Module 1 – Lecture 2:

Spatial Models of Disease Spread
&
Public Health Control Measures

“To suppress and control the epidemic, countries must **isolate**, **test**, **treat** and **trace**”

Tedros Adhanom Ghebreyesus
Director, World Health Organization (WHO)

Outline

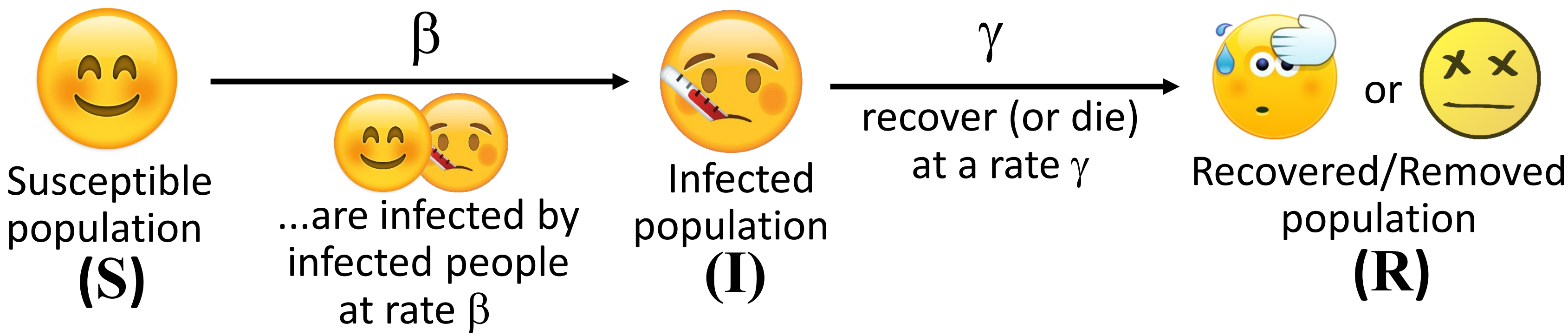
1) Extensions of the SIR Model: Additional States

2) Spatial models and network theory

3) Public policy measures for controlling disease spread
   → Test, trace, and isolate

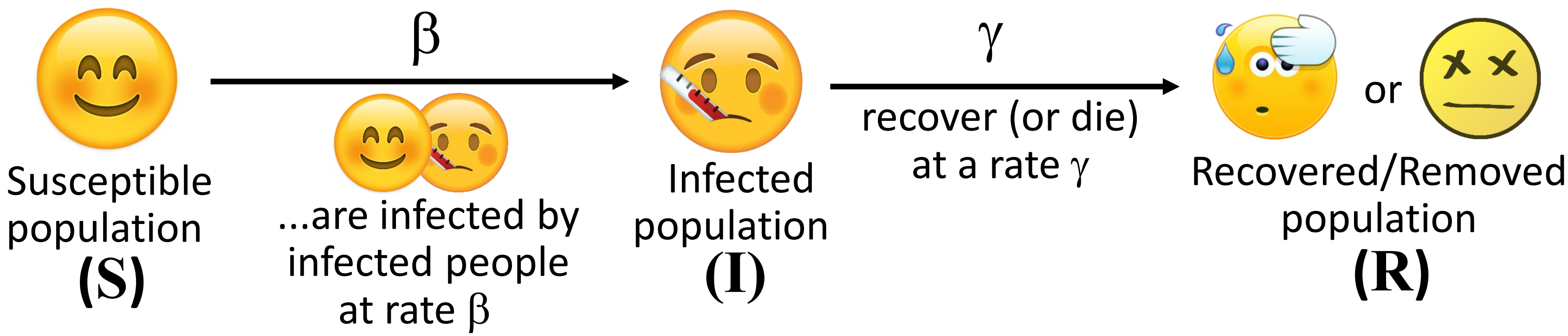
Review: SIR model

SIR Model:

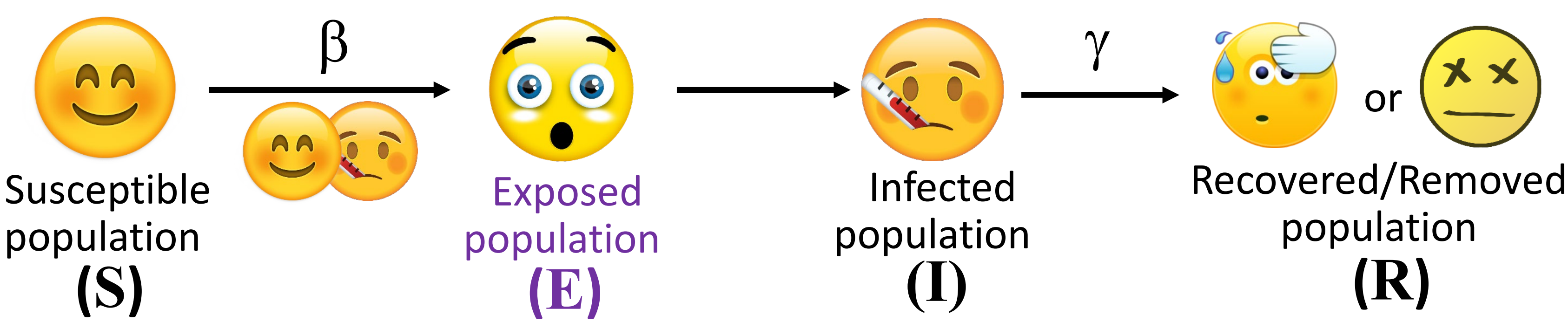


Relevant Extensions: Additional States

SIR Model:



SEIR Model: Add an "exposed" but latent period before becoming infectious



Relevant Extensions: Additional States

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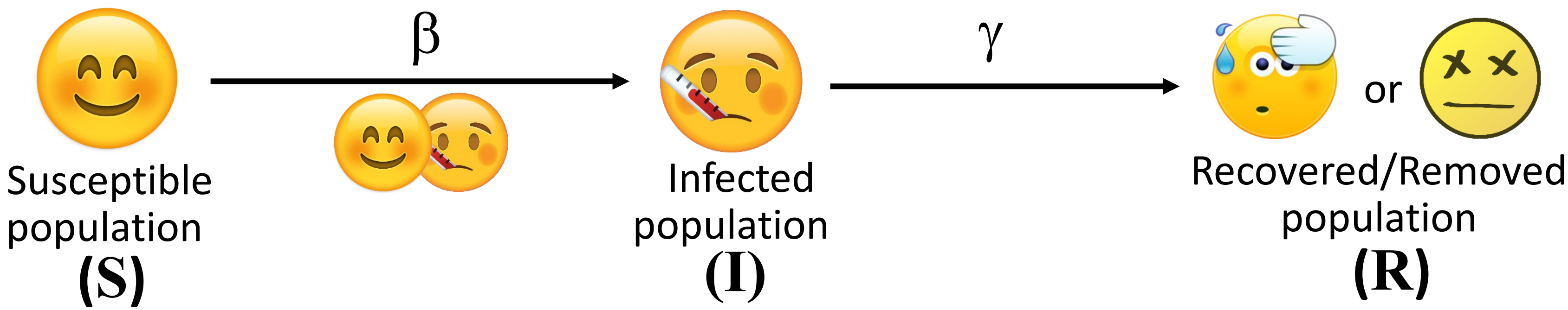
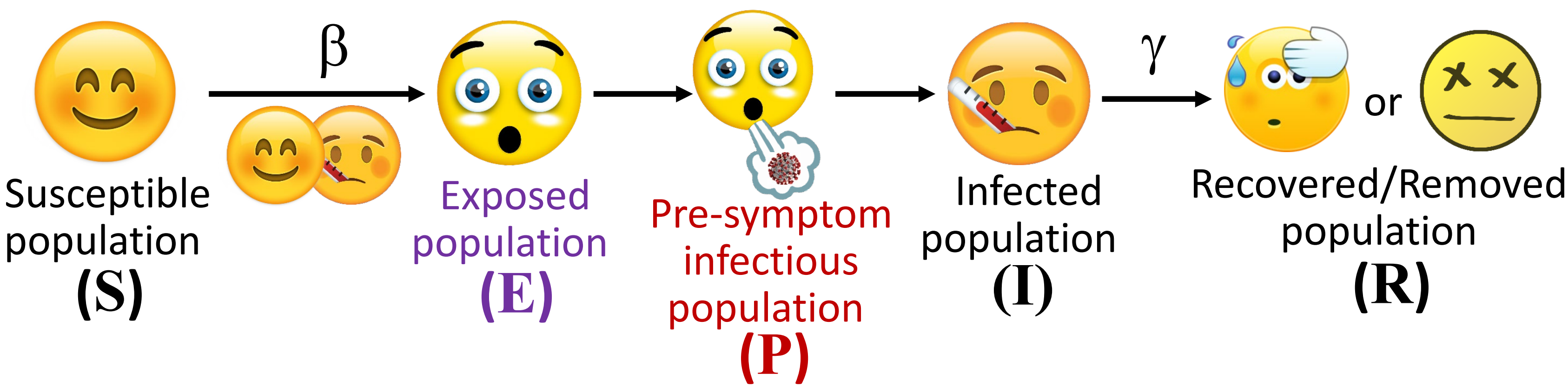
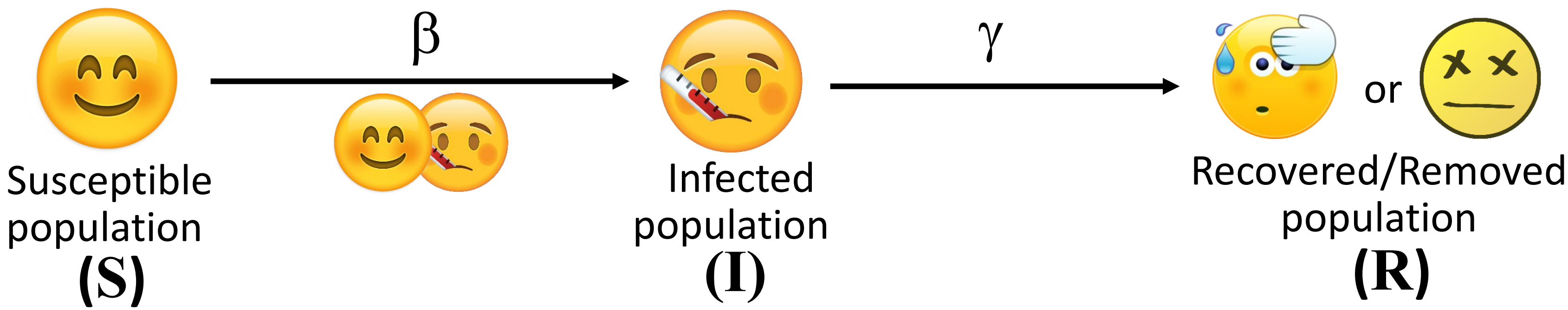


