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A Brief Tutorial on Private Automated Exposure Notification for COVID-19

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CSAIL

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Massachusetts Institute of Technology

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PACT is a collaboration led by the MIT Computer Science and Artificial Intelligence Laboratory (CSAIL), MIT Internet Policy Research Initiative, Massachusetts General Hospital Center for Global Health and MIT Lincoln Laboratory. It includes close collaborators from Boston University, Brown University, Carnegie Mellon University, the MIT Media Lab, the Weizmann Institute and a number of public and private research and development centers. The PACT team is a partnership among cryptographers, physicians, privacy experts, scientists and engineers. PACT's mission is to enhance contact tracing in pandemic response by designing exposure detection functions in personal digital communication devices that have maximal public health utility while preserving privacy.

PACT Sponsors

DARPA
CDC Centers for Disease Control and Prevention
IBM Research

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**
- **There is both mod/sim and operational data that show that the system works**
- **Significant opportunities for future technical innovation exist**

Acknowledgment Upfront

- Beginning early in the pandemic, many international teams of:
  - Cryptographers
  - Engineers and computer scientists
  - Physicians and public health professionals
  - System analysts, privacy experts and other specialists

  proposed approaches to private, automated detection of potential exposure to COVID-19-infected individuals using Bluetooth signaling on smartphones that could supplement conventional, manual contact tracing

- Many of these teams worked in parallel, in collaboration with each other, and in collaboration with Apple|Google

- This talk provides an overview of some of that work

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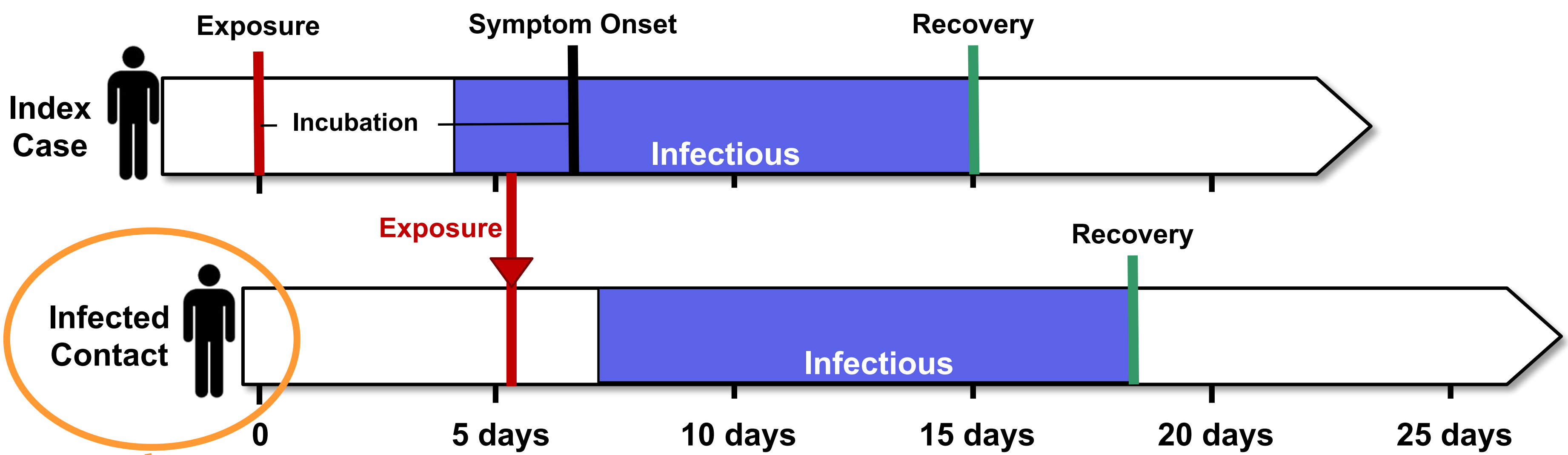
COVID-19 Infection Progression



Goal: Find this person quickly, i.e. *before* they might infect others

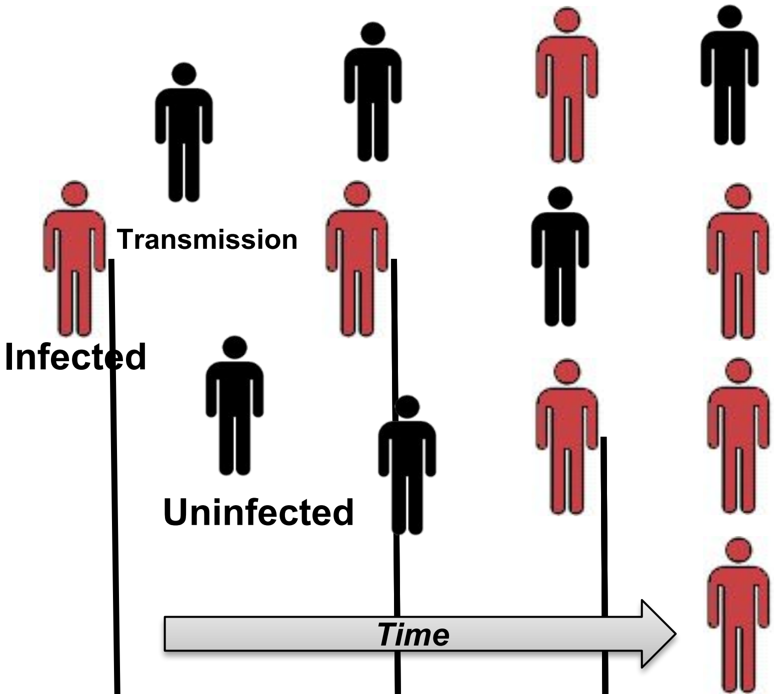
- **Identify "contacts" that could have infected this person (reverse)**
- **Identify "contacts" that this person could infect (forward)**

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

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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

