PACT: Private Automated Contact Tracing

Marc A. Zissman, PhD

Lincoln Laboratory, Massachusetts Institute of Technology

18 December 2020

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MIT Lincoln Laboratory
MAZ@LL.MIT.EDU

Protocol Definition Working Group

Sponsors

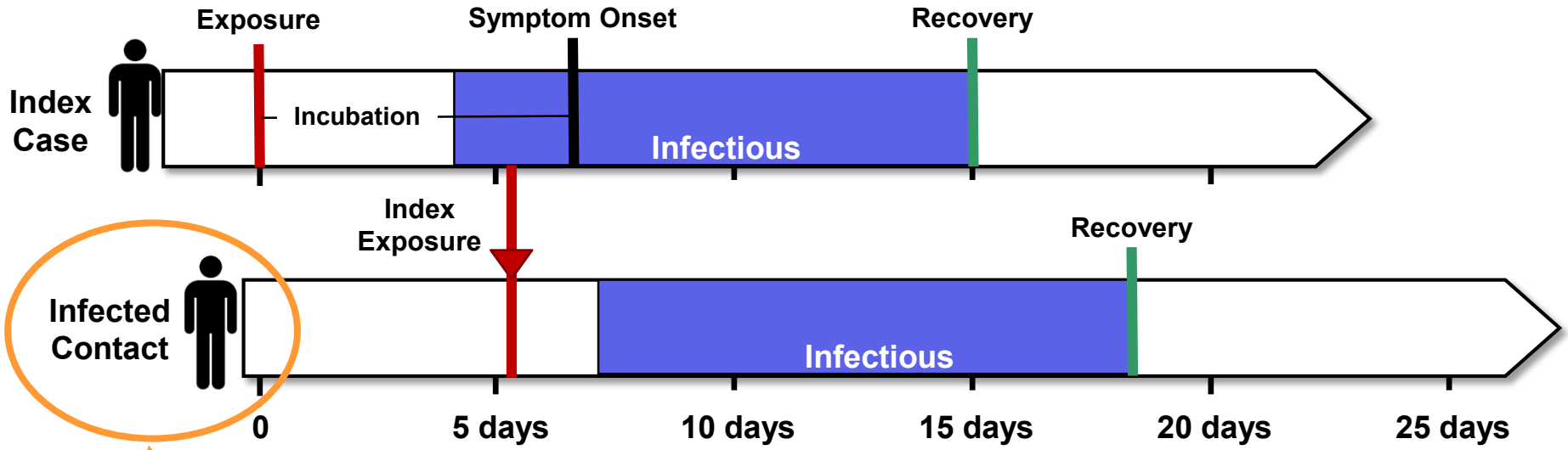
Data Collection Coalition

Bottom Line Up Front

- **Many non-pharmaceutical interventions to COVID spread can and do have impact, e.g.**
  - **Mask wearing, social distancing, testing, quarantine, isolation, contact tracing, etc.**
- **Automated exposure notification (AEN) can supplement manual contact tracing efforts**
  - **Automatic detection of high-risk exposure events**
  - **Hypotheses: AEN can decrease delay, decrease workload, broaden exposure detection**
- **PACT seeks to advance the state-of-the-art in private automated contact tracing solutions**
- **Significant opportunities for future technical innovation exist**

PACT serves as trusted technical advisor to federal, state and local public health authorities (PHAs) and as a convening center for collecting and sharing data and best practices for private automated contact tracing

COVID-19 Infection Progression



Goal: Find this person *before* they might infect others

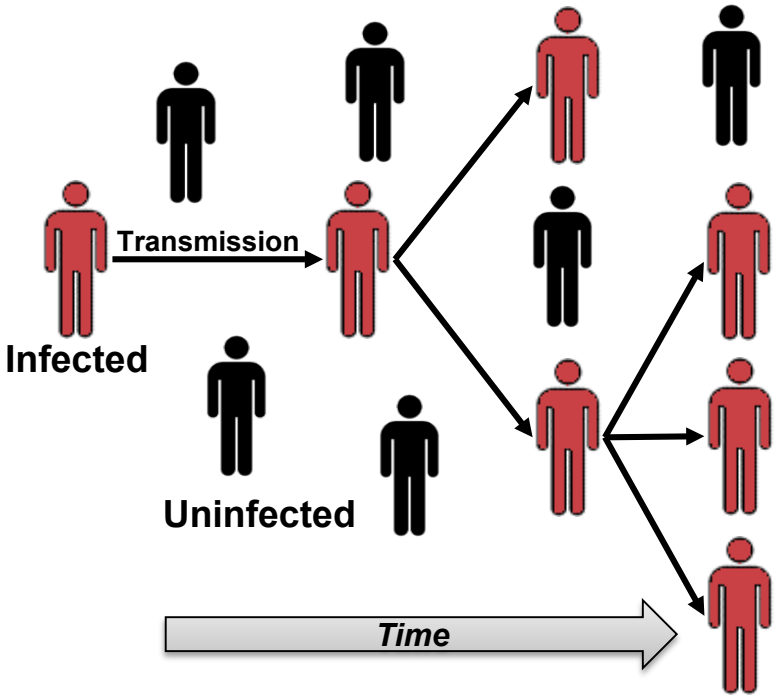
- **Identify "contacts" that could have infected this person (reverse)**
- **Identify "contacts" that this person could infect (forward)**

https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-guidance-management-patients.html
The Incubation Period of Coronavirus Disease 2019 (COVID-19) From Publicly Reported Confirmed Cases: Estimation and Application
https://wwwnc.cdc.gov/eid/article/26/7/20-0282_article https://www.harvardmagazine.com/2020/05/r-nought
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7054855/ ; https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7121626/

Contact Tracing

Contact tracing **is an epidemiological technique used to identify people who have had "contact" with an infected person**

- **Traditional uses (examples):**
  - **Tuberculosis**
  - **Smallpox**
  - **Sexually transmitted diseases**



Contact tracing can help inform public health interventions to slow virus transmission

Contact Tracing Tools

- Prior to COVID-19, contact tracing was primarily a manual process
- Primarily used for diseases with longer temporal characteristics

