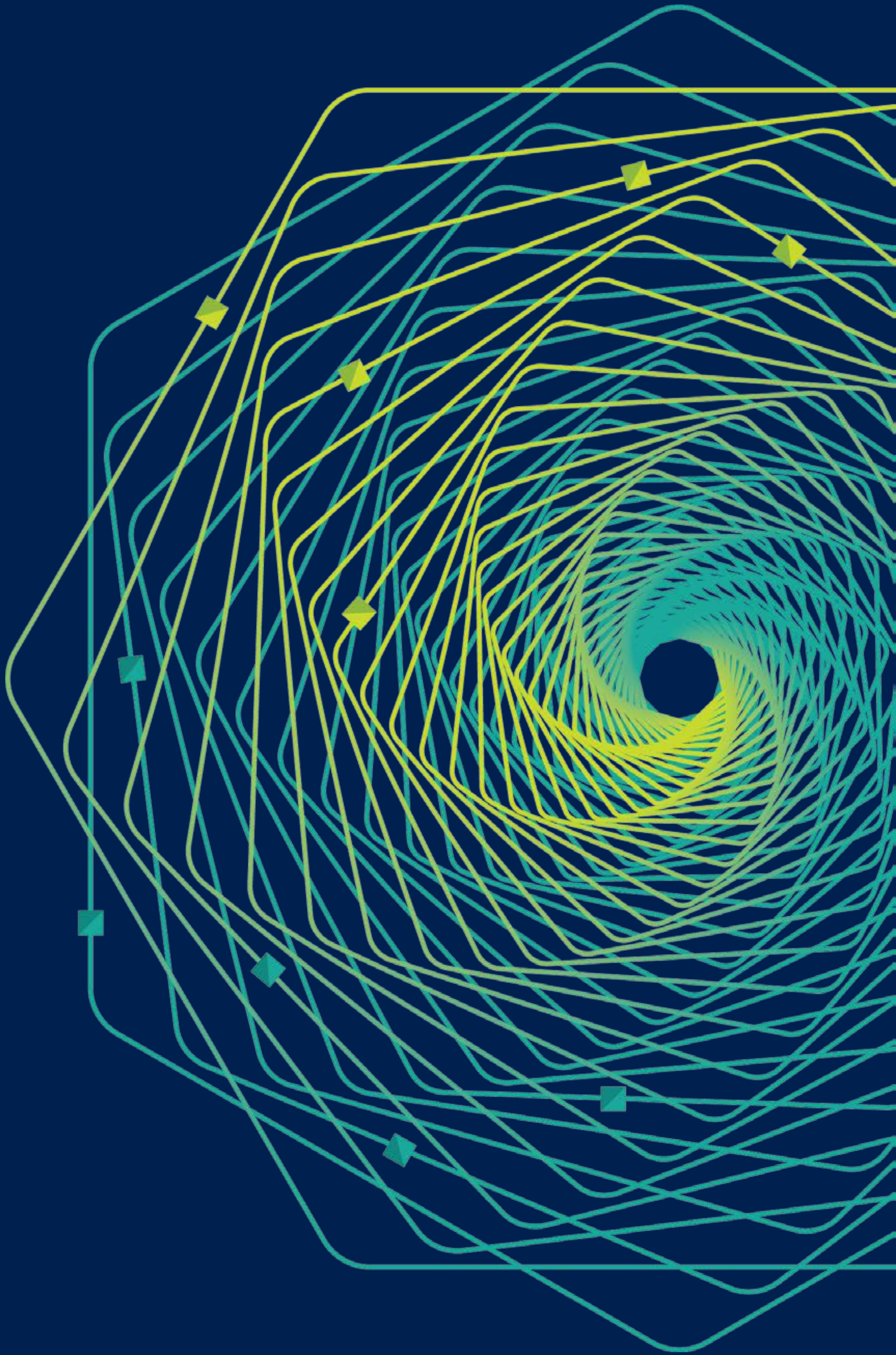
Microsoft

Research Faculty Summit 2018

Systems | Fueling future disruptions



Oasis: Privacy-Preserving Smart Contracts at Scale

Dawn Song

Professor, UC Berkeley

Founder and CEO, Oasis Labs

Berkeley
UNIVERSITY OF CALIFORNIA

OASIS LABS

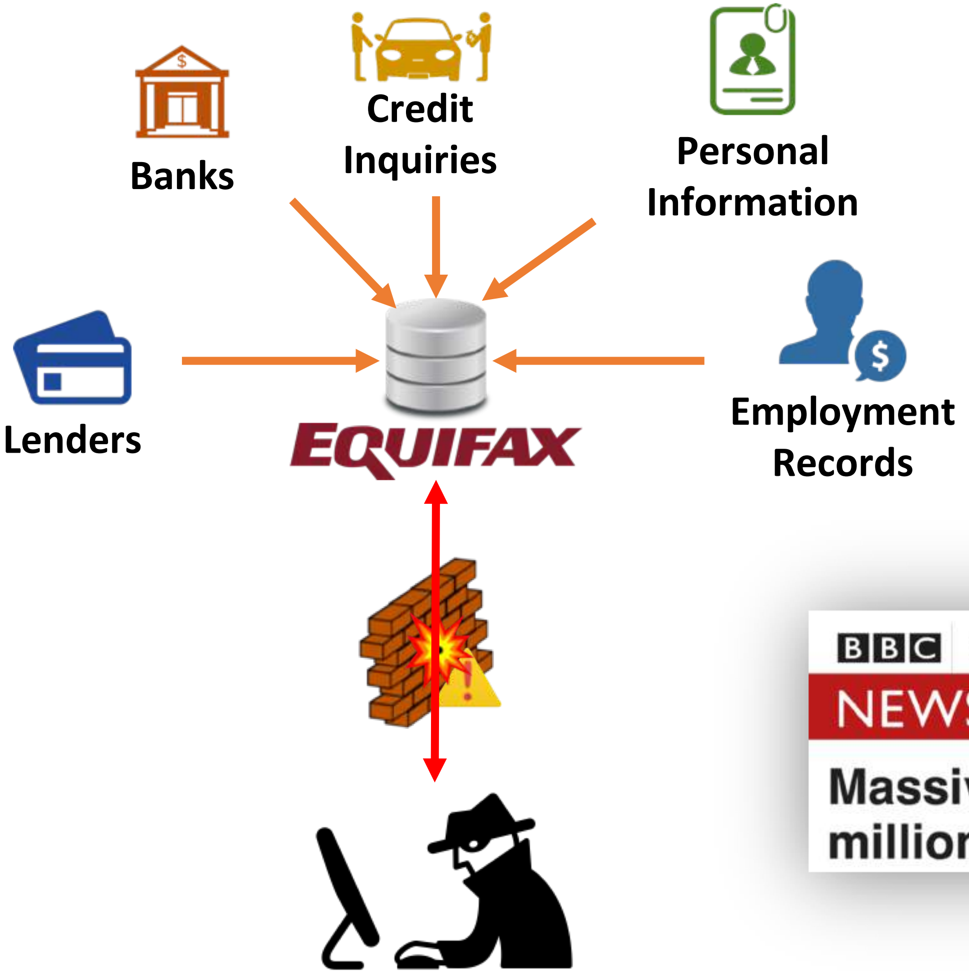
The Value of Data Analytics and Machine Learning

Data analysis and machine learning has many applications, huge potential impact

“Data is the New Oil”

What are **biggest problems** affecting data today?

