FAME: Fast Attribute-based Message Encryption

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Attribute-based Encryption

- Applications in a variety of settings:
  - network privacy [BBSBS09], pay-per-view broadcasting [TBEM08], health-record access control [APGLPR11, CDEN12], cloud security [SRGS12, verifiable computation [PRV12], forward-secure messaging [GM15], easy-to-use secure email [RAHZS16], ...

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- Not a surprise: Fine-grained control

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- Central issues:
  - Strong security guarantee
  - Fast operations
  - Desirable features

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- **Improve upon popular and state-of-the-art schemes in several ways**

Time to Upgrade!

- Ciphertext-policy ABE
  - Bethencourt, Sahai, and Waters, IEEE S&P, 2007
  - Our scheme: more secure, faster, lighter

ABE, *formally*

Attributes & Policies

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AgeGroup:Over65

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(Zipcode:90240 OR City:BeverlyHills)
AND (AgeGroup:18-25)

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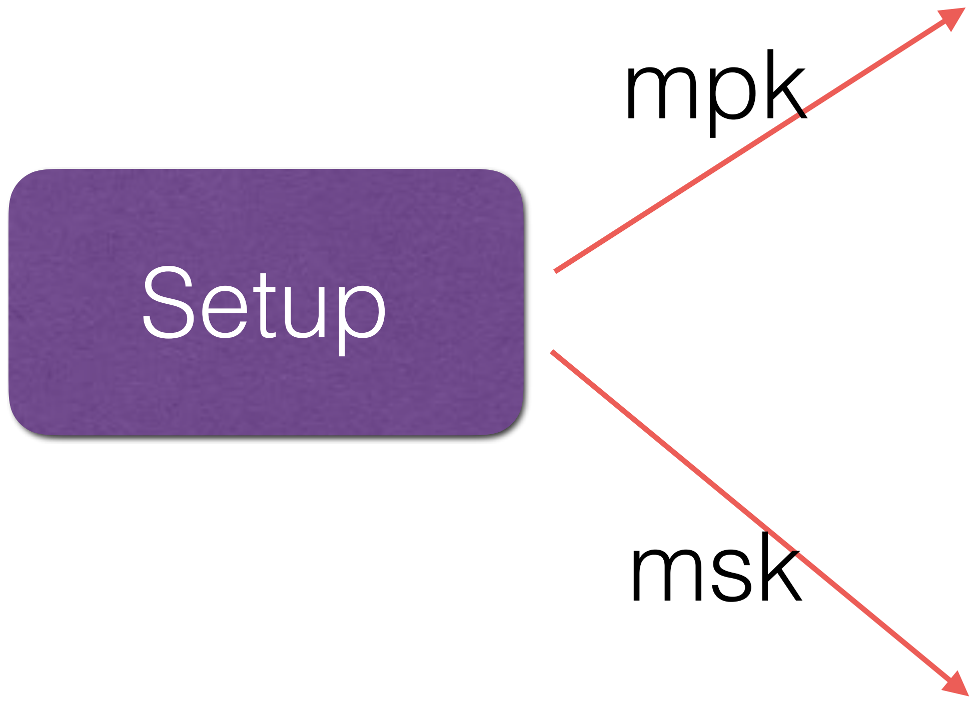

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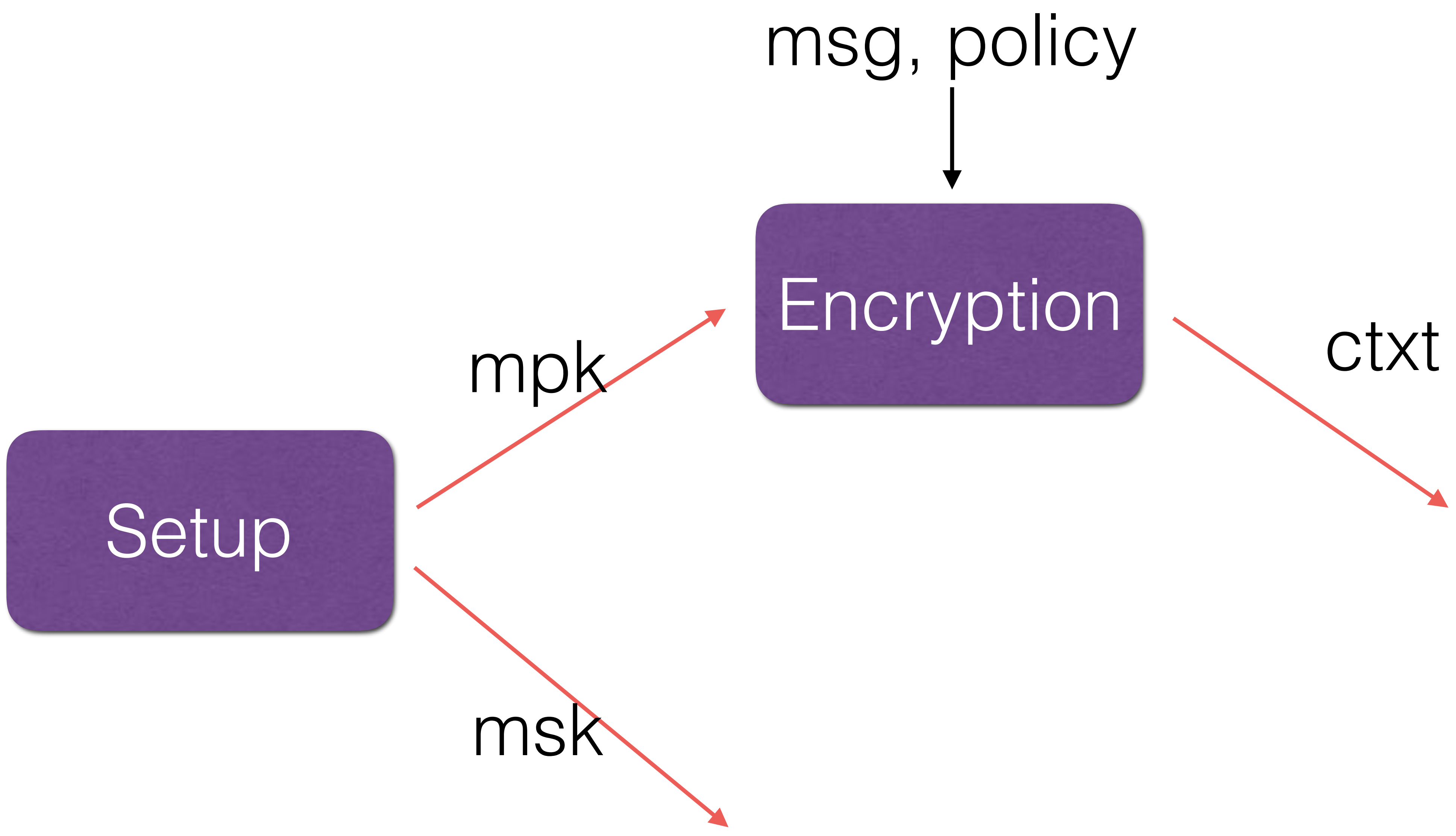