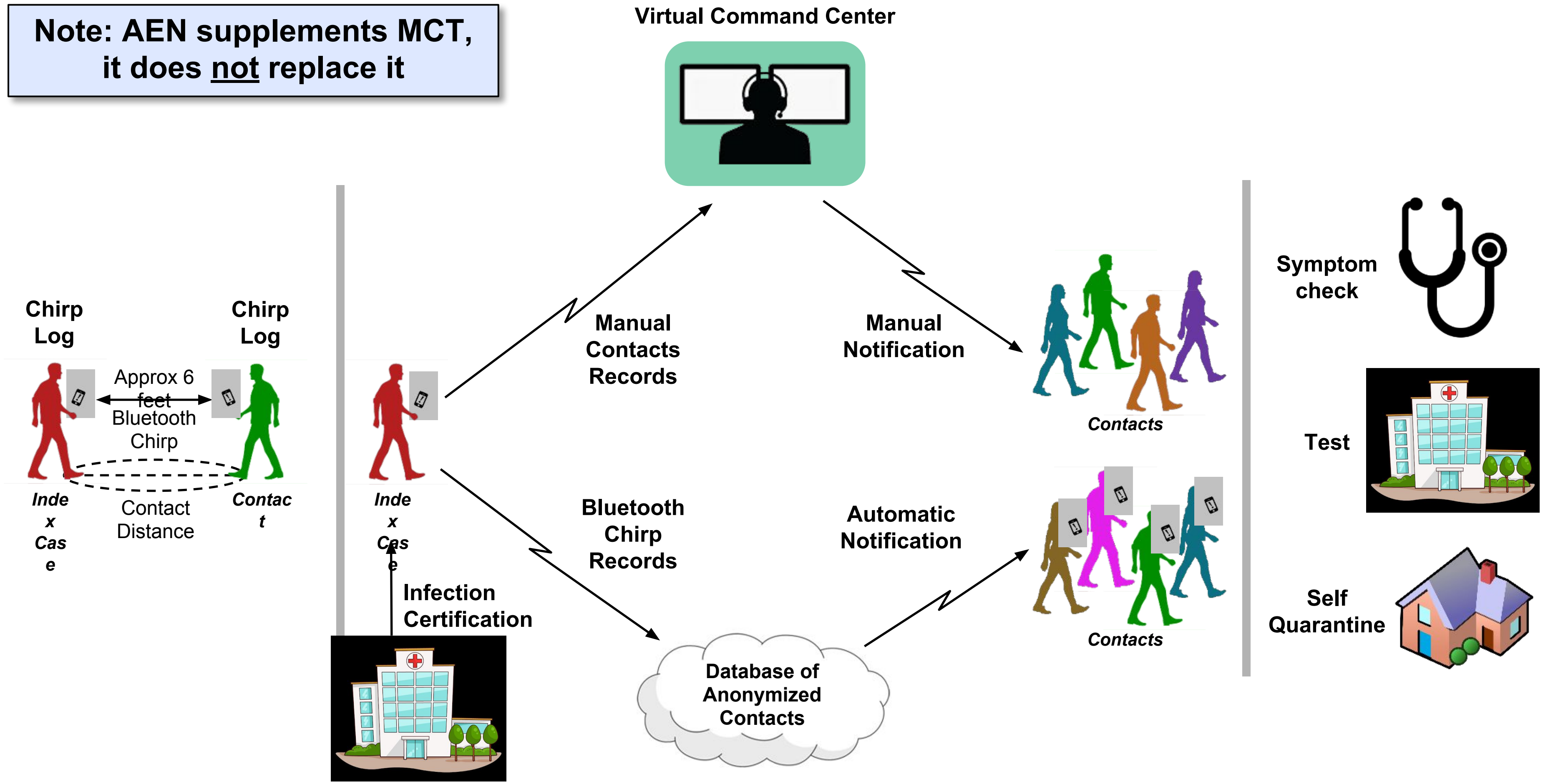
How AEN Works*

(video available on YouTube… see below)

***Video courtesy of Robin Marsden (RGM Productions),** https://youtu.be/qQYM25bpiLo

General Approach

Note: AEN supplements MCT, it does not replace it



1 **Contact Detection**

2 **COVID-19 Test Confirmed Positive**

3 **Exposure Query & Notification**

4 **Contact Actions**

The AEN Value Proposition* (Hypothesized in Spring 2020)

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

5. Public health can set an operating point such that benefits from AEN detection of true exposures outweigh potential costs from AEN false positives

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

See also: von Wyl Viktor, et al. A research agenda for digital proximity tracing apps. https://smw.ch/article/doi/smw.2020.20324

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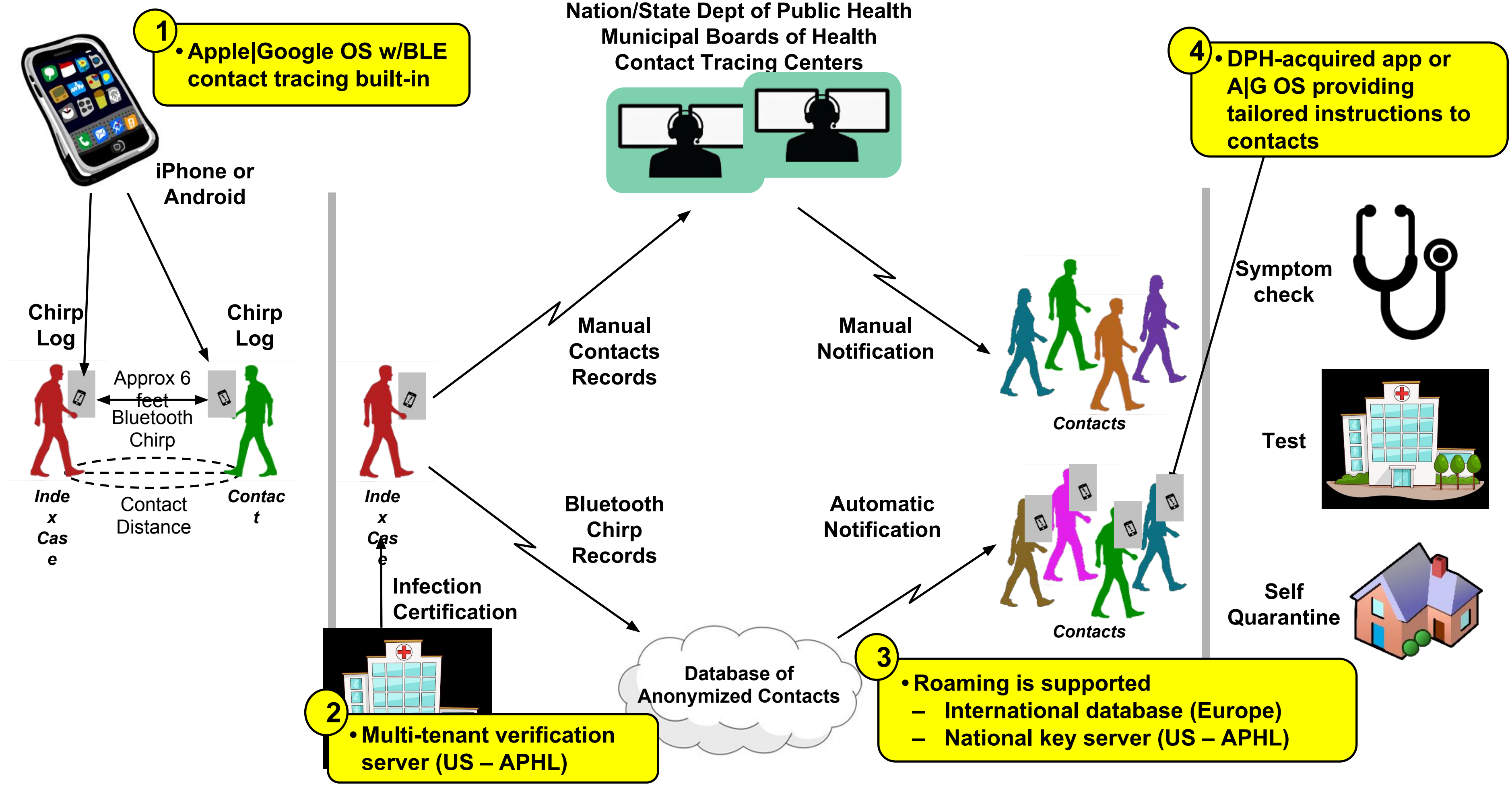
January 2021 Status: >30 Nations and U.S. States



