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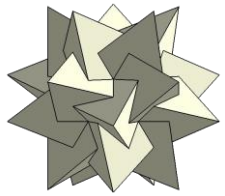

Function Secret Sharing for PSI-CA: With Applications to Private Contact Tracing

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Intro

Our Approach

- **We describe new methods of increasing accuracy and privacy in decentralized contact tracing**

- **Key insight**
  - **Accuracy: Context-aware risk score attached to tokens**
  - **Robustness: Hash location+time with token in TEE for hardening against malicious context attacks**
  - **Privacy: New cryptographic protocol that hides infected tokens and only reveals weighted risk score**

mSense App – Decentralized Contact Tracing with Extensions

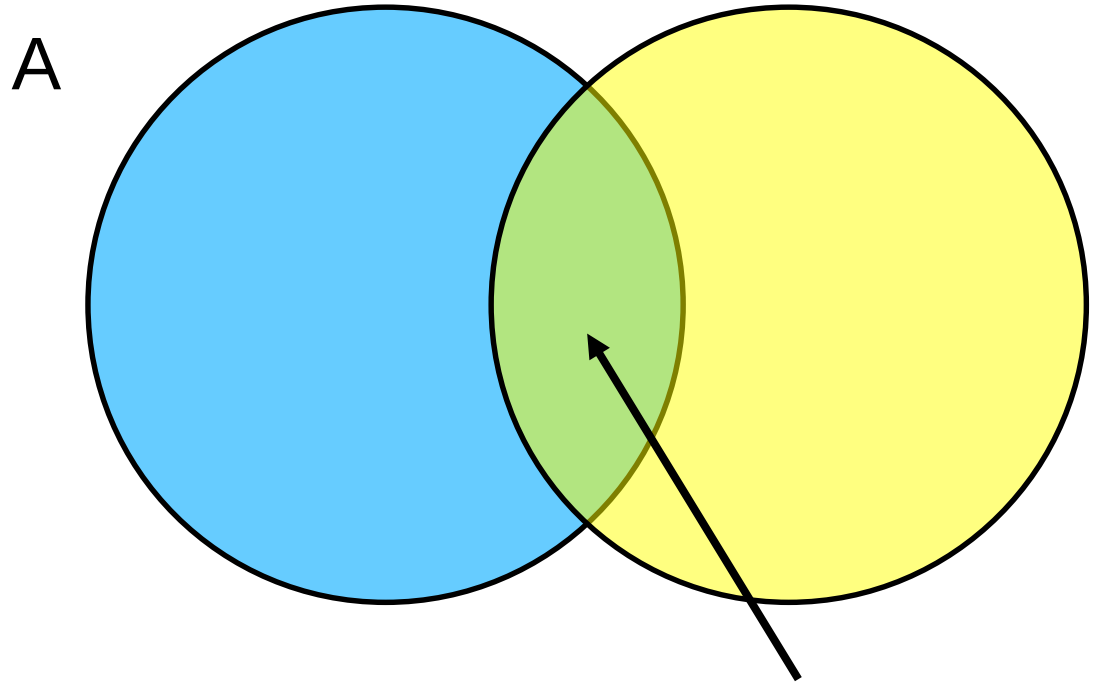
Key Innovations	High Level System Requirements
1. Tracking risk of infection; not tracking people •Does NOT expose all contacts •Does expose probable exposure	1.High Accuracy
2.Hardware proximity sensing and geolocation •Edge anonymization for data at rest and in transit •Server-side cryptographic calculations on anonymized users and locations	2.High Scalability
3.Fully encrypted database AND computation •Fast updates with parallel scaling •Data, queries, and responses are ALL encrypted; including from servers	3.Strong Privacy
	4. Robustness

		Centralized [TraceTogether,...]	Decentralized [D3-PT, Apple/Google, PACT,...]	Epione [TSS+20]	CleverParrot [CKL+20]	**This Work [mSense/ PSI-WCA]**
Servers	Trusted Server	Yes	No	No	No	No
	Number of Servers	1	1	2	1	2
Privacy	Social Graph					
	Server					
	User-to-user					
Robustness Against	Relay					
	Replay					
	Upload Omission				Feature	
	Trace Omission					

