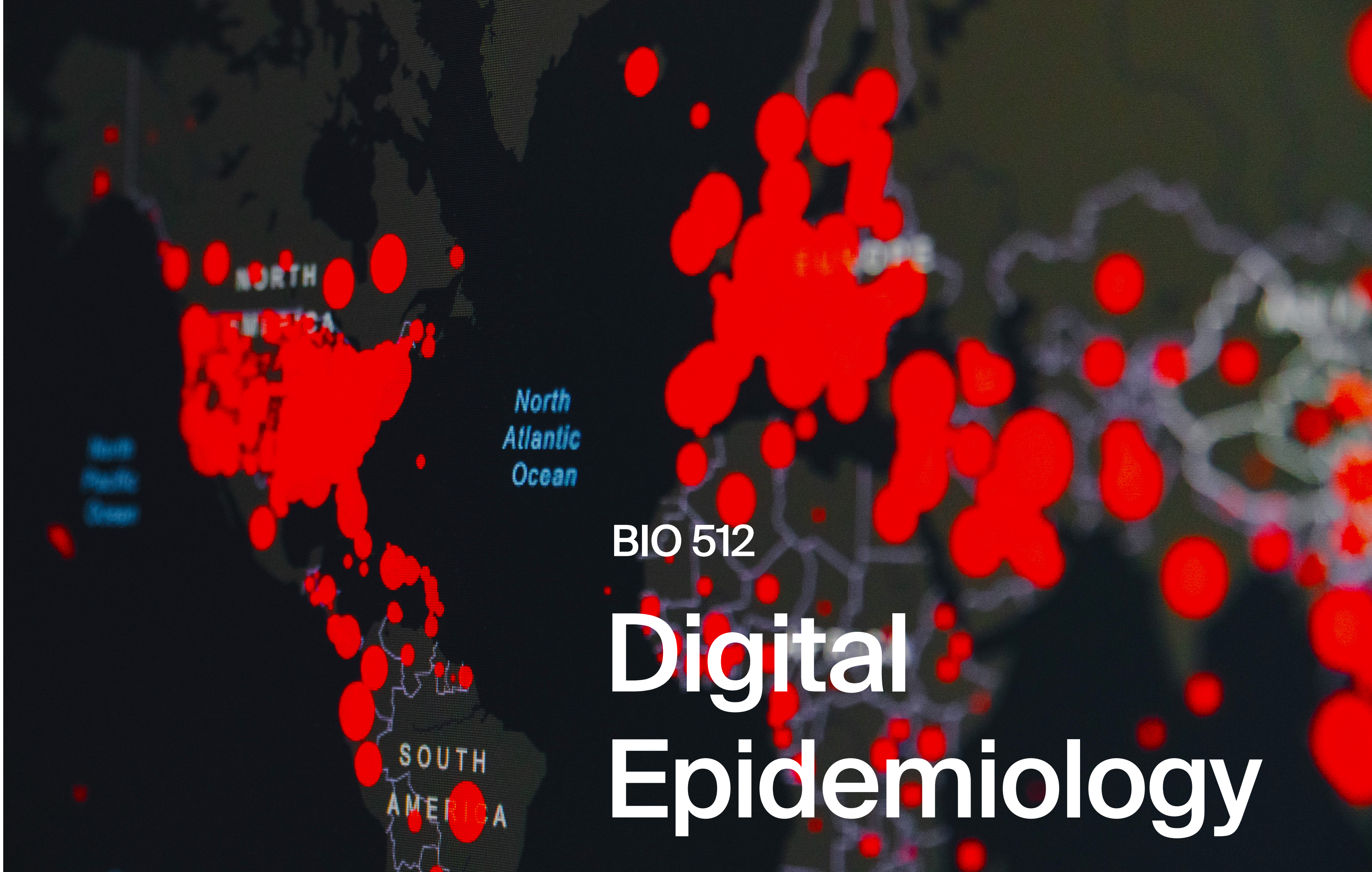
EPFL

Digital Epidemiology Lab

BIO-521

Spring semester 2025



BIO 512

Digital Epidemiology

Digital Contact Tracing
Learning Objectives

- Understand key principles of TTIQ
- Understand how conventional contact tracing works
- Understand why digital contact tracing was developed
- Understand digital contact tracing protocols
- Learn about some implementations
- Learn about known efficacies
- Discuss possible futures of digital contact tracing

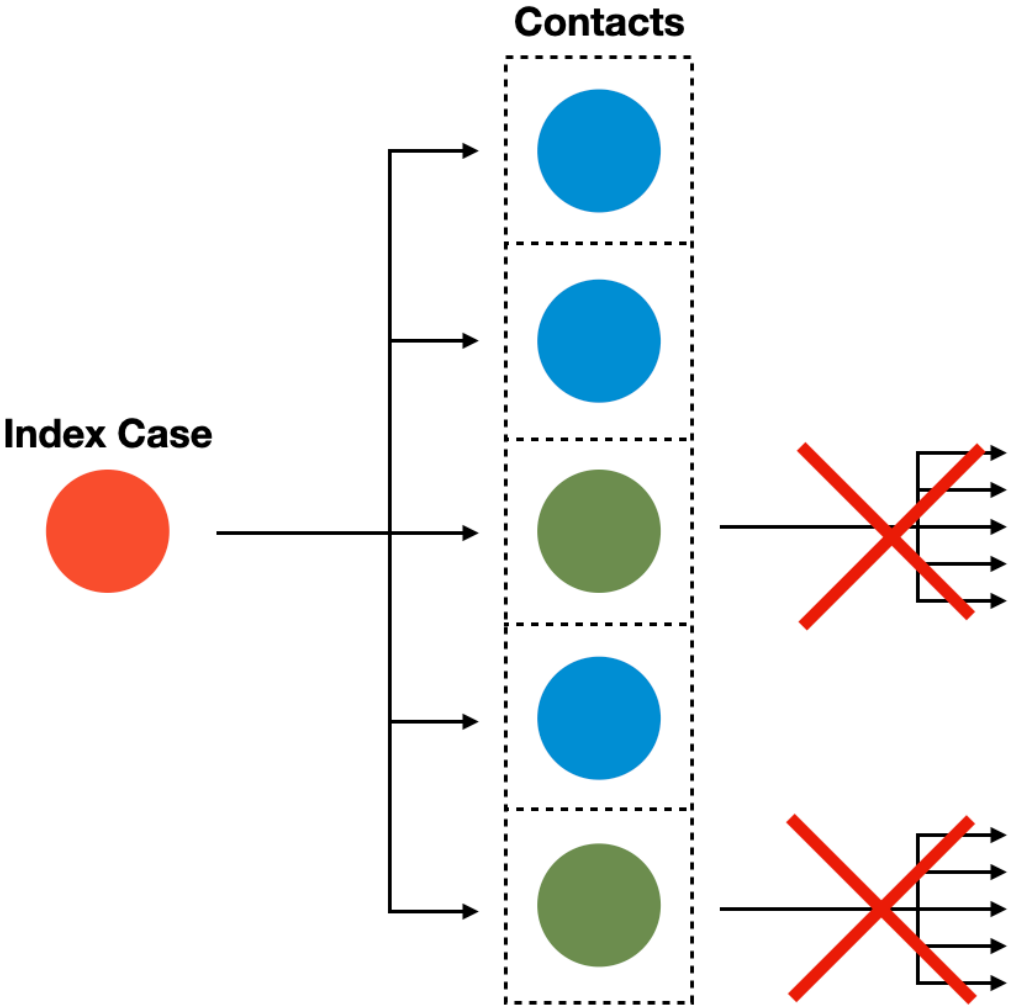
Digital Contact Tracing
Historical Context

- Digital Contact Tracing is the largest roll out of a digital epidemiology technology in history.

- How do we define digital epidemiology?

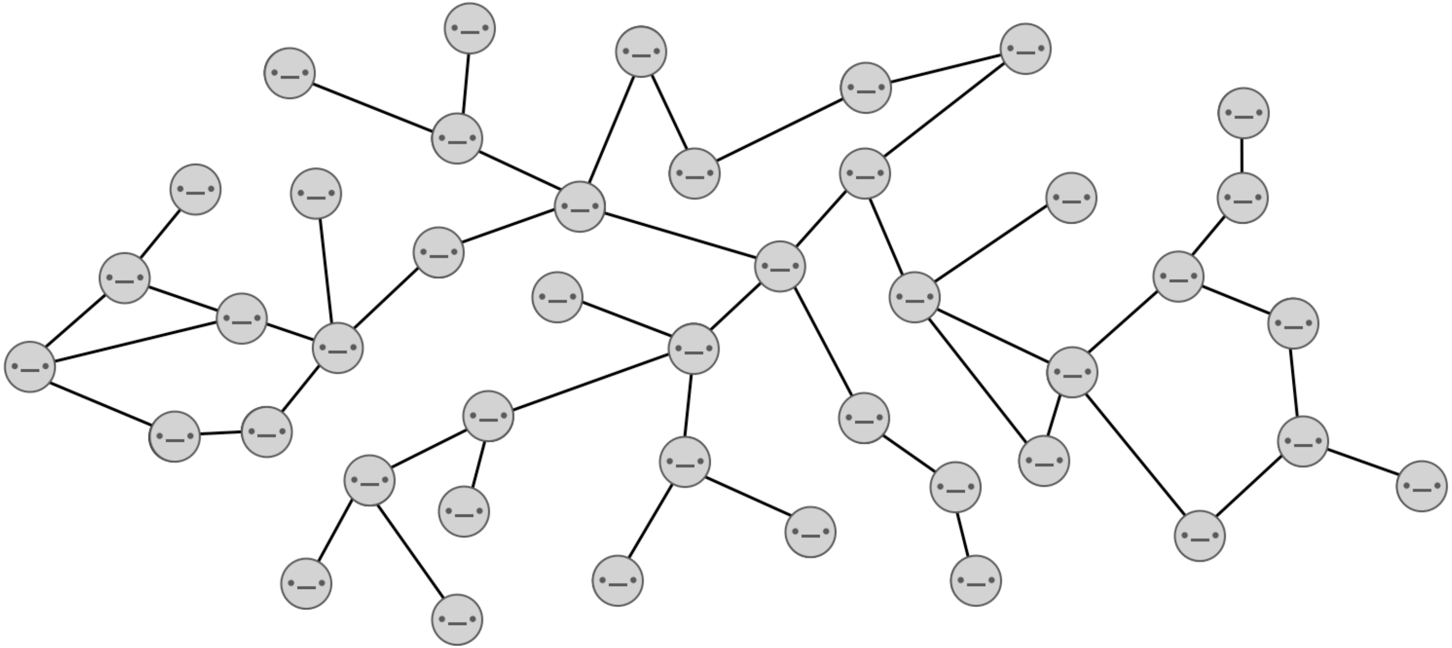
Digital Contact Tracing
Conventional Contact Tracing