1 Contact Detection

2 COVID-19 Test Confirmed Positive

3 Exposure Query & Notification

4 Contact Actions

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AEN Stack Layers

Layer 3A: Public Health Interface

Major Challenges

- Integration into manual contact tracing systems
- Certification of infection
- Interoperability across public health 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 AEN 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

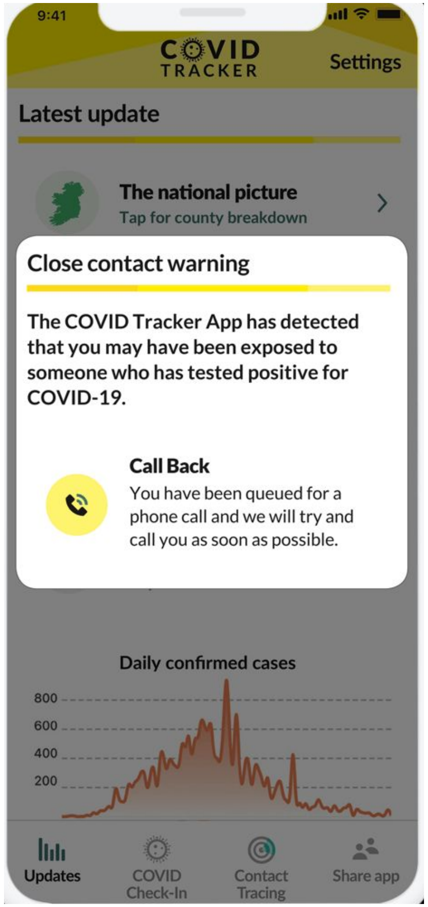
Layer 1: Proximity Measurement

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 Interface

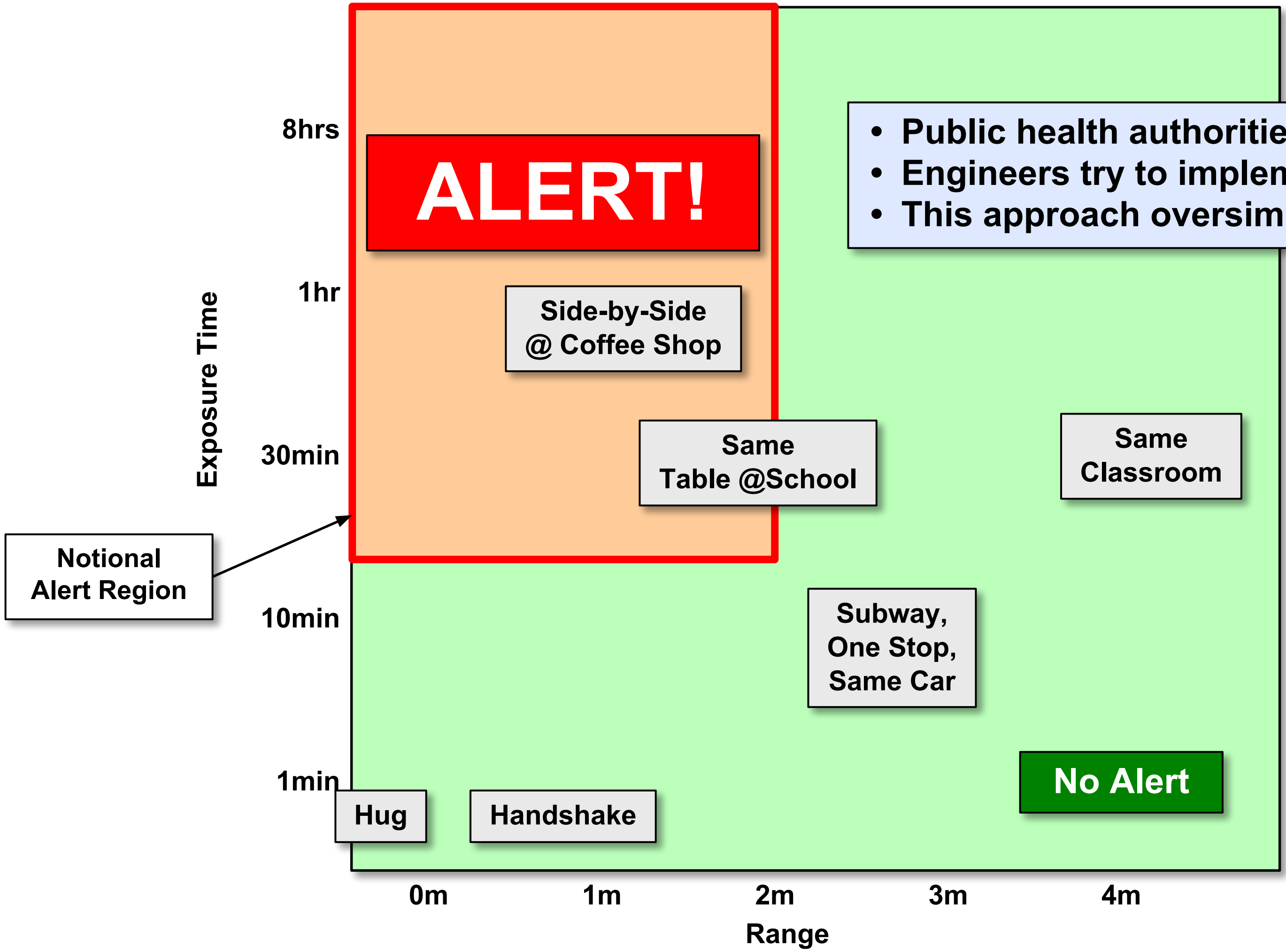
Mobile Phone App*



- For individual smartphone users
- Turns exposure notification on and off
- Alerts user of potential exposure
- May provide additional functionality, e.g.
  - PHA updates for users
  - Daily user health inputs for PHA
- Simpler "App-less" version also available (EN Express for iOS)

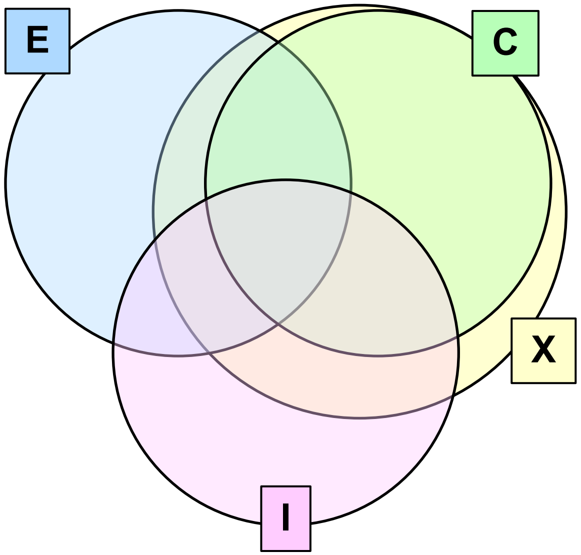
*Ireland "COVID Tracker" App built by NearForm

"Too Close for Too Long" (TC4TL)



- Public health authorities define alert region
- Engineers try to implement it accurately
- This approach oversimplifies the problem

Example Assessment Approach: The 4-Circle Venn Diagram



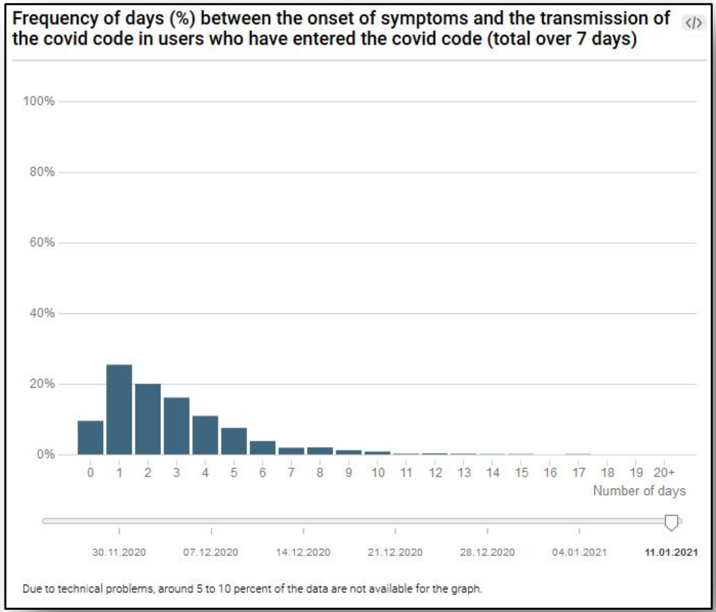