SEPIR Model: Also add a “Pre-symptomatic but infectious” period



Relevant Extensions: Additional States

SIR Model:



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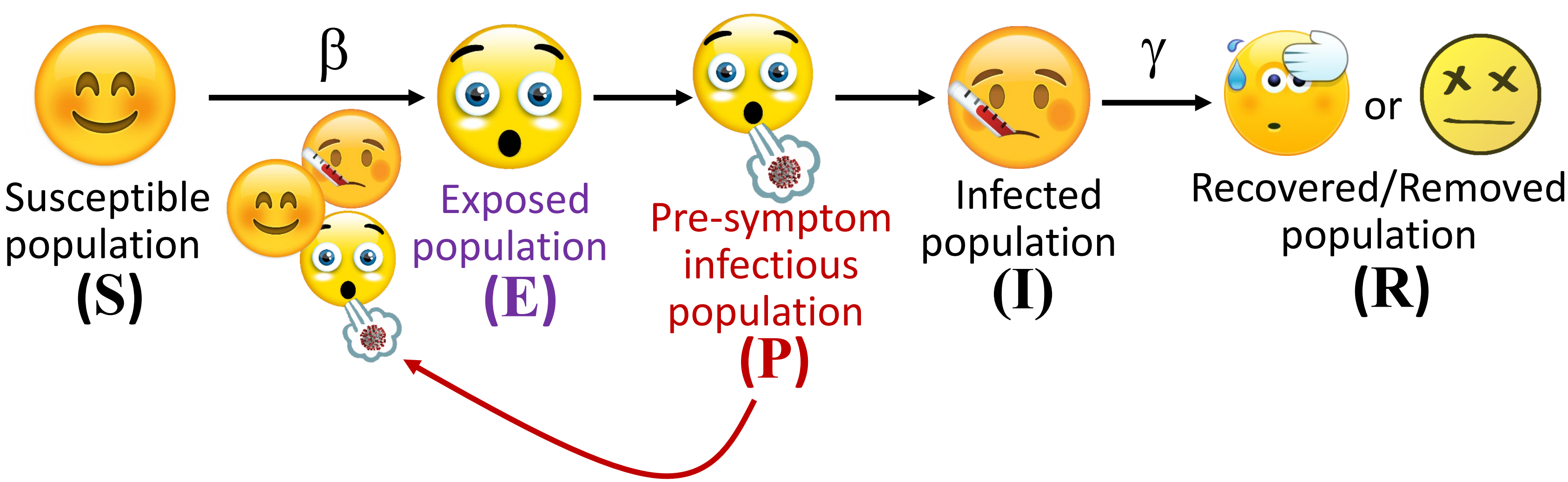
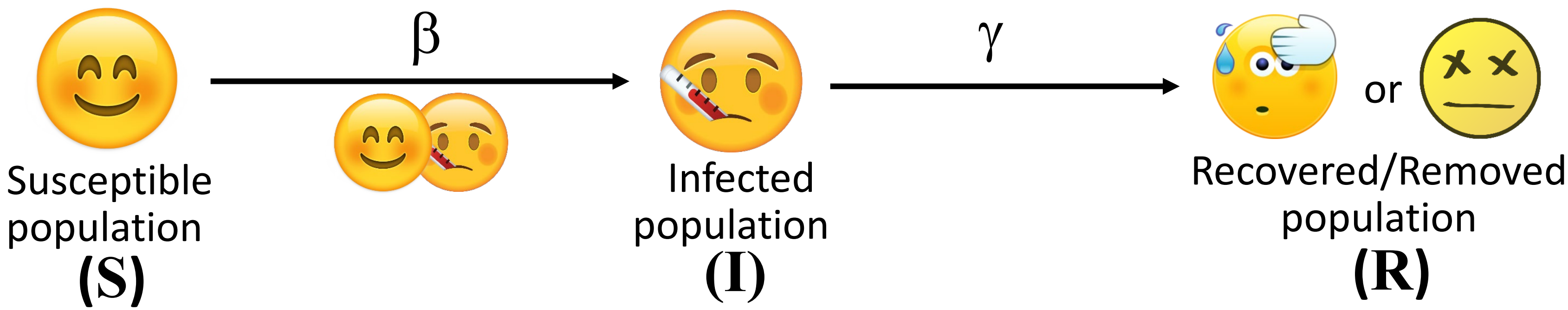
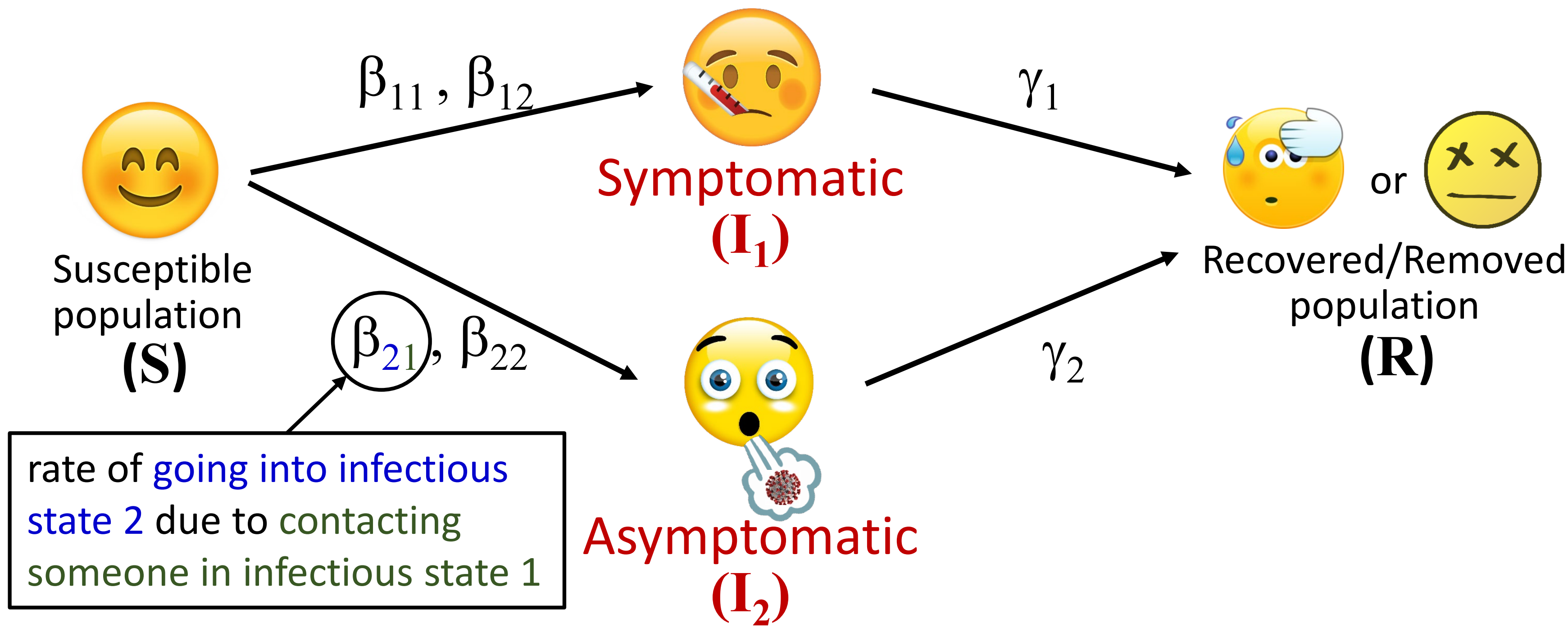


Relevant Extensions: Additional States

SIR Model:

