ENCRYPTED COMPUTING SDK
POLYNOMIAL INSTRUCTION SET ARCHITECTURE TOOLS

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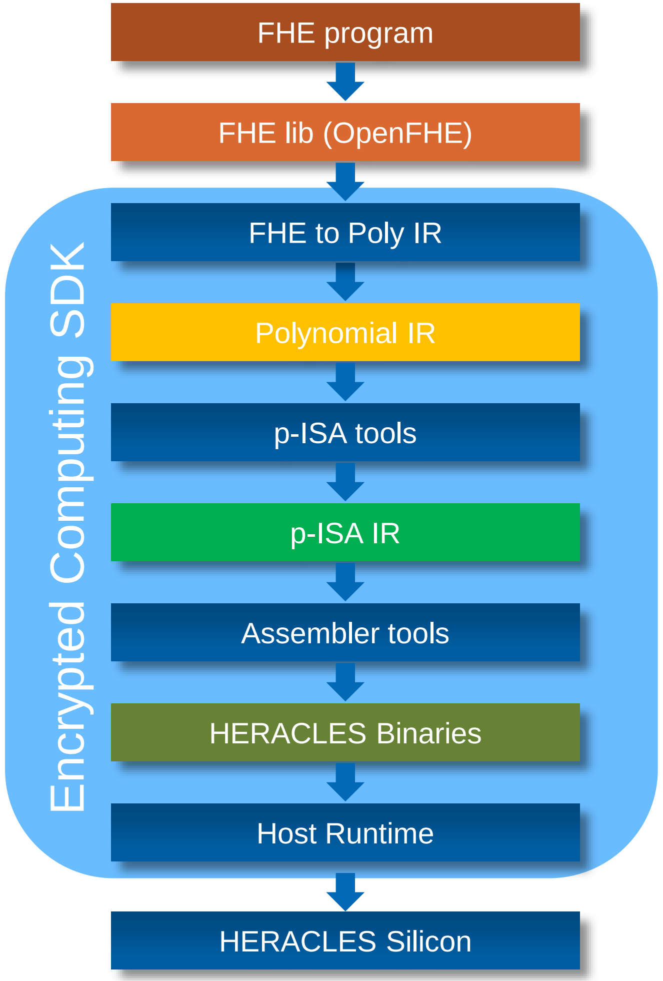
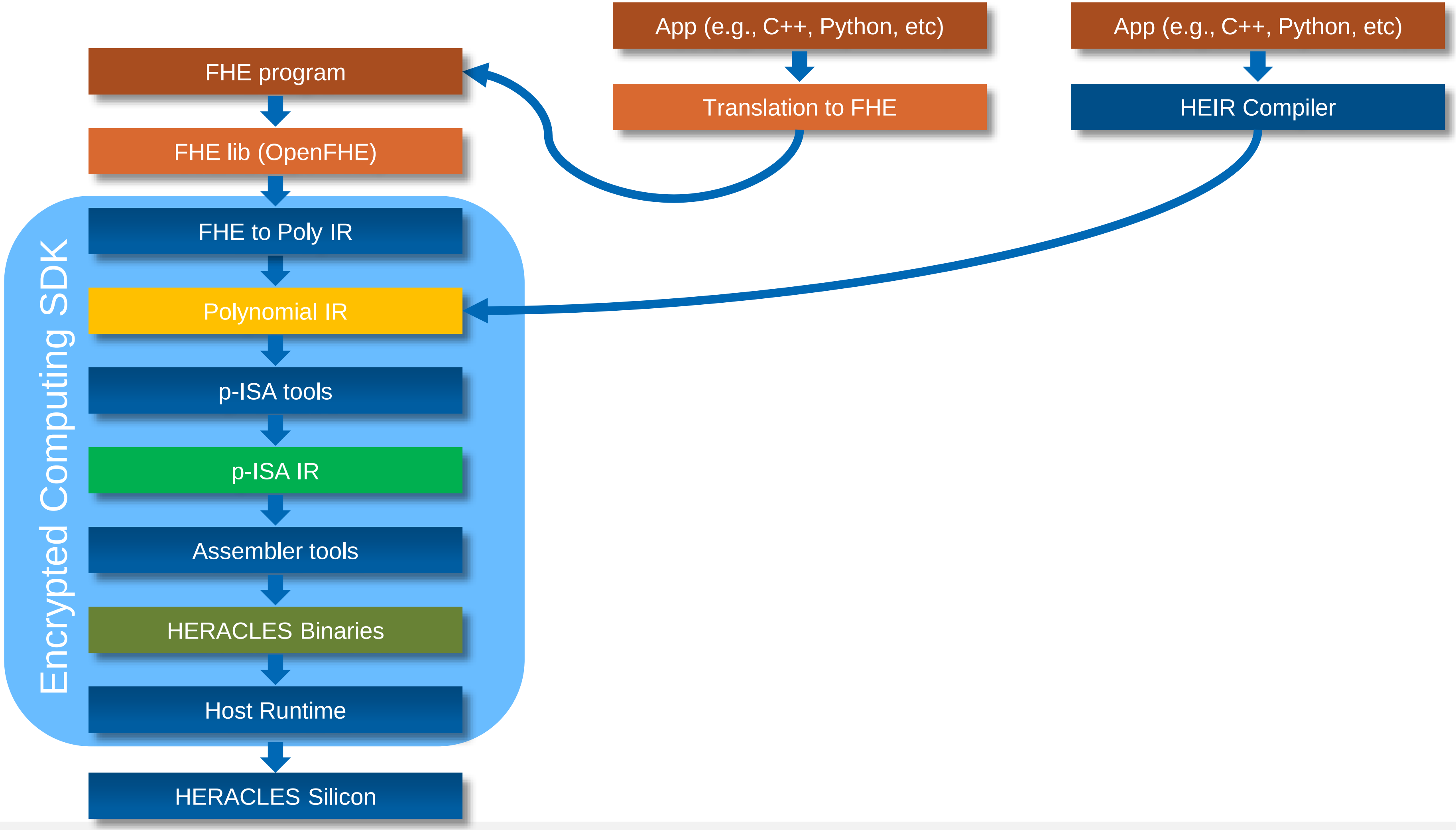
Encrypted Computing SDK Modular Approach



