BME AI-Studio Manual

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1 Overview

1.1 Getting started

Welcome to our "Getting Started" section of the Bosch BME AI-Studio. The BME AI-Studio brings together our BME Board x8 (equipped with the new BME688 gas sensor) and our BSEC Software (BME Library).

This section will give you a short introduction and a hands-on example on how to use the application.
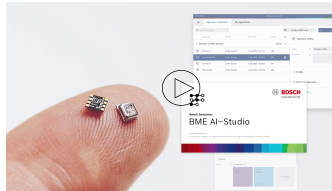
[Click to Watch Getting Started Video](#)

1.1.1 The BME688 Gas Sensor

[See: "0:25 - The BME688 Gas Sensor"](#)

The BME688 gas sensor is like a digital nose. It can detect gases by measuring their unique electric fingerprint and therefore distinguish different gas compositions.

However, the sensor has to be teached about these different gases first. That means, we have to train the sensor using Machine Learning.

And that's where the BME AI-Studio comes in: It let's you explore and verify your specific use cases: With the application, you can collect your gas measurements, train Machine Learning algorithms and export a final algorithm to be used with the BSEC Software (BME Library) in your project.

1.1.2 Example: Coffee vs. Normal Air

[See: "1:03 - Example: Coffee vs. Normal Air"](#)

Let's take a look at a real world example.

Assume, you want to use the BME688 to detect coffee beans. Or in other words: distinguish the gas composition of coffee from the gas composition of normal air and other smells.

So in order to train an algorithm for that, we first have to record gas measurements of coffee and normal air.

1.1.3 A Few Things To Keep In Mind

See: "1:26 - A Few things To Keep In Mind"

Before we start with the measurements, there are three things to keep in mind:

▶ If you have a brand new BME Board, you should stabilize the sensors on the board before taking any measurements. To do so, connect the board to power with a Micro USB cable and let it run for at least 24 hours. This procedure is neccessary only once and your board is then ready to take reliable measurents.

▶ Make sure that your BME Board is configured correctly. New BME Boards come already preconfigured with a standard setting – so if you have a brand new board, you don't have to worry about the configuration for now.

▶ Make sure that an SD card is inserted in the board.

1.1.4 Step 1: Record Normal Air

See: "2:08 - Step 1: Record Normal Air"

OK – let's start the Measurement Session for our Coffee Detection Example.

Let's record normal air as our first Specimen. We are just going to record the gas composition of the room. Additional smells to make the detection more robust should be added later. But to keep it simple in this example we just stick to normal air for now.

Connect the BME Board to power and place the board on your table. Always be careful not to touch the sensors with your fingers while handling the board.

If everything is OK and the board is recording data, the red LED is flashing every two seconds. Let the board record for about 30 minutes.

1.1.5 Step 2: Record Espresso Coffee

See: "2:48 - Step 2: Record Espresso Coffee"

Now, let's move on to the coffee. For this example, we prepared two types of coffee in order to have a bit of variance in our measurements: Espresso and filter coffee. Let's measure the espresso coffee first.

Place the espresso coffee in a relatively air-tight container. Press "Button 1" (labeled "S1") on the board to mark this moment in the data. Place the board in the container together with the coffee, and record the gas composition for 30 minutes.

1.1.6 Step 3: Record Normal Air Again

See: "3:19 - Step 3: Record Normal Air Again"

After that, let's measure normal air again. Take the board out of the container. This time, press "Button 2" (labeled "S2") on the board to set another marker in the data.

Place the board again on your table, and record the gas composition for another 30 minutes. Put the container with the coffee far away, so it doesn't interfere with the recording.

1.1.7 Step 4: Record Filter Coffee

See: "3:36 - Step 4: Record Filter Coffee"

Finally, let's record the last Specimen: Filter coffee. Same procedure as with the espresso coffee: Place the filter coffee in a second container, press "Button 1" on the board and place it in the container along with the coffee. Again, record the gas composition for 30 minutes.

Once you are finished with your Measurement Session, you can just power off the board by unplugging the USB cable.

1.1.8 Step 5: Import & Label The Data

See: "4:04 - Step 5: Import And Label The Data"

Now it's time to open BME AI-Studio on your computer. Create a new project and select a location, where you want to save it on your hard drive. Let's call the project "Coffee Example". Then select Import data . Remove the SD card from the BME Board and select the file on the card with the ending .bmerawdata .

The application now gives you an overview of your recorded data. There's a plot showing you the data on a timeline. First, give your Measurement Session a name. Let's call it "Coffee Session".

As you can see below the plot, there are already four Specimens defined − one that started with powering on the board, and three that started when we pressed the buttons during measurment. On the left, there are input fields to label each Specimen. We measured normal air first, then espresso coffee, then again normal air, and finally filter coffee.

If you forgot to press a button during the measurement, you could define Specimens manually here as well.

Select Import Data to finish. The data is now copied to the project folder on your hard drive.

Once the import is finished, you can see your four Specimens in your Specimen Collection . The Specimen Collection is where you can collect and manage all of your recorded data for a specific

project. If you select one of the Specimens, you can see all available details about this Specimen on the right hand side.

1.1.9 Step 6: Create New Algorithm and Classes

See: "5:37 - Step 6: create New Algorithm And Classes"

So now that we have recorded and imported the data into the Specimen Collection, it is finally time to create and train an algorithm.

Switch to My Algorithms and select New algorithm . We can give this algorithm a name, let's call it "Coffee or Not".

As you remember, in our example use case we wanted to detect when coffee is present. That means, we need to teach our algorithm the difference between two so called "classes": Coffee and other smells. So let's create these two classes. Select Add class and give this class a name. Let's call it "Coffee".

Next, we have to select the Specimens from our Specimen Collection that should be part of that class. In our example, that would be the two Specimens "Espresso Coffee" and "Filter Coffee".

Now, let's create the second class. We call this one "Normal Air" and select the two "Normal Air" Specimens to be associated with this class.

1.1.10 Step 7: Train And Evaluate The Algorithm

See: "6:38 - Step 7: Train And Evaluate The Algorithm"

Now, that we have defined our two classes with their respective Specimens, we can train our algorithm. There are additional settings for the algorithm and the training, but for now you can leave these settings at their default values. Just hit Train Neural Net and BME AI-Studio will start to train the algorithm.

Once the training is finished, you can see the results. The most important value to check is the Accuracy . The higher the Accuracy the better the algorithm's performance.

One thing you should be aware of though: The algorithm training results can be too perfect. If you have recorded too little data, it might happen that the algorithm adapts too closely to that specific data – and gives perfect results. However, it won't be able to predict other data that is slightly different. To make the algorithm more robust, you could record additional coffee blends or other smells, like tea or juices. In short: always make sure to record enough data with a bit of variance.

A second thing to check is the so called Confusion Matrix , which you will find under Details . It shows the algorithm's performance to distinguish our two classes "Coffee" and "Normal Air".

A part of the Specimen's data has been reserved just for this perfomance test. The rows show what the actual classes of these test elements were, while the columns show which classes were predicted by the algorithm. That means, for a good result, the upper left quadrant and the lower right quadrant should be dark blue and have a high number – indicating how often the algorithm made the right prediction for both classes. At the same time, the upper right and lower left quadrants should be light blue and have a low number, since these numbers indicate how often the algorithm made the wrong prediction. The upper right quadrant tells you how often the algorithm falsely predicted "Normal Air", when in fact it was "Coffee". And the lower left quadrant tells you how often the algorithm predicted "Coffee", when it actually was "Normal Air".

In our example, the results look pretty good. More than 90% accuracy and very few false predictions in the Confusion Matrix. That's a good result for a first training.

1.1.11 Step 8: Export The Algorithm

See: "8:55 - Step 8: Export The Algorithm"

As a last step, if you are happy with the result, you can export the algorithm as a BSEC Configuration File for the BSEC Software (BME Library). This config file can be used together with the BME Library (BSEC) in your project.

1.1.12 Conclusion

See: "9:09 - Conclusion"

If you have any questions or if you want to get further information, for example on how to use the BSEC Software (BME Library), please write us an email or check out the Bosch Sensortec Community.

Happy training!

1.2 Introduction

The combination of BME AI-Studio with the BME Board allows you to explore the great possibilities of the BME688 and the BSEC Software (BME Library). It helps you validate gas sensor use cases for your product or application. Try and find out how well your gas sensing application can be fulfilled by the BME688.

1.2.1 What is it about? – An analogy

In a nutshell the BME AI-Studio can be explained within the following analogy:

Using the BME AI-Studio can be compared to creating a picture book for children. Within that analogy training an algorithm can be compared to teaching a child how different animals look like. This analogy should help you grasp the essence of the BME AI-Studio with it's two major parts: the Specimen Collection and My Algorithms .

BME world	Child analogy
Goal: Teaching the sensor to distinguish different gas compositions with labeled Specimen Data, recorded with the BME Board	Goal: Teaching a child to distinguish different animals with a picture book, that has photos captured with your photo camera
Specimen Collection: Collection of recorded Measurement Sessions and labeled Specimens	Picture book: Collection of photos labeled with the name of the animals
My Algorithms: Machine learning process to teach the algorithm which gases are which (or which classes of gasses are which), so that they can later be distinguished by the sensor	Teaching a child: Process of showing the labeled photos to a child to teach him/her which animals are which, so that they can later be distinguished by the child
Example Algorithms: A trained algorithm that can distinguish apples from oranges. This works because apples and oranges produce different gases, which produce different sensor signals. The algorithm was trained to detect these differences and is now able to classify the two	Example: A child that can distinguish giraffes from elephants. This works because giraffes and elephants have different appearances, which look different on a photograph. The child learned to detect these differences and is now able to classify the two

Table 1: An analogy

Within that analogy the individual steps are:

	BME AI-Studio BME board	Photo software Camera
1	Configure the BME Board with BME AI-Studio	Choose the settings in the camera
2	Record data with the BME Board	Take photos with the camera
3	Import data into the BME AI-Studio	Import photos into photo editing software
4	Label different Specimens within the data	Label different animals in the photos
5	Train algorithm with labeled Specimens	Teach a child with labeled photos
6	Evaluate and test algorithm	Ask the child what he/she has learned

Table 2: Steps

1.2.2 Why the BME688?
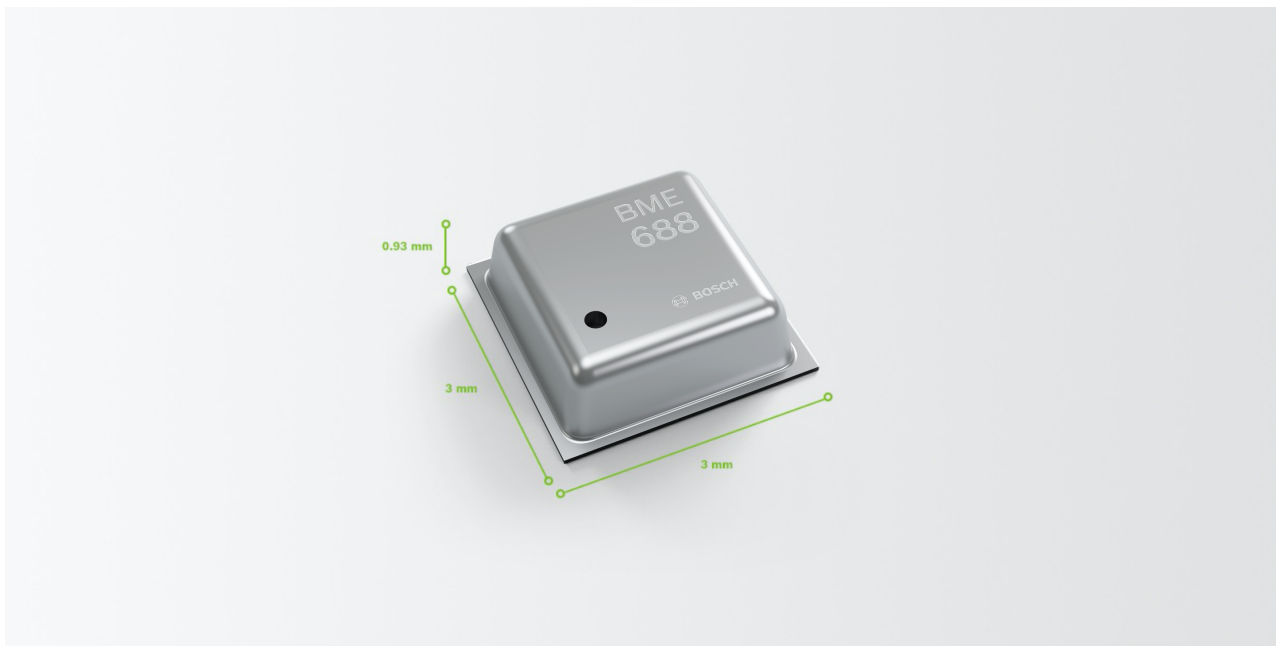
Fig. 1: BME688

With the BME688 gas sensor you experience the world's most advanced gas sensor with unique capabilities:

▶ High sensitivity and selectivity towards various gases (a variety of gases have already been studied in the lab of Bosch Sensortec. For detailed information please refer to the Bosch Sensortec Website or the Bosch Sensortec Community)

▶ Sensitivity and selectivity can be adjusted during operation

▶ Low power consumption

▶ Small footprint

▶ Additional sensing capabilities for temperature, relative humidity and barometric pressure

With this unique capabilities the BME688 gas sensor can be applied to numerous use cases. A gas sensor can be regarded as a digital nose, which has a lot of advantages if compared to the human nose. The following table may inspire you to find unique use cases:

Human nose	Sensor cabability	Digital nose
attached to the body	location independent	extended nose
needs recovery time	always ready for use	hardworking nose
blind for slow and steady changes	reproducible precision	absolute nose
sensitive to special gases	sensitive for different gases	complementary nose
individual sensitivity	calibrated sensitivity	objective nose
highly emotional	sober and rational	not my own nose

Table 3: Use Cases

1.2.3 What is a use case for a gas sensor?

The magic lies within the question itself and it is up to your explorations to fully cover the possible space of use cases for the BME688. This is exactly where the BME AI-Studio is aiming for.

A use case is a potential application for the BME688. From a gas sensing perspective it is the ability to classify different gas compositions (with different combinations and concentrations of gases) that occur in different situations. The goal is to find a configuration in which the sensor is able to reliably distinguish the different gas compositions.

Interestingly, it is not necessarily important to know the exact composition of gases, as long as you have defined specific cases and you are able to reproduce these cases and their corresponding gas compositions.

A specific gas sensor use case may be a part of product premise you are aiming for. It can detect different situations and thus provide real value added to your product. Typically use cases are the detection of various pleasant or unpleasant smells or the detection of gases which are odorless.

1.2.4 What is special about the BME688 gas sensor?

The gas sensing element of the BME688 is mounted on a micro-hotplate, so its temperature can be changed individually. This happens during Scanning Cycles. Depending on the Heater Profile (HP) the sensor cycles through a list of 10 predefined temperatures. The exact time sequence of these temperatures defines the surface chemistry of the gas sensing element and thus the sensitivity and selectivity of the sensor.

Therefore the Heater Profile has a substantial influence on the performance of the gas sensor. Choosing the right Heater Profile for your use case can be the key to getting a good performance in

classifying different situations.

These Heater Profiles are one of key advantages of the BME688. This allows the sensor to adopt to individual gases by adopting the measurement scheme to the gases' individual fingerprints.

1.2.5 How can I evaluate BME688 performance for a specific use cases?

The BME AI-Studio is the perfect tool to support you in the quest of finding out whether a specific use case can be tackled with the BME688 gas sensor. Basically there are the following degrees of freedom that you can vary within the testing conditions:

▶ Data recording and testing environment
▶ Heater Profile configuration
▶ Duty Cycle configuration
▶ Algorithm training parameters

In general the process can be viewed as a careful exploration and an iterative approach. The following procedure has proven to be very efficient:
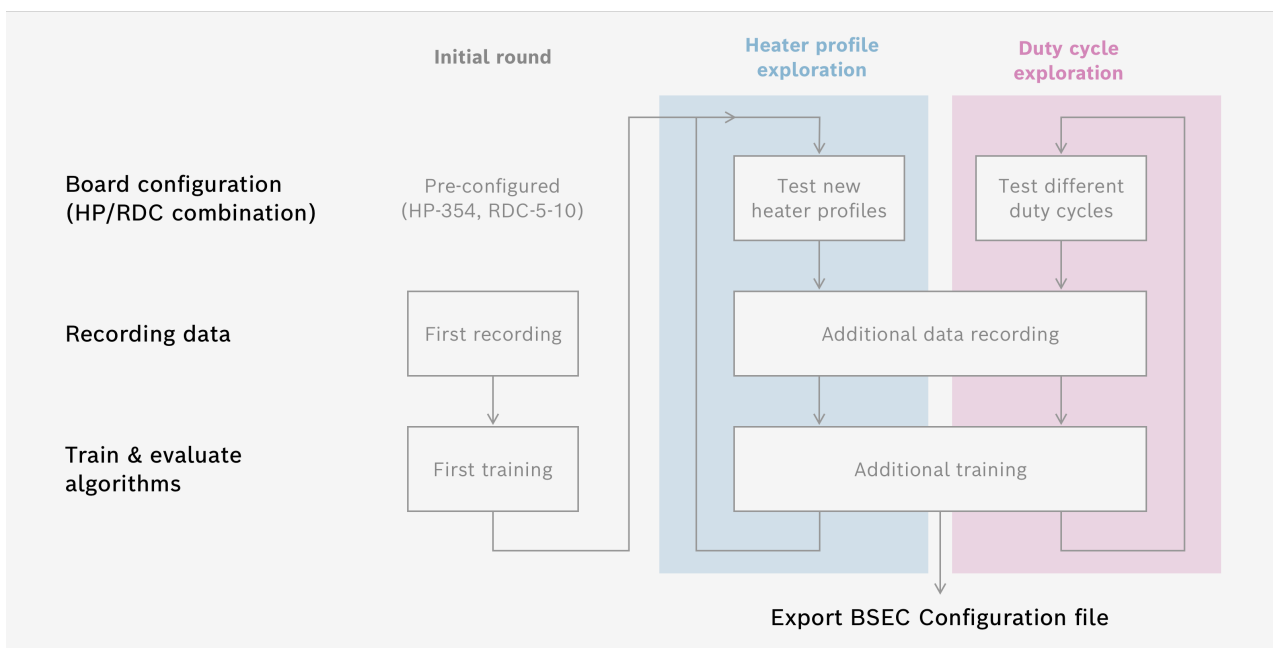
Fig. 2: Use case Evaluation

1.2.6 Phase I: Doing the first measurements

The best thing is to just start recording whatever use case you have in mind. On your way of exploring the use case more and more, you will gain knowledge and sometimes you have to redo some of the measurements. That's very normal when exploring new use cases.