- Find index case (testing!)
- identify contacts
- quarantine contacts


Contacts
Index Case

Digital Contact Tracing

Conventional Contact Tracing



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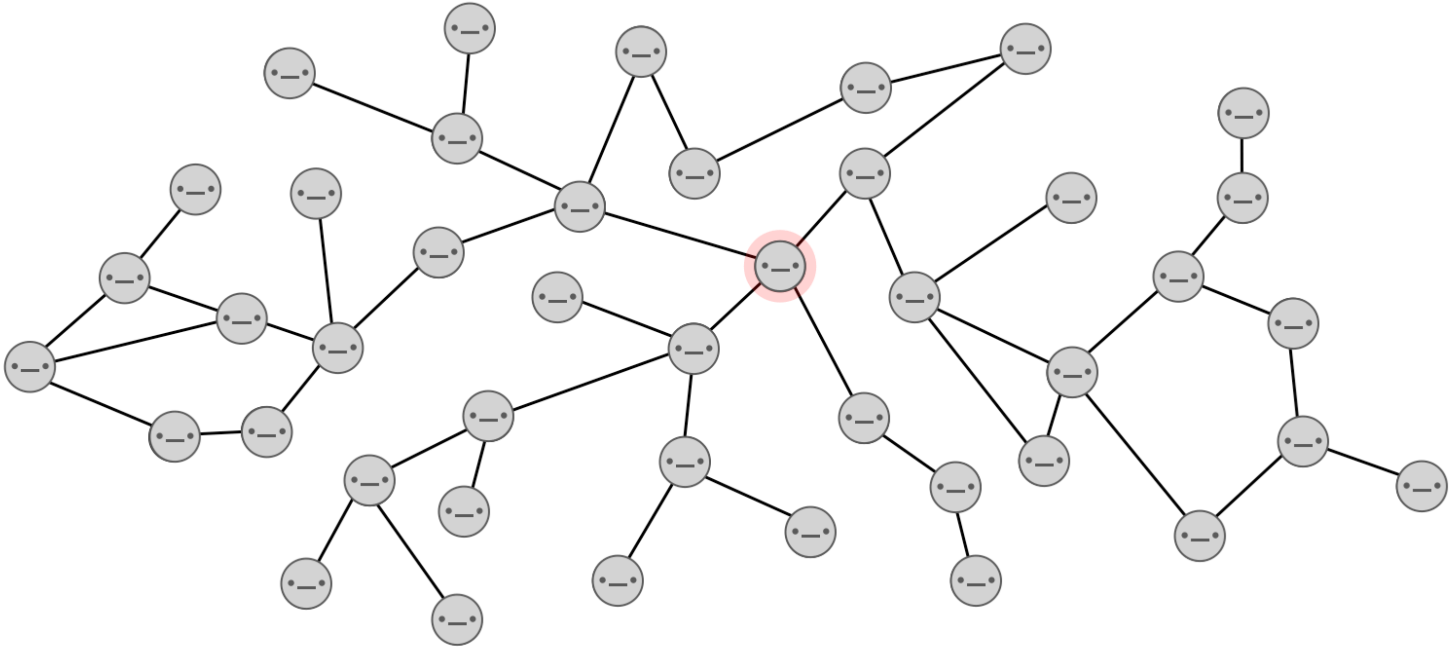
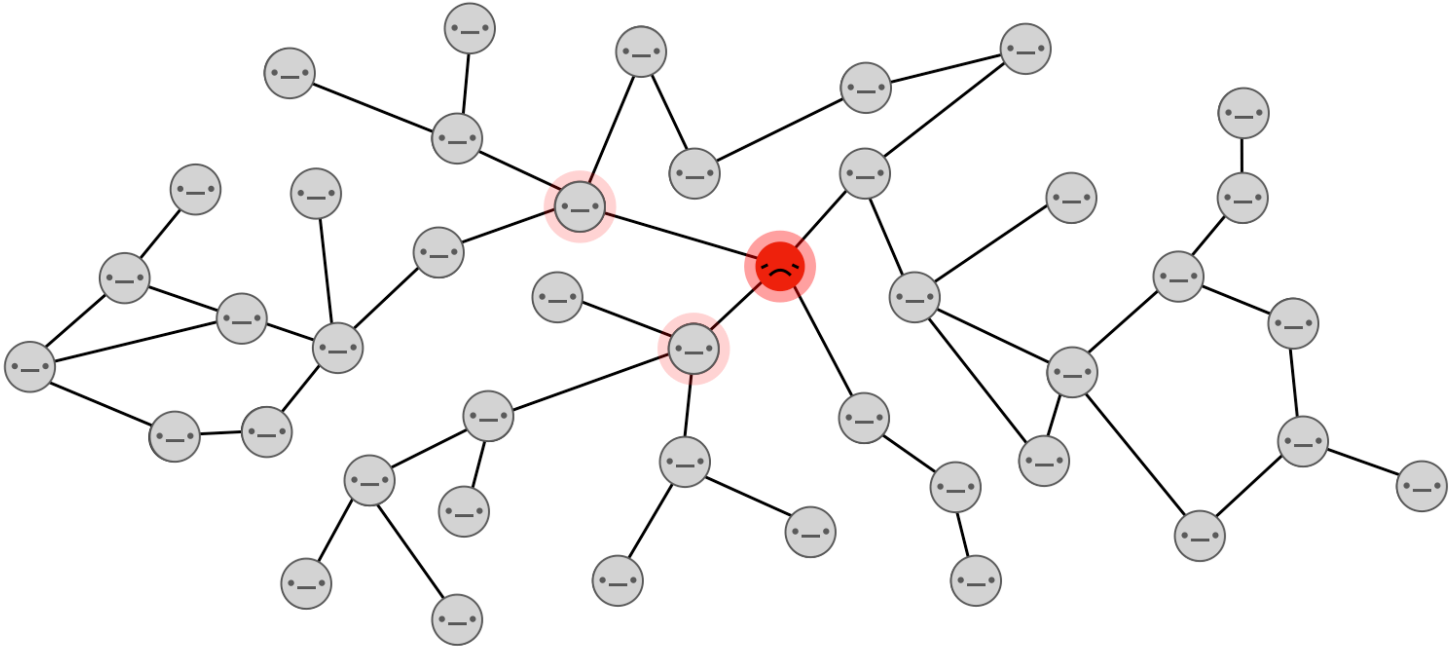
Digital Contact Tracing

