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1 ABY – Overview

ABY [DSZ15] is a framework that allows to use mixed-protocol secure two-party computation protocols, which in turn allow two parties to evaluate functions on sensitive data, while preserving the privacy of this data. The protocols are represented as arithmetic or Boolean circuits and can be evaluated privately using arithmetic sharing, Boolean sharing (the GMW protocol) or Yao’s garbled circuits. These protocols can also be combined freely, as ABY introduces efficient conversions between them, as depicted in Fig. 1.1.

![Diagram of ABY framework](image)

Figure 1.1: Overview of the ABY framework that allows efficient conversions between Cleartexts and three types of sharings: Arithmetic, Boolean, and Yao.

To evaluate a function, ABY represents it internally as an arithmetic or Boolean circuit that consists of potentially many gates. The computing parties then secret share all private values and use arithmetic sharing, Boolean sharing, or Yao sharing to securely evaluate these gates. For a detailed background on the techniques please refer to [DSZ15].

A typical example in secure computation is Yao’s millionaires problem, in which two millionaires (here denoted as SERVER and CLIENT) want to identify who among them is richer without disclosing their actual wealth. In Listing 1.1, we provide a very basic code example which shows every detail that is needed to implement Yao’s millionaires problem in ABY using Yao’s garbled circuits and also verifying the result of the computation. The corresponding ABY circuit description is depicted in Fig. 1.2 and will serve as a reference example throughout this guide. In the remainder of this guide, we define our terminology (§1.1), detail the main components of ABY (§2), give an outline of the gates that can be used to define the functionality (§3), and outline how to build special SIMD circuits that reduce the memory overhead and improve the computation time (§4).
```c
int32_t test_millionaire_prob_simple_circuit(e_role role) {

    // Setup parameters
    string address = "127.0.0.1";
    uint16_t port = 6677;
    seclvl seclvl = get_sec_lvl(128);
    e_sharing sharing = S_YAO;
    uint32_t bitlen = 32;
    uint32_t nthreads = 1;

    ABYParty* party = new ABYParty(role, (char*)address.c_str(),
                                         port, seclvl, bitlen, nthreads);
    vector<Sharing*>& sharings = party->GetSharings();
    Circuit* circ = sharings[sharing]->GetCircuitBuildRoutine();

    // Plaintext values for testing and their bit length
    uint32_t alice_money = 5;
    uint32_t bob_money = 7;
    uint32_t money_bitlen = 3;

    // Input shares
    share* s_alice_money = circ->PutINGate(alice_money,
                                                       money_bitlen, CLIENT);
    share* s_bob_money = circ->PutINGate(bob_money, money_bitlen,
                                          SERVER);

    // Greater-than operation
    share* s_out = circ->PutGTGate(s_alice_money, s_bob_money);

    // Output share
    s_out = circ->PutOUTGate(s_out, ALL);

    // Execute secure computation protocol
    party->ExecCircuit();

    // Get plain text output
    uint32_t output = s_out->get_clear_value<uint32_t>();

    // Verification
    cout << "Testing Millionaire's Problem in " <<
             get_sharing_name(sharing) << " sharing: " << endl;
    printf("\nAlice Money:\t %d", alice_money);
    printf("\nBob Money:\t %d", bob_money);
    printf("\nCircuit Result:\t %s", (output ? "Alice" : "Bob"));
    printf("\nVerify Result: \t%s", ((alice_money > bob_money) ? "Alice" : "Bob"));

    delete party;
    return 0;
}
```

Listing 1.1: Simple ABY Code Example for Yao's Millionaires Problem
Figure 1.2: Millionaires problem that compares the wealth of Alice and Bob by computing $\text{output} = \text{alice\_money} > \text{bob\_money}$ the amount of money both parties have has a length of 3 bits and each wire represents a single bit.

1.1 Terminology

In this section, we briefly explain the terminology used in this guide. We refer the reader to [DSZ15] and references therein for details.

1.1.1 Sharings

By sharings we refer to the underlying secure computation techniques that are used to protect the privacy of the processed data. In ABY there are three sharings available: Arithmetic sharing (S_ARITH), Boolean sharing using GMW (S_BOOL), or Yao sharing using Yao’s garbled circuits (S_YAO).

As an example, in Listing 1.1 the plaintext values alice\_money and bob\_money are secret shared using the S_YAO sharing, from which we obtain secret shared variables s_alice\_money and s_bob\_money. These variables are hidden (encrypted in some sense) and can only collaboratively be reconstructed to plaintexts.
1.1.2 Circuits and Gates

A secure computation protocol evaluates a function, represented as a circuit, on private values by secret sharing them and evaluating the gates on the secret shared data. ABY allows to represent a function either as arithmetic or Boolean circuits. Typically, secure computation protocols use two primitive gate operations: linear gates (addition in arithmetic circuits, XOR in Boolean circuits) and non-linear gates (multiplication in arithmetic circuits, AND in Boolean circuits). While the linear gates can be evaluated locally without communication using simple operations, the non-linear gates require communication and the evaluation of cryptographic operations. Hence, the performance of securely evaluating a function can be improved by reducing the number of non-linear gates. Other than these primitive gate operations, ABY includes various gates for secret sharing inputs, reconstructing outputs, and high-level operations that are translated internally.

In ABY, we use a circuit object called Circuit from which we derive two sub-classes called ArithmeticCircuit and BooleanCircuit. In our example in Listing 1.1 the parties define a Circuit object circ, on which they put a high-level greater-than gate (GTGate), which is internally translated by ABY into a Boolean circuit consisting of XOR and AND gates. Additionally, the parties use the PutINGate to secret share their plaintext values and the PutOUTGate to reconstruct the plaintext output. These gates are explained in detail in §3.

1.1.3 Wires

The gates in the circuit are connected by wires that hold elements in the group $\mathbb{F}_{2^\ell}$. In Boolean or Yao sharing these elements are single bits ($\ell = 1$), while in arithmetic Sharing these elements are char, short, integer or double types ($\ell \in \{8, 16, 32, 64\}$), i.e. all operations are mod $2^\ell$. In ABY, wires are uniquely identified by a global identifier (called wire ID) of type uint32_t. This wire ID representation is used mostly internally, while the share object abstracts from it and is intended for use in most common operations by the developer.

Remark: With SIMD operations it is also possible to have multiple elements on a single wire simultaneously. This is explained in more detail in §4 and can be ignored for now.

1.1.4 Shares

To simplify the design of circuits, we abstract from single wires and bundle one or multiple wires in a share object. Intuitively, a share can be seen as a variable in ABY, which can be passed to gates to perform operations, and which can be assigned the output of a gate operation. After the secure computation protocol has been executed, the plaintext values can be obtained from the respective share object, which was returned by an output gate. In our example in Listing 1.1 Alice and Bob obtain secret shares of their plaintext input values in Lines 18 and 19, which they input in the GTGate in Line 22 to compute the greater-than
operation. Its result is then reconstructed to plaintext using the OUTGate in Line 25, from which we obtain the plaintext value in Line 31.