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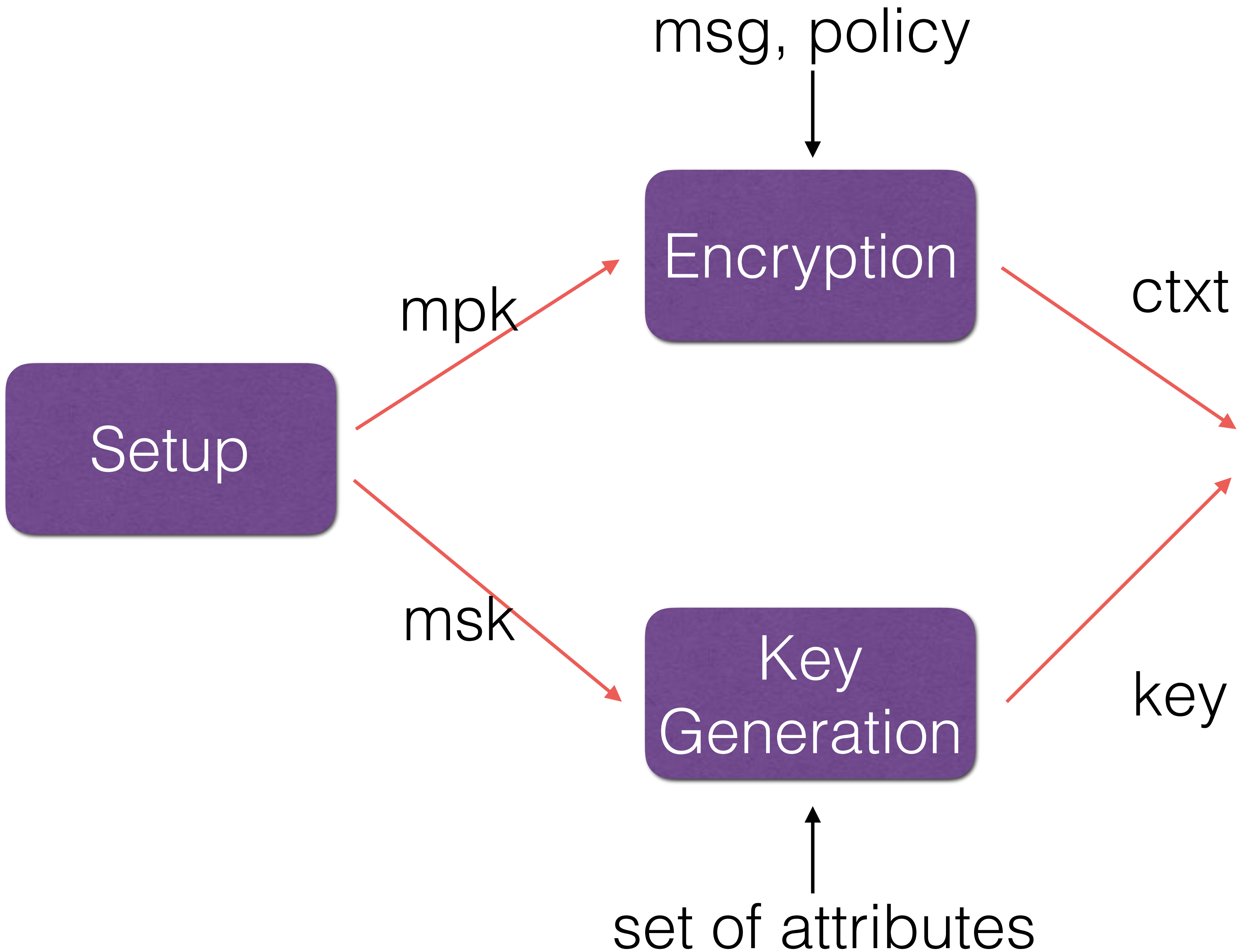

