for 10 years after

Investigation of the Smog Incident in Donora, Pa., and Vicinity James G. Townsend
Health Emergency Scenario

Scenario

• Developed with City of Pittsburgh under the 100 Resilient Cities Project (Rockefeller Foundation)
• Pittsburgh experiences a severe heat wave
• At the same time, an air pollution event occurs
• An air temperature inversion occurs, trapping dense smog at lower elevations

Focus

• How well does the City's emergency response system deal with the crisis?
FRED Simulation of EMS Requests

FRED assigned asthma and heat stroke risks to individuals in the Pittsburgh synthetic population to match known prevalence based on age, gender and race.

Simulated air pollution at lower elevations, and heat wave throughout area.
Simulation shows how EMS response times would be delayed.
Summary

- FRED is a flexible model framework
- Large-scale, realistic synthetic populations
- Investigation of epidemic scenarios
- Evaluate health behavior effects
- Can be used to inform policy and planning
Acknowledgments

FRED Team
- Don Burke, Bob Frankeny, David Galloway, John Grefenstette, Mary Krauland, Mark Roberts,

Support
- Robert Wood Johnson Foundation
- NIH / NIGMS (MIDAS Program)
- Bill and Melinda Gates Foundation
- Benter Foundation