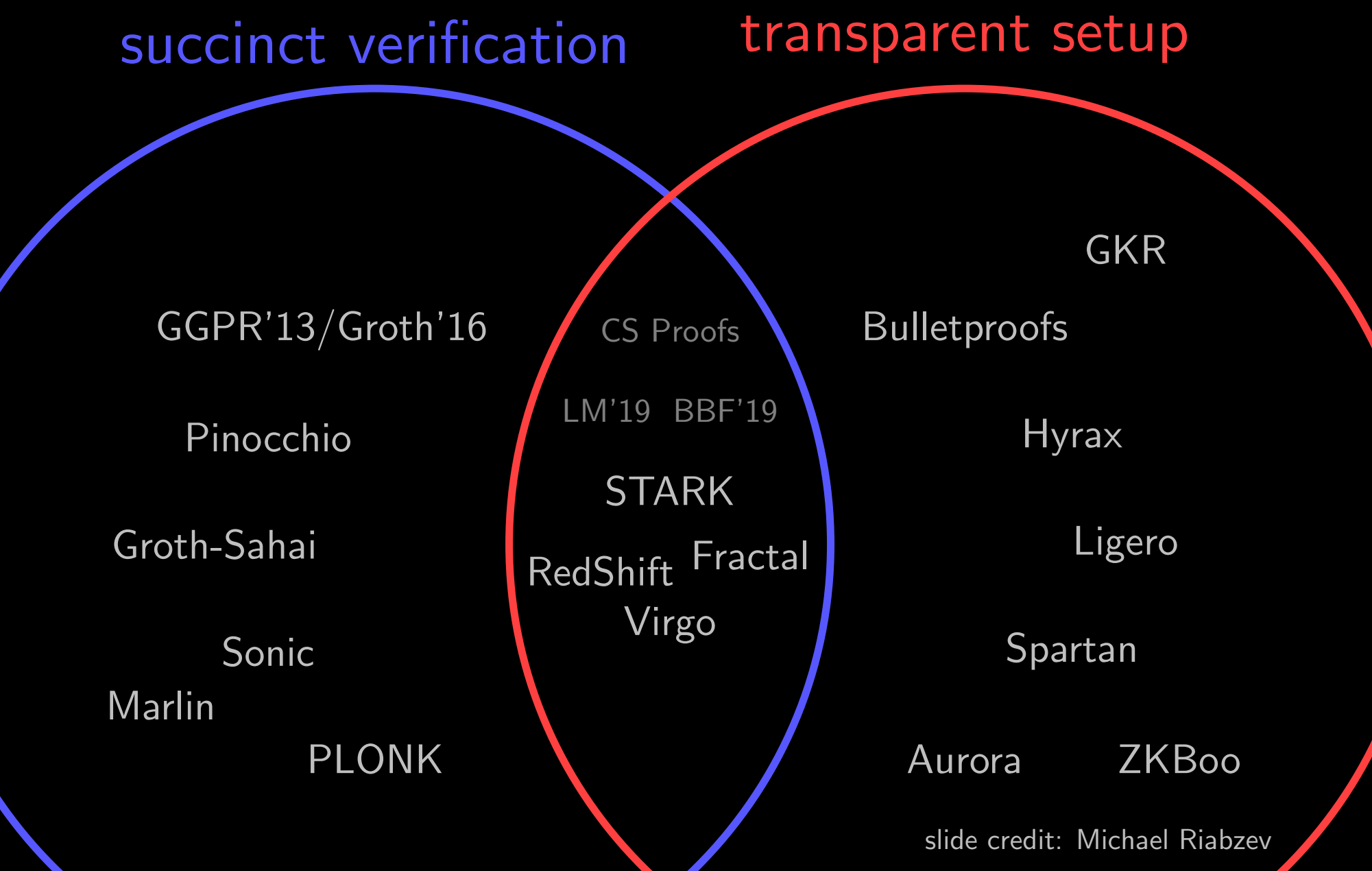
Transparent SNARKs from DARK Compilers

Benedikt Bünz[1] and Ben Fisch[1] and **Alan Szepieniec**[2]

[1]Stanford [2]Nervos Foundation

Eurocrypt 2020

General Purpose Zero-Knowledge Proofs



slide credit: Michael Riabzev

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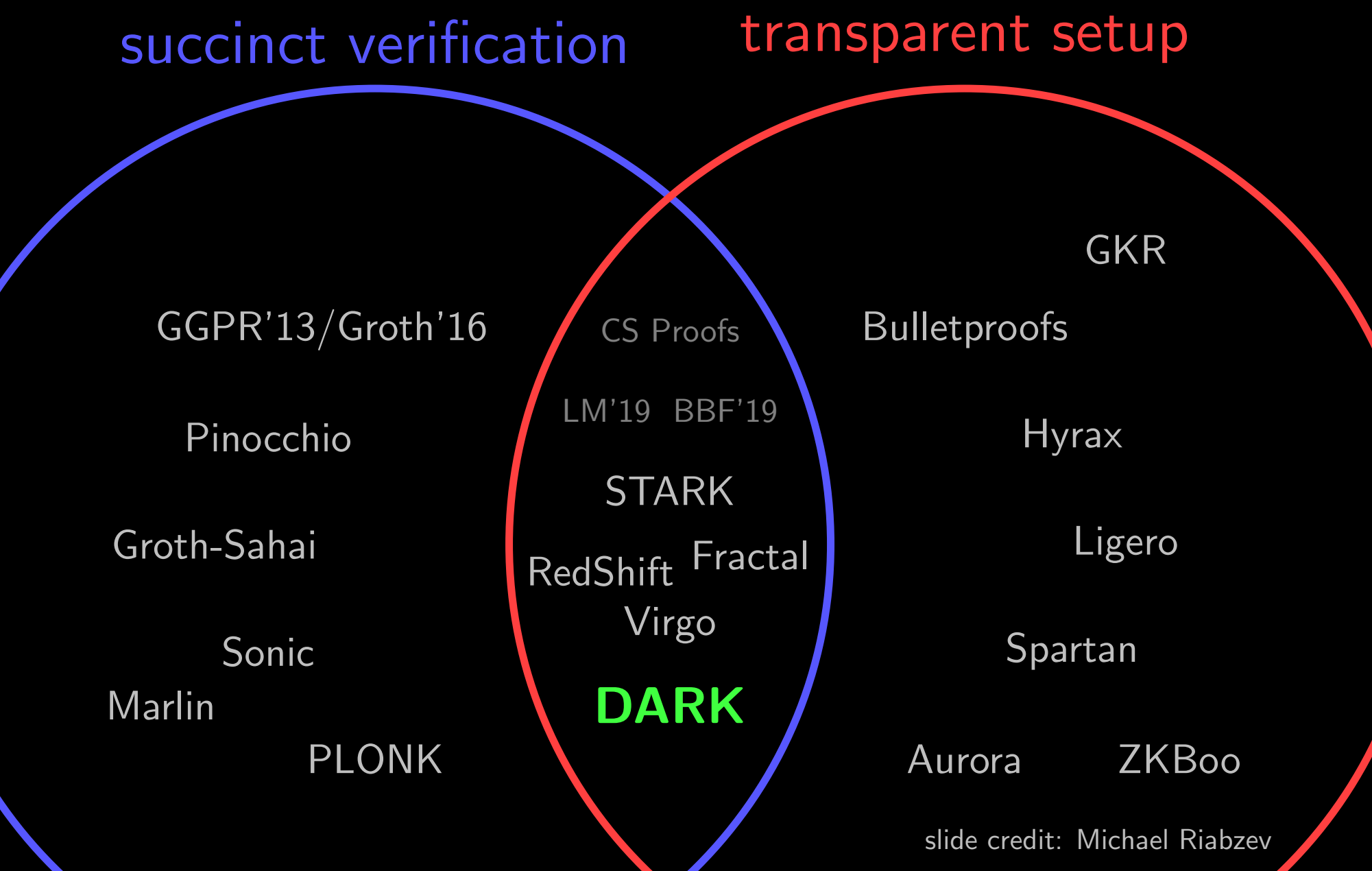

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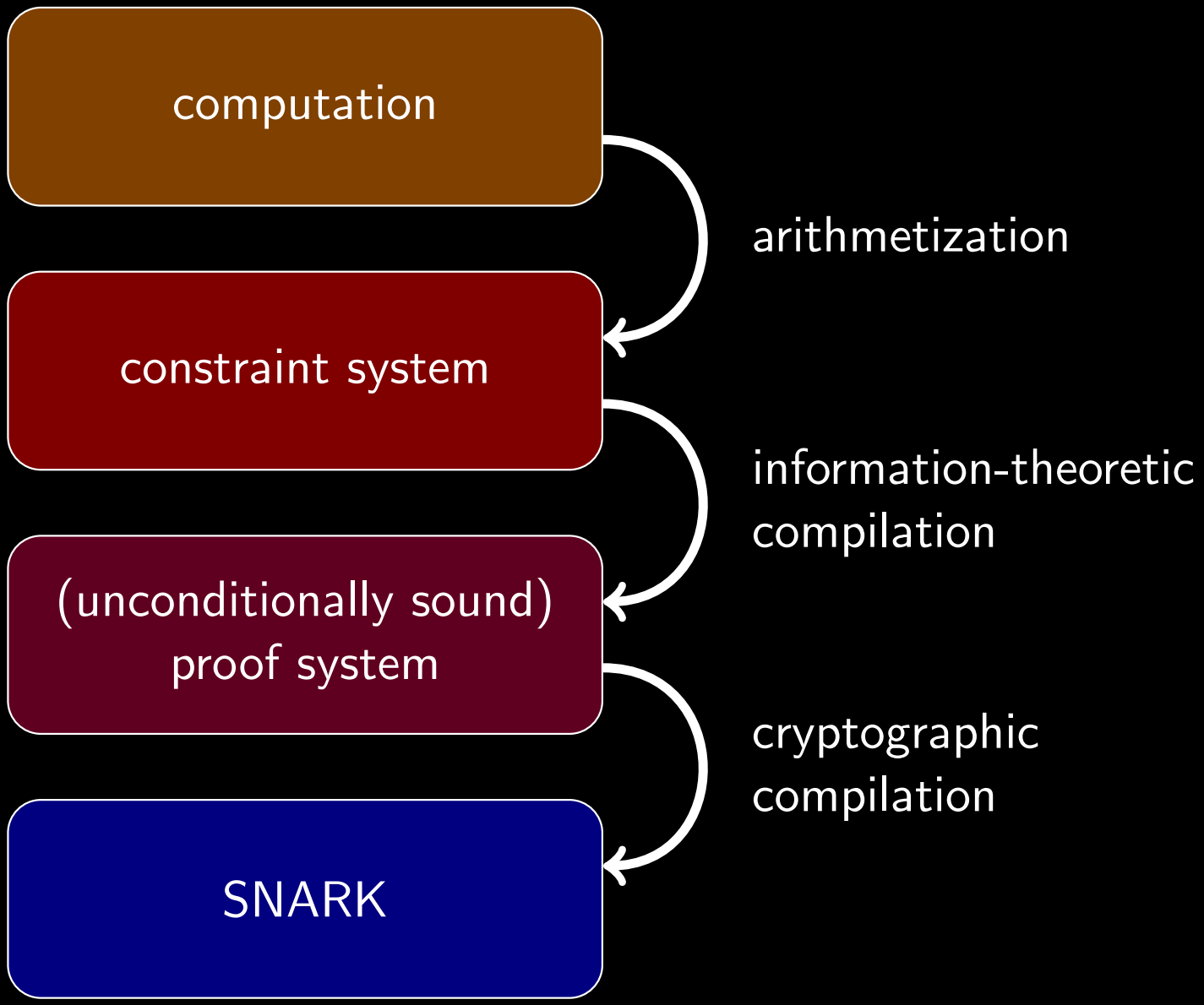
Compilation Pipeline



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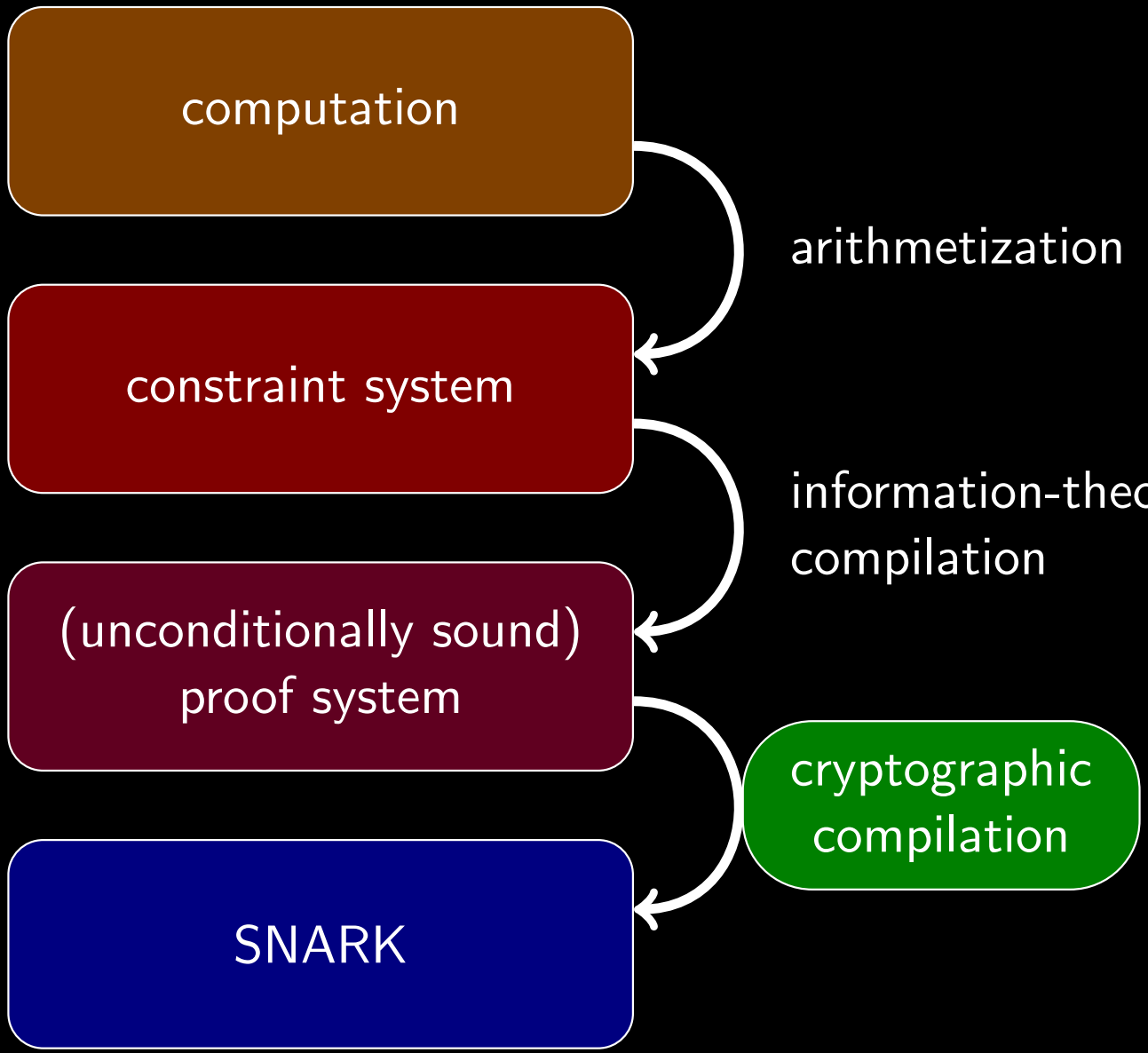

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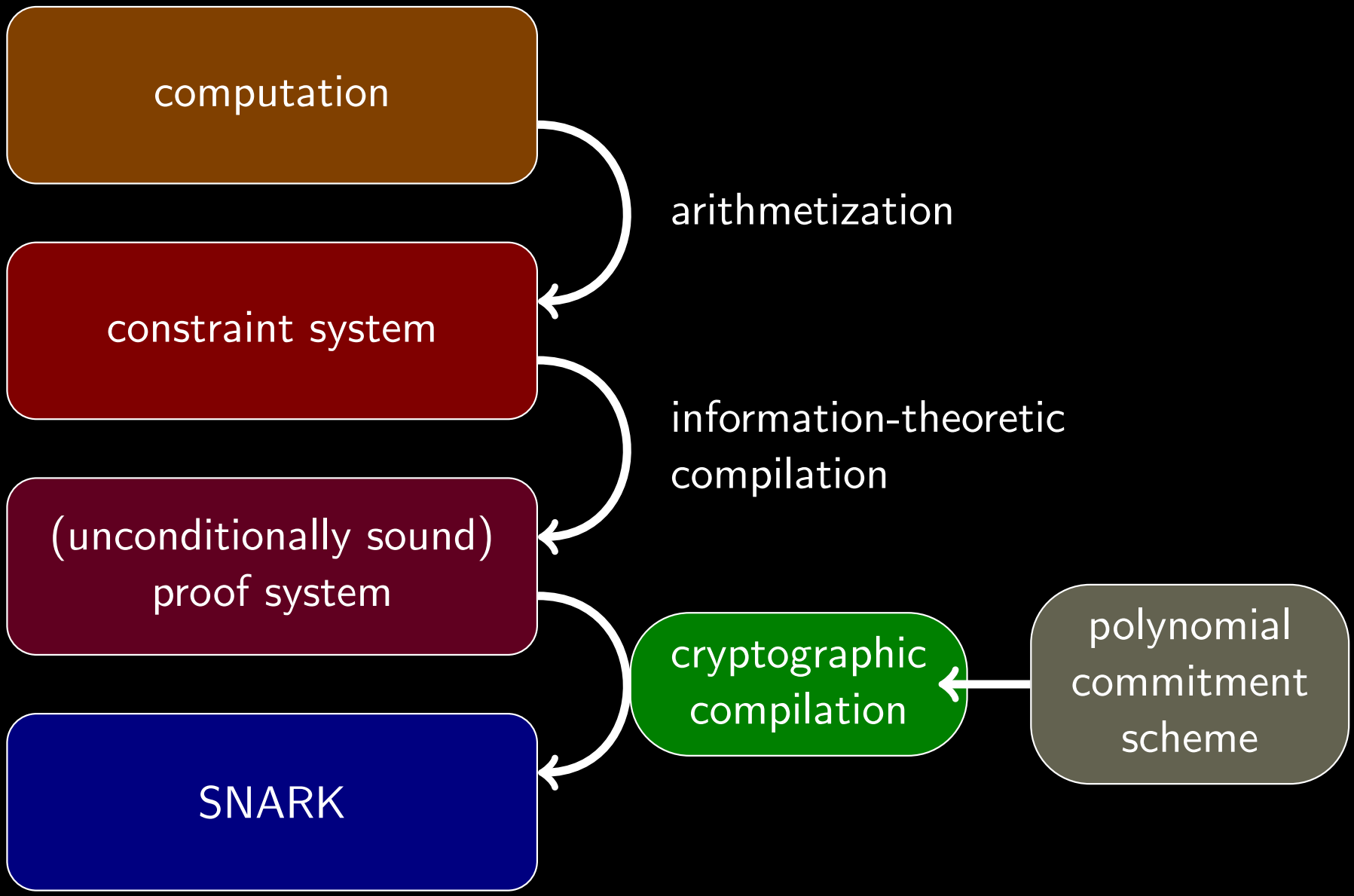

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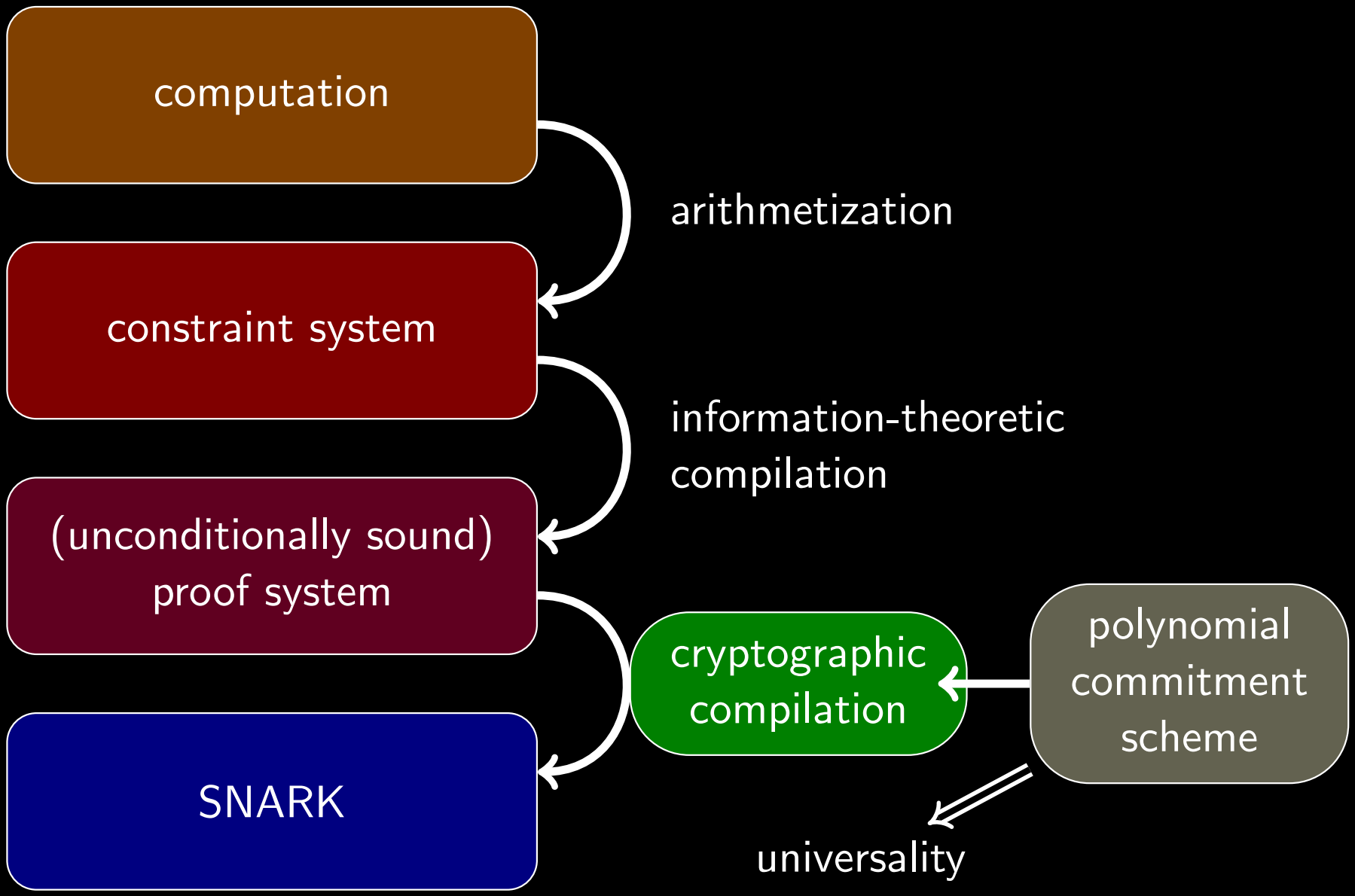

