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KU LEUVEN

FACULTY OF ENGINEERING SCIENCE

COSIC

# Unlinkable Policy-Compliant Signatures for Compliant and Decentralized Anonymous Payments

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Input Output

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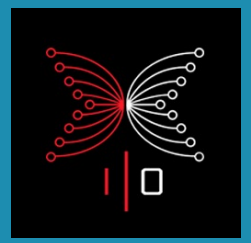

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PETS'24, Bristol, UK – July 9th

# Digital Signatures: An Equivalence of Written Signature

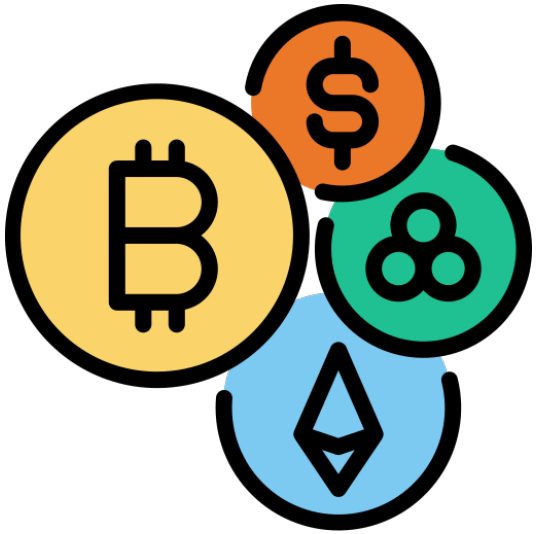

**Authentication**

**Integrity**

**Non-Repudiation**

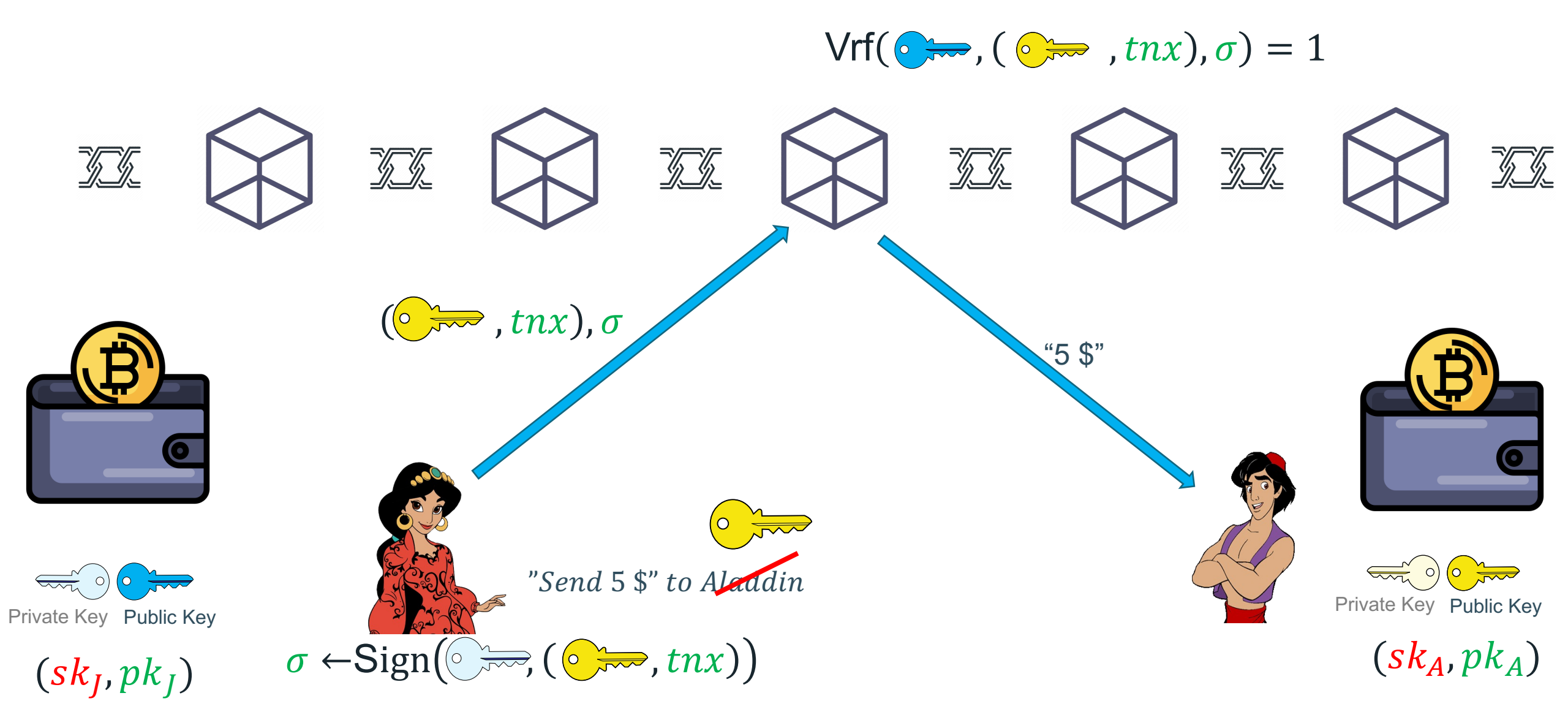
The main Goal: To bind a message to its author.