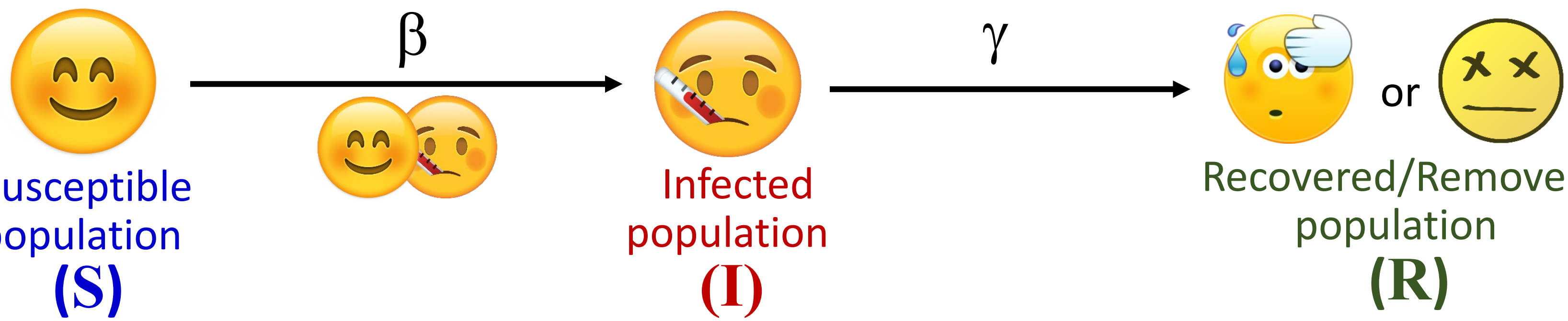


SIR Model with Different Infectious States (e.g. symptomatic & asymptomatic):

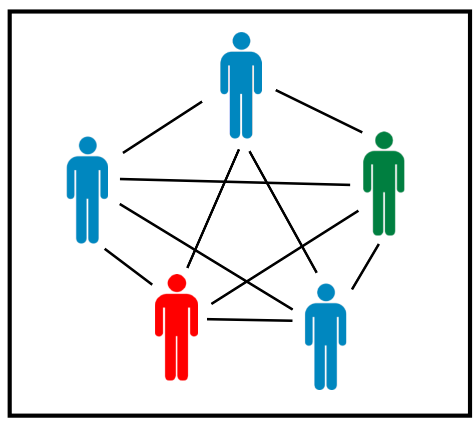


Major Limitation of Basic SIR Model: Single Variable for Entire Population

SIR Model:



<u>Implicit assumption 1</u>: Everyone contacts everyone

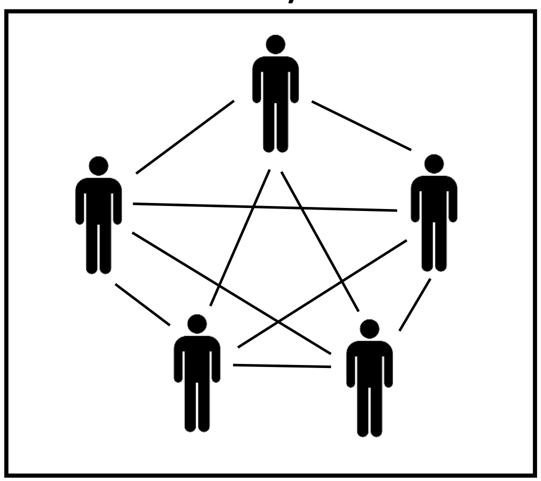


<u>Implicit assumption 2</u>: No randomness: describes average behavior of large populations

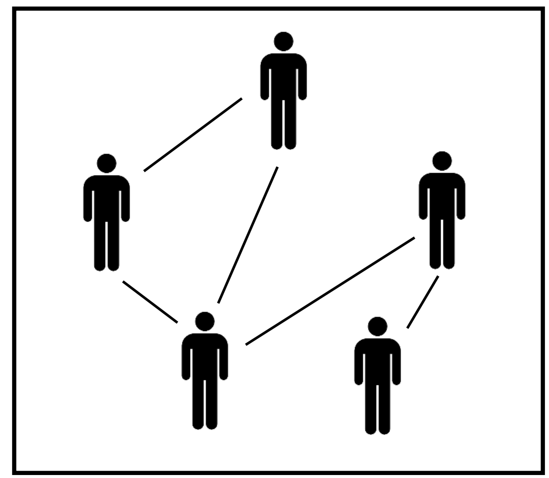
Spatial ("Individual-Based") Models

1) *Spatial models allow for individuals to contact different people:*

Everyone contacts everyone



Different contacts for different people



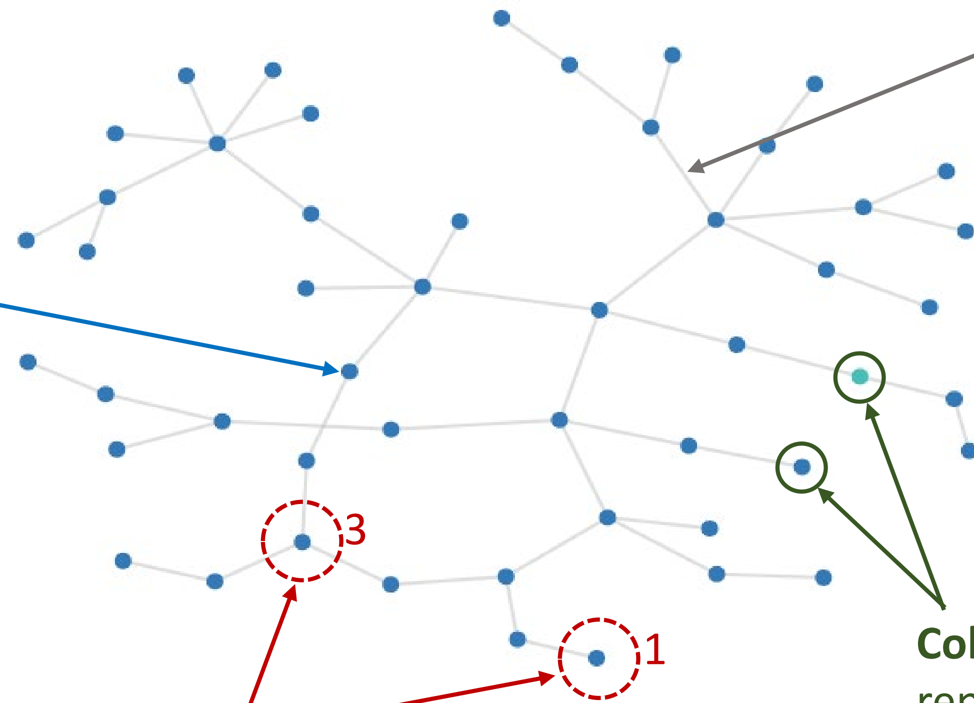
2) *Often in spatial models, transmission of infection is probabilistic (aka "stochastic"):*

→ At each moment of time, for every contacting pair, the simulator "rolls the dice" to determine if a transmission occurs

Key Concepts from Network Theory: Nodes, Edges, & Degrees

<u>Key concept 1</u>: Networks (aka ‘graphs’) are made up of nodes connected by edges

network from epidemix:



Node: represents a unit (e.g. a person)

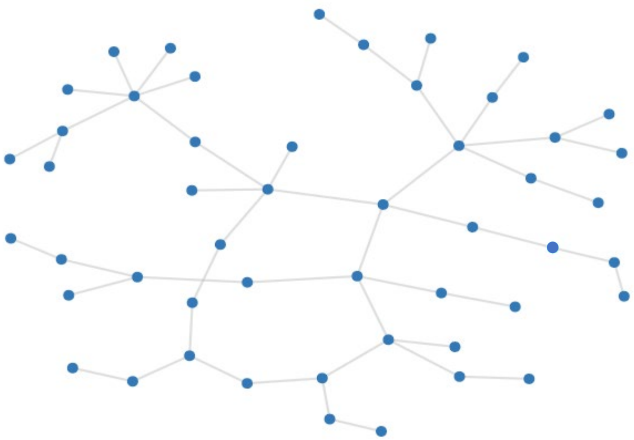
Edge: represents connections between nodes (e.g. contacts between people)

Degree (of a node): the number of edges it connects to

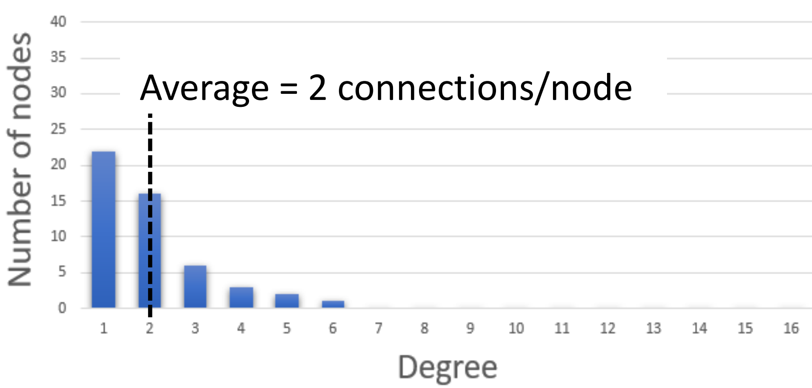
Color of a node can represent different states (e.g. susceptible or infectious)

