An embedded Recursive SIR model for County Level Analysis

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

Virtual Workshop on Geospatial Needs for a Pandemic-Resilient World
Mapping Science Committee
June 17, 2020
1:00–5:15 pm eastern

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Modeling Covid 19 Spread

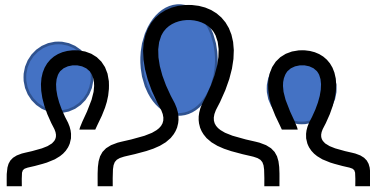
- What approach to modeling?
  - Data driven
    - Poor data
    - No constraint on “what is possible”
    - Can result (and did) in gross overestimations of deaths
  - Epidemiological Model
    - Poor data but contextualized within epidemiological framework
    - Epidemiology captures process of viral spread and attenuation
    - Model provides constraint on “what is possible”.

Conceptual Model (SIR)

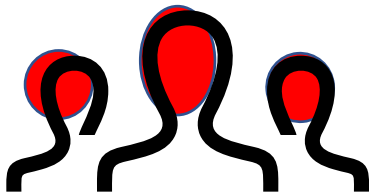
Origin

Ro & diffusion

Susceptible Individual



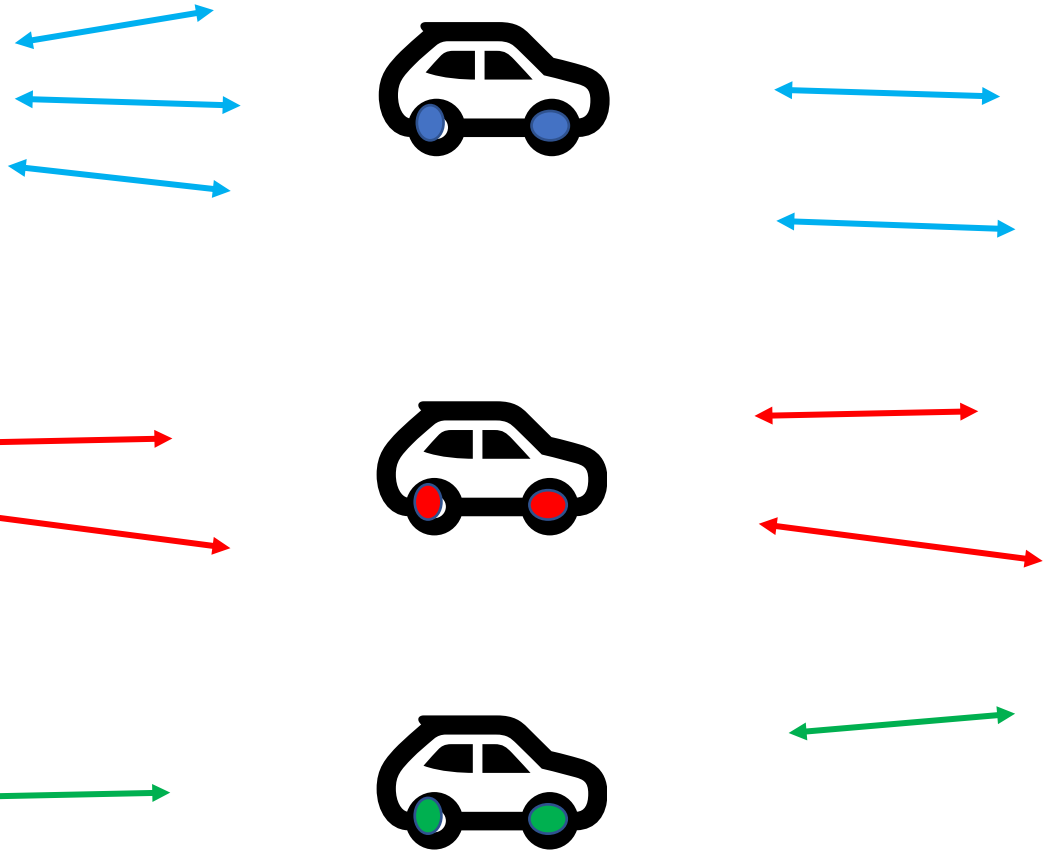
Infected Individual



Recovered Individual

Transportation

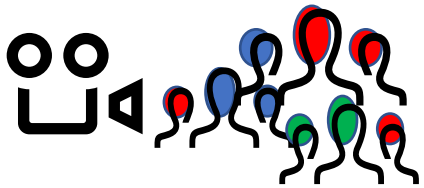
Ro & diffusion (LA: Ro = 1.78; D = .022)