		Centralized [TraceTogether,...]	Decentralized [D3-PT, Apple/Google, PACT,...]	Epione [TSS+20]	CleverParrot [CKL+20]	**This Work [mSense/ PSI-WCA]**
Tracing Cost	User to Server Comm	O(n)	N/A	O(n log N)	N/A	O(nk)
	Server to User Comm	O(1)	O(N)	O(n)	O(N')	O(1)
	User Crypto Work	N/A	Non-crypto O(N) match	O(n) asym	O(N') asym	O(n) sym
	Server Crypto Work	Non-crypto match	N/A	O(nN) asym	N/A	O(N) sym
	Rounds	1	0.5	2	0.5	1
Result	Result Returned	Yes/No	All "infected tokens"	Count of exposures	Tokens of exposures	Weighted risk score
Underlying Crypto	Primary Crypto Tools	Central trust	PRF-style "PSI"	DH-style PSI-CA plus 2PIR	DH-style PSI	PSI-(W)CA from FSS

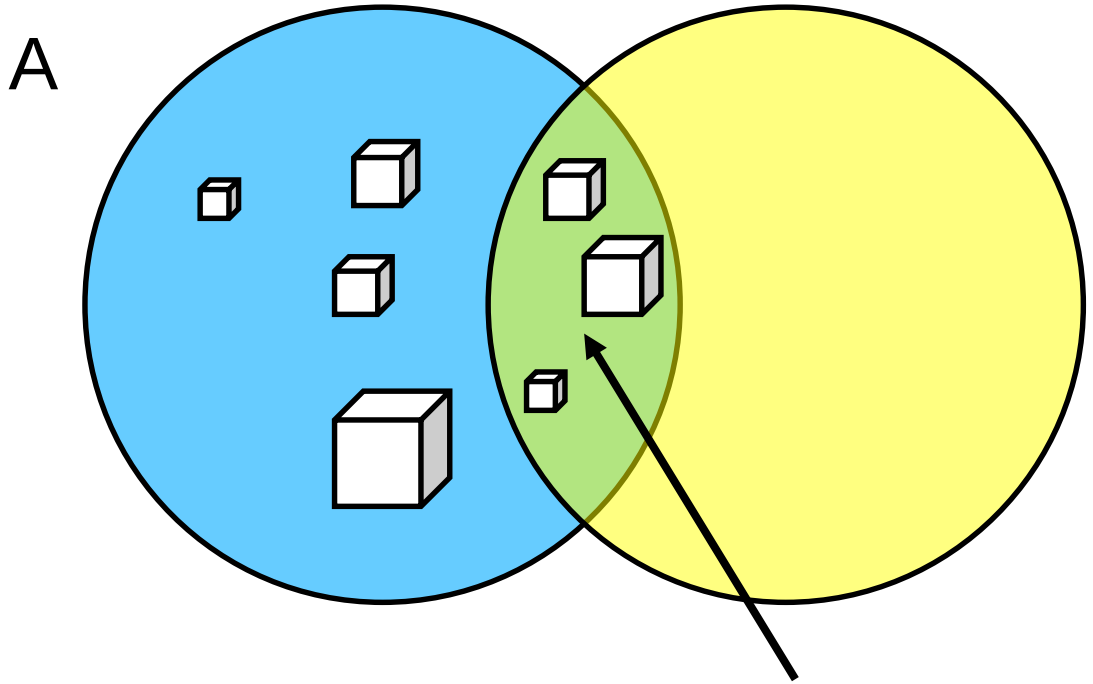
Private Set Intersection

Private Set Intersection [M86, HFH99, FNP04, KS04, FIPR05,...]



Reveal only the intersection, hide non-intersected data

Private Set Intersection – Weighted Cardinality (PSI-WCA)



Reveal only the size intersection, hides the intersection and non-intersected data

A = Set of tokens I've received + mSense weights

B = Set of tokens of infected individuals

PSI-WCA provides weighted risk score!

