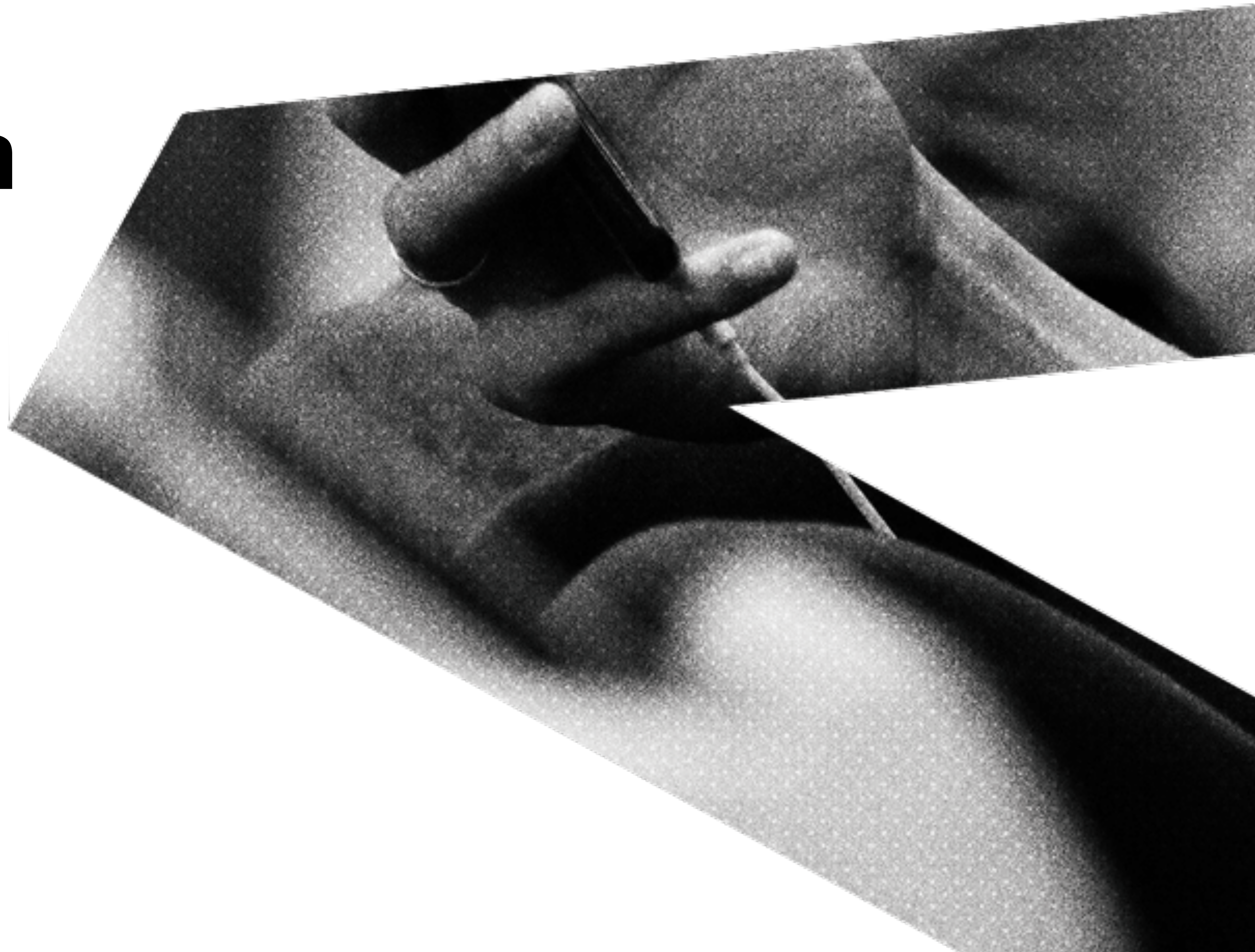
ZAMA

Recent advances in homomorphic compilation

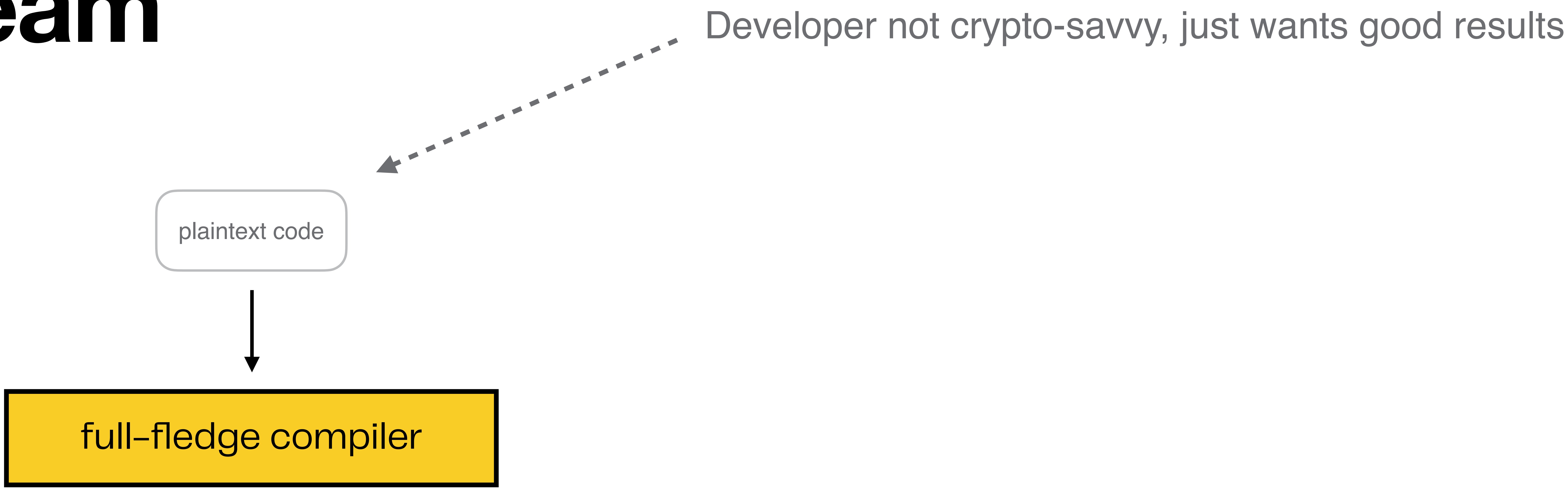


Pascal Paillier, Zama

FHE.org conference 2023

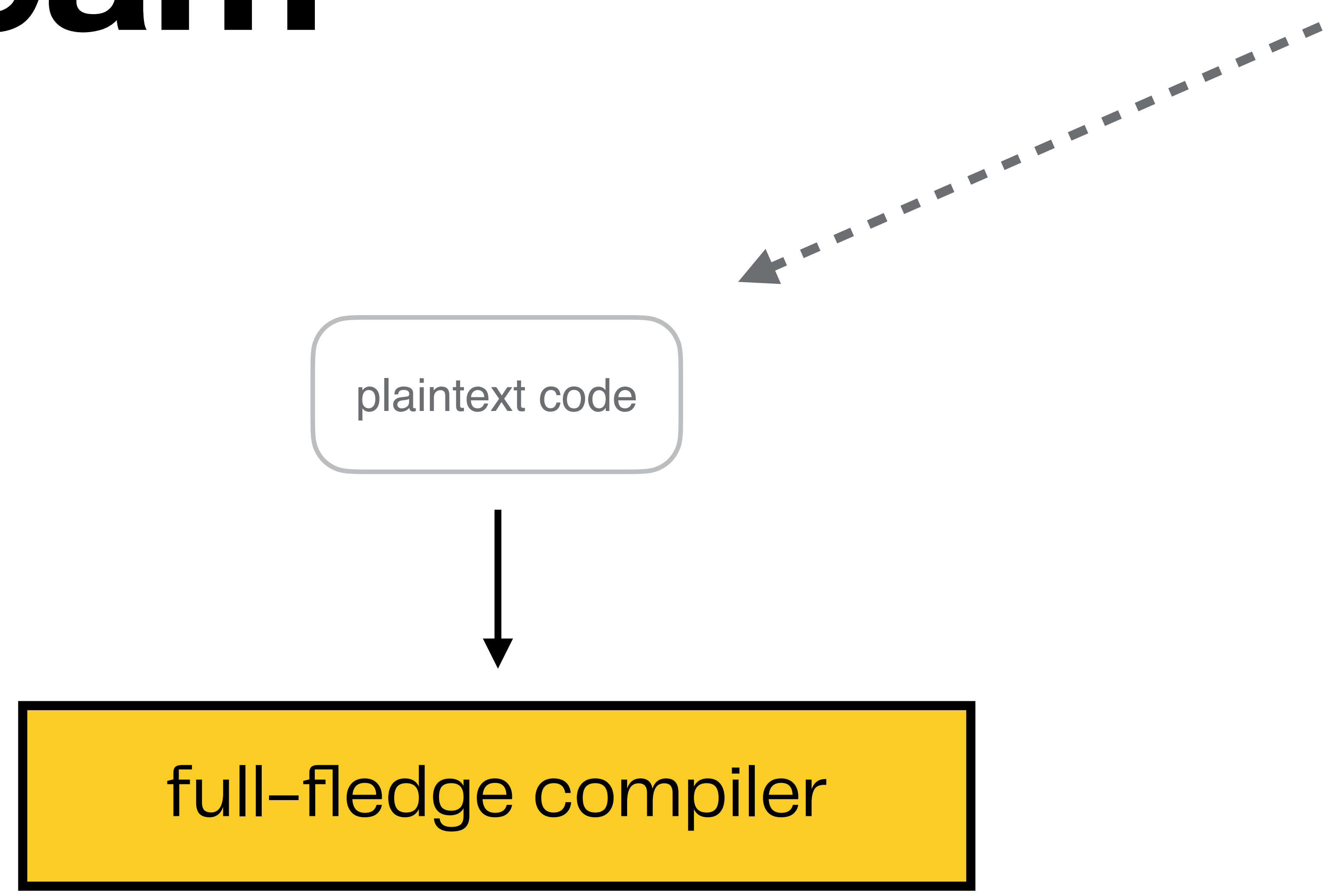
What is homomorphic compilation?

The big dream



The big dream

Developer not crypto-savvy, just wants good results



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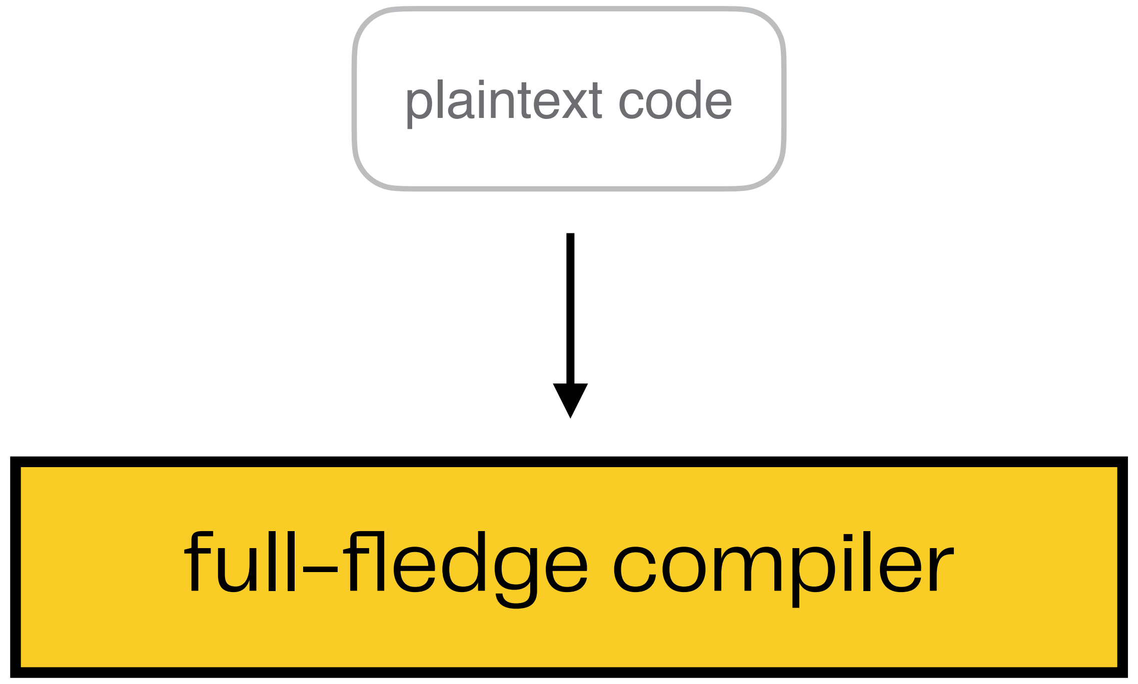
1 Converts input code into an FHE circuit



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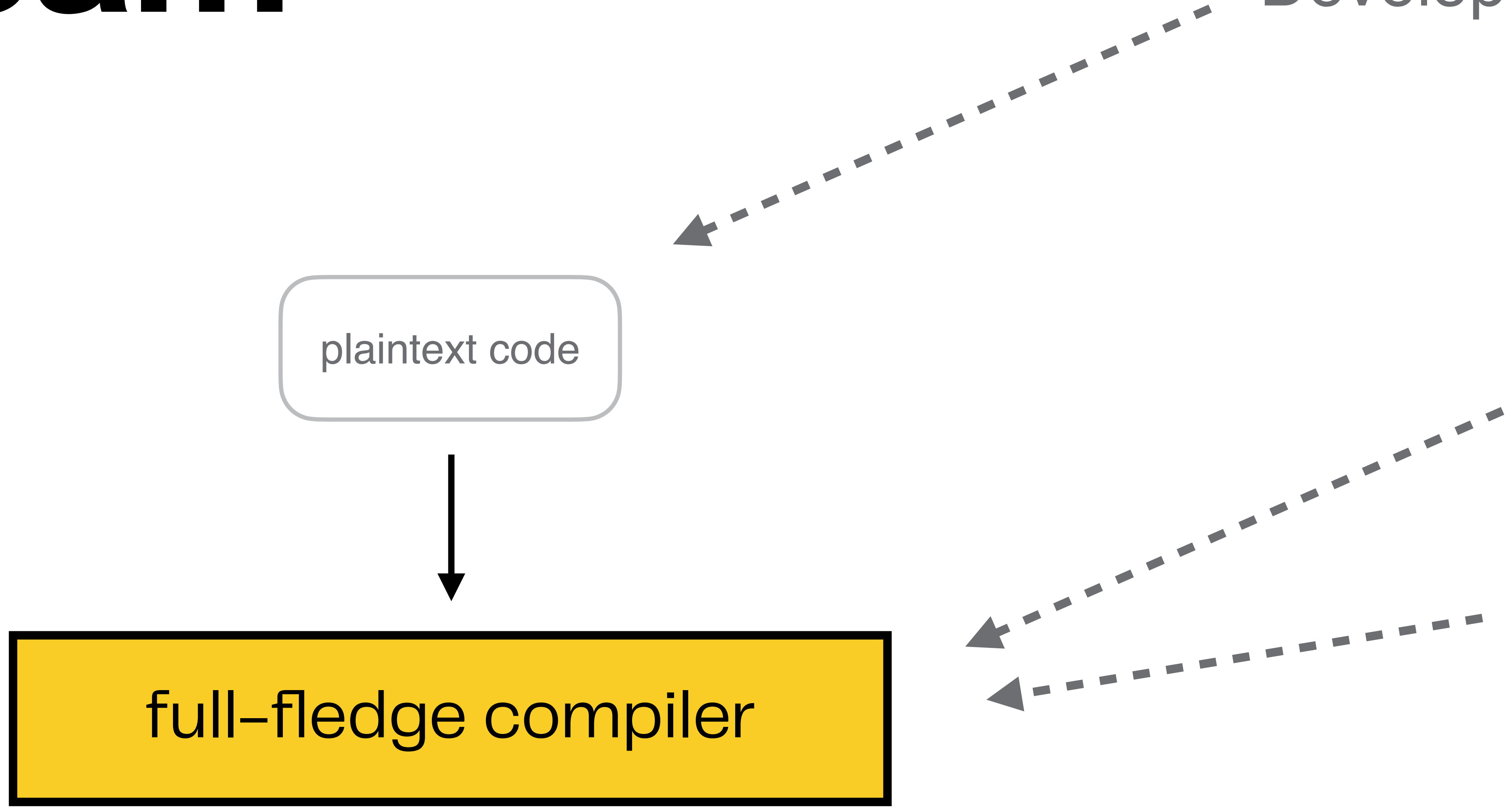
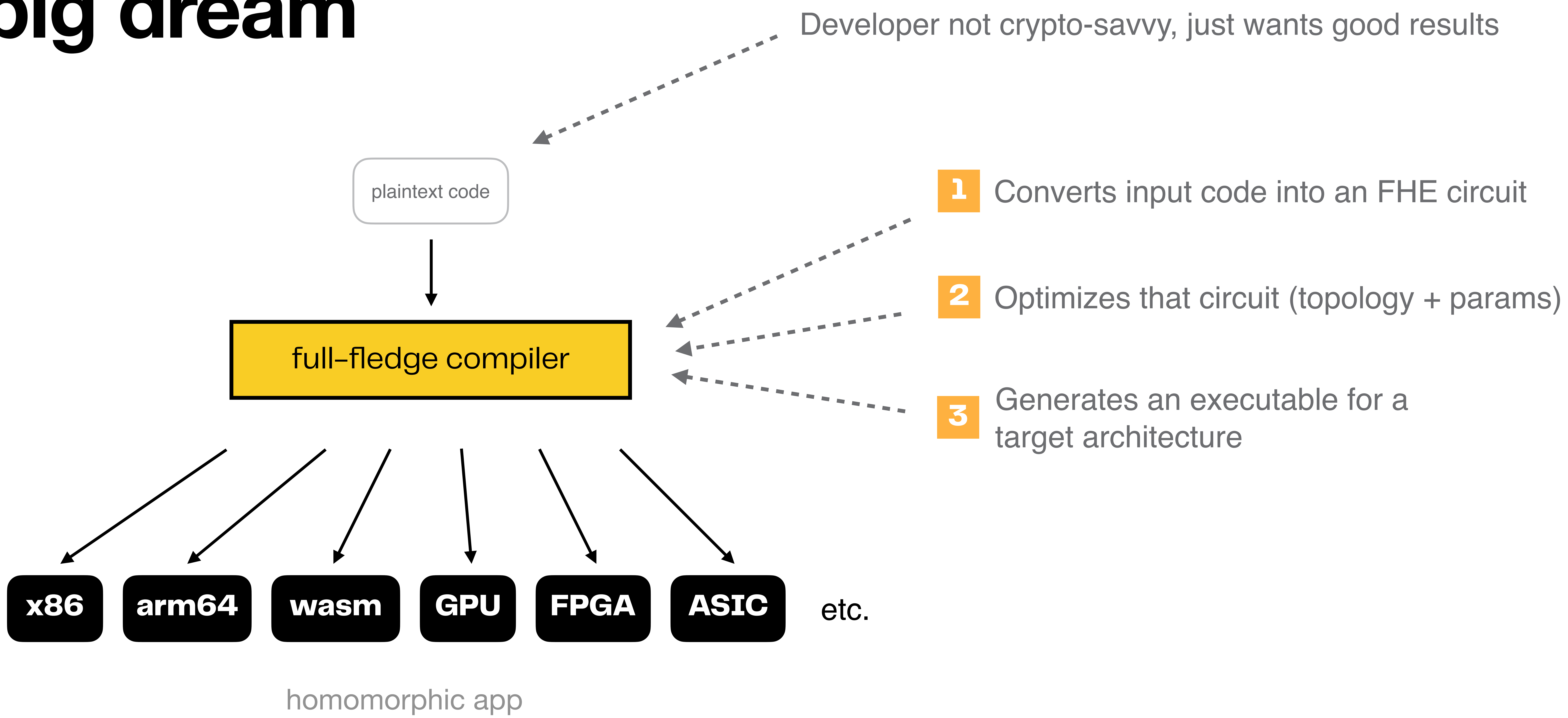


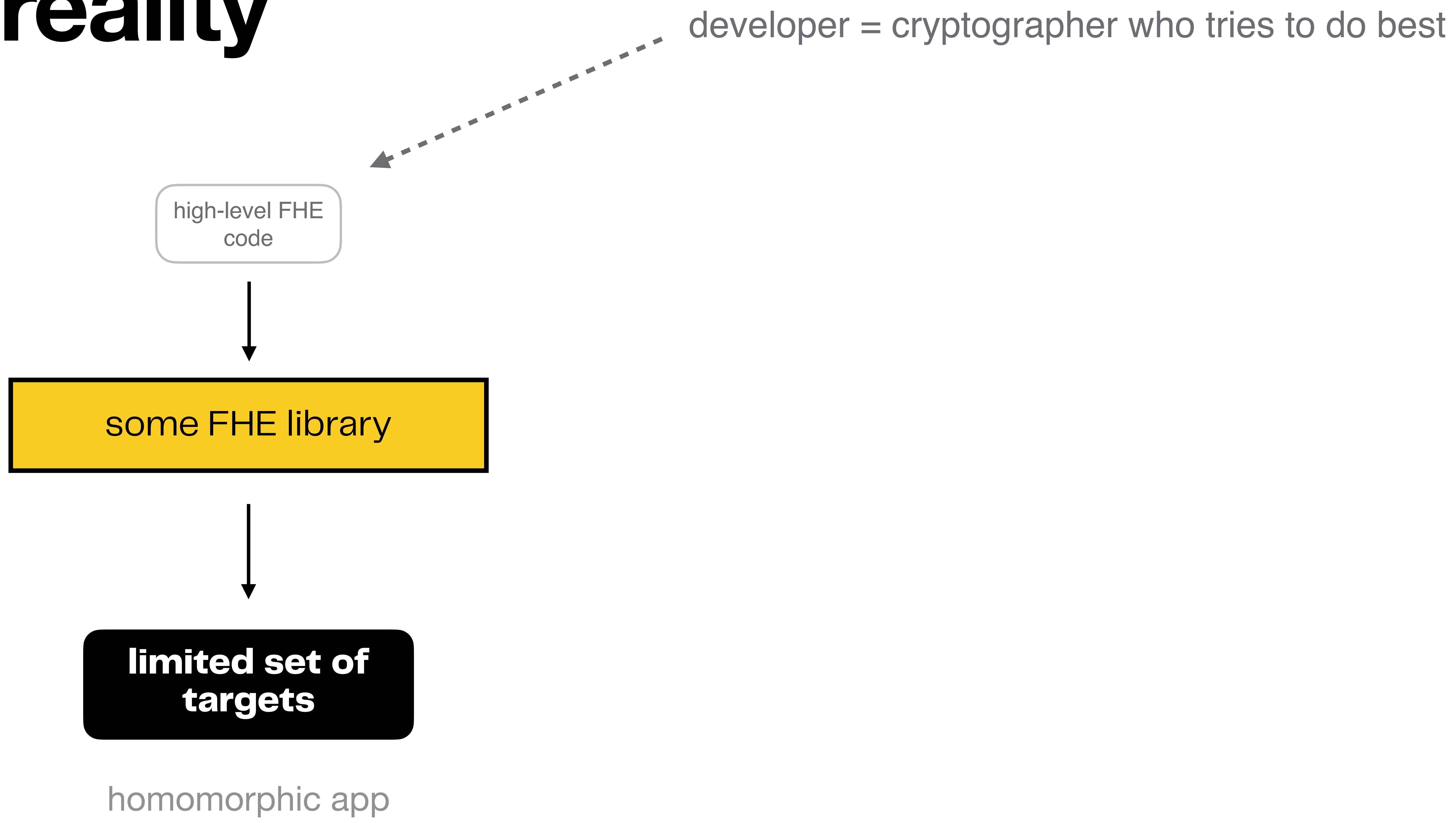
1 Converts input code into an FHE circuit