Digital Signatures are everywhere on the internet.

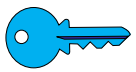


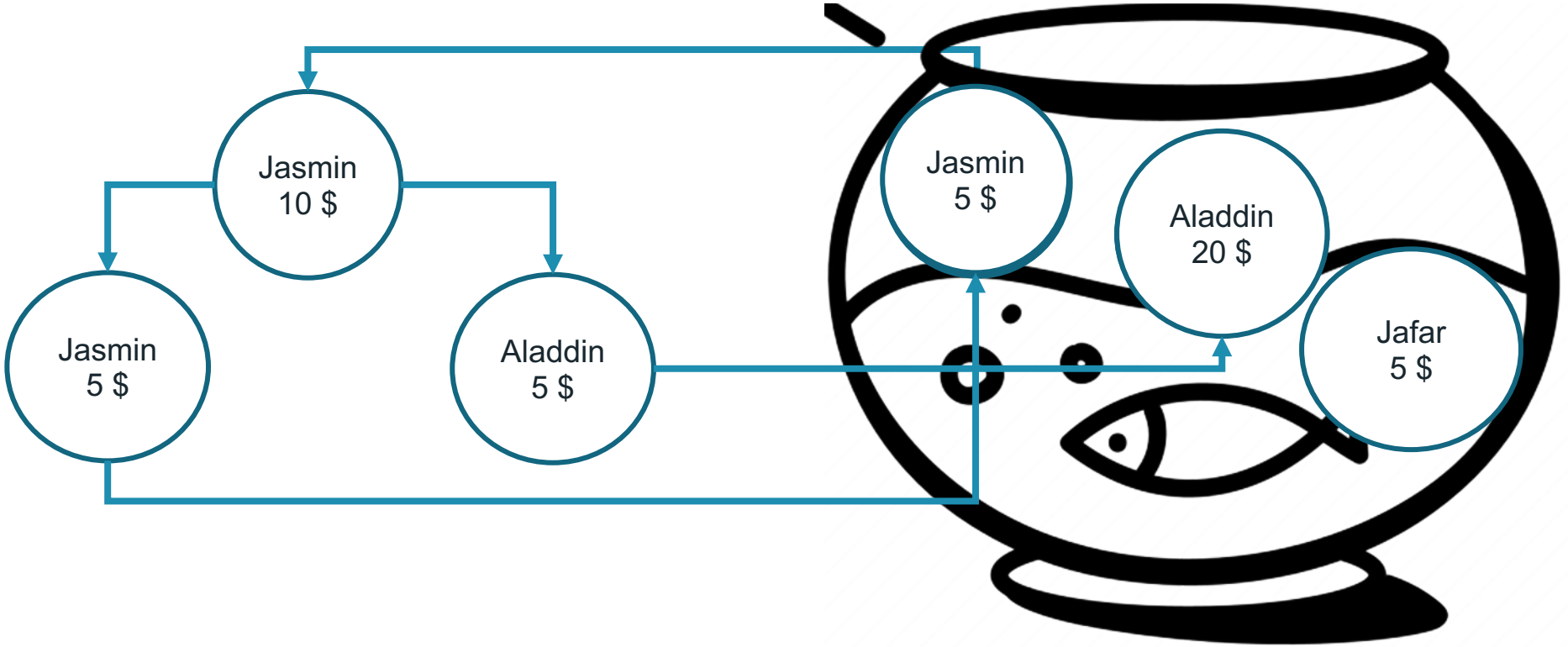
Especial focus on financial transactions.

