TM213

Automation Runtime

PERFECTION IN AUTOMATION
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Prerequisites and requirements

Training modules	TM210 – Working with Automation Studio
Software	Automation Studio 4.2.5 Automation Runtime 4.25
Hardware	X20 controller

Table of contents

1 Introduction

The real-time operating system Automation Runtime is an integral component of Automation Studio. Automation Runtime provides services for freely configuring and troubleshooting the target system and for executing programs.

In addition, Automation Runtime features a modular structure, configurability and the ability to quickly execute applications repeatedly within a precise time frame. This makes it possible to achieve optimal product quantities while guaranteeing quality and precision at runtime.

Figure 1: Automation Runtime: A software platform for the entire B&R product range

This training module will provide a general overview of Automation Runtime and its features.

1.1 Learning objectives

This training module uses selected examples illustrating typical applications to help you learn how to configure Automation Runtime for your own application in Automation Studio.

- You will learn what demands are placed on a real-time operating system in the field of automation.
- You will learn about the features and functionalities available in Automation Runtime.
- You will get an overview of integrated server and client functions and diagnostic options.
- You will learn how a uniform runtime system can benefit integrated automation solutions.
- You will learn how memory management, variable scope and remanent variables are handled in Automation Runtime.

- You will learn about the startup and runtime behavior of B&R controllers.
- You will learn how Automation Runtime I/O management works.
- You will learn about the interrelationships involved in multitasking.
- You will learn about Automation Runtime's configuration options.

1.2 Symbols and safety notices

Unless otherwise specified, the descriptions of symbols and safety notices listed in "TM210 – Working with Automation Studio" apply.

2 Automation Runtime

The fundamental idea of integrated automation and the free scalability of automation solutions results in challenges for the configuration tool as well as the runtime system it's based on.

Challenges for Automation Studio and Automation Runtime

Automation Studio is the project development environment used specifically for B&R automation components. This includes controllers, motion control components, safety modules and HMI applications. Clearly organized project structuring options and the ability to manage multiple configurations ensure that teams can work together efficiently and all machine variants can be represented in a single project.

Users are able to choose from a wide range of programming languages, diagnostic tools and editors to assist them at every stage of engineering. Standard libraries provided by B&R and the integrated IEC programming languages allow for a highly efficient workflow. Extensive simulation options enable applications to be configured and tested independently of the hardware.

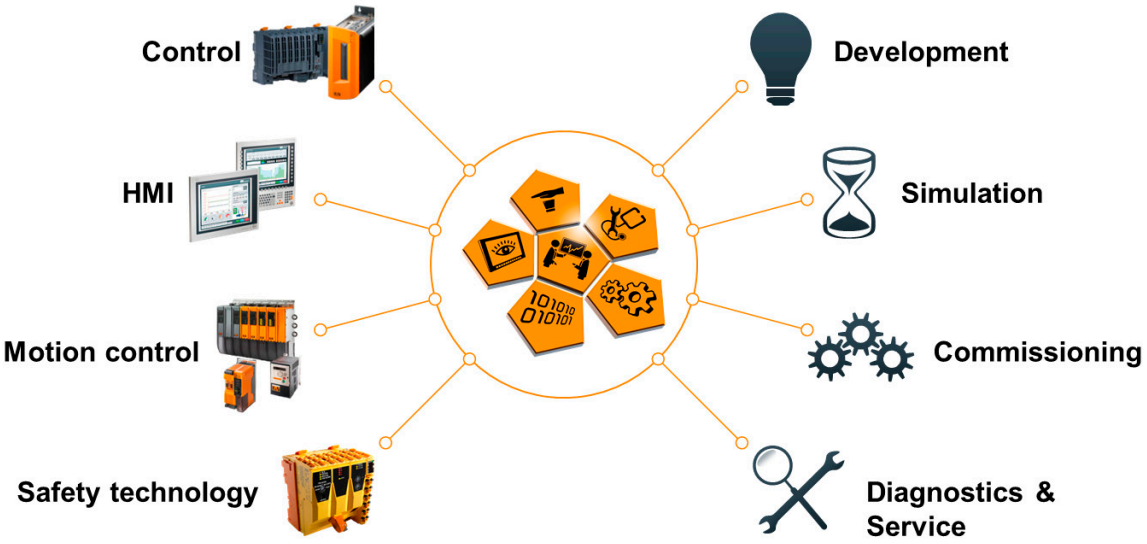


Figure 2: Automation Studio: one engineering tool for the machine's entire lifecycle

Automation Runtime characteristics

The characteristics of Automation Runtime result from the challenges faced by the configuration tool and the required runtime system functions. Automation Runtime is fully integrated into B&R target systems. It supports all hardware platforms and makes application creation hardware-independent.

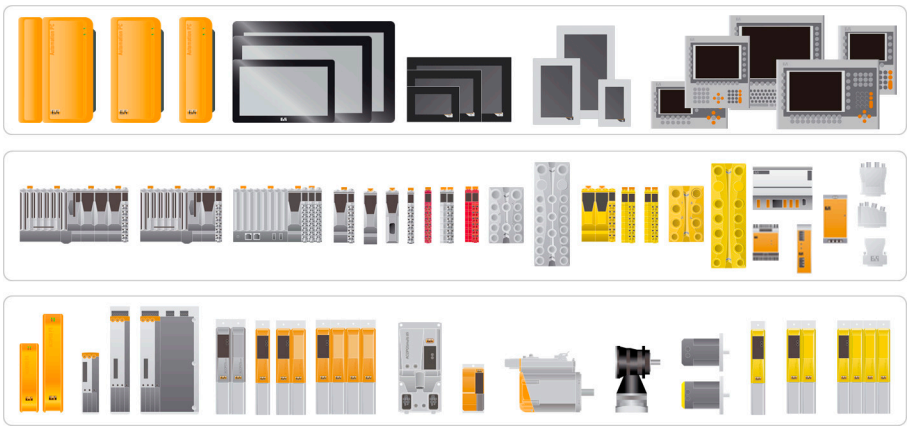


Figure 3: Automation Runtime - The platform for a scalable system

It allows application programs to access I/O systems, interfaces, fieldbuses, networks and storage devices. Comprehensive configuration options for timing as well as client and server applications allow the flexibility that is required by a modern control system.

Automation Runtime provides a number of important features:

- Runs on all B&R target systems
- Makes the application hardware-independent
- Guarantees deterministic behavior with a cyclic runtime system
- Allows the configuration of 8 different task classes and cycle times
- Guarantees a response to timing violations
- Provides configurable tolerance limits for all task classes
- Offers extensive function libraries in accordance with IEC 61131-3
- Provides access to all networks and bus systems
- Contains integrated client and service interfaces
- Offers an OPC UA client and server interface as well as user management
- Provides comprehensive diagnostic functions

? Real-time operating system \ Method of operation

2.1 Automation Runtime structure

Automation Runtime provides the user with a deterministic, hardware-independent, multitasking tool for creating applications. It manages hardware and software resources and offers complete diagnostics.

The IEC library functions in Automation Runtime make programming faster and easier while helping to avoid errors.

Automation Runtime meets the highest demands for deterministic behavior and speed.

To take advantage of this performance advantage in the application, an abstraction layer is put over the real-time OS. This ensures the user that no adjustments will need to be made to the application if a different operating system is used. The uniform programming interface always remains the same.

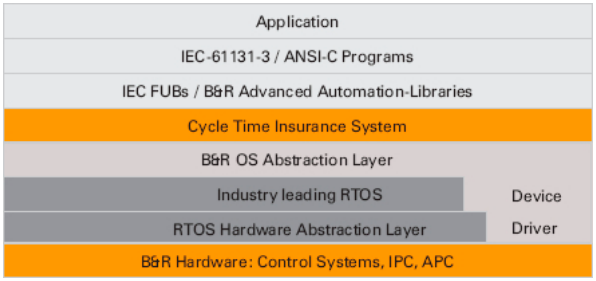


Figure 4: Automation Runtime architecture

Programs, tasks and task class

A program that is assigned to a task class and executed on the target system is often called a task.

Tasks are executed cyclically in a task class.

Cycle time and priority are determined via the task class.

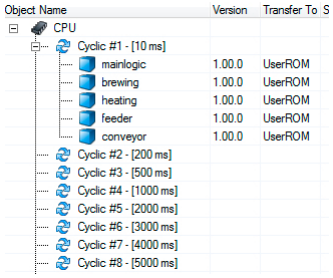


Figure 5: Task class system with cyclic tasks in task class #1

Real-time operating system

2.1.1 Automation Runtime target systems

Automation Runtime can run on many different hardware platforms. For X20 controllers, Power Panels and Automation PCs, PC-based hardware platforms are used.

Automation Runtime Embedded

Automation Runtime Embedded can be implemented on all target systems where Automation Runtime is run as an independent operating system. The X20 operating system, Power Panels and PC-based hardware platforms are suitable for Automation Runtime Embedded.

Figure 6: Automation Runtime on all types of controllers

Automation Runtime simulation - ARsim

Arsim is an Automation Runtime system based on Windows which isn't real-time capable, but essentially corresponds to the functionality of all other target systems.

Figure 7: Automation Runtime simulation on the PC

Automation Runtime Windows - ARwin

ARwin is a target system capable of running on all Windows operating systems. A real-time operating system imposes itself over the Windows operating system, which assumes complete control of computer resources. The host operating system itself is handled as a low-priority task on the real-time operating system.

Figure 8: Automation Runtime - real-time applications on Windows

Real-time operating system \ Target systems

- ARsim
- ARwin

Project management \ Simulation \ ARsim

2.1.2 Server and client functions

Numerous client and server functions are available on Automation Runtime. Different network services and protocols are supported.

The individual protocols are highlighted in color in the image. The protocols that are already enabled for a new Automation Studio configuration are highlighted in green.

Those protocols that can be additionally enabled and configured via configuration entry are highlighted gray.

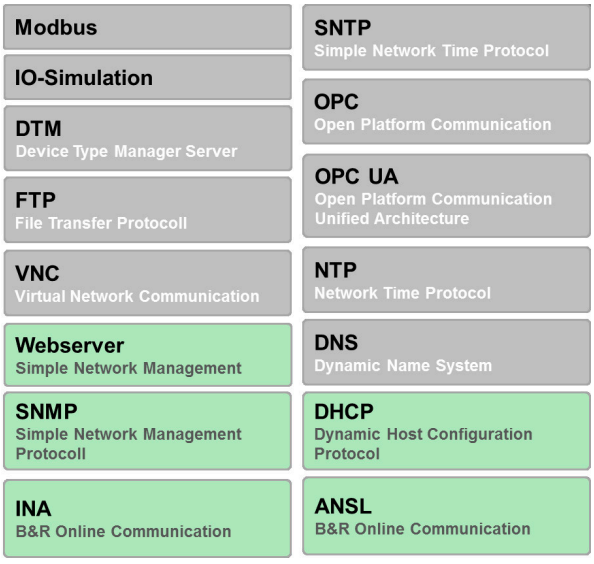


Figure 9: Configurable Automation Runtime server and client functions

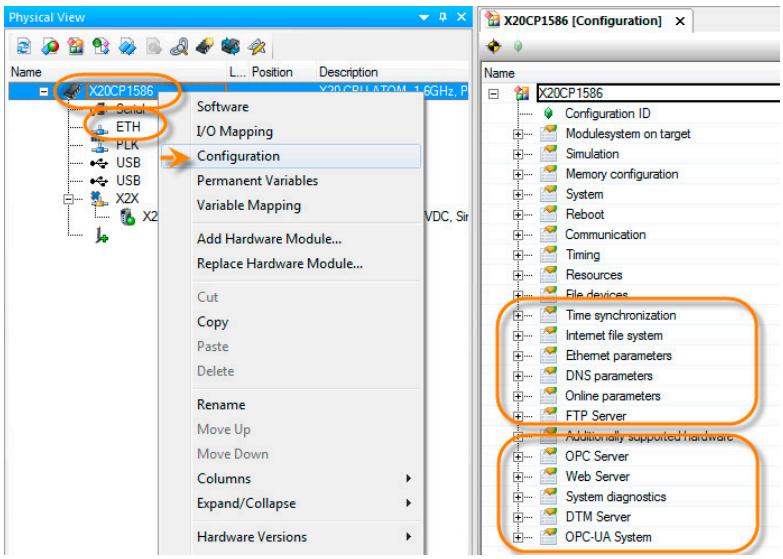


Figure 10: Open CPU and Ethernet configuration via the shortcut menu

Open the configuration entries from the shortcut menu for the CPU and the Ethernet interface. Every protocol has a standalone configuration entry that is used to enable and configure the corresponding protocol.

Many of the functions offered can be diagnosed and configured at runtime using libraries.

Programming \ Editors \ Configuration editors \ Hardware configuration \ CPU configuration \ SG4

Communication \ Ethernet \ AR configuration \ Interface configuration (SG4)

Programming \ Libraries

- Configuration, system
- Communication

2.2 Automation Runtime diagnostics capability

Independent of the implemented hardware platform, Automation Runtime supports many diagnostic tools that provide information about the current system state. A list of different diagnostic access options for Automation Runtime is provided below.

The use of the integrated diagnostic tools is documented in Automation Help. Additional executions and exercises can be found in the "TM223 - Automation Studio Diagnostics" training module.

Figure 11: Automation Runtime - complete diagnostics integrated

Diagnostics and service \ Diagnostic tool

- Status bar
- Information about the target system
- System Diagnostics Manager
- Monitors \ Online comparison
- Logger
- Profiler

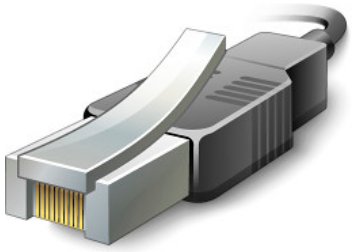
Diagnostics and service \ I/O and network diagnostics

Programming \ Libraries \ Configuration, system

2.3 Connectivity and access & security

The B&R solution is completely open for seamless integration in existing networks and allows direct integration in devices from other manufacturers. B&R components can be implemented as either fieldbus masters or slaves.

