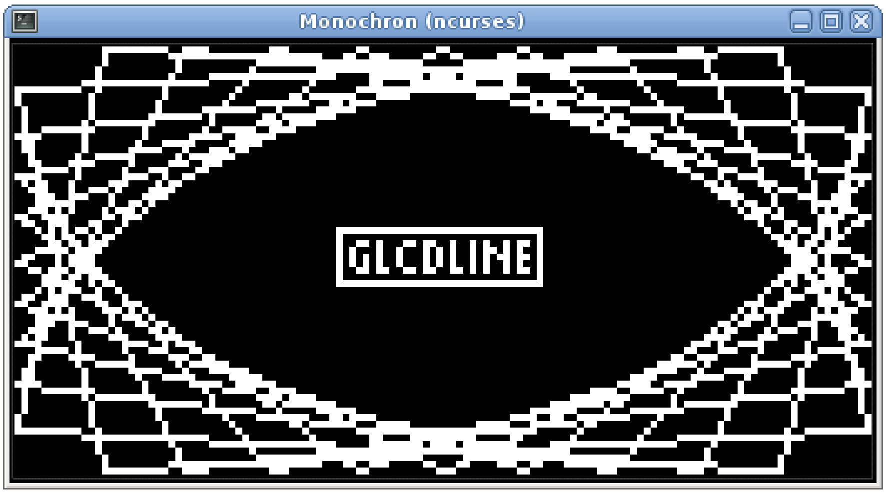
```
# File: Emuchron/script/line2.txt
# This script is used for testing glcdLine()

# Erase LCD display
le

# Set horizontal and vertical display size
vs hor=127
vs ver=63

# Paint in total 9x4 edge-to-edge lines
rf factor=0.1 factor<=0.9 factor=factor+0.1
  # From left to top and left to bottom
  pl f 0 ver*factor hor-(hor*factor) 0
  pl f 0 ver*factor hor*factor ver
  # From right to top and right to bottom
  pl f hor ver*factor hor*factor 0
  pl f hor ver*factor hor-(hor*factor) ver
rn

# Paint the glcdline function name in a rectangle box
pr f 48 27 31 9
pa f 50 29 5x5p h 1 1 glcdline
```

- EMUCHRON -
A Monochron emulator for Debian Linux



Author: Toine Ceulemans
Version: v2.1
Date: 30 June 2016

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Disclaimer

Intended audience

This document is intended for:
- Monochron clock programmers

Prerequisites

The reader of this document is familiar with Linux in general and Debian Linux in particular.

Acknowledgements

- CaitSith2 and ladyada
  The Emuchron project started with the original Monochron pong clock firmware.
  https://github.com/adafruit/monochron
- Balza3
  The Mario alarm in Emuchron is based on notes, beats and play logic provided in an Arduino project.
  http://www.youtube.com/watch?v=VqeYvJpibLY
- Tz / HarleyHacking
  The core functionality to encode a QR uses code from project qrduino.
  https://github.com/tz1/qrduino

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Version history

<table>
<tr><th>Version (date)
Author</th><th>Description</th></tr>
<tr><td>v2.0 (2015-12-15)
T. Ceulemans</td><td>Emuchron emulator code base:
– Support for Debian 8 (Jessie) 64-bit.
– Restructured mchron interpreter code.
– Interpreter is now fully based on a command dictionary and the use of type <code>double</code>.
– A variable name is now unlimited in length and consists of any combination of uppercase/lowercase characters a..z.
– Extended functionality and use of expression evaluator.
– Added if-then-else logic commands.
– Added commands to show the command dictionary, the result of an expression and paint a formatted number on the stubbed LCD display.
– Command 'rw' (repeat-while) is replaced by 'rf' (repeat-for) with an improved syntax structure.
– The wait command 'w' now has a wait granularity of 0.001 sec instead of 0.01 sec.

Monochron firmware code base:
– Alarming/snoozing will stop upon pressing the 'M' button.
– Improved single-press detection of '+' button.
– Press-hold increment steps are doubled after 10 regular increments for min/sec/year elements.
– Improved pong clock game play.
– Improved object code execution efficiency over entire code base.
– Optimizations in glcd module resulting in improved draw performance in almost all high-level glcd functions.
– Code optimizations aimed at reducing firmware size.

Relevant bug fixes:
– An mchron crash occurs when printing mchron statistics ('sp') under certain circumstances.
– In <code>glcdPutStr3v()</code> for orientation <code>ORI_VERTICAL_TD</code>, text for horizontal location <code>x</code> is incorrectly painted at location <code>x-1</code>.

Generic:
– Minor bug fixing in both code bases and documentation.</td></tr>
<tr><td>v2.1 (2016-06-30)
T. Ceulemans</td><td>Emuchron emulator code base:
– Expanded scope and improved compatibility by emulating ks0108 LCD controllers.
– Added commands to interact with LCD controllers.
– Added help message command.
– Expression evaluator support for bit operator functions and hexadecimal number format using prefix '<code>0x</code>'.
– Variable name may now contain underscore characters.
– Added keypress to print glcd/controller statistics when in clock single cycle mode.
– Support for readline command line functionality in combination with ncurses LCD stub device.
– Support for ncurses LCD stub device backlight brightness using mchron command line argument -b.
– Minor mchron code restructuring and optimizations.</td></tr>
</table>

Version (date) Author	***Description***
	Monochron firmware code base: – Optimized LCD controller cursor management and prevent unnecessary writes to LCD controller registers, resulting in improved draw performance in all high-level glcd functions. – Added `animAlarmAreaUpdate()` for generic alarm/date area handling. – Configuring the use of Mario alarm is moved from the Makefiles to monomain.h [firmware]. – Analog and mosquito clock will now always show the date and have the alarm time shown in a separate area. – Added select-to-build 'glitch' mode in digital clock using the controller start line and display registers. – Added bare bone yet fully functional example clock for those new to Emuchron and its clock plugin framework. – Code optimizations aimed at reducing firmware size. Relevant bug fixes: – None. Generic: – Minor bug fixing in Emuchron code base, clock code and documentation.

Summary

Emuchron is a lightweight Monochron emulator for Debian Linux 6, 7 and 8. It features a test and debugging platform for Monochron clocks and high level glcd graphics functions, and a software framework for clock plugins.

Included in the software are enhancements to the high level glcd graphics library, modified clock configuration pages, several example clocks, a graphics performance test module, a two-tone and Mario melody alarm, and demo and test scripts.

Preface

Even before I bought Adafruit's Monochron clock in mid-2012 I thought about the clocks I wanted to code.

While waiting for the clock to be delivered at my doorstep and for a friend with the right tools to put it together, by using the pong firmware as a base I started coding some basic clocks. However, without an actual Monochron clock to upload the firmware to it is rather difficult to verify the correctness of the code. Being too impatient I wrote a very simple tool in a Debian Linux environment that was able to dump the (perceived) results of a glcd graphics function in a plain text file, thus allowing me to analyze the output of functional clock code. Over time that tool was enhanced and parts were rewritten several times, up to the moment that I got myself a basic Monochron emulator fitting my needs very well. This emulator then served as a base to develop, debug and optimize both new and existing code.

Since then parts of Emuchron were, again, rewritten while enhancing its features and making it more robust. In late 2013 documentation was written in preparation for a first publication on github in early 2014.

Document conventions

Throughout the document examples are provided of Emuchron command line interface sessions.

Relevant end-user input is printed in black/bold. See example below.

```
mchron> # A command prompt is no end-user input and comment lines are usually not
mchron> # relevant end-user input. They are therefor not in bold. Actual mchron
mchron> # commands are relevant and as such are printed in bold.
mchron> # See the bold 'pl' (paint line) mchron command example below.
mchron> pl f 100 10 126 62
mchron>
```

Relevant end-user actions and tool feedback is printed in red/bold. See example below.

```
mchron> # Press '<ctrl>d' on an empty line to exit mchron
mchron>
<ctrl>d - exit                                   Press '<ctrl>d'
$
```

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Table of contents

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1 Introduction

1.1 About this manual

The purpose of this manual is to provide background information on Monochron and the Emuchron emulator.
With respect to Monochron and Emuchron, this document in combination with actual code and test and demo scripts should provide enough information to get started.

1.2 Problem description and solution

Coding clocks for the Monochron open source clock is (debatable) fun, but has its drawbacks. The main drawback is not being able to properly test clock and graphics code on a functional level. Clocks sometimes seem to hang, the graphics turn out not to be fluid or are simply incorrect.
Up to now the only way to debug a functional clock and graphics functionality is to generate debug output strings in the Monochron clock and send them via the FTDI bus to a terminal application on the connected computer. Although this debug method is useful, it is considered cumbersome and inflexible.

Enter Emuchron, a lightweight Monochron emulator for Debian Linux.

The main feature of Emuchron is to emulate the Monochron hardware and keep the emulator stubs as far away as possible from functional clock code and high-level graphics functions. This allows a programmer to code, debug and test clocks and graphics functions in a controlled Debian Linux environment ahead of uploading firmware to Monochron. Emuchron is controlled via a command line tool dedicated to supporting these development and test features.

Next, effort is put into creating a Monochron clock plugin environment with the aim to reduce efforts for developing new clocks and building Monochron firmware. This is demonstrated by the list of clocks built from scratch and a migrated pong clock, all included in the firmware node.

And finally, to enhance the graphic capabilities of Monochron clocks, the high-level glcd graphics library now includes a 5x5 proportional font and new text, area fill and support routines.

1.3 Emuchron features and limitations

1.3.1 The Emuchron emulator

The main reason for creating Emuchron is to acquire a means to develop, test and debug clock and graphics functions ahead of uploading it to the Monochron clock. This is achieved by emulating the underlying Monochron hardware using data and function stubs.

These stubs do not implement hardware specific elements such as timing on ports and hardware interrupts. In other words, Emuchron is not meant to be used to develop and debug low level firmware functionality that interacts with hardware.
Instead, Emuchron relies on the fact that this low level firmware functionality is stable. By providing a hardware emulation layer for the low level firmware, Emuchron is then able to provide an environment upon which high level functionality, being software clocks and high-level graphics functions, can be built.

So, Emuchron depends on the stability of the low level firmware functionality. This requirement is fulfilled by taking the original Monochron pong clock firmware, that has been stable for a long time, and use that as a strong foundation. In Emuchron, the core of this firmware has been left unchanged, but most of the other routines have been modified, replaced or enhanced to fit Emuchron requirements.

An example of the Emuchron emulator approach is a function that writes a data byte, containing 8 bit pixels, to the LCD display. The actual firmware does this by setting up a data connection to one of the LCD controllers with built-in delays to compensate for hardware response times. In our emulator case, Emuchron has a module that implements the controller hardware as a finite state machine. It processes the data byte by storing it in a data structure representing local LCD display memory. When the data byte actually leads to a change in the LCD display, it is passed on to an LCD emulator device. Eventually, the data byte will show up as individual pixels in the window driven by the LCD emulator device.
Like the stub for the LCD controllers and LCD devices there are others that emulate all other hardware elements, being the real time clock, the clock buttons and alarm on/off switch, the piezo speaker and LCD backlight. Some of these stubs re-use Monochron code while others require fully dedicated stub code.

1.3.2 The Emuchron clock plugin framework

From a software development point of view, Emuchron requires that functional clock code should never access the hardware directly but instead use a (stubbed) interface to low level functionality. This is seen as a software architecture requirement.

This is fulfilled by creating a software layer in which a software clock is regarded as a plugin that only needs to implement functional clock code. Of course, the clock code will access graphics functions that eventually write to the LCD, but the hardware aspect of this access will be hidden from clock plugin level. Even better, some aspects do not need to be dealt with in a clock plugin at all. Sounding the alarm, snoozing, and scanning the buttons and the alarm on/off switch are handled outside the scope of a clock plugin, thus greatly simplifying the efforts needed to create new clocks.

The software framework is implemented by creating a list of global variables that represent the hardware state of the clock that is accessible at clock plugin level. It is the task of the software layers underneath the clock plugins to make these global variables truly represent the hardware state. And in addition to that, have it guaranteed that these variables are stable during the execution of functional clock code.
Clock plugins need to expose only two public functions with a defined interface for clock initialization and clock update. An optional third public function can be defined for clock button handling.

An example of the representation of the clock state in data is a variable that indicates that the time has changed. In addition to this variable there are others that hold the previous timestamp and the new timestamp. This allows a clock plugin to find out what needs to be changed in the layout of a clock, to be achieved by calling the appropriate graphics functions. The main point here is that a clock plugin never needs to interact with the real time clock itself.

1.3.3 The Emuchron command line tool mchron

Emulating hardware and providing software layers to simplify the creation of new clocks and graphics functions is however incomplete as the end user of the emulator must be given proper testing tools as well.

For this, Emuchron provides a command line tool named mchron that allows accessing clock plugins at will, feed clocks with a continuous stream of time and keyboard events, change the time/date/alarm, access the graphics library to draw on the stubbed LCD display, and run a stubbed Monochron application ahead of building the actual firmware. In combination with the standard gdb debugger and a gdb GUI frontend this is a powerful means to test specific functionality and find and solve bugs.

The mchron interpreter supports named variables representing numeric values, repeat and if-then-else logic constructs, and basic mathematical expression evaluation for numeric command arguments. Commands for mchron can be prepared using a standard text editor and saved as a script file. This script file can then be loaded and executed in mchron, which comes in handy for creating demos and standard test suites for clocks and graphics functions.

An example on how to use the mchron command line tool is the following scenario, using only five mchron commands:

- `mchron>` **`cs 2`**
  Select the second built-in clock plugin, being an analog clock.
  The clock will initialize and paint itself on the stubbed LCD device, yet remains static.
- `mchron>` **`ap 0`**
  Set the stubbed alarm switch position to off to make sure the alarm will not be tripped by subsequent mchron commands.
- `mchron>` **`e s ../script/minutes.txt`**
  Execute the mchron commands from a text file to feed the clock with 60 minute timestamps between 16.00pm and 16.59pm.
  Each timestamp will differ a minute from the previous one and will be displayed on the stubbed LCD device for 0.2 seconds.
  We use this script to see how the clock reacts to changes in minutes.
- `mchron>` **`ts 23 59 15`**
  Set the mchron time to nearly midnight.
  The clock will update itself to the new time but remains static.
- `mchron>` **`cf n`**
  Feed the clock with a continuous stream of time and keyboard events.
  The clock is now started in a test environment that is rather similar to the actual Monochron application, so it will update itself every second.
  We will now be able to see on the stubbed LCD device whether the clock correctly processes a day change in its date area.

1.4 Debian Linux and AVR

Emuchron is developed in Debian 6 and has been verified to work in Debian 7 and 8. The table below provides the details of the several environments in which Emuchron is verified to work at the time of writing this document. This list is not actively maintained.

Debian version and host	***Version info***
Version: Debian 6 32-bit Host: Windows-7 Professional VM Memory: 512MB	VirtualBox: 5.0.14 Linux kernel: 2.6.32-5-686 gcc/avr-gcc: 4.4.5/4.3.5
Version: Debian 7 32-bit Host: Windows-7 Professional VM Memory: 512MB	VirtualBox: 5.0.14 Linux kernel: 3.2.0-4-486 gcc/avr-gcc: 4.7.2/4.7.2
Version: Debian 8 64-bit Host: Windows-7 Professional VM Memory: 1GB	VirtualBox: 5.0.14 Linux kernel: 3.16.0-4-amd64 gcc/avr-gcc: 4.9.2/4.8.1
Version: Debian 6 32-bit Host: OS-X 10.11 VM Memory: 512MB	VMware Fusion: 7.1.3 Linux kernel: 2.6.32-5-686 gcc/avr-gcc: 4.4.5/4.3.5
Version: Debian 7 64-bit Host: OS-X 10.11 VM Memory: 768MB	VMware Fusion: 7.1.3 Linux kernel: 3.2.0-4-amd64 gcc/avr-gcc: 4.7.2/4.7.2
Version: Debian 8 64-bit Host: OS-X 10.11 VM Memory: 1GB	VMware Fusion: 7.1.3 Linux kernel: 3.16.0-4-amd64 gcc/avr-gcc: 4.9.2/4.8.1

Table 1: The Emuchron runtime environments for Debian and AVR

Please consider the following notes:

- 64-bit is supported on Debian 7 and 8. 32-bit is supported on Debian 6 and 7.
- The information above shows up-to-date version info at the time of writing. In the development stage of Emuchron older versions of VM tools, Linux kernels and hosts were used as well.
- Support for Emuchron in Debian 6 is limited to existing installations only. As per February 2016, Debian 6 has reached end-of-life, making it difficult to obtain all relevant packages required to support Emuchron. It is expected that support for Debian 6 will be deprecated in an upcoming release of Emuchron.
- As of VirtualBox 5.0.16, the software architecture of its so-called Guest Additions Extension Pack has changed, introducing several undesired side effects and regression in functionality. For a Windows 7 host it shows serious problems when playing small beep audio samples, resulting in audio being clipped, as well as performance and stability issues with OpenGL modules. The latest version of VirtualBox, being 5.0.20 at the time of writing this document, has not resolved these issues yet.
  Because of this it is highly recommended to install VirtualBox 5.0.14 and its accompanying Guest Additions Extension Pack that has proven to be stable for Debian 6, 7 and 8 clients. Older builds of VirtualBox can be downloaded at: https://www.virtualbox.org/wiki/Download_Old_Builds_5_0.
  Downgrading VirtualBox from a higher to a lower version is done by downloading and older version and installing that over the newer version. After downgrading you are required to downgrade the VirtualBox Guest Addition Extension Pack as well. This is done by first removing the newer extension package after which the older version is installed. And finally, in your Debian client you must then downgrade the Guest Additions by re-installing them. In some cases it has been observed that downgrading VirtualBox will not solve the issues mentioned above. In that case the only remedy is either to switch back to a recent VM snapshot, or install a fresh Debian VM.

1.5 Migrating from Emuchron v1.x to v2.x

Compared to v1.x, both the core of the Monochron firmware and the clock plugin framework are left unchanged. This means that clocks plugins created in v1.x are expected to function properly in v2.x without any code changes.

However, in v2.x the v1.x modules ratt.c/ratt.h [firmware] are renamed to monomain.c/monomain.h [firmware]. This means that clock plugins must replace an include reference in order to build properly in v2.x. See below an example for clock plugin nerd.c [firmware/clock].

```
   //*****************************************************************************
   // Filename : 'nerd.c'
   // Title    : Animation code for MONOCHRON nerd clock
   //*****************************************************************************

   #ifdef EMULIN
   #include "../emulator/stub.h"
   #endif
   #ifndef EMULIN
   #include "../util.h"
   #endif
   #include "../ks0108.h"
-- #include "../ratt.h"
++ #include "../monomain.h"
   #include "../glcd.h"
   #include "../anim.h"
   #include "nerd.h"
```

From an emulator perspective, specific functionality of the mchron interpreter is modified in v2.x. This requires changes in command scripts that are created in v1.x. Find below an overview.

In Emuchron v2.x, variables are assigned a value using an expression based on the assignment operator.

```
# Emuchron v1.x: assign value to variable using two command arguments
vs x 15

# Emuchron v2.x: assign value to variable using assignment operator
vs x=15
```

In Emuchron v2.x, the 'rw' (repeat-while) command is replaced by 'rf' (repeat-for). The syntax structure of the new repeat command is improved and more or less conform a 'C'-style `for()` construct.

```
# Emuchron v1.x: repeat while
rw x < 128 0 1
  # Do something
rn

# Emuchron v2.x: repeat for
rf x=0 x<128 x=x+1
  # Do something
rn
```

In Emuchron v2.x, the operator to check for inequality of argument values is changed from '<>' into 'C'-style operator '`!=`'.

```
# Emuchron v1.x: repeat while with '<>' comparison
rw y <> 64 0 1
  # Do something
rn

# Emuchron v2.x: repeat for with '!=' comparison
rf y=0 y!=64 y=y+1
  # Do something
rn
```

In Emuchron v2.x, the wait command uses a granularity of 0.001 sec.

```
# Emuchron v1.x: wait 0.25 sec (granularity = 0.01 sec)
w 25

# Emuchron v2.x: wait 0.25 sec (granularity = 0.001 sec)
w 250
```

2 The Emuchron project

2.1 The project folder structure

The Emuchron project uses the following folder structure.

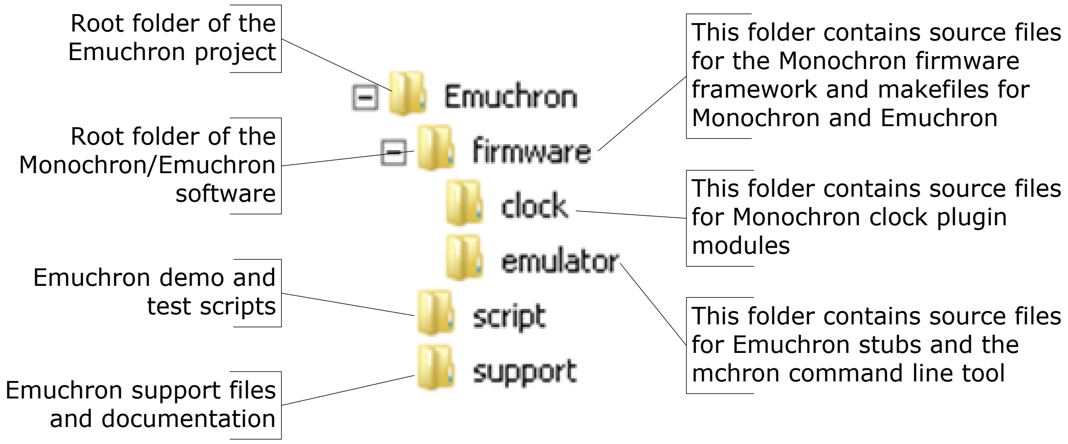


Figure 1: The Emuchron project folder structure

2.2 Monochron firmware high-level runtime environment

The following graph depicts the Monochron runtime environment, including references to source files being used to build the firmware.

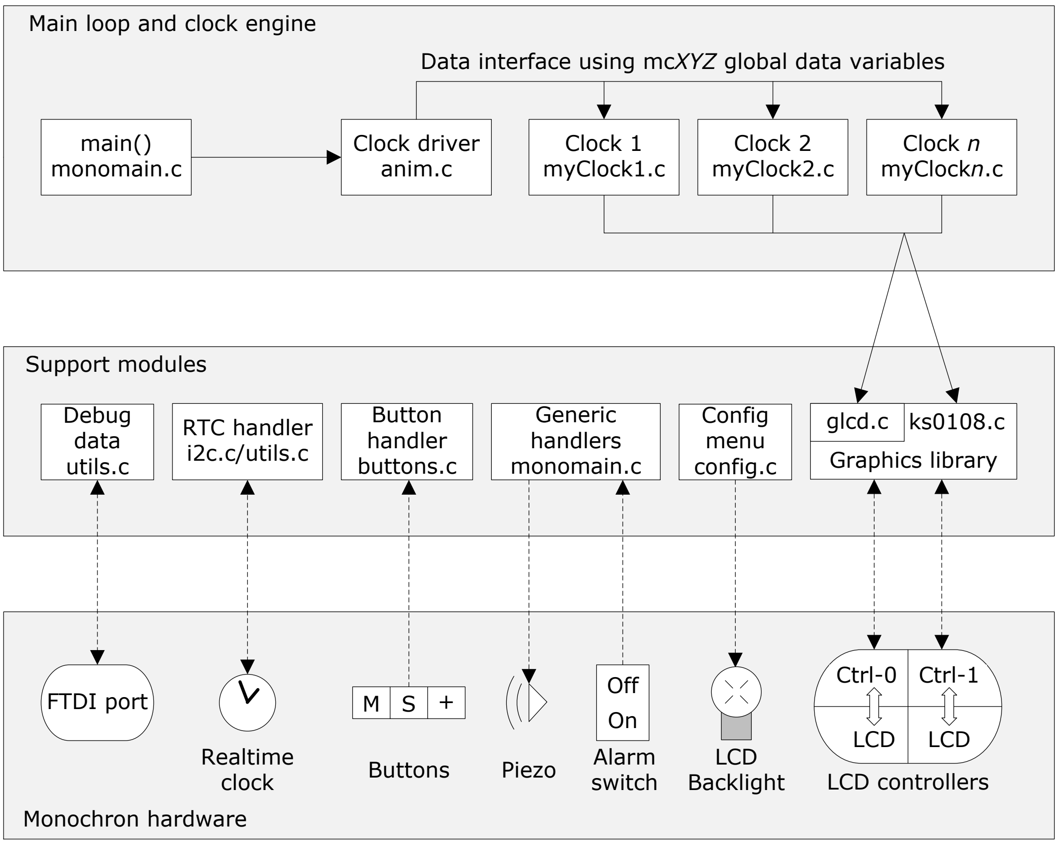


Figure 2: The Monochron runtime environment

Note that this high-level view only shows how the several modules are linked to another from a clock plugin perspective, and is not fully correct. For example, the graph does not show that upon startup, `main()` in monomain.c [firmware] will take care of initializing the LCD hardware via the graphics library.

The following modules apply:

Module	***Description***
anim.c [firmware]	In module anim.c we find the handler for all plugin clocks. It will take care of initializing and updating clocks and switching between clocks. It prepares the software interface to the plugin clocks. It is responsible for most of the mc*XYZ* data interface to the clock plugins.
buttons.c [firmware]	The button support handler module takes care of button press and button hold events and mapping these into a software state. Its functionality is used in monomain.c [firmware].
config.c [firmware]	This support module contains the main entry for the configuration menu as used in the Monochron application. It is activated in `main()` by pressing the 'M' button. Via the menu the LCD backlight is changed by setting a dedicated register.
glcd.c [firmware]	The high-level graphics library. It contains functions to draw text, lines, dots, (filled) circles and (filled) rectangles. This module does not contain hardware agnostic code and uses ks0108.c [firmware] for the actual interface to the LCD controllers.
i2c.c [firmware]	In module i2c.c we find the interface to the real time clock (RTC).
ks0108.c [firmware]	The low-level graphics library. It contains functions to interact with two hardware ks0108 LCD controllers, each driving either the left or right side of the LCD display. This module initializes the controller hardware, interact with controller hardware registers, clear the LCD, and write data to and read data from the LCD.
monomain.c [firmware]	In module monomain.c we find the `main()` function. Next to `main()`, monomain.c contains much additional functionality related to interrupt handlers, handling the real time clock, the alarm and snooze, the piezo speaker and handling the state of the alarm switch. The `main()` function contains an infinite loop and will interact with the clock driver in anim.c [firmware] and the clock configuration menu in config.c [firmware] when appropriate. It is responsible for a subset of the mc*XYZ* data interface to the clock plugins.
myClock*x*.c [firmware/clock]	A Monochron plugin clock. Based on the mc*XYZ* data interface the module is responsible for drawing and updating itself on the LCD. This is where functional clock code resides.
utils.c [firmware]	This support module contains formatting utility routines used by the RTC interface. It also provides a means to format and send debug strings over the FDTI port at runtime. Reading and logging the FTDI debug strings requires a terminal application on the connected computer. This method used to be the only method of debugging a Monochron application.