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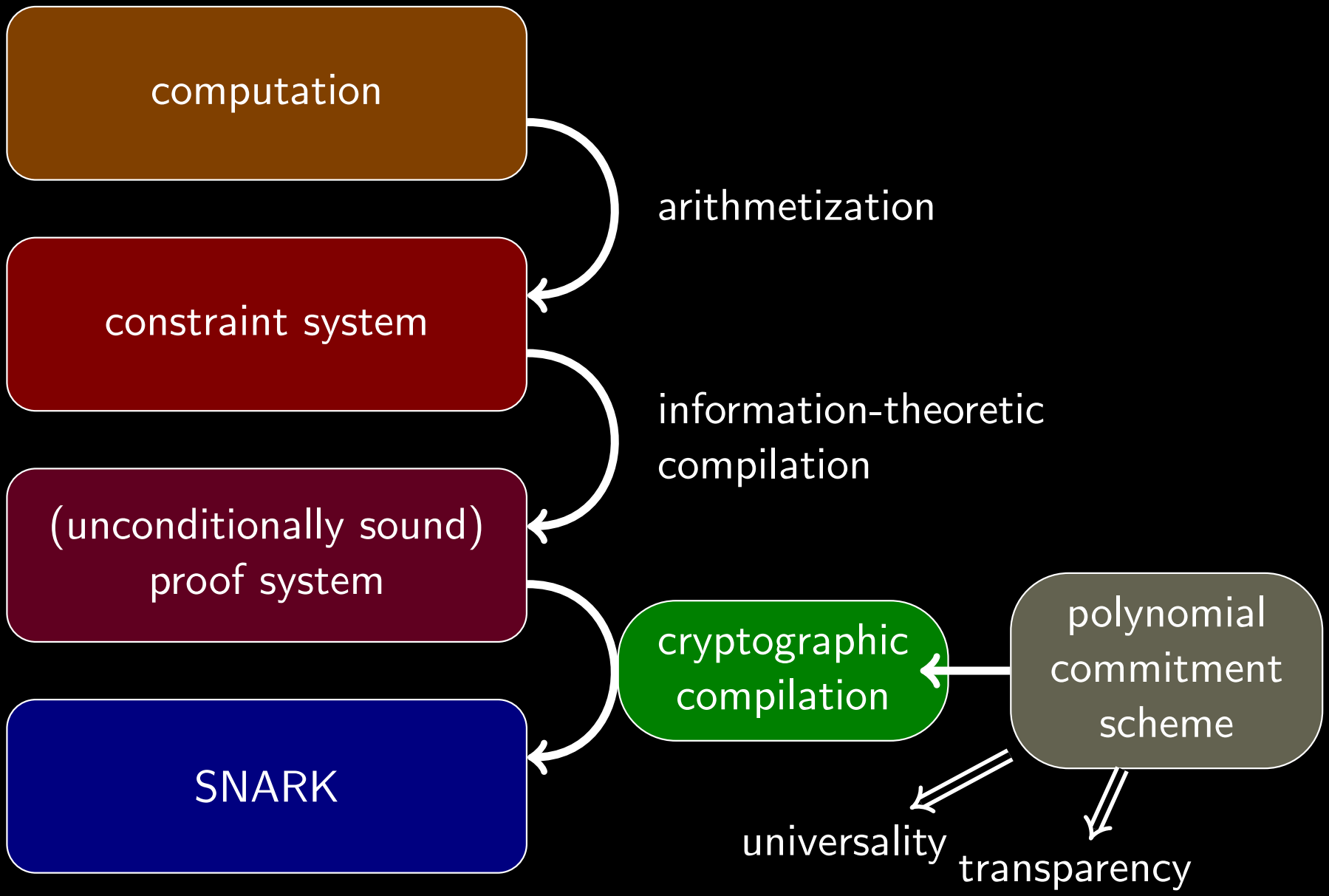
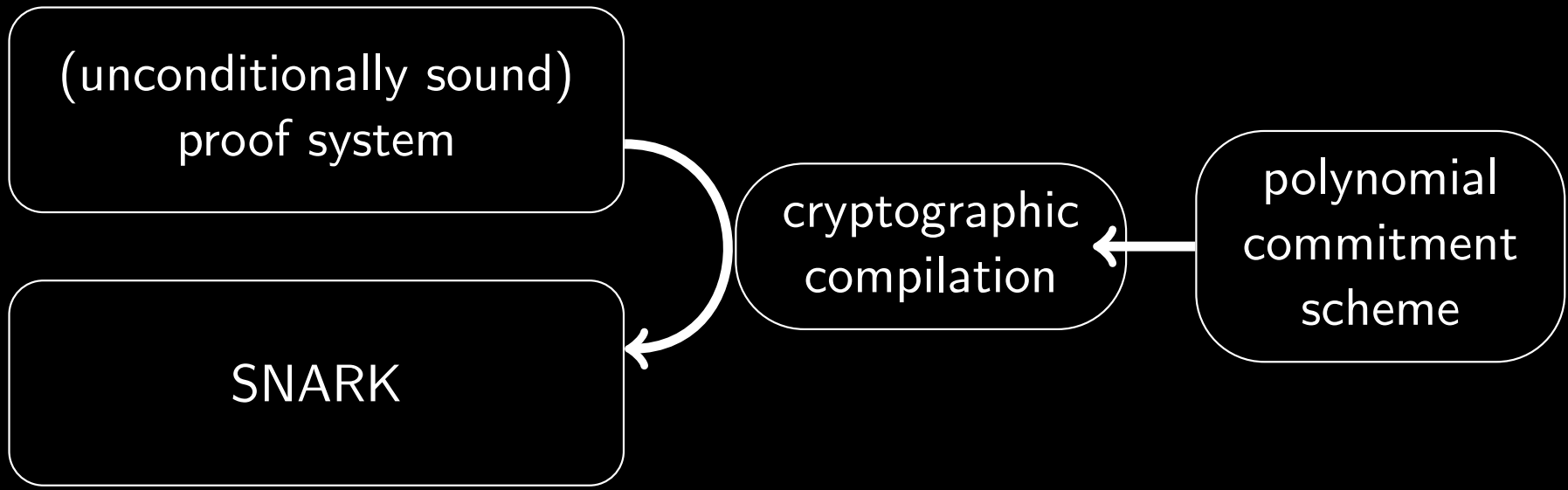
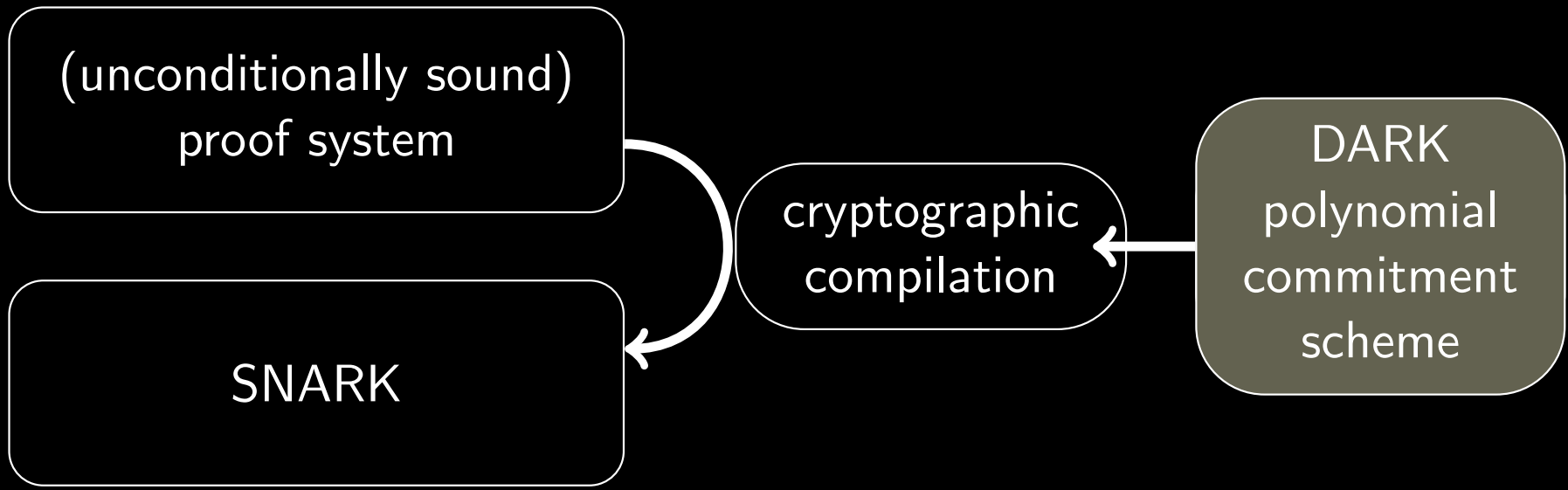


Contributions



Contributions

1. **polynomial commitment scheme** based on **groups of unknown order**



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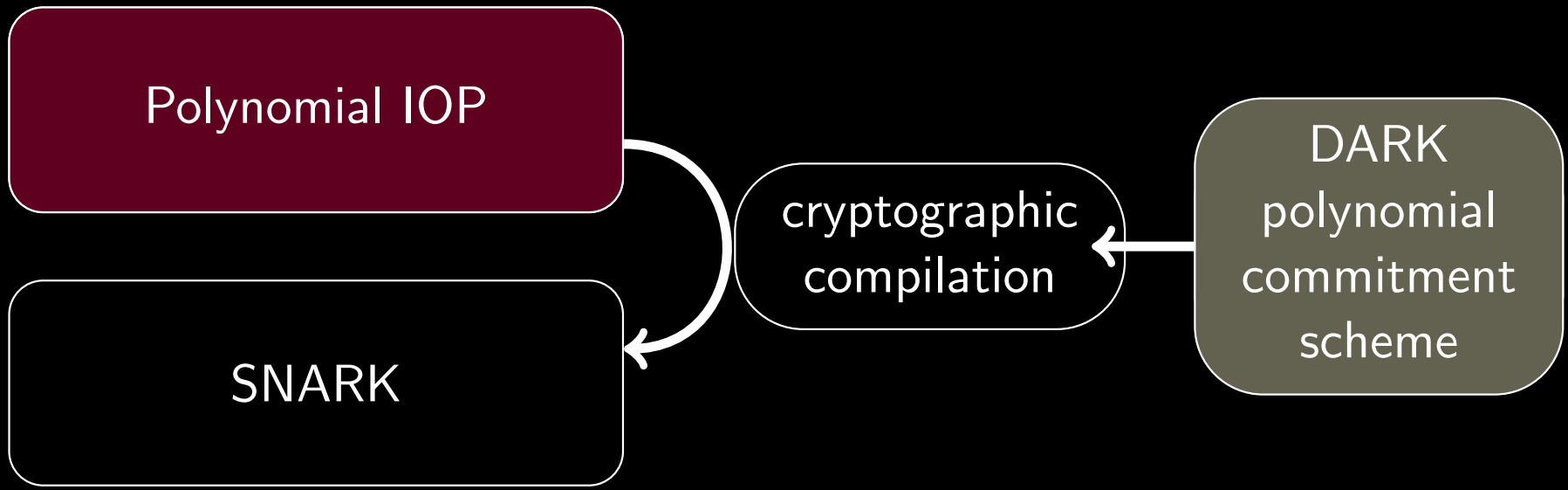

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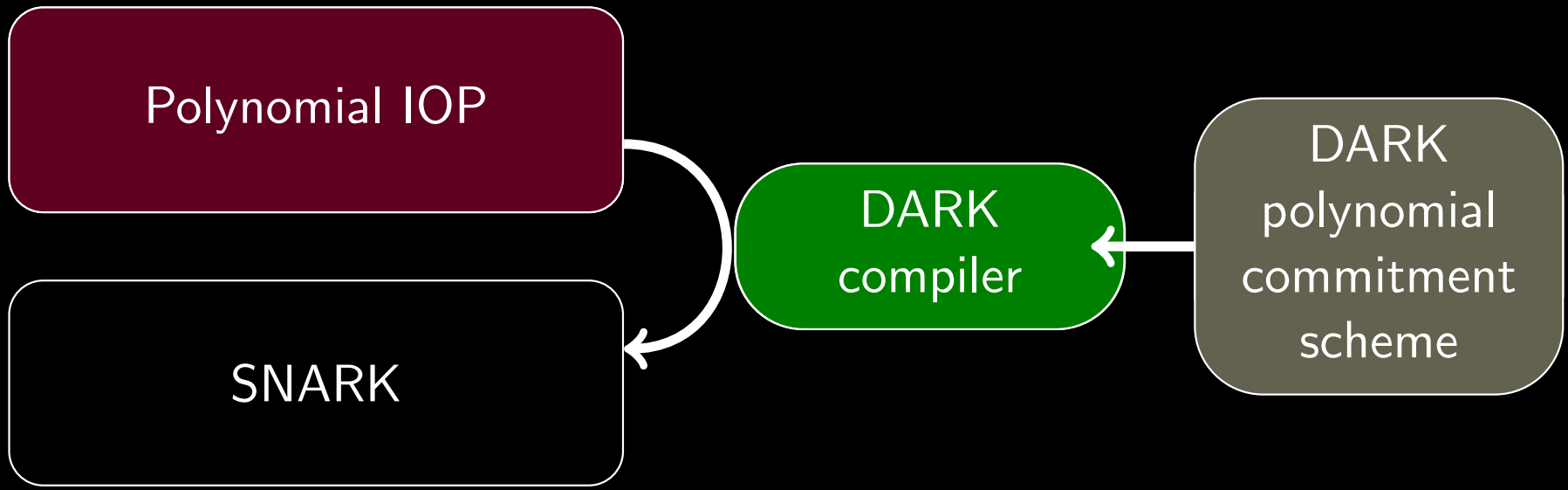

Contributions

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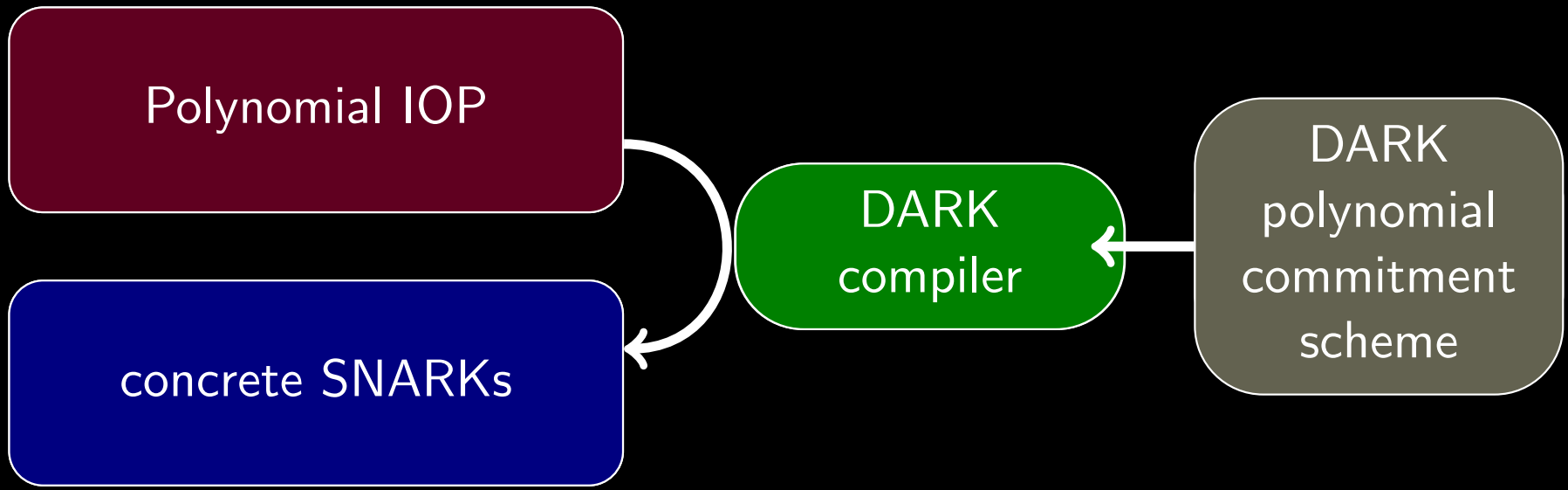
4. **DARK + Sonic = Supersonic** $\leftarrow$ transparent SNARK (and other constructions)



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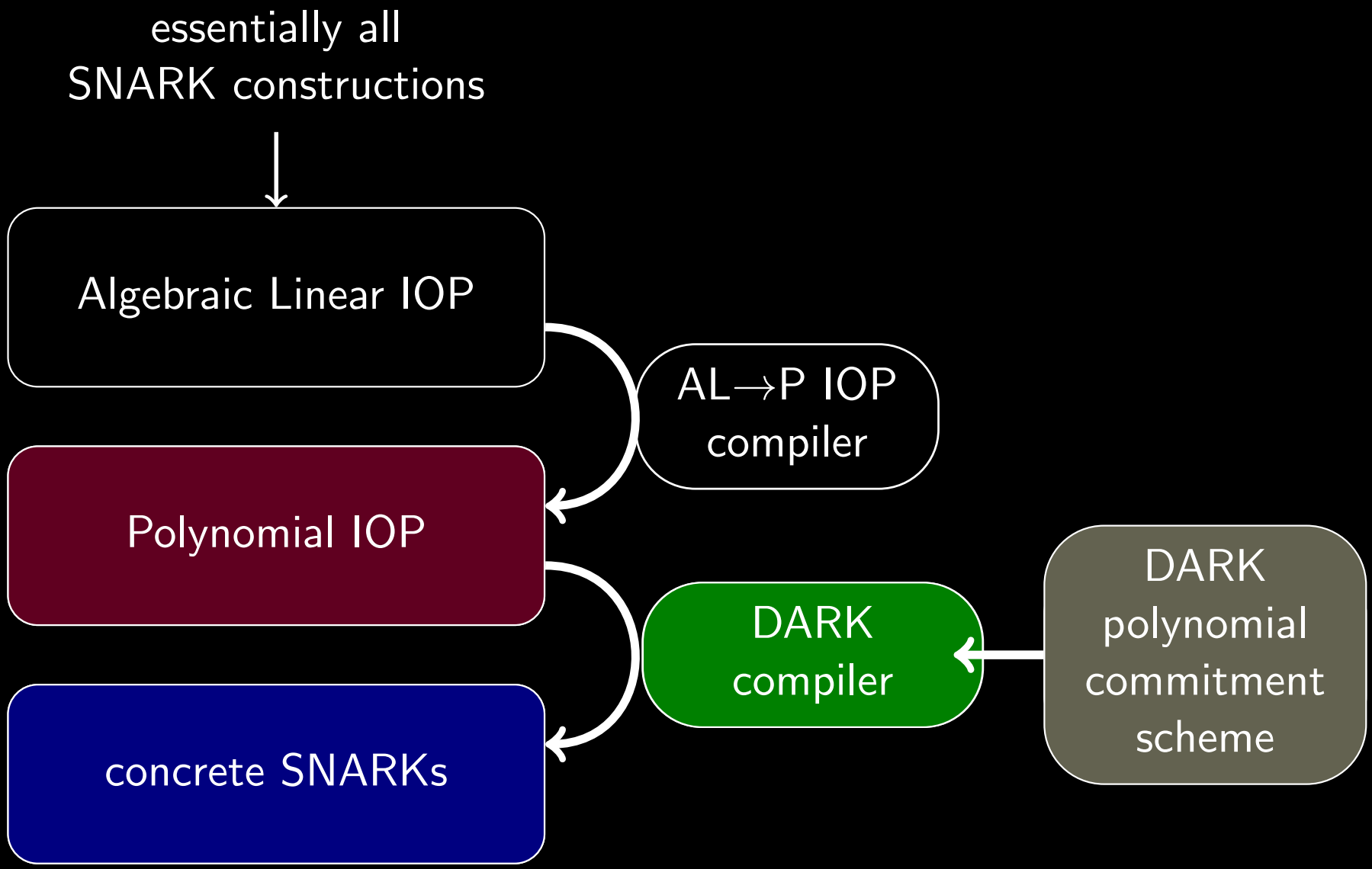

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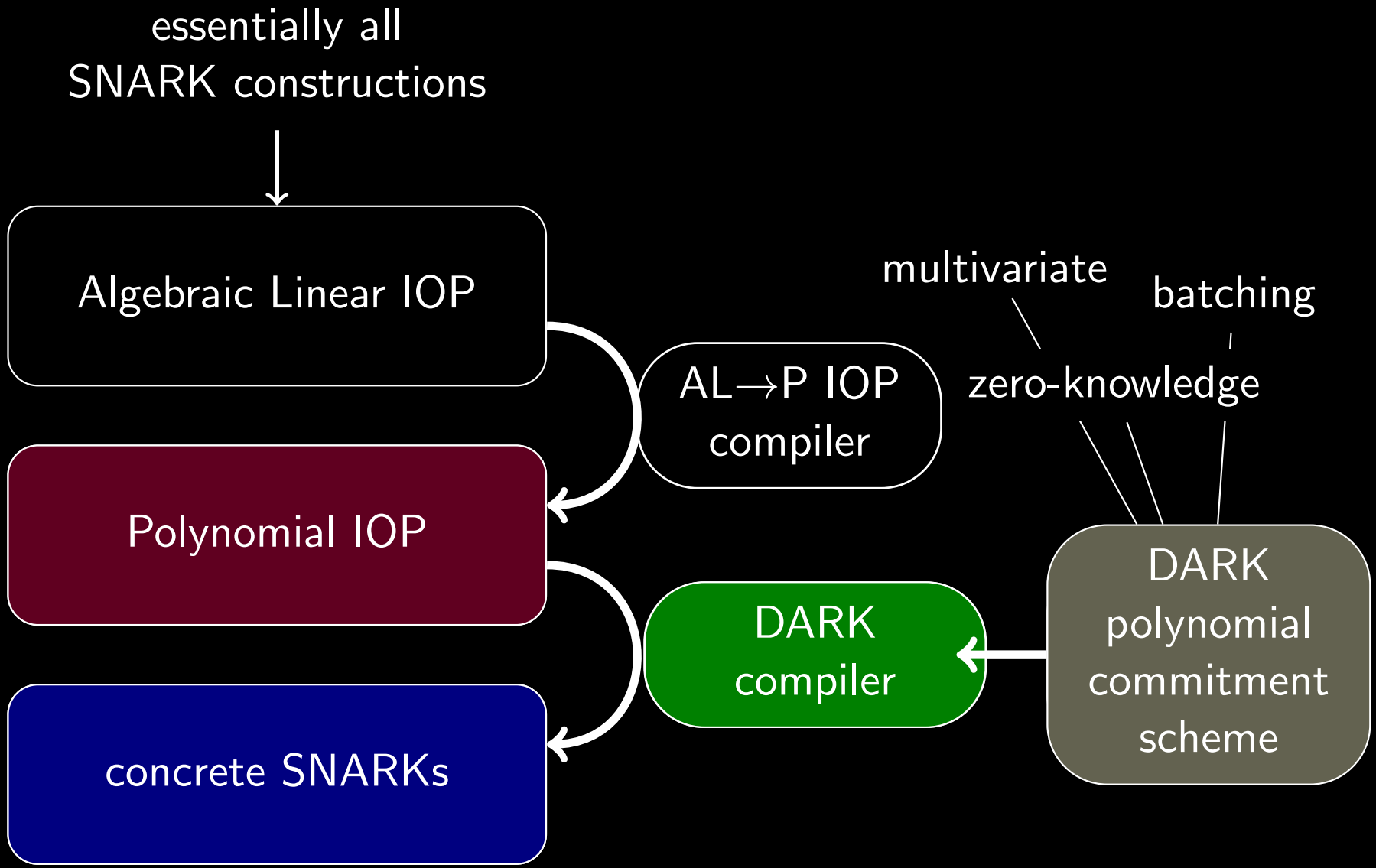

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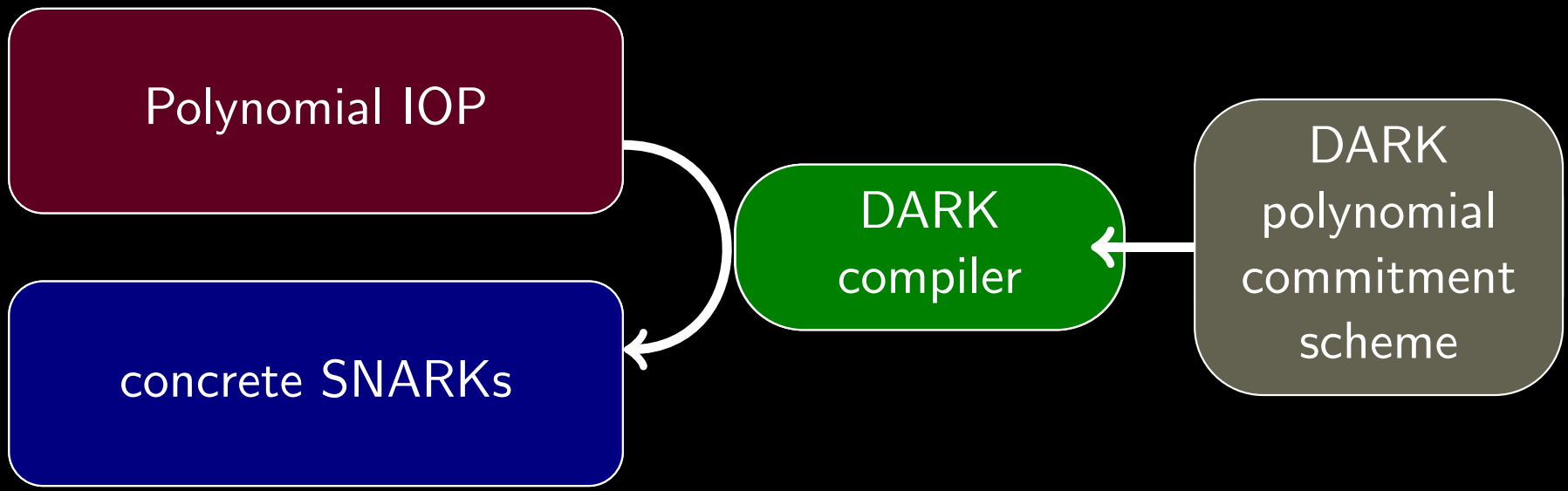