An OPC UA server and client enable the publication and exchange of process data. The user roles system helps with the limitation of read and write access. An encrypted connection is enabled using Transport Layer Security (TLS).



Support of devices from other manufacturers

Automation Studio allows fieldbuses and also devices from other manufacturers to be directly integrated. Master and slave devices are added to Automation Studio – like all other B&R components – in the Physical View or in the System Designer.

Communication \ Fieldbus systems

Access & security - User management system

Automation Studio supports configuration of a user system, a role system and a certificate management system as well as management of SSL configurations. These configurations are managed in the "Access & Security" package in the Configuration View.

Access & Security \

- User role system
- TLS / SSL

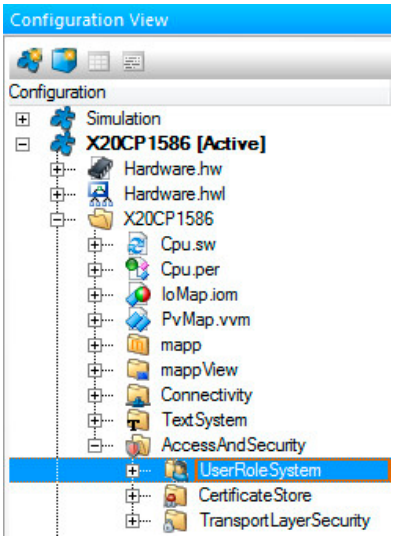


Figure 12: User management system in the Configuration View

OPC UA server and client

Automation Studio supports the configuration of an OPC UA server. Read/write access for the individual OPC UA codes is managed using the user role system. OPC UA client functions are offered via a library.

Communication \ OPC UA

Libraries / Communication / AsOpcUac

3 Installation and startup

All target systems launch Automation Runtime and load the Automation Studio project from flash memory. Depending on the device, the target system has a CompactFlash, CFast card or integrated flash memory as a data storage medium.

There are different options for installing Automation Runtime. Automation Runtime is installed via the online connection, offline installation or the creation of a remote install structure.

Automation Studio provides support during the installation process, independent of the selected method.

During initial installation, the flash memory of the controller is partitioned according to the requirements of the application.

When installing Automation Runtime, settings like the I/O configuration and the interface configuration are included.

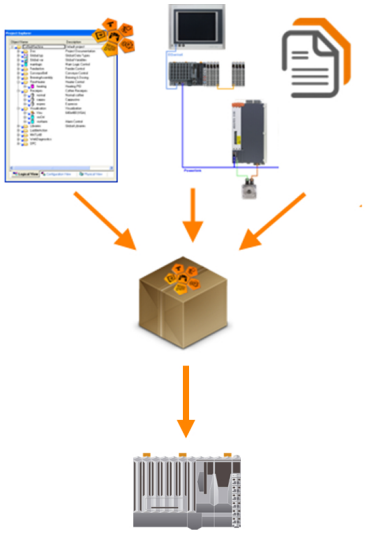


Figure 13: Installation and startup

The exception with PC-based target systems is Automation Runtime for Windows (ARwin). In this case, Automation Runtime is installed the first time using a special setup tool.

Hardware \ X20 system \ X20 modules \ CPUs

- X20CP1301, X20CP1381 and X20CP1382 \ Programming the system flash
- X20(c)CP158x and X20(c)CP358x \ Programming the system flash

Project management \ Simulation \ ARsim \ Creating an executable project structure

Real-time operating system \ Target Systems \ SG4 \ ARwin \ Installation / Configuration

3.1 Changing and updating Automation Runtime

If new software versions are available for the runtime environment of Automation Runtime, Visual Components, motion, etc., then these software versions can be added via the upgrades to Automation Studio. The upgrade dialog box is opened by selecting **<Tools> / <Upgrades>** from the menu. The versions for the runtime environment are changed in the Automation Studio project for the respective active configuration.

Software versions for the runtime environment can be modified by selecting **<Project> / <Change Runtime Versions...>** from the main menu.

Changing motion control, CNC software and Visual Components versions affects all hardware configurations since the libraries linked with it are managed in the Logical View.

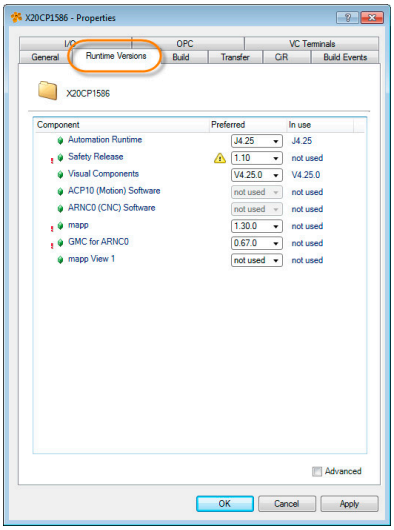


Figure 14: Changing runtime versions

Project management

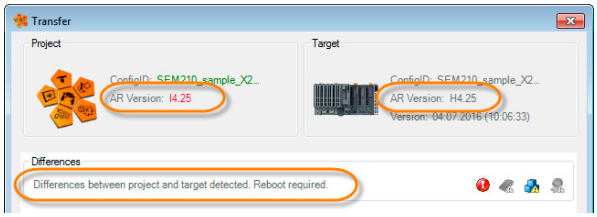
- Workspace \ Upgrades
- Changing runtime version

Real-time operating system \ Version overview

Upgrading from Automation Studio

If Automation Runtime is already installed on the target system, the project can be transferred along with the new Automation Runtime version. Alternatively, the creation of installation media, such as a CompactFlash, CFast and USB flash drive, is supported.

- See "Online and offline installation" on page 16.



When transferring the project to the target system, any Automation Runtime version conflicts are detected and displayed in a dialog box.

Figure 15: Display of version differences in the transfer dialog box; restart required

Upgrade without Automation Studio

If it is not possible to update using Automation Studio, the Runtime Utility Center can be used to create a complete image for installation. For example, it can then be transferred to a USB flash drive.

Diagnostics and service \ Service tool \ Runtime Utility Center \ Creating a list / data medium \ Generating an installation package

3.2 Configuration ID and partitioning

Before project installation, the settings for the configuration ID and the partitioning of the flash memory should be checked in the project. The settings are called via the shortcut menu for the CPU.

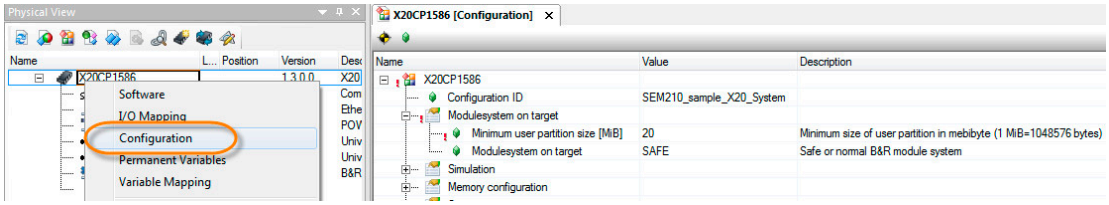


Figure 16: Open the CPU configuration; settings for configuration ID and partitioning

Configuration ID

With Automation Runtime 4.25 and later, a unique configuration ID is assigned to each configuration in the Automation Studio project. The configuration ID serves as a unique identifier of the project and is preset to "<AS Project name>_<Configuration name>". The assignment of a unique configuration ID is necessary. This allows the system to differentiate between an update transfer (same ID) or initial transfer (different ID) during project installation.

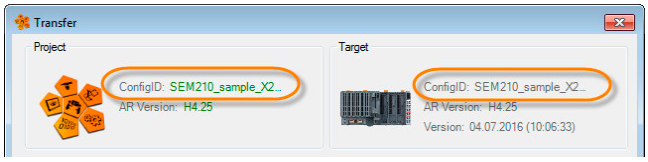


Figure 17: Comparison of the configuration ID in the transfer dialog box

Partitioning

The flash memory of a controller is organized as a file system. Depending on the selected partition option, a distinction is made between the normal and secure file system. For the normal file system, a partition is created in the flash memory, on which Automation Runtime and the user data are saved.

For the secure file system on the other hand, Automation Runtime and the application are stored on different partitions. The partition sizes for Automation Runtime and the application are calculated automatically.

A user partition can be added to the normal and secure file system. On this partition, the user can save e.g. recipe data at runtime. The memory size is manually determined for the user partition.

Programming \ Editors \ Configuration editors \ Hardware configuration \ CPU configuration \ SG4

Project management \ Project installation

- Operation \ Settings \ Settings before build
- Procedure
- General information \ FAQ

3.3 Online and offline installation

It is possible to transfer Automation Runtime over an online connection. In order to do this, the online interface must be configured correctly and be in the right mode. ("Starting Automation Runtime" on page 28). Alternatively, offline installation and the remote install structure are available for transferring the Automation Studio project including Automation Runtime.

Establishing a connection

A connection to the controller is established using the "Browse for target system" feature in Automation Studio. This function searches the network for B&R controllers. The connection settings of the controllers can be temporarily changed in the search dialog box.

Programming \ Building and transferring projects \ Establishing a connection to the target system \ Ethernet connections \ Browse for targets

Online installation

Automation Runtime can be transferred or project installation performed once the connection has been established.

Programming \ Building and transferring projects \ Online services \ Transfer Automation Runtime \ Transferring to SGx target systems \ Installing via an online connection

Project management \ Project installation

Offline installation

During offline installation, Automation Studio generates the required installation media, which is subsequently connected with the target system and specifies its entire configuration.

Project management \ Project installation \ Operation \Transfer dialog box \ Offline installation

Remote install structure

Automation Runtime and application software can be transferred to the target system by creating a remote install structure, either with a USB flash drive, a CompactFlash card or a DHCP server.

With a remote installation, the user has to define the number and size of partitions. The project installation, on the other hand, calculates the partition sizes itself. There may therefore be differences between the calculated partition sizes and the sizes assigned by the user. This results in an initial transfer being performed.

Project management \ Project installation \ General information \ FAQ

Real-time operating system \ Target systems \ SG4 \ AR remote install

Exercise: Check and update the Automation Runtime version

The goal of this exercise is to get to grips with the options for updating Automation Runtime on the target system. Automation Runtime upgrades are searched for, the settings of the Runtime versions are checked in the project, Configuration ID and partitioning are determined and the appropriate mechanism for updating the target system is selected.

1) Search for Automation Runtime upgrades

   <Tools> / <Upgrades> menu

2) Check and adjust Runtime versions

   <Project> / <Change Runtime Versions...> menu

3) Specify configuration ID and partitioning

   CPU configuration (configuration ID, module system on the target system)

4) Select options for online and offline transfer for the selected target system

   Notes on this are offered in the respective data sheet under section "Programming the system flash".

5) Perform installation

   For an online installation: Force initial transfer

4 Memory management

Memory on an Automation Runtime target system is divided into RAM and ROM.

Parts of these areas are used exclusively by Automation Runtime at runtime; the rest is available for the application.

4.1 Logical partitioning of the Flash memory

During the build process for Automation Runtime, an Automation Studio project generates modules that can be executed. These are transferred to the flash memory during project installation. CompactFlash, CFast and integrated flash memory are used as storage mediums.

A target memory is automatically assigned to every module in the software configuration. Modules that belong to Automation Runtime are transferred to the system ROM. Modules that belong to the application are transferred to the user ROM. This is a purely logical subdivision. The data transferred is saved on the same data storage device.

For the normal B&R file system, modules from the system ROM and user ROM are stored in different folders on the C partition.

For the secure B&R file system, modules from the system ROM and user ROM are stored on the C partition. The modules in the user ROM are stored on the D partitions and a copy of this data is stored on partition E.

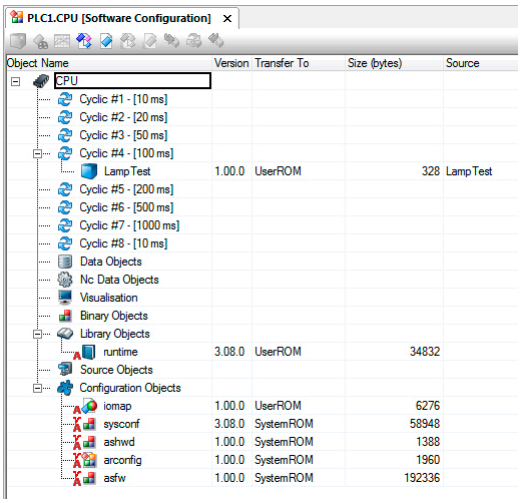


Figure 18: Target memory for software objects in the software configuration

System modules are separated from the application by this mechanism.

In addition, another user partition can be configured for managing files generated at runtime. Data is transferred to the user partition using the transfer settings.

See: "Settings when transferring programs" on page 43

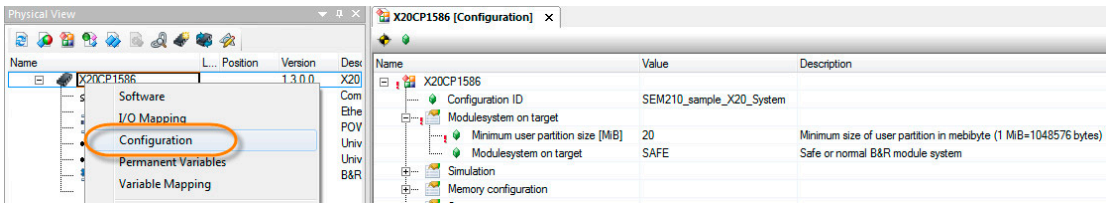


Figure 19: Partitioning configuration for the flash memory in the CPU configuration

Real-time operating system \ Method of operation \ Memory \ Memory types

Programming \ Configuration View \ Software configuration

Project management \ Project installation \ Operation \ Settings

- Settings before a build
- Settings during a transfer

4.2 Used RAM

A DRAM is used as a fast read/write memory for the execution of Automation Runtime and the application.