Destination

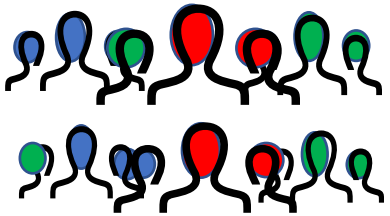
Ro & diffusion

entertainment



work

demonstration



Conceptual Model (SIR)

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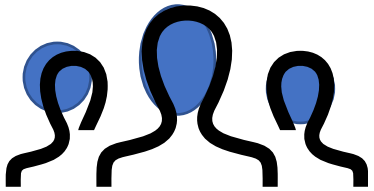
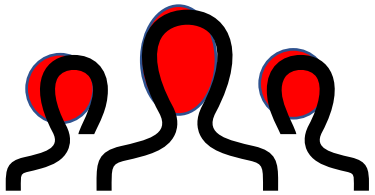


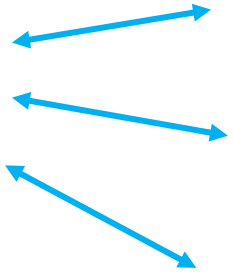
Infected Individual

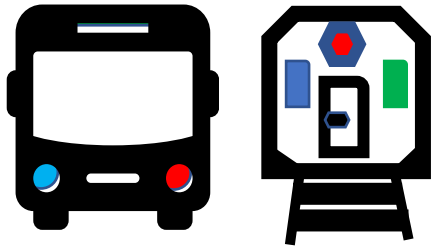


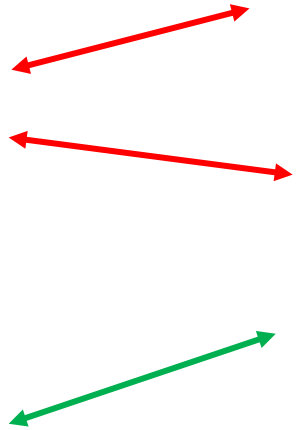
Recovered Individual

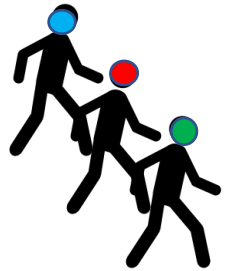
Transportation

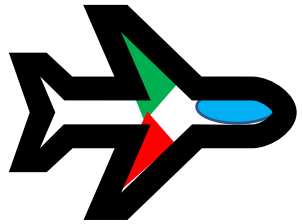
Ro & diffusion (NYC: Ro = 2.6; D = .107)

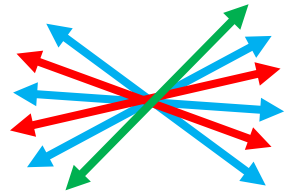


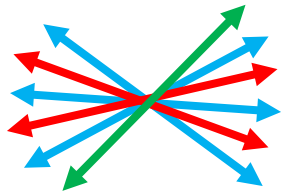








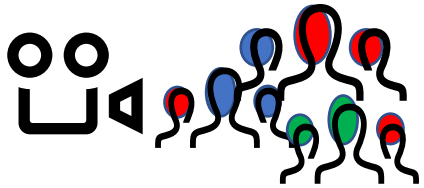




Destination

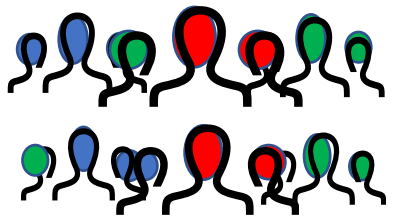
Ro & diffusion

entertainment



work

demonstration



Goal: Understand and reduce transmission & predict the trajectory of the virus's impact

Modeling and prediction

- What is the transmission rate of individuals? Ro
- How dispersed is the interaction of individuals? Diffusion

Logical Model

- Use classic SIR Model (modified)
  - Susceptible – Infected - Removed
- Model deaths, not case data, due to lack of testing
- Model every county separately
- Establish parameters (assumptions)
  - Death rate = 0.023 (South Korea)
  - Initial infection rate = io = .00125
  - Duration from S -> I -> R …….
    nu = 0.071428 (21 days)

- Calculated parameters using embedded recursion
  - *Ro* - # individuals infected by an infected individual
  - *Diffusion*: # rate of spread of virus. i.e. what percent of population is exposed to virus?

