

Reopening Cornell During the COVID-19 Pandemic

Peter Frazier
Associate Professor
Operations Research & Information Engineering



J. Massey
Cashore



Ning
Duan



Alyf
Janmohamed



Jiayue
Wan



Yujia
Zhang



Shane
Henderson



David
Shmoys

New York
 Ithaca, New York
 Add destination

Leave now OPTIONS

Send directions to your phone

via I-80 W and I-81 N **3 h 55 min**
 Fastest route, the usual traffic
 ▲ This route has tolls.

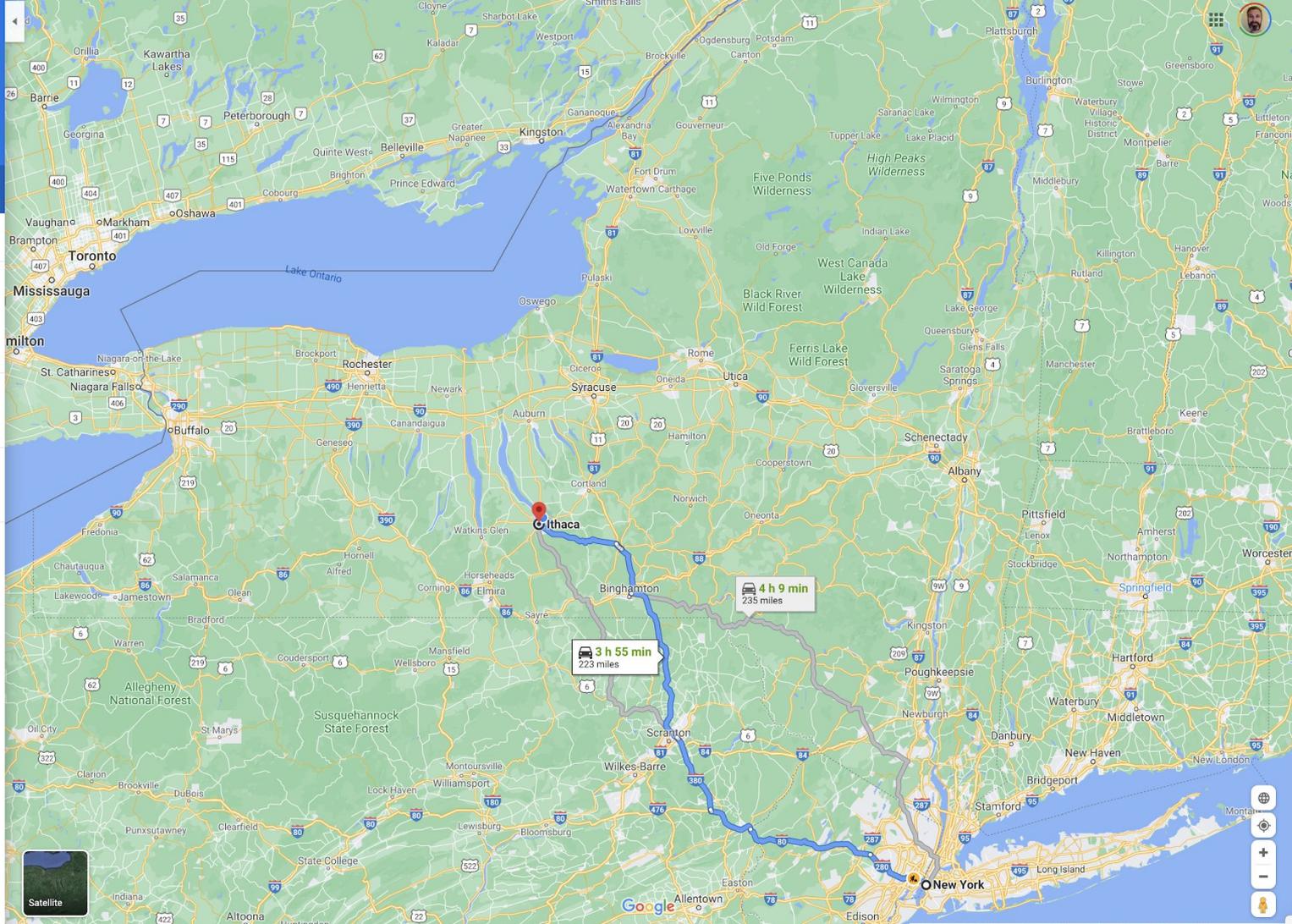
[DETAILS](#)

via NY-17 W **4 h 9 min**
 235 miles

via I-80 W **4 h 39 min**
 226 miles

Explore Ithaca

Groceries
 Hotels
 Gas stations
 Parking Lots
 More



OPINION | COMMENTARY

Why Cornell Will Reopen in the Fall

Students will return to Ithaca in any case. On campus, we can track and isolate Covid cases.

By Michael I. Kotlikoff and Martha E. Pollack
June 30, 2020 12:45 pm ET

SAVE PRINT TEXT

229



Cornell University in Ithaca, N.Y.

PHOTO: UNIVERSAL IMAGES GROUP VIA GETTY IMAGES

Consider two scenarios. University A decides to reopen. For the health and safety of students, faculty and staff, it institutes a screening program to identify asymptomatic students infected with the novel coronavirus and prevent them from spreading it by repeated testing and isolation. The school also monitors symptoms daily, restricts group sizes, modifies classrooms and dorms, secures extensive quarantine capacity, restricts travel, and imposes requirements for masks and social distancing.

University B decides that this is too risky and chooses to play it safe. The school doesn't reopen for residential instruction this fall and opts instead to teach all courses online. It takes cautious steps to open for selected professional or graduate programs and research efforts, but doesn't implement the complex process of screening thousands of undergraduates and modifying the learning environment for social distancing.

Surprisingly, [epidemiological modeling](#) done by a group led by Cornell Prof. Peter Frazier

suggests that despite playing it safe, sometime during the fall University B may well experience markedly worse health outcomes in its community, while University A will have more effectively safeguarded public health.

For many universities, closing the campus to undergraduates is probably not the safest option—notwithstanding concerns that college students may not adhere to public-health

guidelines. That's because at many colleges, students will gather on and around campuses whether classes are held in person or online.

NEWSLETTER SIGN-UP

Opinion: Morning Editorial Report

All the day's Opinion headlines.

PREVIEW

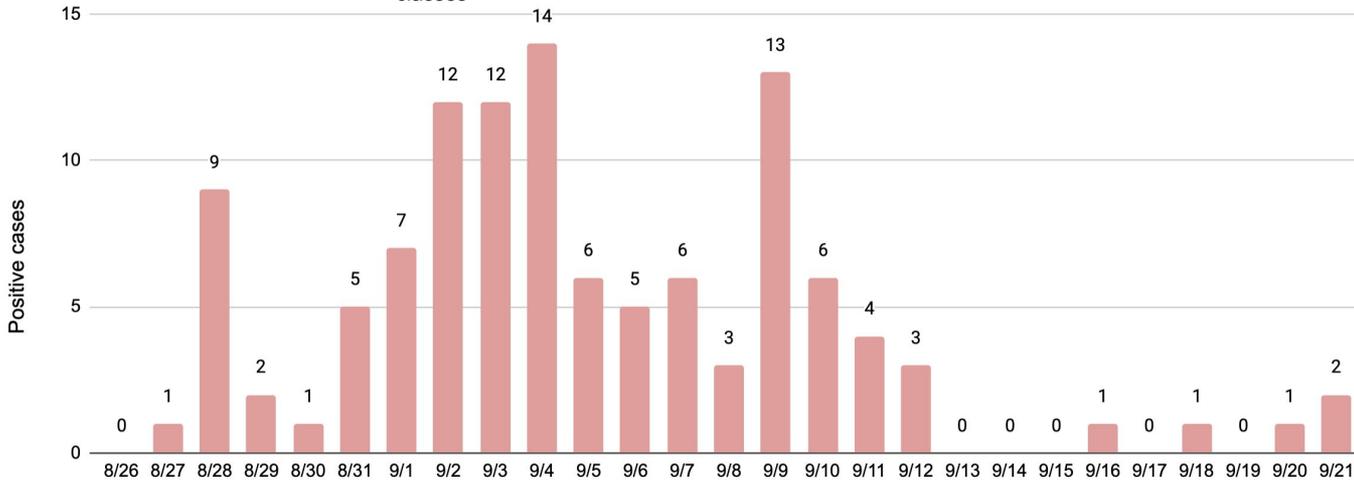
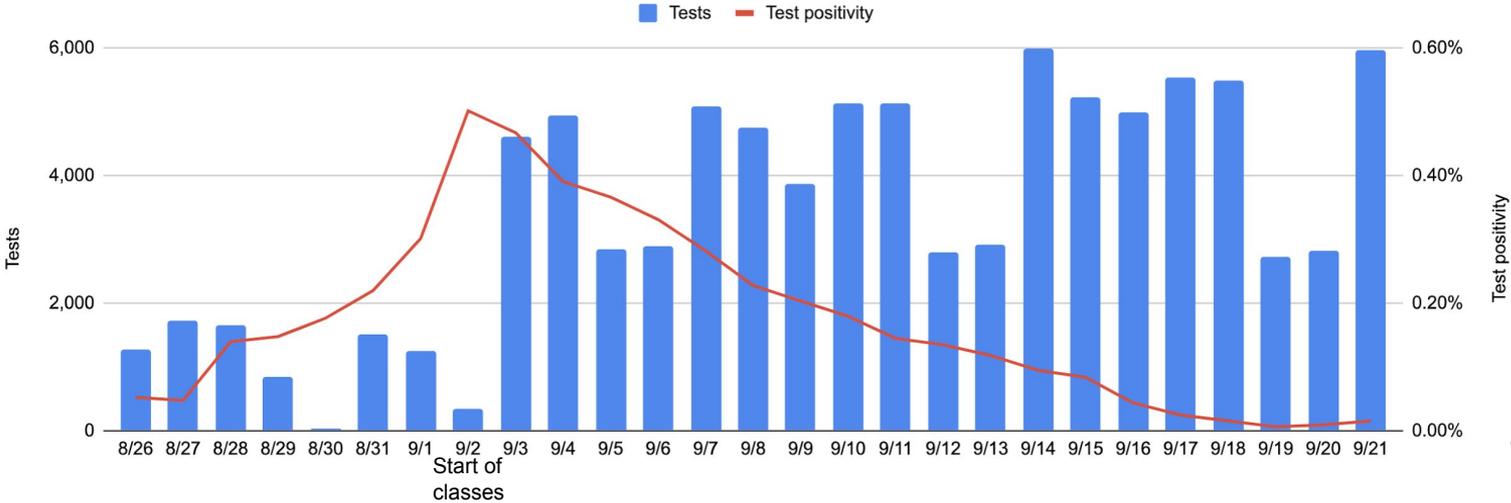


SUBSCRIBE

Cornell's strategy

- Bring back ~75% of UG and graduate students to campus
- ~80% of students have at least one in-person class
- Arrival testing
- Aggressive asymptomatic screening:
test all UG's 2x / week, most others 1x / week
- Adaptive testing: expands traditional contact tracing to full social circle
- Large-scale testing enabled by pooling + vet school lab
- Travel beyond Ithaca strongly discouraged

It has worked so far



- 12K UG in Ithaca (5K in dorms)
- Another 10K grad students + staff + faculty on campus
- 121 positives since 8/16
- 5 in the last week
- 0.12% test positivity

Agenda

1. COVID-19 at universities that opened without aggressive screening
2. Cornell's screening program
3. Takeaways for impacting policy with data science

1. COVID-19 at universities that opened without aggressive screening

Over 1,000 students have tested positive for Covid-19 at University of Alabama since classes resumed

By **Hollie Silverman** and Dakin Andone, CNN

Updated 5:06 PM ET, Sat August 29, 2020



AUGUST 30, 2020 | Albany, NY

Governor Cuomo Deploys SWAT Team to SUNY Oneonta to Contain COVID-19 Cluster

CORONAVIRUS

PUBLIC SAFETY

HEALTH

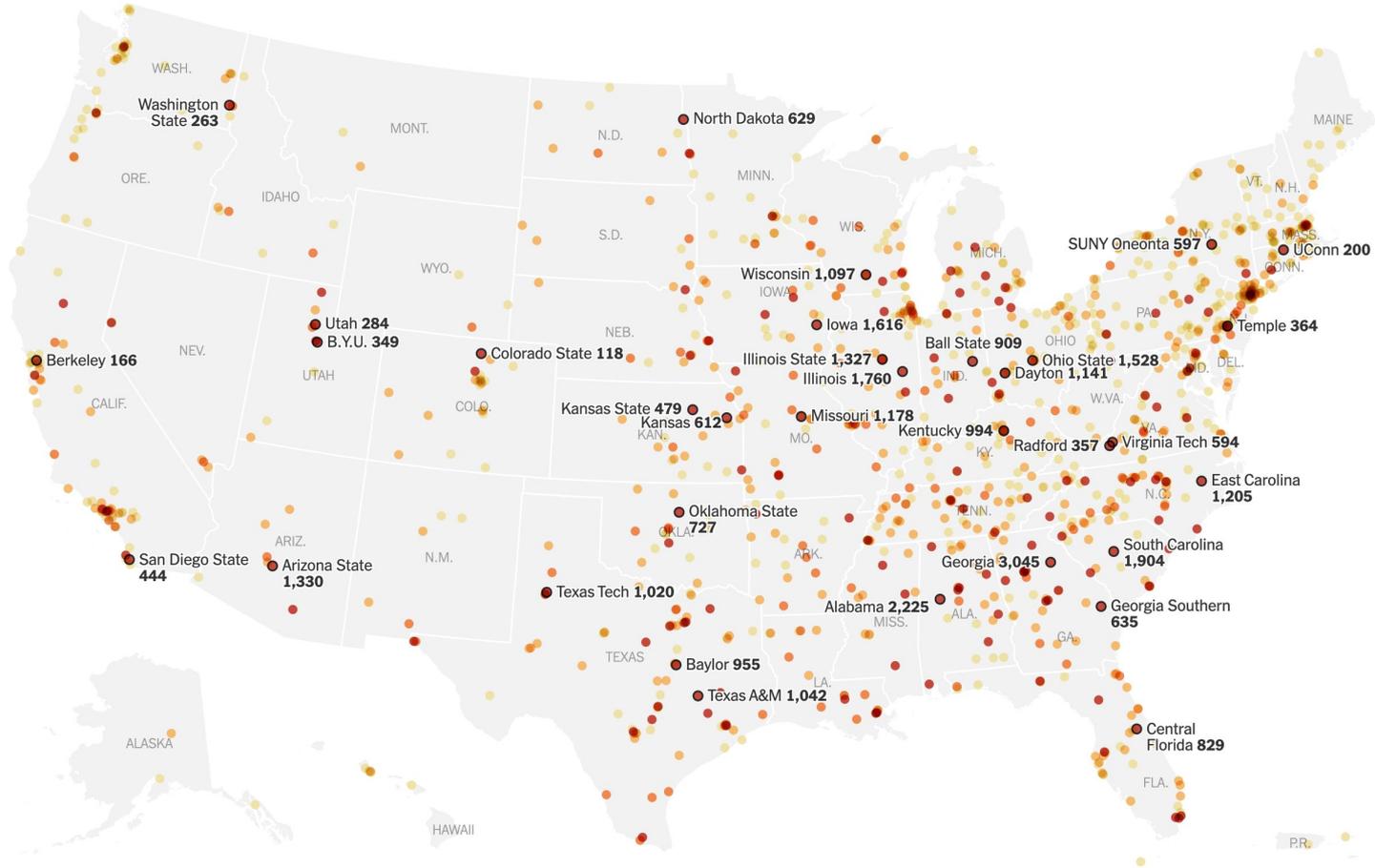
North Carolina's flagship university moves online after 130 Covid-19 cases

