MATRIX Concept Manual

Version 1.2

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1. Architectural Overview

MATRIX has been designed to be a flexible and powerful forward-looking platform for all sorts of experimental ideas. Provisions have been made to combine a modular, open architecture design with options for variation, adaptation and extension and at the same time adhere to current standards. Powerful service and development options can be used by customers and developers alike to improve and adapt the system with expanding experimental demand.

MATRIX applies to different user groups providing the full bandwidth from a pre-configured ready-to-start system to a modular development environment with various levels between the two extremes.

The MATRIX system consists of a MATRIX control unit (MATRIX CU, 19" card frame) and a MATRIX software package (on Windows XP PC). Note that the Windows XP PC will be referred to as "computer" in this document.

The underlying philosophy is the independent "intelligence" of the native circuit boards of the MATRIX CU: the computer can initiate a process and "leave the board alone" until the process is finished. This fact allows controlling several Experiments with a single program entity.

The MATRIX SPM Control System couples advances in digital electronics with the requirements of the latest SPM applications to offer an unprecedented level of experimental flexibility and data processing control.

Based on knowledge gained over the past 15 years with SCALA, Omicron has developed a series of advanced digital boards (native boards) each equipped with the latest microprocessor technology. A "native" circuit board here means a board that has been specifically developed for MATRIX. One of the key features is an on-board processor which allows independent communication between the boards and with the computer in both directions.

Some state-of-the-art boards such as the coarse positioning board and the piezo driver, that served so successfully in SCALA, could be adapted with only a few revisions ("legacy boards"). Note however, that it is **not** possible to upgrade a SCALA system to a MATRIX system: they are much too different in operation philosophy.

In the beginning all MATRIX control units will be "hybrid", i.e. contain native as well as legacy boards and elements. Note that legacy boards cannot communicate directly with the computer. They can receive commands but for data return they need a native board as a mediator. This is uncomplicated since most legacy boards do not produce data anyway (e.g. coarse positioning board, piezo driver). Legacy boards will be replaced by native solutions in future versions of the MATRIX system in order to support independent communication and make these boards truly modular.

Between native boards and the computer, commands and data can be passed asynchronously either way via an IP interface using dedicated Omicron-specific protocols. Experiment control via Internet or LAN will be possible in later versions but may cause performance degradation. Remote access to measurement data is also intended for future versions.

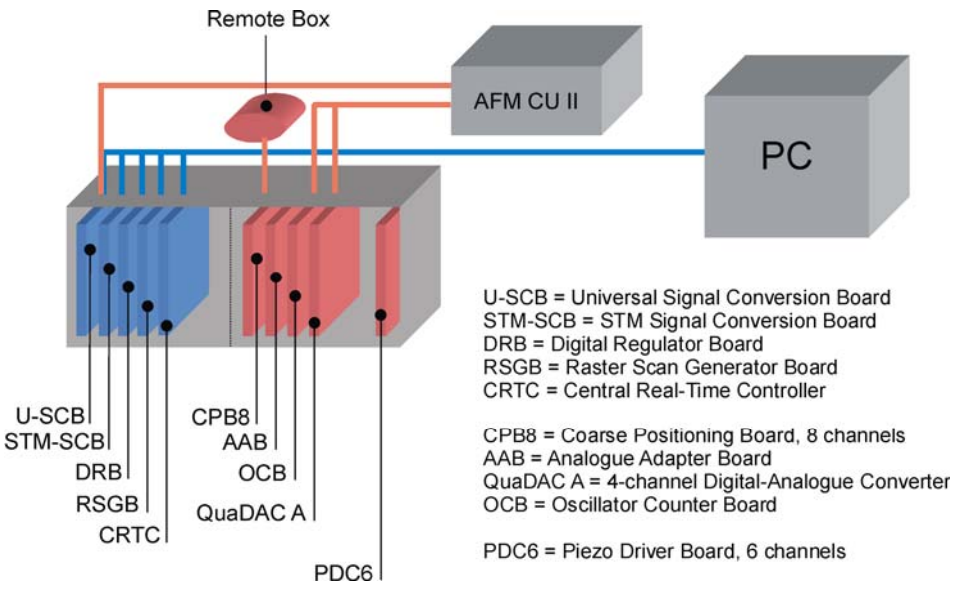


Figure 1. MATRIX basic configuration plus AFM functionality, schematic diagram.

Profile

The MATRIX Software supports different users and user groups. This concept is an add-on to the regular user management of the Windows XP operating system and allows MATRIX users to utilise dedicated user profiles for specific purposes.

MATRIX will keep the Sessions (see on page 6), Projects (see on page 7) and Experiments (see on page 8) data associated with each user in a data tree at the following location:

```
c:\documents and settings\<login_name>\application data\
omicron nanotechnology\matrix\default\...
```

For an Omicron standard installation, measurement results will be directed to

```
d:\Omicron NanoTechnology\MATRIX\default\Results
```

Each time the MATRIX software is started it will load the saved state of the user profile, i.e. Projects, GUI configuration, settings and the instrument file to be used for Experiments, see below.

Instruments

An Instrument in MATRIX context is a collection of information on the microscopy hardware to be used for Experiments. Instrument information includes:

- A description of the resources provided by a particular hardware configuration
- Calibration information to be used when interpreting or changing data from the microscopy hardware.

Note that the instrument file cannot be changed during a session. It is, however, possible to switch between several previously defined parameter sets and instrument calibration configurations.

Instrument information is kept in the Instruments folder of the user's MATRIX data tree.

User Perspective

Normally, a user will obtain a functional system consisting of hardware and software, fully installed and preconfigured for typical applications of the particular SPM. In addition, MATRIX provides a number of dedicated "Projects" that are ready-to-use and provide solutions for typical experimental tasks. From the operator's point of view a Project consists of one or several "Experiments", each of which again consists of several Experiment Elements (also referred to as "components"), and Scripts, Views, parameters etc. For a description of the expressions in quotation marks please see below.