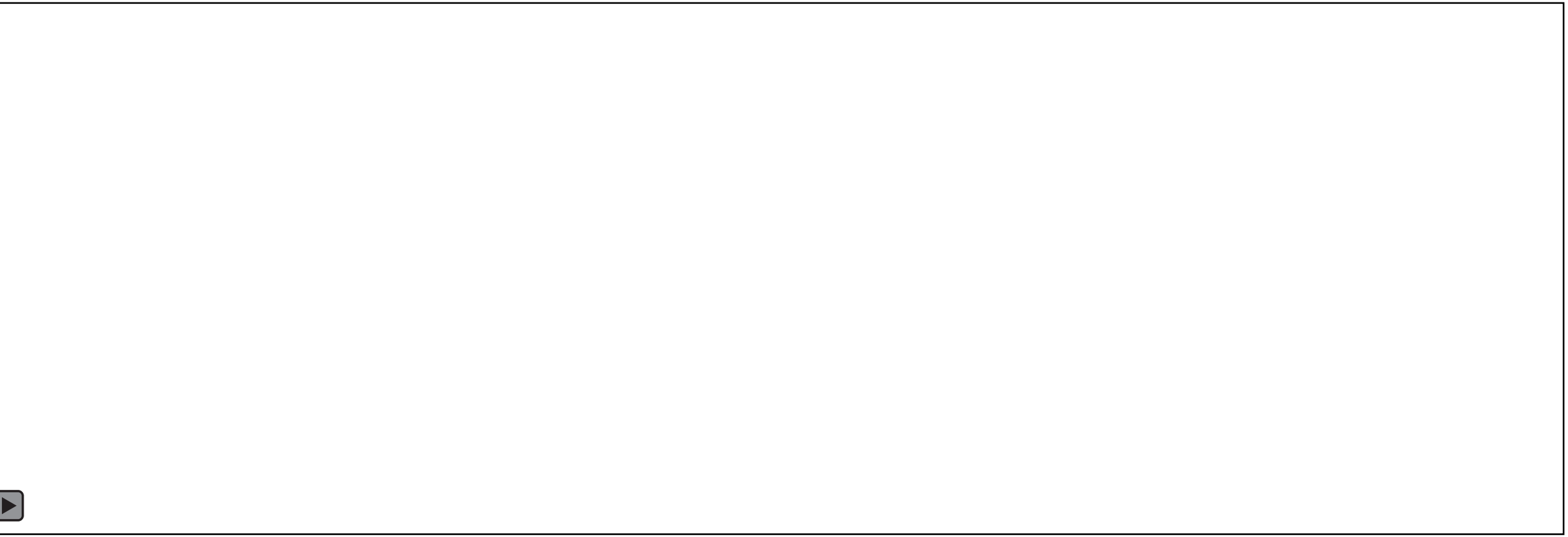
```
P = (1/(1 + (exp(-beta*t)*(1-io)/io)))
```

Calculated Parameters: Ro and Diffusion

Pre-lockdown	Lockdown	Open lag	Open social distancing
Ro f(place)	*Ro* f(decay *Ro)	*Ro* increasing to ***x%*** of pre-lockdown	
Diffusion f(movement)	*Diffusion* Stalls	*Diffusion* rate increase as ***y%*** of pre-lockdown	

Imbedded Recursive SIR Model (CARSI Model)

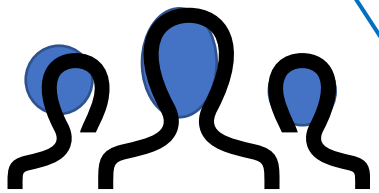
Classic SIR model with recursive Curve Fitting of Ro and Diffusion



