ABY Developer Guide

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Contents

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.
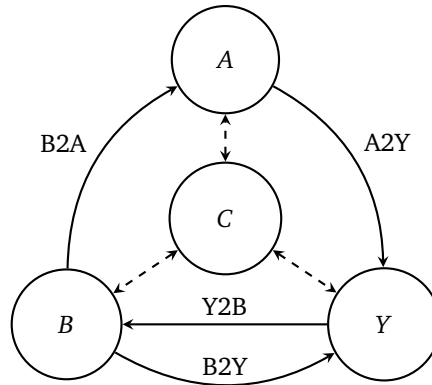

Figure 1.1: Overview of the ABY framework that allows efficient conversions between **C**leartexts and three types of sharings: **A**rithmetic, **B**oolean, and **Y**ao.

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).

Listing 1.1: Simple ABY Code Example for Yao's Millionaires Problem

```cpp
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\n",((alice_money > bob_money) ?
        "Alice" : "Bob"));

    delete party;
    return 0;
}
```
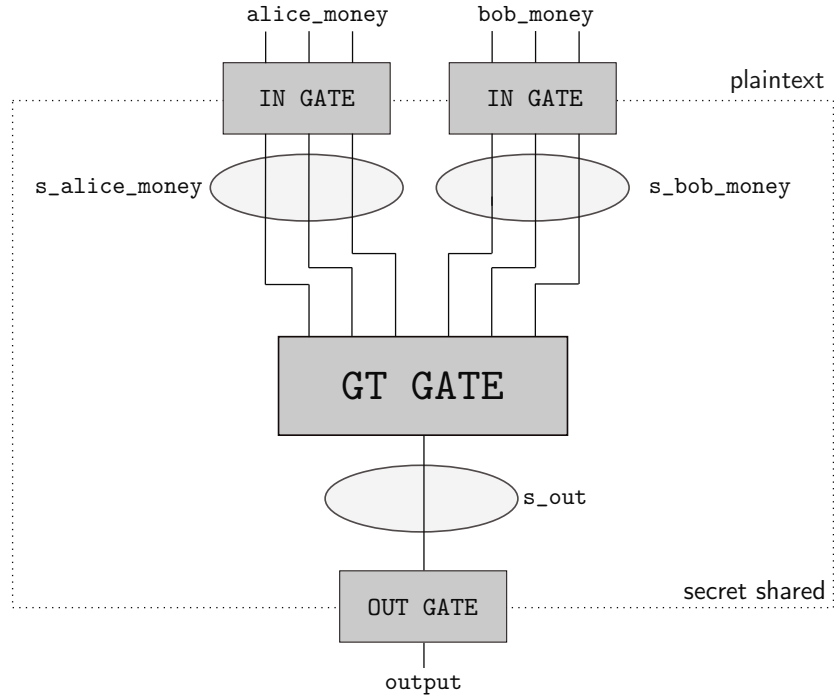
Figure 1.2: Millionaires problem that compares the wealth of Alice and Bob by computing output = alice_money > bob_money the amount of money both parties have has a length of 3 bits and each wire represents a single bit.

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^ℓ. 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

```
1   int32_t test_millionaire_prob_simple_circuit(e_role role) {
2       //Setup
3       string address = "127.0.0.1";
4       uint16_t port = 6677
5       seclvl seclvl = get_sec_lvl(128);
6       e_sharing sharing = S_YAO;
7       uint32_t bitlen = 32;
8       uint32_t nthreads = 1;
9
10      ABYParty* party = new ABYParty(role, (char*) address.c_str(),
            port, seclvl, bitlen, nthreads);
11      vector<Sharing*>& sharings = party->GetSharings();
12      Circuit* circ = sharings[sharing]->GetCircuitBuildRoutine();
13      // the circuit is defined here...
14
15      party->ExecCircuit();
16      uint32_t output = s_out->get_clear_value<uint32_t>();
17      // the output can be processed here...
18
19      delete party;
```

```
20      return 0;
21  }
```

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.

```
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.

```
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.

```
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.

```
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 $\in \{\texttt{S\_ARITH}, \texttt{S\_BOOL}, \texttt{S\_YAO}\}$. 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`.

```
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.

```
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.

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

2.1.5 Deletion

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

```
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.

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

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

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

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

```
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.

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

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

```
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.

```
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`.

```
uint32_t output = s_out->get_clear_value<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.