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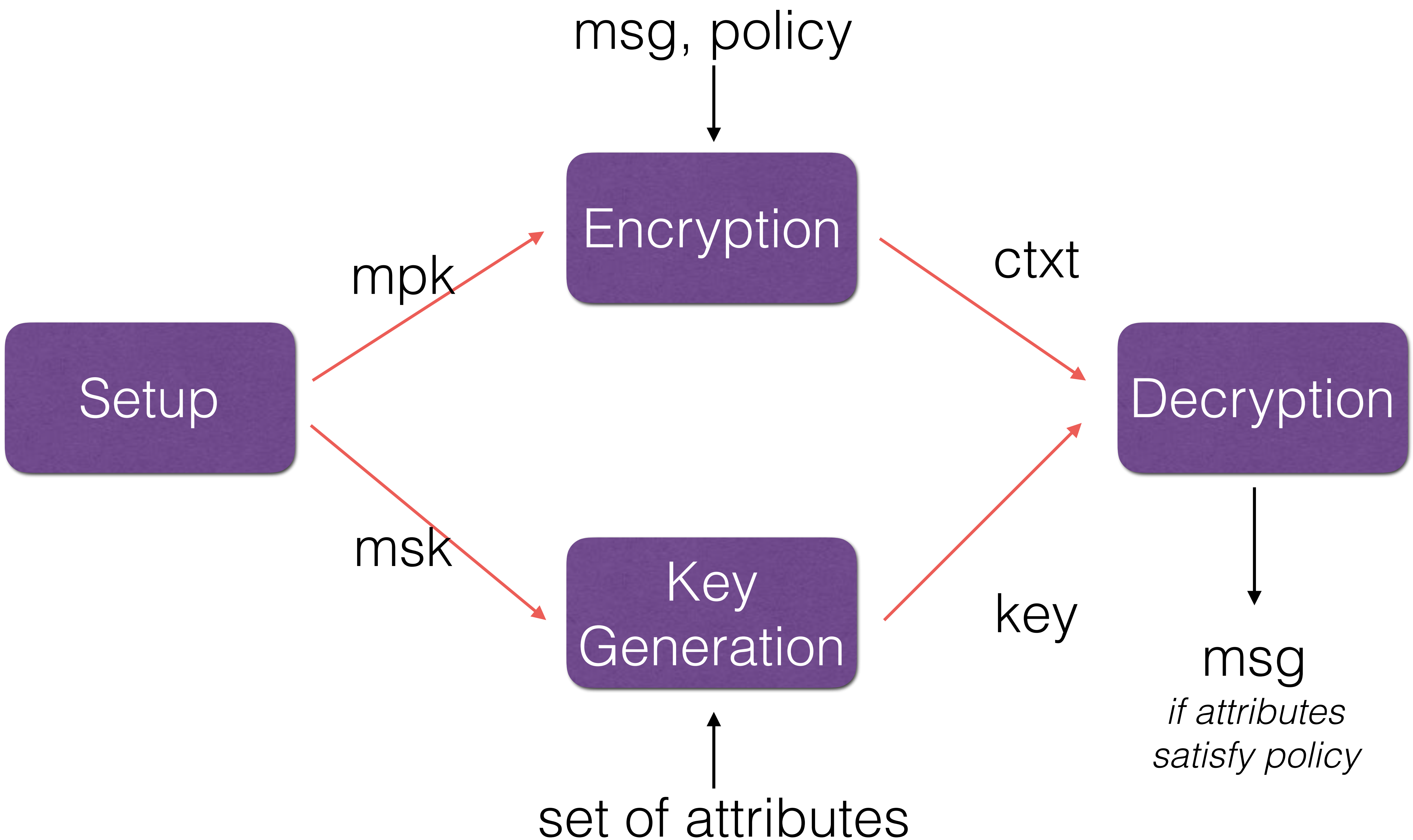

Properties, *we desire*

Unrestricted Policies & Attribute Sets

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- Our schemes: No restriction on size of attributes sets & policies

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- Our schemes: **arbitrary string** can be an attribute

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  - Prime-order asymmetric (Type-III)

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- Our work: 6 pairing operations

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- Hardness assumption
  - Decisional linear (DLIN) vs q-type

Designing, *our schemes*

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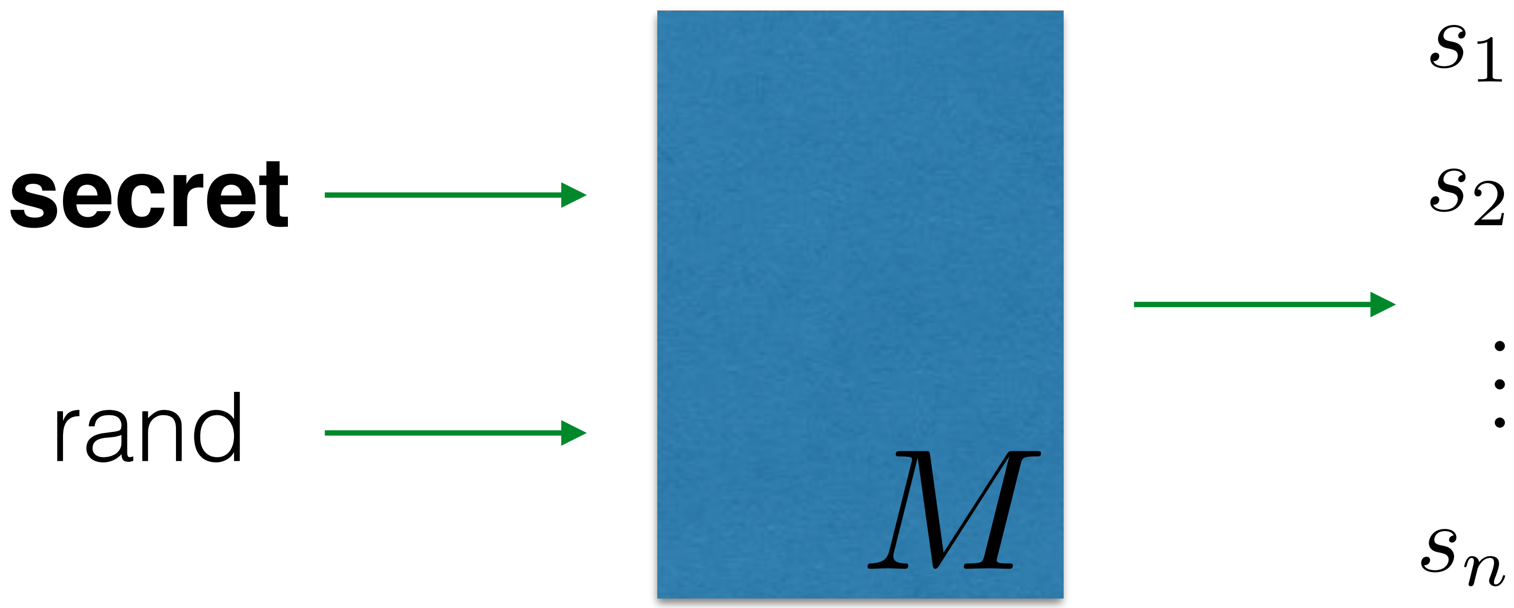
$$\left[\begin{array}{c} \\ \\ \\ \\ M \end{array}\right] \begin{array}{l} \xrightarrow{\pi} \mathsf{attr}_1 \\ \longrightarrow \mathsf{attr}_2 \\ \\ \\ \longrightarrow \mathsf{attr}_n \end{array}$$

