

# MATRIX MULTIPLICATION I

## NAIVE METHOD

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### 1. THE PROCESS

- (1) The circuit operates over the finite field  $\mathbb{Z}/p\mathbb{Z}$ , where  $p$  is an  $n$ -bit prime (typically,  $n \approx 256$  in practice):

$$2^{n-1} < p < 2^n.$$

- (2) Let  $A = [a_{ik}]$  and  $B = [b_{kj}]$  be integer matrices of dimensions  $\ell \times m$  and  $m \times n$ , respectively. Let  $U$  be an integer such that, for all  $i, k, j$ ,

$$-U \leq a_{ik}, b_{kj} \leq U.$$

- (3) Assume<sup>1</sup> that

$$mU^2 < \frac{p}{2}.$$

In practice, typical values of  $m$  include 28, 256, and 1568, while typical values of  $U$  include  $2^{16}$ ,  $2^{21}$ , and  $2^{32}$ .

- (4) Let  $C = [c_{ij}]$  be an  $\ell \times n$  integer matrix and assume<sup>2</sup> that, for all  $i, j$ ,

$$-\frac{p}{2} < c_{ij} \leq \frac{p}{2}.$$

- (5) Convert each  $a_{ik}$ ,  $b_{kj}$ , and  $c_{ij}$  to its least-residue modulo  $p$ , denoted  $a'_{ik}$ ,  $b'_{kj}$ , and  $c'_{ij}$ , respectively. This conversion is necessary because frameworks typically do not support signed integers even in unconstrained environments.

- (6) For all  $i, j$ , impose the constraint [Algorithm 4.1, Listing 1]

$$c'_{ij} \equiv \sum_{k=1}^m a'_{ik} b'_{kj} \pmod{p}. \quad (1.1)$$

This is of course equivalent to the same congruence with  $c_{ij}, a_{ik}, b_{kj}$ .

- (7) Assuming  $|a_{ik}|, |b_{kj}| \leq U$ ,  $mU^2 < p/2$ , and  $-p/2 < c_{ij} \leq p/2$ , the constraint (1.1) ensures [Proposition 3.1] that

$$c_{ij} = \sum_{k=1}^m a_{ik} b_{kj}.$$

Therefore, if such a constraint is imposed for all  $i, j$ , we are assured that

$$AB = C.$$

**Remark 1.1** (Detection of Negative-to-Positive Substitution Attack). A dishonest prover might attempt to mask a negative matrix entry (e.g.,  $-a$  for some  $a > 0$ ) by providing its least-residue modulo  $p$ , namely  $p - a$ , in order to claim it is positive. However, by design the circuit enforces that all entries satisfy

$$-\frac{p}{2} < x \leq \frac{p}{2}.$$

Since  $p - a > p/2$  (for any  $0 < a \leq U$ , given that  $p > 2U$ ), such a substitution would violate the range constraint. Hence, the circuit will detect any attempt to disguise a negative value in this manner. ■

<sup>1</sup> Assuming that each  $a_{ik}$  and  $b_{kj}$  is stored as a 64-bit signed integer (i.e.,  $\pm 64$ ), we set  $U = 2^{63}$ . Provided  $m \leq 2^{64}$ , it follows that  $mU^2 \leq 2^{190}$ , which is less than  $p/2$  for any prime  $p > 2^{191}$ . If no such off-circuit reasoning applies, or if tighter bounds are desired, a range check is required.

<sup>2</sup> A similar remark to Footnote 1 applies.

## 2. PARAMETER ROLES: PUBLIC, PRIVATE, AND COMPUTED

For the circuit verifying matrix multiplication, we distinguish between public parameters, private inputs (the prover's witness), and values computed within the circuit. These roles are summarized as follows:

### Public Parameters

- **Field Modulus  $p$ :** The prime  $p$  defining the finite field  $\mathbb{Z}/p\mathbb{Z}$  is public and fixed during circuit setup.
- **Matrix Dimensions  $\ell, m, n$ :** The dimensions of the matrices, with  $A$  of size  $\ell \times m$ ,  $B$  of size  $m \times n$ , and  $C$  of size  $\ell \times n$ , are public. Hence, no in-circuit verification of these bounds is necessary.
- **Bound  $U$ :** The bound  $U$  on the absolute values of matrix entries (for example,  $U = 2^{63}$  when using 64-bit signed integers) is public. This is used to ensure that  $mU^2 < p/2$ .

### Private Inputs (Prover's Witness)

- **Matrices  $A$  and  $B$ :** These matrices are provided by the prover as private inputs. Their entries must be preprocessed into their least-residue representations modulo  $p$  (since the API does not allow signed integers).
- **Matrix  $C$ :** Typically, the prover also supplies the matrix  $C$  as the claimed product  $AB$ . Alternatively, if  $C$  is derived from other computations, it may be computed off-circuit and provided as input.

### Computed Within the Circuit

- **Matrix Product  $AB$ :** The circuit computes the product  $A \times B$  using the provided matrices  $A$  and  $B$ . This computed product is then compared against the supplied matrix  $C$  to verify correctness.
- **Derived Matrices:** In some applications (e.g., a neural network), one of the matrices (such as a weight matrix) may be computed within the circuit from other inputs rather than being provided directly.