A share object internally stores an array of uint32_t wire IDs and we refer to the size of this array as the bitlength of the share. The wires in a share can be accessed through getter and setter methods in order to operate on these wires directly. However, we recommend accessing single wires only in special cases, since this can become very complex, depending on the functionality.

# 2 Environment

In order to use the ABY framework, an instance of the class ABYParty has to be generated. This ABYParty object represents a secure computation party and can be used to obtain methods for defining the functionality and starting the secure computation. Defining the functionality that should be evaluated securely is done via interaction with a Circuit object. A Circuit object of a certain sharing type sharing can be obtained from the ABYParty object. Once the functionality has been defined, the secure computation protocol can be performed via the ExecCircuit() function of ABYParty. In this section, we first describe the ABYParty routines (§2.1) and then detail methods for accessing a share (§2.2). We outline gates separately in §3.

Listing 2.1: ABY Environment Setup

```cpp
int32_t test_millionaire_prob_simple_circuit(e_role role) {
    // Setup
    string address = "127.0.0.1";
    uint16_t port = 6677;
    seclvl seclvl = get_sec_lvl(128);
    e_sharing sharing = S_YAO;
    uint32_t bitlen = 32;
    uint32_t nthreads = 1;

    ABYParty* party = new ABYParty(role, (char*) address.c_str(),
                                      port, seclvl, bitlen, nthreads);
    vector<Sharing*>& sharings = party->GetSharings();
    Circuit* circ = sharings[sharing]->GetCircuitBuildRoutine();
    // the circuit is defined here...
    party->ExecCircuit();
    uint32_t output = s_out->get_clear_value<uint32_t>();
    // the output can be processed here...
    delete party;
}```
The code segment in Listing 2.1 will be used as a reference in the following section, that describes how to set up the environment.

2.1 ABYParty

To set up the framework environment, an object of the class ABYParty needs to be instantiated. The instantiated object of ABYParty corresponds to one of the two parties (denoted as SERVER or CLIENT) which participates in the secure computation protocol and receives information about the setup as input parameters.

```cpp
ABYParty(e_role pid, char* addr = (char*) "127.0.0.1", uint16_t port = 7766, seclvl seclvl = LT, uint32_t bitlen = 32, uint32_t nthreads = 2, e_mt_gen_alg mg_algo = MT_OT, uint32_t maxgates = 4000000);
```

**Parameters**

- **role** specifies the role of the party, which can be either SERVER or CLIENT. The difference between the SERVER and CLIENT roles is that the SERVER listens for an open connection and acts as circuit garbler in Yao’s garbled circuits while the CLIENT connects and acts as circuit evaluator in Yao’s garbled circuits.

- **address** specifies the IP address of the server. If the party acts as server, it opens a socket on this IP address, whereas if the party acts as client, it tries to connect to this IP address.

- **port** specifies the port to listen on / connect to. The default port is 7766.

- **seclvl** specifies the security level that is used internally and defaults to long-term security. The required seclvl struct can be returned by providing a symmetric security parameter to get_sec_lvl or by using the respective constant. Available choices are short (ST, 80-bit symmetric security), mid (MT, 112-bit), long (LT, 128-bit), extra-long (XLT, 192-bit), or extra-extra-long (XXLT, 256-bit) term.

- **bitlen** specifies the bit-length of variables in the arithmetic sharing and can be \{8, 16, 32, 64\}. The default value is 32 bits. In Boolean sharing and Yao’s garbled circuits, this value is set as the default value for the maximum bitlength of shares.

- **nthreads** specifies the number of threads that are used in the setup phase.
• **mg_algo** is an optional parameter which can be used to change the algorithm with which arithmetic multiplication triples are generated (see [DSZ15] for details). Possible choices are: MT_OT, MT_PAILLIER, MT_DGK, i.e., MT generation based on OT extension, on the Paillier public-key encryption scheme or on the Damgård-Geisler-Krøigaard public-key encryption scheme. The default is MT_OT.

• **maxgates** specifies the maximum number of gates which can be built. By default, the value is set to 4 000 000.

**Example**  In Listing 2.1, we instantiate a party (of role server/client) which listens on/ connects to localhost (127.0.0.1) on port 7766 with a long-term security parameter of 128-bits symmetric security, uses internal variables of at most 32-bit length, and uses one thread in the setup phase.

```cpp
ABYParty* party = new ABYParty(role, (char*)address.c_str(), port , seclvl, bitlen, nthreads);
```

After the ABYParty object is created, it can be used to execute the defined circuit implementation with code described next.

### 2.1.1 GetSharings

In the ABY framework, a sharing describes a secure computation protocol which can be used to define and evaluate a given circuit. The currently supported sharings are: Arithmetic sharing (S_ARITH), Boolean sharing (S_BOOL) and Yao sharing (S_YAO). In order to access such a sharing and define a functionality that should be evaluated, the `GetSharings()` method of the `ABYParty` class is invoked.

```cpp
vector<Sharing*>& ABYParty::GetSharings();
```

This method returns a vector of all the supported sharings by the framework.

**Example**  In Listing 2.1, in line 10, we obtain the vector of sharings and store it in the variable sharings.

```cpp
vector<Sharing*>& sharings = party->GetSharings();
```
2.1.2 GetCircuitBuildRoutine

To define the functionality that should be evaluated, one needs to obtain a corresponding Circuit object of the desired sharing.

This Circuit object can be obtained using the GetCircuitBuildRoutine() on the desired sharing ∈ {S_ARITH, S_BOOL, S_YAO}. Note that, if sharing is S_ARITH, the circuit is of type ArithmeticCircuit, while for S_BOOL and S_YAO the circuit is of type BooleanCircuit.

```c
Circuit* circ = sharings[sharing]->GetCircuitBuildRoutine();
```

2.1.3 Execution

After the environment has been set up as described above, the actual circuit consisting of several gates has to be constructed. We detail high-level gates that can be used to define the function in more detail in §3. After the circuit has been built, it is evaluated securely by invoking the ExecCircuit() method.

```c
party->ExecCircuit();
```

2.1.4 Reset

After the circuit has been evaluated, the ABYParty object can be re-used to build a second circuit to evaluate securely. In this case, the Reset method has to be invoked before building the second circuit in order to reset the internal state. Network connections remain open and some initializations and allocations are re-used, thus saving time compared to a full restart of the entire framework.

```c
party->Reset();
```

2.1.5 Deletion

The party object should be deallocated before the program terminates via:

```c
delete party;
```

When handling huge implementations with the ABY Framework, it is recommended to deallocate the ABYParty object after its scope has been terminated.
2.2 Shares

The share objects are used as variables within the ABY framework. In the following section, we detail several methods that can be used to access and modify the internal state of shares.

2.2.1 Getter Methods

Each wire has a unique wire ID of type uint32_t. The wires in a share are stored internally as vector<uint32_t>. These wires can be read using the methods: get_wire_id(), get_wire_ids(), or get_wire_ids_as_share().

get_wire_id() Returns a single wire at position posid.