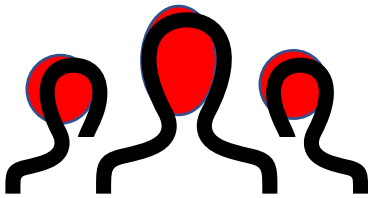
Modeling the spread and predicting the future

Embedder Recursive SIR model (CARSI model): initial diffusion

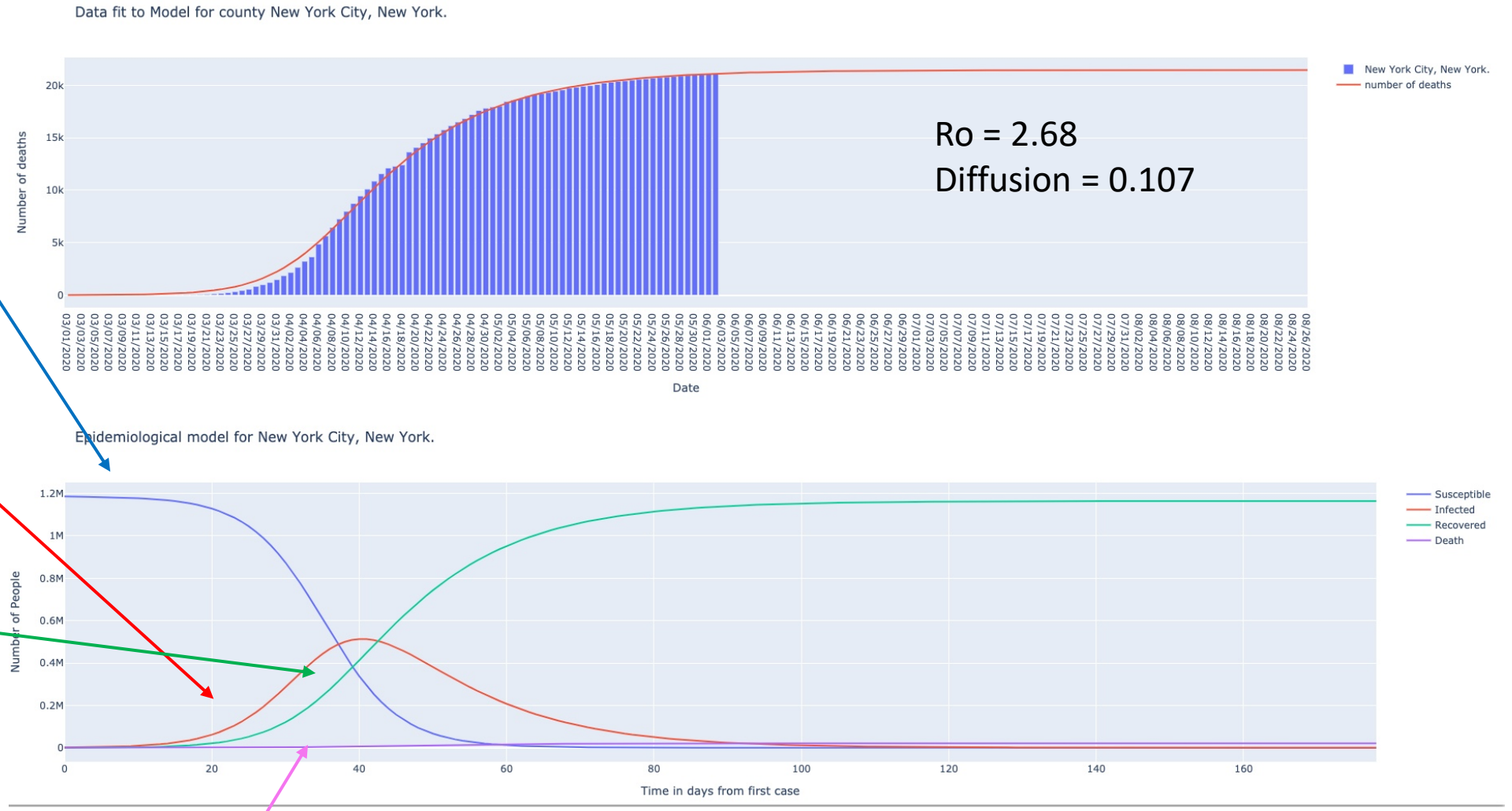
Susceptible Individual



Infected Individual



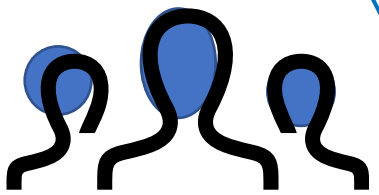
Recovered Individual