Table 2: The Monochron runtime environment

2.3 Emuchron emulator high-level runtime environment

The following graph depicts the Emuchron emulator environment, including references to source files being used to build the software.

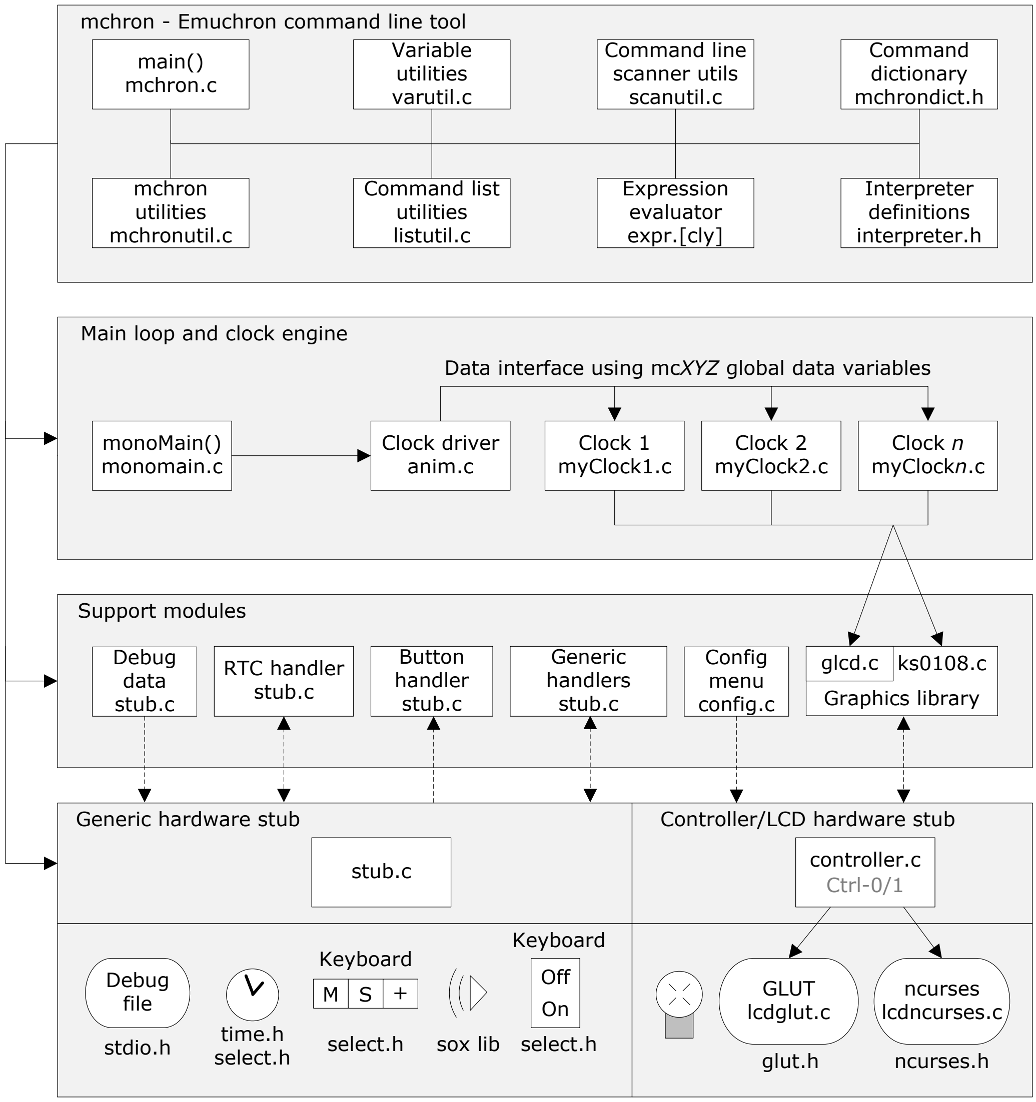


Figure 3: The Emuchron runtime environment

Again, note that this is a high-level view only showing how the several modules are linked to another from a clock plugin perspective.

Compared to figure 2 notice the following:

- On top of the environment we find the mchron.c [firmware/emulator] module with the `main()`. It controls the entire emulator environment using the mchron command line interface.
- The 'Main loop and clock engine' block (monomain.c [firmware] – anim.c [firmware] – myClock*x*.c [firmware/clock]) and its link to glcd.c [firmware] is unaffected, conform the emulator requirement that clock plugins should be as much as possible free from hardware stubs.
  Most important is that code in myClock*x*.c [firmware/clock] and glcd.c [firmware] does not require any stub functionality.

- In monomain.c [firmware] the `main()` has been renamed into `monoMain()` but besides that effectively remains the same function.
  Note that the mchron command line tool can start a fully functional Monochron application using a call to `monoMain()`.
- All hardware has been stubbed by stub.c [firmware/emulator] and controller.c [firmware/emulator] and is emulated using off-the-shelf Linux libraries.
- Monochron modules like i2c.c [firmware], button.c [firmware] and utils.c [firmware] are not part of the Emuchron environment. Their functionality has been incorporated in stub.c [firmware/emulator]. This means that changes in these modules cannot be tested in Emuchron.
- There are two LCD stub devices defined, being OpenGL2/GLUT and ncurses. Select the device to use on mchron startup, or use both, thus showing duplicate output in two separate windows. Each of these devices has its pros and cons.

The following new modules apply:

<table>
<tr><th>Module</th><th>Description</th></tr>
<tr><td>controller.c
[firmware/emulator]</td><td>The controller module implements the stubbed controller and LCD data structures and acts as a driver for the two LCD device stubs. It initializes the requested LCD stub devices and dispatches LCD updates to each of those, including changes in the backlight brightness setting.
Note: As controller.c implements fixed function calls to each of the two LCD devices, such a device can be considered as an LCD plugin. Another LCD device type can be added to controller.c as long as it publishes functions similar to the GLUT and ncurses modules.</td></tr>
<tr><td>expr.c/expr.l/expr.y
[firmware/emulator]</td><td>The flex (expr.l) and bison (expr.y) modules implement an expression evaluator. The code generated by flex and bison code is included in the master module (expr.c) and compiled into a separate expression evaluator object.
The following elements are supported:
– Math operators
+, -, *, /, % (modulo), ^ (power), =, ( )
– Bit operators
<<, >>, &, |, ~
– Logic operators
<, >, <=, >=, ==, !=, &&, ||, ?: ('C'-style ternary operator)
– Functions
abs(), cos(), frac(), int(), sin()
– Constants
null, pi, true, false</td></tr>
<tr><td>interpreter.h
[firmware/emulator]</td><td>This module defines the core structures and constants for the mchron interpreter.</td></tr>
<tr><td>lcdglut.c
[firmware/emulator]</td><td>This module implements an OpenGL2/GLUT LCD device.
The GLUT device is implemented using a separate thread, meaning that the GLUT window is updated asynchronously from the mchron application. As a result, the GLUT interface is less suited for use in a debugging session when LCD output is essential.
The upside however is that the GLUT interface does not require end-user setup and that the GLUT window can be resized at will while retaining the 2:1 aspect ratio.</td></tr>
</table>

Module	***Description***
lcdncurses.c [firmware/emulator]	This module implements an ncurses LCD device. The ncurses device runs in the same main thread as mchron. As such, LCD updates need to be actively flushed in ncurses at the end of an application cycle, thus making the LCD device always in-sync with the mchron application. This makes the ncurses interface much better suited for use in a debugging session when LCD output is essential. Disadvantages of the ncurses device are that in order to make the ncurses device work properly it requires (one-time only) configuration steps in GNOME, that its window cannot be freely resized (but we can use keyboard shortcuts instead) and that the ncurses library does not play nice with gdb (refer to section 6.3.2).
listutils.c [firmware/emulator]	This module implements the utilities to build and cleanup command lists.
mchron.c [firmware/emulator]	The mchron module implements the command line interface to the Emuchron emulator environment and all command handlers. Each mchron command will have its associated command handler in this module. The command line interface supports the use of named numeric variables, basic repeat loop and if-then-else logic constructs, basic expression evaluation for numeric command arguments and executing scripts that are prepared in plain text files. An overview of the command set is found in section 5.8.
mchrondict.h [firmware/emulator]	The mchrondict header module creates the mchron command dictionary. The command dictionary is an aggregated set of structures of domain values, command arguments, commands in a command group and finally the dictionary itself that consists of a collection of command groups.
mchronutil.c [firmware/emulator]	Whereas the mchron module implements the command handlers, this module implements several mchron utility functions, as well as mchron initialization and signal handler functionality.
scanutil.c [firmware/emulator]	The scanutil module implements command input streams (command line and file), the command line scanner, and functions to access the command dictionary.
stub.c [firmware/emulator]	The stub module is the heart of the Emuchron emulator functionality. It contains stubs replacing all Monochron hardware except the LCD.
varutils.c [firmware/emulator]	This module implements the administration of the named interpreter variables.

Table 3: The Emuchron modules

2.4 Monochron main loop, buttons and clocks

The Monochron main loop is coded in `main()` in monomain.c [firmware]. In combination with functionality in anim.c [firmware] it handles initializing clocks, updating clocks, switching between clocks and handling button presses.
The functional behavior of clocks as implemented in these two modules depends on how many clocks have been configured in the static `monochron[]` array in anim.c [firmware], and whether or not for a clock a public button handler function is exposed. Refer to section 2.12 where the structure of the static `monochron[]` array is explained.

Generic functionality in `main()`:
- A single loop cycle is executed every 75 msec.
  This is defined by `#define ANIMTICK_MS` in monomain.h [firmware].
- In a single loop cycle button presses are scanned after which one or more functions in anim.c [firmware] are called to update the current active clock, to switch to and initialize the next clock or to handle a button press.

Per application loop cycle when not in alarming/snoozing state, in case only a single clock is configured in the static `monochron[]` array:

Event	***Action***
Press 'M' button	Enter the clock configuration menu in config.c [firmware]. After exit of configuration menu: invoke `init()` for clock with `DRAW_INIT_FULL` invoke `cycle()` for clock
Press 'S' button	if `button()` is defined for clock then invoke `button()` for clock end-if invoke `cycle()` for clock
Press '+' button	if `button()` is defined for clock then invoke `button()` for clock end-if invoke `cycle()` for clock
No button pressed	invoke `cycle()` for clock

Table 4: Single loop cycle actions for a single-clock configuration

Per application loop cycle when not in alarming/snoozing state, in case multiple clocks are configured in the static `monochron[]` array:

Event	***Action***
Press 'M' button	Enter the clock configuration menu in config.c [firmware]. After exit of configuration menu: invoke `init()` for clock with `DRAW_INIT_FULL` invoke `cycle()` for clock

Press 'S' button	if `button()` is defined for clock
	then
	   invoke `button()` for clock
	else
	   select next clock in `monochron[]` (round-robin)
	   invoke `init()` for clock with `monochron[].initType`
	end-if
	invoke `cycle()` for clock

Press '+' button	select next clock in `monochron[]` (round-robin) invoke `init()` for clock with `monochron[].initType` invoke `cycle()` for clock
No button pressed	invoke `cycle()` for clock

Table 5: Single loop cycle actions for a multi-clock configuration

Per application cycle when in alarming/snoozing state, regardless the number of clocks configured in the static `monochron[]` array:

Event	***Action***
Press 'M' button	stop alarming/snoozing (by forcing alarm timeout) invoke `cycle()` for clock
Press 'S' button	reset snooze timer timeout invoke `cycle()` for clock
Press '+' button	reset snooze timer timeout invoke `cycle()` for clock
No button pressed	invoke `cycle()` for clock

Table 6: Single loop cycle actions when in alarming/snoozing state

Note: For more information on the snooze timer timeout value refer to section 2.8.

2.5 Monochron variables for clock plugins

When any of the published clock functions is invoked, it can make use of the following variables below. These variables are defined in anim.c [firmware] and represent a stable software representation of the state of the Monochron clock.

Variable	***Description***
`mcAlarmH` `mcAlarmM`	The active alarm time (hour, min), regardless whether the alarm switch position is on or off.
`mcAlarming`	Value: `GLCD_TRUE / GLCD_FALSE` Indicates whether the clock is alarming/snoozing (`GLCD_TRUE`) or not (`GLCD_FALSE`).
`mcAlarmSwitch`	Value: `ALARM_SWITCH_NONE / ALARM_SWITCH_ON / ALARM_SWITCH_OFF` Current on/off state of the alarm switch. – `ALARM_SWITCH_NONE` This value clears the stored value and forces an alarm switch change event in `mcUpdAlarmSwitch`. It is normally set by a clock in its `init()` function. Note: The clock `cycle()` should only see values `ALARM_SWITCH_ON` and `ALARM_SWITCH_OFF`. – `ALARM_SWITCH_ON` Indicates that the alarm switch position is switched on. – `ALARM_SWITCH_OFF` Indicates that the alarm switch position is switched off.
`mcBgColor` `cFgColor`	Value: `ON` (white pixel) / `OFF` (black pixel) The variables holding the background and foreground draw color. The value of both variables are mutually exclusive. The Monochron configuration menu can swap the values between the two variables. A clock, when it has properly implemented its drawing graphics with these variables, can freely swap between showing itself white-on-black and black-on-white without any code changes.
`mcClockInit`	Value: `GLCD_TRUE / GLCD_FALSE` Indicates that a clock must initialize itself. It is set prior to calling the clock `init()` and is reset after executing a clock `cycle()`.

Variable	***Description***
mcClockNewTH mcClockNewTM mcClockNewTS mcClockNewDD mcClockNewDM mcClockNewDY	The new Monochron clock time (hour, min, sec) and date (day, month, year).
mcClockOldTH mcClockOldTM mcClockOldTS mcClockOldDD mcClockOldDM mcClockOldDY	The previous Monochron clock time (hour, min, sec) and date (day, month, year).
mcClockPool mcMchronClock	`mcClockPool` is a pointer to the clock array and `mcMchronClock` is the current index in that array. In Monochron the clock array being used is `monochron[]` in anim.c [firmware]. In Emuchron the clock array being used is `emuMonochron[]` in mchron.c [firmware/emulator].
mcClockTimeEvent	Value: `GLCD_TRUE / GLCD_FALSE` Indicates that the time has changed. This event must be handled in the clock `cycle()` as it is reset every clock cycle.
mcCycleCounter	A counter that is incremented every clock cycle. It can be used as input for a random number generator or serve as a base for blinking LCD elements.
mcU16Util[1..4] mcU8Util[1..4]	Value: Free for use in an active clock Whenever a clock plugin has a need for global data, instead of defining that in its own module, these variables can be used. There are in total eight variables, of which four are 16 bit wide and four are 8 bit wide. An example of its usage can be found in some demo clocks where `mcU8Util1` is used to store the blinking state of the alarm draw area when alarming or snoozing. Note that these variables are under control of the active clock and as such must be initialized, set and processed in clock code.
mcUpdAlarmSwitch	Value: `GLCD_TRUE / GLCD_FALSE` Signals a change in the alarm switch position. This event must be handled in the clock `cycle()` as it is reset every clock cycle. Use it in combination with `mcAlarmSwitch`.

Table 7: The Monochron variables for clock plugins

In a clock plugin the population of variables `mcClockNew`*XY* and `mcClockOld`*XY* are tied to variables `mcClockTimeEvent` and `mcClockInit` as described below.

Variables	***Impact***
mcClockTimeEvent = GLCD_FALSE mcClockInit = GLCD_FALSE	mcClockOld*XY* = the previous timestamp mcClockNew*XY* = the last created timestamp
mcClockTimeEvent = GLCD_TRUE mcClockInit = GLCD_FALSE	mcClockOld*XY* = the previous timestamp mcClockNew*XY* = the current timestamp
mcClockTimeEvent = GLCD_FALSE mcClockInit = GLCD_TRUE	mcClockOld*XY* = the last created timestamp mcClockNew*XY* = the last created timestamp
mcClockTimeEvent = GLCD_TRUE mcClockInit = GLCD_TRUE	mcClockOld*XY* = the current timestamp mcClockNew*XY* = the current timestamp

Table 8: The Monochron time and initialization variables

2.6 The glcd graphics library enhancements

This project is based on the original Monochron pong firmware. To enhance the graphics capabilities of clocks a number of glcd functions have been added, modified or enhanced. In general, a high-level glcd graphics function can be accessed directly via the mchron command line tool for testing purposes.
To test these enhancements, a dedicated clock plugin has been created that runs glcd performance tests on Monochron hardware.

2.6.1 Overview of high-level glcd functions

The functions are found in glcd.c [firmware]. Please find below a rough overview of the changes when compared to the original Monochron pong firmware.

Function	***Description***
-Generic-	The interface and code of legacy glcd functions is updated to include parameter color that is required for implementing the mcBgColor and mcFgColor functionality.
glcdCircle()	Superseded by glcdCircle2().
glcdCircle2()	Similar to glcdCircle() but in addition supports drawing a dotted (1:2 and 1:3) circle outline.
glcdClearDot() glcdSetDot()	Superseded by glcdDot().
glcdDot()	Draw a dot.
glcdFillCircle2()	Draw a filled circle with several fill patterns. Note that this function does not draw the circle outline. An additional call to glcdCircle2() is required for drawing a complete filled circle.
glcdFillRectangle2()	Similar to the existing glcdFillRectangle() function that is retained, yet supports several fill patterns.
glcdGetWidthStr()	Utility function that returns the width of a string in unscaled display pixels.
glcdPrintNumberBg() glcdPrintNumberFg() glcdPutStrFg() glcdWriteCharFg()	Proxy functions for legacy functions glcdPrintNumber(), glcdPutStr() and glcdWriteChar() with a reduced interface regarding the draw color, allowing to optimize code on object size.
glcdPutStr2()	Proxy function for glcdPutStr3() with a reduced interface regarding font scaling, allowing to optimize code on object size.

Function	Description
`glcdPutStr3()`	For background information consider function `glcdPutStr()`. It draws text very fast but is limited in use as the text y-position is limited to eight character lines (multiple of 8 vertical pixels) and supports a non-proportional 5x7 font only. In contrast, the new `glcdPutStr3()` function draws horizontal text at any (x,y) pixel location, allows independent font scaling on the x and y axis, and supports an additional 5x5 proportional font. It returns the string width of horizontal pixels drawn. Note that `glcdPutStr()`is still supported as it is lightweight, fast and heavily used in config.c [firmware].
`glcdPutStr3v()`	Similar to `glcdPutStr3()`. However, this function draws text vertically (top-down or bottom-up). It returns the string width of vertical pixels drawn.

Table 9: Enhancement overview of the high-level glcd library

2.6.2 The `lcdLine[]` buffer

It appears that the Monochron firmware and/or the LCD controller is slow in switching between LCD read and LCD write operations.
To reduce switching between LCD read and write operations, most graphics functions have implemented a method to read all relevant LCD bytes from a single LCD byte row in buffer `lcdLine[]` first, then apply changes to the buffered data and then write the modified data back to the LCD.
This method greatly reduces switching between LCD read and LCD write operations and significantly improves the speed of the graphics interface to the LCD. The downside of this method is that 128 bytes of stack RAM (out of 2K) is constantly allocated for this purpose.

2.6.3 Text fonts and font scaling

Specific glcd text functions allow painting text in two fonts.

In glcd.h [firmware] the following fonts are defined:

Font	Description
`FONT_5X5P`	A 5x5 proportional font. It supports only uppercase characters. The font is defined in font5x5p.h [firmware]. Note: A few non-standard characters in this font are remapped to special graphics characters as required by clocks.
`FONT_5X7N`	A 5X7 non-proportional font. It supports both uppercase and lowercase characters. The font is defined in font5x7.h [firmware]. Note: This is the unmodified original Monochron font.

Table 10: Text font overview

Next to that, specific glcd text functions allow individual horizontal and vertical font scaling.

Refer to the screenshots below. All text is drawn using a single glcd graphics function, being `glcdPutStr3()`.

2.6.4 Text orientation

The glcd text functions allow painting text in several orientations.
The (x,y) start location for text to be painted is linked to the position of the top-left font pixel of the first character.

In glcd.h [firmware] the following text orientations are defined:

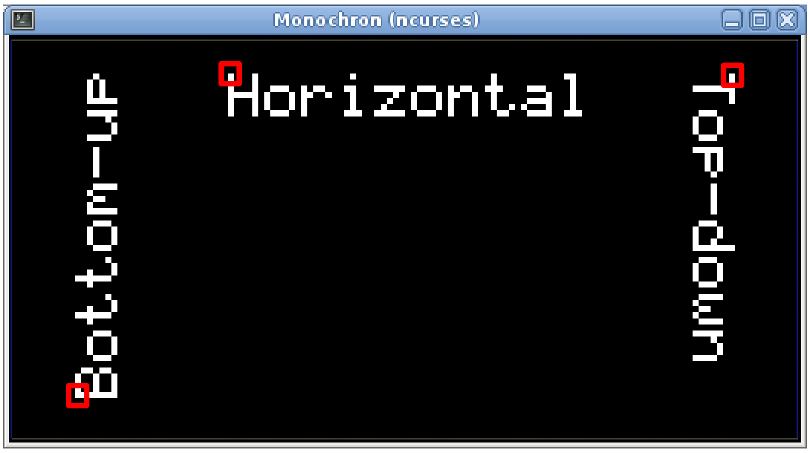
Text orientation	Description
`ORI_HORIZONTAL`	Paint the text horizontally.
`ORI_VERTICAL_BU`	Paint the text vertically in a bottom-up direction.
`ORI_VERTICAL_TD`	Paint the text vertically in a top-down direction.

Table 11: Text orientation overview

Enter the following mchron commands.

```
mchron> pa f 35 5 5x7n h 1 1 Horizontal
mchron> pa f 10 57 5x7n b 1 1 Bottom-up
mchron> pa f 117 5 5x7n t 1 1 Top-down
```

This will yield the following output. Note the markers identifying the pixel draw start location for each string.



2.6.5 Fill patterns

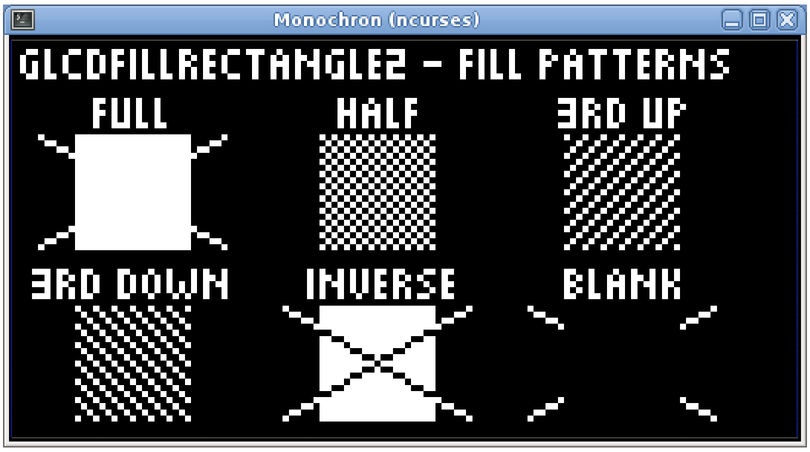
The `glcdFillRectangle2()` and `glcdFillCircle2()` functions provide a method to fill an area with several fill patterns.

In glcd.h [firmware] the following fill patterns are defined:

Pattern	***Description***
`FILL_FULL`	The area is filled with the given paint color.
`FILL_HALF`	The area is filled with a 50% fill pattern using the given paint color.
`FILL_THIRDUP`	The area is filled with a 1/3rd pattern using the given paint color giving an upward illusion.
`FILL_THIRDDOWN`	The area is filled with a 1/3rd pattern using the given paint color giving a downward illusion.
`FILL_INVERSE`	The area is inverted. Note: This fill pattern is not supported in `glcdFillCircle2()`.
`FILL_BLANK`	The area is filled with the inverted value of the given paint color.

Table 12: Fill pattern overview

Refer to the screenshot below for examples of each fill pattern.



2.6.6 Fill alignment

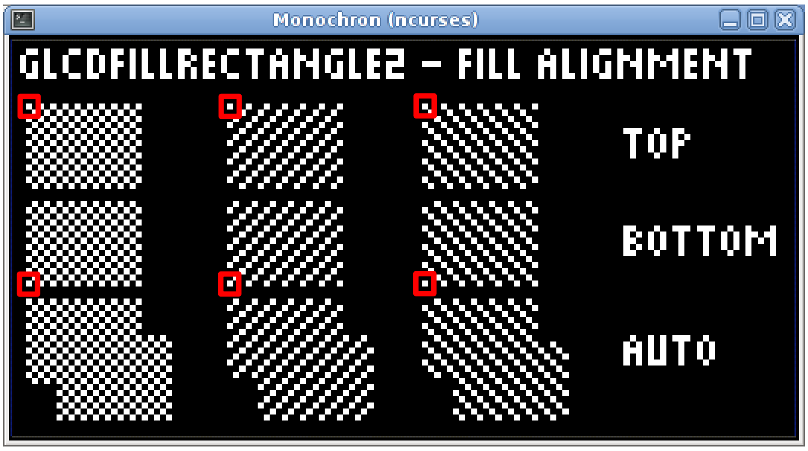
The `glcdFillRectangle2()` function supports a fill alignment option for fill patterns `FILL_HALF`, `FILL_THIRDUP` and `FILL_THIRDDOWN`.

In glcd.h [firmware] the following fill alignments are defined:

Alignment	***Description***
`ALIGN_TOP`	The top-left pixel of the fill area is filled with the given paint color.
`ALIGN_BOTTOM`	The bottom-left pixel of the fill area is filled with the given paint color.
`ALIGN_AUTO`	A pixel in the fill area is filled with the given paint color relative to pixel (0,0) being assumed to be filled. This alignment will make fill areas overlap properly.

Table 13: Fill alignment overview

Refer to the screenshot below for an example for every fill alignment option. Note the markers identifying the fill alignment pixels.



2.6.7 Circle draw patterns

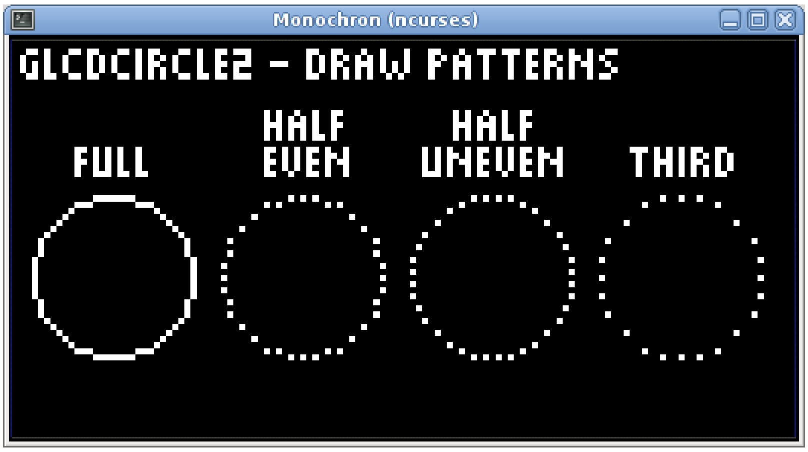
The `glcdCircle2()` function provides a method to draw a circle using several patterns.
Note that the method to determine which pixels are being drawn is rather crude. The quality of the non-full draw patterns will vary depending on the radius and center of the circle being drawn.