Structure of a network can be characterized by its "degree distribution"

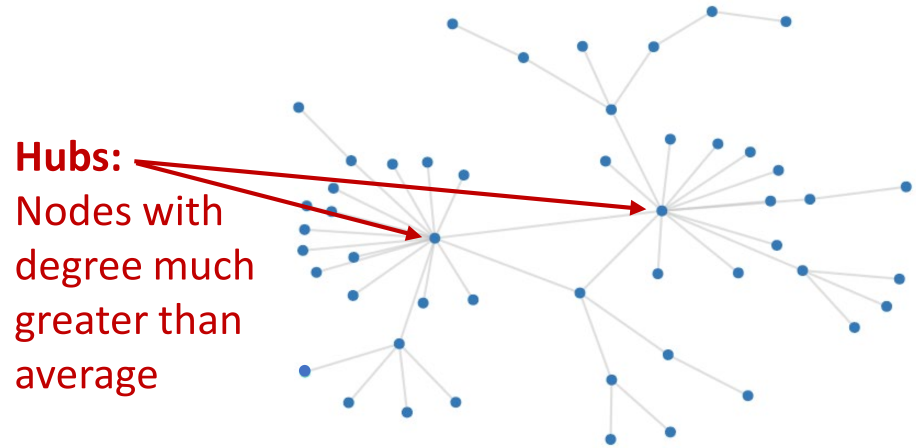
Randomly connected network



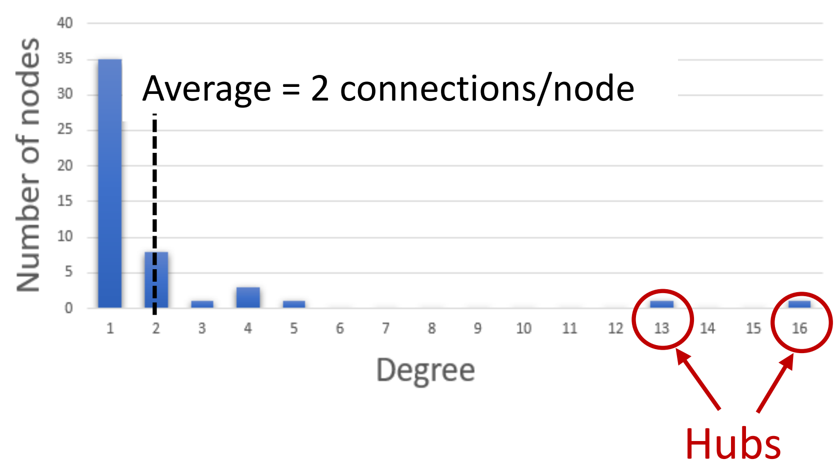
Degree distribution



Clustered network

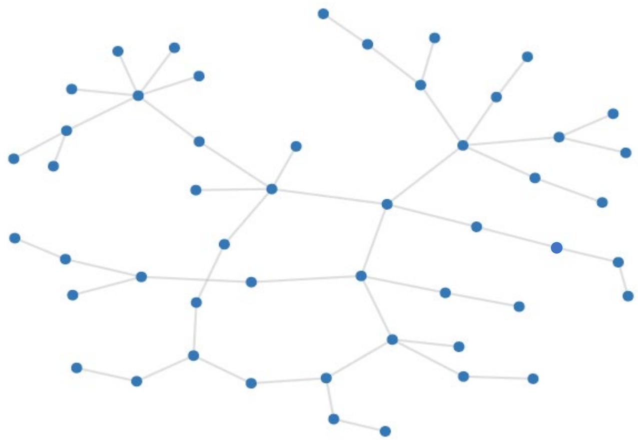


Degree distribution

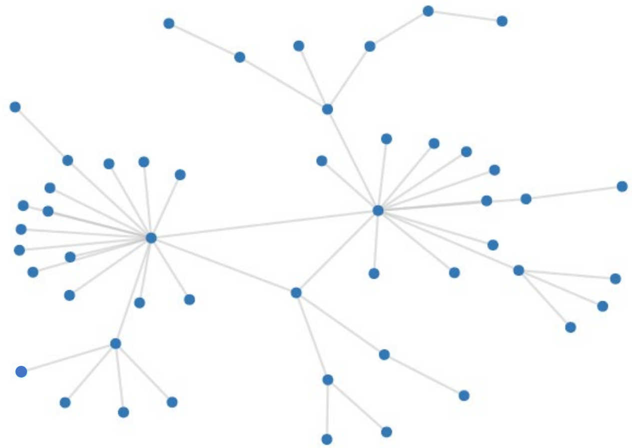


Question: Which type of network do you think has faster disease spread?

Randomly connected network



Clustered network



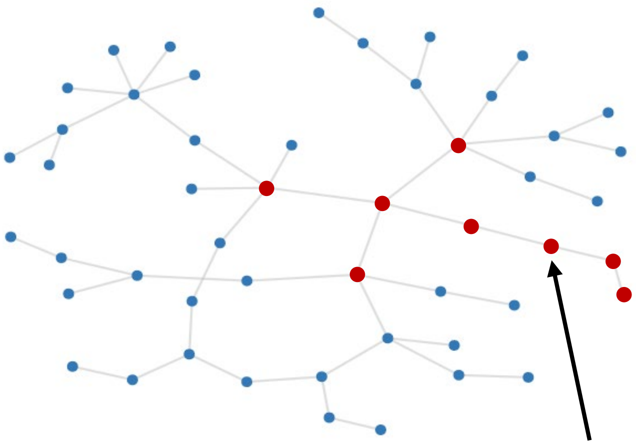
Answer: Networks with more clustering (hub-like nodes) tend to spread disease faster, because disease spreads rapidly across the network after reaching a hub

The “Mail Carrier” Network

Randomly connected network

(Shown for p=1: each contact leads to infection)

t = 3



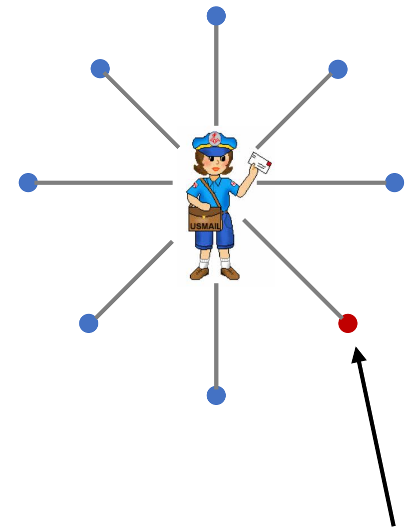
initial
infected
person

random network → spread is relatively slow

“Mail carrier” network

(Shown for p=1: each contact leads to infection)

t = 0



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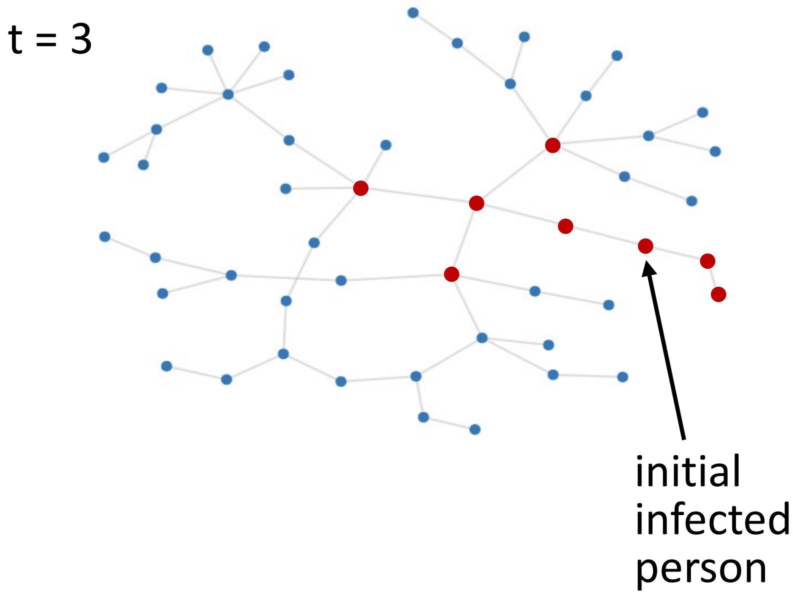