- I: Individuals who are infected with the virus
- E: Individuals who are exposed as defined by a PHA
- C: Contacts identified via manual contact tracing (MCT)
- A: Contacts identified via automated exposure notification
- X: Union of MCT and AEN, i.e. C U A

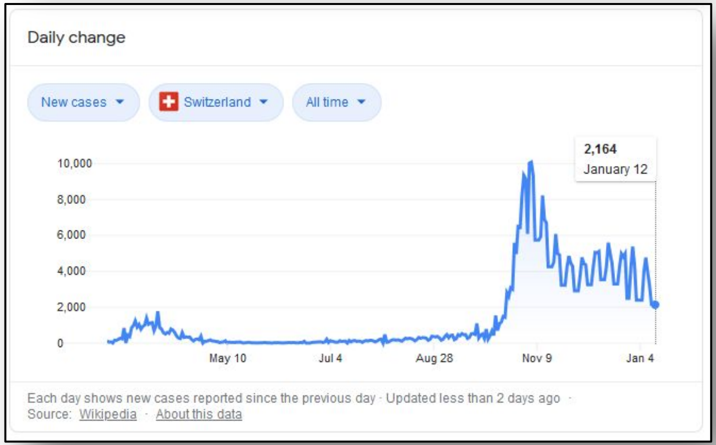
Note: These Venn diagrams don't capture speed of either MCT or AEN

- Many classes of false alarms
  - Class 1: Contact was actually further than 6ft from index, or was close but for less than 15min
  - Class 2: Contact was too close for too long, but just didn't get infected
  - Class 3: Contact was too close for too long, but was unexposable (e.g. in an adjacent apartment)

A|G ENS/ENX Around the World

- **>30 nations and US states using A|G ENS/ENX operationally**
- **Example: Switzerland (week ending 11 Jan 2021)**
  - **Data updated publically, daily**
  - **MCT performed ~26 cantons**
  - **AEN managed at national level**
  - **~2K-5K new cases per day in past week**
  - **1.8M active AEN apps (total population = 8.5M people)**
  - **~200-500 COVID codes entered by users per day**
    - **~2500 COVID codes entered in seven days ending 11 January**
  - **~20-40 calls per day to SwissCovid infoline re AENs rec'd (had been 300-400 per day in December)**
  - **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)