The University of North Carolina at Chapel Hill changes course after coronavirus spreads during the first week of classes



Colleges with coronavirus cases since the pandemic began

● 100 or more cases ● 50-99 cases ● 10-49 cases ● Fewer than 10 cases

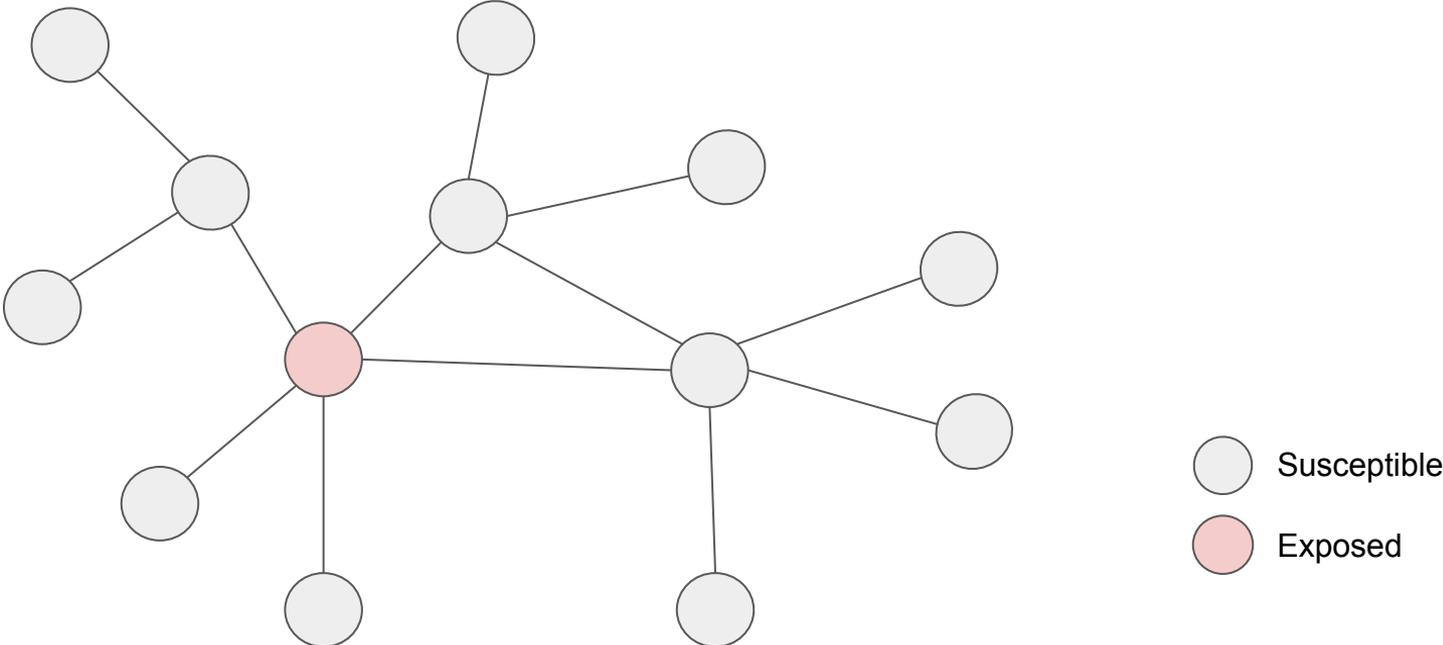


Why does this happen?

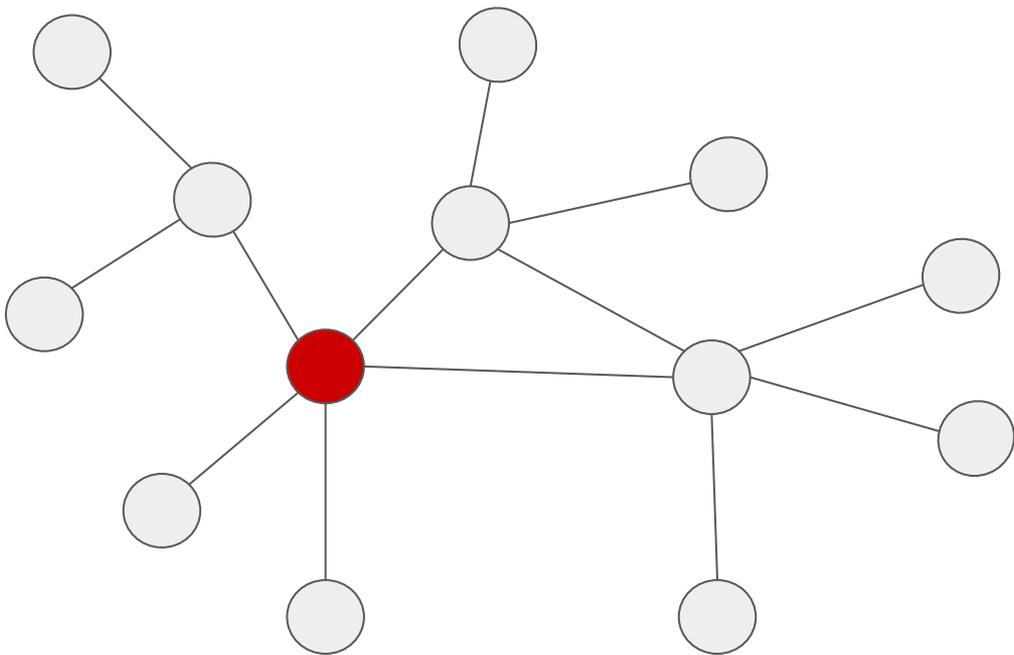
The approach followed by most other colleges offering in-person instruction

- Test students on arrival (maybe)
- Test students with symptoms
- Do traditional contact tracing on positive cases