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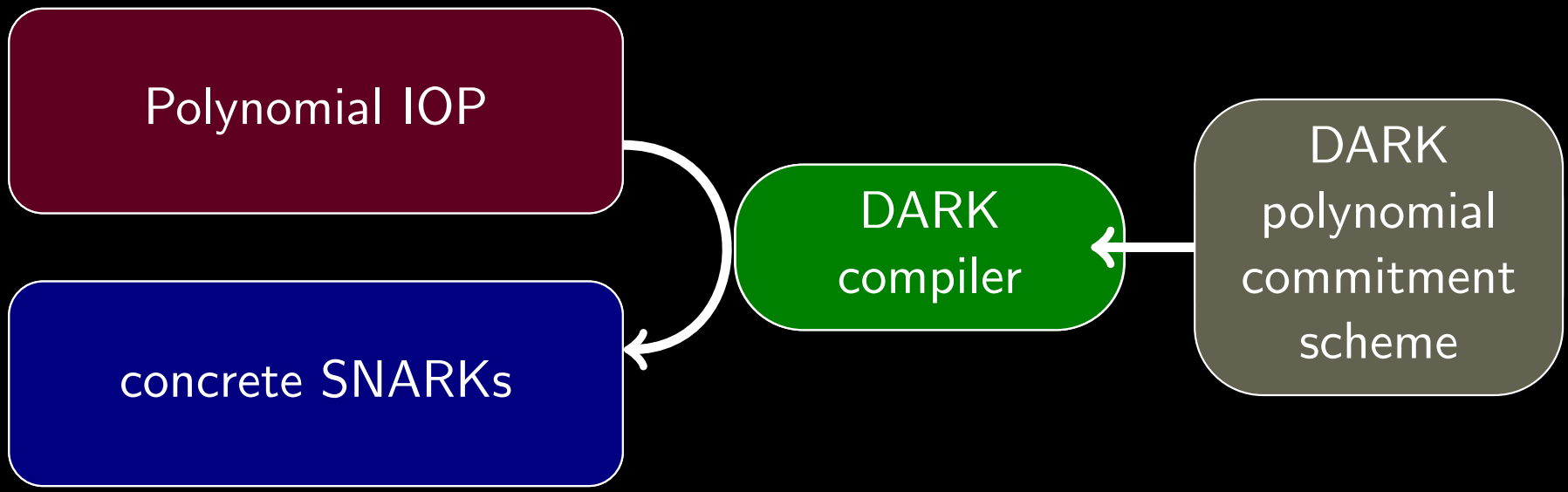
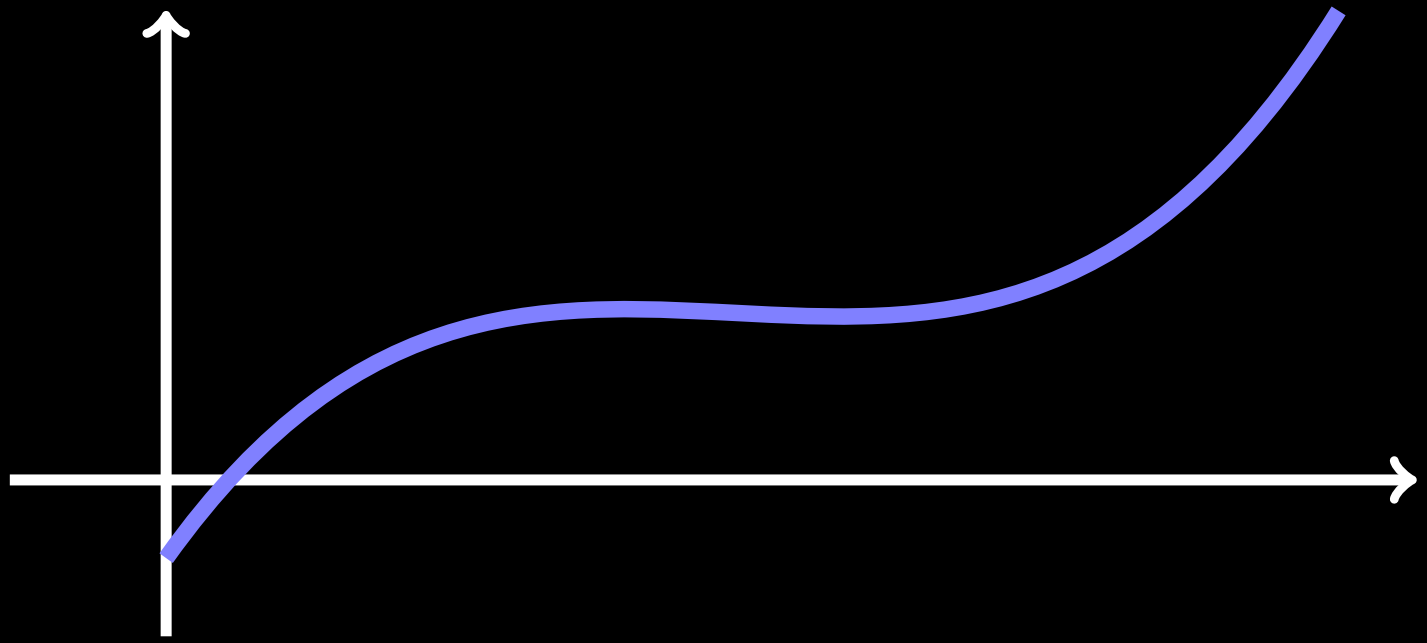


Polynomial Commitment Scheme



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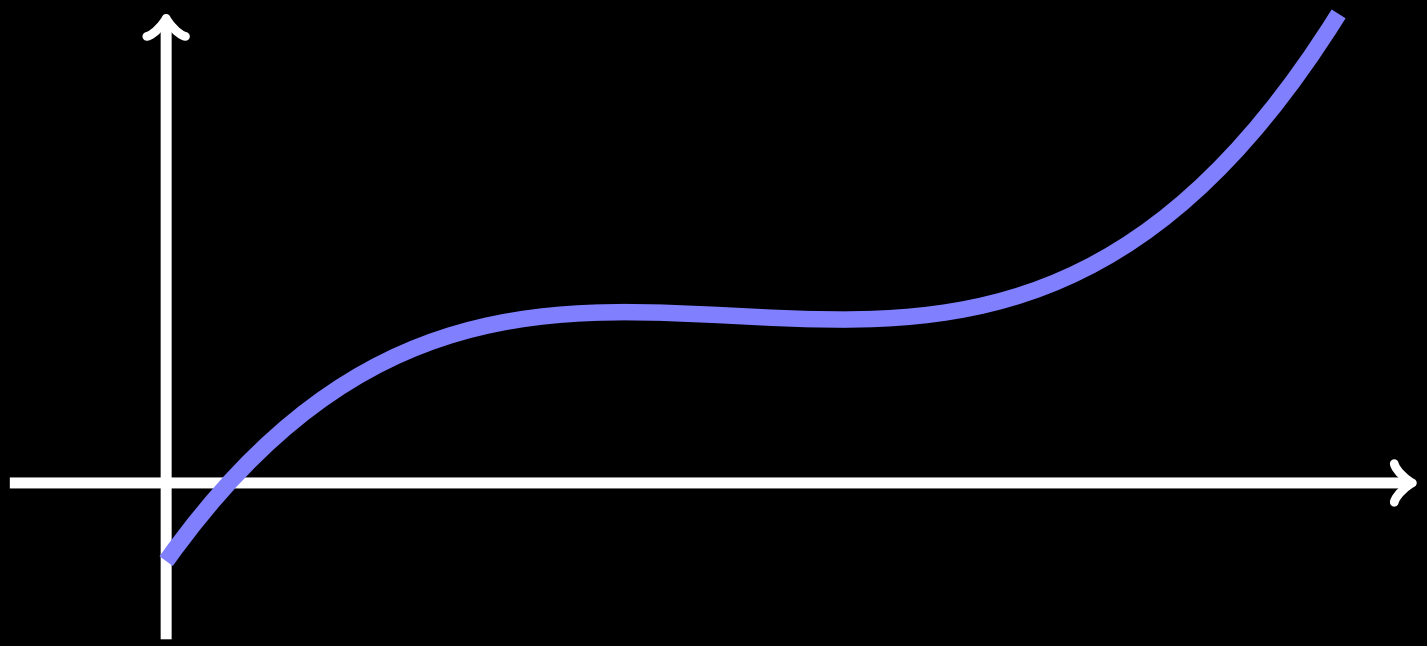

lots of coefficients

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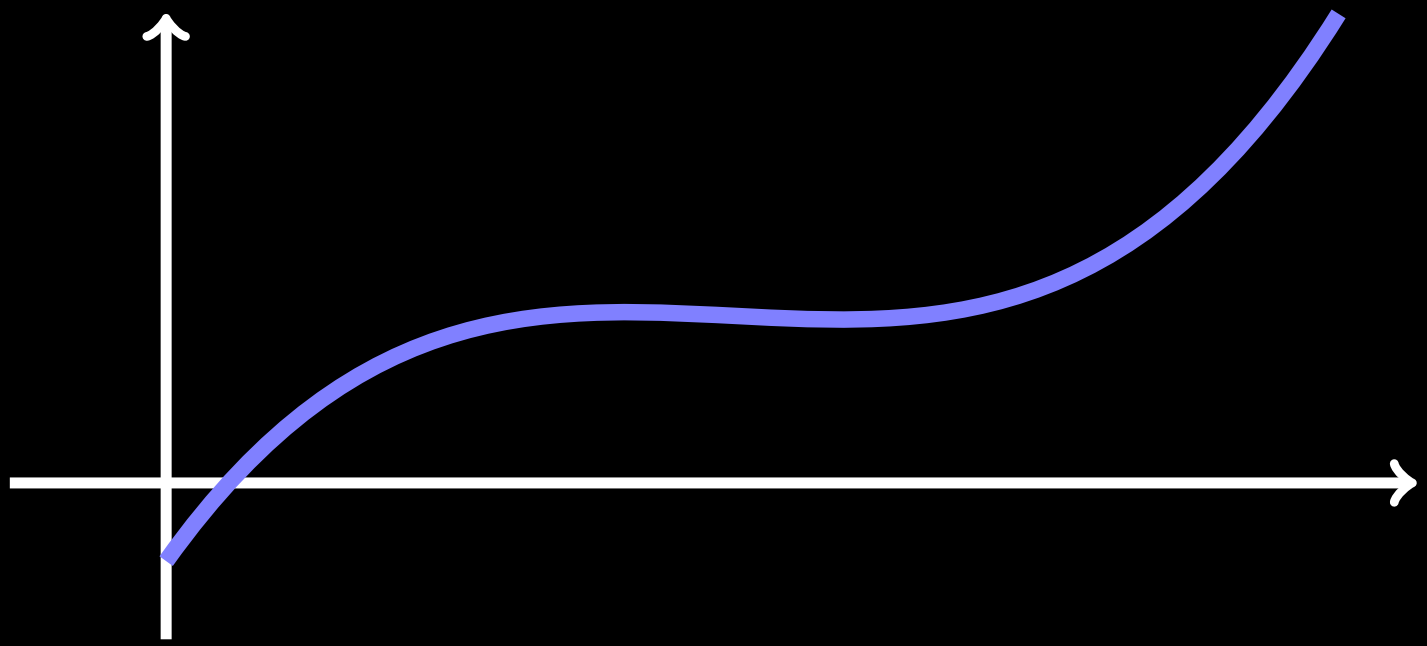

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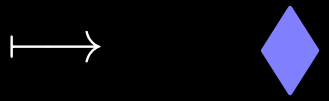
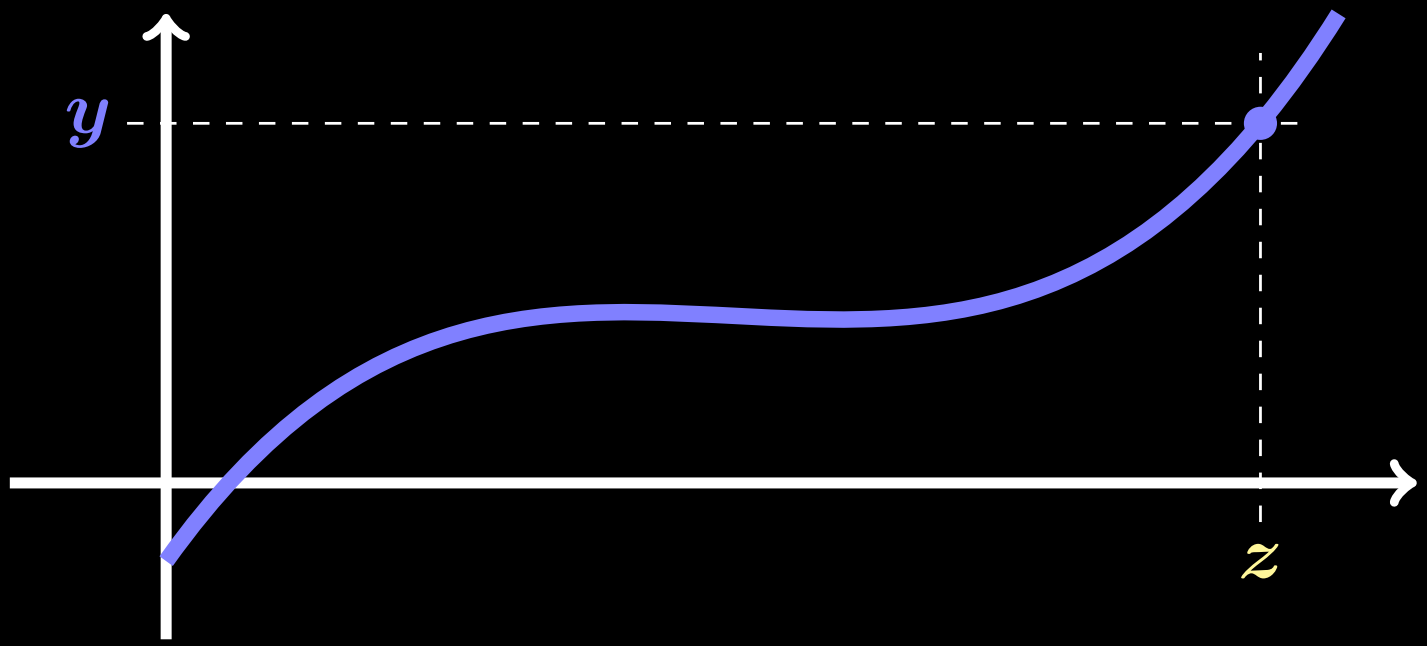


short commitment

Polynomial Commitment Scheme



lots of coefficients

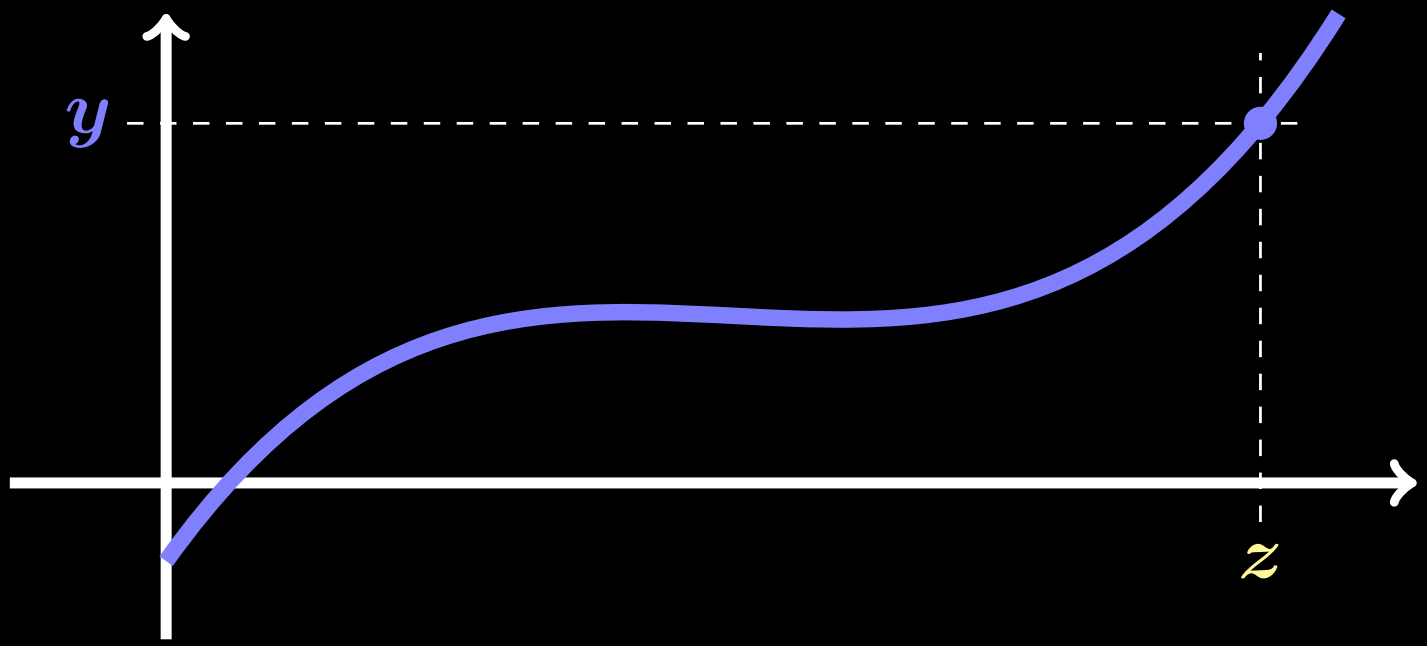
$\longmapsto$

short commitment

$f(z) = y$ $\longmapsto$ π

evaluation proof

Polynomial Commitment Scheme



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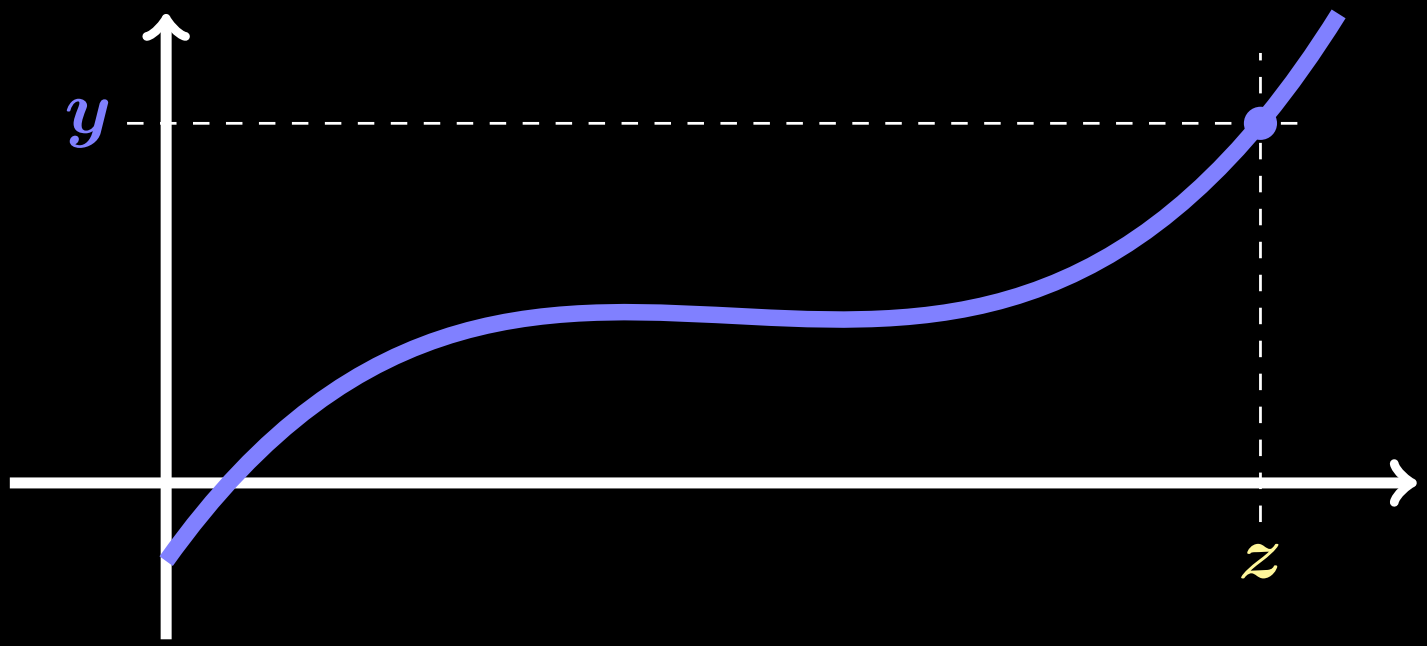

lots of coefficients

$\longmapsto$ ♦ $\longleftarrow$ binding

short commitment

$f(z) = y$ $\longmapsto$ π $\longleftarrow$ extractable

evaluation proof

Evaluation Protocol with Special Homomorphic Commitment

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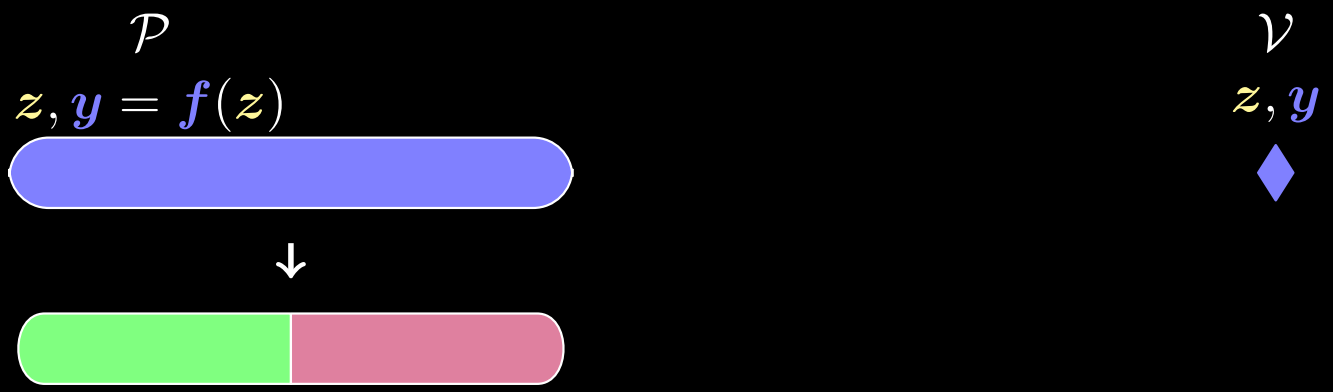

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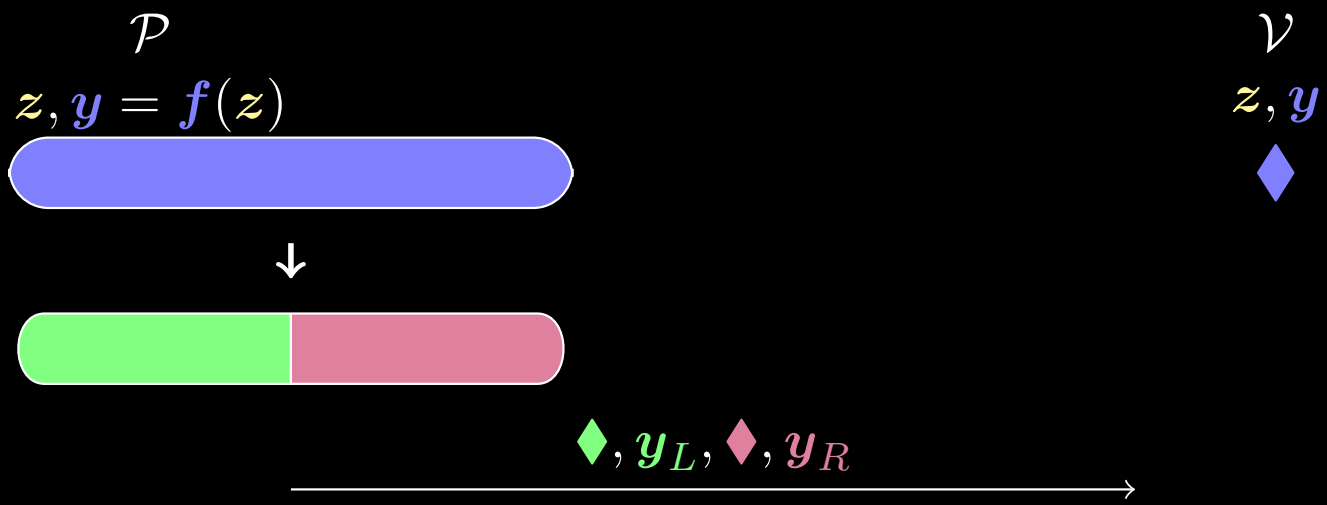

