ZK Circuits VS FHE Circuits

A comparison of the programming model behind zk circuis and FHE circuits

Difference: Constraints VS circuit

- (most) zk proof systems: set of constraints.
  - Can use non-determinism
  - Example: R1CS, CCS, Plonkish, AIR
- 1st: Compute a solution (witness)
- 2nd: Verify the solution with constraints
  - Example: c = a / b
    - Constraint: b * c == a

Difference: Constraints VS circuit

- MPC & FHE [1]: Arithmetic/boolean circuit
  - Example: Garbled Circuits, FHEW, Shamir Secret Sharing MPC
- 1st: Define the function as an arithmetic/boolean circuit
- 2nd: Evaluate the circuit from the inputs
  - Example: a = (b AND c) OR d
    - Evaluation: tmp = b AND c; a = tmp OR d

[1] And some zk proof systems like GKR

Similarity: No branching [1]

- Loops need to be unrolled
- Encoding branches means taking both paths and then unifying
- Example:

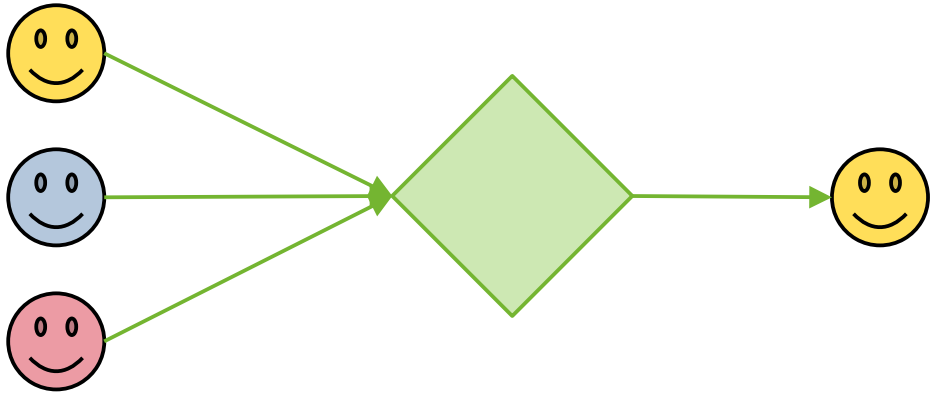
```
if cond == 1 {
  x = a + b
} else {
  x = c * d
}
```

```
x1 = a + b
x2 = c * d
x = cond * x1 +
  (1 – cond) * x2
```

[1] Unless you have a zkVM

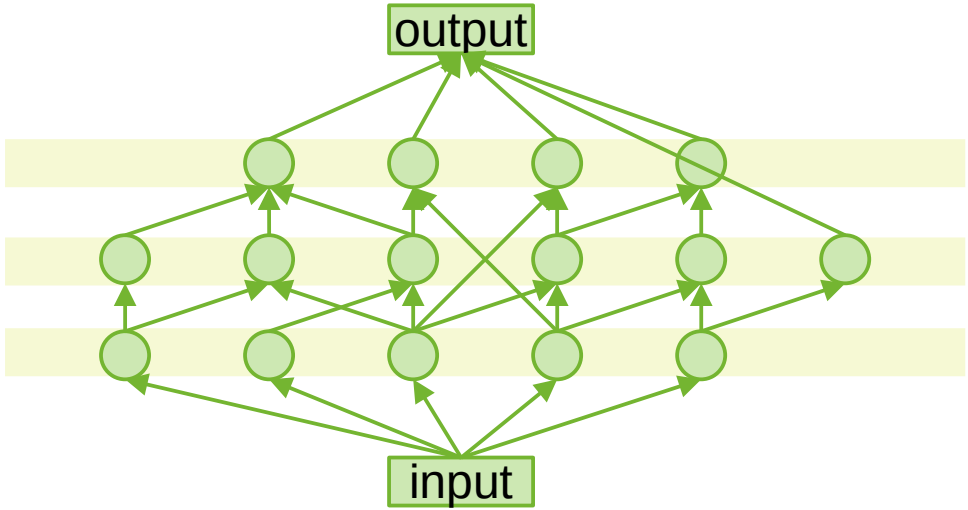
Difference: private data ownership

- zk: Single private data source
  - Public & private
- MPC/mpFHE: Multiple users private data
  - Public & private(for whom?)



Difference: Parallelism

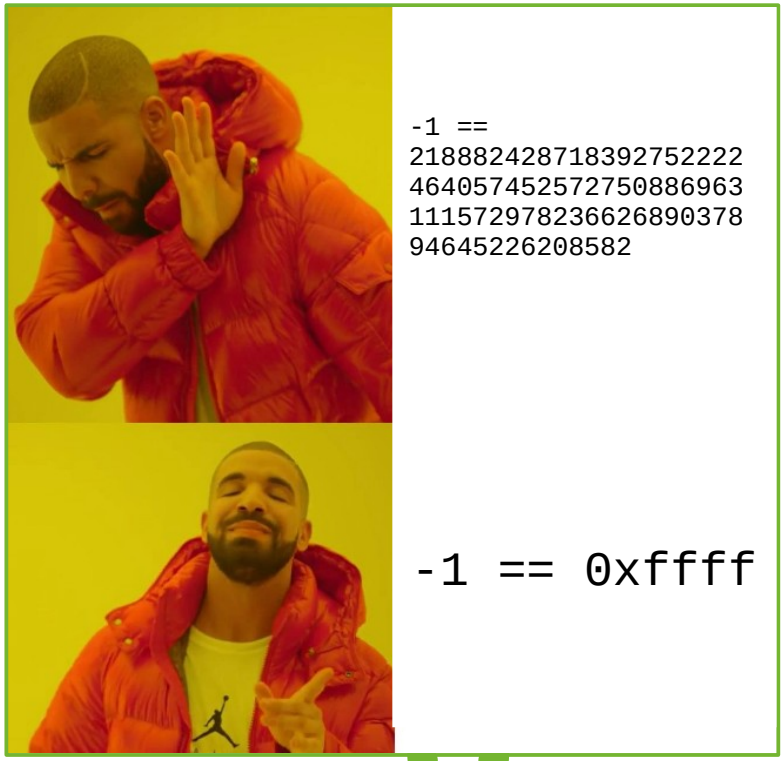
- ZK: parallelism at the proof system level
- FHE/MPC: parallelism at the circuit level



Each layer is evaluated in parallel

Difference: Fields VS booleans

- (many) zk proof systems use field arithmetic
- FHE/MPC can work with boolean circuits
- Boolean logic:
  - expensive in zk
  - cheap in FHE/MPC
- u8, u16, u32:
  - expensive in zk
  - cheap in FHE/MPC



Difference: circuit compilers

- ZK: quite mature, lots of options, good integration
  - circom, noir, RISCV zkVMs, PIL, Lurk, Leo, o1js, Cairo
- FHE/MPC: less mature, few options, non-reusable
  - MP-SPDZ, concrete, HEIR, google/fully-homomorphic-encryption, summon

The End