PACT: Private Automated Contact Tracing

Marc A. Zissman, PhD
Lincoln Laboratory, Massachusetts Institute of Technology
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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
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)
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:
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
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

1. **Contact Detection**
   - Smartphone with Apple|Google OS w/BLE contact tracing built-in
   - Chirp Log
   - Approx 6 feet
   - Bluetooth Chirp
   - Index Case
   - Contact Distance

2. **COVID-19 Test Confirmed Positive**
   - Manual Contacts Records
   - Bluetooth Chirp Records
   - Infection Certification
   - Index Case
   - Database of Anonymized Contacts

3. **Exposure Query & Notification**
   - Manual Notification
   - Automatic Query & Notification
   - Contacts

4. **Contact Actions**
   - DPH-acquired app or A|G OS providing tailored instructions to contacts
   - Database of Anonymized Contacts
   - International database (Europe)
   - National database (US)

- Symptom check
- Test
- Self Quarantine

- iPhone or Android
- Nation/State Dept of Public Health
- Municipal Boards of Health
- Tracing Centers
- Manual Notification
- Automatic Query & Notification

- Manual Contacts Records
- Bluetooth Chirp Records
- Infection Certification

- Verification code distribution
PACT Stack

Layer 1: Proximity Measurement

- 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

Layer 2: Private Cryptographic Protocol

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

Layer 3A: Public Health Interface

- 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

- 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

Major Challenges
- Integration into manual contact tracing systems
- Certification of infection
- Interoperability across public health authorities
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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)

- Public health authorities define alert region
- Engineers try to implement it accurately

Exposure Time

- 8hrs
- 1hr
- 30min
- 10min
- 1min

Range

- 0m
- 1m
- 2m
- 3m
- 4m

Notional Alert Region

Alert!

- Side-by-Side @ Coffee Shop
- Same Table @ School
- Subway, One Stop, Same Car
- Same Classroom
- No Alert

Hug
Handshake
Assessing TC4TL Systems

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

Experiment-based AEN Evaluation

Simulation
Test many hypothetical scenarios

Lab-based Evaluation
Highly controlled experiments

In situ Pilots
Real users, real environments

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

Agent-based Models

MIT LL Test Range

In-the-wild

- 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
(MITLL Test Range)

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

Decision Error Tradeoff (DET) Curve*

- 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

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• 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/iat/mig/nist-tc4tl-challenge
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Example Assessment Approach: The 4-Circle Venn Diagram

- What would be perfect performance of traditional approaches?
  - $I \cap E = I \cup E$, i.e. the public health def'n of an exposure yields all and only infected individuals, $I = E$
  - $I \cap C = I \cup C$, 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 ($I \cap X$) > Size ($I \cap C$), i.e. AEN helps alert extra infected individuals vs. what MCT could do alone
  - Size ($X$) – Size ($I \cap X$) – (Size ($C$) - Size ($I \cap C$)) $\approx$ 0, i.e. AEN alerts as few non-infected individuals as possible
  - The combination of these two, i.e. $I \cap X \approx I \cup X$, i.e. $I = X$
  - Latency($I \cap X$) $<<$ Latency ($I \cap C$), 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

- $I$: 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. $C \cup A$
>30 nations and US states using A|G ENS/ENX operationally

**Example: Switzerland (week ending 29 Nov 2020)**
- Data updated publicly, 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)
Current Focus Areas

- **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

This plot shows the effect of AEN user adoption on the effective reproduction number (Rt).

Increasing adoption decreases Rt, as expected.

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

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

Exposure notification for iOS and Android

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

• Many non-pharmaceutical interventions to COVID spread can and do have impact, e.g.
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* Surely just a partial list