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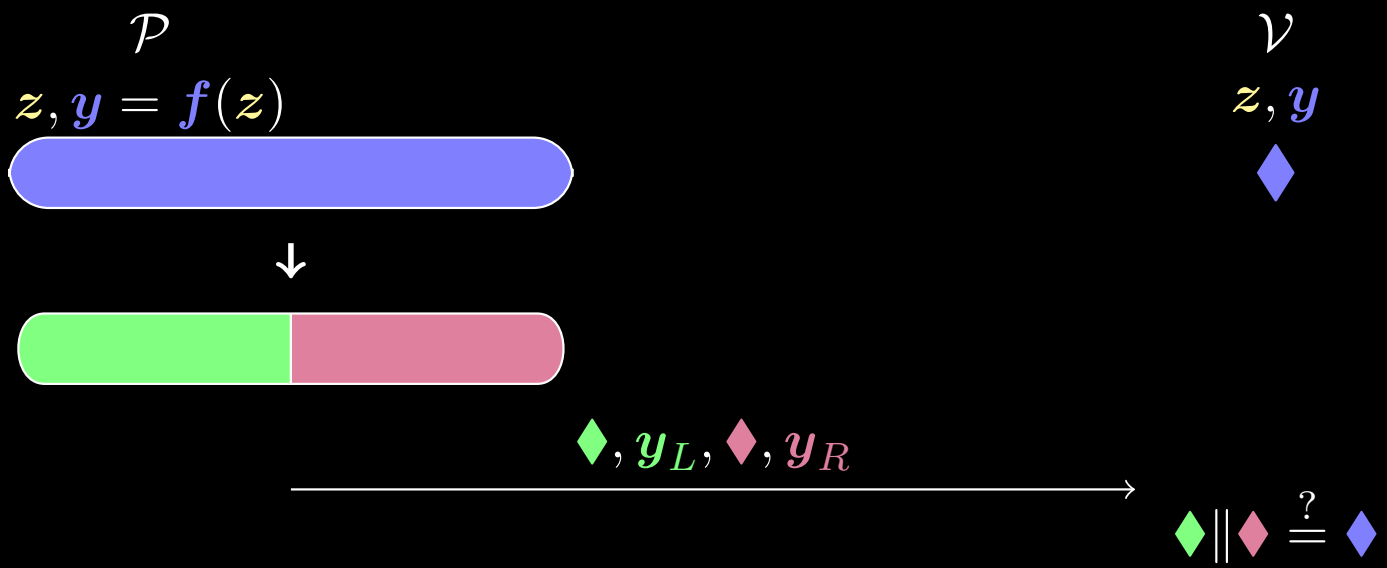

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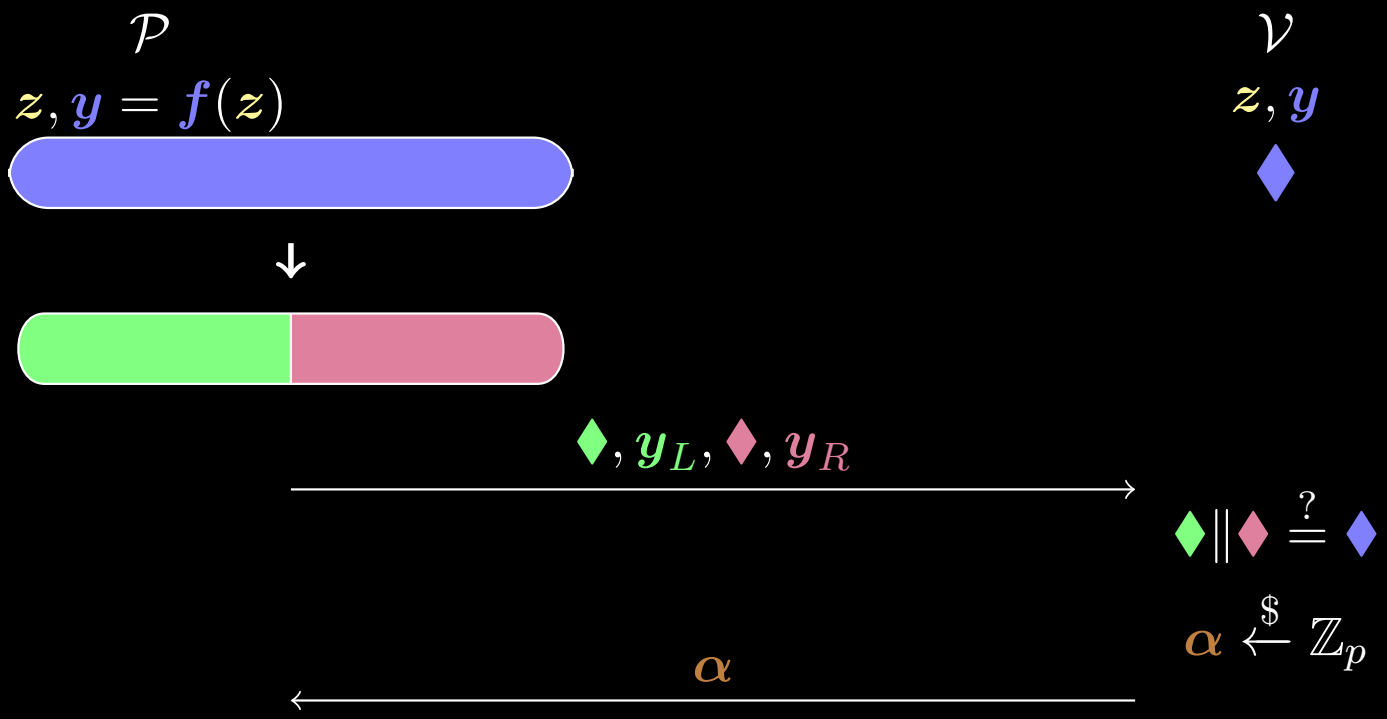

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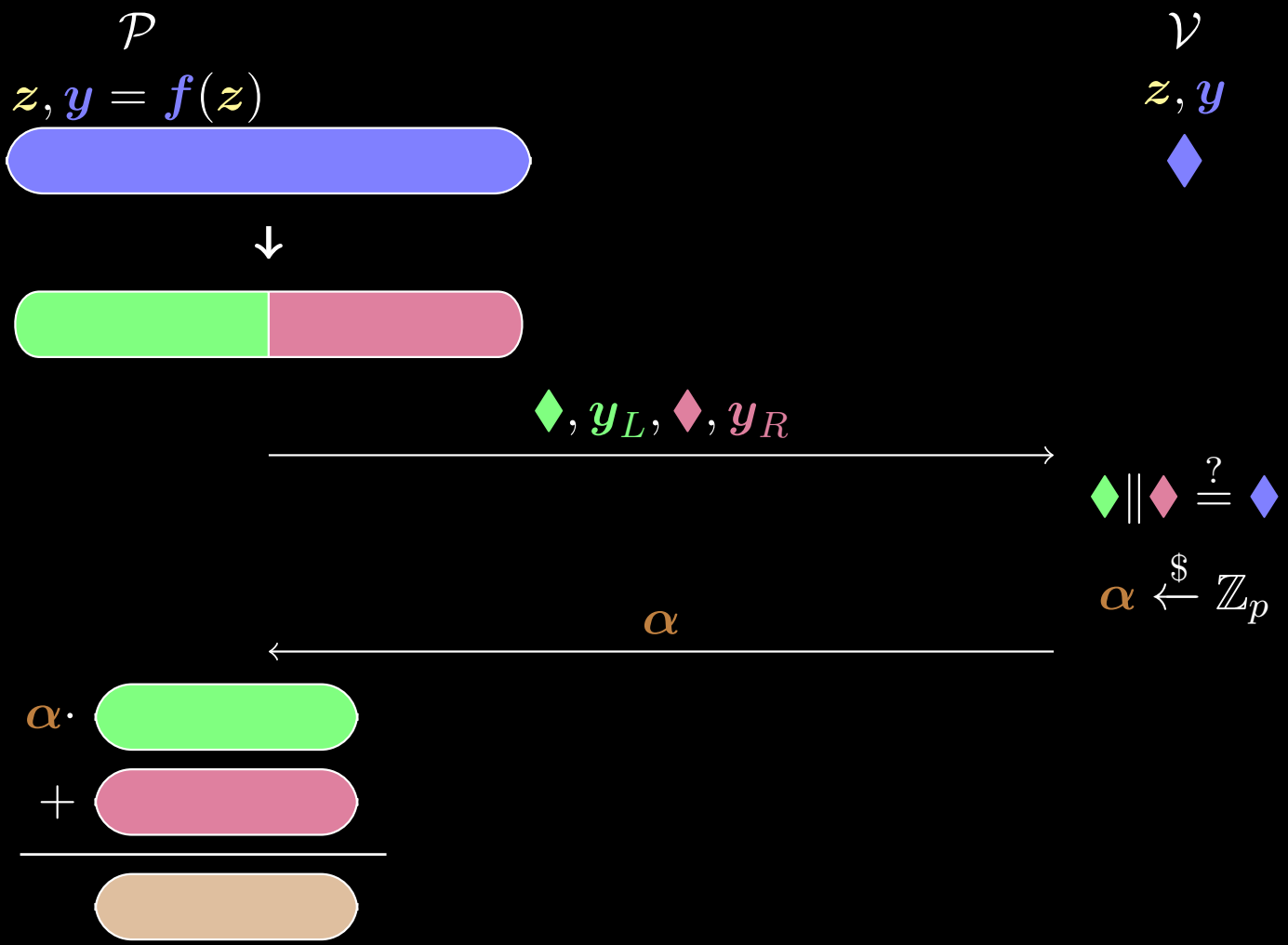

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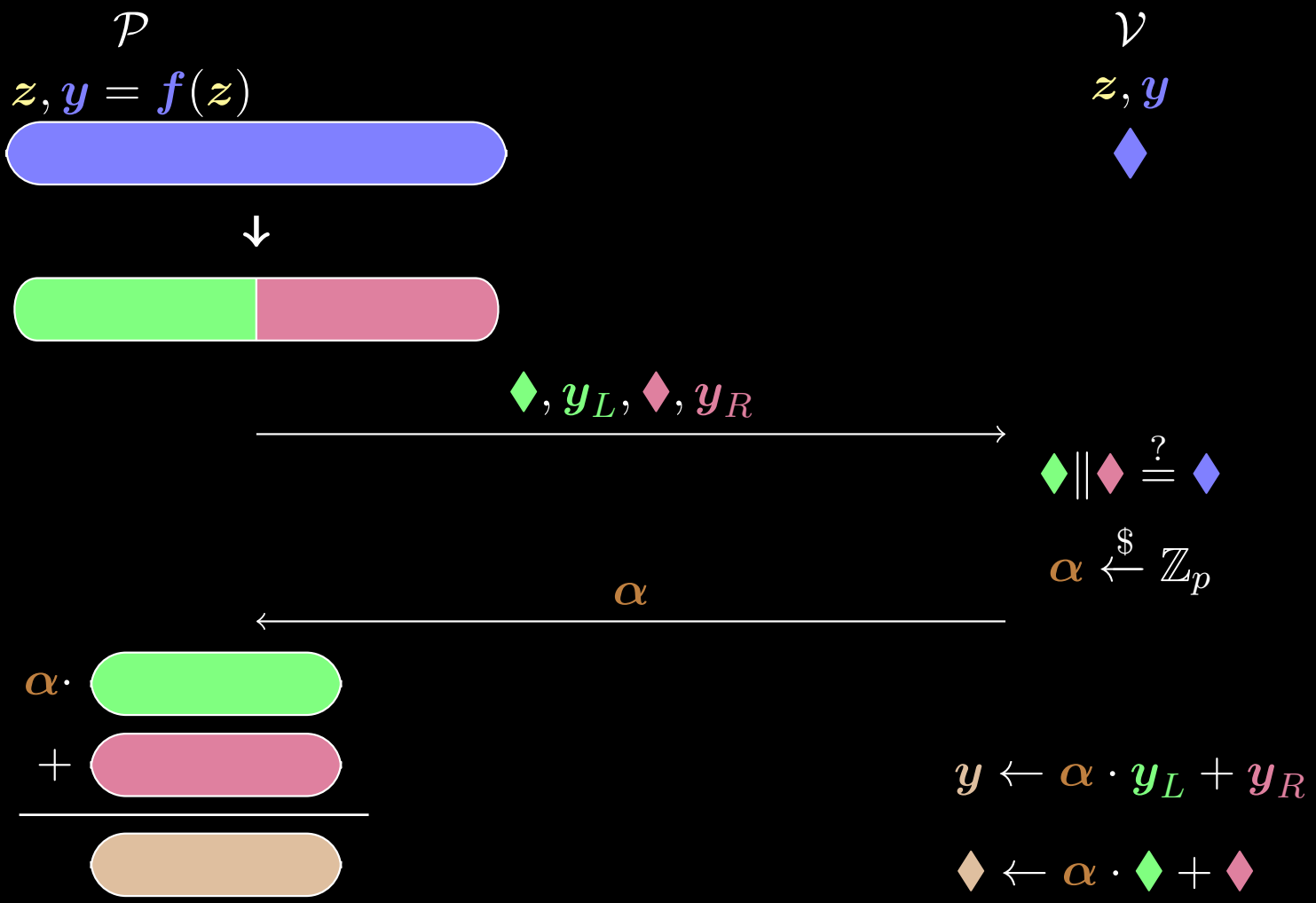

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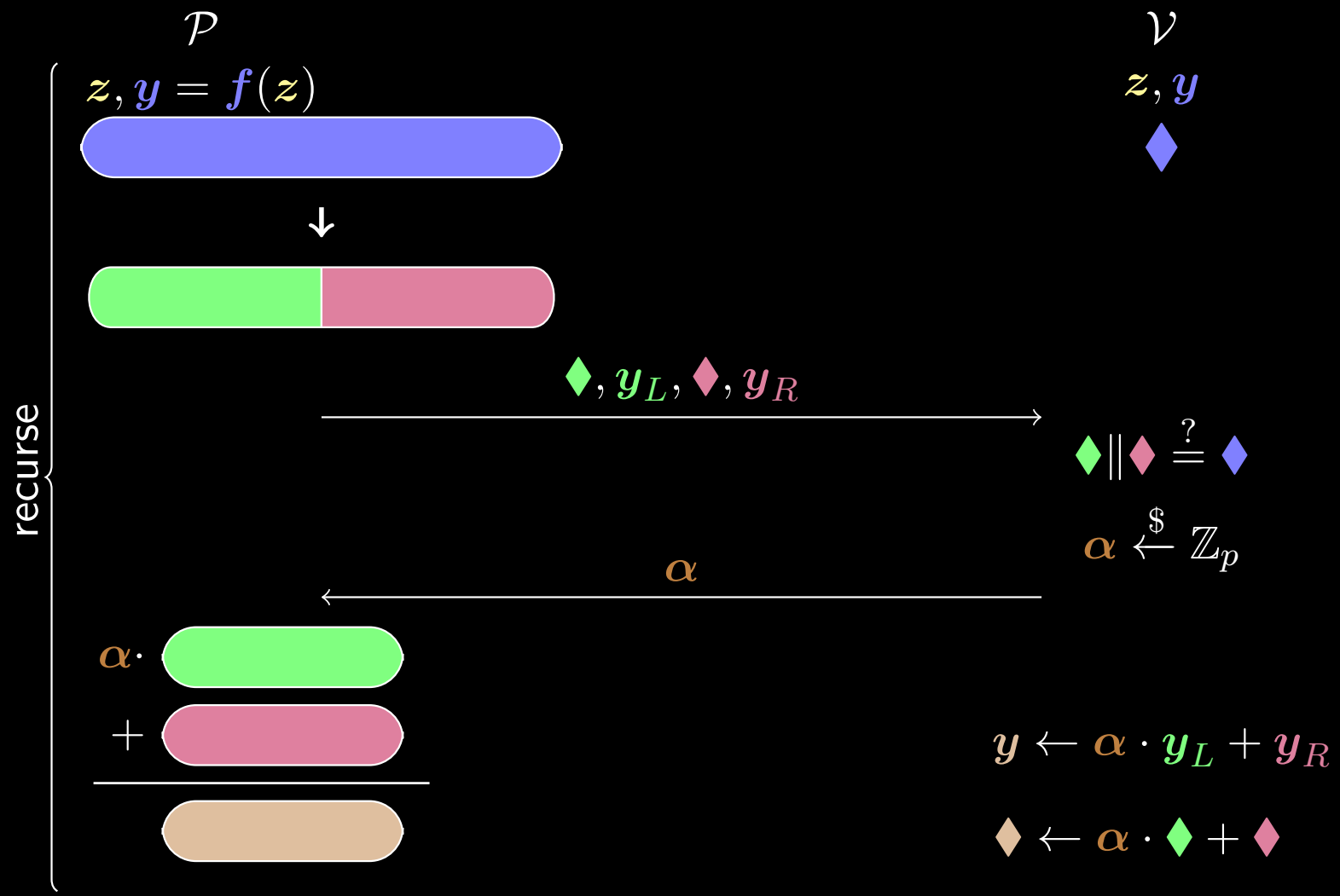

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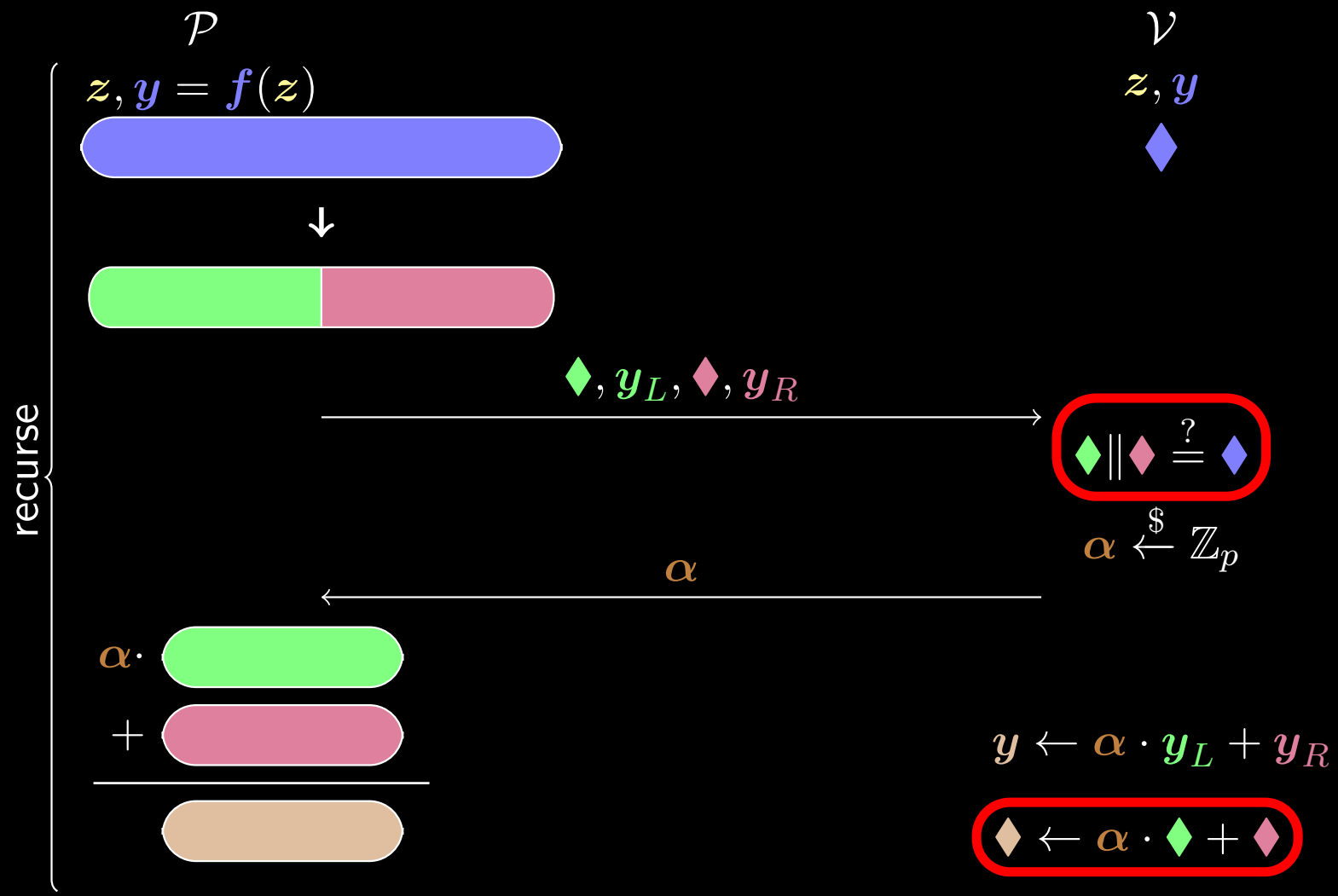

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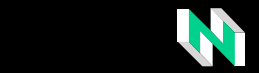
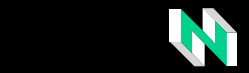


0. commitment to elements from infinite set

Special Homomorphic Commitment ♦



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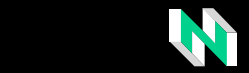

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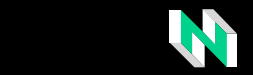

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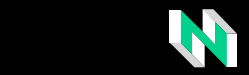

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$\rightarrow$ Groups of Unknown Order

Groups of Unknown Order

RSA Group

- $\mathbb{Z}_n^*/\langle -1 \rangle, \times$ $n = pq$
- big
- trusted setup

Class Group

- $\mathcal{C}\ell(\Delta), \times$ of $\mathbb{Q}(\sqrt{\Delta})$
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not post quantum

Hardness Assumptions

Strong RSA Assumption:

$$\frac{\begin{array}{l}\mathsf{g} \xleftarrow{\$} \mathbb{G} \\ (\mathsf{u}, \ell) \leftarrow \mathcal{A}(\mathsf{g})\end{array}}{\mathcal{A} \text{ wins} \Leftrightarrow \mathsf{u}^{\ell} = \mathsf{g}}$$

Adaptive Root Assumption:

$$\frac{\begin{array}{l}(\mathsf{g}, \mathsf{st}) \leftarrow \mathcal{A}_0(\mathbb{G}) \\ \ell \xleftarrow{\$} \mathsf{Primes}(\lambda 2^{\lambda}) \\ \mathsf{u} \leftarrow \mathsf{A}_1(\ell, \mathsf{st})\end{array}}{(\mathcal{A}_0, \mathcal{A}_1) \text{ wins} \Leftrightarrow \mathsf{u}^{\ell} = \mathsf{g}}$$

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falsifiable ✓

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Diophantine Arguments of Knowledge

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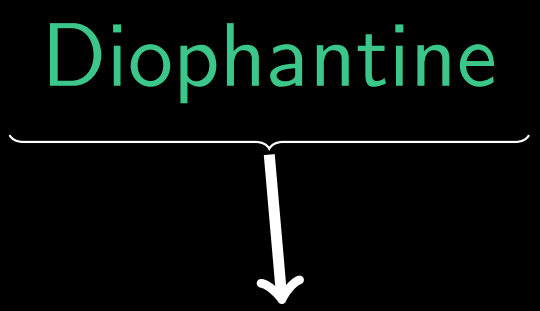

Arguments of Knowledge

polynomial equations

over the integers

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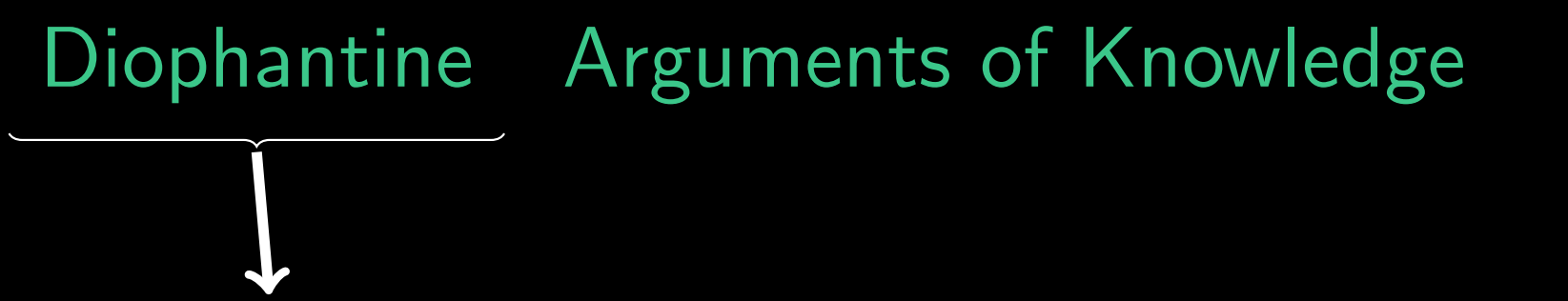