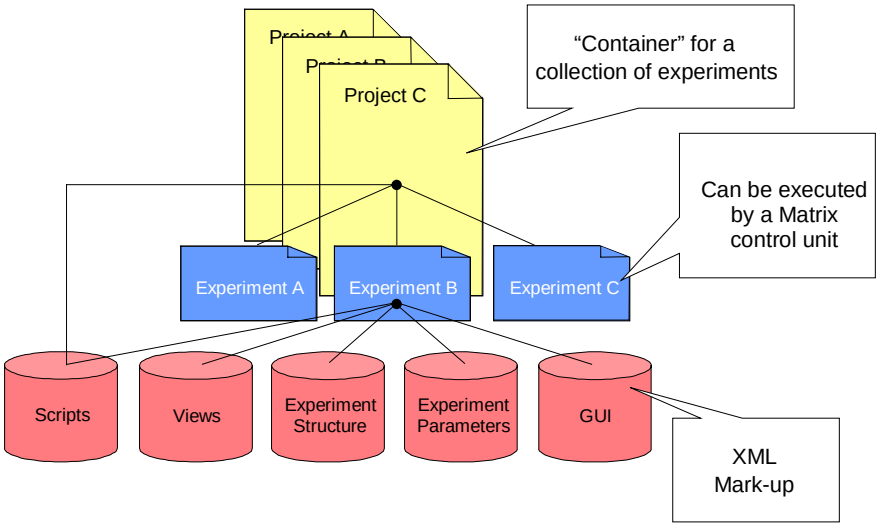


Figure 2. MATRIX hierarchy of constituents.

This sub-structure is something that you do not need to but may want to know more closely. Every Omicron SPM comes with fully configured Projects that can be started right away from the straightforward intuitive graphical user interface (GUI).

In order to help you understand the structure, we will take and analyse an existing standard Project below.

However, you may additionally want to do some very special Projects, and this is also possible. You can change the number and type of Experiments in a Project as well as the number and composition of Elements within an Experiment. For this purpose MATRIX comes with a catalogue of Experiment Elements which can be combined like building blocks similar to the assembling of electronics components on a board.

Please note. For the moment editing Projects and Experiments is only possible by directly modifying the relevant XML-files. A graphical editor will be available with future versions of MATRIX.

Session

Figure 3 below visualises the interconnections within MATRIX software: When a session is started MATRIX loads profile and instrument data. During the session various projects may be accessed.

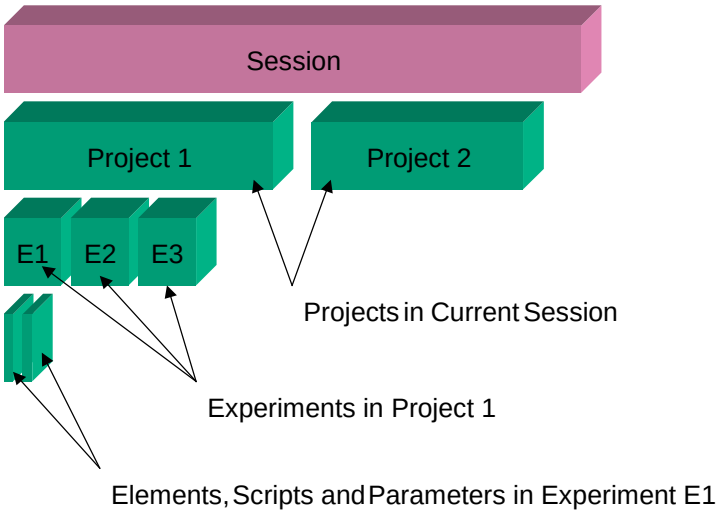


Figure 3. Session, Project and Experiment, graphical visualisation.

Project

A *Project* is a container for a collection of *Experiments*. It can be used much like a sub-folder in a file system. It is up to you to define which Experiments go into which Project. Every Omicron SPM comes with at least one pre-configured Project but you can create as many as you want. In addition a Project can also contain Scripts.