```c
uint32_t get_wire_id(uint32_t posid);
```

get_wire_ids() Returns a list of wires stored in a share as vector<uint32_t>.

```c
vector<uint32_t> get_wire_ids();
```

get_wire_ids_as_share() Returns a share object of the wire at position posid.

```c
share* get_wire_ids_as_share(uint32_t posid);
```

2.2.2 Setter Methods

Internal wires that are stored in the share can be written using the methods: set_wire_ids() or set_wire_id(). By setting wires one can assign a subset of the outputs of a gate as input to another gate or perform bit permutations without evaluating gates.

set_wire_ids() Sets the wires in a given share object to the provided wireids.

```c
void set_wire_ids(vector<uint32_t> wireids);
```

set_wire_id() Sets the wire at position posid to the wire with ID wireid.

```c
void set_wire_id(uint32_t posid, uint32_t wireid);
```
2.2.3 Plaintext Access Methods

A share stores wires which again hold secret-shared values. After the secure computation protocol has been executed using execCircuit, plaintext values on the output wires (see PutOutGate in §3.1.4) can be retrieved from share objects using the get_clear_value() method. The output type can be varied using a template T.

\[
\text{template <class T> T get_clear_value();}
\]

Example The following example illustrates how to use get_clear_value() to obtain the plaintext output of the share s_out as uint32_t.

\[
\text{uint32_t output = s_out->get_clear_value<\text{uint32_t}>();}
\]

There is also get_clear_value_ptr(), that returns a pointer to a plaintext result. It is used when the result does not fit into a standard data type, typically, if it is longer than 64 bits.

\[
\text{uint8_t *output = s_out->get_clear_value_ptr();}
\]

2.2.4 Share Creation

In order to create a share object, one can either secret-share a plaintext input value (see PutInGate in §3.1.1) using a Circuit object or initialize the object and manually assign wires from scratch using the static create_new_share() methods described in the following.

1. \[
\text{static share* create_new_share(uint32_t size, Circuit* circ);} \]
2. \[
\text{static share* create_new_share(vector<\text{uint32_t}> wireids, Circuit* circ);} \]

Initializes and returns a pointer to a share object. The first option (Line 1) creates an empty share object to which wires need to be assigned using the setter methods before it can be used as an input to a gate. The second option (Line 2) creates the share from the vector of wire IDs.

Parameters

- size the number of wires that can be stored in the share, initialized to zero.
- wireids the wires that should be stored in the share.
- circ the Circuit object from which the wires come.
2.2.5 Share Bitlengths

Shares hold values of a specific bitlength and internally store the maximum bitlength to which a value is allowed to grow. The bitlength of a share and the maximum bitlength that it can support can be accessed via the following methods: `get_bitlength()`, `set_bitlength()`, `get_max_bitlength()`, and `set_max_bitlength()`. By default, the maximum bitlength of each share is set to the bitlength that is passed in the `ABYParty` object (see §2.1).

`get_bitlength()`  Returns the current bitlength of the share.

```c
uint32_t get_bitlength();
```

`set_bitlength()`  Sets the bitlength of the current share to `bitlength`. Note, however, that this routine does not add any wires. Using such a share will cause errors if used in a gate unless wires are added by the developer via `set_wire()`. Changing the bitlength only works for Boolean or Yao sharing, but not for arithmetic sharing.

```c
void set_bitlength(uint32_t bitlength);
```

`get_max_bitlength()`  Returns the maximum bitlength up to which values in this share can grow.

```c
uint32_t get_max_bitlength();
```

`set_max_bitlength()`  Sets the maximum bitlength to which values in this share can grow to `max_bitlength`, which must be at least as big as the current bitlength of the share. Changing the maximum bitlength only works for Boolean sharing or Yao sharing, but not for arithmetic sharing. For Boolean circuit-based protocols, the bitlength of the results from operations such as addition or multiplication will grow up to `max_bitlength` and larger results will be truncated to `max_bitlength`.

```c
void set_max_bitlength(uint32_t max_bitlength);
```

3 Gates

The ABY framework implements several secure computation protocols that operate on arithmetic or Boolean circuits. In the previous chapter §1.1.1 we have described how values are
secret shared between two parties and internally represented as wires in a circuit. In this chapter, we explain how values on these wires can be processed using Gates. In other words, gates are used for executing various operations on the provided user inputs.

These Gates can be created in ABY using Circuit objects (§1.1.2). We first describe I/O gates (§3.1) that transform plaintext values into secret-shared values and back to recover the plaintext value from a share. Next, we describe Function gates (§3.2) that compute on secret shared values using. Then, we describe how to convert secret shared values between different secure computation schemes using Conversion gates (§3.3). Finally, we describe Debug gates that ease the development process (§3.4).

3.1 Input/Output Gates

Input and output gates are used for the transition between plaintext values and hidden (encrypted/secret-shared) values and back. Input gates (PutINGate, see §3.1.1) take plaintext values and perform an encryption/secret-sharing operation to create a share object that can be processed with function gates. Constant gates (PutCONSGate, see §3.1.3) can be used to input constant values to the circuit that are known by both parties. After computations on shares are finished, the encryption/secret-sharing operation can be undone with an output gate (PutOUTGate, see §3.1.4), which transforms the resulting shares back to plaintext values. ABY also allows to input pre-shared values (PutSharedINGate, see §3.1.2) and output the secret shares of a value (PutSharedOUTGate, see §3.1.5).

3.1.1 PutINGate

PutInGate is used to load the plaintext inputs of the respective parties to their shares.

```c
share* PutINGate(uint64_t val, uint32_t bitlen, e_role role);
share* PutINGate(uint32_t val, uint32_t bitlen, e_role role);
share* PutINGate(uint16_t val, uint32_t bitlen, e_role role);
share* PutINGate(uint8_t val, uint32_t bitlen, e_role role);

share* PutINGate(uint64_t* val, uint32_t bitlen, e_role role);
share* PutINGate(uint32_t* val, uint32_t bitlen, e_role role);
share* PutINGate(uint16_t* val, uint32_t bitlen, e_role role);
share* PutINGate(uint8_t* val, uint32_t bitlen, e_role role);
```

The method returns a share object holding a share or encryption of a plaintext value.
Parameters

- **val** is the input value loaded by one of parties to generate the shared secret. This variable can be of type `uint8_t`, `uint16_t`, `uint32_t`, `uint64_t`, or a pointer to an array of such a datatype.

- **bitlen** states how many bits of the plaintext should be read and specifies the number of wires in the generated share.

- **role** defines which party provides the input value for this share. The role value can be either CLIENT or SERVER.

Example

```c
// Share creation
uint32_t alice_money = 5;
uint32_t bob_money = 7;
uint32_t bitlen = 3;