Index case is infected, not yet infectious

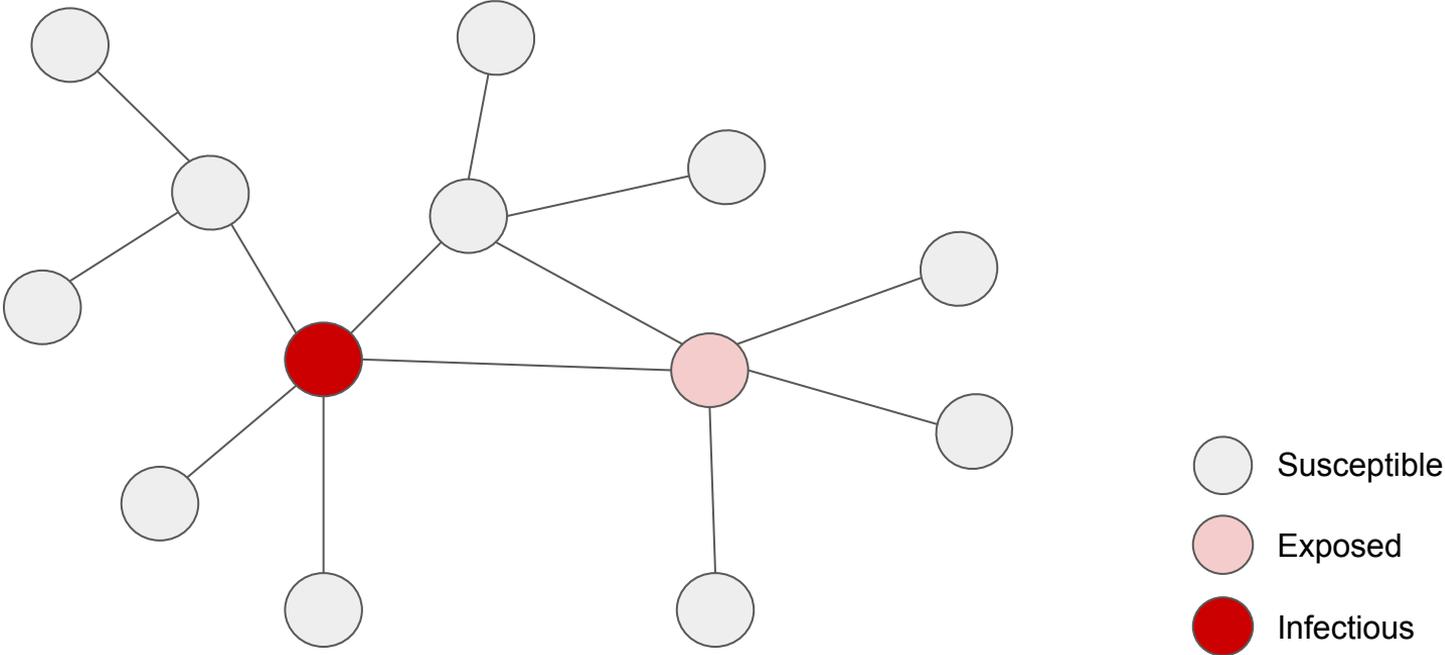


Index case is infectious & asymptomatic

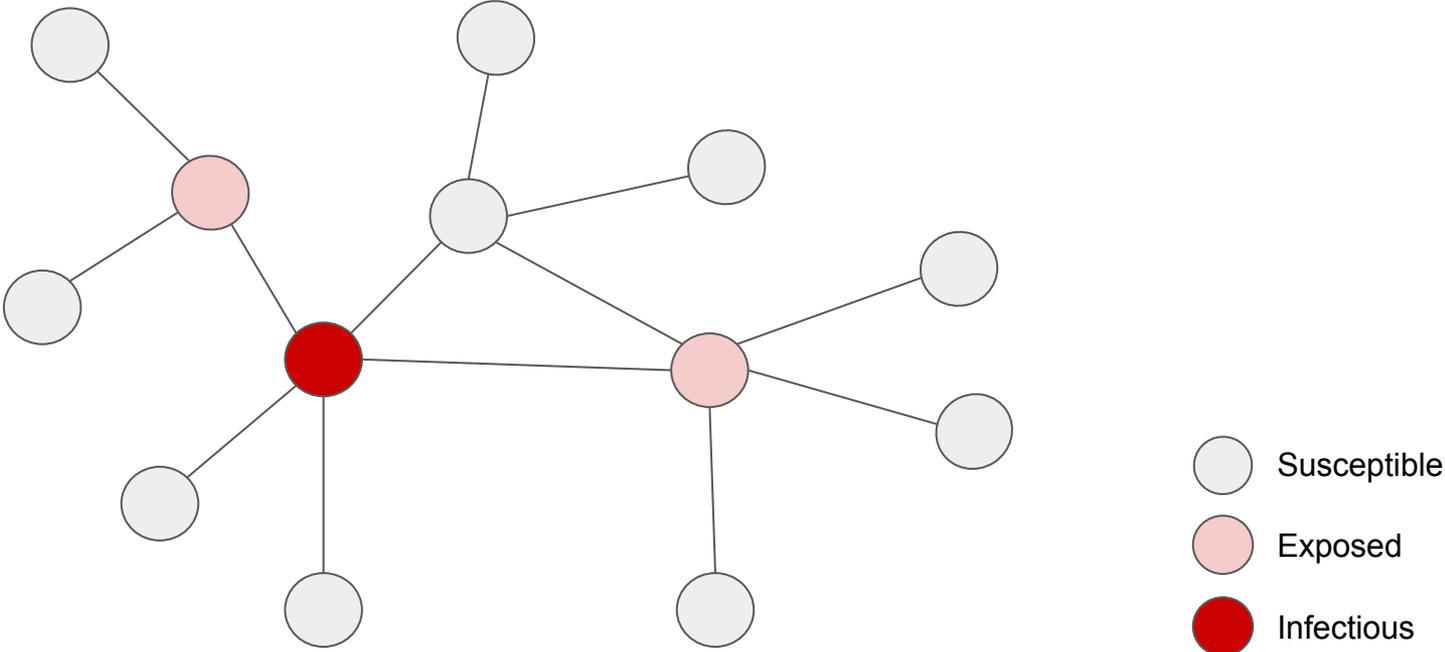


-  Susceptible
-  Exposed
-  Infectious

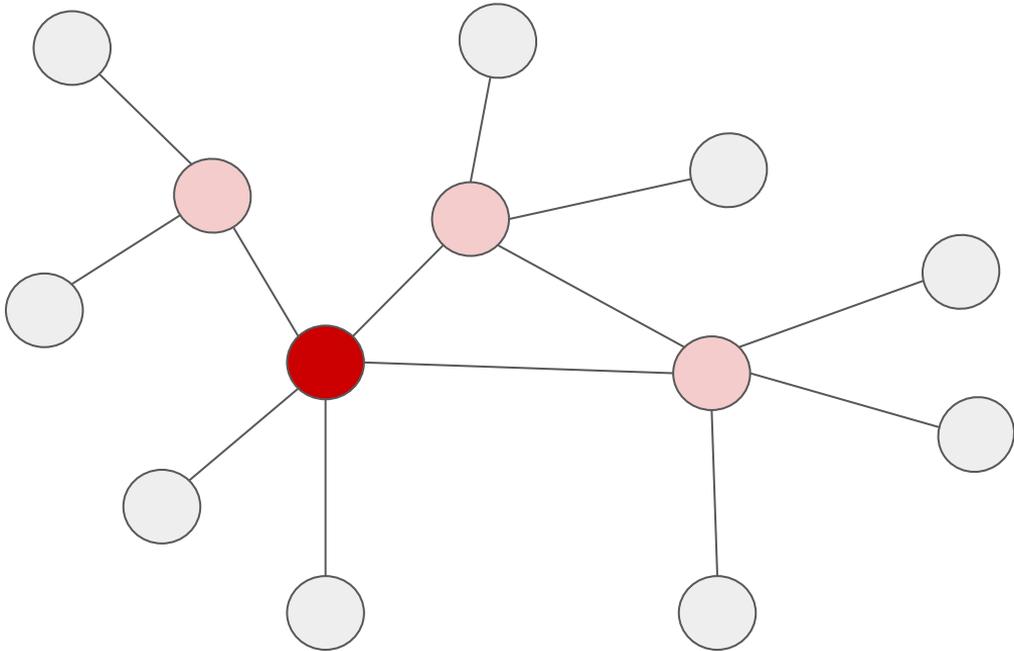
Another person becomes infected



Another person becomes infected

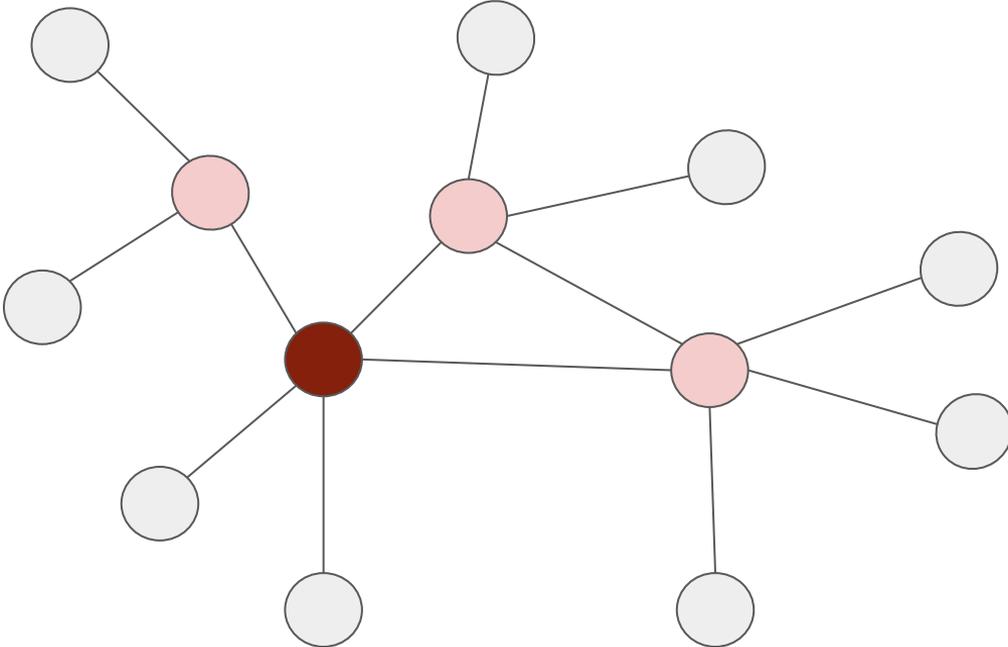


Another person becomes infected



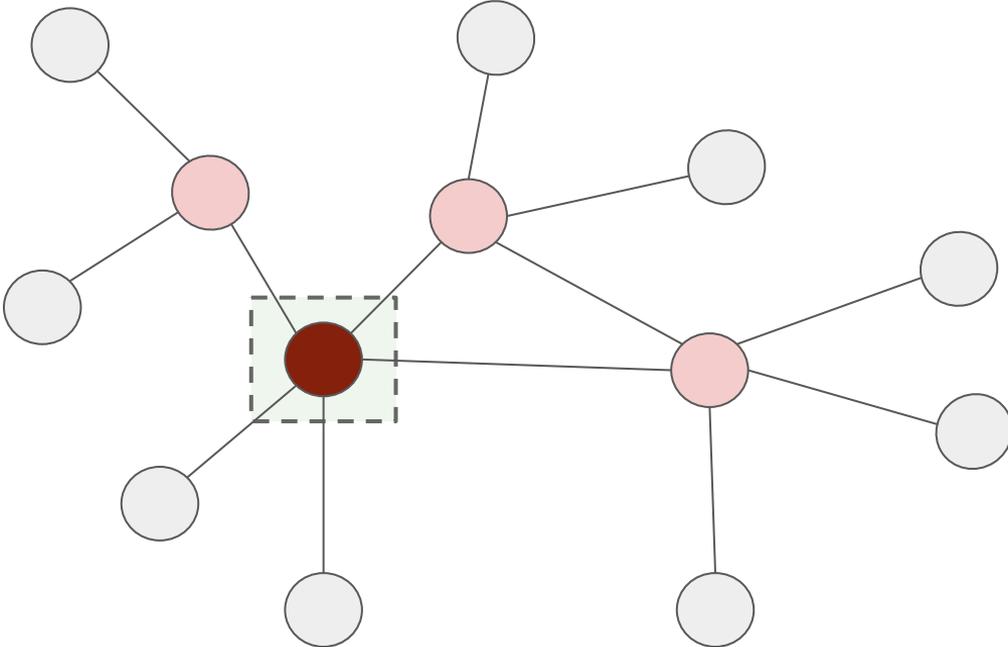
-  Susceptible
-  Exposed
-  Infectious

Index case shows symptoms



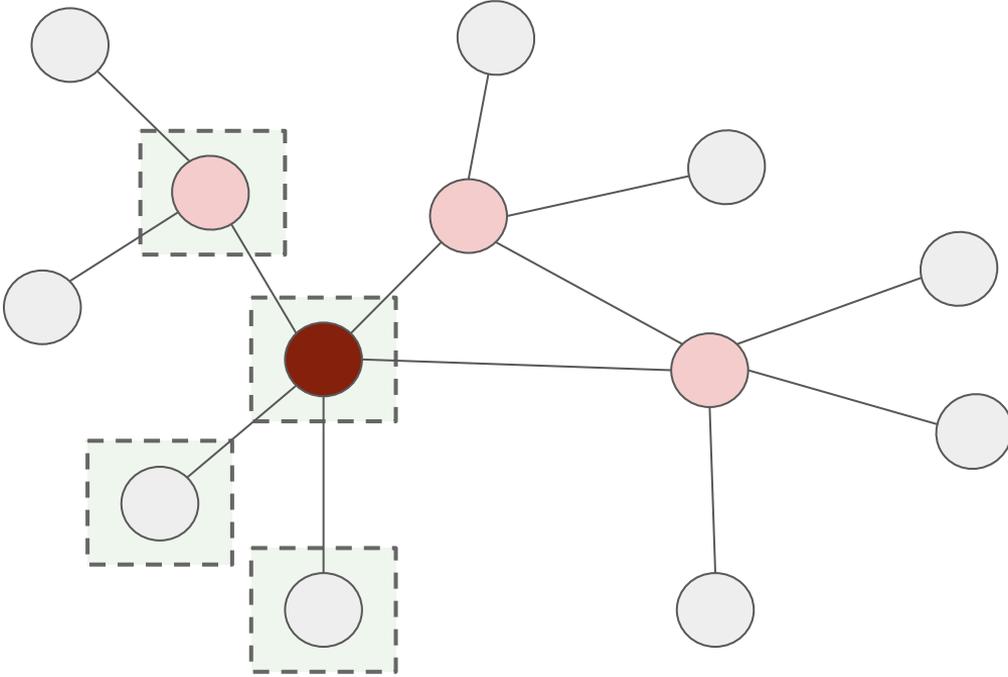
-  Susceptible
-  Exposed
-  Infectious
-  Symptomatic

Index case calls doctor, is tested, then isolated by health department



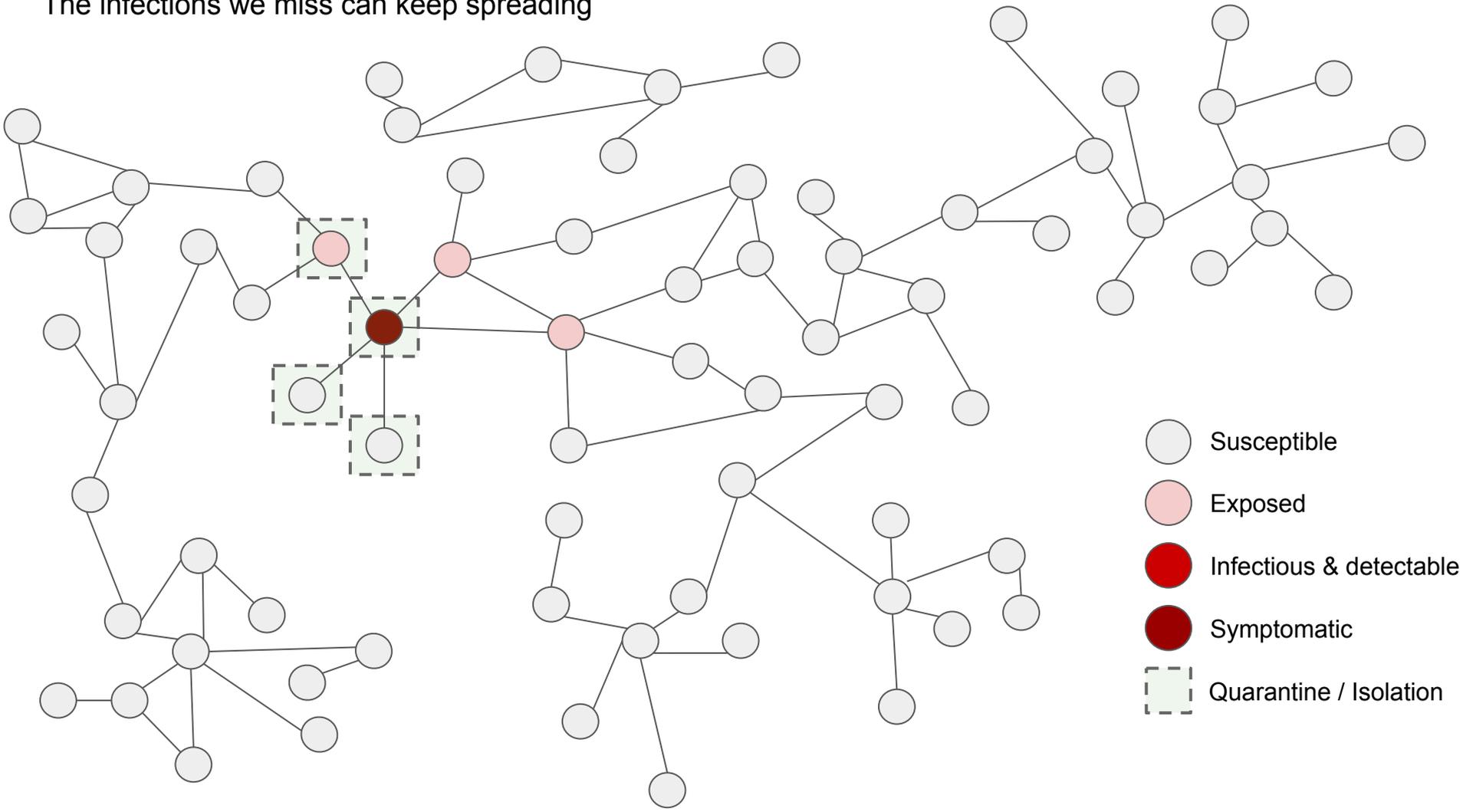
-  Susceptible
-  Exposed
-  Infectious & detectable
-  Symptomatic
-  Quarantine / Isolation

Contacts are traced and quarantined, but two are missed



-  Susceptible
-  Exposed
-  Infectious & detectable
-  Symptomatic
-  Quarantine / Isolation

The infections we miss can keep spreading



Why contact tracing can miss cases

1. Identified carriers may not remember / know / report their contacts
2. Contacts may not answer their phone
3. Carriers are most infectious **before** becoming symptomatic
4. Carriers may not report their symptoms
5. Many carriers (~50%) **never** become symptomatic,
especially among young people

Why might contact tracing be more likely to miss cases at college campuses?

Making contact tracing less effective on college campuses:

- Young people are more likely to be asymptomatic carriers, giving more contacts during their pre-symptomatic infectious period
- Young people have more contacts per day
- Young people tend to comply less with behavioral modifications

Making it more effective:

- Behavior is more monitored and controlled than in the general population
- Young & otherwise healthy people may be less susceptible to infection and may be less infectious when infected

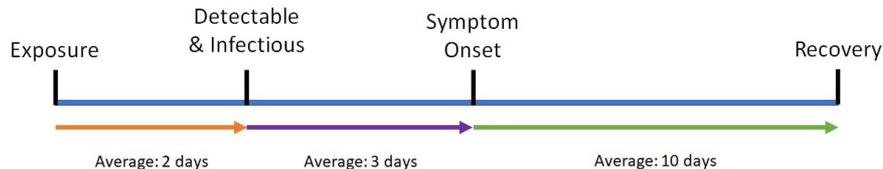
Mathematical Models

- A. Stochastic Compartmental Simulation
- B. Differential Equations

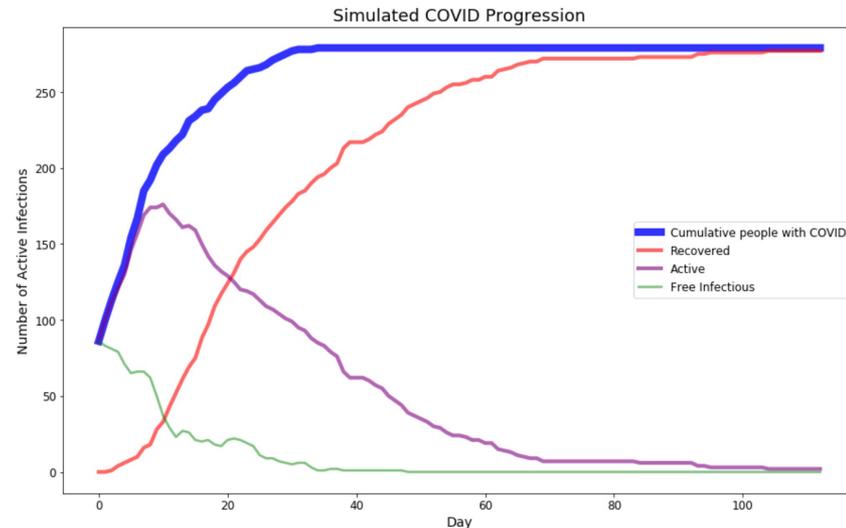
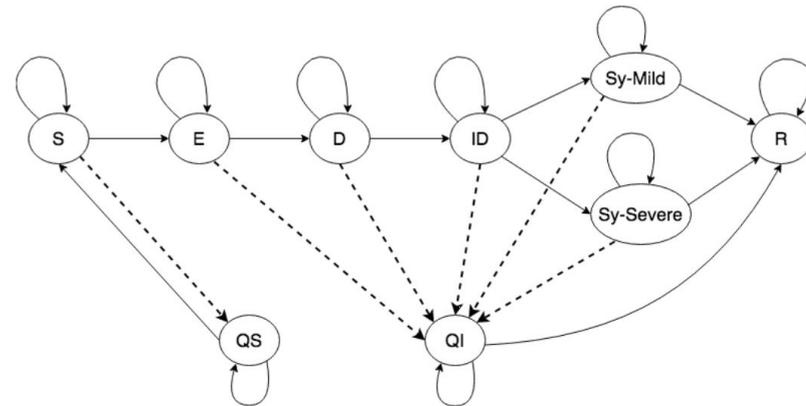
Stochastic Compartmental Simulation

<https://github.com/peter-i-frazier/group-testing>

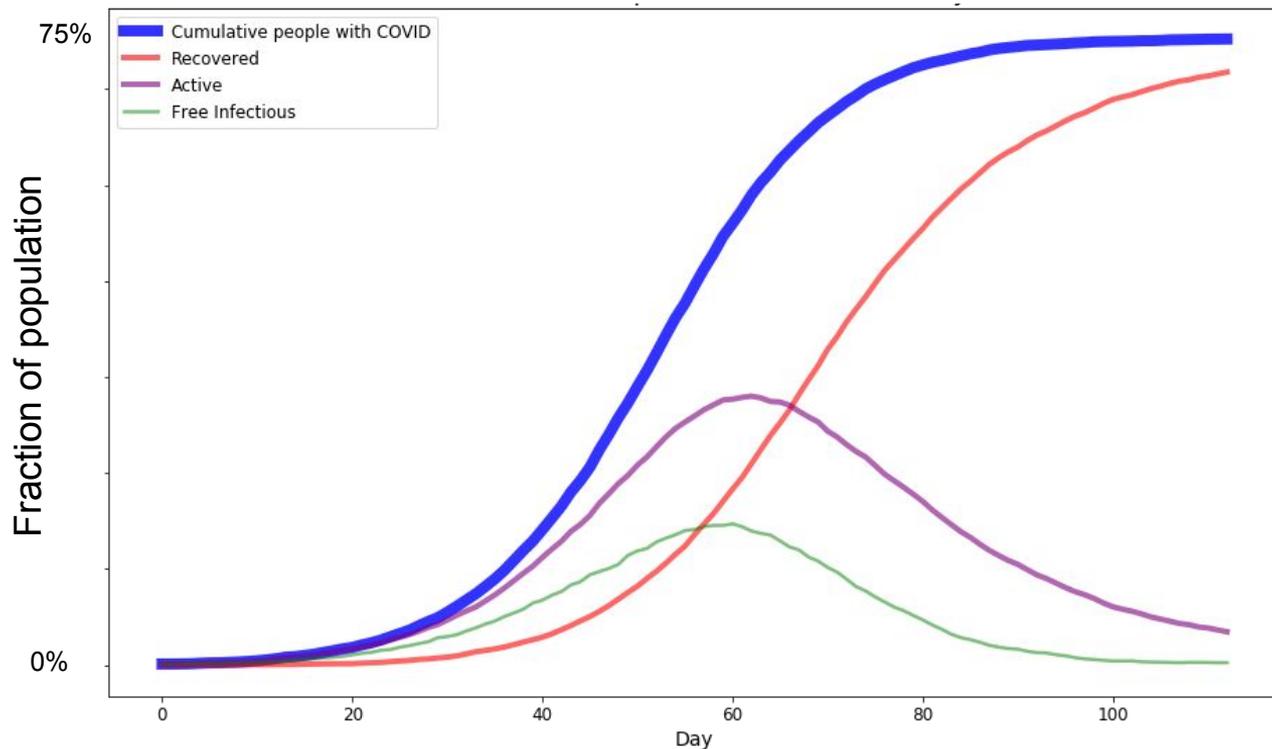
- Simulation tracks # of people in compartments described by:
 - Disease state (susceptible, infectious, symptomatic w/ severity, recovered / removed)
 - Whether or not they are in isolation / quarantine
 - How long they have been in this compartment
 - Group (UG in high-density housing, etc.)
- Population age distribution is accounted for in transition probabilities