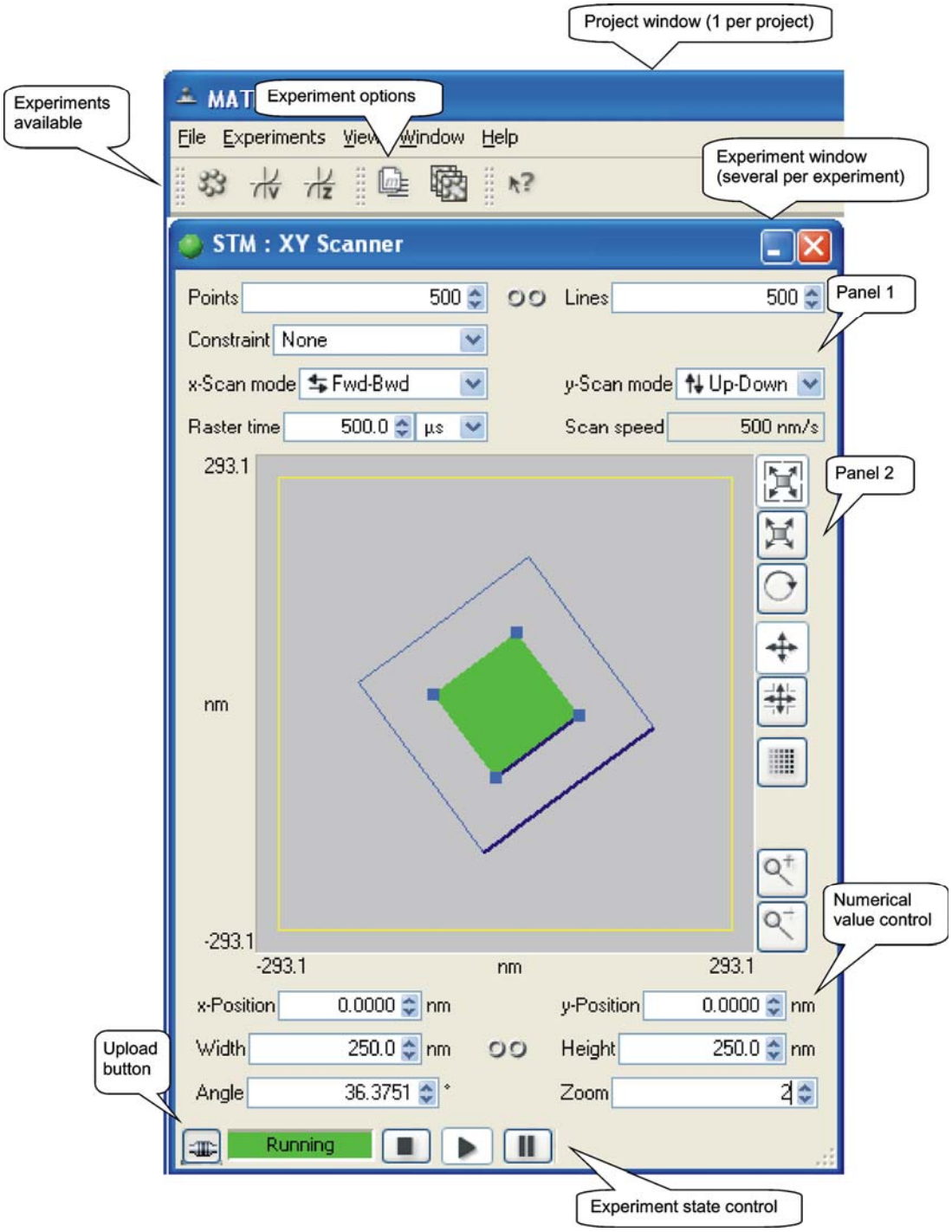


Figure 4. Project window with one Experiment window.

Experiment

An Experiment is an executable Element of a Project, similar to a computer program. It includes Views, Experiment Structure, parameters, the graphical user interface (GUI) and, possibly, Scripts.

For every Omicron SPM there are a number of Experiments, all of which are already grouped into Projects. Changing the parameter set may well be all you need in order to customise these Experiments and Projects. However, you can also assemble new Projects from existing Experiments or create entirely new Experiments.

Experiments are created from Experiment Elements which act as building blocks of the functionalities of an Experiment. Each Experiment Element provides some logic (e.g. a scanner provides the logic to generate a scan movement) and one or more Panel(s).

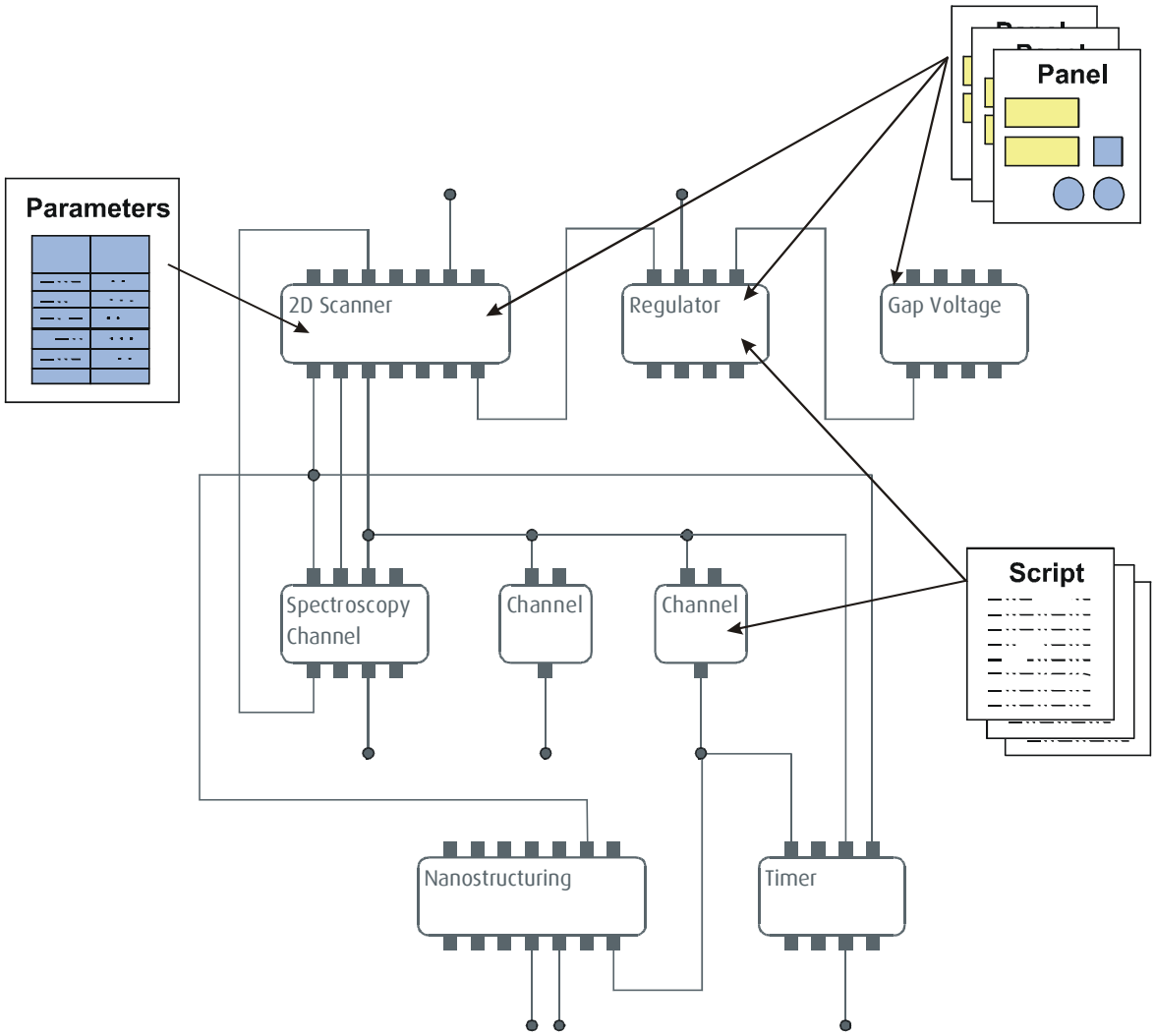


Figure 5. Graphical representation of an Experiment with experiment elements and wiring.

A Panel is a fixed set of GUI controls such as buttons, sliders, numerical value controls, etc. that have been carefully arranged by the designer of an Experiment Element. A user can arrange Panels in windows thus customising the GUI of an Experiment.