Modeling the spread and predicting the future

Embedder Recursive SIR model (CARSI model): increased diffusion

Susceptible Individual



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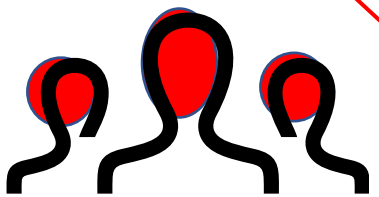

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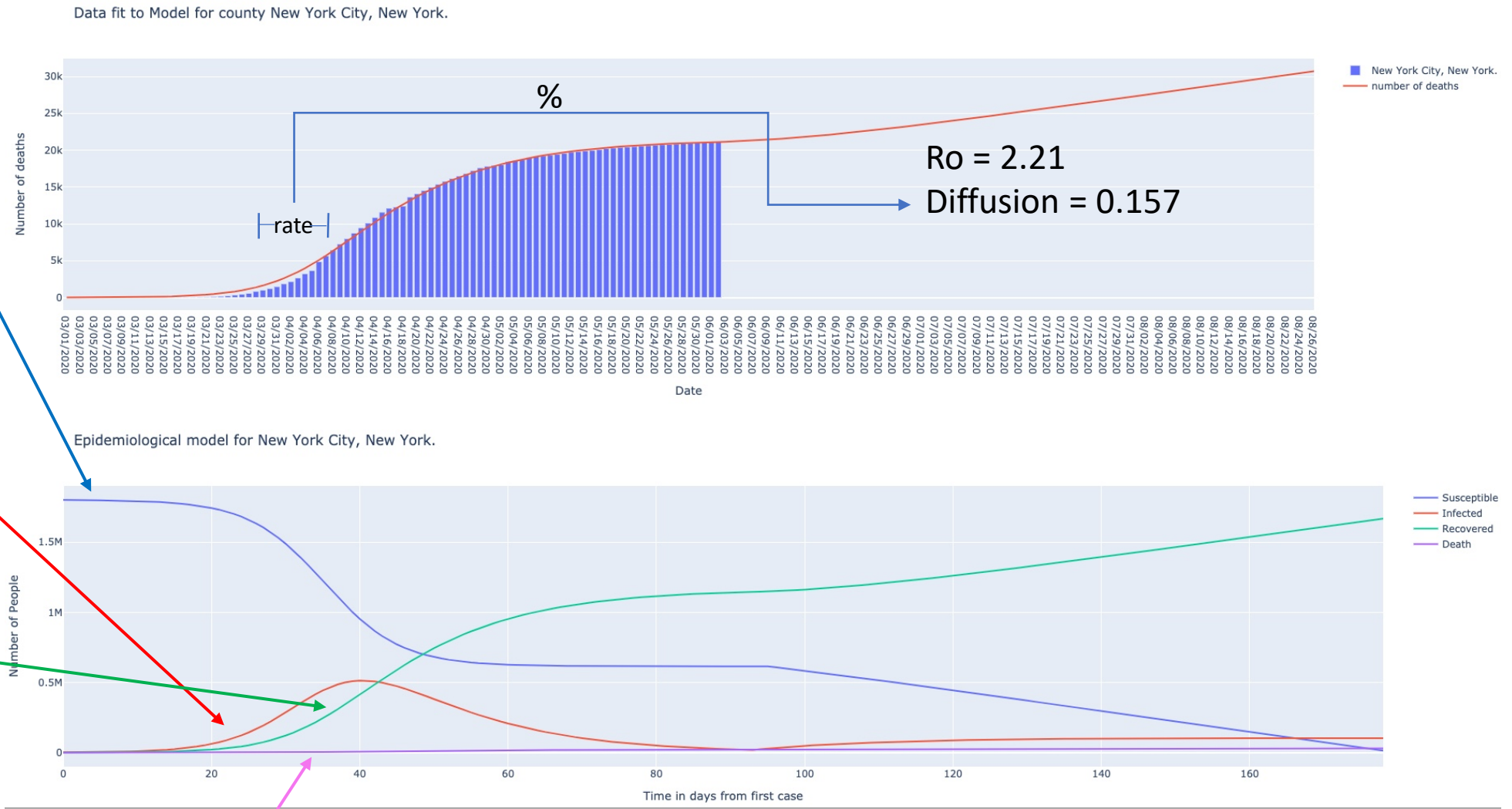