See also: Salathé Marcel, et al, "Early evidence of effectiveness of digital contact tracing for SARS-CoV-2 in Switzerland," *Swiss Medical Weekly*, 2020;150:w20457 December 2020.

https://down.dsg.cs.tcd.ie/tact/tek-counts/ downloaded 13 January 2021
https://www.experimental.bfs.admin.ch/expstat/en/home/innovative-methods/swisscovid-app-monitoring.html downloaded 13 January 2021
https://www.google.com/search?client=firefox-b-1-e&q=switzerland+covid+cases+today downloaded 13 January 2021

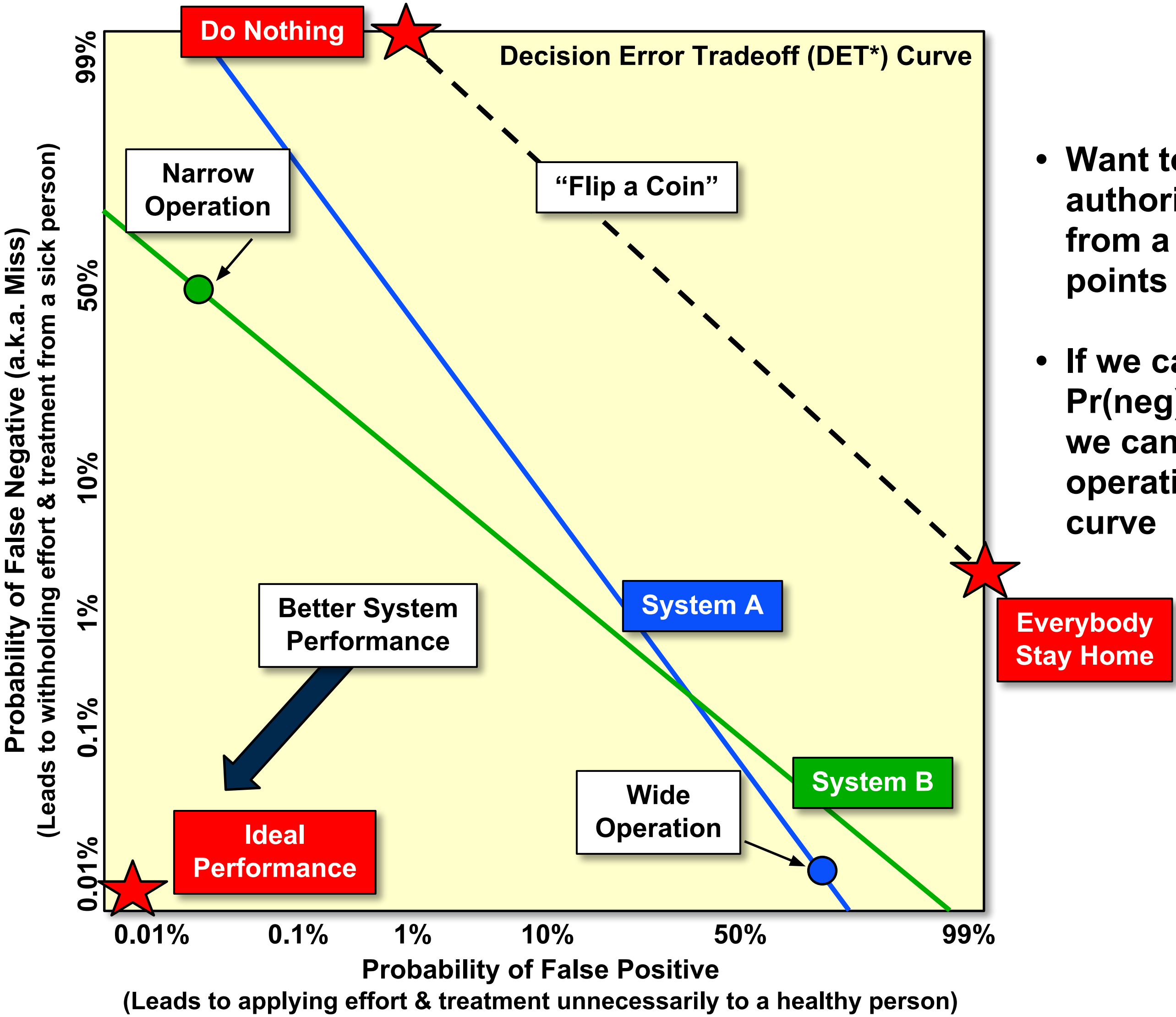
Recent Results from Canton of Zurich, Switzerland*

- **AEN is faster than manual contact tracing**
  - AEN-notified contacts with exposure risk outside own household entered quarantine <u>one day earlier</u> (on average) vs manual contact tracing (MCT)

- **AEN finds infected people that MCT would miss**
  - Analysis of Sept 2020 results in Zurich
  - 324 of 1923 (16.8%) PCR positive cases uploaded CovidCodes
  - 722 persons called the help line after they received an AEN
  - 170 of the 722 were given a quarantine recommendation
  - 30 of the contacts receiving AENs tested PCR positive

* Viktor von Wyl, "The SwissCovid GAEN app after six months: It's not just about technology!" NIST workshop (26 January 2021)

Assessing TC4TL Systems (<u>Notional</u> DET Curves)



- 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.