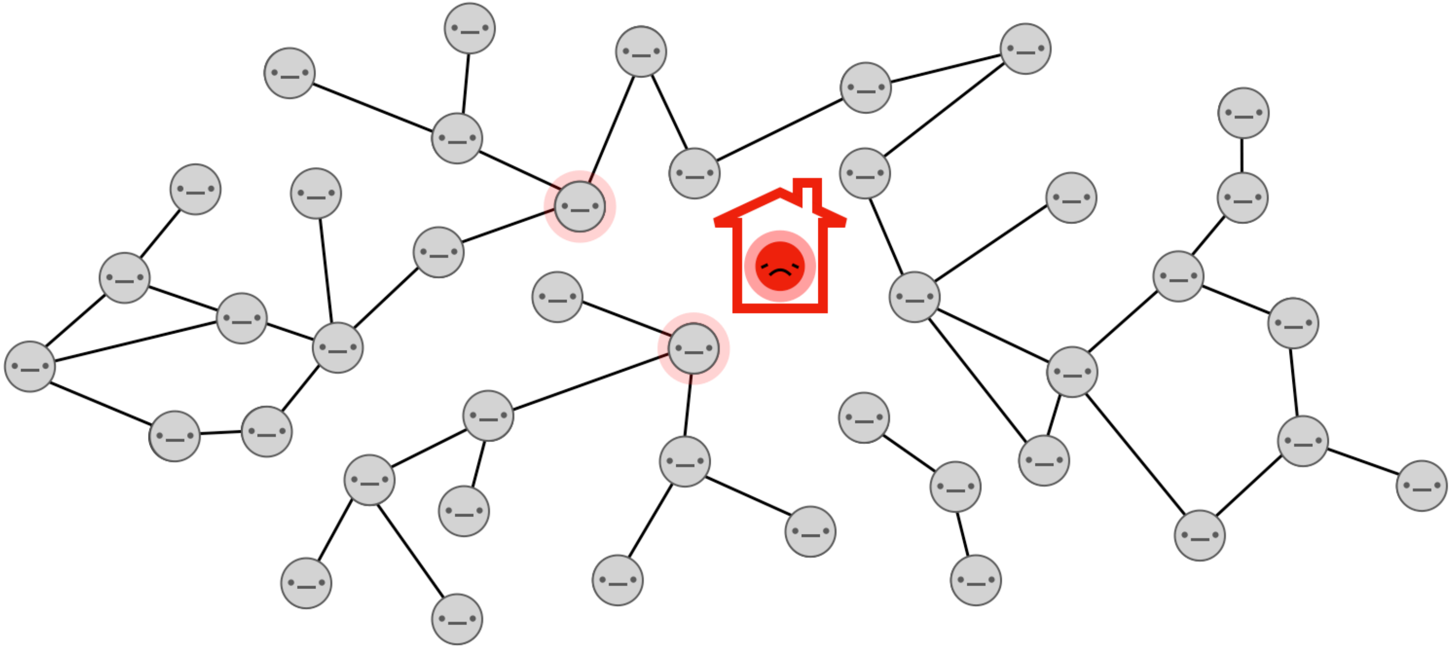
Conventional Contact Tracing



Digital Contact Tracing
Conventional Contact Tracing

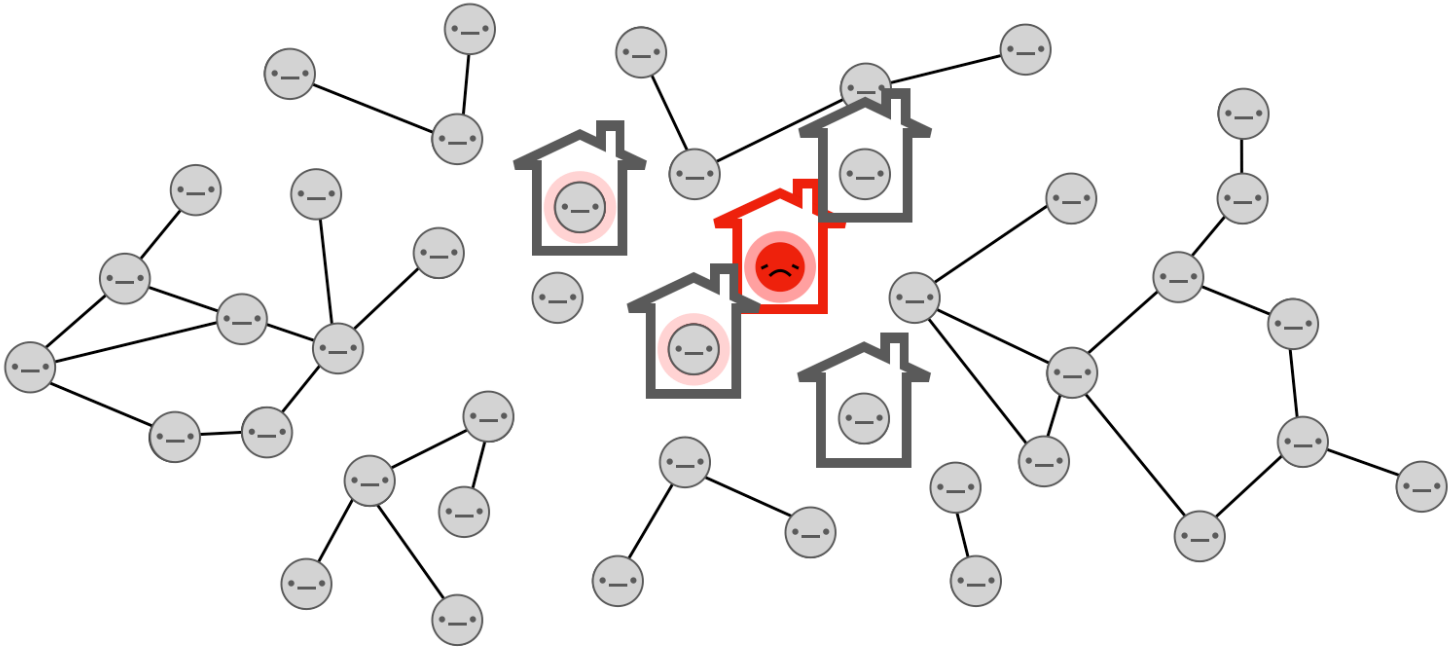


Digital Contact Tracing
Conventional Contact Tracing



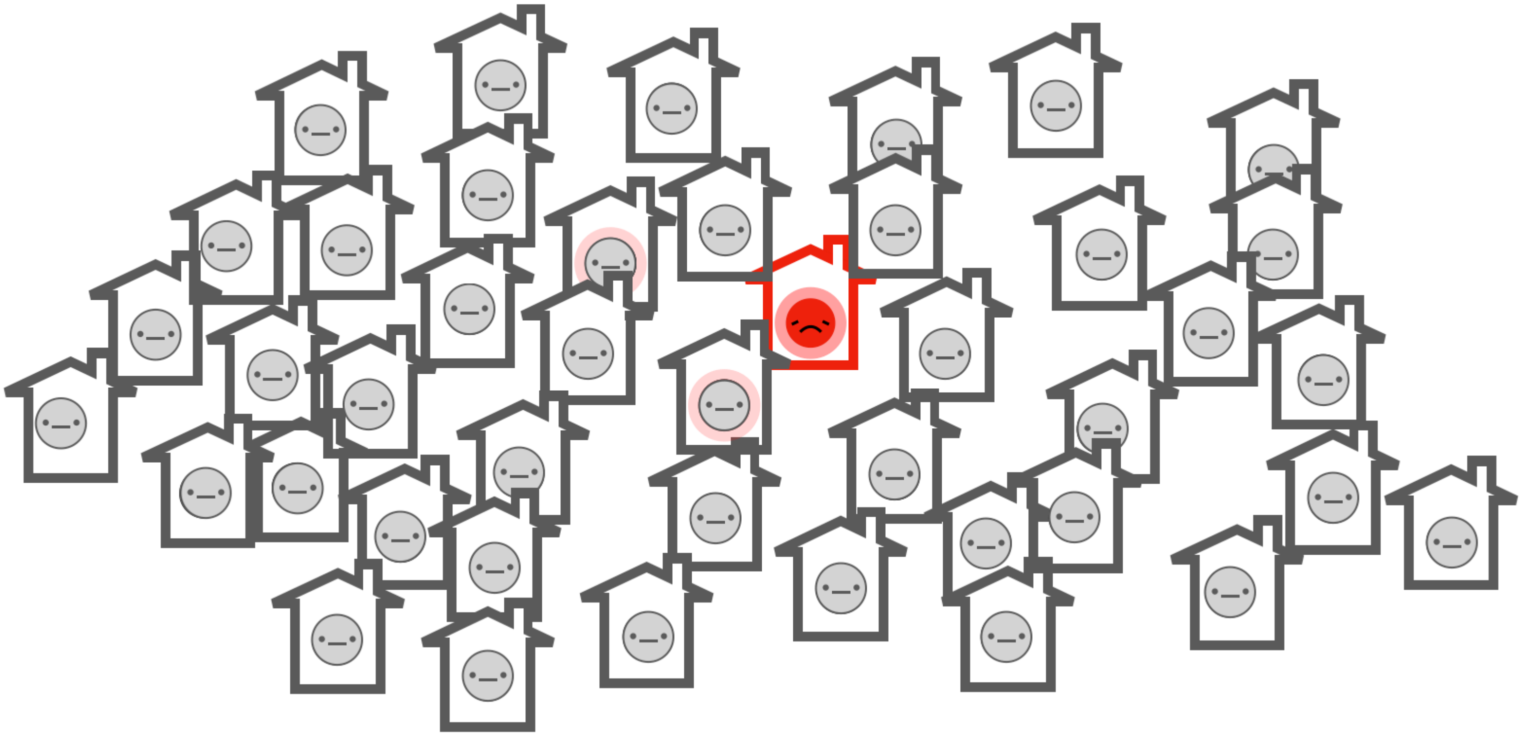
Digital Contact Tracing

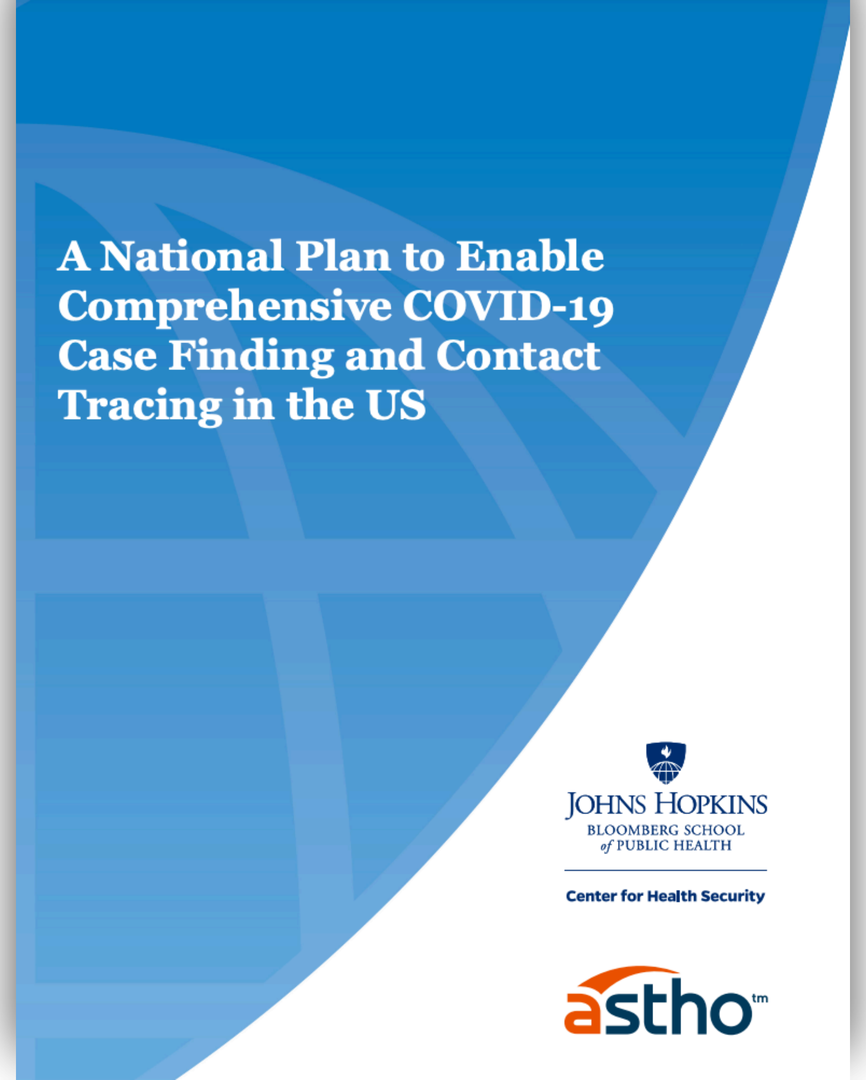
Conventional Contact Tracing



Digital Contact Tracing

Conventional Contact Tracing





- Published in April 2020

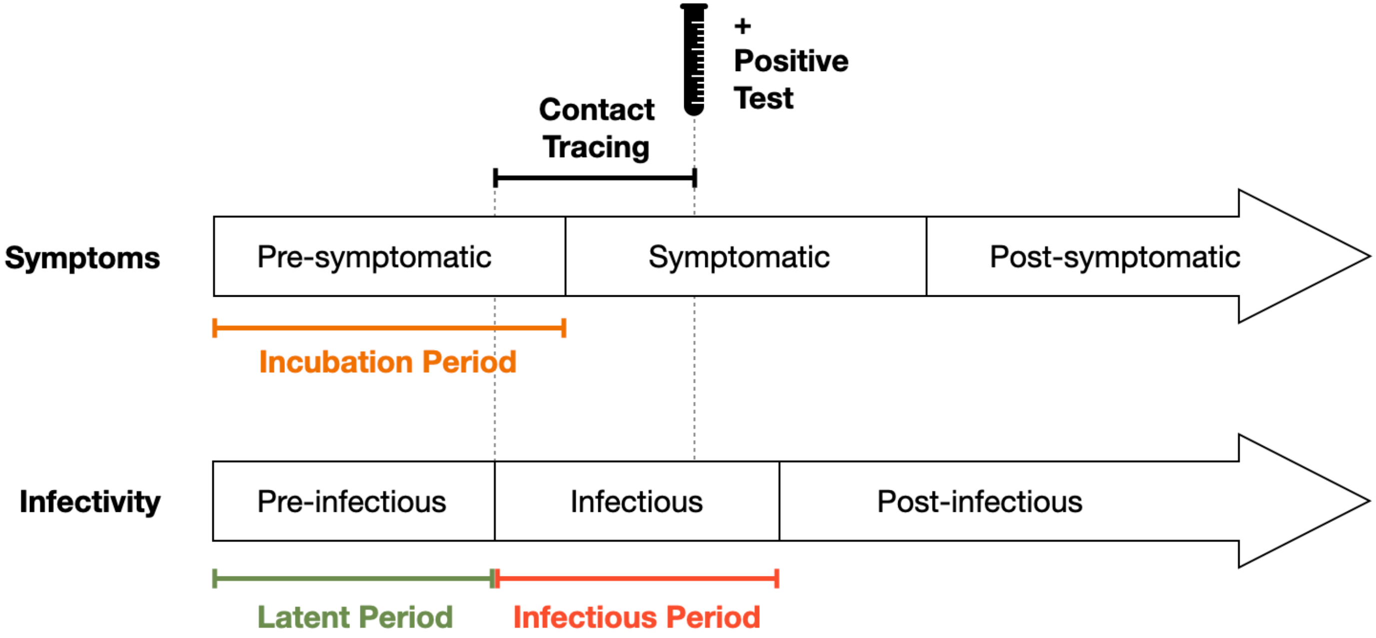
EPFL

Digital Contact Tracing

Conventional Contact Tracing

To manage COVID-19 epidemics going forward, communities in the United States need: (1) ready access to rapid diagnostic tests for all symptomatic cases or those with a reasonable suspicion of COVID-19 exposure; (2) widespread serological testing to understand underlying rates of infection and identify those who have developed immunity and could potentially return to work or school without fear of becoming infected; and (3) the ability to trace all contacts of reported cases. In order to trace all contacts, safely isolate the sick, and quarantine those exposed, we estimate that our public health workforce needs to add approximately 100,000 (paid or volunteer) contact tracers to assist with this large-scale effort. This workforce could be strategically deployed to areas of greatest need and managed through state and local public health agencies that are on the front lines of COVID-19 response. To do this, we also estimate that Congress will need to appropriate approximately $3.6 billion in emergency funding to state and territorial health departments.