```
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  static share* create_new_share(uint32_t size, Circuit* circ);
2  static share* create_new_share(vector<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.

```
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.

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

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

```
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`.

```
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.

```
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

```
1  //Share creation
2  uint32_t alice_money = 5;
3  uint32_t bob_money = 7;
4  uint32_t bitlen = 3;
5
6  //Input
7  share *s_alice_money, *s_bob_money;
8  s_alice_money = circ->PutINGate(alice_money, bitlen, CLIENT);
9  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.

```
share* PutSharedINGate(uint64_t val, uint32_t bitlen);
share* PutSharedINGate(uint32_t val, uint32_t bitlen);
share* PutSharedINGate(uint16_t val, uint32_t bitlen);
share* PutSharedINGate( uint8_t val, uint32_t bitlen);

share* PutSharedINGate(uint64_t* val, uint32_t bitlen);
share* PutSharedINGate(uint32_t* val, uint32_t bitlen);
share* PutSharedINGate(uint16_t* val, uint32_t bitlen);
share* PutSharedINGate( uint8_t* val, uint32_t bitlen);
```

The method returns a `share` object for the pre-shared value `val` of bit-length `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 `val` into the circuit. `val` has bit-length `bitlen`, which is known to both parties. The function returns a share object, which represents the secret-shared/encrypted constant.

```
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`.

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

Parameters

- `s_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.

- `role` defines the party which is allowed to see the output value. The role value can be CLIENT, SERVER, or ALL.

Example

```
s_out = circ->PutOUTGate(s_val, ALL);
```

In the above example, we assume the share object `s_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_out`. In this example both parties can access the computation result after the circuit execution using `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.

```
share* PutSharedOUTGate(share* s_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 ($\wedge$), OR ($\vee$), 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 3.1: Operations

Operations	AND	XOR	OR	ADD	MUL	SUB	GT	MUX	INV
Arithmetic	✗	✗	✗	✓	✓	✓	✗	✗	✓
Boolean	✓	✓	✓	✓	✓	✓	✓	✓	✓
Yao	✓	✓	✓	✓	✓	✓	✓	✓	✓

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.

```
share* PutANDGate(share* ina, share* inb);
```

PutXORGate `PutXORGate` performs a bitwise XOR operation on the two input shares and returns theresult as a share object of the same bitlength as the longer input share.

```
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.

```
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^ℓ, where ℓ 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).

```
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^ℓ, where ℓ 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.

```
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^ℓ, where ℓ 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 bitlength of either `ina` or `inb`.

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

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

```
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 ℓ 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.

```
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.

```
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.

```
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.

```
//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).

```
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);
```

```
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);
```

Example   The following example adds the values `alice_money` and `bob_money` and verifies that the secret-shared output `s_sum` equals the result `sum_money` that is computed in plaintext.

```
//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 `share` were non-SIMD. In particular, a `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 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

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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.
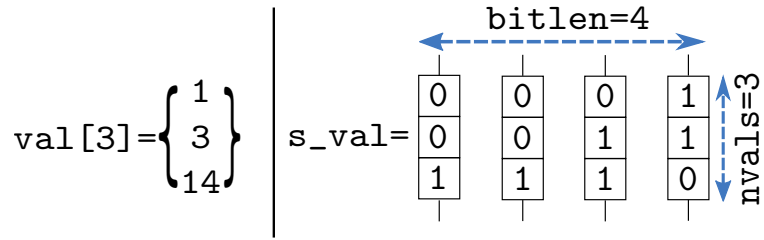

Figure 4.1: SIMD representation example for a Boolean circuit `share` with 4 wires and where each wire stores 3 elements in $\mathbb{F}_2$.

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`.

```
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., money_bitlen = 4-bit, and where each share stores nvals = 3 elements.

```
1  //Share creation with nvals as 3
2  uint32_t nvals = 3;
3  uint32_t alice_money[nvals] = {1, 3, 14};
4  uint32_t bob_money[nvals] = {6, 12, 5};
5  uint32_t money_bitlen = 4;
6
7  //Build input gates to obtain the corresponding SIMD shares
8  share* s_alice_money = circ->PutSIMDINGate(nvals, alice_money,
       money_bitlen, CLIENT);
9  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).