Every Experiment Element comes with one or more Panel(s) for user control. A Panel can consist of just one window element (such as a slider or a button) or several. A window may contain one or several Panels. An Experiment Element will need specific parameters and relate to the other Elements by means of input and output. Stuck together in a sensible order the Elements will join together and form a self-contained Experiment, e.g. a topographic scan. Using the provided command language additional Scripts can be created to relate or manipulate parameters and/or components, etc.

An Experiment is uploaded to the electronics components as a whole (as a unit). This has the following implications:

- Every Experiment must contain a full set of compulsory parameters ("deployment parameters")
- Every Experiment normally has a single "master component" which contains the start/stop controls

A simulation mode for trying out Experiments before actually executing them is projected and will be made available in a future version of MATRIX. For further details on single Experiment Elements please refer to the MATRIX Element Catalogue.

2. Graphical User Interface

A graphical user interface is that part of the program that interacts with the person on the other side of the screen/keyboard, i.e. the user. The program itself comes up with at least one interactive window (Main window) even before a Project is loaded or an Experiment is defined.

On top of that nearly every component will interact in some way or other with the user:

- by showing its presence, e.g. in form of a tick in a tickbox,
- by demanding input in form of tick-boxes, input fields or sliders,
- by presenting output in form of images, curves, meters or even text.

Generally, most window specific actions are available from the context menu (available when you click the right mouse button).

Some Experiment Elements may simply supply a slider while others come with their own window and several GUI Elements. Because of the configurability, the software developer cannot group and sort the GUI Elements of all components, as is the case with ready-to-use no-options products. As you would expect, all preconfigured Experiments and Projects come with optimised sets of windows. But as soon as you start changing the configuration you may well end up with a large number of small windows containing only a few or even a single GUI Element, e.g. a slider.

MATRIX therefore allows moving GUI Elements between windows. The GUI configurations are saved as part of the Experiment.

Omicron provides pre-configured GUIs for all Projects and Experiments shipped with the system. It is also possible to move Panels between the windows for your special preferences. Note however, that all manuals and instructions are based on the standard GUI configuration as shipped.

GUI Concept

The MATRIX graphical user interface (GUI) includes a main window plus at least one Project window, i.e. one window per open Project. The main window allows access to Projects/Project windows and general user settings, such as the user name and preferences. Experiment windows appear inside the Project window. An Experiment may have one or several windows and several Experiments can be opened at the same time.

In order to run an Experiment it has to be uploaded to the electronics components (Control Unit). For this purpose one Experiment Element in an Experiment is made the Master Component which contains a special control panel for Experiment control, see also figure 4 on page 7.

Experiment windows can be moved around inside the respective Project window only. Feel free to arrange the windows as necessary. The Project window menu additionally offers to arrange the windows in tiles or rows. A Project window may be minimised and restored as a whole but you can also minimise single Experiment windows inside the Project window, e.g. to have more space for the Master Component.

Upon starting a measurement, the provided online displays (one window per selected channel) will come alive. Online displays have several display options (available from the context menu) and may change size depending on the options selected. They also must stay inside their parent Project window.

Hide Panels

Some panels have a little button near the top right corner. These panels can be hidden/minimised in order to save screen space.

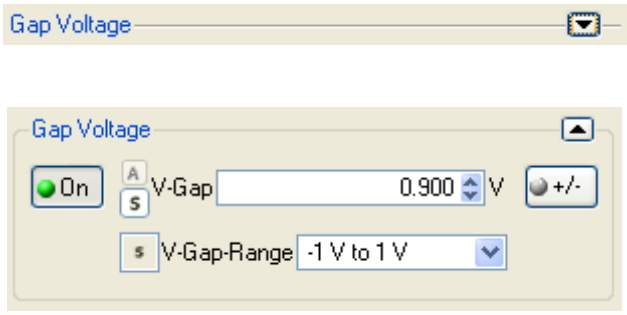


Figure 6. Hide/show panels, example shown.

Numerical Value Control

Numerical value controls consist of a tag (e.g. "Height"), a number (e.g. "100") and a unit (e.g. "nm"). Click on the number field to enter numerical values.

Hold down the mouse button on a numerical value control field to unfold a smart slider for convenient value adjustment. This works with all numerical value control fields.

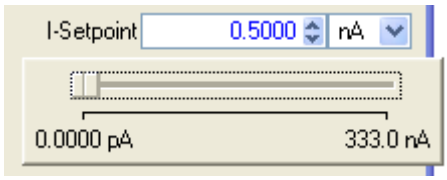


Figure 7. Unfolding smart slider on numerical value control, example shown .

Numerical values can be applied instantly, e.g. while moving the smart slider, or after pressing "Return". In the latter case the numerical value is displayed in blue until it is actually applied. The behaviour of the numerical value control can be configured via the context menu.

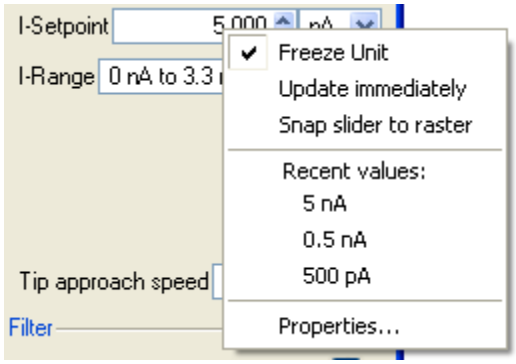


Figure 8. Context menu of numerical value control, example shown.

In the example (figure 8 on page 11) the following options are available

- **Freeze Unit:** when enabled prevents the adaptation of the unit when entering very large or very small numbers (otherwise 10000 nm will be displayed as "10 µm").
- **Update immediately:** when enabled numerical values are directly uploaded to the hardware when moving the smart slider or using the up-down control. For direct numerical input always press "Return" to accept the typed value.
- **Snap slider to raster:** when enabled allows rastered values for smart slider input (same raster as for up-down control. This can facilitate input if you want rounded values only. The raster size can be configured via Properties in the context menu.
- **Recent values ...:** resets the number and unit fields to a previous values (choose from list). This is very useful if you have slipped off the slider or find that a previous value was much mor suitable. Note that the number and unit are treated as a combined entity.
- **Properties:** configure the properties of the numerical value control, e.g. range, raster, handling, formatting.