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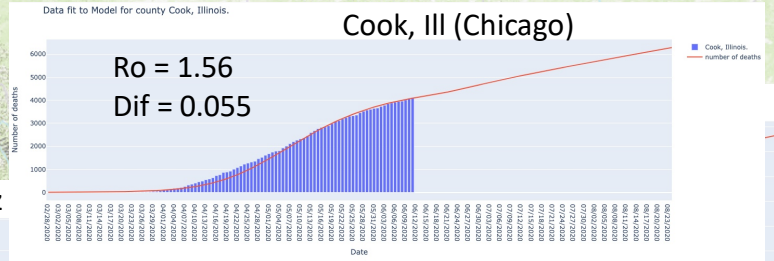
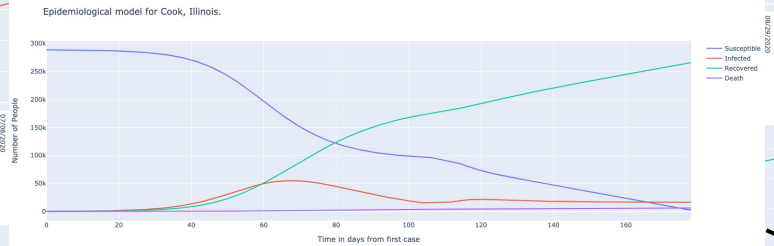
Cook, Ill (Chicago)