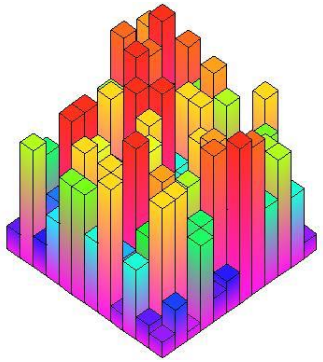
Putting It Together

This work: Building PSI-(W)CA From Function Secret Sharing

What is Function Secret Sharing [GI14, BGI15, BGI16,...]?

- Crypto protocol to split a function F into F_1 and F_2 such that $F_1(x)+F_2(x) = F(x)$ and individually F_1, F_2 reveal nothing about F

Theorem [GI14]: Sharing a point function P can be done using only symmetric-key crypto (e.g. AES)



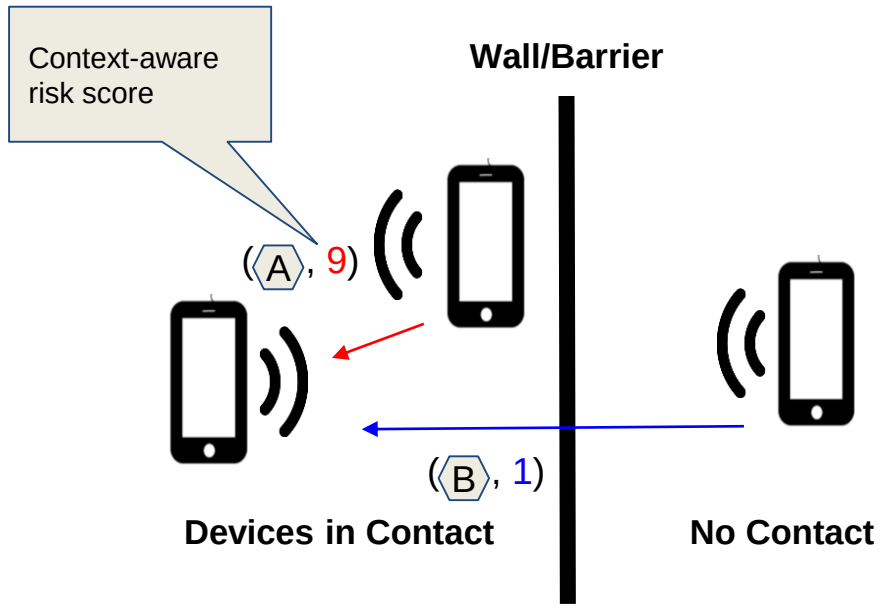
$$P(x) = \begin{cases} b \text{ if } x=a \\ 0 \text{ otherwise} \end{cases}$$