> **Please note**
>
> Fabric-new BME Boards need to undergo an initial stabilization procedure. Please let the board run for at least 24 hours before recording any meaningful data.

A factory-new BME Board comes preconfigured with the Heater Profile HP-354 and the Duty Cycle RDC-5-10 . This means you can start right away capturing the first data. As a more advanced user, you might want to configure the board with a selection of different Heater Profiles.

Before starting the measurement it is wise to spend some thoughts on the right testing environment. This also means choosing how controlled your setup should be. The two kinds of measurements are:

▶ **Lab recording** where the gas atmosphere is fully controlled. These measurements make it easy for the algorithm to distinguish between different gas compositions and are therefore ideal to test first. If the algorithm has a hard time distinguishing data from lab recordings, it is most likely even more difficult to distinguish data later within the application. You may also want to think about certain nuisances to be added to the test to be more stable towards external influences later on.

▶ **Field recordings** where changing backgrounds of the gas composition are not controlled but taken into account as a statistical fluctuation. These changing conditions help the algorithm to get more robust. Try to get a variance of the situations that is a little bit worse than it will be later within the application. If the algorithm was trained in difficult conditions, it will have an easier time later. However, do not go to extremes while changing the situations – otherwise you make the training process more complicated than necessary.

Once you finished recording, you can import the data. Build up a small collection of specimens and try an early training of an algorithm.

Evaluating the results of the first measurements the performance indicators should look very good. Small amounts of data should make it very easy for the algorithm to find features that allow for distinguishing the different gas compositions.

If you do not see good results, please go back and check whether previous steps are properly done. If so it may be the case that the sensitivity and selectivity of the BME688 does not match your use case. For example carbon dioxide is known to be hard to measure with the BME688.

If you see good results, please proceed with a Heater Profile Exploration.

1.2.7 Phase II: Heater Profile Exploration – the space of possible heater profiles

Within the Heater Profile Exploration the goal is to find the Heater Profile that best suits your use case. Therefore try and configure multiple Heater Profiles and record data to compare the results of different Heater Profiles.

You may want to record as much data as possible during Heater Profile Exploration by choosing the Duty Cycle RDC-1-0 Continuous , where the sensors are continuously recording data without any

Sleeping Cycles in between. You can record multiple sessions with multiple Specimens and import them all into your Specimen Collection.

When you train algorithms for data with multiple HP/RDC Combinations (Heater Profile / Duty Cycle Combinations) an independent neural net will be trained for each instance, giving you the opportunity to compare the performance of different HP/RDCs. By iterating that process in terms of configuring the BME Board with different Heater Profiles, recording data and then comparing the performances, you can determine the best suitable Heater Profile for your specific use case.

After you found the best Heater Profile, you may want to proceed with a Duty Cycle Exploration, if power consumption is an issue for your use case. If power consumption is irrelevant you can directly export your BSEC configuration to be used the BSEC Software (BME Library).

1.2.8 Phase III: Duty Cycle Exploration − balancing power consumption and performance

A Duty Cycle Exploration is important if you want to optimize power consumption of the BME688 for your application. Therefore the purpose of Duty Cycle Exploration is to find the best Duty Cycle for your use case − it is the one that uses a minimum amount of energy while still providing very good performance.

Try configuring multiple Duty Cycles, while keeping the Heater Profile that was perfoming best and that you determined within the Heater Profile Exploration. While comparing different Duty Cycles, keep in mind that the ratio of Scanning Cycles to Sleeping Cycles determines the average power consumption of the sensor. You find an estimated power consumption within the board configuration in your Specimen Collection.

Once you found your optimal Duty Cycle, you can export your BSEC configuration to be used with the BSEC Software (BME Library).

1.2.9 How can I use the results for my product development?

The BME AI-Studio with BME Board and the BME Library (BSEC) are build around the BME688 gas sensor. Together they form an ecosystem to explore, validate and prototype gas sensor use cases. With the BME Board you can record data to be used within the AI-Studio for training neural nets. These can be exported to be used with the BME Library (BSEC) and inside an embedded application.
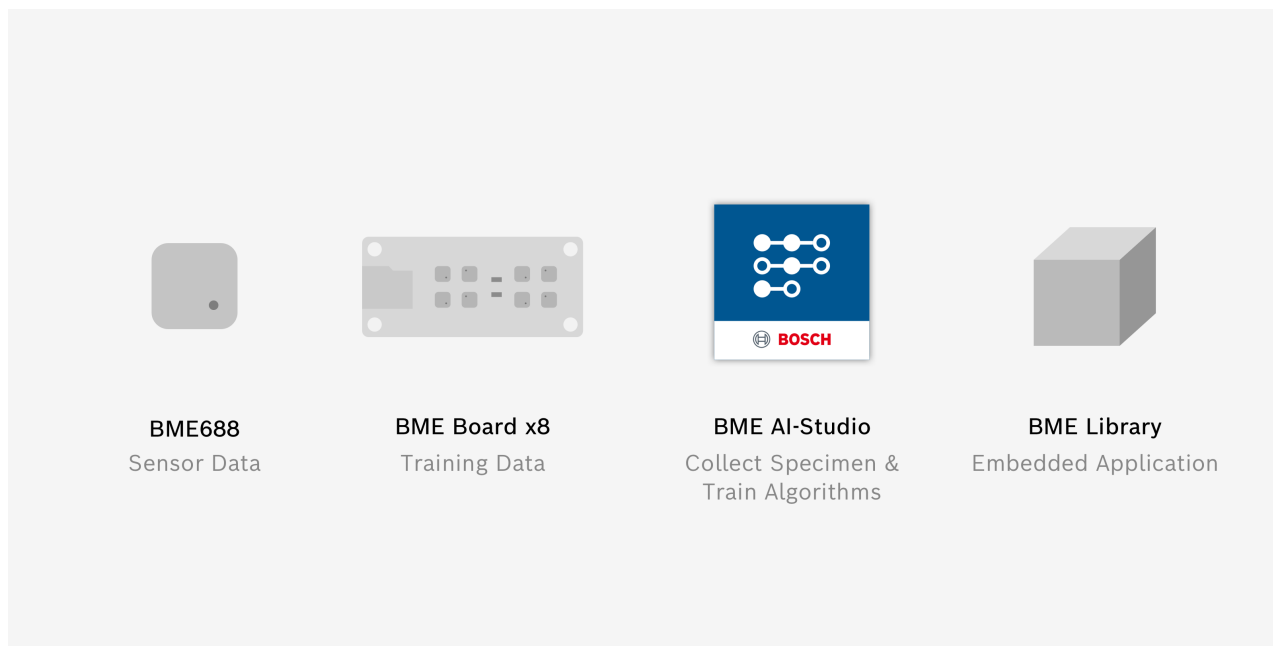
Fig. 3: Integration

For any trained algorithm you can export a BSEC configuration file that can be used with the BSEC Software (BME Library).

Please refer to the website of Bosch Sensortec BME Software for further information.

1.3 Glossary

1.3.1 Sensor Board

BME Board x8 / Development Kit

BME Board x8 (which is also referred to as BME Development Kit) is an experimental board with eight BME688 sensors.
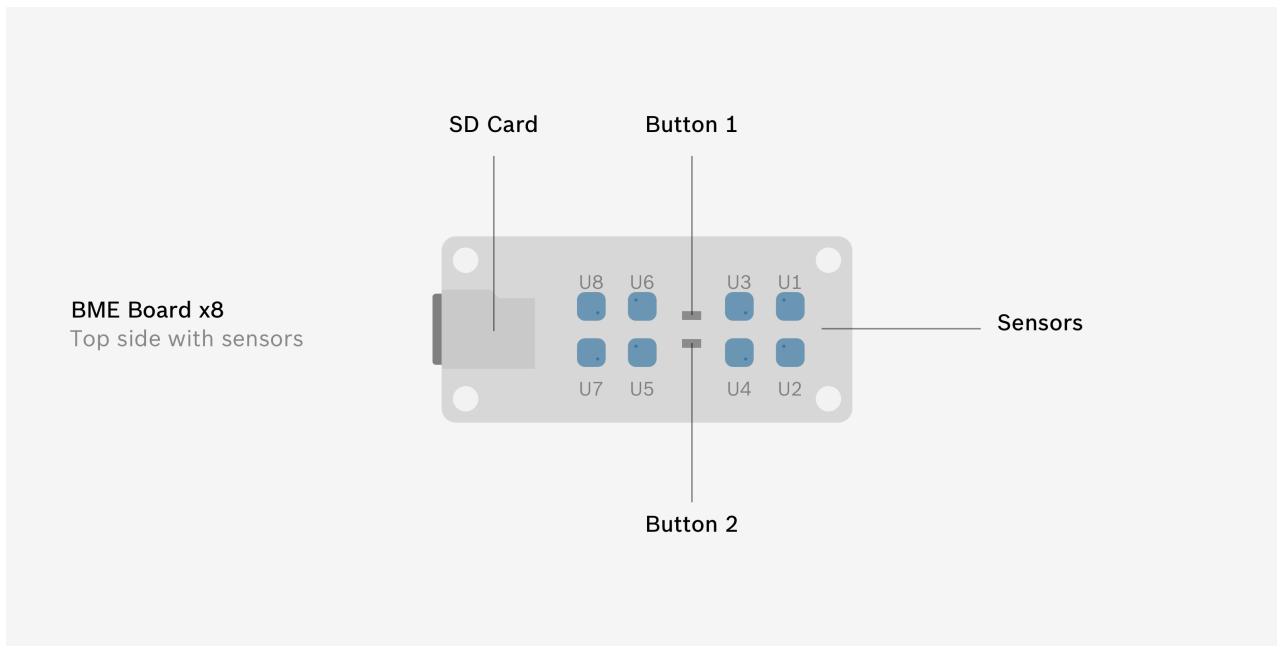
Fig. 4: BME688 Board

BME Board Configuration

The Board Configuration states which sensor runs which sensor mode.

HP/RDC Combination

Each sensor can operate with a specific setting which consists of
▶ Heater Profile (HP)
▶ Duty Cycle (RDC)
Hence, the term HP/RDC Combination.

Heater Profile

Temperature profile with 10 steps which is run through by the sensor during a Scanning Cycle. Each of the 10 steps consists of:
▶ A temperature

▶ A duration (timebase is 140 ms)

At the end of each step, a measurement is recorded and stored in the data.
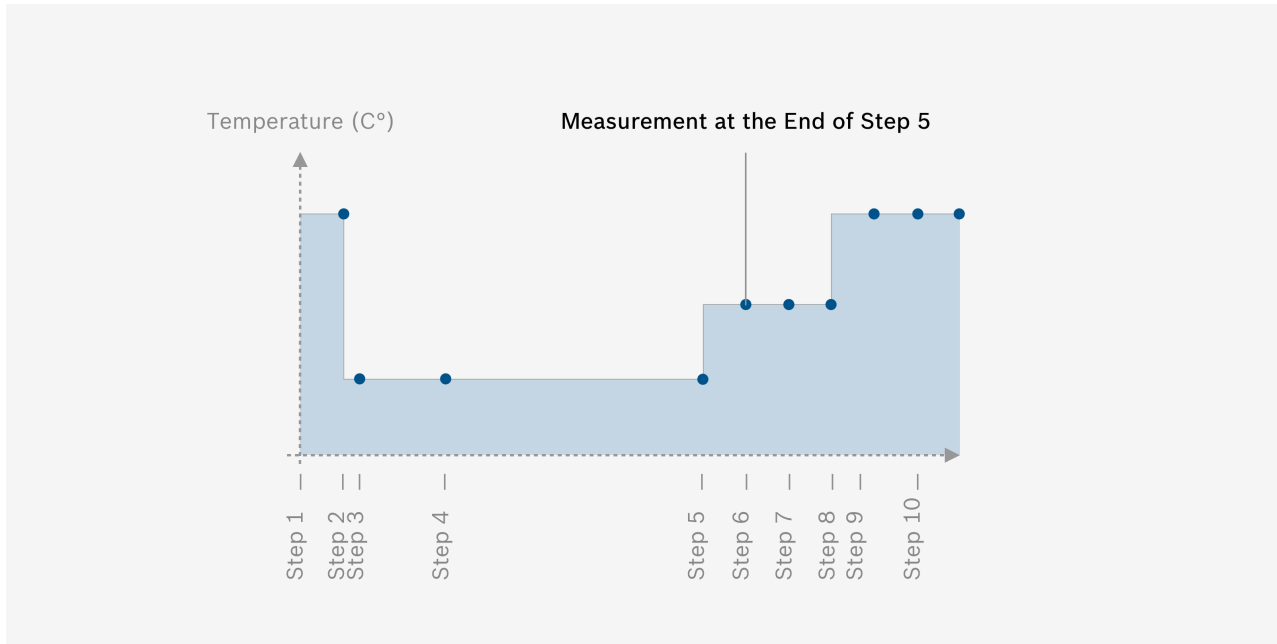
Fig. 5: Heater Profile

Please note

The duration of a step of a Heater Profile is calculated with a timebase of 140 ms. That means e.g. a duration of 2 will result in a duration of 2 * 140 ms = 280 ms .

Duty Cycle

Repeated sequence of a defined number of Scanning Cycles followed by a defined number of Sleeping Cycles.

E.g. Duty Cycle with 5 Scanning Cycles and 10 Sleeping Cycles (RDC-5-10):
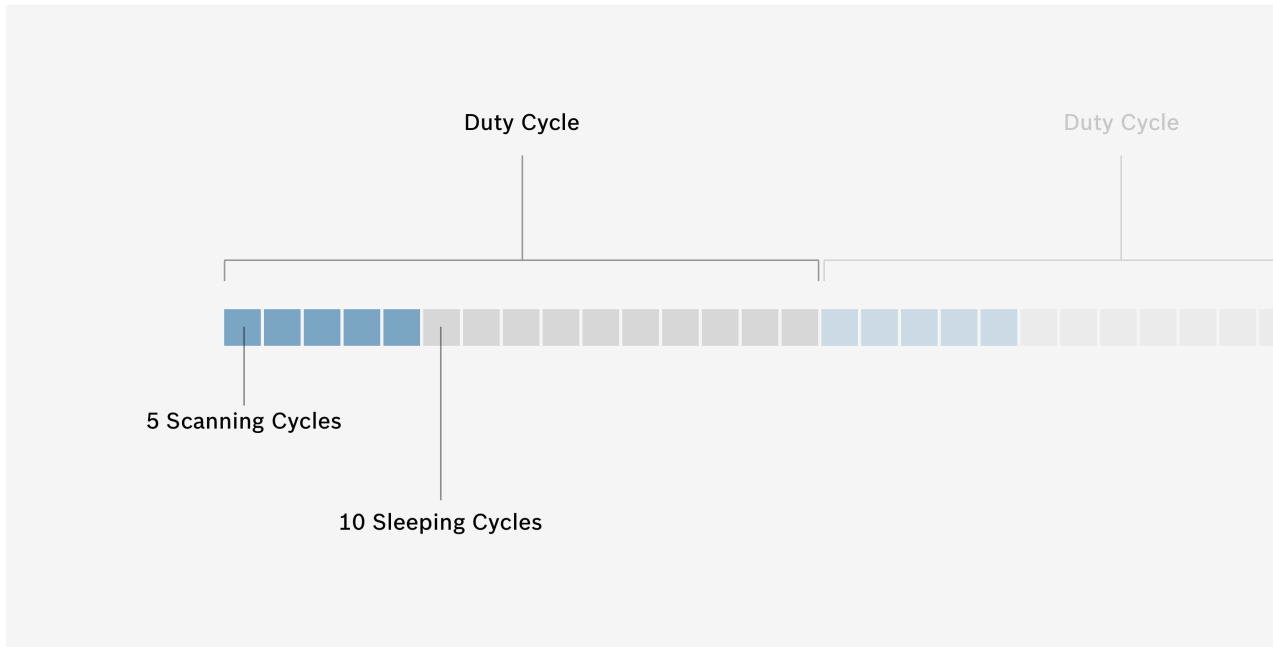
Fig. 6: Duty Cycle

Each Scanning Cycle can be viewed as one iteration of a Heater Profile. Therefore the duration of each Scanning Cycle is derived from the duration of the Heater Profile used. The duration of each Sleeping Cycle is always equal to the duration of a Scanning Cycle.