2 Optimizes that circuit (topology + params)

The big dream



The (poor) reality



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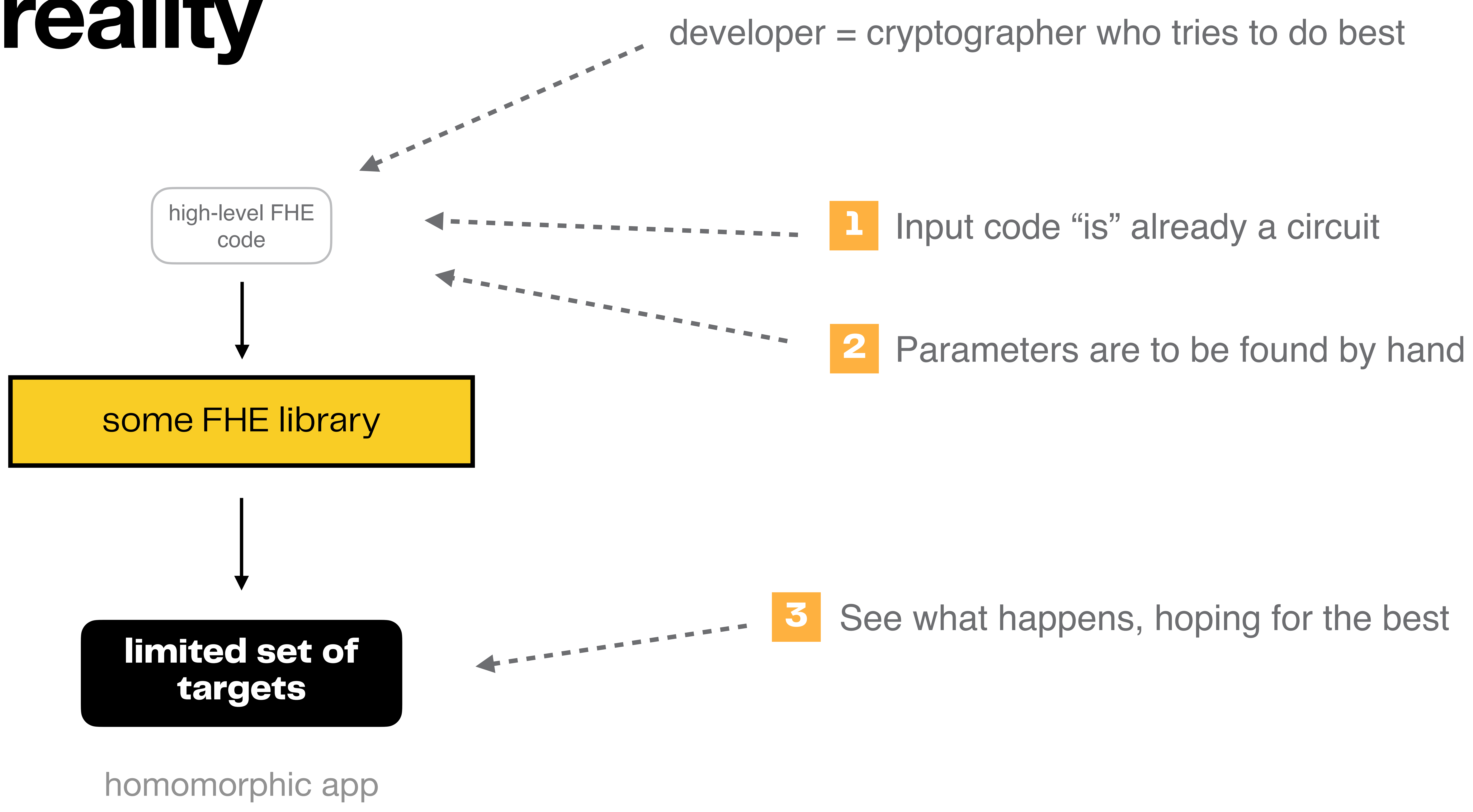
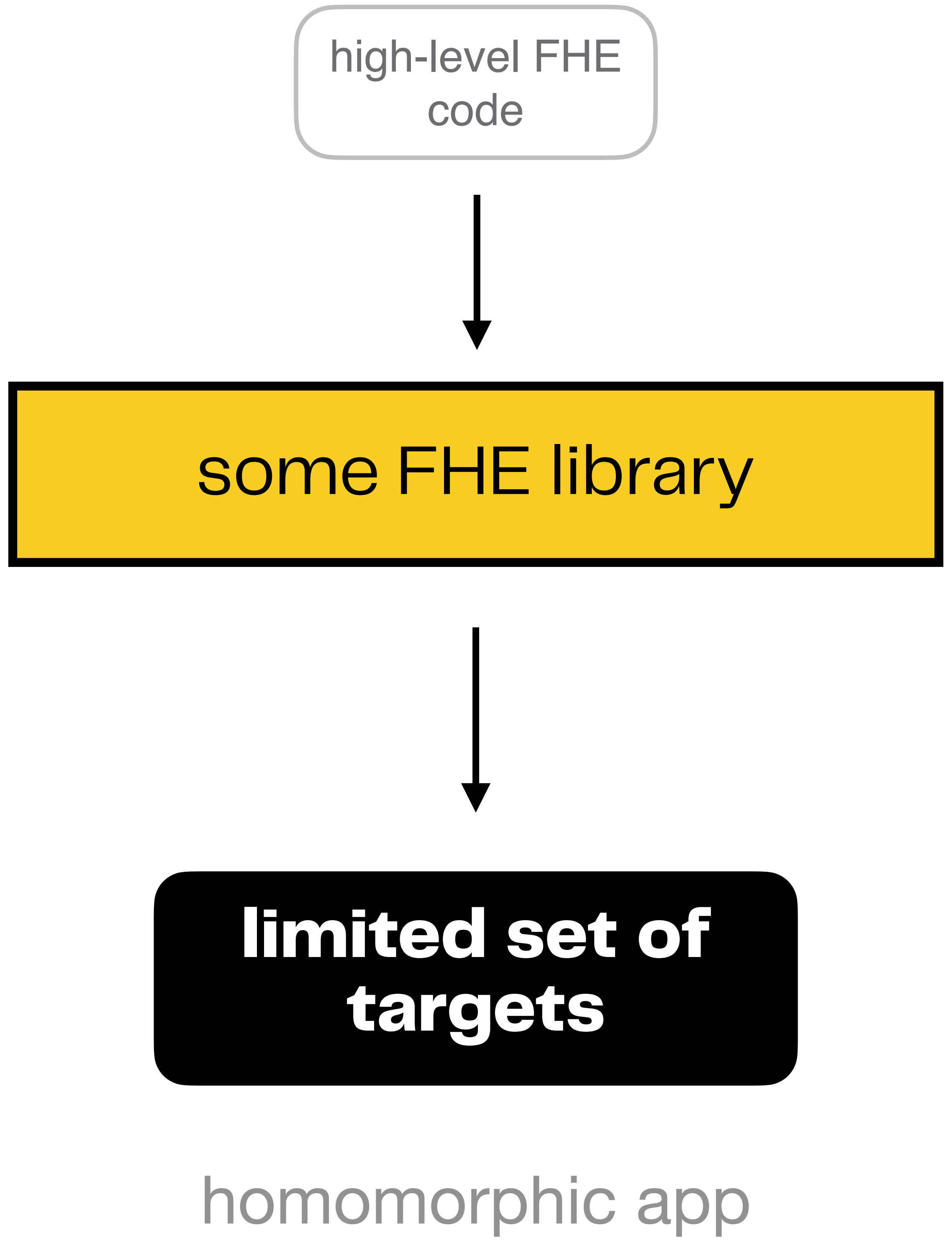
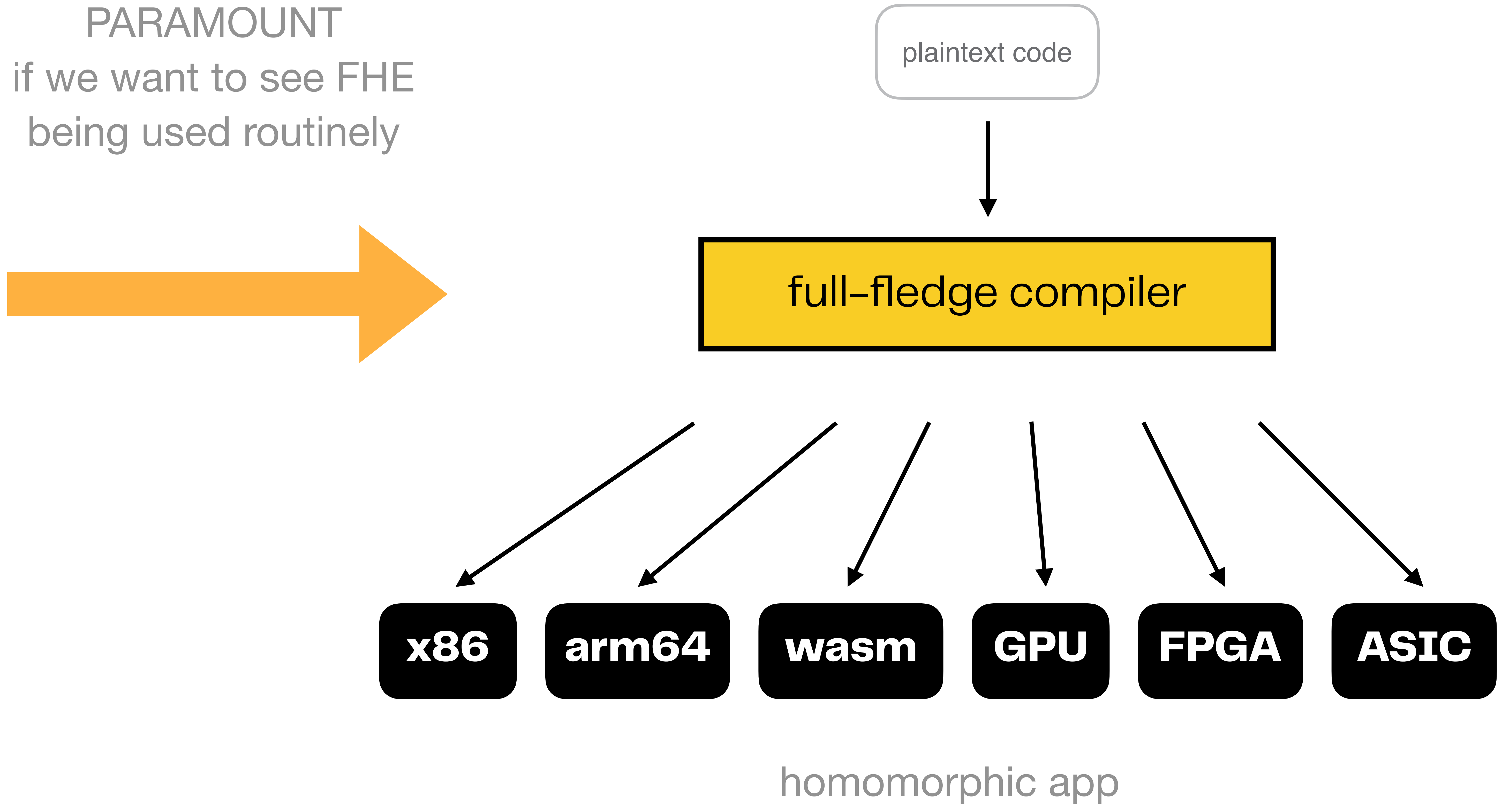


What is blocking this transition?



PARAMOUNT
if we want to see FHE
being used routinely

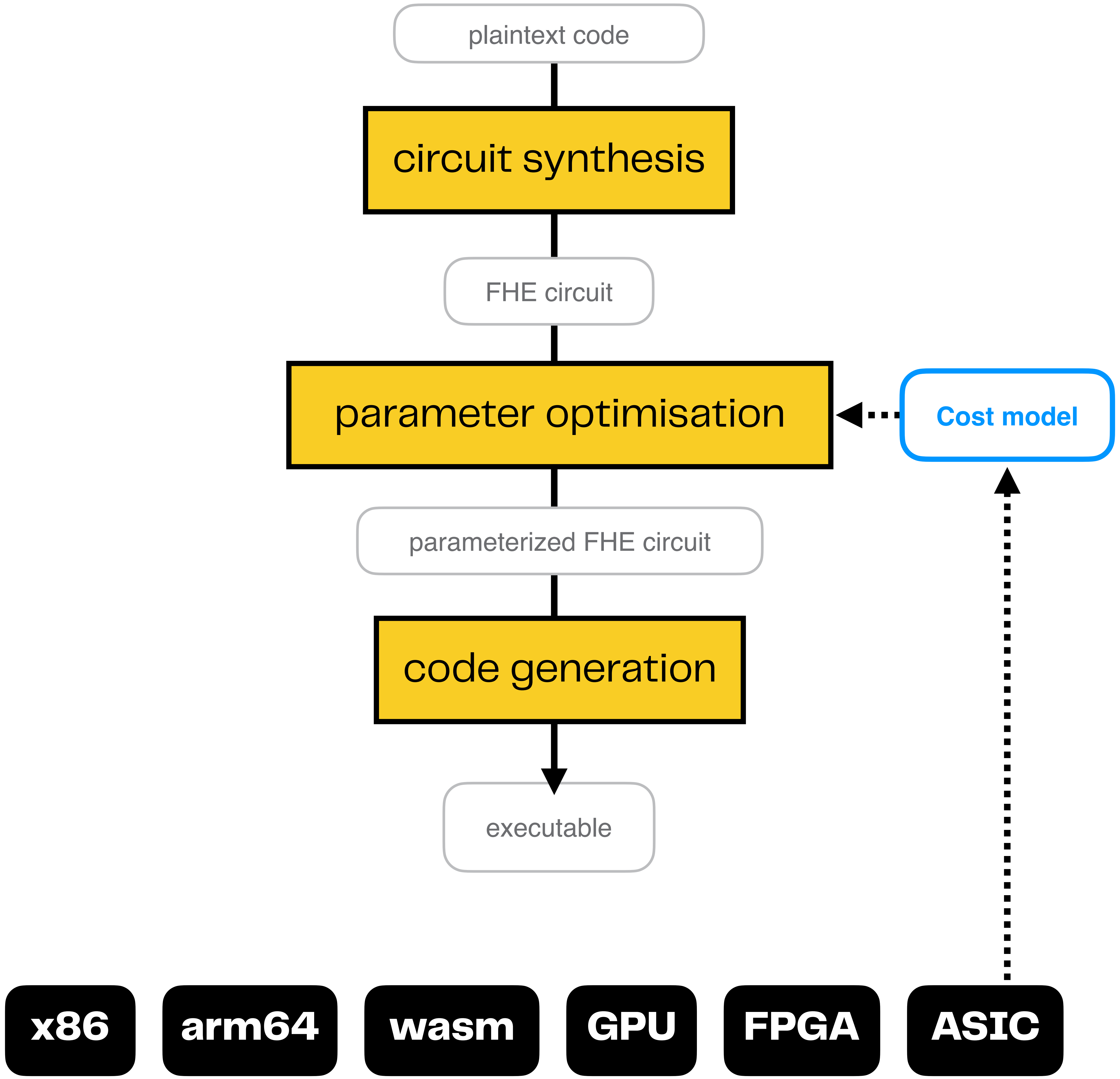


The inner ingredients of hom. compilers

1 Converts input code into an FHE circuit

2 Optimizes that circuit (topology + params)

3 Generates an executable for a target architecture



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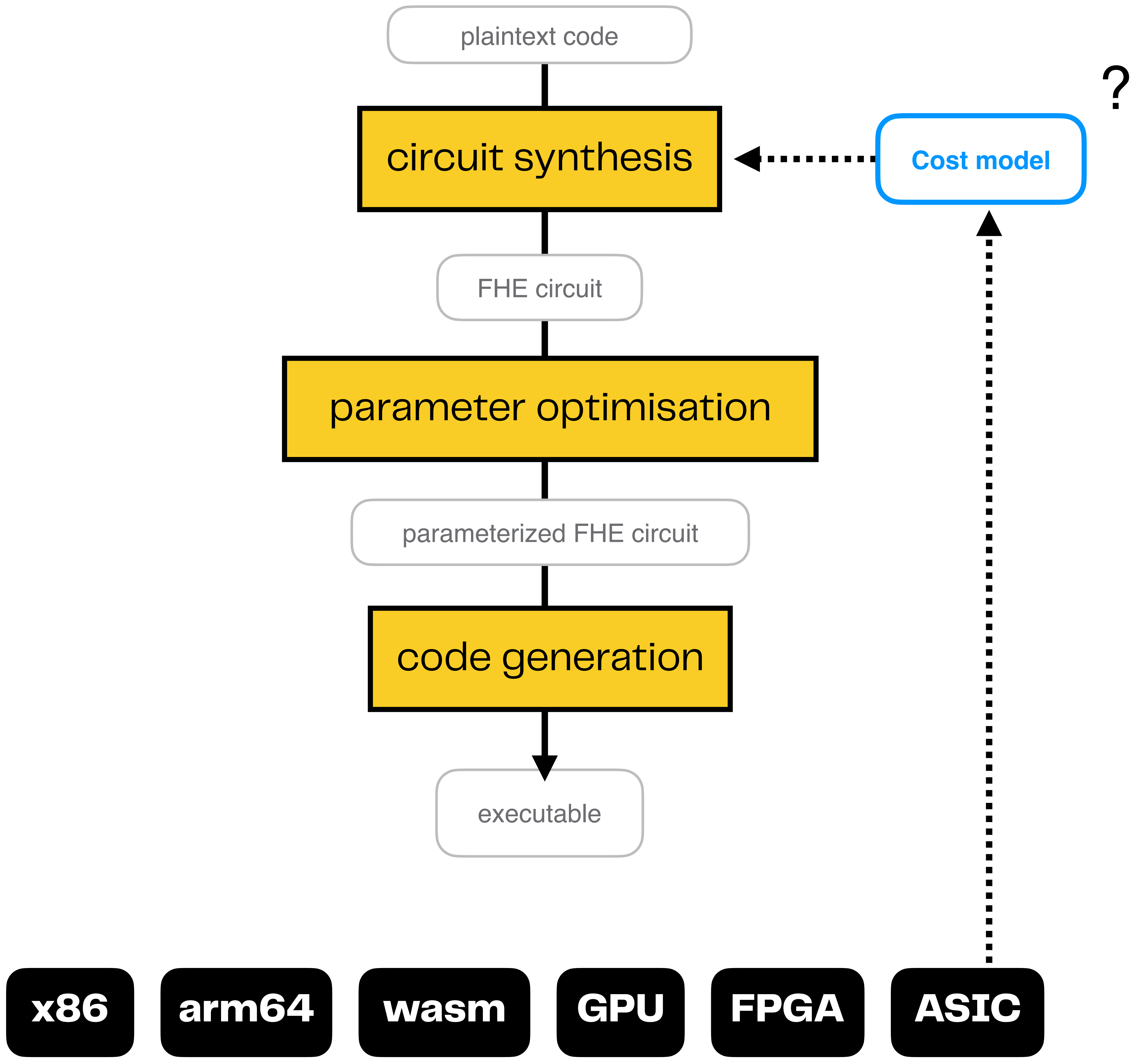
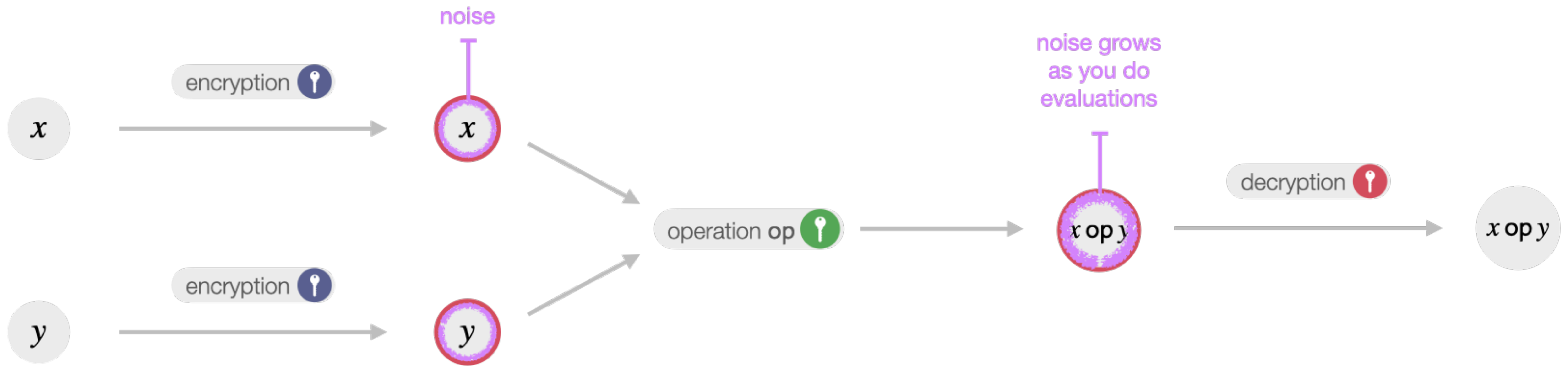
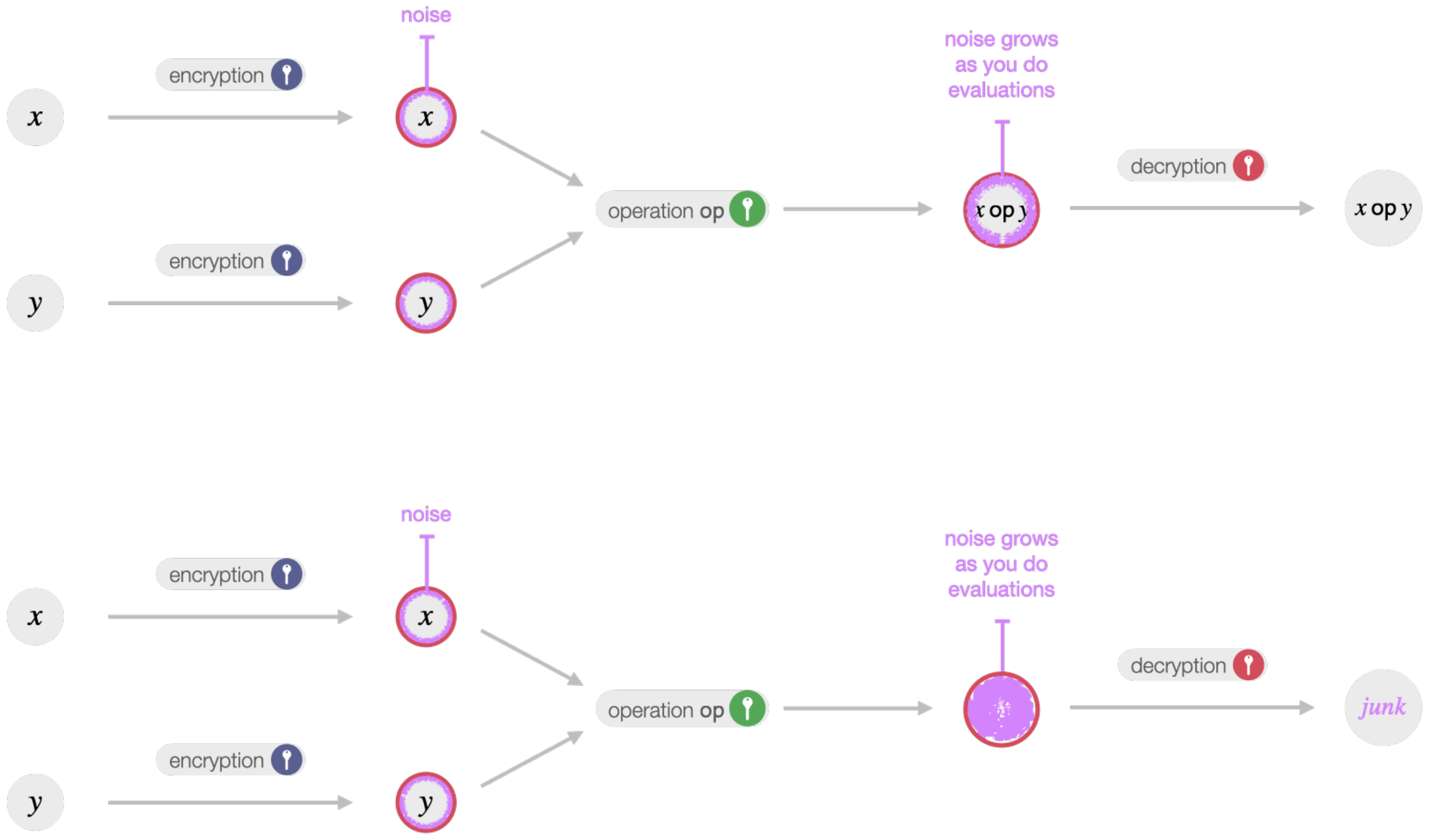