In glcd.h [firmware] the following circle draw patterns are defined:

Pattern	Description
`CIRCLE_FULL`	The circle is fully drawn with the given paint color.
`CIRCLE_HALF_E`	The circle is drawn 50% with the given paint color. Only the even circle pixels are drawn, making it the inverse of `CIRCLE_HALF_U` when drawn at the same location.
`CIRCLE_HALF_U`	The circle is drawn 50% with the given paint color. Only the uneven circle pixels are drawn, making it the inverse of `CIRCLE_HALF_E` when drawn at the same location.
`CIRCLE_THIRD`	The circle is drawn with 1/3rd of the pixels with the given paint color.

Table 14: Circle draw pattern overview

Refer to the screenshot below for examples for each draw type.



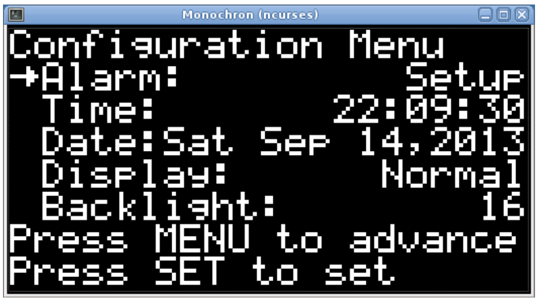
2.7 Monochron configuration screens

In Emuchron the method of navigating through the configuration menu, selecting items for editing and modifying values has not changed.

However, compared to the original Monochron firmware, a number of changes in the configuration module are applied.

- The keypress hold and increment timers have been modified to decrease the keypress hold delay and increase the value scrolling speed. For minute, second and year elements, increments will double after 10 regular press-hold increments.
- The configuration screen no longer 'blinks' upon pressing a button.
- The backlight setting is put under keypress hold control.
- Whereas in the original firmware every incremental change is saved in eeprom, it now applies only to the final value.
- Whereas the original firmware supports a single alarm time only, it now supports a separate alarm setup menu page that allows setting four independent alarm times and a selector determining which alarm is active.
- The original firmware allows configuring the format of the time and date within the configuration module. This is no longer supported.
  Time will now use the 24 hour HH:MM format. Date will now use a full day of the week, month, day and year format. See below.
- The new firmware supports configuring the display behavior of the application which is either 'Normal' (white pixels on black background) or 'Inverse' (black pixels on white background).

For code refer to config.c [firmware].



Note: In the main configuration menu (left screendump), upon pressing the 'Set' button at the 'Alarm' item, the alarm setup menu (right screendump) is accessed.

2.8 Monochron two-tone and Mario alarm melodies

The original firmware supports a simple yet effective single-tone alarm.
In Emuchron this has been replaced by two distinctive alarm melodies.

The first is a two-tone alarm, which is basically an enhancement of the single-tone alarm. The second melody is Mario, the world’s most famous chiptune. For this refer to mario.h and mariotune.h [firmware].

The two alarm melodies are mutually exclusive. Switching between the two is done by (un)defining `MARIO` in monomain.h [firmware]. In the same file specify the two-tone alarm tones and tone duration. See below an excerpt where is chosen to use the Mario alarm.

```
// Uncomment this if you want a Mario tune alarm instead of a two-tone alarm.
// Note: This will cost you ~615 bytes of Monochron program and data space.
#define MARIO

// Two-tone alarm beep
#define ALARM_FREQ_1   4000
#define ALARM_FREQ_2   3750
#define ALARMTICK_MS   325
```

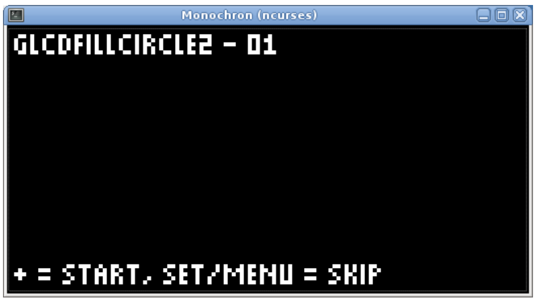
Alarming and snoozing timeouts are controlled by the following defines in monomain.h [firmware]. Note that for the emulator reduced timeouts are specified.

```
// Set timeouts for snooze and alarm (in seconds)
#ifndef EMULIN
#define MAXSNOOZE      600
#define MAXALARM       1800
#else
// In our emulator we don't want to wait that long
#define MAXSNOOZE      25
#define MAXALARM       65
#endif
```

2.9 Performance tests for high-level glcd functions

Modifying a glcd function is mostly done for performance and/or object size optimization reasons. In order to verify whether code changes impact the draw performance of a glcd function, a dedicated clock plugin has been created that, instead of providing a functional clock, allows running high-level glcd performance tests on Monochron hardware.
The performance test module covers most of the high-level glcd functionality. The tests are split-up in tests suites per glcd function where a test suite contains one or more individual tests. Using the Monochron buttons one can navigate through a menu-like structure of test suites and individual tests within a suite, or abort a running test.

In appendix B test results are described and discussed for several performance test runs.
For code refer to perftest.c [firmware/clock].



2.10 Demo and test mchron command scripts

In node [script] mchron demo and test command scripts are available. Refer to section 5.8.6 on how to execute a command script.

Below is an overview of those considered most relevant:

Script	***Description***
alarm.txt [script]	This script is used for testing a clock plugin. It will run through all minutes in a day and have each minute displayed in the alarm area of the clock of choice. It requires preset values for two variables that control the minute skip size and the display time per generated timestamp. Refer to the script itself for an example on how to use it. See also time-hm.txt that focuses on the clock time instead of alarm time.
circle*X*.txt [script]	A total of five scripts for testing high-level glcd graphics. The first three scripts verify the correctness of the circle functions.
controller*X*.txt [script]	A total of 4 scripts for testing the LCD controller state machine. It verifies the correctness of the controller command set and its impact on the LCD devices.
demo.txt [script]	This script is a shell that executes other scripts that demo the graphic capabilities of the enhanced high-level glcd library. Some of the other scripts listed here are executed via demo.txt.
line*X*.txt [script]	A total of seven scripts for testing high-level glcd graphics. It verifies the correctness of the line function.
rectangle*X*.txt [script]	A total of seven scripts for testing high-level glcd graphics. It verifies the correctness of the rectangle functions.
time-hm.txt [script]	This script is used for testing a clock plugin. It will run through all minutes in a day and have each minute displayed in the clock of choice. It requires preset values for two variables that control the minute skip size and the display time per generated timestamp. Refer to the script itself for an example on how to use it. See also time-ms.txt and alarm.txt.
time-ms.txt [script]	This script is used for testing a clock plugin. It will run through all seconds in one hour and have each second displayed in the clock of choice. It requires preset values for two variables that control the seconds skip size and the display time per generated timestamp. Refer to the script itself for an example on how to use it. See also time-hm.txt.
year.txt [script]	This script is used for testing a clock plugin. It will run through all days in a leap year and have a clock display each day in its date area. It requires a preset value for a variable that controls the display time per generated date. Refer to the script itself for an example on how to use it.

Table 15: Relevant command scripts overview

2.11 The pre-built monochron.hex firmware

This project contains a pre-built monochron.hex [firmware] firmware file using avr-gcc 4.3.5 (Debian 6).
As all clocks [firmware/clock] combined will result in a firmware file that exceeds the Monochron firmware size limit a selection has been made.
Refer to the contents of `monochron[]` in anim.c [firmware] to see which clocks are configured and monomain.h [firmware] to see which alarm melody is used.
Refer to section 4.3 on how to upload firmware to Monochron.

2.12 Quick guide into the `clockDriver_t` structure

The `clockDriver_t` structure is the basis of the static `monochron[]` and `emuMonochron[]` arrays and contains the public functions of configured clock plugins. Below is detailed info on the structure members.

Refer to anim.c [firmware] and mchron.c [firmware/emulator] for examples on how the arrays are populated.

The structure elements are as follows.

Element	***Description***
`clockId`	This is the unique clock Id assigned to a clock.
`initType`	The initialization mode that is forwarded to the `init()` function of a clock. It has two distinctive values as defined in anim.h [firmware]. – `DRAW_INIT_FULL` The clock must begin from scratch, so it should clear the entire LCD display and make a complete graphic build-up of the clock. – `DRAW_INIT_PARTIAL` The preceding clock in the clock array has a shared clock layout with the new one. So, instead of rebuilding the clock from scratch we can keep certain graphic elements as-is and therefor need to clear and draw only those elements that differ. This will result in a faster and smoother graphic build-up of the new clock. For examples refer to the clocks defined in analog.c [firmware/clock] and digital.c [firmware/clock].
`init()`	This is the published initialization function for a clock. It is invoked via anim.c [firmware] when the clock needs to initialize itself.
`cycle()`	This is the published cycle function for a clock. It is invoked via anim.c [firmware] every main loop cycle, thus giving the clock the opportunity to update itself. For example, it needs to handle changes in time, changes in the position of the alarm on/off switch and changes in the alarming/snoozing state of the clock.
`button()`	This is the optional published function for a clock. When published, it is invoked via anim.c [firmware] in a main loop cycle when a button is pressed.

Table 16: The `clockDriver_t` clock driver structure elements

2.13 Quick guide into adding a new clock plugin

Find below an overview of the files to be created/modified when adding a new clock in the Emuchron clock plugin framework.
This overview is based on the `CHRON_EXAMPLE` clock as found in example.c and example.h [firmware/clock]. It is a bare bone yet fully functional Monochron clock plugin with proper date, time and alarm area handling.

File	***Description***
anim.h [firmware]	– Create a unique id for the clock `#define CHRON_EXAMPLE 19`
anim.c [firmware]	– Include the clock header `#include "clock/example.h"` – When you want to test or upload your new clock to the actual Monochron clock, add the clock id and public `init()`, `cycle()` and (optional) `button()` functions for the clock in static array `monochron[]`.
example.c [firmware/clock]	– Create a clock source file that implements the public and private functions for the clock.
example.h [firmware/clock]	– Create a clock header file that publishes the public `init()`, `cycle()` and (optional) `button()` functions for the clock.
help.txt [firmware/emulator]	– Modify the help text for command 'cs' by adding the numeric id and description of the clock. See also changes for mchron.c.

File	***Description***
Makefile [firmware]	– When appropriate add the example.c file in variable `SRC`. This is required for building Monochron firmware that includes the new clock.
MakefileEmu [firmware]	– Add the example.c file in variable `CSRC`. This is required for building Emuchron and the mchron command line tool.
mchron.c [firmware/emulator]	– Include the new clock header `#include "../clock/example.h"` – Add the clock id and public `init()`, `cycle()` and (optional) `button()` functions for the clock in static array `emuMonochron[]`. – Verify if the clock requires special handling in `doAlarmSet()`.
mchronutil.c [firmware/emulator]	– Verify if the clock requires special handling in `emuClockUpdate()`.

Table 17: What to create/modify when adding a new clock plugin

3 Setting up the software environment

3.1 Introduction

Emuchron is supported on Debian 6, 7 and 8. In order to be able to build and upload Monochron firmware, and to build the mchron emulator we need compilers and several Linux libraries. Next, in order to be able to use the ncurses LCD device we need to configure a terminal profile and create a shortcut to start a Gnome terminal with a specific command line.

3.2 Configuring Debian

3.2.1 General Debian requirements

In order to be able to use Emuchron configure Debian with GNOME or GNOME Classic. Apart from this, Emuchron does not require out of the ordinary CPU, memory or graphics card performance.

When running Debian in a VM it is highly recommended that in the BIOS of the host machine the CPU is enabled to use Intel (VT-x) or AMD (AMD-V) Virtualization Technology as this will significantly improve VM performance. On Intel Macs this is enabled by default.
Also, make sure that the VM accepts USB devices. In general, if you're able to see the contents of a plugged-in USB flash disk, the VM is able to successfully attach to the FTDI USB device as well.
In section 1.4 an overview is provided of hypervisors used and observed issues.

3.2.2 Configuring a Debian VM in VirtualBox

As OpenGL2/GLUT performance benefits from the availability of basic hardware acceleration, enable the 3D acceleration tick box for the Debian VM. See below. If not ticked on, the GLUT LCD device will show less fluent video behavior.

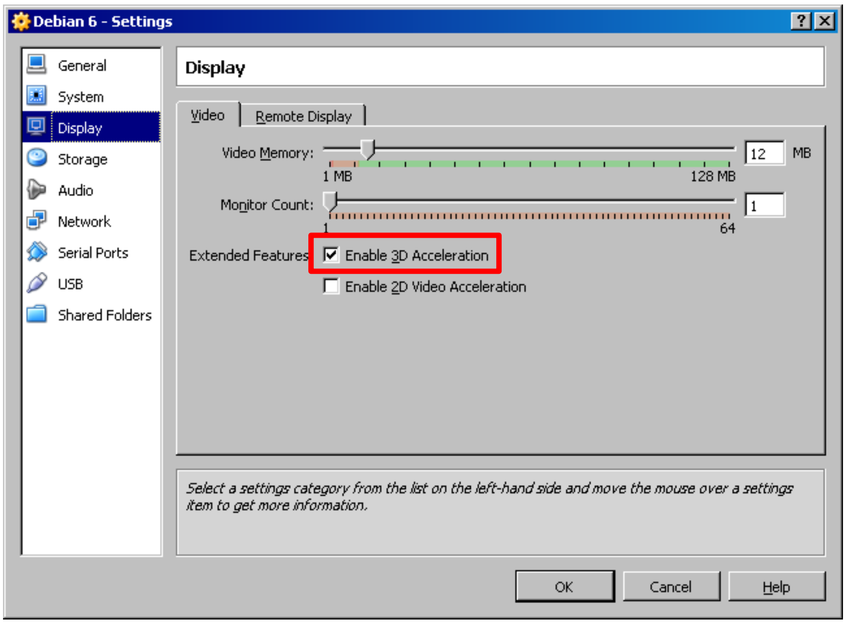


Figure 4: Enable 3D acceleration for a Debian VM in VirtualBox

Next, in the VM itself, after logging on, add the following line at the bottom of file $HOME/.bashrc.

```
export LIBGL_ALWAYS_SOFTWARE=1
```

Adding this line will prevent warnings, crashes and coredumps caused by OpenGL2 upon starting the mchron tool with the OpenGL2/GLUT LCD device.

3.2.3 Configuring a Debian VM in VMware Fusion

As OpenGL2/GLUT performance benefits from the availability of basic hardware acceleration, enable the Acceleration 3D Graphics option for the Debian VM. See below. If not enabled, the GLUT LCD device will show less fluent video behavior.

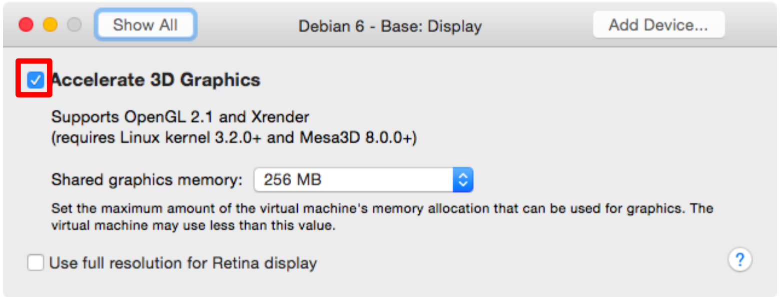


Figure 5: Enable 3D acceleration for a Debian VM in VMware Fusion

3.3 Unpacking the project software

The Emuchron project package can be downloaded via github location https://github.com/tceulema/Emuchron and can be unpacked in any location. Make sure that full read and write access is granted to the project root and its structure below. The project root location is referenced in command shell examples as <install_dir>.

3.4 Installing required Linux packages

Setting up an AVR toolchain environment for Linux is described on http://www.ladyada.net/learn/avr/setup-unix.html and includes instructions to manually download and build several packages.

Fortunately, for Debian Linux there is no need to do all of this. Instead, all required packages can be retrieved and installed using `apt-get`. This also applies to installing the required libraries for the Emuchron environment, LCD and piezo stub devices, debugging tools and, for Debian 8, glibc source files.

In the Emuchron node a shell script is available to download and install all required packages.

For this start a command shell and execute the commands below.

```
$ # Only an admin user is allowed to install stuff
$ su - root
$ # When logged in as root first update the list of package sources
$ apt-get update
$ # Then execute the script to install required packages
$ cd <install_dir>/support
$ . ./packages.txt
```

Note: For the 'su' command you need to supply the root password to acquire administrator rights.

Note: During the installation of several packages you are asked to confirm installing dependency packages. As the default is 'Y', all that is needed is to press the enter key.

Note: Depending on the configuration of `apt-get` it is possible that the tool asks the end-user to insert the original installation media. If the installation media is not inserted, the installation of several packages will fail. To prevent `apt-get` using any installation media, the end-user can manually comment out the reference(s) to physical installation media in sources.list [/etc/apt]. This will require admin rights. When needed, rerun the packages script.

Note: Regarding usage aspects of downloading and installing glibc source files for Debian 8, refer to section 3.7.4.

3.5 Copying configuration file for minicom

The `minicom` application is used for debugging the Monochron clock. It allows making a connection to Monochron via the FTDI port and, when proper firmware is uploaded to Monochron, to extract runtime debug text strings from the port. It is installed as part of the software installation procedure as described in section 3.4. The specifics for connecting minicom to Monochron using FTDI Friend v1.1 are saved in a configuration profile in [support] that needs to be copied to the minicom environment.
For more information on how to use minicom refer to section 6.1.

To copy the Monochron profile for minicom execute the commands below.

```
$ # Only an admin user is allowed to install stuff
$ su - root
$ cd <install_dir>/support
$ cp minirc.Monochron /etc/minicom
```

Note: For the 'su' command you need to supply the root password to acquire administrator rights.

3.6 Setting up and using an ncurses Monochron terminal

Emuchron supports two LCD stub devices, being a GLUT device and an ncurses device. The GLUT device requires no setup. The ncurses device however does.

Ncurses is a terminal type of device. In order to be used for Emuchron it needs to reproduce square pixels with geometry 128x64.
GNOME allows creating so-called terminal profiles in which characteristics like font and font size, foreground and background colors and scrollbar behavior can be configured. By creating a dedicated profile for a Monochron ncurses terminal, a one-time only action, we can create a GNOME terminal that can be used as an ncurses Monochron LCD stub device.

3.6.1 Creating a Monochron terminal profile

The instructions for creating a Monochron terminal profile in Debian 6 and 7 is found in appendix C.1.
The instructions for creating a Monochron terminal profile in Debian 8 is found in appendix C.2.

3.6.2 Starting a Monochron ncurses terminal

Once a terminal profile is created we can start a Monochron ncurses terminal by executing the proper shell command.

A command shortcut named Monochron [support] or 'gnome-terminal.desktop' [support] is available that will do this. Copy this shortcut to the desktop for easy access.

Note: Although the actual name of the shortcut is 'Monochron' it is very well possible that it is named 'gnome-terminal.desktop' [support]. GNOME may see the shortcut as a potential security risk and as such will initially refuse to see it as a legitimate file. Upon copying or double-clicking the shortcut you may be asked to confirm the validity of the shortcut. When confirmed, GNOME will rename the file to a shortcut named 'Monochron'.

When double-clicked, the Monochron shortcut will execute the following command:

```
gnome-terminal --window-with-profile=Monochron --hide-menubar --geometry=258x66
-e "bash -c \"tty > ~/.mchron; bash\""
```

This command implements the following functionality:
1. Start a GNOME terminal.
2. The terminal will use terminal profile "Monochron", as configured according instructions in appendix C.
3. The terminal will hide its menubar.
4. The terminal geometry is 258x66 characters. This is quite big, but as the font size in the profile is set to 2, the terminal itself will have about the same size as a regular bash terminal.
5. Upon startup, a bash is started that will copy the tty info of the window in file $HOME/.mchron. The mchron command line tool will then use this info to automatically link the ncurses LCD stub device output to that tty.
   For more info on the mchron command line arguments refer to section 5.2.

When the Monochron terminal profile is properly setup, double-clicking the Monochron shortcut will create a blank black Monochron ncurses terminal. The terminal header as shown in the screendump below is not supported in Debian 8. Note the small command prompt at the top left of the window, caused by the very small font point size.

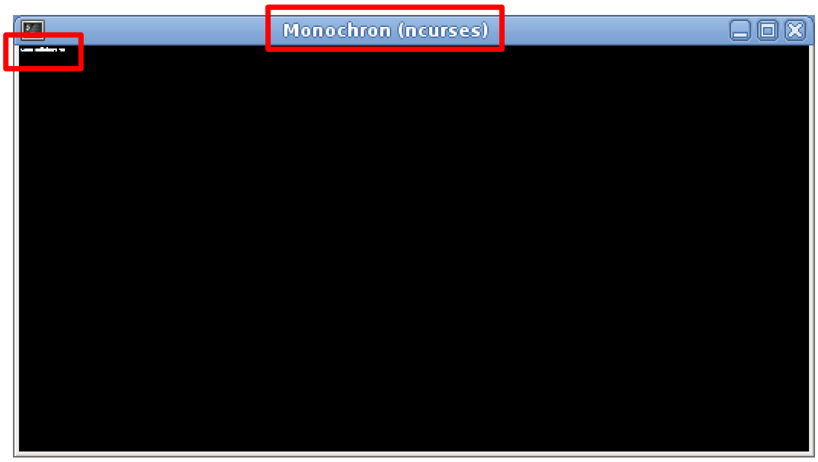


Figure 6: A blank Monochron terminal

In addition to that, a file .mchron will appear in the home folder, containing the tty of the Monochron terminal. See below.

```
$ cat ~/.mchron
/dev/pts/1
```

3.6.3 Changing the size of a Monochron ncurses terminal

When running the emulator in an ncurses terminal, its size may not be increased or decreased in terms of the number of horizontal columns or vertical rows. This will confuse ncurses and will permanently disturb the layout of the window.
However, the window size can be increased or decreased by means of changing the character font size that is used within the terminal.

- To increase the font size in a Monochron terminal activate the window and type '<ctrl>+'.
- To decrease the font size in a Monochron terminal activate the window and type '<ctrl>-'.

Note that only a limited number of font sizes will produce square 'pixels'.

3.7 Debian 8 issues and regression in functionality

Debian 8, at the time of writing this document, suffers from a number of inconveniences as well as regression in functionality when compared to Debian 6 and 7. These issues combined make Debian 8 a less friendly environment to setup in general and for Emuchron in particular.

3.7.1 ALSA audio is getting ever less responsive

To illustrate the problem, in mchron, execute script beep.txt [script] in Debian 6, 7 and 8.
In Debian 6 the beeps are fluid and there is hardly any delay in between individual beeps. In Debian 7 the time between individual beeps is increased significantly, but ALSA remains stable as a means to generate audio. In Debian 8 however, in between beeps random underflow buffer errors occur, requiring a code change in stub.c [firmware/emulator] to redirect the audio `play` error stream to `/dev/null`. Similar buffer errors have occasionally been seen while playing alarm audio.
In general, the ALSA audio interface gets less and less responsive with each Debian release.

3.7.2 There may not be audio at all

In certain circumstances audio in Debian 8 may be totally missing, caused by an erroneous setup of audio devices during installation. This issue was seen after installing Debian 8 in both a VirtualBox and VMware Fusion VM.

In case audio is missing first try this:
1. Via the main menu or activities overview launch the Settings tool and next select Sound.
   Verify that audio is unmuted. If muted, unmute and retry audio.

If audio is still missing then try the following:
1. In a command shell execute the following command: `alsamixer`
2. In `alsamixer` press the F6 key.
   This will provide an overview of available audio devices.
3. Use cursor up/down to navigate to the non-default sound card (for example: Intel 82801AA-ICH) and press Enter to select.
   This will display the playback settings for the non-default audio device.
4. The two most left bars identify the Master Mono and Master Surround controllers.

Use cursor left/right to navigate to these bars.
5. In each of these bars use cursor up to increase the volume to 100%.
6. Also, at the bottom of the bar a marker indicates the current mute status where 'MM' indicates mute and '00' indicates unmute.
Press the 'm' key to toggle the mute state. Unmute both masters.
7. After applying these changes, the result should look similar to graph below.
8. Use the esc key to exit and retry audio.

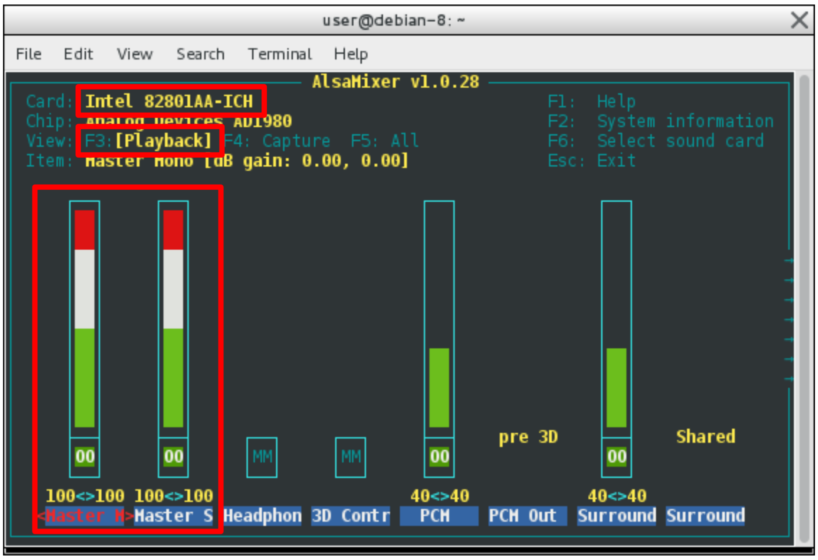


Figure 7: ALSA mixer with unmuted playback Master controllers

3.7.3 A terminal profile can no longer set a terminal header

In section 3.6.1 a Monochron terminal profile is created for use in a Monochron LCD ncurses stub device. In Debian 8 it is no longer possible to set the header of the terminal to "Monochron (ncurses)".

3.7.4 The gdb debugger cannot find file "syscall-template.S"

In Debian 8, using DDD or Nemiver as a graphical front-end for gdb is suffering from multiple popups at every debugger breakpoint indicating that file "syscall-template.S" cannot be found.
The issue originates from within the gdb debugger that forwards the problem to the graphical front-end. In short, as of Debian 8, gdb/DDD/Nemiver like to have glibc sources available.
This in itself is not really an issue as long as we're able to install the glibc sources using `apt-get`, and the packages.txt script [support] will do this specifically for Debian 8 systems.
The main problem however is that the location where gdb expects to find the sources is not static and may differ per Debian 8 installation. Note that only Nemiver will provide the full path of the file not being found. Refer below for an example.