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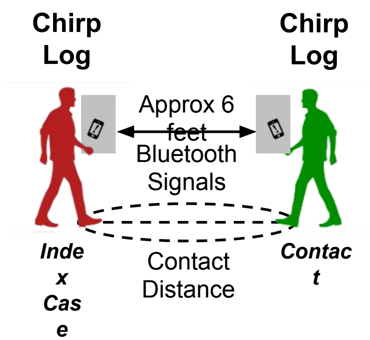
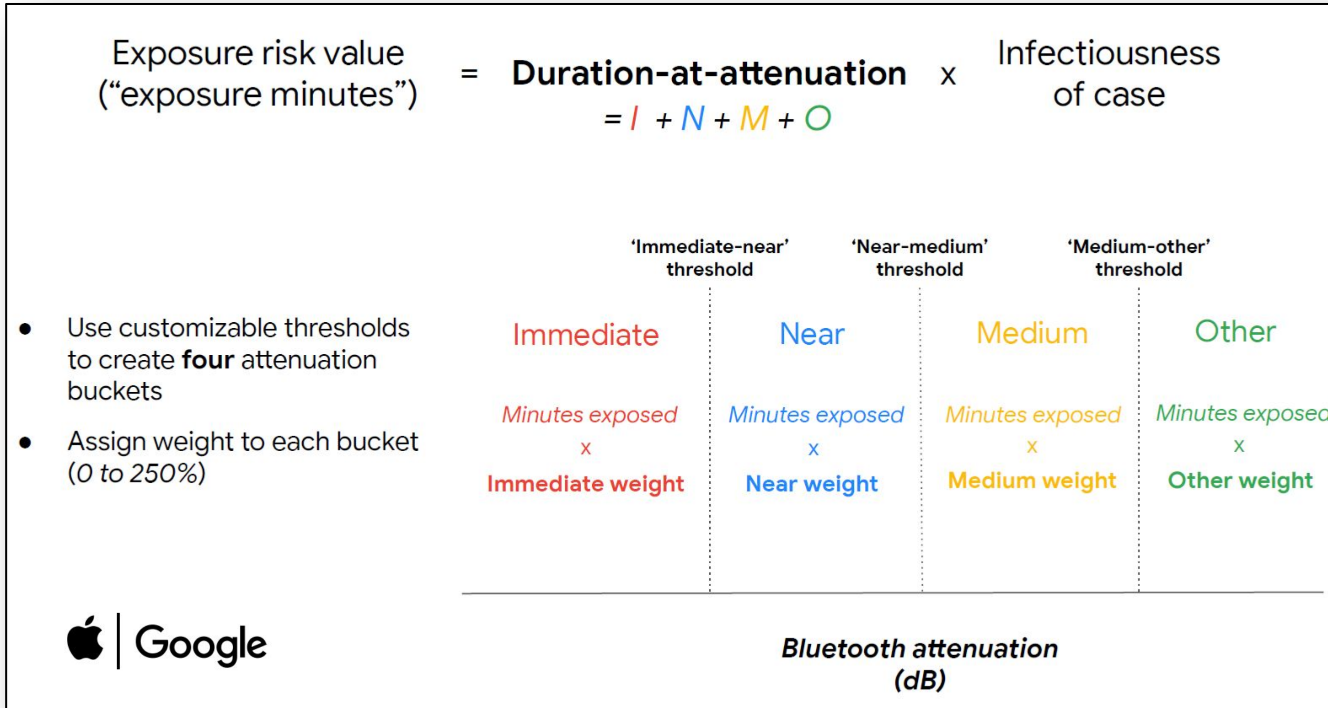
The Basics of Estimating Risk Exposure





- **Contact receives Bluetooth signals from the index**
  - **Random, binary data (no personal information)**
  - **Distance is estimated by measuring attenuation in the Bluetooth signal between when it was transmitted and when it was received; duration is measured too**
- **Overall risk is a weighted sum of exposure minutes, which is then multiplied by case infectiousness (which itself is a function of days since symptom onset)**

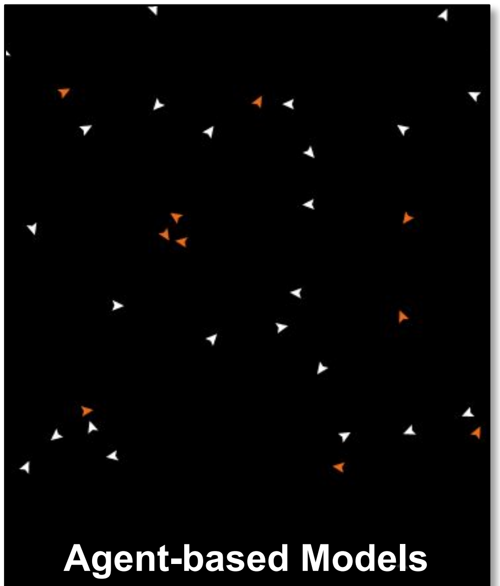
Standard Parameters Sets

- For simplicity, most states have adopted one of two sets of standard AEN parameters (e.g. thresholds, weights, etc.)
  - "Narrower Net" – Prioritizes lower PFA at the expense of higher PMISS
  - "Wider Net" – Prioritizes lower PMISS at the expense of higher PFA
- The standard parameter sets were defined at an international workshop when a modest amount of real data was available*
- Much more data collected since then permits quantification of what the standard parameter sets really do
  - Permits more informed public health authority decisions
  - Might possibly indicate that the standard parameter sets should be adjusted

*Linux Foundation Public Health: Risk Score Symposium Invitational ("RSSI") Workshop, Nov 2020
https://github.com/lfph/gaen-risk-scoring/blob/main/risk-scoring.md

Experiment-based AEN Evaluation

Simulation	Lab-based Evaluation	In situ Pilots
Test many hypothetical scenarios	Highly controlled experiments	Real users, real environments