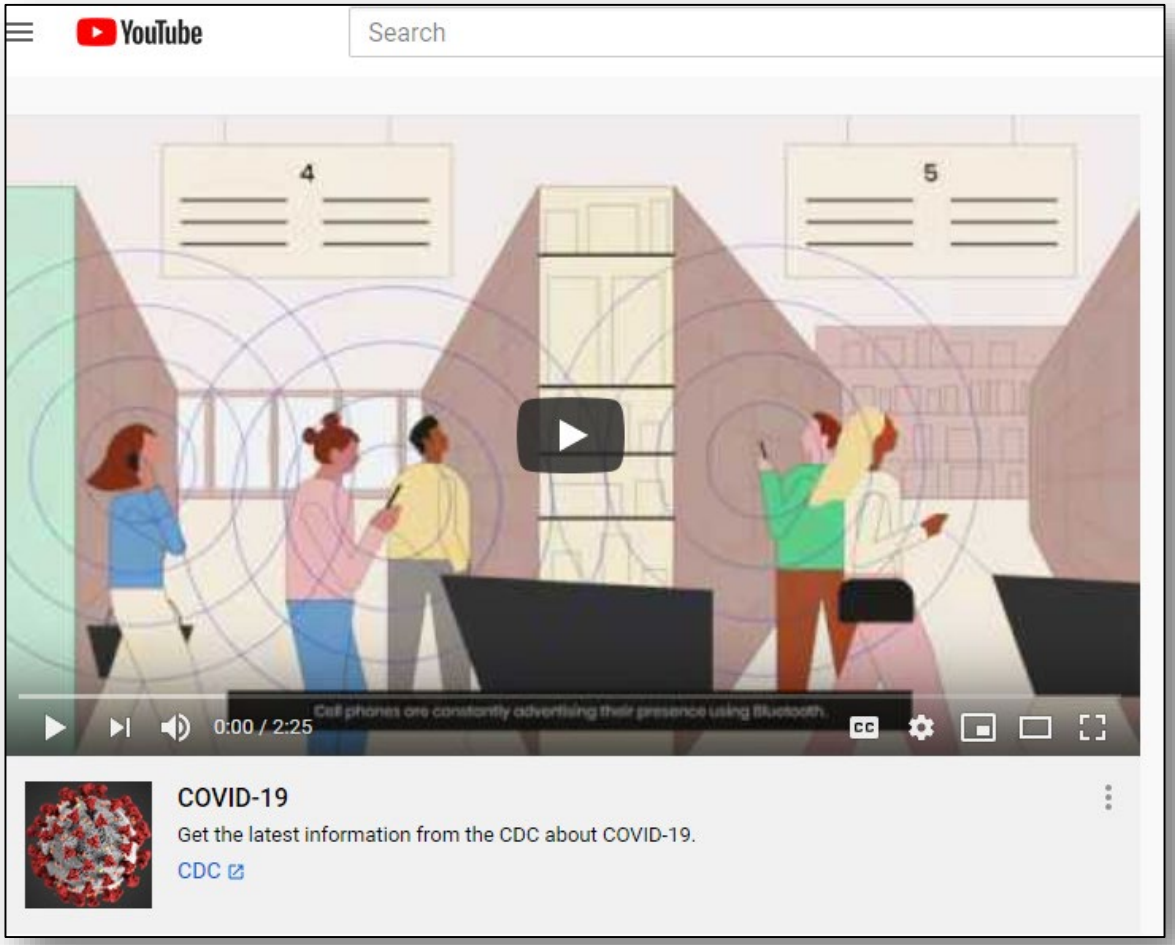
Public Health Contact Tracing Tools

Challenges

- Index case must remember who they were in contact with, where they were
- Index case must know identifying information for contacts
- Labor intensive and time consuming
- Risk of data errors
- Difficult to apply analytics
- May not scale to need

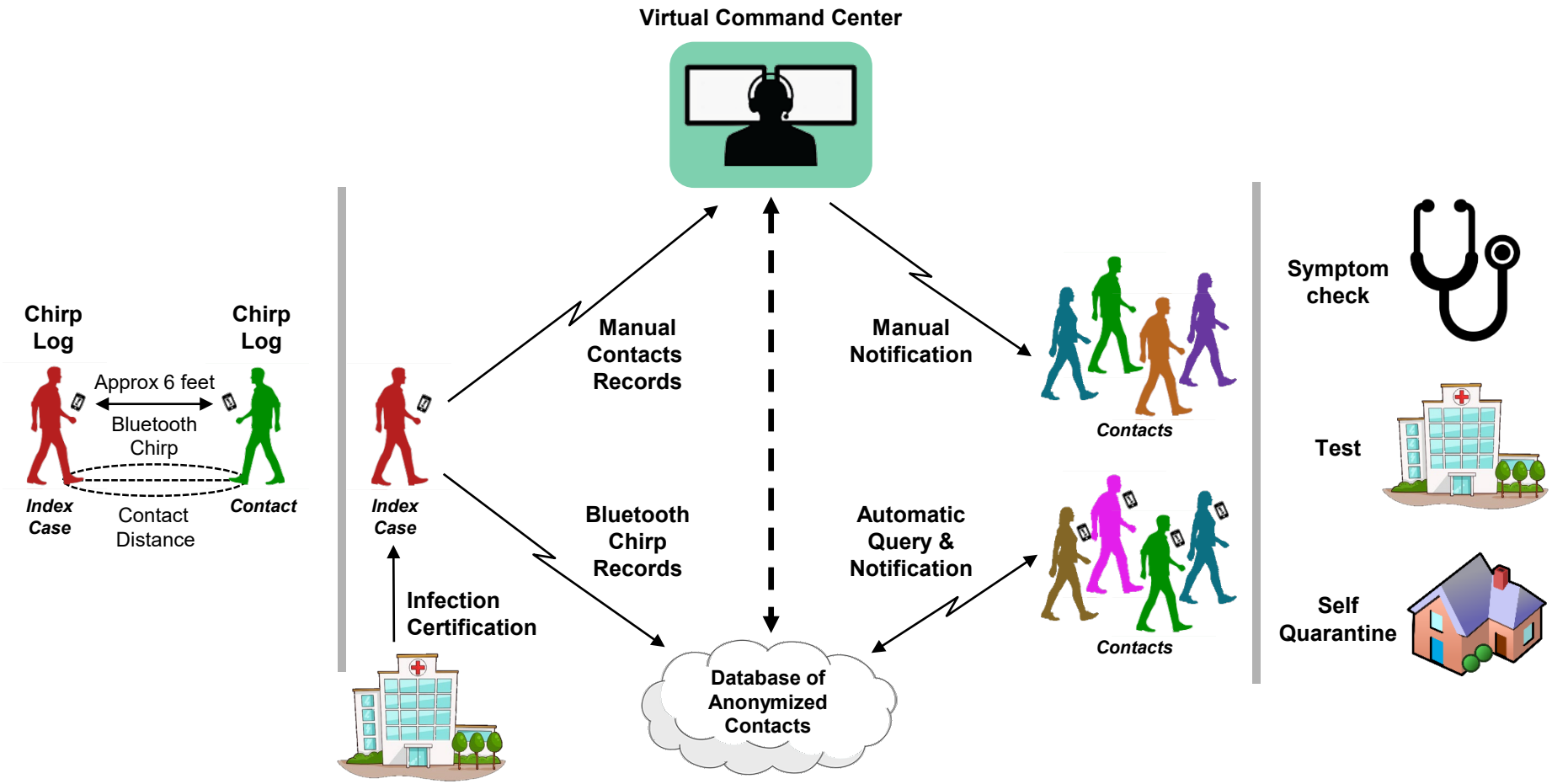
Advanced contact tracing tools are urgently needed to handle COVID-19

Animation Video



Animation Video:
https://www.youtube.com/watch?v=yuXzAh4sINw

General Approach



1 Contact Detection

2 COVID-19 Test Confirmed Positive

3 Exposure Query & Notification

4 Contact Actions

The AEN Value Proposition*
(Hypothesized)

1. Automatic exposure notification (AEN) can lead to faster exposure notification vs traditional manual contact tracing (MCT) alone