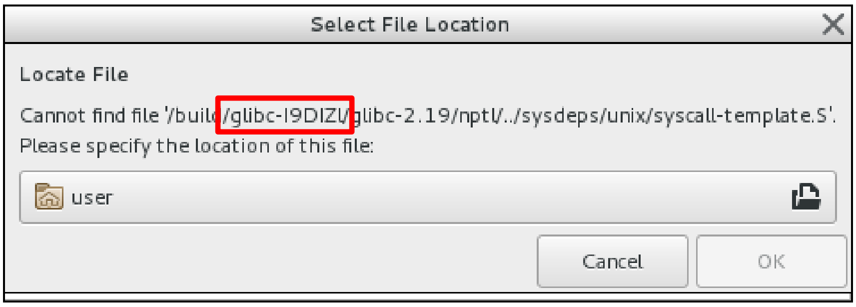


Figure 8: The gdb debugger cannot find file syscall-template.S

The part in the path that may vary per Debian 8 system is highlighted, in this case "glibc-I9DIZI".
The problem can be resolved by creating a symbolic link that points to the actual installation folder of the glibc sources. The packages.txt [script] that installs the glibc sources already creates a number of these symbolic links by default that appear to be commonly used.
In case another symbolic link needs to be created, depending on the information shown in the Nemiver popup, refer to the instructions below that create a symbolic link for imaginary folder "glibc-*ABC*".

```
$ # Only an admin user is allowed to install stuff
$ # If needed, remove a symbolic link using: rm glibc-ABC
$ su - root
$ cd /build
$ ln -s glibc glibc-ABC
```

Note: For the 'su' command you need to supply the root password to acquire administrator rights.

When a proper symbolic link has been created, gdb and its graphical frontends will no longer complain about not being able to access the source file.

4 Building firmware and the emulator

4.1 Building Monochron firmware

The `make` command builds Monochron firmware. For Monochron firmware it is driven by the default file named Makefile [firmware].

The Monochron firmware build needs to be configured:

– Makefile [firmware]
  Verify that variable SRC, next to the common modules in [firmware], contains the proper list of clock plugin modules.
– anim.c [firmware]
  Verify that static array `monochron[]` contains the correct set of clocks, limited by the Makefile SRC variable.

When configured enter the following commands:

```
$ cd <install_dir>/firmware
$ make <all | clean | rebuild>
```

Details for the Monochron firmware make command:

– `make all`
  Build all modules that require a (re)build and generate the Monochron firmware in file monochron.hex [firmware].
– `make clean`
  Clean all object and dependency files.
– `make rebuild`
  A combination of '`clean`' followed by '`all`'.

When the build has successfully completed an overview is provided of the firmware memory map. See below for an example.

```
Size after:
monochron.elf  :
section          size       addr
.data            1230    8388864
.text           29014          0
.bss              297    8390094
.stab           64380          0
.stabstr        16069          0
Total          110990
```

The Monochron Atmel CPU contains 32KB flash memory, of which 30KB is available for Monochron firmware. Verify that the sum of .data and .text does not exceed 30720 bytes (=30KB). If it does you need to optimize code, save space by using the two-tone alarm instead of the Mario alarm, make sure the debug output flag is switched off (refer to section 6.1.1), or remove one or more clocks from the `monochron[]` array and the Makefile [firmware] `SRC` variable.

Note: There is a substantial difference between avr-gcc 4.3.5 (Debian 6) and 4.7.2/4.8.2 (Debian 7/8) with respect to the size of generated object code. Upon nearing the 30Kb limit of available flash storage for a hex file, avr-gcc version 4.7.2/4.8.2 generates a hex file that is ~500 bytes smaller than a hex file based on identical code that is built with version 4.3.5. Unfortunately, smaller code does not imply faster execution. Code generated by avr-gcc 4.7.2 tends to run consistently slower than code generated by avr-gcc 4.3.5. Refer to appendix B for detailed information on compiler object size and performance tests.

Note: When the previous build was for Emuchron, use 'make clean' first or use 'make rebuild' to clean up the build environment. The reason for this is that Emuchron x86 object code is incompatible with Monochron AVR Atmel object code, resulting in link failures.

Note: The Monochron firmware and clock plugin code as downloaded from github will build warning free.

4.2 Building Emuchron and mchron command line tool

Emuchron and its mchron command line tool will use its dedicated make file, being MakefileEmu [firmware]. The Emuchron build does not require any configuration.

In Monochron code the build switch EMULIN is used to build dedicated Emuchron stubs. This build switch is enabled by default.
Building Emuchron and mchron is done using the make command below.

```
$ cd <install_dir>/firmware
$ make -f MakefileEmu <all | clean | rebuild>
```

Details for Emuchron and the mchron command line tool make command:
- make -f MakefileEmu all
  Build all modules that require a (re)build and build the mchron tool.
- make -f MakefileEmu clean
  Clean all object and dependency files.
- make -f MakefileEmu rebuild
  A combination of 'clean' followed by 'all'.

Note: When the previous build was for Monochron firmware, use 'make -f MakefileEmu clean' first or use 'make -f MakefileEmu rebuild' to clean up the build environment. The reason for this is that Monochron AVR Atmel object code is incompatible with Emuchron x86 object code, resulting in link failures.

Note: The Emuchron, emulator and clock plugin code as downloaded from github will build warning free.

4.3 Uploading Monochron firmware to Monochron clock

Use the avrdude command to upload Monochron firmware to the Monochron clock. Installing avrdude is described in section 3.4.
More information on configuring and using avrdude is found on:
http://www.ladyada.net/learn/avr/setup-unix.html
http://www.ladyada.net/learn/avr/avrdude.html
Specific information on updating Monochron firmware is found on:
https://learn.adafruit.com/monochron/updating.

Please note the following regarding the use of avrdude on Linux and Linux VM’s, in combination with FTDI Friend v1.1 (https://learn.adafruit.com/ftdi-friend).

- When using a Debian VM, make sure that the VM is setup to support USB devices. If not, the USB FTDI device will not be recognized.

- Plugin the FTDI device in Monochron with the chip and USB port facing down, and the settings jumpers facing up. When plugged in and seen from above you'll notice the settings jumpers on the FTDI circuit board.
- The USB FTDI device will appear as logical device /dev/ttyUSB*x*.
  In normal circumstances the USB FTDI device will be the only USB terminal device that is connected to your machine. If so, it will map to logical device /dev/ttyUSB0.
- To prevent confusion on which hardware USB device is which logical /dev/ttyUSB*x* device, unplug all other USB devices. If you do need other USB devices as well you need to verify which logical /dev/ttyUSB*x* device will be assigned to the USB FTDI device.
- When using Debian Linux as a VM, after plugging in the USB FTDI device you need to attach it to your VM. The device to attach to will show up with a name similar to 'FTDI FT232R USB UART'. Note that both VirtualBox and VMware Fusion have succeeded in using `avrdude` on the USB FTDI device to upload firmware to Monochron.
- Getting the USB FTDI device to attach to your machine or VM may take some time, especially the first time as Linux may need to do configuration tasks. If you have no other USB devices plugged in, wait for device /dev/ttyUSB0 to pop up in /dev.
  In one case when the USB FTDI device was plugged in for the very first time, it did not get fully recognized at first. In case this occurs, by un/replugging or rebooting Linux the device eventually becomes visible for `avrdude`. Be patient and give Linux time to get its act together.
- By default the USB device can be accessed by root only, meaning that only the root user is allowed to use `avrdude` on the FTDI device. By using the appropriate `chmod` command you can open up this device to other user groups as well. The examples below however will use the root user to upload the firmware.

Find below the Linux commands needed to upload firmware to Monochron. A text copy, including similar commands for a toolchain when installed on Windows, is available in avrdude.txt [support].

```
$ # You must have admin rights or you'll be denied access to /dev/ttyUSBx
$ su - root
:
$ # You must be in the same folder where monochron.hex firmware resides
$ cd <install_dir>/firmware
:
$ # First verify whether avrdude can talk to the Monochron clock
$ # Device /dev/ttyUSB0 may differ depending on which USB devices are attached
$ # For parameter -p use either "m328p" or "atmega328p"
$ avrdude -c arduino -p m328p -P /dev/ttyUSB0 -b 57600
:
$ # Then upload firmware to the Monochron clock
$ # Device /dev/ttyUSB0 may differ depending on which USB devices are attached
$ # For parameter -p use either "m328p" or "atmega328p"
$ avrdude -c arduino -p m328p -P /dev/ttyUSB0 -b 57600 -U flash:w:monochron.hex
```

If an attempt is made to upload firmware that is larger than 30KB, a firmware verification error is reported at the 30KB memory address. See the example below. Don't be surprised when your clock will hang soon after it has been started.

```
:
avrdude: verifying
avrdude: verification error, first mismatch at byte 0x7800
         0x00 != 0x0c
avrdude: verification error; content mismatch

avrdude: safemode: Fuses OK

avrdude done.  Thank you.
```

5 The mchron command line tool

5.1 Introduction

Emuchron is controlled via its command line tool mchron. It provides commands to access clock plugins at will, feed clocks with a continuous stream of time and keyboard events, change the time/date/alarm, access the graphics library to draw on the stubbed LCD display, and run a stubbed Monochron application ahead of building and uploading actual firmware.

5.2 Starting mchron

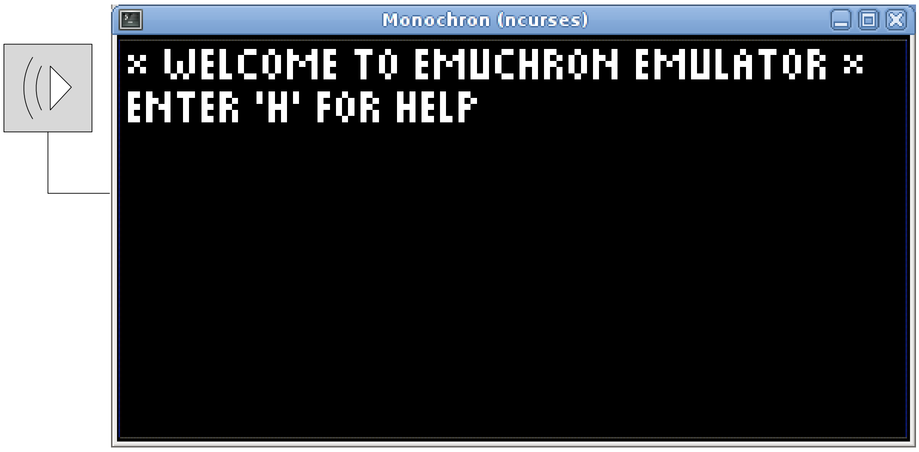
Find below an excerpt from the help file as found in help.txt [support].

```
mchron - Emuchron emulator command line tool

Use: mchron [-l <device>] [-t <tty>] [-g <geometry>] [-p <position>]
            [-d <logfile>] [-b] [-h]
  -b             - Backlight brightness support in ncurses terminal
  -d <logfile>   - Debug logfile name
  -g <geometry>  - Geometry (x,y) of glut window
                   Default: "520x264"
                   Examples: "130x66" or "260x132"
  -h             - Give usage help
  -l <device>    - Lcd stub device type
                   Values: "glut" or "ncurses" or "all"
                   Default: "glut"
  -p <position>  - Position (x,y) of glut window
                   Default: "100,100"
  -t <tty>       - tty device for ncurses of 258x66 sized terminal
                   Default: get <tty> from $HOME/.mchron

Examples:
  ./mchron
  ./mchron -l glut -p "768,128"
  ./mchron -l ncurses
  ./mchron -l ncurses -t /dev/pts/1 -d debug.log
```

When Emuchron is successfully built, for this refer to section 4.2, the mchron command line tool can be started.
When using the ncurses LCD stub device, first read and execute all the necessary steps in sections 3.6.1 and 3.6.2 on how to setup and start a Monochron ncurses terminal.

```
$ # When using the (default) OpenGL2/GLUT LCD stub device
$ # Note: No additional configuration is needed
$ cd <install_dir>/firmware
$ ./mchron

$ # When using the ncurses LCD stub device
$ # Note: Refer to 3.6.1 and 3.6.2 to setup and start an ncurses terminal
$ cd <install_dir>/firmware
$ ./mchron -l ncurses

$ # When using both the OpenGL2/GLUT and ncurses LCD stub devices
$ # Note: Refer to 3.6.1 and 3.6.2 to setup and start an ncurses terminal
$ cd <install_dir>/firmware
$ ./mchron -l all
```

Starting mchron should result in an audible startup beep and the following screen layout in the LCD stub device(s).



The mchron command terminal will show tool and runtime information and provides a command entry prompt. See below.

```
$ ./mchron -l ncurses

*** Welcome to Emuchron command line tool (build Oct 22 2015, 13:32:00) ***

mchron PID = 3382
ncurses tty = /dev/pts/1

time   : 13:38:35 (hh:mm:ss)
date   : 22/10/2015 (dd/mm/yyyy)
alarm  : 22:09 (hh:mm)
alarm  : off

Enter 'h' for help.
mchron>
```

Note: In the unfortunate event that mchron crashes or properly fails to initialize at startup refer to section 7.6.

5.3 Interrupting and stopping mchron

Within mchron there are several ways to interrupt command execution and to stop it. Also, mchron has a built-in mechanism to protect itself against invalid LCD operations requested by end-user commands, incorrect clock code or incorrect graphics code.

Note: Regardless the event causing an intended or unintended shutdown, mchron will always try to shutdown gracefully. A graceful shutdown however cannot be guaranteed at all times and may cause the mchron terminal to stop echoing keyboard input. Refer to section 8.1 for its symptoms and a simple method to resolve this.

The following options are available to interrupt and stop mchron:

– Interrupt command execution by using keypress 'q'.
  The execution of a command file or multi-command list (refer to section 5.10) or a wait command is interrupted by using a 'q' keypress. When appropriate a stack trace of nested load commands is reported for informational purposes. Internally, the interpreter will properly clean-up the entire stack after which the mchron prompt will re-appear. For a stack trace example refer to section 5.5.
– Stop mchron at any moment using '<ctrl>c'.
  This keypress will generate a `SIGINT` signal.

– Stop mchron at command prompt level using command 'x' or '<ctrl>d' on an empty line.
  Example:

```
mchron> # Press '<ctrl>d' on an empty line to exit mchron
mchron>
<ctrl>d - exit                                   Press '<ctrl>d'
$
```

– Quit mchron multi-line command mode using '<ctrl>d' on an empty line.
  Example:

```
mchron> # Press '<ctrl>d' on an empty line to quit multi-line command mode
mchron> rf x=0 x<128 x=x+1
2>> pd f x y
3>>
<ctrl>d - quit                                Press '<ctrl>d'
mchron>
```

– Stop mchron at any moment using '<ctrl>z'.
  This keypress will generate a `SIGTSTP` signal. The effect of this method is similar to using keypress '<ctrl>c'.
– Force a coredump at any moment using '<ctrl>\'.
  This keypress will generate a `SIGQUIT` signal that on its turn will generate a `SIGABRT` signal that will cause mchron to coredump.

5.4 Pre-emptive coredump of mchron

Mchron coredumps itself when it detects an invalid LCD operation.
It is very well possible to enter an mchron command that attempts to draw pixels outside the boundaries of the LCD area. Also, it is very well possible that, due to a bug, clock code attempts to do the same.
Whenever an attempt is made to read or write pixels outside the boundaries of the LCD display, mchron will actively force itself to coredump since this is an unacceptable situation that needs to be resolved.

In case only the OpenGL2/GLUT LCD device is used, the user is presented a confirmation prompt prior to the actual coredump, allowing to inspect the display as-is and/or create a screendump before it is closed down. When using the ncurses LCD device, the current display is retained after the coredump.

Note: In case mchron will coredump, an actual coredump file will be created in [firmware] only when in the command shell the following command is executed once prior to starting mchron: `ulimit -c unlimited`

```
$ # Make sure a coredump file will be created in this shell upon coredumping
$ ulimit -c unlimited
$ # Start mchron
$ ./mchron -l ncurses
:
Enter 'h' for help.
mchron> # Let's try to paint outside the LCD display boundaries :-0
mchron> pr f 120 60 50 50

*** invalid graphics api request in glcdSetAddress()
api info (controller:x:y:data) = (0:121:13:0)
*** registered variables
variables in use: 0
*** debug by loading coredump file (when created) in a debugger
Aborted (core dumped)
$ ls -l core
-rw------- 1 user user 25608192 Oct 28 18:35 core
$
```

5.5 The mchron stack trace

When executing commands from a command file or multi-command input, mchron provides a stack trace for informational purposes whenever it is interrupted or encounters an error.

A stack trace line consists of 4 items separated by a colon. For an example, see below.

```
mchron> # Demo execution interrupt using 'q' keypress on wait
mchron> e s ../script/demo.txt
<wait: q = quit, other key will continue>
quit
--- stack trace ---
2:../script/paint.txt:17:w 0
1:../script/demo.txt:12:e i ../script/paint.txt
0:mchron:-:e s ../script/demo.txt
mchron>
```

Press 'q'

File depth File name or 'mchron' Line number in file Command

5.6 Recovering from command syntax and parse errors

Whenever mchron detects a syntax or parse error in a command it will abort its execution. Information will be provided on the circumstances causing the command to abort. A command stack trace will be provided when appropriate. For an example of a stack trace refer to section 5.5.

Refer to the example below.

```
mchron> # The paint dot x position argument is beyond the LCD display boundaries
mchron> pd f 153 30
x? invalid: 153
mchron>
```

5.7 The mchron command line history log

Standard readline library functionality is used by mchron for command line input and caching, and flushing the command line history in a file.

The default command history log file is $HOME/.mchron_history that is created by mchron when not present. Clear the history by stopping mchron and then removing the file. Its configuration is found in scanutil.c [firmware/emulator]. See below.

```
// The readline unsaved cache and history file with size parameters
#define READLINE_CACHESIZE     15
#define READLINE_HISFILE       "/.mchron_history"
#define READLINE_MAXHISTORY    250
```

Some examples of functionality provided by the readline library:
Browsing the command log is done using the up/down arrows. Navigating in a command line is done using the left/right arrows, or '<ctrl-a>' and '<ctrl-e>' for respectively the beginning and end of a command line. A reverse-order search in the log is started using '<ctrl-r>'.

5.8 The mchron command groups

The structure of an mchron command is simple.

```
<command> <arg1> <arg2> .. <argn>
```

Note the following:

- A command is always a single text word. An argument can be a single character, a text word, a text string (many words) or a numeric expression.
- An mchron command line contains a single command only.
- Command and arguments are separated by white space (space or tab). The only exception is an argument of type text string that consists of all remaining text on a command line.
- As arguments are not named, it will have a negative impact on the readability. Consider this a learning curve. The purpose of mchron is to provide a command line interface with a simple syntax structure.
- Mchron supports named numeric variables that are identified by a word of mixed upper/lowercase characters in the range 'a'..'z' and underscores '_'.
- Numeric type arguments are read as a text word that is fed through an expression evaluator. In combination with named variables it provides great flexibility in passing calculated numeric values to mchron command arguments.
  Note that command handlers that implement numeric arguments are responsible for casting expression evaluator results, being of type `double`, into an integer type. Casting macros are provided for this purpose in mchron.c [firmware/emulator]. These macros also take care of value rounding to the nearest integer number.
- An mchron command line is not limited in length.

An example of several commands can be seen on the front page of this document. On the top of the front page a script is listed that results in the Monochron screendump at the bottom.

Below is an overview of all main command groups. A command group consists of one or more individual commands. Many examples of commands are found in script files in [script]. The command description text boxes contain an excerpt from help.txt [support].

5.8.1 '#' – Comments

The comment command serves no other purpose than to provide information to the end-user.

```
Command:
  '#'   - Comments
          Argument: <comments>
              comments: optional ascii text
```

Usage specifics:

- The comments command and the actual comments must be separated by a white space character.
- Comments are optional.
- When a comment command is entered on the mchron command line in combination with debug logging being active, the comments are added in the debug log to serve as a debug log marker.

Example:

```
mchron> # This is a comment
mchron> #
mchron> # An empty comment in the line above is also allowed
mchron>
```

5.8.2 'a' – Alarm

The alarm commands allow setting the alarm time and the alarm switch position. Related command groups are date ('d') and time ('t').

```
Commands:
  'ap'  - Set alarm switch position
          Argument: <position>
              position: 0 = off, 1 = on
  'as'  - Set alarm time
          Arguments: <hour> <min>
              hour: 0..23
              min: 0..59
  'at'  - Toggle alarm switch position
```

Usage specifics:

- When an alarm command is used, an active clock is called to update itself using the modified settings.

Example:

```
mchron> # Set alarm time to 14:51
mchron> as 14 51
time  : 17:03:34 (hh:mm:ss)
date  : 28/10/2015 (dd/mm/yyyy)
alarm : 14:51 (hh:mm)
alarm : off
mchron> # Set alarm switch to 'on'
mchron> ap 1
time  : 17:03:50 (hh:mm:ss)
date  : 28/10/2015 (dd/mm/yyyy)
alarm : 14:51 (hh:mm)
alarm : on
mchron> # Toggle alarm switch
mchron> at
time  : 17:03:55 (hh:mm:ss)
date  : 28/10/2015 (dd/mm/yyyy)
alarm : 14:51 (hh:mm)
alarm : off
mchron>
```

5.8.3 'b' – Beep

The beep command plays a beep with a specific frequency and duration.

```
Command:
  'b'   - Play audible beep
          Arguments: <frequency> <duration>
              frequency: 150..10000 (Hz)
              duration: 1..255 (msec)
```

Usage specifics:

- The stubbed piezo interface spawns a Linux play process for each individual beep, making it relatively slow. When playing multiple beeps in a script file, you will hear a pause between each beep. The duration of this pause will grow progressively worse between Debian 6 versus Debian 7 and 8.
- The quality of the actual piezo speaker is worse than miserable. It has a very narrow frequency range in which tones are played with a decent volume without audible distortion. So, tones that are played in mchron are likely to sound near-horrible when played by the actual piezo speaker.

Example:

```
mchron> # Play a 4000 Hz tone lasting 150 msec
mchron> b 4000 150
mchron>
```

5.8.4 'c' – Clock

The clock commands allow selecting a clock in the Emuchron test environment and feeding it with a continuous stream of time and keyboard events.

```
Commands:
  'cf'  - Feed clock with time and keyboard events
          Argument: <mode>
              mode: 'c' = start in single cycle mode, 'n' = start normal
  'cs'  - Select clock
          Argument: <clock>
              clock: 0 = [detach], 1 = example, 2 = analogHMS, 3 = analogHM,
                     4 = digitalHMS, 5 = digitalHM, 6 = mosquito, 7 = nerd,
                     8 = pong, 9 = puzzle, 10 = slider, 11 = cascade,
                     12 = speed, 13 = spider, 14 = traffic, 15 = bigdigOne,
                     16 = bigdigTwo, 17 = qrHMS, 18 = qrHM, 19 = perftest
```

Usage specifics:

- For the clock commands, mchron uses the clocks defined in the `emuMonochron[]` array in mchron.c [firmware/emulator].
- In case no clock is selected (clock 0), changing the mchron date/time/alarm will still work, but these changes will not be reflected in the LCD display as there is no clock to update.
- When selecting a clock, the time displayed in the clock will most likely not be the actual mchron time. Effectively it will be the timestamp from the last executed time command or the last known timestamp in the 'cf' and 'm' emulator commands. This is per design and allows the user to switch between clocks while displaying the same time for comparison purposes. Flushing the current mchron time to a selected clock is done using the 'tf' command.
- When the alarm is audible and the clock is moved into the single application cycle mode using keypress 'c', audible alarm is temporarily stopped. Audible alarm resumes upon switching back to normal mode.
- After entering single cycle mode the user can use keypress 'p' to execute a single application cycle after which its glcd and controller statistics are printed. This allows to quantify the graphics interface impact of a clock.
- Audible alarm can be stopped by using keypress 'a' to toggle the alarm switch position, or by keypress 'q' to quit the clock emulator.
- Clock 19, perftest, is a special clock plugin used for running high-level glcd performance tests. For this, refer to section 2.9.

Example:

```
mchron> # Select the analog HMS clock
mchron> cs 2
mchron> # Start this clock in a testbed environment
mchron> cf n
emuchron clock emulator:
  c = execute single application cycle
  h = provide emulator help
  p = print performance statistics
  q = quit
  r = reset performance statistics
  t = print time/date/alarm
hardware stub keys:
  a = toggle alarm switch
  s = set button
  + = + button
```

Clock emulator specifics:

- Keypress 'a' is identical to command 'at'
- Keypress 'p' is identical to command 'sp'.

- Keypress 'r' is identical to command 'sr'.
- Keypress 't' is identical to command 'tp'.

Single application cycle 'c' keypress specifics:

- Keypress 'c' results in executing the next clock application cycle.
- Keypress 'p' results in executing the next clock application cycle after which the glcd and controller statistics for this cycle are printed. For details on glcd and controller statistics refer to section 5.8.13.
- Any other key will resume normal clock cycle execution.

5.8.5 'd' – Date

The date commands allow setting a dedicated date or reset the date to the current system date. Related command groups are alarm ('a') and time ('t').

```
Commands:
  'dr'  - Reset clock date to system date
  'ds'  - Set clock date
          Arguments: <day> <month> <year>
              day: 1..31
              month: 1..12
              year: 0..99
```

Usage specifics:

- When a date command is used, an active clock is called to update itself using the modified settings.
- The year is placed in 20*xx*.
- When setting a date, an offset is calculated between the system date and the requested date. Daylight savings settings are taken into account to compensate for time offsets between the old and new date. The calculated offset will be used as a delta between the system date and the mchron date.
- To determine the delta between the current and requested date the `mktime()` system call is used. This system call allows specifying a date into the future up to approx. 25 years. When the requested date is beyond that range an error message is provided.
- The 'ds' command verifies whether the requested date is valid. For example, date April 31 will be rejected.

Example:

```
mchron> # Set our own date to Jan 27 2015
mchron> ds 27 1 15
time  : 17:08:10 (hh:mm:ss)
date  : 27/01/2015 (dd/mm/yyyy)
alarm : 14:51 (hh:mm)
alarm : off
mchron> # Reset to system date
mchron> dr
time  : 17:08:26 (hh:mm:ss)
date  : 28/10/2015 (dd/mm/yyyy)
alarm : 14:51 (hh:mm)
alarm : off
mchron> # September 31 does not exist
mchron> ds 31 9 15
date? invalid
mchron> # Year 2065 is too far ahead into the future
mchron> ds 1 8 65
date? beyond system range
mchron>
```

5.8.6 'e' – Execute

The execute command loads the content of a plain text file and executes it as mchron commands. Refer to section 5.10 where is described how this is internally accomplished.

```
Command:
  'e'   - Execute commands from file
          Arguments: <echo> <filename>
              echo: 'e' = echo commands, 'i' = inherit, 's' = silent
              filename: full filepath or relative to startup folder mchron
```

Usage specifics:

- Upon loading the file contents, each line is checked whether it contains a valid command, being part of linking it to a command dictionary entry. However, at loading time no check is made whether any command arguments are complete and valid. Command argument validation is performed at execution time.
- The depth level of nested command files is supported up to the value of `#define CMD_FILE_DEPTH_MAX` in scanutil.h [firmware/emulator].
- The echo argument value 'e' indicates that all commands, accompanied by file line number, are echoed in the mchron command shell. Especially in combination with repeat command 'rf' this may generate lots of output.
- The echo argument value 's' indicates that no command echoing will occur. Normally this is the value to use upon typing the 'e' command on mchron command prompt level.
- The echo argument value 'i' is used in case of a nested command file. Using this setting the echo value that is used in the current command depth level (either 'e' or 's') is forwarded to the next level.
- The execution of a command file can be interrupted at any depth level by using a 'q' keypress immediately or via a 'q' keypress in a wait command.