- Simulation applies these interventions
 - Contact tracing
 - Later: Asymptomatic surveillance



Here's what happens when contact tracing isn't good enough



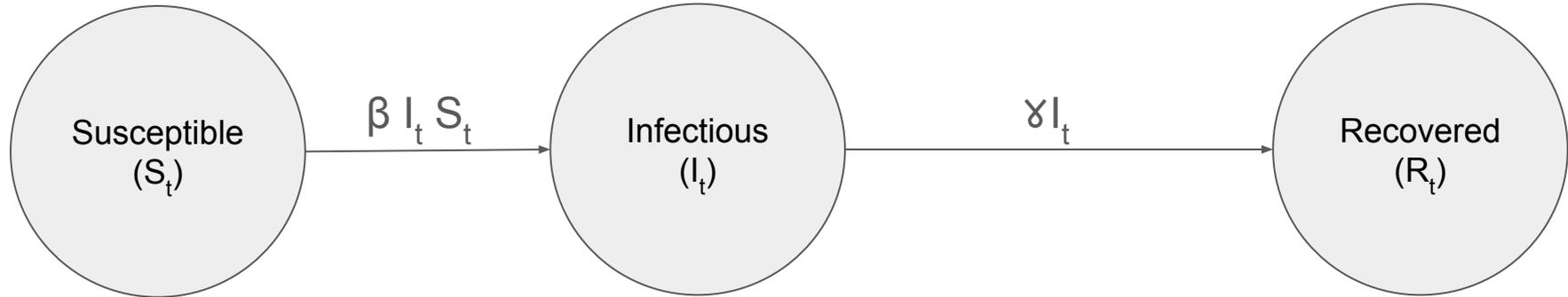
(Results shown are from stochastic compartmental simulation, though resemble a differential equation due to large population size used)

Differential Equation (SIR) models

S_t, I_t, R_t = fraction of population that is susceptible (**S**), infectious (**I**), or recovered (**R**)

β = (# contacts / day / person) (# infections transmitted / contact)

Infectious period lasts Exponential(γ) days



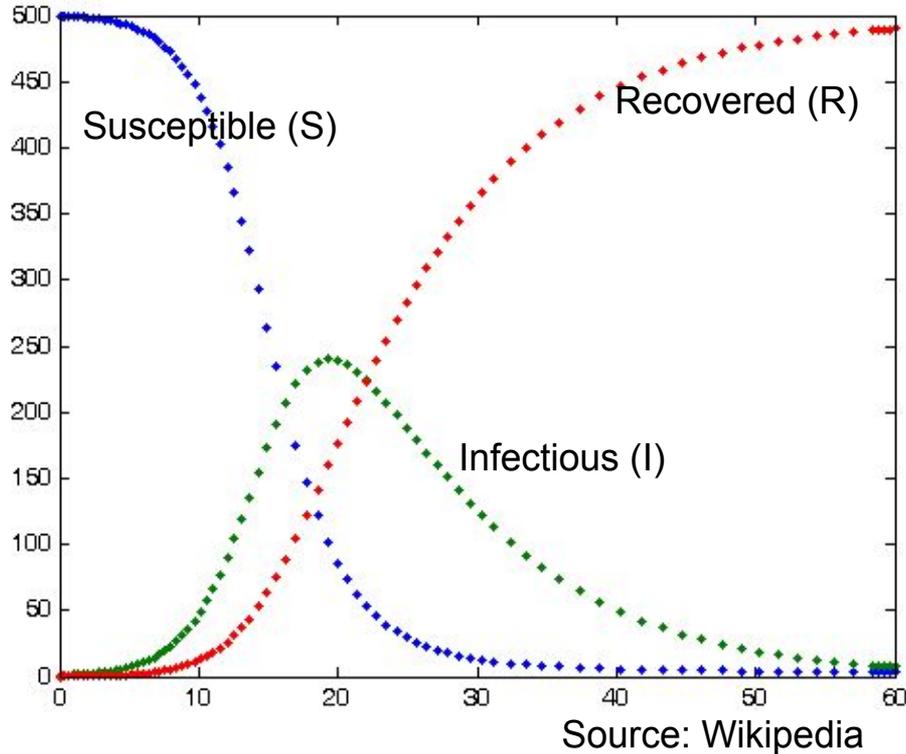
$$\Rightarrow dS_t / dt = -\beta I_t S_t$$

$$dI_t / dt = \beta I_t S_t - \gamma I_t$$

$$dR_t / dt = \gamma I_t$$

Note: SIR model is shown to provide intuition.
Our compartmental sim is much more detailed.

The SIR differential equation produces trajectories like these



When does an epidemic happen?

Recall:

- Infectious period lasts $1/\gamma$ days on average
- $\beta =$ (# contacts / day / person) (# infections transmitted / contact)

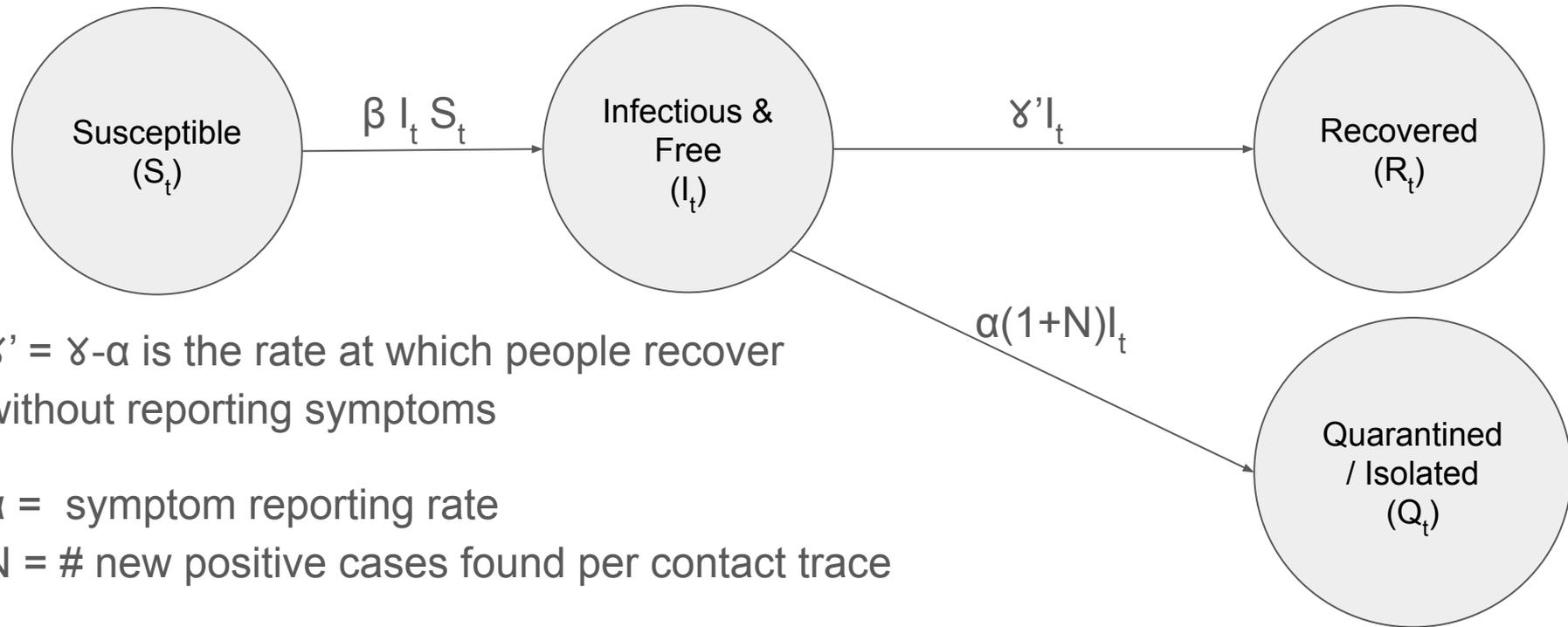
An epidemic happens if:

- Each infectious person infects more than 1 other person at $S_0=1$, i.e., $R_0 = \beta/\gamma > 1$

We can see this from the differential equation

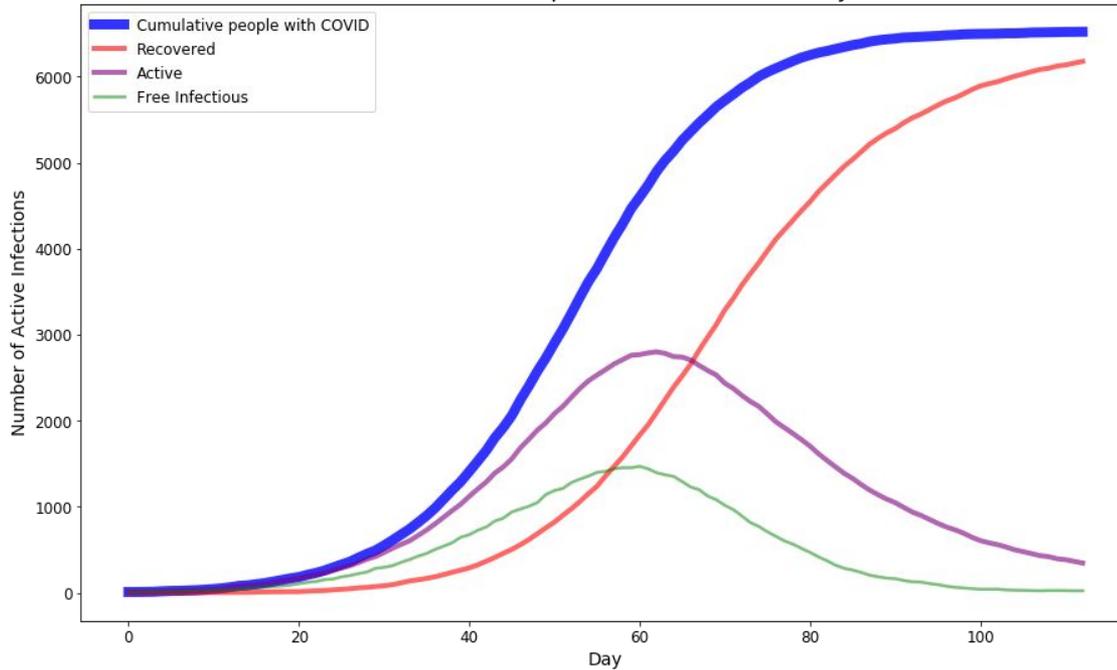
- Recall: $dl_t / dt = \beta I_t S_t - \gamma I_t$
- At $S_0 = 1$,
- $dl_t / dt = (\beta - \gamma) I_t = \gamma (R_0 - 1) I_t$
- So $I_0 > 0$ grows iff $R_0 > 1$

You can expand these models to account for contact tracing



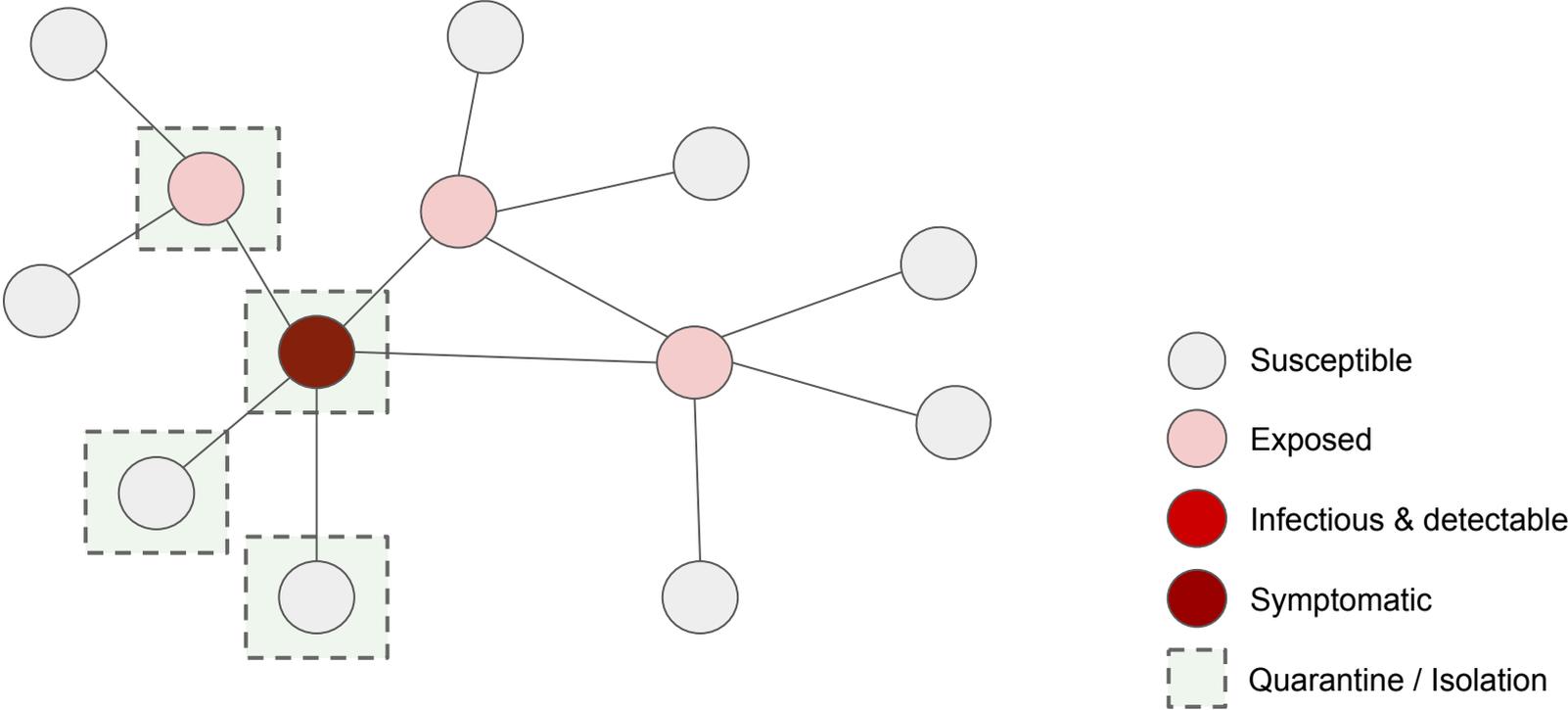
If effective $R_0 > 1$, the epidemic still grows¹

effective R_0 = net # secondary free infections from each primary infection
= (infections/day)*days - (# traced / report) * P(report)
= $R_0 - N*\alpha/(\alpha+\gamma')$



¹ Can be shown from the differential equations in the previous slide, with some extra algebra

If “effective R0” (net # free secondary infections per primary) > 1, the epidemic still grows



Contact tracing isn't good enough on its own. It needs social distancing.