# **Motivation:** UTxO-based cryptocurrencies



# **Motivation:** UTxO-based cryptocurrencies

Vrf(  , (  , $tnx$), $\sigma$) = 1



# Pseudonymity ≠ Anonymity

The PID of the **payee** and **payer** and the **value** in Bitcoin are publicly available!!

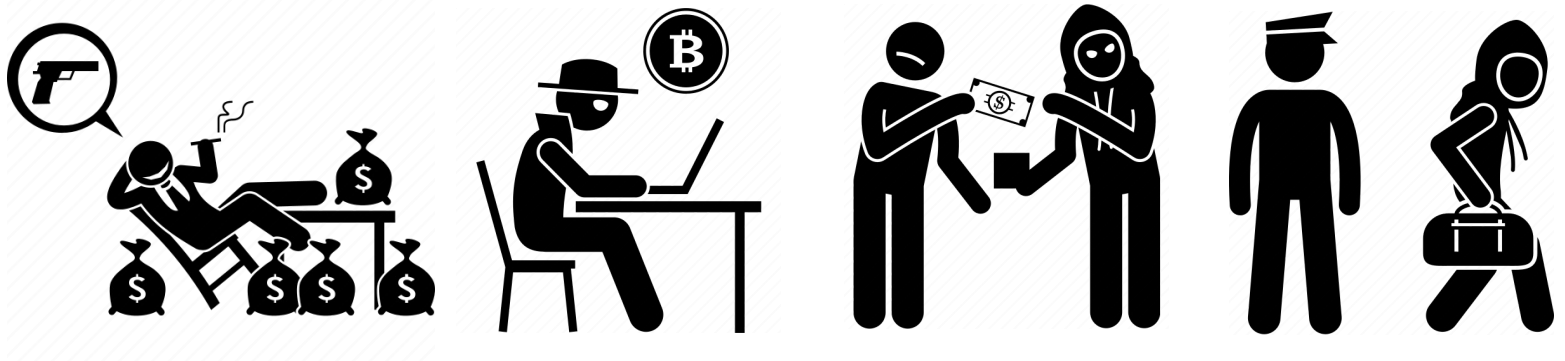
If your employer pays employee in Bitcoin?! All salaries are visible

Distributed anonymous payments (DAP).

The identity and the values are hidden.

Such cryptocurrencies can be used in an illegal context

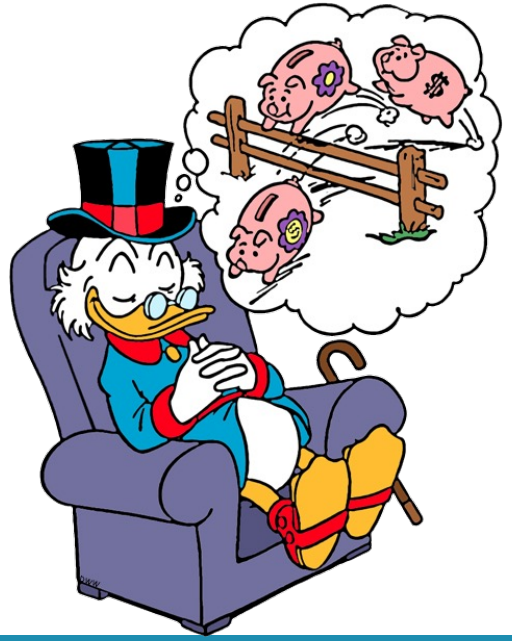
- Tax evasion
- Ransomware
- Drug trafficking
- Terrorist funding
- etc.