Monotone Span Programs



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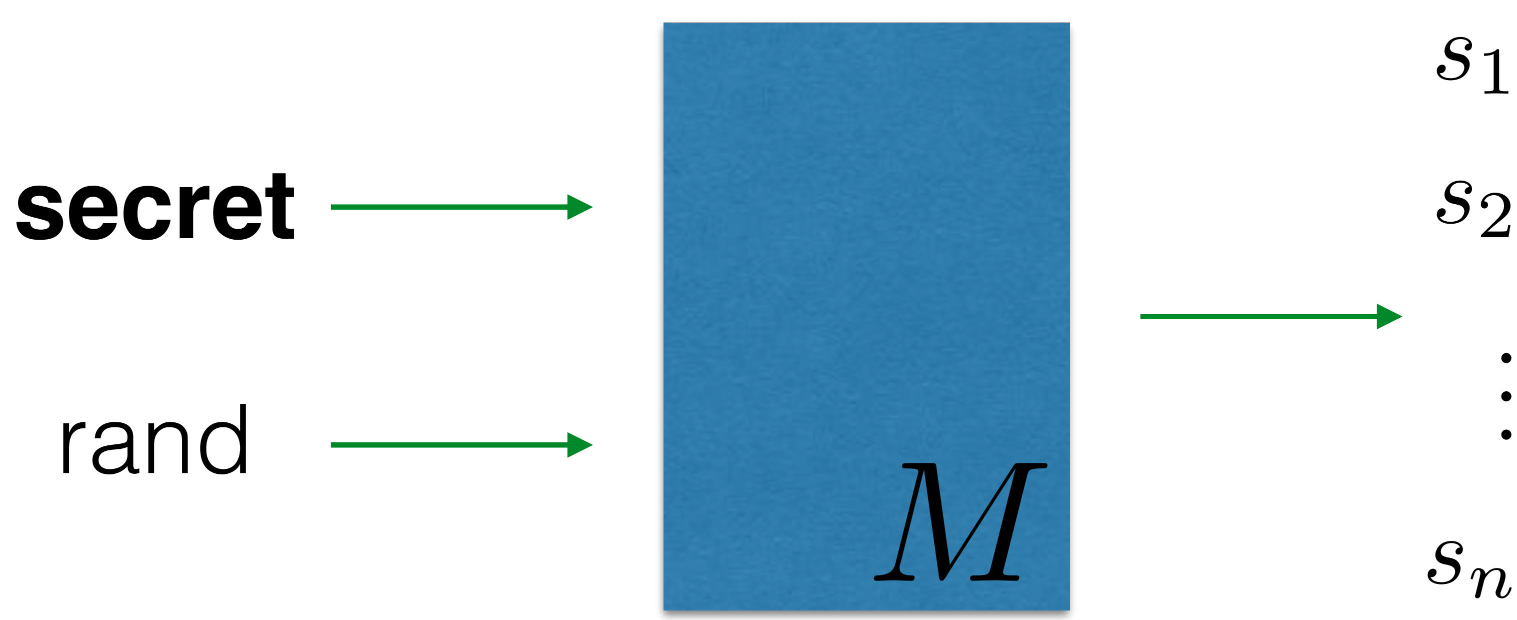

set of attributes

$S = \{\mathsf{attr}_1, \mathsf{attr}_5\}$ satisfies (M, π) $\xrightarrow[s_1,\, s_5]{\text{linearly combine}}$ **secret**