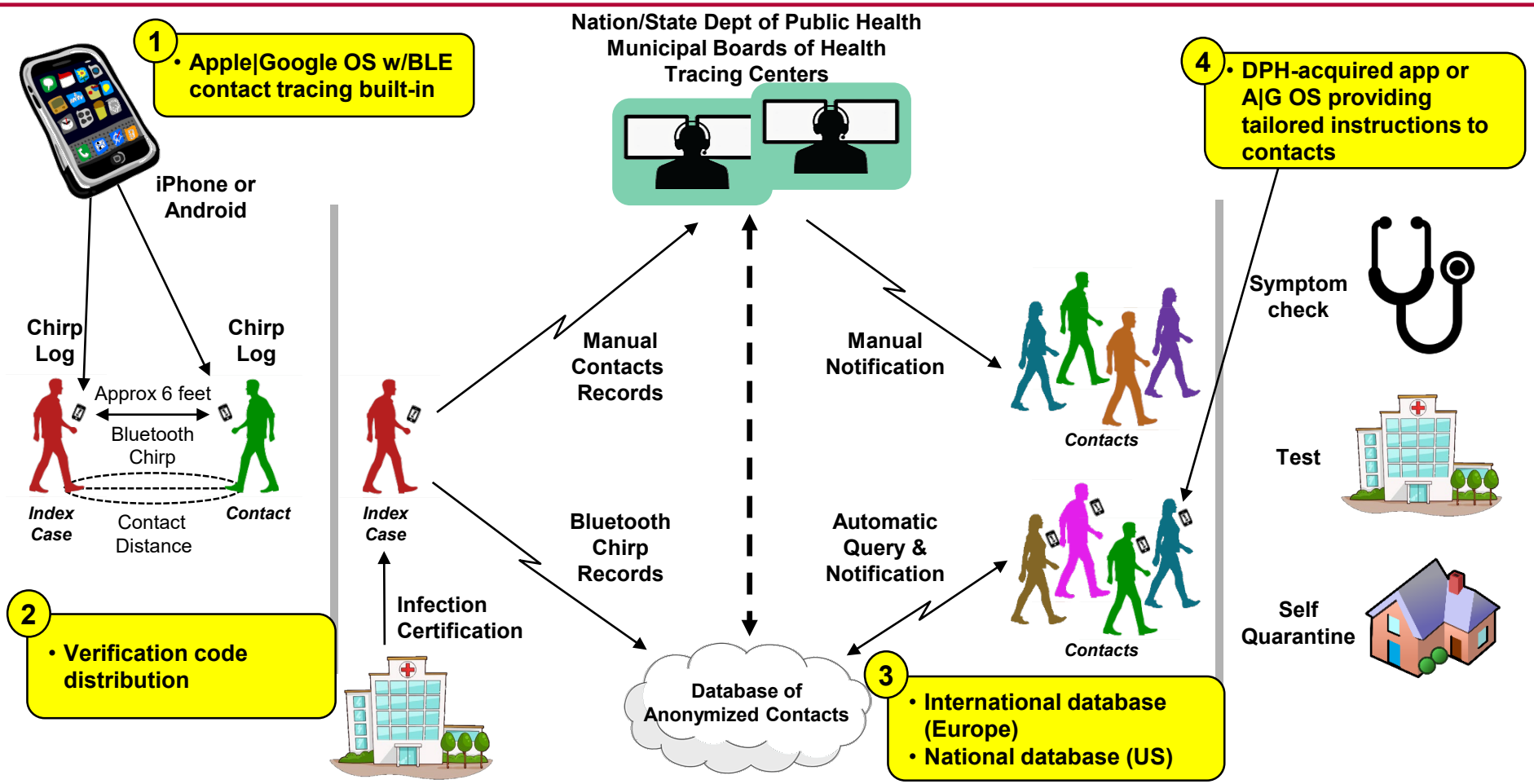
2. AEN can reach persons who are not personally known to an index case

3. AEN can still work when MCT reaches resource limits or breaks down

4. AEN alerts contacts privately and automatically about potential exposure, enabling them to choose how they wish to engage with public health authorities

*Adapted from Viktor von Wyl (University of Zurich) et al.

December 2020 Status: >30 Nations and U.S. States



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PACT Stack

Layer 3A: Public Health Interface

Major Challenges

- Integration into manual contact tracing systems
- Certification of infection
- Interoperability across public heath authorities
- Specifying "Too Close for Too Long" requirements
- Trustworthy systems to earn broad societal trust

Layer 3B: Individual Interface

Major Challenges

- Clear and local culture-appropriate opt-in instructions and explanation of privacy guarantees
- Simple functionality for reporting and certifying infection
- Simple functionality for notification of possible "too close for too long" contact and related instructions
- Integration with other public health functionality not directly PACT related

Layer 2: Private Cryptographic Protocol

Major Challenges

- Privacy preservation
- Chirp rollover frequency
- Reporting chirps sent vs chirps rec'd
- Mitigating threats posed by malicious parties

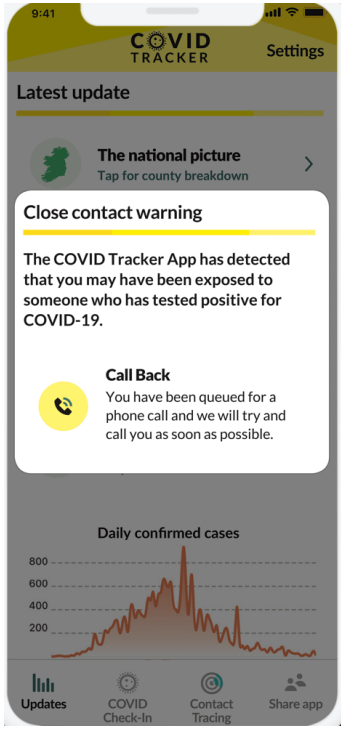
Layer 1: Proximity Measurement

Major Challenges

- Bluetooth phenomenology & data collection
- Implementing & evaluating "Too Close for Too Long" analytic
- Android, iOS interoperability
- Operating system policy compliance
- Smartphone power constraints
- OS vs app functional decomposition
- Other signaling options, e.g. ultrasound and UWB

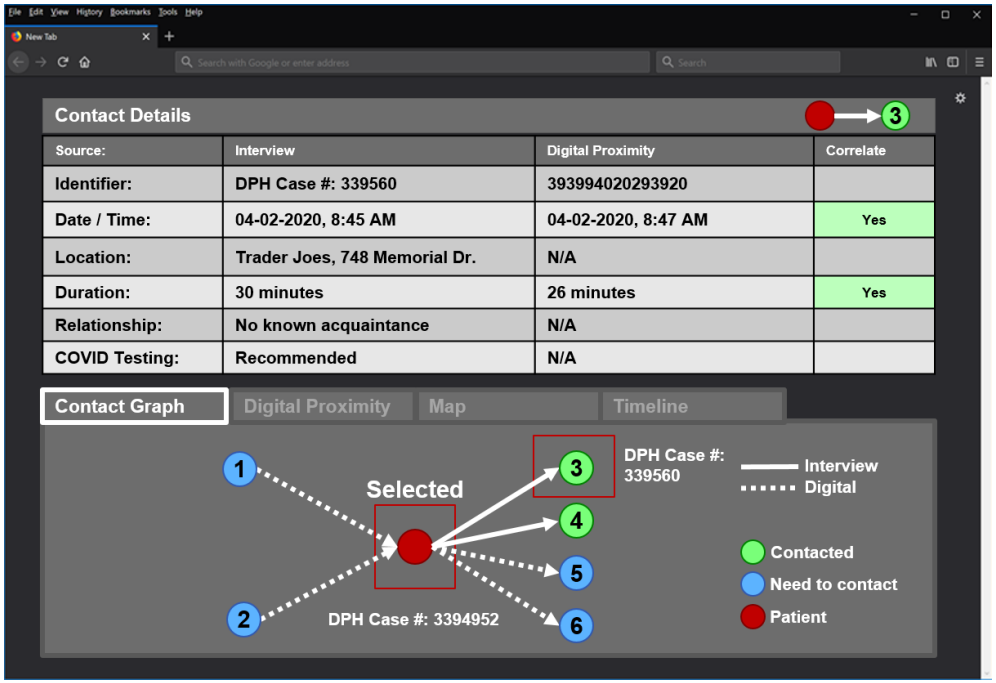
User Interfaces

Mobile Phone App*



- For individual citizens
- Alerts user of potential exposure
- Turns exposure tracing on and off