- Multistage transformation (compiler) pipeline
- Inspired by the LLVM
- Based on language independent intermediate representations (IR)
- Each stage promotes a separation of concerns
- Each stage applies dedicated transformations and optimizations

HERACLES SDK Integration with future 3rd Party Tools



FHE program

FHE lib (OpenFHE)

Encrypted Computing SDK

FHE to Poly IR

Polynomial IR

p-ISA tools

p-ISA IR

Assembler tools

HERACLES Binaries

Host Runtime

HERACLES Silicon

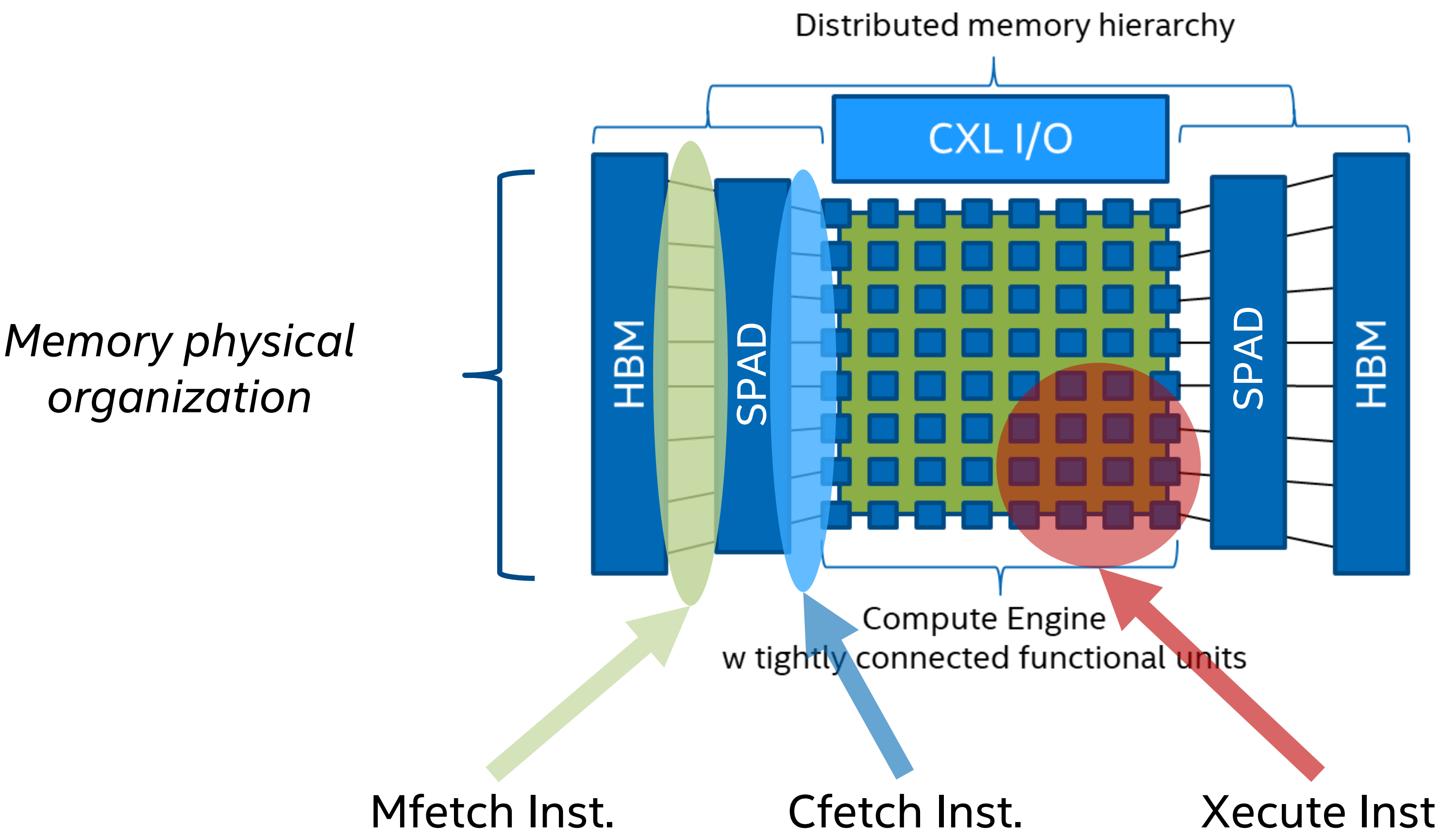
App (e.g., C++, Python, etc)

