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Do not put all eggs in one basket:

Securing your wallet with threshold cryptography

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Outline

- (wallet) security in cryptocurrency
- What is threshold cryptography
- State-of-the-art of threshold cryptography
- Applications

Cryptocurrency

>$ 381 B

The market capitalization of Bitcion is > $381 B

9000
70 x(>$1 B)

more than 70 had a market cap exceeding $1 billion

Cryptocurrency (wallet) security

>$ 381 B

The market cap of Bitcion is > $381 B

$ 2.66 B

$2.66 Billion has been stolen since 2012

70 x(>$1 B)

more than 70 had a market cap exceeding $1 billion

>46 Hacked

Since 2012, at least 46 cryptocurrencies have been hacked

List of Hacked Cryptocurrencies

Bitcoin's Biggest loss

At the beginning of 2014, Mt Gox was handling 70% of Bitcoi's transactions.

In Feb. 2014, Mt. Gox lost about 740,000 bitcoins (6% of all bitcoin in existence at the time)
due to a "leak" in the wallet.

DATE	EXCHANGE	CAUSE OF HACK	AMOUNT STOLEN (USD)
2022, January 17	Crypto.com	Unknown	$34 million
2021, December 11	AscendEX	Obtained access to hot wallet	$80 million
2021, December 5	BitMart	Obtained access to hot wallet	$150 million
2021, August 19	Liquid	Obtained access to hot wallet	$97 million
2021, April 29	Hotbit	Obtained access to hot wallet	Nil
2020, December 23	Livecoin	Compromised system/servers	Unknown
2020, December 21	EXMO	Obtained access to hot wallet	$4 million
2020, December 1	BTC Markets	Internal staff error/mistake	270,000 user's private details
2020, September 25	KuCoin	Data leak	$275 million
2020, July 11	Cashaa	Malware	$3.1 million
2020, June 29	Balancer	Vulnerability in protocol	$500,000
2020, April 19	Lendf.me	Bugs and Re-entrancy attack	$24.5 million
2020, April 19	Uniswap	Bugs and Re-entrancy	$500,000

https://cryptosec.info/exchange-hacks/
https://www.hedgewithcrypto.com/cryptocurrency-exchange-hacks/

Loss of key = loss of money ☹

A transaction in bitcoin looks like

Tr_1 :

Alice sends
$100 to Bob

h=hash (Tr_1)

Signature (sk_A, h)

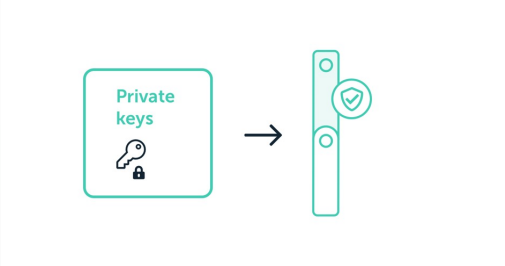
Signature is the standard ECDSA proposed by NIST

The private key sk_A is the only secret that Alice uses to generate this transaction

Lessons Learned

In cryptocurrency, we need to protect the private key

- **Cold Wallet:** a hardware wallet only stores and protects your **private key.**