```
share* PutSIMDAssertGate(share* in, uint32_t nvals, uint64_t*
    assert_val, uint32_t bitlen);
share* PutSIMDAssertGate(share* in, uint32_t nvals, uint32_t*
    assert_val, uint32_t bitlen);
share* PutSIMDAssertGate(share* in, uint32_t nvals, uint16_t*
    assert_val, uint32_t bitlen);
share* PutSIMDAssertGate(share* in, uint32_t nvals,  uint8_t*
    assert_val, uint32_t bitlen);
```

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` $= \sigma$ 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.

```
share* PutCombinerGate(share* input);
share* PutCombinerGate(share* ina, share* inb);
```

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);
```
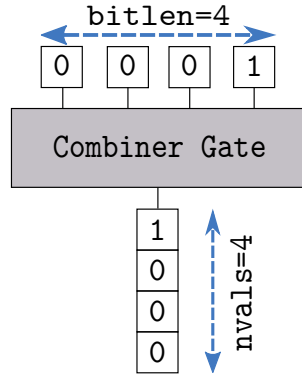
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Figure 4.2: The combiner gate creates a SIMD `share` with $nvals = 4$ single bit values from a non-SIMD share with a $\sigma = 4$ bit element.

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.

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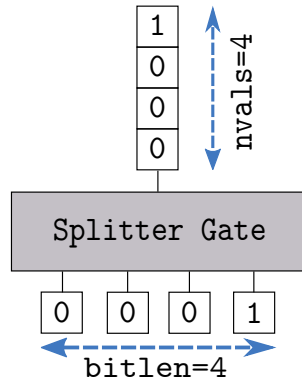

Figure 4.3: The splitter gate creates a non-SIMD `share` with $\sigma = 4$ wires from a SIMD share with a single wire and $nvals = 4$ elements.

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 $nvals = 1$.

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

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```
share* s_out = circ->PutSplitterGate(s_val);
```

4.2.3 PutCombineAtPosGate

The *combine at position gate (CombineAtPosGate)* takes a SIMD share `input` with σ 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 σ values on that wire. The CombineAtPosGate is useful when a SIMD share needs to be transposed.

```
share* PutCombineAtPosGate(share* input, uint32_t pos);
```

Parameters

- `input` the input share object containing σ wires and `nvals_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 $\{0, \ldots, \texttt{nvals\_in}-1\}$.
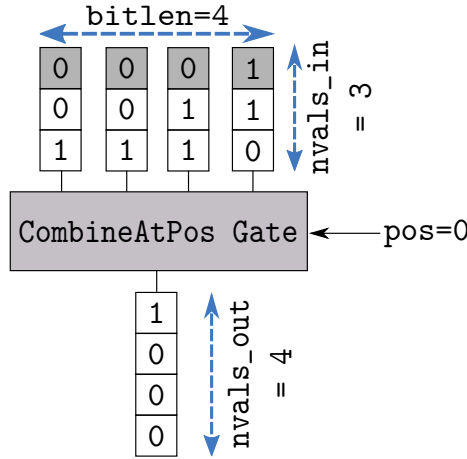

Figure 4.4: The CombineAtPos gate creates a SIMD `share` with a single wire that holds $\texttt{nvals\_in} = 4$ values from a SIMD share with $\sigma = 4$ wires where each wire holds $\texttt{nvals} = 3$ values.

Example   In the example, which is graphically illustrated in Fig. 4.4, a SIMD share `s_val` with $\sigma = 4$ wires and $\texttt{nvals} = 3$ values on each wire is transformed into a SIMD share `s_out` with $\sigma = 1$ wire which has $\texttt{nvals} = 4$ values.

```
uint8_t vals[3] = {1, 3, 14};

share* s_val = circ->PutSIMDINGate(3, vals, 4, SERVER);
share* s_out = circ->PutCombineAtPosGate(s_val, 0);
```

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`.

```
share* 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 (σ>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.