// Input
share *s_alice_money, *s_bob_money;
s_alice_money = circ->PutINGate(alice_money, bitlen, CLIENT);
s_bob_money = circ->PutINGate(bob_money, bitlen, SERVER);
```

`alice_money` and `bob_money` are the plaintext inputs for their respective shares. The inputs are values with a length of 3 bits, which are indicated by the input `bitlen`. The third parameter provided is the role of the party which provides the input to the share. The value of `role` can be CLIENT or SERVER, depending on the role played by the party.

Note that, although the inputs for both roles have to be defined, every party can set only its own input values and receives the values of the other party encrypted or secret-shared. This also means, that the input values of the respective other party are ignored and can be set to zero or an arbitrary value. More specifically, both parties need to specify the existence of all inputs and who provides the corresponding plaintext input. The actual plaintext value needs to be provided only by the respective party. The `PutDummyINGate` can be used to explicitly mark an input of the other party without providing plaintext input values. It has the same interface as the `PutINGate` but without the plaintext value `val`.

The SIMD version of the same gate is discussed in the SIMD Gates chapter §4.

### 3.1.2 PutSharedINGate

`PutSharedINGate` is used to load pre-shared inputs of the parties to shares. Both parties need to provide an input and hence the source role is omitted. These gates are used for values that come from a third party that secret shares them to outsource computation (sometimes referred to as client/server model), or for intermediate values from a previous computation.
The method returns a share object for the pre-shared value \( \text{val} \) of bit-length \( \text{bitlen} \). PutSharedINGate can be used together with PutSharedOUTGate (see §3.1.5) to pass shared values between different ABY executions.

**Remark:** Currently, PutSharedINGate only works for arithmetic and Boolean sharing.

### 3.1.3 PutCONSGate

The PutCONSGate function can be used to input a constant plaintext value \( \text{val} \) into the circuit. \( \text{val} \) has bit-length \( \text{bitlen} \), which is known to both parties. The function returns a share object, which represents the secret-shared/encrypted constant.

```c
share* PutCONSGate(uint64_t val, uint32_t bitlen);
```

### 3.1.4 PutOUTGate

PutOUTGate is used to interactively decrypt a share or reconstruct a secret-shared value to plaintext and stores the result in a share. After the ExecCircuit() method has been called, the plaintext values can be accessed using get_clear_value(). This access is only possible by the party defined in role.

```c
share* PutOUTGate(share* s_out, e_role role)
```

**Parameters**

- \( s_{\text{out}} \) is the share object which should be output after the circuit is evaluated. The plaintext value is extracted and converted into the specified datatype by the respective party using the get_clear_value() methods.
- \( \text{role} \) defines the party which is allowed to see the output value. The role value can be CLIENT, SERVER, or ALL.
Example

\[
s_{\text{out}} = \text{circ} \rightarrow \text{PutOUTGate}(s_{\text{val}}, \text{ALL});
\]

In the above example, we assume the share object \(s_{\text{val}}\) contains a computed result. The output gate performs a recombination operation that generates a plaintext value of the computation result and stores it in \(s_{\text{out}}\). In this example both parties can access the computation result after the circuit execution using \(\text{get\_clear\_value()}\) (see §2.2.3).

### 3.1.5 PutSharedOUTGate

PutSharedOUTGate is used to output the secret shared value of a share into a variable that can be used outside of the circuit. Both parties receive a shared output and hence the destination role is omitted as parameter.

\[
\text{share}\ast \ \text{PutSharedOUTGate}(\text{share}\ast \ s_{\text{out}})
\]

The method returns a share object for the pre-shared value. PutSharedOUTGate can be used together with PutSharedINGate (see §3.1.2) to pass shared values between different ABY executions.

**Remark:** Currently, PutSharedOUTGate only works for arithmetic and Boolean sharing.

### 3.2 Function Gates

Function gates are used to compute on shares. The ABY framework includes several standard operations, listed in Tab. 3.1. Note that the operations AND (\(\land\)), OR (\(\lor\)), XOR (\(\oplus\)), MUX and GT (\(>\)) are only available for Boolean circuits (i.e., in Boolean and Yao sharing) and not for arithmetic circuits. We provide an overview of the operations in the following.

<table>
<thead>
<tr>
<th>Operations</th>
<th>AND</th>
<th>XOR</th>
<th>OR</th>
<th>ADD</th>
<th>MUL</th>
<th>SUB</th>
<th>GT</th>
<th>MUX</th>
<th>INV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arithmetic</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Boolean</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Yao</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

**PutANDGate**  
PutANDGate performs a bitwise AND operation on the two input shares and returns the result as a share object of the same bitlength as the longer input share.

\[
\text{share}\ast \ \text{PutANDGate}(\text{share}\ast \ \text{ina}, \ \text{share}\ast \ \text{inb});
\]
**PutXORGate**  PutXORGate performs a bitwise XOR operation on the two input shares and returns the result as a share object of the same bitlength as the longer input share.

```c
share* PutXORGate(share* ina, share* inb);
```

**PutORGate**  PutORGate performs a bitwise OR operation on the two input shares and returns the result as a share object of the same bitlength as the longer input share.

```c
share* PutORGate(share* ina, share* inb);
```

**PutADDGate**  PutADDGate performs an arithmetic addition operation on the two input shares and returns the result as a share object. In arithmetic circuits the addition is carried out modulo $2^\ell$, where $\ell$ is the bitlength of the sharing. In Boolean circuits, the result of the addition also includes the carry bit in case the bitlength of the result does not exceed the maximum bitlength of both shares (see §2.2.5 on how to get and set the maximum bitlength of shares).

```c
share* PutADDGate(share* ina, share* inb);
```

**PutMULGate**  PutMULGate performs an arithmetic multiplication operation on the two input shares and returns the result as a share object. In arithmetic circuits the multiplication is carried out modulo $2^\ell$, where $\ell$ is the bitlength of the sharing. In Boolean circuits, the bitlength of the output is the smaller value of either: 1) the sum of both inputs’ bitlengths or 2) the largest maximum bit length of the inputs.

```c
share* PutMULGate(share* ina, share* inb);
```

**PutSUBGate**  PutSUBGate performs an arithmetic subtraction operation on the two input shares and returns the result $ina - inb$ as share object. In arithmetic circuits the subtraction is carried out modulo $2^\ell$, where $\ell$ is the bitlength of the sharing. Thus the result is always positive. In Boolean circuits, the subtraction is carried out modulo $2^{max}$, where $max$ is the larger maximum bit length of either $ina$ or $inb$.

```c
share* PutSUBGate(share* ina, share* inb);
```

**PutGTGate**  PutGTGate performs a greater-than operation ($>$) on the two input shares $ina$ and $inb$ and returns 1 if $ina > inb$ and 0 otherwise.

```c
share* PutGTGate(share* ina, share* inb);
```
**PutMUXGate**  PutMUXGate implements a multiplexer and returns one of two given data inputs based on a selection bit. If the selection bit `sel` is 1, the content of `ina` is returned. If `sel` is 0, `inb` is returned.