Properties

The properties window is available from the context menu e.g. of numerical value controls. Depending on the context this window may present different options. The screen shot below shows an example for the AFM Light Source Intensity control.

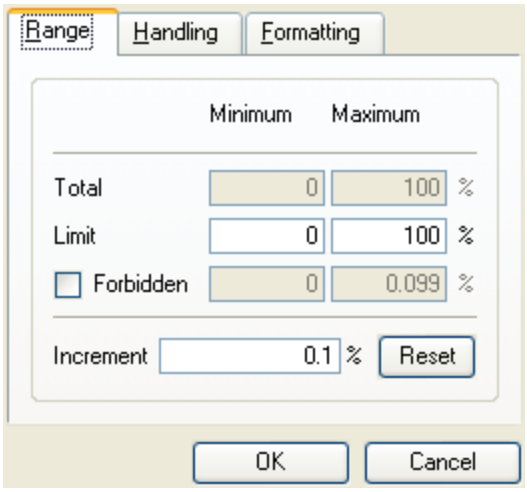
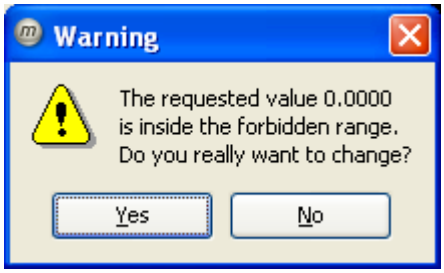


Figure 9. AFM Light Source Intensity properties window: Range.

The Range tab in this case shows the total parameter range provided by the software and allows setting the value control limits, a forbidden value range that you want to exclude from the up-down control and slider, e.g. zero, and the increment (step width) for the up-down control (and slider).

Please note. When using the numerical value control a parameter value within the forbidden range will be displayed in red digits. However, this value will nevertheless be set on the hardware, if the related query is answered with "Yes".



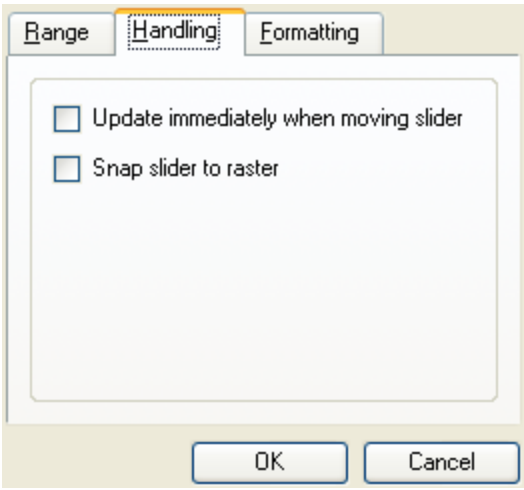


Figure 10. AFM Light Source Intensity properties window: Handling.

On the Handling tab you can freeze the current unit (which is "%"), switch the "update immediately" and "snap slider to raster" features on / off. Note that these settings are also available directly from the context menu.

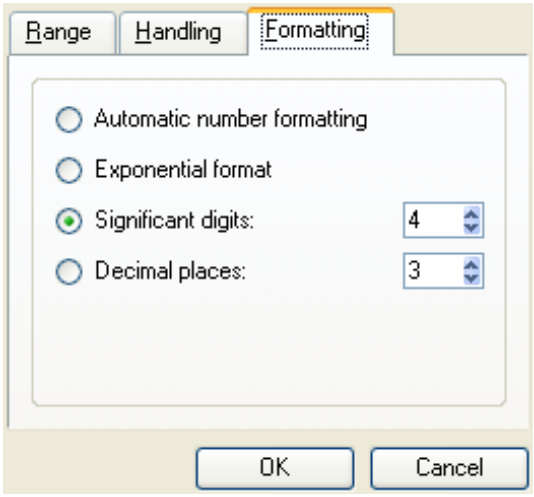


Figure 11. AFM Light Source Intensity properties window: Formatting.

On the Formatting tab select a number of options concerning the formatting of the displayed numbers, e.g. the number of leading and decimal digits.

Uploading - Controlling Experiment State

The Master Component of an Experiment has an experiment state control field by default in the bottom left hand corner. This consists of a symbol button, a status display and three radio buttons, see figure 12 below.

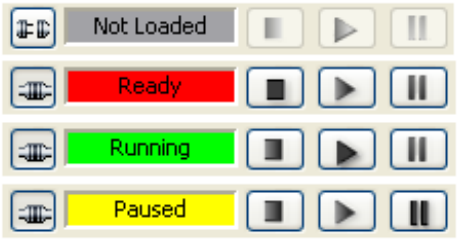


Figure 12. Experiment state control field in different states of operation.

The symbol shows a plug and socket pictogram  . Click this button to load (i.e. upload to MATRIX hardware) or unload the experiment (including all its components).

After uploading, the symbol changes to a closed link pictogram  and the radio buttons become active. Note that uploading may take some time. The display field then indicates the current state. e.g. "loading".

The pictograms on the radio buttons  are well-known from multi-media applications, tape recorders etc. They have the following symbolism (from left to right): Stop, Start, Pause.

The display field indicates the current state: Not Loaded, (Loading,) Stopped, Running, (Stopping,) Paused... Temporary states like Loading, Stopping, etc. are not shown in figure 12 above.

After uploading, the symbol in the window title changes from grey (not loaded) to red (when not yet running or stopped), green (when running), or yellow (when paused). This helps to identify loaded and running components even if their windows have been minimised.