Data breaches are becoming more common



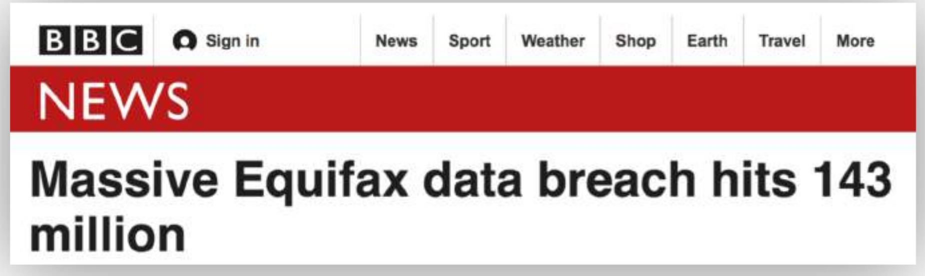
Banks

Credit Inquiries

Personal Information

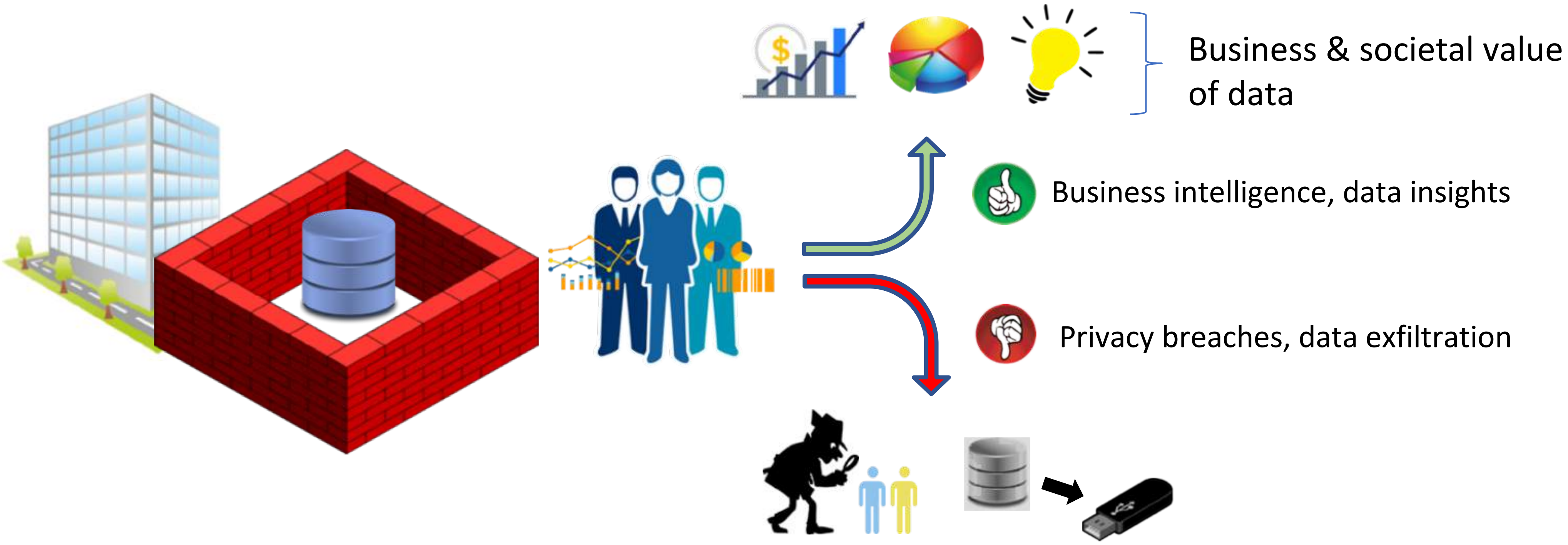
Lenders

Employment Records



Massive Equifax data breach hits 143 million

Most Data Is Siloed

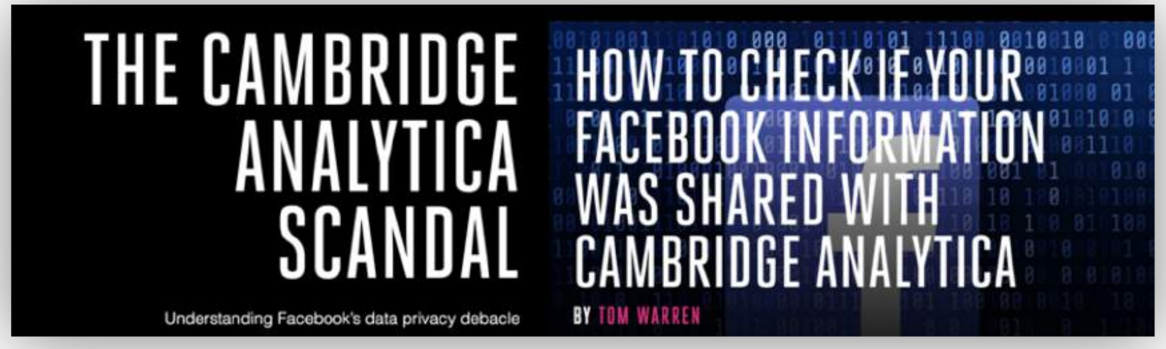


Business & societal value of data

Business intelligence, data insights

Privacy breaches, data exfiltration

Users Are Losing Control of Their Data

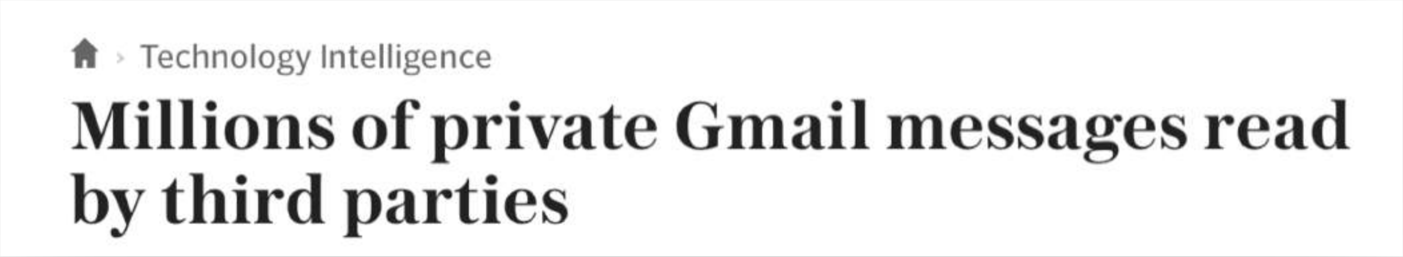


THE CAMBRIDGE ANALYTICA SCANDAL

Understanding Facebook's data privacy debacle

HOW TO CHECK IF YOUR FACEBOOK INFORMATION WAS SHARED WITH CAMBRIDGE ANALYTICA

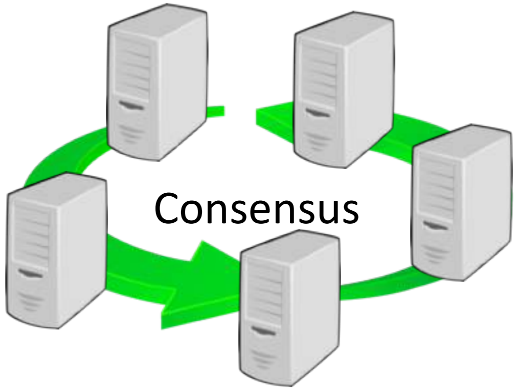
BY TOM WARREN



Technology Intelligence

Millions of private Gmail messages read by third parties

Blockchain: a Transformative Technology



Openness & transparency

No reliance on a central party

Automatic enforcement of agreements

The future of blockchain

Payments

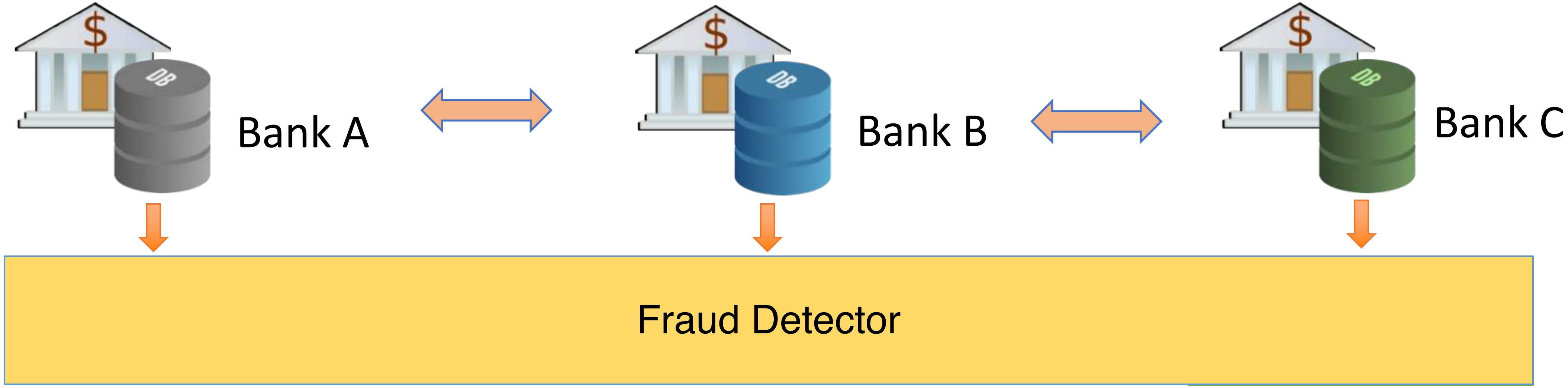
Tokens

Cryptokitties

- Fraud detection
- Credit scoring
- Decentralized exchange
- Decentralized hedge fund
- Medical diagnostics
- Personalized medicine
- Private auctions
- Internet of Things applications

ethereum

Motivating example: Fraud detection

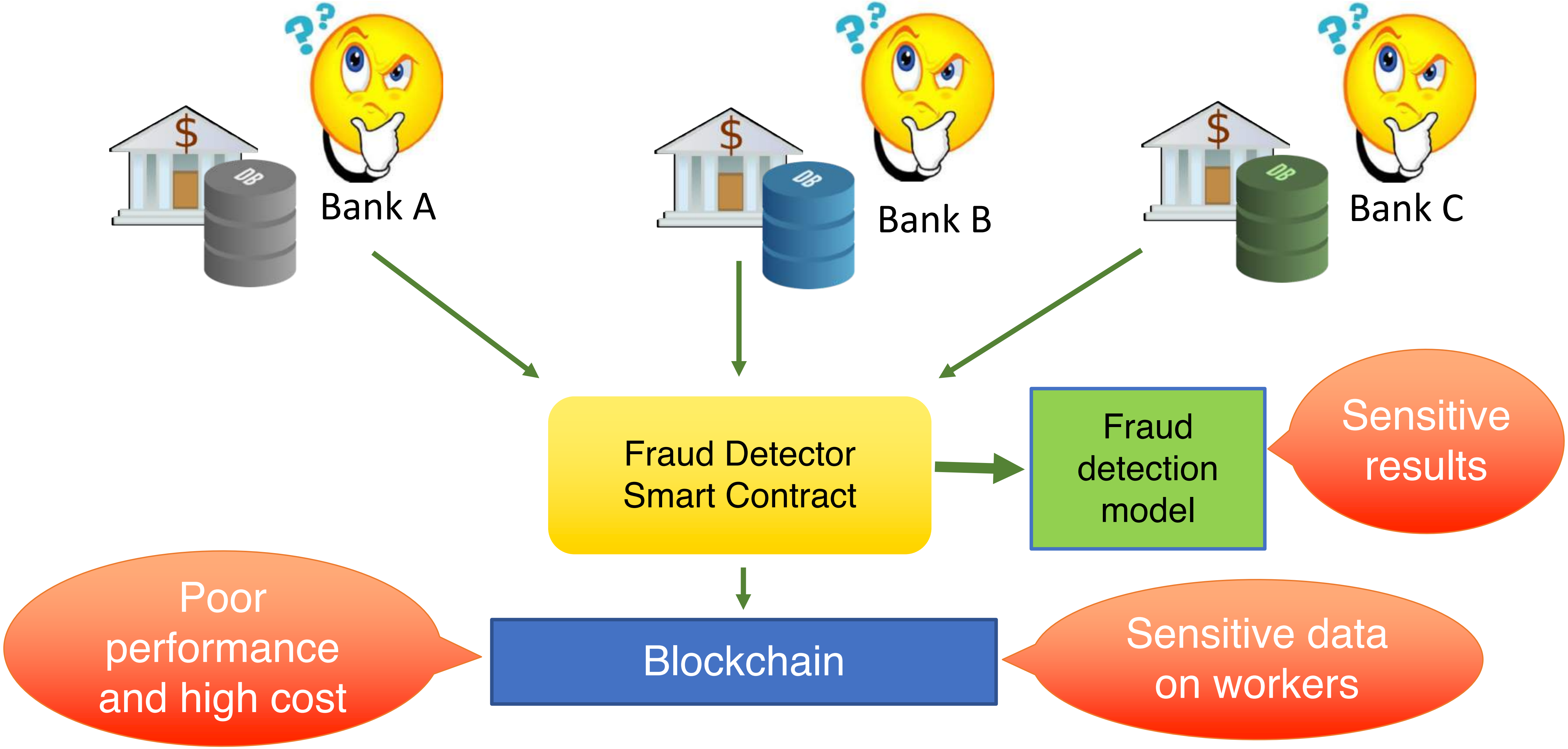


Banks would all benefit by combining data to train better model

Can't do this today because:

- Privacy concerns
- Regulatory risk
- Misaligned incentives

Motivating example: Fraud detection



Bank A

Bank B

Bank C

Fraud Detector Smart Contract

Fraud detection model

Sensitive results

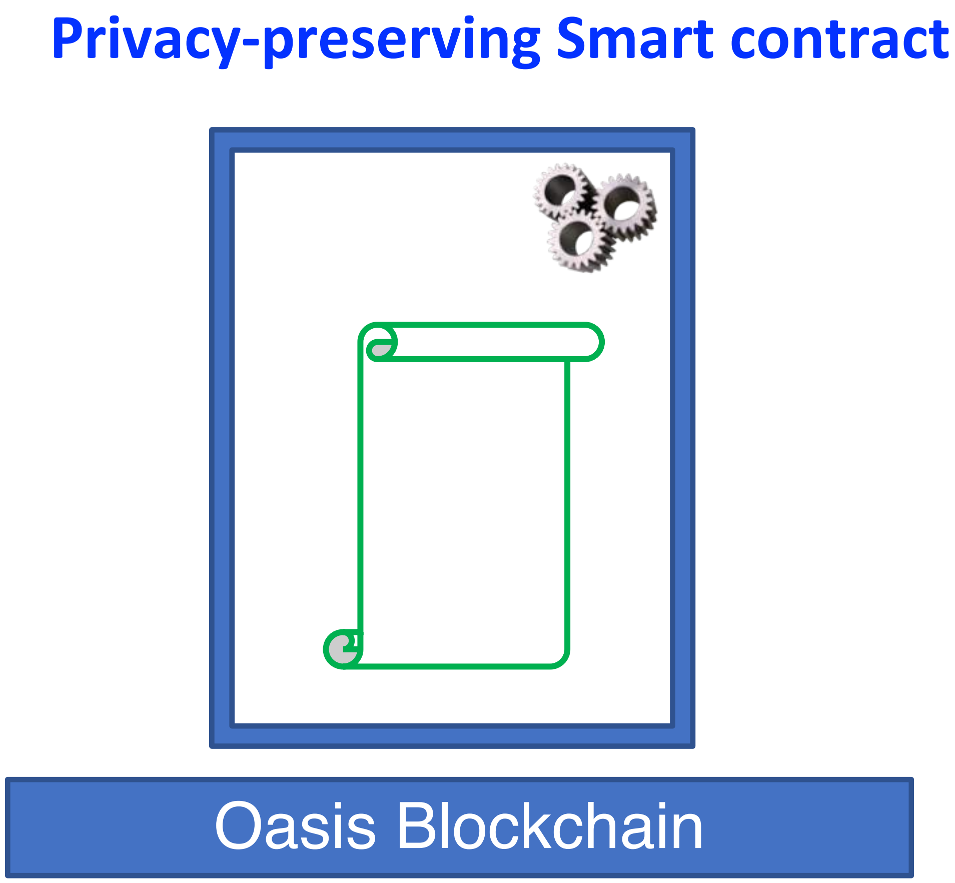
Blockchain

Poor performance and high cost

Sensitive data on workers

Oasis: Privacy-preserving Smart Contracts at Scale

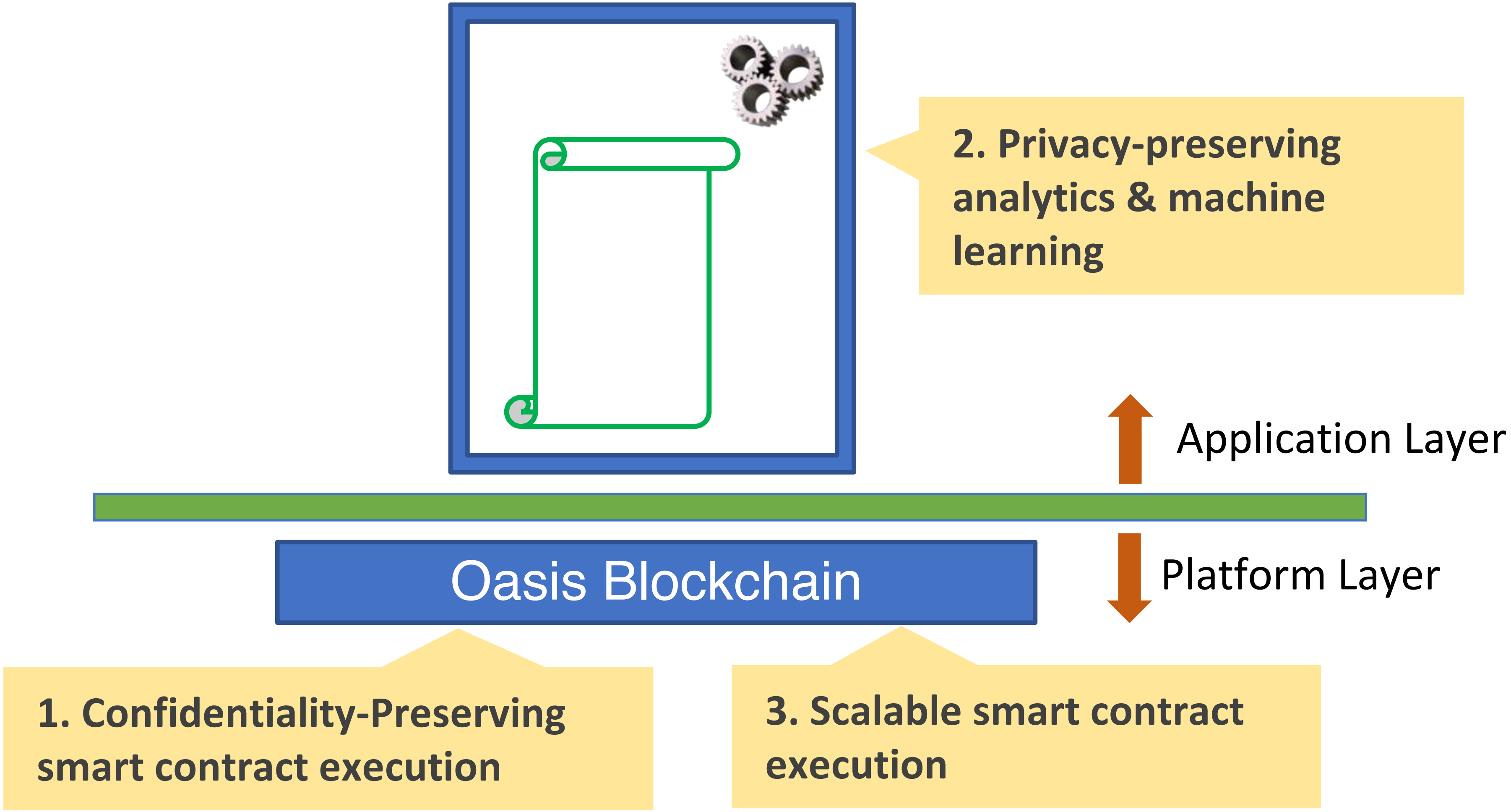
Our Solution



Properties of Our Solution

- Automatic enforcement of codified privacy requirements
- Without relying on any central party
- Scale to real-world applications including machine learning
- Easy to use for developers without privacy expertise

Privacy-Preserving Smart Contracts At Scale



2. Privacy-preserving analytics & machine learning

Application Layer

Oasis Blockchain

Platform Layer

1. Confidentiality-Preserving smart contract execution

3. Scalable smart contract execution

Outline

1. **Confidentiality-Preserving smart contract execution**

2. **Privacy-preserving analytics & machine learning**

3. **Scalable smart contract execution**

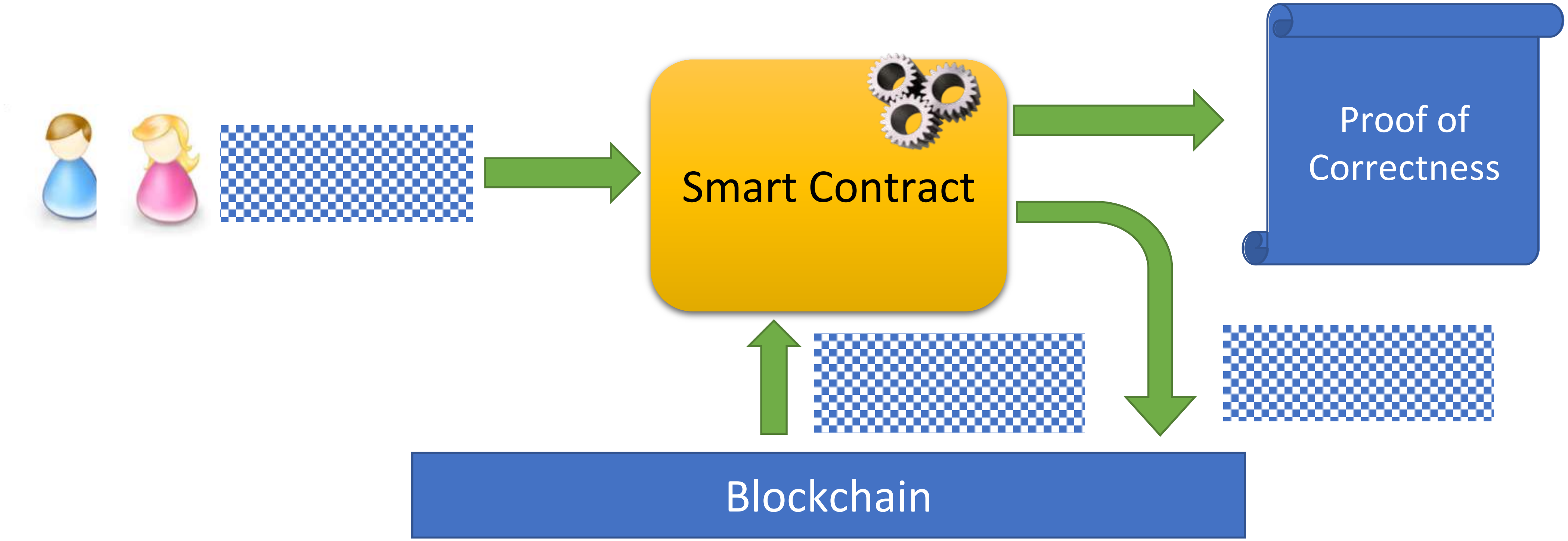
Outline

1. Confidentiality-Preserving smart contract execution

2. Privacy-preserving analytics & machine learning

3. Scalable smart contract execution

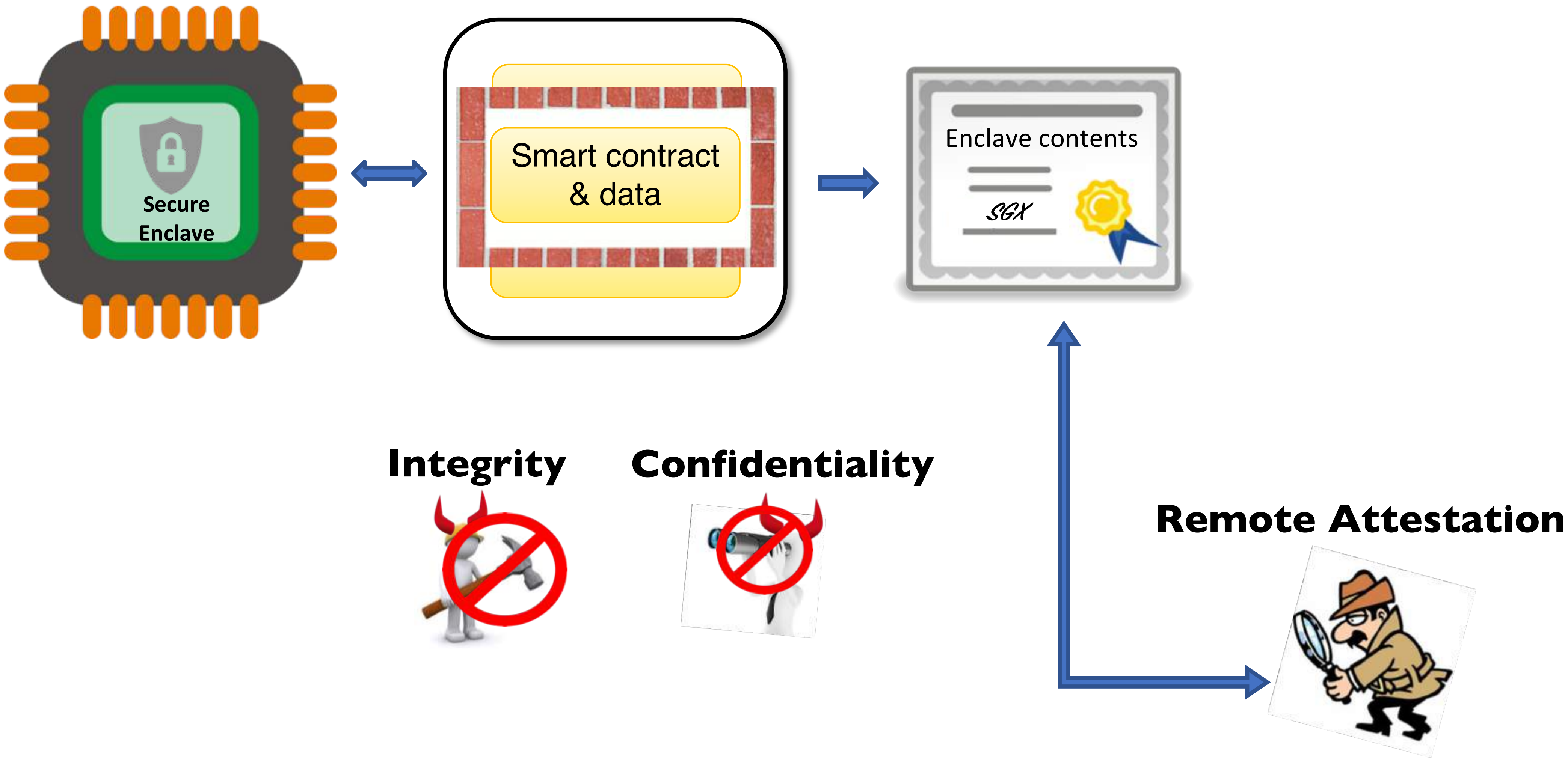
Confidentiality-preserving Smart Contract Execution