Agent-based Models


MIT LL Test Range


In-the-wild

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

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

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

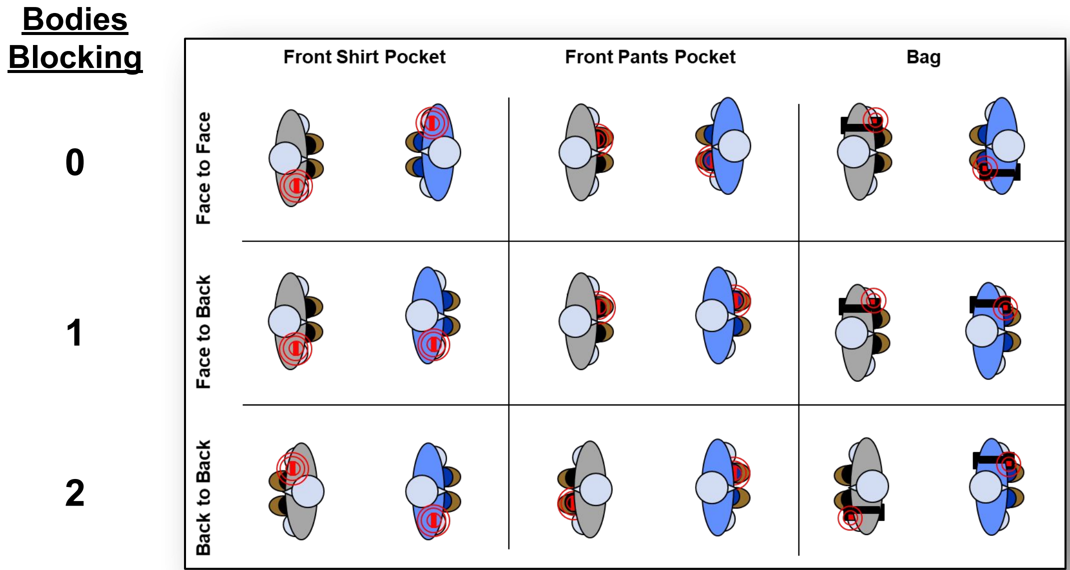
PH = public health

The Robot Dance (MIT LL Test Range)

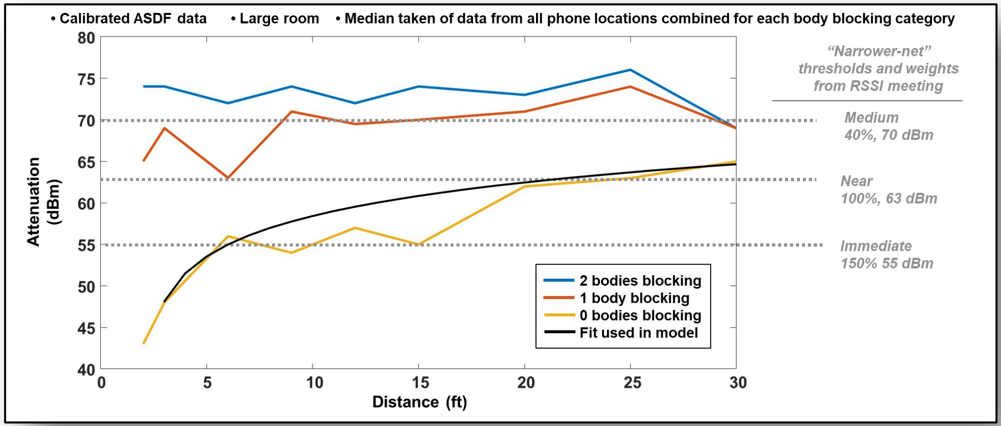
Video of robots available on YouTube at:
https://www.youtube.com/watch?v=1F6TEvpy5g0&t=15s

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

Bluetooth Phenomenology

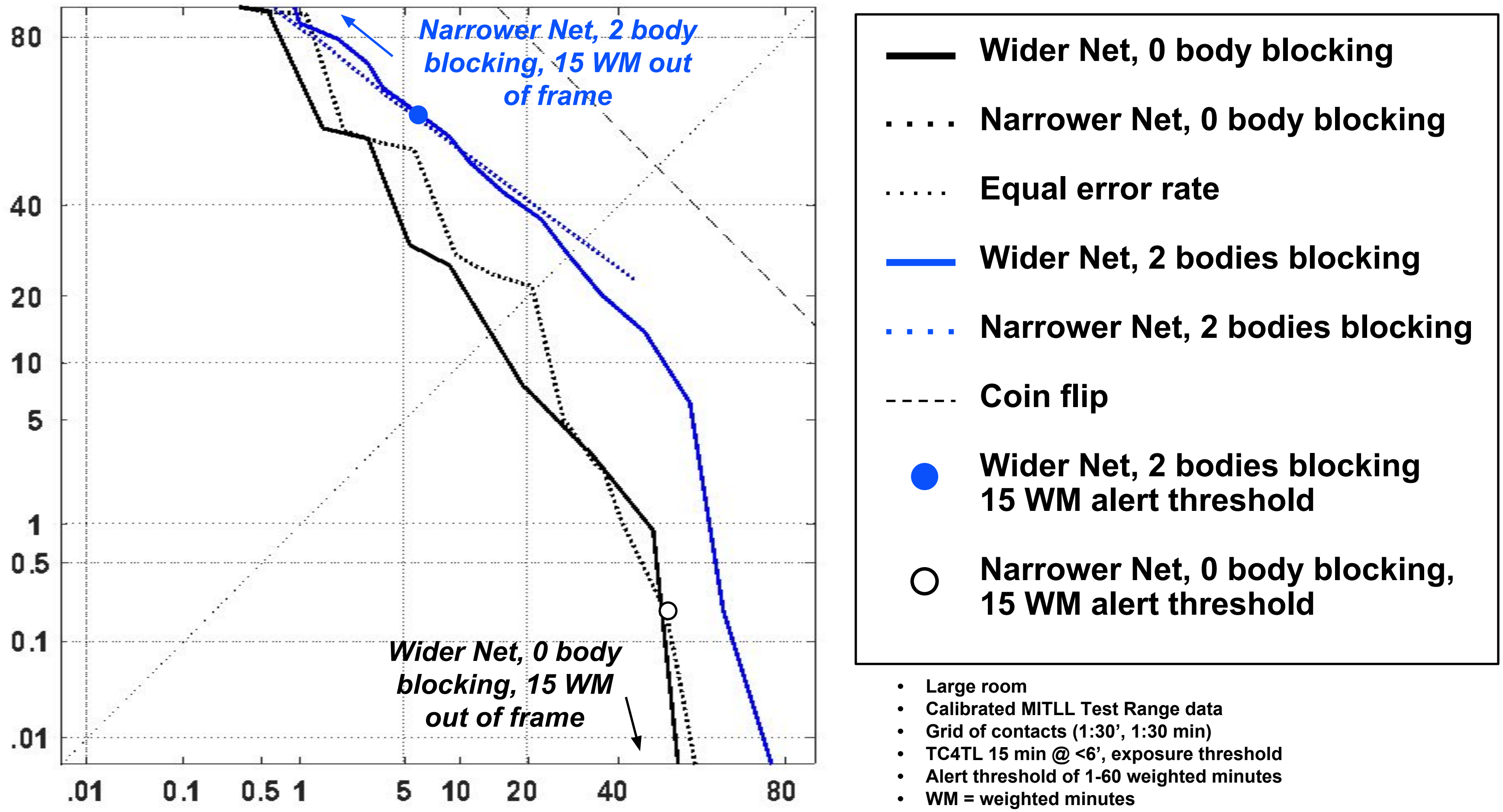


- **Data collected using human-like robots with smartphones on at a test range at MIT Lincoln Laboratory**
- **Variety of distances, poses, orientations, body blocking, bags, pockets, etc.**
- **Phone conditions can lead to >20dB (>100x) variation in RSSI* at fixed distances**