Alternatively, the target systems have different battery-backed RAM memories that are used, for example, for data retention after a restart.

The memory types and memory sizes used in the target system are documented in the data sheet of the selected CPU.

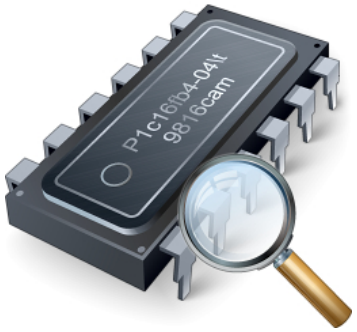


Figure 20: DRAM, SRAM and FRAM

DRAM

During startup, Automation Runtime, all configurations and the tasks are copied into DRAM and executed there. This is necessary because access to the DRAM is quicker than flash memory.

In DRAM, a task also requires the configured local or global variable memory. Initialization of this memory is carried out automatically.

SRAM and FRAM

SRAM (static RAM) is buffered by a battery. This allows data to be retained even after a power failure. Of course, the backup battery must be functional.

Newer controller models don't require a backup battery anymore. FRAM saves data on a nonvolatile electronic memory type, as opposed to SRAM and DRAM.

See also:

- "Initializing variable memory" on page 25
- "Restarting and power failures" on page 30
- "Using retain variables" on page 32

Information about the service interval of the backup battery and instructions regarding changing it are documented in the data sheet of the respective CPU.

Real-time operating system \ Method of operation \ Memory \ Memory types

4.3 Tools for determining memory information

Automation Studio unites many diagnostic tools that, among other things, provide information about the system state. Diagnostic tools for calculating memory information will be introduced below.

Online info

Selecting **<Online> / <Info>** from the main menu shows general information about the amount of available memory. This option is not available for all target systems. In the online info, you can also read and set the status of the backup battery as well as the current time and date on the controller. The change of time and date are logged in the "System" Logger module.

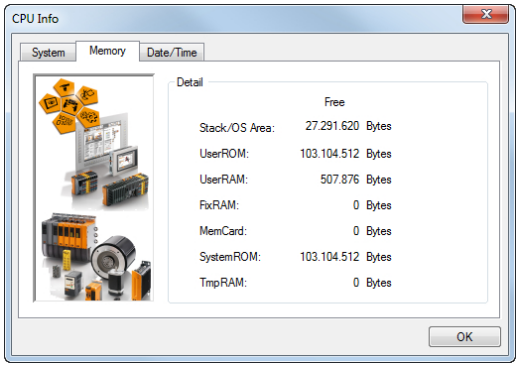


Figure 21: Reading information from the CPU

System Diagnostics Manager (SDM)

System Diagnostics Manager (SDM) is an integral component of Automation Runtime. Selecting **<Tools> / <System diagnostics>** from the main menu opens SDM in a browser window.

Information about memory usage is shown in the category "System \ Memory". In the "Software" category, you can find information about the modules that were loaded on the target system.

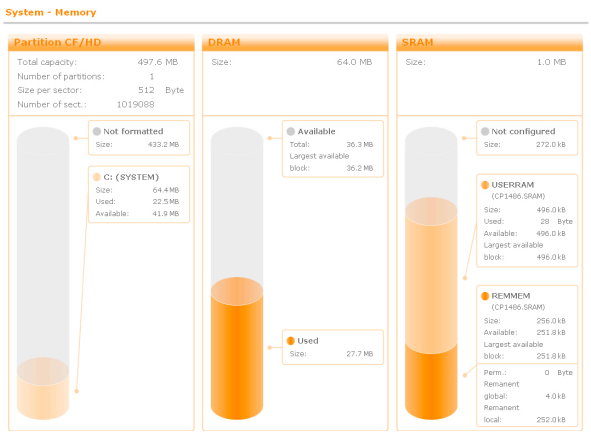
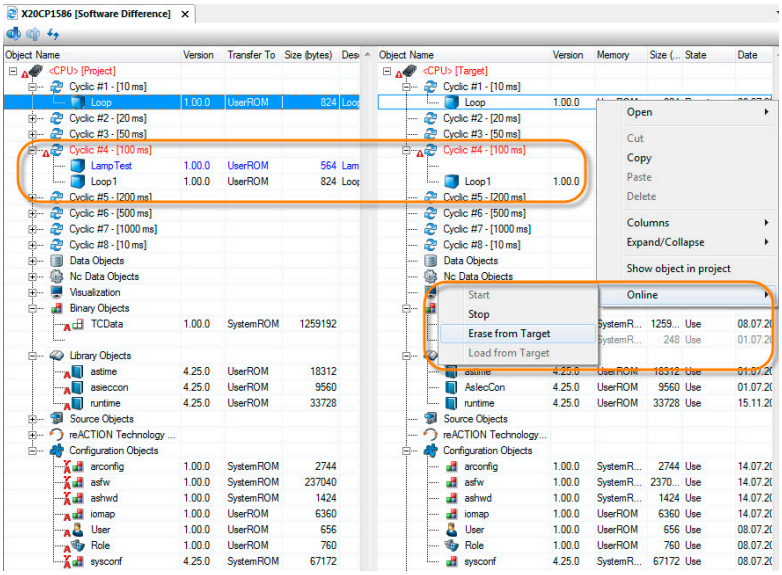


Figure 22: Memory allocation being shown in SDM

Online software comparison

With the online software comparison, the modules configured in Automation Studio are compared with the modules installed on the target system.

This online software comparison is launched by selecting **<Online> / <Comparison> / <Software>** from the main menu.



The software comparison window displays all of the modules in the project as well as on the controller. The "Size (bytes)" column displays the target memory of the module on the target system. It is possible to compare the version, size, target memory and build date of modules.

Options are displayed in the shortcut menu for a module. Modules can be deleted or stopped individually.

Figure 23: Opening the online software comparison window

Library functions

Using function block MEMxInfo() from library AsHW, the free memory on the target system can be calculated in the application.

For example, you get direct access to the file system on the flash memory with the FileIO and MpFile libraries.

Diagnostics and service \ Diagnostic tool

- Information about the target system
- System Diagnostics Manager
- Monitors \ Online software comparison

Programming \ Libraries

- Configuration, system \ AsHW
- Data access and data storage \ FileIO

Application layer - mapp Technology \ Components \ Infrastructure \ MpFile - File management system

Exercise: Set the time and date

It's necessary to set the time and date properly on the controller in order to interpret system events correctly. This can be done in the online info dialog box. The change is logged in the "System" Logger module.

1) Change the time and date with **<Online> / <Info>**.
2) Check result in the "System" Logger module

   The Logger is opened by selecting **<Open> / <Logger>**.

In the "System" Logger module, the entry "`WARNING: Time / Date changed`" is now displayed.

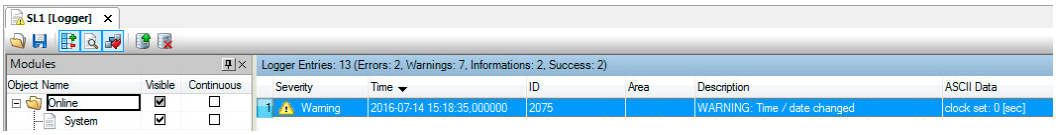


Figure 24: The "System" Logger module displays the change of time and date.

Exercise: Check the amount of memory available on the target system

The project, which was created while working with the training module "TM210 – Working with Automation Studio", is already installed on the target system.

Determine the memory allocation on the target system using one of the methods described previously. It should be determined what memory types exist on the used target system and how they are used. In addition, which modules were loaded on the target system must be checked.

1) Calculate free DRAM memory with the online info
2) Calculate free flash memory with the System Diagnostics Manager
3) Check which tasks were loaded on the target system with System Diagnostics Manager
4) Check which tasks were loaded on the target system with online software comparison
5) Delete the "LampTest" program in the online software comparison

4.4 Global and local variables

Variables are symbolic programming elements whose structure and size is determined by their data type. During the build, a memory location is assigned to the variables by the compiler.

A variable's scope and properties determine its behavior during startup and runtime.

Programming \ Variables and data types

4.4.1 Local variables

Local variables are defined in the scope of a program. Direct access to these variables from other programs is not possible.

A local variable is managed in a .var file at the same level as the program.

If local variables from a program must be transferred to local variables of another program, this is carried out using a variable assignment file in the Configuration View.

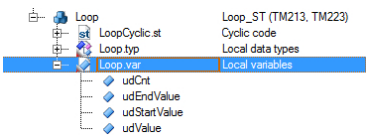


Figure 25: Local variables in the "Loop" program

Exercise: Create a "Loop" program using local variables

A new Structured Text program named "Loop" is created.

Declare four variables named "udCnt", "udValue", "udStartValue" and "udEndValue" of data type UDINT.

Create a loop in the cyclic section of the program. This loop will be explained and used in later exercises.

1) Add a new ST program with the name "Loop".
2) Open the "Loop.var" file and add the variables.
3) After saving the "Loop.var" file, the variables in the program "LoopCyclic.st" can be used.

```
PROGRAM _CYCLIC
    FOR udCnt := udStartValue TO udEndValue DO
        udValue := udValue + 1;
    END_FOR
END_PROGRAM
```

Exercise: Multiple assignment of a program in the software configuration

After completing the last task, move the same program twice from the Logical View to the software configuration using drag-and-drop.

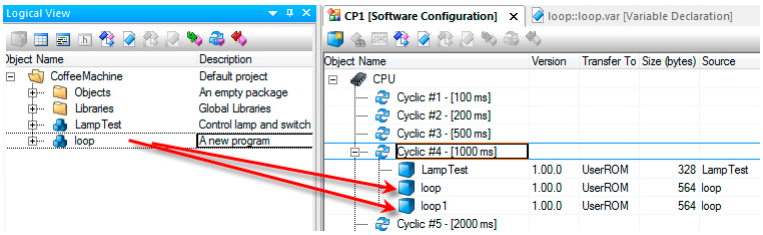


Figure 26: Multiple assignment of programs

1) Open the software configuration
2) Switch to the Logical View in the Project Explorer
3) Move the "Loop" program to the software configuration using drag-and-drop

The Watch window for both instances of the "Loop" program can be opened by selecting it from the shortcut menu in the software configuration or in the Logical View. A selection dialog box appears when the Watch window is opened via the Logical View with regard to which instance the Watch window should be opened.

The Watch window can also be opened by pressing the key combination **<CTRL + W>**.

All variables are added in the Watch window for tasks "Loop" and "Loop1". Both tasks only have local variables. Changing the variables in the Watch monitor has no effect on the other respective instance of the "Loop" program.

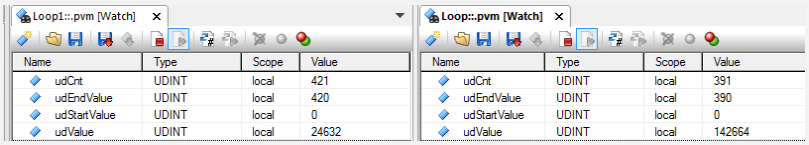


Figure 27: Variable monitor for the "loop" and "loop1" tasks

Variables that are included in the variable file but not used in the program are not available on the target system.

A corresponding warning is output during the build process.

Warning 424: Variable <variable name> is declared but not being used in the current configuration.

Programming \ Variables and data types \ Scope of declarations

Diagnostics and service \ Diagnostics tool \ Variable watch

4.4.2 Global / Package-global variables

Global variables are displayed at the top level of the Logical View. They can be used throughout the entire Automation Studio project. They can be used in every program.

A global variable is managed at the top level in the Global.var file. Additional .var files can also be created to provide a better structure for the project.

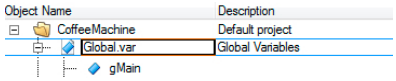


Figure 28: Global variables in the Logical View

Variables that were declared within a package are package-global variables. These are only visible within the respective package and all subordinate packages.

Global variables should only be used if it is necessary to exchange data between several programs. Another alternative is to connect local variables in different programs together using variable mapping.

Exercise: Create a global variable named "gMain" and use it in the "Loop" program

Enter a new variable in the global variable declaration "**Global.var**" with the name "**gMain**" and data type UDINT.

This variable should be incremented cyclically in the "**Loop**" program.

```
gMain := gMain + 1;
```

1) Open the "**Global.var**" file.
2) Add the "**gMain**" variable with data type UDINT.
3) Once the "**Global.var**" file has been saved, the variable in "**LoopCyclic.st**" can be used in the program.

If the variable "**gMain**" is added in the Watch window for tasks "**Loop**" and "**Loop1**", the value change in both tasks is visible.

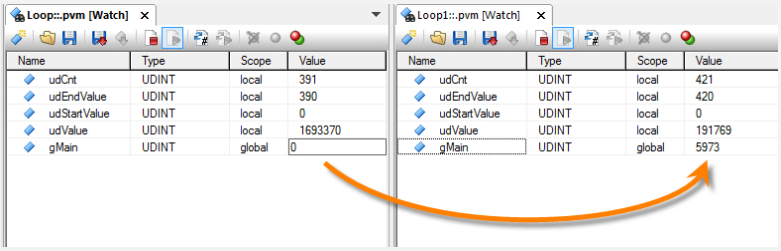


Figure 29: Writing to global variables

Programming \ Variables and data types \ Scope of declarations

Programming \ Editors \ Configuration editors \ Variable mapping

4.4.3 Initializing variable memory

During startup, all variables which haven't been given an initial value are automatically initialized with the value "0". An initialization value can be specified in the variable declaration in the "value" column.