Secure computation techniques

	Performance	**Support for general-purpose computation**	**Security mechanisms**
Trusted hardware	🟩🟩🟩	🟩🟩🟩	Secure hardware
Secure multi-party computation	🟩⬜⬜	🟩⬜⬜	Cryptography, distributed trust
Zero-knowledge proof	🟩⬜⬜	🟩⬜⬜	Cryptography, local computation
Fully homomorphic encryption	⬜⬜⬜	🟩⬜⬜	Cryptography

Secure Hardware



Secure Enclave

Smart contract & data

Enclave contents

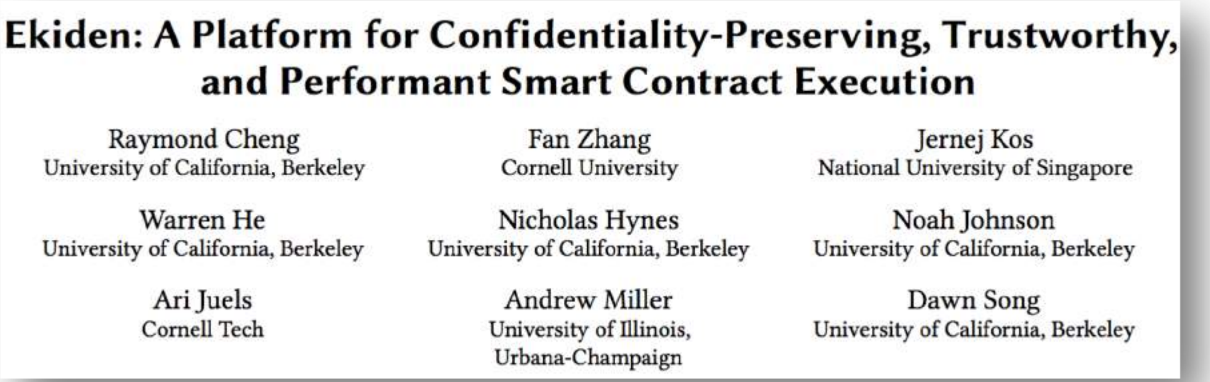
SGX

Integrity

Confidentiality

Remote Attestation

Ekiden: Confidentiality-preserving Smart Contracts



Ekiden: A Platform for Confidentiality-Preserving, Trustworthy, and Performant Smart Contract Execution

Raymond Cheng
University of California, Berkeley

Fan Zhang
Cornell University

Jernej Kos
National University of Singapore

Warren He
University of California, Berkeley

Nicholas Hynes
University of California, Berkeley

Noah Johnson
University of California, Berkeley

Ari Juels
Cornell Tech

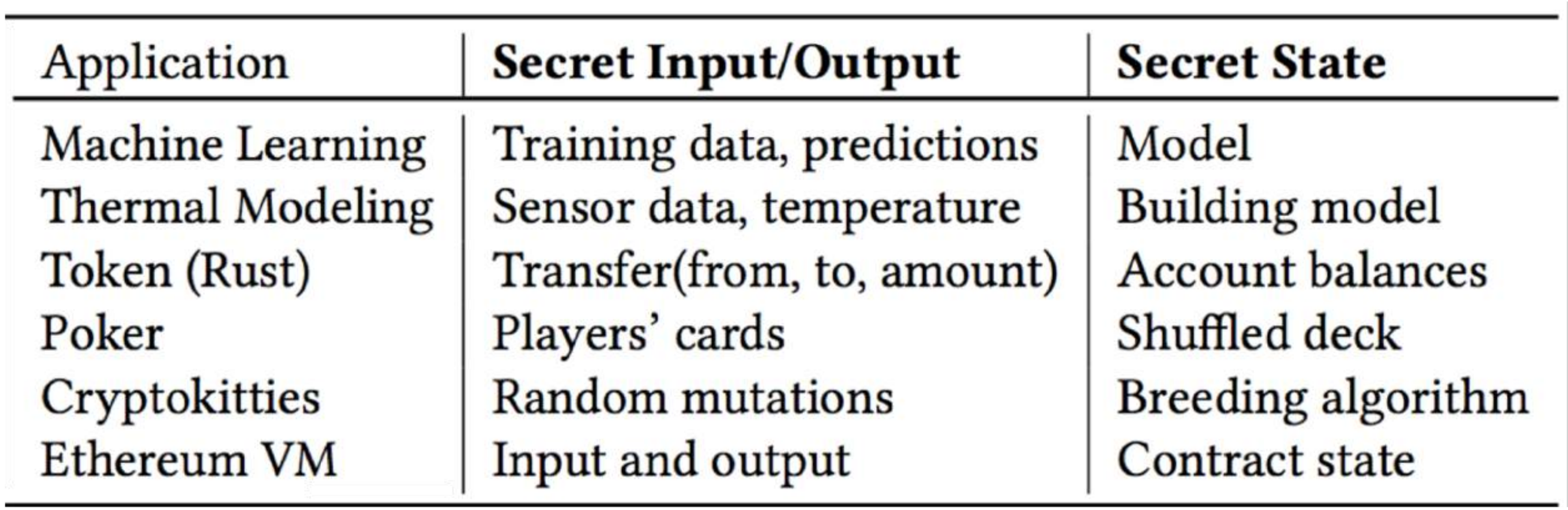
Andrew Miller
University of Illinois,
Urbana-Champaign

Dawn Song
University of California, Berkeley

https://arxiv.org/abs/1804.05141

- Smart contract execution using **secure computation**:
  - Secure Enclave (e.g. Intel SGX)
  - Cryptographic protocols: secure MPC or Zero-knowledge Proofs
- **Security proof**: Universal Composability

Ekiden: Sample Applications



Application	**Secret Input/Output**	**Secret State**
Machine Learning	Training data, predictions	Model
Thermal Modeling	Sensor data, temperature	Building model
Token (Rust)	Transfer(from, to, amount)	Account balances
Poker	Players' cards	Shuffled deck
Cryptokitties	Random mutations	Breeding algorithm
Ethereum VM	Input and output	Contract state

Secure Enclave as a Cornerstone Security Primitive

- Strong security capabilities
  - Authenticate itself (device)
  - Authenticate software
  - Guarantee the integrity and privacy of execution
- Platform for building new security applications
  - Couldn’t be built otherwise for the same practical performance
  - Many examples
    - Haven [OSDI’14], VC3 [S&P’15], M2R[USENIX Security‘15], Ryoan [OSDI’16], Opaque [NSDI’17]

Trusted hardware timeline

Closed source

ARM TrustZone

Hardware-based isolation for embedded devices

SGX: Software Guard Extensions

Built in to all Core™ processors (6th-generation and later)

Trusted Execution Environment

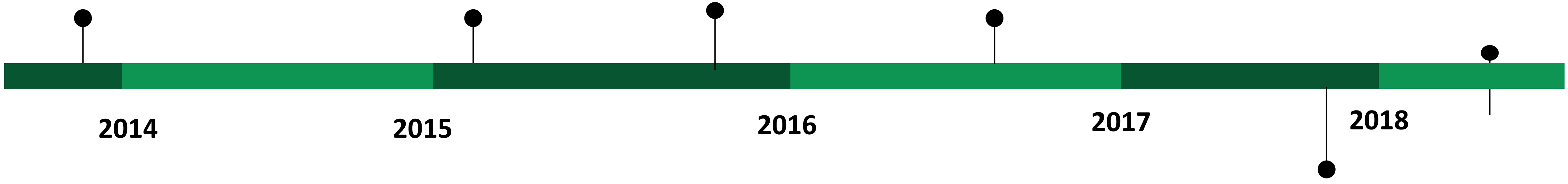
- Hardware-based isolation
- TLK: open-source stack for TEE

SEV: Secure Encrypted Virtualization

- Introduced in EYPC server processor line
- Provides confidentiality but not integrity

Intel SGX version 2

- In pipeline
- Drivers already available



Open source

Keystone: Open-source secure enclave

https://keystone-enclave.github.io

- Collaboration between Berkeley & MIT
- Remedies issues in previous secure hardware
- Can be publicly analyzed and verified
- Can be manufactured by any manufacturer
- First release: Fall 2018

Challenges in Secure Hardware

- How secure can it be? Under what threat models?
- What would you entrust with secure hardware?
  - Your bitcoin keys
  - Financial data
  - Health data
- Can we create trustworthy secure enclave as a cornerstone security primitive?
  - Widely deployed, enable secure systems on top
  - A new secure computation era

Path to Trustworthy Secure Enclave

- Open source design
  - Provides transparency & enables high assurance
  - Builds a community
- Formal verification
- Secure supply-chain management

Keystone Enclave

- What is the Keystone Enclave?
    - Open-source Trusted Execution Environment (TEE) based on RISC-V
- Strong Memory Isolation
    - ISA-enforced memory access management
    - Separate virtual memory management without relying on the OS
- Simple and Portable
    - Exploits standard RISC-V ISA primitives: PMP, TVM
- Remote Attestation
    - Extends MIT Sanctum’s remote attestation
- Open Source
    - Full software/hardware stack will be released
    - Run on many platforms: QEMU, Amazon AWS FPGA (FireSim), HiFive Unleashed, ...

Berkeley Architecture Research

DRAPER

bluespec

C-SKY

Mentor A Siemens Business

LATTICE SEMICONDUCTOR

Mellanox TECHNOLOGIES

NXP

cortus

Rambus Cryptography Research

SiFive

Micron

SAMSUNG

Google

NVIDIA

QUALCOMM

HUAWEI

IBM

Western Digital

Microsemi

RISC-V Foundation: 100+ Members

ESPRESSIF

MEDIATEK

ANDES TECHNOLOGY

antmicro EMBEDDED SYSTEMS

runtime.io

DOVER MICROSYSTEMS

BAE SYSTEMS

Esperanto Technologies

VeriSilicon

inside secure DRIVING TRUST

GRAY RESEARCH

IDT

INDIAN INSTITUTE OF TECHNOLOGY MADRAS

ISTUARY INNOVATION GROUP

SEGGER It simply works!