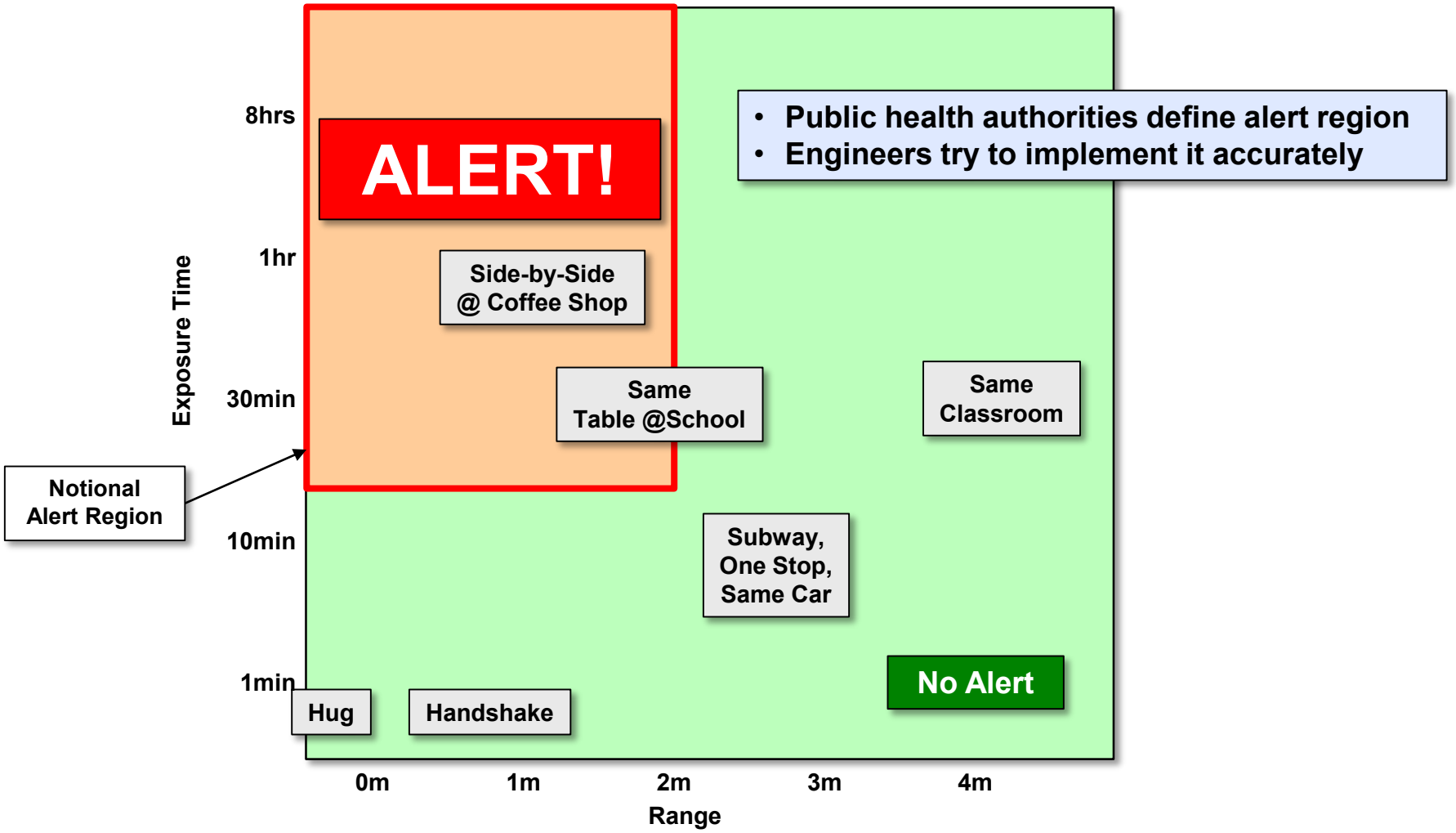
Epidemiology Dashboards



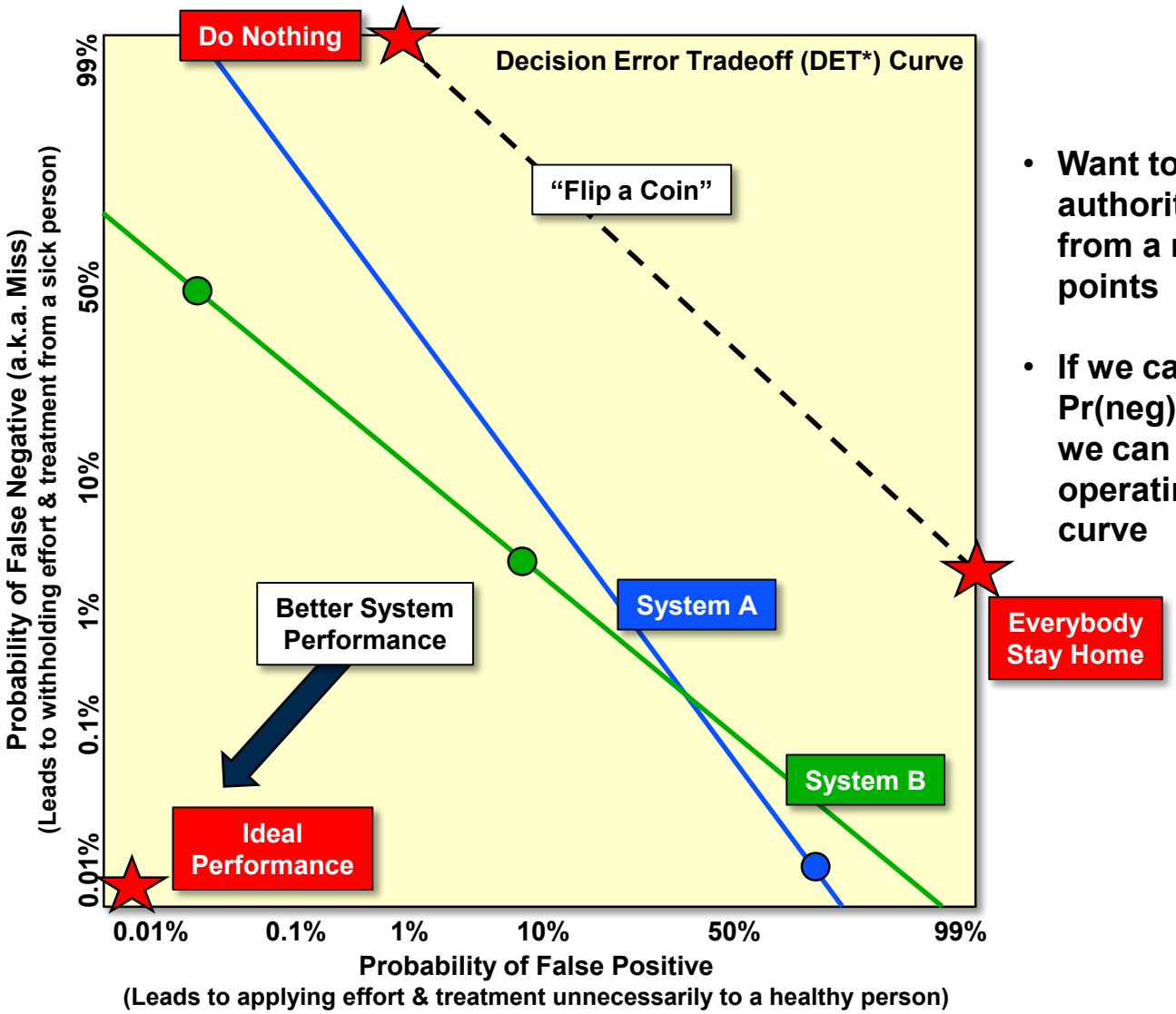
- For public health professionals
- Helps contact tracers manage cases
- Provides summary epidemiological metrics

*Ireland "COVID Tracker" App built by NearForm

"Too Close for Too Long" (TC4TL)



Assessing TC4TL Systems



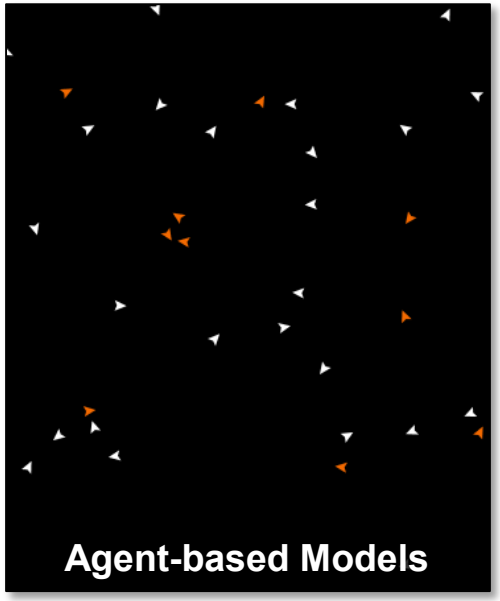
- Want to give public health authorities freedom to pick from a range of operating points
- If we can estimate Pr(pos), Pr(neg), Cost(FN), Cost(FP), we can find the lowest-cost operating point on the DET* curve

*A. Martin, A., G. Doddington, T. Kamm, M. Ordowski, and M. Przybocki. "The DET Curve in Assessment of Detection Task Performance", Proc. Eurospeech '97, Rhodes, Greece, September 1997, Vol. 4, pp. 1895-1898.