Digital Contact Tracing
All About Timing



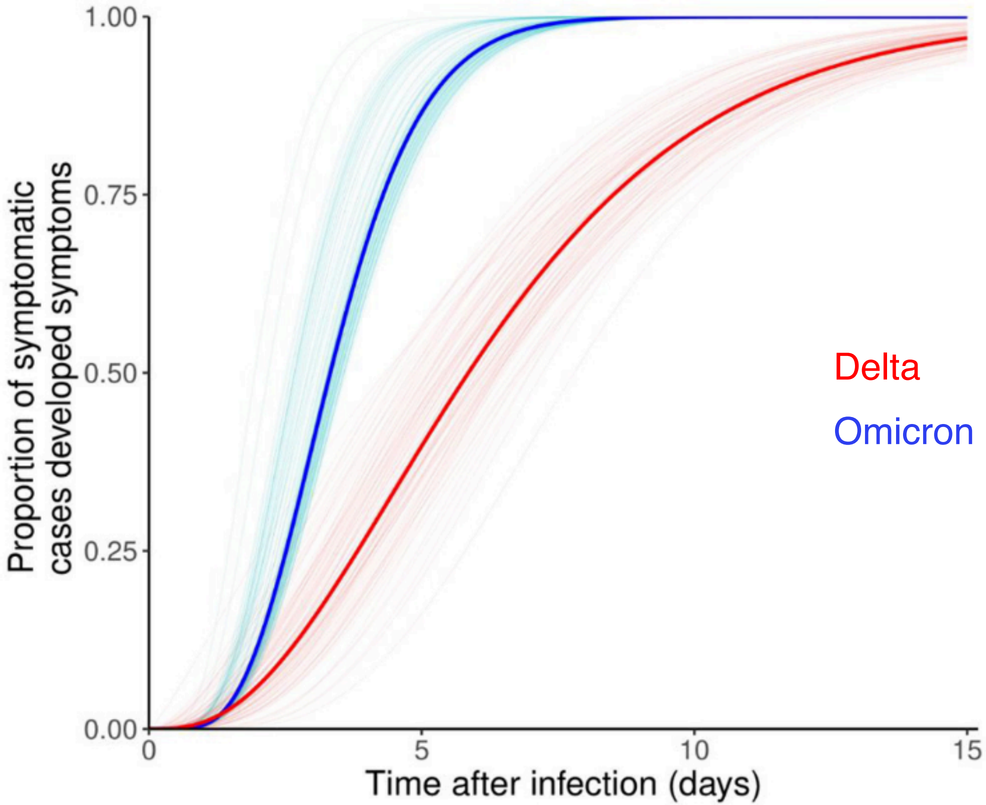
Digital Contact Tracing
Problems

- Secondary Attack Rate (SAR) is low: single digits % (up to 20% in households).

  i.e. many false positives.

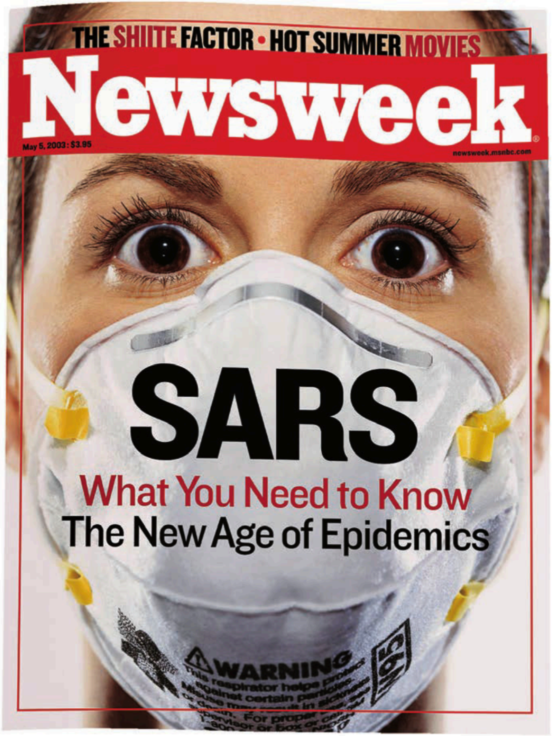
- So, when to leave quarantine?

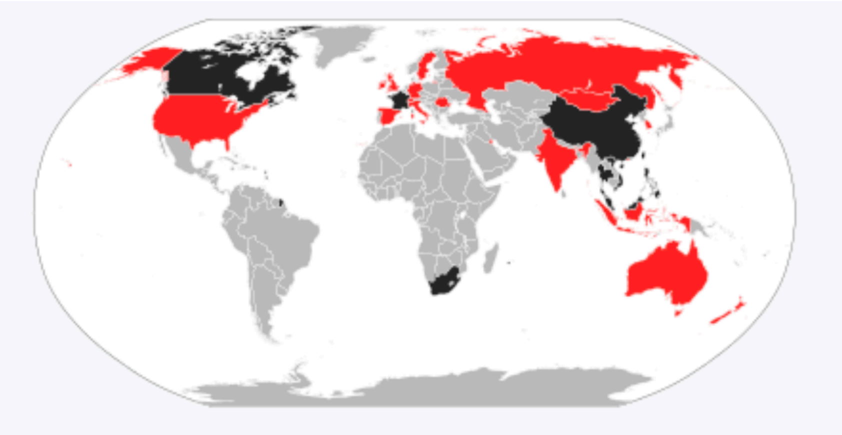
Digital Contact Tracing
Problems



Source: Liu et al. 2022

Digital Contact Tracing
Potential Of Contact Tracing

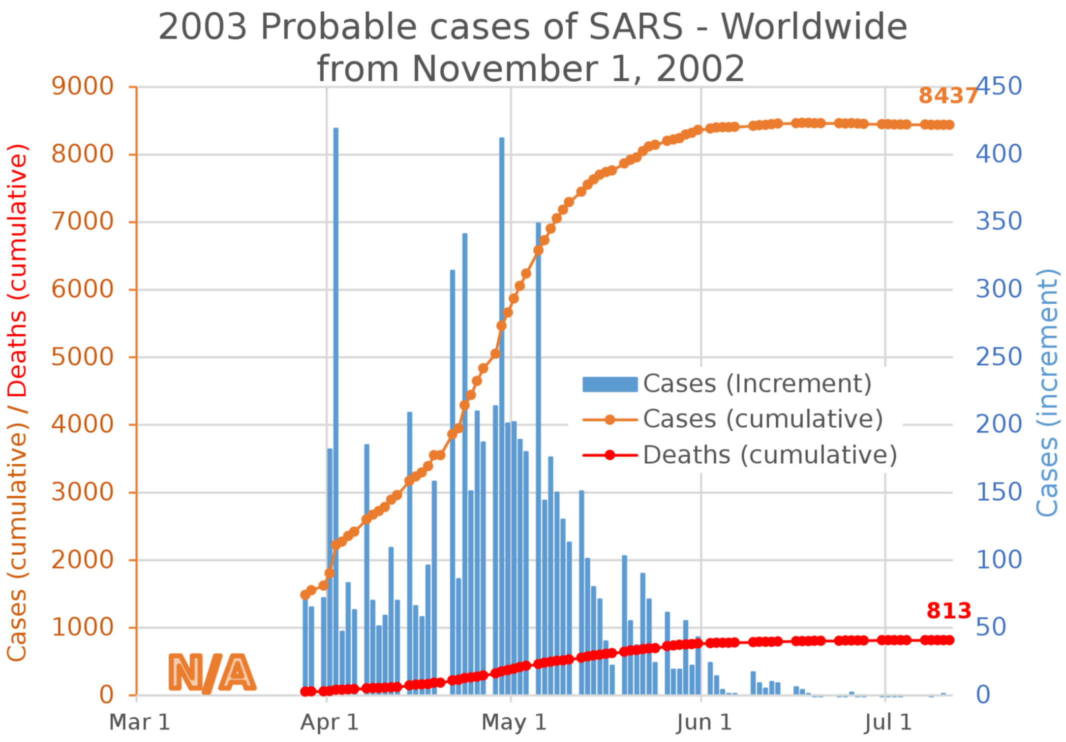




https://en.wikipedia.org/wiki/2002%E2%80%932004_SARS_outbreak

Digital Contact Tracing

Potential Of Contact Tracing



https://en.wikipedia.org/wiki/2002%E2%80%932004_SARS_outbreak

Digital Contact Tracing
Potential Of Contact Tracing

Factors that make an infectious disease outbreak controllable

Christophe Fraser*†, Steven Riley*, Roy M. Anderson, and Neil M. Ferguson

Department of Infectious Disease Epidemiology, Imperial College, St. Mary's, London W2 1PG, United Kingdom

Edited by Robert May, University of Oxford, Oxford, United Kingdom, and approved February 27, 2004 (received for review November 13, 2003)

The aim of this study is to identify general properties of emerging infectious agents that determine the likely success of two simple public health measures in controlling outbreaks, namely (*i*) isolating symptomatic individuals and (*ii*) tracing and quarantining their contacts. Because these measures depend on the recognition of specific disease symptoms, we investigate the relative timing of infectiousness and the appearance of symptoms by using a mathematical model. We show that the success of these control measures is determined as much by the proportion of transmission occurring prior to the onset of overt clinical symptoms (or via asymptomatic infection) as the inherent transmissibility of the etiological agent (measured by the reproductive number R_0). From published studies, we estimate these quantities for two moderately transmissible viruses, severe acute respiratory syndrome coronavirus and HIV, and for two highly transmissible viruses, smallpox and pandemic influenza. We conclude that severe acute respiratory syndrome and smallpox are easier to control using these simple public health measures. Direct estimation of the proportion of asymptomatic and presymptomatic infections is achievable by contact tracing and should be a priority during an outbreak of a novel infectious agent.

increases. Actions taken during this period to isolate or quarantine ill patients can effectively interrupt transmission.

Modeling Infectious Disease Outbreaks

We develop a mathematical model of infectious disease outbreak dynamics that captures the distributions of times to symptoms and infectiousness for the etiological agent concerned and provides an alternative approach to earlier theoretical studies (8). This model can be used to evaluate the impact of simple public health control measures. By exploring different distributions and different intervention strategies, we aim to establish a general quantitative framework that can help predict whether simple control measures can be successful in reversing epidemic growth if applied efficaciously at an early stage of an outbreak.

In our analyses, we focus on an infectious disease outbreak in its early stages within a community. We assume that the people in the community mix homogeneously; i.e., all susceptible individuals are equally likely to become infected. We characterize individuals in terms of their infectiousness as a function of the time (τ) since they were infected, $\beta(\tau)$, and also the probability that they have not yet medrxiv.org

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Previous Next

Posted March 12, 2020.