NUS National University of Singapore

WWW.GLORYSPACE.CN

GOWIN

GRIDOOG "Eyes on the Grid, Eyes on the Buck"

LAUTERBACH DEVELOPMENT TOOLS

INTRINSIX

ETH zürich

MIT CSAIL

ICT 中科院计算所 INSTITUTE OF COMPUTING TECHNOLOGY, CAS

ASHLING THE DEVELOPMENT SYSTEMS COMPANY

codasip

GREENWAVES TECHNOLOGIES

Roa Logic Silicon Proven IP for FPGA and ASIC

SH CONSULTING

MINIMA PROCESSOR

Rumble Development

TRINAMIC

imperas

XtremeEDA

VectorBlox embedded supercomputing

UBILITE Hello IoT World

SEAGATE

EMDALO TECHNOLOGIES

EMBECOSM

SECURE RF Securing the Internet of Things

BERKELEY LAB

Syntacore Custom cores and tools

lowRISC

TechanaLye

SIEMENS

优矽科技 UC TECH IP

Technolution

ultraSoC

csem

PRINCETON UNIVERSITY

Blockstream

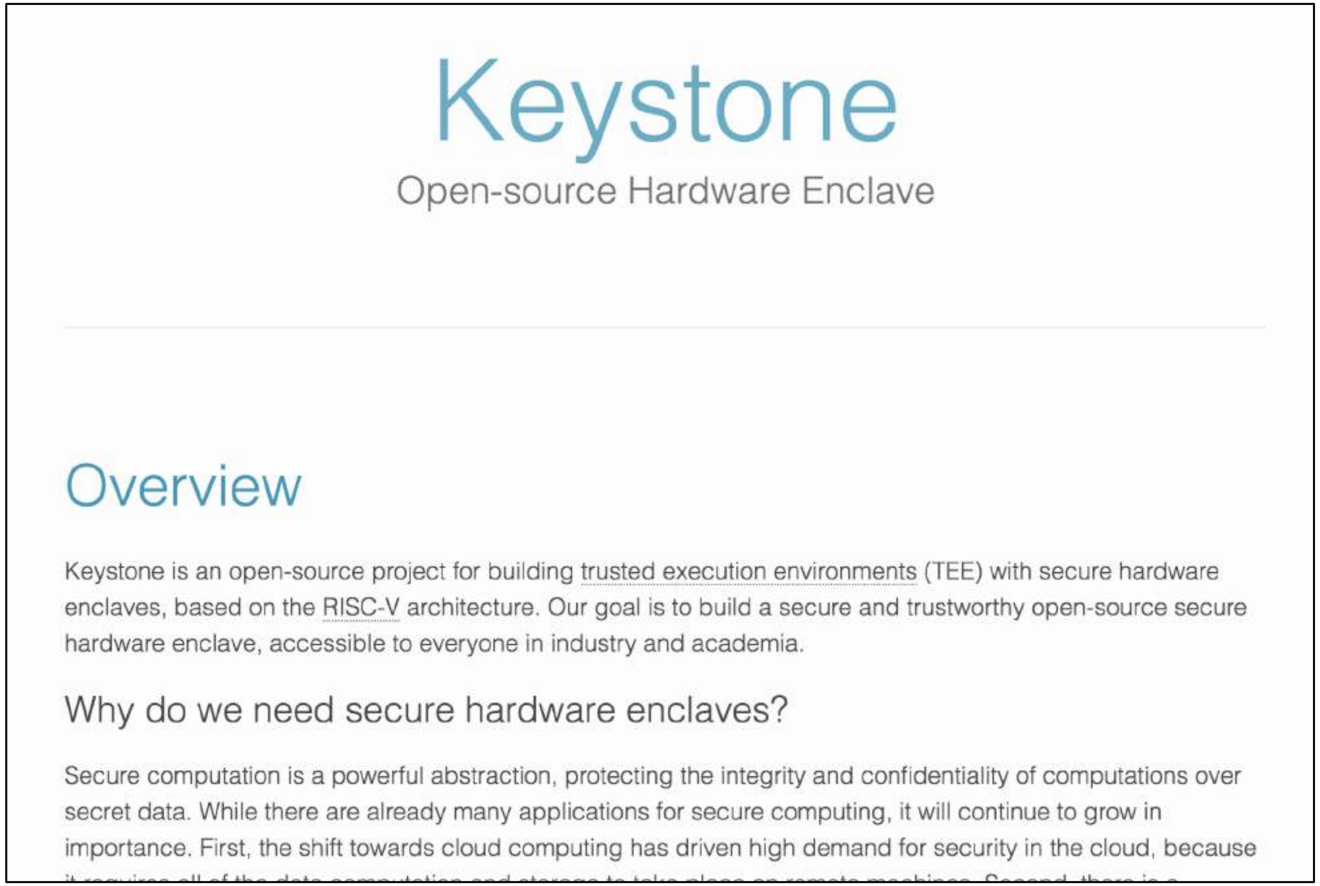
dxcorr

GLOBALFOUNDRIES

expresslogic

Keystone Goals and Roadmap

Website: https://keystone-enclave.org



Keystone

Open-source Hardware Enclave

Overview

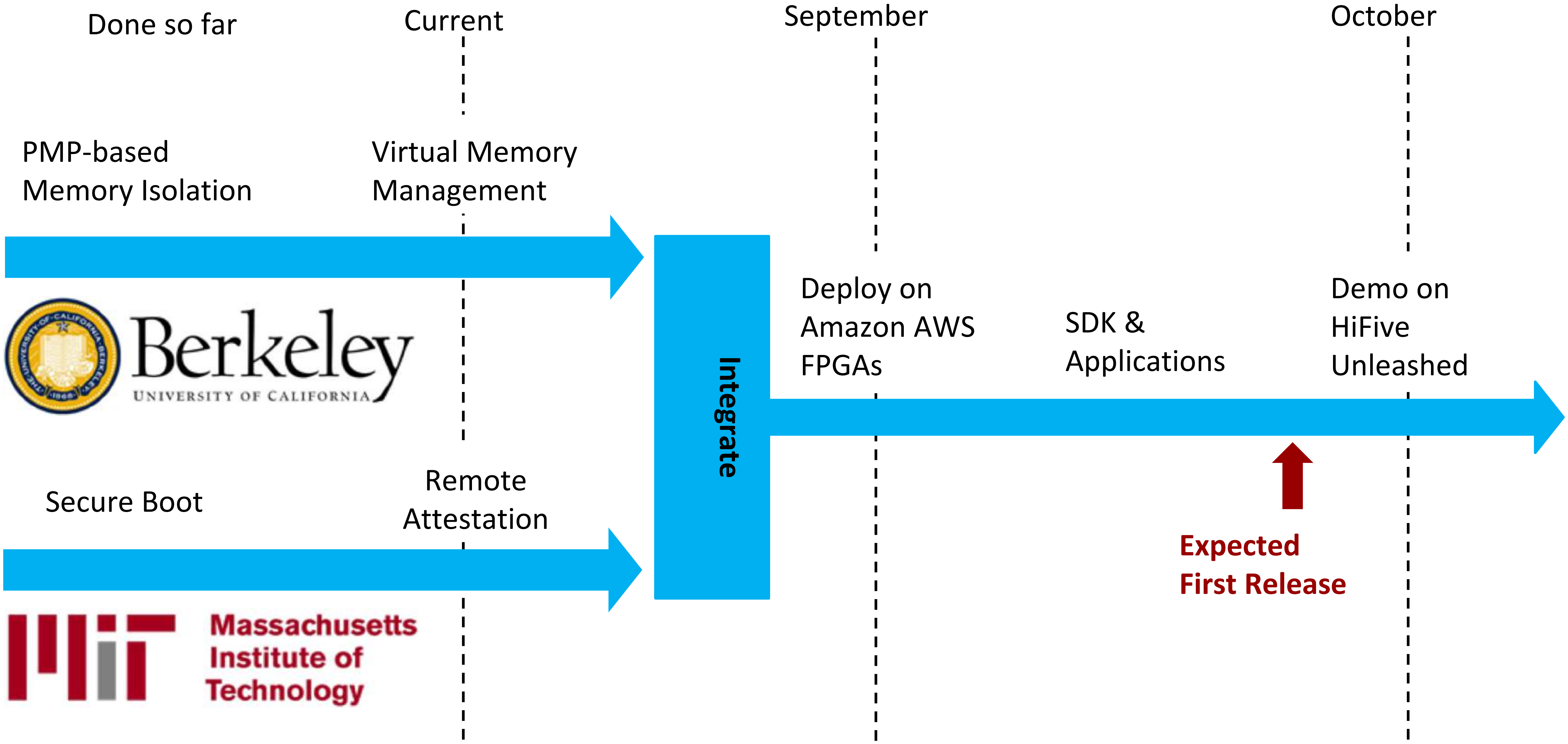
Keystone is an open-source project for building trusted execution environments (TEE) with secure hardware enclaves, based on the RISC-V architecture. Our goal is to build a secure and trustworthy open-source secure hardware enclave, accessible to everyone in industry and academia.

Why do we need secure hardware enclaves?

Secure computation is a powerful abstraction, protecting the integrity and confidentiality of computations over secret data. While there are already many applications for secure computing, it will continue to grow in importance. First, the shift towards cloud computing has driven high demand for security in the cloud, because

1. Chain of Trust
   - Secure boot
   - Remote attestation
   - Secure key provisioning (PUF)
2. Memory Isolation
   - Physical memory protection
   - Page table isolation
3. Defense against Physical Attack
   - Memory encryption
   - Memory address bus encryption
4. Defense against Side-channel Attack
   - Isolated architecture
5. Formal Verification
6. Deployment
   - RISC-V QEMU
   - Amazon AWS FPGAs (FireSim)
   - HiFive Unleashed
7. Tape Out to Chip
8. Secure supply-chain management

Timeline



Done so far

Current

September

October

PMP-based Memory Isolation

Virtual Memory Management

Berkeley UNIVERSITY OF CALIFORNIA

Secure Boot

Remote Attestation

Massachusetts Institute of Technology

Integrate

Deploy on Amazon AWS FPGAs

SDK & Applications

Demo on HiFive Unleashed

Expected First Release

Outline

1. Confidentiality-Preserving smart contract execution

2. Privacy-preserving analytics & machine learning

3. Scalable smart contract execution

Privacy Risks in Analytics

How many trips were taken in New York last year?

Reflects a **trend**

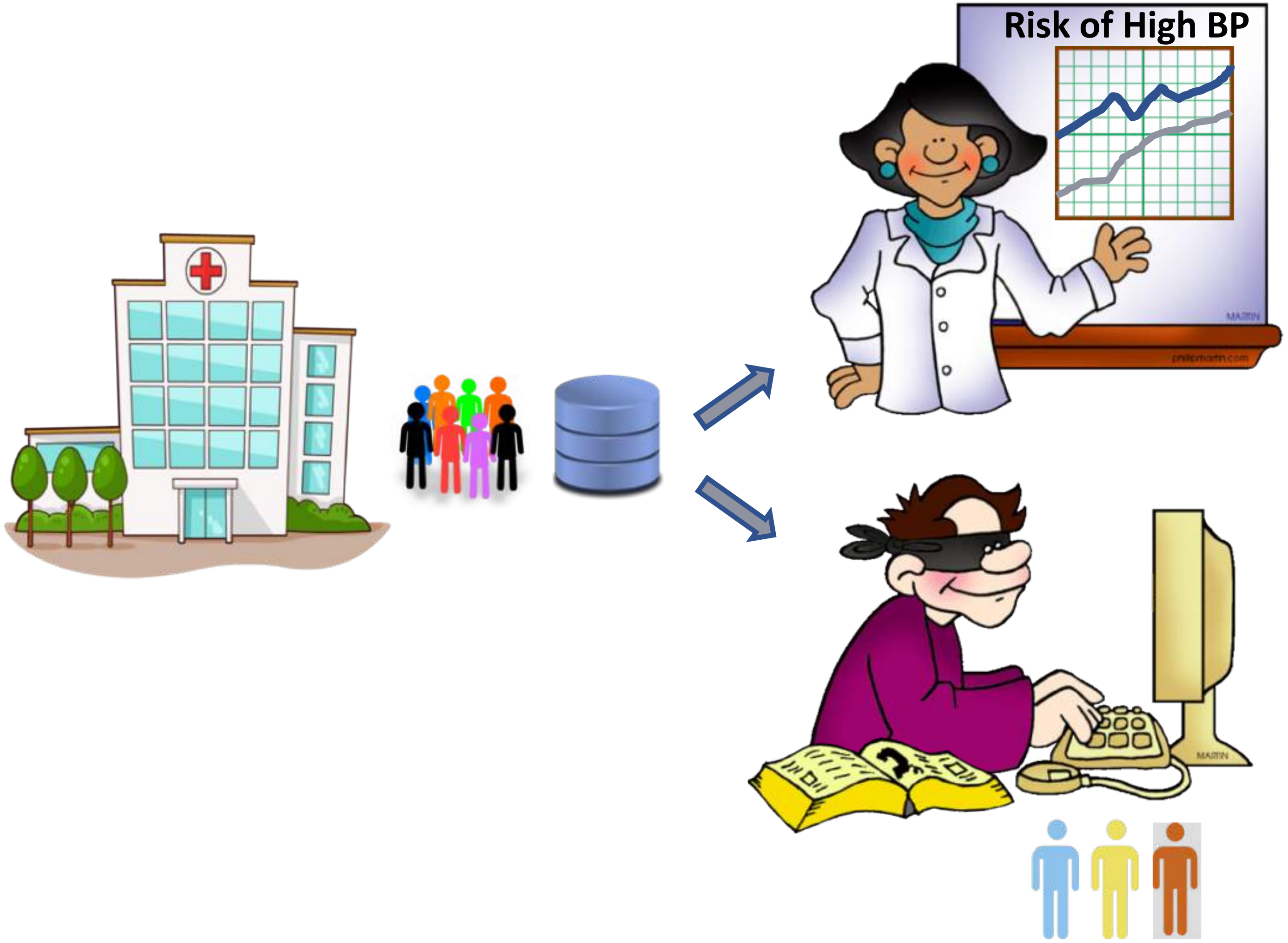
How many trips did Joe take last week?