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$a^n + b^n = c^n$ ✓

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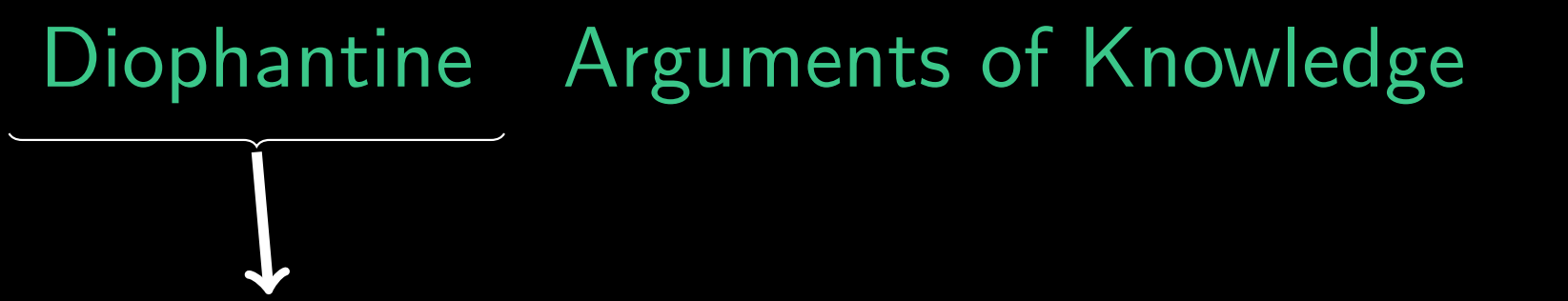

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$x^2 - ny^2 = \pm 1$ ✓

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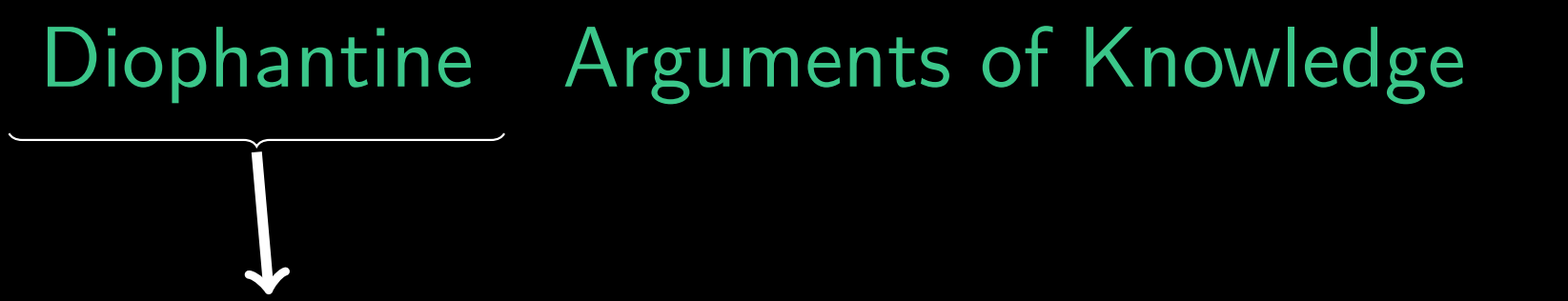

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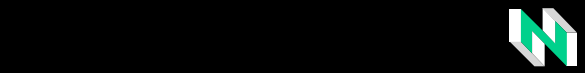

Diophantine Arguments of Knowledge

polynomial equations

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$a^n + b^n = c^n$ ✓

$x^2 - ny^2 = \pm 1$ ✓

$e^\pi = (-1)^i$ ×

$\lceil e \rceil - \lfloor \pi \rfloor = 0$ ✓

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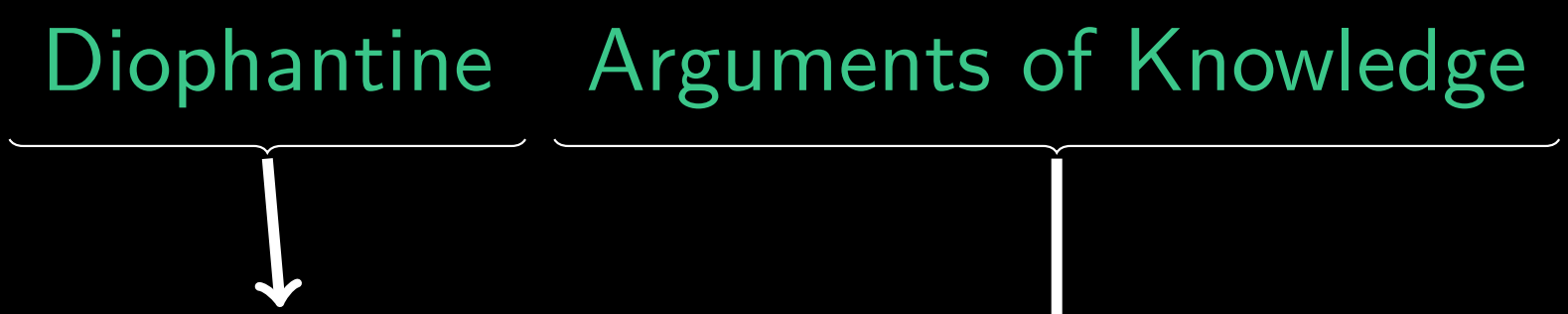

polynomial equations

over the integers

"I know $\mathbf{y} \in \mathbb{Z}^m$ such that $\mathcal{P}(\mathbf{x}, \mathbf{y}) = 0$"

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$x^2 - ny^2 = \pm 1$ ✓

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$\lceil e \rceil - \lfloor \pi \rfloor = 0$ ✓

Integer Encoding

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solution:

example:

Integer Encoding

have:
arguments for $\mathbb{Z}$

want:
arguments for $\mathbb{F}_p[X]$

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example:

$$2X^3 + 3X^2 + 4X + 1 \in \mathbb{F}_5[X]$$

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3. evaluate: $\hat{f}(q)$

example:

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$q = 10$

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*: if q is large enough

Commitment

0. commitment
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Wesolowski 2019: PoE (proof of exponentiation)

$\mathcal{P}$	claim: $\mathsf{u}^x = \mathsf{v}$	$\mathcal{V}$
		$\ell \stackrel{\$}{\leftarrow} \mathsf{Primes}(\lambda \cdot 2^{2\lambda})$
$q = \lfloor x/\ell \rfloor \quad r = x \bmod \ell$		
$\mathsf{Q} = \mathsf{u}^q$		
		$\mathsf{Q}^\ell \mathsf{u}^r \stackrel{?}{=} \mathsf{v}$

Talk Outline

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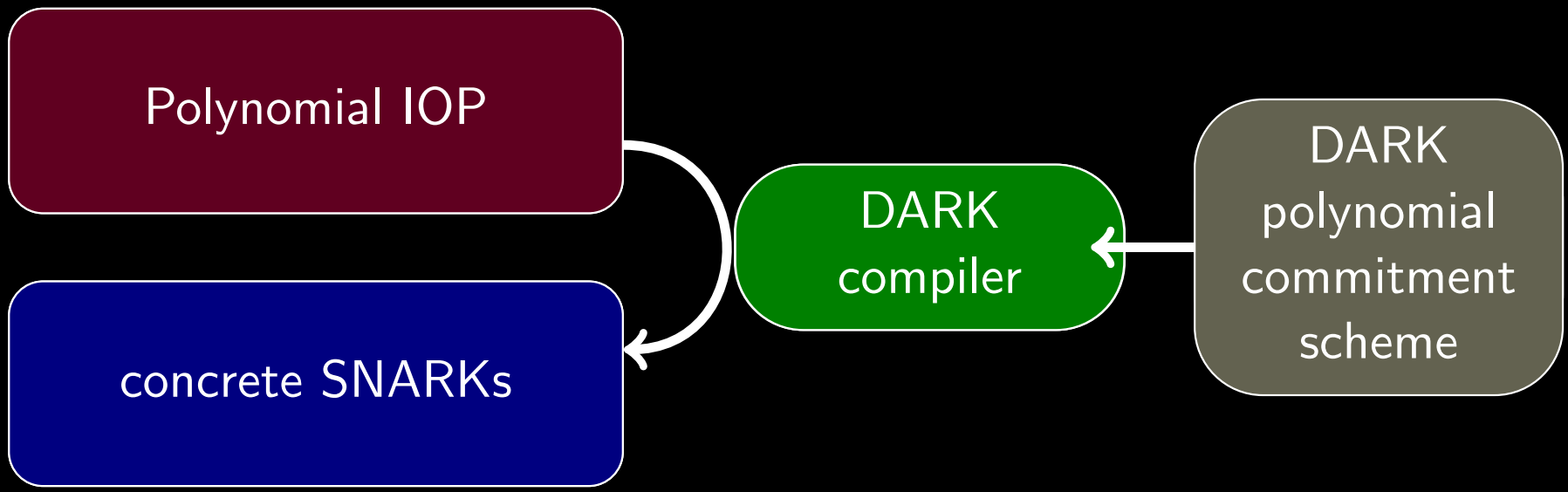
2. **information-theoretic formalism**
3. **cryptographic compiler**
4. **DARK + Sonic = Supersonic** ← transparent SNARK (and other constructions)



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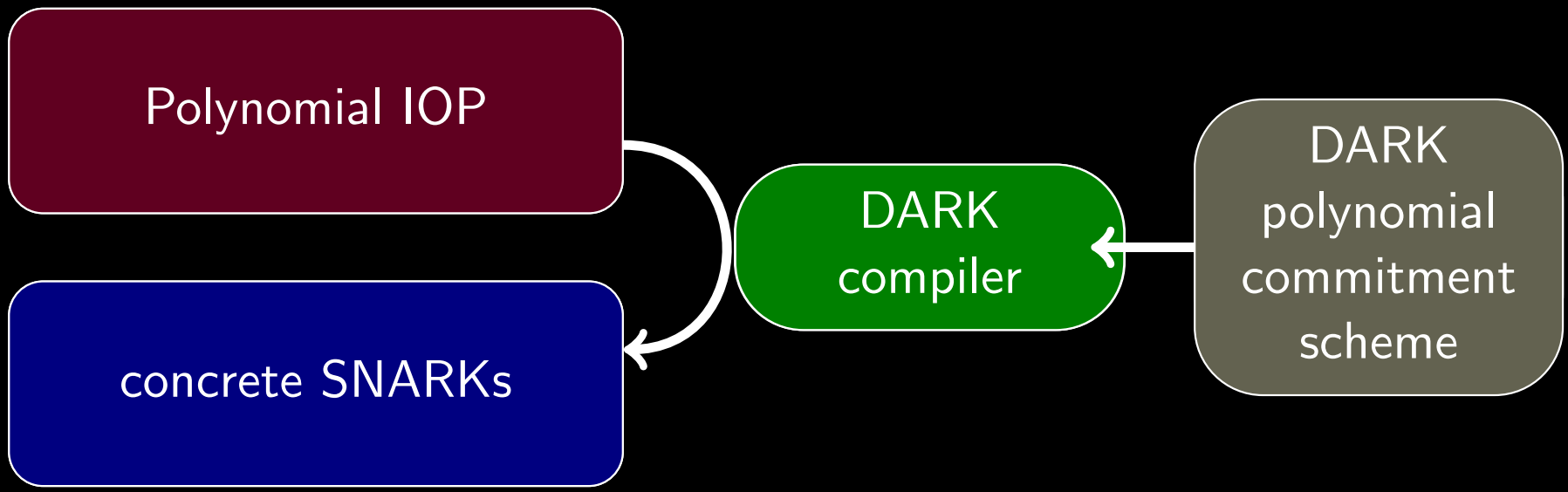

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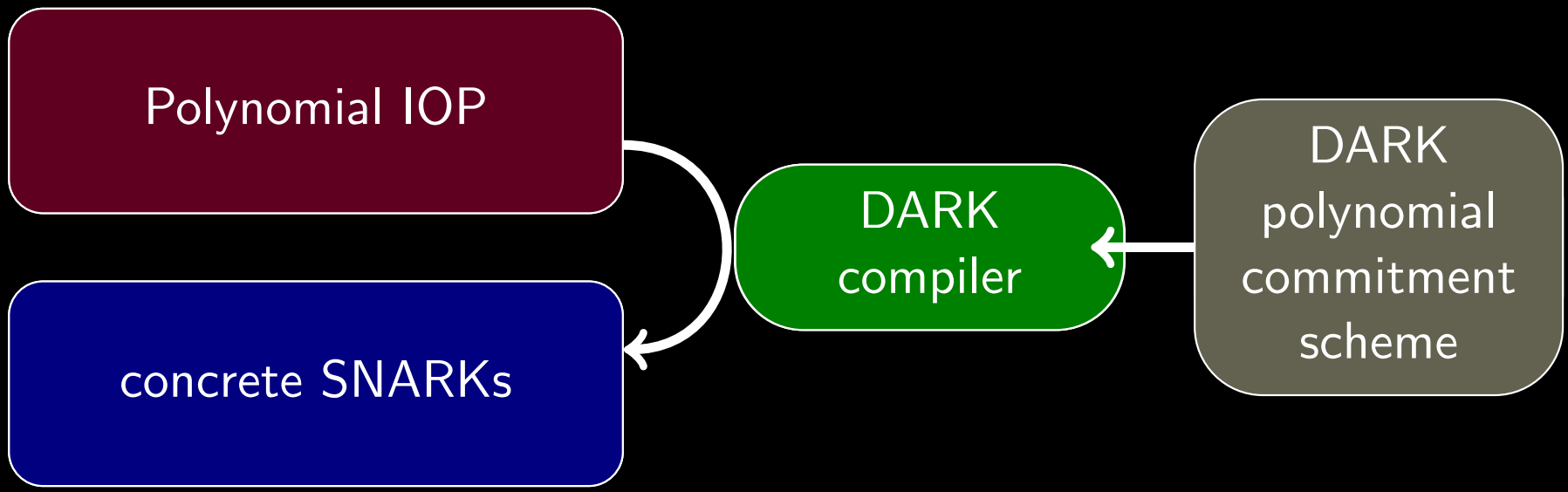
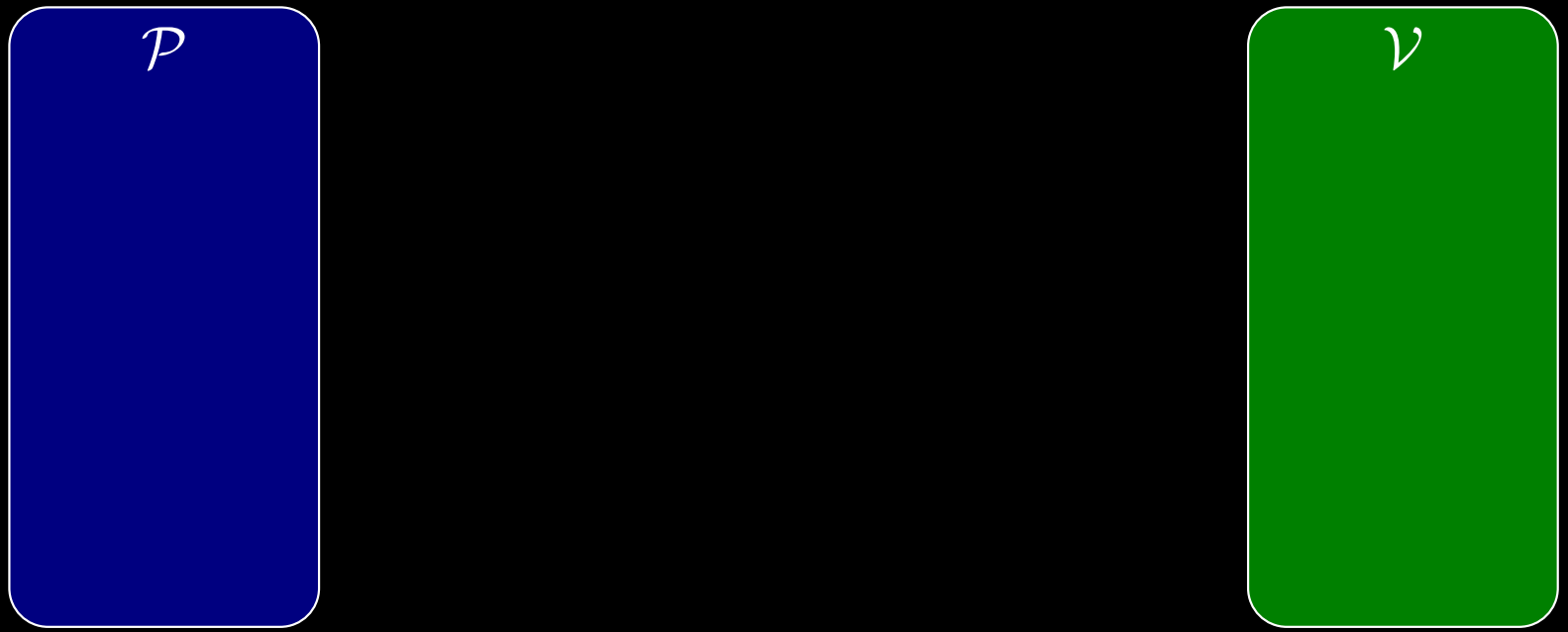


Polynomial IOP



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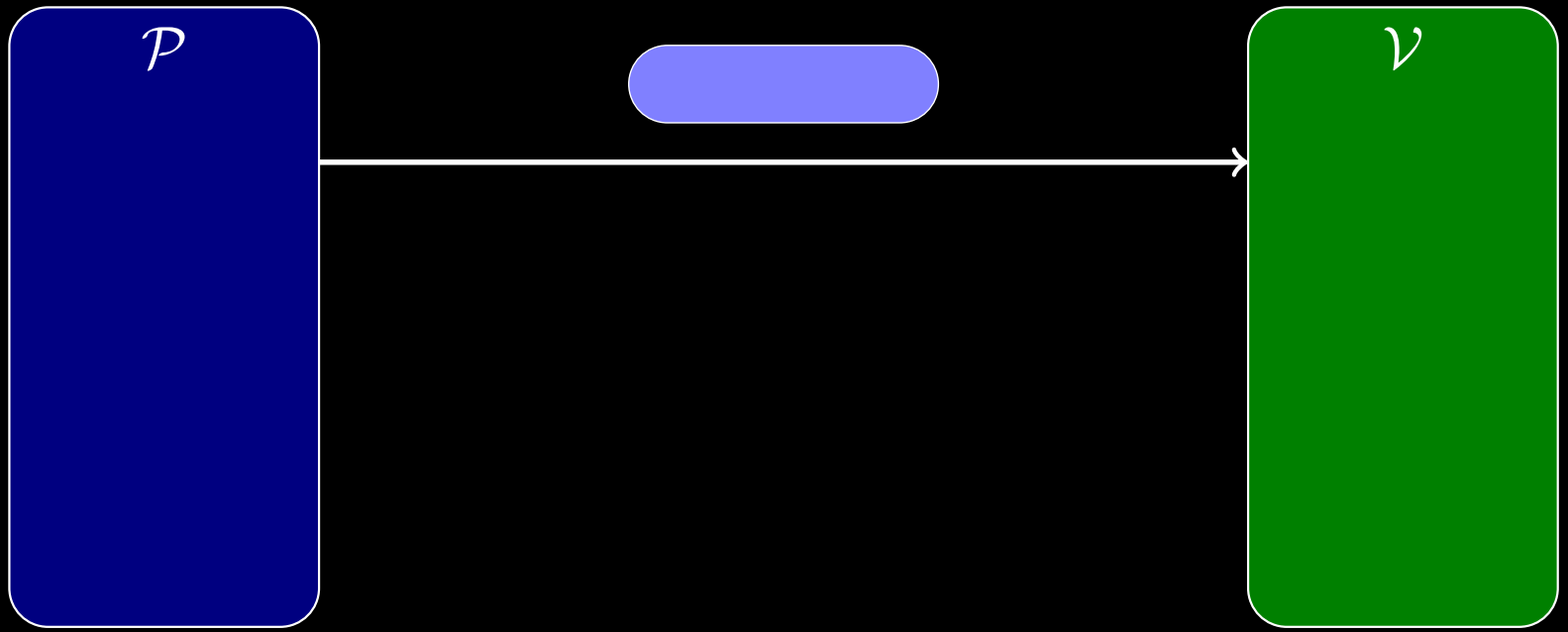

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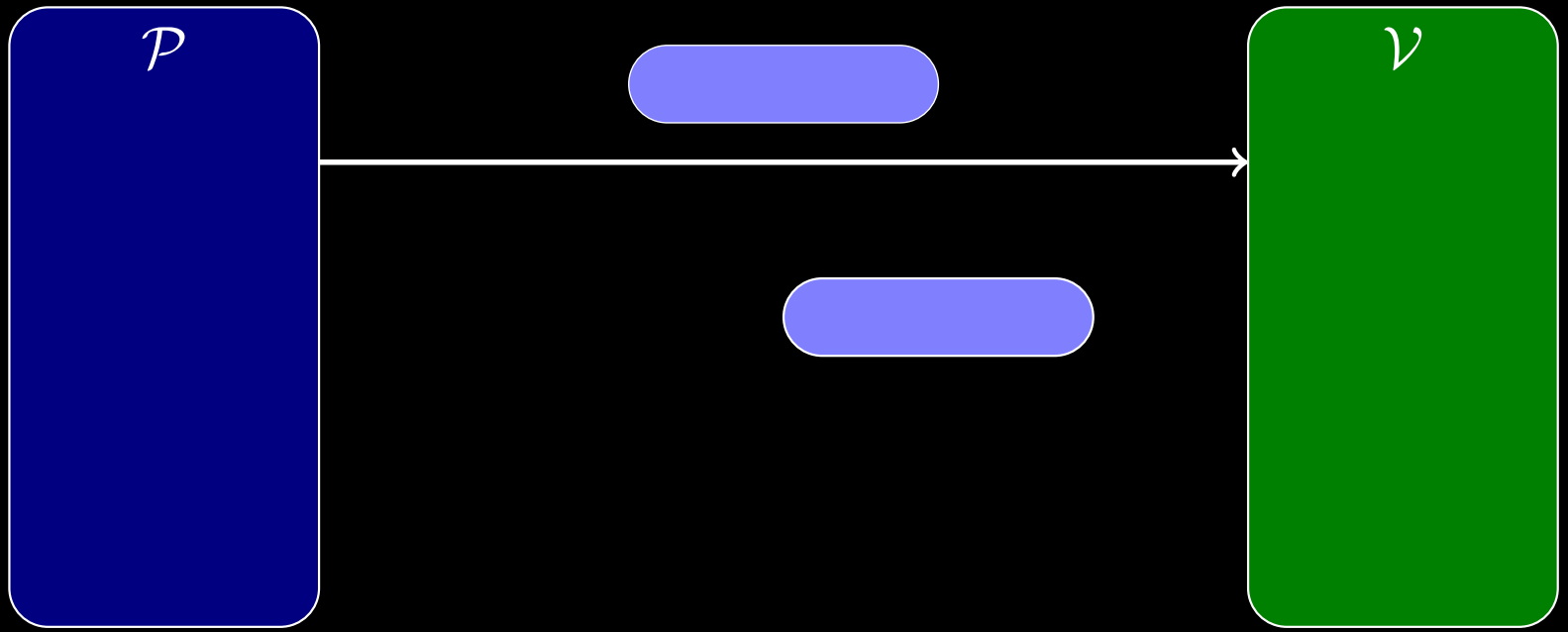