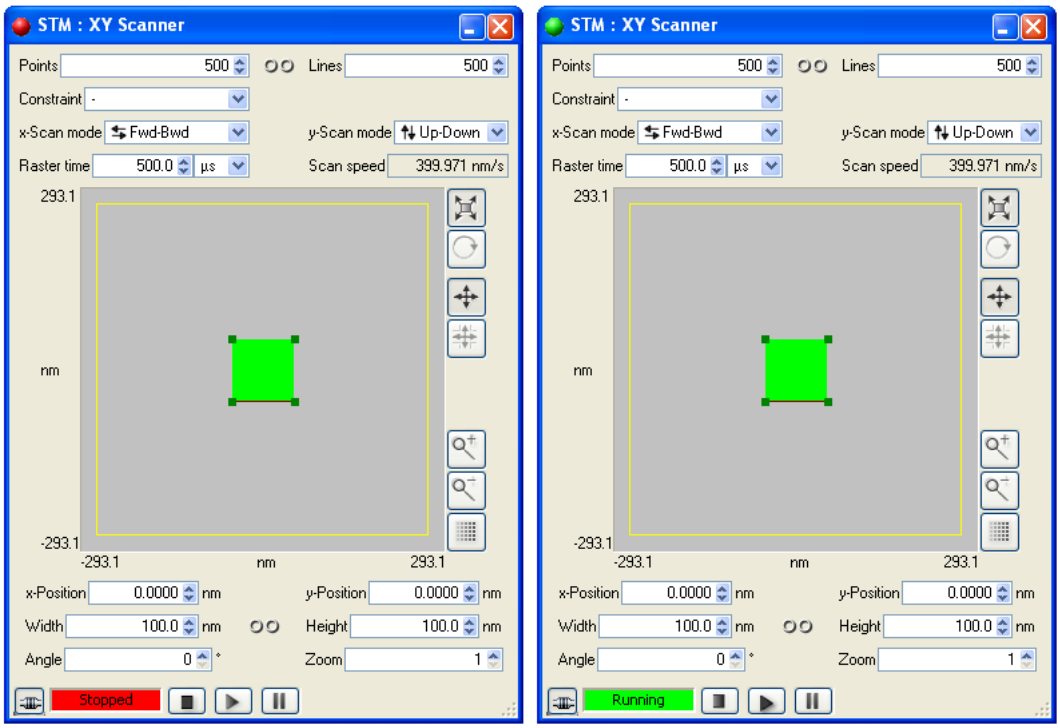


Figure 13. Colour changes from stopped to running. Note the matching colours of display field and window title symbol.

Help System

In addition to printed manuals MATRIX offers two types of pop-up help: ToolTips and context sensitive help. ToolTips appear when you move the mouse pointer over an input box or a button. A ToolTip gives a very short explanation of the item in question.

Figure 14. Context sensitive help button and corresponding ToolTip.

For more information click the What's this help icon  or press Shift+F1 on your keyboard and click the resulting help-pointer on the parameter of interest.

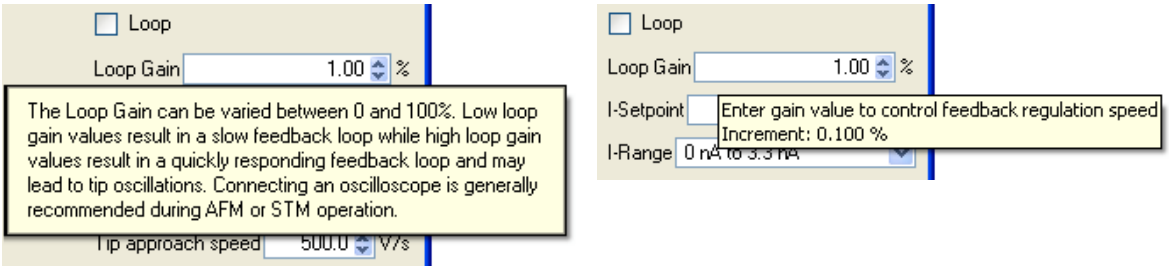


Figure 15. Context sensitive help or What's This help and ToolTip for the feedback setpoint parameter in the regulator window.

3. Data

A novel data concept allows arbitrary, even non-rectangular, areas of interest (in future versions of MATRIX). The acquired data can be made visible during the scan process in flexible Views defined or customised by the user.

Online data displays can also be used to evaluate parameters that are then fed back into the system for parameter optimisation or for changing the area of interest. All Experiment data will be saved in a special MATRIX format, see below.

Please note. For offline data processing the MATRIX SPM Control System software includes a Scanning Probe Image Processor (SPIP) professional data analysis package from Image Metrology.

The version of SPIP used has been modified for the data formats created by the MATRIX SPM Control System and is also able to handle SCALA file formats. The package offers a variety of data processing functions such as cross-section profile analysis, histogram, calibration, correlation averaging, extended Fourier analysis, roughness analysis, grain analysis, 3D visualisation studio, batch processing, filter modules, force curve analysis, Continuous Imaging Tunnelling Spectroscopy (CITS), I/V data analysis etc.

A result file or result file chain records log information and data information in different blocks: parameter blocks, data file references, time stamp etc. It is not possible to modify or delete single blocks later-on as every file carries a signature. This allows detailed analysis of the experiment as a whole, including all parameter changes and other events. Data manipulation is thereby excluded. Single chain elements cannot be deleted without corrupting the entire chain.

File Organisation

Matrix stores the acquired data on a per-channel basis. The data resulting from one scan cycle will be stored in a separate file for each channel supported by an experiment.

The result file chain itself does not contain acquired data, but stores other experiment information. In addition, the result file chain will keep references to the "external" data files in order to allow the association of acquired data with experiment calibration information, experiment run incident data, and similar information.

Note that for later data access the entire **RESULT** file chain must be preserved together with the files storing acquired data because SPIP needs to access the result files even when loading selected data files only. You may however safely delete **DATA** files that you consider obsolete.

Attention. If you delete a result file from a chain, or even the entire chain, all data generated during the respective experiment runs will be lost, even if the data files produced are still available. Without the information provided by a result file chain, a correct interpretation of acquired data is impossible.

Example

For an experiment with three channels MATRIX generates a result file (chain), then three additional data files after the first scan cycle has been completed, another three data files after the second scan cycle has completed, and so forth. Every data file contains the acquired data of one channel and one scan cycle, i.e. up to four images (forward/up scan, backward/up scan, forward/down scan, and backward/down scan).

Result file	Data files	Images		
1 file chain	3 files for scan cycle 1	File 1: Cycle1_Channel 1 forward/up, backward/up, forward/down, backward/down	File 2: Cycle1_Channel 2 forward/up, backward/up, forward/down, backward/down	File 3: Cycle1_Channel 3 forward/up, backward/up, forward/down, backward/down
	3 files for scan cycle 2	File 4: Cycle2_Channel 1 forward/up, backward/up, forward/down, backward/down	File 5: Cycle2_Channel 2 forward/up, backward/up, forward/down, backward/down	File 6: Cycle2_Channel 3 forward/up, backward/up, forward/down, backward/down
	...	...	...	...