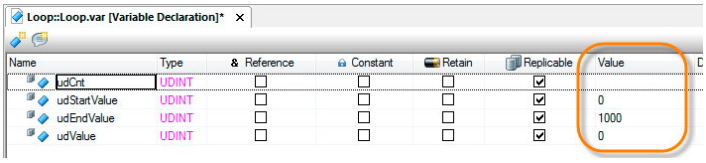


Figure 30: Variable initialization in "Loop.var"

Initialization via the variable declaration replaces, for example, the following program lines in the initialization subroutine "**LoopInit.st**":

```
PROGRAM _INIT
    udEndValue := 1000;
END_PROGRAM
```

Exercise: Initialize the "udEndValue" variable

Configure variable "**udEndValue**" in the "**Loop**" program with an initial value of 1000. Monitor the value in the Watch window.

1) Open the "**Loop.var**" variable declaration.
2) Set the value for the "**udEndValue**" variable in the "**Value**" column.

In the variable monitor for the "**Loop**" and "**Loop1**" tasks, variable "**udEndValue**" is initialized with the value 1000. During runtime, this value can be changed to any other value.

Programming \ Editors \ Table editors \ Declaration editors \ Variable declaration

4.4.4 Use of constants

Constants are variables whose values never change while the program is running. They are implemented in the programming instead of fixed numerical values. This makes programs easier to read and maintain.

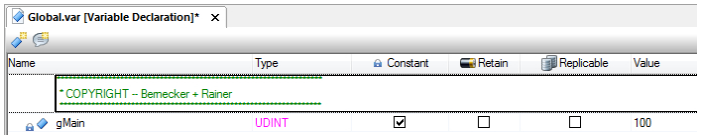


Figure 31: Declaring constants

Exercise: Global variable "gMain" as a constant

Configure the global variable "**gMain**" as a constant with a value of 100.

1) Open the "**Global.var**" variable declaration.
2) Set the value in the "**Value**" column for the "**gMain**" variable.
3) Define the "**gMain**" variable as a constant.

An error message appears during the build, because there is write access to "**gMain**".

Write access to constants in programs is not permitted. In order for the program to operate without error, the "**gMain**" variable must not be defined as a constant.

LoopCyclic.st (Ln: 19, Col: 8) : Error 1138: Cannot write to variable 'gMain'.

It makes more sense to initialize the variable "**udStartValue**" as a constant with the value "0". This variable is defined as read-only in the program.

The cross-reference list is used to determine read and write access of variables in programs. A cross-reference list is generated by selecting **<Project> / <Create cross-reference>** from the main menu.

Programming \ Variables and data types \ Variables \ Constants

Project management \ Workspace \ Output window \ Cross reference

5 Runtime performance

This section describes the runtime behavior of the application on the target system. Startup behavior, program initialization as well as the cyclic program process are explained.

5.1 Starting Automation Runtime

Automation Runtime boots when the target system is switched on. The following tasks are executed before execution of the cyclic programs.

- Hardware check
- Check if hardware firmware upgrade is required
- Checking the BR modules
- BR modules copied from ROM to DRAM
- Retain variables copied to DRAM
- Variable memory set to initialization value
- Execution of initialization subroutine
- Activation of cyclic programs

If no errors occur during the boot phase, the target system starts in RUN mode.

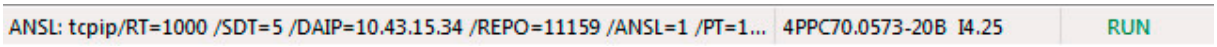


Figure 32: Power Panel C70 in RUN mode

Real-time operating system \ Method of operation \ Boot behavior

Real-time operating system \ Method of operation \ Module \ Data security

5.1.1 Automation Runtime operating states

The boot process of Automation Runtime can be divided into the following four operating states. Once an operating state has been reached successfully, the check for changing to the next operating state occurs.

In the "RUN" operating state, Automation Runtime starts the application created with Automation Studio and executes it cyclically.

Certain events lead to the target system canceling startup and staying in the corresponding operating state for diagnostic purposes. The current operating state is read using the LED status indicators on the CPU and the status bar in Automation Studio. Details are logged in the "System" Logger module.

Figure 33: Operating states of Automation Runtime

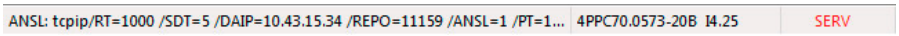
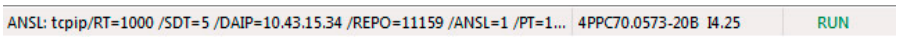
Operating state	Conditions that lead to this system state
BOOT	• No CompactFlash inserted • No operating system available on the CompactFlash/CFast card[1] • Node number switch to "00", mode selector switch to "BOOT", reset button [2]  Figure 34: Status bar - BOOT mode
DIAGNOSTICS	• Clearing memory • Fatal system error • Node number switch to "FF", mode selector switch to "DIAG", reset button  Figure 35: Status bar - DIAGNOSTICS mode
SERVICE	• Division by zero • PageFault • Cycle time violation • Missing hardware modules • CPU halted by Automation Studio  Figure 36: Status bar - SERVICE mode
RUN	• No errors  Figure 37: Status bar - RUN mode

Table 1: Overview of Automation Runtime operating states

Real-time operating system \ Method of operation \ Operating status

Hardware \ X20 system \ X20 modules \ CPUs

- X20(c)CP158x and X20(c)CP358x \ Operating mode switch
- X20CP1381-RT and X20CP1382-RT \ Button for reset and operating mode

[1] A requirement for this is that the implemented system has Automation Runtime by default. PC-based systems don't have Automation Runtime by default. In this case, a connection to the target system can't be established. Offline installation must be performed.

[2] Depending on the device used, the node selector switches, the mode selector switch or the reset button are used for setting the operating mode. The description can be found in the respective user's manual.

5.1.2 Automation Runtime boot phases

During startup of the controller, the intermediate steps will be followed. These states are also indicated in the Automation Studio status bar. These phases are usually very short.

System state	Description
STARTUP	Initialization procedures relevant to the operating system are performed during this phase.
FIRMWARE	Firmware is updated during this phase.
INIT	The application's initialization subroutines are executed during this phase.

Table 2: Overview of Automation Runtime boot phases

The phases before the RUN state (STARTUP, FIRMWARE, INIT) are indicated by a blinking green R/E LED on the X20 system.

Real-time operating system \ Method of operation \ Boot phases

5.1.3 Restarting and power failures

The restart behavior of target systems when changing operating states and after reset is documented in sections "Operating mode and node number switches", "Operating mode switch" and "Reset" in the respective data sheet for the controller used.

In addition, the restart behavior is configured in the CPU properties after a reset and power failure.

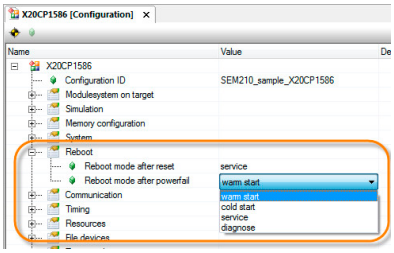


Figure 38: Configuring the restart behavior in the CPU settings

Warm restart

A restart (warm restart) is triggered by the following actions:

- PowerON after power failure
- Pressing the reset button
- Changing a system configuration and transferring it to the target system
- Performing a warm restart with Automation Studio
- Performing a warm restart with SYSreset() function

The restart behavior after a reset or power failure is configured in Automation Studio.

Retain variables keep their values after a warm restart.

Cold restart

A cold restart is triggered by the following actions:

- Restarting after exchanging a CompactFlash card
  See offline installation and initial transfer description
- Restarting after clearing UserROM
- Pressing the reset button
- Performing a cold restart with Automation Studio
- Performing a cold restart with SYSreset() function
- Restarting if the backup battery for the SRAM is defective

The restart behavior after a reset or power failure is configured in Automation Studio.

During a cold restart, retain variables with the value "0" or the initial value from the variable declaration are reinstalled. Permanent variables retain their original value.

Programming \ Libraries \ Configuration, system \ SYS_Lib \ Functions and function blocks \ System functions

Power-on handling

SYSROM and USERROM are located on the CompactFlash, CFast card or internal flash memory when power is not on. The remanent variables (RETAIN) and the USERRAM are located on the battery-backed RAM.

Real-time operating system \ Method of operation \ Module / Data security \ Power-on handling

Power-off handling

Many B&R target systems are equipped with a power failure logic. This allows the system to enter a defined state in the event of a power failure. The following tasks are performed in event of a power failure:

- Access to data objects located in USERRAM is locked.
- The remanent variables (RETAIN) are copied into the battery-backed SRAM.

Real-time operating system \ Method of operation \ Module / Data security \ Power-off handling

Exercise: Startup and operating states

First check the configuration for the restart behavior of the implemented target system. Different operating states should be entered using the mode selector switch, reset button and via Automation Studio. In the data sheet of the target system used, the functions of mode selector switches and reset buttons are documented. Check the "System" Logger module after restarting in a certain operating state.

5.1.4 Using retain variables

All boot phases are run through during startup of the target system. In order for the values of process variables to be retained after a warm restart, they must be stored in the remanent memory. During startup, the data is automatically restored.

Retain variables

In order to store variables in nonvolatile (remanent) memory, the following requirements must be met on the target system and in the variable declaration:

- Target system with battery-backed RAM - see data sheet
- Configure the variable by enabling the "Retain" option

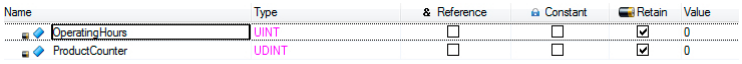


Figure 39: Configure retain variables in the variable declaration

Different target systems have varying amounts of remanent memory available. Information about the size and availability can be found in the respective data sheet or in the Automation Help.

Examples of the use of retain variables:

- Operating time counters
- Type counters and data for system efficiency
- Condition and status of the machine at the time of a power failure
- Etc.

Alternatively, data that is only read or written once when the program is started or when a change is made can be stored on the flash memory. To this end there are the function blocks of the MpRecipe library.

Real-time operating system \ Method of operation \ Memory

Programming \ Editors \ Table editors \ Declaration editors \ Variable declaration

Hardware \ X20 system \ X20 modules \ CPUs

- X20(c)CP158x and X20(c)CP358x \ Technical data
- X20CP1301, X20CP1381 and X20CP1382 \ Technical data

Application layer - mapp Technology \ Components \ Infrastructure \ MpRecipe - Recipe management

Permanent variables

In order for retain variables to be retained after a cold restart, they must be added to the permanent variables in the Configuration View (CPU.per).

Examples of data to be stored permanently:

- Operating time counters
- All data that isn't written to a flash memory but must also be retained after a cold restart.

Only **global** retain variables can be configured as permanent variables.

It is the responsibility of the user to manage the values of variables in the permanent memory.

If the state of permanent variables are not based on a proper foundation, this can result in undesired program behavior. This is especially important to remember when replacing the CPU or backup battery.

Data storage on a Technology Guard can be used as an alternative to permanent variables, which are always connected to a certain controller. Access to the data storage of a Technology Guard can be gained via the AsGuard library.

Programming \ Variables and data types \ Variables \ Variable remanence

Programming \ Editors \ Configuration editors \ Permanent variables

Automation software \ Technology Guarding

Programming \ Libraries \ Configuration, system information, runtime control \ AsGuard

Exercise: Use RETAIN variables

The "udValue" variable is increased with every loop in the "loop" program. During a warm restart, the last value of the "udValue" variable must be retained.

1) Declare "udValue" variable as RETAIN
2) Transfer program - Check value "udValue" in the Watch window
3) Perform warm restart
4) Check the result

5.2 Program initialization

An initialization subroutine can be managed for every program. For example, variables can be initialized through calculations in an initialization subroutine.

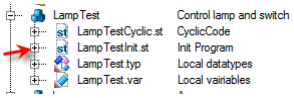


Figure 40: Program initialization

Running the initialization subroutine

Before the first cyclic program is started, all initialization subroutines are executed once in the order defined in the software configuration. As long as the initialization subroutines are executed, this is indicated in the status bar as well as by the LED status indicators on the CPU.

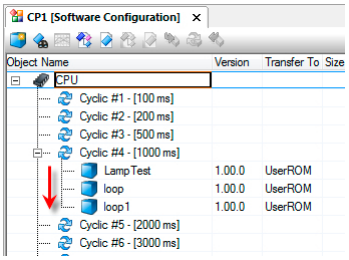


Figure 41: Executing initialization subroutines

In this example, the initialization subroutines would be executed in the following order:

1) Initialization subroutine for the "LampTest" task
2) Initialization subroutine for the "Loop" task
3) Initialization subroutine for the "Loop1" task

Because initialization subroutines are not subject to cycle time monitoring, a violation will not be triggered by longer initializations.

Function calls in an initialization subroutine

When using functions, it is important that the function returns a result the first time it is called.

Functions that must be called several times must be called in the cyclic section of the program.

Real-time operating system \ Target systems \ SG4 \ Runtime performance \ Starting initialization subroutines

5.3 Execution of cyclical programs

A program is assigned a certain execution time, or task class, in the software configuration.

The programs assigned to the software configuration are identified as tasks. The programs that are assigned in the software configuration are only executed after the transfer.

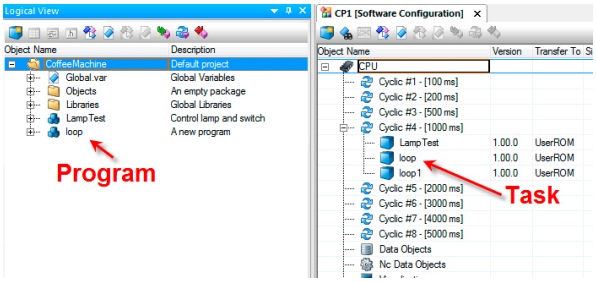


Figure 42: Programs and tasks

Automation Runtime is a deterministic, real-time multitasking operating system.