What we are building at Zama

Homomorphic Encryption: Basic Concepts

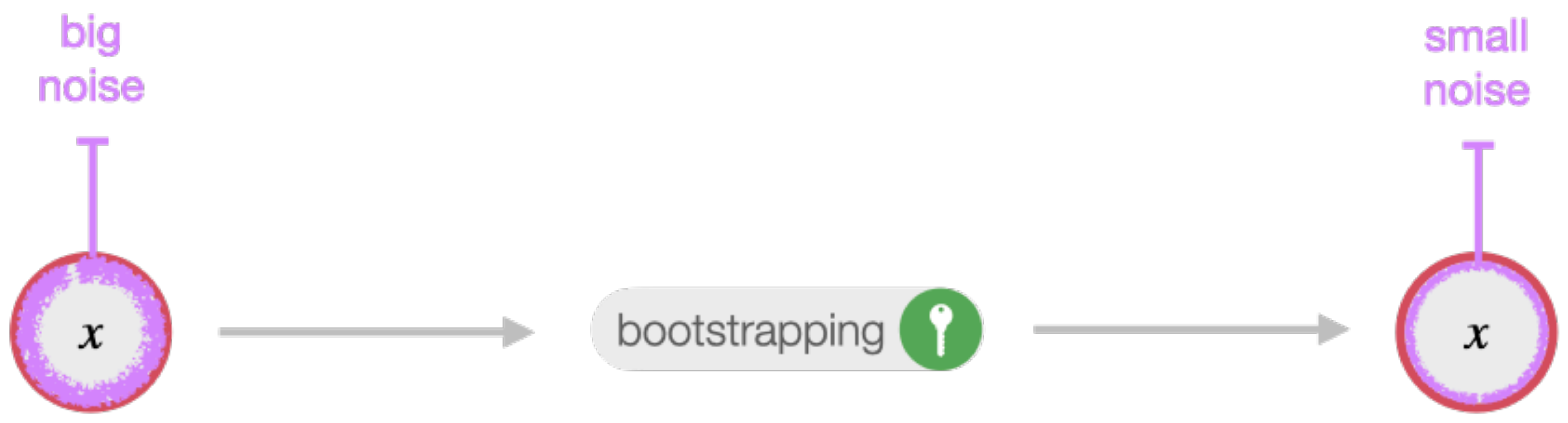


Homomorphic Encryption: Basic Concepts



Homomorphic Encryption: Basic Concepts

Bootstrapping



Homomorphic Encryption: Basic Concepts

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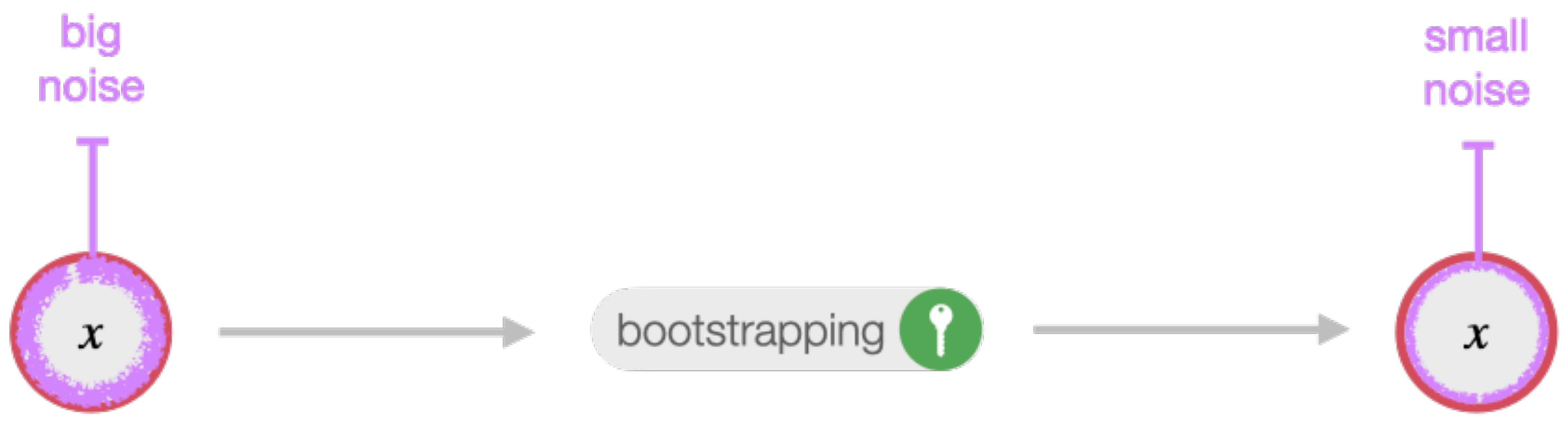
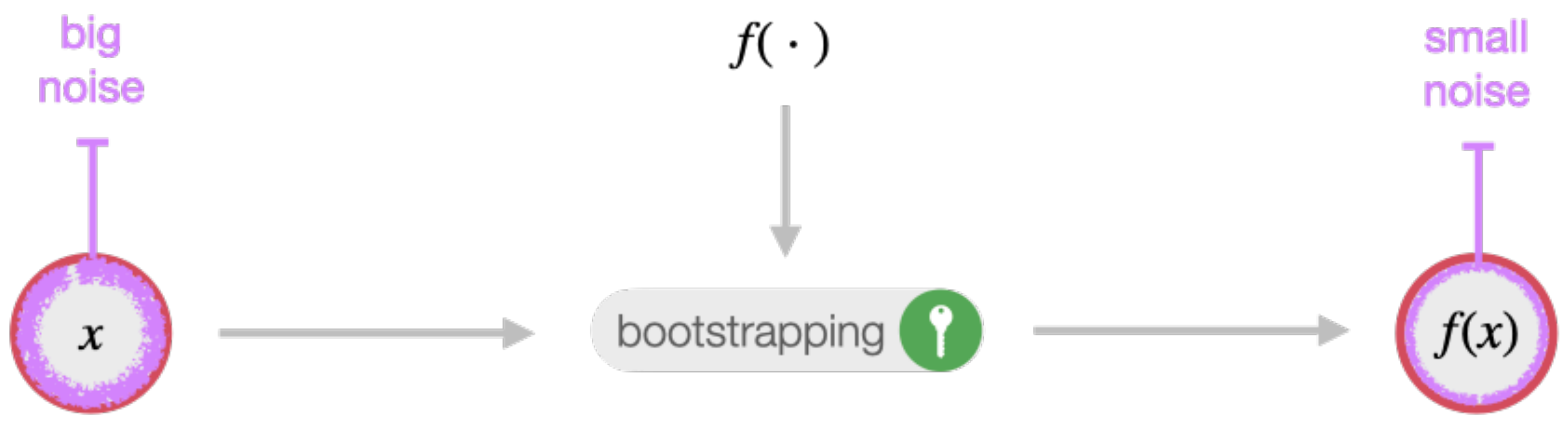
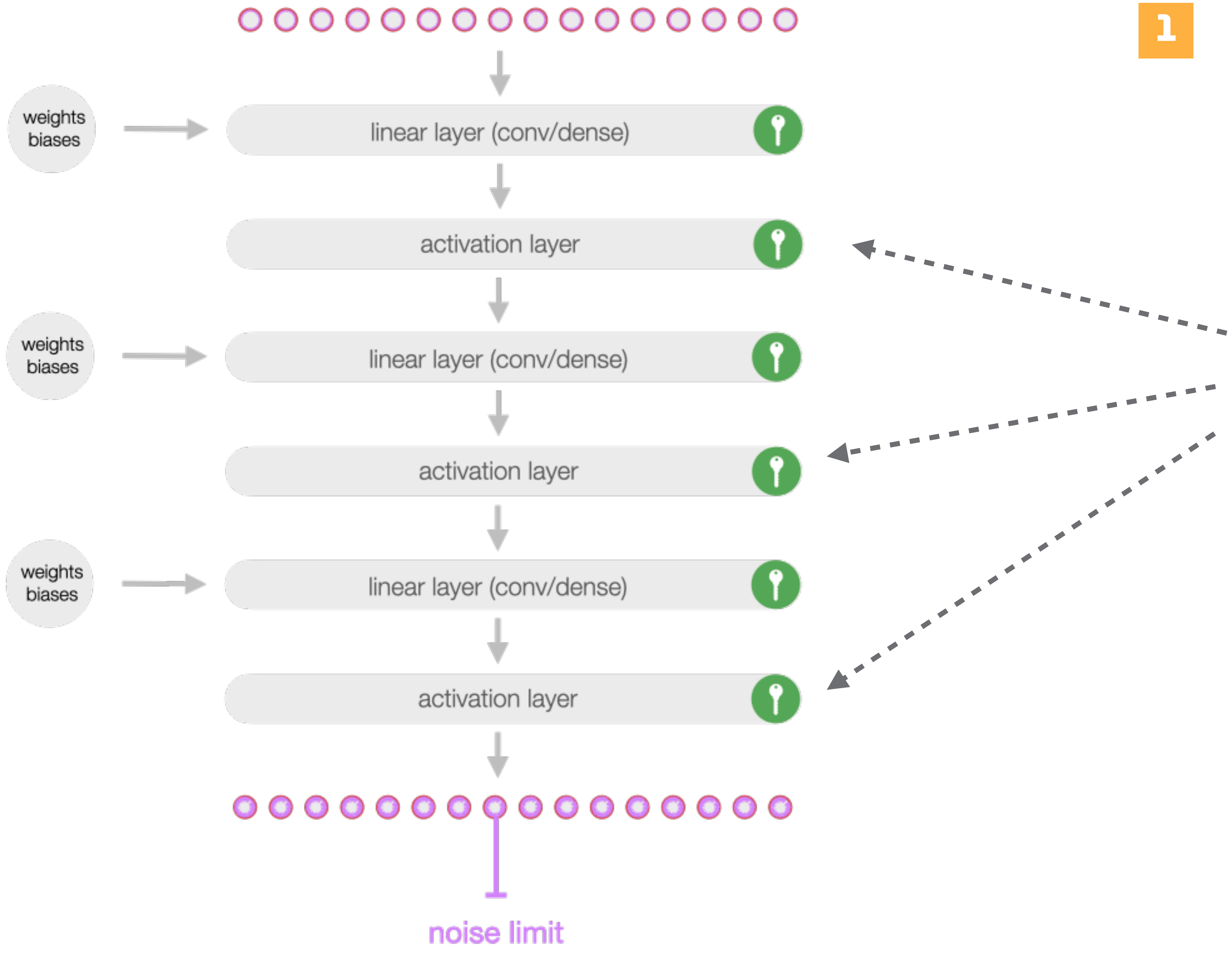


Programmable Bootstrapping

(PBS)



Homomorphic Inference: Leveled HE

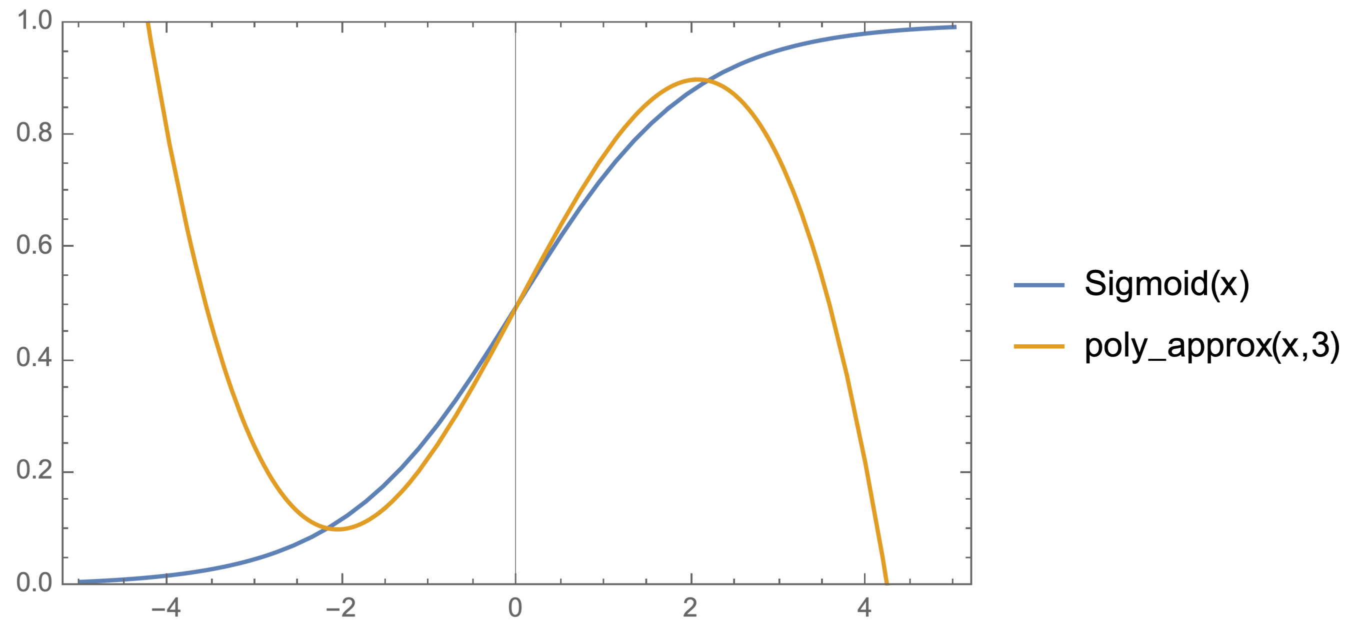


1

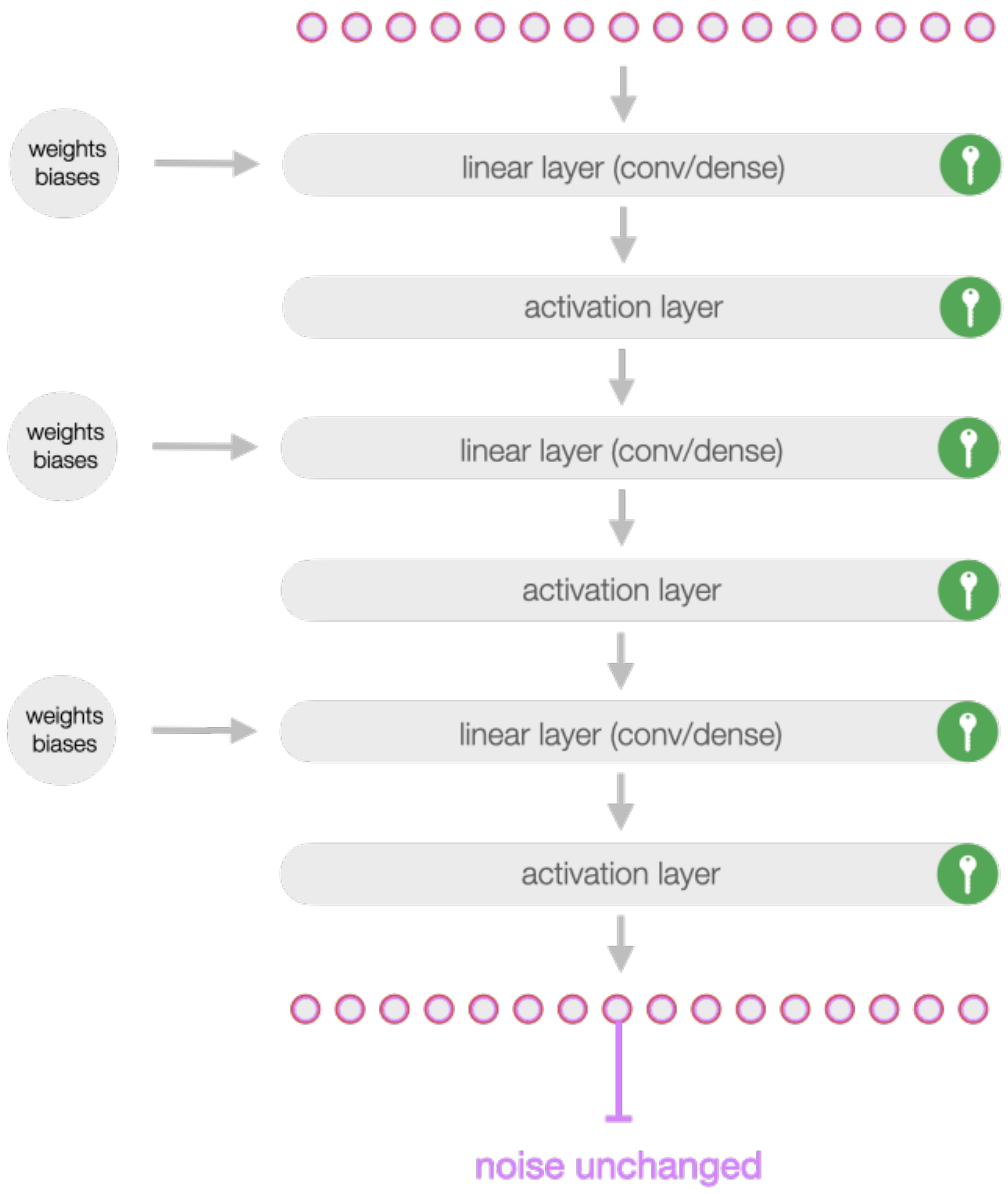
No bootstrapping: way too slow!