Quantifying dynamics of SARS-CoV-2 transmission suggests that epidemic control and avoidance is feasible through instantaneous digital contact tracing

Luca Ferretti, Chris Wymant, Michelle Kendall, Lele Zhao, Anel Nurtay, David Bonsall, Christophe Fraser

doi: https://doi.org/10.1101/2020.03.08.20032946

Now published in *Science* doi: 10.1126/science.abb6936

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Abstract

Mobile phone apps implementing algorithmic contact tracing can speed up the process of tracing newly diagnosed individuals, spreading information instantaneously back through a past contact network to inform them that they are at risk of being infected, and thus allow them to take appropriate social distancing and testing measures. The aim of non-pharmaceutical infection prevention is to move a population towards herd protection, a state where a population maintains R_0<1, thus making it impossible for a pathogen to cause an epidemic. Here, we address

COVID-19 SARS-CoV-2 preprints from medRxiv and bioRxiv

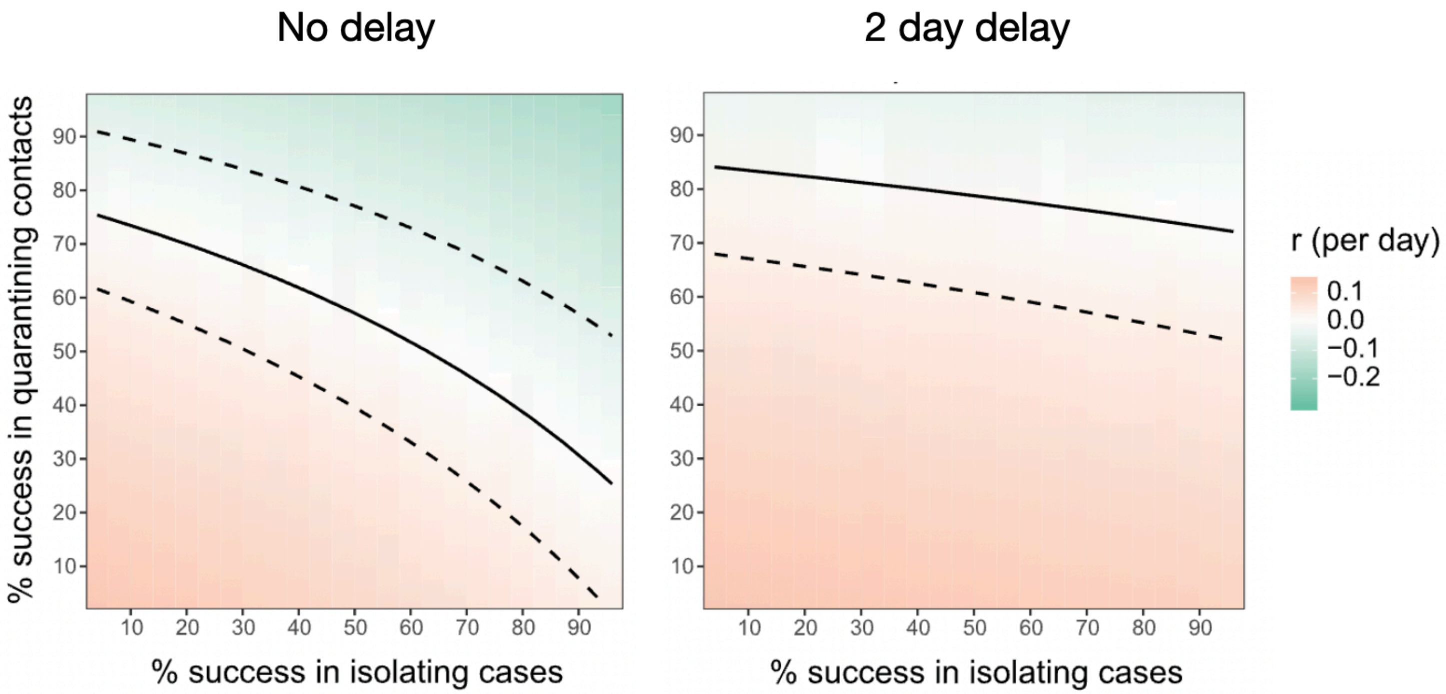
Subject Area

Epidemiology

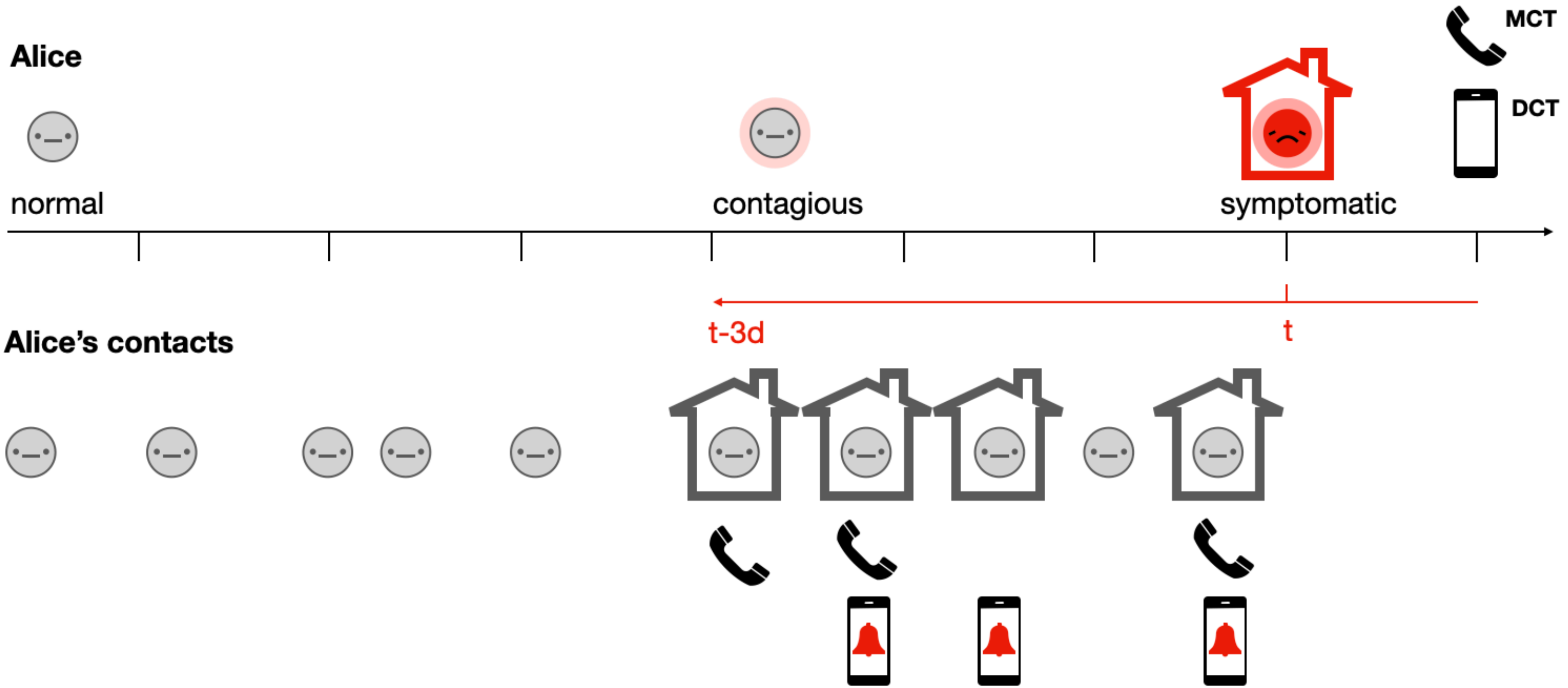
Subject Areas

All Articles

Digital Contact Tracing
Speed Matters



Digital Contact Tracing
Speed Matters



Digital Contact Tracing
Speed Matters

People in China, as well as in democracies, worry about how tech companies use the data they garner from their customers. But if covid-19 becomes a pandemic, they may well become more inclined to forgive a more nosy use of personal data if doing so helps defeat the virus. ■

The Economist, 29.2.2020

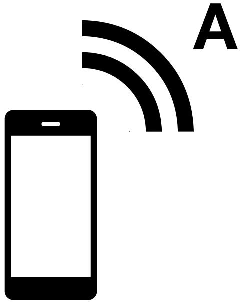
Digital Contact Tracing
Developing A Protocol

- Many different groups.
- In Europe, PEPP-PT (Pan-European Privacy-Preserving Proximity Tracing). Gains some traction, but eventually, DP3T (Decentralized Privacy-Preserving Proximity-Tracing splits off due to disagreements on transparency and protocol architecture).

- Central vs decentral: where is the risk calculation carried out?

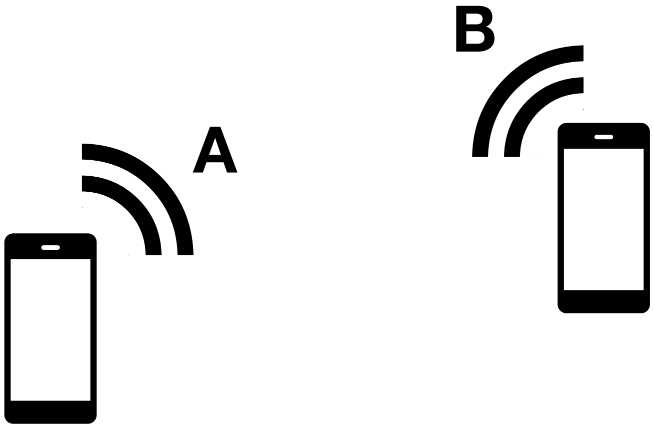
Digital Contact Tracing

Developing A Protocol

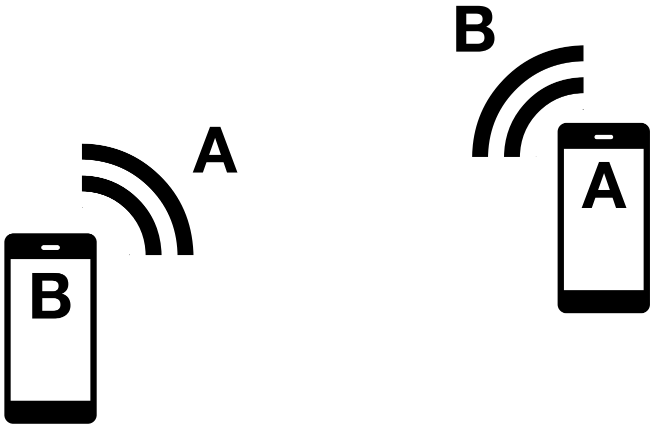


Digital Contact Tracing

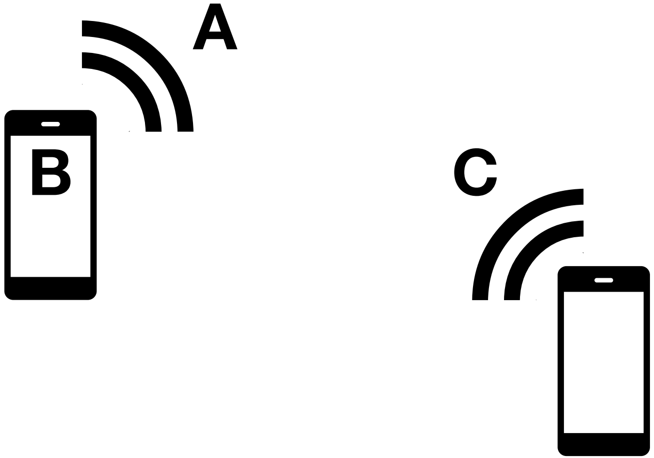
Developing A Protocol



Digital Contact Tracing
Developing A Protocol

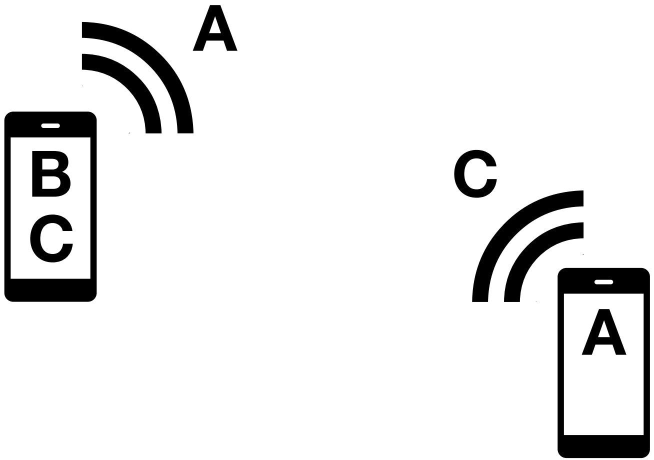


Digital Contact Tracing
Developing A Protocol



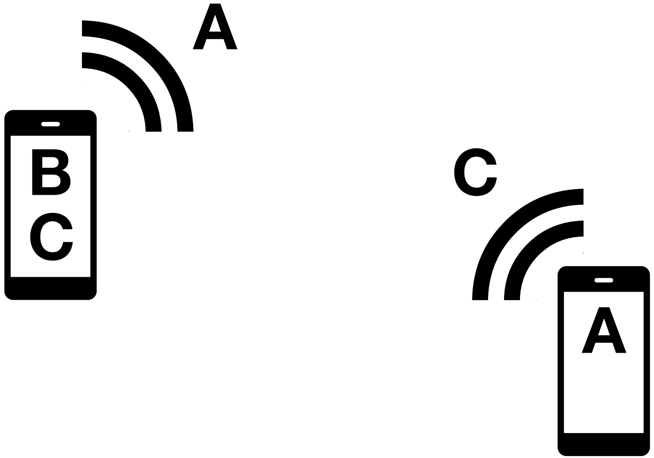
Digital Contact Tracing

Developing A Protocol



Digital Contact Tracing

Developing A Protocol



- IDs are ephemeral, rotating, generated by the phone
- They are broadcast along with the day and the signal strength.