The tasks are assigned to configurable task classes and executed one after the other. The execution time of the tasks may vary. However, the times when the tasks start as well as when the I/O system is accessed are deterministic.

5.3.1 Task classes and cycle times

A task is executed cyclically in the time defined by its task class i.e. its cycle time.

Up to eight task classes with a configurable cycle time are provided to help optimize a task for its particular requirements. Every task class contains tasks with the same cycle time, priority and tolerance.

In this example, the task class #4 contains three tasks. A cycle time of 100 ms is configured.

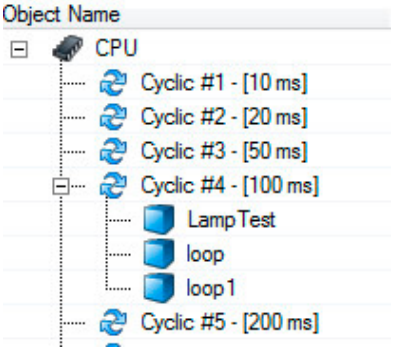


Figure 43: Task class #4 with three tasks

> Not all tasks need to run within the same task class. Control tasks that must be executed quickly should be assigned to a task class with a smaller cycle time. For slower processes, a task class with a correspondingly higher cycle time is selected.

Ignoring the time it takes to execute the tasks, the program sequence would look like this:

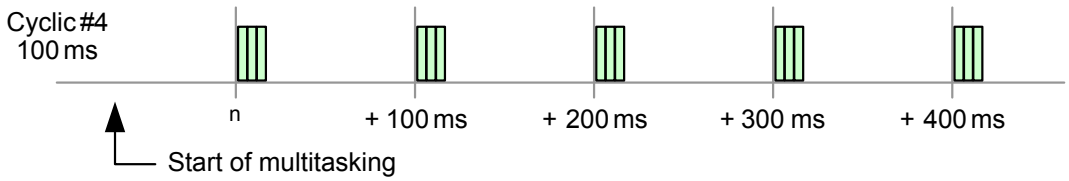


Figure 44: Tasks are called again during each cycle.

This means that the tasks in this task class are executed every 100 milliseconds. In order to do that, the sum of the execution time of the assigned programs can't exceed the configured cycle time.

Real-time operating system \ Target systems \ SG4 \ Runtime performance \ Start of cyclic tasks

5.3.2 Cycle time and priority

The priority of a task class is determined by the number of the task class.

The lower the number, the higher the priority of the task class.

Moving a task between task classes changes its priority and cycle time.

Task class #8 has the lowest priority in the system. (see: "Task class with high tolerance" on page 42)

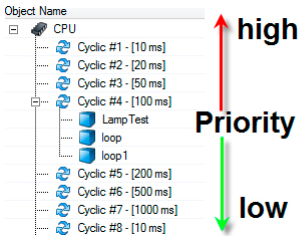


Figure 45: Task class priority

If the "Loop" task is moved from task class #4 to task class #1, it will be executed every 10 milliseconds.

The execution time of a task is not influenced by moving it to a different task class. It just changes the number of times it is called in a given period of time.

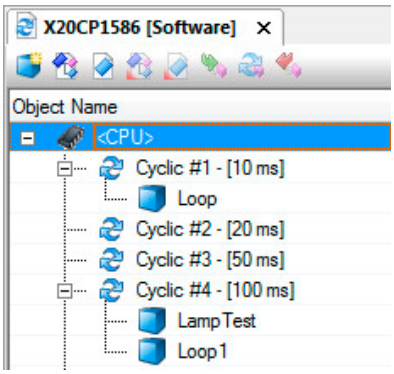


Figure 46: Different task classes

The "**Loop**" task is now executed every 10 ms. The tasks "**LampTest**" and "**Loop1**" in task class #4 are executed every 100 milliseconds, as before.

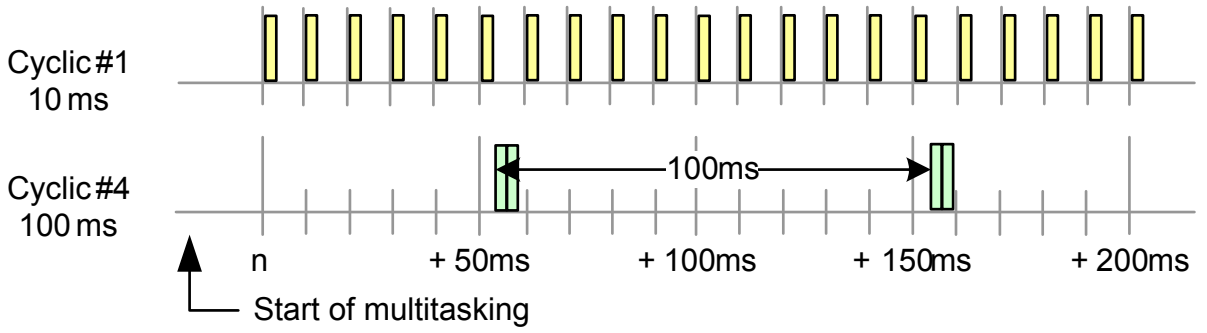


Figure 47: Executing tasks in different task classes

Exercise: Move the "Loop" task to task class #1

The "**Loop**" task in the software configuration should be moved to task class #1.

In the Watch window, observe the changes to the cycle times of "**Loop**" and "**Loop 1**", which reference the same program.

1) Open the software configuration
2) Move the "**Loop**" task from task class #4 to task class #1
3) Open the Watch window for both tasks.
4) Monitor the "**udValue**" variable.

The "Loop" program is executed 10 times as frequently as "Loop1". As a result, the value of the "udValue" variable is increased more often by this factor.

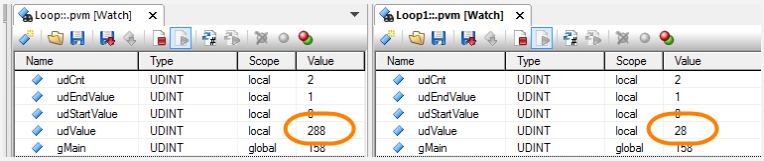


Figure 48: Cycle times in different task classes

5.3.3 Idle time

During operation, Automation Runtime performs other system tasks in addition to the execution of tasks. They provide the user with useful functions. For example, a constant module verification process is performed and online communication is available.

The speed at which these tasks are executed can vary depending on processor performance.

The time when no Automation Runtime or user tasks are being executed is referred to as **idle time**. Automation Runtime uses this idle time, for example, for the following tasks:

- Online communication
- Visual Components application
- Access to the file system

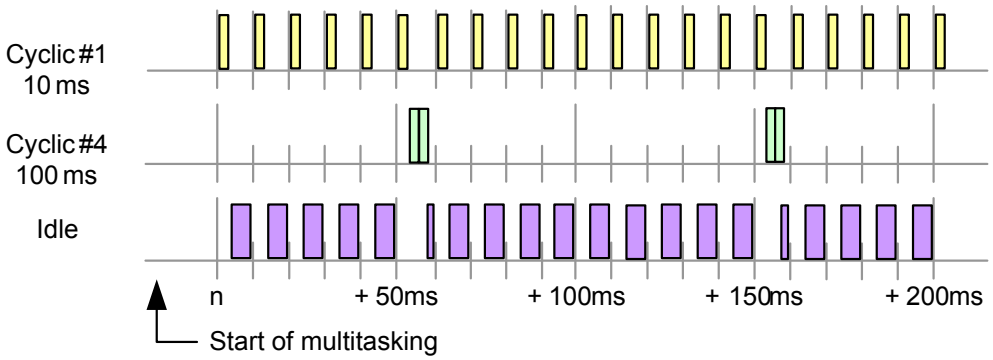


Figure 49: Idle time in the cyclic system

The basic task class for the idle time is established in the CPU configuration. The configured idle time of the system is provided in the context of this task class.

The **Profiler** can be used to determine the idle time. The **System Diagnostics Manager** can also be used to display the average system load.

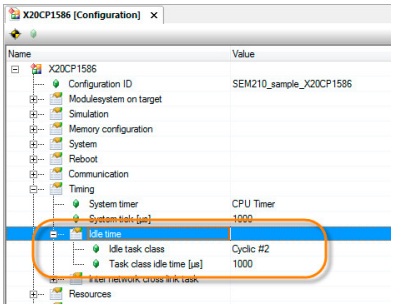


Figure 50: CPU configuration: Basic task class for idle time

If the idle time is not sufficient, the required amount of idle time can be increased by moving programs in slow task classes or by adjusting the task class cycle time.

Real-time operating system \ Method of operation \ Runtime performance \ Scheduling \ Idle time

5.3.4 Starting task classes

Not all task classes are started simultaneously after the multitasking system has been started.

The starting point is always half of the task class cycle time.

This means, for example, that the 100 ms task class will be started after 50 ms. Distributing the start time of all task classes makes better use of processor performance and allows, for example, output jitter to be kept to a minimum.

Real-time operating system \ Target systems \ SG4 \ Runtime performance \ Start of cyclic tasks

5.3.5 Task interrupted by another task

Task class priority makes it possible for a task of higher priority to interrupt a task of priority task class that takes longer.

Using the Watch window, the limit of the variable "**udiEndValue**" can be changed in such a way in tasks "**Loop**" and "**Loop1**" that the task "**Loop1**" is interrupted exactly **two times** by the task "**Loop**".

The schematic diagram shows how the timing can look in this case. In order to be complete and promote better understanding, the image was updated with the timing of task class #3.

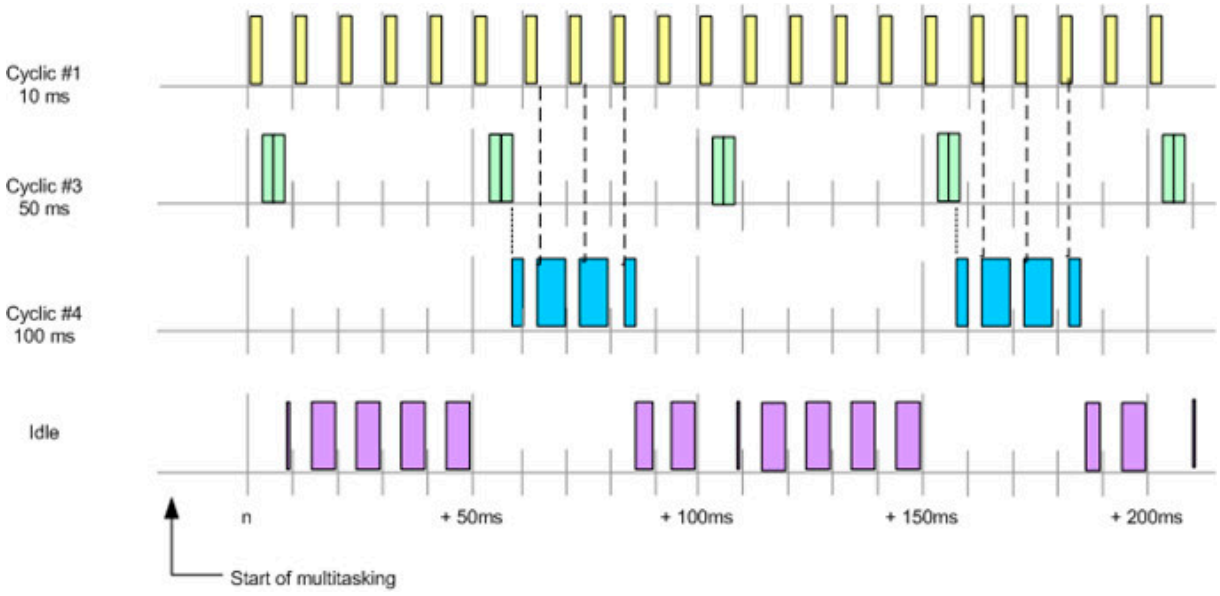


Figure 51: Multitasking with task class #1, #3 and #4; Task class #4 is interrupted by task class #1

For task class #4, a consistent I/O input image is available over the entire execution time. That's why the tasks in this task class are not influenced by the interruption.

5.4 Cycle time and tolerance

Each task class has a **predefined** cycle time. All of the tasks in a task class must be executed within this cycle time.

The cycle time of a task class is defined when a project is created and can be changed by the user later depending on requirements.

If the sum of the runtimes of the tasks in a task class exceeds the configured cycle time, a cycle time violation occurs. A configurable tolerance delays the cycle time violation.

The cycle time and tolerance can be configured in the properties of the task class. Open the Properties window from the shortcut menu for the task class.

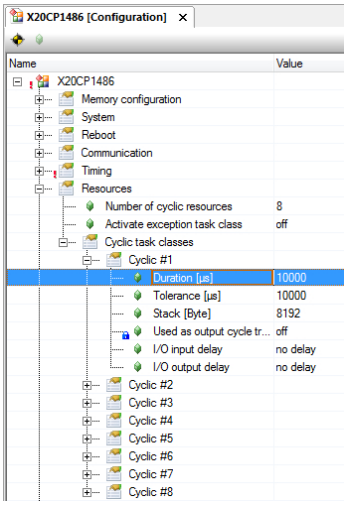


Figure 52: Configuring the cycle time and tolerance

If the configured cycle time of a task class is exceeded, the start of the next cycle is moved backwards by the set tolerance. This can lead to problems in the timing of the application. This behavior is avoided by setting the tolerance to the value "0".

Programming \ Editors \ Configuration editors \ Hardware configuration \ CPU configuration

Exercise: Check the system load using the "Loop" program

In the "**Loop**" task, which runs in task class #1, an increased runtime must be triggered by changing the value of the "**udEndValue**" variable.