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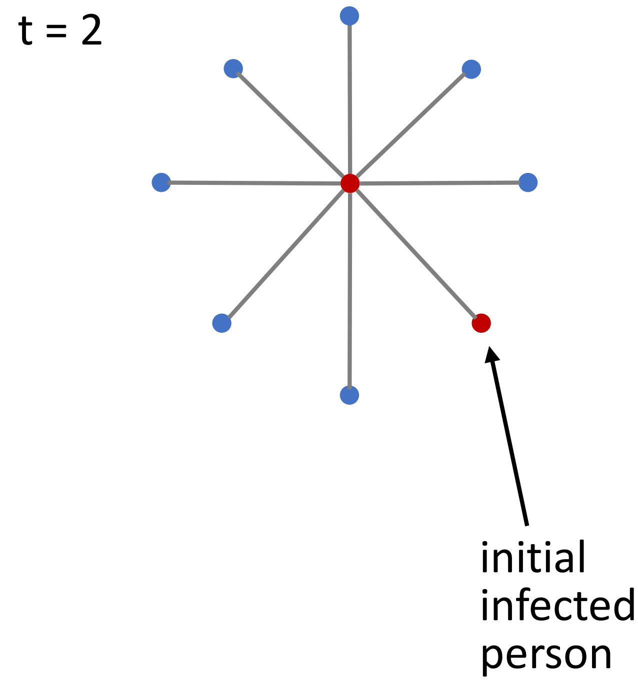
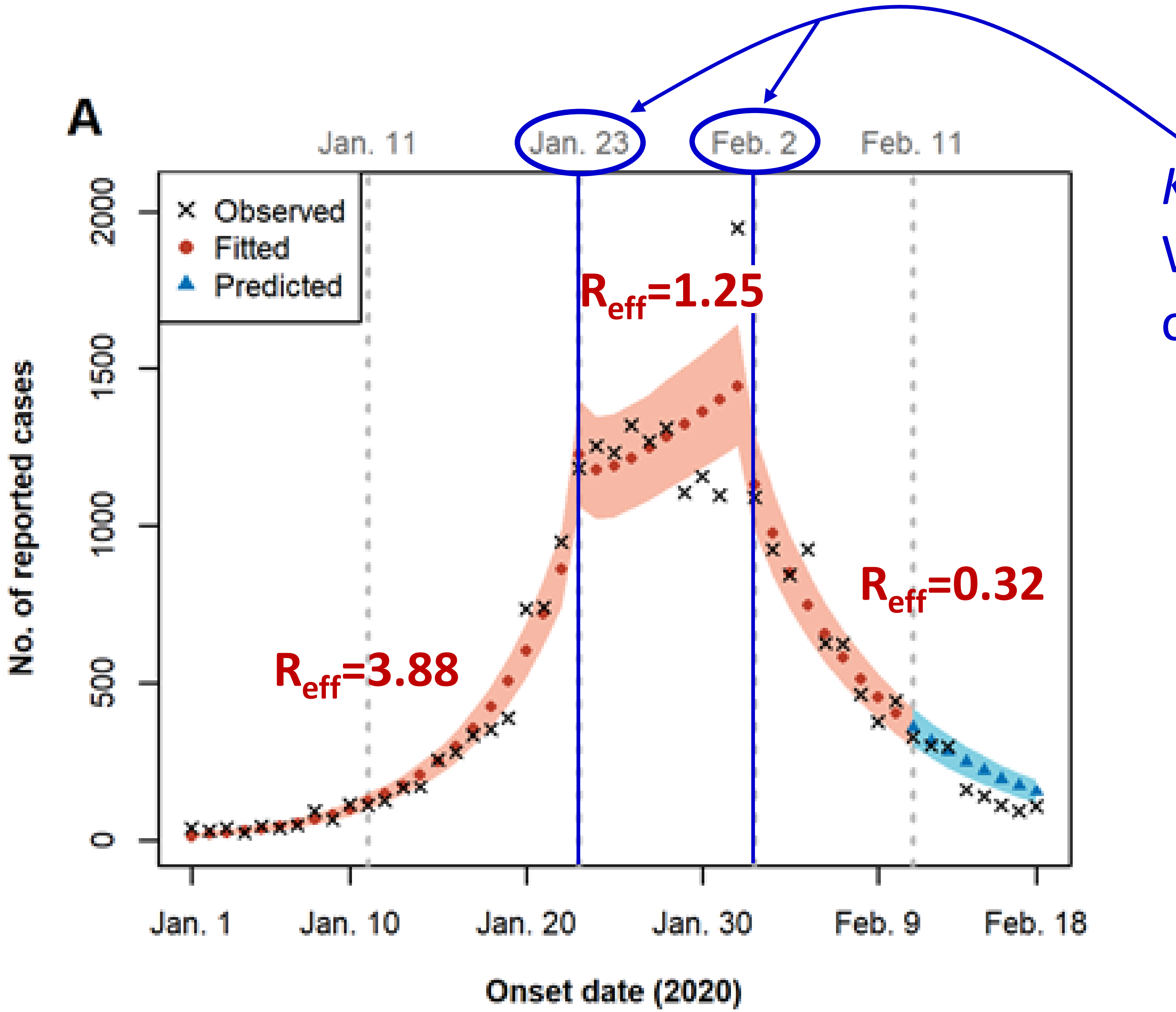


hub-like network: faster spread

Part 2:
Public Policy Measures for Reducing Disease Spread

Example Case: China



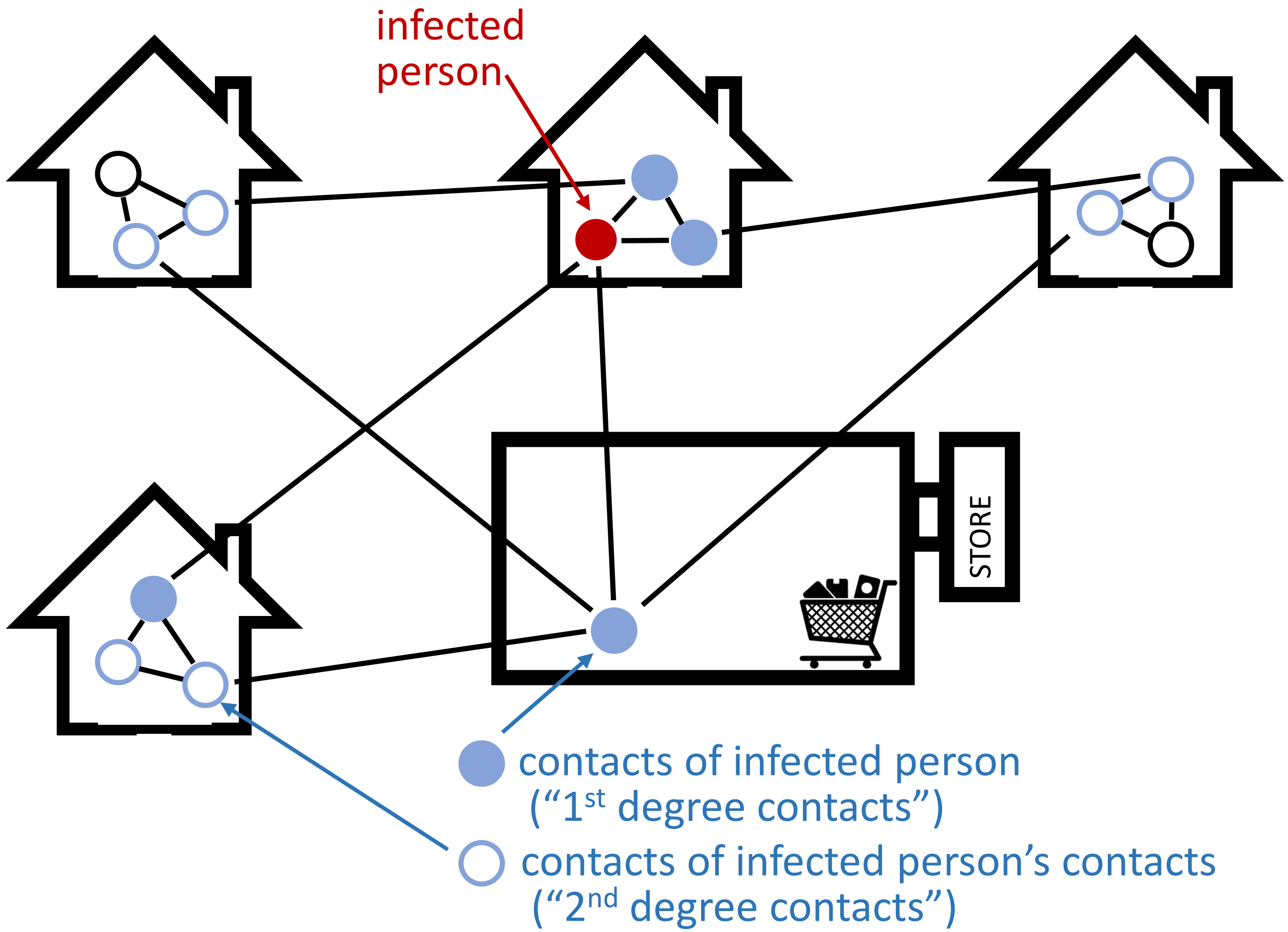
Key question:
What happened
on these dates?

data & fits from Wang et al., medRxiv, 2020

Control Measures of Progressive Strength

Social distancing/Shelter-at-home (imperfect):