Digital Contact Tracing
DP3T Protocol, Part 1

- Each phone generates a seed SK_t.
- Each day, a daily seed $SK_{t+1} = H(SK_t)$ is generated.
- The daily seed is used to generate ephIDs, valid for 15 minutes (i.e. 96 ephIDs per day)
- Phones broadcast ephID, date, and transmit power. They record ephID, date, and received signal strength

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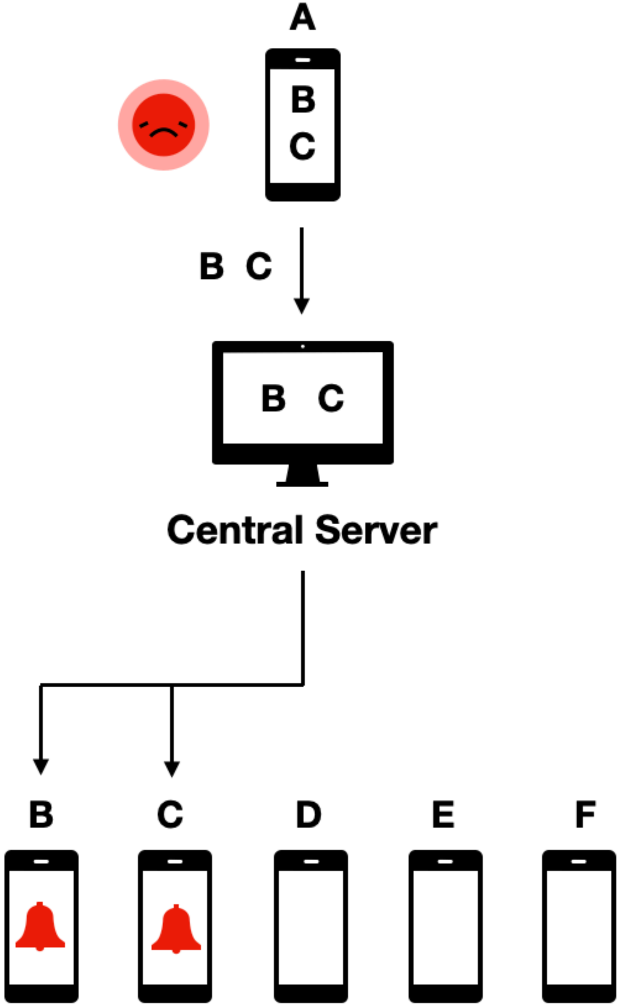
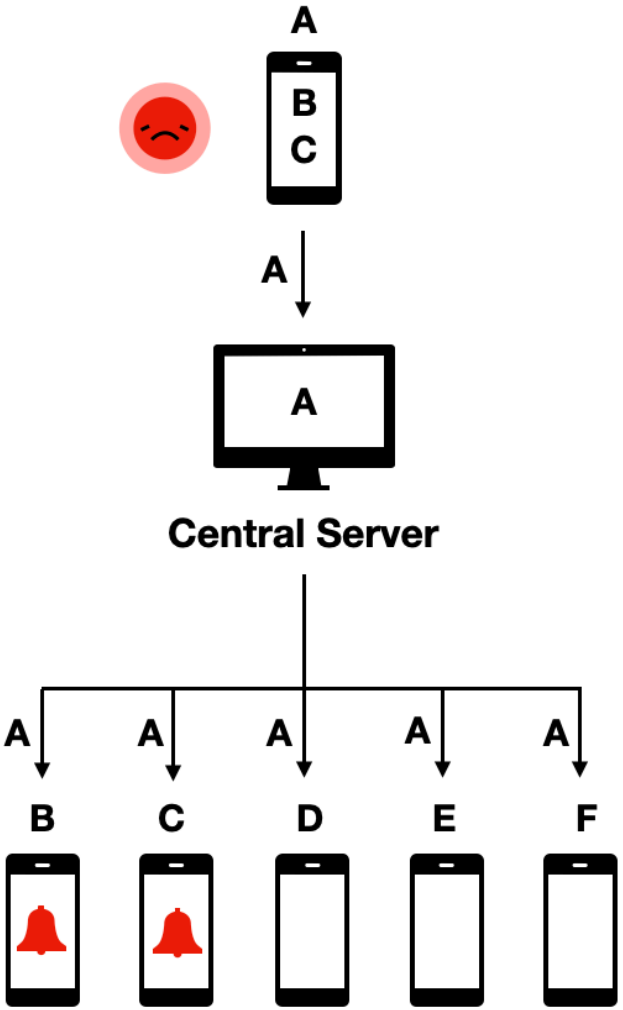
Digital Contact Tracing
DP3T Protocol, Part 2

- When tested positive, users upload seed SK_{t_c}, where t_c is the first day of contagion.
- Other phones periodically download seeds, and reconstruct all ephIDs. They then compare them with recorded ephIDs.
- The difference between transmit power and received signal strength corresponds to signal attenuation, and is used for distance estimation. All of these parameters then flow into a risk calculation.



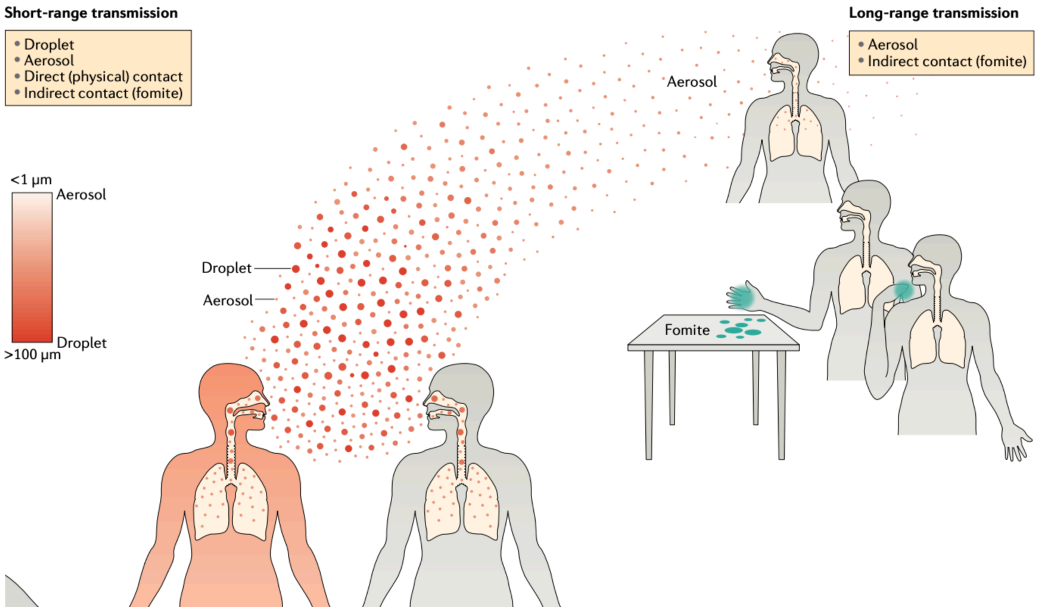
- Index case shares contact info
- Centralized server can notify contacts of exposure if risk sufficiently high
- Potential for centralized contact network data collection



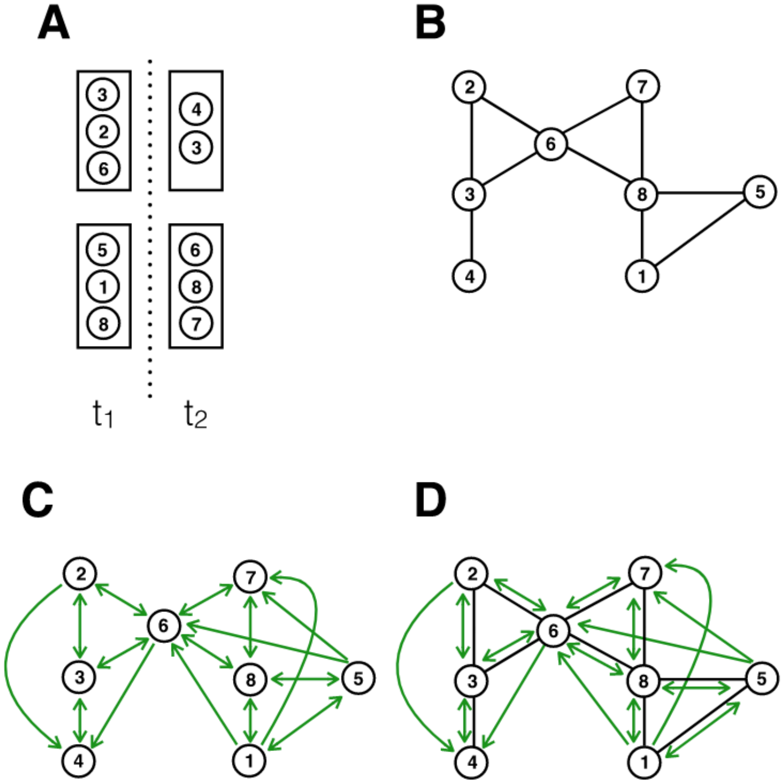
- Index case shares status
- Centralized server broadcasts status to all participants
- Participants check locally - i.e. fully decentralized - if risk sufficiently high for notification

Digital Contact Tracing
Presence Tracing

- Proximity Tracing is optimized for close contacts, but cannot capture fully aerosol transmission.



Digital Contact Tracing
Presence Tracing

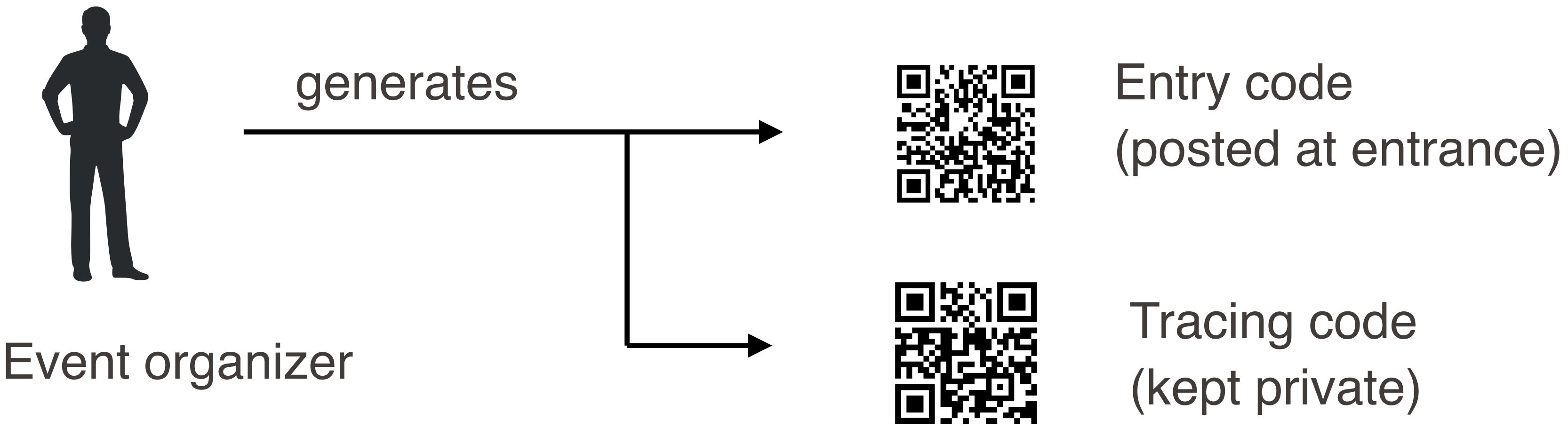


Source: Smieszek et al, 2019

Digital Contact Tracing
Presence Tracing

- Presence tracing was solved with QR codes. No OS support needed -> many apps, often without privacy guarantees.