The duration of the whole Duty Cycle defines the algorithms response time.

Sleeping Cycle

During a Sleeping Cycle the sensor is in sleep mode and does not perform any measurements.

Scanning Cycles

During a Scanning Cycle the sensor uses the internal micro-hotplate to run through a sequence of temperature steps according to a specific Heater Profile.

1.3.2 Measurement Session

Measurement Session

Data acquisition within one "session" with one BME Board Configuration. The Measurement Session begins with powering on the board and ends with powering off the board. Multiple sessions can be conducted one after another using the same SD card. Typically, multiple Specimens are measured during a Measurement Session.
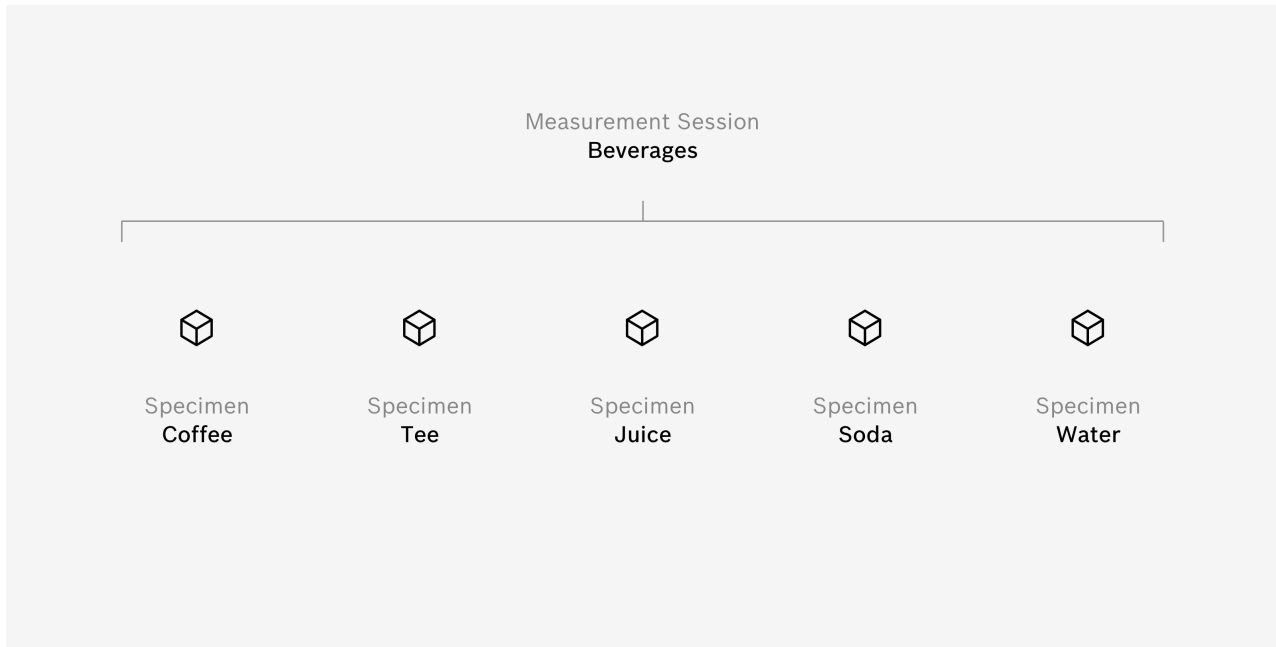
Fig. 7: Measurement Session

Specimen

One specific gas composition that the sensors on the BME Board are exposed to during measurement (e.g. an object, a specific situation, a smell, gas, etc.).

Session Raw Data / Raw Data

The raw data recorded during a Measurement Session which is saved to the SD card. This includes data from all 8 sensors on the BME Board x8.

Session Raw Data is split into multiple files when board power is switched on/off or the file limit (297 MB) is exceeded.

Session Raw Data can be marked during measurement for easy splitting into Specimen Data by pressing one of the buttons S1 or S2 on the BME Board x8.

Specimen Data

A part (a set of cycles that belong to one Specimen) of the Session Raw Data of one Measurement Session. The Specimen Data can be curated and labeled with respect to the measured Specimen within the application.

Specimen Data includes four data channels (for each sensor on the board):
▶ Gas Data Channel (10 data points)

▶ Humidity Data Channel (1 data point)

▶ Temperature Data Channel (1 data point)

▶ Barometric Pressure Data Channel (1 data point)

1.3.3 Algorithm

Algorithm

A neural net for classification, including multiple classes with added Specimens, as well as machine learning settings and results.

The Specimen Data of the added Specimens are split and used for training and verification of the the neural net (Training and Test Data).

Training result consists of a Confusion Matrix and performance indicators, e.g. Accuracy.

Classes

Classes are the possible outcomes of the classification algorithm. Each class has added Specimens. The corresponding Specimen Data is used for the classification training and verification (Training and Test Data).

Training and Test Data

The Specimen Data of all classes of a Algorithm is split into two parts:
▶ Training Data: Used to train the neural net
▶ Test Data: Used to test the performance of the neural net after training

BSEC Configuration File

A configuration file that can be exported from the application for each algorithm. It contains all parameters (weights and biases) of the trained neural net. It is meant to be used with the **BSEC Software**.

2 Process Steps

2.1 Configure Board

2.1.1 Overview

The first step in the process of using a BME Board with the BME-AI Studio is to configure the board. This step prepares the boards with a proper configuration for recording. The configuration is first defined within the application and then saved as a configuration file, that has to be transferred onto the SD card of the BME Board.

> **Good to know**
>
> If you have a factory-new BME Board and just want to get started, you can also skip this step. New boards are already configured with a default configuration (HP-354 / RDC-5-10). In this case, check out our Getting started section.

Create a configuration file

Open the application and create a new project by clicking Create new project on the Welcome screen. Alternatively, you can open the menu and select New project... . Next, a file dialogue opens. Please select, where you want to save your new project.

If you already have an existing project, just open the project and switch to your Specimen Collection .

To set up a configuration, click Configure Board . A new overlay opens that lets you define the configuration and save it as a configuration file to the SD card.

Three types of configurations

The operation with the boards is divided into three categories, which are intented for different phases with different goals:

1. **Default configuration**
   BME Boards that are straight from the factory come with a default configuration, that suits most use cases. This mode can also be used for an initial stabilization which is needed before you can use them for data recording.

2. **Finding the right Heater Profiles**
   The power of adapting the BME688 gas sensor to a specific use case lies within the concept of Heater Profiles. Finding the right Heater Profile that suits best for your use case is key to getting peak performance results. Therefore we advise you to spend some time finding the optimal Heater Profile, which delivers the best results specifically for your use case. This involves sensitivity and selectivity. To explore a variety of Heater Profiles and find the best one for your use case, please use the board mode Heater Profile Exploration .

3. **Optimizing the Duty Cycle**
   The BME688 allows you to adopt its mode of operation in order to save energy. During a Sleeping Cycle the sensor is in low-power mode and will be automatically woken up after a

certain amount of time to enter a Scanning Cycle. The balance between sleeping and scanning is defined by the Duty Cycle. To explore a variety of Duty Cycles and find the best one for your use case, please use the board mode Duty Cycle Exploration .

It is important to pay attention to individual combinations of Heater Profiles (HP) and Duty Cylces (RDC), so called HP/RDC combinations. Each sensor runs in a specific HP/RDC combination that determines the behavior how data is recorded. Not only is this important to the configuration of the boards and the recording of the data, but also for creating and training algorithms. One algorithm can use only identical HP/RDC combinations for training.

2.1.2 Board Type

Here you can choose the type of BME Board you want to create a configuration file for. In this version of BME AI-Studio, you can choose one board type:

▶ BME Board with 8 BME688 sensors (BME Board x8)
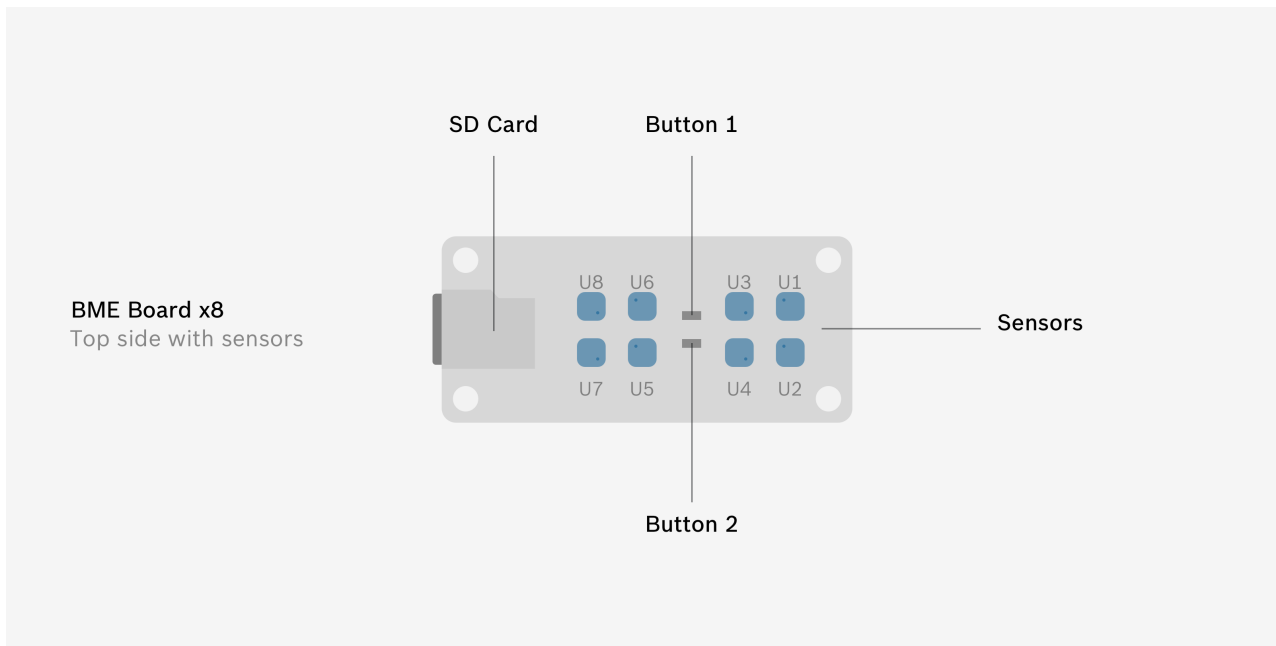
Fig. 8: BME board x8
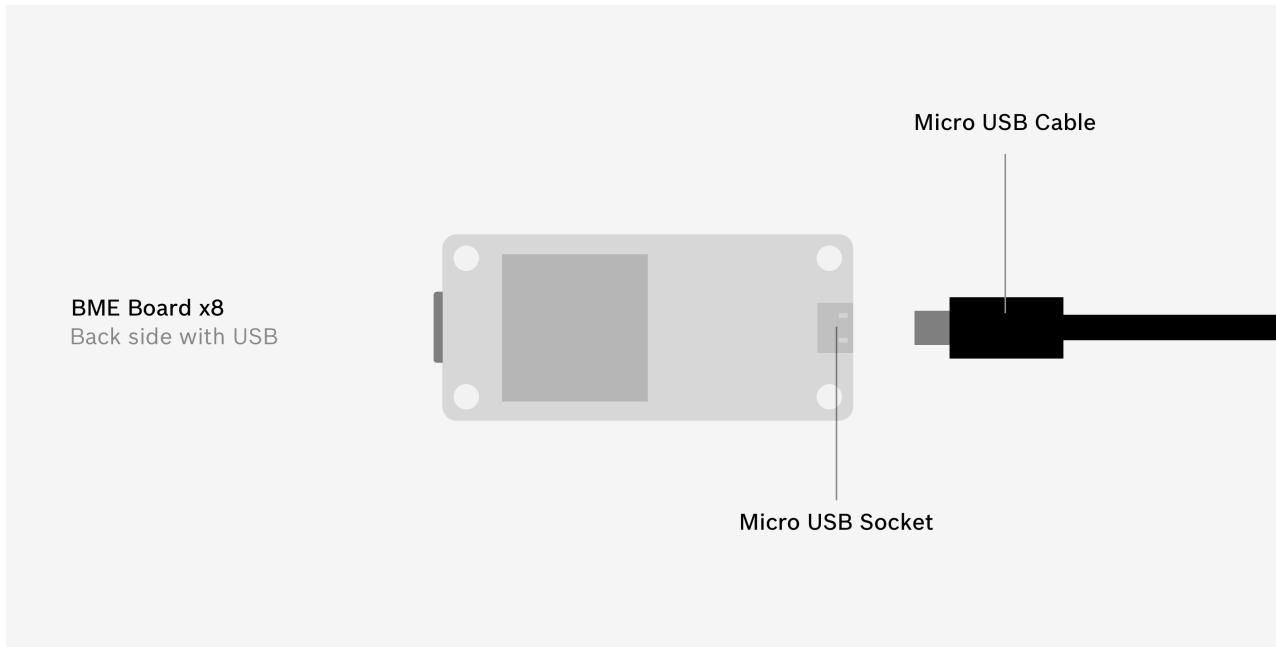
Fig. 9: BME board x8 Back

Other board types `Coming soon`

In a future release of BME AI-Studio we plan to have the possibility to chose other BME Boards.

2.1.3 Board Mode

The board mode can be set to different modes, depending on your goal.

> **Warning**
>
> Fabric-new boards need to undergo a stabilization procedure. For stabilization you can use any board mode as long as you let it run for 24 hours.

▶ **Sensorboard Default HP/RDC** is used to perform standard measurements. It uses the HP-354 heater profile, a versatile and short profile, which is best to begin with.

▶ **Heater Profile Exploration** is used to scan a variety of Heater Profiles in order to find the one best suitable for a specific use case. In this mode you are able to choose multiple Heater Profiles, but only one Duty Cycle.

▶ **Duty Cycle Exploration** is used if you want to optimize the Duty Cycling for a given Heater Profile. In this mode you are able to choose multiple Duty Cycles, but only one Heater Profile. Usually this mode is used for optimizing the energy efficiency, when you already found the best Heater Profile for your use case.

2.1.4 Heater Profile

In this section you can choose the Heater Profiles to be used in the Sensor Board configuration.

Select Heater Profiles

In order to make a selection of Heater Profiles, click on Select Heater Profiles ... and choose the desired Heater Profiles from the list. You can select multiple Heater Profiles, if you have chosen "Heater Profile Exploration" as Board Mode. You can select only one Heater Profile, if you have chosen "Duty Cycle Exploration" as Board Mode. Each Heater Profile can be viewed with its temperature sequence (graph and table) as well as a description of its purpose.

> Different groups of Heater Profiles
>
> The pre-defined Heater Profiles can be viewed as profiles that belong to different profile groups. This is also indicated by the numbering system within the name of the Heater Profiles. While exploring new use cases it is good advise to try Heater Profiles from various groups in the first place. Once it is clear which group of Heater Profiles work best you may explore this group in depth, by recording data with various Heater Profiles from this group and compare the results.

Maximum number of Heater Profiles

The maximum number of Heater Profiles (in Heater Profile Exploration) is given by the board type:

▶ BME Board x8 can be configured with a maximum of 4 Heater Profiles

Review Heater Profiles

Once you have selected your desired Heater Profiles, you will see them in the corresponding table. To quickly remove Heater Profiles from the list, you can click on X .

> **Please note**
>
> If you have chosen "Sensorboard Default HP/RDC" for Board Mode you can not choose any Heater Profile. The standard profile is selected automatically.

Individual Heater Profiles

In the current version of BME AI-Studio you can choose pre-defined Heater Profiles. In a future release we plan to have the possibility of defining individual Heater Profiles.

2.1.5 Duty Cycle

In this section you can choose the Duty Cycles to be used in the Sensor Board configuration.

Select Duty Cycles

In order to make a selection of Duty Cycles, click on Select Duty Cycles ... and choose the desired Duty Cycles from the list. You can select multiple Duty Cycles, if you have chosen "Duty Cycle

Exploration" as Board Mode. You can select only one Duty Cycle, if you have chosen "Heater Profile Exploration" as Board Mode. Each Duty Cycle can be viewed with its specific number of Scanning Cycles and Sleeping Cycles and a schematic.

Additionally, you can see the percentage of Scanning Cycles within one iteration of a Duty Cycle. E.g. a 25% value means that for a quarter of the overall time the sensor is in scanning mode. This ratio also translates to the estimated energy consumption.

Maximum number of Duty Cycles

The maximum number of Duty Cycles (in Duty Cycle Exploration) is given by the board type:

▶ BME Board x8 can be configured with maximum 4 Duty Cycles

The table shows you the selected Duty Cycles. By clicking on X you can easily remove Duty Cycles from the list.

Individual Duty Cycles

In the current version of BME AI-Studio you can choose pre-defined Duty Cycles. In a future release we plan to have the possibility of defining individual Duty Cycles.

2.1.6 Board Layout

This option determines how the HP/RDC combinations are distributed over the available sensors on the BME Board. You can choose between three options:

▶ **Grouped** places the combinations in a grouped way on the board. This can be thought of sequentially picking the sensors combination by combination and placing them on the board. It is the most obvious and easy to understand distribution.

▶ **Shuffled** places the combinations in a shuffled or alternated way. This can be thought of sequentially picking sensors from each group and placing them on the board. This option gives a reproducible and evenly distribution. You may want to use this combination if you want to avoid grouping of sensors at certain positions on the BME Board. This may come in handy when you flush the BME Board with a focused stream of gas and you want to avoid the risk of having a systemic error in the gas concentrations per sensor configuration.