```
share* PutMUXGate(share* ina, share* inb, share* sel);
```

**PutINVGate**  The PutINVGate function inverts an input value `in`. In arithmetic circuits, the inversion is performed by computing $2^\ell - in$, while in Boolean circuits the inversion is performed bit-wise by computing $\forall i \leq \ell 1 \oplus in[i]$, where $\ell$ is the bitlength of `in` and $in[i]$ refers to the $i$-th bit of `in`.

```
share* PutINVGate(share* in);
```

### 3.3 Conversion

The ABY framework allows to perform secure computation using arithmetic, Boolean or Yao sharing and to arbitrarily convert secret-shared values between them using Conversion gates. Unlike the function gates, introduced in §3.2, conversion gates do not change the secret-shared value. Instead, conversion gates transform the shares, held by each of the parties, from the representation of one secure computation scheme into another secure computation scheme. Like all previous operations, the conversion is also done in a way that reveals nothing about the plaintext.

In the following, we use the short notation `A2B` to denote that a method converts a share from arithmetic to Boolean sharing. Given the existing schemes, this gives us six possible conversion methods: `A2B`, `A2Y`, `B2A`, `B2Y`, `Y2A`, and `Y2B`. Note that only four of these methods are implemented: `A2Y`, `B2A`, `B2Y`, and `Y2B`, as depicted in Fig. [1.1](#). The remaining two methods, namely `A2B` and `Y2A` are implemented by computing `Y2B(A2Y)` and `B2A(Y2B)`, respectively.

Note that the conversion gate function needs to be invoked from a Circuit of the target sharing, i.e., the `A2Y` function would need to be called on a Circuit for Yao sharing.

**A2Y**  The A2Y function converts an arithmetic share `in` into a Yao share. The returned share is a Yao share, that has the same plaintext value as the input arithmetic share. Note that the A2Y function needs to be called on a Circuit in Yao sharing.

```
share* A2Y(share* in);
```
Example  The following example secret shares two 32-bit numbers $A$ and $B$ in the arithmetic sharing and multiplies them. The product is converted to Yao sharing and again multiplied by two.

```c
share *s_a, *s_b, *s_res;
Circuit* ac = sharings[S_ARITH]->GetCircuitBuildRoutine();
Circuit* yc = sharings[S_YAO]->GetCircuitBuildRoutine();
s_a = ac->PutINGate(A, 32, SERVER);
s_b = ac->PutINGate(B, 32, CLIENT);
s_res = ac->PutMULGate(s_a, s_b);
s_res = yc->PutA2YGate(s_res);
s_res = yc->PutADDGate(s_res, s_res);
```

B2A / B2Y / Y2B  Similarly to A2Y, after creating the respective circuits and shares, the other conversions can be performed using the following functions: B2A, B2Y, and Y2B.

A2B / Y2A  The A2B and Y2A conversions are performed by invoking two primitive conversions in sequence: $A2B(x) = Y2B(A2Y(x))$ and $Y2A(x) = B2A(A2B(x))$. In contrast to the primitive conversions, the A2B and Y2A gates require the circuit of the intermediate conversion as additional parameter. I.e., the A2B conversion requires a circuit from S_YAO while the Y2A conversion requires a circuit from S_BOOL.

```c
share* A2B(share* in, Circuit* yaosharingcircuit);
share* Y2A(share* in, Circuit* boolsharingcircuit);
```

3.4 Debug Gates

Debugging applications that use secure computation is a tedious task since the intermediate values are secret-shared and hence not easily verifiable. In the following, we outline two gates that support the development process of secure computation applications: the PrintValueGate and the AssertGate. Note that both gates should only be used during the development process and not when private data is processed, since they leak intermediate values. In order to deactivate the Debug gates, set the macro ABY_PRODUCTION to 1 in src/abycore/ABY_utils/ABYconstants.h:25.

3.4.1 PutPrintValueGate

PutPrintValueGate can be used to print the plaintext value of the share object in during the secure function evaluation together with a pre-defined string infostring. Note that the output will be printed once the gate is evaluated, hence the order in which the gates are
printed during function evaluation can vary from the order in which they were built during circuit construction.

```c
share* PutPrintValueGate(share* in, string infostring);
```

**Example**  The following example prints the sum and the logical and of the two 3-bit numbers `alice_money` and `bob_money`. Note that if a Boolean circuit is used, the logical AND will be printed before the sum since ABY schedules the gates depending on their multiplicative (AND) depth.

```c
//Share creation
uint32_t alice_money = 5;
uint32_t bob_money = 7;
uint32_t bitlen = 3;

//Input
share *s_alice_money, *s_bob_money, *s_and, *s_add;
s_alice_money = circ->PutINGate(alice_money, bitlen, CLIENT);
s_bob_money = circ->PutINGate(bob_money, bitlen, SERVER);

s_add = circ->PutADDGate(s_alice_money, s_bob_money);
circ->PutPrintValueGate(s_add, "Sum");

s_and = circ->PutANDGate(s_alice_money, s_bob_money);
circ->PutPrintValueGate(s_and, "Logical AND");

party->ExecCircuit();
```

### 3.4.2 PutAssertGate

`PutAssertGate` verifies that the plaintext value of a share `in` is equal to a `bitlen`-bit plaintext value `assert_val`. If the verification succeeds, the program continues and if the verification fails, the program stops. The format of the plaintext input `assert_val` is the same as for the `PutINGate` (see §3.1.1).

```c
share* PutAssertGate(share* in, uint64_t assert_val, uint32_t bitlen);
share* PutAssertGate(share* in, uint32_t assert_val, uint32_t bitlen);
share* PutAssertGate(share* in, uint16_t assert_val, uint32_t bitlen);
share* PutAssertGate(share* in, uint8_t assert_val, uint32_t bitlen);
share* PutAssertGate(share* in, uint64_t* assert_val, uint32_t bitlen);
```
Example  The following example adds the values \(alice\text{\_}money\) and \(bob\text{\_}money\) and verifies that the secret-shared output \(s\_sum\) equals the result \(sum\_money\) that is computed in plaintext.