Digital Contact Tracing
Presence Tracing



Digital Contact Tracing
Presence Tracing

- In case of positive test: event organizer shares tracing keys (via private QR code), keys are shared publicly.
- CrowdNotifier: implemented in SwissCovid, privacy-preserving.

Digital Contact Tracing
Implementations

- Pre-GAEN: Apps with Bluetooth Scanning (e.g. TraceTogether in Singapore) did not work because of iOS limitations.
- GAEN apps: Controlled by Google and Apple - one app per country, must be by health authority (except US, by state).
- Switzerland: required a legal basis, which slowed down roll out. But remained first country to roll out GEAN app (SwissCovid).

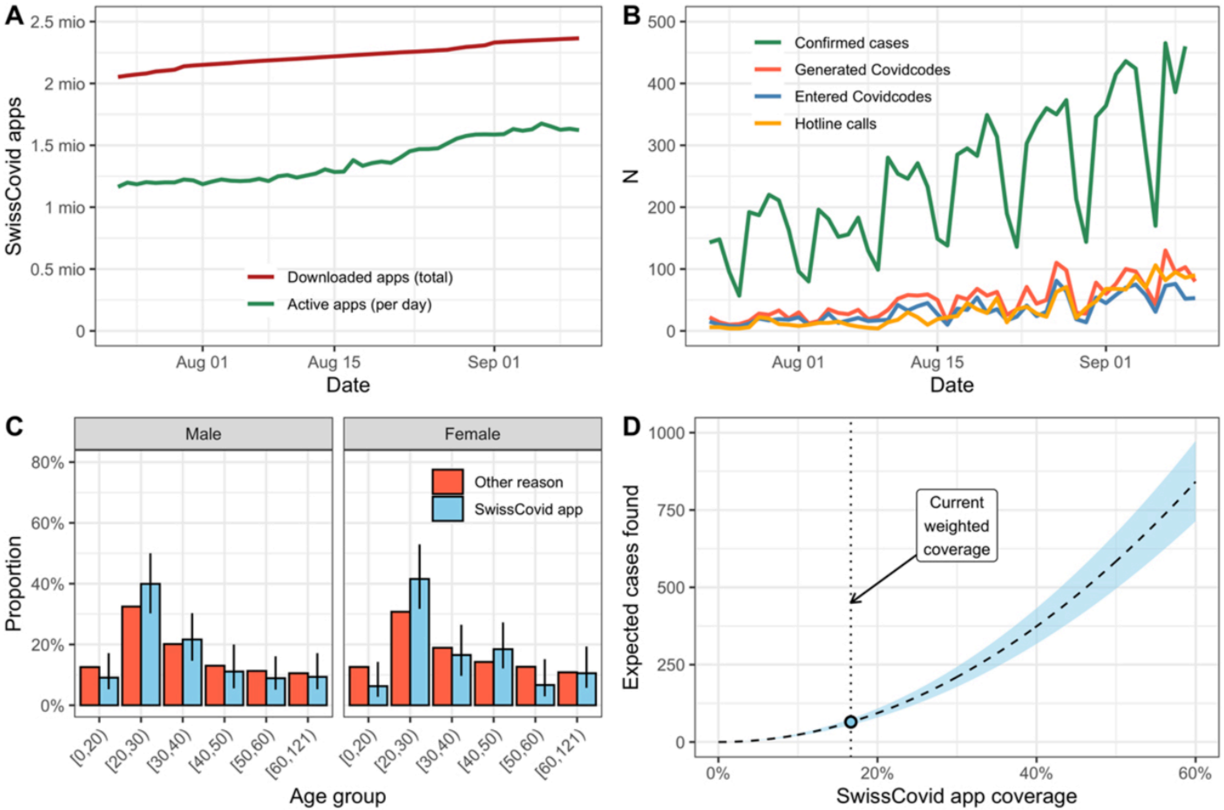
Digital Contact Tracing
Implementations

- Many countries did not like the decentralized approach, and tried to convince Google and Apple to change (unsuccessfully).
- UK NHS Covid app had already a fully functional centralized prototype and had to start from scratch. This delayed the release until early fall 2020.

Digital Contact Tracing
Implementations

- One app per country: many different implementations
- Key obstacles:
  - update
  - activation
  - UI
  - international compatibility

Digital Contact Tracing
Effectiveness: CH



Source: Salathé et al, 2020

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Digital Contact Tracing
Effectiveness: CH

- Study period: 23 July 2020 to 10 September 2020
- Total number of cases reported: 12,456
- Activation codes issues: 2,447
- Activation codes entered: $c = 1{,}645$
- Estimated cases that received notification $n = 65$ (95% CI 54–77)
- Usage: $\mu = 16.7\%$
- # notified positive people per participating index case = 0.24 (95% CI 0.20 - 0.27).

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Digital Contact Tracing
Effectiveness: ES

- Data from a simulation experiment (La Gomera)
- 33% downloaded the app, authorities triggered fake infections (10%)
- Compliance with code: 64%
- Detected 6.3 close contacts of index case (2x yield of conventional contact tracing)
- ~30% strangers

Digital Contact Tracing

Effectiveness: UK

- Upon app installation, users were promoted to enter geographic code
- Test management and code activation was handled by the app

Digital Contact Tracing
Effectiveness: UK

Article

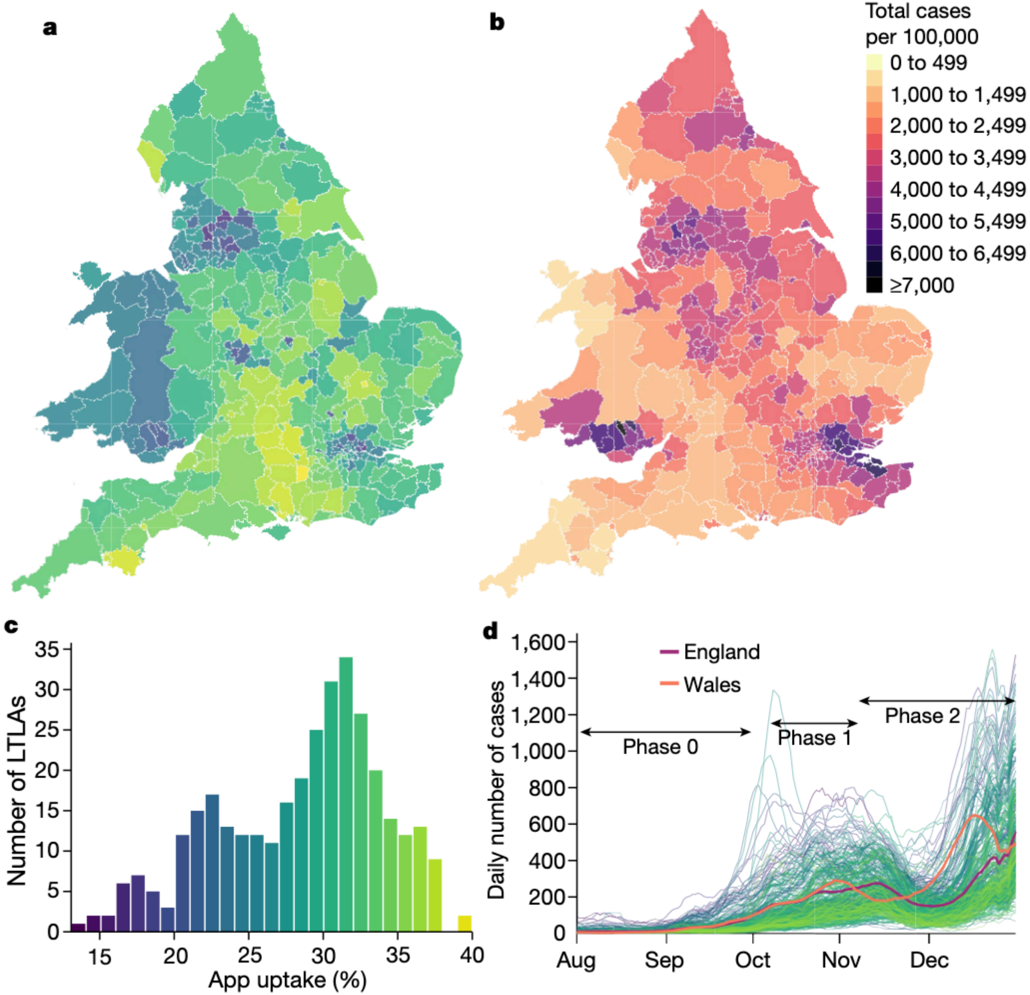
The epidemiological impact of the NHS COVID-19 app

https://doi.org/10.1038/s41586-021-03606-z
Received: 10 February 2021
Accepted: 3 May 2021
Published online: 12 May 2021

Check for updates

Chris Wymant[1,7], Luca Ferretti[1,7], Daphne Tsallis[2], Marcos Charalambides[3], Lucie Abeler-Dörner[1], David Bonsall[1], Robert Hinch[1], Michelle Kendall[1,4], Luke Milsom[5], Matthew Ayres[3], Chris Holmes[1,3,6], Mark Briers[3] & Christophe Fraser[1]✉

The COVID-19 pandemic has seen the emergence of digital contact tracing to help to prevent the spread of the disease. A mobile phone app records proximity events between app users, and when a user tests positive for COVID-19, their recent contacts can be notified instantly. Theoretical evidence has supported this new public health intervention[1–6], but its epidemiological impact has remained uncertain[7]. Here we investigate the impact of the National Health Service (NHS) COVID-19 app for England and Wales, from its launch on 24 September 2020 to the end of December 2020. It was used regularly by approximately 16.5 million users (28% of the total population), and sent approximately 1.7 million exposure notifications: 4.2 per index case consenting to contact tracing. We estimated that the fraction of individuals notified by the app who subsequently showed symptoms and tested positive (the secondary attack rate (SAR)) was 6%, similar to the SAR for manually traced close contacts. We estimated the number of cases averted by the app using two complementary approaches: modelling based on the notifications and SAR gave an estimate of 284,000 (central 95% range of sensitivity analyses 108,000–450,000), and statistical comparison of matched neighbouring local