▶ **Random** places the combinations in a randomized way. This can be thought of mixing sensors from each group and placing them on the board. This option gives an unintentional and evenly distribution. You may want to try selecting this option multiple times to get a new and independent randomization each time.

If the number of sensors on the BME Board is not divisible by the number of combinations, there will be residual sensors. These are filled up in an unbalanced manner, independent of the chosen board layout.

The actual distribution is shown in the corresponding schematic.

2.2 Record Data

2.2.1 Overview

Once you configured your BME Board, you are ready to make some measurements and record data. During this step, you don't need the BME AI-Studio application. You can record data with just the BME Board.

In order to produce meaningful data, you should pay attention to the following important points:

▶ **Try to capture realistic situations**
The data that you record will later be used to train algorithms. In order to evaluate whether the algorithm will work under realistic conditions it is important to record data under realistic conditions as well.This means: if you want to distinguish apples from oranges that are lying on a table with the BME688 gassensor, do not record data where you cut the fruit and put it in a closed box with the sensor. Gas concentrations will be very different from the use case you intend to have later.

▶ **Take some time**
Depending on the Heater Profiles and Duty Cylces you are using the sensor takes between 15 seconds and several minutes for each measurement. Try to collect at least 50 data points (which is a recording duration of 50 times the Duty Cycle length) per situation. This means: if you use a Duty Cycle with a duration of 30 seconds, try to record each situation for at least 30 minutes.

▶ **Vary the situations**
Try recording the use case you intend to do in various situations and across multiple days. The more you vary the more robust your algorithm will be. Temperature and humidity have a substantial influence on the sensitivity and selectivity of the sensor. Measuring across different situations and with different background gases will increase the variety of measurements that go into the training of the algorithm, which will give you a better feedback on how robust the algorithm is across different situations

Some questions you could ask yourself

Depending on what you want to measure, it is important to prepare the appropriate setup and context. Some questions you should ask yourself:

▶ What do I want to measure? What is my Specimen?

▶ Can I reproduce the Specimen and if yes, how?

▶ Does the measurement take place inside or outside?

▶ How could the sourroundings affect the measurement?

▶ Which nuisances could influence the use case and need to be included?

> **Warning**
>
> Do not touch the sensors with your fingers. Fat on your skin will stick to the surface of the sensor enclosure and outgas for a long time. This will alter your gas recordings and lead to the training of unrealistic algorithms.

2.2.2 Start recording
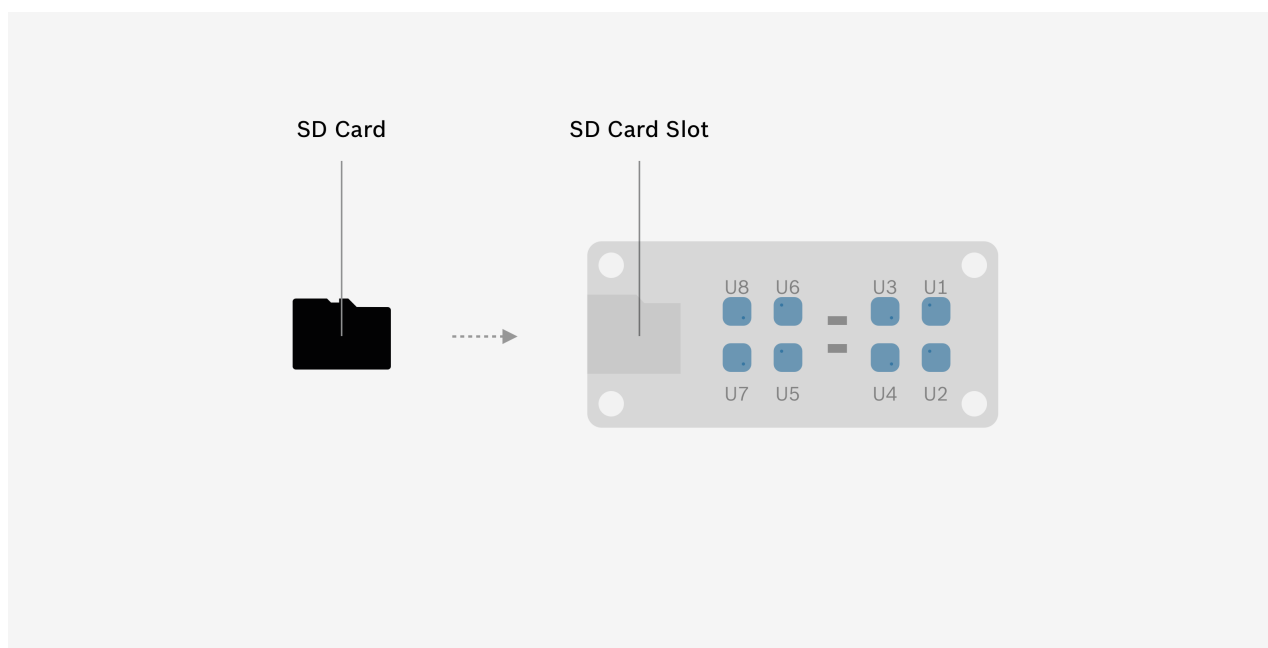
Fig. 10: Inserting SD Card

Insert the SD card into the BME Board. The SD card slot is on the top side of the BME Board. Insert the card with its contacts facing towards the upper circuit board.

BME Board x8
Bottom side with USB

Red LED blinks every two
seconds when recording data
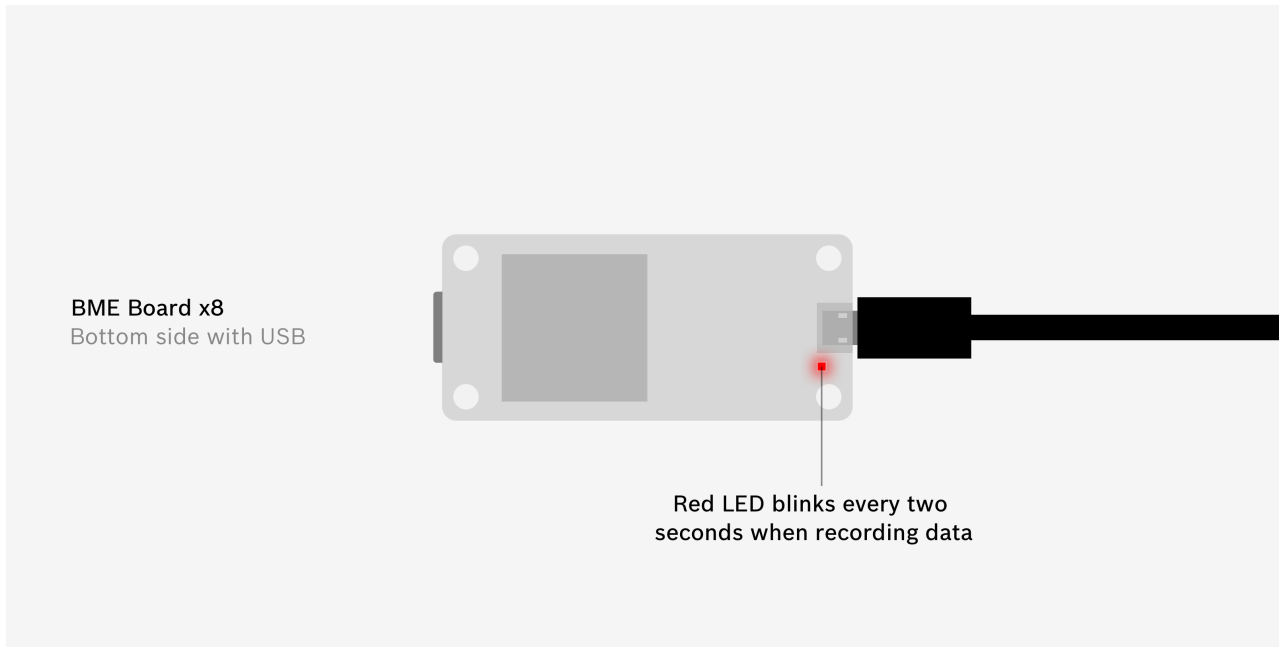
Fig. 11: Start Recording

Connect the BME Board to power with a Micro USB cable. Once the board is connected to power it will automatically turn on and start recording. The red LED next to the USB connector should blink every two seconds. If it blinks rapidly, the board is not recording.

Best practice

The BME Board x8 has an internal battery to keep track of time, but it is good practice to note down the exact date and time when you start your recording, so you can verify the data later.

Using BME Board with a Battery Pack

For recordings in closed environments you can use a battery pack to power the sensor board. A battery pack with 10.000 mAh should power your board for at least 24 hours, depending on the Duty cycle used and the surrounding temperatures.

2.2.3 During recording

You can record multiple Specimens during your Measurement Session without the need to turn off the BME Board. To mark different Specimens during your recording on the fly, you can either press the buttons on the BME Board or use the BME mobile App:

Define Specimens during measurement via on-board buttons

During measurement you can use either Button 1 (labeled S1) or Button 2 (labeled S2) on the BME Board x8 to mark specific moments as a new Specimen. If you do, these Specimen definitions will appear as Specimens during data import.
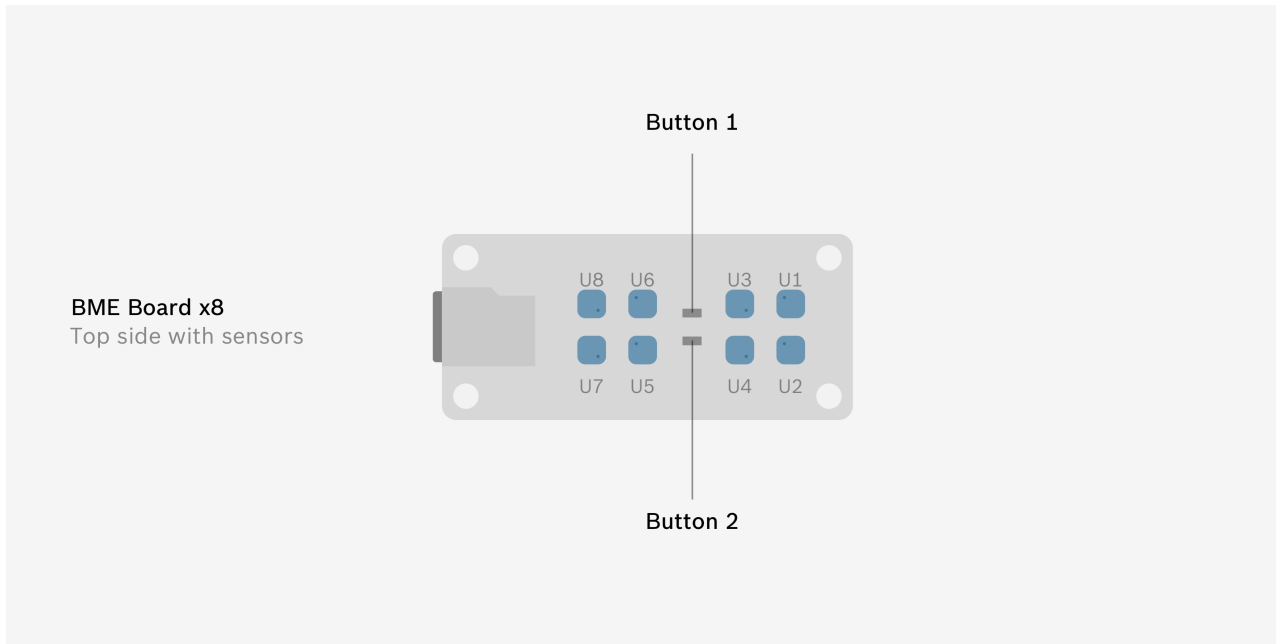
Fig. 12: During Recording

Define Specimens during measurement via BME mobile app Coming soon

Documentation for the BME mobile app will be added soon.

Define Specimens manually during data import

You can also add Specimen definitions manually during import. See Import Data for further details.

> **Best practice**
>
> As with the start of your recording, we recommend keeping notes of which Specimens were recorded with the exact date and time for each Specimen.

2.2.4 End recording

Once you are finished recording your Specimens, you can simply unplug the power. The BME Board will turn off and the recording will stop.
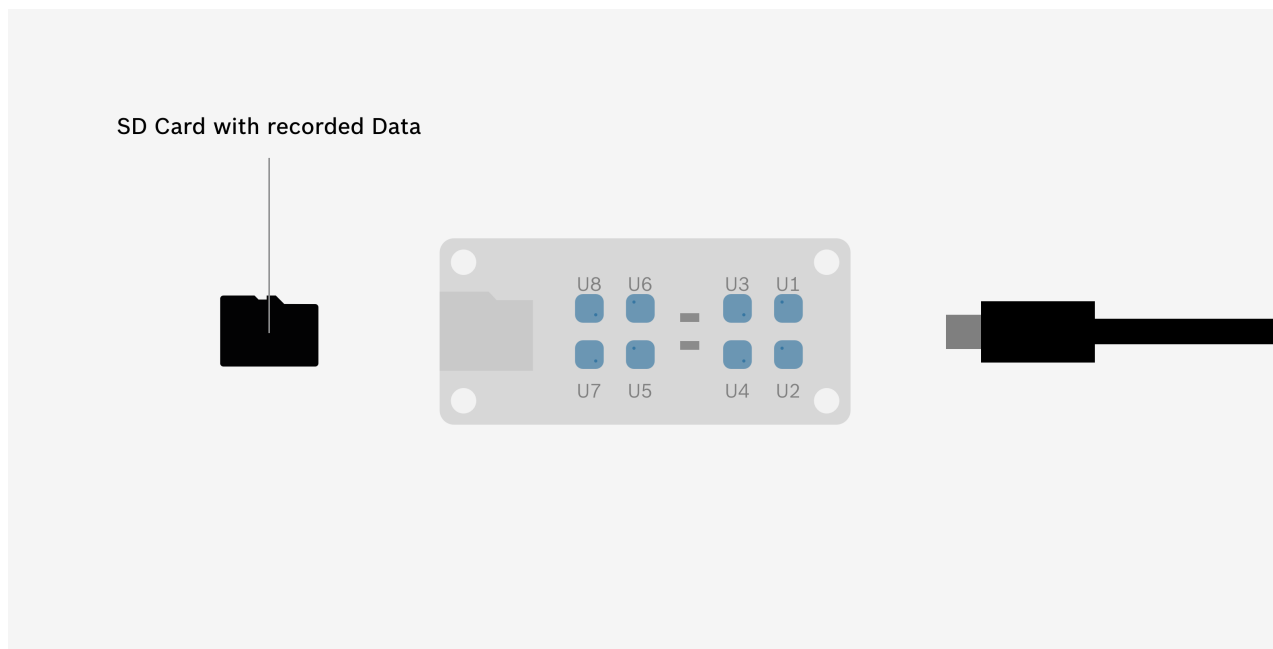
Fig. 13: End Recording

2.3 Import Data

2.3.1 Overview

After you recorded data with the BME Board, it is now time to import the data into the application. During import, you can verify the data and define your Specimens. You can import several measurements and collect everything in your Specimen Collection, before later proceeding to train Algorithms. You can import data into a new project or into existing projects.

Access Files on SD Card

After your measurements, take the SD card out of the BME Board. Access the files on the SD card from your computer via an SD card reader.

SD Card with recorded Data

SD Card Reader   Computer with BME AI-Studio
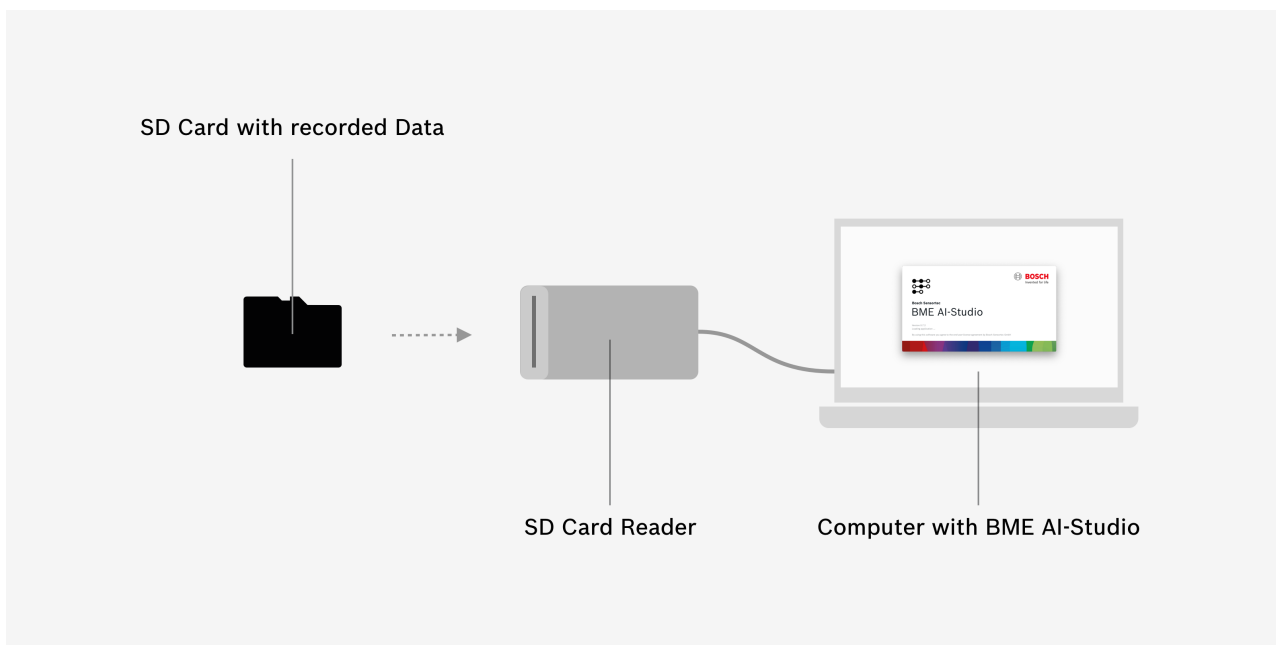
Fig. 14: Start Recording

> **Please note**
>
> If you do not see any data on the SD card, it is likely your board needs to be configured. To create a configuration file for your board, please see Configure Board.