2

Activation layers: polynomial approximation



Homomorphic Inference: Fully HE

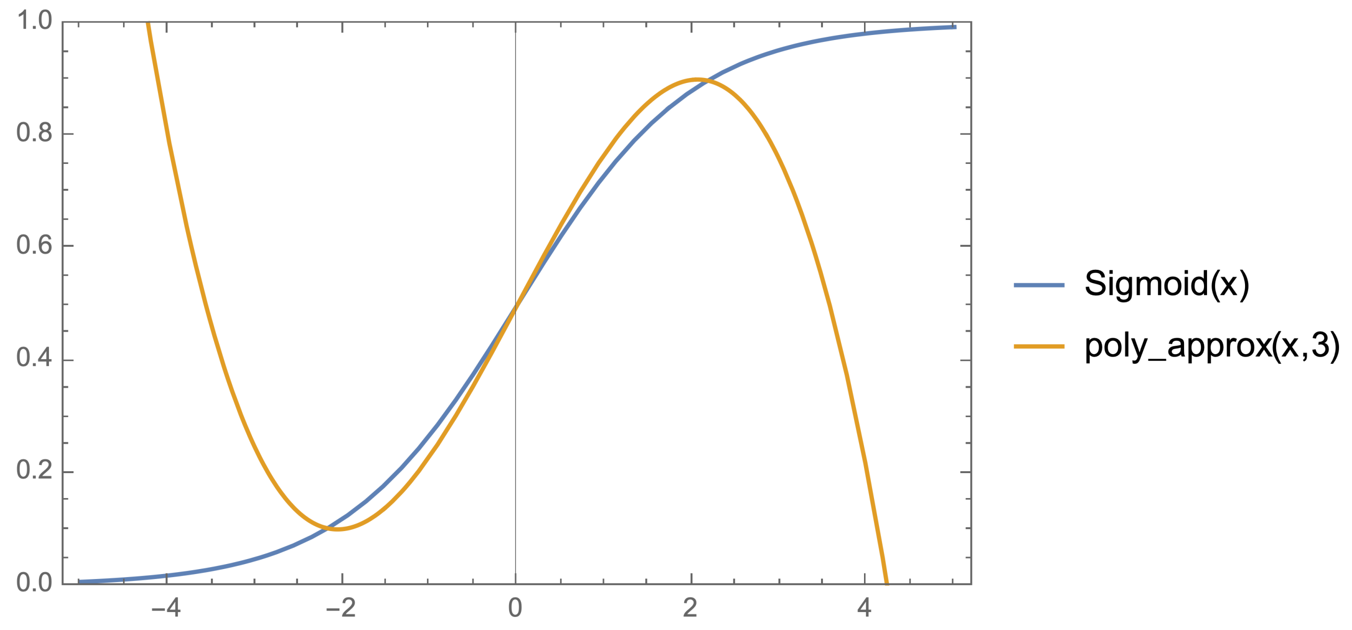


1

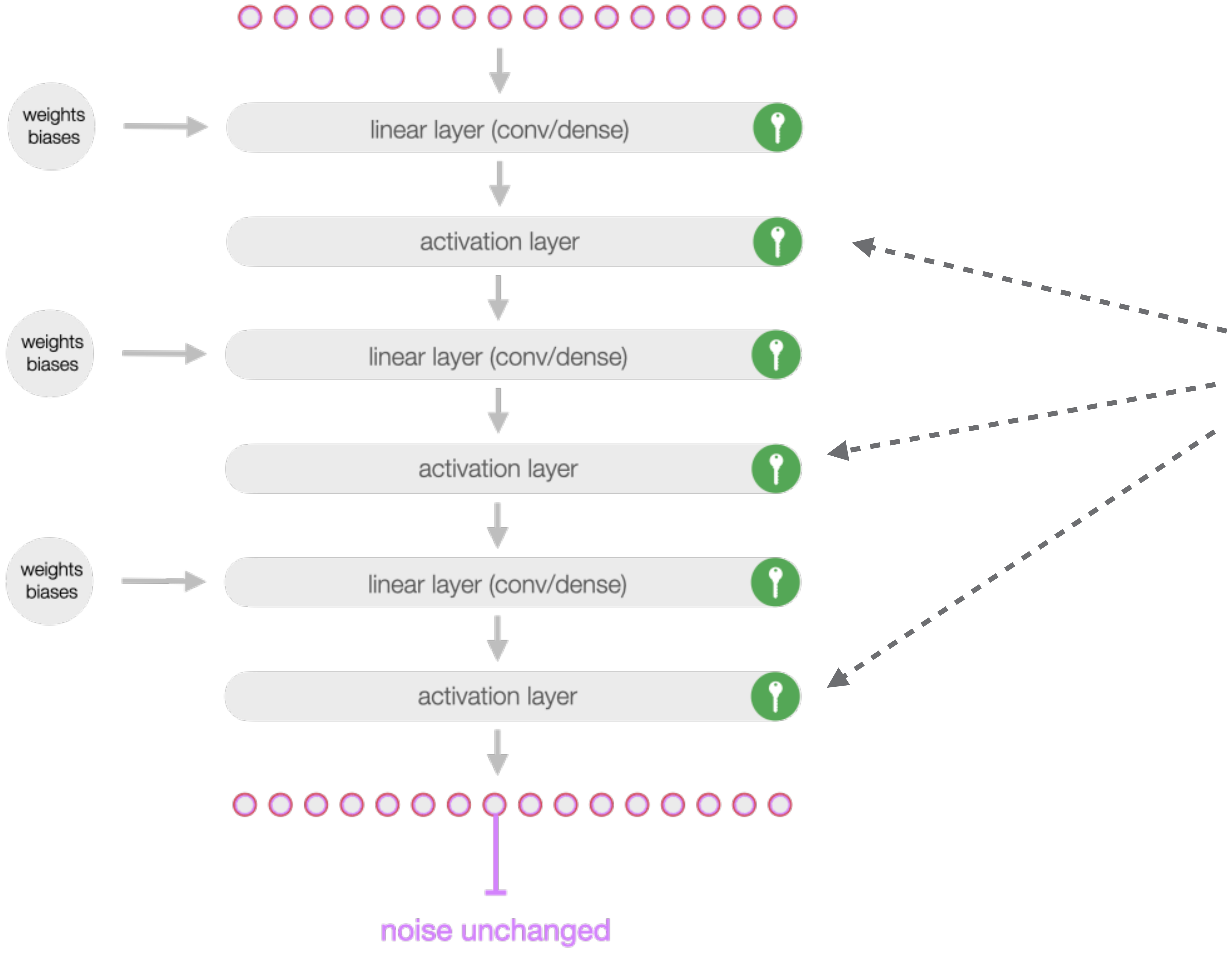
Bootstrapping (but super slow)

2

Activation layers: polynomial approximation

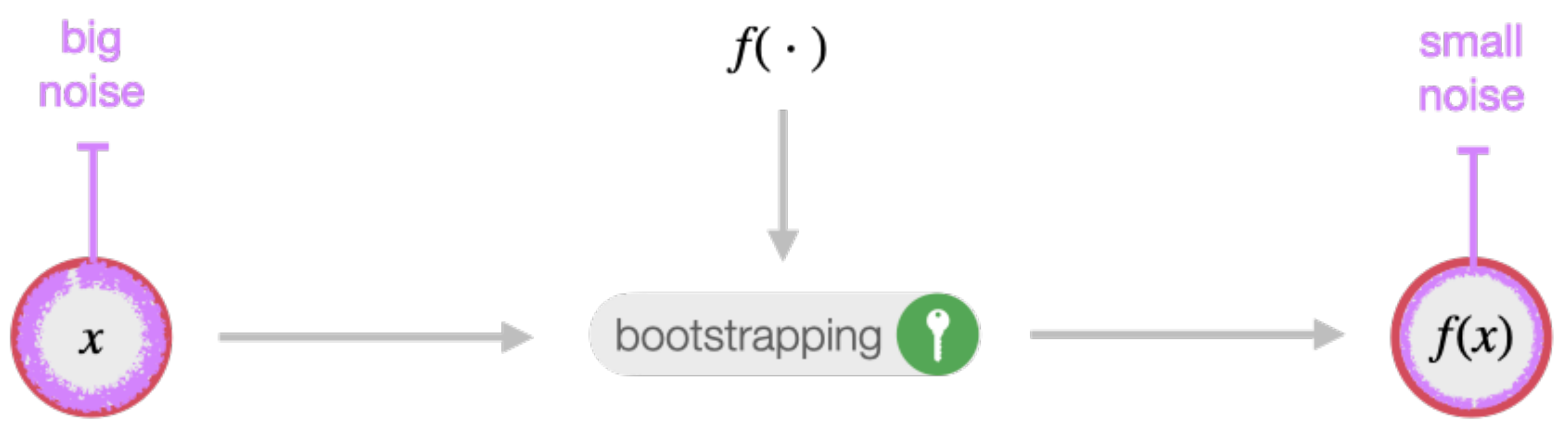


Homomorphic Inference: The "Zama way"



1+2

Activation layers: programmable bootstrapping



PBS is super fast: ~20 ms

A new computational paradigm

ZAMA

Kolmogorov Superposition Theorem (KST)

1957

$$f(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{2n+1} g_i \left(\sum_{j=1}^{n} f_{ij}(x_j) \right)$$

univariate

A new computational paradigm

ZAMA

Kolmogorov Superposition Theorem (KST) 1957

$$f\left(x_1, x_2, \ldots, x_n\right) = \sum_{i=1}^{2n+1} g_i\left(\sum_{j=1}^{n} f_{ij}\left(x_j\right)\right)$$

univariate

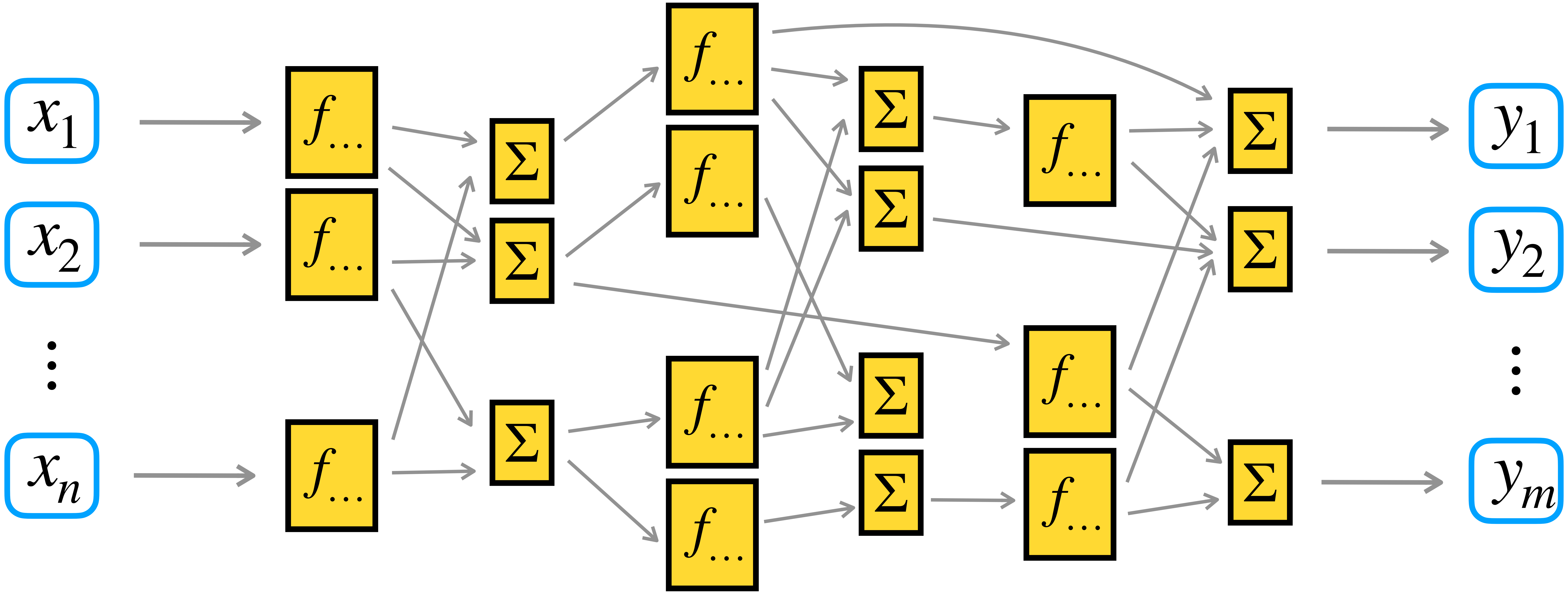
Ridge decomposition or approximation

$$f(x_1, \ldots, x_n) \approx \sum_{i=1}^{r} g_i\left(\sum_{j=1}^{n} a_{ij} \cdot x_j\right)$$

univariate $a_{ij} \in \mathbb{Z}$

A new computational paradigm

circuit of univariate functions



= graph mixing univariate functions and linear combinations

The Concrete Compiler

(and a glance at the whole Concrete stack)

Exact vs. approximate computing with TFHE

	plaintexts	continuous torus encoding	discretized torus encoding	noisy discretized torus	encrypted domain
exact paradigm	$m \in \mathbb{Z}_p$ • p odd • p even	$\mu \in \mathbb{R}/\mathbb{Z}$ $\mu = \frac{m}{p} \mod 1$	$\mu \in \mathbb{Z}_{2^{32}}$ $\mu = \left\lfloor \frac{2^{32}}{p} \right\rceil m \mod 2^{32}$	$\mu + \varepsilon \in \mathbb{Z}_{2^{32}}$ pdf $\left(\frac{\varepsilon}{2^{32}}\right) \approx \mathcal{N}(0,\sigma)$	$\mathrm{LWE}_{sk}\left(\mu + \varepsilon\right)$ $\in \mathbb{Z}_{2^{32}}^{n+1}$
approximate paradigm	$x \in [x^-, x^+] \subset \mathbb{R}$ pdf$(x) \approx \mathcal{N}(x, \sigma_x)$ $\Pr\left[x \notin [x^-, x^+]\right] = 0$	$\mu \in \mathbb{R}/\mathbb{Z}$ $\mu = \frac{x - x^-}{x^+ - x^-} \mod 1$	$\mu \in \mathbb{Z}_{2^{32}}$ $\mu = \left\lfloor \frac{x - x^-}{x^+ - x^-} \cdot 2^{32} \right\rceil \mod 2^{32}$		