Using the **System Diagnostics Manager**, the system load caused by the tasks and the available idle time are monitored.

1) Set the "udEndValue" variable to 50000

   Determine the system load using System Diagnostics Manager

2) Increase "udEndValue" variable in steps

The results in the System Diagnostics Manager must be analyzed between the respective steps.

In the System Diagnostics Manager, the average system load is displayed over a selectable time period. In the graphic, the mean and the maximum can be read.

Details about the runtime behavior of a certain task can only be obtained with the Profiler. Additional exercises are planned in training module "TM223 - Automation Studio Diagnostics".

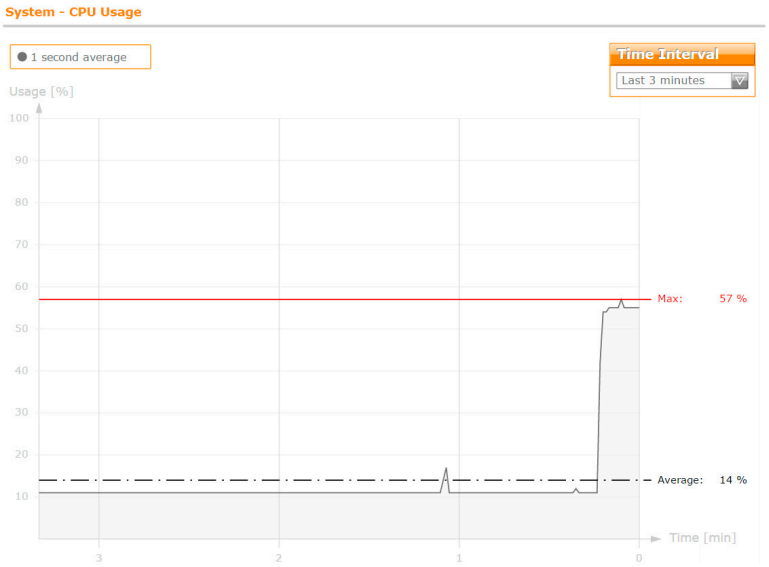


Figure 53: Display of the CPU load in the System Diagnostics Manager

Diagnostics and service \ Diagnostic tool

- System Diagnostics Manager
- Profiler

5.4.1 Cycle time violation

Automation Runtime monitors the timing when executing the task classes. A cycle time violation is triggered if the execution time of the tasks exceeds the configured cycle time. If a cycle time violation is detected, the target system starts up in SERVICE mode.

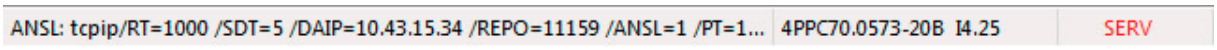


Figure 54: CPU in SERVICE mode

In this example, the cycle time violation is the result of changing values in the Watch window. When a cycle time violation occurs, all values in the Watch window are "frozen" and initialized with 0 after restarting in SERVICE mode.

Use the Logger to analyze why the system rebooted in SERVICE mode.

The Logger window can be opened by selecting **<Open> / <Logger>** from the main menu or using the keyboard shortcut **<CTRL> + <L>**.

In the image, a cycle time violation in task class #1 was entered as the cause of error.

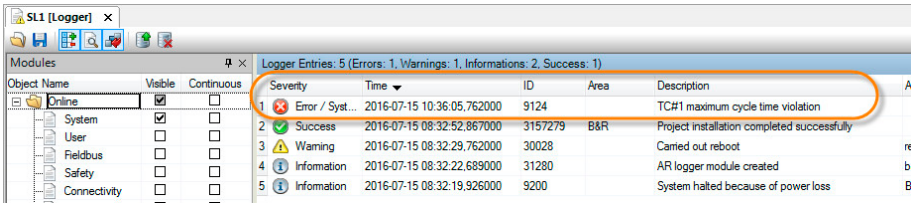


Figure 55: Analyze the cause of the error in the Logger: Cycle time violation in task class #1

The cause of the cycle time violation can be determined using the Profiler. Exercises for this are included in training manual TM223 – Automation Studio Diagnostics.

When the target system is restarted – either by turning the power OFF/ON, or by performing a warm restart or reset – it boots in RUN mode.

Diagnostics and service \ Diagnostic tools \ Logger window

Exercise: Increase the value of the "udEndValue" variable until a cycle time violation occurs

The goal of this exercise is to raise the "udEndValue" variable in the "Loop" program incrementally until a cycle time violation occurs. The target system is restarted. The controller starts in SERVICE mode. Next an analysis with the Logger has to be performed.

1) Increase the value of "udEndValue" until a cycle time violation occurs
2) Analyze entry for the cycle time violation in the Logger.

5.4.2 React to the cycle time violation in the application program

In a live production system, changing to SERVICE mode without an option for a response is undesired. Events like a cycle time violation can be reacted to in an exception program.

The exception task class is enabled in the properties of the CPU configuration under the Resources category.

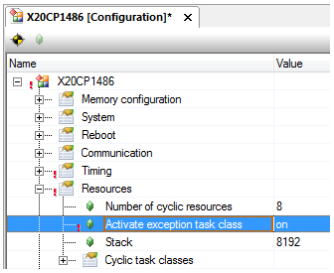


Figure 56: Enabling the exception task class

A program is added from the Logical View into the software configuration in the exception task class.

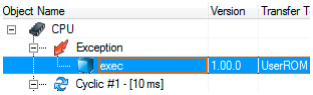


Figure 57: Assign program in exception task class

An exception number is specified in the properties of the exception task. The exception number is specified by the system and can be looked up in Automation Help.

A cycle time violation (exception no. 145) occurring at runtime will call this task. Depending on requirement, you can react to the cycle time violation in the exception task.

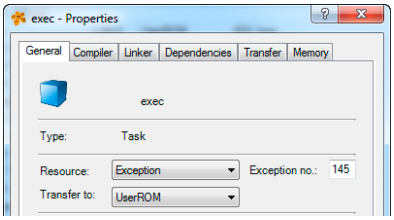


Figure 58: Configuring the exception task

Programming \ Editors \ Configuration editors \ Hardware configuration \ CPU configuration \ Resources

Real-time operating system \ Target Systems \ SG4 \ Runtime performance \ Exception task class

5.4.3 Task class with high tolerance

Tasks that are executed as quickly as possible but with a low priority should be executed in task class #8.

If possible, this is called every 10 ms, but can be interrupted by any higher priority task class. The configured tolerance determines that task class #8 must be executed to completion at least once every 30 seconds.

Tasks that should be assigned to task class #8:

- File access from application program
- Complex, non-time-critical calculations

5.5 Settings when transferring programs

Programs and configurations are transferred after changing to the target system. A restart is required when changing a system configuration.

When transferring program changes, you have to decide whether this occurs during development or on the production system.

Depending on the use case, the transfer settings for project installation can be adjusted. The image shows the standard values for project installation.

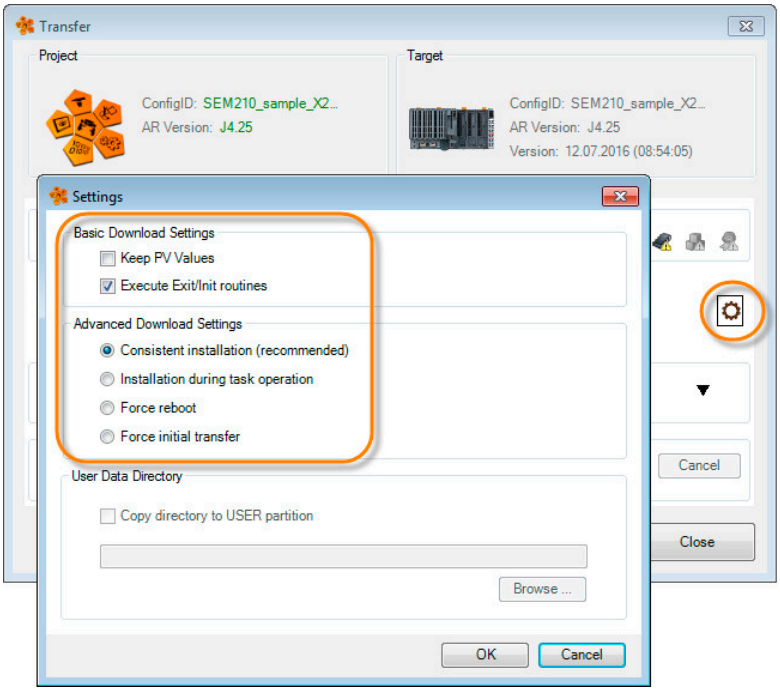


Figure 59: Configuration of the transfer settings for project installation

Retain PV values

This setting defines whether the values of process variables are retained over the installation procedure for existing tasks and tasks updated by the transfer.

Execute Exit/Init routines

If resources (memory, interfaces) were used in the initialization or cyclic subroutine, then these resources can be freed up again using the Exit subroutine.

Consistent installation

All task classes are halted during installation. This guarantees the consistency of all tasks that run on the target system.

Installation during task operation

Only those tasks are halted that are being installed during the installation procedure. The other tasks continue to be executed cyclically and are unaffected by the installation.

Force restart or initial transfer

Via the force restart option, the target system is restarted after the project transfer. An initial transfer is executed with the force initial transfer option.

User directory

If a user partition has been defined, user data is copied to the user partition via this option.

See: "Configuration ID and partitioning" on page 15

Project management \ Project installation \ Operation \ Settings \ Settings during the transfer

Exercise: Adjust transfer settings

In the initialization subroutine for "loop", the limit for the loop is set to the value 1000. The goal of these exercises is to experience effects of the extended transfer settings. Change the limit of the loop in the variable monitor at runtime. Then change something in the "loop" program. Changing a comment is enough. Compile and transfer the change. Using the transfer settings, the limit previously set in the variable monitor must be retained.

1) Change "udEndValue" variable to an arbitrary value
2) Execute the program change in the "loop" program
3) Start compilation and transfer
4) Adjust transfer settings
5) Check if the value of "udEndValue" is retained

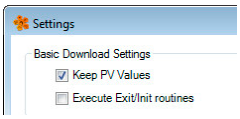


Figure 60: Settings for preserving the values of process variables; the execution of init/exit programs is prevented

6 I/O handling

A central function of a controller is to transport input and output states deterministically and as quickly as possible from and to I/O terminals in the application.

Automation Runtime I/O Management is designed to meet the highest requirements for **response times** and **configurability**.

The I/O scheduler transfers the input image from the I/O terminal before the beginning of the task class and the output image at the end of the task in a task class.

The image shows the basic sequence of I/O handling in Automation Runtime. The I/O scheduler makes a consistent input image available to the task class. This is indicated with the green arrow. At the end of the last task in the task class, the output data is transferred to the I/O scheduler. This is indicated with the red arrows.

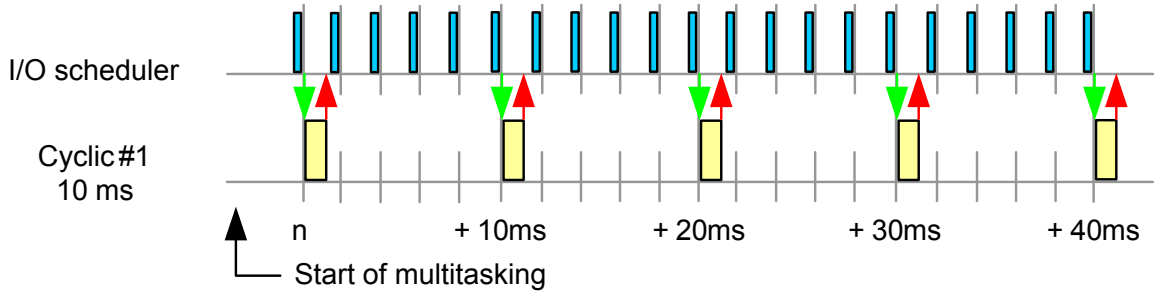


Figure 61: I/O scheduler: Provide input image; write the output image at the end of the execution time of the tasks.

In the I/O mapping, process variables are connected with I/O module channels. The I/O scheduler is controlled by the I/O mapping.

By default, task class #1 is set to 10 milliseconds.

The default configuration for the POWERLINK and X2X interfaces is a cycle time of 2 milliseconds.

The task class cycle time can be adjusted to the I/O cycle time in the CPU configuration.

Programming \ Editors \ Configuration editors \ Hardware configuration \ CPU configuration

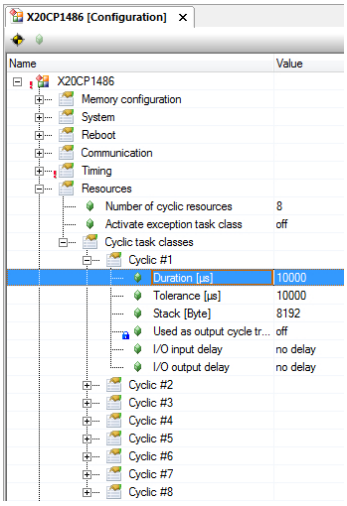


Figure 62: Configuring the cycle time for task class #1

Real-time operating system \ Target systems \ SG4 \ I/O management

Real-time operating system \ Target systems \SG4 \ I/O management \ Method of operation

6.1 Handling I/O images

The I/O scheduler provides a consistent I/O image for the execution of all tasks in a task class and starts the task class at the exactly configured time. This ensures that the inputs at the beginning of the task class and the outputs at the end of the task class are transferred.

Each task class uses a separate I/O image. The input states remain consistent during the entire task runtime.

Cycle of I/O data

The provision of I/O data occurs in the set I/O cycle time of the bus system used.

The configuration is opened via the shortcut menu for the respective fieldbus.