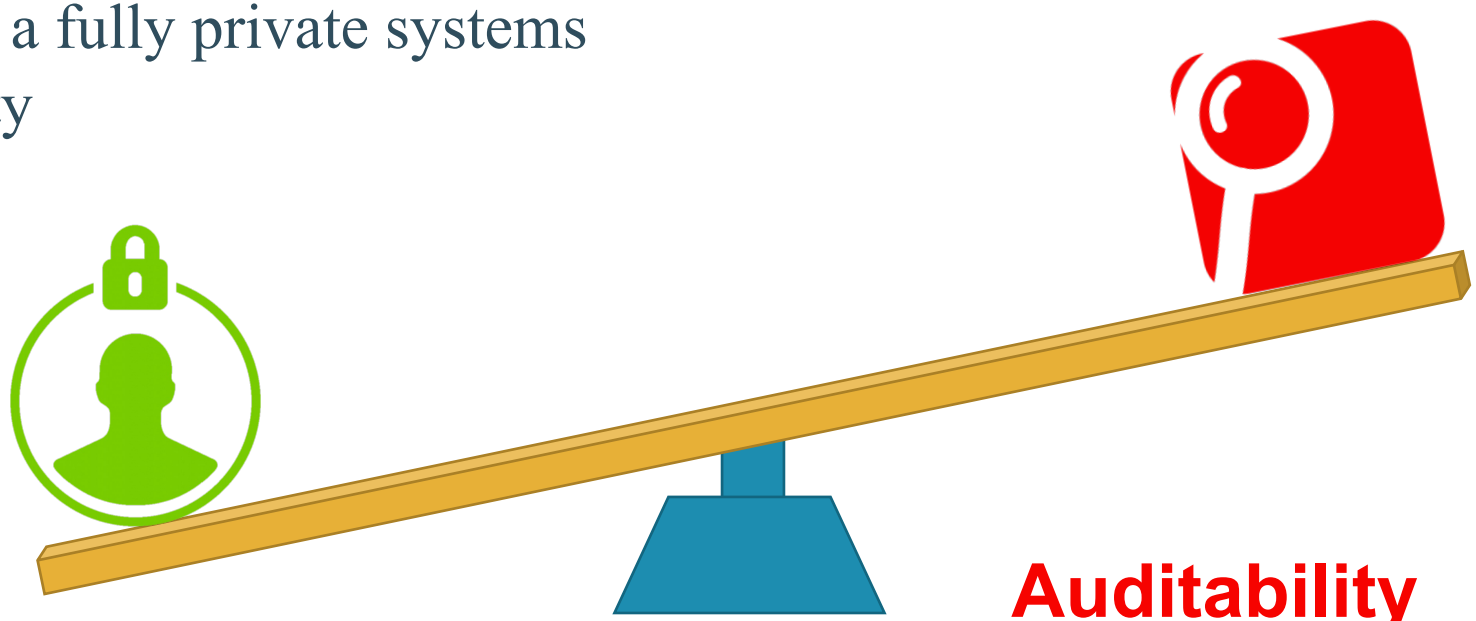


# Privacy vs. Accountability: In theory

## Privacy

- Users willing a fully private systems
- No traceability
- Unlinkability






## Auditability

- To prevent possible illicit activities
- To trace the suspicious actions

# Some Existing Solutions: Accountable Privacy

1. Public Key Encryption:

2. Threshold Encryption:

1- Prevention is better than cure!

2- How an auditor can be suspicious to a fully anonymous tnx?!

# Prevention vs. Detection:


**We are interested on:**
**Joint policy**

# Possible solution for UTxO-based systems:

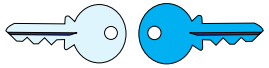
Policy

$((\text{key}, tnx), \sigma$

1 $\text{Vrf}(\text{key}, (\text{key}, tnx), \sigma) = 1$

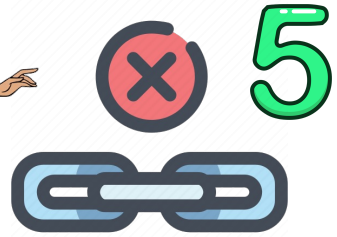
2 3 If $\text{Policy}(x_J, x_A) = 1$

4



Private Key Public Key

$(sk_J, pk_J, x_J)$



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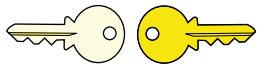


Private Key Public Key

$(sk_A, pk_A, x_A)$

# Some Possible Solutions: Related Cryptographic Primitives

| | 1<br>Unforgeability | 2<br>P/A-based | 3<br>Joint policy | 4<br>S/R privacy | 5<br>Unlinkability |
|---|---|---|---|---|---|
| **Digital Signatures** | + | − | ⊘ | ⊘ | ⊘ |
| **Attribute-based Signatures** | + | + | − | ⊘ | ⊘ |
| **Policy-based Signatures** | + | + | + | − | ⊘ |
| **Policy-Compliant Signatures** | + | + | + | + | − |

# Unlinkable Policy-Compliant Signatures:

It improves PCS [BMW21] from TCC'21.