```c
// Share creation
uint32_t alice_money = 5;
uint32_t bob_money = 7;
uint32_t bitlen = 3;
uint32_t sum_money = alice_money + bob_money;

// Input
share *s_alice_money, *s_bob_money, *s_add;
s_alice_money = circ->PutINGate(alice_money, bitlen, CLIENT);
s_bob_money = circ->PutINGate(bob_money, bitlen, SERVER);

s_add = circ->PutADDGate(s_alice_money, s_bob_money);
circ->PutAssertGate(s_add, sum_money, bitlen+1);
```

4 SIMD Gates

SIMD (Single Instruction Multiple Data) denotes operations that process multiple data elements using a single operation. It is a concept from parallel programming that can be adapted to secure computation to reduce the memory footprint of the circuit and improve the circuit evaluation time.

In the previous chapters, all operations on a \textit{share} were non-SIMD. In particular, a \textit{share} was a one-dimensional array that internally stored multiple wires, each of which held a single element in \(\mathbb{F}_2^\ell\). For the SIMD operations in this chapter, we extend the shares to a second dimension by allowing multiple elements in \(\mathbb{F}_2^\ell\) to be stored on a wire. We give an example in Fig. 4.1 where we depict a two-dimensional Boolean circuit share \textit{s\_val} with \(\sigma = 4\) wires (bits) and where each wire stores \(nvals = 3\) elements. Note that in the figures in this chapter, the wires are ordered such that the least significant bit is on the rightmost wire while
the most significant bit is on the leftmost wire. SIMD values are ordered from top to bottom, i.e., the value at index 0 is displayed at the top and increasing indices follow below.

Figure 4.1: SIMD representation example for a Boolean circuit share with 4 wires and where each wire stores 3 elements in $\mathbb{F}_2$.

In the following, we first detail the changes to the input gates compared to a non-SIMD evaluation (§4.1). Then, we introduce new data management gates that are needed for re-organizing the elements on the wires to build circuits with high data-dependency (§4.2). Finally, we outline miscellaneous functions that are changed or added compared to a non-SIMD evaluation (§4.3).

**Remark**: Throughout this chapter, as well as in many ABY implementations, the value $nvals$ indicates if a share is non-SIMD (i.e., $nvals = 1$) or SIMD (i.e., $nvals > 1$).

### 4.1 Changes to Input Gates

The ABY framework abstracts from the SIMD programming style and hence all function gates from §3 can be used exactly as for non-SIMD gates without requiring the developer to explicitly keep track of the dimensions. The only gates that explicitly require the developer to specify the dimension of SIMD gates are input gates §4.1.1, constant gates §4.1.2, and assert gates §4.1.3. Note, however, that the dimensions of shares that are input to a gate have to match or else an assertion error will occur.

#### 4.1.1 PutSIMDINGate

To create SIMD circuits, the PutINGate (see §3.1.1) is replaced by a PutSIMDINGate that additionally allows to specify the number of elements on a wire to be shared using the variable $nvals$. The method returns a share object that encapsulates the shared secrets and which can be used analogue to a non-SIMD share. Note that a call to PutSIMDINGate with $nvals=1$ is the same as a call to PutINGate.

```c
share* PutSIMDINGate(uint32_t nvals, uint64_t val, uint32_t bitlen, e_role role);

share* PutSIMDINGate(uint32_t nvals, uint32_t val, uint32_t bitlen, e_role role);
```
share* PutSIMDINGate(uint32_t nvals, uint16_t val, uint32_t bitlen, e_role role);
share* PutSIMDINGate(uint32_t nvals, uint8_t val, uint32_t bitlen, e_role role);
share* PutSIMDINGate(uint32_t nvals, uint64_t* val, uint32_t bitlen, e_role role);
share* PutSIMDINGate(uint32_t nvals, uint32_t* val, uint32_t bitlen, e_role role);
share* PutSIMDINGate(uint32_t nvals, uint16_t* val, uint32_t bitlen, e_role role);
share* PutSIMDINGate(uint32_t nvals, uint8_t* val, uint32_t bitlen, e_role role);

Parameters

- \( nvals \) indicates the number of SIMD elements to be stored on a single wire.
- \( val \) is the input value loaded by one of the parties to generate the shared secret. This variable can be of type uint8_t, uint16_t, uint32_t, uint64_t or a pointer to an array of such a datatype. We give more information about the input format in the example below.
- \( bitlen \) states how many bits of the plaintext should be read and specifies the number of wires in the generated share.
- \( role \) defines the party which generates the share based on the input value provided. The role value can be CLIENT or SERVER.

Example  In the example given below, PutSIMDINGate is used to generate two shares with bitlength 4, i.e., \( \text{money.bitlen} = 4 \)-bit, and where each share stores \( nvals = 3 \) elements.

```c
// Share creation with nvals as 3
uint32_t nvals = 3;
uint32_t alice_money[nvals] = {1, 3, 14};
uint32_t bob_money[nvals] = {6, 12, 5};
uint32_t money_bitlen = 4;

// Build input gates to obtain the corresponding SIMD shares
share* s_alice_money = circ->PutSIMDINGate(nvals, alice_money, money_bitlen, CLIENT);
share* s_bob_money = circ->PutSIMDINGate(nvals, bob_money, money_bitlen, SERVER);
```

Remark: The input format is such that all \( nvals \) values are written into separate array positions and the remaining unused bits are ignored. The following code shows a more
complex input format example where two 10-bit values are secret-shared using the uint8_t type, that holds at most 8 bit values:

```
uint32_t nvals = 2;
uint32_t bitlen = 10;
uint32_t bytelen = (bitlen + (bitlen - 1)) / 8; // 2 bytes for 10 bits
uint8_t * vals[nvals * bytelen]; // uint8_t array with 2*2 positions

// First 10-bit value: 0x03FF
vals[0] = 0xFF;
vals[1] = 0x03;

// Second 10-bit value: 0x02AA
vals[2] = 0xAA;
vals[3] = 0x02;

// Build input gates to obtain the corresponding SIMD shares
share* s_val = circ->PutSIMDINGate(nvals, vals, bitlen, CLIENT);
```

**Remark:** As for the non-SIMD PutINGate, each party has to create an input gate for both roles. However, only the input of each party for its own role will be set in the circuit while the input to the gate of the other party will be ignored. In a similar fashion, PutSharedSIMDINGate can be used to input pre-shared SIMD inputs (see §3.1.2 for more information on pre-shared inputs).

### 4.1.2 PutSIMDCONSGate

Similar to the input gates, the PutCONSGate method (see §3.1.3) is also replaced by the method PutSIMDCONSGate when working in the SIMD setting that adds the parameter nvals. In contrast to the SIMD input gates, the SIMD constant gates only take a single value val of bitlen-bit length as input and create a SIMD share with nvals copies of val.

```
share* PutSIMDCONSGate(uint32_t nvals, uint64_t val, uint32_t bitlen);
```

**Example** In the example below, the constant 42 is copied nvals=3 times.