Modular TFHE circuits

exact paradigm

$m \in \mathbb{Z}_p$

M = multisum

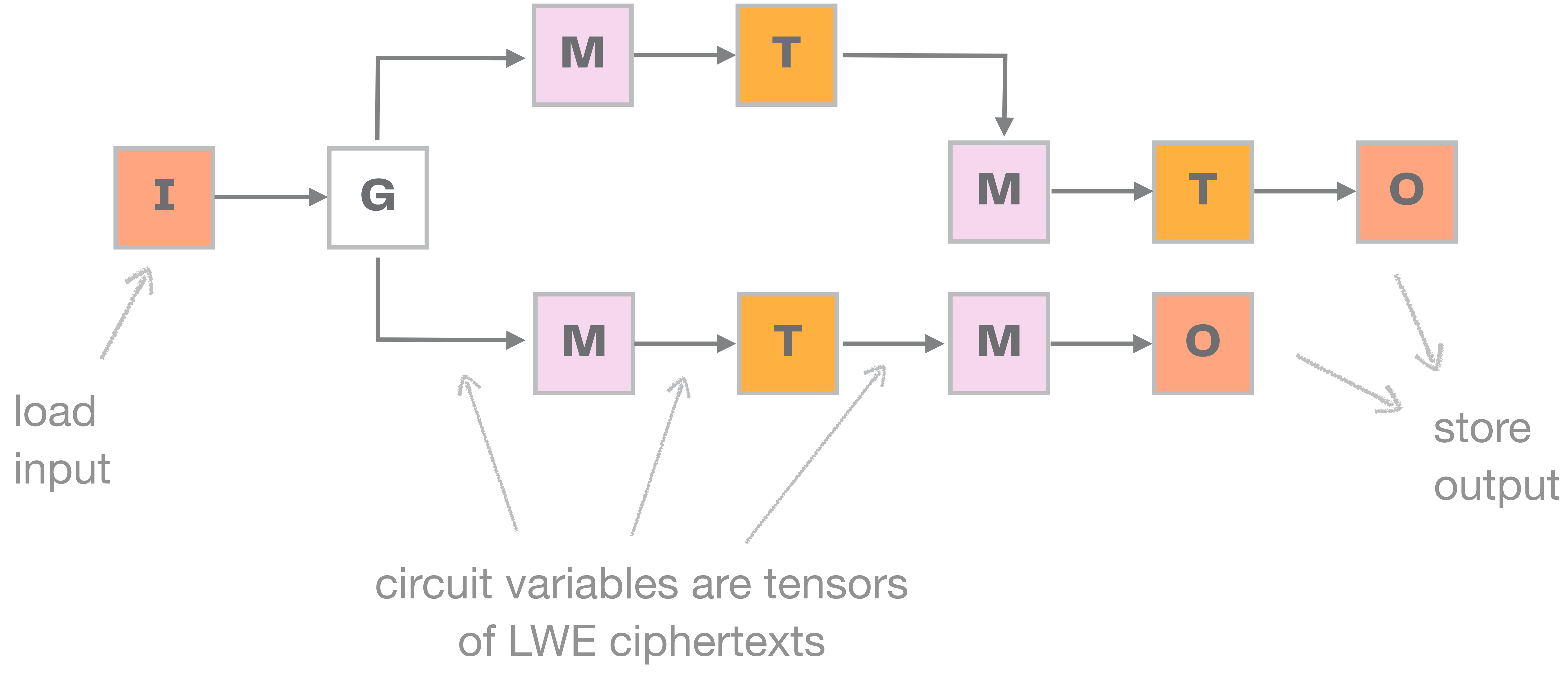
T = lookup table

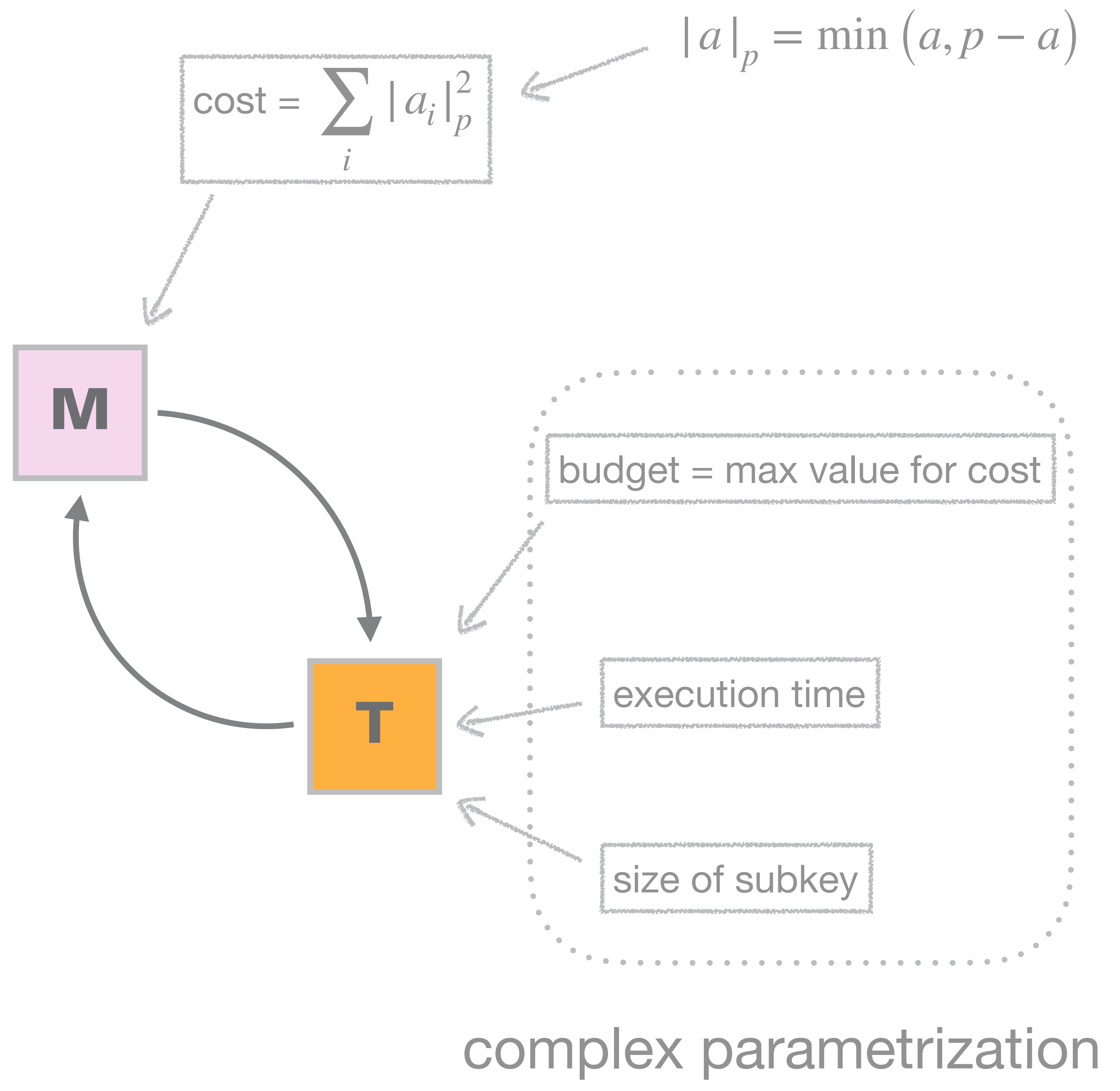
G = grab

- concatenation
- splits
- reshape

I = input

O = output



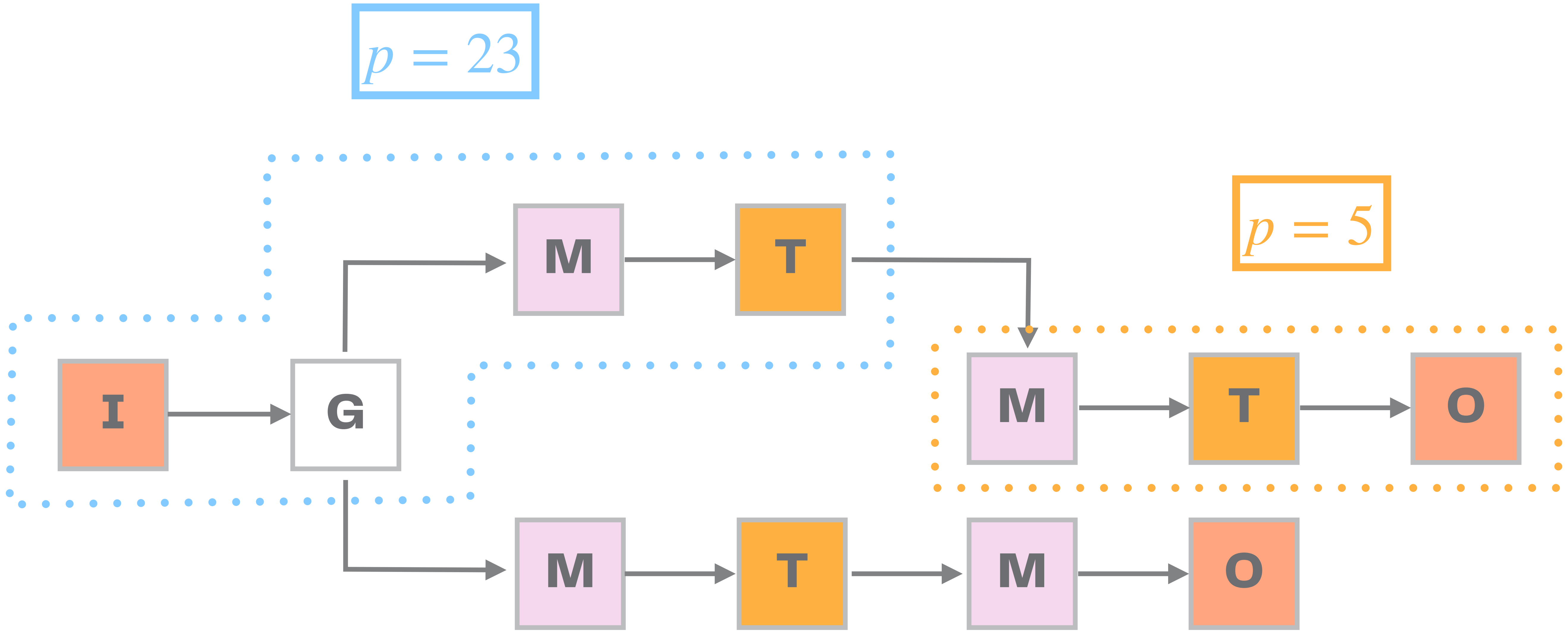


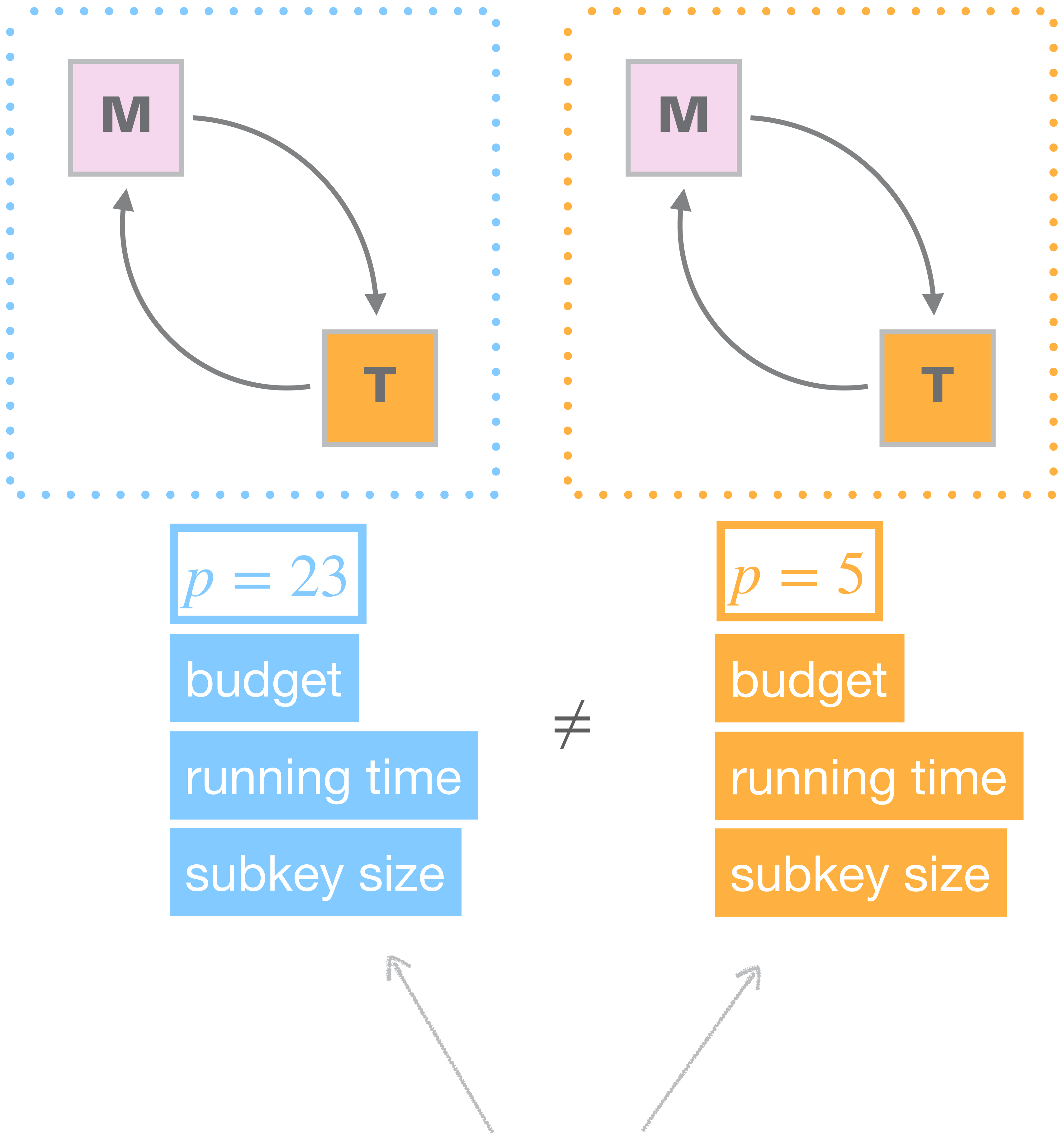
Multi-modular TFHE circuits

exact paradigm

$m \in \mathbb{Z}_p$

Circuits typically switch back and forth between several moduli $p_1, \ldots, p_k$





automated generation of optimal parameters from circuit topology

The Concrete Compiler (CC)

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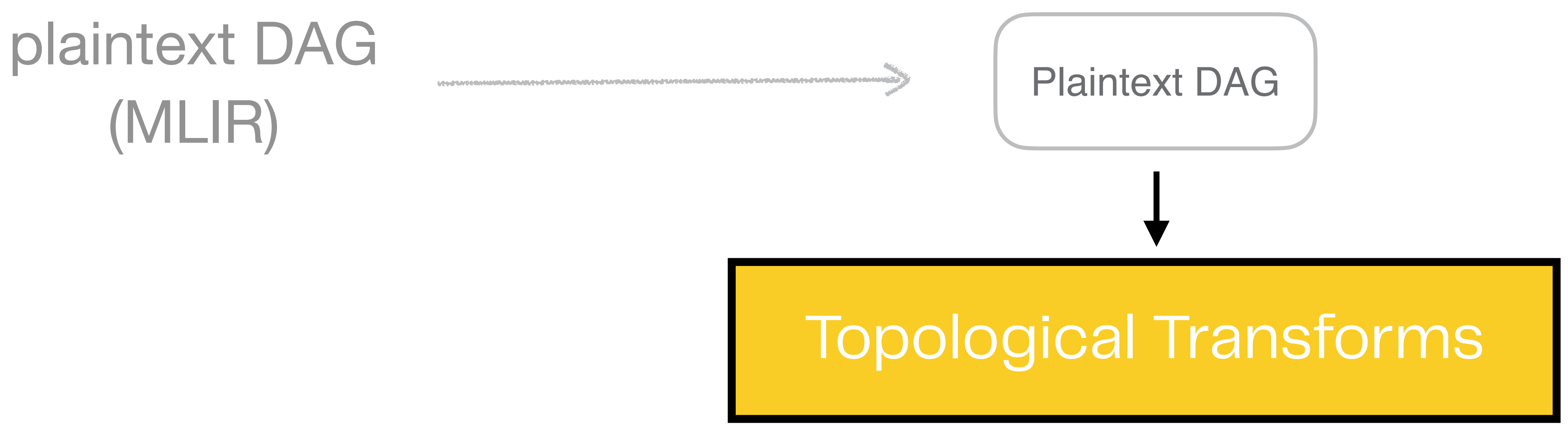
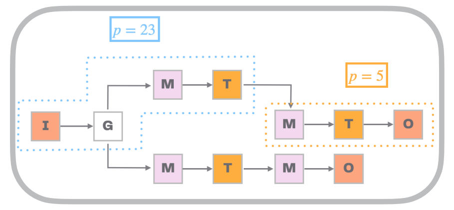


The Concrete Compiler (CC)

plaintext DAG
(MLIR)

Plaintext DAG

Topological Transforms



The Concrete Compiler (CC)

plaintext DAG
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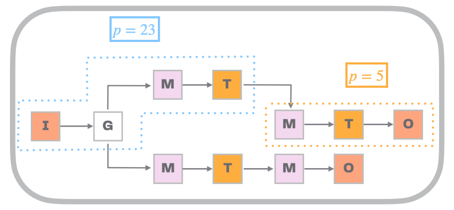
Plaintext DAG

Topological Transforms

TFHE DAG
(MLIR)



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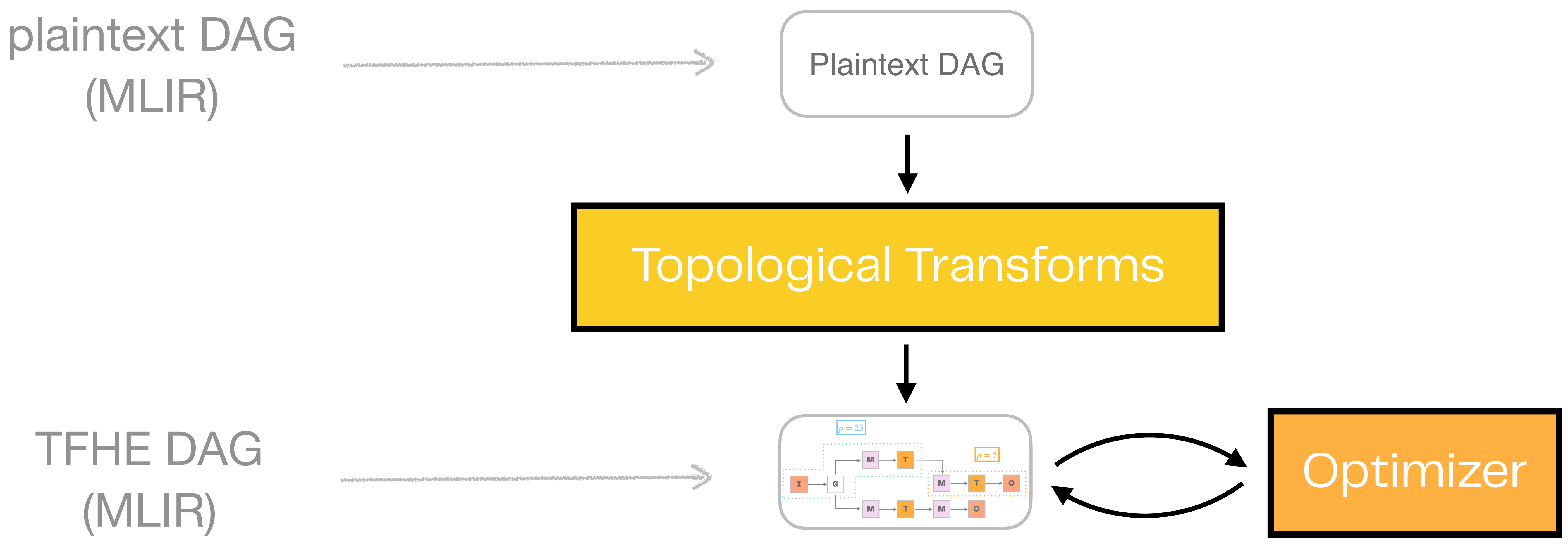

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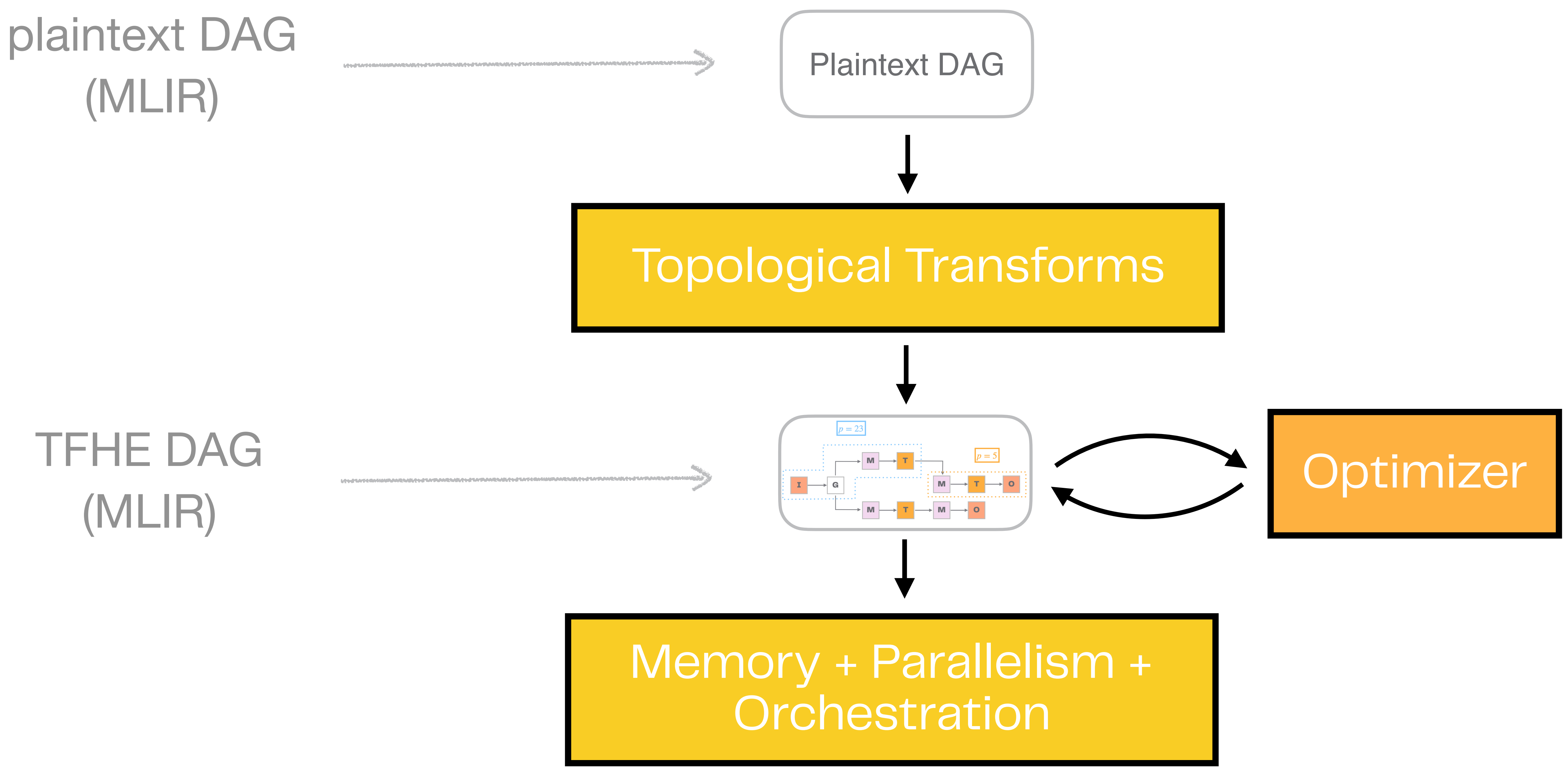

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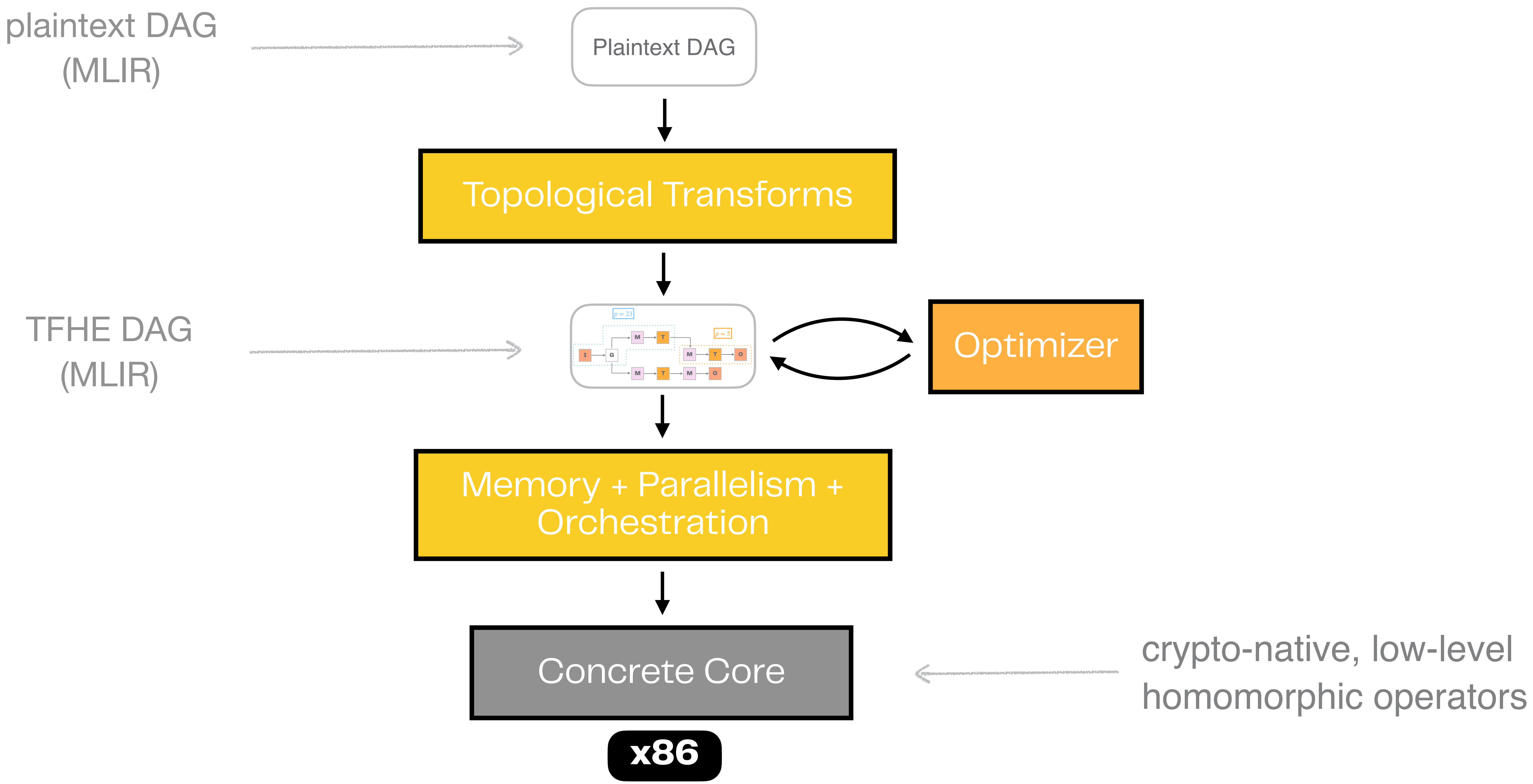

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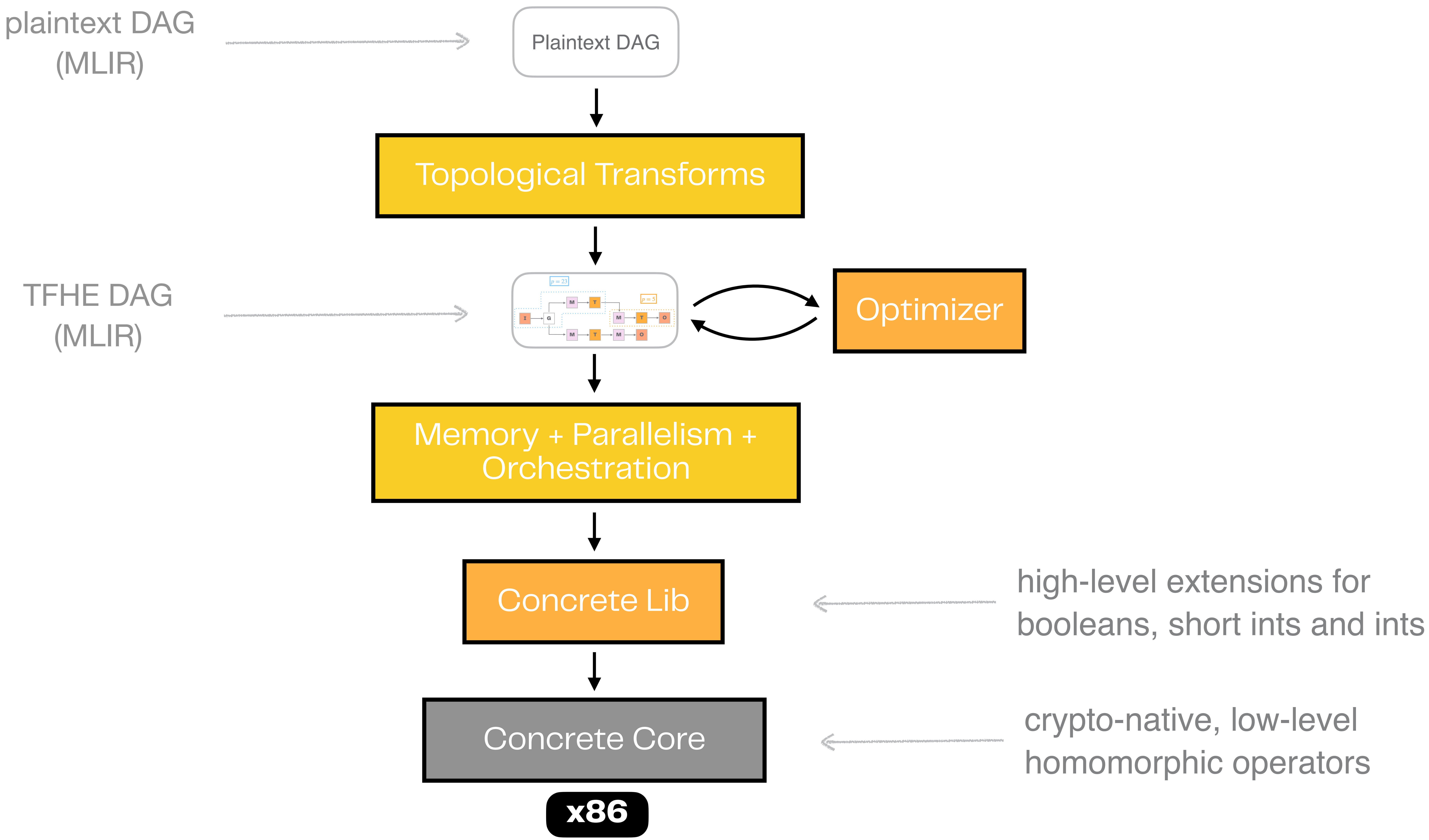