*** RSSI: Received signal strength indicator**

Narrower vs Wider Net Settings



- Large room
- Calibrated MITLL Test Range data
- Grid of contacts (1:30’, 1:30 min)
- TC4TL 15 min @ <6’, exposure threshold
- Alert threshold of 1-60 weighted minutes
- WM = weighted minutes

Narrower and wider net settings yield very similar options for operating points

The AEN Value Proposition* (Revisited)

1. Automatic exposure notification (AEN) can lead to faster exposure notification vs traditional manual contact tracing (MCT) alone — ✓ Yes – data confirm

2. AEN can reach persons who are not personally known to an index case — ✓ Yes – the A|G protocol provides this functionality by design and data confirm

3. AEN can still work when MCT reaches resource limits or breaks down — ✓ Yes – MCT has broken down in some jurisdictions**, and yet AEN still functions

4. AEN alerts contacts privately and automatically about potential exposure, enabling them to choose how they wish to engage with public health authorities — ✓ Yes – the A|G protocol preserves privacy by design

5. Public health can set an operating point such that benefits from AEN detection of true exposures outweigh potential costs from AEN false positives — ✓ Yes – 20+M users, no significant issues; Low PFA ops points can be set as desired

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

*See also: von Wyl Viktor, et al. A research agenda for digital proximity tracing apps. https://smw.ch/article/doi/smw.2020.20324

** https://www.swissinfo.ch/eng/top-epidemiologist-urges-greater-uptake-of-contact-tracing-app/46108064

** https://www.grandforksherald.com/newsmd/coronavirus/6726337-Overwhelmed-by-cases-North-Dakota-tells-residents-with-COVID-19-to-do-their-own-contact-tracing

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Challenges (An Incomplete List!)

- Adoption
  - By public health authorities
  - By the public within these jurisdictions
- Speed of distribution of verification codes
- Willingness to use the verification codes and actually upload keys
- Willingness to follow public health instruction upon receiving an AEN
- Assessments
  - Measures of performance
  - Measures of effectiveness
- And the "big one": The trade-off between privacy and public health effectiveness… did we all get it right?

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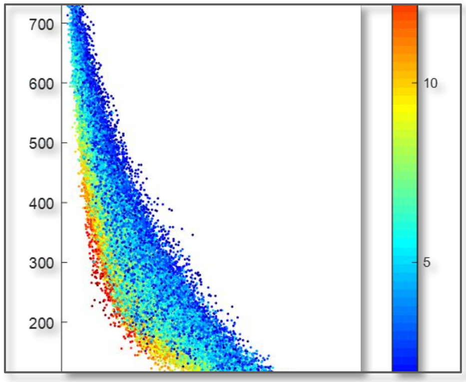
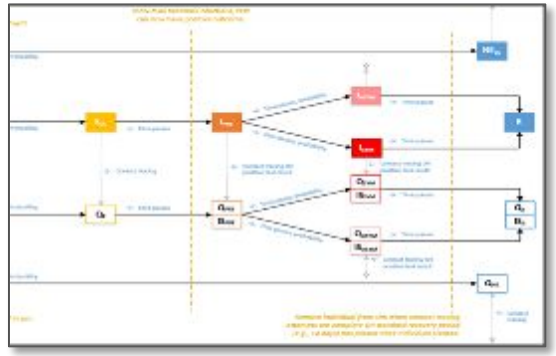
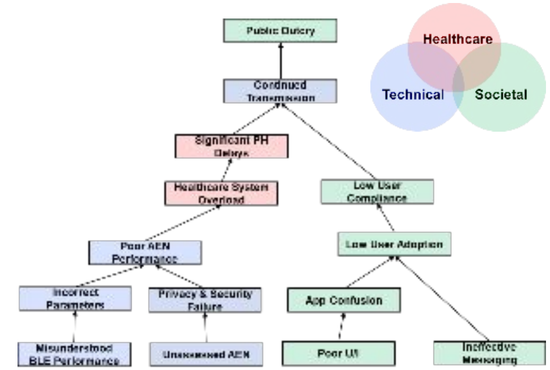
Example R&D Focus Areas



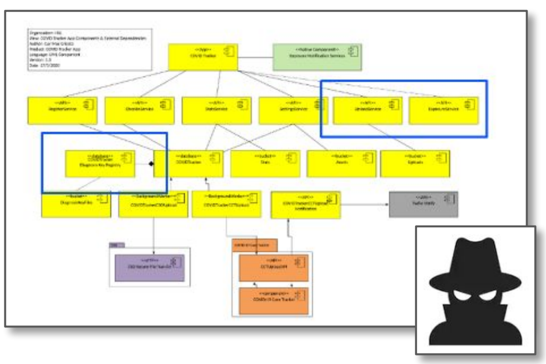
Optimization & Tuning



Workflow Analysis M&S



Risk Assessment



Code and Design Analysis

Bluetooth, Ultrasound, UWB

User Adoption / Messaging

M & S = modeling and simulation
UWB = Ultra-Wideband

NIST TC4TL Challenge
September 2020

NIST
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/

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
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- Significant opportunities for future technical innovation exist

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Acknowledgments

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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 academic and public health communities of Arizona, Pennsylvania and Massachusetts**

Protocol Definition Working Group

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

Data Collection Coalition

ARL · NREC · Carnegie Mellon University · Draper Laboratory · Lawrence Livermore National Laboratory · MassRobotics · Lincoln Laboratory, Massachusetts Institute of Technology · MITRE · Northeastern · Qualcomm · Raytheon BBN Technologies · Sandia National Laboratories · Government Digital Services, Singapore · STR Systems & Technology Research · WPI · Waypoint Robotics

*** A partial list of the PACT team members working at MIT and MGH on automatic exposure notification. Many other such teams have been working on AEN worldwide since the beginning of the pandemic.**