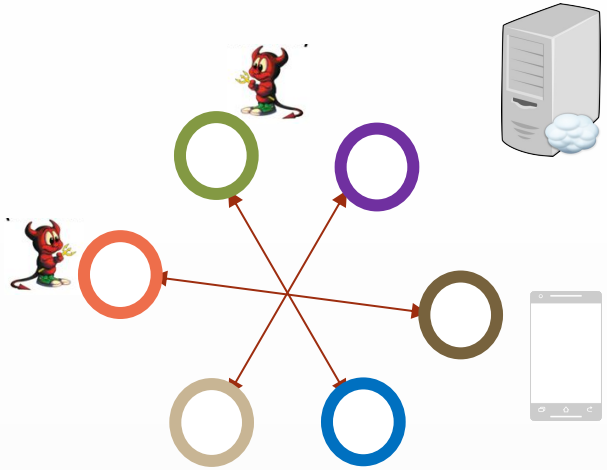


- **Threshold Cryptography:** Distribute the trust

Threshold Cryptography

-Do not put all you eggs in one basket

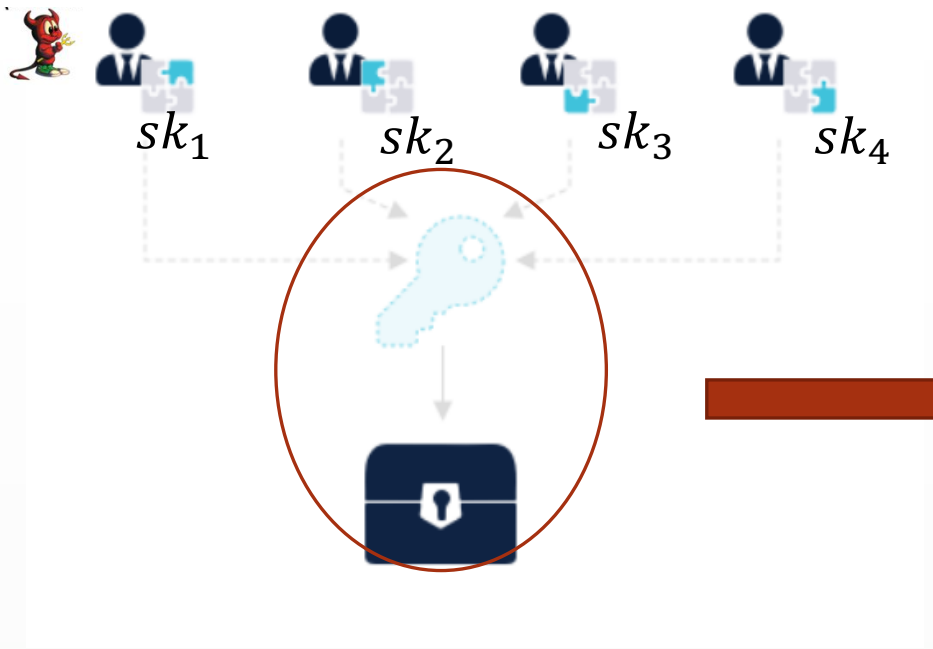
How to address
single-point
of failure ?



The threshold approach

Yvo Desmedt. 1987. Society and group-oriented cryptography: A new concept.

Threshold signature in cryptocurrency



- Ex. At least 2 of the 4 partis could generate the signature
- Need cryptography tools
  - Homomorphic encryption (HE)
  - Oblivious Transfer
  - and so on

Threshold Cryptography Project at NIST

- Upcoming call for standardization of threshold schemes
  - ECDSA(related to cryptocurrency), EdDSA
  - RSA, EC-KE, etc.

https://csrc.nist.gov/projects/threshold-cryptography

A short Summary

- In cryptocurrency, loss of the private key = the loss of money
- We need to protect the private key to reduce the risk
- Threshold signature (e.g. ECDSA) helps to distribute the trust

State-of-the-art of Threshold Cryptography

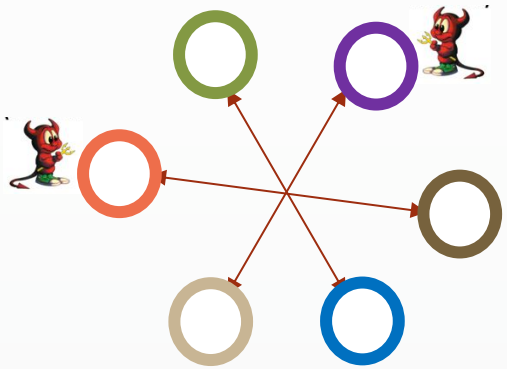
- **R**esearch: Paillier, CL, JL, OT
- **I**ndustry: ZenGo, Unbounded, Coinbase, etc.
- **G**overnment: NIST

We focus on Threshold ECDSA

- ECDSA
  - Digital Signature Standard using Elliptic Curve Cryptography
  - Widely deployed in cryptocurrency, such as Bitcoin etc.

single-points
of failure ?