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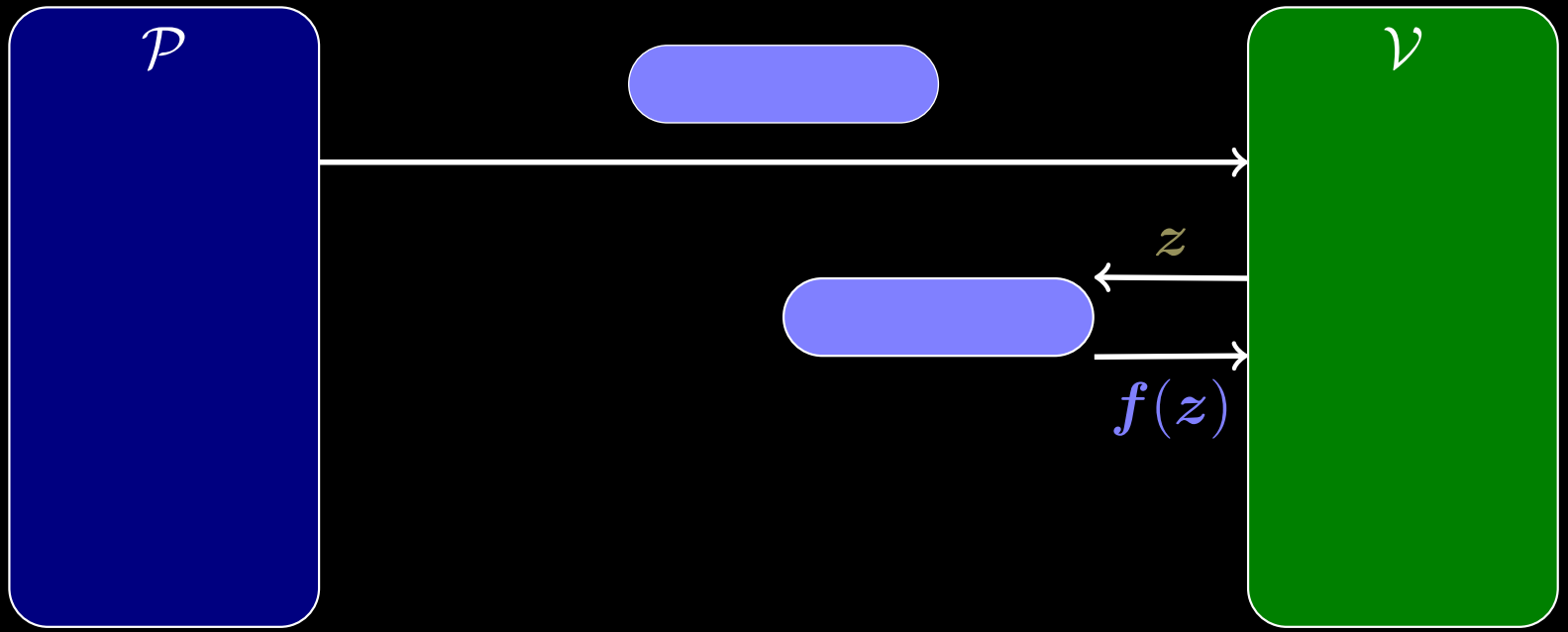

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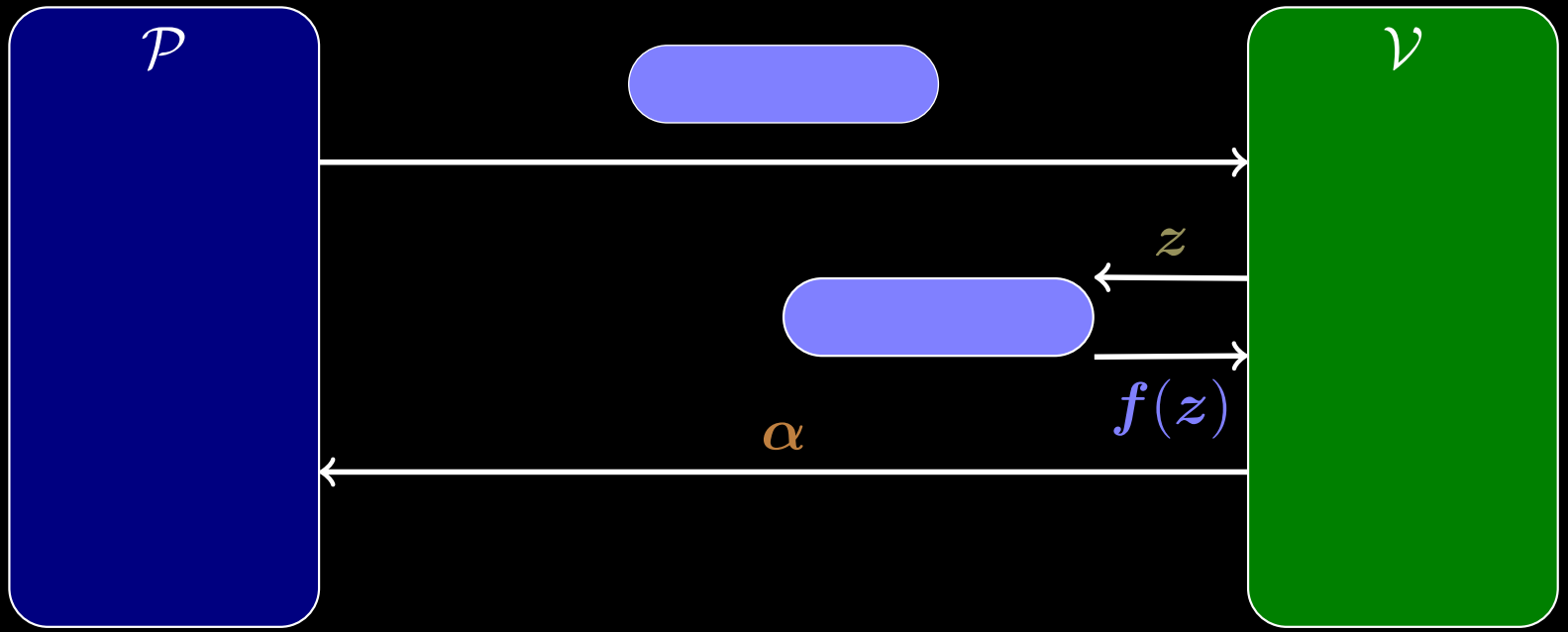

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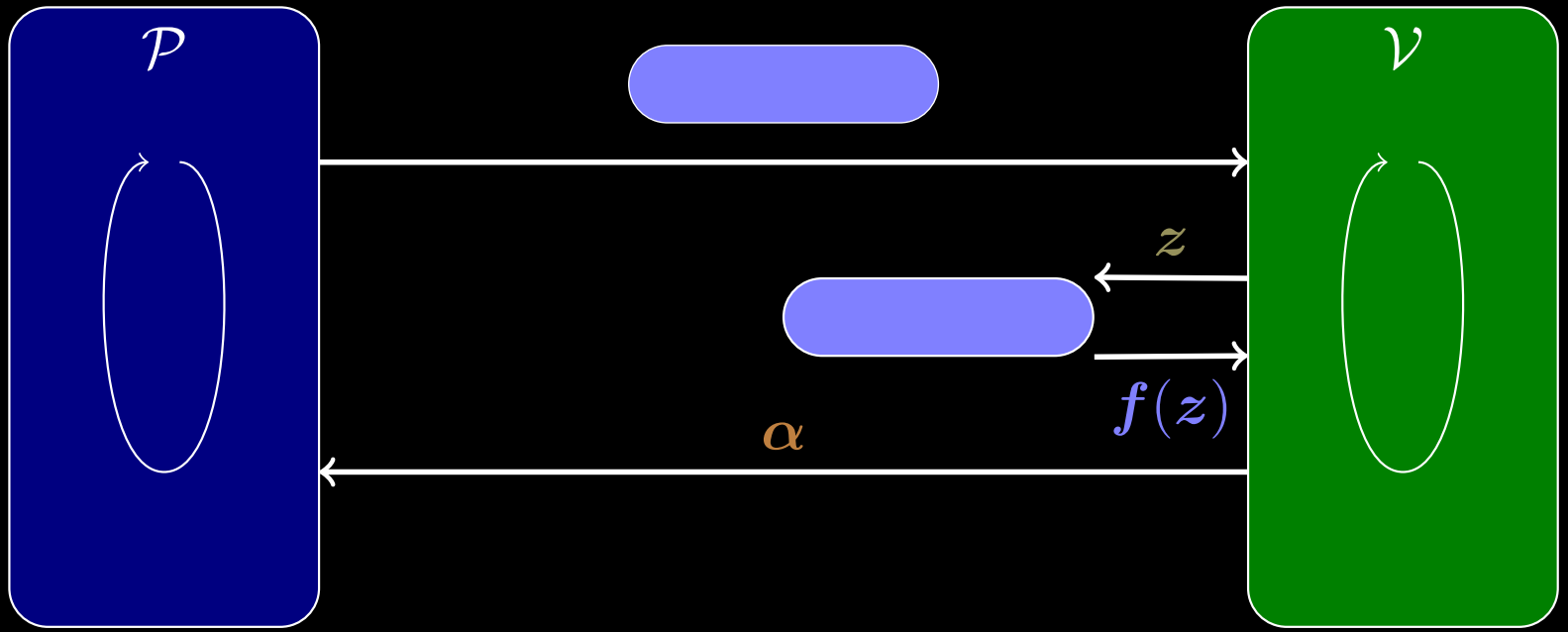

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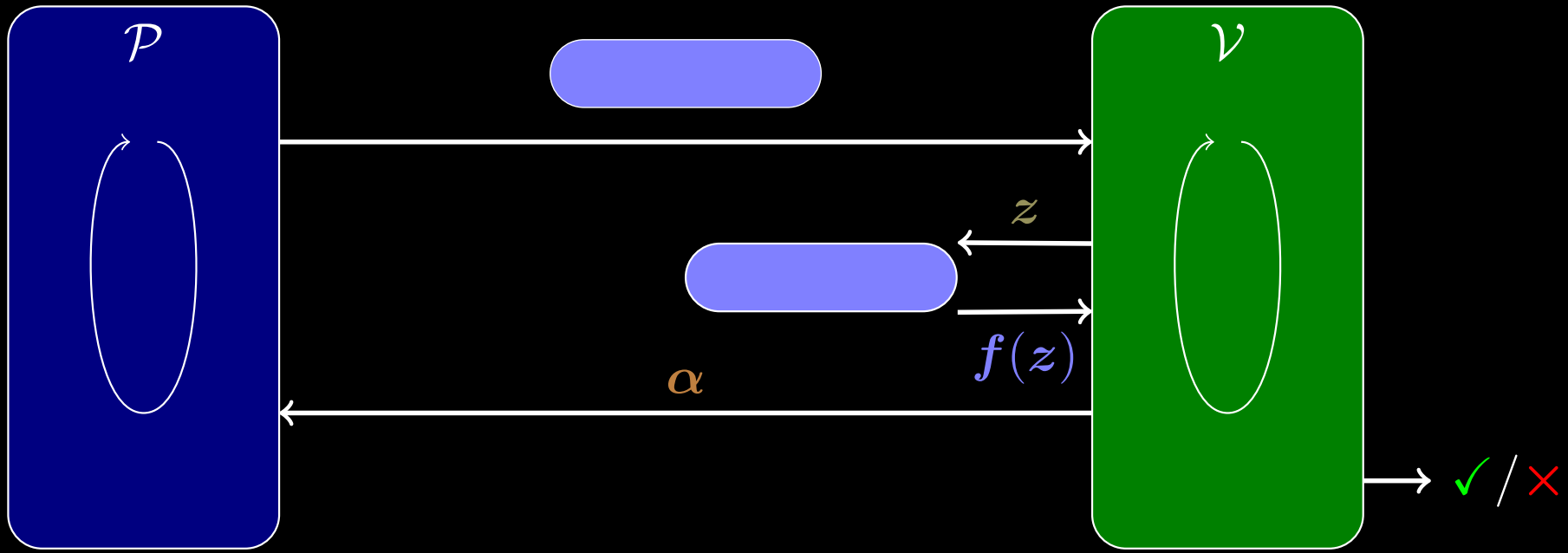

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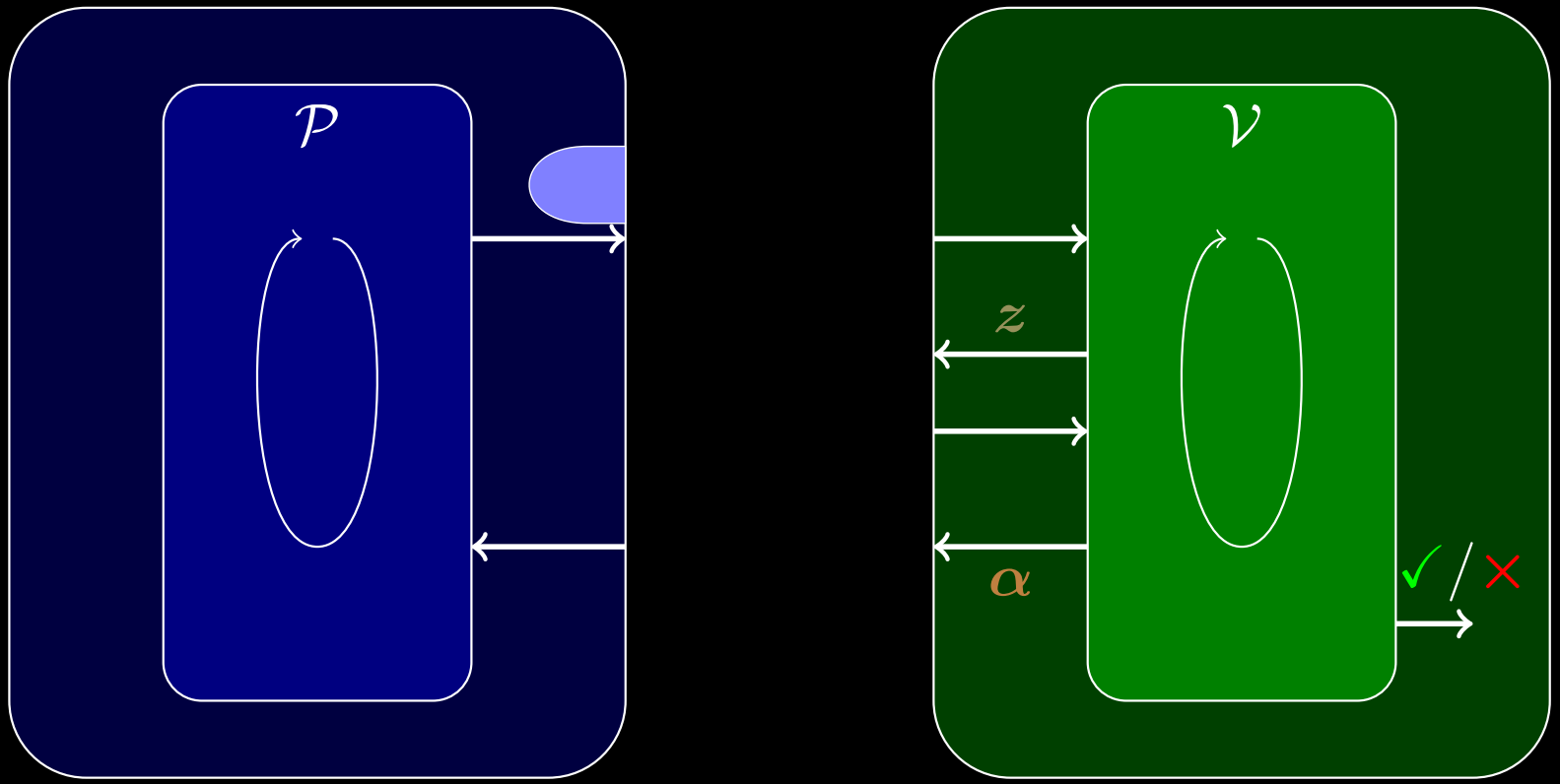

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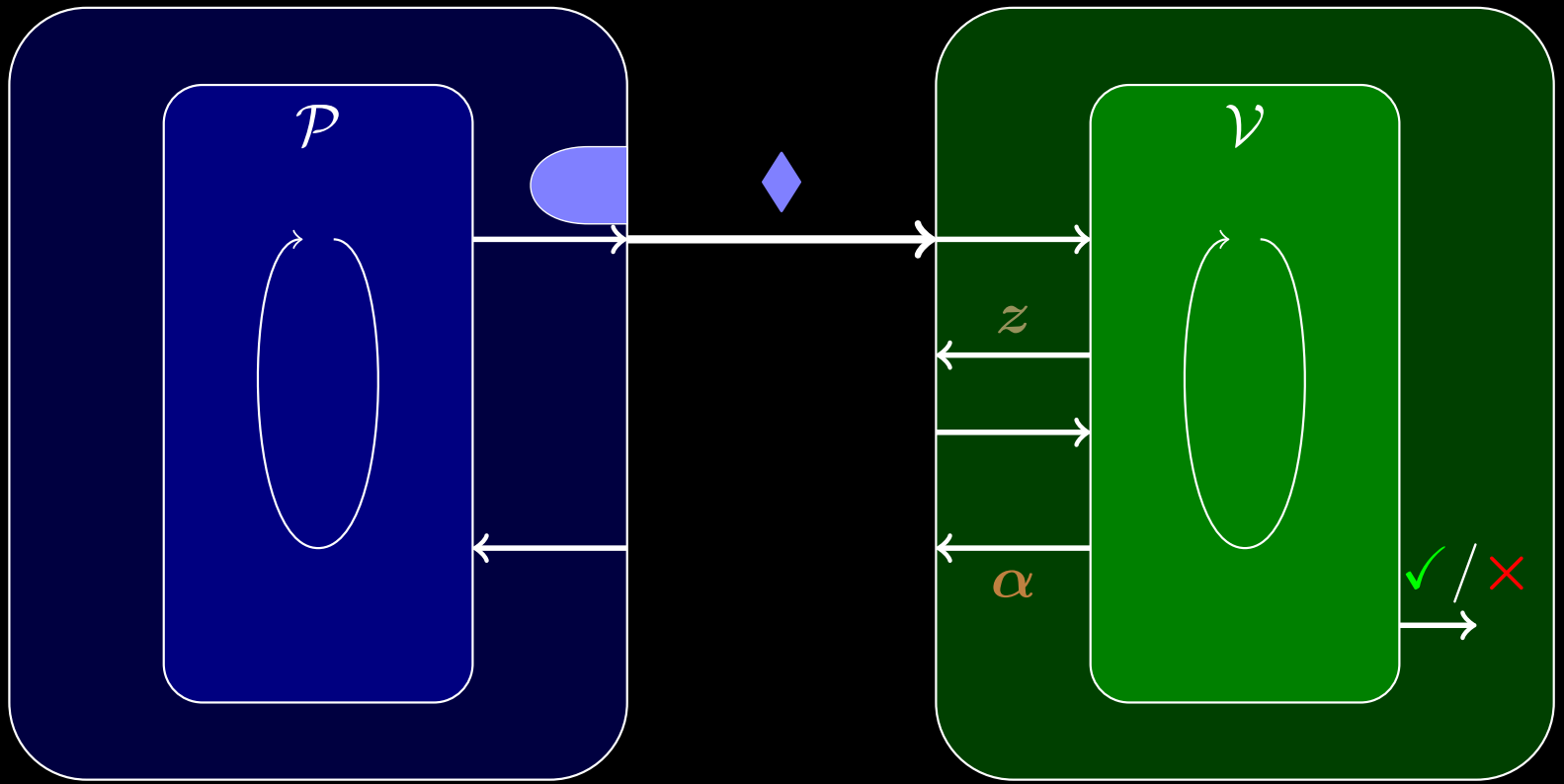

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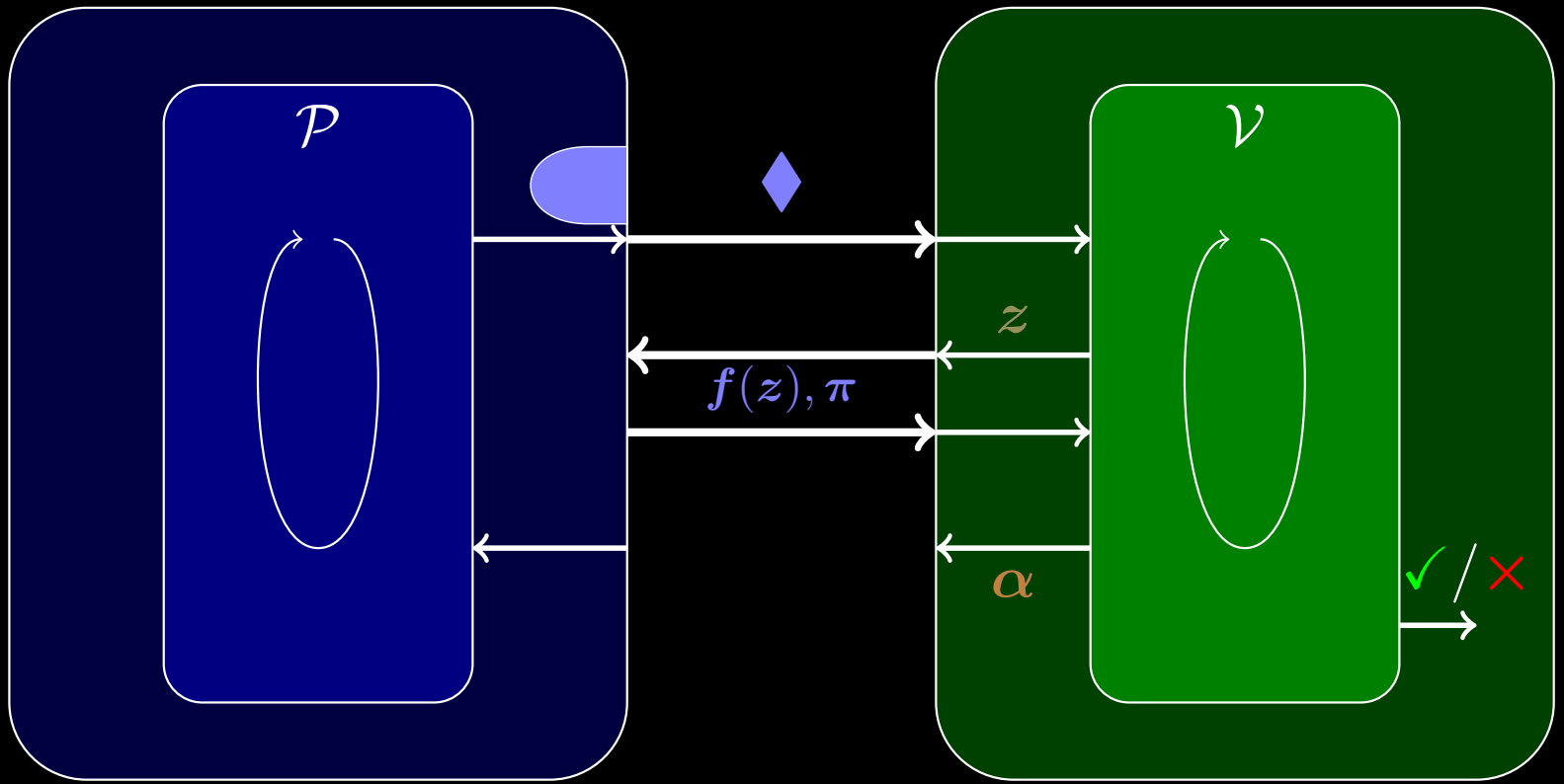

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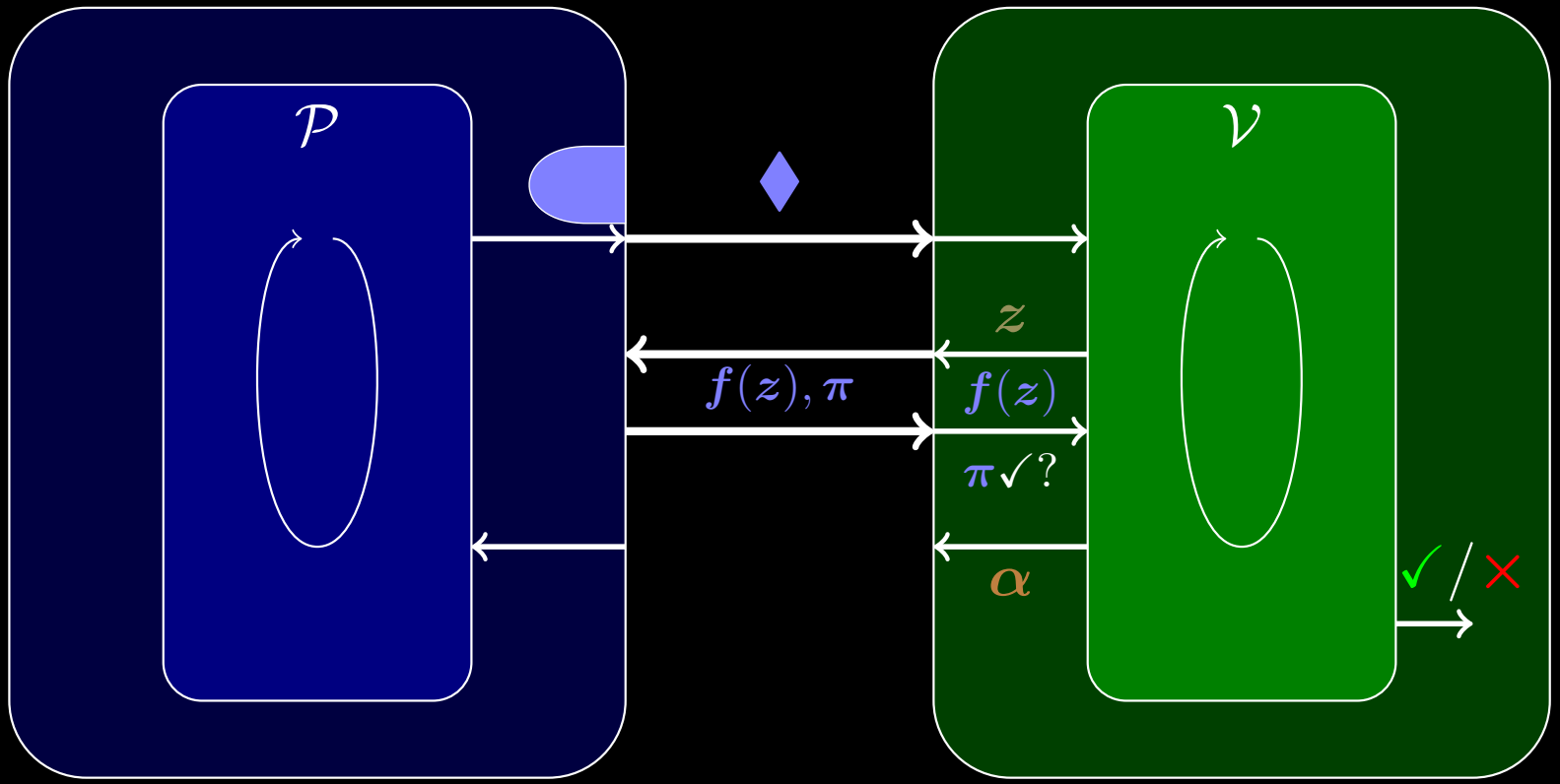