Setup

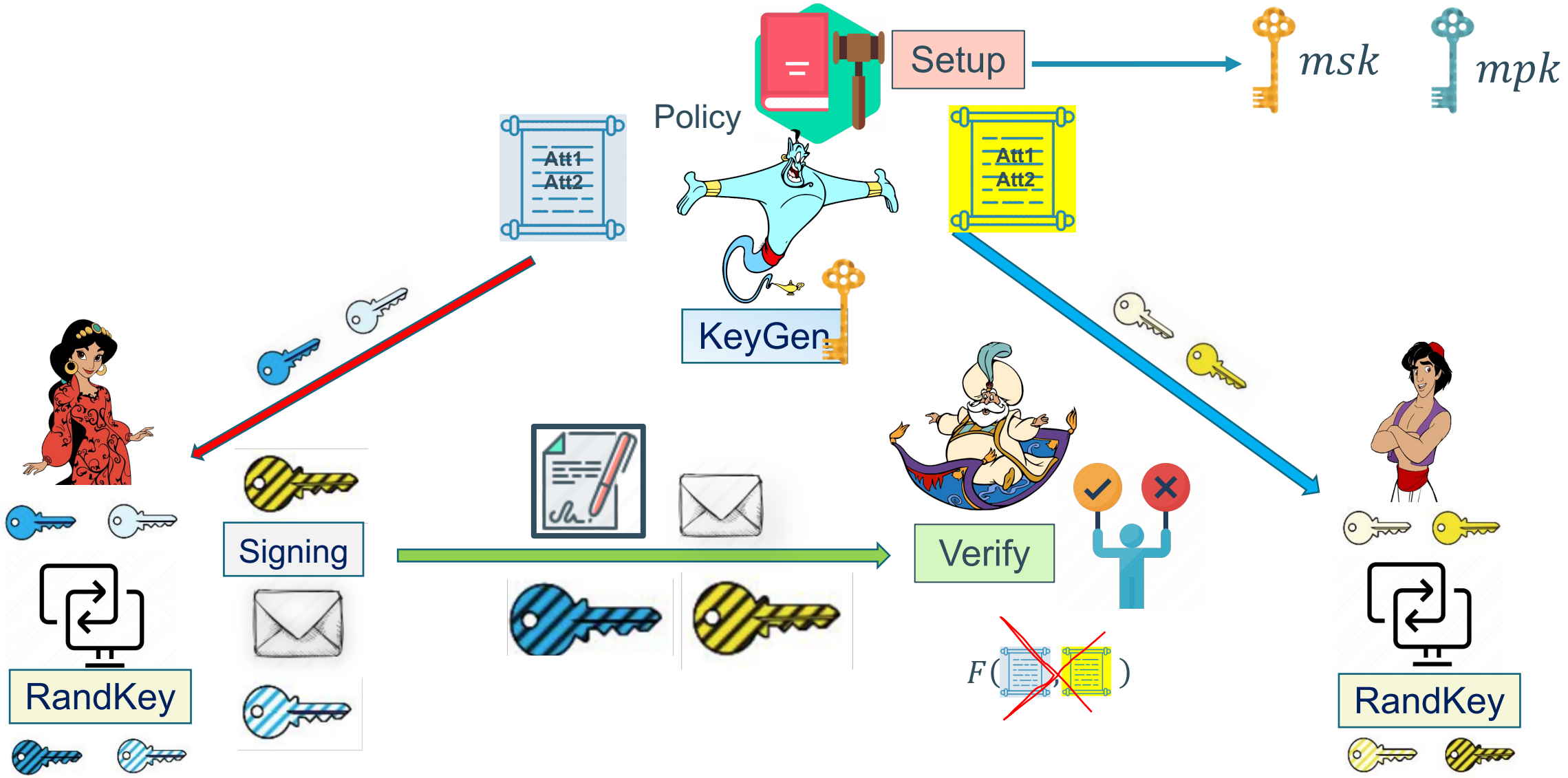
KeyGen

RandKey

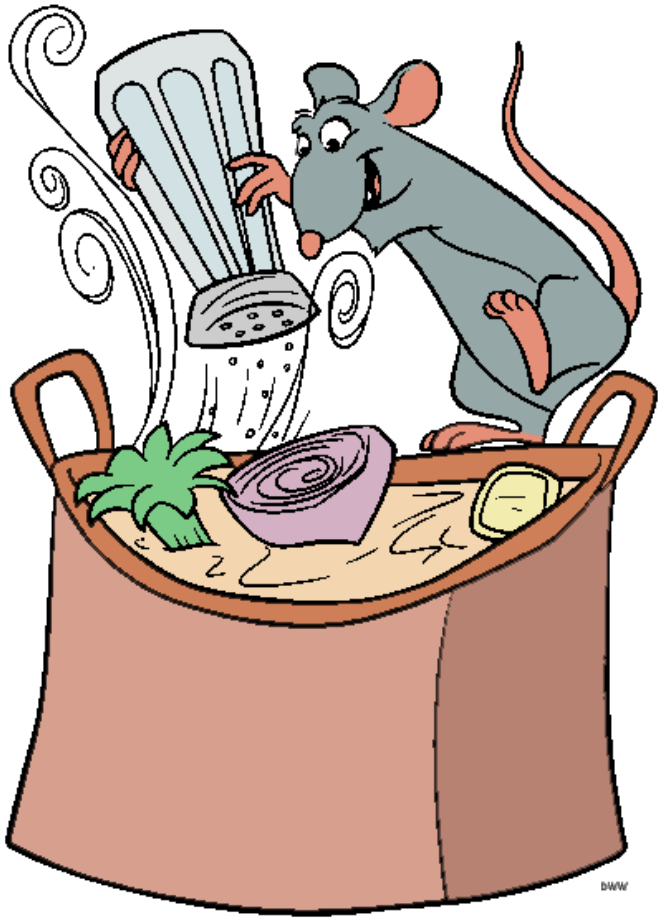
Signing

Verify

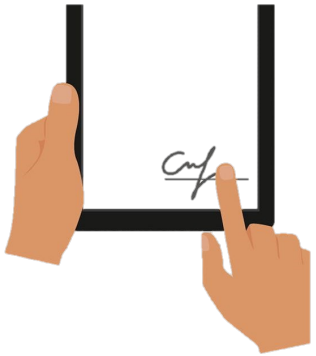
# Unlinkable Policy-Compliant Signatures:



# Main Ingredients:



Digital Signatures



Predicate-Only
Predicate Encryptions

Pseudo-Random Functions

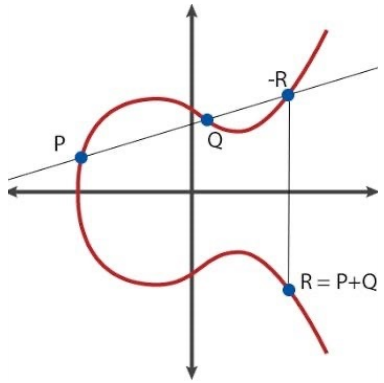
Zero-Knowledge proofs

# An Instantiation of Generic construction:

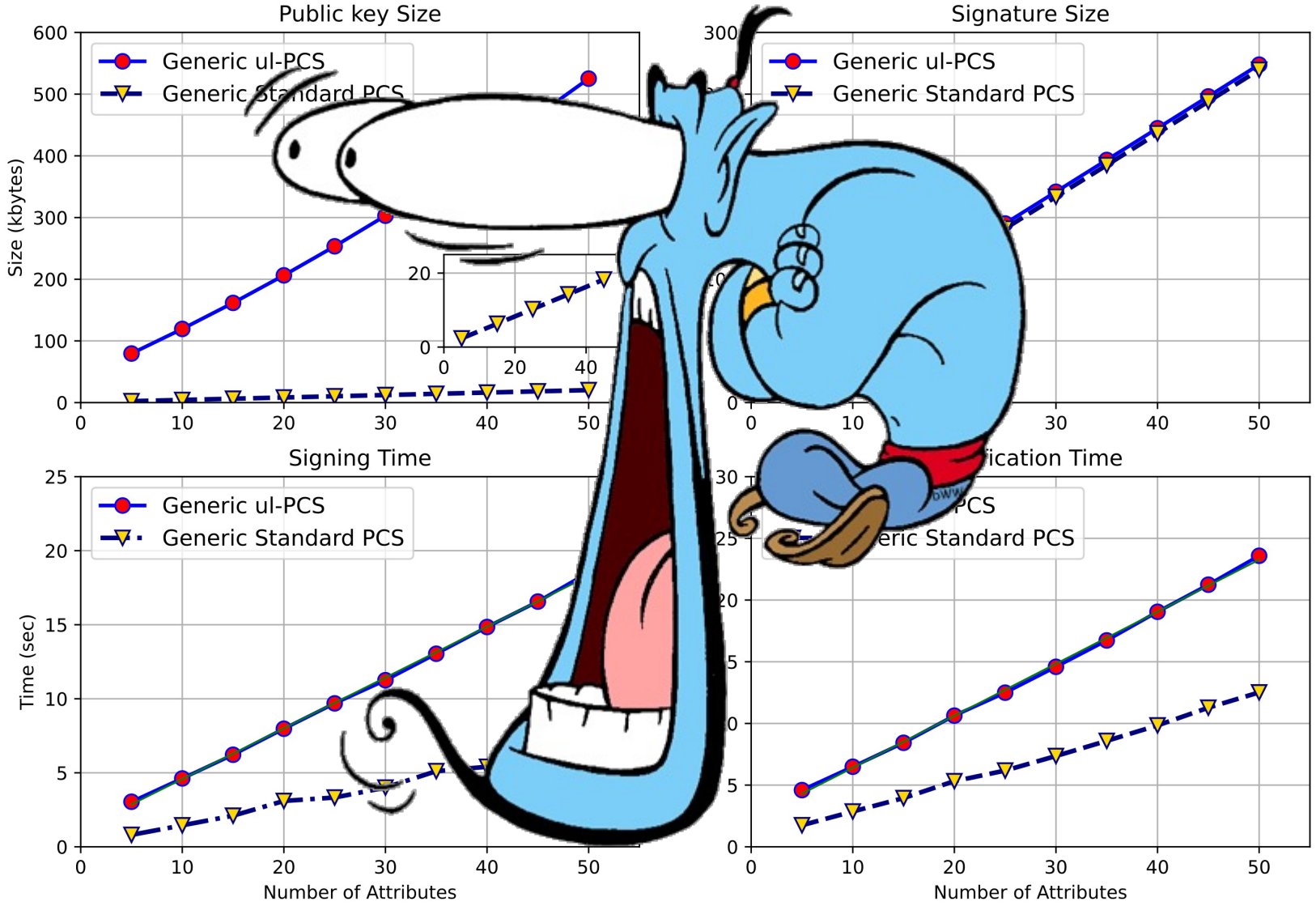
1. **Digital Signatures**
   - BLS signatures [BLS04] when message and signatures are public, else
     - Selectively Randomizable SPS and SPS-EQ in [FHS19]
     - Constant signature size (3 base group elements)
     - Groth-Sahai [GS08] proof system friendly
2. **Predicate-Only Predicate Encryptions**
   - Okamoto-Takashima [OT12]
     - Policy: Inner-products predicate functionalities
3. **Pseudo-Random functions**
   - Dodis-Yampolsky PRF [DY05]
4. **NIZK**
   - Sigma protocols [Sch89]: when the scalar is known
   - Groth-Sahai [GS08] proof systems: when all witnesses are group elements (batched version from ACM CCS'2017 [HHKRR17])
   - Bulletproof range-proofs [BBPWM18]