Importing Raw Data

Open the application and create a new project by clicking Create new project on the Welcome screen. Alternatively, you can open the menu and select New project... . Next, a file dialogue opens. Please select, where you want to save your new project.

If you want to import data into an existing project, just open the project and switch to your Specimen Collection .

Now, to import data, click `Import Data` . A file dialogue opens. You can

▶ select the Raw Data File directly from the SD card.

▶ first copy the Raw Data File from the SD card onto your computer hard drive, and then select the file from your hard drive.

Once you selected the Raw Data File, the data is being imported into your project and stored within the project folder of your project.

A new overlay opens that gives you an overview over the recorded data and lets you define your Specimens within the recording.

Importing Specimen Data

You can also import Specimen Data, that you exported from another project. The Specimens will be imported including their respective Measurement Sessions.

> **Please note**
>
> If you import Specimens that are already part of your project, the Specimens will im-ported as second duplicate. This can be interesting, if you want to weight specific Specimens as double or triple within algorithm training.

Importing whole projects

You can also import a whole project, by selecting the respective project folder. All Measurement Sessions and their Specimens will be imported.

2.3.2 Data Overview

This section gives you a brief summary of the data you just imported into your project. Verify the information to make sure everything went fine during your measurement:

▶ **Adjacent raw data files:** If the data was automatically split into multiple parts during measurement, BME AI-Studio automatically recognizes all adjacent files and imports them as well, no matter if you choose the first or any other of these files. Automatic splitting of Raw Data files can happen when the BME Board power is switched on/off or the file limit (297 MB) is exceeded during measurement.

▶ **Number of sensors found within raw data:** This number should correspond with the number of sensors on the BME Board used to record the data. If you used the BME Board x8, which has eight sensors, the imported Raw Data should include data from eight sensors as well. However, in some cases the number of sensors found within the data does not match with the number of sensors on the board. This usually indicates that one or more sensors were malfunctioning or not recording any data for some reason.

▶ **Number of HP/RDC Combinations found within raw data:** This number should correspond with the specific BME Board Configuration used to record the data. E.g. if your configuration included four Heater Profiles and one Duty Cycle (so 4 HP/RDC Combinations in total), the imported Raw Data should include data from four HP/RDC Combinations as well. However, in some cases the number of HP/RDC Combinations found within the data does not match with the original BME Board Configuration. This usually indicates that one or more sensors were malfunctioning or not recording any data for some reason.

2.3.3 Board ID

This indicates which BME Board has been used to record the data. Each board has a unique ID that is permanently stored on the board itself, which makes it uniquely identifiable.

2.3.4 Board Type

This indicates the type of BME Board used to record the data.

2.3.5 Board Mode

This indicates the Board Mode in which the BME Board was configured in when used to record the data.

2.3.6 Session Name

Give your Measurement Session a name – this could be a topic, a specific location or special occasion. Choose your Session name in a way that helps you identify and distinguish your Measurement Session later on.

2.3.7 Session Date

This indicates the date and time the Measurement Session has been recorded. Within the Raw Data, the time information is stored in Coordinated Universal Time (UTC) and is here automatically displayed in your respective local time zone. You can manually overwrite the time information if needed.

Start Date

The time the BME Board was powered on.

End Date

The time the BME Board was powered off.

> **Please note**
>
> If your BME Board lost its time information (e.g. if you disconnected the battery of BME Board x8), the date and time of the Measurement Session will always be January 1, 1970 by default. In this case, please overwrite the date and time with the actual correct date and time of your measurement.

2.3.8 Specimen Data

This section gives you a visual representation (data plot) of the Measurement Raw Data and an overview of the Specimens in this session.

Specimens within a Measurement Session reflect what you have measured during that session. This can be an object, a specific situation, a smell, gas, etc. – or in other words: One specific gas composition the sensors on the BME Board were exposed to during the measurement.

Defined Specimens are shown in the data plot as well as a list below.

Data Plot

You can view the Specimen Data in a visual plot. You can switch between:
- ▶ Four Data Channels
- ▶ Gas Data Channel
- ▶ Humidity Data Channel
- ▶ Temperature Data Channel
- ▶ Barometric Pressure Data Channel
- ▶ each Sensor on the BME

Define Specimens during measurement via on-board buttons

During measurement you can use the two buttons on the BME Board x8 to mark specific moments as a new Specimen. If you did, these Specimen definitions will appear in here this section (in the data plot and in the list of Specimens below). See Record Data for further details.

Define Specimens during measurement via BME mobile app `Coming soon`

Documentation for the BME mobile app will be added soon.

Define Specimens manually during data import

You can also add new Specimen definitions manually during import by clicking Add Specimen . This creates a new Specimen definition in the list and you can specify the respective start and end time

within the Measurement Session. You can also add the corresponding Label here.

Edit Specimen Definitions during data import

You can edit the start and end time of Specimen definitions manually. When editing a Specimen definition, the respective area is highlighted in the data plot above.

> **Good to know**
>
> Although it is possible to define "overlapping" Specimens within a Session where the end time of the first Specimen lies after the start time of the second Specimen (so the same data is used in two Specimens), we recommend not doing so.

> **Please note**
>
> The start and end time of Specimens can not exceed the start and end time of the overall session.

Label Specimens

You can label your recorded Specimens either here during Import, or later within the Specimen Collection (see Collect Specimens).

Delete a Specimen definition

You can easily delete a Specimen definition by clicking the X button.

2.4 Collect Specimens

2.4.1 Overview

Once you imported the Raw Data files from your measurements, you find the imported data as individual Specimens in your Specimen Collection . The Specimens in this list are grouped by Measurement Session and sorted by import date by default. You can organize all your data here, before later proceeding to train Algorithms.

Fig. 15: Specimen Collection

The purpose of the Specimen Collection is to collect various Specimens that belong to one use case. You may collect a lot of different Specimens over time and use different combinations of Specimens to try out the training of different algorithms.

Good to know

It is recommended to start a new project (with a fresh Specimen Collection) for each use case you want to investigate. Therefore you can collect all Specimens that you want to use for training of use-case-specific algorithms within one project. You can easily export Specimens and import them in other projects.

Sort Specimens

You can change the sorting of Specimens by clicking repeatedly on the respective column header on top of the list. A little caret icon indicates the sorting direction:

▶ ∧ means ascending order (A-Z, 0-9, early-late)

▶ ∨ means descending order (Z-A, 9-0, late-early)

Search Specimens

You can search for specific Specimens within the Specimen Collection via the search field above the list. Once you entered a search term, the list below will be filtered according to your search and show only Specimens matching your search.

Measurement Session Settings

After importing Measurement Raw Data into your Specimen Collection you can always come back to the settings of each Measurement Session. Click the Settings button next to each Measurement Session in your Specimen Collection to access these settings.

Here you can see information about the session, change its name and date, as well as edit Specimen definitions, add additional Specimen definitions or remove them.

See Specimen details

Once you select a Specimen within the Specimen Collection, detail information of the selected Specimen is shown on the right hand side. Here you can add and change the label of the Specimen, add and edit a corresponding comment, and see all additional details regarding the Specimen.

Select multiple Specimens

You can also select multiple Specimens by clicking on the respective checkbox on the right hand side of each list entry. The detail information on the right now reflects which information has equal values and which information has multiple values within your selection.

If you select the checkbox of a whole Measurement Session, all Specimens within that session are selected. If you select the checkbox inside the column header of the Specimen Collection, all Specimens of all Measurement Sessions are selected.

Export Specimen Data

Once you select one or multiple Specimens, you can export these Specimens as individual files. Each file will include everything related to that specific Specimen, including its Label, Comment, etc.

Export Specimen Data if you want to use these Specimens in another BME project, if you want to share the data with others or if you want to manually back up that data.

Delete Specimens

Once you select one or multiple Specimens, you can delete these Specimens from your Specimen Collection. BME AI-Studio will ask you to confirm the action before deleting the Specimens.

The action can not be undone, however only the definition of the Specimen (e.g. its start and end time, its Label, etc.) is deleted. The underlying Measurement Raw Data will be kept in the background, as

long as you have one or more other Specimens from the same Measurement Session in your collection. If you delete all Specimens from a session, the Measurement Raw Data will be deleted as well.

> **Please note**
>
> Be careful with deleting Specimens that you associated with a class as part of an algorithm. After deleting the Specimen, it will be missing from your class and therefore affect the outcome of the algorithm training.
> If you try to delete a Specimen which is or has been associated with a Class as part of an Algorithm, BME AI-Studio will give you warning.

2.4.2 Label

The label of each Specimen specifies what exactly has been measured – this could be an object, a specific situation, a smell, gas, etc. You can confirm your edit by pressing Enter or selecting the blue √ button. If you press ESC or select the grey X button, your edit will be discarded and the original value of the field will be kept.

> **Good to know**
>
> Label your Specimens as explicitly and clear as possible. "Apple Granny Smith, 1 day old" is better than "Apple 1".

> **Please note**
>
> Labels are not to be confused with classes. Labels can include additional information and differentiate Specimens, that will later go into the same class. E.g. you might want to label your Specimens "Red apple", "Green apple" and "Apple bio", but use all three of them in one Class called "Apples".

2.4.3 Comment

Add a comment to your Specimen to add extra information or notes. This might help you identify and distinguish your Specimen later on.

2.4.4 Session

This indicates the Measurement Session the selected Specimen belongs to.

2.4.5 Start & End Time

This indicates the date and time the selected Specimen has been recorded within the respective Measurement Session. Within the Raw Data, the time information is stored in Coordinated Universal

Time (UTC) and is here automatically displayed in your respective local time zone.

2.4.6 Duration

This indicates the length of the measurement of the selected Specimen, according to its start and end time.

2.4.7 Cycles Total

This indicates the total number of Scanning Cycles in the Measurement Raw Data of the selected Specimen.

> **Please note**
>
> Since each Heater Profile has slightly different cycle lengths, the number of Scanning Cycles within a Specimen can vary and might be different for equal measurement durations.

2.4.8 Cycles Dropped

This indicates the number of Scanning Cycles that have been dropped during import. When importing Raw Measurement Data, BME AI-Studio automatically checks the data of every Scanning Cycle and excludes incomplete cycles from the import.

The number of dropped Scanning Cycles is also indicated as a percentage of the total number of Scanning Cycles.

2.4.9 Remaining Cycles

This indicates the number of remaining Scanning Cycles of the selected Specimen after dropping incomplete cycles.

2.4.10 Board Configuration

This section provides detail information about the BME Board which was used to record the data of the selected Specimen. You can see the unique board ID, the board type and access the BME Board Configuration used by clicking Show configuration . This opens up an overlay with the following information:

Board Type

This indicates the type of BME Board used to record the data of the selected Specimen.

Board Mode

This indicates the board mode in which the BME Board was configured in during recording of the data of the selected Specimen.

Heater Profiles

The Heater Profile or list of Heater Profiles used to record the data of the selected Specimen. If multiple Heater Profiles have been used, you can click Show Heater Profiles to see additional details of each Heater Profile.

Duty Cycle

The Duty Cycle or list of Duty Cycles used to record the data of the selected Specimen. If multiple Duty Cycles have been used, you can click Show Duty Cycles to see additional details of each Duty Cycle.

Board Layout

This indicates how the HP/RDC combinations were distributed over the available sensors on the BME Board during recording of the data of the selected Specimen.

2.4.11 Board ID

This indicates which BME Board has been used to record the data of the selected Specimen. Each board has a unique ID that is permanently stored on the board itself, which makes it uniquely identifiable.

2.4.12 Board Type

This indicates the type of BME Board used to record the data of the selected Specimen.

2.4.13 Board Mode

This indicates the board mode in which the BME Board was configured in when used to record the data of the selected Specimen.

2.4.14 Show Configuration

You can see the Board Configuration of the BME Board which was used to record the data by selecting Show Configuration .

2.5 Train Algorithms

2.5.1 Overview

Within the section | My Algorithms | you are able to use the data collected in your Specimen Collection to train (classification) algorithms. You are able to create multiple algorithms with a different data basis as well as various settings. Once trained you can compare the performance of the different algorithms and choose the one algorithm that fits best your use case (see Evaluate Algorithms). An algorithm can be exported as file for the BSEC Software (BME Library), which is basically a set of specific settings for the sensor, that enables it to distinguish different gas compositions, once provided with these settings.

Create new Algorithm

First switch to | My Algorithms |, then select | New Algorithm | to create a new Algorithm. On the left you will see all your algorithms in a list view.

See Algorithm details

Once you select an algorithm within that list of algorithms, detail information of the selected algorithm is shown on the right hand side. Make sure you select | Algorithm Settings |. Here you can set up everything for the training of your Algorithm.

Train Algorithm

After setting up your algorithm, you can click | Train Algorithm | to start the training. Depending on the amount of data, the training can take from a few seconds up to several minutes. After the training, you can see the training results under | Training Results |. Jump to Evaluate Algorithms for further information.

Duplicate Algorithm

Once you select an algorithm, you can duplicate that algorithm, if you want to repeat your training with slightly different settings. Just click | Duplicate Algorithm | on the bottom of the screen or via the context menu by clicking | ... |.

Delete Algorithm

Once you select an algorithm, you can delete that algorithm by clicking | Delete Algorithm | on the bottom of the screen or via the context menu by clicking | ... |.

2.5.2 Name

Give your algorithm a name. Choose a name that might help you to identify and distinguish your Algorithms later on.

2.5.3 Created

The date and time you created that algorithm.

2.5.4 Classes

Classes are the most important part of your algorithm. Each class represents one of the different gas compositions you want to distinguish in your use case. For example, if you want to distinguish apples and oranges, you would create two classes – one class for apples, one class for oranges.

Once you created a class, you can then select Specimens from your Specimen Collection to add to that class. For example, if you recorded data from five different apples, you would add these Specimens to your apple class. And those Specimens where oranges were recorded, you would add to your oranges class.
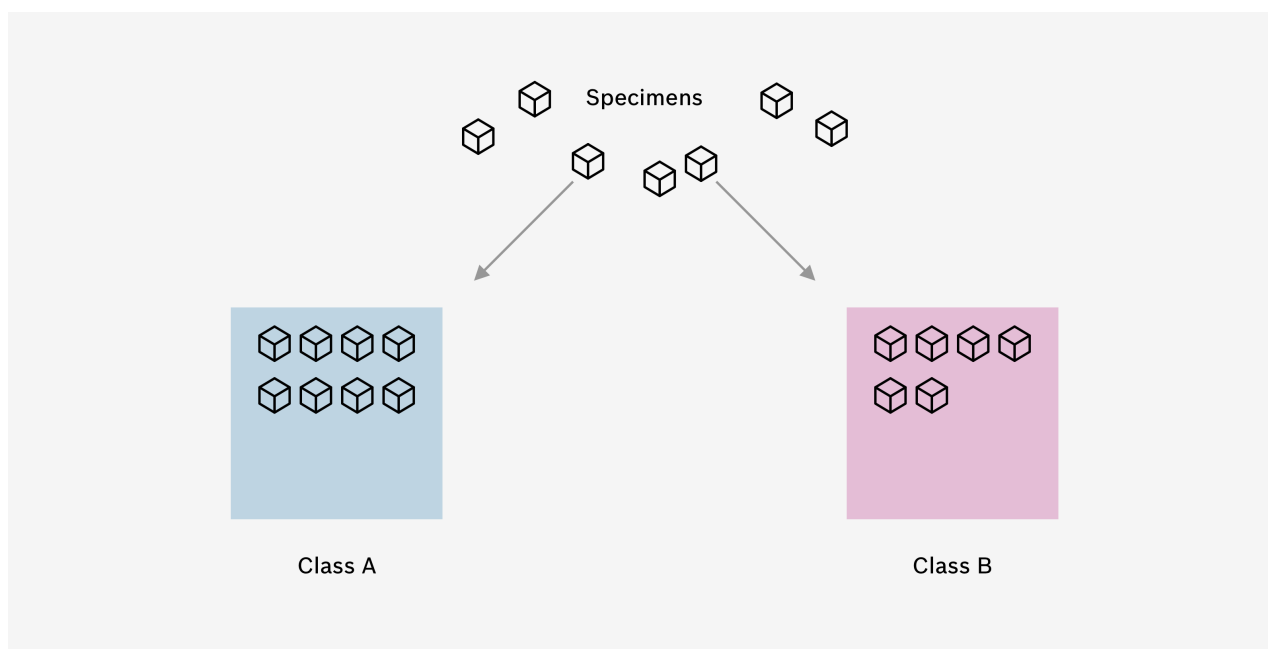
Fig. 16: Train Algorithms

2.5.5 Class Name & Color

Give your class a name that describes the gas composition you want to distinguish. Additionally, you can give your class a color of your choice.