Parameters* from



Centers for Disease Control and Prevention
CDC 24/7: Saving Lives, Protecting People™

<https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html>

- $R_0 \cong 2.5$ (Early in the pandemic, without social distancing)
- % symptomatic = 65%
- Assume all symptomatic cases seek care (optimistic)

Effective $R_0 = R_0 - (\# \text{ traced / report}) * P(\text{report}) = 2.5 - (\# \text{ traced / report}) * (0.65)$

=> Contact tracing needs to find 2.3 positives per report (92% of the 2.5 secondary cases the reporting case infects).

=> We must rely on compliance with social distancing & masks to reduce R_0

2. Cornell's testing program

What's different at Cornell

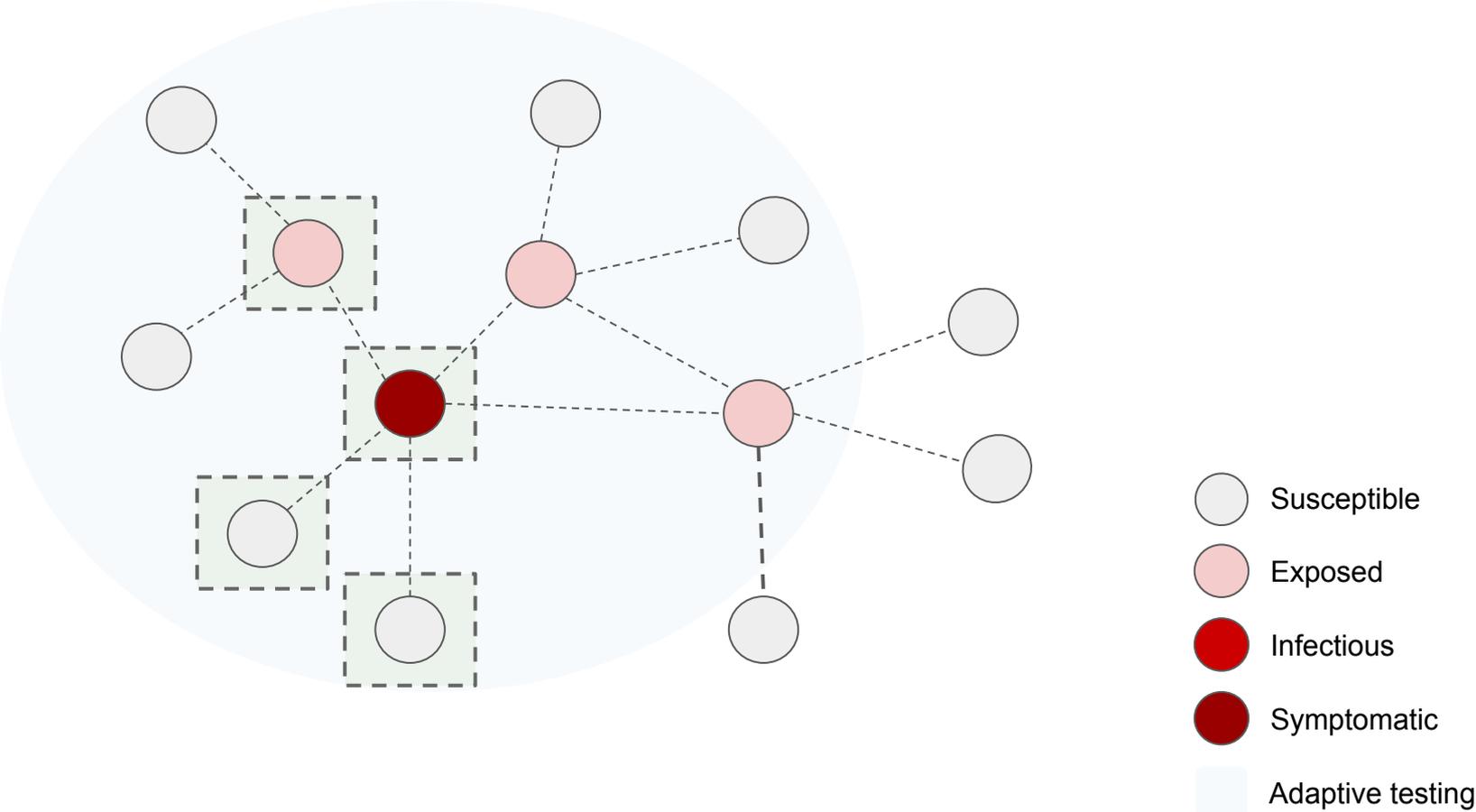
- Test all students on arrival
- Test students with symptoms
- Test students without symptoms 2x / 1x per week (**asymptomatic screening**)
- Do traditional contact tracing + **adaptive testing** on positive cases

Massive # of tests with is enabled by:

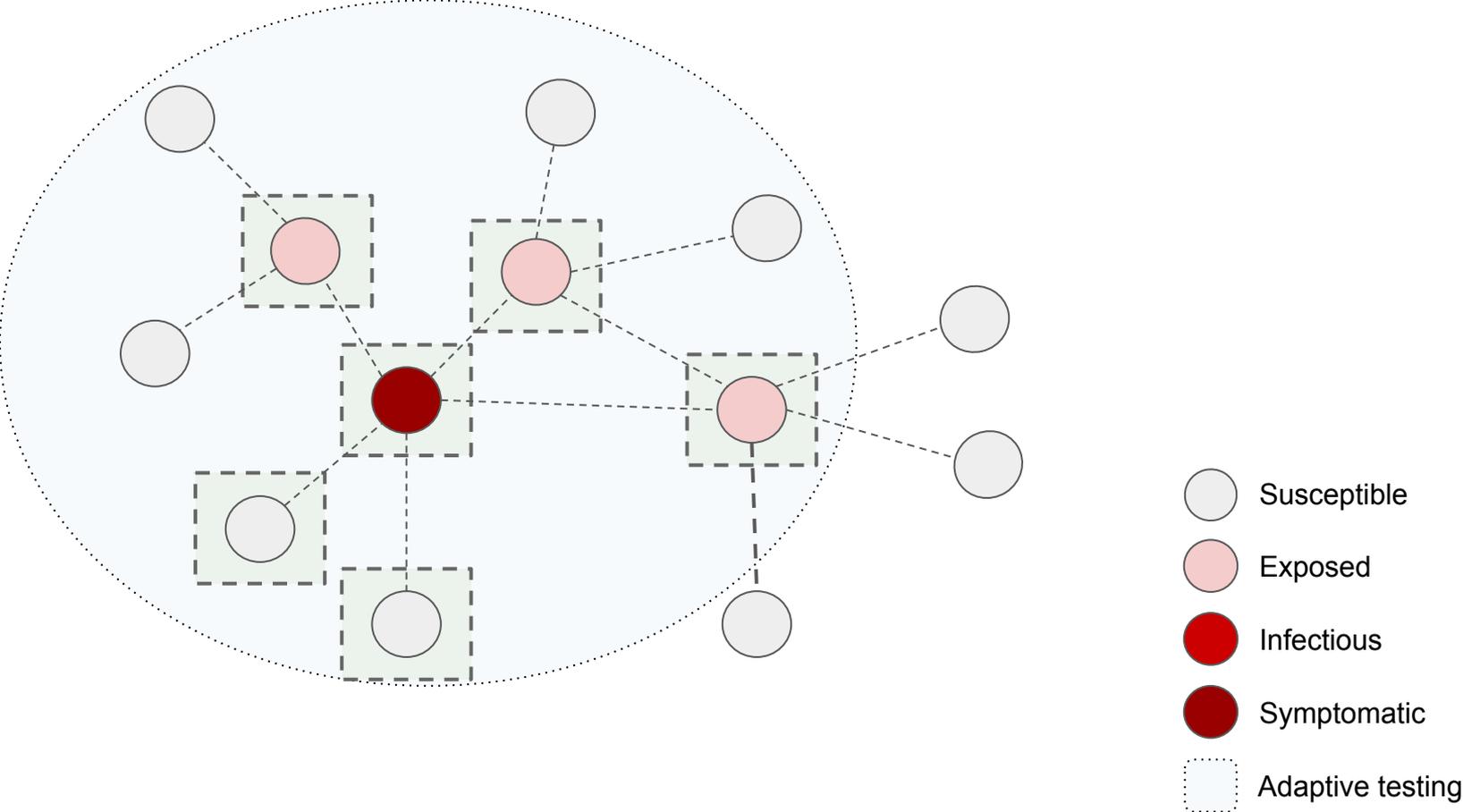
- Large PCR capacity at the Vet College
- **Pooled testing**
- Collaboration with Cayuga Health Systems

Adaptive Testing

Adaptive testing tests the social circle of the index cases.

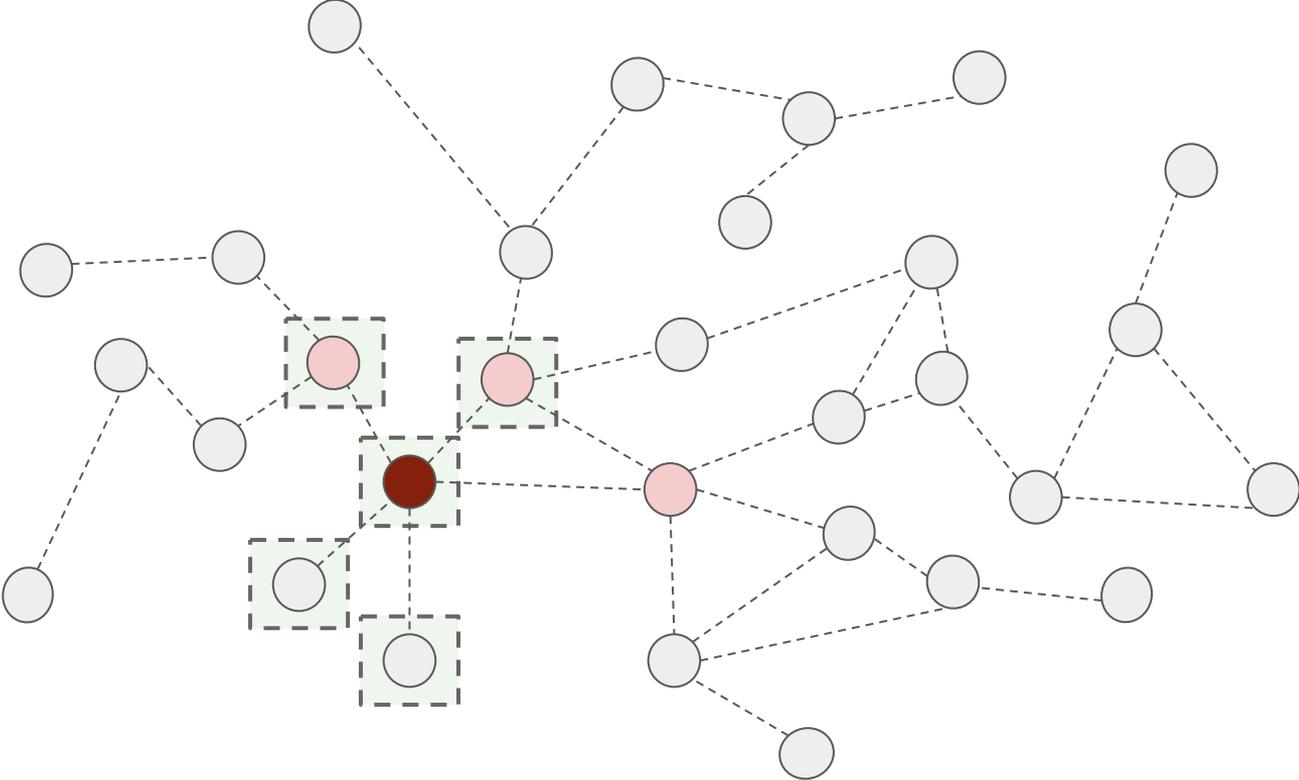


Adaptive testing catches the cases missed by contact tracing.

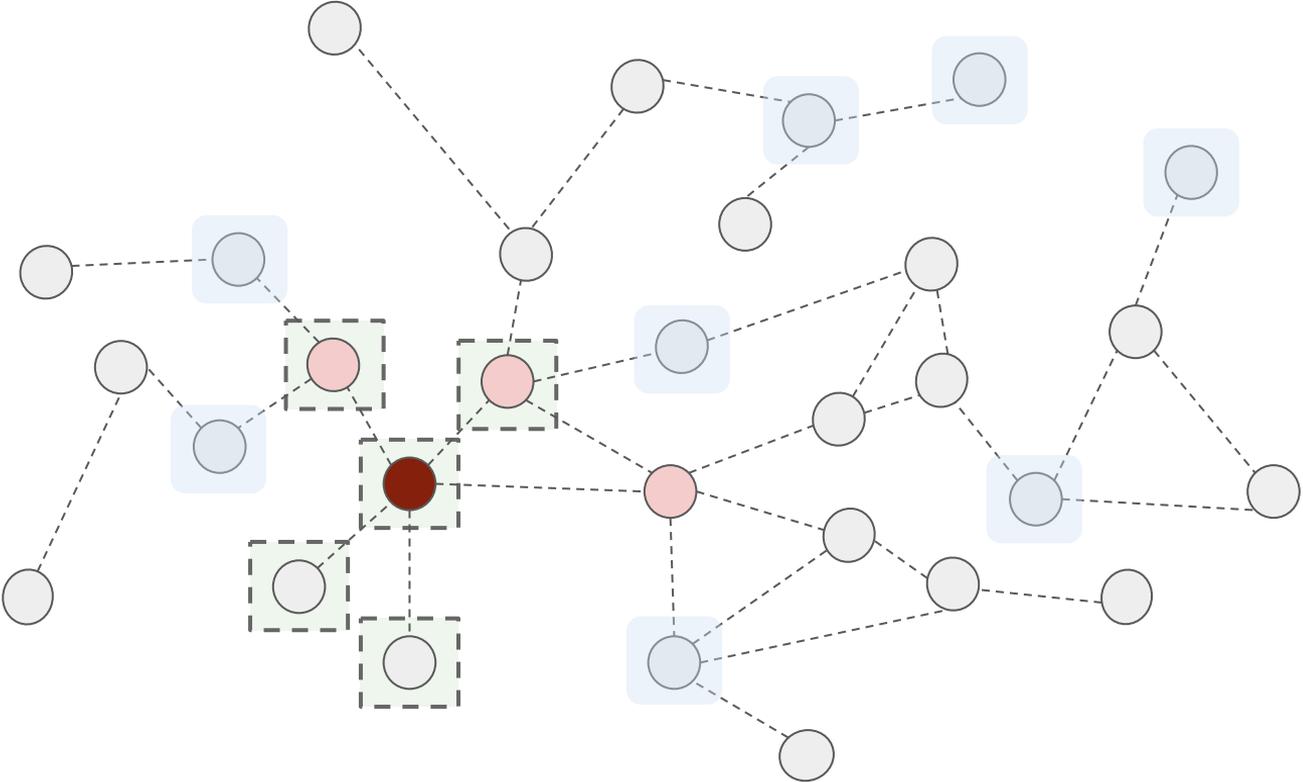


Asymptomatic Screening

What if we missed one in adaptive testing?