```
uint32_t nvals = 3;
uint32_t bitlen = 6;
uint64_t constant = 42;

// creates a SIMD share with 3 copies of the constant 42
share* s_val = circ->PutSIMDCONSGate(nvals, constant, bitlen);
```
4.1.3 PutSIMDAssertGate

When verifying SIMD shares, the PutAssertGate method (see §3.4.2) is replaced by the PutSIMDAssertGate method that adds the parameter `nvals`. The input format is the same as for PutSIMDINGate (see §4.1.1).

<table>
<thead>
<tr>
<th>share *</th>
<th>PutSIMDAssertGate ( share * in , uint32_t nvals , uint64_t * assert_val , uint32_t bitlen );</th>
</tr>
</thead>
<tbody>
<tr>
<td>share *</td>
<td>PutSIMDAssertGate ( share * in , uint32_t nvals , uint32_t * assert_val , uint32_t bitlen );</td>
</tr>
<tr>
<td>share *</td>
<td>PutSIMDAssertGate ( share * in , uint32_t nvals , uint16_t * assert_val , uint32_t bitlen );</td>
</tr>
<tr>
<td>share *</td>
<td>PutSIMDAssertGate ( share * in , uint32_t nvals , uint8_t * assert_val , uint32_t bitlen );</td>
</tr>
</tbody>
</table>

4.2 Data Management Gates

To allow data management for SIMD shares, we introduce several new gate types. Note that none of these gates changes the actual value on a wire. Instead, these gates allow to form SIMD shares of a certain format which can then be evaluated using existing function gates.

4.2.1 PutCombinerGate

The combiner gate takes as input a non-SIMD share `input` containing `σ` wires and joins them to a SIMD share with a single wire with `nvals = σ` values. The combiner gate is used to group together non-SIMD values before inputting them into a SIMD operation. Alternatively, the wires can be input as multiple shares objects `ina` and `inb`, where the input shares can already be SIMD shares. In this case, it combines the values on all wires, e.g., if two wires with 3 and 4 values are input into the combiner gate, the resulting wire will hold 7 values.

<table>
<thead>
<tr>
<th>share *</th>
<th>PutCombinerGate ( share * input );</th>
</tr>
</thead>
<tbody>
<tr>
<td>share *</td>
<td>PutCombinerGate ( share * ina , share * inb );</td>
</tr>
</tbody>
</table>

Example In the example, which is graphically illustrated in Fig. 4.2, a non-SIMD 4-bit share `s_val` is transformed into a SIMD share `s_out` with `nvals = 4` single bit values.

```
uint8_t val = 1;
share * s_val = circ->PutINGate(val, 4, CLIENT);
share * s_out = circ->PutCombinerGate(s_val);
```
4.2.2 **PutSplitterGate**

The *splitter* gate takes as input a SIMD share `input` with a single wire with `nvals` values and splits it into a non-SIMD share with \( \sigma = nvals \) wires, each with `nvals = 1` values. The splitter gate is the reverse operation to the combiner gate and can be used to transform a SIMD gate back into a non-SIMD gate.

```c
share* PutSplitterGate(share* input);
```

---

**Example**  In the example, which is graphically illustrated in Fig. 4.3, a SIMD single-bit share `s_val` with `nvals = 4` is transformed into a non-SIMD share `s_out` with `\( \sigma = 4 \)` wires and `nvals = 1`.

```c
uint8_t val[4] = {1, 0, 0, 0};
share* s_val = circ->PutSIMDINGate(4, val, 1, CLIENT);
```
4.2.3 PutCombineAtPosGate

The combine at position gate (CombineAtPosGate) takes a SIMD share input with \( \sigma \) wires as input and combines the element at position \( pos \) on each wire of input into a new SIMD share with a single wire and \( \sigma \) values on that wire. The CombineAtPosGate is useful when a SIMD share needs to be transposed.

\[
\text{share} \ast \text{PutCombineAtPosGate}(\text{share} \ast \text{input}, \text{uint32}_t \ pos);
\]

Parameters

- **input** the input share object containing \( \sigma \) wires and \( nvals_{\text{in}} \) values on each wire, which requires joining.
- **pos** the position at which joining is performed. The value of pos must be in the range \( \{0, \ldots, nvals_{\text{in}} - 1\} \).

Example

In the example, which is graphically illustrated in Fig. 4.4, a SIMD share \( s_{\text{val}} \) with \( \sigma = 4 \) wires and \( nvals = 3 \) values on each wire is transformed into a SIMD share \( s_{\text{out}} \) with \( \sigma = 1 \) wire which has \( nvals = 4 \) values.
4.2.4 PutSubsetGate

The subset gate takes as input a SIMD share input with a single wire with multiple values and an arbitrary list of positions posids that is of size nvals_out. It returns a SIMD share with a single wire that consists of nvals_out values of input at the positions specified in posids.

\[
\text{share* } \text{PutSubsetGate(share* input, uint32_t* posids, uint32_t nvals_out);}
\]

Parameters

- input the input share with nvals_in > 1. If it contains more than one wire (\(\sigma>1\)), then the same subset of nvals is selected from every wire.
- posids an array of nvals_out positions to be selected from the input share. Every position must be in the range \(\{0, \ldots, \text{nvals_in}-1\}\). The number of supplied positions can be chosen freely. Positions can occur an arbitrary number of times.
- nvals_out the number of positions in posids and the number of values of the resulting output share.

Example In the example, which is graphically illustrated in Fig. 4.5 a SIMD share s_out with \(\sigma = 2\) wires and nvals_out = 3 values is created from the positions \(\{0, 2, 2\}\) of a share s_val with \(\sigma = 2\) wires and nvals_in = 4 values.

\[
\text{uint32_t nvals_in = 4;}
\text{uint32_t nvals_out = 3;}
\text{uint8_t val[4] = \{2, 1, 1, 3\};}
\text{uint32_t posids[nvals_out] = \{0, 2, 2\};}
\text{share* s_val = circ->PutSIMDINGate(nvals_in, val, 2, SERVER);}
\text{share* s_out = circ->PutSubsetGate(s_val, posids, nvals_out);}
\]
Figure 4.5: The subset gate creates a SIMD share with $\sigma = 2$ wires that hold $nvals = 3$ values each from a SIMD share with $\sigma = 2$ wires that hold $nvals_{\text{in}} = 4$ values each.

4.2.5 PutPermutationGate

The permutation gate takes as input a SIMD share input with $\sigma$ wires each with $nvals_{\text{in}}$ values and a list of positions $\text{posids}$ with $\sigma$ entries. It returns a single wire SIMD share $s_{\text{out}}$ with $nvals = \sigma$ values, where the $i$-th value of $s_{\text{out}}$ comes from the $i$-th wire of input at position $\text{posids}[i]$.

```c
share* PutPermutationGate(share* input, uint32_t* posids);
```

**Parameters**

- **input** the share with the $\sigma$ input wires and $nvals_{\text{in}}$ values from which the values should be taken.

- **posids** contains the position on the wires from input from which the values should be read. posids must have $\sigma$ entries, i.e., one entry for each wire in the input share (its bitlength). Each position must be in the range $\{0, \ldots, nvals_{\text{in}} - 1\}$ for the given wire.

**Example** In the example below that is depicted in Fig. 4.6, the share $s_{\text{out}}$ with a single wire is assigned $nvals = 4$ values from the share $s_{\text{vals}}$ with $\sigma = 4$ wires and $nvals_{\text{in}} = 3$ values. More detailed, after the PutPermutationGate, $s_{\text{out}}$ contains the values on positions $\{0 - 0, 1 - 0, 2 - 2, 3 - 1\}$, where the notation $i - j$ denotes the $j$-th element on wire $i$ of $s_{\text{vals}}$. 
Figure 4.6: The permutation gate creates a SIMD share with a single wire that holds \( nvals = 4 \) values from a SIMD share with \( \sigma = 4 \) wires that each hold \( nvals_{in} = 3 \) values.