2.5.6 Common Data

After adding Specimens to your classes, BME AI-Studio will check the underlying data and the corresponding Heater Profiles and Duty Cycles, which were used to record that data. This section indicates, how many different combinations of Heater Profiles and Duty Cycles were found within all the data, and how many of these combinations are shared with all selected Specimens. If there is a little checkmark, everything is okay and there are common HP/RDC combinations found for training.

44

2.5.7 Data Balance

This indicates how the data for your algorithm training is distributed over your classes. Ideally the distribution should be balanced. If there is a little checkmark, everything is okay and the data is balanced enough for training.

How Data Balance is calculated

Each class consists of multiple Specimens and each Specimen has a duration. The application checks if the total duration (sum of all Specimen durations) of any of the classes is below the following threshold:

threshold = 24% / number of classes

E.g.

▶ threshold for 2 classes: 12%

▶ threshold for 3 classes: 8%

▶ threshold for 4 classes: 6%

2.5.8 Data Channels

Specimen Data includes four data channels. You can choose, which Data Channel of each Specimen should be part of the training:

▶ Gas Data Channel (10 data points)

▶ Humidity Data Channel (1 data point)

▶ Temperature Data Channel (1 data point)

▶ Barometric Pressure Data Channel (1 data point)

By default, only the Gas Data Channel is used for training. If other channels play a key role in your use case, you can try to include additional channels in the training and compare the training results.

Please note

Be careful with **using additional channels** for your training. Using additional Data Channels does not automatically mean better training results. The algorithm might focus only on one of the additional Data Channels during training, which might not be what you actually want. E.g. if one of your recorded Specimens has a strong impact on humidity, the algorithm might only focus on the correlation between the Specimen and the corresponding rise in humidity, ignoring all other data. Your training results may look very good, but the algorithm only "learned" to distinguish your Specimen by looking at the humidity, completely ignoring the respective gas data.

> **Please note**
>
> Be aware that including the **Temperature Data Channel** and **Humidity Data Channel** needs careful attention, since the temperature and relative humidity may not directly reflect the environmental conditions. This is due to the fact that both values are measured inside the metal packaging, which can be affected by self-heating effects of the BME688. For example running the sensor in a continuous cycling leads to a significant temperature increase inside the metal packaging and thus to a decrease of the relative humidity. This introduces transient effects on the recorded data, that do not originate from the actual sample you are measuring and therefore may mislead the training of the algorithm.

> **Please note**
>
> Be aware that including the **Barometric Pressure Data Channel** may introduce unwanted side effects. Since the barometric pressure signal is changing with your local weather, this may have an uncontrolled influence on the training process. Only include the Barometric Pressure Data Channel if you are sure that different Specimen or situations differ in their barometric pressure signal.

2.5.9 Neural Net

Here you can see the Neural Net Architecture used for the training of the algorithm.

Choose other Neural Nets `Coming soon`

In the current version of BME AI-Studio you can choose one pre-defined Neural Net Architecture. In a future release we plan to have the possibility of chose other architectures.

2.5.10 Training Method

Choose the training method for the training. In this version of BME AI-Studio, only one optimizer function is available (ADAM optimizer). You can choose between different batch sizes:

▶ ADAM optimizer, batch size 4

▶ ADAM optimizer, batch size 16

▶ ADAM optimizer, batch size 32

▶ ADAM optimizer, batch size 64

The batch size tells you how many data-points are taken into account for the optimization at once. This has influence on the training speed and stability.

As a rule of thumb, one can say the larger the batch size is the faster and more stable the training will be. The disadvantage of having larger batch sizes and the reason to go to smaller batch sizes is that it is more likely for the algorithm to be stuck in a local minima.

> **Please note**
>
> This is an expert setting. If you wan't to know more about Training Rounds, please get in touch with us.

2.5.11 Max. Training Rounds

Choose the maximum number of training rounds for the training.

> **Please note**
>
> This is an expert setting. If you wan't to know more about Training Rounds, please get in touch with us.

2.5.12 Data Splitting

Choose how much data should be used for training and testing respectively.

> **Please note**
>
> This is an expert setting. If you wan't to know more about Training Rounds, please get in touch with us.

2.6 Evaluate Algorithms

2.6.1 Overview

The evaluation process of Machine Learning algorithms is maybe the most important part of all. It is about evaluating the performance of the different neural nets trained for each HP/RDC combination. Not only does the evaluation tell you how good the predictions of the algorithm are, but you also get information on how robust and stable the algorithm will operate in the field.

> **Good to know**
>
> The performance of an algorithm should always be evaluated as a compromise of two factors:
>
> ▶ Variance of the input data (the more variance the better)
>
> ▶ Accuracy of the neural net (the higher the better)

Too little variance

An example: You want to distinguish coffee from normal air and you trained your algorithm with data from freshly opened coffee only. So that means, the neural net only knows the smell of fresh coffee compared to normal air and you are probably getting great results with high accuracies and F1 Scores, as well as low False Positive rates. However, this does not necessarily imply that the algorithm would give you a great performance in all coffee situations. It only means that in this special situation (with freshly opened coffee) you are achieving good performance. So in order to get meaningful performance evaluations as well as effective training, it is important to reflect the variance of different situations also within the data recording used for training.

Too much variance

If your neural net performance is very low, you might try to reduce the variance of the data and experiment with different subsets of the original data used for training. This might lead to better performance results, which give you some indication on which situations are very easy to handle for the algorithm and which are not.

2.6.2 Confusion Matrix

The Confusion Matrix describes the performance of a (classfication) algorithm. Therefore it uses the Test Data, which was defined before the training and was not used for training (see Data Splitting). The individual matrix elements represent how many samples of the actual test have been predicted to a certain class.

For a perfect algorithm all test data samples have been predicted to their actual class, which are the diagonal elements of the Confusion Matrix. Off-diagonal elements represent false predictions and you may find it interesting which kind of false predictions are present.
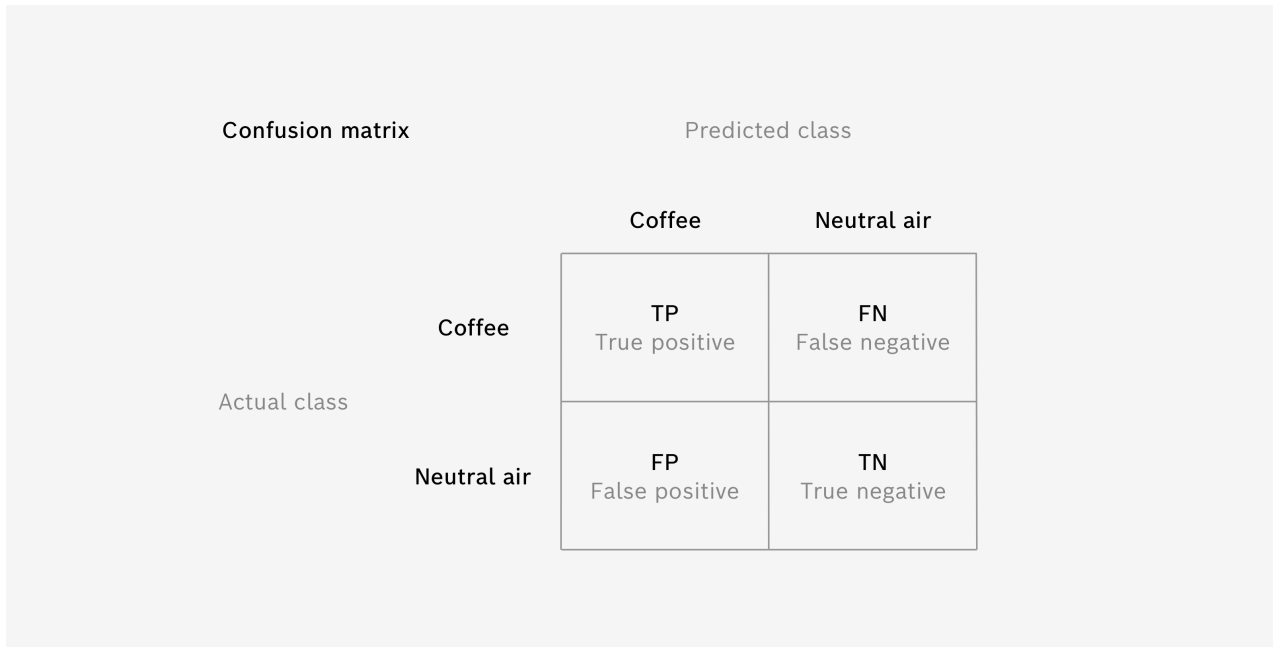
Fig. 17: Confusion Matrix

The Confusion Matrix also helps you evaluate how severe errors are for your specific use case. False alarms in one or the other direction may be very different in their impact on your use case. For example, if you want to detect coffee to warn the user, who maybe has an allergy against coffee, the case where the algorithm missed to detect coffee (so called "False Negative case") is much more severe than the opposite way, where you have an alarm, although there is no coffee involved (so called "False Positive case").

2.6.3 Accuracy

The accuracy is the standard performance measurement for a (classification) algorithm. It tells you how likely it is that the algorithm will give the correct classification.

In other words it gives the ratio between correct and incorrect predictions. It is calculated by dividing the sum of the diagonal elements of the Confusion Matrix by the total sum of all elements (which is the amount of Test Data used).

2.6.4 Macro-averaged F1 Score

The F1 Score is another performance indicator on how well the prediction of test data samples is working. It comes in handy when class distributions are unevenly distributed and therefore accuracy values are harder to interpret.

$$R = \frac{TP}{TP + FN} \quad \text{Recall per class}$$

$$P = \frac{TP}{TP + FP} \quad \text{Precision per class}$$

$$MR = \frac{1}{n} \sum_{i=1}^{n} R_i \quad \text{Macro-averaged recall}$$

$$MP = \frac{1}{n} \sum_{i=1}^{n} P_i \quad \text{Macro-averaged precision}$$

$$F1 = \frac{2 \cdot MR \cdot MP}{MR + MP} \quad \text{Macro-averaged F1 Score}$$
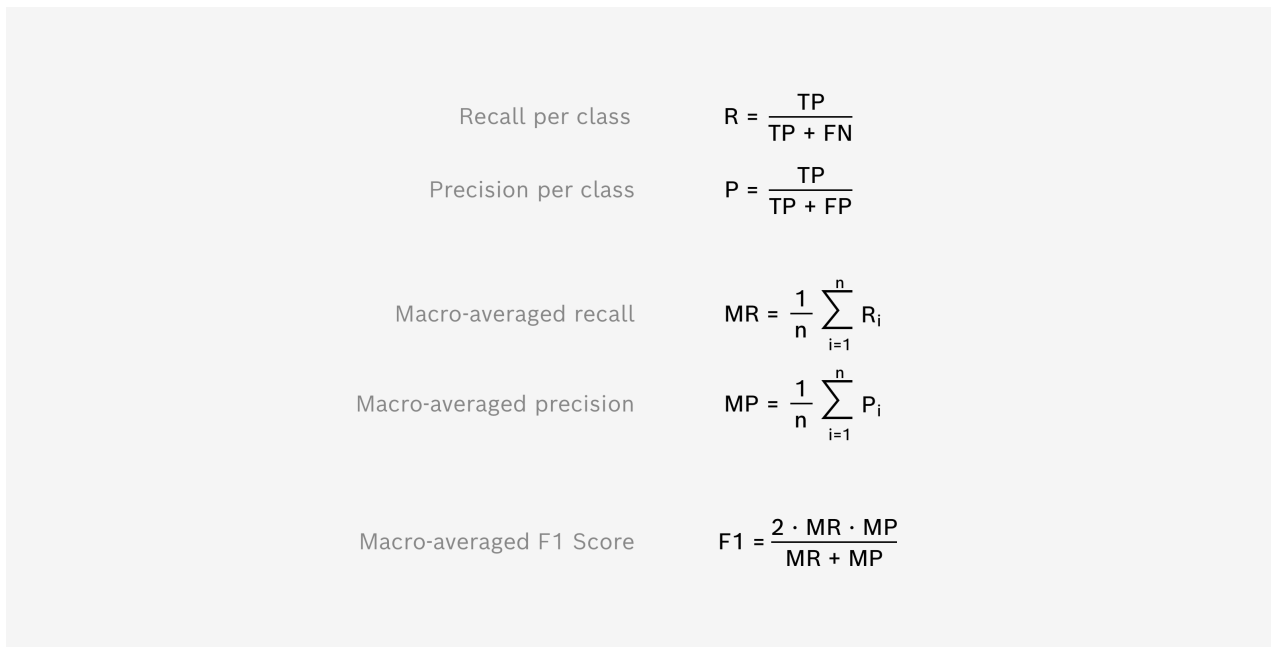
Fig. 18: Macro-averaged F1 Score

It is based on the recall and precision, two quantities that relate the True Positive case with its false alarms. Recall relates between all correctly predicted elements to a given class and all elements that actually belong to this class. While Precision relates between all correctly predicted elements to a given class and all elements that were predicted to this class. Both values are calculated for each class and then averaged (so "called macro-averaging"). The shown F1 Score represents the harmonic mean of macro-averaged recall and precision.

Further information on performance measures

We follow the findings of *Sokolova, Marina, and Guy Lapalme. "A systematic analysis of performance measures for classification tasks." Information processing & management 45.4 (2009): 427-437* in order to use F1 Score as a harmonic mean of macro-averaged recall and precision rather than calculating the macro-average of class independent F1 Scores.

2.6.5 Macro-averaged False Positive rate

The False Positive rate (also called miss rate) gives you an indication of how many false alarms (or more general: how many false predictions) will happen in your algorithm. Therefore a lower False Positive rate indicates a better performance of the algorithm.

The False Positive rate is defined as the relation between elements that belong to a different class, but have been falsely predicted to the given class (often called false alarms) and all elements predicted to the given class. The shown False Positive rate is calculated as the macro-average of the class-specific False Positive rates.

2.6.6 Training Data

This indicates which fraction of the data samples were used as training data.

2.6.7 Test Data

This indicates which fraction of the data samples were used as test data.

2.6.8 BSEC Export

To export a BSEC Configuration File, first select the BSEC Version you want to use on your micro-controller and then click on Export as BSEC Config File .

2.6.9 Additional Testing

After training your Algorithm, you can perform further tests of your Algorithm using additional data from your Specimen Collection. These tests are meant to be conducted with Specimen Data, which has *not* been used during the original training of the Algorithm, in order to give insight on how the Algorithm performs with previously unknown or completely different data, that you do not want to inlcude in the training process. This helps you validate the robustness of the Algorithm, when facing exotic and unknown data.

To perfom an additional test, simply select Test Algorithm . A new overlay opens, showing you the same Classes which where originally used for Algorithm training, but without any associated Specimens. You can now associate new, additional Specimen Data – the data you want to test – to each Class. Once you associated Specimen Data to each Class, you can select Run Tests .

> **Please note**
>
> As of this version of BME AI-Studio, additional tests and their results are not stored within your project. You can, however, save the results as a CSV-File by selecting Save Results .

3 Technical Specification

3.1 Raw Data Format

The Raw Data Format developed for the Bosch Sensortec BME688 is used to store the Board Configuration as well as the raw data. It is recommended to use this data format whenever data with the BME688 is recorded. The BME Board x8 also uses this data format.

3.1.1 File Name

The filename consists of the following parts (each seperated by a _):

▶ <date>

▶ <boardId>

▶ <counterPowerOnOff>

▶ <seedPowerOnOff>

▶ <counterFileLimit>

▶ .bmerawdata

Example: 2021_03_06_09_15_Board_2462ABD29048_PowerOnOff_1_pfqncv1hjow4xm4t_File_0.bmerawdata

part	Description
<date>	Date created with the format: "**yyyy_mm_dd_hh_mm**"
<boardId>	Board-specific ID prefixed with "**Board_**" (each board has a unique ID)
<counterPowerOnOff>	Counter for power interruptions prefixed with "**PowerOnOff_**" (a new file is created every time the board is powered on)
<seedPowerOnOff>	Unique seed that labels raw data that belongs to the same Measurement Session
<counterFileLimit>	Counter for consecutive raw data files prefixed with "**File_**" (after a file limit of 299 MB is reached a new file is created)
.bmerawdata	BME AI-Studio specific ending with JSON syntax

Table 4: File Name

3.1.2 Structure

The file is structured into 4 parts:

▶ configHeader

▶ configBody

▶ rawDataHeader

▶ rawDataBody

The parts *configHeader* and *configBody* represent the board configuration. They are also saved within the `.bmeconfig file` . The parts *rawDataHeader* and *rawDataBody* store the actual recorded raw data.

The following subsections give a description of each parameter used.

3.1.3 configHeader

Parameter	Description
dateCreated	Creation date and time of the board configuration, according to ISO 8601 in Coordinated Universal Time (UTC)
appVersion	Application version number of BME AI-Studio that created the board configuration
boardType	Identifier for the type of hardware used. `board_8` refers to the BME Board x8 (see Board type). Other **boardType** are also accepted, and can be used when data is recorded with other hardware devices.
boardMode	Identifier for Board Mode. **burn-in** refers to the sensorboard's default HP/RDC, **heater_profile_exploration** refers to Heater Profile Exploration, **duty_cycle_profile_exploration** refers to Duty Cycle Exploration. Other **boardMode** are also accepted, and can be used when data is recorded with specific settings.
boardLayout	Identifier for Board Layout. **grouped** refers to Grouped Board Layout, **shuffled** refers to Shuffled Board Layout, **random** refers to Random Board Layout.