Token

Weight

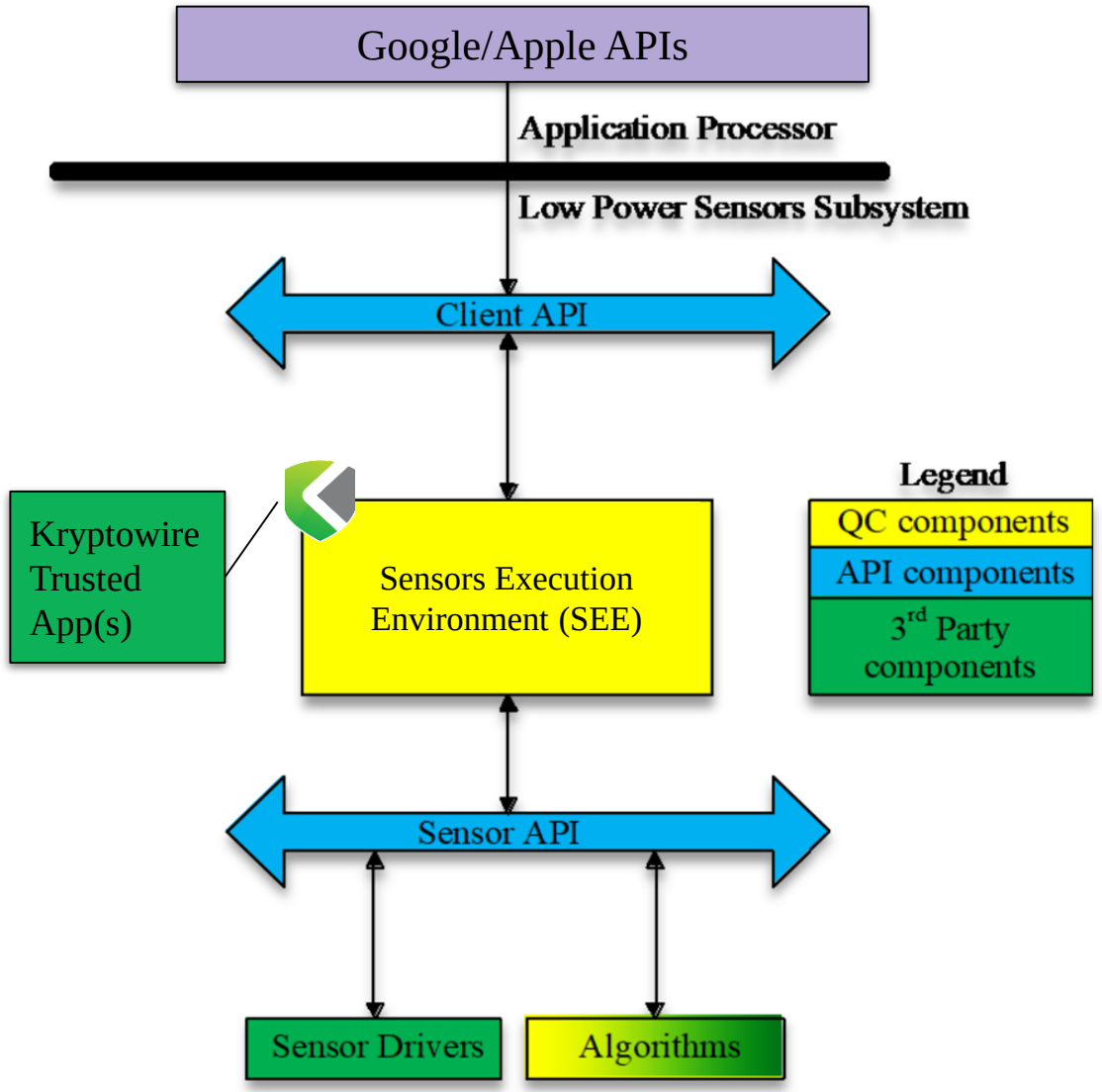
Situational Accuracy

- Improved sensor timings via chipset level access and experience
- Use of additional modalities to establish trusted location, sensor assisted positioning for more accurate location
- Utilize APIs to perform barrier detection (WiFi, Audio, etc)
- Context detection and baselining



Sensory Accuracy

- Access to the chipset level sensing environments with raw sensor data to assist in correcting for differences across APIs & Devices
- Chipset level applications work on wearables & mobile phones
- Access to raw sensory data and ability to load custom fusion algorithms