CP-ABE: High-level Design

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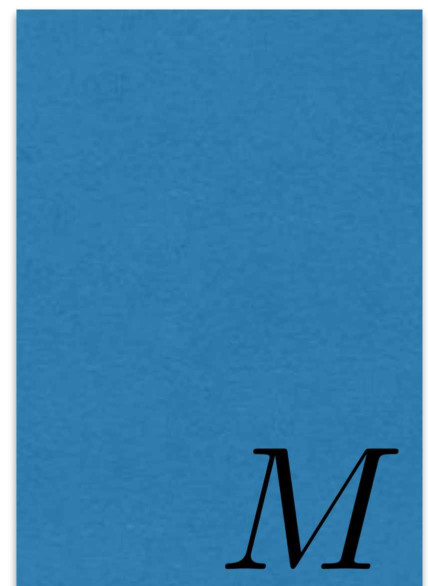

s_1

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$\vdots$

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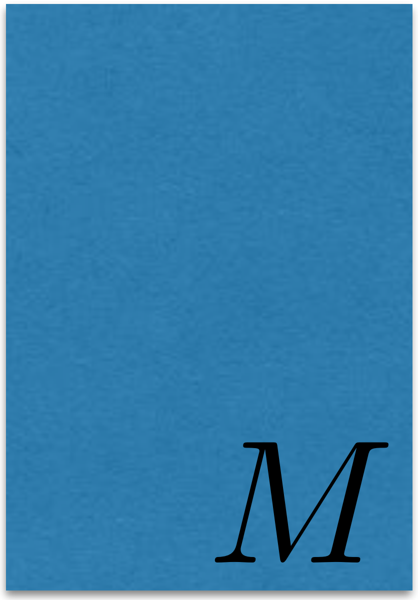

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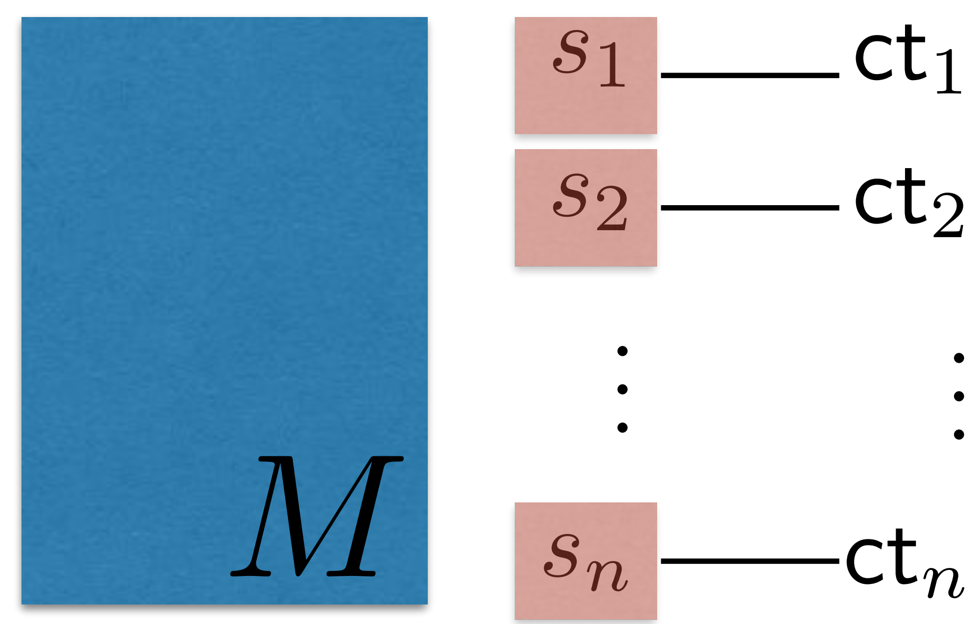

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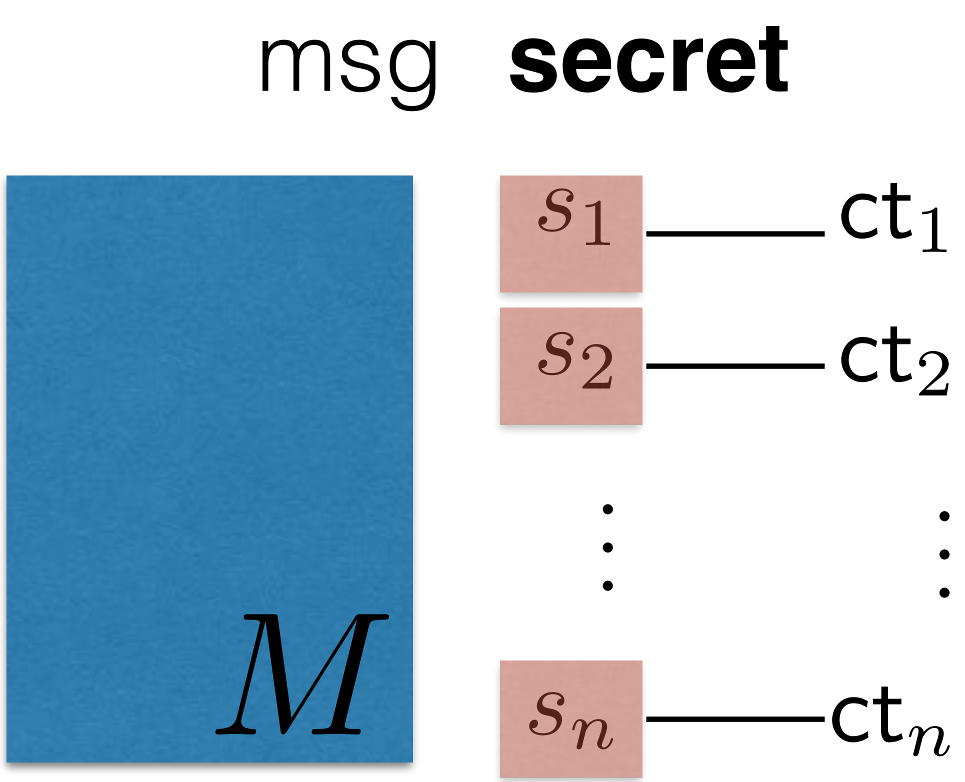

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Public key

Chen, Gay, and Wee [EC'15]

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- Small universe; Restrictions on policies
- Overcome problems *without compromising performance*
  - Perform better on most metrics