In summary, public parameters such as  $p$ , the dimensions  $\ell, m, n$ , and the bound  $U$  are fixed and known to all parties, while the matrices  $A, B$ , and  $C$  form the prover's private witness. The circuit uses these inputs to compute and verify the relation  $AB = C$ .

## 3. THE MATHS

**Proposition 3.1.** *Let  $p$  be a positive integer (not necessarily a prime), and let  $a_{ik}, b_{kj}$ , and  $c_{ij}$  be integers satisfying*

$$c_{ij} \equiv \sum_{k=1}^m a_{ik} b_{kj} \pmod{p}.$$

*Assume there is a constant  $U$  such that  $|a_{ik}| \leq U$  and  $|b_{kj}| \leq U$  for all  $i, k, j$ , and also assume  $|c_{ij}| \leq p/2$ . If  $mU^2 < p/2$ , then*

$$c_{ij} = \sum_{k=1}^m a_{ik} b_{kj}.$$

*The congruence guarantees that the computed sum and  $c_{ij}$  coincide as integers.*

*Consequently, interpreting the entries  $a_{ik}, b_{kj}, c_{ij}$  as the components of matrices  $A, B, C$ , we conclude that  $AB = C$  as integer matrices, not merely modulo  $p$ .*

*Proof.* By the given congruence condition, there is an integer  $t$  such that

$$c_{ij} = tp + \sum_{k=1}^m a_{ik} b_{kj}.$$

We claim  $t = 0$ . Suppose not; then  $|t| \geq 1$ . We split into two cases:

(1) Case  $t \geq 1$ . Then

$$c_{ij} \geq p + \sum_{k=1}^m a_{ik} b_{kj} \geq p - mU^2 > p - \frac{p}{2} = \frac{p}{2},$$

hence  $c_{ij} > p/2$ . But this contradicts the bound  $|c_{ij}| \leq p/2$  (we assume  $|c_{ij}| \leq p/2$ ).

(2) Case  $t \leq -1$ . Then

$$c_{ij} \leq -p + \sum_{k=1}^m a_{ik}b_{kj} \leq -p + mU^2 < -p + \frac{p}{2} = -\frac{p}{2},$$

hence  $c_{ij} < -p/2$ . But this contradicts the bound  $c_{ij} \geq -p/2$  (we assume  $|c_{ij}| \leq p/2$ ).

Since in either case we reach a contradiction, the only possibility is  $t = 0$ . This concludes the proof.  $\square$

#### 4. THE CODE

We assume that the bounds of Proposition 3.1 hold and that all matrix elements have been converted to their least-residue equivalents in preprocessing.

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**Algorithm 4.1** `mat_mul`: verify matrix multiplication

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**Require:** Matrices  $A$  of size  $(\ell \times m)$ ,  $B$  of size  $(m \times n)$ , and  $C$  of size  $(\ell \times n)$ . Each entry is represented by a circuit variable.

```

1: function MATRIX_PRODUCT( $A, B$ )                                 $\triangleright$  Compute  $A \times B$  in the circuit.
2:    $P \leftarrow$  new  $(\ell \times n)$  matrix of circuit variables
3:   for  $i \leftarrow 0$  to  $\ell - 1$  do
4:     for  $j \leftarrow 0$  to  $n - 1$  do
5:        $P[i][j] \leftarrow \sum_{k=0}^{m-1} (A[i][k] \times B[k][j])$ 
6:     end for
7:   end for
8:   return  $P$ 
9: end function

10: function VERIFY_MAT_MUL( $A, B, C$ )
11:    $P \leftarrow$  matrix_product( $A, B$ )
12:   for  $i \leftarrow 0$  to  $\ell - 1$  do
13:     for  $j \leftarrow 0$  to  $n - 1$  do
14:       assert_is_equal( $C[i][j], P[i][j]$ )
15:     end for
16:   end for
17: end function

```

---

```

1 // Example dimension constants for A, B, and AB.
2 const L: usize = 3; // Number of rows in A
3 const M: usize = 4; // Number of columns in A (also rows in B)
4 const N: usize = 2; // Number of columns in B
5
6 declare_circuit!(Circuit {
7   // A has shape (\ell x m)
8   matrix_a: [[Variable; M]; L],
9
10  // B has shape (m x n)
11  matrix_b: [[Variable; N]; M],
12
13  // AB has shape (\ell x n)
14  matrix_product_ab: [[Variable; N]; L],
15 });
16
17 impl<C: Config> GenericDefine<C> for Circuit<Variable> {
18   fn define<Builder: RootAPI<C>>(&self, api: &mut Builder) {
19     // 'matrix_product' is a helper function that multiplies two
20     // matrices within the circuit, returning a new (\ell x n) matrix.
21     let computed_product = matrix_product(api, self.matrix_a, self.matrix_b);
22
23     // For each entry (i, j) in the expected product, assert equality
24     // with the corresponding computed entry in 'computed_product'.
25     for i in 0..L {
26       for j in 0..N {
27         api.assert_is_equal(
28           self.matrix_product_ab[i][j],
29           computed_product[i][j],

```

```
30  
31  
32  
33  
34
```

Listing 1: ECC Rust API: verify matrix multiplication

EXPANDERCOMPILERCOLLECTION [1]

#### REFERENCES

- [1] Polyhedra Network. *ExpanderCompilerCollection*. <https://github.com/PolyhedraZK/ExpanderCompilerCollection.git>. GitHub repository. Accessed March 19, 2025.