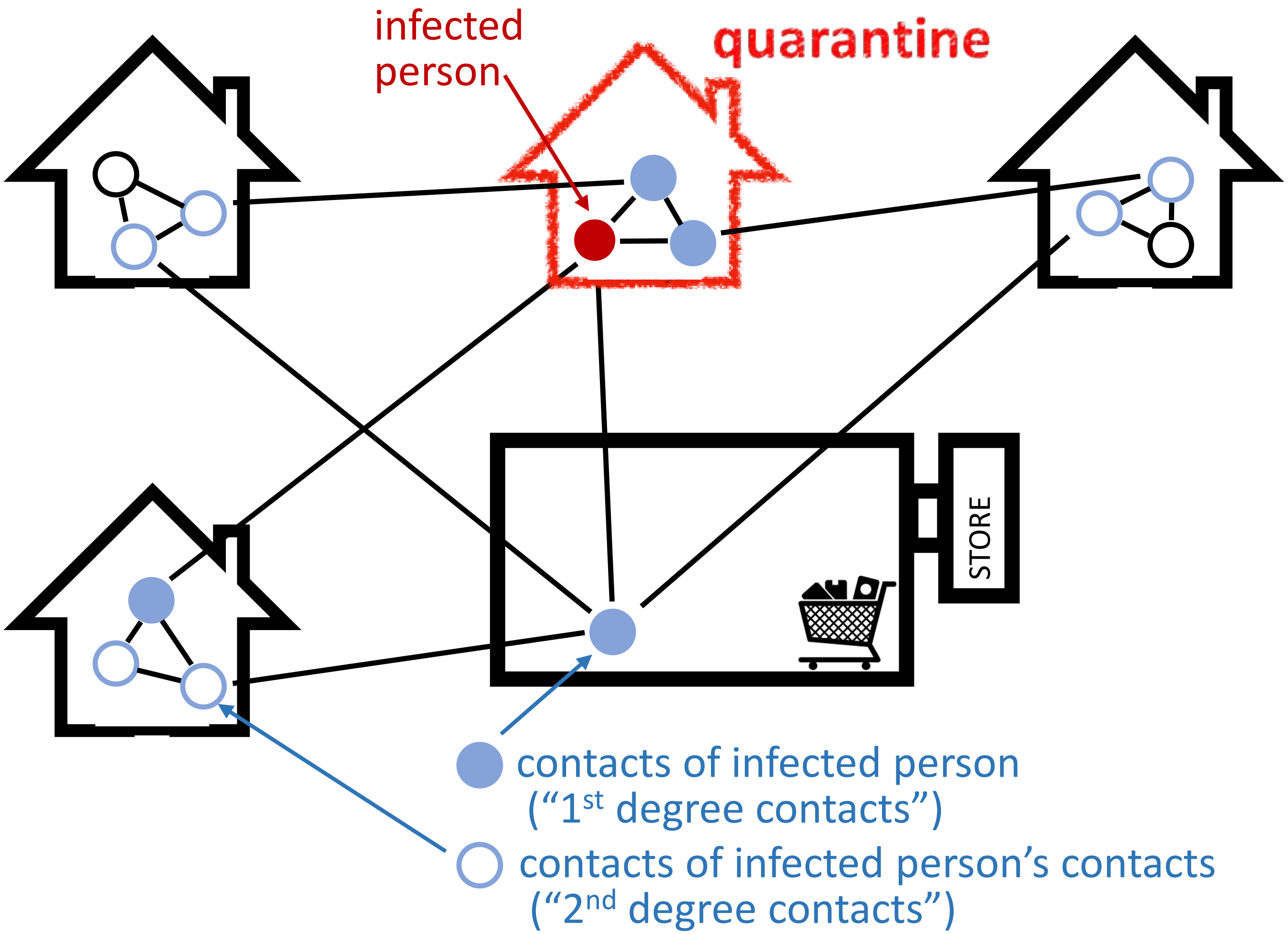
Most people at home, but go to grocery store, imperfect compliance



Control Measures of Progressive Strength

Household quarantine:

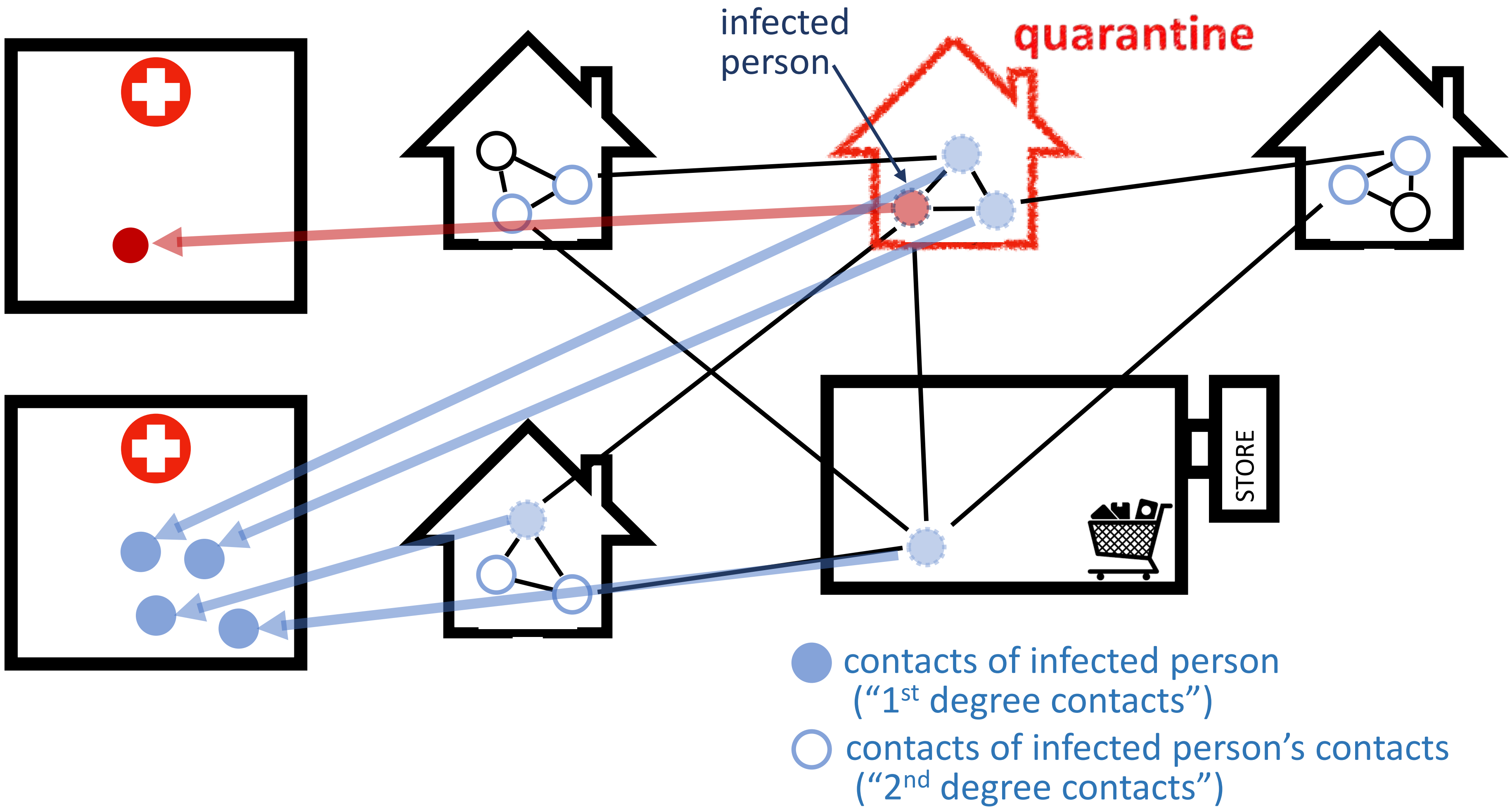
If someone sick, whole household is quarantined at their home



Control Measures of Progressive Strength

Centralized quarantine:

If someone sick, they & their contacts are quarantined at separate facilities



Test, Trace, Isolate/Quarantine

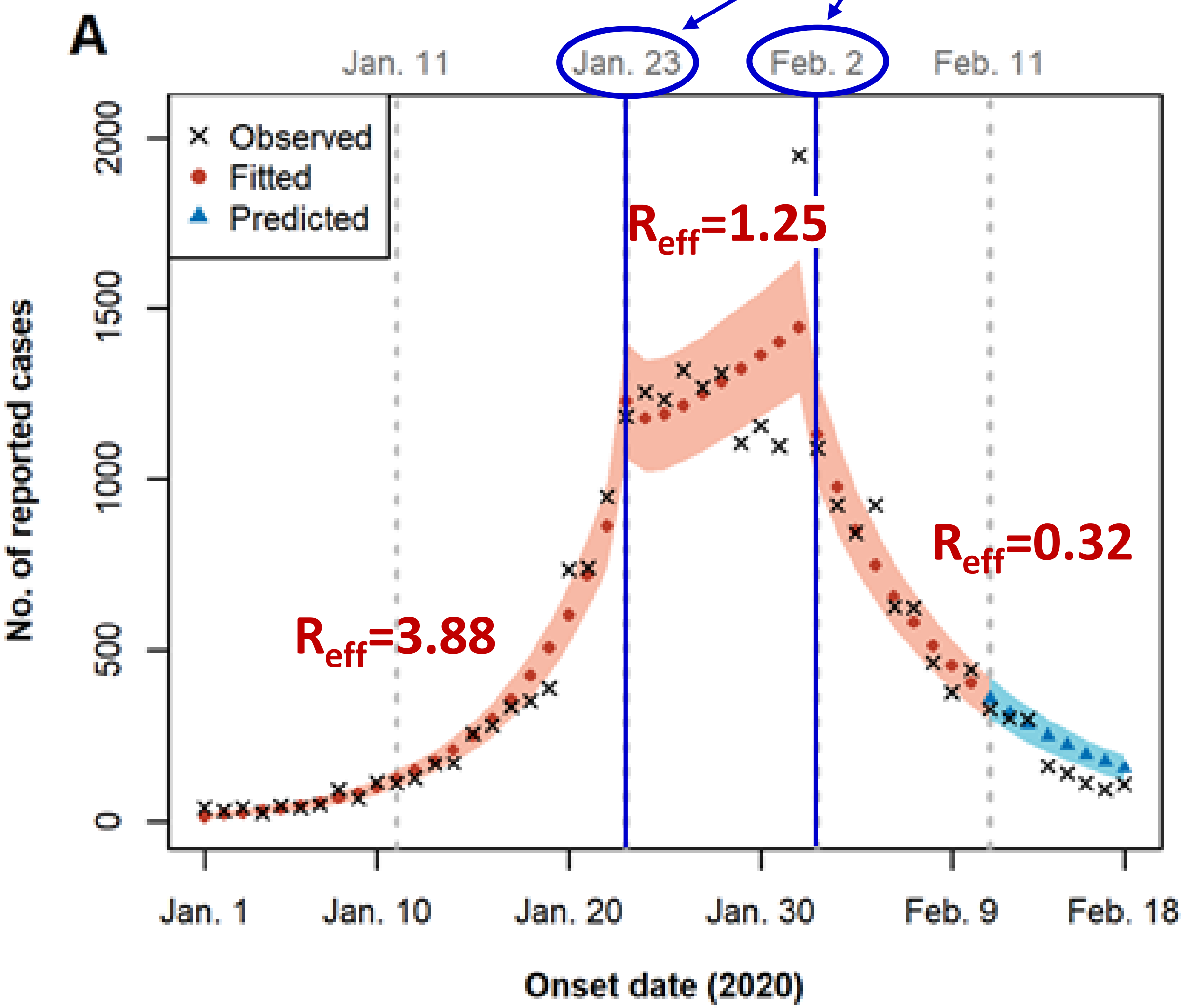
Test: Identify (by symptoms or invasive test) people with coronavirus