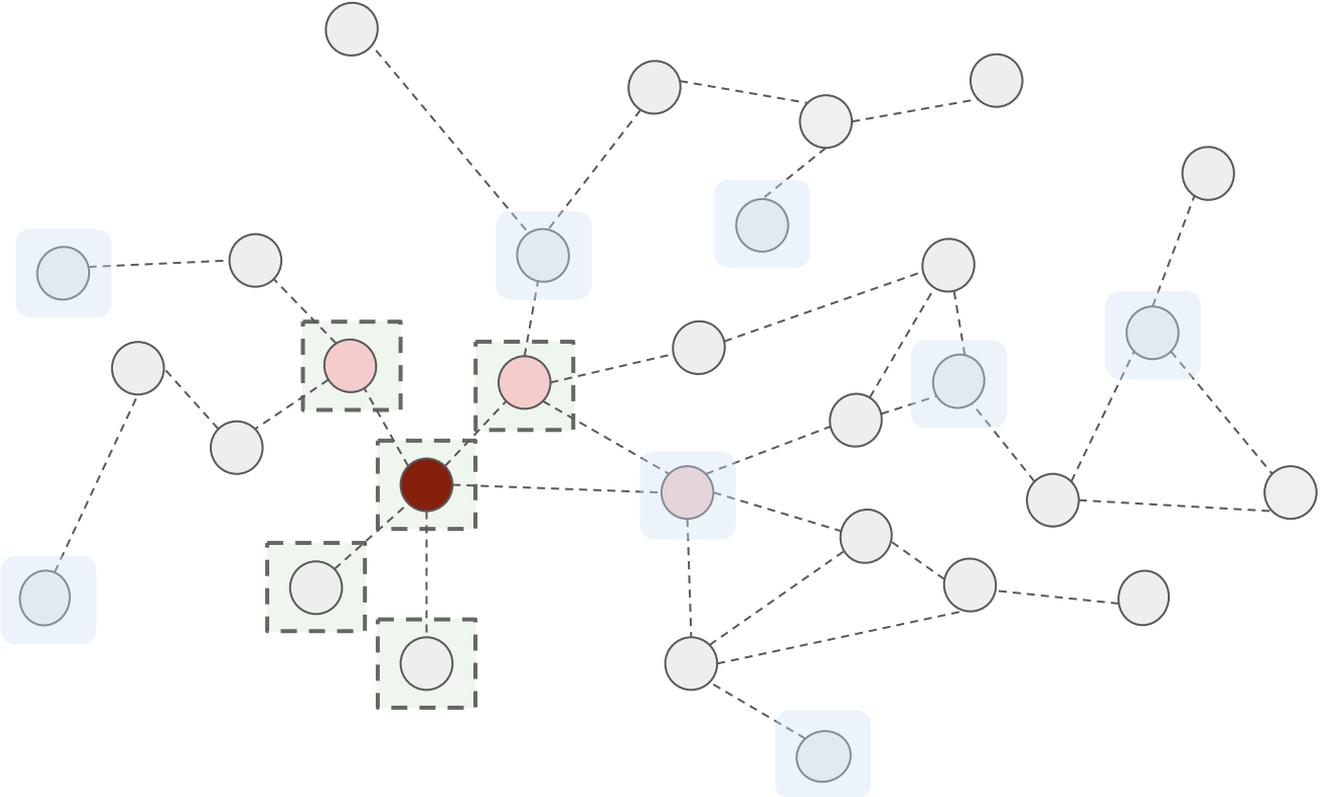


Screen everyone 2 times per week (Monday)



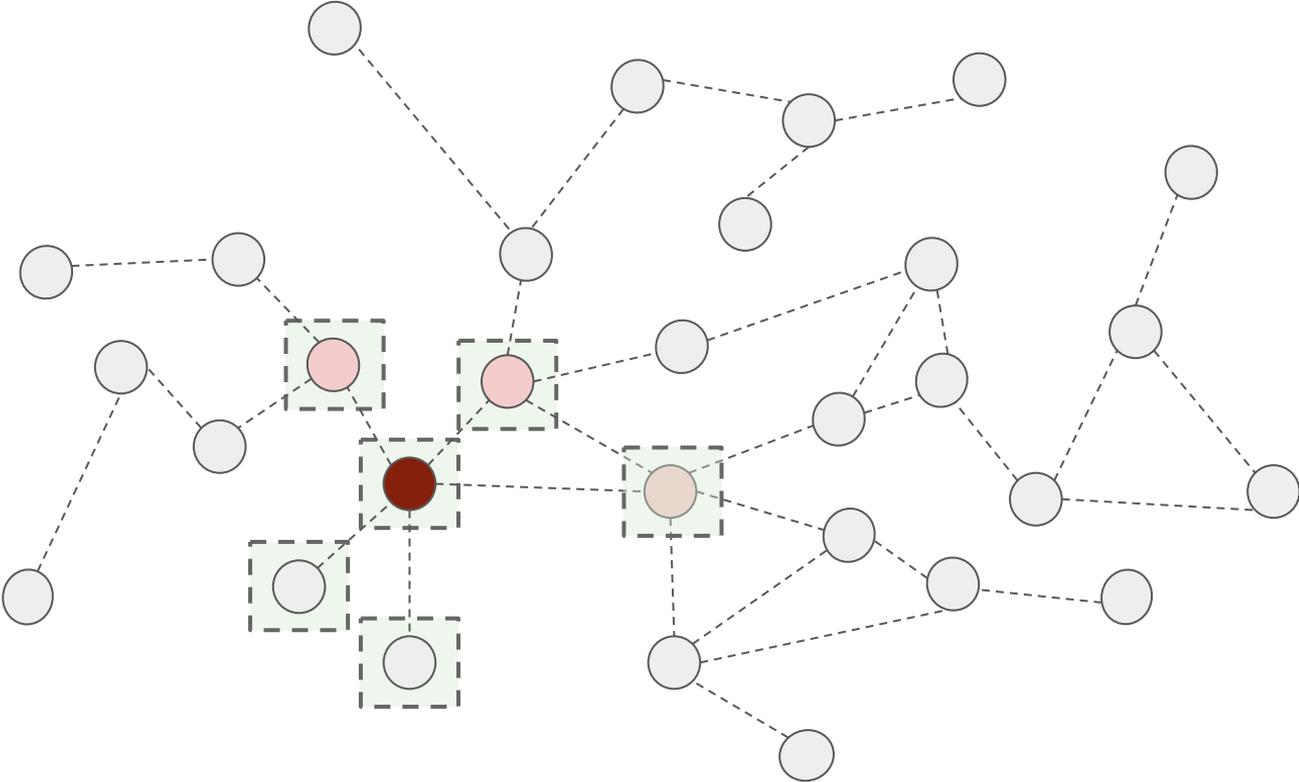
Asymptomatic testing

Screen everyone 2 times per week (Tuesday)



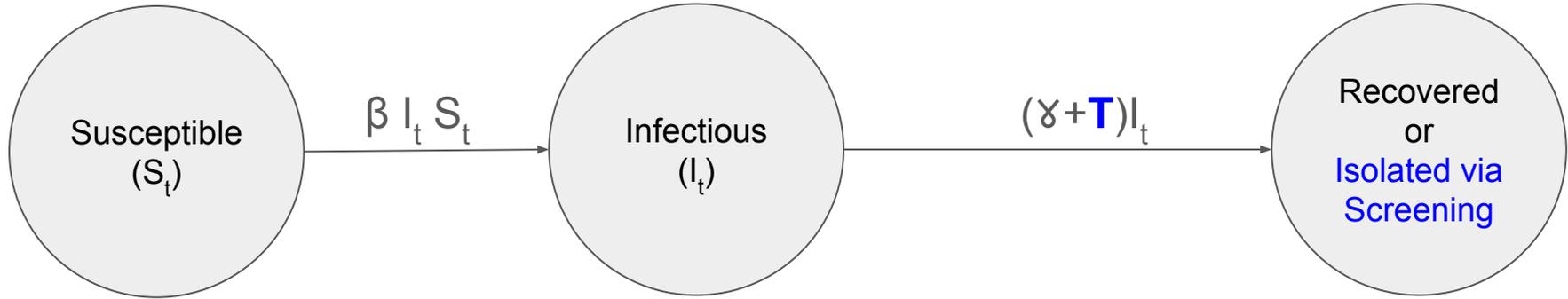
 Asymptomatic testing

Screen everyone 2 times per week (Tuesday)



 Asymptomatic testing

Screening 1x per week might be enough, 2x is safer



Without screening:

epidemic grows if $R_0 = \beta/\gamma > 1$

(2.5 > 1)

With screening,

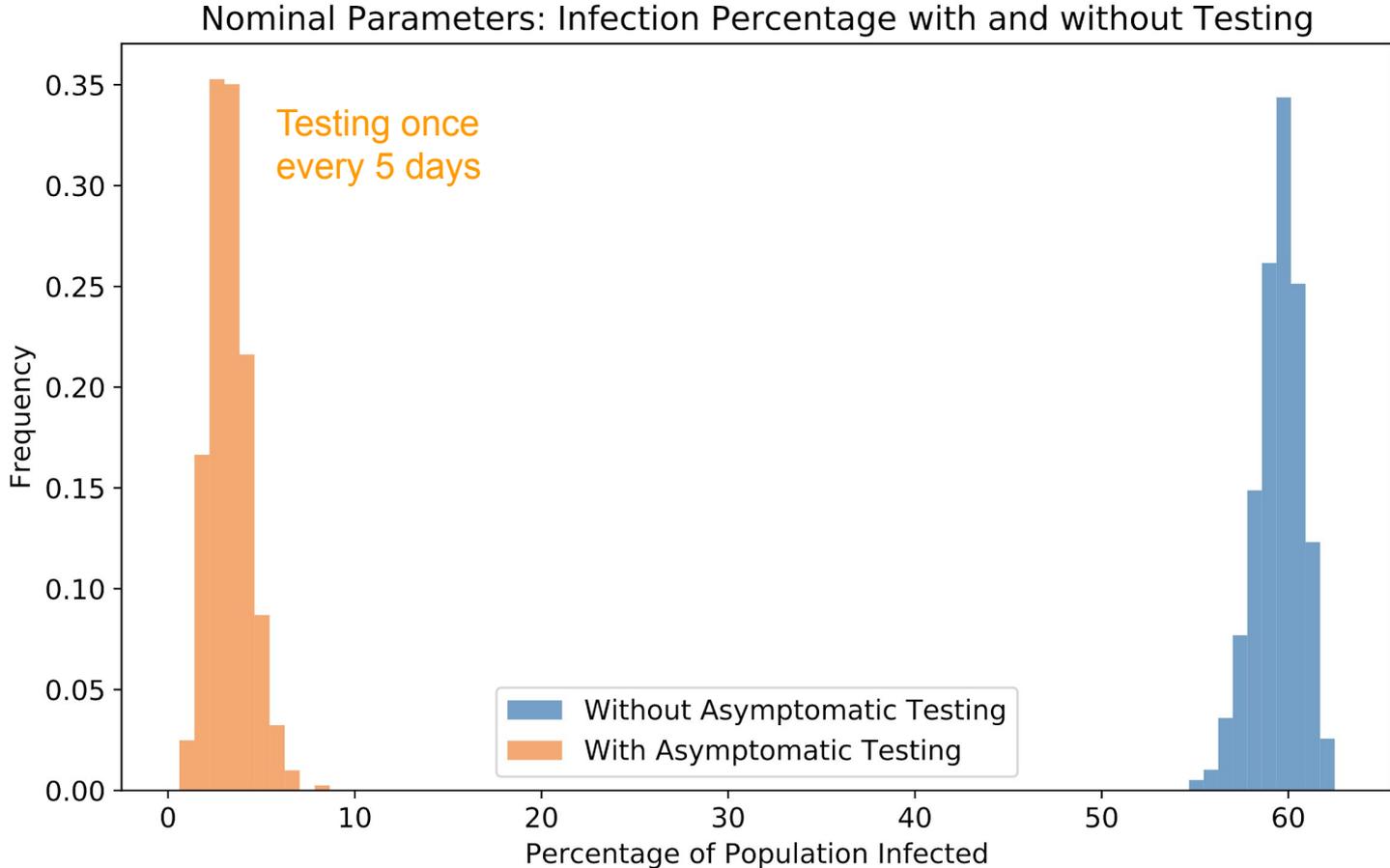
epidemic grows if

Effective $R_0 = \beta/(\gamma+T) < 1$

To keep the epidemic from growing,
screen at least 15% of the population per day,
i.e., screen everyone once per week.

(Assumes infectious period $1/\gamma$ is 10 days)