# Privacy is expensive?!

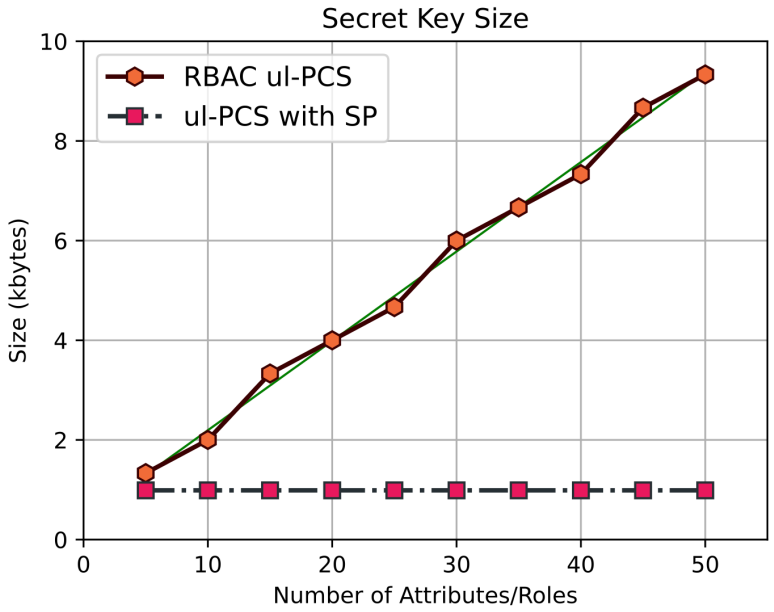
Ubuntu 20.04.2 LTS
an Intel Core i7-9850H CPU @ 2.60 GHz
with 16 GB of memory

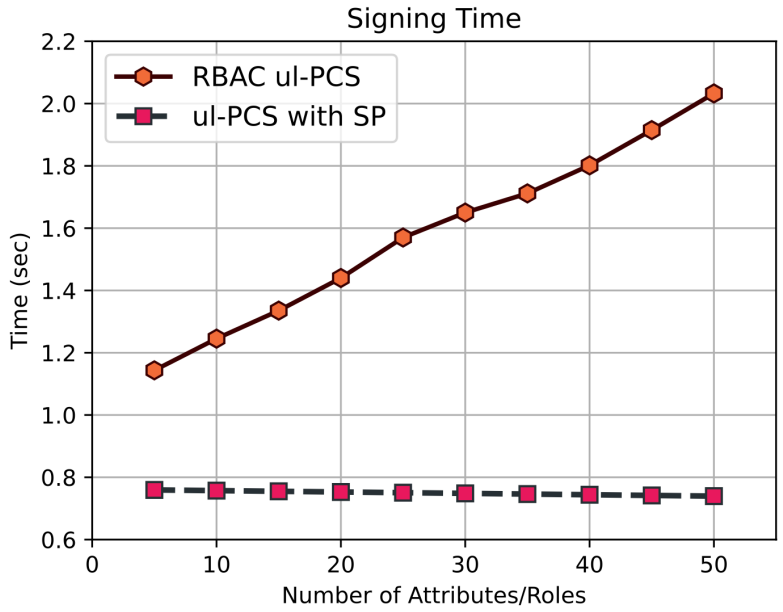



Charm-Crypto framework
BN254



# **Benchmarks:** Role-based and Separate Policies




| **Scheme** | KeyGen time (ms) | RandKey time (ms) | Verify time (ms) | pk size (kbytes) | $\sigma$ size (kbytes) |
|---|---|---|---|---|---|
| ul-PCS, role-based | 750 | 550 | 1 630 | 28 | 16 |
| ul-PCS, separable policies | 490 | 480 | 1 020 | 28 | 14.5 |

# Conclusion: What we didn't cover

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We formally define/prove 4 different security properties:

- Correctness
- Unforgeability
- Attribute-Hiding
- Unlinkablity

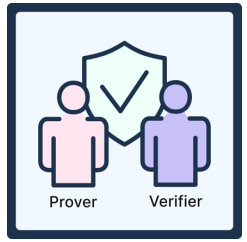
Details about more efficient alternatives:

- Role-based policies
- Separable policies

Detailed ZK instantiation for all proposed schemes.

Application to DAPs. Regulated One-Time Account.

- More applications.




# Potential Future Work:

- Minimize the needed trust to the central issuer.

- Design more efficient PO-PE → more efficient generic construction.

- Take a different approach with the same security properties. (Implement it using zk-SNARKs)

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# Thank You!

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