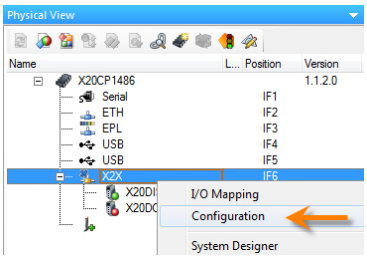


Figure 63: Opening the properties of the X2X Link interface

The I/O cycle time configured in the properties is used as the basis for copying I/O data to the I/O image. This means that the inputs are provided as an I/O image and the output image is described in the set X2X cycle time.

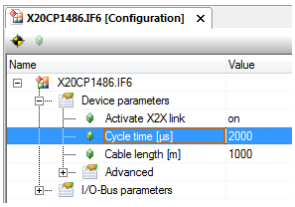


Figure 64: Configuration of the X2X cycle time

The graphic shows that an input image is provided every 2 milliseconds. For the application, this means that the input data is not older than the configured cycle time when the task class starts; the output data will be written after this time has passed at the latest.

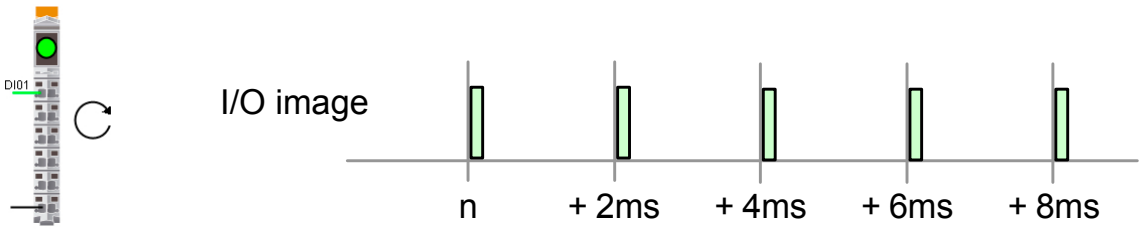
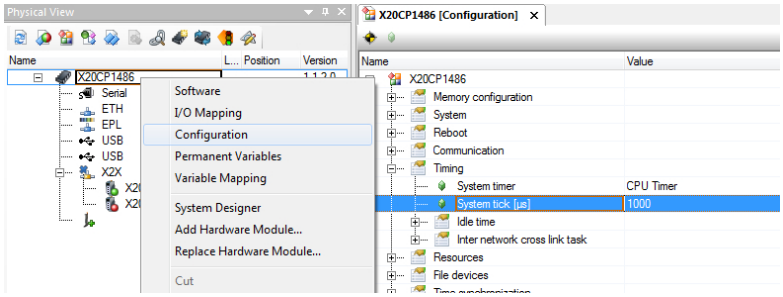


Figure 65: Reading the input image

I/O data in the task class

The I/O scheduler controls when the I/O image for the task classes is provided and the task classes are started.



By default, the I/O scheduler is opened with a system tick of 1000 µs.

The system tick is set in the CPU configuration in the "Timing" category.

Figure 66: Configurable system tick

The graphic shows that the I/O scheduler is called twice as often as the I/O image is updated.

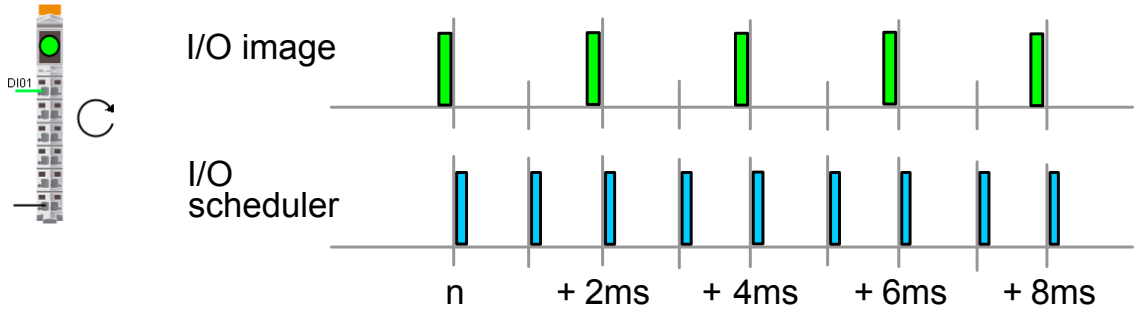


Figure 67: Reading the input image; Calling the I/O scheduler

The cycle time of the fieldbus can be used as a system timer in the timing configuration. By default, the fieldbus cycle time is applied in a 1:1 ratio for the I/O scheduler. I/O cycle and I/O scheduler now work synchronously in the set ratio.

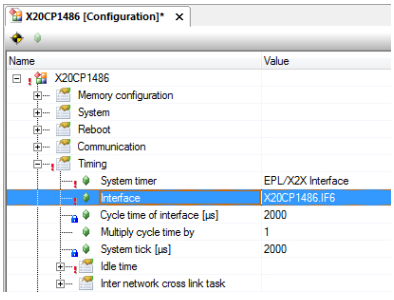


Figure 68: Synchronizing the system tick

By using the fieldbus timer as a system timer and multiplying the cycle time by a factor of 1, the I/O scheduler is called with the configured I/O cycle time.

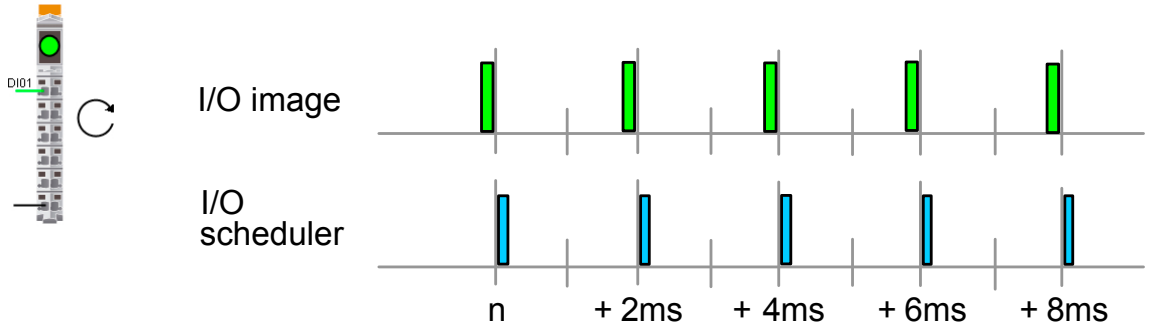


Figure 69: Synchronizing the I/O image and I/O scheduler

As is established in the I/O mapping, the I/O data from the input image is assigned to the configured process variables.

For the tasks of a task class, this results in the following when the I/O scheduler is called in a cycle time of 2 milliseconds:

Task class #1

The I/O scheduler starts task class #1 every 10 ms and provides it with the input image for the assigned variables (green arrow).

At the end of the tasks in task class #1, the variables of the assigned outputs are written to the output image (red arrow).

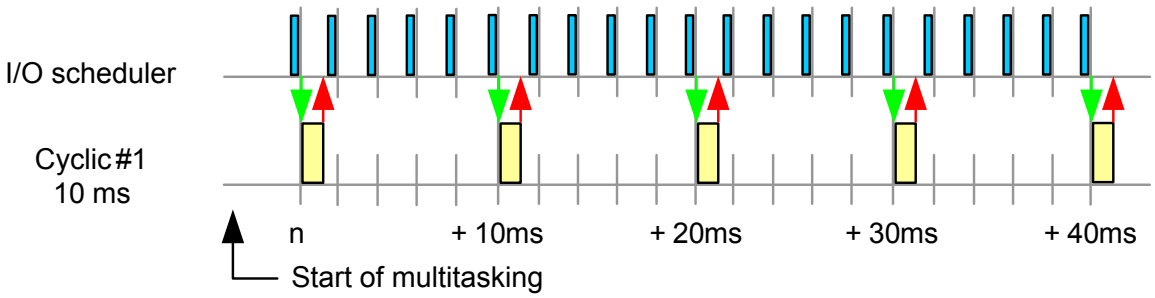


Figure 70: I/O handling for task class #1

Task class #4

The I/O scheduler starts task class #4 at the time, n+50 ms, n+150 ms and provides it with the input image for the assigned variables (green arrow).

At the end of the tasks in task class #4, the variables of the assigned outputs are written to the output image (red arrow).

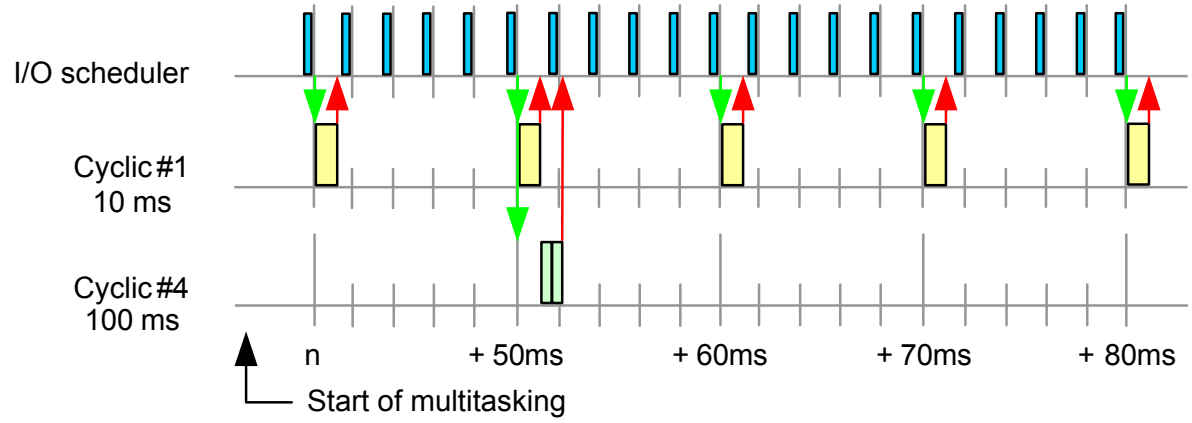


Figure 71: I/O handling for task class #4

Real-time operating system \ Target systems \ SG4 \ I/O management

6.1.1 Startup

Booting the controller transfers the I/O configuration to the I/O modules and initializes the interfaces and fieldbus devices. This occurs even before the programs are initialized. This ensures that valid I/O data can be accessed in the initialization subroutine.

6.1.2 Mapping I/O data

The following image displays the relationship between the I/O configuration and the I/O mapping.

The I/O configuration is transferred to the module when the controller boots up or when a configured I/O module is recognized.

In cyclic operation, the input data is provided as a memory block and distributed by the I/O mapping to the configured process variables. In order to write the output data, the process variables are collected and transferred as a memory block to the I/O system.

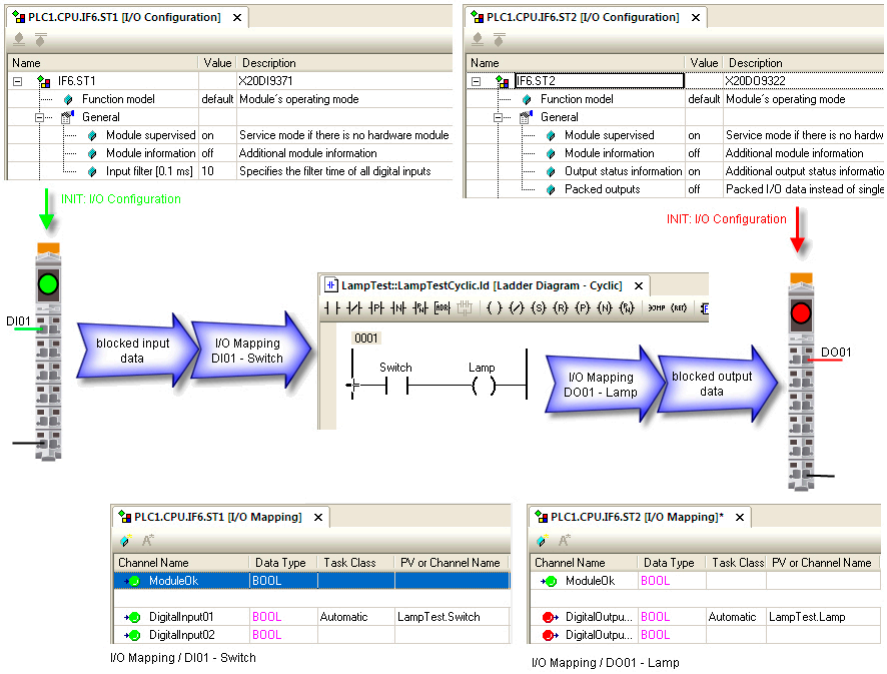


Figure 72: Basic I/O functionality

6.1.3 Settings for the timing of I/O images

There are configuration options available for the task classes for the chronological handling of I/O images. The standard case is the immediate writing of the outputs when ending the last task in the task class. This causes jitter on the outputs when the task runtime fluctuates.

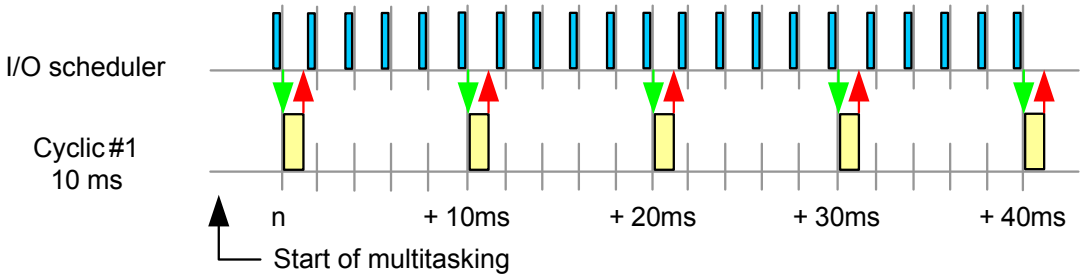


Figure 73: Outputs are transferred immediately to the I/O system after the task has ended.