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- Use **H** to generate $[\mathbf{W}_x^\intercal \mathbf{A}]_1$

  How to generate $[\mathbf{W}_x \mathbf{B}]_2$ without explicit knowledge of $\mathbf{W}_x$

Goyal et al. KP-ABE [CCS'06]

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part of the public key $\qquad$ *master key has* t_x

g^{t_x} derived directly from **H**

so that t_x is not available

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$\mathbb{G}$ $\mathbb{H}$

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Associativity

Overcoming Problems

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Overcoming Problems

$\mathbf{W}_x^{\mathsf{T}}\mathbf{A}, \mathbf{W}_x\mathbf{B}$: through **H**?

$$\mathbf{H} \longrightarrow [\mathbf{W}_x^{\mathsf{T}}\mathbf{A}]_1$$

Overcoming Problems

$\mathbf{W}_x^{\mathsf{T}}\mathbf{A}, \mathbf{W}_x\mathbf{B}$: through **H**?

H $\longrightarrow [\mathbf{W}_x^{\mathsf{T}}\mathbf{A}]_1$

$[\mathbf{W}_x\mathbf{B}]_1$ without $\mathbf{W}_x$?

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Different approach: <u>generate keys with $[\mathbf{W}_x^\mathsf{T}\mathbf{A}]_1$, $\mathbf{B}$</u>

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Different approach: <u>generate keys with $[\mathbf{W}_x^\mathsf{T}\mathbf{A}]_1, \mathbf{B}$</u>

Keys have different structure vs CGW

Performance Benefit

Basis: $\boxed{([\mathbf{A}]_1, [\mathbf{b}^{\perp}]_1) \qquad ([\mathbf{B}]_2, [\mathbf{a}^{\perp}]_2)}$ $\mathbb{H}$

Each attr x: $\boxed{([\mathbf{W}_x^{\top}\mathbf{A}]_1, [\mathbf{W}_x^{\top}\mathbf{b}^{\perp}]_1) \qquad ([\mathbf{W}_x\mathbf{B}]_2, [\mathbf{W}_x\mathbf{a}^{\perp}]_2)}$ $\mathbb{G}$

Performance Benefit

$\mathbb{H}$

Basis: $\boxed{([\mathbf{A}]_1, [\mathbf{b}^\perp]_1) \qquad ([\mathbf{B}]_2, [\mathbf{a}^\perp]_2)}$

$\mathbb{G}$

Each attr x: $\boxed{([\mathbf{W}_x^\top \mathbf{A}]_1, [\mathbf{W}_x^\top \mathbf{b}^\perp]_1) \qquad ([\mathbf{W}_x \mathbf{B}]_2, [\mathbf{W}_x \mathbf{a}^\perp]_2)}$

Almost all of ciphertext and key in $\mathbb{G}$

Key Features

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- Set-up time is constant.
- Ciphertexts and keys:
  - 3 elements from $\mathbb{H}$
  - 3 elements from $\mathbb{G}$ for every attribute
- Decryption only 6 pairing operations
  - Many exponentiations, but all in $\mathbb{G}$
  - Lewko Waters' conversion

Implement, *and evaluate*

Implementation

- Python 2.7.10 using Charm 0.43 [AGMPRGR13]

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Implementation

- Python 2.7.10 using Charm 0.43 [AGMPRGR13]
- MNT224 curve for pairings
- Macbook Pro laptop
  - 2.7 GHz Intel Core i5, 8GB RAM

Group Operations

(in milliseconds)

Groups	*Multiplication*	*Exponentiation*	*Hash*
$\mathbb{G}$	.009	1.266	.099
$\mathbb{H}$	.065	14.412	76.767
$\mathbb{G}_T$	.020	3.356	-

Pairing	10.243

Access Policies

$\mathsf{attr}_1 \text{ AND } \mathsf{attr}_2 \text{ AND } \ldots \text{ AND } \mathsf{attr}_n$ [GHW11]

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$$10, 20, \ldots, 100$$

Policies => Monotone Span Program [LW11]