Translation to FHE

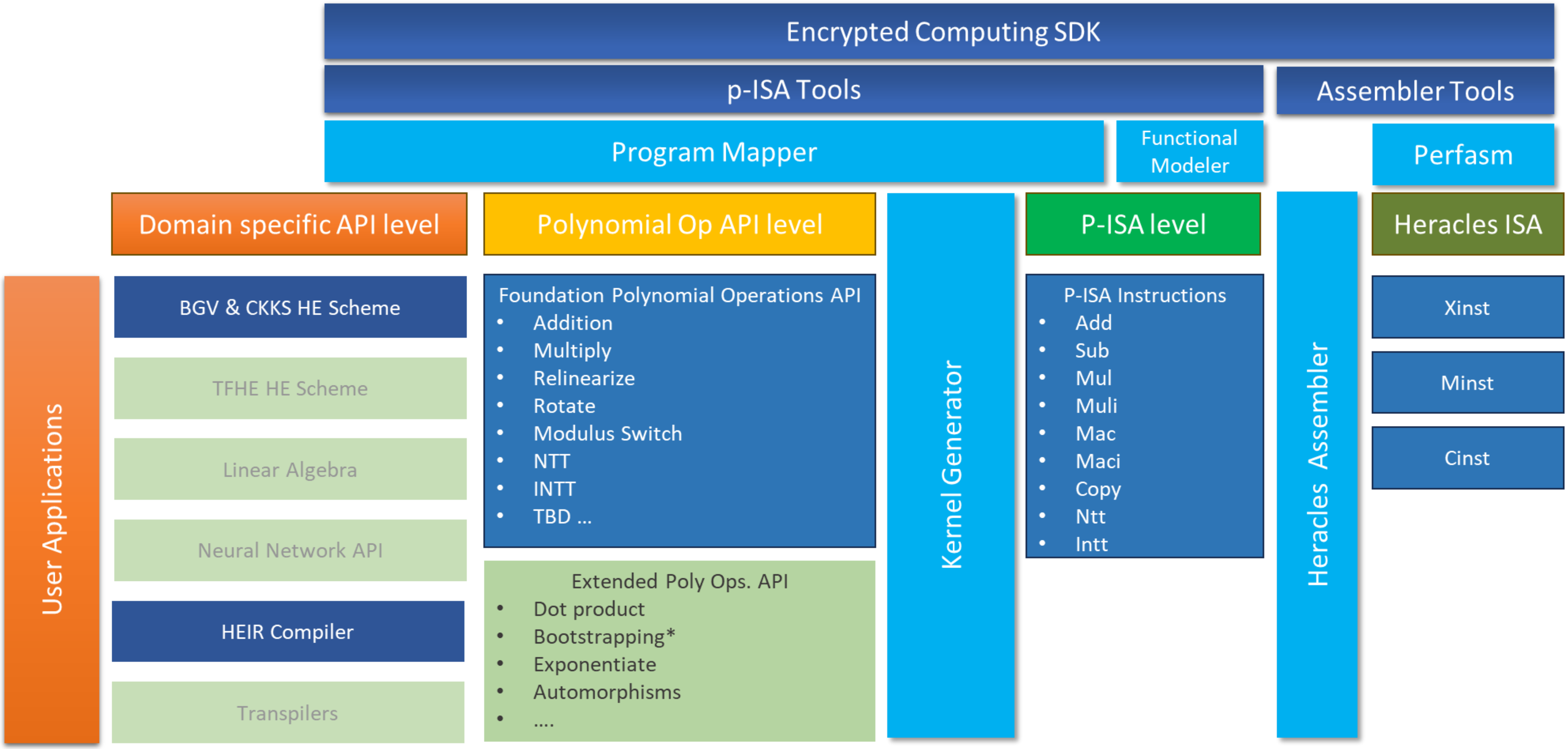
App (e.g., C++, Python, etc)

HEIR Compiler

HERACLES Overview


Distributed memory hierarchy
CXL I/O
Memory physical organization
HBM
SPAD
SPAD
HBM
Compute Engine
w tightly connected functional units
Mfetch Inst.
Cfetch Inst.
Xecute Inst

Encrypted Computing SDK Components Overview



Encrypted Computing SDK

p-ISA Tools

Assembler Tools

Program Mapper

Functional Modeler

Perfasm

User Applications

Domain specific API level

BGV & CKKS HE Scheme

TFHE HE Scheme

Linear Algebra

Neural Network API

HEIR Compiler

Transpilers

Polynomial Op API level

Foundation Polynomial Operations API

- Addition
- Multiply
- Relinearize
- Rotate
- Modulus Switch
- NTT
- INTT
- TBD …

Extended Poly Ops. API

- Dot product
- Bootstrapping*
- Exponentiate
- Automorphisms
- ….