Reflects an **individual**

Access control policies cannot enable the use of data while protecting the privacy of individuals

Data Anonymization

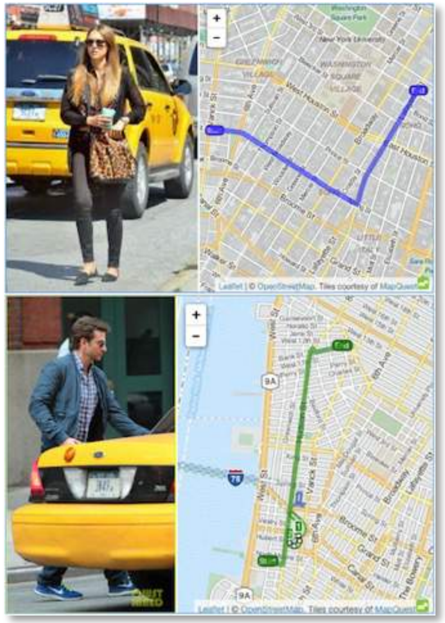
Data Anonymization



Reidentification attacks

Netflix prize (Narayanan et al.)

NYC taxi data (Anthony Tockar)



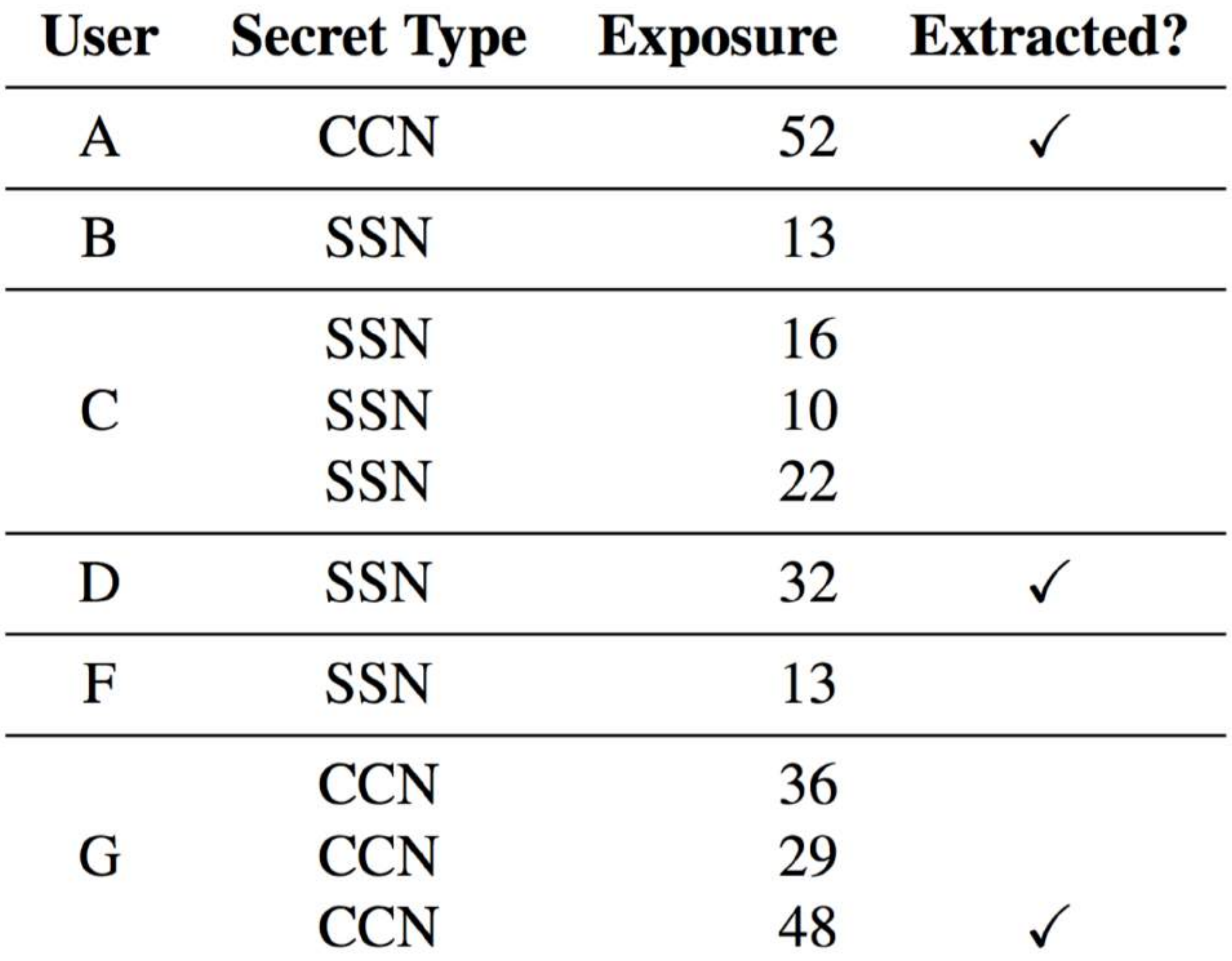
Do Neural Networks Remember Training Data?

Can Attackers Extract Secrets (in Training Data) from (Querying) Learned Models?

N Carlini, C Liu, J Kos, Ú Erlingsson, and D Song.
"The Secret Sharer: Measuring Unintended Neural Network Memorization & Extracting Secrets". 2018.

Extracting Social Security Number from Language Model

- Learning task: train a language model on Enron Email dataset
    - Containing actual people’s credit card and social security numbers
- New attacks: can extract 3 of the 10 secrets completely by querying trained models
- New measure “Exposure” for memorization
    - Used in Google Smart Compose

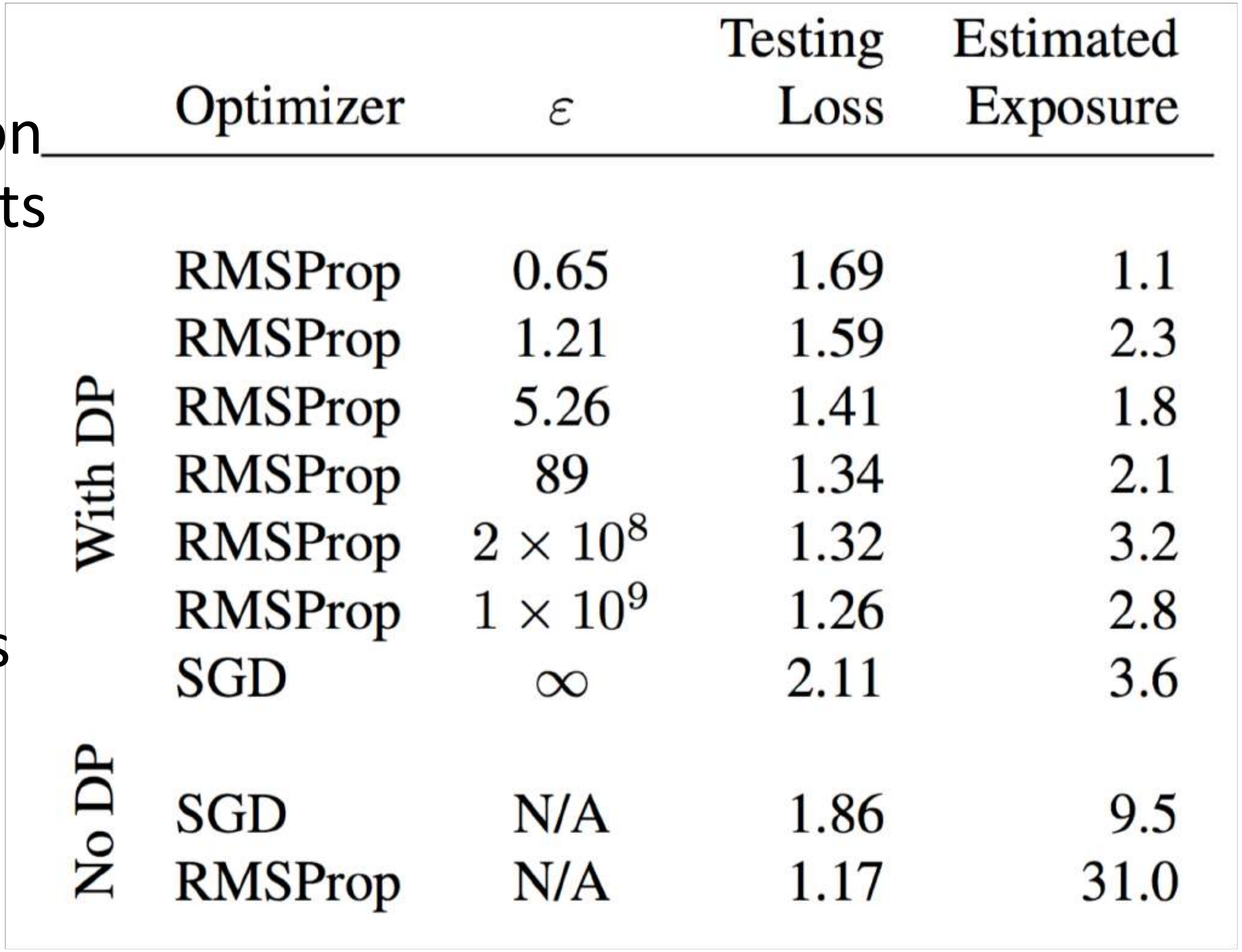


User	Secret Type	Exposure	Extracted?
A	CCN	52	✓
B	SSN	13	
C	SSN SSN SSN	16 10 22	
D	SSN	32	✓
F	SSN	13	
G	CCN CCN CCN	36 29 48	 ✓