- Threshold ECDSA
  - Protect the key by sharing it among n parties
  - Such that no fewer t users (here, t is called the threshold) could generate a valid ECDSA signature

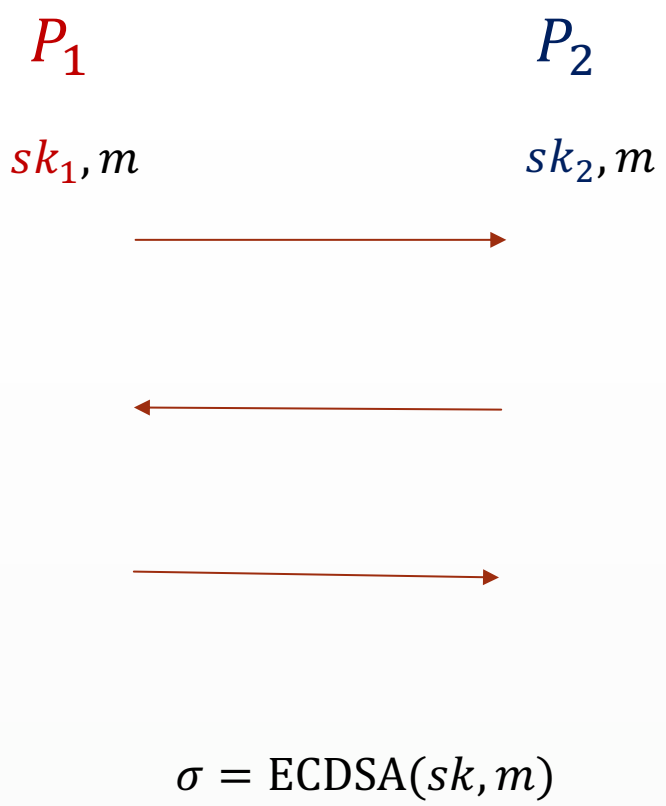


The threshold approach

Threshold Signature (with threshold $t = 2$)

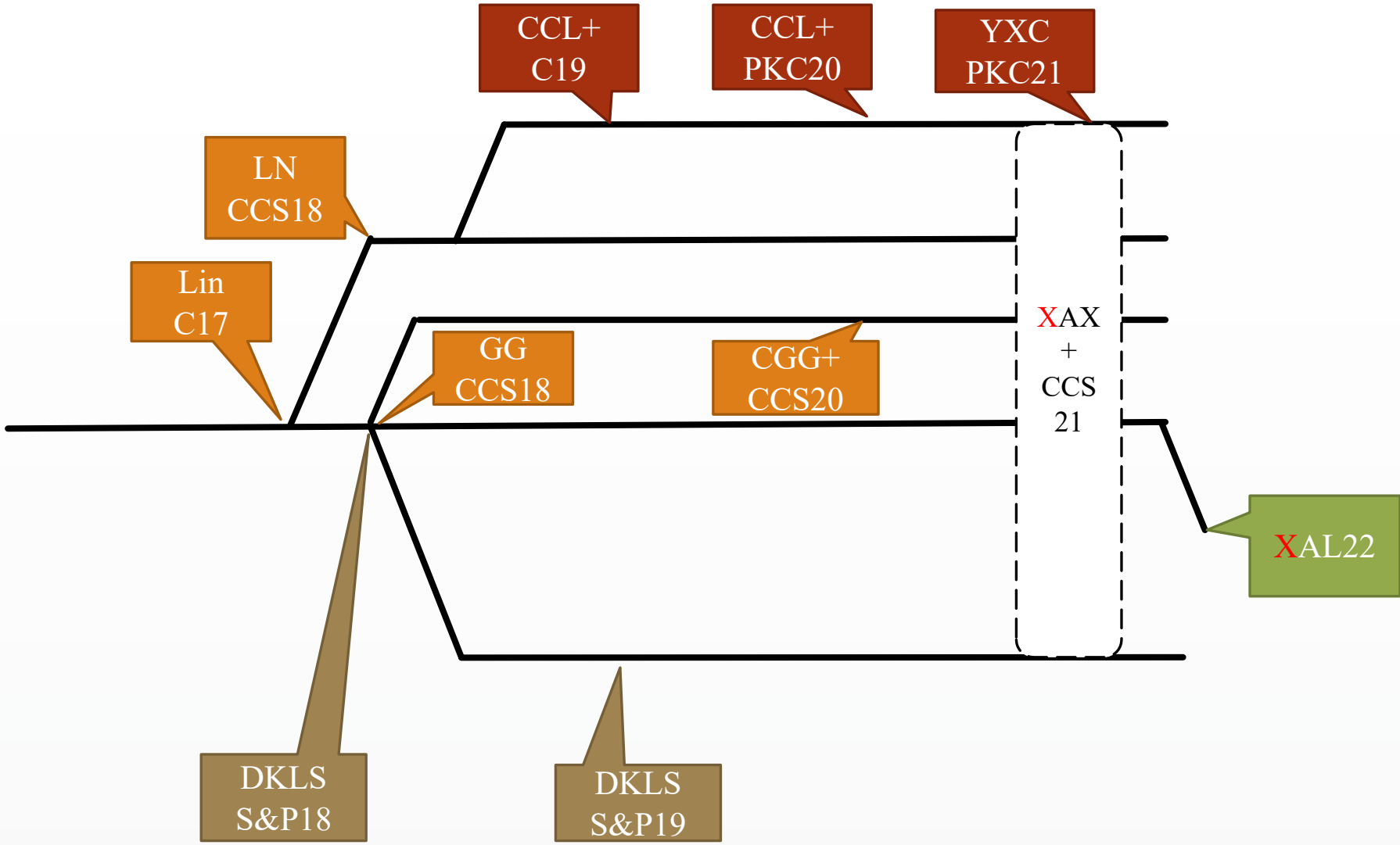
- **KeyGen:** The signing key is secretly shared across n parties
- **Interaction:** The t parties may collaborate to generate the signature.