Experiment-based AEN Evaluation

Simulation → **Lab-based Evaluation** → **In situ Pilots**

Test many hypothetical scenarios



- Explore A|G parameter space
- Estimate system impacts
- Explore PH integration modes

Highly controlled experiments

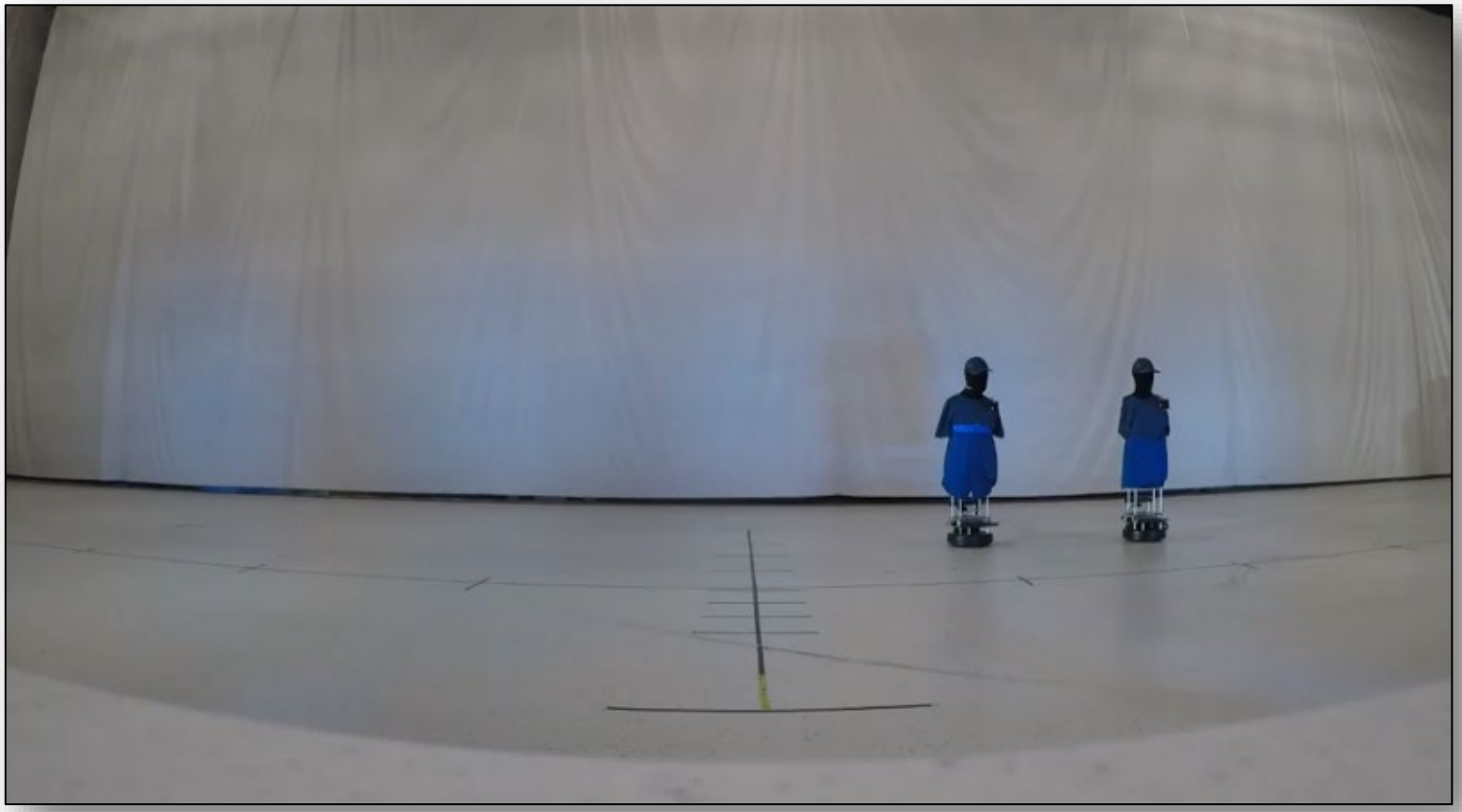
- Test A|G proximity alerts
- Examine app data flows
- Baseline P(miss) vs. P(fa)

Real users, real environments

- Assess app usability
- Estimate real P(miss) vs. P(fa)
- Test end-to-end PH workflow

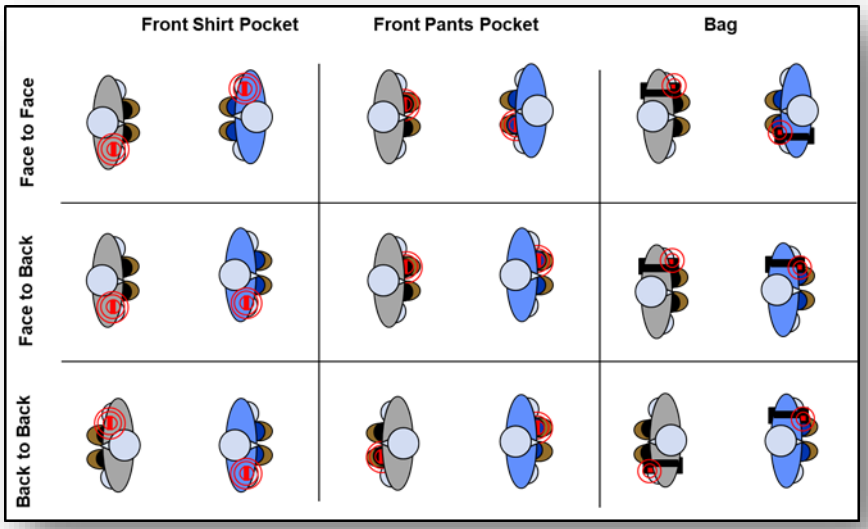
PH = public health

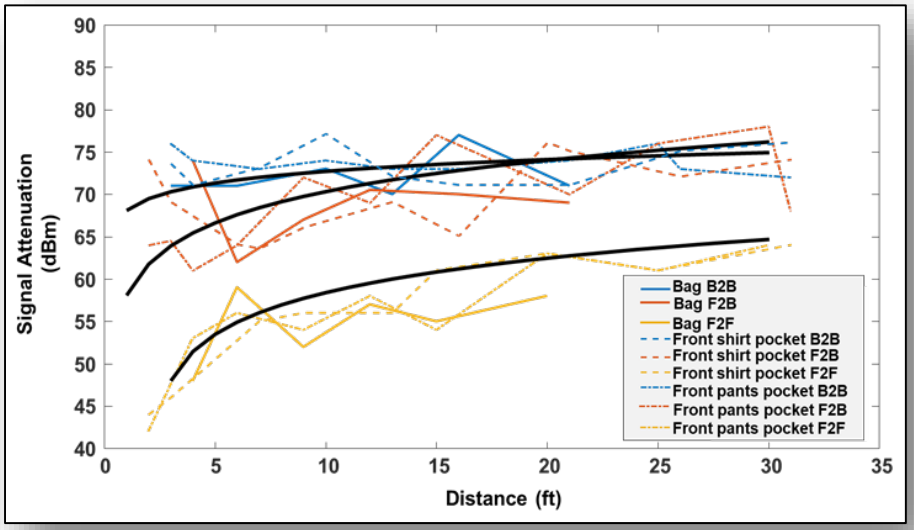
The Robot Dance (MITLL Test Range)