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

share* s_val = circ->PutSIMDINGate(nvals_in, val, 2, SERVER);
share* s_out = circ->PutSubsetGate(s_val, posids, nvals_out);
```
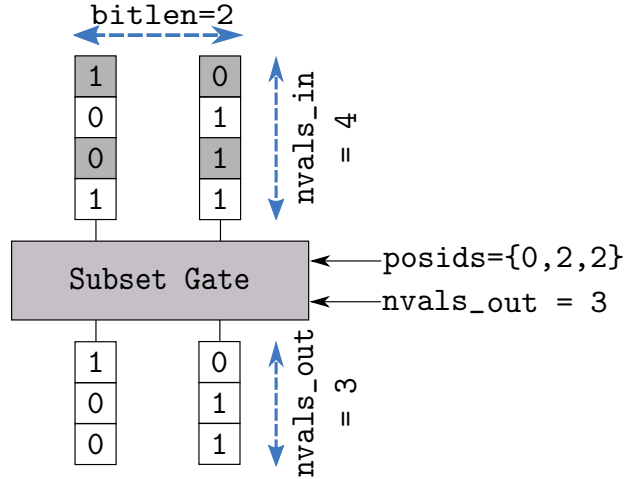
Figure 4.5: The subset gate creates a SIMD `share` with $\sigma = 2$ wires that hold `nvals` $= 3$ values each from a SIMD `share` with $\sigma = 2$ wires that hold `nvals_in` $= 4$ values each.

4.2.5 PutPermutationGate

The *permutation* gate takes as input a SIMD share `input` with σ wires each with `nvals_in` values and a list of positions `posids` with σ entries. It returns a single wire SIMD share `s_out` with `nvals`=σ values, where the i-th value of `s_out` comes from the i-th wire of `input` at position `posids[i]`.

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

Parameters

- `input` the share with the σ input wires and `nvals_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 σ entries, i.e., one entry for each wire in the input share (its bitlength). Each position must be in the range $\{0, \ldots,$ `nvals_in`$-1\}$ for the given wire.

Example In the example below that is depicted in Fig. 4.6, the share `s_out` with a single wire is assigned `nvals` $= 4$ values from the share `s_vals` with $\sigma = 4$ wires and `nvals_in` $= 3$ values. More detailed, after the `PutPermutationGate`, `s_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_vals`.
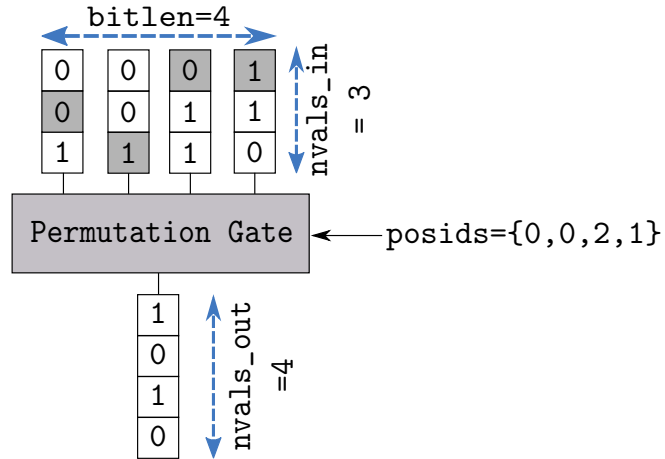
Figure 4.6: The permutation gate creates a SIMD `share` with a single wire that holds `nvals=4` values from a SIMD `share` with $\sigma = 4$ wires that each hold `nvals_in` $= 3$ values.

```
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 *repeater* gate takes as input a non-SIMD share `input` and a integer value `nvals` and outputs a SIMD share that contains the values of `input` `nvals` times.

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

Parameters

- `nvals` size of the output SIMD share.

- `input` non-SIMD input share from which the value is taken that is "repeated" `nvals` times on the output share.
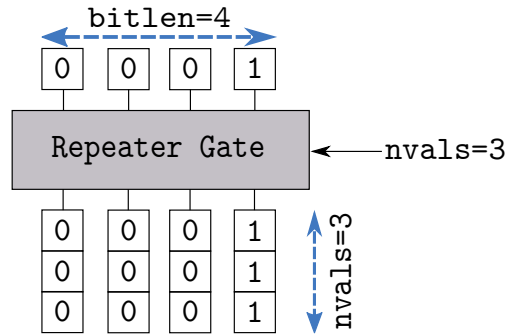
Figure 4.7: The repeater gate creates a SIMD share by copying the value of a non-SIMD input
share `nvals` times.

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

```
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`.

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

Parameters

- `wireid` value uniquely identifies a given wire in a share.

4.3.2 get_clear_value_vec()

The get_clear_value_vec() method is the SIMD pendant of the get_clear_value()
(see §2.2.3) 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.

```
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().

```
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);
share* s_out = circ->PutOUTGate(s_vals, 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:32` 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 gates: 286936
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 / 4571324 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

[DSZ15] D. Demmler, T. Schneider, and M. Zohner. ABY – a framework for efficient
mixed-protocol secure two-party computation. In *Network and Distributed System Security (NDSS'15)*. The Internet Society, 2015. Code: `https://github.com/encryptogroup/ABY`.