- **Correctness:** sign a message in a threshold manner
- **Security:**
  - Any P_i can not forge signature alone, or learn anything on sk



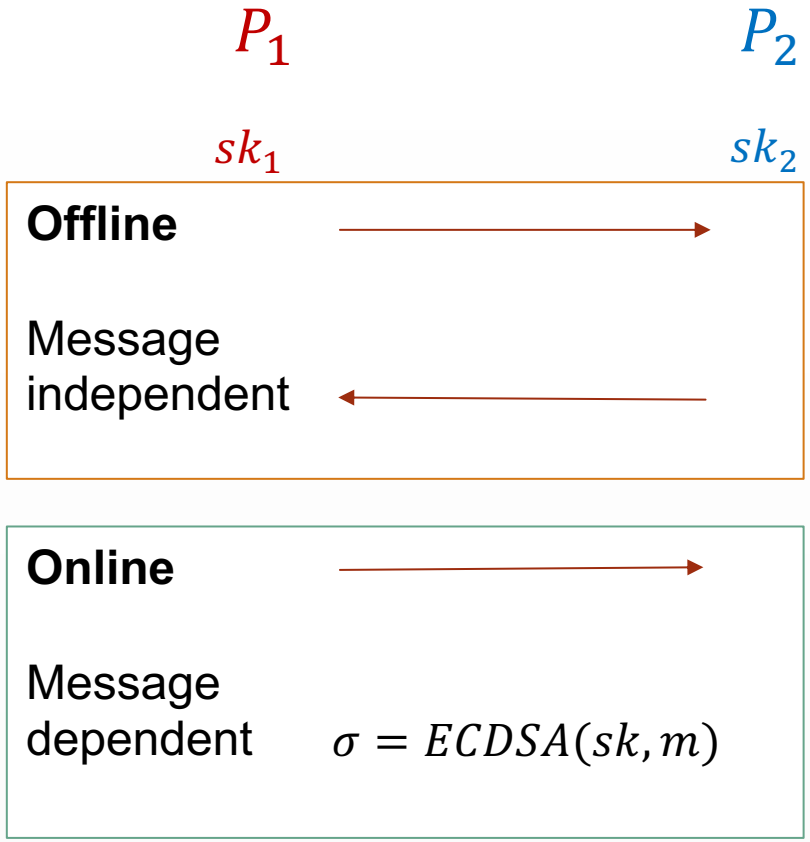
State-of-the-art in **R**esearch

- Homomorphic Enc: CL
- Homomorphic Enc: Paillier
- Homomorphic Enc: JL
- Oblivious Transfer (OT)