Contact trace: Trace (manually or digitally) contacts of infected people

Quarantine: Quarantine both infected people and their contacts

Can this work in practice?

Example Case: China



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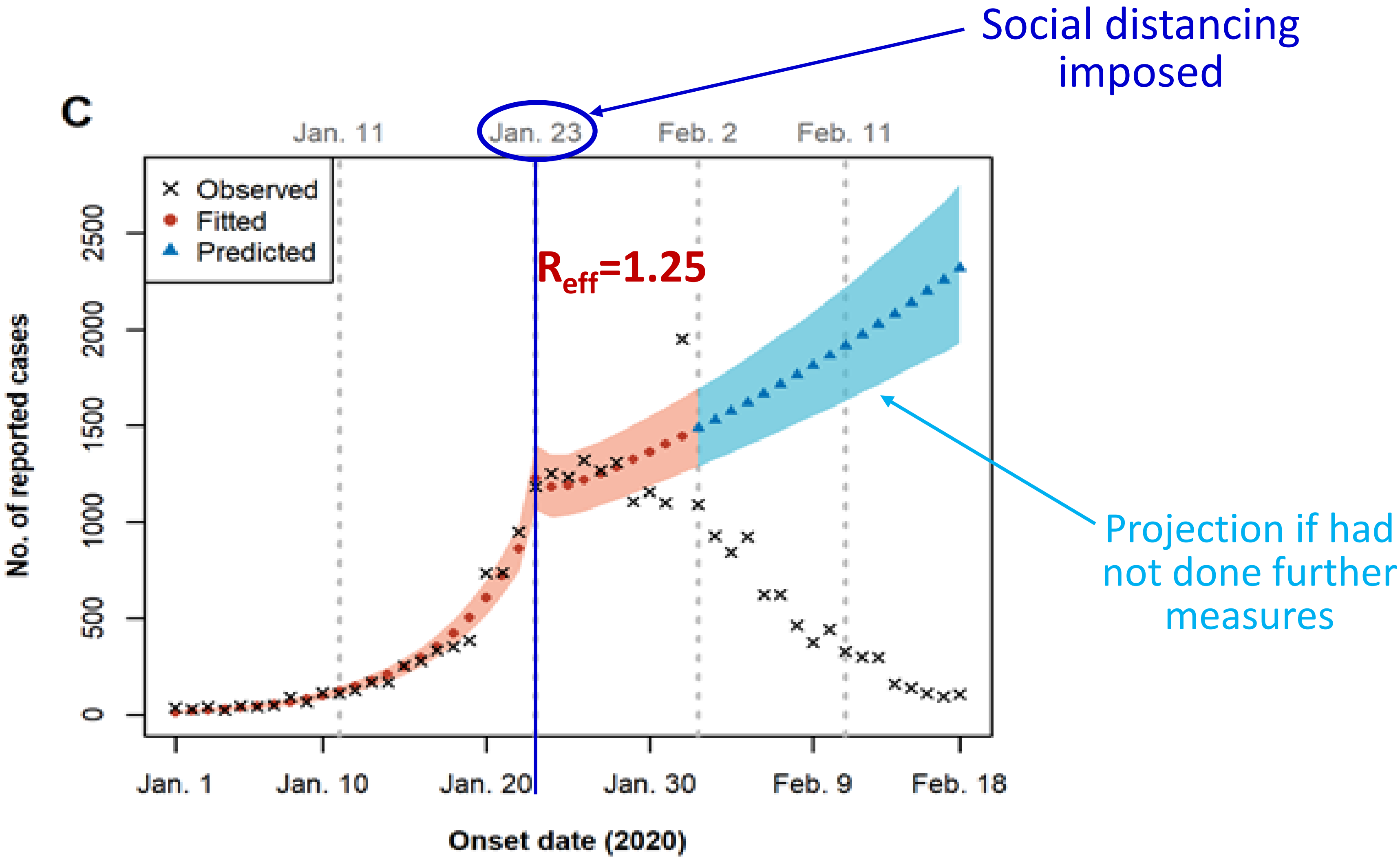
Example Case: China



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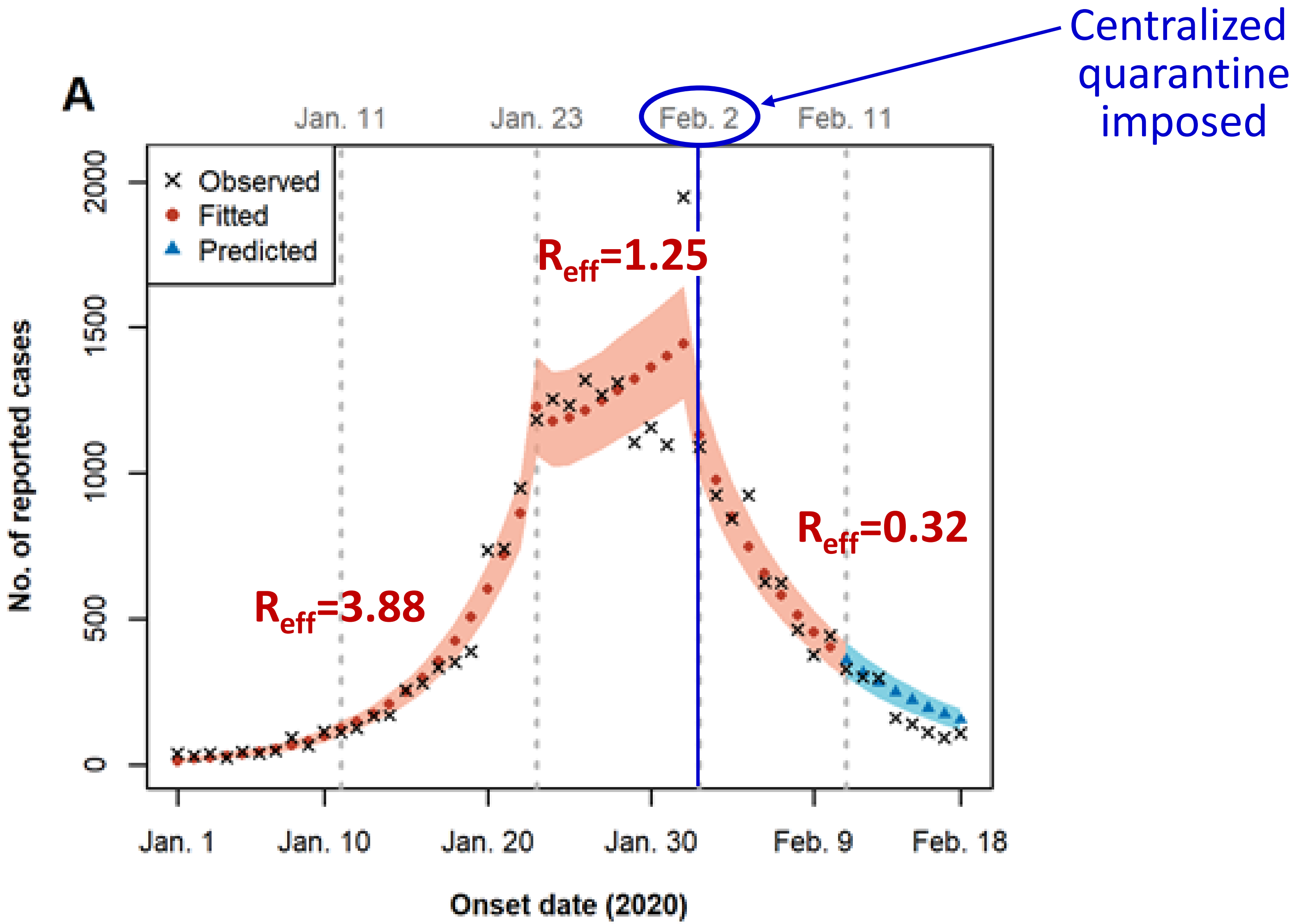

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Will Test, Trace, Isolate/Quarantine Work in the U.S.?