Example:

```
mchron> # Run script to test all 1440 minutes of a day in about 30 seconds
mchron> # for an analog clock
mchron> cs 3
mchron> vs s=1
mchron> vs w=20
mchron> e s ../script/time-hm.txt
(wait ~30 seconds for the script to finish)
mchron>
```

5.8.7 'h' – Help

The help commands provide generic help on mchron, its command dictionary and expression evaluator.

```
Commands:
  'h'   - Help
  'hc'  - Help command
          Argument: <command>
              command: mchron command or '*' for all commands
  'he'  - Help expression
          Argument: <number>
              number: expression
  'hm'  - Help message
          Argument: <message>
              message: ascii text
```

Usage specifics:

- The help commands 'h' and 'hc' can only be used at mchron command prompt level.
- The 'h' command displays the included help.txt [support] file using the Linux `more` command.
- The 'hc' command reports mchron command and command argument information based on the command dictionary as built in mchrondict.h [firmware/emulator].
- The 'he' command passes the expression argument to the expression evaluator and prints its result, making it a kind of built-in calculator.

Example:

```
mchron> # Print command dictionary info for command 'pd' (paint dot)
mchron> hc pd
command: pd (paint dot)
usage  : pd <color> <x> <y>
         color: 'b','f' (b = background, f = foreground)
         x: 0..127
         y: 0..63
handler: doPaintDot()
mchron> # Print the result of an expression
mchron> he sin(pi/6)
0.500000
mchron> hm Provide help message to end user while executing script
Provide help message to end user while executing script
mchron>
```

5.8.8 'i' – If

The if-then-else commands provide branching capabilities in mchron command blocks.

```
Commands:
  'iei' - If else if then
          Argument: <condition>
              condition: expression determining block execution
  'iel' - If else
  'ien' - If end
  'iif' - If then
          Argument: <condition>
              condition: expression determining block execution
```

Usage specifics:

- An if-then-else construct start with an 'iif' (if-then) command, followed by optionally one or more 'iei' (else-if) commands, followed by an optional 'iel' (else) command and always closes with an 'ien' (if-end) command.
- When used in a command file, each if command must be matched with an if-end command in the very same file.
- If-then-else commands can be nested without any limitation.
- When an 'iif' command is entered at the mchron command prompt, the interpreter will enter a multi-line mode that is completed when an 'ien' command is entered that matches the 'iif' that invoked the multi-line command buildup.
  To abort the entry of a multi-line mode 'iif' command, type '<ctrl>d' on an empty line. For an example of this refer to section 5.3.

Example:

```
mchron> # If-then-else logic that results in value 20 for variable y
mchron> vs x=2
mchron> iif x==1
2>>   vs y=10
3>> iei x==2
4>>   vs y=20
5>> iel
6>>   vs y=30
7>> ien
mchron> vp y
y=20
mchron>
```

5.8.9 'l' – LCD

The LCD commands allow interacting with the LCD controllers, erase or inverse the LCD contents and set the LCD backlight brightness.

```
Commands:
  'lbs' - Set lcd backlight brightness
          Argument: <backlight>
              backlight: 0..16 (0 = dim .. 16 = bright)
  'lcs' - Set controller lcd cursor
          Arguments: <controller> <x> <yline>
              controller: 0, 1
              x: 0..63
              yline: 0..7
  'lds' - Switch controller lcd display on/off
          Arguments: <controller-0> <controller-1>
              controller-0: 0 = off, 1 = on
              controller-1: 0 = off, 1 = on
  'le'  - Erase lcd display
  'li'  - Inverse lcd display
  'lp'  - Print controller state/registers
  'lr'  - Read controller lcd data in variable
          Arguments: <controller> <variable>
              controller: 0, 1
              variable: word of [a-zA-Z_] characters
  'lss' - Set controller lcd start line
          Arguments: <controller-0> <controller-1>
              controller-0: 0..63
              controller-1: 0..63
  'lw'  - Write data to controller lcd
          Arguments: <controller> <data>
              controller: 0, 1
              data: 0..255
```

Usage specifics:

- Changes in the LCD backlight using command 'lbs' are shown in the ncurses LCD device only when enabled using mchron command line argument '-b'.
- The 'li' command will, next to inversing the contents of the LCD display, also swap the LCD foreground and background colors. This will make clocks and graphics functions automatically swap their painting behavior.

Example:

```
mchron> # Paint a clock so we have something on the LCD display
mchron> cs 11
mchron> # Set LCD backlight brightness to a medium setting
mchron> lbs 8
mchron> # Inverse LCD display and inverse back
mchron> li
mchron> li
mchron> # Set display offset only for right side and switch back to normal
mchron> lss 0 25
mchron. lss 0 0
mchron> # Switch left side of the LCD display off and switch it on again
mchron> lds 0 1
mchron> lds 1 1
mchron> # Set cursor in controller 0 and write a byte to the LCD at bottom left
mchron> lcs 0 0 7
mchron> lw 0 0x55
mchron> # Read the contents of that location. Note that excuting a sequence
mchron> # of controller reads requires two reads for obtaining the first byte.
mchron> lcs 0 0 7
mchron> lr 0 myLcdByte
myLcdByte=254
mchron> lr 0 myLcdByte
myLcdByte=85
mchron> # Erase the LCD
mchron> le
mchron>
```

Command 'lp' prints the state and the stubbed hardware registers for each of the controllers.

```
mchron> # Print controller state and stubbed hardware registers
mchron> lp
ctrl-0 : state=write, display=1, startline=0
       : x=31, y=5, write=0x8a, read=0x92
ctrl-1 : state=write, display=1, startline=0
       : x=8, y=4, write=0x36, read=0xc8
mchron>
```

The content of a controller report is as follows:

Item	***Description***
display	Indicates whether the display is on or off. Note that even when the display is off, LCD contents are refreshed when writing to the LCD. Use command 'lds' to set its value.
read	The data result of the last LCD read operation on the controller. Use command 'lr' to read directly from the LCD controller.
startline	The current value of the LCD display line offset. Use command 'lss' to set its value.
state	The current machine state of the controller. For more information on the implemented controller finite state machine refer to controller.c [firmware/emulator].
write	The data of the last LCD write operation on the controller. Use command 'lw' to directly write data to the LCD controller.
x	The current cursor x position. Use command 'lcs' to set its value.
y	The current cursor y line (containing 8 vertical pixels) position. Use command 'lcs' to set its value.

Table 18: Controller state and register values

5.8.10 'm' – Monochron

The Monochron command will start an emulated Monochron application.

```
Command:
  'm'   - Start Monochron application
          Arguments: <mode> <eeprom>
              mode: 'c' = start in single cycle mode, 'n' = start normal
              eeprom: 'k' = keep, 'r' = reset
```

Usage specifics:

- The Monochron eeprom settings are initialized at startup of mchron and are changed when using the stubbed Monochron application.
- When the 'm' command is used more than once, value 'k' for eeprom will keep the stubbed eeprom settings as they were when the previous stubbed Monochron application session was stopped.
  Note: The behavior of value 'k' for eeprom is similar to unplugging and replugging the Monochron power adapter.
- When using value 'r' for eeprom it will reset the eeprom contents back to its default values.
- After entering single cycle mode the user can use keypress 'p' to execute a single application cycle after which its glcd and controller statistics are printed. This allows to quantify the graphics interface impact of a clock.

Example:

```
mchron> # Start the emulated Monochron application
mchron> m n k
emuchron monochron emulator:
  c = execute single application cycle
  h = provide emulator help
  p = print performance statistics
  q = quit (valid only when clock is displayed)
  r = reset performance statistics
  t = print time/date/alarm
hardware stub keys:
  a = toggle alarm switch
  m = menu button
  s = set button
  + = + button
```

Monochron emulator specifics:

- Keypress 'a' is identical to command 'at'
- Keypress 'p' is identical to command 'sp'.
- Keypress 'r' is identical to command 'sr'.
- Keypress 't' is identical to command 'tp'.

Single application cycle 'c' keypress specifics:

- Keypress 'c' results in executing the next clock application cycle.
- Keypress 'p' results in executing the next clock application cycle after which the glcd and controller statistics for this cycle are printed. For details on glcd and controller statistics refer to section 5.8.13
- Any other key will resume normal clock cycle execution.

5.8.11 'p' – Paint

The paint commands provide access to high-level glcd graphics functions.

```
Commands:
  'pa'  - Paint ascii
          Arguments: <color> <x> <y> <font> <orientation> <xscale> <yscale>
                     <text>
              color: 'f' = foreground, 'b' = background
              x: 0..127
              y: 0..63
              font: '5x5p' = 5x5 proportional, '5x7n' = 5x7 non-proportional
              orientation: 'b' = bottom-up vertical, 'h' = horizontal,
                           't' = top-down vertical
              xscale: 1..64
              yscale: 1..32
              text: ascii text
  'pc'  - Paint circle
          Arguments: <color> <x> <y> <radius> <pattern>
              color: 'f' = foreground, 'b' = background
              x: 0..127
              y: 0..63
              radius: 1..31
              pattern: 0 = full line, 1 = half (even), 2 = half (uneven),
                       3 = 3rd line
  'pcf' - Paint circle with fill pattern
          Arguments: <color> <x> <y> <radius> <pattern>
              color: 'f' = foreground, 'b' = background
              x: 0..127
              y: 0..63
              radius: 1..31
              pattern: 0 = full, 1 = half, 2 = 3rd up, 3 = 3rd down
                       4 = <unsupported>, 5 = clear
  'pd'  - Paint dot
          Arguments: <color> <x> <y>
              color: 'f' = foreground, 'b' = background
              x: 0..127
              y: 0..63
  'pl'  - Paint line
          Arguments: <color> <xstart> <ystart> <xend> <yend>
              color: 'f' = foreground, 'b' = background
              xstart: 0..127
              ystart: 0..63
              xend: 0..127
              yend: 0..63
  'pn'  - Paint number
          Arguments: <color> <x> <y> <font> <orientation> <xscale> <yscale>
                     <number> <format>
              color: 'f' = foreground, 'b' = background
              x: 0..127
              y: 0..63
              font: '5x5p' = 5x5 proportional, '5x7n' = 5x7 non-proportional
              orientation: 'b' = bottom-up vertical, 'h' = horizontal,
                           't' = top-down vertical
              xscale: 1..64
              yscale: 1..32
              number: expression
              format: 'c'-style format string containing '%f', '%e' or '%g'
  'pr'  - Paint rectangle
          Arguments: <color> <x> <y> <xsize> <ysize>
              color: 'f' = foreground, 'b' = background
              x: 0..127
              y: 0..63
              xsize: 1..128
              ysize: 1..64
  'prf' - Paint rectangle with fill pattern
          Arguments: <color> <x> <y> <xsize> <ysize> <align> <pattern>
              color: 'f' = foreground, 'b' = background
              x: 0..127
              y: 0..63
              xsize: 1..128
              ysize: 1..64
              align (for pattern 1-3): 0 = top, 1 = bottom, 2 = auto
              pattern: 0 = full, 1 = half, 2 = 3rd up, 3 = 3rd down
                       4 = inverse, 5 = clear
```

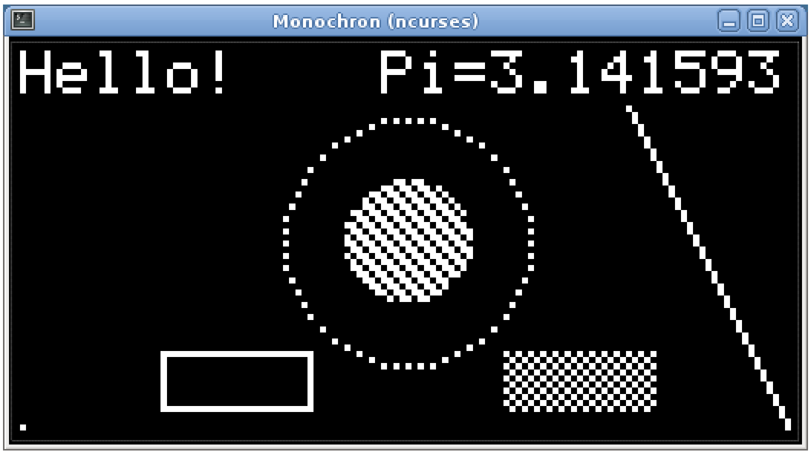
Usage specifics:

– Many script examples are available in [script] that use paint commands. See also the script on the front page of this document.
– The 'pn' command does not have an equivalent glcd function but is meant to provide a simple mechanism to print numbers in an mchron LCD stub device. For using the 'C'-style '%f', '%e' or '%g' formatting options refer to the many resources on the web. Examples are also found in paintnum.txt [script].

Example:

```
mchron> # Paint ascii
mchron> pa f 1 1 5x7n h 1 1 Hello!
hor px=36
mchron> # Paint dotted circle
mchron> pc f 64 32 20 1
mchron> # Paint filled circle
mchron> pcf b 64 32 10 3
mchron> # Paint dot at bottom left
mchron> pd f 1 62
mchron> # Paint line
mchron> pl f 100 10 126 62
mchron> # Paint number
mchron> pn f 60 1 5x7n h 1 1 pi Pi=%f
mchron> # Paint rectangle
mchron> pr f 24 50 25 10
mchron> # Paint filled rectangle
mchron> prf f 80 50 25 10 0 1
mchron>
```

These commands will produce the following output.



5.8.12 'r' – Repeat

The repeat commands implement a command loop mechanism.
A repeat loop is setup with a repeat-for ('rf') command. Each 'rf' command must be matched with a repeat-next ('rn') command.

```
Commands:
  'rf'  - Repeat for
          Arguments: <init> <condition> <post>
              init: expression executed once at initialization
              condition: expression determining loop continuation
              post: expression executed after each loop
  'rn'  - Repeat next
```

Usage specifics:

- A repeat loop is skipped immediately when the repeat condition is false at attempting to enter the first loop.
- When used in a command file, each 'rf' must match an 'rn' command in the very same file.
- Repeat loops can be nested without limitation.
- When an 'rf' command is entered at the mchron command prompt, the interpreter will enter a multi-line mode that is completed when an 'rn' command is entered that matches the 'rf' that invoked the multi-line command buildup.
  To abort the entry of a multi-line mode 'rf' command, type '<ctrl>d' on an empty line. For an example of this refer to section 5.3.
- Refer to section 5.10 for a detailed description on what will happen internally within mchron upon building up and executing repeat constructs.

Example:

```
mchron> # Demo multi-line 'rf' commands to quickly paint all minutes in a day
mchron> cs 3
mchron> rf h=0 h<24 h=h+1
2>>   rf m=0 m<60 m=m+1
3>>     ts h m 30
4>>     w 20
5>>   rn
6>> rn
mchron>
```

5.8.13 's' – Statistics

The statistics commands provide performance information on the Emuchron clock stub, the Monochron glcd interface, the stubbed controller and Emuchron LCD stub device(s).

```
Commands:
  'sp'  - Print application statistics
  'sr'  - Reset application statistics
```

Usage specifics:

- The stub section provides info on the emulator clock cycle wait stub that is used while executing the 'cf' and 'm' commands.
- The sections on the GLUT and ncurses LCD stubs are provided only when the device is actually being used.

Example:

```
mchron> sp
statistics:
stub   : cycle=75 msec, inTime=4132, outTime=6, singleCycle=0
         avgSleep=73 msec, minSleep=72 msec
glcd   : dataWrite=81087, dataRead=57411, setAddress=18797
ctrl-0 : write=32025 (41%), read=19707 (79%), display=14 (0%)
       : x=8465 (93%), y=3488 (100%), startline=14 (0%)
ctrl-1 : write=49062 (40%), read=37704 (83%), display=14 (0%)
       : x=12820 (96%), y=5522 (100%), startline=14 (0%)
glut   : lcdByteRx=33040, bitEff=24%
         msgTx=33041, msgRx=33041, maxQLen=1638, avgQLen=96
         redraws=343, cycles=9242, updates=343, fps=29.4
ncurses: lcdByteRx=33040, bitEff=24%
mchron> sr
statistics reset
mchron>
```

The statistics KPI’s for the Emuchron stub are as follows:

KPI	***Description***
avgSleep	The average duration of the time that the emulator is at sleep per cycle. This should be as close as possible to the value of the cycle KPI. Only cycles that are completed as being inTime are taken into account for calculating its value.
cycle	This value represents the duration of a clock cycle as defined by `#define ANIMTICK_MS` in monomain.h [firmware].
inTime	The number of clock cycles that were completed within the given cycle KPI duration. A clock plugin requires CPU to complete a clock cycle, and in normal operation it should complete way within the cycle duration. Note: Emulator cycles that are run in single cycle mode are not taken into account for calculating the inTime KPI.
minSleep	The duration of the cycle that took most time to complete, resulting in the shortest cycle sleep. Only cycles that are completed as being inTime are taken into account for calculating its value.

KPI	***Description***
outTime	The number of clock cycles that that were not completed within the given cycle KPI duration. In normal operation this value should be zero as a clock plugin will finish a single cycle way before 75 msec of raw CPU power. If a clock plugin is not able to complete a clock cycle when run in Emuchron on a modern Intel class CPU, it is likely it will not be able to complete the same cycle on a simple 8 Mhz Atmel CPU. Note: As the ncurses LCD interface runs in the same thread as mchron, flushing the ncurses display will have a negative impact on the clock cycle performance. Note: Emulator cycles that are administered under KPI singleCycle are not taken into account for calculating the outTime KPI. Note: As Emuchron runs as a standard Linux process, it can be interrupted by high priority processes. In an unlikely scenario it may result in outTime to be incremented while a clock plugin is perfectly able to complete its clock cycle well within the given timeframe.
singleCycle	The number of executed single application cycles as invoked by emulator command argument <mode> or emulator keypress 'c'.

Table 19: Emuchron stub statistics

The statistics for the glcd interface are as follows:

KPI	***Description***
dataWrite	The number of pixel bytes written to the LCD. It is administered by counting the number of calls to `glcdDataWrite()`.
dataRead	The number of pixel byte read operations from the LCD. It is administered by counting the number of calls to `glcdDataRead()`. Note: This number does not fully represent the actual number of LCD pixel bytes read. After a write operation or when switching between LCD controllers, the hardware requires two sequential read operations of which the first is a dummy read.
setAddress	The number of explicit requests to set the LCD display cursor. It is administered by counting the number of calls to `glcdSetAddress()`. Note: Upon calling a `glcdDataWrite()` or a non-dummy `glcdDataRead()` the internal controller LCD display cursor is automatically incremented to the next LCD byte. The automatic hardware increment action is not included in this KPI.

Table 20: Monochron glcd interface statistics

Monochron has two ks0108 LCD controllers. The statistics for each of the stubbed controllers are as follows:

KPI	***Description***
display (%)	The number of commands to switch on/off the LCD. The percentage indicates the number of commands that actually lead to a change.
read (%)	The number of LCD read operations. The percentage indicates the number of read operations that actually return a proper value. Executing a sequence of read operations requires two read operations for obtaining the first byte. The first read operation in a sequence of reads is a dummy read and will lower the percentage value. In essence, the lower the percentage, the higher the number of read sequence operations are executed.

KPI	***Description***
startline (%)	The number of commands to set the LCD display start line. The percentage indicates the number of commands that actually lead to a change.
write (%)	The number of LCD write operations. The percentage indicates the number of write operations that actually lead to a change in the LCD.
x (%)	The number of commands to set the x cursor in the LCD. The percentage indicates the number of commands that actually lead to a change of the x cursor.
y (%)	The number of commands to set the y cursor in the LCD. The percentage indicates the number of commands that actually lead to a change of the y cursor.

Table 21: Monochron controller statistics

The statistics KPI's for the GLUT LCD stub are as follows:

KPI	***Description***
avgQLen	This KPI is calculated by dividing KPI msgRx by updates. It gives the average length of the GLUT message queue to be processed.
bitEff	The percentage of bits in a processed LCD byte that will lead to a change in the LCD display. In the example above, out of 8 bits/pixels per byte, on average about 2 pixels per LCD byte will lead to a change in the LCD display.
cycles	The number of GLUT thread cycles in which internal GLUT events and the GLUT message queue are processed. Such a cycle may or may not lead to a GLUT window redraw.
fps	This is the frames per second redraw rate of the GLUT window. The GLUT thread has a sleep cycle of 33 msec, giving a theoretical refresh rate of ~30 fps. In practice this will be lower due to the processing power needed to process the GLUT message queue and to redraw its window, in combination with latency caused by the Linux thread and process scheduler.
lcdByteRx	The number of LCD bytes (with 8 pixel bits) that are received in the interface. The interface will, via the controller, only receive LCD bytes that lead to a change on the LCD.
maxQLen	The GLUT interface runs in its own thread. The GLUT thread can be at sleep while mchron or clock plugins send messages to the GLUT interface. This queue of messages will be waiting to be processed when the GLUT thread wakes up. This KPI shows the maximum length of the GLUT message queue that is waiting to be processed.
msgRx	The number of LCD commands processed by the GLUT interface. Note that in the example above the msgRx KPI is 3 higher than the lcdByteRx KPI. This is explained by a number of controller and backlight commands sent to the GLUT interface at mchron initialization time.
msgTx	The number of LCD commands sent to the GLUT interface. It includes commands to process an LCD byte, to process a change in LCD backlight, change the display and startline registers and shutting down the GLUT interface. In the example above notice that msgTx and msgRx are identical, which is normally the case. They may differ when statistics are reset while GLUT messages are still waiting to be processed.

KPI	***Description***
redraws	This KPI shows the total number of GLUT window redraws. The GLUT thread is forced to redraw its display in two scenarios. The first is by processing the messages in the GLUT message queue as sent by mchron and/or a clock plugin. When all messages from the queue have been processed and at least one display change is detected, the GLUT window is instructed to redraw itself. The second is internal to GLUT itself. Whenever the GLUT window is resized, when another window moves over the GLUT window or when the GLUT window is minimized or restored, an internal GLUT redraw event is generated.
updates	This KPI shows the total number of GLUT window redraws caused by processing messages in the GLUT message queue. Note: As the redraws KPI also includes updates caused by messages in the GLUT message queue, the difference between the updates and redraws KPI's will give the number of GLUT redraws caused by internal GLUT events.

Table 22: Emuchron GLUT statistics

The few statistics KPI's for the ncurses LCD stub are identical to their counterparts in the GLUT interface.
Note that in the example output above the values of the ncurses statistics are identical to their GLUT counterparts. This is explained by the fact that both stub devices have implemented identical mechanisms to optimize draw behavior and implement statistics administration.

KPI	***Description***
bitEff	The percentage of bits in a processed LCD byte that will lead to a change in the LCD display. In the example above, out of 8 bits/pixels per byte, on average about 2 pixels per LCD byte will lead to a change in the LCD display.
lcdByteRx	The number of LCD bytes (with 8 pixel bits) that are received in the interface. The interface will, via the controller, only receive LCD bytes that lead to a change on the LCD.

Table 23: Emuchron ncurses statistics

5.8.14 't' – Time

The time commands allow setting, resetting and reporting the time as used in mchron and forcing a clock to update itself using the mchron time. Related command groups are alarm ('a') and date ('d').

```
Commands:
  'tf'  - Flush Monochron time and date to active clock
  'tp'  - Print time/date/alarm
  'tr'  - Reset time to system time
  'ts'  - Set time
          Arguments: <hour> <min> <sec>
              hour: 0..23
              min: 0..59
              sec: 0..59
```

Usage specifics:

- When a time command is used, except for 'tp', an active clock is called to update itself using the modified settings.
- When setting a time manually, an offset is calculated between the system time and the requested time. This offset will then be used as a delta between the system time and the mchron time.

Example:

```
mchron> # Get a basic digital clock
mchron> cs 4
mchron> # Print the current time/date/alarm (clock layout is not updated)
mchron> tp
time  : 11:10:55 (hh:mm:ss)
date  : 30/10/2015 (dd/mm/yyyy)
alarm : 22:09 (hh:mm)
alarm : off
mchron> # Set time to near happy hour (clock layout will update)
mchron> ts 16 45 00
time  : 16:45:00 (hh:mm:ss)
date  : 30/10/2015 (dd/mm/yyyy)
alarm : 22:09 (hh:mm)
alarm : off
mchron> # Reset to system time (clock layout will update)
mchron> tr
time  : 11:12:07 (hh:mm:ss)
date  : 30/10/2015 (dd/mm/yyyy)
alarm : 22:09 (hh:mm)
alarm : off
mchron> # Wait a few minutes...
mchron> # Flush current mchron time to active clock (clock layout will update)
mchron> tf
time  : 11:14:32 (hh:mm:ss)
date  : 30/10/2015 (dd/mm/yyyy)
alarm : 22:09 (hh:mm)
alarm : off
mchron>
```

5.8.15 'v' – Variable

Mchron supports named variables representing a `double` type value that can be used in expressions for numeric command arguments.

```
Commands:
  'vp'  - Print value of variable(s)
          Argument: <variable>
              variable: word of [a-zA-Z_] characters, '*' = all
  'vr'  - Reset variable(s)
          Argument: <variable>
              variable: word of [a-zA-Z_] characters, '*' = all
  'vs'  - Set value of variable
          Argument: <assignment>
              assignment: <variable>=<expression>
```

Usage specifics:

- A variable name is identified by any mixed combination of upper/lowercase characters in the range 'a'..'z' and '_', excluding reserved function and constant keywords.
  Examples: x (=ok), radius (=ok), my_Local_Var (=ok), a1 (=bad), abc$ (=bad), true (=bad)
- Variables must explicitly be set a value before being allowed to be used in expressions.
- Refer to the script on the front page for an example on using variables hor, ver and factor in multiple commands.

Example:

```
mchron> # Try to initialize a few variables
mchron> vs rank=10
mchron> vs f=key
variable not in use: key
assignment? parse error
mchron> vs key=rank*4
mchron> # Show all variables currently in use
mchron> vp *
key=40    rank=10
variables in use: 2
mchron> # Set another variable and reset an active one
mchron> vs index=key*rank
mchron> vr rank
mchron> # Show what is left
mchron> vp *
key=40    index=400
variables in use: 2
mchron> # Reset all active variables
mchron> vr *
mchron> vp *
variables in use: 0
mchron>
```

5.8.16 'w' – Wait

The wait command will make mchron wait.

```
Command:
  'w'   - Wait for keypress or amount of time
          Argument: <delay>
              delay: 0 = wait for keypress, 1..1000000 = wait (msec)
          When waiting, a 'q' will return control back to the mchron command
          prompt
```

Usage specifics:

- The wait command supports two flavors. One flavor will wait a dedicated amount of time and another waits for an end-user keyboard keypress.
- The wait command is used in many scripts to temporarily halt script execution or wait a while after updating the LCD display with new information.