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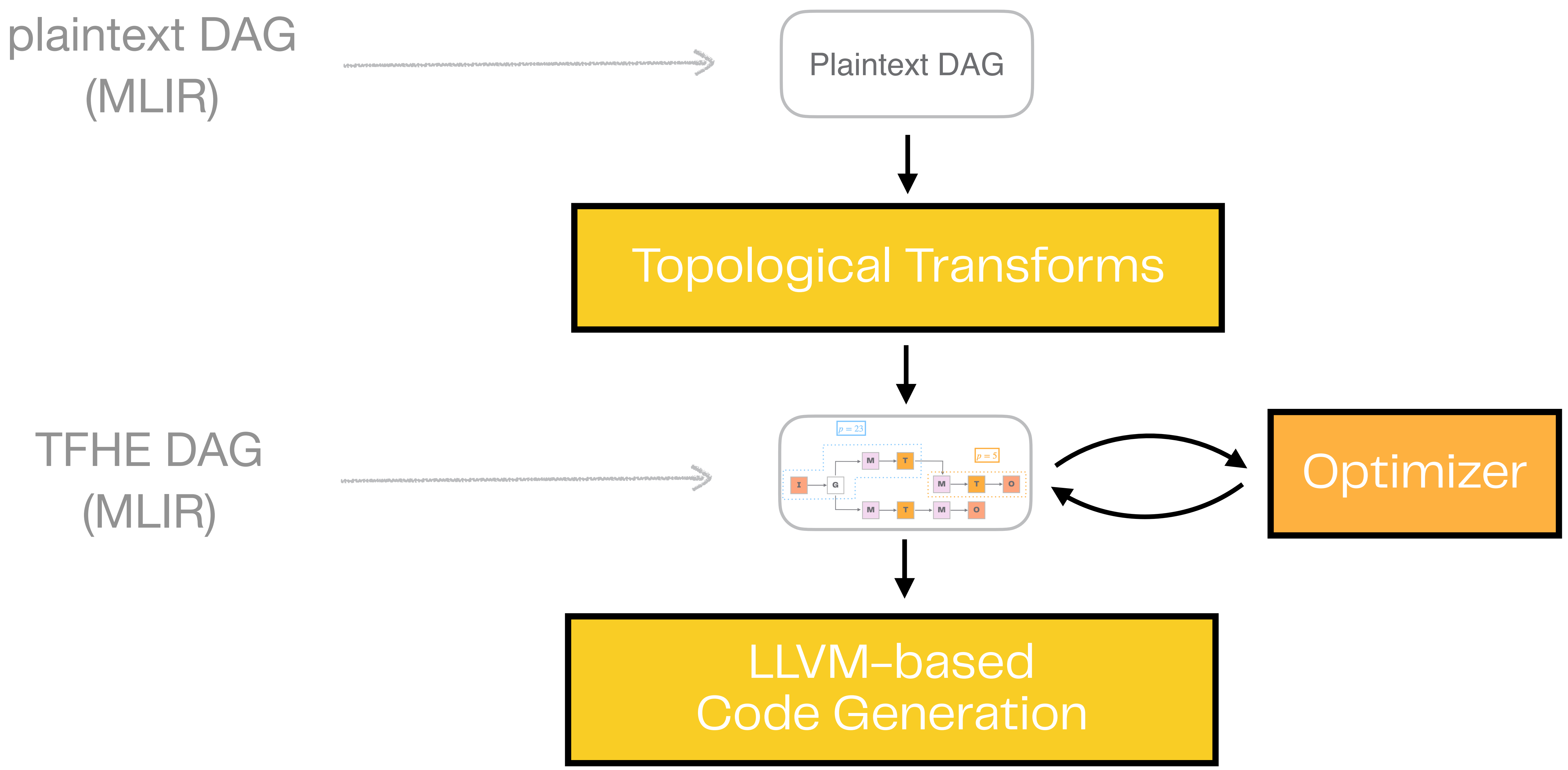

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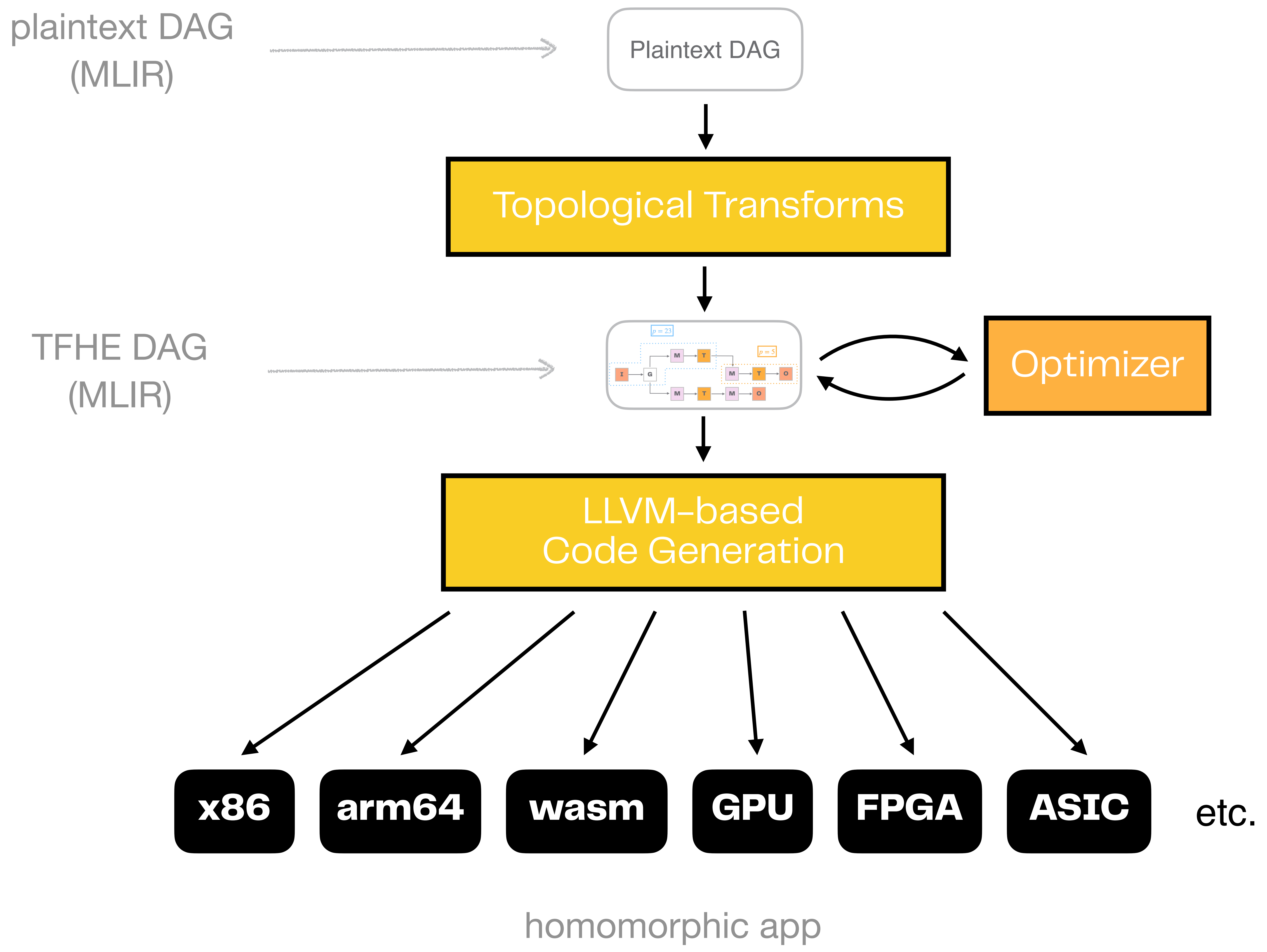

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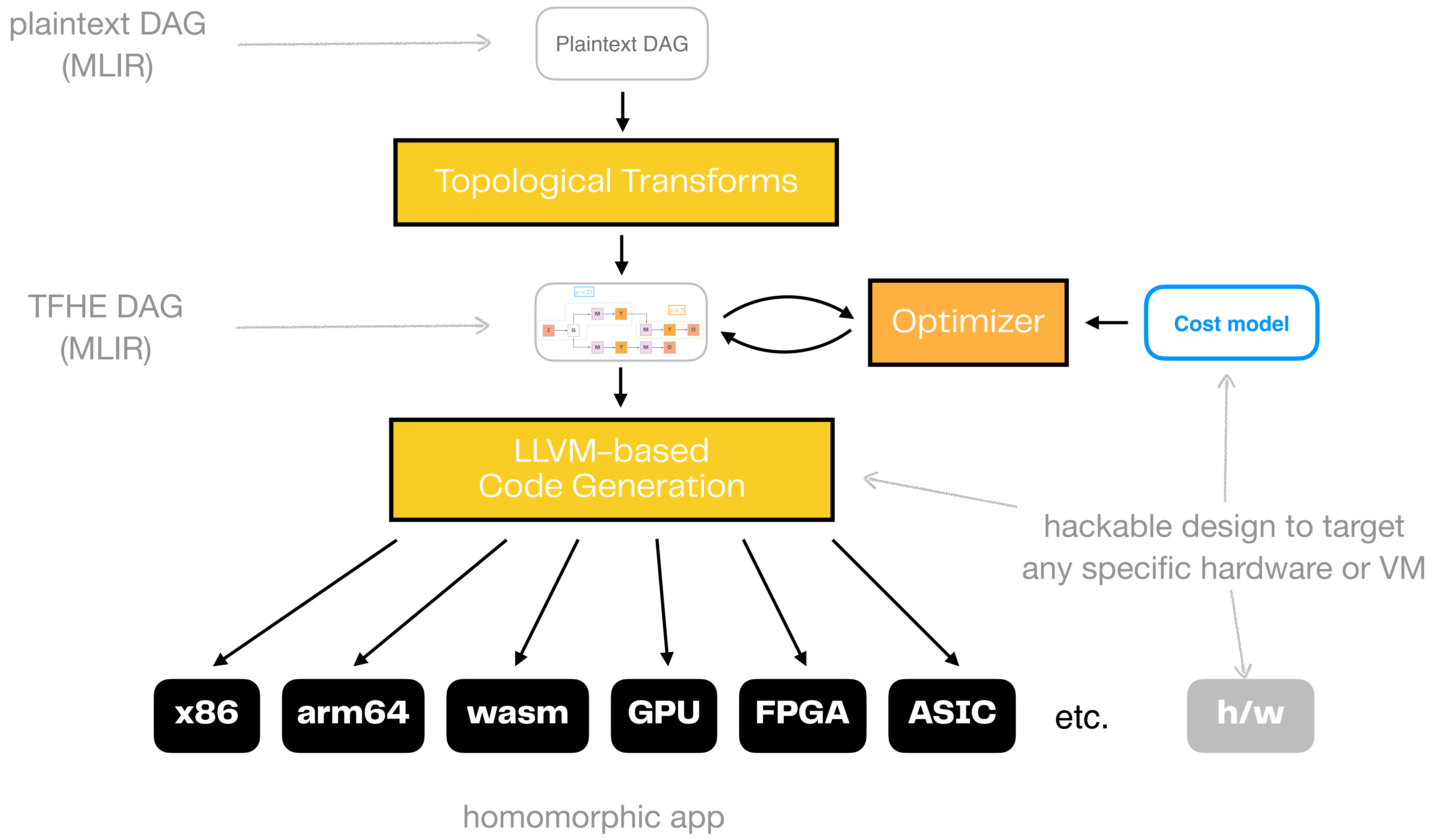

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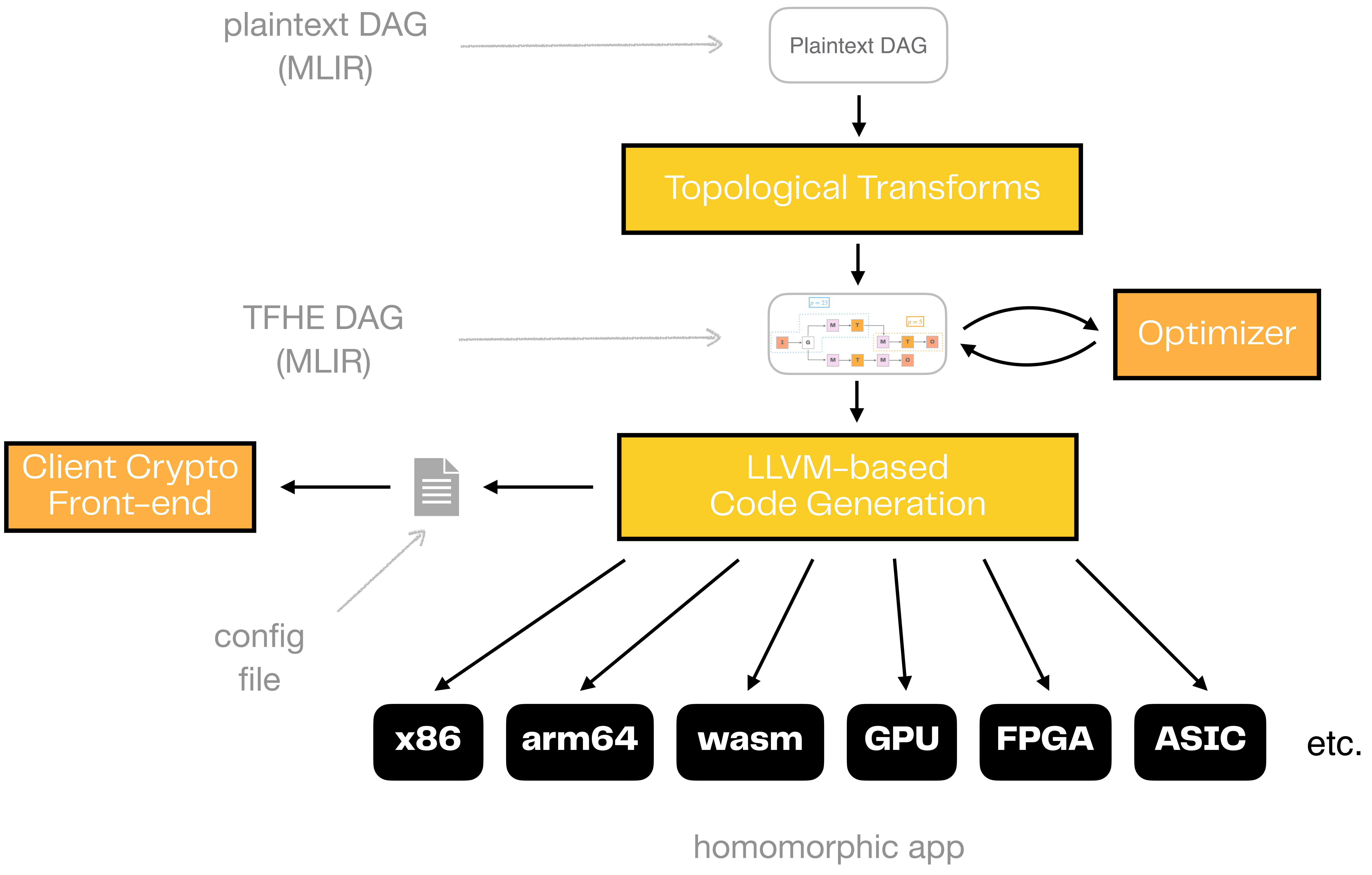

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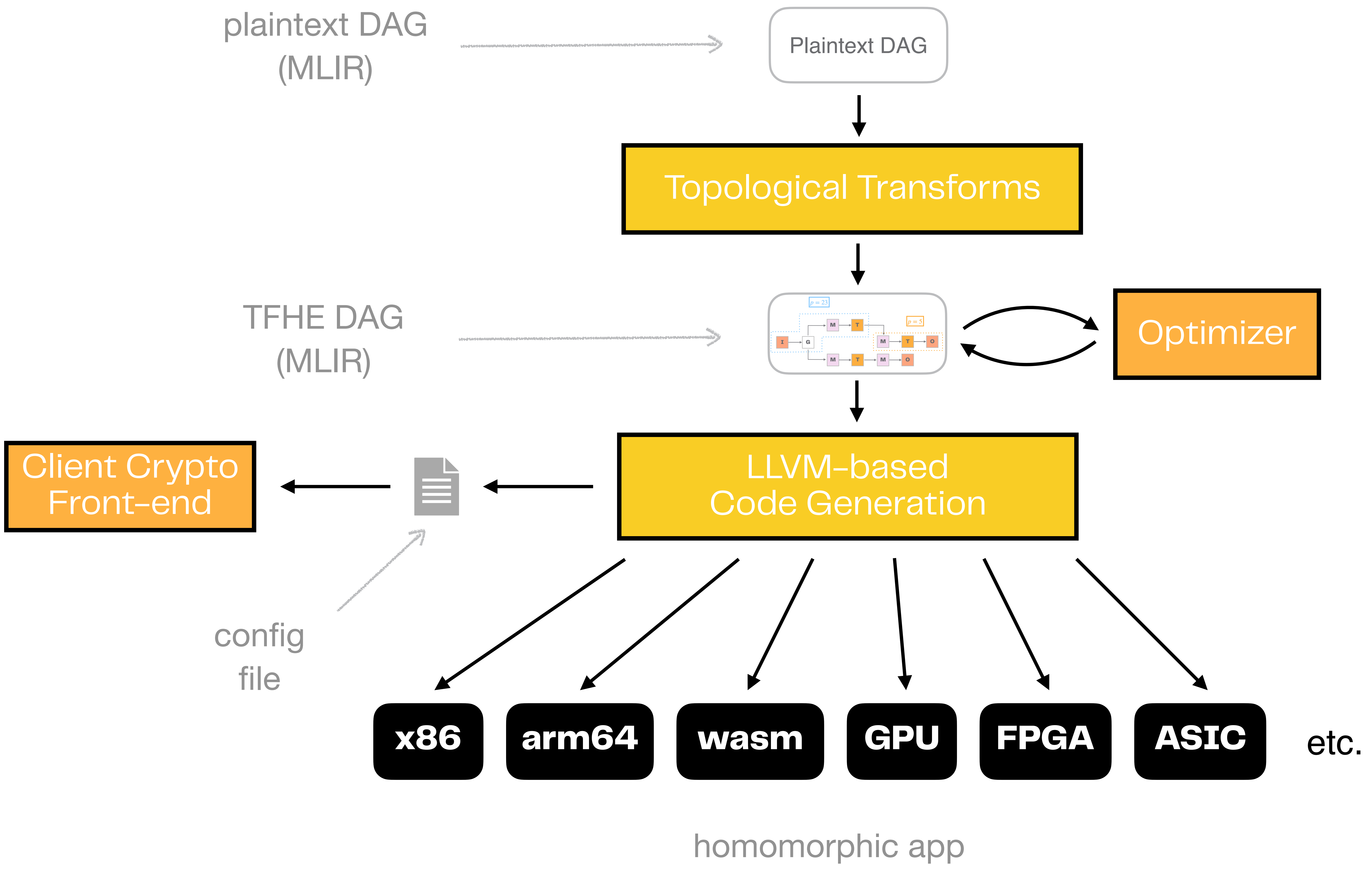


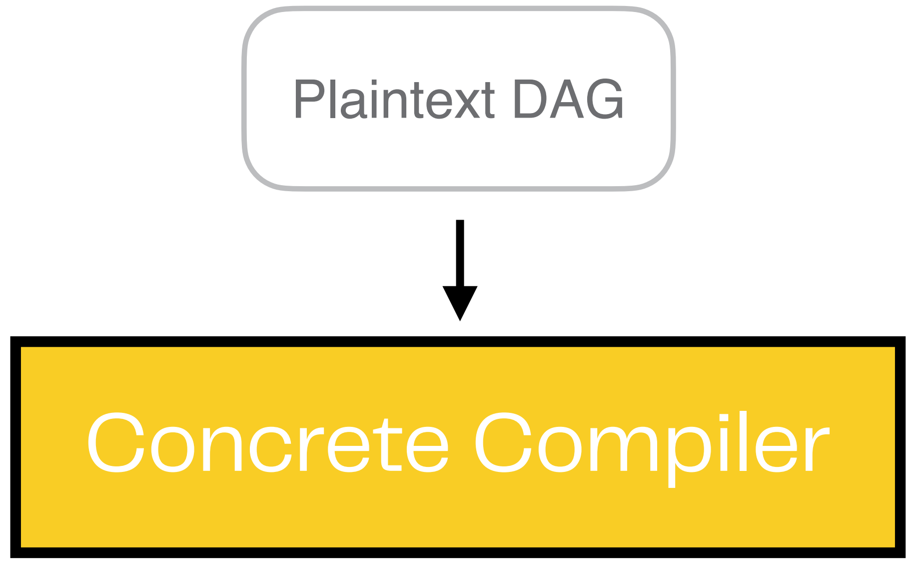
+ TFHE.rs

(for handmade circuits)