Screening 1x per week might be enough, 2x is safer

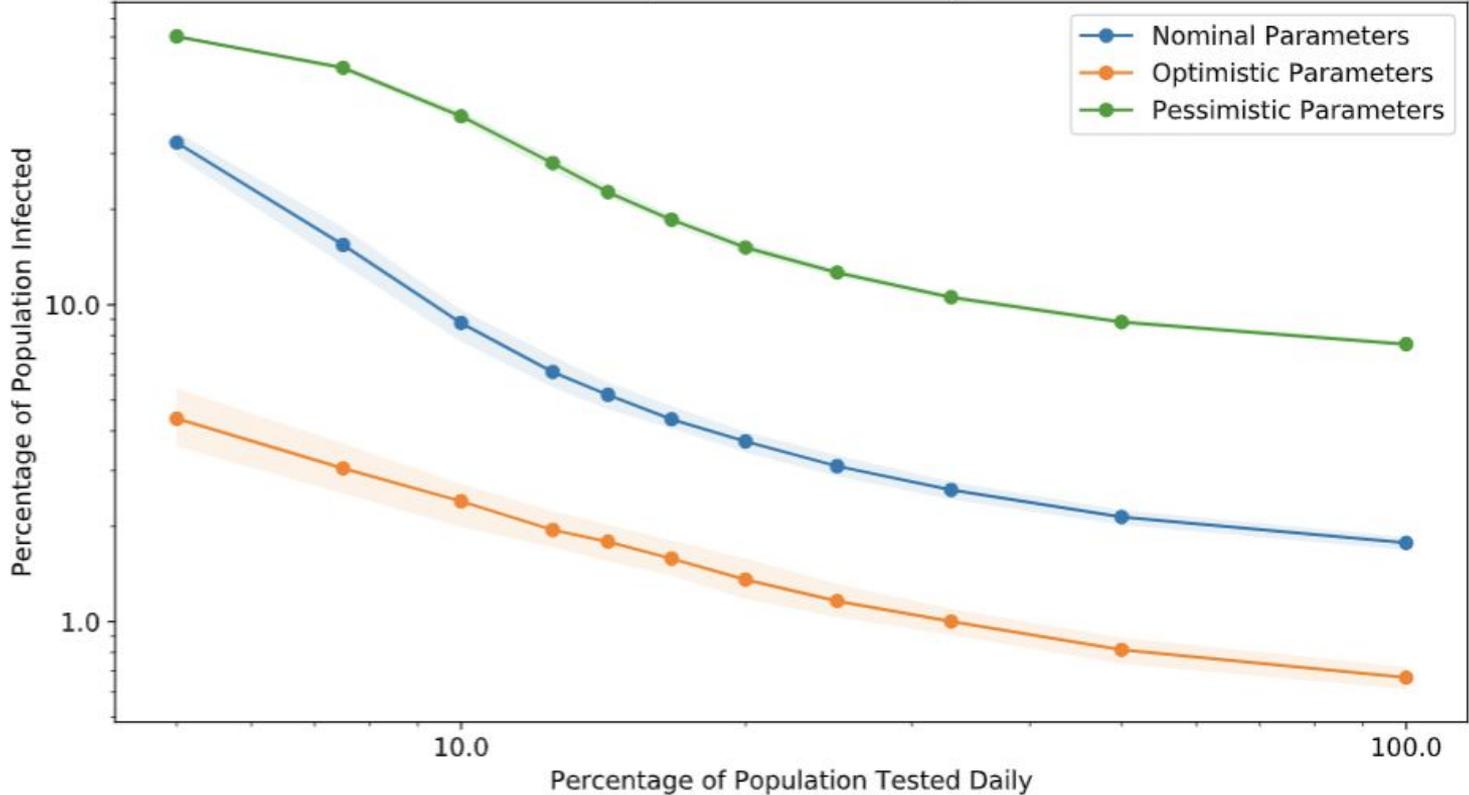


Results from our compartmental simulation model

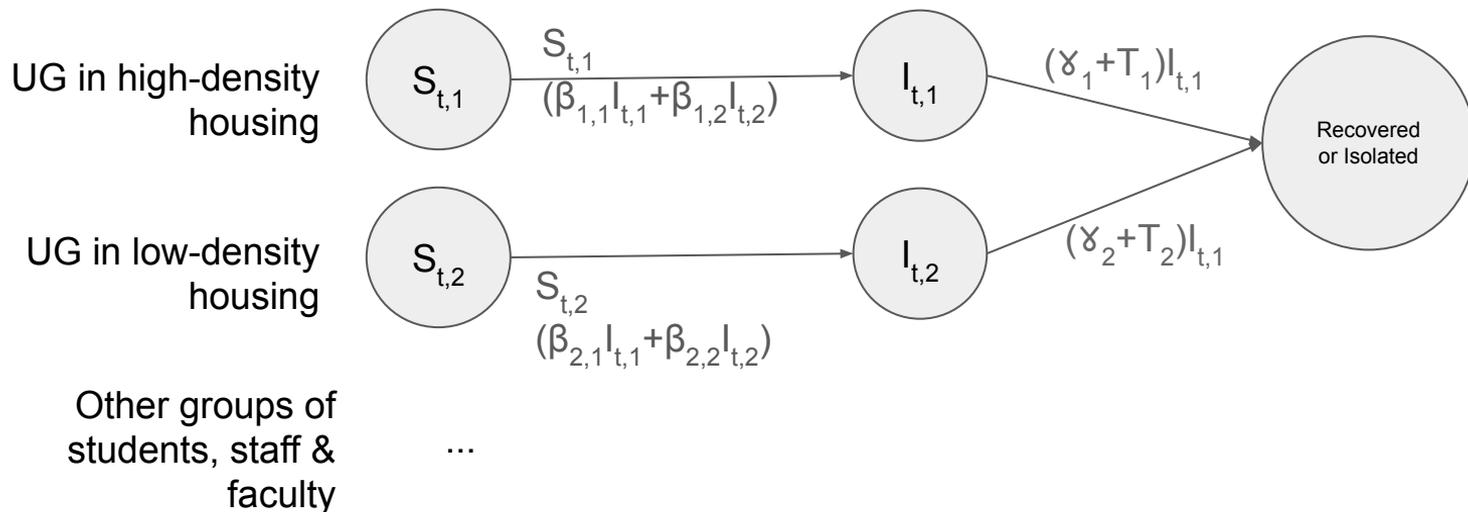
Screening 1x per week might be enough, 2x is safer

Nominal Parameters: Infection Percentage vs. Percentage of Population Tested Daily

Results from our compartmental simulation model

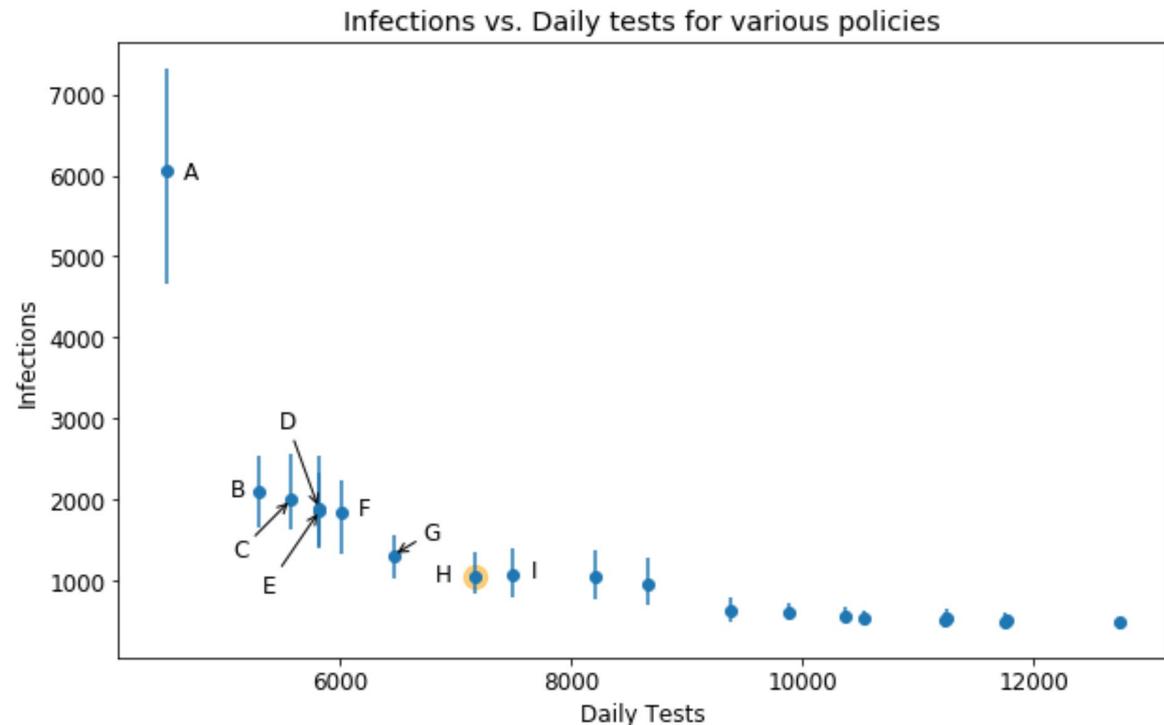


Screening should be targeted



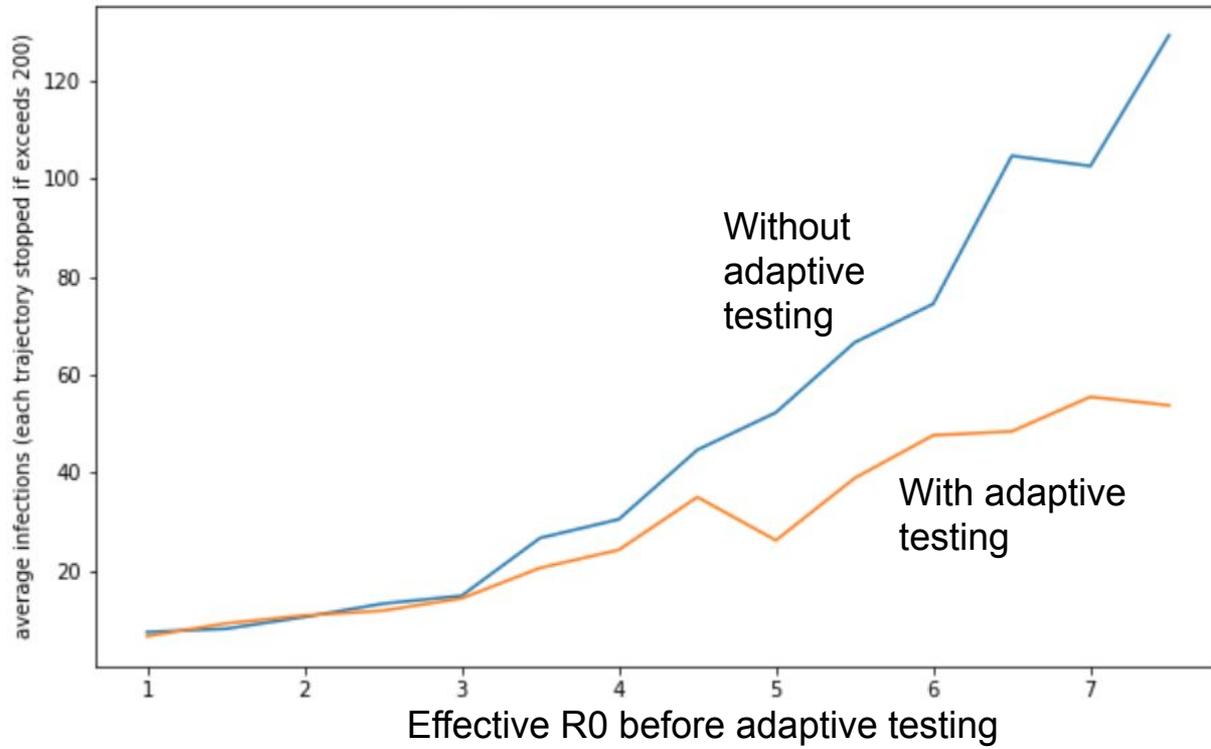
- $dl_t / dt = S_t \circ \beta I_t - \text{diag}(\gamma + T) I_t$
- At $S_0 = [1, \dots, 1]$, $dl_t / dt = (\beta - \text{diag}(\gamma + T)) I_t$
- Need all eigenvalues of $\beta - \text{diag}(\gamma + T)$ to be negative (note β is symmetric \Rightarrow eigenvalues are real)
- If β is diagonal, decomposes to $\beta_i < \gamma_i + T_i$ for each i
(Equivalently, each subpopulation's effective $R_0 = \beta_i / (\gamma_i + T_i) < 1$)

Screening should be targeted



- β is almost diagonal
- T is discrete (1x / wk, 2x / wk, etc.)
- We enumerate options & use compartmental simulation to trace a Pareto frontier
- Each letter corresponds to a collection of test frequency assignments
- E.g., “B” means:
UG in high-density housing 2x / week
Off-campus staff 1x / month
Everyone else 1x / week

Adaptive testing gives good infection control with few tests if you can't screen enough



Why Cornell Will Reopen in the Fall

Students will return to Ithaca in any case. On campus, we can track and isolate Covid cases.

By Michael I. Kotlikoff and Martha E. Pollack
June 30, 2020 12:45 pm ET

SAVE PRINT TEXT

229



Cornell University in Ithaca, N.Y.

PHOTO: UNIVERSAL IMAGES GROUP VIA GETTY IMAGES

Residential instruction is safer than virtual instruction*

- Based on surveys & leases signed with landlords, several thousand undergraduates seemed likely to return to Ithaca, even with virtual instruction only
- Asymptomatic screening would have been hard to mandate and enforce for these students
- Under many realistic parameter regimes, epidemics grow exponentially in the virtual instruction population

* Realizing that we don't know what virtual instruction would have brought, and have substantial parameter uncertainty (still)



2 Michigan Colleges Face Coronavirus Outbreaks In The 1st Week Of School

September 15, 2020 · 4:12 PM ET
Heard on All Things Considered

“at Michigan State University, there's been a big jump in cases since some students returned to the town last month, and that's **despite the fact that they're not taking any classes in person.**”

Michigan State University COVID-19 Dashboard

NEW KNOWN POSITIVE CASES

WEEK OF 09/07/20

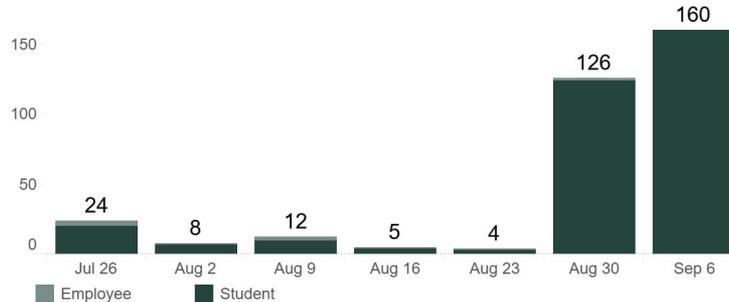
160

SINCE JULY 27

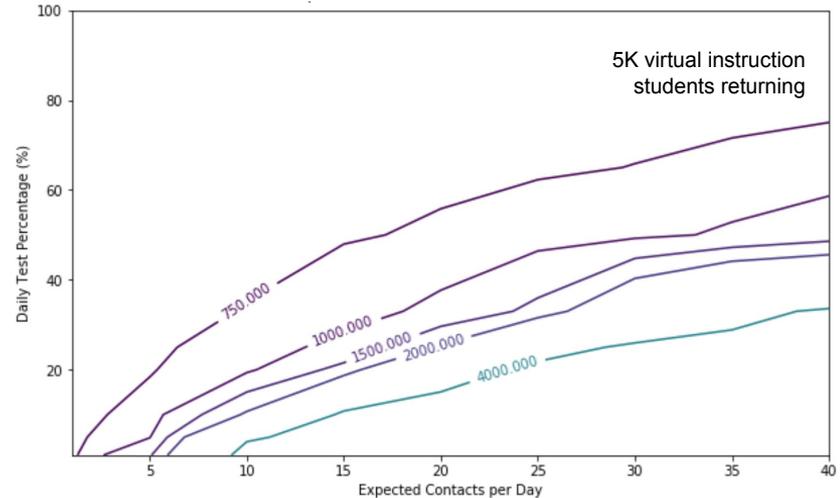
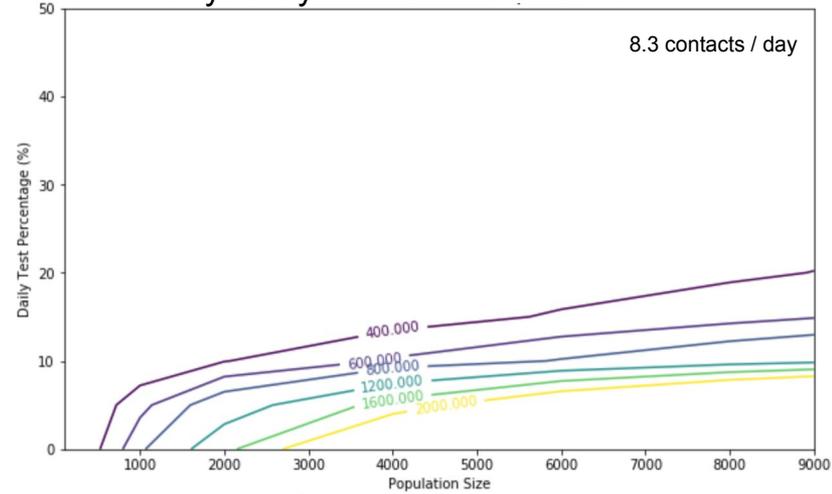
339