- **Electro-magnetic phantoms support Bluetooth proximity measurements**

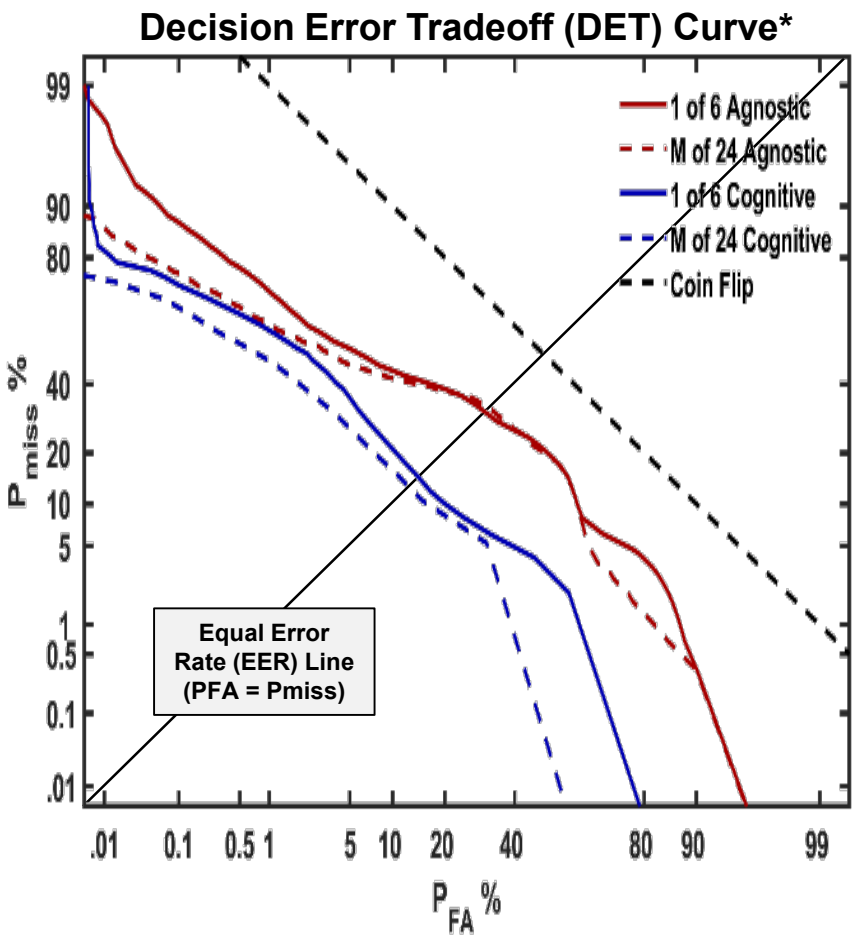
Bluetooth Data Collection





- **Data collected using human-like robots with smartphones on at a test range at MIT Lincoln Laboratory**
- **Phone conditions can lead to >20dB (>100x) variation in RSSI at fixed distances**

Preliminary TC4TL Performance**



- 1 of 6, Agnostic: 30 min duration, phone wakes up 6 times, one attenuation per wake up period, no info re phone carriage
- M of 24, Agnostic: 30 min duration, phone wakes up 6 times, 4 samples per wake up period, no info re phone carriage
- 1 of 6, Cognitive: Same as 1 of 6 above except threshold specific to perfect phone carriage information
- M of 24, Cognitive: Same as M of 24 above except threshold specific to perfect phone carriage information
- Data: "Range-Angle" data set. Collected at distances of 3 to 15 feet at every 45-degree angle for a variety of conditions (e.g. phone in pocket, hand, purse, bag, etc.)

Better signal processing with additional metadata sent with chirp (no additional power, storage) can reduce EER from ~40% to ~15% EER

*A. Martin, A., G. Doddington, T. Kamm, M. Ordowski, and M. Przybocki. "The DET Curve in Assessment of Detection Task Performance", Proc. Eurospeech '97, Rhodes, Greece, September 1997, Vol. 4, pp. 1895-1898.
** G. F. Hatke et al. "Using BLE Signal Strength Estimation to Facilitate Contact Tracing for COVID-19" https://arxiv.org/abs/2006.15711

NIST TC4TL Challenge September 2020

National Institute of Standards and Technology
U.S. Department of Commerce

- **Explored promising new ideas in TC4TL detection using BLE signals**
- **Supported the development of advanced technologies incorporating these ideas**
- **Measured and calibrated the performance of the state-of-the-art TC4TL detectors**

https://www.nist.gov/itl/iad/mig/nist-tc4tl-challenge
https://tc4tlchallenge.nist.gov/

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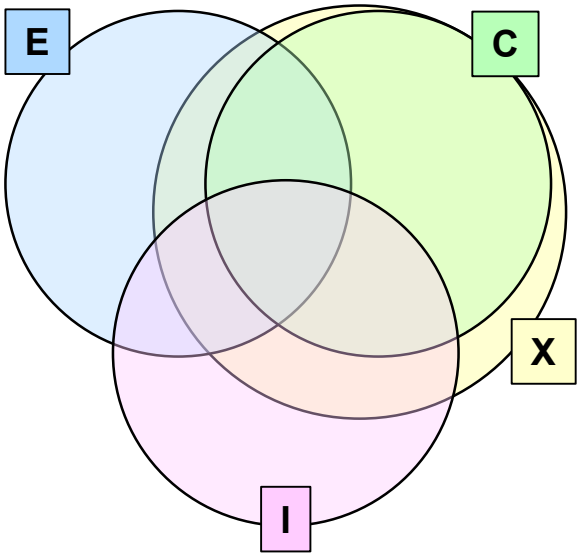
Example Assessment Approach: The 4-Circle Venn Diagram

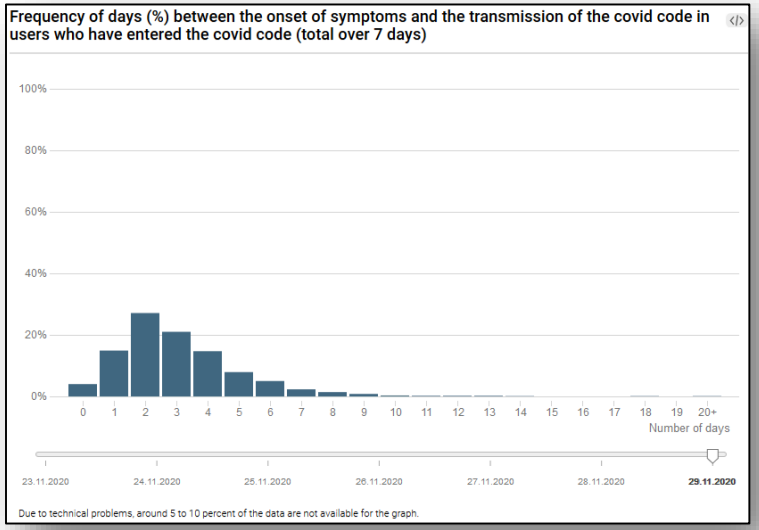


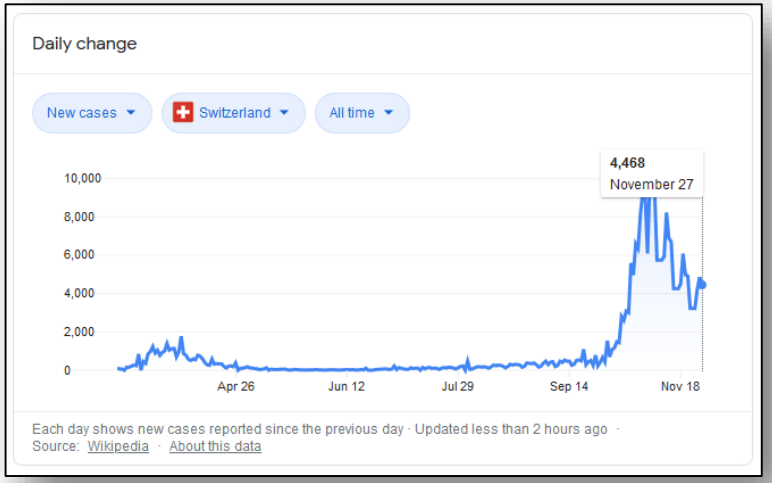
- I: Individuals who are infected with the virus
- E: Individuals who are exposed as defined by a PHA
- C: Contacts identified via manual contact tracing (MCT)
- A: Contacts identified via automated exposure notification
- X: Union of MCT and AEN, i.e. C U A