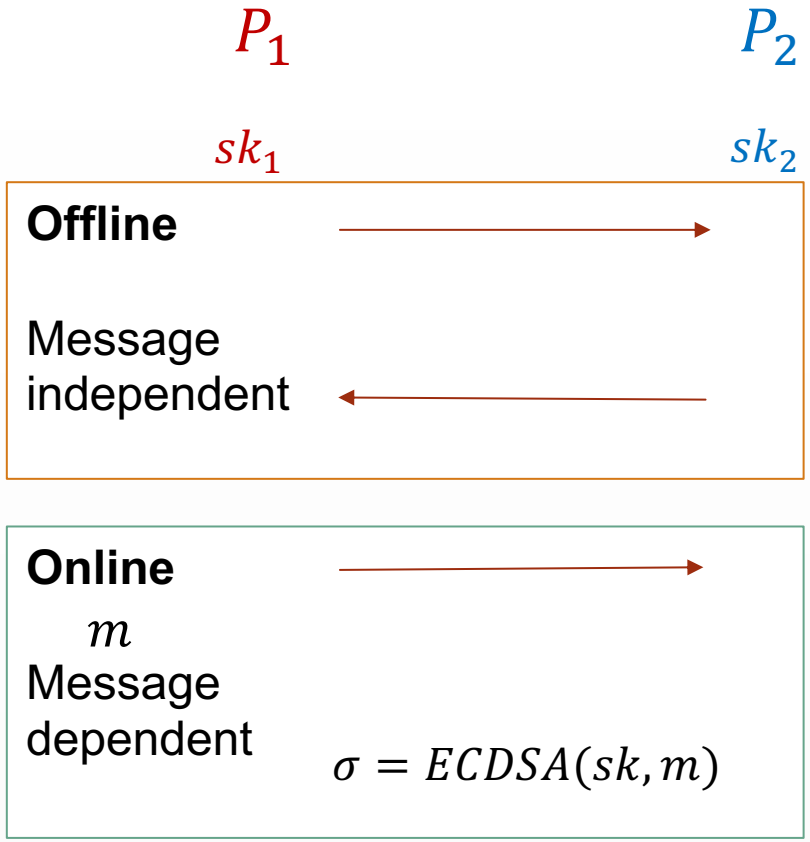
Previous works

- According to the message (that we would like to sign) is needed or not,
- Offline: Message independent
- Online: Message dependent
- Online cost is less, the better



Previous works （ in case t =2 ）

Schemes	Offline	Online
[Lin17, CCL+19]	Enc	Dec
[LN18]	2*MtA	MtA
[GG18, CCL+20,YXC21]	4*MtA	Fast
[DKLS18]	2~3*MtA	Optimal
[CGG+20, DKLS19]	4*MtA	Optimal



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Costly

Paillier	~10ms	~1KB
CL	~200ms	~200B

Multi-to-Add protocol

Paillier	~240ms	~9KB
CL	~1200ms	~2KB
OT	cheap	~90KB

What we could do, and have done

Schemes	Offline	Online
[Lin17,CCL+19]	Enc	Dec
[LN18]	2*MtA	MtA
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?	1*MtA	Optimal

Haiyang Xue, Man Ho Au, Xiang Xie, Tsz Hon Yuen, Handong Cui: Efficient friendly Two-party ECDSA. ACM CCS 2021

What we could do, and have done

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[CGG+20, DKLS19]	4*MtA	Optimal
Our work: 2ECDSA	1*MtA	Optimal

Haiyang Xue, Man Ho Au, Xiang Xie, Tsz Hon Yuen, Handong Cui: Efficient friendly Two-party ECDSA. ACM CCS 2021

State-of-the-art in Industry

ZenGo X

Multi-party ECDSA

build passing License GPL v3

This project is a Rust implementation of {t,n}-threshold ECDSA (elliptic curve digital signature algorithm).