Preventing Memorization

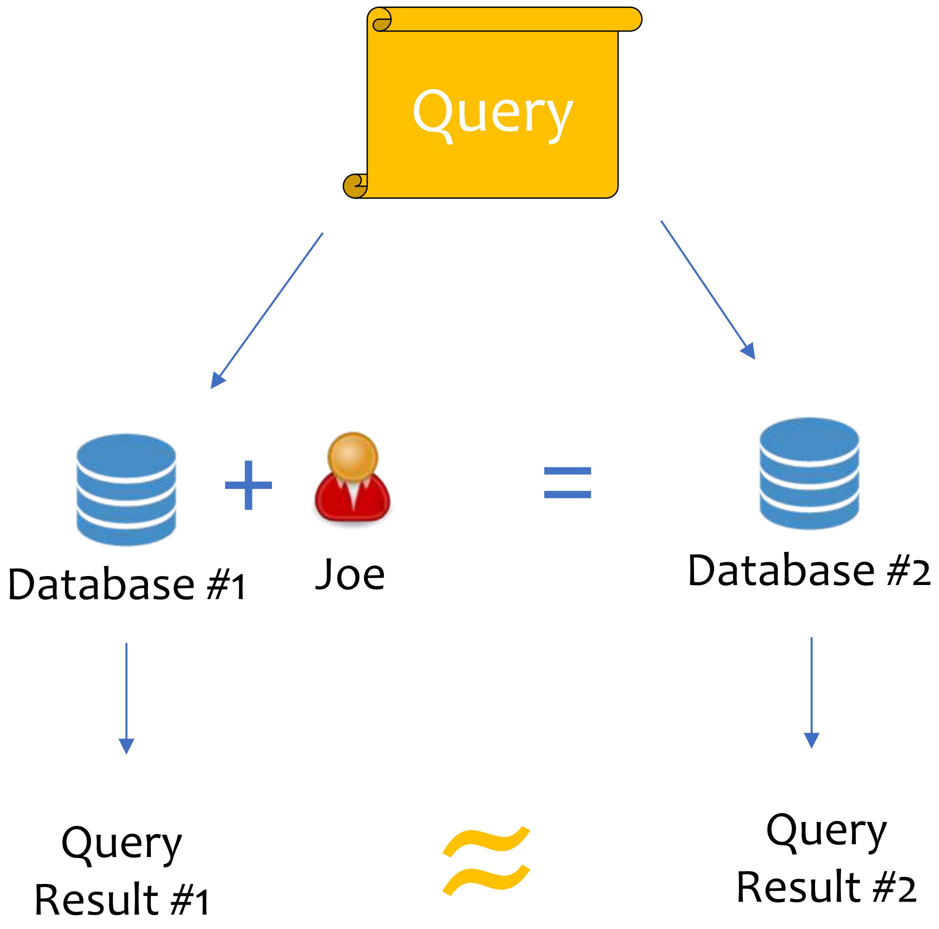
- **Differential Privacy:** a formal notion of privacy to protect sensitive inputs

- Solution: train a differentially-private neural network
  - Exposure is lower empirically
  - Attack unable to extract secrets



	Optimizer	ε	Testing Loss	Estimated Exposure
With DP	RMSProp	0.65	1.69	1.1
	RMSProp	1.21	1.59	2.3
	RMSProp	5.26	1.41	1.8
	RMSProp	89	1.34	2.1
	RMSProp	2×10^8	1.32	3.2
	RMSProp	1×10^9	1.26	2.8
	SGD	∞	2.11	3.6
No DP	SGD	N/A	1.86	9.5
	RMSProp	N/A	1.17	31.0

Differential Privacy: a Formal Privacy Definition



- Outcome is the same **with or without** Joe’s data
  - Holds for *every* user and *every* database
- Immune to re-identification attacks
- Parameterized by ε (the *privacy budget*)

Real-world Use of Differential Privacy

- Previous work on differential privacy is either:
  - Theoretical
  - Targeted for specialized applications
    - Google: top websites visited
    - Apple: top emojis used

- No previous real-world deployments of differential privacy for general-purpose analytics

Challenges for Practical General-purpose Differential Privacy for SQL Queries

- Usability for non-experts
- Broad support for analytics queries
- Easy integration with existing data environments

No existing system addresses these issues

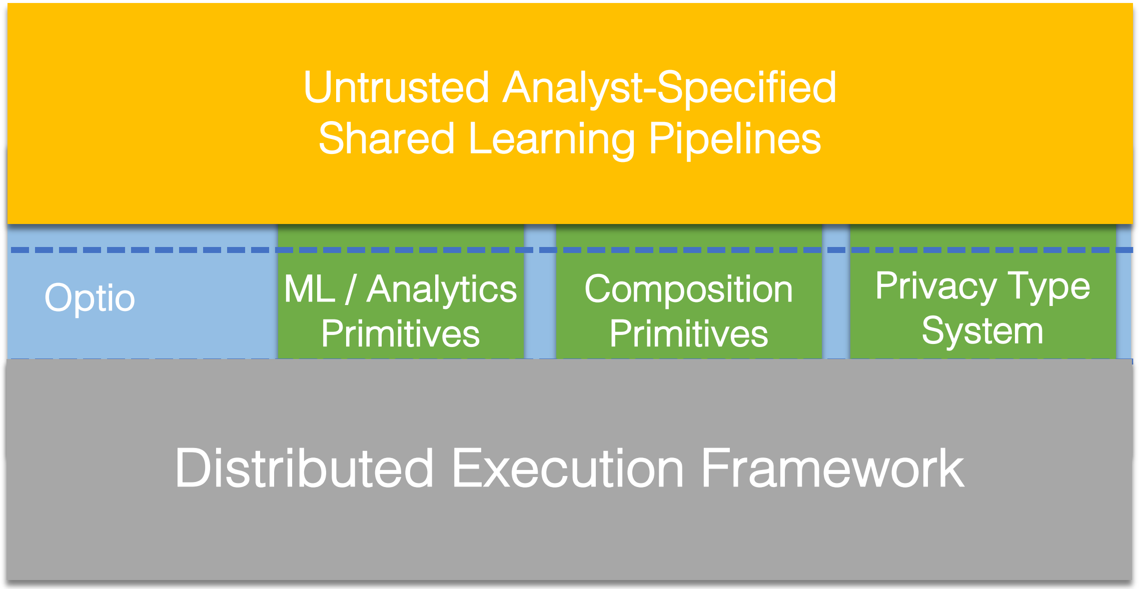
Collaboration with Uber: address practical deployment challenges

Chorus: a Framework for Privacy-preserving Analytics

- **Usable by non-experts**
  - Analyst does not need to understand differential privacy
  - Chorus automatically enforces differential privacy for SQL queries
- **Broad support for analytics queries**
  - Modular design to support wide variety of mechanisms
  - Implemented mechanisms support 93% of queries in our workload
- **Easy integration with existing data environments**
  - Chorus works with standard SQL databases
- **Designed for real-world use**
  - Deployment underway at Uber

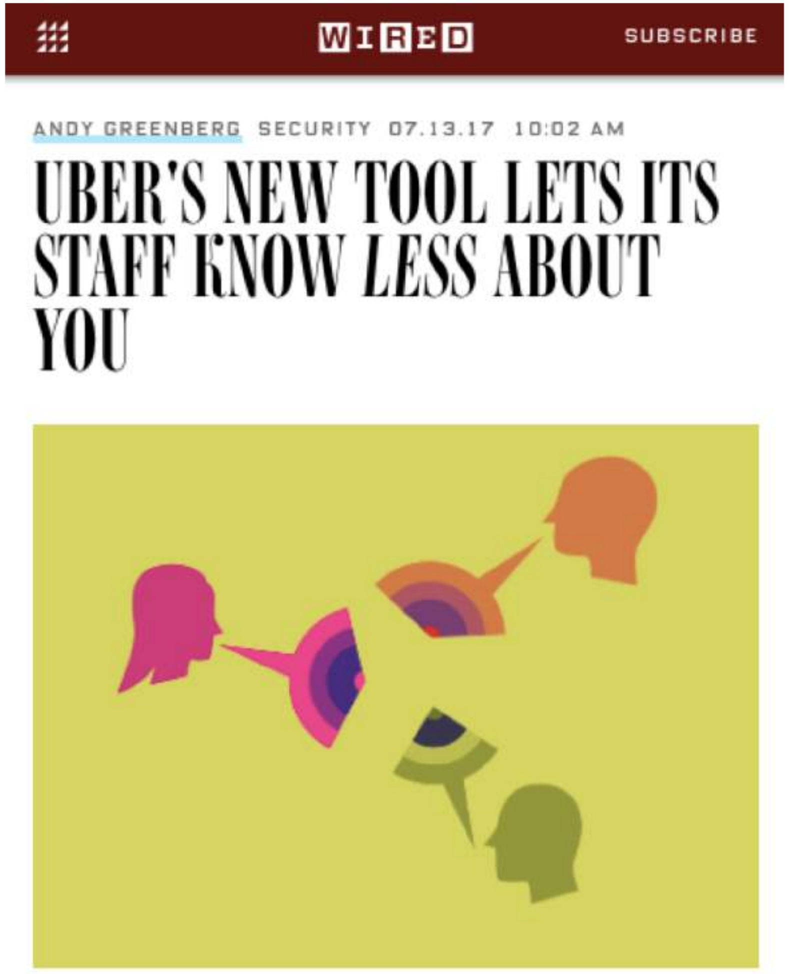
Optio: Privacy-Preserving Machine Learning

- Optio provides automatic differential privacy guarantees
  - Rewriting and verifying analytics and ML pipelines
  - Type system to enforce privacy policies


Untrusted Analyst-Specified
Shared Learning Pipelines
Optio
ML / Analytics Primitives
Composition Primitives
Privacy Type System
Distributed Execution Framework

Real-world Deployment at Uber

- Ongoing **deployment** for analytics
  - Differential privacy
  - GDPR
- Plans for public-facing systems
- Open-source release: https://github.com/uber/sql-differential-privacy



ANDY GREENBERG SECURITY 07.13.17 10:02 AM

UBER'S NEW TOOL LETS ITS STAFF KNOW *LESS* ABOUT YOU

Kara

A Privacy-Preserving Tokenized Data Market for Medical Data

Oasis Labs Berkeley UNIVERSITY OF CALIFORNIA ETH Zürich Stanford HEALTH CARE

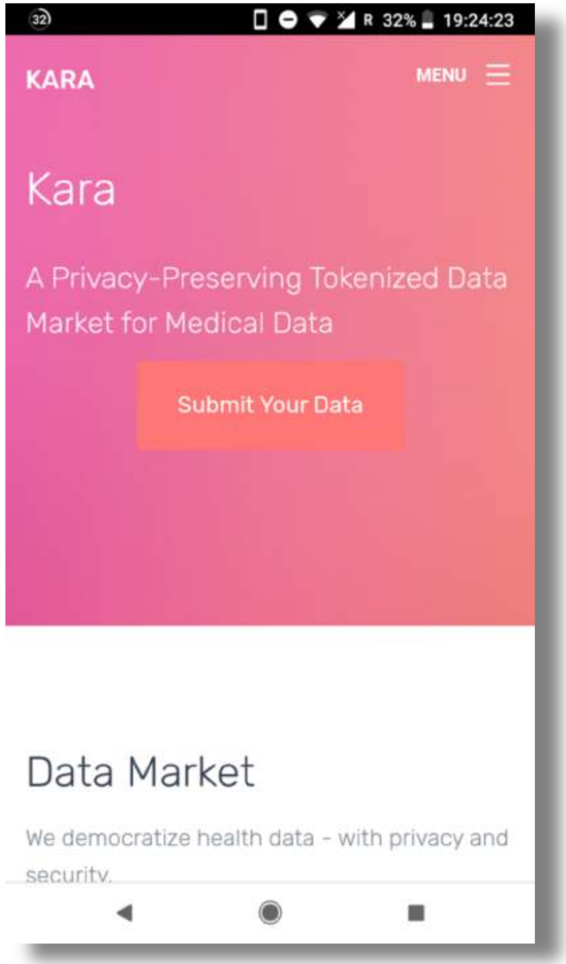
Medical data is locked in "Data Silos".

Goal: Incentivize doctors and patients to share data and improve medical research!

“

Meet Kara!