Weekly New Known Positive Cases

By self-reported date; weeks beginning on Monday

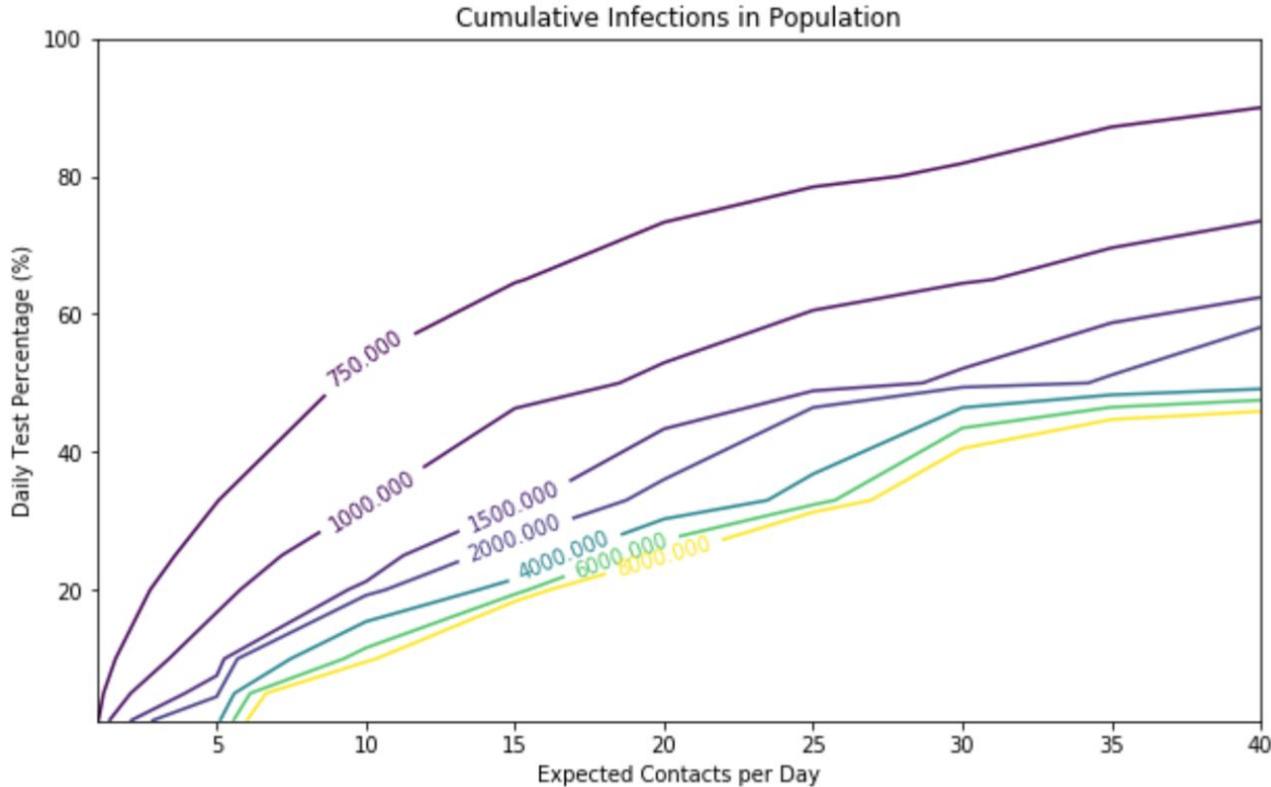


Sensitivity analysis of virtual instruction infections



Takeaways for impacting policy with data science

Sensitivity analysis was critical



Communication was critical

46 thoughts on “Updates from the Modeling Team”



1. **F29** says:

[June 26, 2020 at 1:00 pm](#)

While I appreciate all of the hard work that went into this report, like many others, I am deeply concerned about the assumptions of the model. By not modeling 50 or 75% compliance and comparing it to 100% compliance in the residential scenario, this report essentially denies us the opportunity to determine what level of compliance would be necessary to limit risk. Maybe 80% compliance is good enough, maybe it's not – but we can't know from what's here. It is also absurd to assume 0 fatalities, based on everything we know about COVID-19 and our local Cornell community. How many members of the Cornell community, exactly, are the president and provost willing to let die to ensure a residential semester? How might different plans affect that number of deaths? Again, we're denied the option to even explore the impacts – any discussion of “risk” that pretends fatality is not on the table is unrealistic at best, deliberately misleading at worst. Making decisions based on this model, given these limitations, is deeply concerning.

4. Testing in the virtual instruction setting + testing compliance in the residential setting

We have analyzed both non-compliance in the residential setting and offering testing in the virtual instruction setting. This was done before the June 15 report was published but was not ready in time to be included in that published report. Some of the results in this analysis are available as a slide in the June 24 faculty senate meeting. We will include a full writeup of this analysis in the addendum.

One way to understand the impact of non-compliance in the residential setting is to look at Figure 15 in the full report, which shows results as a function of the percentage of the population tested each day. If non-compliance is distributed uniformly across the population, then failure to comply is equivalent to 100% compliance with less frequent testing. Using this reasoning, we can see that 71% compliance with 5-day testing in the residential setting is comparable to 100% compliance with 7-day testing with results pictured in Table 14 (1800 infections, 22 hospitalizations).

The analysis to be included in the addendum shows that if we achieve high compliance with once-per-5-day testing in the virtual instruction setting, then we do see fewer infections than the residential setting, with the breakeven point around 50% compliance. (A number of details will be discussed in the addendum.)

Although this falls outside of the realm of modeling, we comment briefly here on some practical reasons that testing with high compliance is difficult in the virtual instruction setting. We defer other legally-focused questions about our ability to mandate testing to University Counsel.

In the residential scenario, Cornell's ability to ensure compliance with testing comes first from the ability to restrict access to physical property for those that miss testing, and also through an RA's ability to talk directly to students who live in dorms. In the virtual instruction scenario, for students that aren't using Cornell's physical property, this first ability goes away.

INDEPENDENT SINCE 1880

The Cornell Daily Sun

CAMPUS MODELING

REGISTRATION

As Classes Begin, Cornell's Reopening Model Is Put to the Test

By Anil Oza



LIKE



TWEET



EMAIL



PRINT



MORE

In June, Cornell modeled for a potential campus reopening, when cases nation wide seemed to have plateaued nationally. But since then, the U.S. has seen almost [3 million more COVID-19 cases](#) and [60,000 deaths](#).

During the past month, many schools, [including several of Cornell's peers in the Ivy League](#), decided to reverse plans for hybrid semesters and opt for entirely virtual learning. Many schools that suddenly changed their plans cited complications from rising COVID-19 cases nationwide, but Cornell has doubled-down on its plan, promising that it can work until Thanksgiving break.

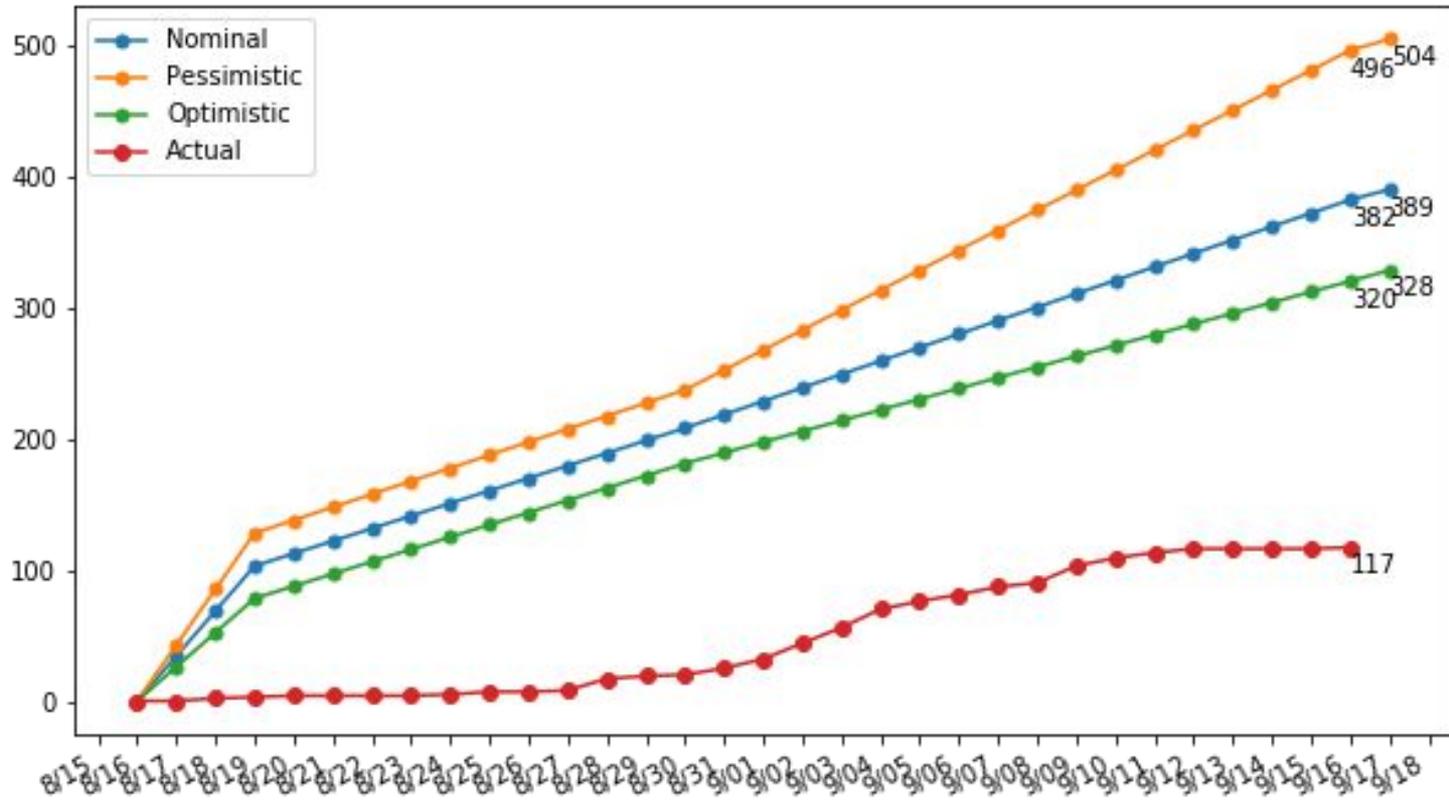
With classes set to begin in two days, how does Cornell's model hold up to reality?

According to Prof. Peter Frazier, operations research and information engineering, and the scientist behind Cornell's model, the recent trend in school closures reinforces the University's focus on noncompliance to social distancing and asymptomatic screening.

"I would say that [monitoring social gatherings and high density housing] was and continues to be a focus. The data that we're getting now kind of allows us to understand that phenomena more." Frazier said. "That particular

There are fewer infections than predicted

infections
among Cornell
students, staff &
faculty

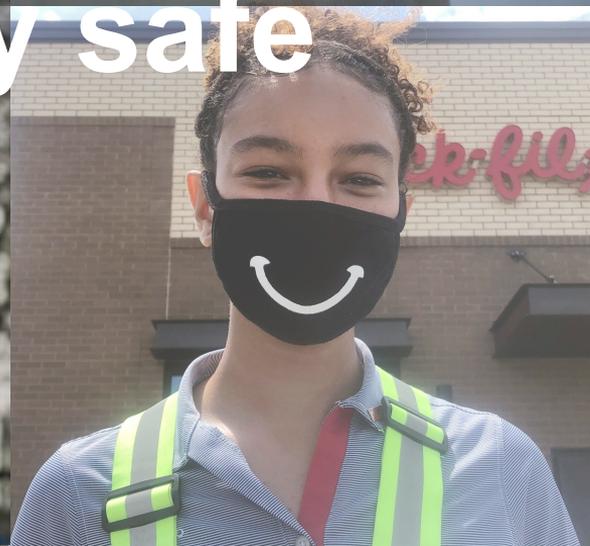


Takeaways for impacting policy with data science

- Do what is needed for the real problem, not for the paper
- Have mental models of your computer models
- Communication is critical
- Understand the political environment in which decision makers operate
- Luck helps: our decision makers were scientists



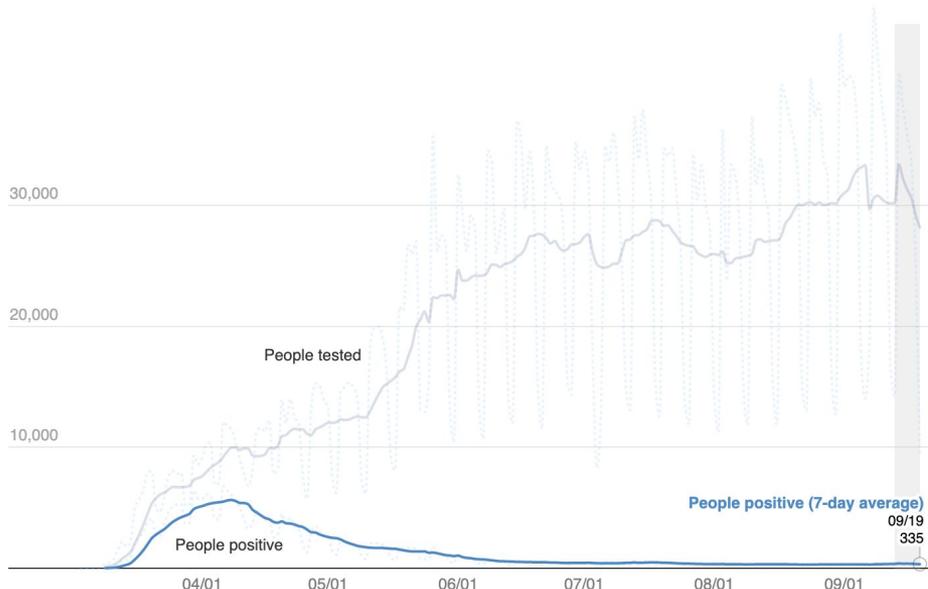
Thank you & stay safe



Virus (Diagnostic) Tests

These charts show the number of people tested for the virus, the number of people who tested positive and the percent of people tested who had positive results. The charts include data from each day of the outbreak in NYC.

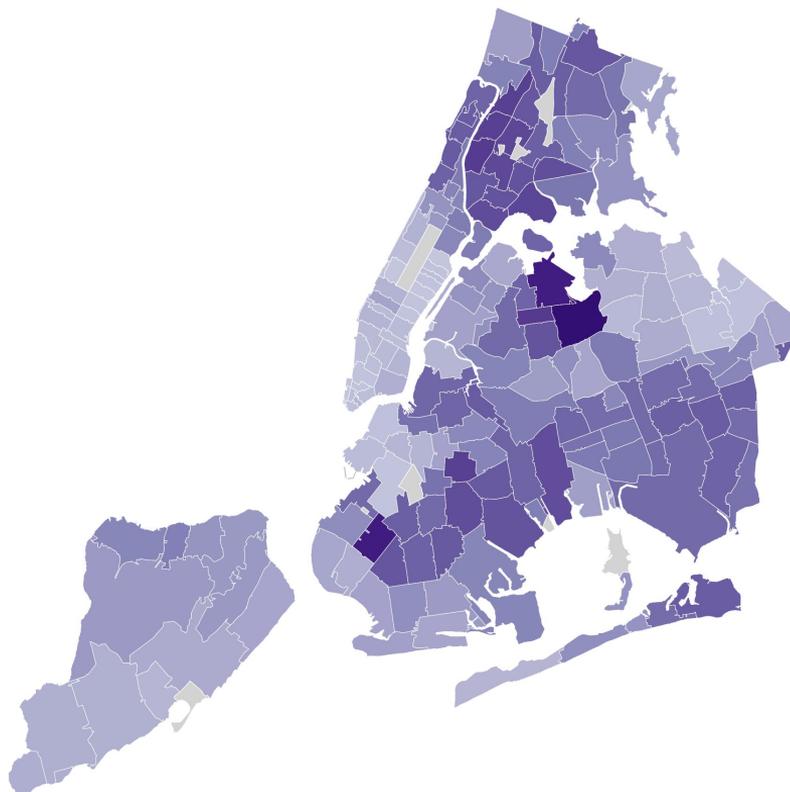
View data: People tested Percent of people with positive results



Antibody Testing by ZIP Code of Residence

These maps show the number of people tested with antibody tests by ZIP code of residence, the testing rate per 100,000 people in that ZIP code and the percent of people tested who had positive results.

Number of people tested Test rate Percent positive



“From March to early May, we discouraged people with mild and moderate symptoms from being tested, so our data from that period represent mostly people with severe illness.”

<https://www1.nyc.gov/site/doh/covid/covid-19-data-testing.page>