Key Issues:

- Do we have enough employees to do manual identifications of cases and contacts?

- Are manual identifications fast enough?

  → Ideally want to identify infectious people immediately, before they infect too many others

Apple and Google to the Rescue?

THE WALL STREET JOURNAL.

English Edition ▾ | April 12, 2020 | Print Edition | Video

Here's How Apple and Google Plan to Track the Coronavirus Through Your Phone

The idea requires widespread adoption and broad testing of potentially infected people
whether government and public-health officials will get behind it

The New York Times

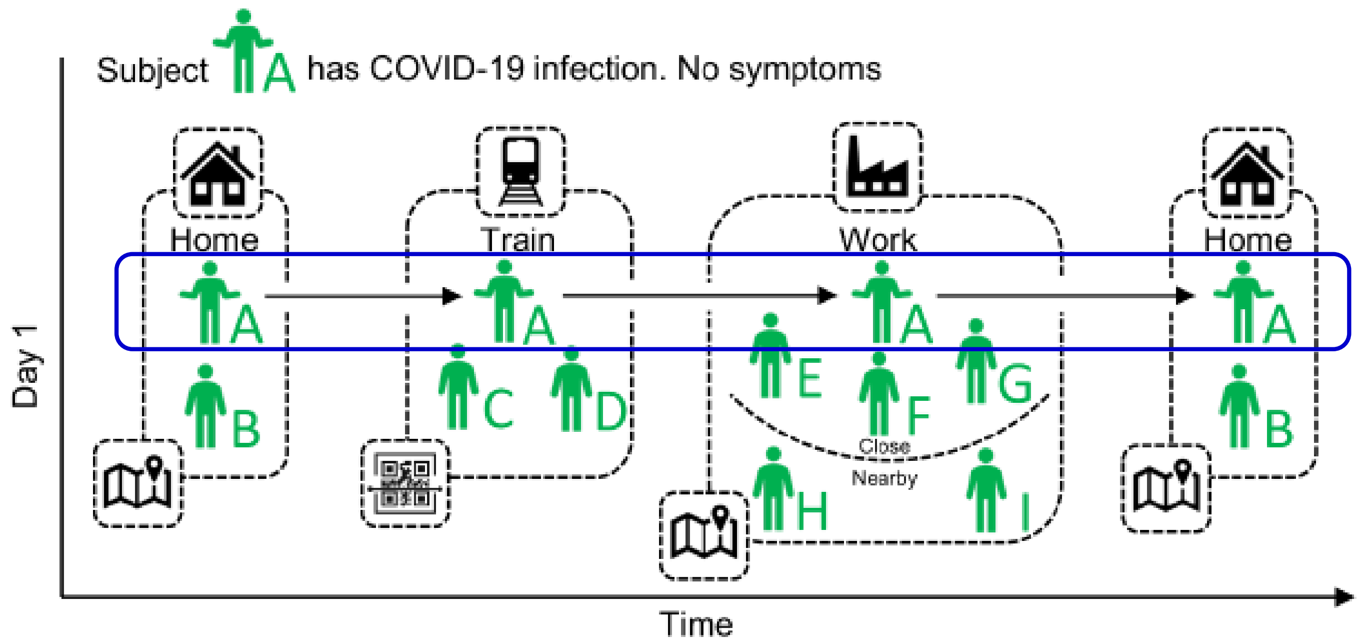
Apple and Google Team Up to 'Contact Trace' the Coronavirus

The technology giants said they would embed a feature in iPhones and Android devices to enable users to track infected people they'd come close to.

Proposal for Digital Tracing

Ferretti et al, *Science*, 2020

1) Contact tracing (always happening while phone on):



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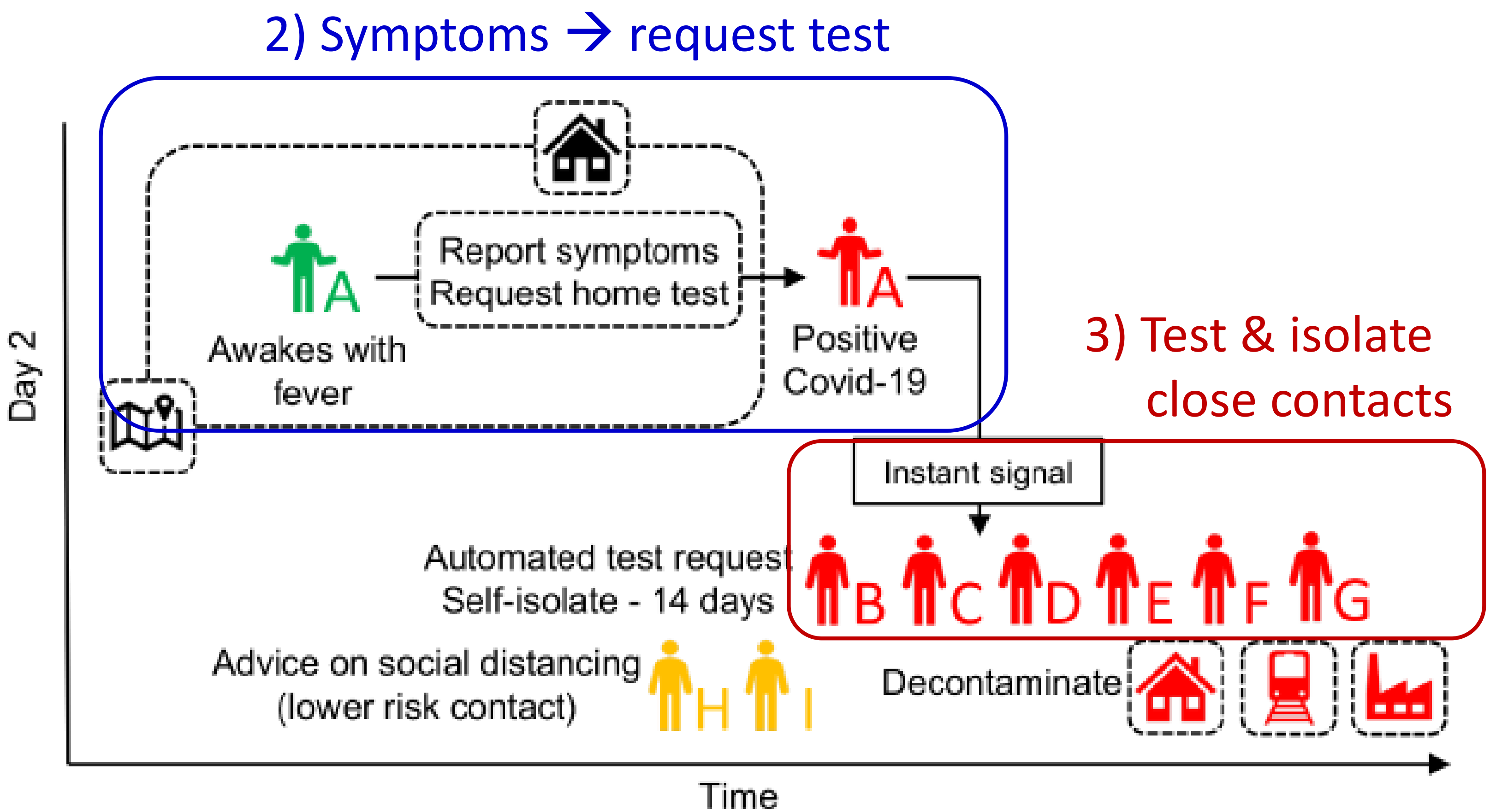

Summary: Disease Modeling ...and Control Policy

1) Control measures attempt to suppress the outbreak: bring $R_{eff} < 1$

2) SIR models can be used to model disease outbreak ...and guide policy by simulating the effects of different control measures

3) Hub people or locations can increase the speed of spread ...but may also provide key targets for control policies (see lab)

4) Test, trace, & isolate: may be able to control the epidemic, especially if done digitally ...but models suggest it must be widely adopted, and privacy issues remain a challenge

A Few Places to Keep Informed

- *NY Times* coronavirus page:
  https://www.nytimes.com/interactive/2020/world/coronavirus-maps.html

- *Science* and *Nature*

- Johns Hopkins Coronavirus Resource Center:
  https://coronavirus.jhu.edu/

- Institute for Health Metrics and Evaluation (IHME)
  http://www.healthdata.org/

How to Learn More About Modeling
(for juniors or your friends...)

- *BIS 20Q*: Models in Biology
  A 'greatest hits album' of key models driving biology research

- *MAT/BIS 27A, 27B, 107*: Math Tools for Biology Series
  Provides the key math needed to understand these studies

- *BIS 23A/B: Genome Hunters*
  Course-based research class: microbial growth & genomics experiments, with bioinformatic analysis of resulting data

And coming soon...

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