Threshold ECDSA includes two protocols:

- Key Generation for creating secret shares.
- Signing for using the secret shares to generate a signature.

ECDSA is used extensively for crypto-currencies such as Bitcoin, Ethereum (secp256k1 curve), NEO (NIST P-
curve) and much more. This library can be used to create MultiSig and ThresholdSig crypto wallet. For a full

https://github.com/ZenGo-X/multi-party-ecdsa

State-of-the-art in Industry

Coinbase

The generic protocol interface pkg/core/protocol/protocol.go. T
implementation.

- Cryptographic Accumulators
- Bulletproof
- Oblivious Transfer
  - Verifiable Simplest OT
  - KOS OT Extension
- Threshold ECDSA Signature
  - DKLs18 - DKG and Signing
  - GG20 - DKG
  - GG20 - Signing
- Threshold Schnorr Signature
  - FROST threshold signature - DKG
  - FROST threshold signature - Signing

https://github.com/coinbase/kryptology

Government-NIST

2023 2024? 1st 2025? 2ed

Contribute to NIST's Threshold standardization?

Presentation from NIST at CRYPTO 2022

Applications

- Threshold signature could be used to enhance security whenever a signature is used.

- Direct applications
  - Blockchain-based cryptocurrency
  - NFT (non-fungible token)

- Authentication
  - Certificate authentication (CA)
  - etc.

Take-home points

- In cryptocurrency, we should protect the private key
- Threshold cryptography (especially, ECDSA) can provide a high level of private key protection
- It involves several cryptographic tools (homomorphic enc, oblivious transfer, etc.)
- More efforts should be done to standardize threshold schemes.

Thank you
Q & A

Emails to haiyangxc@gmail.com are welcome.

Reference

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- [CCL+20] Guilhem Castagnos, Dario Catalano, Fabien Laguillaumie, Federico Savasta, and Ida Tucker. 2020. Bandwidth-efficient threshold ECDSA. PKC 2020
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- [DKLS18] Jack Doerner, Yashvanth Kondi, Eysa Lee, and Abhi Shelat. Secure two-party threshold ECDSA from ECDSA assumptions. IEEE S&P 2018
- [DKLS19] Jack Doerner, Yashvanth Kondi, Eysa Lee, and Abhi Shelat.Threshold ECDSA from ECDSA assumptions: the multiparty case. IEEE S&P 2019
- [GG18] Rosario Gennaro and Steven Goldfeder. Fast multiparty threshold ECDSA with fast trustless setup. ACM CCS 2018
- [LN18] Yehuda Lindell and Ariel Nof. Fast secure multiparty ECDSA with practical distributed key generation and applications to cryptocurrency custody. ACM CCS 2018
- [Lin17] Yehuda Lindell. Fast secure two-party ECDSA signing. CRYPTO 2017

Preliminary: Homomorphic Encryption

- Additive Homomorphic Encryption Scheme:

$$\mathrm{Enc}(m_1 + m_2) = \mathrm{Enc}(m_1) \oplus \mathrm{Enc}(m_2)$$

$$\mathrm{Enc}(a \cdot m) = \mathrm{Enc}(m)^a = a \odot \mathrm{Enc}(m)$$

Schemes	over	Message Space
Paillier	Z_{N^2} (N is RSA modulus)	Z_N
CL Encryption	Class group	Z_q ($=\#G$)

Paillier Encryption

- Let $N = pq$ be RSA modulus. Secret key: $\phi(N)$ public key : N

$$\mathrm{Enc}(m) = \mathrm{c} = (1 + \mathrm{N})^m \, r^N \; mod \; N^2$$

$$\mathrm{c}^{\phi(N)} = 1 + m \, \phi(N) N \;\; mod \; N^2$$

Oblivious Transfer (OT)

OT is a fundamental primitive of multiparty computation (MPC).