Table 5: config Header

3.1.4 configBody

Parameter	Description
heaterProfiles	Definition of Heater Profiles. **id** can be any identifier string. **timeBase** is stated in milliseconds and defines the base unit of time used for **temperatureTimeVectors**. In order to work properly it should be set to 140. **temperatureTimeVectors** are defined as [temperature,time], where temperature is stated in degree Celsius and time spans are stated as multiples of **timeBase**.
dutyCycleProfiles	Definition of Duty Cycles. **id** can be any identifier string. **numberScanningCycles** derlineScanning Cycles. **numberSleepingCycles** states the number of Sleeping Cycles.
sensorConfigurations	Allocation of sensors to HP/RDC Combinations referencing to already defined heaterProfiles and dutyCycleProfiles by their **id**. **sensorIndex** states the index of one of the sensors on the board (usually counting starts at 0). **heaterProfile** states the **id** of one of the defined **heaterProfiles**. **dutyCycleProfile** states the **id** of one of the defined **dutyCycleProfiles**.

Table 6: config Body

3.1.5 rawDataHeader

part	Description
counterPowerOnOff	Counter for power interruptions prefixed with **PowerOnOff_** (a new file is created every time the board is powered on). This parameter is also reflected within the File Name.
seedPowerOnOff	Unique seed that labels raw data that belongs to the same Measurement Session. This parameter is also reflected within the File Name.
counterFileLimit	Counter for consecutive rawdata files prefixed with **File_** (after a file limit of 299 MB is reached a new file is created). This parameter is also reflected within the File Name.
dateCreated	Creation date and time of the start of raw data recording, according to UnixTime (seconds since 1 January 1970 in Coordinated Universal Time (UTC))
dateCreated_ISO	Creation date and time of the start of raw data recording, according to ISO 8601 in Coordinated Universal Time (UTC)
firmwareVersion	Firmware version of the BME Board x8
boardId	Unique board id for the BME Board x8 used for recording

Table 7: Raw Data Header

3.1.6 rawDataBody

This section is divided into two parts. The first part (dataColumns) acts as a column description for the second part (dataBlock), which actually carries the raw data in a condensed form. Every block within dataColumns describes one of the 12 data columns.

Here are some additional remarks concerning the column descriptions:

▶ sensor_id is a unique id per sensor, that can be used to trace back data to an individual sensor element

▶ heater_profile_step_index is a counter for 10 heater steps that will be cycled continously (see Heater Profile). Counting starts at 0 up to 9.

▶ label_tag records when the buttons on the BME Board x8 are used. The encoding is:
  0 if no button was pressed so far,
  1 if Button 1 (SW2) was pressed,
  2 if Button 2 (SW3) was pressed, and
  3 if both buttons (SW2+SW3) were pressed simultaneously.
  The current state is carried on until another button is pressed. (see During recording).

▶ error_code states errors that happened during recording with the follwing encoding:

  1 for invalid Heater Profiles (affects all data points that follow)
  2 for time stamp mismatch or data loss (affects only a single data point, dropping the whole cycle is recommended)
  3 for communication errors (affects only a single data point, dropping the whole cycle is recommended).

3.1.7 Example

```
{
  "configHeader":
  {
      "dateCreated": "2020-09-29T13:00:55.202Z",
      "appVersion": "1.6.0",
      "boardType": "board_8",
      "boardMode": "heater_profile_exploration",
      "boardLayout": "grouped"
  },
  "configBody":
  {
      "heaterProfiles": [
        {
          "id": "heater_412",
          "timeBase": 140,
          "temperatureTimeVectors": [
            [100,64],
            [320,2],
            [170,64],
            [320,2],
            [240,2],
            [240,31],
            [240,32],
            [320,2],
            [320,31],
            [320,32]
          ]
        }
      ],
      "dutyCycleProfiles": [
        {
          "id": "duty_1",
          "numberScanningCycles": 1,
          "numberSleepingCycles": 0
        },
        {
          "id": "duty_5_10",
          "numberScanningCycles": 5,
          "numberSleepingCycles": 10
        }
      ],
      "sensorConfigurations": [
```

```
      {
        "sensorIndex": 0,
        "heaterProfile": "heater_412",
        "dutyCycleProfile": "duty_1"
      },
      {
        "sensorIndex": 1,
        "heaterProfile": "heater_412",
        "dutyCycleProfile": "duty_5_10"
      },
      {
        "sensorIndex": 2,
        "heaterProfile": "heater_412",
        "dutyCycleProfile": "duty_1"
      },
      {
        "sensorIndex": 3,
        "heaterProfile": "heater_412",
        "dutyCycleProfile": "duty_5_10"
      },
      {
        "sensorIndex": 4,
        "heaterProfile": "heater_412",
        "dutyCycleProfile": "duty_1"
      },
      {
        "sensorIndex": 5,
        "heaterProfile": "heater_412",
        "dutyCycleProfile": "duty_5_10"
      },
      {
        "sensorIndex": 6,
        "heaterProfile": "heater_412",
        "dutyCycleProfile": "duty_1"
      },
      {
        "sensorIndex": 7,
        "heaterProfile": "heater_412",
        "dutyCycleProfile": "duty_5_10"
      }
    ]
  },
  "rawDataHeader":
  {
      "counterPowerOnOff": 1,
      "seedPowerOnOff": "jecxzq530rhj2r5x",
      "counterFileLimit": 1,
      "dateCreated": "1601459722",
      "dateCreated_ISO": "2020-09-30T09:55:22+02:00",
      "firmwareVersion": "1.5.0",
      "boardId": "1730555495",
```

```
    },
    "rawDataBody":
    {
        "dataColumns": [
        {
          "name": "Sensor Index",
          "unit": "",
          "format": "integer",
          "key": "sensor_index"
        },
        {
          "name": "Sensor ID",
          "unit": "",
          "format": "integer",
          "key": "sensor_id"
        },
        {
          "name": "Time Since PowerOn",
          "unit": "Milliseconds",
          "format": "integer",
          "key": "timestamp_since_poweron"
        },
        {
          "name": "Real time clock",
          "unit": "Unix Timestamp: seconds since Jan 01 1970. (UTC); 0 =
          missing",
          "format": "integer",
          "key": "real_time_clock"
        },
        {
          "name": "Temperature",
          "unit": "DegreesCelcius",
          "format": "float",
          "key": "temperature"
        },
        {
          "name": "Pressure",
          "unit": "Hectopascals",
          "format": "float",
          "key": "pressure"
        },
        {
          "name": "Relative Humidity",
          "unit": "Percent",
          "format": "float",
          "key": "relative_humidity"
        },
        {
          "name": "Resistance Gassensor",
          "unit": "Ohms",
          "format": "float",
```

```
      "key": "resistance_gassensor"
    },
    {
      "name": "Heater Profile Step Index",
      "unit": "",
      "format": "integer",
      "key": "heater_profile_step_index"
    },
    {
      "name": "Scanning Mode Enabled",
      "unit": "",
      "format": "integer",
      "key": "scanning_mode_enabled"
    },
    {
      "name": "Label Tag",
      "unit": "",
      "format": "integer",
      "key": "label_tag"
    },
    {
      "name": "Error Code",
      "unit": "",
      "format": "integer",
      "key": "error_code"
    }
    ],
    "dataBlock": [
    [0,1730555495,4104,1615022156,27.862839,983.447632,40.376171,5684.846191,0,1,0,0],
    [1,1730565479,4126,1615022156,27.521061,983.286804,40.225910,5684.846191,0,1,0,0],
    [2,1730573669,4130,1615022157,27.673712,983.577271,40.541809,5684.846191,0,1,0,0],
    [3,1730557288,4134,1615022157,27.794174,983.404114,40.968414,5684.846191,0,1,0,0],
    [4,1730572647,4138,1615022157,27.552378,983.289185,42.118191,6240.249512,0,1,0,0],
    [5,1730567013,4141,1615022157,27.541058,983.432556,41.143063,5684.846191,0,1,0,0],
    [6,1730580836,4145,1615022157,27.639883,983.590149,43.335255,5684.846191,0,1,0,0],
    [7,1730556517,4149,1615022157,27.760021,983.735229,41.513172,5684.846191,0,1,0,0],
    [0,1730555495,4383,1615022157,27.792160,983.495789,40.256760,10213.852539,1,1,0,0],
    [1,1730565479,4406,1615022157,27.463169,983.366150,40.086674,33376.792969,1,1,0,0],
    [2,1730573669,4410,1615022157,27.615894,983.594910,40.396038,21850.460938,1,1,0,0],
    [3,1730557288,4414,1615022157,27.741306,983.456482,40.813091,29137.263672,1,1,0,0],
    [4,1730572647,4418,1615022157,27.519522,983.327698,42.050274,70213.929688,1,1,0,0],
    [5,1730567013,4421,1615022157,27.503132,983.463196,41.004383,28100.988281,1,1,0,0],
    [6,1730580836,4425,1615022157,27.599720,983.625610,42.526207,24601.191406,1,1,0,0],
    [7,1730556517,4429,1615022157,27.686945,983.767456,40.948986,26862.539062,1,1,0,0],
    [0,1730555495,5783,1615022158,28.203604,983.499878,39.452438,10352.636719,2,1,0,0],
    [1,1730565479,5806,1615022158,27.825611,983.341309,39.227486,33560.566406,2,1,0,0],
    [2,1730573669,5810,1615022158,27.992977,983.589050,39.522552,22284.123047,2,1,0,0],
    [3,1730557288,5814,1615022158,28.144110,983.448120,39.906544,29337.611328,2,1,0,0],
    [4,1730572647,5818,1615022158,27.944128,983.347229,41.179039,70796.460938,2,1,0,0],
    [5,1730567013,5821,1615022158,27.920330,983.499451,40.089077,28419.183594,2,1,0,0],
    [6,1730580836,5825,1615022158,28.016439,983.607971,41.731613,25048.923828,2,1,0,0],
```

```
        [7,1730556517,5829,1615022158,28.052332,983.758484,40.062920,27432.490234,2,1,0,0],
        [0,1730555495,9983,1615022162,28.726116,983.515198,37.202606,10536.713867,3,1,0,0],
        [1,1730565479,10006,1615022162,28.381857,983.376282,36.991051,33272.679688,3,1,0,0],
        [2,1730573669,10010,1615022162,28.541010,983.613831,37.000546,22076.578125,3,1,0,0],
        [3,1730557288,10014,1615022162,28.687897,983.449951,37.366409,28822.337891,3,1,0,0],
        [4,1730572647,10018,1615022162,28.505222,983.394104,38.104702,70098.578125,3,1,0,0],
        [5,1730567013,10021,1615022162,28.504414,983.488953,37.240280,28343.666016,3,1,0,0],
        [6,1730580836,10025,1615022162,28.556171,983.658813,38.780487,24990.238281,3,1,0,0],
        [7,1730556517,10029,1615022162,28.591593,983.813904,37.237930,27898.867188,3,1,0,0],
        [3,1730557288,10573,1615022163,29.246792,983.437073,36.985844,8719.345703,4,1,0,0],
        [0,1730555495,10684,1615022163,29.289021,983.541565,36.938293,5684.846191,4,1,0,0],
        [1,1730565479,10706,1615022163,28.917973,983.321167,36.683632,10021.922852,4,1,0,0],
        [2,1730573669,10710,1615022163,29.086529,983.609131,36.590668,7426.316895,4,1,0,0],
        [4,1730572647,10717,1615022163,29.071375,983.355774,37.663334,19265.501953,4,1,0,0],
        [5,1730567013,10721,1615022163,29.032871,983.472229,36.849651,8961.075195,4,1,0,0],
        [6,1730580836,10725,1615022163,29.088375,983.648865,38.384171,7982.040527,4,1,0,0],
        [7,1730556517,10729,1615022163,29.148499,983.783630,36.861649,9052.333984,4,1,0,0],
        [3,1730557288,11273,1615022164,29.629461,983.469971,36.604248,9184.844727,5,1,0,0],
        [0,1730555495,11384,1615022164,29.647461,983.527710,36.560806,5684.846191,5,1,0,0],
        [1,1730565479,11406,1615022164,29.290485,983.375427,36.365276,10663.112305,5,1,0,0],
        [2,1730573669,11410,1615022164,29.463619,983.659912,36.612564,7744.433594,5,1,0,0],
        [4,1730572647,11417,1615022164,29.455547,983.397217,37.305729,19656.019531,5,1,0,0],
        [5,1730567013,11421,1615022164,29.260437,983.493042,36.240665,9329.446289,5,1,0,0],
        [6,1730580836,11425,1615022164,29.444851,983.617310,37.934799,8456.659180,5,1,0,0],
        [7,1730556517,11429,1615022164,29.513889,983.805298,36.431786,9386.916992,5,1,0,0],
        [3,1730557288,11974,1615022164,29.810726,983.466003,36.180058,9555.090820,6,1,0,0],
        [0,1730555495,12084,1615022164,29.829205,983.547729,36.165672,5684.846191,6,1,0,0],
        [1,1730565479,12106,1615022164,29.476742,983.376709,35.954807,11084.170898,6,1,0,0]
        ]
    }
}
```

3.2 Specimen Data Format

The Specimen Data Format developed for the Bosch Sensortec BME688 is used to store data for a specific specimen. BME AI-Studio can be used to import Raw Data Raw Data Format, which then can be sliced into one or multiple specimens. Specimen Data files can be exchanged between different BME AI-Studio projects. If curated correctly they should only contain gas data that belongs to one specific specimen or situation.

3.2.1 File Name

The filename consists of the following parts (each seperated by a _):

▶ <specimen_name>

▶ <id>

▶ .bmespecimen

Example: coffee_2.bmespecimen

part	Description
<specimen_name>	individual name that can be defined within the BME AI-Studio (strings are converted to lowercase and spaces are replaced with dashes)
<id>	project-specific id per specimen
.bmerawdata	BME AI-Studio specific ending with JSON syntax

Table 8: File Name

3.2.2 Structure

The file is structured into a metadata part (meta) and data part (data).

The meta part consists of:

▶ appVersion states application version number of BME AI-Studio that created the board configuration

▶ exportedAt states export date and time, according to ISO 8601 in Coordinated Universal Time (UTC)

The data part consists of:

▶ specimenData

▶ measurementSession

▶ boardConfig

▶ boardType

▶ heaterProfiles

▶ dutyCycleProfiles

▶ sensorConfigs

▶ sensors

▶ cycles

▶ dataColumns

▶ specimenDataPoints

The following subsections give a description of each parameter used.

3.2.3 Specimen Data

Parameter	Description
id	Project-specific Specimen id (automatically defined by BME AI-Studio)
uuid	Universally unique identifier (UUID) per Specimen
name	Specimen Label (see Specimen Label)
comment	Comment that further describes the Specimen
startTime	Start time of time interval that references to **real_time_clock** within specimenDataPoints
endTime	End time of time interval that references to **real_time_clock** within specimenDataPoints
cloneOfUuid	Used for BME AI-Studio internal data handling
measurementSessionId	Reference to **id** of Measurement Session to which this Specimen belongs to
createdAt	Creation date and time of Specimen, according to ISO 8601 in Coordinated Universal Time (UTC)
updatedAt	Update date and time of Specimen, according to ISO 8601 in Coordinated Universal Time (UTC)

Table 9: Specimen Data

3.2.4 measurementSession

part	Description
id	Project-specific Measurement Session id (automatically defined by BME AI-Studio)
uuid	Universally unique identifier (UUID) per Measurement Session
name	Measurement Session label (see Session Name)
comment	Comment that further describes the Specimen
startTime	Recording start date and time of Measurement Session, according to ISO 8601 in Coordinated Universal Time (UTC)
endTime	Recording end date and time of Measurement Session, according to ISO 8601 in Coordinated Universal Time (UTC)
boardId	Unique board id for the BME Board x8 used for recording
createdAt	Creation date and time of Measurement Session, according to ISO 8601 in Coordinated Universal Time (UTC)
updatedAt	Update date and time of Measurement Session, according to ISO 8601 in Coordinated Universal Time (UTC)

Table 10: measurementSession

3.2.5 boardConfig

part	Description
id	Project-specific Board Configuration id (automatically defined by BME AI-Studio)
boardMode	Identifier for Board Mode. **burn-in** refers to Sensorboard Default HP/RDC, **heater_profile_exploration** refers to Heater Profile Exploration, **duty_cycle_profile_exploration** refers to Duty Cycle Exploration. Other **boardMode** are also accepted, and can be used when data is recorded with specific settings.
measurementSessionId	Reference to **id** of Measurement Session to which this Board Configuration belongs t0
boardTypeId	Reference to **id** of Board Type to which this Board Configuration belongs to
createdAt	Creation date and time of Board Configuration, according to ISO 8601 in Coordinated Universal Time (UTC)
updatedAt	Update date and time of Board Configuration, according to ISO 8601 in Coordinated Universal Time (UTC)

Table 11: boardConfig

3.2.6 boardType

part	Description
id	Project-specific Board Type id (automatically defined by BME AI-Studio)
uid	Unique identifier for the type of hardware used. **board_8** refers to the BME Board x8. See Board type. Other **boardType** are also accepted, and can be used when data is recorded with other hardware devices.
name	Individual name of the hardware used (e.g. **BME Board x8**)
numSensors	Number of (BME688) sensors on the hardware
createdAt	Creation date and time of Board Type, according to ISO 8601 in Coordinated Universal Time (UTC)
updatedAt	Update date and time of Board Type, according to ISO 8601 in Coordinated Universal Time (UTC)

Table 12: boardType

3.2.7 heaterProfiles

Parameter specification per Heater Profile:

part	Description
id	Project-specific Heater Profile id (automatically defined by BME AI-Studio)
uid	Unique identifier for the Heater Profile
name	Individual name of the Heater Profile
useCase	Additional information on specific use cases
timeBase	Defines the base unit of time used for **temperatureTimeVectors** (stated in milliseconds). In order to work properly it should be set to 140.
steps	Temperature-duration steps, where **temperature** is stated in degree Celsius and **duration** is stated as multiples of **timeBase**.
createdAt	Creation date and time of Heater Profile, according to ISO 8601 in Coordinated Universal Time (UTC)
updatedAt	Update date and time of Heater Profile, according to ISO 8601 in Coordinated Universal Time (UTC)

Table 13: heaterProfiles

3.2.8 dutyCycleProfiles

Parameter specification per Duty Cycle Profile:

part	Description
id	Project-specific Duty Cycle id (automatically defined by BME AI-Studio)
uid	Unique identifier for the Duty Cycle Profile
name	Individual name of the Duty Cycle Profile
description	Additional information
energyConsumption	States the energy consumption of the Duty Cycle Profile in mA
scanningCycles	States the number of Scanning Cycles
sleepingCycles	States the number of Sleeping Cycles
createdAt	Creation date and time of Duty Cycle Profile, according to ISO 8601 in Coordinated Universal Time (UTC)
updatedAt	Update date and time of Duty Cycle Profile, according to ISO 8601 in Coordinated Universal Time (UTC)

Table 14: dutyCycleProfiles

3.2.9 sensorConfigs

The Sensor Configuration attaches a Board Configuration and individual Heater Profiles and Duty Cycle Profiles to a specific sensor.