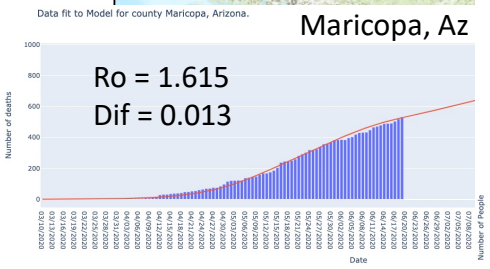
Ro = 1.56
Dif = 0.055

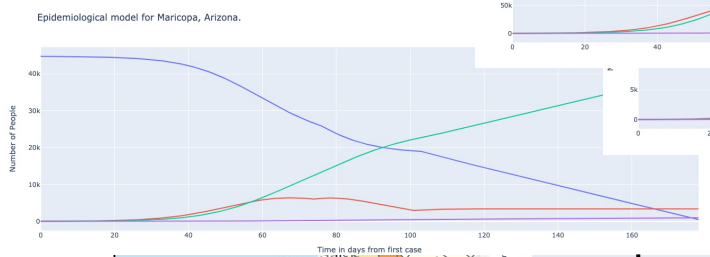




Maricopa, Az

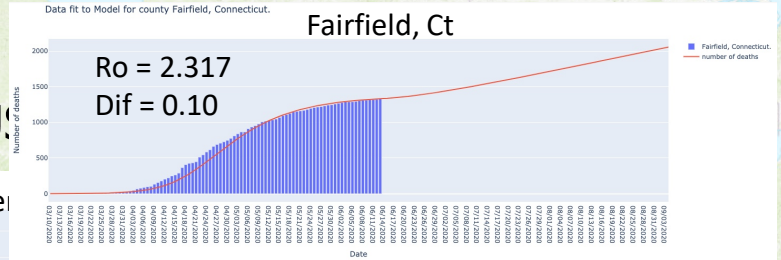
Ro = 1.615
Dif = 0.013





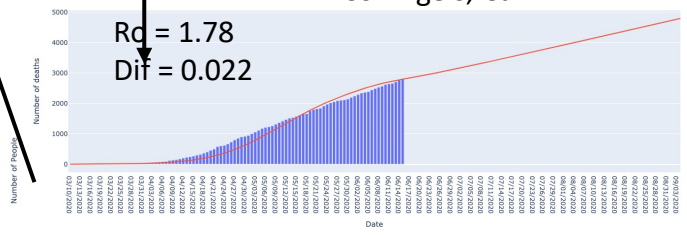
Fairfield, Ct

Ro = 2.317
Dif = 0.10



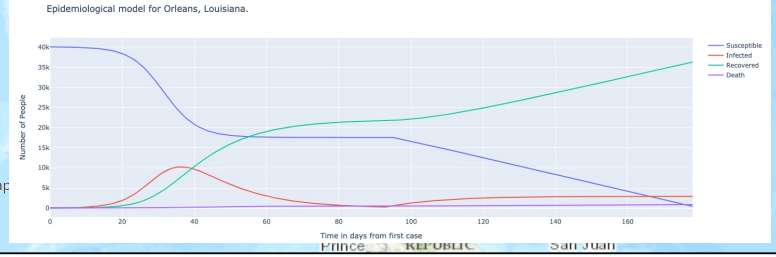
Los Angels, Ca

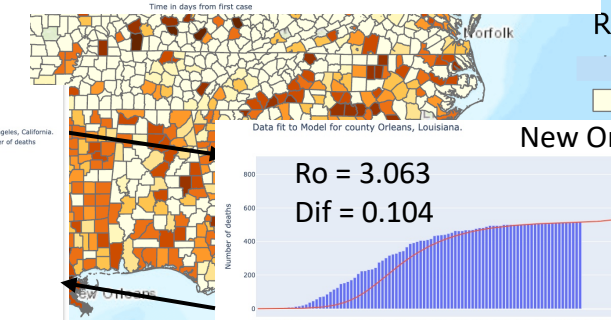
Ro = 1.78
Dif = 0.022



New Orleans

Ro = 3.063
Dif = 0.104





N

Bottom-line predictions

Sum for all counties:

$$\sum_{1}^{3000}(\#\ deaths\ in\ each\ county \mid SIR\ model\ prediction)$$

For August 7, 2020 estimate = 172,303

Problem for prediction

How to estimate values of *Ro* and *Diffusion* going forward?

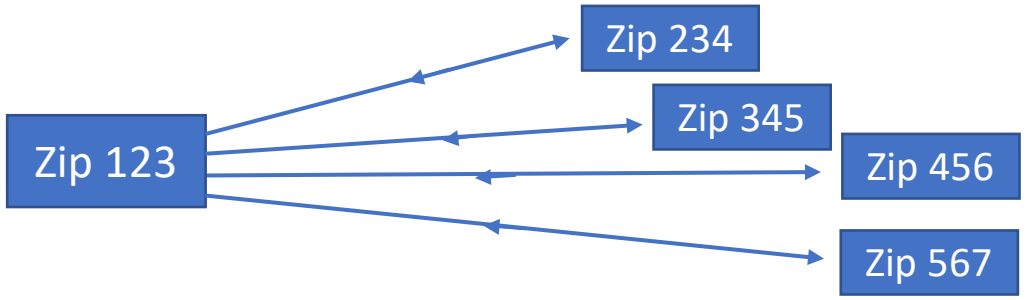
New Sources of Movement Data

- Movement data of individuals from apps has been consolidated to capture movement from origin to destination(s) (*diffusion*)
- Proximity of devices (*Ro*)
- These data can be used to calibrate both *diffusion* and *Ro by relating it to model output.*

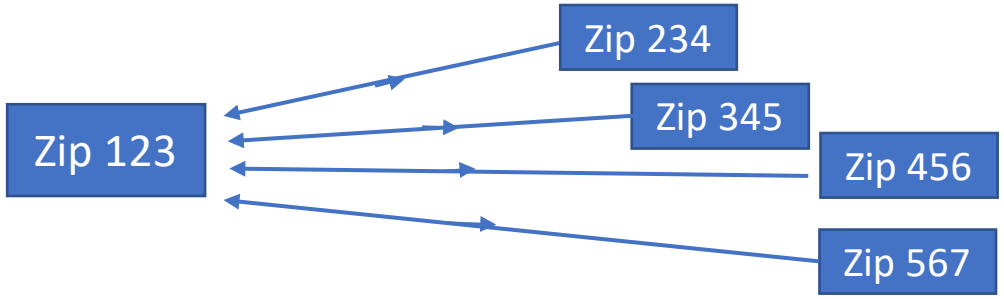
Metrics: calibrate Ro and Diffusion from real-time device data

Diffusion

To: # of zip codes visited by the population in a given zip code



From: # of zip codes that visitors come from that are visiting this zip code.