Example:

```
mchron> # Wait one second
mchron> w 1000
mchron> # Wait for keypress
mchron> w 0
<wait: press key to continue>
mchron>
```

5.8.17 'x' – Exit

The exit command will exit mchron.

```
Command:
  'x'   - Exit
```

Usage specifics:
- The 'x' command can only be used at mchron command prompt level.

Example:

```
mchron> # Exit mchron
mchron> x
$
```

5.9 Processing an mchron 'hello world!' command

Mchron supports many commands. For the sake of stability and consistency a common approach has been implemented to scan and parse commands and command arguments.

It is chosen not to implement the command scanner and parser in flex and bison. Instead, dedicated scanner and parser functionality has been created to fit mchron purposes. The main reason for this is that flex and bison are considered by many to be not easy to comprehend and work with, including the author, making it difficult to find out how-it-all-works.

In the example below is depicted and explained on what will happen when an mchron command is entered to paint a text string on the LCD display.

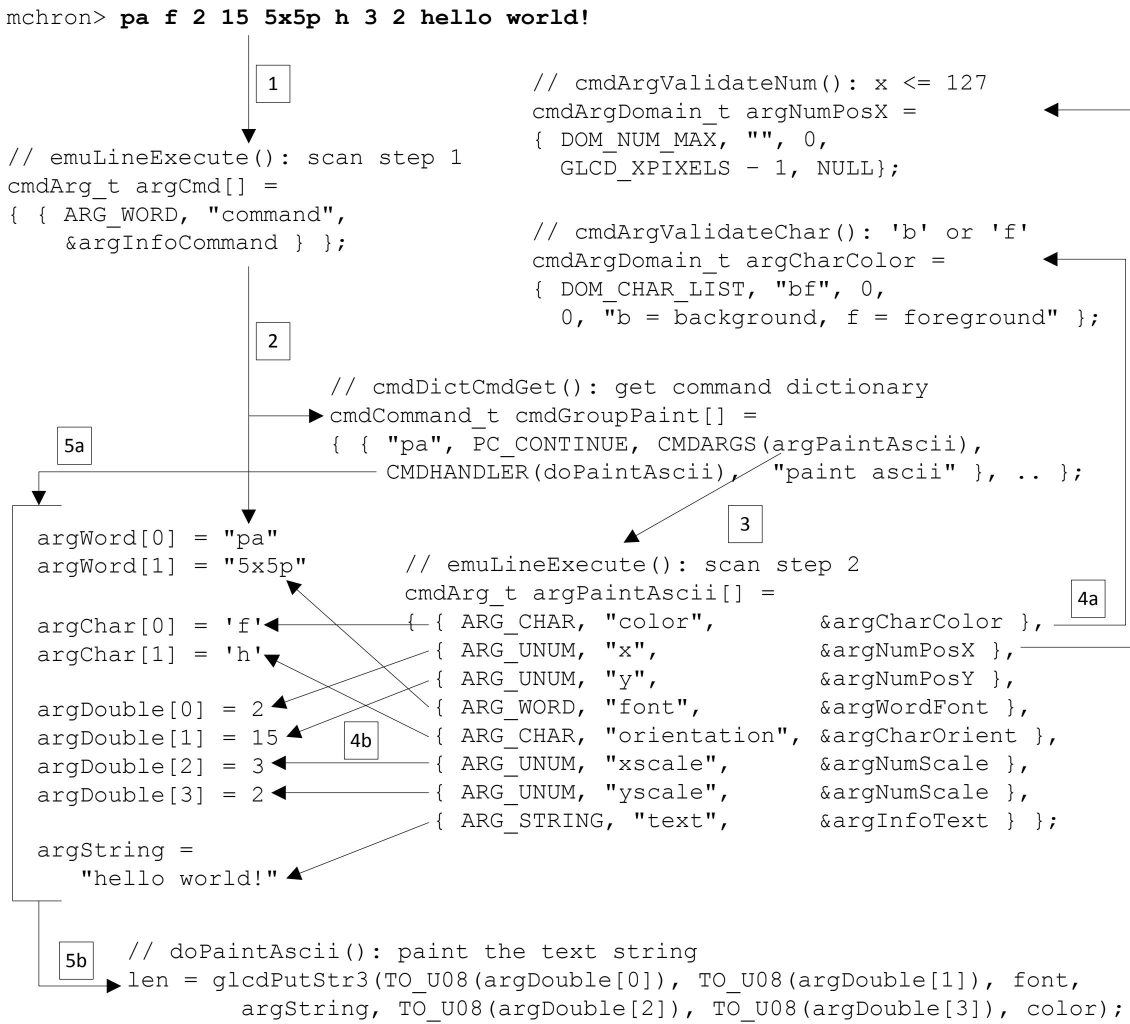


Figure 9: Processing an mchron 'hello world!' command

Step 1:
The user enters a 'pa' (paint ascii) command using the keyboard, or has it prepared in an mchron command file.
Main command processing takes place in `emuLineExecute()` in mchronutil.c [firmware/emulator].
Command and argument scanning takes place in `cmdArgScan()` in scanutil.c [firmware/emulator].

Step 2:
In `emuLineExecute()` the main command will be scanned from the input string based on an `cmdArg_t` structure array. In this case, the scanner needs to scan a single word, as instructed by `ARG_WORD`. The functional name of the argument is "command" that can be used to provide end-user feedback in case an error occurs. The scanned argument is put in a dedicated array for storing argument text words, being `argWord[]`. The end result of the scan is that `argWord[0]` will contain the text "pa".
For an mchron command its associated command dictionary is retrieved using `cmdDictCmdGet()`.The command dictionary not only provides information regarding the command itself but also about the command arguments and its handler function. This means that the rest of the generic command handling is based upon information from the command dictionary.

Step 3:
In `emuLineExecute()` the remaining part of the command will be scanned, parsed and processed. In the command dictionary for the 'pa' command a dedicated `cmdArg_t` structure array is defined that will drive the scan of all its remaining arguments. For details refer to step 4a and 4b.

Step 4a:
Each command argument is now scanned and parsed. In case the data type of an argument is `ARG_NUM` or `ARG_UNUM` (unsigned number) its argument value is considered to be a mathematical expression with named variables. The text string of the argument will be fed into an expression evaluator that will return a `double` type value. Whenever the expression evaluator encounters a problem an error message is provided.
Additional functionality for an argument value is provided via structure `cmdArgDomain_t` where the argument value is matched with a domain profile. This prevents repetitive and error-prone argument value verification in the command handlers. In our example, the 'color' character argument must have either value 'b' or 'f', and the 'x' unsigned number argument may not exceed the maximum value 127. Each argument refers its own argument domain structure. Whenever an argument does not match its domain profile an error message is provided.
In general, a domain profile will take care of properly validated argument values, but in some cases additional domain value verification is required. If so, it needs to be implemented in the appropriate command handler in step 5b below.

Step 4b:
The end result value of each of the arguments is copied into dedicated argument arrays for characters, doubles and a string. They are respectively `argChar[]` and `argDouble[]` and `argString`. In the example above, the `ARG_WORD` font argument is added in `argWord[]` as an additional array element.

Step 5a+5b:
When the command line has been fully scanned and parsed, all command argument values are now available for final processing.
The command handler function for the 'pa' command is referenced via the command dictionary, in this case `doPaintAscii()` that is defined in mchron.c [firmware/emulator]. That function is now called.
In `doPaintAscii()`, after converting the color and font arguments into an enum value, function `glcdPutStr3()`is called to paint the requested text string on the LCD.

When the command has been processed, control is given back to the caller of `emuLineExecute()`.

When completed, the content of the LCD stub device will appear as below.

5.10 Building and executing an mchron command list

Single line commands in mchron are executed as described in section 5.9. However, mchron also supports executing multi-line commands.

Executing a multi-line command is invoked via two methods:

- Use the execute command 'e' to load and execute mchron commands prepared in a plain text file.
- Use the repeat-for 'rf' or if-then 'iif' command to enter and execute a list of mchron commands interactively via the command prompt.

With respect to the first method consider the following imaginary mchron script below as saved in a plain text file. From a functional point of view it is identical to the time-hm.txt [script] script, except that all variables, instructions, comments and white lines are removed.

```
# Demo script
cs 3
rf h=0 h<24 h=h+1
  rf m=0 m<60 m=m+1
    ts h m 30
    w 50
  rn
rn
```

This imaginary script can be invoked by the mchron execute command.

```
mchron> e s ../script/imaginary.txt
```

With respect to the second method consider the repeat-for 'rf' command below that will invoke an interactive buildup of the commands to be executed. The commands will be executed when an 'rn' command is entered that matches the 'rf' that invoked the interactive command buildup.
Note: To abort the entry of an interactive 'rf' command type '<ctrl>d' on an empty line.

```
mchron> # Demo multi-line command entry via 'rf' to paint all minutes in a day
mchron> cs 3
mchron> rf h=0 h<24 h=h+1
2>>   rf m=0 m<60 m=m+1
3>>     ts h m 30
4>>     w 50
5>>   rn
6>> rn
mchron>
```

Using the demo script of the first method as an example, upon entering the 'e' (execute) command the following will take place.

Step 1: Load the file contents in linked lists.

- The 'e' command is interpreted in `emuLineExecute()`. This function will then invoke the handler of the execute command, being `doExecute()`.
- In `doExecute()` function `cmdListFileLoad()` is called to load the file contents into linked list structures as depicted in figure 10 below. Part of loading the file is matching each line with its associated command dictionary entry. Also, the integrity of the command list is checked by matching each 'rf' command with an 'rn' command. When an unknown command is encountered or repeat commands cannot be matched, file loading will abort.
- Two pointers are available that administer the root of the linked lists, being `cmdLineRoot` and `cmdPcCtrlRoot`.

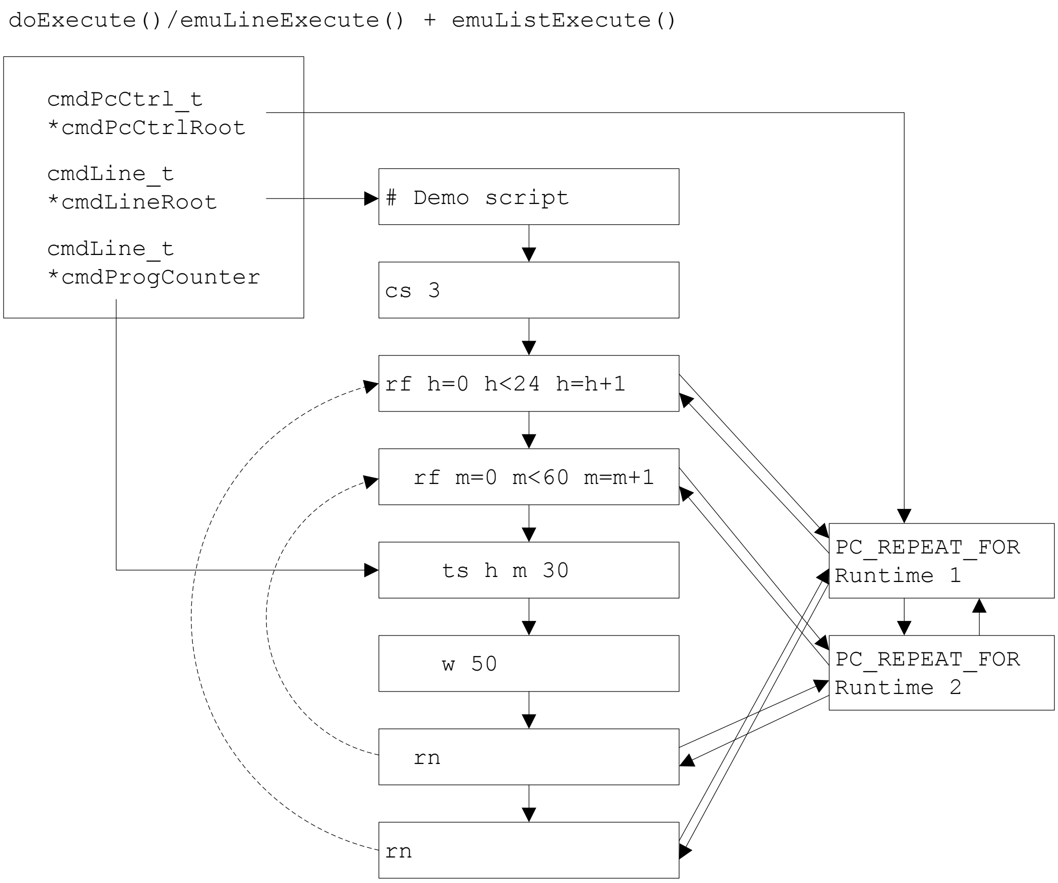


Figure 10: Creating and executing an mchron command list

Step 2: Execute the commands in the linked list.

– When loaded, in `doExecute()` the linked list structure is then executed via function `emuListExecute()`. In this function a third pointer, `cmdProgCounter`, is available that will serve as a list execution program counter.
– In `emuListExecute()` the program counter pointer is used to execute all the commands in the linked list one by one. The program counter will of course start at the top of the list using the root pointer.
– Execution of the list is interrupted by pressing the 'q' key.
– Each command in the list is executed in `emuLineExecute()`.
– When a non-repeat command in the list has been executed, the program counter is incremented to point to the next list element.
– However, for repeat commands its handler will initialize and/or process the repeat condition via the appropriate repeat-for runtime structure. Via this structure the program counter can be changed, thus making the linked list loop or continue at the 'rn' command of a repeat construct.
– List execution ends when a list element has no pointer to a next one.
– When list execution is completed, command and control block list cleanup will take place after which `doExecute()` returns control back to its caller.

Next to repeat-for constructs, mchron also support if-then-else constructs. The basics of creating a linked list using if-then-else logic is identical to repeat-for constructs; create appropriate `cmdPcCtrl_t` structures and link them to associated command line `cmdLine_t` structures. The runtime execution logic for if-then-else constructs will of course differ from repeat-for constructs.
Repeat-for and if-then-else constructs can be mixed in the same command list into any depth. An example of this can be found in circle4.txt [script]. An example of nesting repeat-for commands with considerable depth is found in nesting.txt [script].

6 Debugging clock and graphics code

Prior to Emuchron the only method to debug clock and graphics function code was to build and upload firmware into the Monochron clock that produces debug output strings. These output strings are sent from the Monochron clock over the FTDI bus to the connected computer where they are picked up in a terminal program.

This debug method still applies to Emuchron. With Emuchron however the user can debug clock and graphics functions using the standard gdb debugger and any GUI on top of that, prior to having its resulting firmware uploaded to the Monochron clock. This makes it a superior debugging experience when compared to the FTDI method.

This does not mean that the FTDI method has become obsolete. It is possible that due to bugs in the stub layer of Emuchron or due to bugs in clock or graphics code, Emuchron will behave different than the Monochron low-level firmware. A good rule on this is as follows: as long as clock or graphics code does not directly interact with (stubbed) low-level firmware, the chance of mismatched behavior between Emuchron and Monochron is considered low. Furthermore, Emuchron provides a stub on the FTDI debug method, allowing the application to write debug strings in a plain text file, making it a useful addition to the gdb debug solution.

6.1 Debugging using the FTDI debug strings method

6.1.1 Requirements and limitations

By default, the debug string method is disabled in the firmware code. The reason for this is that it produces a much larger firmware file that depends on the amount of debug strings and the size of the debug library that needs to be linked into the final firmware.

The master switch for the debug string method is found in monomain.h [firmware].

```
// Debugging macros.
// Note that DEBUGGING is the master switch for generating debug output.
// 0 = Off, 1 = On
#define DEBUGGING      0
```

When changed it is required to rebuild Monochron and/or Emuchron.

The several methods to generate debug strings are macros and functions as exposed in monomain.h [firmware] and util.h [firmware].
In Emuchron the stubs for these are found in stub.h [firmware/emulator].
Many examples of debug strings are found throughout the firmware and emulator source code.

6.1.2 Monochron debug strings via FTDI port on Debian Linux

The connection specifics for a terminal program that connects to Monochron are as follows:

```
FTDI debug string output connection settings:
Bits per second:       38400
Data bits:             8
Parity:                None
Stop bits:             1
Flow control:          None
```

Note that the configuration profile connection specifics have proven to work in combination with FTDI Friend v1.1 (https://learn.adafruit.com/ftdi-friend). When using other means of connecting Monochron with a USB cable other connection settings may apply, such as a baudrate of 19200.

When proper debug string enabled firmware has been uploaded to Monochron connect it to the computer via a USB cable. When Debian is used as a VM, have the FTDI USB device attached to your VM.

The instructions below cover the use of the Linux `minicom` program. Refer to section 3.5 to install a pre-configured Monochron connection profile for minicom.

- By default the logical /dev/ttyUSB*x* device that represents the hardware FTDI USB device is accessible to root only.
  Decide to run minicom either as root, or use `chmod` on the /dev/ttyUSB*x* device to grant access to other users.
- Start minicom from a shell prompt. In the example below minicom is executed using the root user.
  Note the command line arguments for minicom.

```
$ su - root
$ # Make minicom capture output to logfile Monochron.log and use the
$ # Monochron profile (installed per instructions in section 3.5)
$ minicom -C Monochron.log Monochron
```

- When minicom is started it connects to Monochron. At that point Monochron will restart and debug strings should be pouring into the minicom terminal and the capture log file Monochron.log.

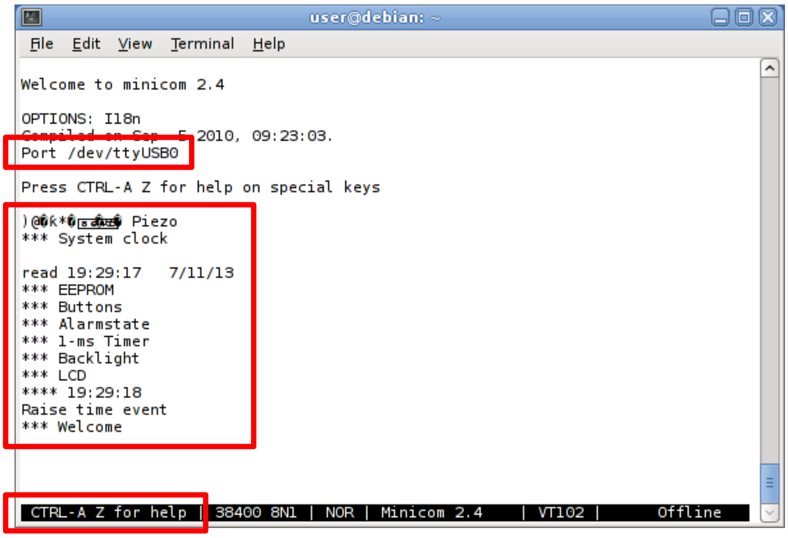


Figure 11: Minicom receiving Monochron debug string

– For help on minicom enter '<ctrl>az'. See below.

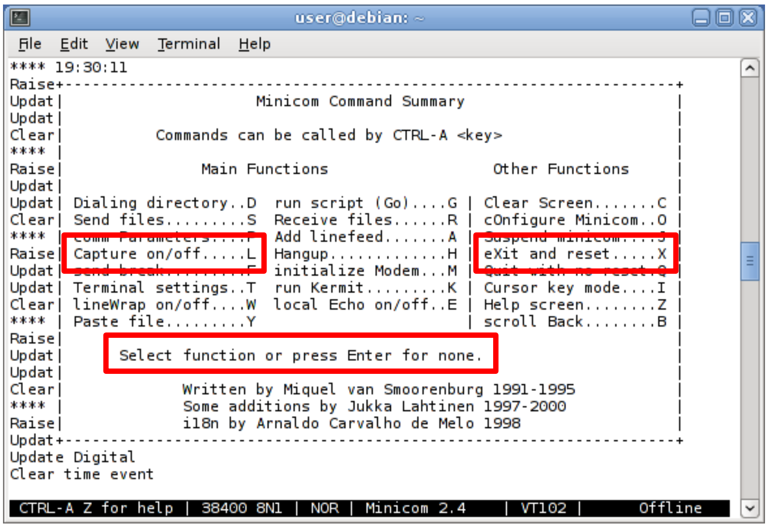


Figure 12: Minicom command summary via '<ctrl>az'

– In another command shell use the following command to trace the contents in the minicom capture log file.

```
$ su - root
$ tail -f Monochron.log
```

Note: Do not have an open connection in minicom or another terminal program while attempting to connect to Monochron via avrdude, or vice versa. The application that has access to Monochron will keep the connection locked and will prevent any other connection request to succeed.

6.2 Debugging using Emuchron stubbed FTDI debug strings

This is the stubbed version of the Monochron FTDI debug strings method. For general info on this method refer to section 6.1.

To re-iterate, to use the debug string output method in Emuchron a rebuild is required with the `DEBUGGING` master switch set to 1, causing the object size to grow. While object size is of great importance for Monochron firmware, for Emuchron it is of no concern.
When rebuilt, mchron must be started with the -d flag to specify the debug log output file. See below.

```
$ ./mchron -d debug.log
```

Note that if mchron is built with the master switch set to 0, mchron will report that debug output cannot be used when invoked with the –d flag. See red text below.

```
$ ./mchron -d debug.log

*** Welcome to Emuchron command line tool (build Oct 10 2015, 11:37:18) ***

WARNING: -d <file> ignored as master debugging is Off.
Assign value 1 to "#define DEBUGGING" in monomain.h [firmware] and rebuild
mchron.

mchron PID = 3157

time   : 11:39:02 (hh:mm:ss)
date   : 10/10/2015 (dd/mm/yyyy)
alarm  : 22:09 (hh:mm)
alarm  : off

Enter 'h' for help.
mchron>
```

Assuming that mchron was properly built, to examine the output log being created open another terminal and type the following commands.

```
$ cd <install_dir>/firmware
$ tail -f debug.log
```

Example output that is generated in file debug.log after entering the mchron command 'm n k' (to start the stubbed Monochron application) is as follows. Note that the output is very identical to output when recorded via minicom as shown in section 6.1.2.

```
$ tail -f debug.log
**** logging started
Clear time event
Raise time event
*** UART
*** Piezo
*** System clock

read 9:25:26   25/10/13
*** EEPROM
*** Buttons
*** Alarmstate
*** 1-ms Timer
*** Backlight
*** LCD
*** Welcome
*** Start initial clock
Clear time event
**** 9:25:29
Raise time event
Init Digital
Alarm info -> Other
*** Init clock completed
(etc..)
```

6.3 Debugging Emuchron using gdb

Emuchron and its mchron frontend are built with gcc option –g, thereby always generating gdb–ready symbolic debugging object code.

The gdb debugger is command-line driven. However, there are many GUI frontends available. In this manual we consider the use of Nemiver and DDD.

For help on using Nemiver and DDD refer to its built-in help menu item. When using only the GLUT LCD device, the mchron program can be loaded and started in gdb with Nemiver or DDD immediately.
In this sense, gdb is not limited by the GLUT device in mchron.

The downside of debugging with the GLUT LCD device is that GLUT runs in its own thread, making LCD updates asynchronous from glcd graphics requests from the clocks. This makes the GLUT LCD device less suited for debugging sessions when LCD output is relevant.

Things are different though when using the ncurses LCD device. This device runs in the same thread as mchron. And as the ncurses display is actively flushed in every clock cycle, it is therefore always in-sync with the mchron application. This makes the ncurses LCD display much better suited for debugging purposes when LCD output is relevant.

6.3.1 Requirements for Debian 8 when using gdb

When using Debian 8, there are gdb requirements with respect to referencing glibc sources. These requirements are described in section 3.7.4.

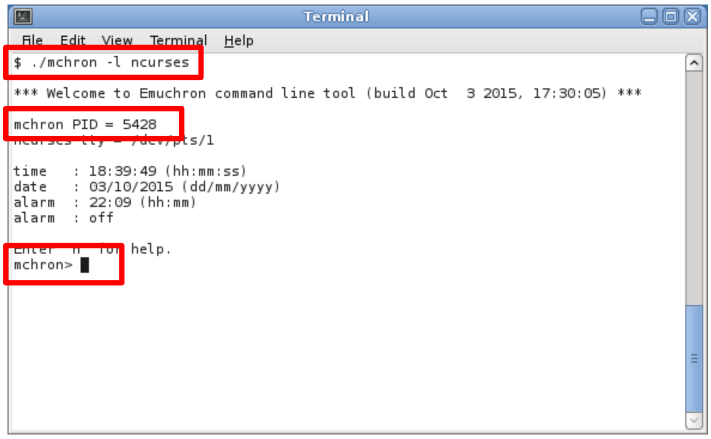
6.3.2 Limitations on using ncurses

There is a downside to using the ncurses library in combination with gdb. In short, gdb and the ncurses library don't like one another. In order to get ncurses properly working in gdb, it requires that ncurses is initialized prior to the gdb environment. If gdb initializes itself before ncurses can do so, ncurses will redirect its output always to the gdb command prompt shell, regardless the configured ncurses output tty.
The only way to get ncurses to work with gdb properly is first to start mchron, thereby allowing ncurses to initialize itself properly, and only then attach gdb (with Nemiver or DDD) to the running mchron process.
When this ncurses/gdb debug startup sequence method is applied, no other limitations apply.

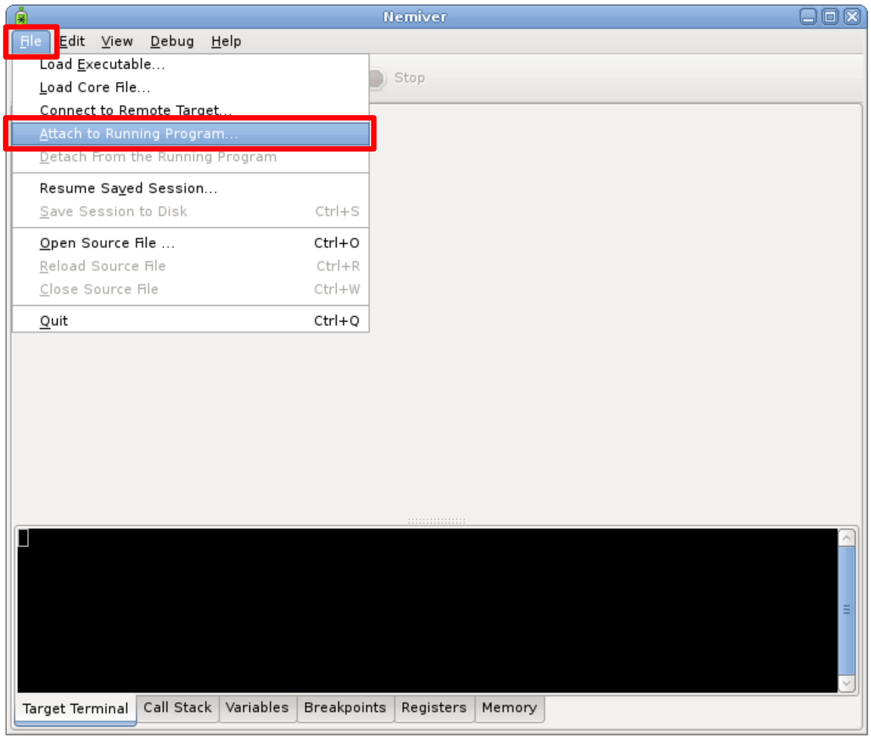
However, depending on the GUI front-end being used, different steps need to be taken. In the sections below is explained on a step-by-step basis how to get an ncurses LCD display functioning properly in a gdb debugging session.