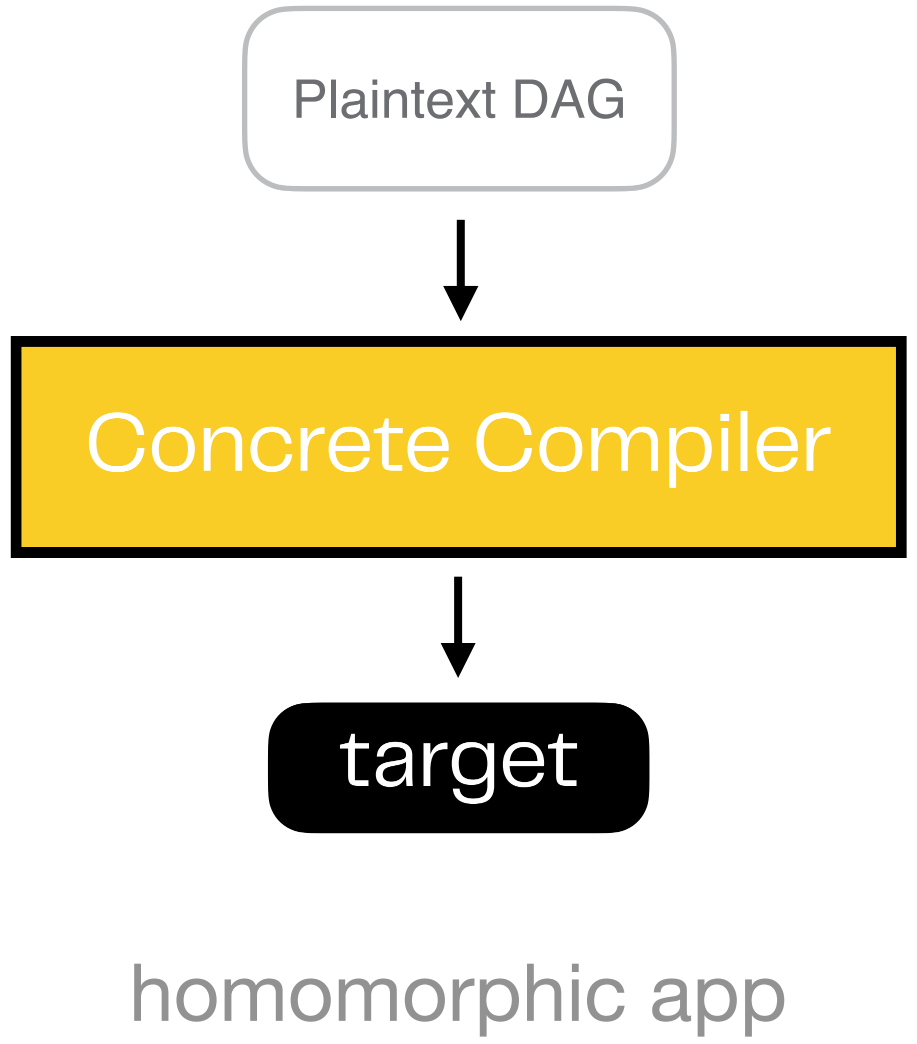
The Concrete stack is a versatile framework

Concrete Compiler

The Concrete stack is a versatile framework



The Concrete stack is a versatile framework



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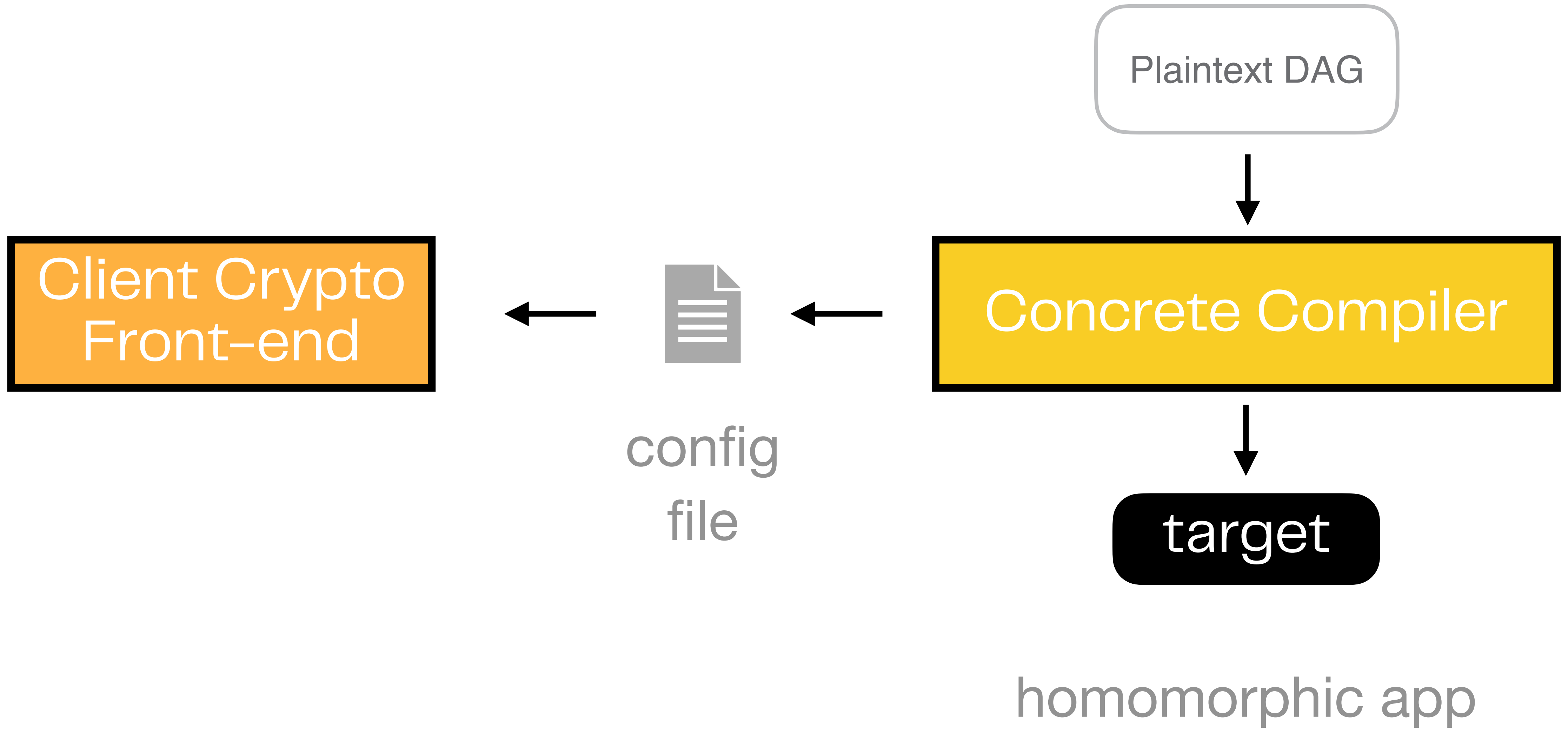

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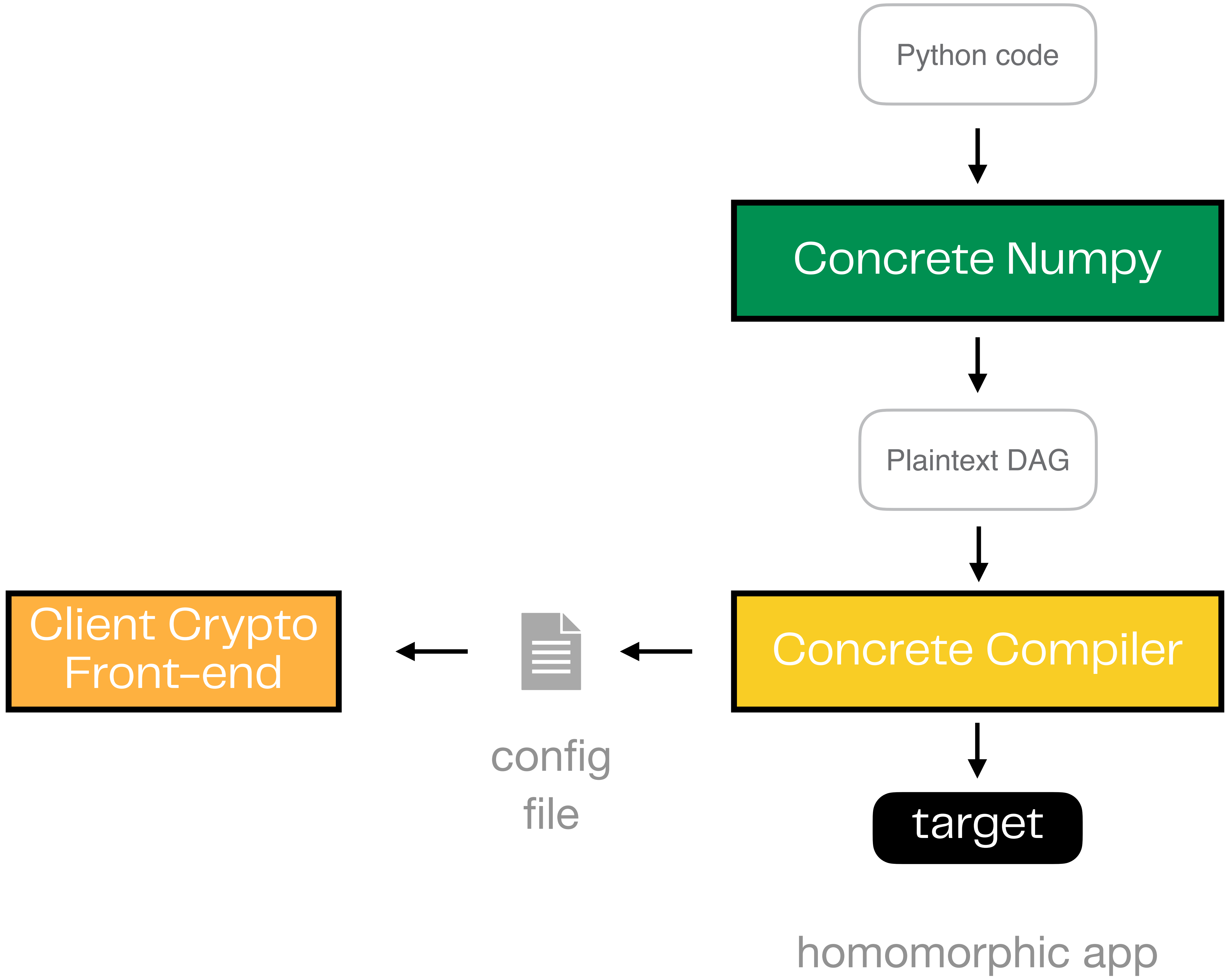

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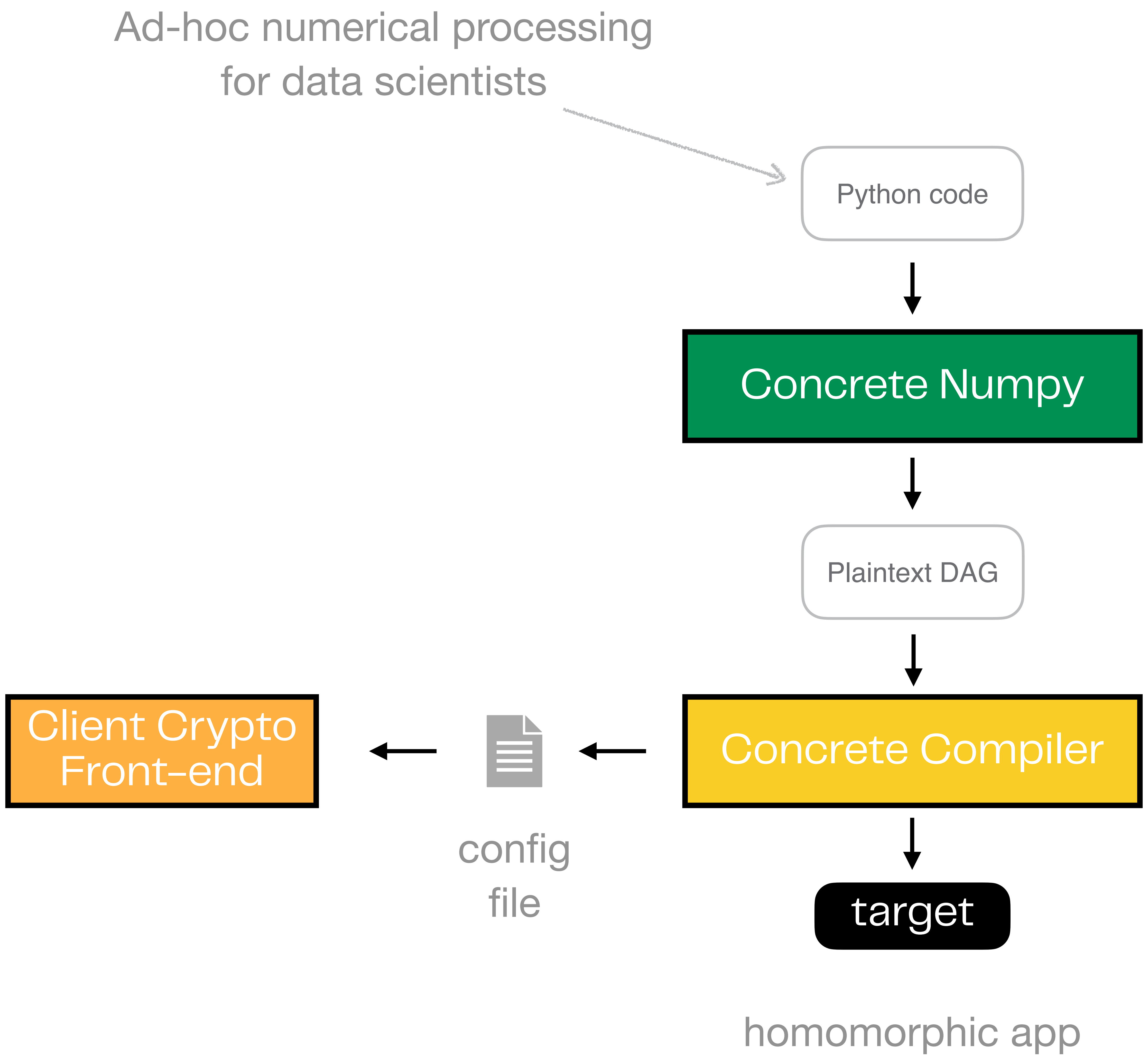

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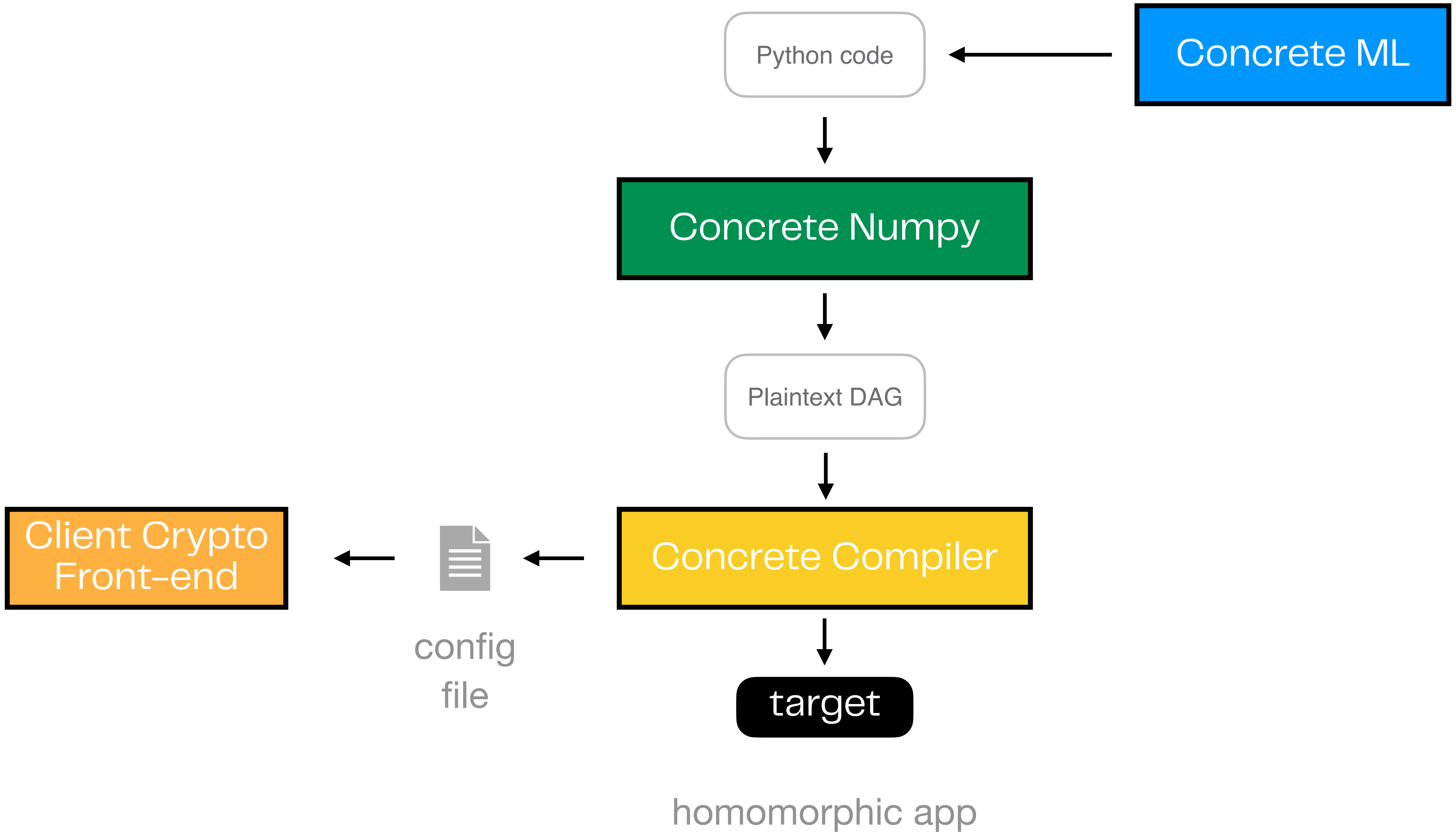

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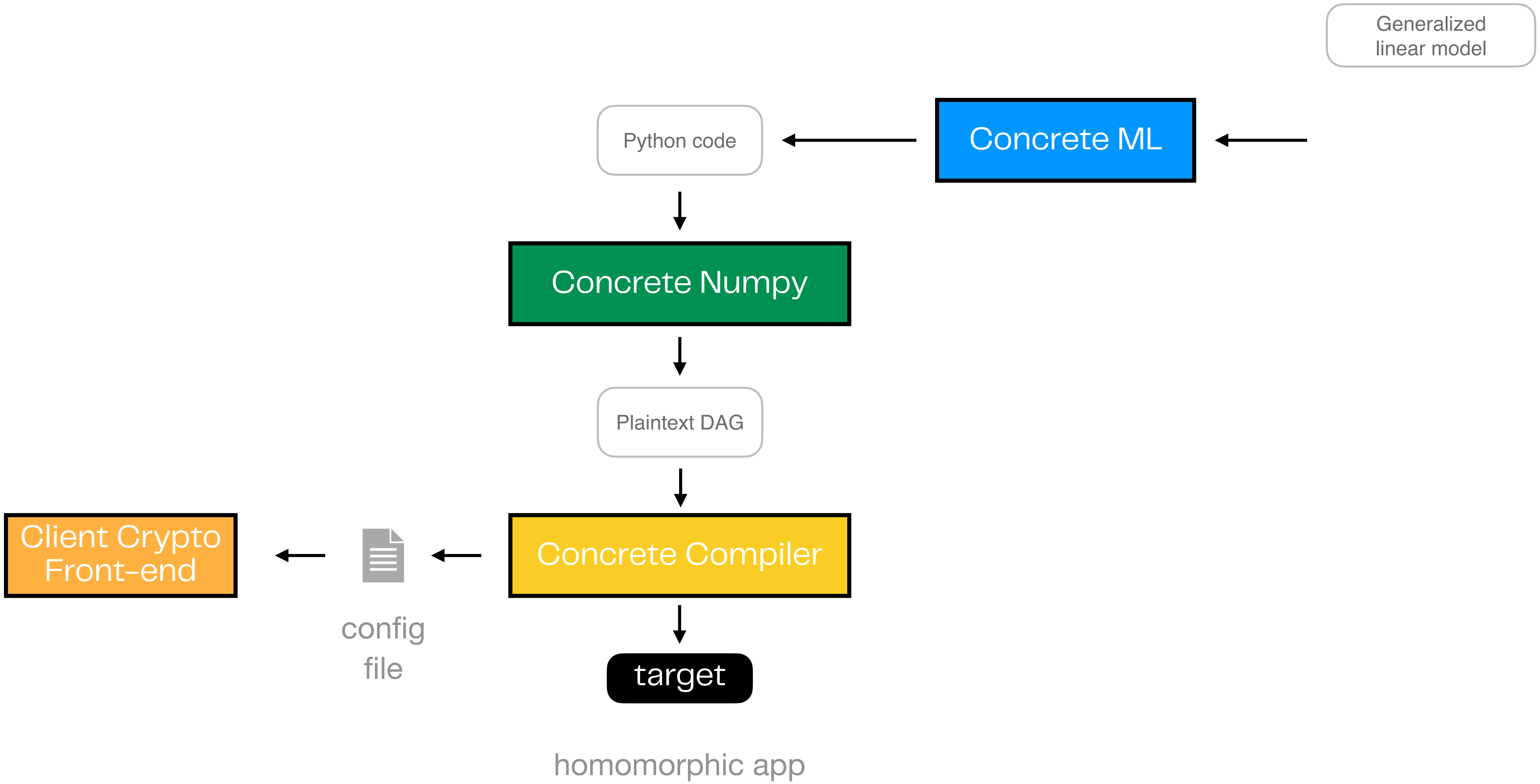