Sum of **To & From** normalized by population.

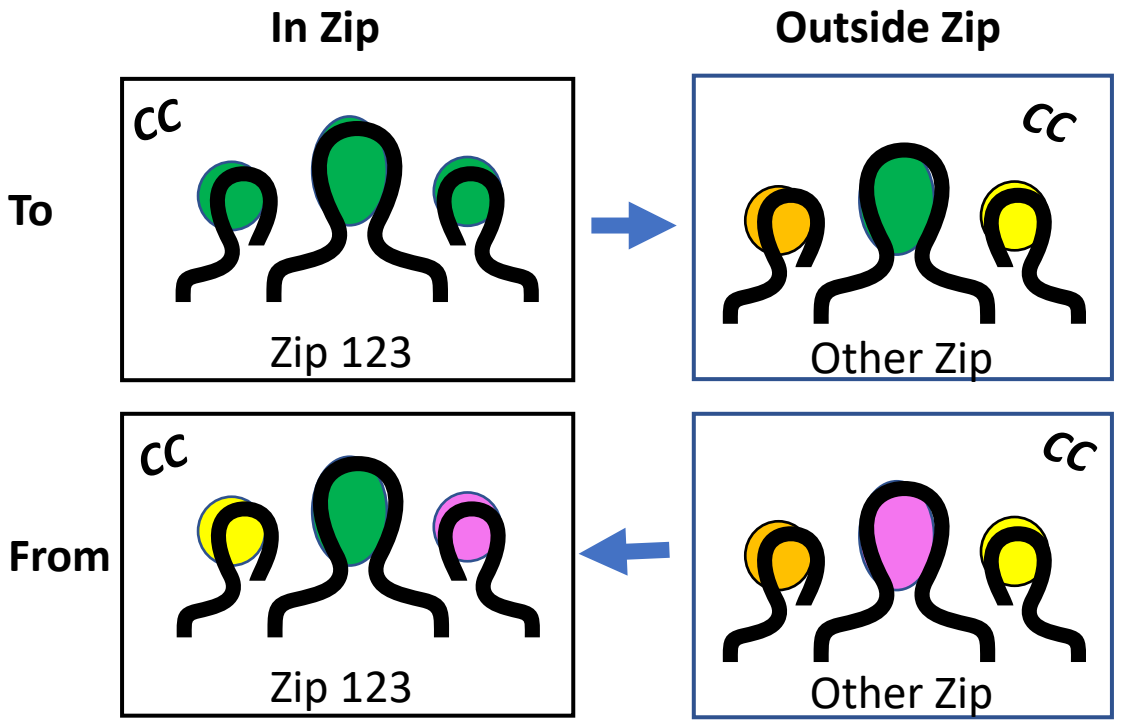
Metrics: calibrate *Ro* and *Diffusion* from real-time device data

Ro

To - In: close contacts (CC) of a device within the zip for someone who **lives in** the zip code
To - Out : are the close contacts (CC) of individuals within the zip when they are outside the zip code

From-In: are CC of a person in a zip code for someone who lives **outside** the zip code
From-Out: are CC of a person for a visitor of a zip code when they are outside the zip code

Sum of matrix normalized by population



What geographic correlates relate to Ro and Diffusion?

- Demographics
  - Income
  - Age
  - Car ownership
- Institutions
  - Nursing homes
  - Prisons
  - Public housing
- Corporate
  - Meat packing
  - Factories
- Transportations systems
  - Cars, subway, bus
- Movement to and from a county or other geo-unit
- Prevalence in surrounding counties

What is the best level of granularity for these analysis?

Conclusion

- A modified Recursive SIR Model (CARSI model) was used to predict Covid19's trajectory into the future

- New mobile data sources are now available to calibrate two key paramters of the model: *Ro* and *diffusion*.

- Process-based models have the advantage of constraining predictions to realistic scenarios of what is likely and possible

Questions?

- Thanks to the New York Times for organizing the county level data used in this research
- Thanks to Harvey Miller & Anne Linn for organization of the workshop.

Image courtesy of BigKnowledge LLC.