In order to keep the amount of stored data as small as possible while still providing data authenticity, MATRIX provides a button for switching data acquisition off while keeping parameter recording running, see figure 16 on page 19.

Matrix result file names are constructed according to the scheme below:

```
user_date-time_project-experiment_count.mtrx
```

For example:

```
default_2005May10-161739_STM-STM_Spectroscopy_0001.mtrx
```

Data files will be named similarly, but the count information found in result file names is replaced by information about the channel and the scan cycle that produced the data stored in this file. Example:

```
default_2005May10-161739_STM-STM_Spectroscopy--2_15_Z.mtrx
```

The above file would contain data from experiment "STM_Spectroscopy" of Project "STM" initialised on the 10th of May 2005 at 16:17:39 by Matrix user "default". The acquired data originated from channel Z during run 2, scan cycle 15.

The "run" and "scan cycle" information hints at internal MATRIX data management structures: Each time an experiment is stopped and re-started, the "run" counter of a data channel is incremented by one if the respective channel is enabled. In contrast, the "scan cycle" is incremented each time a complete scan cycle (e.g. an up/down scan) has been finished. In the above example, data channel Z was started twice and the acquired data of the 15th scan cycle during this second run has been stored in this data file.

Data Analysis

The SPIP package shipped as part of the Matrix kit is capable of reading both types of files: When loading the first file of a result file chain all images associated with the respective result file chain will be loaded and displayed. However, feeding a single data file into the SPIP software will result in loading and displaying only those images that originated from the channel and scan cycle associated with that data file.

The "run" and "scan cycle" information can be shown in all online data displays so that users can determine the associated file names at a glance. Please use the "Display Properties" dialogue to show or hide this information in the online display.

Favourites Gallery and Data Analysis

The Favourites Gallery window can be opened by selecting "Favourites Gallery" from the "View" menu of a Project window or directly from the icon bar. It displays images that have been marked as being of interest for processing and presents these images in a concise way.

Please note. The images displayed here are only stored as data files if the **Store Measurement box had been ticked before**!

In order to save disk space, data recording can be switched off. Make sure the Store Measurement box is not ticked. In this case only the result file records log information, parameter changes, etc. but no data files are generated.

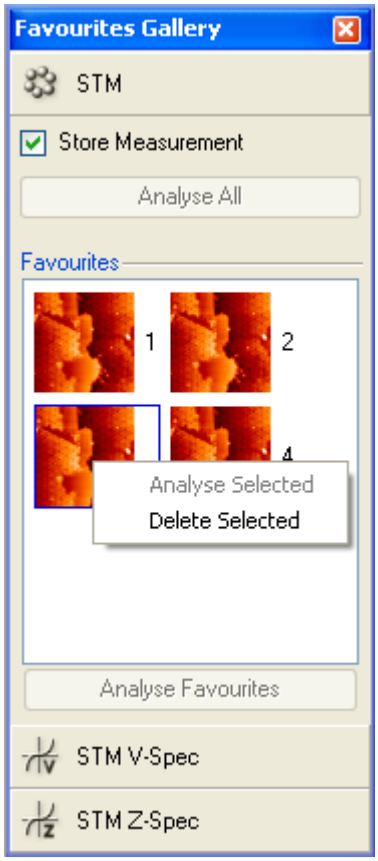


Figure 16. Favourites gallery.

Omicron MATRIX data can be analysed with the provided SPIP data analysis package. In order to open the recorded images click one of the Analyse buttons in the Favourites Gallery window, see figure 16 on page 20. For further details on the SPIP data analysis package, please refer to the SPIP manual.

Standard Projects

Click  or select Experiment Options from the View menu to change the Experiment options, e.g. select another parameter set for a different scanner or temperature range. MATRIX comes with at least one preconfigured Project to suit the needs of your specific Omicron SPM.