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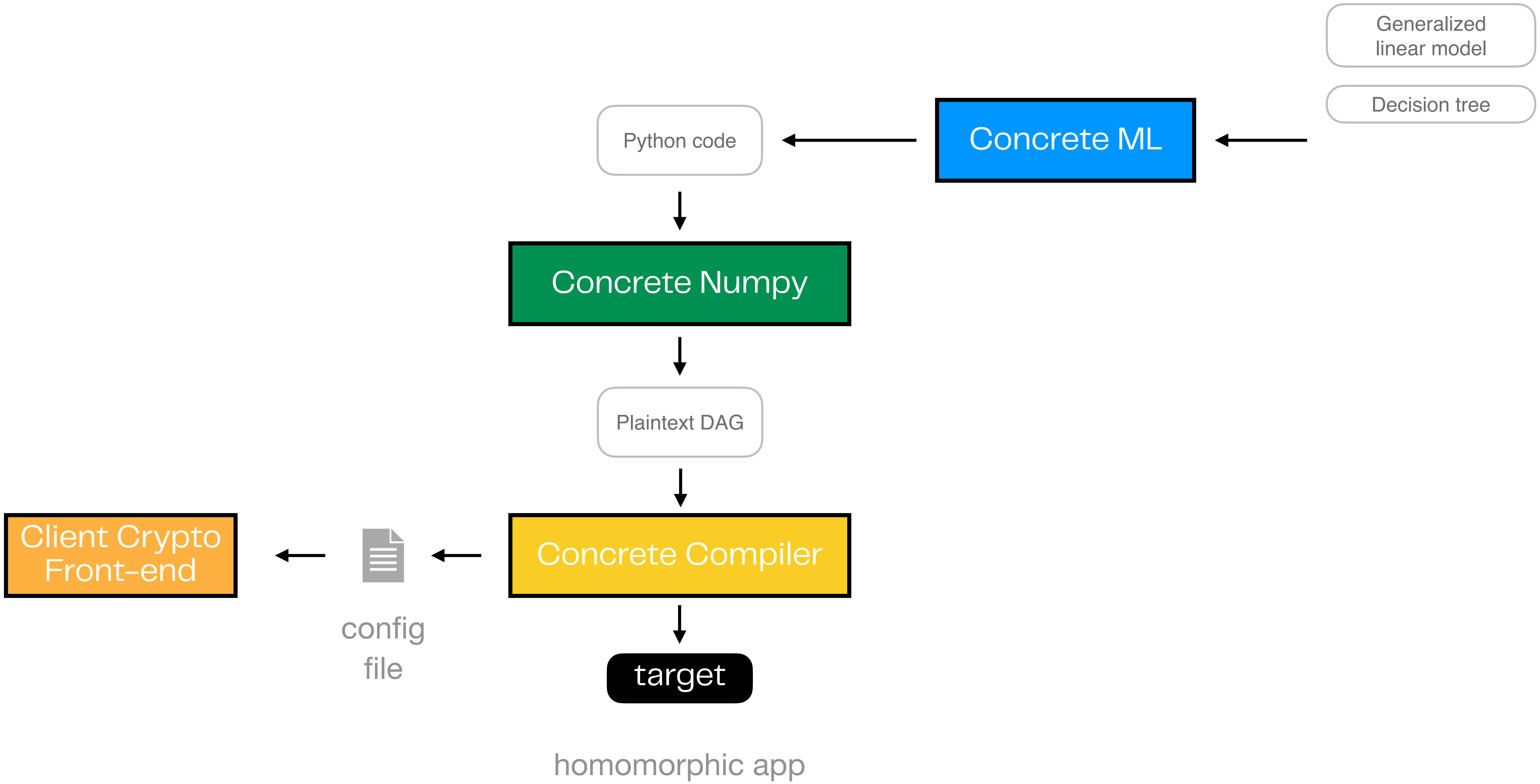

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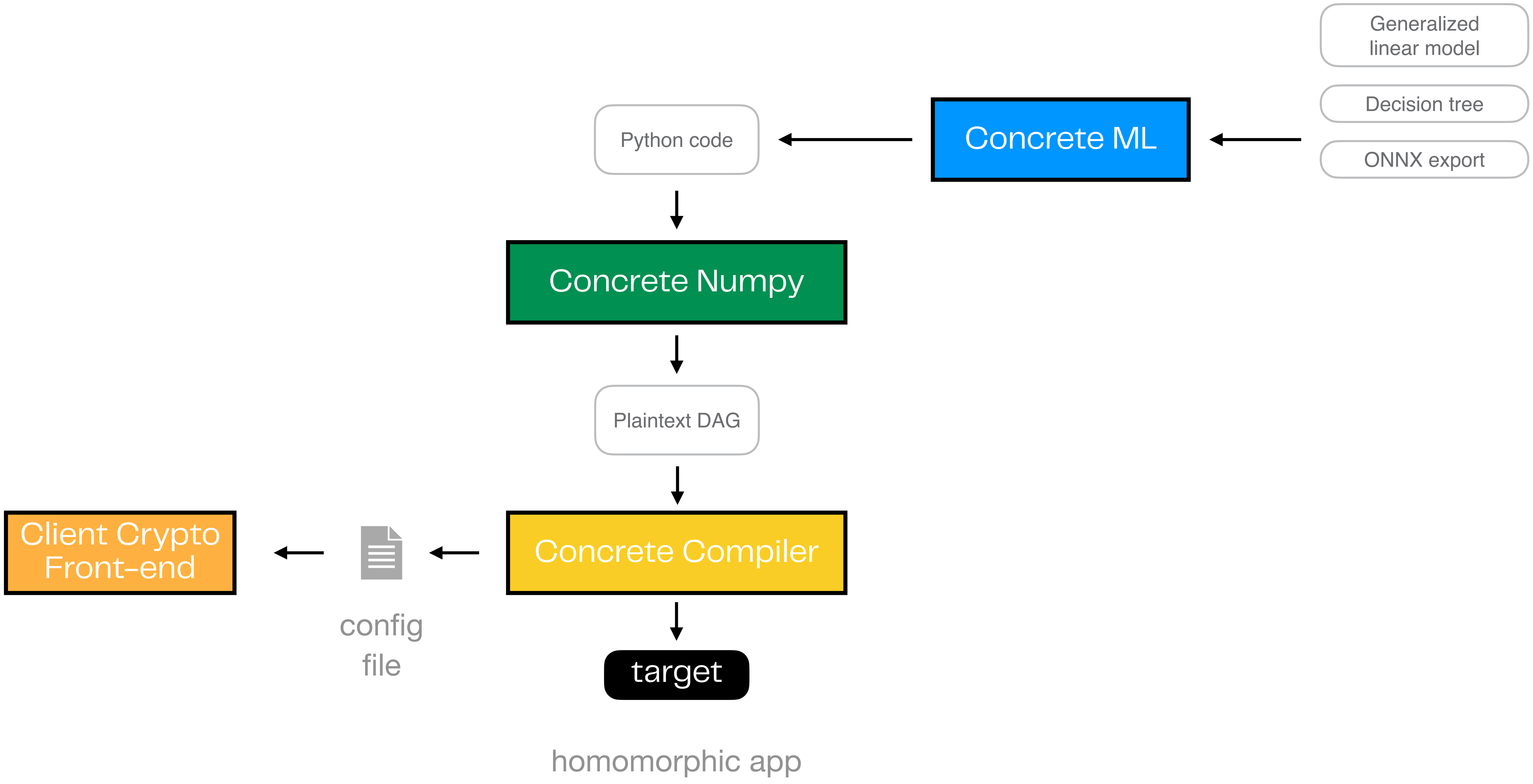

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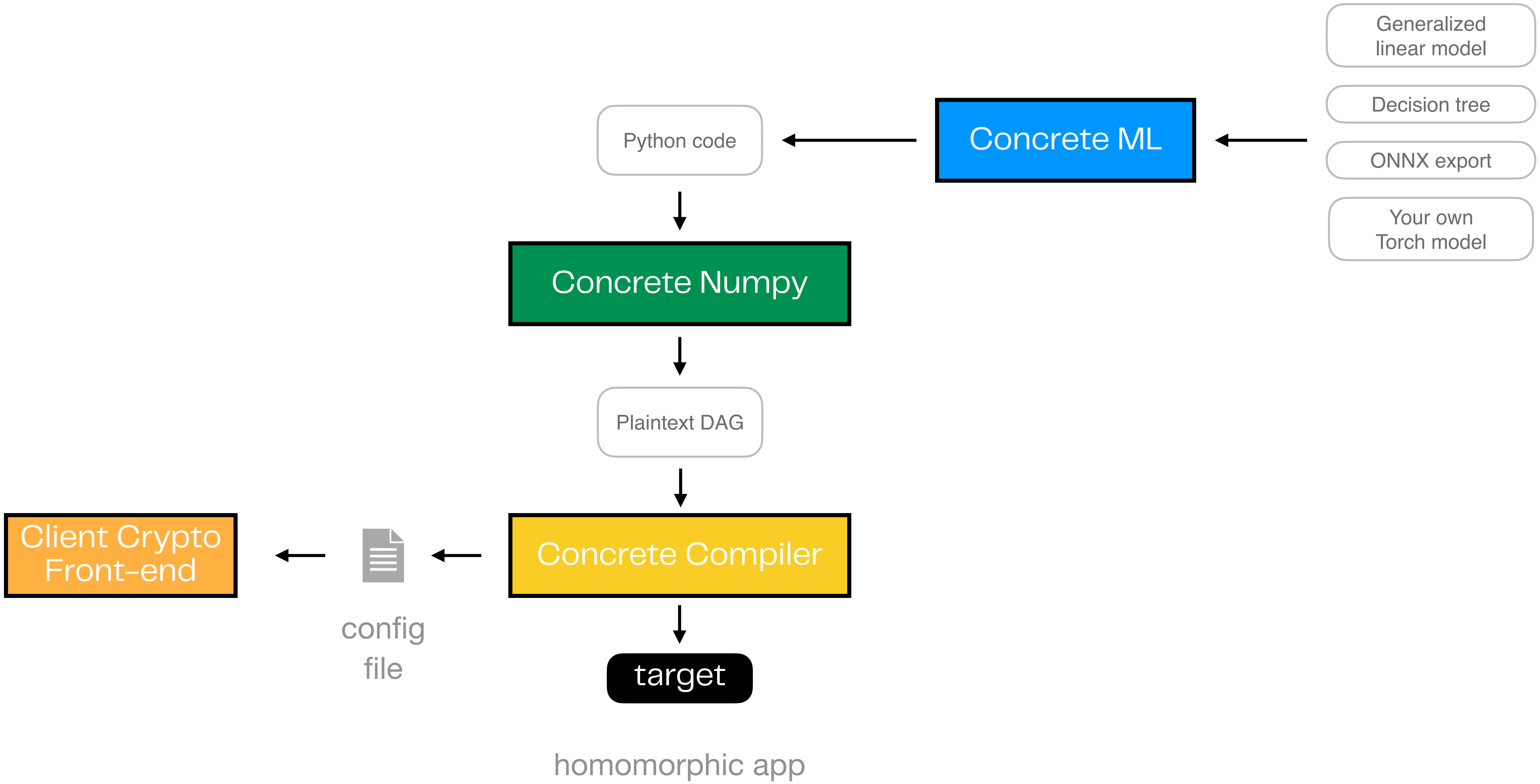

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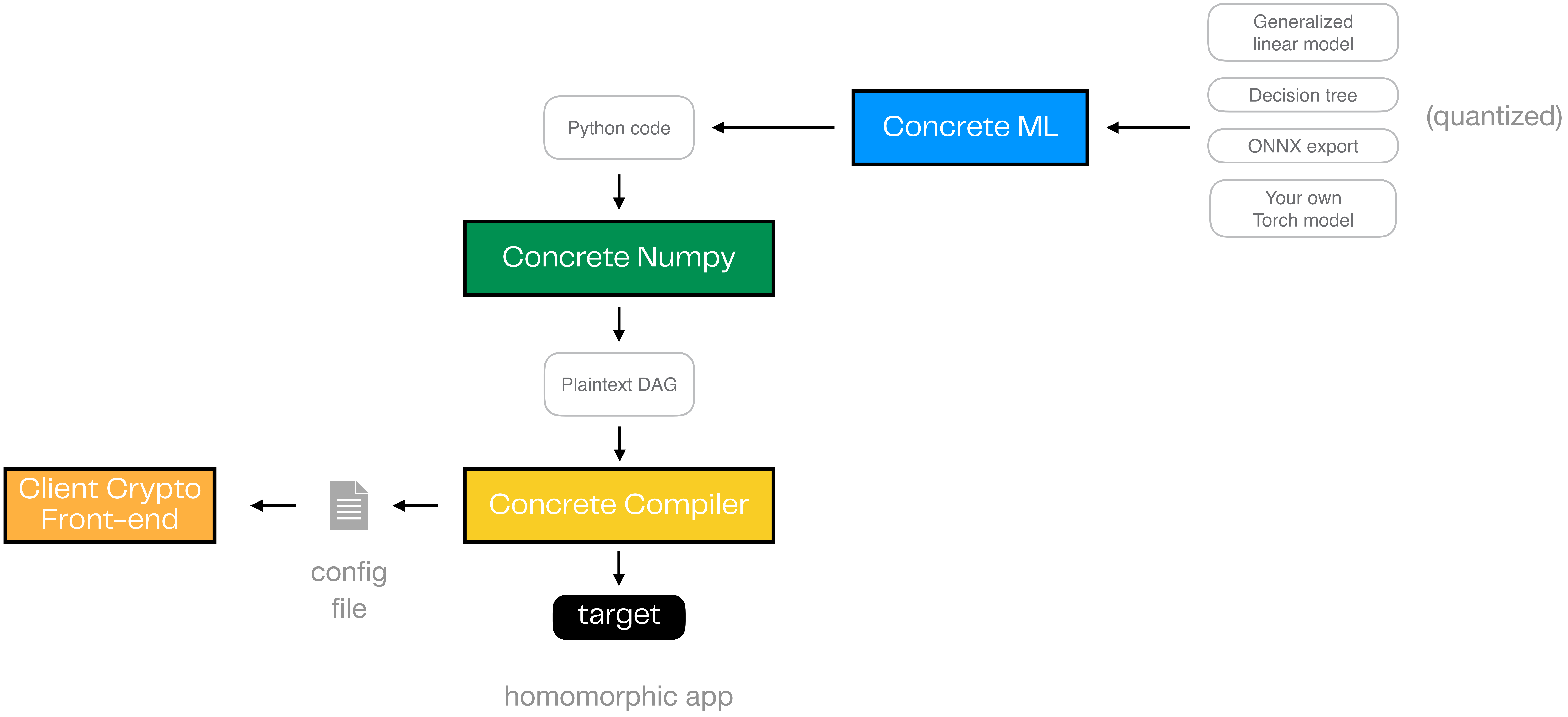

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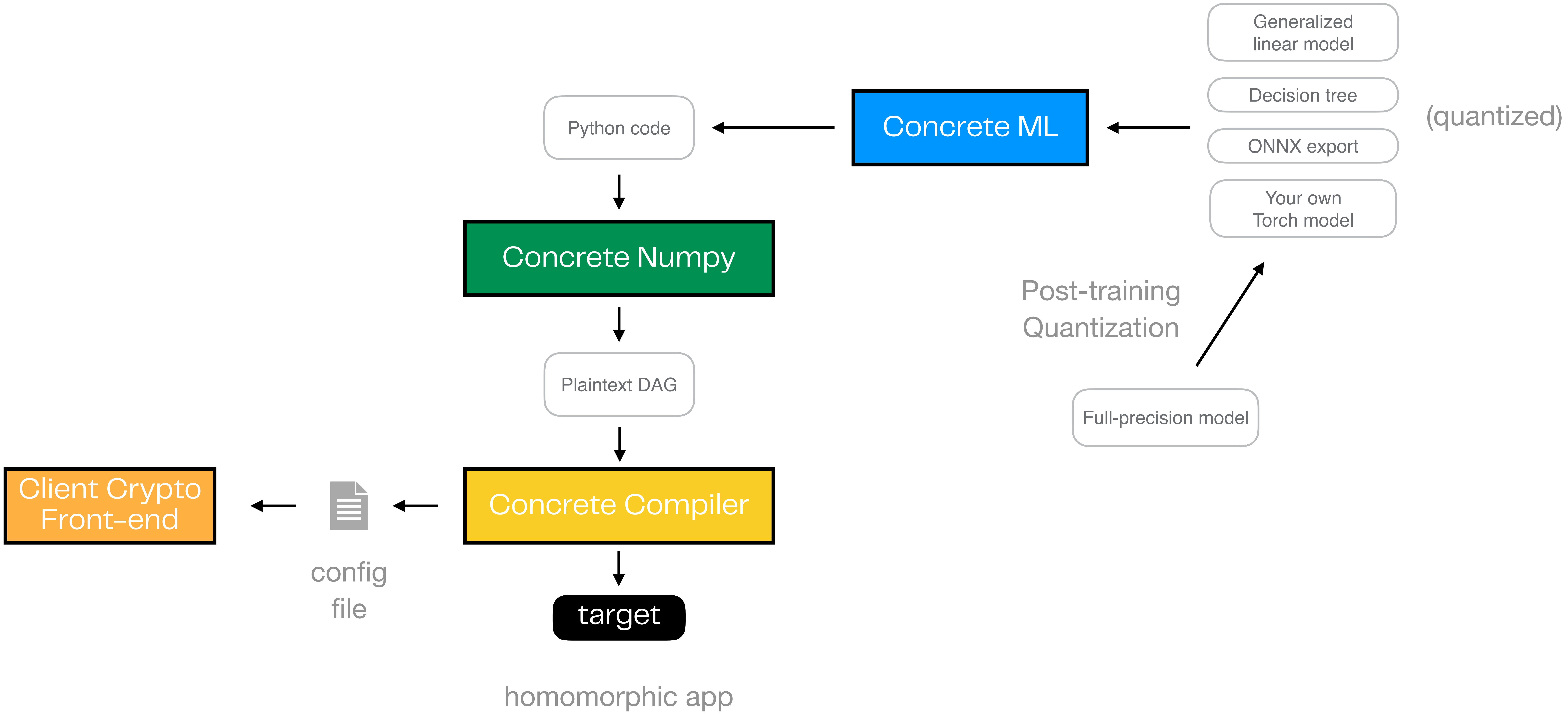

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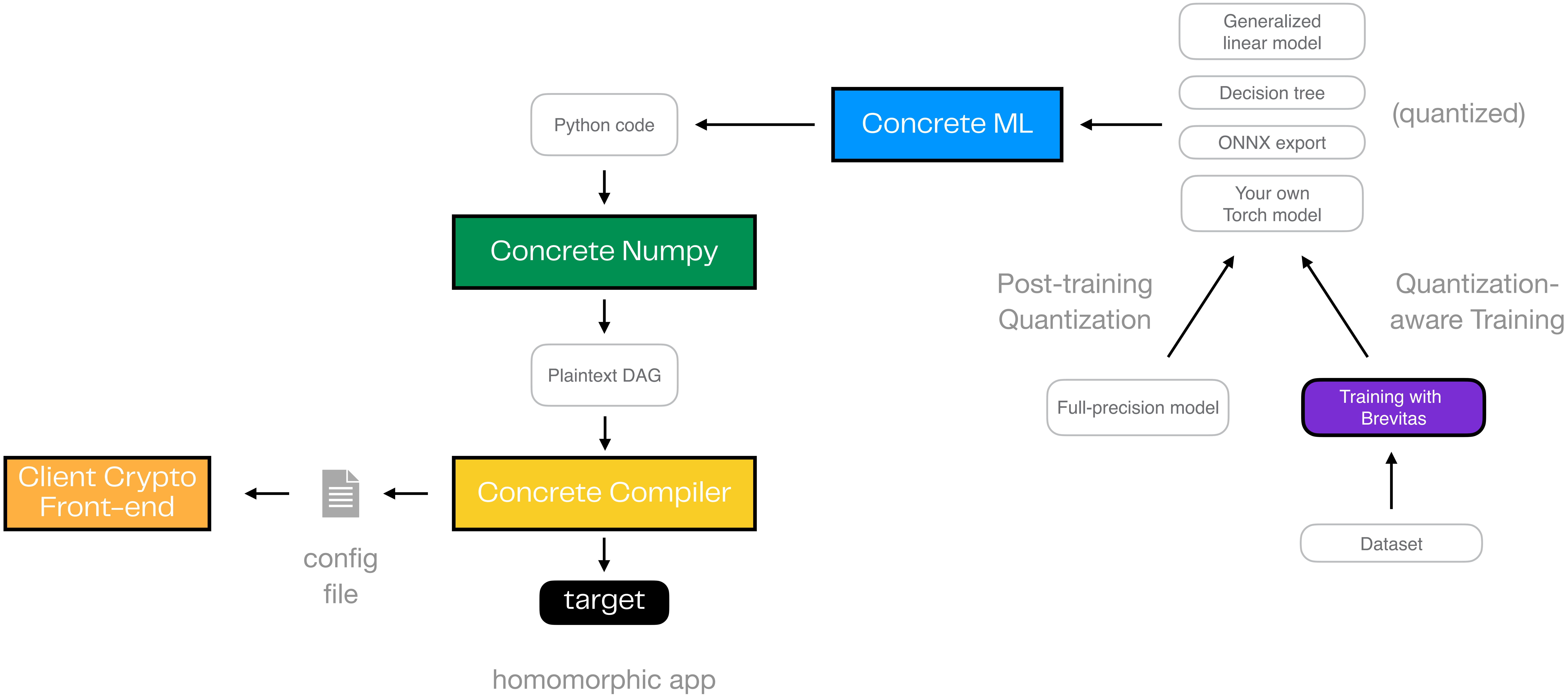

Check it out!

Homomorphic Everything

Clone from **https://github.com/zama-ai** and get support on https://discord.fhe.org/ (#concrete channel)