6.3.3 Debugging Emuchron with ncurses device using Nemiver

First startup mchron and make sure there is a command prompt.

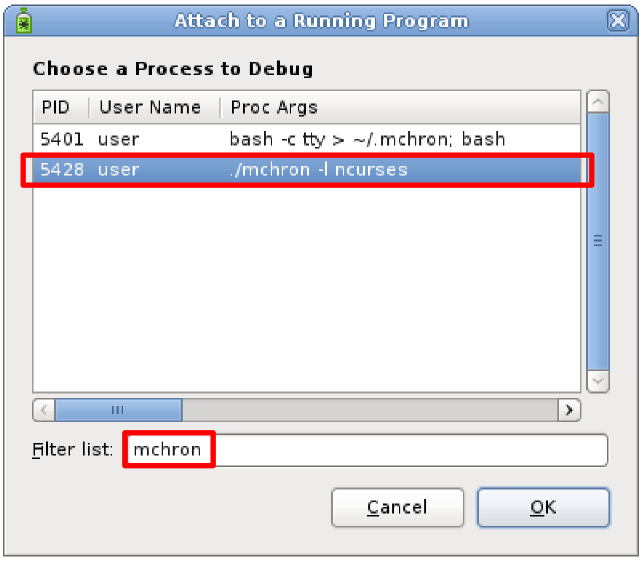


Then, start Nemiver and select "File→Attach to Running Program…" to attach to a running process.



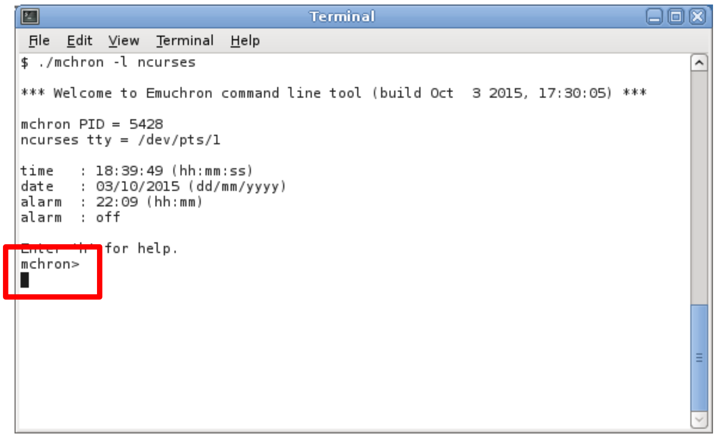
In the popup list search for the mchron command and click 'OK'.

Note: You can use the reported mchron PID in the mchron shell as a cross reference in the list below. For quick process pre-filtering enter 'mchron' in the filter list.

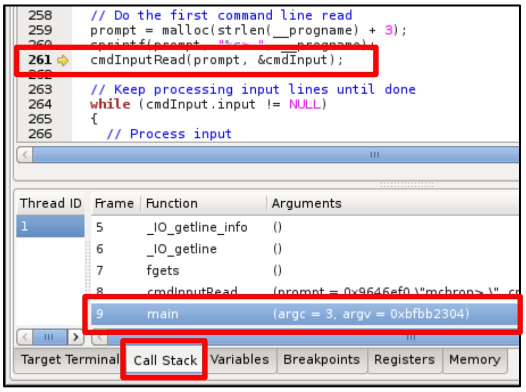


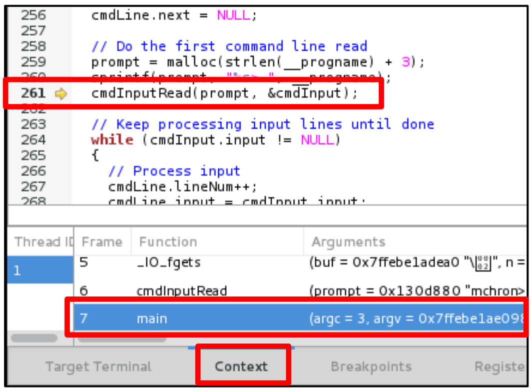
Nemiver now tries to attach to the process, but for now it cannot. The reason for this is that the mchron process is not active at this time as it waits for a command on the command line.
So, what needs to be done is to enter a blank command by hitting the return key in the mchron console. When hit, mchron now seems to hang as the mchron process is brought under control of Nemiver. See below.

Note: The cursor being at the beginning of the next line is optional. Upon pressing the return key, the cursor may remain static at its current location at the end of the prompt. In any case, mchron seems to hang as it is brought under control of gdb.



In Nemiver we are now be able to browse the application sources. The easiest way to open the first source is to go to the tab that provides the runtime call stack and select the lowest call stack level available, which is `main()` in the mchron.c [firmware/emulator] source. See below.
Note that in Nemiver in Debian 6 the tab is named 'Call Stack' (left screendump) whereas in Debian 7 and 8 the tab is named 'Context' (right screendump).

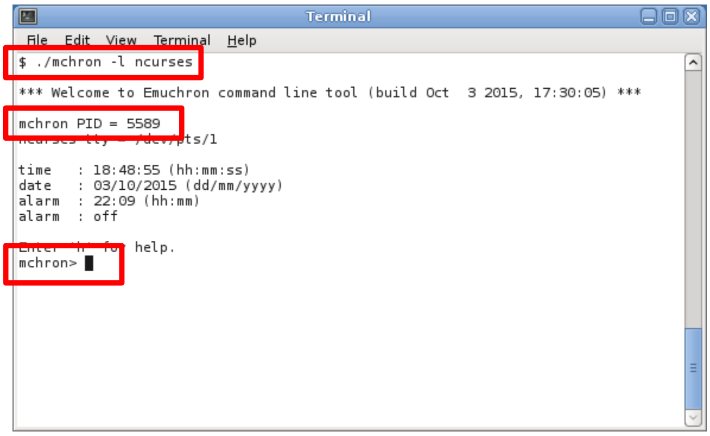




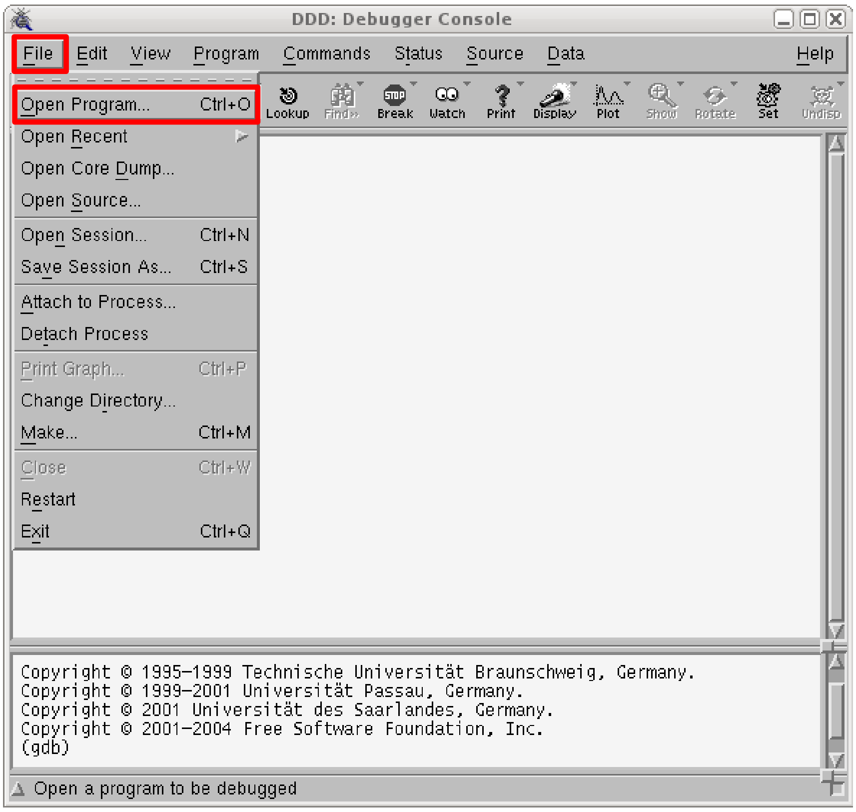
From this point on you are able to open any Emuchron source, set, disable and re-enable breakpoints, and verify local and global data.
For more information on using Nemiver use the 'Help' menu.

6.3.4 Debugging Emuchron with ncurses device using DDD

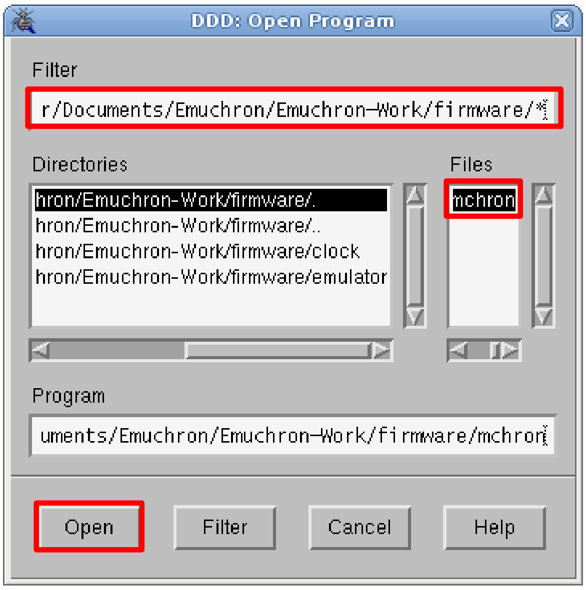
First startup mchron and make sure there is a command prompt.



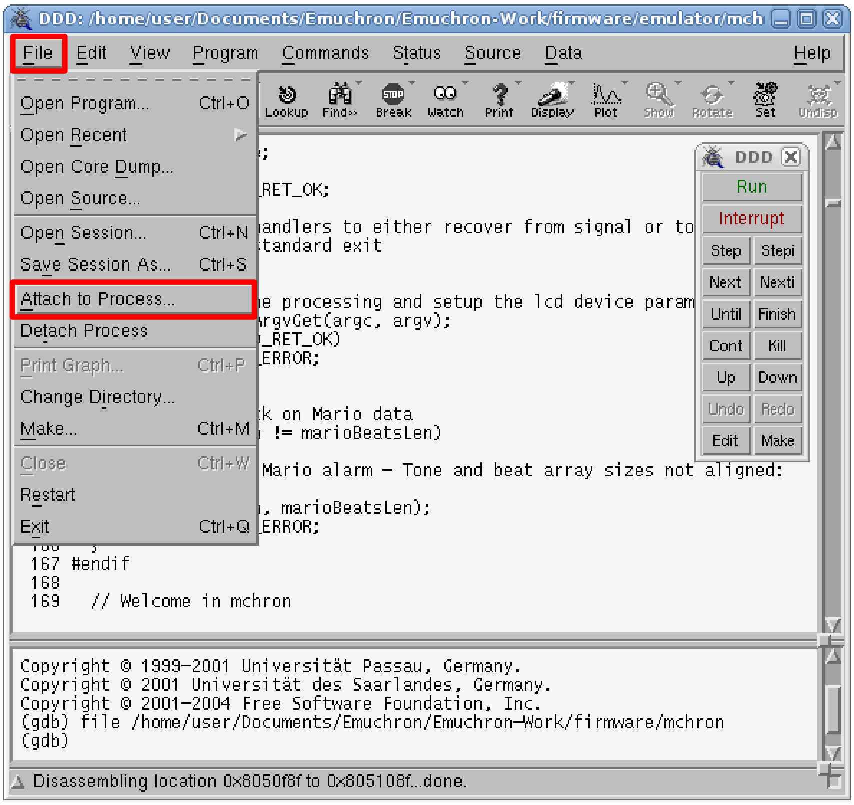
Then, start DDD and select "File→Open Program..." to open an executable program.



In the form browse to the <install_dir>/firmware folder, select the mchron program and click 'Open'.

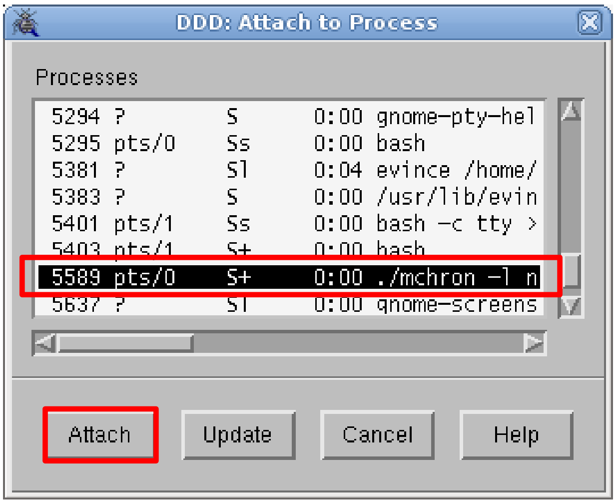


DDD should now display the mchron.c [firmware/emulator] source file, but we're not running an actual debug session yet. For this, attach to the running mchron process using "File→Attach to Process…".



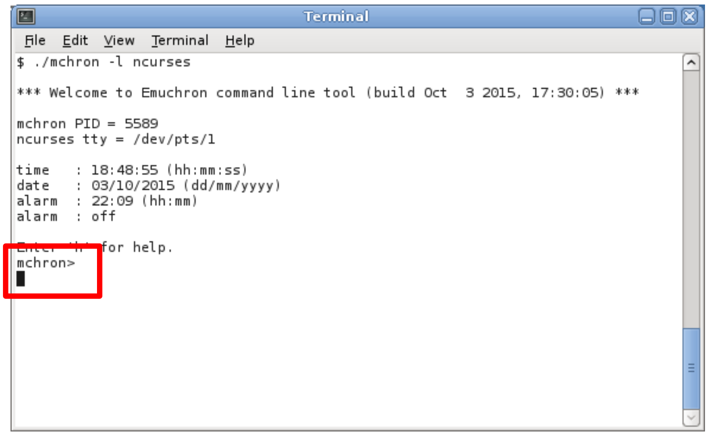
In the popup list search for the mchron command and click 'Attach'.

Note: You can use the reported mchron PID in the mchron shell as a cross reference in the list below.



DDD now tries to attach to the process, but for now it cannot. The reason for this is that the mchron process is not active at this time as it waits for a command on the command line.
So, what needs to be done is to enter a blank command by hitting the return key in the mchron console. When hit, mchron now seems to hang as the mchron process is brought under control of DDD. See below.

Note: The cursor being at the beginning of the next line is optional. Upon pressing the return key, the cursor may remain static at its current location at the end of the prompt. In any case, mchron seems to hang as it is brought under control of gdb.



In DDD, from this point on, you are able to open any Emuchron source, set, disable and re-enable breakpoints, and verify local and global data.
For more information on using DDD use the "Help" menu.

6.3.5 Debugging an mchron coredump file

The method of debugging an mchron coredump file does not differ from coredumps of other applications. For this, refer to the "Help" menu of Nemiver and DDD and the `man` page of gdb.

7 Frequently asked questions

7.1 Differences between Monochron and Emuchron

To re-iterate, Emuchron is meant to be used to debug and test functionality implemented in clock plugins and high-level graphics code. Low-level Monochron firmware routines and interrupt handlers are out-of-scope. Refer to figure 2 and figure 3 that depict the two runtime environments.

Monochron uses several interrupt handlers to take care of button presses, scanning the real-time clock (RTC) and controlling the audible alarm. As such it is considered to be a kind of multi-threaded application. Emuchron does not implement this approach for the sake of simplicity.

This means that on a certain level the runtime behavior of both environments will start to differ. However, the areas in which both applications won't differ are the functional clock plugins and the high-level glcd graphics modules, and this is what matters most.
Because of this difference in implementation, the programmer must be aware of the fact that whenever low-level code is touched, code in Monochron may not work properly in Emuchron, or vice versa. But, again, when restricting oneself to clock plugin and high-level glcd graphics code, no impact is to be expected.

The most high-level example showing the consequences of the different runtime behaviors is found in `mchronTimeInit()` in monomain.c [firmware]. In this function the requested functionality requires fully dedicated code sections for Monochron and Emuchron.

7.2 Linux mathlib accuracy vs. AVR mathlib accurary

Monochron is built using AVR libraries whereas Emuchron is built using Linux libraries. The AVR libraries are built keeping in mind that both memory and CPU capacity is limited. These restrictions are much less of a concern to Linux libraries where focus is also put on accuracy and completeness.

When using integer math, both the AVR and Linux libraries have shown to be completely compatible. However, when using mathematical functions based on `float` or `double` types, AVR and Linux libraries tend to differ.

In a nutshell, the AVR mathlib is less accurate than the Linux mathlib.

A good example on how this will impact clock plugin code is found in mosquito.c [firmware/clock]. In this clock a `float` type is used to move a time element over the LCD display in separate x and y directions. To determine the cut-off values on which a floating time element will bounce off a display border, a certain threshold needs to be implemented to counteract the inaccuracy of the AVR mathlib.
See the example below where cut-off values 1.00 and 2.00 include a 1% inaccuracy compensation (1.01 and 2.02), which has proven to be far more than adequate.

```
// Check bouncing on left and right wall
if (mathPosXNew + element->textOffset - 1.01 <= 0L)
{
  mathPosXNew = -(mathPosXNew + 2 * element->textOffset - 2.02);
  element->dx = -element->dx;
}
```

Note that the code to compensate for inaccuracies is mostly not needed in Emuchron as it uses the very accurate Linux mathlib. The tricky part in here is to realize that a clock in Monochron may show a slightly different behavior in Emuchron, based on the mathematical functions used.

Giving another example:
You may see that the position of individually painted pixels in Emuchron and Monochron sometimes are off by one x and/or y value when `sin()` and `cos()` are used to determine its position. When pixel positions are well within the boundaries of the LCD display this is normally not of a concern. But, as the code example above shows, whenever a pixel position may result in an underflow or overflow value for LCD display locations this needs to be properly taken care of.

Important note:
All glcd graphics functions are implemented using integer math. As such, the graphics behavior of glcd functions will not differ between Monochron and Emuchron.

7.3 Accuracy and reliability of the expression evaluator

For numeric command arguments and variable assignment operations the mchron interpreter uses an expression evaluator implemented in flex and bison.

In the expression evaluator all calculations are done in type `double` except for bit operators. As bit operators require an integer type, numbers are temporarily cast to type `unsigned int` and are cast back to type `double` upon completing the operation.
The expression evaluator will return an error in case of an overflow, a division by zero or a modulo by zero operation.
The logic for comparing two `double` values for being equal is based on relative accuracy cutoff value epsilon. Both the comparison function `exprCompare()` and epsilon are defined in expr.y [firmware/emulator].

```
// The relative accuracy of comparing values being equal in exprCompare().
// Current value 1E-7L is considered to provide a wide margin of error,
// but for our mchron purpose it is accurate enough.
#define EPSILON               1E-7L
```

7.4 Monochron real time clock (RTC) scanning

This section is related to section 7.1, but its information is important enough to warrant a separate one.

In Emuchron, the Linux system clock is scanned every clock cycle, being 75 msec that equals to a ~13.3Hz scan frequency. This results in a very smooth behavior of the seconds indicator in a clock. Using this scan frequency the timespan between two consecutive seconds time events may last up to 1.08 seconds.

In the original Monochron code, the timer interrupt handler that deals with the RTC has been designed such that the RTC scan frequency to generate time events is ~5.7Hz. This means that the timespan between two consecutive seconds time events may last up to 1.18 seconds. This scan frequency is sufficient for the original Monochron Pong clock that does not have a seconds indicator. However for clocks with a seconds indicator, every now and then this results in visually choppy behavior of the seconds indicator by showing an unusually long or short time to switch from one seconds value to the next one.

As this was deemed unacceptable, the timer interrupt handler firmware has been reconfigured such that the RTC scan frequency has been increased to ~8.5Hz. This leads to an acceptable worst-case timespan interval of 1.12 seconds.
The RTC scan frequency is controlled using the following defines in monomain.h [firmware].

```
// Uncomment to implement i2ctime readout @ ~5.7Hz
//#define TIMER2_RETURN_1     80
//#define TIMER2_RETURN_2     6
// Uncomment to implement i2ctime readout @ ~8.5Hz
#define TIMER2_RETURN_1       53
#define TIMER2_RETURN_2       9
```

7.5 The ncurses output appears somewhere else

By default, mchron reads its ncurses tty from file $HOME/.mchron. The content of this file is created upon starting a Monochron ncurses terminal. For this, refer to section 3.6.2.

What mchron cannot anticipate is the situation where the Monochron terminal is deleted while $HOME/.mchron still exists, and its tty gets re-used by another bash shell.
Upon starting mchron, it is detected that the tty as read from $HOME/.mchron is in use and mchron will then redirect ncurses output to that particular shell. The result is that mchron is likely to report an error on startup as the destination terminal will not meet the minimum size requirements set by the mchron application.
Note that the shell to receive ncurses output may even be the one in which mchron is started.

To recover from this, update the information in $HOME/.mchron by starting a new Monochron terminal and next restart mchron. Another option is to start mchron using the –t flag to manually set the Monochron ncurses tty.

7.6 VirtualBox: mchron OpenGL warnings/failure/coredump

Starting mchron in a Debian 6 VM with the OpenGL2/GLUT LCD device in combination with 3D acceleration may cause OpenGL2 warnings appearing at random places when initializing the OpenGL2/GLUT LCD device. See below.

```
$ ./mchron

*** Welcome to Emuchron command line tool (build Nov 11 2015, 21:00:45) ***
OpenGL Warning: XGetVisualInfo returned 0 visuals for 0x98b2700
OpenGL Warning: Retry with 0xcb returned 1 visuals
OpenGL Warning: XGetVisualInfo returned 0 visuals for 0x98b2700
OpenGL Warning: Retry with 0xcb returned 1 visuals
OpenGL Warning: vboxCall failed with VBox status code -39

OpenGL Warning: vboxCall retry(1) succeeded

mchron PID = 2762

time  : 07:44:33 (hh:mm:ss)
date  : 12/11/2015 (dd/mm/yyyy)
alarm : 22:09 (hh:mm)
alarm : off

Enter 'h' for help.
mchron>
```

Starting mchron in a Debian 7 VM with the OpenGL2/GLUT LCD device in combination with 3D acceleration may fail to start or abort due to a segmentation fault. See example below.

```
$ ./mchron

*** Welcome to Emuchron command line tool (build Nov 30 2015, 10:51:50) ***
OpenGL Warning: XGetVisualInfo returned 0 visuals for 0x93a1f08
OpenGL Warning: Retry with 0x8002 returned 0 visuals
Segmentation fault
$
```

Starting mchron in a Debian 8 VM with the OpenGL2/GLUT LCD device in combination with 3D acceleration may fail and may also partially lock the mchron bash terminal. See example below.

```
$ ./mchron

*** Welcome to Emuchron command line tool (build Oct  2 2015, 21:14:45) ***
libGL error: pci id for fd 4: 80ee:beef, driver (null)
OpenGL Warning: glFlushVertexArrayRangeNV not found in mesa table
:
OpenGL Warning: XGetVisualInfo returned 0 visuals for 00007f6ad017f510
OpenGL Warning: Retry with 0x8003 returned 0 visuals
freeglut (Monochron (glut)):  ERROR:  Internal error <visualInfo could not be
retrieved from FBConfig> in function fgOpenWindow
$
```

In general, these issues are prevented by defining a specific OpenGL environment variable in $HOME/.bashrc, forcing a proper initialization of the OpenGL environment. For this refer to section 3.2.2.

In case mchron fails or crashes, despite the modification in $HOME/.bashrc, unchecking the 3D acceleration tickbox for the VM has shown to be an effective workaround. For this refer to section 3.2.2.
The drawback of this workaround is that GNOME will not be able to use its graphics potentials to the fullest extent. As a result, the mchron OpenGL2/GLUT device will show a slightly less fluent graphics behavior that still remains very acceptable.

For unlocking a (partially) locked bash terminal refer to section 8.1.

7.7 Controller behavior and controller stub compatibility

Emuchron supports stubbed ks0108 LCD controllers using a finite state machine implemented in controller.c [firmware/emulator]. The state machine has proven to be compatible with actual hardware behavior when using the controllers as intended. This means the following:

- A sequence of read or write operations consists of first setting the cursor in the LCD controller after which a series of read or write operations are executed on the controller.
- Setting the LCD controller cursor requires setting the x position register or the y position register, or both.
  Note: In ks0108.c [firmware], the Monochron firmware sets the LCD controller cursor position by always setting x position register and by setting the y position register only when its position changes.
- When reading from the LCD controller, a hardware limitation requires reading the first byte with two sequential read operations. After that, each subsequent read operation will retrieve the next LCD byte. Also, the LCD controller will automatically increase the x cursor position.

- When writing to the LCD, the first write will write to the cursor location. Each subsequent write operation will write to the next LCD byte. Also, the LCD controller will automatically increase the x cursor position.
- After reading from or writing to the last x position for a controller, the controller will reset the x position to 0. The y position remains unchanged.

7.8 Performance of the mchron interpreter

It turns out that performance is good enough.
To illustrate this, execute either the commands below in mchron or execute script loop.txt [script] that provides the same functionality. Repeat the commands or script a few times to level out runtime differences.

```
mchron> # Do a dummy loop 1 million times
mchron> rf x=0 x<1000000 x=x+1
2>>   # Dummy comments
3>>   vs y=x+1
4>> rn
mchron>
```

On the Intel based hypervisor VMs that are used to develop and test Emuchron the repeat loop will take about 5 to 8 seconds to complete, depending on available CPU power.

As performance has never been an issue while developing mchron, no out of the ordinary efforts were made to optimize the interpreter code on speed. Instead, focus was put on accuracy, reliability and the prevention of memory leaks.

In case Linux is run in a VM and it takes much longer to complete the test script above, verify that in the BIOS of the host system the CPU has enabled Intel (VT-x) or AMD (AMD-V) Virtualization Technology. For this, refer to section 3.2.1.

7.9 After an mchron coredump there is no coredump file

A coredump will create a coredump file only after executing a one-time only command in the current shell prior to starting mchron: `ulimit -c unlimited`
Refer to section 5.4 for an example.

7.10 There is a delay in starting a stubbed Mario alarm

The audio stub that starts the Mario alarm generates a command consisting of almost 600 piped shells combining all individual Mario tune tones and tune pauses. It turns out it takes Linux about two seconds to start this up which is, considering its highly unusual length and structure, very acceptable.

In Emuchron it means that Mario alarm starts playing a rough two seconds after the alarm is tripped.

In case Linux is run in a VM and it takes much longer to start playing the Mario alarm, for example 25 seconds, verify that in the BIOS of the host system the CPU has enabled Intel (VT-x) or AMD (AMD-V) Virtualization Technology. For this, refer to section 3.2.1.

7.11 Firmware size penalty for new Emuchron functionality

Of course, the additional functionality provided by Emuchron, when added to the original Monochron firmware, will cost data and program space. One may expect that Emuchron, due to its implementation of a generic clock plugin framework with generic support functions, an additional configuration page, an additional font, and enhanced and optimized graphics functions, results in a substantially bigger firmware file when compared to the original Monochron firmware.