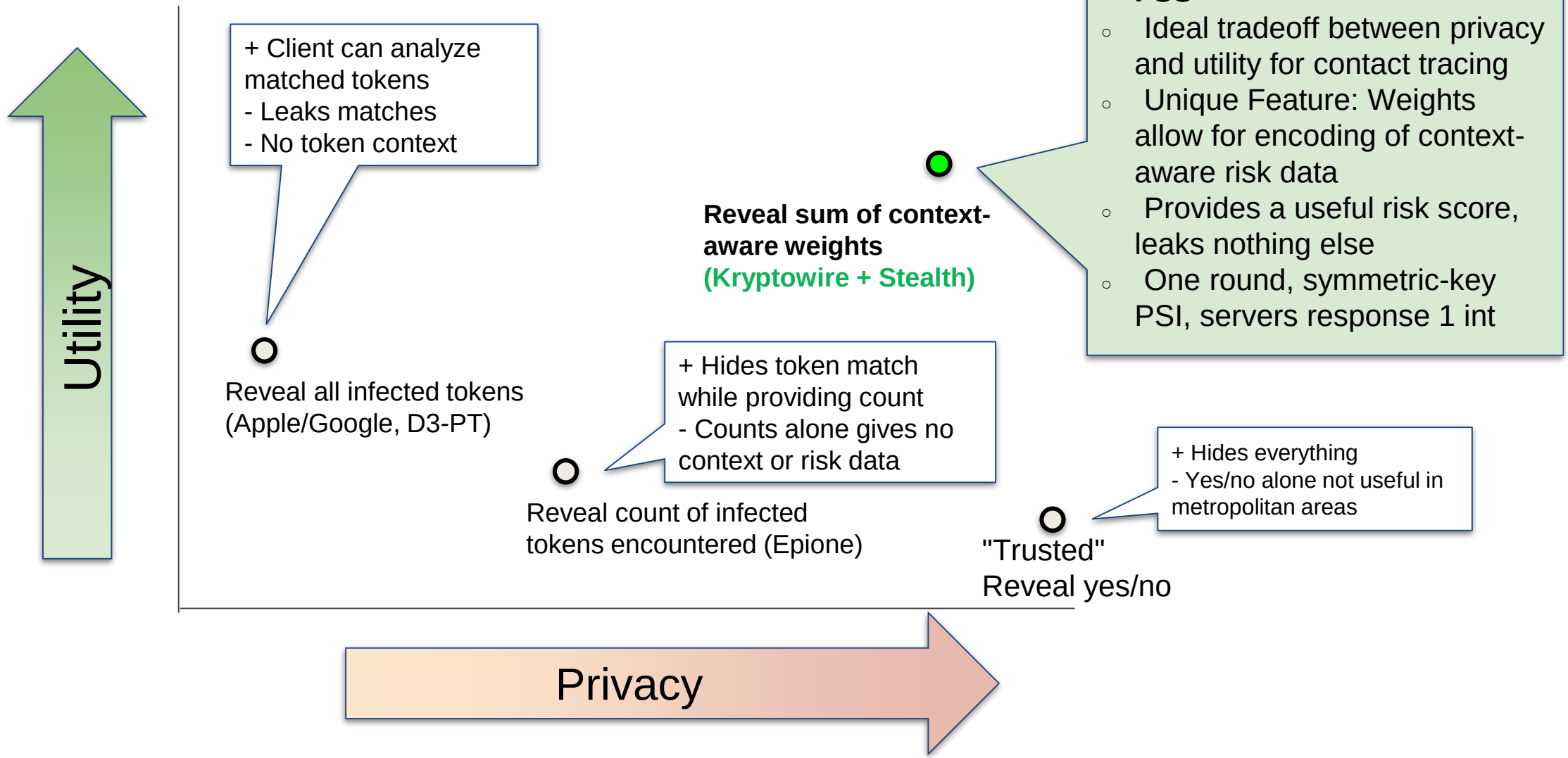
Building PSI-(W)CA From Function Secret Sharing

- For each token a_i, phone splits P_i into $P_{i,1}$ and $P_{i,2}$, sends each $P_{i,b}$ to server b (two servers)
  - Split server model has a long theoretical history (e.g. [CGKS95]) and recently used to great effect in practical privacy technologies (e.g [Prio])
- Each server b computes sum over all N infected tokens y_j, all n phone splits P_i:

$$\text{response}_\text{b} = \sum_{i=1}^{n} \sum_{j=1}^{N} P_{i,b}(y_j)$$

Sum of the responses = weighted risk score!

- Naïve computation is O(nN), we also use careful combinatorial hashing to reduce server work


Utility
+ Client can analyze matched tokens
- Leaks matches
- No token context
Reveal all infected tokens (Apple/Google, D3-PT)
+ Hides token match while providing count
- Counts alone gives no context or risk data
Reveal count of infected tokens encountered (Epione)
+ Hides everything
- Yes/no alone not useful in metropolitan areas
"Trusted" Reveal yes/no
Reveal sum of context-aware weights (Kryptowire + Stealth)
• Tech: Private Set Intersection - Weighted Cardinality (PSI-WCA) via FSS
◦ Ideal tradeoff between privacy and utility for contact tracing
◦ Unique Feature: Weights allow for encoding of context-aware risk data
◦ Provides a useful risk score, leaks nothing else
◦ One round, symmetric-key PSI, servers response 1 int
Privacy

Thank You!

Paper

arXiv: https://arxiv.org/abs/2012.13053