Source: Wymant et al, 2021

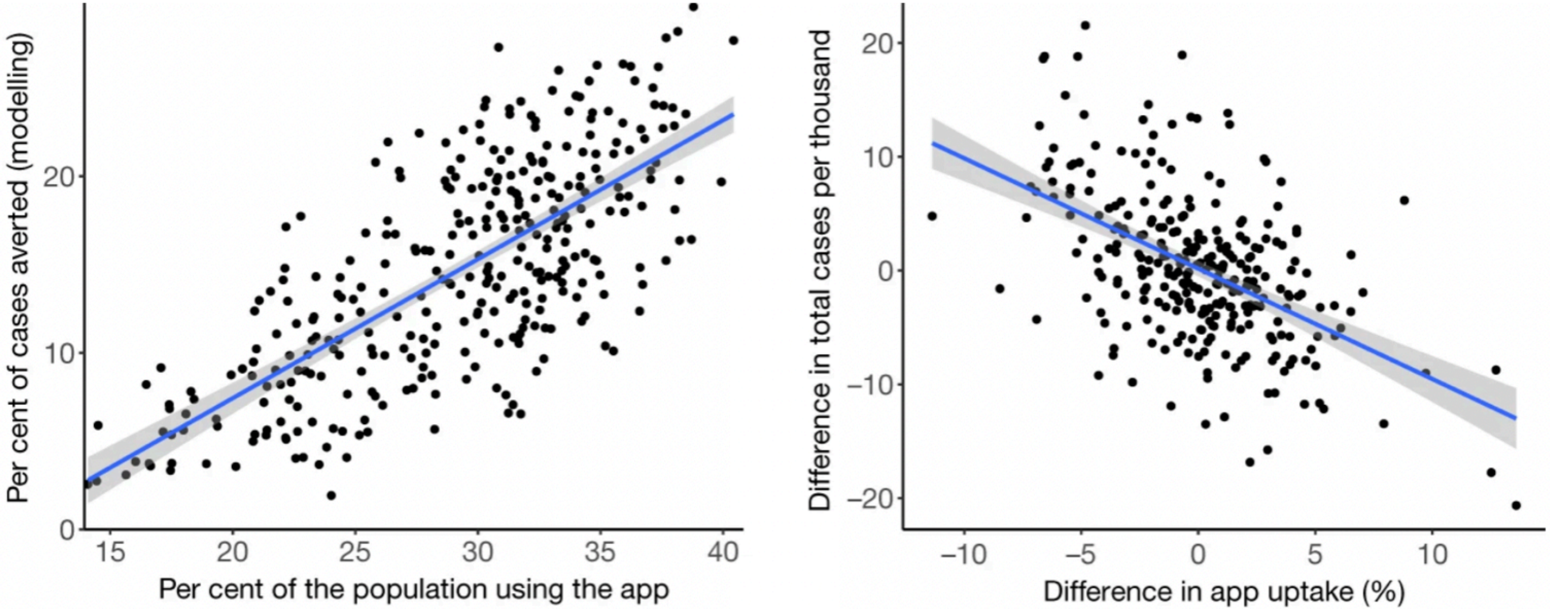
Digital Contact Tracing

Effectiveness: UK

- App triggered 1.7 million notifications (4.2 per index case, compared to 1.8 in conventional CT)
- SAR 6%
- Two approaches to study epidemiological impact: modeling, and spatial analysis. App prevented 284,000 or 594,000 cases, (combined 95% CI: 108,000 - 914,000)
- Estimates for averted deaths due to digital contact tracing: 4,200 or 8,700 (combined 95% CI: 1,600 – 13,500).

Digital Contact Tracing

Effectiveness: UK



Source: Wymant et al, 2021

nature communications

Article

https://doi.org/10.1038/s41467-023-36495-z

Epidemiological impacts of the NHS COVID-19 app in England and Wales throughout its first year

Received: 23 September 2022

Accepted: 2 February 2023

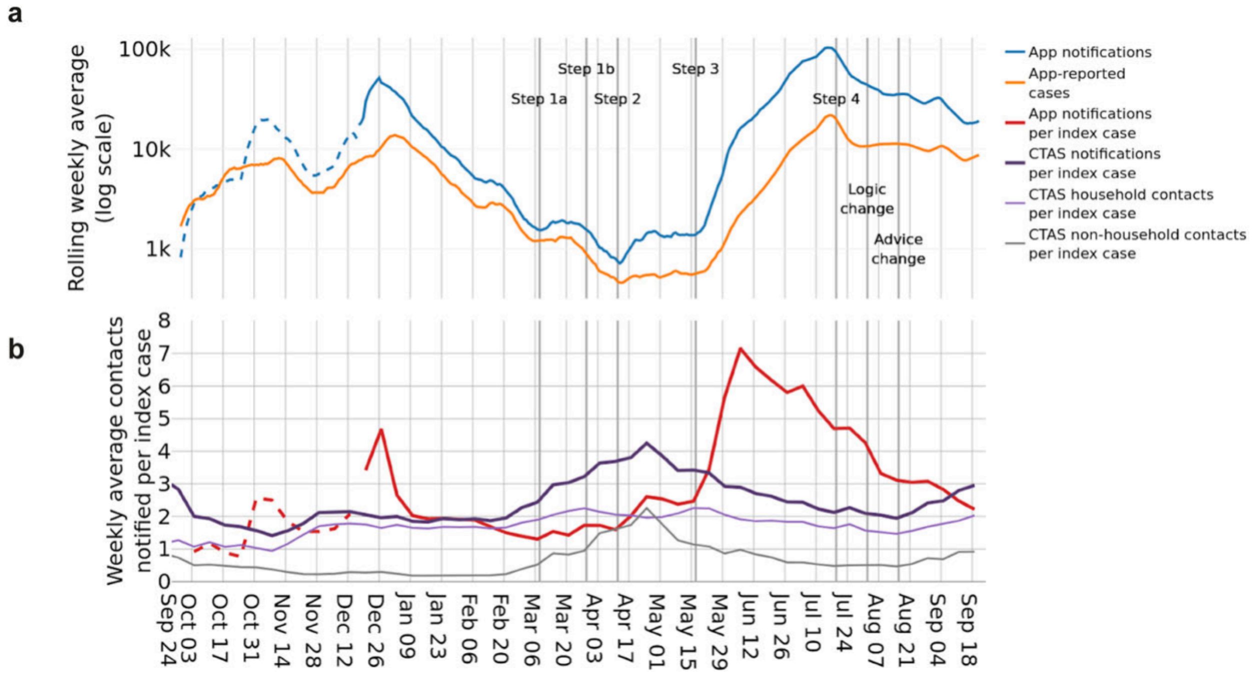
Published online: 22 February 2023

Check for updates

Michelle Kendall[1], Daphne Tsallis[2], Chris Wymant[3,4], Andrea Di Francia[5], Yakubu Balogun[5], Xavier Didelot[1,6], Luca Ferretti[3,4] & Christophe Fraser[3,4,7]

The NHS COVID-19 app was launched in England and Wales in September 2020, with a Bluetooth-based contact tracing functionality designed to reduce transmission of SARS-CoV-2. We show that user engagement and the app's epidemiological impacts varied according to changing social and epidemic characteristics throughout the app's first year. We describe the interaction and complementarity of manual and digital contact tracing approaches. Results of our statistical analyses of anonymised, aggregated app data include that app users who were recently notified were more likely to test positive than app users who were not recently notified, by a factor that varied considerably over time. We estimate that the app's contact tracing function alone averted about 1 million cases (sensitivity analysis 450,000–1,400,000) during its first year, corresponding to 44,000 hospital cases (SA 20,000–60,000) and 9,600 deaths (SA 4600–13,000).

Digital Contact Tracing
Effectiveness: UK



Source: Kendall et al, 2023

Article

Digital measurement of SARS-CoV-2 transmission risk from 7 million contacts

https://doi.org/10.1038/s41586-023-06952-2

Received: 9 May 2023

Accepted: 7 December 2023

Published online: 20 December 2023

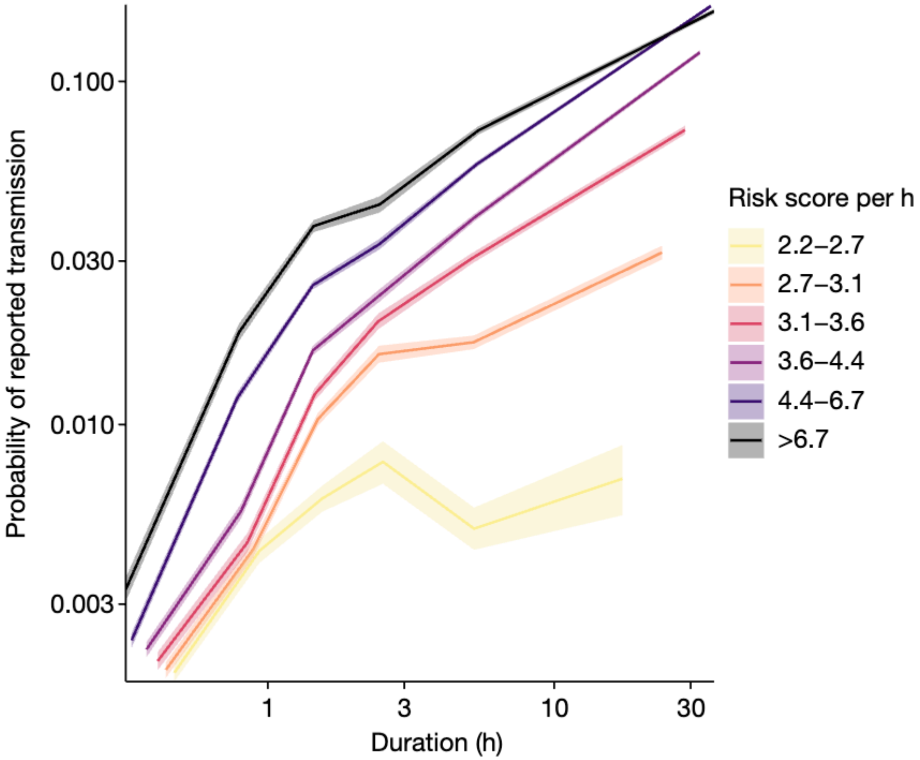
Open access

Check for updates

Luca Ferretti[1,2,7]✉, Chris Wymant[1,2,7], James Petrie[1,2], Daphne Tsallis[3], Michelle Kendall[4], Alice Ledda[5], Francesco Di Lauro[1,2], Adam Fowler[1,2], Andrea Di Francia[5], Jasmina Panovska-Griffiths[1,2,5], Lucie Abeler-Dörner[1,2], Marcos Charalambides[6], Mark Briers[6] & Christophe Fraser[1,2]✉

How likely is it to become infected by SARS-CoV-2 after being exposed? Almost everyone wondered about this question during the COVID-19 pandemic. Contact-tracing apps[1,2] recorded measurements of proximity[3] and duration between nearby smartphones. Contacts—individuals exposed to confirmed cases—were notified according to public health policies such as the 2 m, 15 min guideline[4,5], despite limited evidence supporting this threshold. Here we analysed 7 million contacts notified by the National Health Service COVID-19 app[6,7] in England and Wales to infer how app measurements translated to actual transmissions. Empirical metrics and statistical modelling showed a strong relation between app-computed risk scores and actual transmission probability. Longer exposures at greater distances had risk similar to that of shorter exposures at closer distances. The probability of transmission confirmed by a reported positive test increased initially linearly with duration of exposure (1.1% per hour) and continued increasing over several days. Whereas most exposures were short (median 0.7 h, interquartile range 0.4–1.6), transmissions typically resulted from exposures lasting between 1 h and several days (median 6 h, interquartile range 1.4–28). Households accounted for about 6% of contacts but 40% of transmissions. With sufficient preparation, privacy-preserving yet precise analyses of risk that would inform public health measures, based on digital contact tracing, could be performed within weeks of the emergence of a new pathogen.

Digital Contact Tracing
Effectiveness: UK



Source: Ferretti et al, 2023

Digital Contact Tracing
How To Improve?

- Your input!