Alternatively, the time when the input images are read and the output images written can be delayed via the CPU settings for the task class.

If for task class #1 the parameter "I/O output delay" is configured to the value "To end of cycle". This way output data is only transferred to the I/O scheduler at the end of the task class. The effect of this is that even during fluctuating task runtime, the outputs of a task class are written jitter-free.

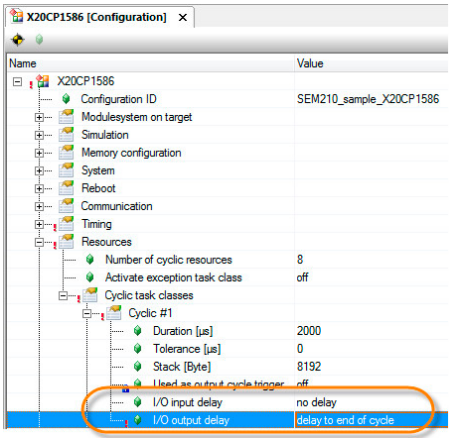


Figure 74: Configuration for the deceleration of the output data to the end of the cycle

The graphic shows the effect of the delay of the output image at the end of the cycle.

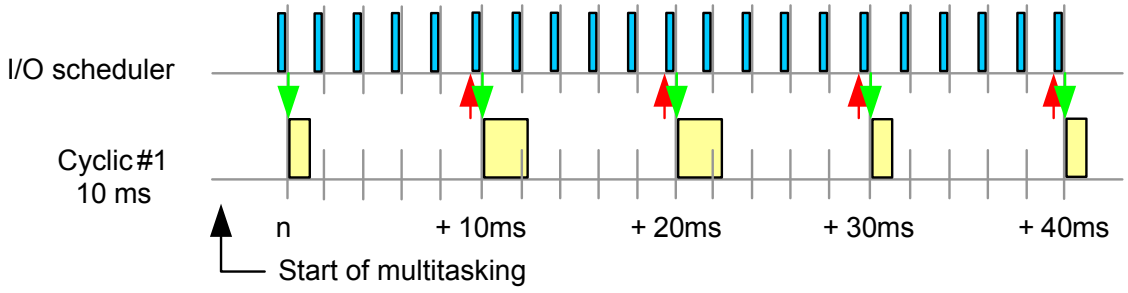


Figure 75: Jitter-free writing of output image at end of cycle

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6.2 I/O configuration and I/O assignment

6.2.1 I/O configuration

Module-specific properties are configured in the **I/O configuration**.

The offered functionality of I/O modules continues to open up many implementation options and operating modes in which they can be used. The behavior for module monitoring, individual configurations and function models, among others, are adjusted in the I/O configuration.

The I/O configuration is opened via the shortcut menu for the desired I/O module. The configuration options of an I/O module are documented in the respective data sheet under section "Register description".

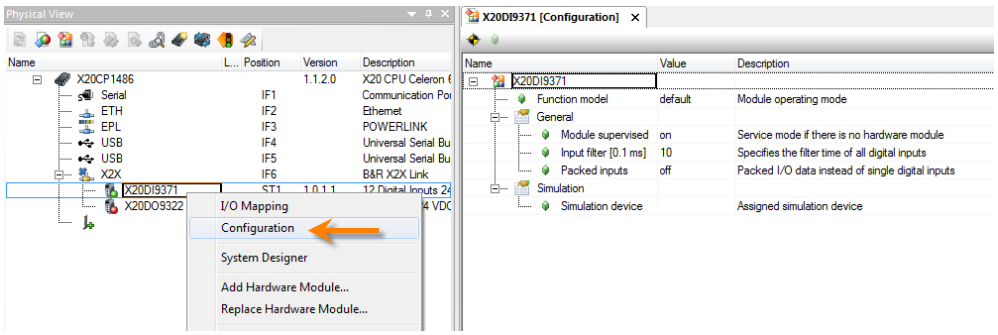

Figure 76: I/O configuration of a digital input module

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6.2.2 I/O mapping

The **I/O mapping** defines which data from the I/O image is assigned to a process variable.

Each variable in a .var file that is used in a program can be assigned to a channel of an I/O module, regardless of its scope.

The I/O mapping is opened via the shortcut menu for an I/O module.

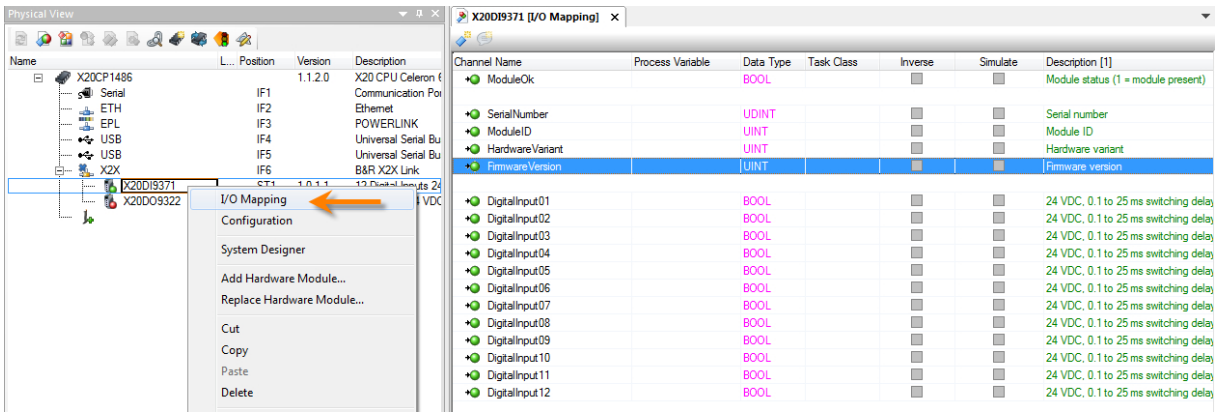

Figure 77: I/O mapping of a digital input card

For global variables, the channel can be assigned a task class in which the data of the I/O image should be transferred.

If "Automatic" is set and the project built, Automation Studio will automatically determine the fastest task class where the variable is being used.

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6.3 Error handling for I/O modules

Every configured I/O module is monitored by the I/O system. The user can configure how the system responds to error situations.

The "**Module monitoring**" property in the **I/O Configuration** can be used to enable or disable the monitoring of an I/O module.

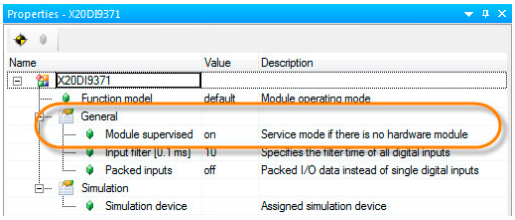

Figure 78: Configuration of module monitoring

Monitoring enabled

When the module monitoring by Automation Runtime is enabled, the following states will cause a restart in SERVICE mode:

- The module defined for a slot is not present (or not connected).
- The module physically connected in a slot doesn't match the module actually configured for the slot.
- The module is not addressed anymore during operation by the I/O system.

If a missing, incorrectly configured or incorrectly inserted I/O module is recognized on startup or during runtime, then this is logged in the "System" Logger file.

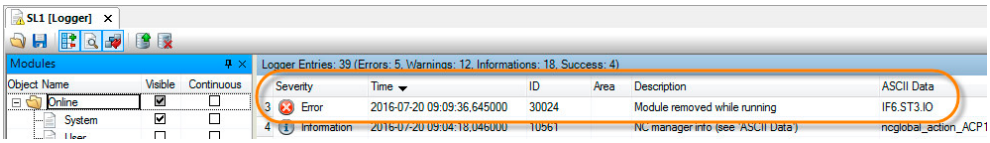

Figure 79: Logger entry "module removed while running"

The slot of the module can be identified using the ASCII data in the Logger entry. "IF6.ST3" means that the "ST3" module on the IF6 interface, which is the X2X interface in this case, was disconnected. This is the third slot on that bus. The CPU interface names can be viewed in the Physical View as well as in the data sheet of the CPU being used.

Monitoring disabled

When module monitoring is disabled, the I/O module can be monitored from the application by variable mapping on the "**ModuleOK**" channel. Missing or incorrectly inserted modules don't cause a reboot in SERVICE mode. Only the value of the "ModuleOk" channel becomes "FALSE". The monitoring of the modules is therefore the responsibility of the application.

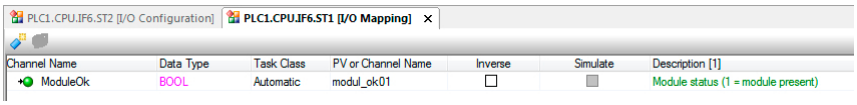

Figure 80: Module monitoring via the application

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Exercise: Remove bus connection or I/O module during operation

Cancel the connection to a X20 bus controller during operation or remove an I/O during runtime. The controller is restarted in SERVICE mode and the execution of the controller application is canceled. Read the Logger file and analyze the entries.

1) Remove bus station or I/O module during operation
2) Wait for reboot and startup in SERVICE mode
3) Read and analyze the Logger file "System"

7 Summary

The operating system provides an interface between the application and the hardware while ensuring consistent management of the resources on the respective target system.

Multitasking in Automation Runtime makes it possible to design an application with a modular structure. The arrangement of the application in tasks grouped into task classes enables optimal usage of resources. The timing of the application can be configured by adapting the multitasking system to the user's unique requirements.

Tasks that should be executed quickly and frequently run in a faster task class, while other important tasks that are less time critical are executed in low-priority task classes.

This makes it possible to achieve an optimal configuration to maximize the performance of the application and machine while using existing resources efficiently.

Figure 81: Automation Runtime: A software platform for the entire B&R product range

The platform-independent configurable interfaces as well as client and server protocols make Automation Runtime a powerful operating system. The openness of the system makes it possible to directly integrate devices from other manufacturers, establish connections to OPC UA clients and servers and implement the required IT safety mechanisms.

The state of Automation Runtime is always transparent thanks to several diagnostic tools and software libraries. This helps with commissioning and the implementation of individual application requirements.

Seminars and training modules

The Automation Academy provides targeted training courses for our customers as well as our own employees.
At the Automation Academy, you'll develop the skills you need in no time!
Our seminars make it possible for you to improve your knowledge in the field of automation engineering.
Once completed, you will be in a position to implement efficient automation solutions using B&R technology. This will make it possible for you to secure a decisive competitive edge by allowing you and your company to react faster to constantly changing market demands.

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Programming and configuration	Diagnostics and service
SEM210 – Basics SEM246 – IEC 61131-3 programming language ST* SEM250 – Memory management and data storage SEM410 – Integrated motion control* SEM441 – Motion control: Electronic gears and cams** SEM480 – Hydraulics** SEM1110 – Axis groups and path-controlled movements** SEM510 – Integrated safety technology* SEM540 – Safe motion control*** SEM610 – Integrated visualization*	SEM920 – Diagnostics and service for end users SEM920 – Diagnostics and service with Automation Studio SEM950 – POWERLINK configuration and diagnostics* If you don't happen to find a seminar on our website that suits your needs, keep in mind that we also offer customized seminars that we can set up in coordination with your sales representatives: SEM099 – Individual training day Please visit our website for more information****.****: **www.br-automation.com/academy**

Overview of training modules

TM210 – Working with Automation Studio TM213 – Automation Runtime TM223 – Automation Studio Diagnostics TM230 – Structured Software Development TM240 – Ladder Diagram (LD) TM241 – Function Block Diagram (FBD) TM242 – Sequential Function Chart (SFC) TM246 – Structured Text (ST) TM250 – Memory Management and Data Storage TM400 – Introduction to Motion Control TM410 – Working with Integrated Motion Control TM440 – Motion Control: Basic Functions TM441 – Motion control: Electronic gears and cams TM1110 – Integrated Motion Control (Axis Groups) TM1111 – Integrated Motion Control (Path Controlled Movements) TM450 – Motion Control Concept and Configuration TM460 – Initial Commissioning of Motors TM500 – Introduction to Integrated Safety TM510 – Working with SafeDESIGNER TM540 – Integrated Safe Motion Control	TM600 – Introduction to Visualization TM610 – Working with Integrated Visualization TM630 – Visualization Programming Guide TM640 – Alarm System, Trends and Diagnostics TM670 – Advanced Visual Components TM920 – Diagnostics and service TM923 – Diagnostics and Service with Automation Studio TM950 – POWERLINK Configuration and Diagnostics TM280 – Condition Monitoring for Vibration Measurement TM480 – The Basics of Hydraulics TM481 – Valve-based Hydraulic Drives TM482 – Hydraulic Servo Pump Drives TM490 – Printing Machine Technology In addition to the printed version, our training modules are also available on our website for download as electronic documents (login required): Visit our website for more information: **www.br-automation.com/academy**

Process control seminars and training modules

Process control standard seminars	Process control training modules
SEM841 – Process control training: Basic 1 SEM842 – Process control training: Basic 2 SEM890 – Advanced Process Control Solutions	TM800 – APROL System Concept TM810 – APROL Setup, Configuration and Recovery TM811 – APROL Runtime System TM812 – APROL Operator Management TM813 – APROL web portal TM820 – APROL solutions TM830 – APROL Project Engineering TM835 – APROL ST-SFC Configuration TM840 – APROL Parameter Management and Recipes TM850 – APROL Controller Configuration and INA TM860 – APROL Library Engineering TM865 – APROL Library Guide Book TM870 – APROL Python Programming TM880 – APROL reporting TM890 – The Basics of LINUX

* SEM210 - Basics is a prerequisite for this seminar.
** SEM410 - Integrated motion control is a prerequisite for this seminar.
*** SEM410 - Integrated motion control and SEM510 - Integrated safety technology are prerequisites for this seminar.
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**** Seminar titles may vary by country. Not all seminars are available in every country.