```c
uint32_t bitlen = 4;
uint32_t nvals_in = 3;
uint8_t val[nvals_in] = {1, 3, 14};
uint32_t posids[bitlen] = {0, 0, 2, 1};

share *s_val, *s_out;
s_val = circ->PutSIMDINGate(nvals_in, vals, bitlen, SERVER);
s_out = circ->PutPermutationGate(s_vals, posids);
```

**4.2.6 PutRepeaterGate**

The \textit{repeater} gate takes as input a non-SIMD share \textit{input} and an integer value \( nvals \) and outputs a SIMD share that contains the values of \( nvals \) times.

```c
share* PutRepeaterGate(uint32_t nvals, share* input);
```

**Parameters**

- \( nvals \) size of the output SIMD share.
- \( \text{input} \) non-SIMD input share from which the value is taken that is “repeated” \( nvals \) times on the output share.
Figure 4.7: The repeater gate creates a SIMD share by copying the value of a non-SIMD input share nvals times.

Example  In the example below, the SIMD share $s_{\text{out}}$ which has wirelen = 4 wires and nvals = 3 values is created such that each element of $s_{\text{out}}$ is equal to $s_{\text{val}}$.

```c
uint32_t nvals = 3;
uint32_t bitlen = 4;
uint8_t val = 1;
share * s_val = circ->PutINGate(val, bitlen, SERVER);
share * s_out = circ->PutRepeaterGate(nvals, s_val);
```

4.3 Misc Operations

The following operations are added to the `share` object to allow handling SIMD shares.

4.3.1 get_nvals_on_wire()

The `get_nvals_on_wire()` method can be used to obtain the nvals value on a specific wire with id `wireid`.

```c
uint32_t get_nvals_on_wire(uint32_t wireid);
```

Parameters
- `wireid` value uniquely identifies a given wire in a share.
The `get_clear_value_vec()` method is the SIMD pendant of the `get_clear_value()` method and can be used to obtain the plaintext value of a share. In contrast to the `get_clear_value()` method, the `get_clear_value_vec()` uses the concept of “call by reference” and returns a vector of outputs, the bitlength of the outputs, and the number of output values of the share. The possible vector datatypes for the vector of outputs are `uint32_t` and `uint64_t`.

```c
void get_clear_value_vec(uint32_t ** vec, uint32_t * bitlen,
                        uint32_t * nvals);
void get_clear_value_vec(uint64_t ** vec, uint32_t * bitlen,
                        uint32_t * nvals);
```

The first prototype is used for obtaining a `uint32_t` vector output, whereas second is used for obtaining a `uint64_t` vector output.

**Parameters**

- `vec` returns the vector which contains the output plain text information retrieved from the share object. This value is a reference and therefore modified by the method. The method is overloaded based on the datatype of `vec`.
- `bitlen` returns the bitlength of the values that are returned in `vec`.
- `nvals` returns the number of values of bitlength `bitlen` that are returned in `vec`.

**Example** The following example illustrates the use of `get_clear_value_vec()`.

```c
uint32_t bitlen = 8;
uint32_t nvals = 4;
uint8_t vals[nvals] = {64, 32, 128, 255};

uint32_t out_bitlen, out_nvals, *out_vals;

share* s_vals = circ->PutSIMDINGate(nvals, vals, bitlen, SERVER);

// as a result it holds that, out_vals[i] == vals[i], out_bitlen == bitlen, and out_nvals == nvals
s_out->get_clear_value_vec(&out_vals, &out_bitlen, &out_nvals);
```
5 Benchmarking

ABY has several benchmarking routines built in. Set the desired macros in `src/abycore/ABY_utils/ABYconstants.h` to 1 in order to print benchmarking numbers for each ABY execution. If you change these macros, you will need to recompile the core of ABY for the changes to have an effect. For this you need to run `make cleanmore` and then `make` again.

Listing 5.1: Benchmarking flags in `src/abycore/ABY_utils/ABYconstants.h`

```
32 #define PRINT_PERFORMANCE_STATS 1
33 #define PRINT_COMMUNICATION_STATS 1
34 #define BENCHONLINEPHASE 1
```

PRINT_PERFORMANCE_STATS will print gate counts and runtime information for both setup and online time. PRINT_COMMUNICATION_STATS shows communication numbers for sent and received data during several phases of the protocols. BENCHONLINEPHASE shows details runtime information of the online phase for every individual sharing type.

With all benchmarking flags set to 1 you will receive output that looks similar to the one shown in Listing 5.2.

Listing 5.2: Example Benchmarking Output

```
./min-euclidean-dist.exe -r 1 -n 1000 -d 2
Online time is distributed as follows:
  Bool: local gates: 94.942, interactive gates: 47.419, layer finish: 23.019
  Yao: local gates: 18.752, interactive gates: 6.147, layer finish: 5.693
  Yao Rev: local gates: 0.033, interactive gates: 0.025, layer finish: 0.024
  Arith: local gates: 0.533, interactive gates: 0.753, layer finish: 0.918
  SPLUT: local gates: 0.039, interactive gates: 0.02, layer finish: 0.179
Communication: 46.544
Complexities:
  Boolean Sharing: ANDs: 202911 (1-bit); 999 (32-bit); Depth: 108
  Total Vec AND: 203910
  Total Non-Vec AND: 234879
  XOR vals: 348874
  Comb gates: 0, CombStruct gates: 0, Perm gates: 0, Subset gates: 0, Split gates: 0
  Yao: ANDs: 31000; Depth: 6
  Reverse Yao: ANDs: 0; Depth: 0
  Arithmetic Sharing: MULs: 2000; Depth: 3
  SP-LUT Sharing: OT-gates: Total OT gates = 0; Depth: 1
Total number of gates: 929800
```
Timings:
Total = 410.593 ms
Init = 0.184 ms
CircuitGen = 0.069 ms
Network = 0.607 ms
BaseOTs = 919.677 ms
Setup = 165.308 ms
OTExtension = 129.077 ms
Garbling = 35.68 ms
Online = 245.284 ms

Communication:
Total Sent / Rcv  5159400 bytes / 7181498 bytes
BaseOTs Sent / Rcv 149064 bytes / 149064 bytes
Setup Sent / Rcv  5083349 bytes / 5563333 bytes
OTExtension Sent / Rcv 5083349 bytes / 4671324 bytes
Garbling Sent / Rcv 0 bytes / 0 bytes
Online Sent / Rcv  76051 bytes / 1618165 bytes

The communication numbers are the Bytes that the individual party sent and received during the protocol execution. The total time is the time for the setup phase and the online phase combined. The time for the base-OTs is not counted into the total time, as this is a one-time expense that only happens when the connection between the two parties is established. The setup phase contains the times for OT-Extension and Garbling.

Bibliography