Kernel Generator

P-ISA level

P-ISA Instructions

- Add
- Sub
- Mul
- Muli
- Mac
- Maci
- Copy
- Ntt
- Intt

Heracles Assembler

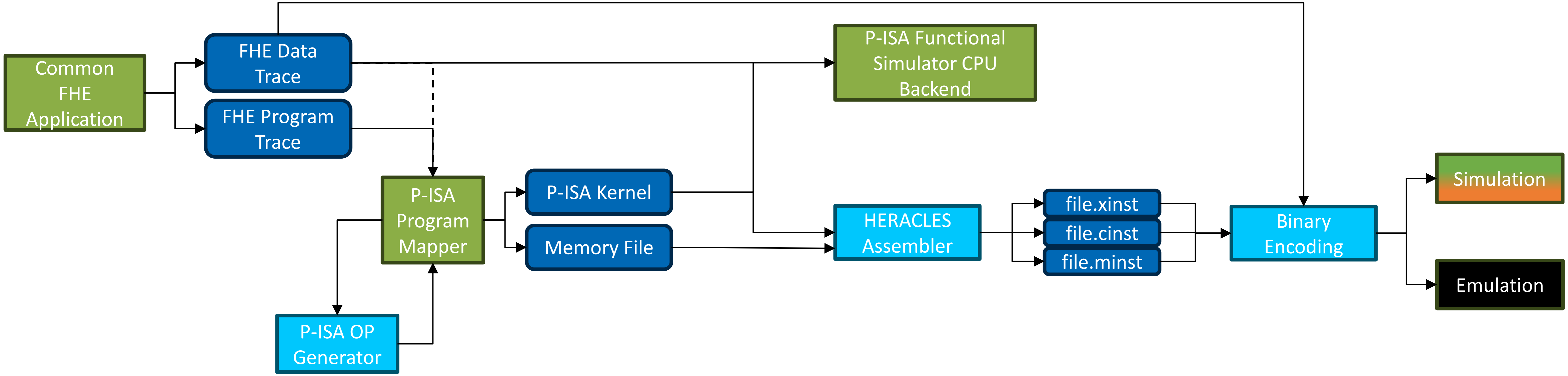
Heracles ISA

Xinst

Minst

Cinst

Current E2E Software Stack – Building Toward an Encrypted Computing SDK



Current syntax & semantic for the program trace

instruction,scheme,ring dimension,krns,arg0,arg1,arg2,…

mul_plain,BGV,16384,5,ctprod0-2-4,ct0-2-4,pt0-1-4

Instruction:Multiply Plain, *Scheme:BGV*, *Ring Dimension:16384*, *krns:5*

arg0: ***output cyphertext*** (ctprod0) with ring dimension 16384, krns 5, order 2, current rns terms 4

arg1: ***input cyphertext*** (ct0) with ring dimension 16384, krns 5, order 2, current rns terms 4

arg2: ***input cyphertext*** (ct1) with ring dimension 16384, krns 5, order 1, current rns terms 4

Revised/proposed syntax & semantic for the program trace

Scheme, Ring Dimension, Instruction, arg1 Ctxt(+params), arg2 Ctxt(+params),...
Ctxt(+params) = Ctxt label, RNS Primes, Order, Mult. Depth, Level

CKKS,16384,MULT,ct01f9,8,3,2,2,ct018d,8,2,1,2,ct01ba,8,2,1,2,

Scheme: CKKS, *Ring Dimension: 16384,* *Operation: Multiplication*

Input cyphertexts (ct018d and ct01ba) each with ring dimension 16384, 8 RNS primes, order 2, depth 1, and level2

Output cyphertext (ct01f9) with ring dimension 16384, 8 RNS primes, order 3, depth 2, and level 2

CKKS,16384,RELIN,ct0298,8,2,2,2,ct01f9,8,3,2,2,

Input cyphertexts (ct01f9) with ring dimension 16384, 8 RNS primes, order 3, depth 2, and level 2

Output cyphertext (ct0298) with ring dimension 16384, 8 RNS primes, order 2, depth 2, and level 2

Questions ?