Matrix has 0, 1, -1 entries

Reconstruction coefficients 0 or 1

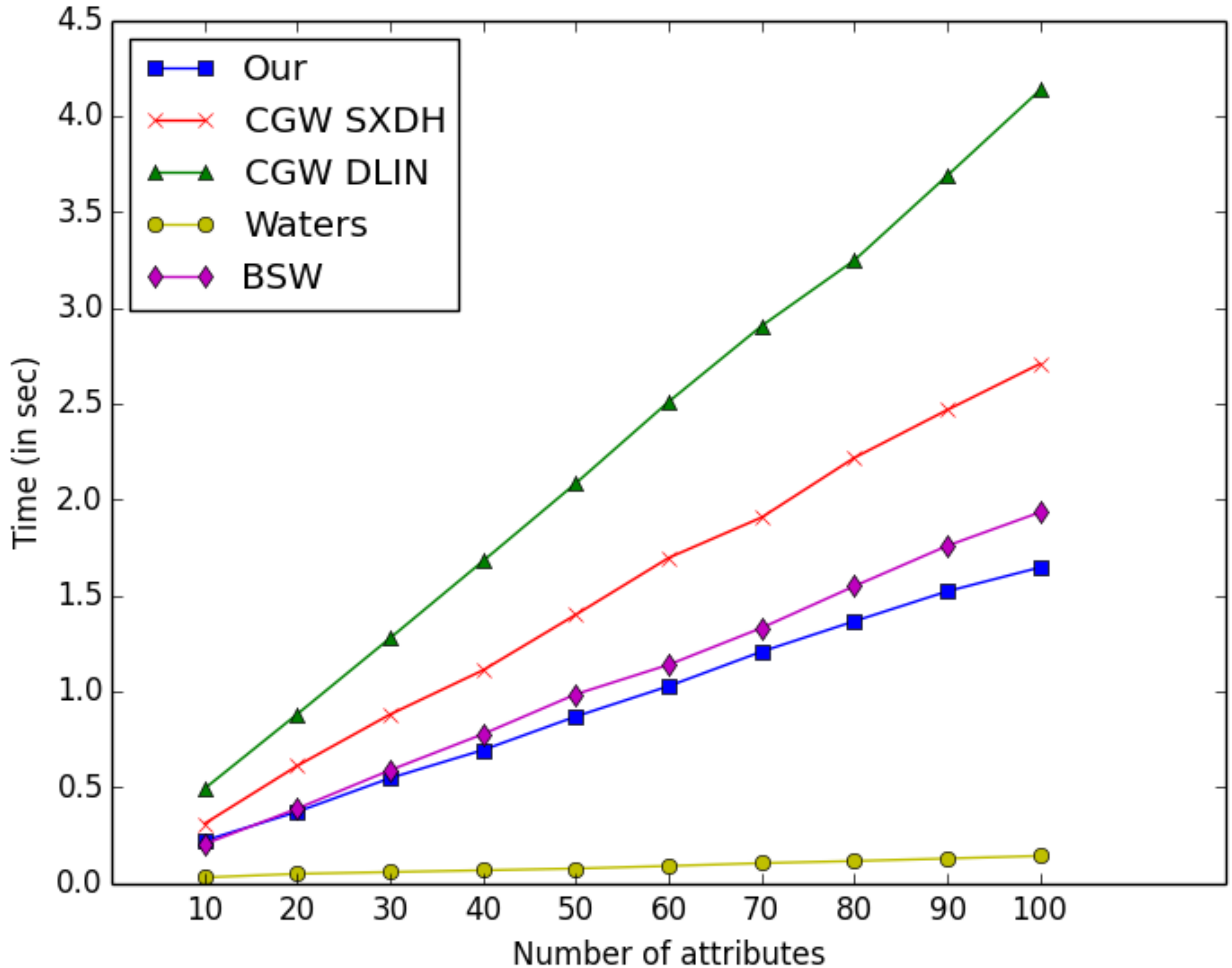
Ciphertext-Policy ABE

- Bethencourt, Sahai, and Waters (BSW) [SP'07]
- Waters [PKC'11]
- Chen, Gay, and Wee (CGW) [EC'15]
  - 1-linear (SXDH)
  - 2-linear (DLIN)