- What would be perfect performance of traditional approaches?
  - I ∩ E = I U E, i.e. the public health def'n of an exposure yields all and only infected individuals, I = E
  - I ∩ C = I U C, i.e. manual contact tracing finds all and only infected individuals, I = C
- What are some goals for AEN effectiveness if traditional MCT is not perfect?
  - Size (I ∩ X) > Size (I ∩ C), i.e. AEN helps alert extra infected individuals vs. what MCT could do alone
  - Size (X) – Size (I ∩ X) – (Size (C) - Size (I ∩ C)) ≈ 0, i.e. AEN alerts as few non-infected individuals as possible
  - The combination of these two, i.e. I ∩ X ≈ I U X, i.e. I = X
  - Latency(I ∩ X) << Latency (I ∩ C), i.e. AEN speeds identification (and quarantine/isolation) of infected individuals
- What else is required?
  - Rapid, accurate testing
  - Rapid, effective quarantine and isolation
  - Integration of AEN, MCT, testing, quarantine, isolation
  - Widespread adoption of AEN
- Hundreds of papers are modeling MCT (and AEN) effectiveness
  - Real data are just now becoming available

A|G ENS/ENX Around the World

- >30 nations and US states using A|G ENS/ENX operationally
- Example: Switzerland (week ending 29 Nov 2020)
  - Data updated publically, daily
  - MCT performed ~26 cantons
  - AEN managed at national level
  - ~3K-5K new cases per day in past week
  - 1.8M active AEN apps (total population = 8.5M people)
  - ~300-600 COVID codes entered by users per day
    - >3500 COVID codes entered in 7-days ending 29 November
  - ~200-350 calls per day to SwissCovid infoline re AENs rec'd
  - Delays between symptom onset and transmission of COVID code grow and shrink
  - Many contacts who have tested positive were first alerted by an AEN, but hard to measure precisely





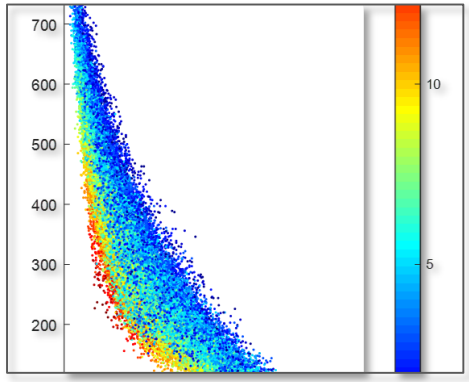
ENS: Exposure notification service (PHA builds app)
ENX: ENS "Express" (PHA not required to build app)

https://down.dsg.cs.tcd.ie/tact/tek-counts/ downloaded 1 December 2020
https://www.experimental.bfs.admin.ch/expstat/en/home/innovative-methods/swisscovid-app-monitoring.html downloaded 1 December 2020
https://www.google.com/search?client=firefox-b-1-e&q=switzerland+covid+cases+today downloaded 1 December 2020

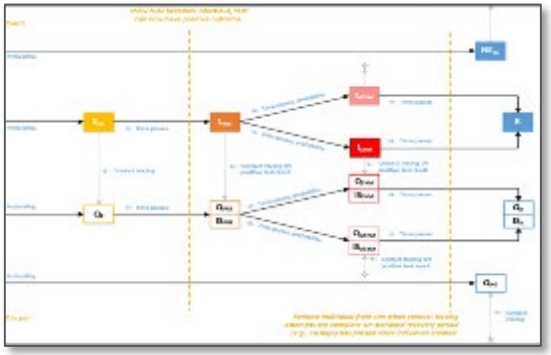
Massachusetts Institute of Technology

Current Focus Areas

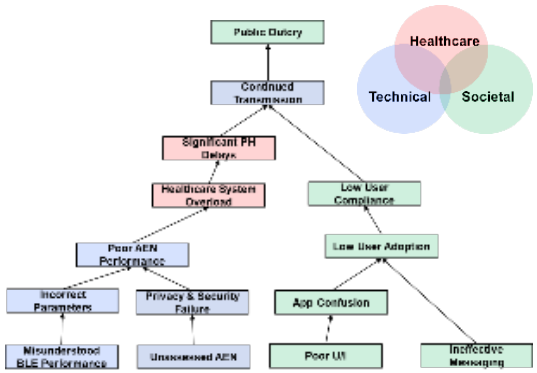
CDC Centers for Disease Control and Prevention