- **Kara** is a privacy-preserving tokenized data market
- **Easy, fast and secure way** for doctors and patients to **earn tokens by sharing data**
- Data is stored **securely and privately** in Oasis Blockchain Platform
- Researchers, doctors, industry can look for certain diseases / categories and **pay to train their models with privacy-preserving machine learning**



KARA

Kara

A Privacy-Preserving Tokenized Data Market for Medical Data

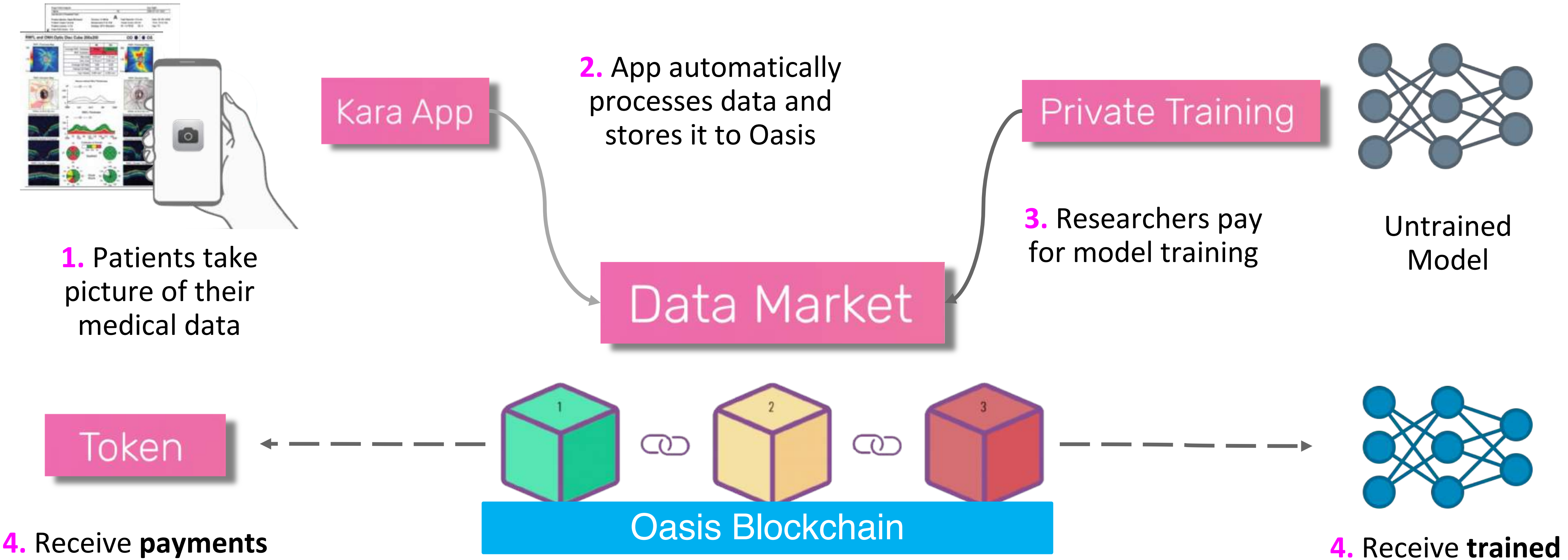
Data Market

We democratize health data - with privacy and security.

How it works

Doctors / Patients

Researchers



1. Patients take picture of their medical data

2. App automatically processes data and stores it to Oasis

3. Researchers pay for model training

Untrained Model

4. Receive **payments**

4. Receive **trained** model

Privacy-preserving smart contracts serve as business logic

Nick Hynes, Raymond Cheng, Noah Johnson, David Dao, Dawn Song. "**A Demonstration of Sterling: A Privacy-Preserving Data Marketplace**" in VLDB'18 (Demo Track)

David Dao, Dan Alistarh, Claudiu Musat, Ce Zhang. "**DataBright: Towards a Global Exchange for Decentralized Data Ownership and Trusted Computation**"

Oasis: Example use cases

Private escrow

Tokens

Prediction market

Regulatory compliance
(enterprise)

Privacy-preserving
machine learning

Personalized medicine

Decentralized exchange

Collaborative analytics

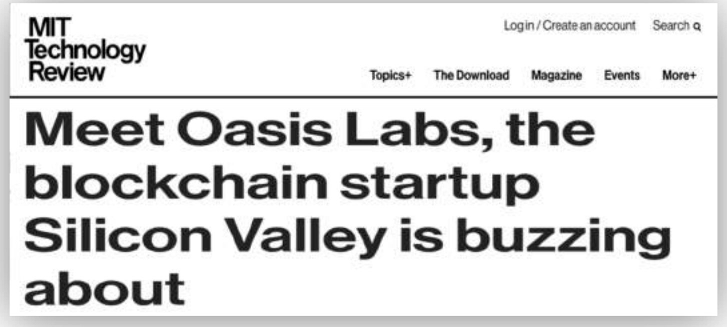
Blind auction

Portfolio manager

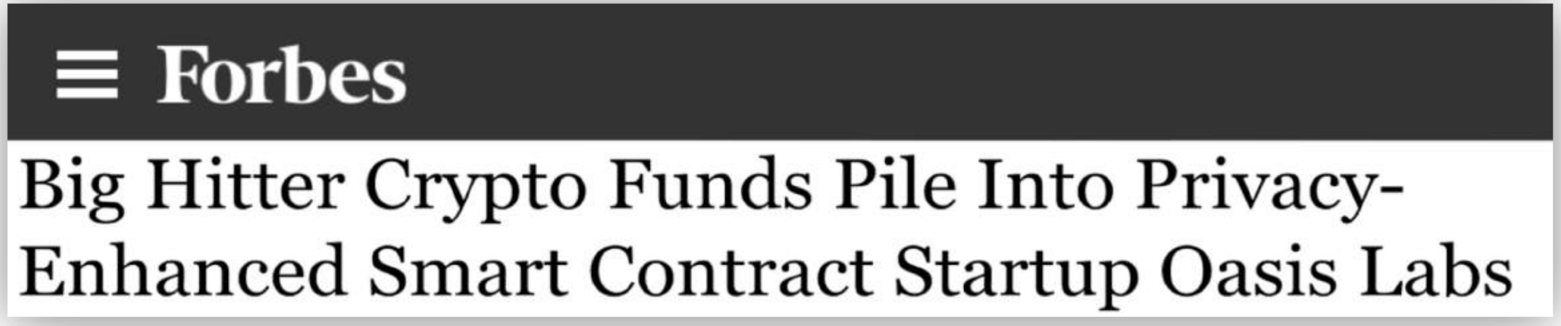
Credit scoring

Blockchain games
(e.g. Poker, Cryptokitties)

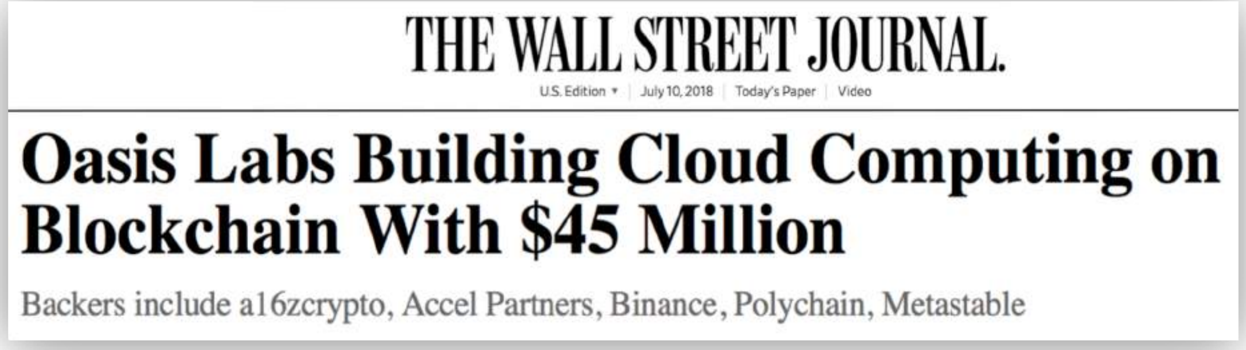
Oasis Labs Just Launched!



Meet Oasis Labs, the blockchain startup Silicon Valley is buzzing about

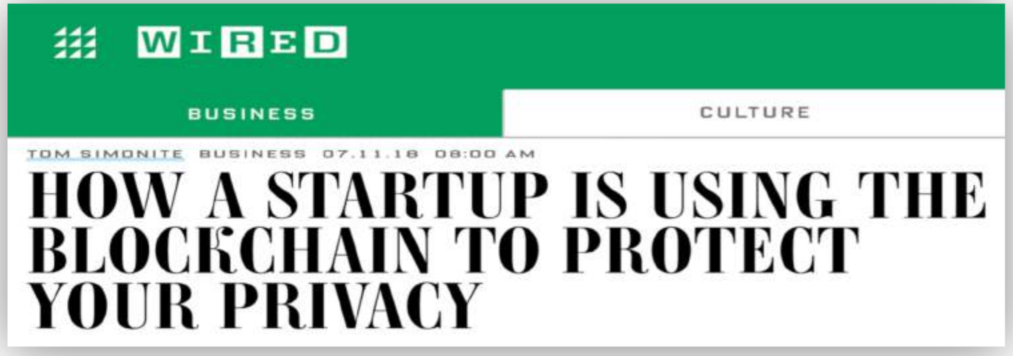


Big Hitter Crypto Funds Pile Into Privacy-Enhanced Smart Contract Startup Oasis Labs



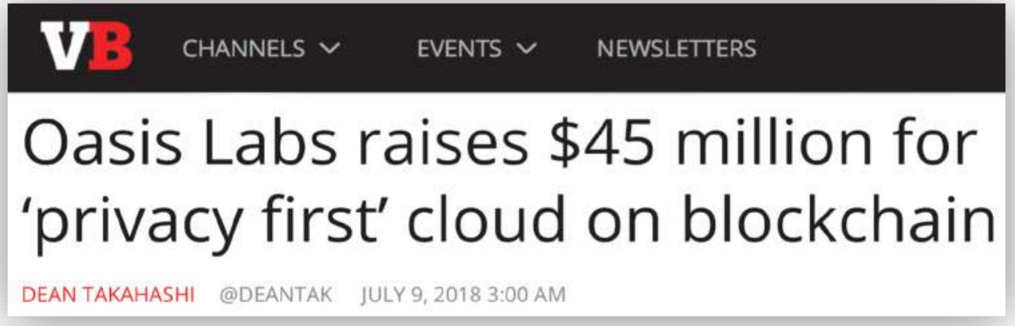
Oasis Labs Building Cloud Computing on Blockchain With $45 Million

Backers include a16zcrypto, Accel Partners, Binance, Polychain, Metastable



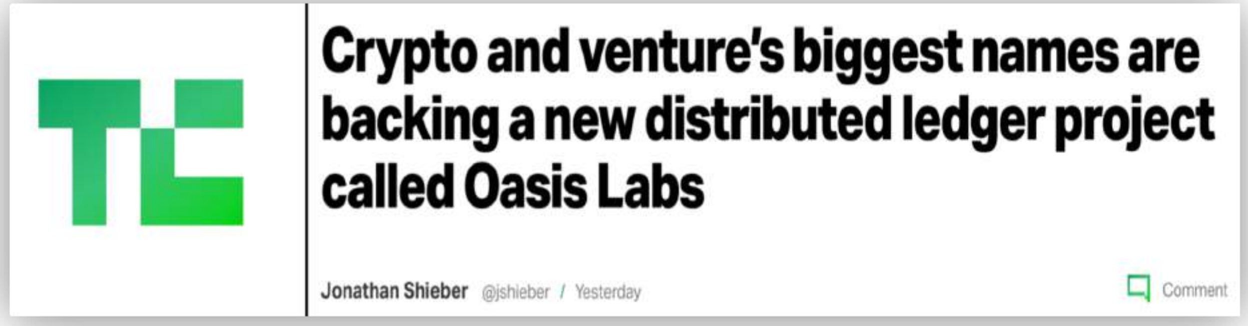
TOM SIMONITE BUSINESS 07.11.18 08:00 AM

HOW A STARTUP IS USING THE BLOCKCHAIN TO PROTECT YOUR PRIVACY



Oasis Labs raises $45 million for 'privacy first' cloud on blockchain

DEAN TAKAHASHI @DEANTAK JULY 9, 2018 3:00 AM



Crypto and venture's biggest names are backing a new distributed ledger project called Oasis Labs

Jonathan Shieber @jshieber / Yesterday

Oasis Testnet

Interested in building an application on Oasis?

Join our private testnet!

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