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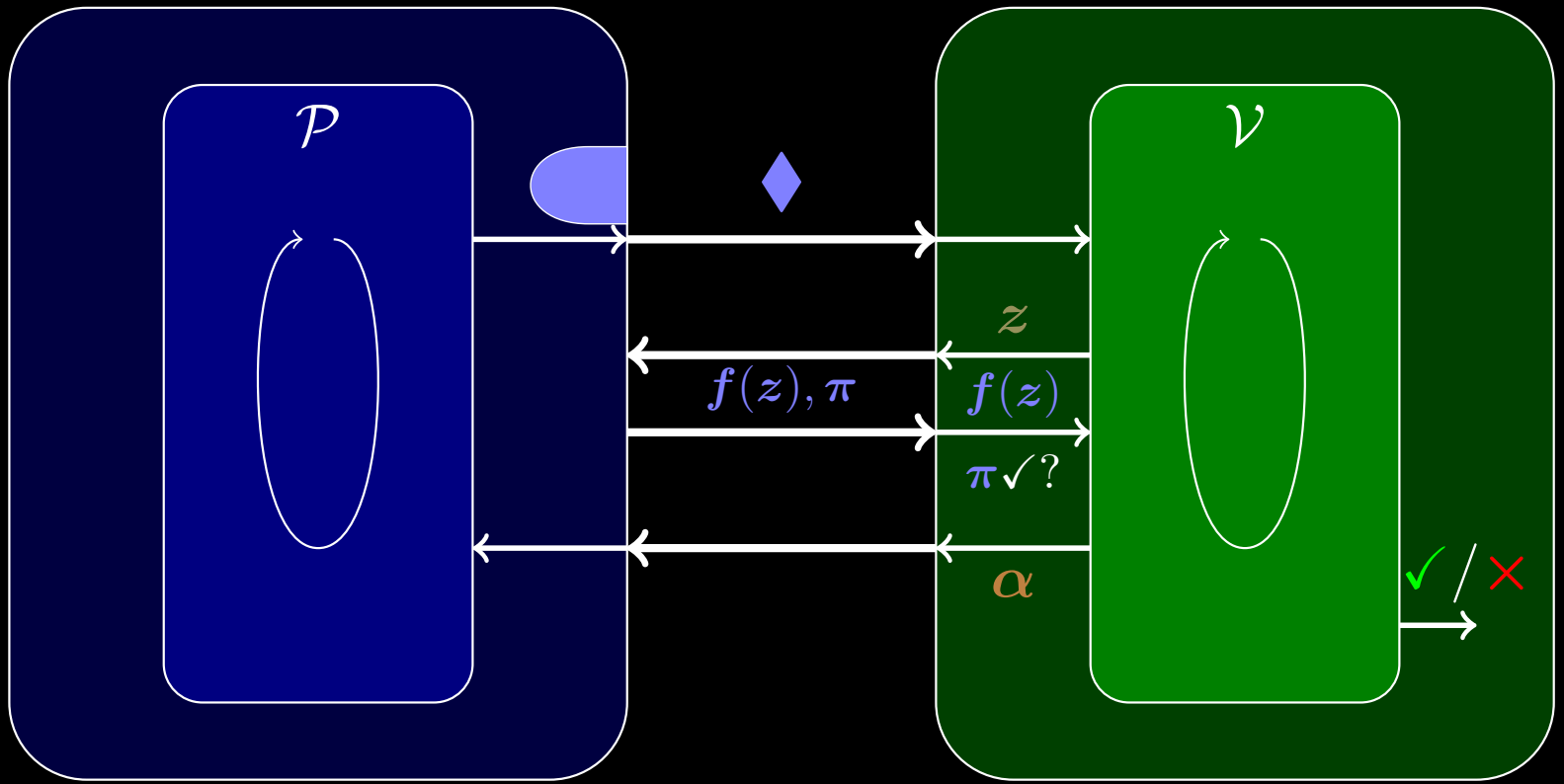

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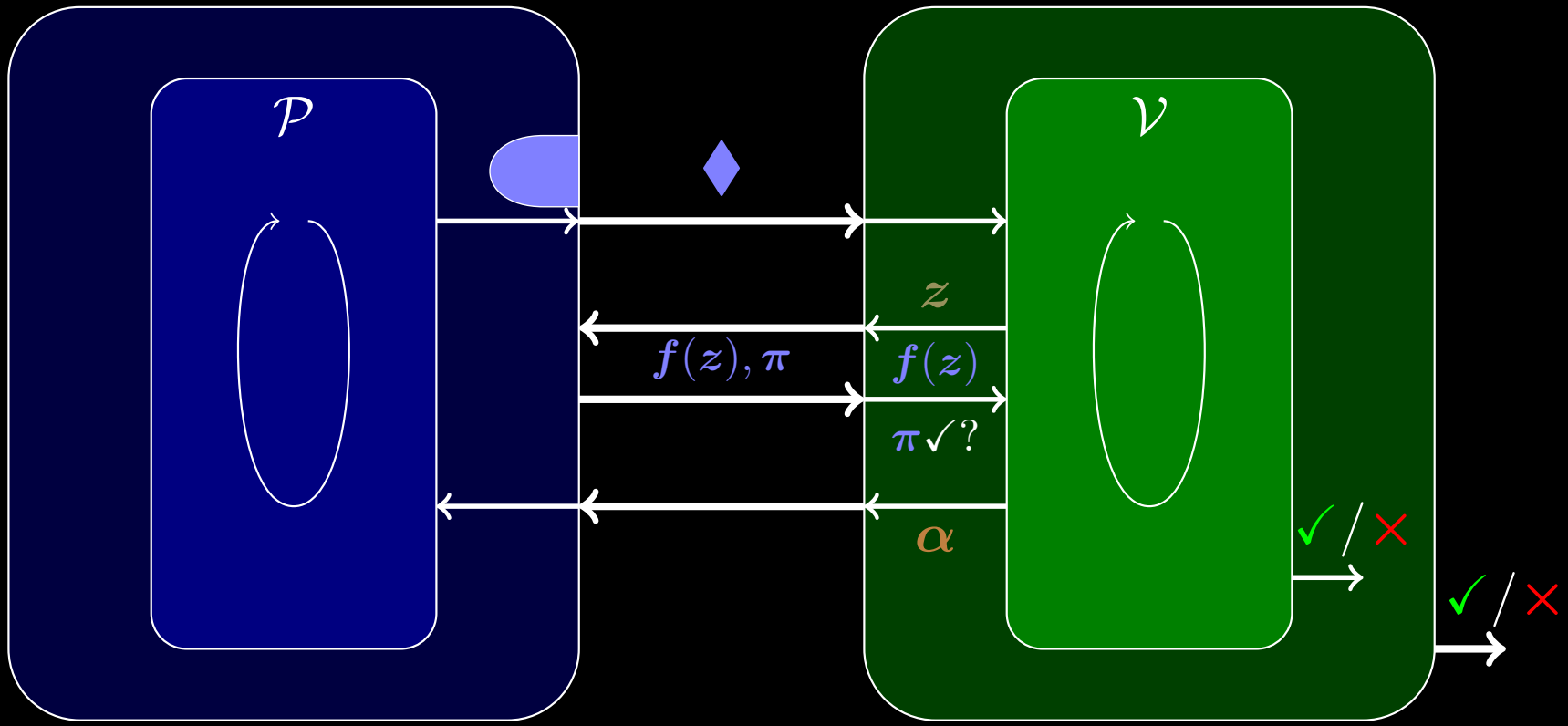
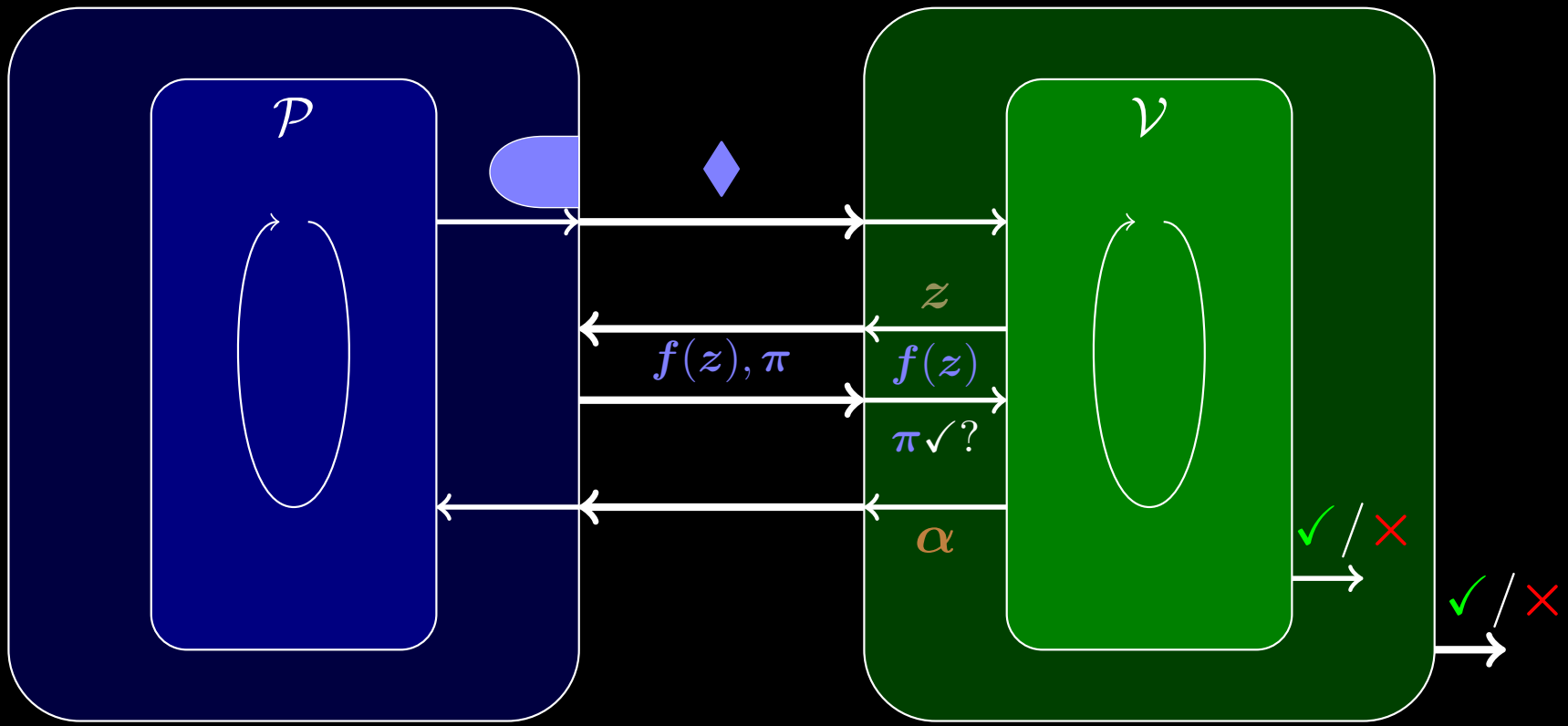


Compiled Polynomial IOP — Soundness



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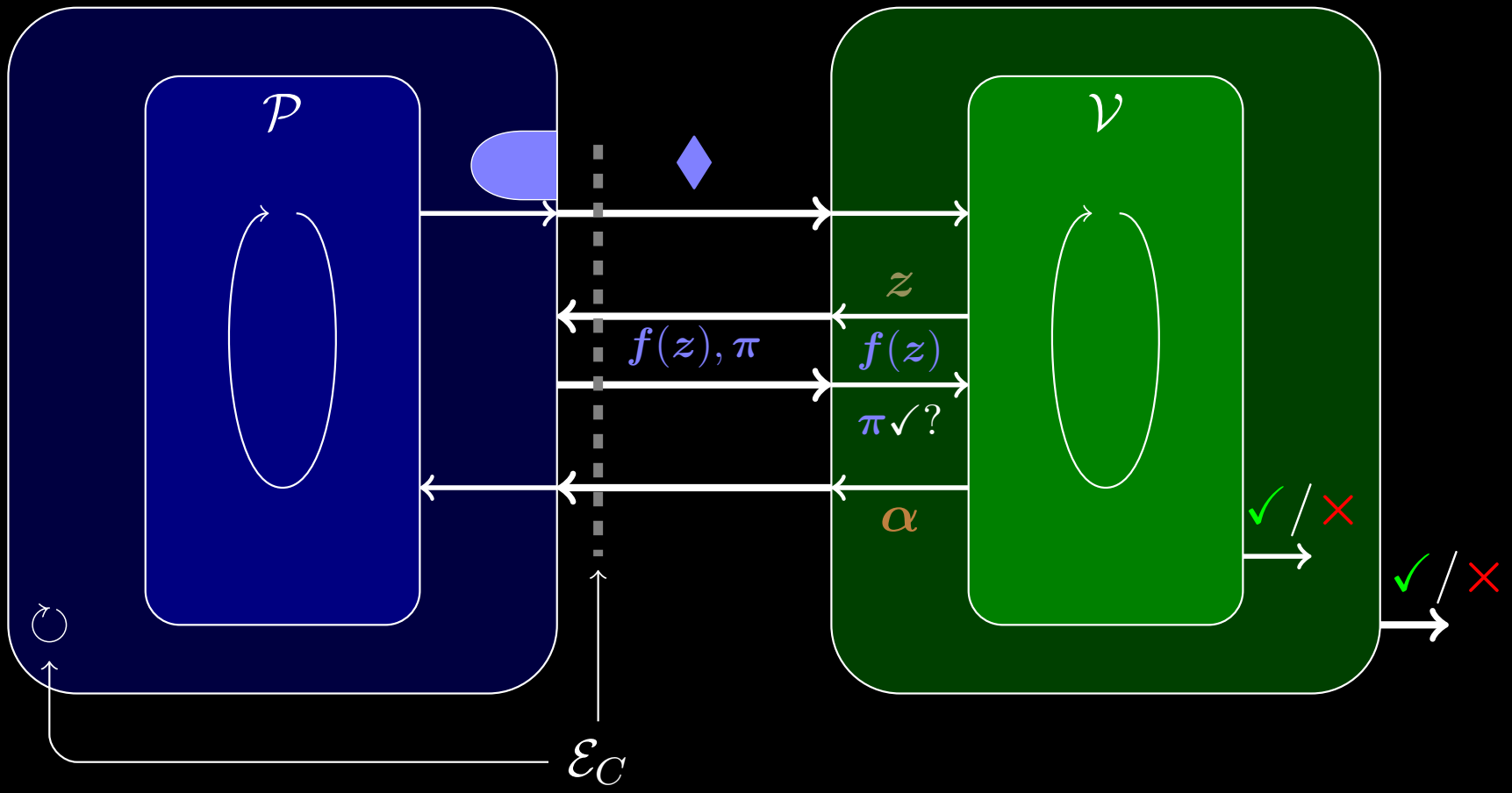

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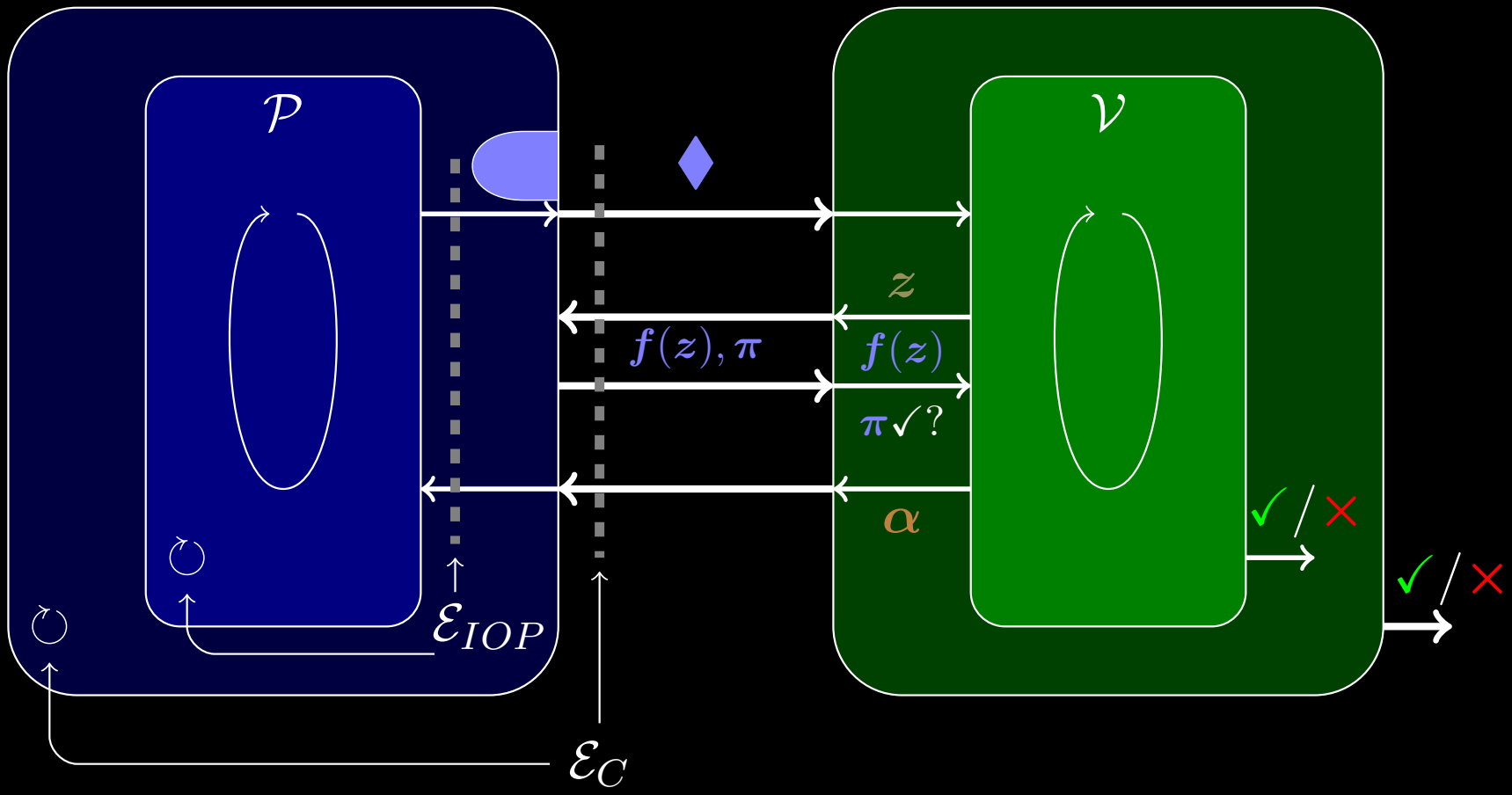

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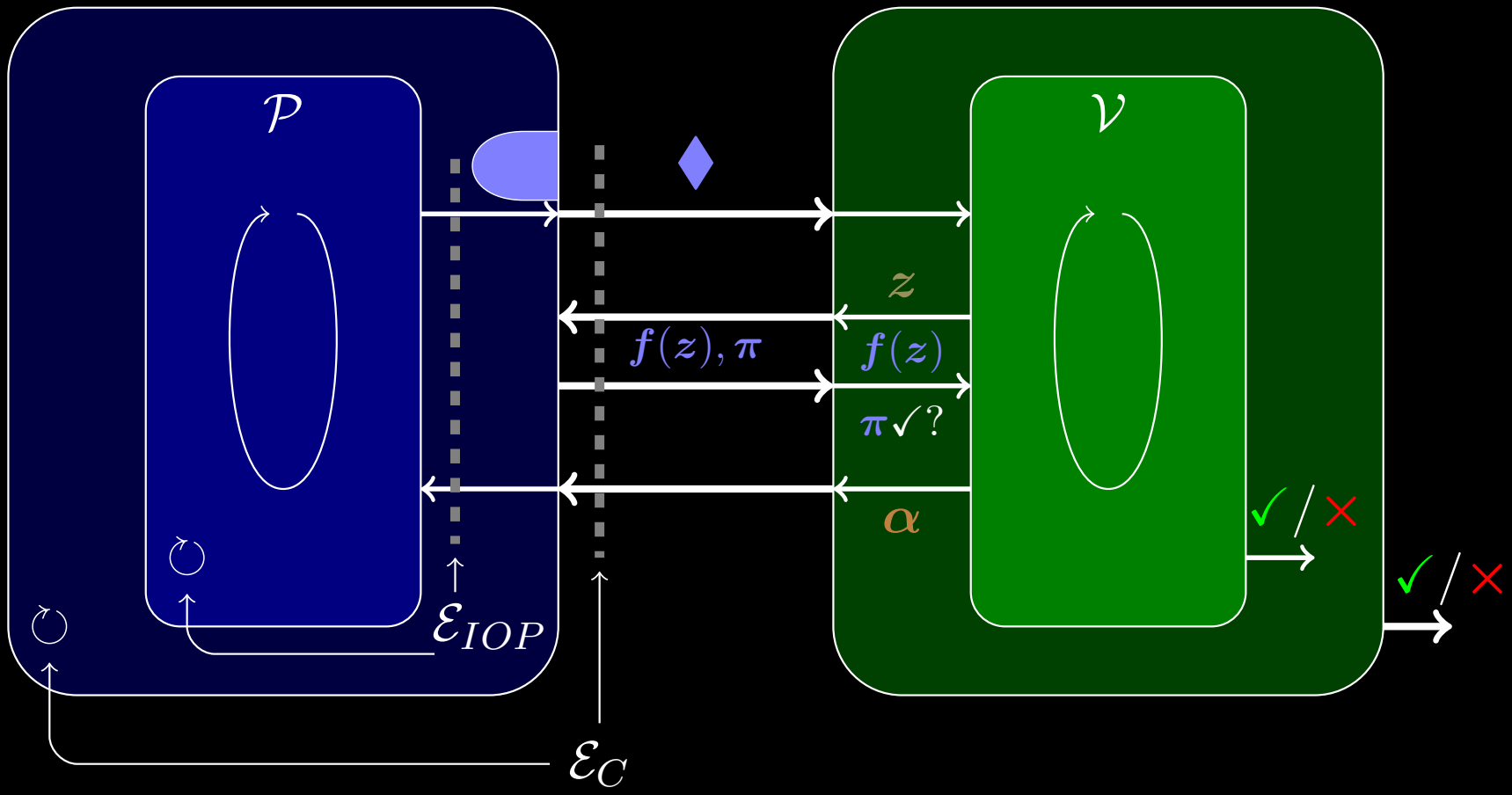