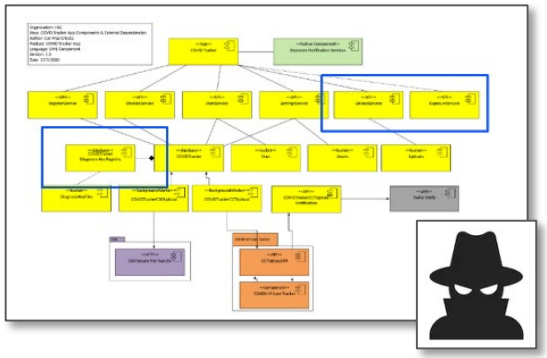
Optimization & Tuning



Workflow Analysis M&S



Risk Assessment



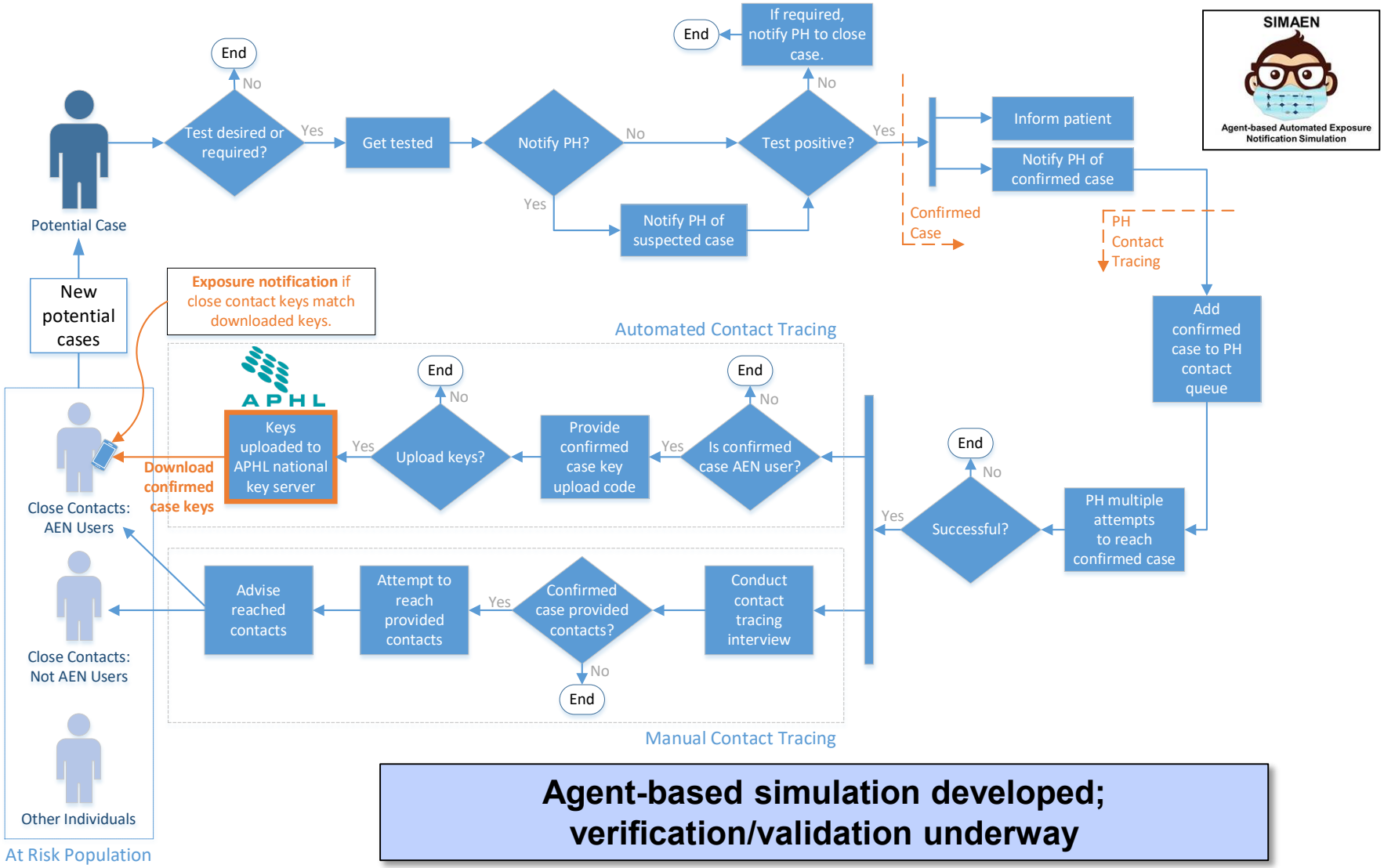
Code and Design Analysis

Bluetooth Proximity Testing

User Adoption / Messaging

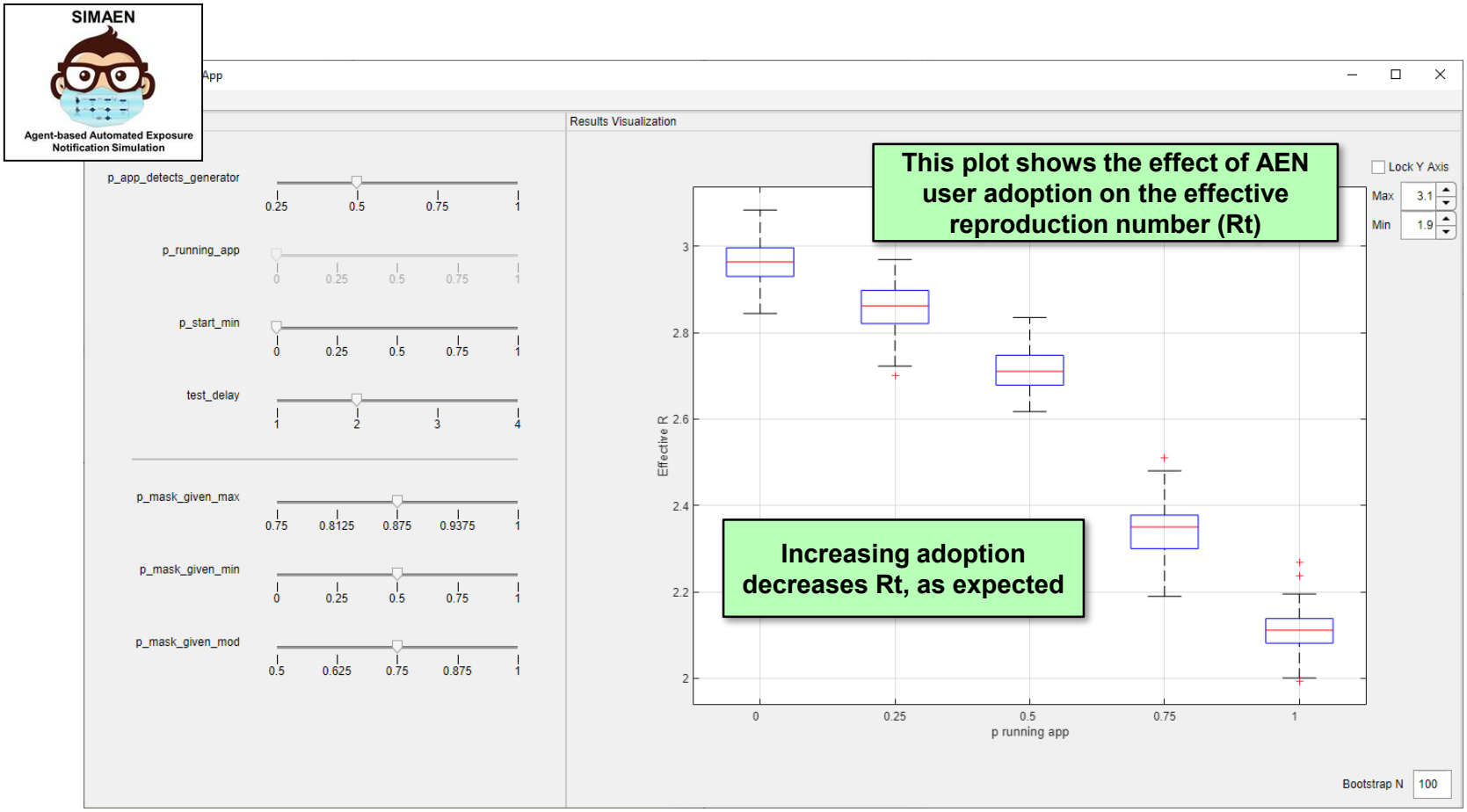
M & S = modeling and simulation

Public Health Simulation
SIMAEN



Agent-based simulation developed; verification/validation underway

Example SIMAEN Results



SIMAEN (Agent-based AEN simulation) helps predict impact of AEN and public health performance

PACT Highlights

- Development and release of PACT protocol specification
- Demonstration of iOS/Android proof of concept
- Bluetooth, ultrasound, ultra-wideband data collection, analysis
- Modeling, simulation, analysis
- Tech support of NIST evaluation
- Tech support to CDC, US states

- Trusted technical advisor to US CDC
- Trusted technical advisor to Massachusetts and Pennsylvania

Exposure notification for iOS and Android

- A|G ENS/ENX is consistent with the PACT protocol
- PACT has multiple technical interchange meetings with A|G teams each week

Summary

- Many non-pharmaceutical interventions to COVID spread can and do have impact, e.g.
  - Mask wearing, social distancing, testing, quarantine, isolation, contact tracing, etc.
- Automated exposure notification (AEN) can supplement manual contact tracing efforts
  - Automatic detection of high-risk exposure events
  - Hypotheses: AEN can decrease delay, decrease workload, broaden exposure detection
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- Significant opportunities for future technical innovation exist

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Acknowledgments*

- PACT Leadership
  - Prof Ron Rivest
  - Danny Weitzner
  - Dr Louise Ivers, MD MPH
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- Our colleagues at Apple and Google
- Our colleagues in Ireland, UK, Switzerland, Singapore, Finland
- Our colleagues at NIST
- Our colleagues in the public health communities of Arizona, Pennsylvania and Massachusetts

Protocol Definition Working Group

CSAIL, Lincoln Laboratory, MIT Media Lab, Boston University, Weizmann Institute of Science, COVID SafePaths, Brown

Data Collection Coalition

ARL, NREC, Carnegie Mellon University, Draper, Lawrence Livermore National Laboratory, mass robotics, Lincoln Laboratory, MITRE, Northeastern, Qualcomm, Raytheon BBN Technologies, Sandia National Laboratories, Government Digital Services, Singapore, STR, WPI, Waypoint Robotics

* Surely just a partial list