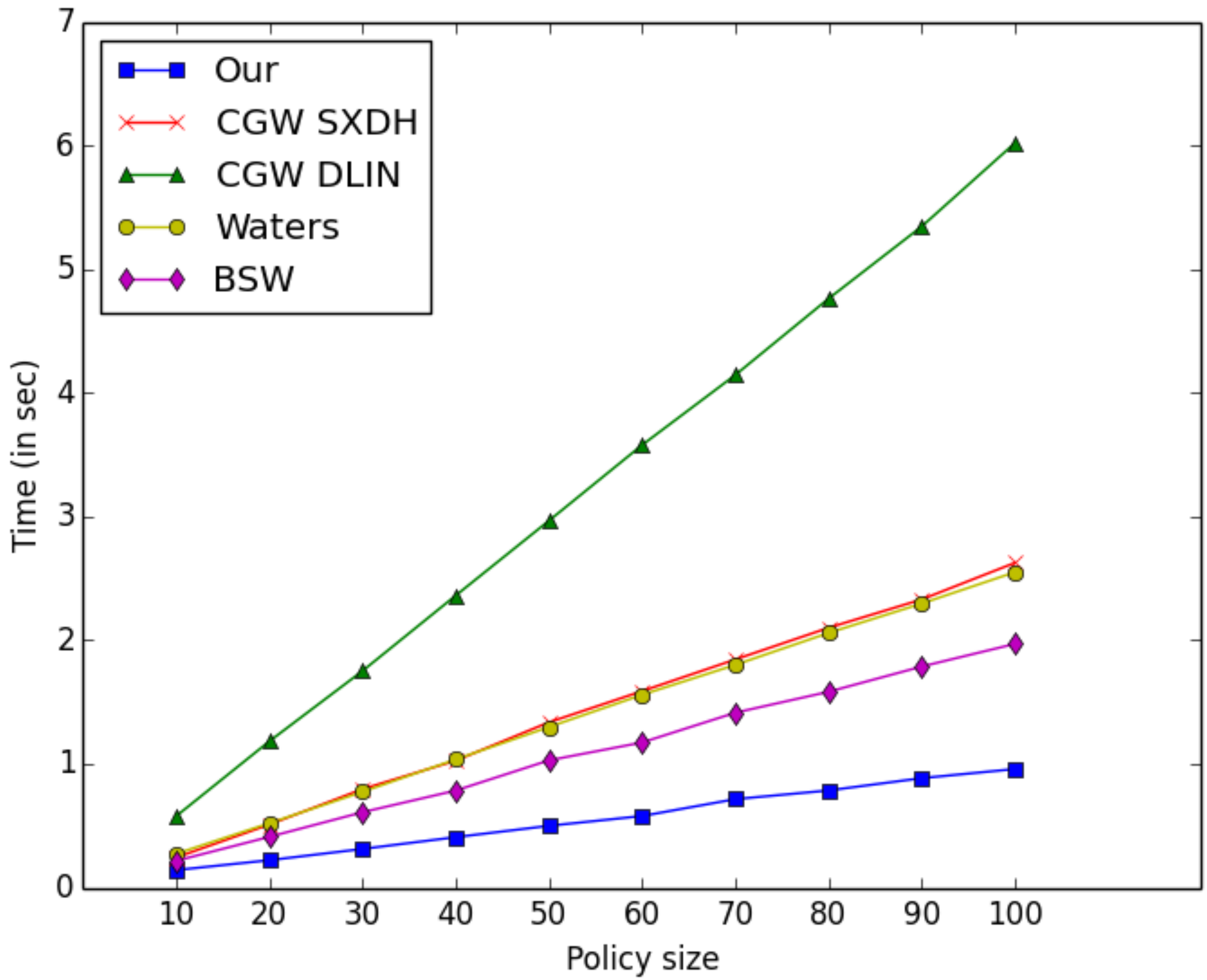
Set-up Time

Scheme	*Uni size*	*Time*
Our	-	0.11s
CGW-1	100	2.23s
CGW-2	100	5.13s
Waters	100	0.64s
BSW	-	0.08s

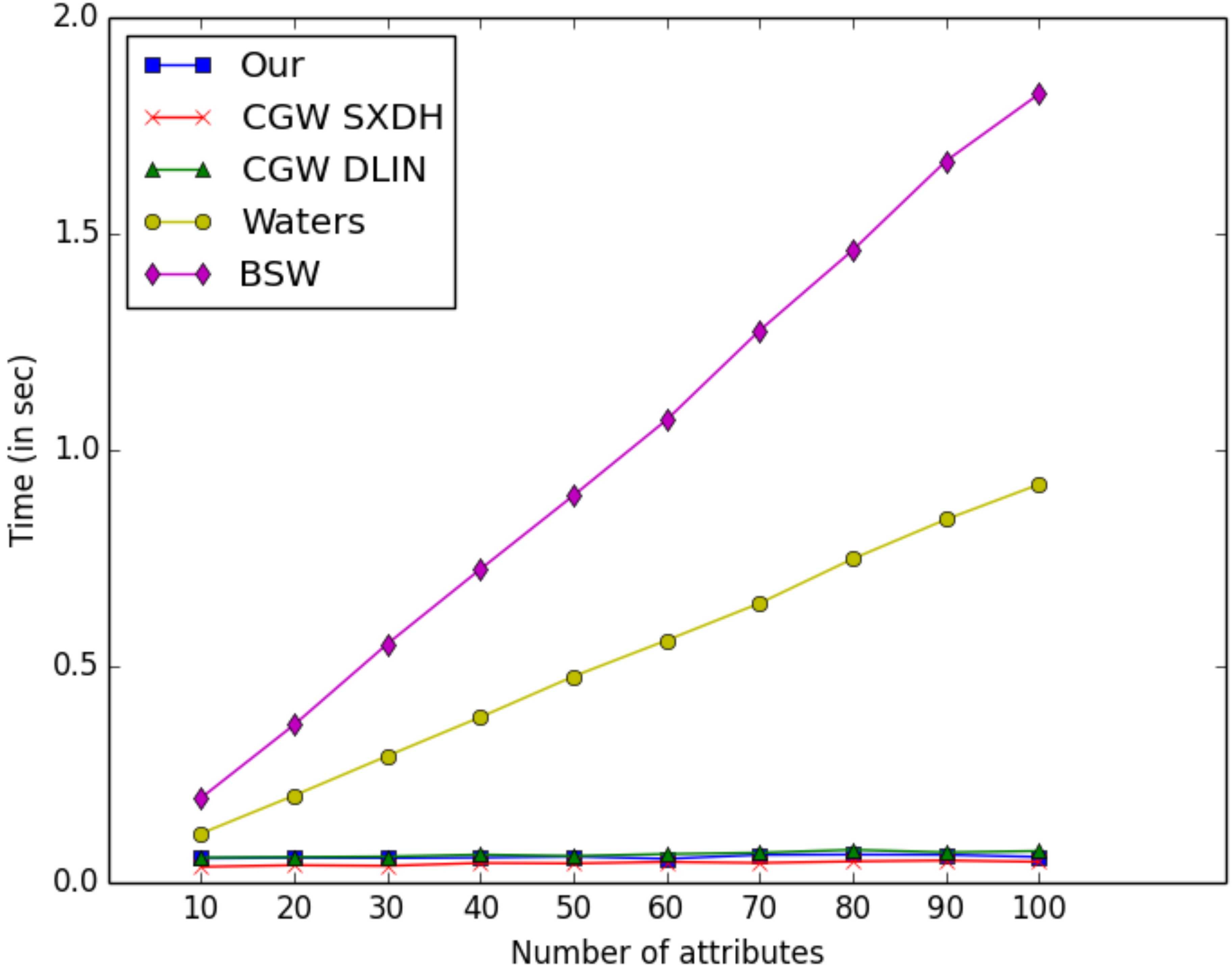
Key Generation



Encryption


Our
CGW SXDH
CGW DLIN
Waters
BSW
Time (in sec)
Policy size
0
1
2
3
4
5
6
7
10
20
30
40
50
60
70
80
90
100

Decryption



Our
CGW SXDH
CGW DLIN
Waters
BSW
Time (in sec)
2.0
1.5
1.0
0.5
0.0
10
20
30
40
50
60
70
80
90
100
Number of attributes

Conclusion

- Fast ABE schemes - good security, desirable features

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Conclusion

- Fast ABE schemes - good security, desirable features
- Clean way to handle negations, multi-use of attributes
- Optimize implementations
    - C/C++ vs Python
    - Charm's features
    - Different curve like BN

Thanks, *to you*

Paper: https://eprint.iacr.org/2017/807

Code: https://github.com/sagrawal87/ABE