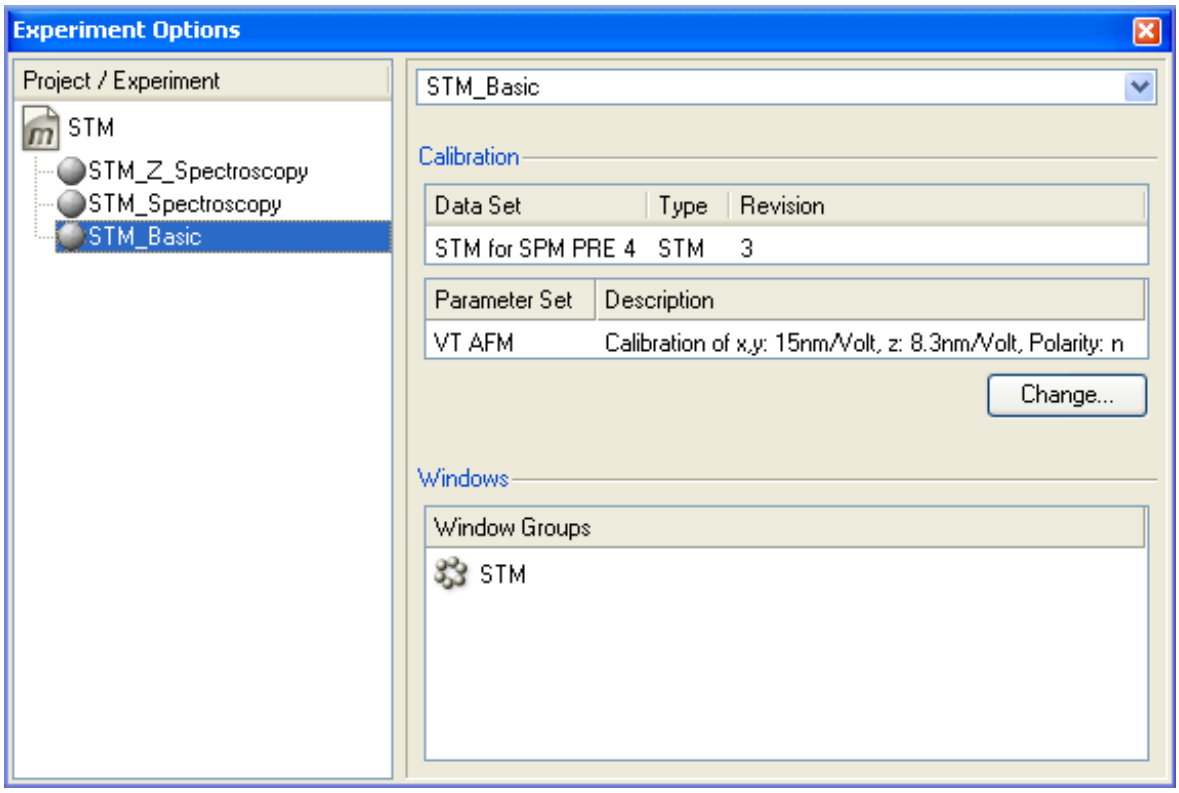


Figure 17. Experiment Options window for an STM project.

Figure 17 above shows the Experiment Options window for an STM project. This project comprises 3 Experiments called STM_Z_Spectroscopy, STM_Spectroscopy and STM_Basic. For each of the experiments a parameter set is loaded. Some Omicron SPMs need more than one parameter set, e.g. for different temperature regions. In this case other parameter sets can be loaded using the change button.

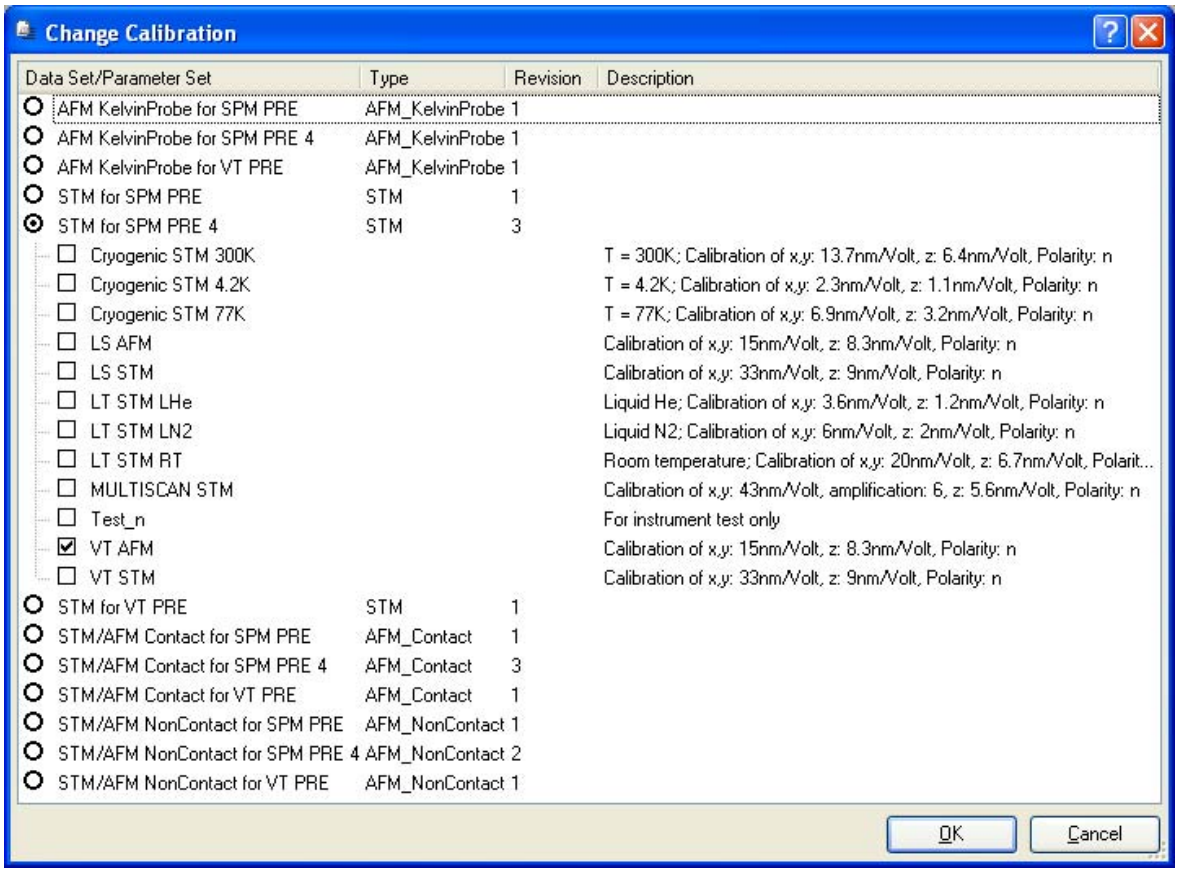


Figure 18. Change Calibration window accessible from Experiment Options.

Hints & Tips

Changing the Result File Path

The installation routine will prompt you for a file folder to be used for storing result files generated during experiment runs. Note that this folder can be changed at any time later on without re-installing the software by simply assigning the path to be used to the environment variable `MATRIX_RESULT_PATH` (You can modify environment variables by selecting the Advanced tab on the Windows XP System control panel and clicking the Environment Variables button.) Note that the Matrix software has to be restarted before any changes to this environment variable will take effect.

Resource Data Folder

When the Matrix software is started for the first time from a new user account (or after upgrading from a previous version) it will be unable to determine its resource data, i.e. Project and experiment descriptions, etc. because the Matrix file tree is not present. The software will thus display a message indicating that the default user account could not be found and will therefore be created. If you click OK afterwards, the Matrix software will install the required files automatically before starting. If you choose to select Cancel instead, the Matrix software will exit, thus allowing you to copy or create the file tree yourselves.

Please note. The default Projects, experiments, and instrument descriptions are located in folder "Templates" available in the Matrix installation folder. You will need to utilise the complete folder hierarchy named "default" in order to run Matrix. The software will search for Project and experiment data in the "Documents and Settings" folder; within the following location:

Document and Settings location\username\Application Data\Omicron NanoTechnology\Matrix\default

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