$$\mathcal{E}_{IOP} \xrightarrow{???} \mathcal{E}_C$$

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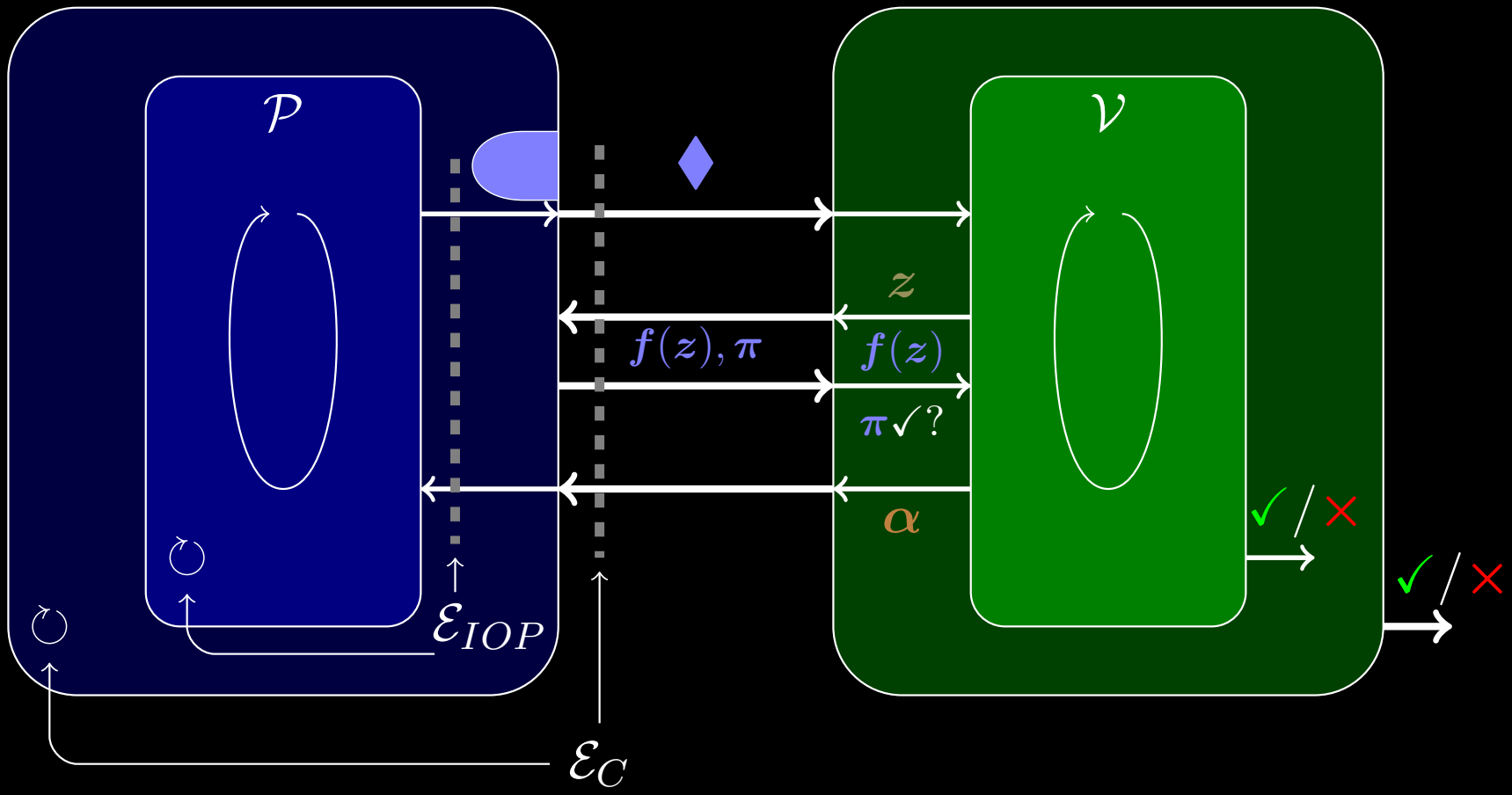

$$\mathcal{E}_{PCS}(\pi) \Rightarrow f(X)$$

$$\mathcal{E}_{IOP} \longrightarrow \mathcal{E}_C$$

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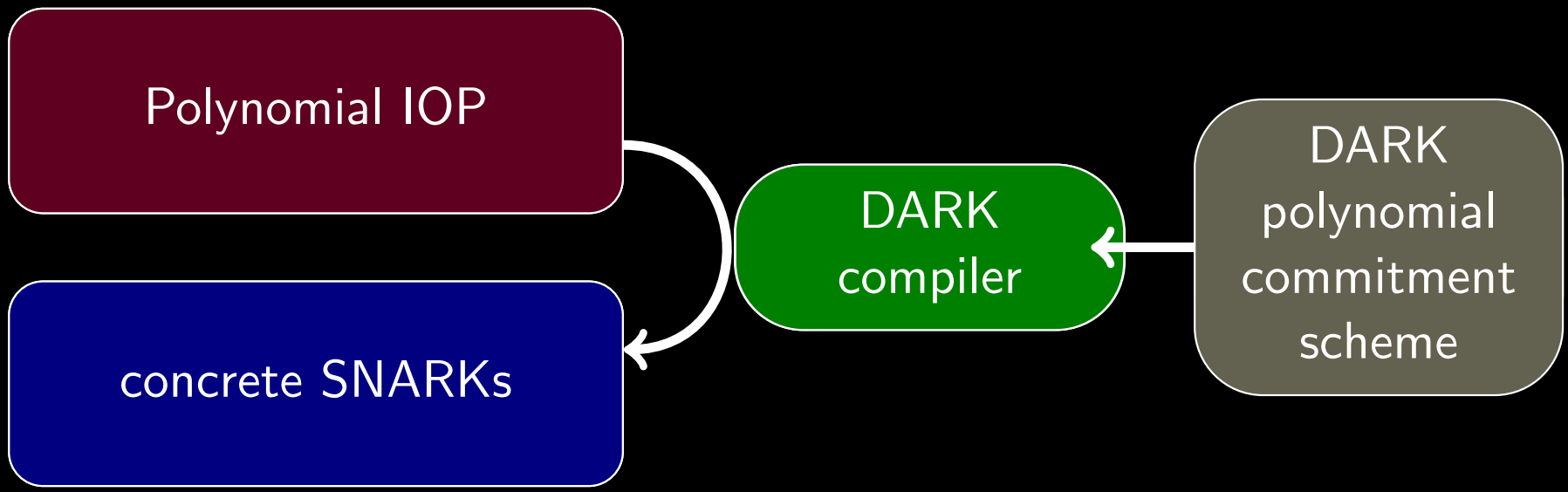

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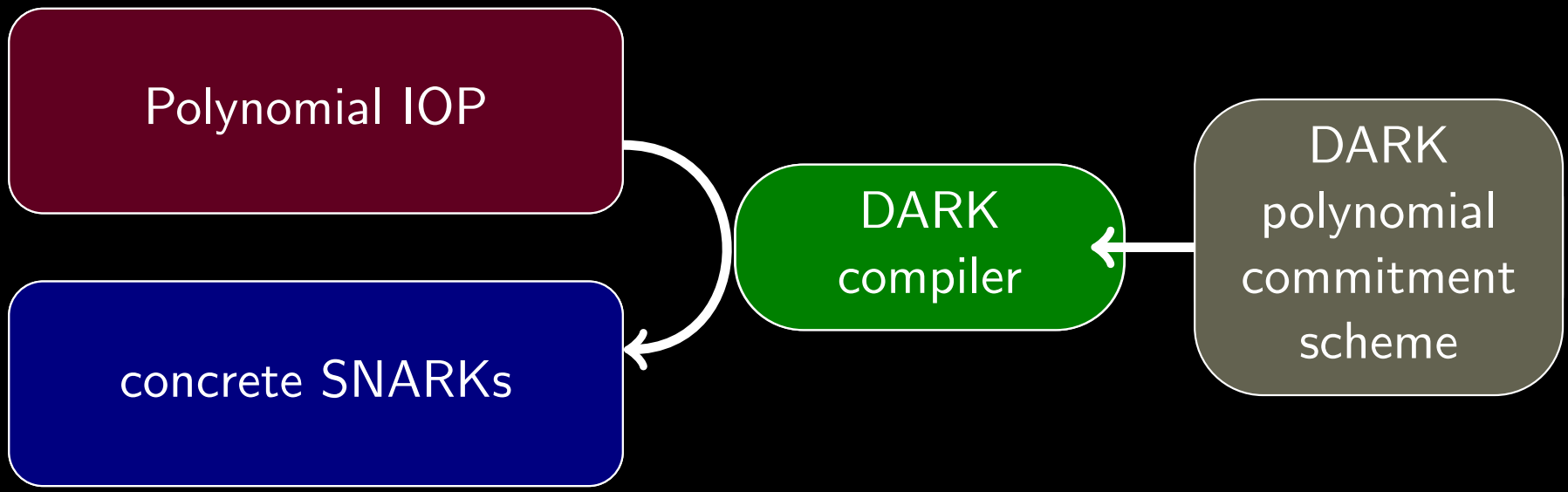

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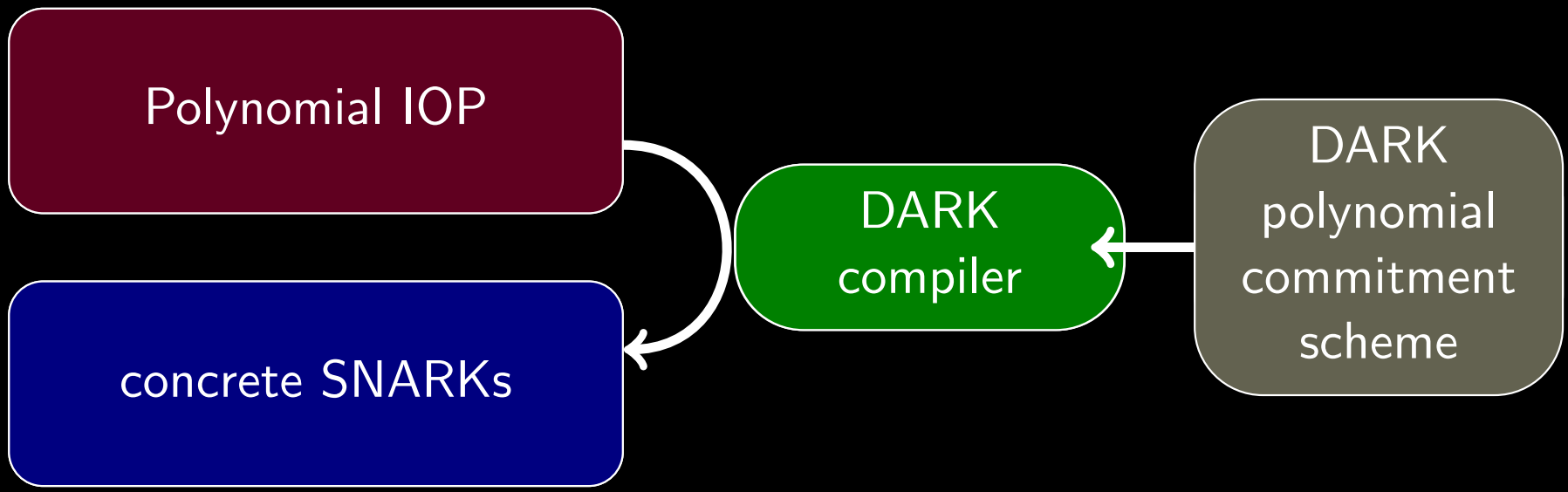

Supersonic / Other Constructions

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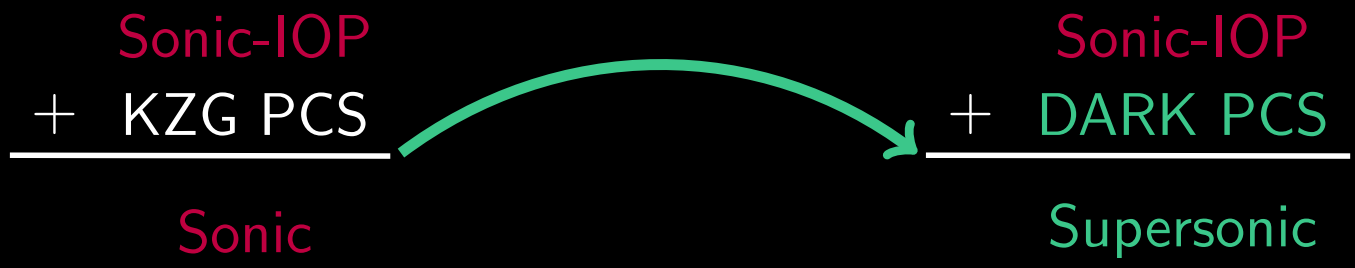

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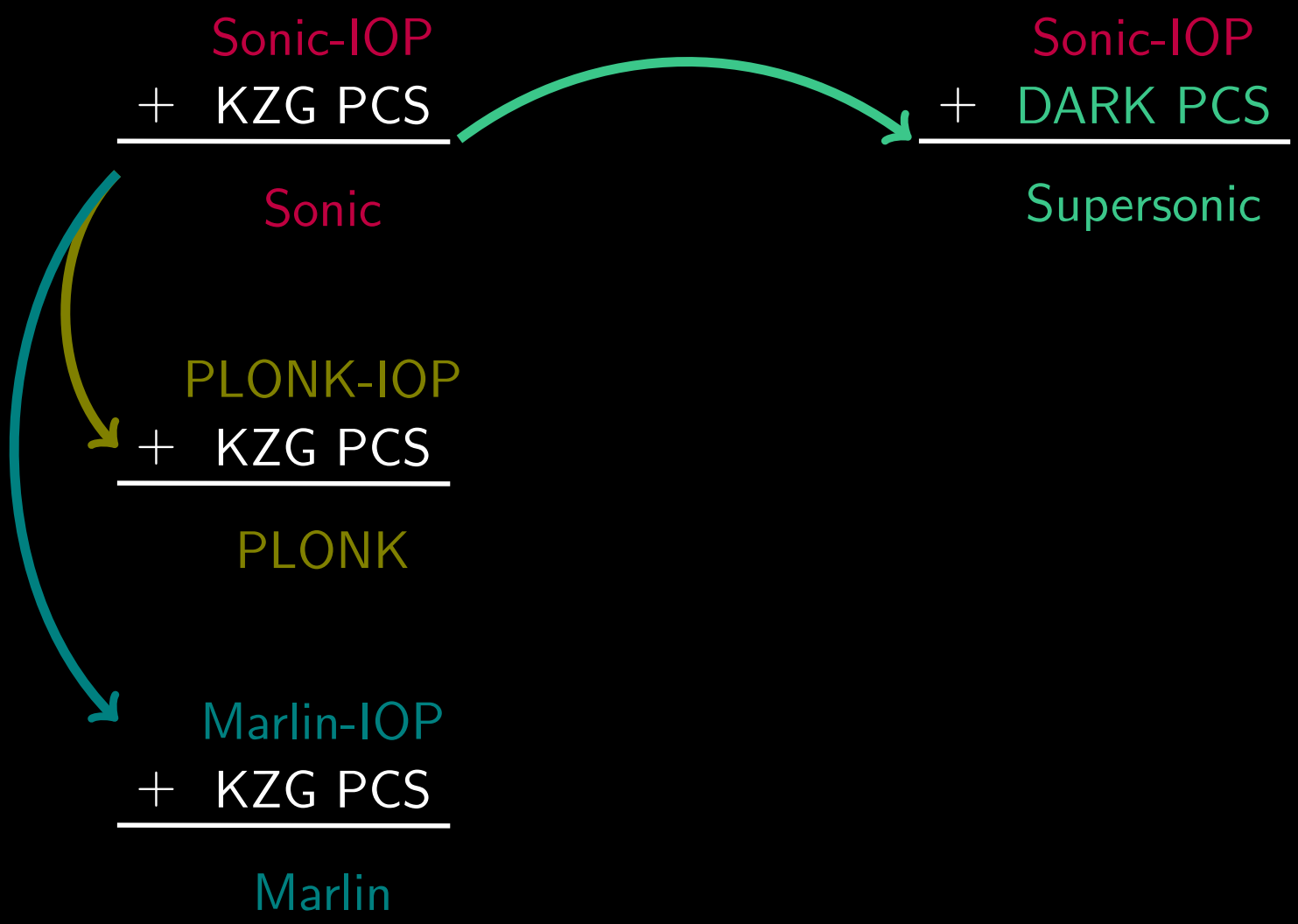

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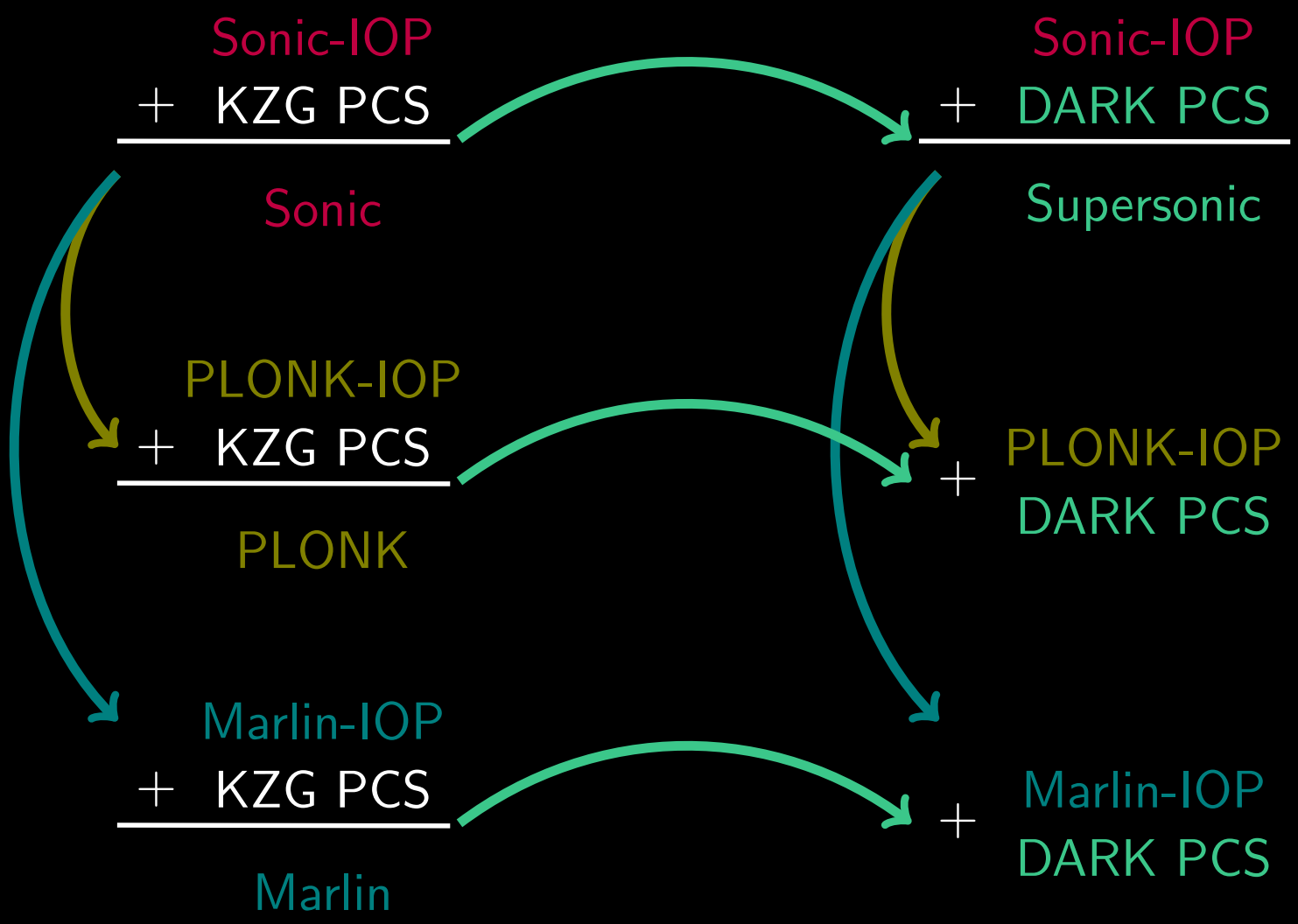

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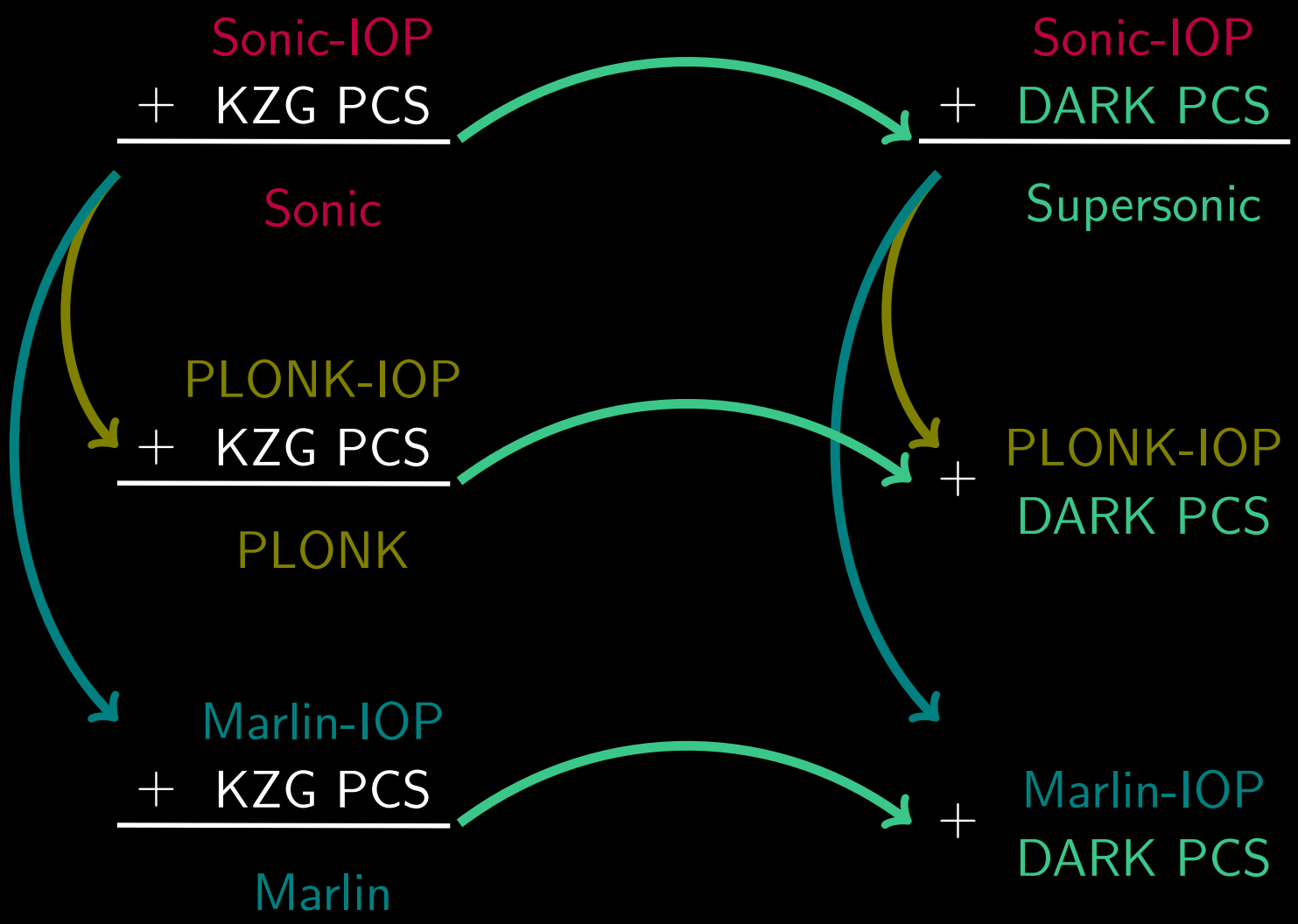

transparent setup (class groups)

constant-size SRS (RSA groups)

Supersonic Performance

Polynomial IOP	# Polynomials	# Eval points	$\|\pi\|$
Sonic	$12 + 15$	12	15.3 KB
PLONK	$7 + 7$	2	10.1 KB
Marlin	$9 + 10$	3	12.3 KB

Scheme	Transp.	|CRS|	Prover	Verifier	$\|\pi\|$	$\|\pi\|$
Supersonic	✓	1	$n\log(n)$	$3\log(n)$	$2\log(n)$	10.1KB
PLONK	×	$2n$	n	1	1	720b
Groth16	×	$2n$	n	1	1	192b
Bulletproofs	✓	$2n$	n	n	$2\log(n)$	1.7KB
STARK	✓	1	λT	$\lambda\log^2(T)$	$\lambda\log^2(T)$	600 KB
Virgo	✓	1	λn	$\lambda\log^2(n)$	$\lambda\log^2(n)$	271 KB

concrete quantities for $n = 2^{20}$ and $\lambda = 120$

Conclusions

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  - theoretical baggage: Polynomial IOP
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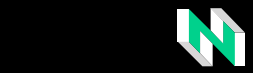

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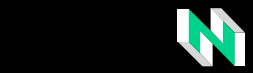

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  - multi-round Fiat-Shamir
- Future work:
  - improvements
  - implementation

Thank you!

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alan@nervos.org

https://eprint.iacr.org/2019/1229