Parameter specification per Sensor Configuration:

part	Description
id	Project-specific Sensor Configuration id (automatically defined by BME AI-Studio)
boardConfigId	Reference to **id** of Board Configuration to which this Sensor Configuration belongs to
sensorId	Reference to **id** of Sensors to which this Sensor Configuration belongs to
heaterProfileId	Reference to **id** of Heater Profile to which this Sensor Configuration belongs to
dutyCycleProfileId	Reference to **id** of Duty Cycle Profile to which this Sensor Configuration belongs to
createdAt	Creation date and time of Sensor Configuration, according to ISO 8601 in Coordinated Universal Time (UTC)
updatedAt	Update date and time of Sensor Configuration, according to ISO 8601 in Coordinated Universal Time (UTC)

Table 15: sensorConfigs

3.2.10 sensors

The list of sensors connects their Id (used within BME-AI Studio) to their index (used in raw data logging).

part	Description
id	Project-specific sensor id (automatically defined by BME AI-Studio)
index	Sensor index which is used within Raw Data Format
createdAt	Creation date and time of sensor, according to ISO 8601 in Coordinated Universal Time (UTC)
updatedAt	Unique seed that labels raw data that belongs to the same Measurement Session
<counterFileLimit>	Update date and time of sensor, according to ISO 8601 in Coordinated Universal Time (UTC)

Table 16: sensors

3.2.11 cycles

The list of curated Scanning Cycles.

Parameter specification per cycle:

part	Description
id	Project-specific cycle id (automatically defined by BME AI-Studio)
uuid	Universally unique identifier (UUID) per cycle that references to **cycle_id** within specimenDataPoints
startTime	Start time of cycle that references to **real_time_clock** within specimenDataPoints
endTime	End time of cycle that references to **real_time_clock** within specimenDataPoints
dropped	Decision (encoded as boolean), whether cycle was selected as "dropped" within import process (see Cycles Dropped
measurementSessionId	Reference to **id** of Measurement Session to which this cycle belongs to
sensorId	Reference to **id** of Sensors to which this cycle belongs to
createdAt	Creation date and time of cycle, according to ISO 8601 in Coordinated Universal Time (UTC)
updatedAt	Update date and time of cycle, according to ISO 8601 in Coordinated Universal Time (UTC)

Table 17: cycles

3.2.12 dataColumns

Every block within `dataColumns` describes one of the 12 data columns within specimenDataPoints.

Here are some additional remarks concerning the column descriptions:

▶ `data_point_id` is a unique id per data point, that can be used to trace back data to an individual sensor element

▶ `error_code states` errors that happened during recording with the follwing encoding:
`1` for invalid Heater Profiles (affects all data points that follow)
`2` for time stamp mismatch or data loss (affects only a single data point, dropping the whole cycle is recommended)
`3` for communication errors (affects only a single data point, dropping the whole cycle is recommended).

▶ `cycle_step_index` is a counter for 10 heater steps that will be cycled continously (see Heater Profile). Counting starts at 0 up to 9.

3.2.13 specimenDataPoints

The part carries the sensor data in a condensed form according to `dataColumns` .

3.2.14 Example

```
{
    "meta": {
        "appVersion": "1.6.0",
        "exportedAt": "2021-05-20T09:07:11.922Z"
    },
    "data": {
        "specimenData": {
            "id": 2,
            "uuid": "a5159d14-f0af-4f05-be13-fbf629d51c39",
            "name": "coffee",
            "comment": "specialty coffee",
            "startTime": 427208,
            "endTime": 1149010,
            "cloneOfUuid": null,
            "measurementSessionId": 1,
            "createdAt": "2021-05-20T08:59:24.000Z",
            "updatedAt": "2021-05-20T08:59:50.000Z"
        },
        "measurementSession": {
            "id": 1,
            "uuid": "137ebdea-3f9b-4cb4-a4e3-b5e00d36894c",
            "name": "Coffee Recording",
            "startTime": "2021-03-06T09:15:56.000Z",
            "endTime": "2021-03-06T10:15:20.000Z",
            "boardId": "2462ABD29048",
            "createdAt": "2021-05-20T08:59:24.000Z",
            "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        "boardConfig": {
            "id": 1,
            "boardMode": "duty_cycle_profile_exploration",
            "measurementSessionId": 1,
            "boardTypeId": 1,
            "createdAt": "2021-05-20T08:59:24.000Z",
            "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        "boardType": {
            "id": 1,
            "uid": "board_8",
            "name": "BME Board x8",
            "numSensors": 8,
            "createdAt": "2021-05-19T12:29:24.274Z",
            "updatedAt": "2021-05-19T12:29:24.274Z"
        },
```

```
"heaterProfiles": [
{
        "id": 6,
        "uid": "heater_354",
        "name": "HP-354",
        "useCase": "Standard BST profile",
        "timeBase": 140,
        "steps": [
        {
                "temperature": 320,
                "duration": 5
        },
        {
                "temperature": 100,
                "duration": 2
        },
        {
                "temperature": 100,
                "duration": 10
        },
        {
                "temperature": 100,
                "duration": 30
        },
        {
                "temperature": 200,
                "duration": 5
        },
        {
                "temperature": 200,
                "duration": 5
        },
        {
                "temperature": 200,
                "duration": 5
        },
        {
                "temperature": 320,
                "duration": 5
        },
        {
                "temperature": 320,
                "duration": 5
        },
        {
                "temperature": 320,
                "duration": 5
        }
        ],
        "createdAt": "2021-05-19T12:29:24.261Z",
        "updatedAt": "2021-05-19T12:29:24.261Z"
```

```
                }
            ],
            "dutyCycleProfiles": [
                {
                    "id": 1,
                    "uid": "duty_1",
                    "name": "RDC-1-0 Continuous",
                    "description": "This is a continous duty cycle profile, which is
                    best suited for maximum data acquisition, but with maximum power
                    consumption. Please not that the sensor will significantly warm up
                    in continous duty cycle profile.",
                    "energyConsumption": 12,
                    "scanningCycles": 1,
                    "sleepingCycles": 0,
                    "createdAt": "2021-05-19T12:29:24.267Z",
                    "updatedAt": "2021-05-19T12:29:24.267Z"
                },
                {
                    "id": 12,
                    "uid": "duty_5_10",
                    "name": "RDC-5-10",
                    "description": "",
                    "energyConsumption": 4,
                    "scanningCycles": 5,
                    "sleepingCycles": 10,
                    "createdAt": "2021-05-19T12:29:24.267Z",
                    "updatedAt": "2021-05-19T12:29:24.267Z"
                }
            ],
            "sensorConfigs": [
                {
                    "id": 1,
                    "boardConfigId": 1,
                    "sensorId": 1,
                    "heaterProfileId": 6,
                    "dutyCycleProfileId": 1,
                    "createdAt": "2021-05-20T08:59:24.000Z",
                    "updatedAt": "2021-05-20T08:59:24.000Z"
                },
                {
                    "id": 2,
                    "boardConfigId": 1,
                    "sensorId": 2,
                    "heaterProfileId": 6,
                    "dutyCycleProfileId": 12,
                    "createdAt": "2021-05-20T08:59:24.000Z",
                    "updatedAt": "2021-05-20T08:59:24.000Z"
                },
                {
                    "id": 3,
                    "boardConfigId": 1,
```

```
                "sensorId": 3,
                "heaterProfileId": 6,
                "dutyCycleProfileId": 1,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        {
                "id": 4,
                "boardConfigId": 1,
                "sensorId": 4,
                "heaterProfileId": 6,
                "dutyCycleProfileId": 12,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        {
                "id": 5,
                "boardConfigId": 1,
                "sensorId": 5,
                "heaterProfileId": 6,
                "dutyCycleProfileId": 1,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        {
                "id": 6,
                "boardConfigId": 1,
                "sensorId": 6,
                "heaterProfileId": 6,
                "dutyCycleProfileId": 12,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        {
                "id": 7,
                "boardConfigId": 1,
                "sensorId": 7,
                "heaterProfileId": 6,
                "dutyCycleProfileId": 1,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        {
                "id": 8,
                "boardConfigId": 1,
                "sensorId": 8,
                "heaterProfileId": 6,
                "dutyCycleProfileId": 12,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        }
```

```
        ],
        "sensors": [
        {
                "id": 1,
                "index": 0,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        {

                "id": 2,
                "index": 1,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        {

                "id": 3,
                "index": 2,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        {

                "id": 4,
                "index": 3,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        {

                "id": 5,
                "index": 4,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        {

                "id": 6,
                "index": 5,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        {

                "id": 7,
                "index": 6,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        },
        {

                "id": 8,
                "index": 7,
                "createdAt": "2021-05-20T08:59:24.000Z",
                "updatedAt": "2021-05-20T08:59:24.000Z"
        }
        ],
```

```
"cycles": [
{
        "id": 221,
        "uuid": "cf0b8cb0-1133-48a1-8f89-2a1a59bf471f",
        "startTime": 431425,
        "endTime": 441386,
        "dropped": false,
        "measurementSessionId": 1,
        "sensorId": 1,
        "createdAt": "2021-05-20T08:59:24.000Z",
        "updatedAt": "2021-05-20T08:59:24.000Z"
},
{

        "id": 225,
        "uuid": "caaadf34-4a68-42d1-90a7-a2e22b79f80e",
        "startTime": 442240,
        "endTime": 452230,
        "dropped": false,
        "measurementSessionId": 1,
        "sensorId": 1,
        "createdAt": "2021-05-20T08:59:24.000Z",
        "updatedAt": "2021-05-20T08:59:24.000Z"
},
{

        "id": 229,
        "uuid": "61d39719-57d5-4f05-8b10-e74a3e2245d4",
        "startTime": 453083,
        "endTime": 462934,
        "dropped": false,
        "measurementSessionId": 1,
        "sensorId": 1,
        "createdAt": "2021-05-20T08:59:24.000Z",
        "updatedAt": "2021-05-20T08:59:24.000Z"
},
{

        "id": 233,
        "uuid": "191e34a6-0e0d-4e30-9a1b-4a0c9b732148",
        "startTime": 463787,
        "endTime": 473778,
        "dropped": false,
        "measurementSessionId": 1,
        "sensorId": 1,
        "createdAt": "2021-05-20T08:59:24.000Z",
        "updatedAt": "2021-05-20T08:59:24.000Z"
},
{

        "id": 237,
        "uuid": "8e285103-6d5e-4b1d-b536-31c3de9d5b66",
        "startTime": 474632,
        "endTime": 484484,
        "dropped": false,
```

```
                    "measurementSessionId": 1,
                    "sensorId": 1,
                    "createdAt": "2021-05-20T08:59:24.000Z",
                    "updatedAt": "2021-05-20T08:59:24.000Z"
            }
        ],
        "dataColumns": [
            {
                    "name": "Data Point ID",
                    "unit": "",
                    "format": "integer",
                    "key": "data_point_id"
            },
            {
                    "name": "Resistance Gassensor",
                    "unit": "Ohms",
                    "format": "float",
                    "key": "resistance_gassensor"
            },
            {
                    "name": "Temperature",
                    "unit": "DegreesCelsius",
                    "format": "float",
                    "key": "temperature"
            },
            {
                    "name": "Pressure",
                    "unit": "Hectopascals",
                    "format": "float",
                    "key": "pressure"
            },
            {
                    "name": "Relative Humidity",
                    "unit": "Percent",
                    "format": "float",
                    "key": "relative_humidity"
            },
            {
                    "name": "Time Since PowerOn",
                    "unit": "Milliseconds",
                    "format": "integer",
                    "key": "timestamp_since_poweron"
            },
            {
                    "name": "Real time clock",
                    "unit": "Unix Timestamp: seconds since Jan 01 1970. (UTC); 0 =
                    missing",
                    "format": "integer",
                    "key": "real_time_clock"
            },
            {
```

```
            "name": "Error Code",
            "unit": "",
            "format": "integer",
            "key": "error_code"
      },
      {

            "name": "Cycle Step Index",
            "unit": "",
            "format": "integer",
            "key": "cycle_step_index"
      },
      {

            "name": "Cycle ID",
            "unit": "",
            "format": "integer",
            "key": "cycle_id"
      }
      ],
      "specimenDataPoints": [
      [2201,38254.632812,38.803349,983.621399,20.660652,431425,1615022588,0,0,221],
      [2202,1483520.5,38.364086,983.688721,20.657352,431705,1615022588,0,1,221],
      [2203,1388474.625,37.36187,983.655579,20.794451,433104,1615022590,0,2,221],
      [2204,1225246.75,36.993301,983.63562,21.063087,437313,1615022594,0,3,221],
      [2205,171294.75,37.652184,983.66449,21.170946,438013,1615022595,0,4,221],
      [2206,167594.109375,37.884438,983.679016,21.192097,438713,1615022595,0,5,221],
      [2207,163892.453125,37.967743,983.635315,21.155724,439413,1615022596,0,6,221],
      [2208,30146.019531,38.407005,983.650452,21.11739,440113,1615022597,0,7,221],
      [2209,27309.580078,38.59634,983.617065,21.088247,440813,1615022597,0,8,221],
      [2210,24917.267578,38.697319,983.634521,20.989874,441386,1615022598,0,9,221],
      [2241,22448.263672,38.752861,983.624512,20.851637,442240,1615022599,0,0,225],
      [2242,583309.625,38.293404,983.699219,20.752279,442531,1615022599,0,1,225],
      [2243,543380.1875,37.26342,983.652344,20.541948,443943,1615022600,0,2,225],
      [2244,473307.15625,36.957958,983.648743,20.68368,448017,1615022605,0,3,225],
      [2245,80935.820312,37.609268,983.647949,20.769163,448718,1615022605,0,4,225],
      [2246,79725.945312,37.828896,983.652527,20.804911,449417,1615022606,0,5,225],
      [2247,78551.703125,37.927353,983.671753,20.806301,450118,1615022607,0,6,225],
      [2248,20990.488281,38.359039,983.63562,20.809202,450818,1615022607,0,7,225],
      [2249,21541.568359,38.558472,983.617615,20.770164,451518,1615022608,0,8,225],
      [2250,22122.365234,38.641781,983.617249,20.681274,452230,1615022609,0,9,225],
      [2281,22686.990234,38.712467,983.644836,20.586311,453083,1615022610,0,0,229],
      [2282,615384.625,38.265633,983.713257,20.30512,453374,1615022610,0,1,229],
      [2283,557127.3125,37.238174,983.68457,20.352257,454648,1615022611,0,2,229],
      [2284,498539.4375,36.937767,983.645142,20.609156,458861,1615022615,0,3,229],
      [2285,84377.0625,37.594124,983.659485,20.710518,459561,1615022616,0,4,229],
      [2286,82580.648438,37.821327,983.678955,20.772936,460261,1615022617,0,5,229],
      [2287,81476.765625,37.899582,983.665833,20.767719,460961,1615022617,0,6,229],
      [2288,20765.736328,38.338844,983.657532,20.786839,461662,1615022618,0,7,229],
      [2289,21326.224609,38.543327,983.627319,20.769142,462362,1615022619,0,8,229],
      [2290,21940.349609,38.634209,983.640198,20.70701,462934,1615022619,0,9,229],
      [2321,22832.679688,38.709942,983.635437,20.622875,463787,1615022620,0,0,233],
      [2322,610432.1875,38.242912,983.704041,20.544394,464079,1615022621,0,1,233],
```

```
      [2323,564031.9375,37.207878,983.680054,20.412897,465492,1615022622,0,2,233],
      [2324,495643.75,36.927666,983.649597,20.671202,469565,1615022626,0,3,233],
      [2325,84544.25,37.581501,983.654846,20.814461,470265,1615022627,0,4,233],
      [2326,83797.054688,37.808704,983.679871,20.87174,470966,1615022628,0,5,233],
      [2327,82341.585938,37.89201,983.675903,20.85638,471665,1615022628,0,6,233]


    ]
  }
}
```