This turns out not to be the case. On the contrary, when building the original Monochron firmware and compare its size with Emuchron firmware that only includes the migrated pong clock and a two-tone alarm, the Emuchron firmware size is about 3.5 KB smaller, a rough 13%, despite its enhancements.
To be fair, the migrated pong clock in Emuchron has slightly reduced functionality, but that is mostly compensated by a much improved gameplay.

In general terms, within Emuchron a lot of data and program space is recovered by removing unused code and data, and optimizing original Monochron and clock code for object code size.

Emuchron firmware aims to keep its object code size small by testing multiple source code solutions for the same functionality. The object size optimized code should not, or only negligible, impact the overall performance, but may have some impact on code readability. It is considered to be an acceptable trade-off.

7.12 Is it required to build firmware on Debian Linux

No.
Only the Emuchron emulator will require Debian Linux to build and run. For building the Monochron firmware however, any machine and operating system can be used that supports an AVR toolchain. For example, if an AVR toolchain is installed on a machine running Windows 7, all that is needed is to copy the project firmware folder onto the machine and follow the build instructions in section 4.1. Refer to section 4.3 on how to upload the firmware to a Monochron clock.
For an actual example refer to appendix A.1 that discusses glcd performance tests. For these performance tests firmware is used that is built on a Fedora distro.

7.13 My debugger cannot find file "syscall-template.S"

This is an annoying Debian 8 'feature'. Although an attempt is made to fix this during the installation of required Debian packages, it may be needed to create a specific symbolic link resolving the missing link in the glibc source path. Instructions for this are found in section 3.7.4.

7.14 Ncurses backlight brightness is not enabled by default

The ncurses LCD device does support changes in backlight brightness, but will be enabled only upon specifying mchron command line argument `-b`.
The reason for this is that ncurses is not very well suited in dealing with fast changing (grey scale) colors as a result of modifying the emulated display backlight brightness, and may result in choppy or delayed display behavior. Because of this, ncurses backlight brightness support requires affirmative action from the end user on the mchron command line.
Please note that the choppy display behavior will only occur when changing the backlight brightness very fast. For example, changing the backlight brightness from within the stubbed Monochron application (command 'm') will not cause any problem. Executing the hal.txt [script] or controller2.txt [script] script on the other hand will show choppy or delayed display behavior.

8 Known bugs

8.1 The mchron terminal no longer echoes characters

When mchron executes a command list or a wait command, it switches the terminal input behavior from using a readline input method where text input is to be completed with a newline, to a keypress input method where every keypress is regarded as a separate event. This allows the end-user to issue keypress commands and provides a convenient method to interrupt command or script execution. When command or script execution has completed, mchron will automatically switch back to the default readline input method.
One of the features of the keypress method is that it will not echo keypress characters in the mchron terminal.

When mchron is interrupted or is about to crash, it attempts to clean up the environment and, most importantly, it attempts to switch back the terminal input mode to the readline method. Although great care has been given to make mchron switch back to the readline method, a full guarantee of this always happening cannot be provided.

When the readline input method is not restored, the mchron terminal appears to be dead as it no longer echoes keyboard characters. Input characters are buffered though, and when a newline character is entered it will make the un-echoed characters become the shell command to be executed.

To recover from this situation, the end-user can simply kill the current terminal and start a new one. Another option is to type a blind (remember, characters are not echoed) terminal `reset` command that will restore the default terminal behavior settings.
The use of the blindly typed terminal `reset` command turns out to be very effective.

8.2 Pending characters in the mchron terminal input buffer

As explained in section 8.1, mchron switches between a readline and keypress input method.

Upon exiting the clock or Monochron emulator (refer to respectively section 5.8.4 and 5.8.10), or completing the execution of a command list (refer to section 5.10), an attempt is made to clear the input buffer from remaining keypresses before control is given back to the mchron command prompt.
This may not always be successful, especially when the end-user holds down a single key, thereby generating multiple repeat keypresses in the input buffer.

Upon returning to readline mode, the buffer may still contain one or more remaining keypress characters in the input buffer that are not echoed, but are taken into account for the next mchron command.
In case this occurs, the next mchron command is likely to fail as the remaining input buffer characters are not expected to make up a correct mchron command.

Note that hitting a keypress one at a time will result in proper keypress processing and will not leave a pending character in the terminal input buffer.

Currently there is no known way to circumvent the erroneous behavior described above.

A Screendumps of example clocks

The ncurses LCD device output screendumps below are taken using a standard Linux window screendump tool. The clocks id's as listed are defined in anim.h [firmware]. For the special performance test clock plugin refer to section 2.9.

How difficult is it to create the clock layouts in this appendix?

- First, we start mchron using the ncurses LCD device.
- Then, five respective mchron commands are used to select the digital HMS clock, set the position of the alarm switch to 'on', to make the clock display the alarm time, set the date to Sep 14th 2013, set the alarm to 06:45, and finally set the time to 22:09:30.
- As the resulting clock layout is static we have all the time to inspect the result and use a screendump tool. The resulting clock layout can be seen in appendix A.3.
- If we now want additional screendumps using the same date and time, just select another clock using command 'cs'.

```
$ ./mchron –l ncurses
:
mchron> cs 4
mchron> ap 1
time  : 19:20:15 (hh:mm:ss)
date  : 22/07/2015 (dd/mm/yyyy)
alarm : 22:09 (hh:mm)
alarm : on
mchron> ds 14 9 13
time  : 19:20:33 (hh:mm:ss)
date  : 14/09/2013 (dd/mm/yyyy)
alarm : 22:09 (hh:mm)
alarm : on
mchron> as 6 45
time  : 19:20:40 (hh:mm:ss)
date  : 14/09/2013 (dd/mm/yyyy)
alarm : 06:45 (hh:mm)
alarm : on
mchron> ts 22 9 30
time  : 22:09:30 (hh:mm:ss)
date  : 14/09/2013 (dd/mm/yyyy)
alarm : 06:45 (hh:mm)
alarm : on
mchron>
```

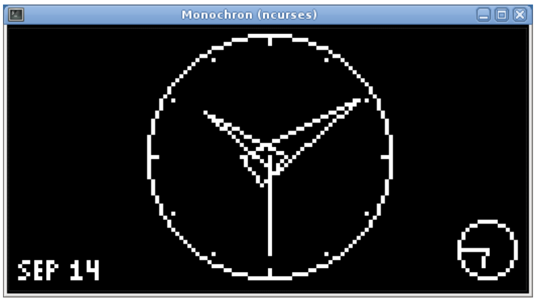
A.1 Analog clocks

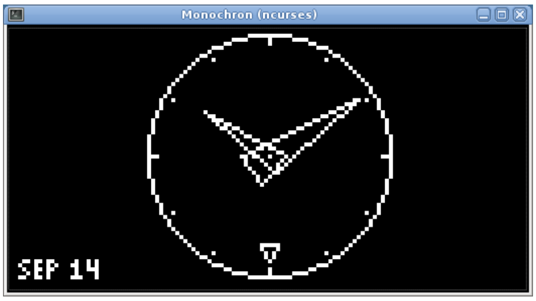
Clock Ids: `CHRON_ANALOG_HMS` and `CHRON_ANALOG_HM`

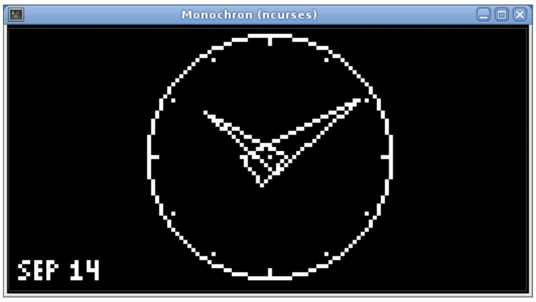
These are basic analog clocks with h/m/s or h/m time notification.
When the alarm switch is on, the alarm time will appear at the bottom right in a small analog clock. When alarming or snoozing, the alarm time will blink.
There are several build options for an analog clock, allowing eight different versions of the h/m/s flavor and two versions of the h/m flavor. See below.

```
// Determine the second indicator shape.
// 0 = Needle
// 1 = Floating arrow
#define ANA_SEC_TYPE          1

// Determine how the second indicator moves.
// 0 = Only at a full second stop
// 1 = Whenever the (x,y) position of a leg changes
#define ANA_SEC_MOVE          1

// Determine how the minute arrow moves.
// 0 = Only at a full minute stop
// 1 = Whenever the (x,y) position of the arrow tip changes
#define ANA_MIN_MOVE          1
```

For code refer to analog.c [firmware/clock].



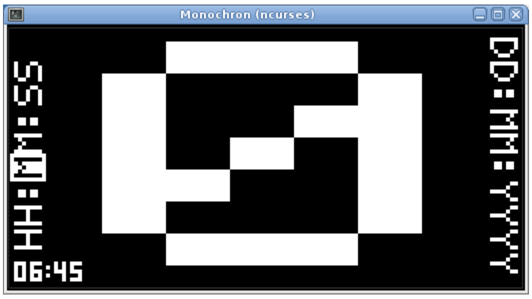


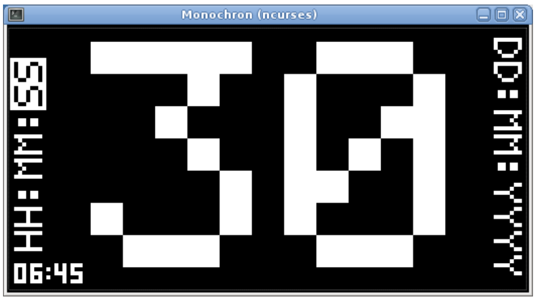


A.2 Big Digit clocks

Clock Ids: `CHRON_BIGDIG_ONE` and `CHRON_BIGDIG_TWO`

These are clocks that display either a single or two digits from the current time and date. On the left and right side of the display the clock shows the available time and date elements, and highlights the one that is currently active. Upon pressing the Set button, or in case only a single clock is configured the '+' button as well, the clock will move to the next time or date element.
When the alarm switch is on, the alarm time will appear at the bottom left.
When alarming or snoozing, the alarm time will blink.
For code refer to bigdig.c [firmware/clock].





A.3 Digital clocks

Clock Ids: `CHRON_DIGITAL_HMS` and `CHRON_DIGITAL_HM`

These are basic digital clocks with hh:mm:ss or hh:mm time notification.
When the alarm switch is on, the alarm time will appear at the bottom left.
When alarming or snoozing, the alarm time will blink.
Note that all the text strings displayed are, at its lowest level, generated using a single glcd graphics function only, being `glcdPutStr3()`.
Using a build option the clocks will 'glitch' every once in a while by randomly setting the LCD controller start line and display on/off registers. See below.
For code refer to digital.c [firmware/clock].

```
// Uncomment if you want to apply a 'glitch' mode to the clock.
// Refer to digiPeriodSet() for setting glitch delay and duration.
//#define DIGI_GLITCH
```

A.4 Example clock

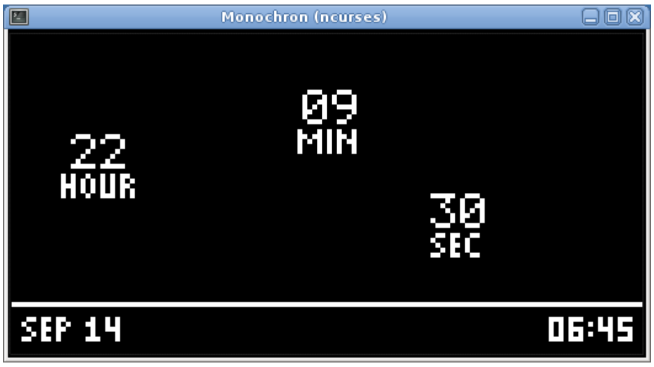
Clock Ids: `CHRON_EXAMPLE`

This is a very basic clock that serves as an example for those new to the Emuchron clock plugin framework. The entire clock requires about 90 lines of code, including blank lines and comments. When the alarm switch is on, the alarm time will appear at the bottom left. When alarming or snoozing, the alarm time will blink.
For code refer to example.c [firmware/clock].

A.5 Mosquito clock

Clock Id: `CHRON_MOSQUITO`

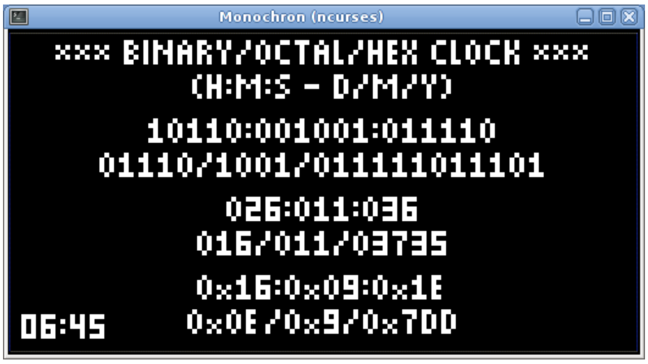
This clock implements the time as separate elements that randomly float over the LCD display. After starting the clock it will initially show the time with static elements. After a few seconds however, first the seconds element will start moving, then the minutes element and finally the hours element as well.
Every minute the angle with which an element will move is randomly set.
When the alarm switch is on, the alarm time will appear at the bottom right.
When alarming or snoozing, the alarm time will blink.
For code refer to mosquito.c [firmware/clock].



A.6 Nerd clock

Clock Id: `CHRON_NERD`

This clock displays the time and date in binary, octal and hexadecimal format.
When the alarm switch is on, the alarm time will appear at the bottom left.
When alarming or snoozing, the alarm time will blink.
For code refer to nerd.c [firmware/clock].



A.7 Pong clock

Clock Id: `CHRON_PONG`

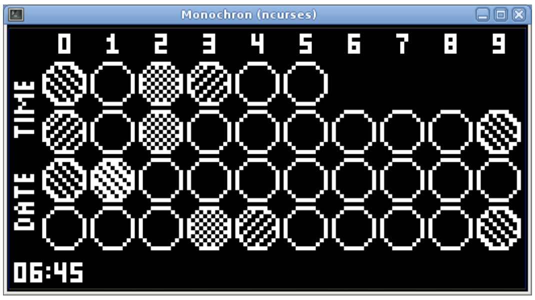
This clock is the original Monochron pong clock, but is migrated to be used in the Emuchron framework. Functionality to process time, date and alarm has been re-implemented to use the Emuchron data environment. The basic migration of the clock code took about one day of efforts.
A number of functional changes have been applied though. Gameplay is much improved by changing the ball motion angle at every paddle bounce instead of only once per minute and by allowing shallow angles. Also, whenever a point is scored, the game is paused for two seconds before resuming. And finally, the built-in random generator is replaced by a much smaller and simpler algorithm, making a significant savings in firmware size.
When the clock is alarming, whereas the original code will inverse the clock layout every second, in the Emuchron framework the alarming state is identified by flashing the center of the paddles.
For code refer to pong.c [firmware/clock].

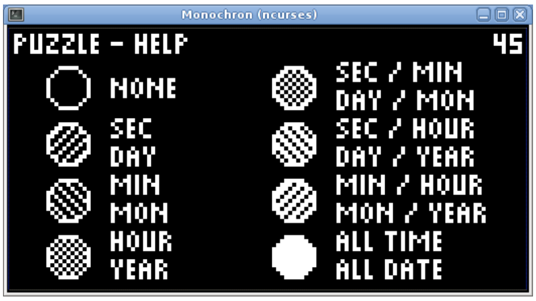
A.8 Puzzle clock

Clock Id: `CHRON_PUZZLE`

This clock combines the hour/min/sec time elements and day/mon/year date elements using filled circles.
Upon pressing the Set button, or in case only a single clock is configured the '+' button as well, a help page is displayed with a display countdown timer.
Pressing the button again will restore the clock layout.
When the alarm switch is on, the alarm time will appear at the bottom left.
When alarming or snoozing, the alarm time will blink.

For code refer to puzzle.c [firmware/clock].





A.9 QR clocks

Clock Ids: `CHRON_QR_HMS` and `CHRON_QR_HM`

These clocks encode the date and either h/m/s or h/m into a QR code. The h/m flavor draws a new QR once a minute whereas the h/m/s flavor draws a new QR every second. Use your favorite smartphone QReader app to read the date and time. The clock has a hardcoded Easter egg on April 1st.
When the alarm switch is on, the alarm time will appear at the bottom left.
When alarming or snoozing, the alarm time will blink.
For code refer to qr.c and qrencode.c [firmware/clock]. The QR encode module uses code from project qrduino (https://github.com/tz1/qrduino).

A.10 Slider clock

Clock Id: `CHRON_SLIDER`

This clock displays the time and date using slider elements.
When the alarm switch is on, the alarm time will appear at the bottom using similar slider elements. When alarming or snoozing, the alarm text labels will blink.
For code refer to slider.c [firmware/clock].

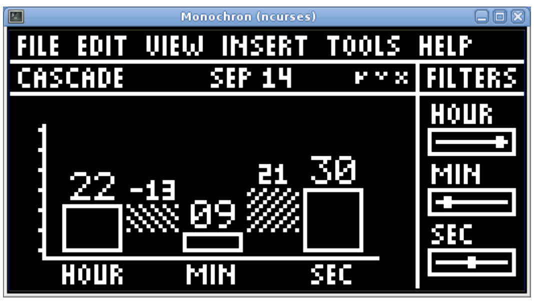
A.11 QuintusVisuals clocks

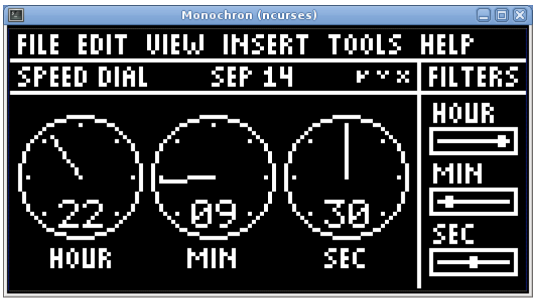
Clock Id: `CHRON_CASCADE`, `CHRON_SPEEDDIAL`, `CHRON_SPIDERPLOT` and `CHRON_TRAFLIGHT`

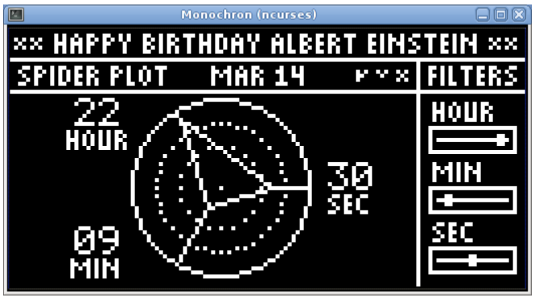
TIBCO Spotfire (http://spotfire.tibco.com) is a professional business analytics tool that provides insight in very large amounts of data using visualizations. QuintusVisuals (http://www.quintusvisuals.com/en/home) is an extension to TIBCO Spotfire and provides additional visualization types. The clocks below are minimalistic implementations of the QuintusVisuals visualizations showing the time, date and alarm.

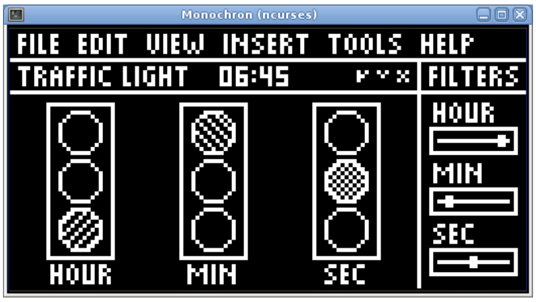
The (non-functional) header of a QuintusVisuals visualization represents the header of TIBCO Spotfire. However, the QuintusVisuals clocks include a hard-coded calendar that will change the header on specific dates to a dedicated message. See the spider plot example for March 14th below.
The filter panel on the right side contains sliders for the hour, minutes and seconds elements that are similar to those in TIBCO Spotfire. They will move along as time progresses.
The date will appear in the center of the visualization header. When the alarm switch is on, the alarm time will replace the date at that location. When alarming or snoozing, the alarm time will blink.

For code refer to spotfire.c (generic module for all QuintusVisuals clocks, including the calendar), cascade.c, speeddial.c, spiderplot.c and trafficlight.c [firmware/clock].






Monochron (ncurses)
** HAPPY BIRTHDAY ALBERT EINSTEIN **
SPIDER PLOT MAR 14
FILTERS
22
HOUR
30
SEC
09
MIN
HOUR
MIN
SEC


Monochron (ncurses)
FILE EDIT VIEW INSERT TOOLS HELP
TRAFFIC LIGHT 06:45
FILTERS
HOUR
MIN
SEC
HOUR
MIN
SEC

B High-level glcd performance tests

In time, in Emuchron several modifications are made in glcd functions to increase the draw performance or to reduce the firmware size. In order to find out how these modifications impact the draw performance, a clock plugin is created that allows running high-level glcd performance tests on Monochron hardware. Some of these tests are written to highlight specific enhancements while some are written specifically to mimic glcd usage in actual Monochron clock code.

The performance clock plugin is originally created in Emuchron v1.3 and is enhanced in Emuchron v2.0 and v2.1. Source code can be found in perftest.c [firmware/clock].

Below is a table with an overview of the average draw performance achieved per high-level graphics function over time.

High-level glcd graphics function name	***Draw performance Emuchron v1.0***	***Draw performance Emuchron v2.1***
`glcdCircle2()`	1.0x	2.5x
`glcdDot()`	1.0x	2.2x
`glcdLine()`	1.0x	3.6x
`glcdFillCircle()`	1.0x	3.6x
`glcdFillRectangle2()`	1.0x	3.9x
`glcdPutStr3()`	1.0x	2.6x
`glcdPutStr3v()`	1.0x	5.9x
`glcdPutStr()`	1.0x	1.3x

Table 24: Draw performance Emuchron v1.0 vs Emuchron v2.1

B.1 Test results Emuchron v2.0 vs v1.3

In Emuchron v2.0 two performance tests are added, being test 6 and 8. These tests are ported back to Emuchron v1.3.

The performance clock firmware is built and tested using two versions of avr-gcc. Find below an overview of version and build sizes.

Version avr-gcc	***Emuchron v2.0 Object size (bytes)***	***Emuchron v1.3 Object size (bytes)***
4.3.5 (Debian 6)	.data: 870 .text: 26,492 **Total: 27,362**	.data: 870 .text: 26,186 **Total: 27,056**
4.8.1 (Debian 8)	.data: 866 .text: 25,656 **Total: 26,522**	.data: 866 .text: 25,386 **Total: 26,234**

Table 25: Performance test firmware Emuchron v2.0 vs Emuchron v1.3

Some remarks on the build statistics:

- The performance test firmware uses code from the analog clock. The analog module is built using the default settings in the Monochron base code. These settings differ from those used in the performance test v1.3 vs v1.2.
- The firmware size of the v2.0 build is larger than the v1.3 build. This is caused by the draw optimizations in the glcd.c [firmware] module that result in a substantial larger module object file. However, much object space is

reclaimed by specific code optimizations aimed at reducing the firmware file size. The net effect of both result in a v2.0 firmware file that has a reduced impact in size when compared to the v1.3 firmware file.
- The higher the version of avr-gcc, the smaller the total object size. This can be a combination of the compiler becoming more clever at optimizing on object size, as well as size optimizations in the underlying avr-libc library.
- Smaller object code will not imply faster code execution. For this, see below.

Each test in the test plugin is run in both the emulator (to obtain glcd interface statistics) and on Monochron hardware (to obtain runtime statistics). For more information regarding the glcd dataWrite, dataRead and setAddress indicators refer to section 5.8.13.

The performance optimizations implemented in Emuchron v2.0 are threefold:
- The entire code base makes consistent use of the 'C' keyword `static`. An early v2.0 performance test that was run prior to other optimizations resulted for most tests in an improved draw performance that averaged to about 6%, with a few notable exceptions that showed improvements up to 10%. Although web resources explain that proper use of the `static` keyword will contribute in creating smaller and more efficient object code, an average performance improvement of 6% is considered to be very high, let alone the observed 10% in a single test. It is unclear what is causing this specific performance improvement.
- Graphics draw optimizations were implemented in functions `glcdCircle2()`, `glcdFillCircle2()` and `glcdLine()`.
  With respect to `glcdCircle2()` and `glcdLine()`, both functions are no longer a wrapper on `glcdDot()`, but instead are now based on a method that uses the `lcdLine[]` buffer that is more complicated to implement yet more efficient at runtime. Code for `glcdFillCircle2()` now merges multiple calls to `glcdFillRectangle2()` into a single one while also preventing redundant calls to the same function.
- Code was implemented in graphics support function `glcdBufferRead()` that optimizes on reading a row of LCD pixel bytes in the `lcdLine[]` buffer. This optimization will benefit all graphics functions that make use of this buffer. Graphics functions that rely on the `lcdLine[]` buffer will see a significant reduction in calls to dataRead and especially setAddress.

Find below a table with the results of the performance tests. The time reported is the time to complete a test in minutes and seconds for each version of avr-gcc.

Test	***Test Name***	***Emuchron v2.0***		***Emuchron v1.3***	
1	glcdCircle2-01	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	1:20 1:15 506,414 594,420 154,590	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:00 2:08 467,526 1,000,064 967,558
2	glcdCircle2-02	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	0:50 0:49 362,880 440,640 155,520	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:00 2:08 453,600 1,036,800 972,000
3	glcdDot-01	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	1:54 2:02 491,520 983,040 983,040	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:01 2:09 491,520 983,040 983,040

Test	Test Name	Emuchron v2.0		Emuchron v1.3	
4	glcdDot-02	Time 4.3.5:	1:54	Time 4.3.5:	2:01
		4.8.1:	2:03	4.8.1:	2:09
		dataWrite:	319,488	dataWrite:	319,488
		dataRead:	1,277,952	dataRead:	1,277,952
		setAddress:	958,464	setAddress:	958,464
5	glcdLine-01	Time 4.3.5:	0:43	Time 4.3.5:	1:56
		4.8.1:	0:44	4.8.1:	2:03
		dataWrite:	236,850	dataWrite:	345,245
		dataRead:	445,456	dataRead:	1,037,262
		setAddress:	135,474	setAddress:	863,854
6	glcdLine-02	Time 4.3.5:	0:45	Time 4.3.5:	2:09
		4.8.1:	0:45	4.8.1:	2:18
		dataWrite:	367,568	dataWrite:	491,952
		dataRead:	430,000	dataRead:	983,904
		setAddress:	111,712	setAddress:	983,904
7	glcdFillCircle2-01	Time 4.3.5:	0:58	Time 4.3.5:	2:01
		4.8.1:	1:00	4.8.1:	2:09
		dataWrite:	464,784	dataWrite:	571,136
		dataRead:	271,768	dataRead:	475,456
		setAddress:	343,344	setAddress:	808,864
8	glcdFillCircle2-02	Time 4.3.5:	0:59	Time 4.3.5:	2:00
		4.8.1:	1:02	4.8.1:	2:07
		dataWrite:	324,000	dataWrite:	408,000
		dataRead:	444,000	dataRead:	720,000
		setAddress:	342,000	setAddress:	768,000
9	glcdFillRectangle2-01	Time 4.3.5:	1:00	Time 4.3.5:	1:59
		4.8.1:	1:01	4.8.1:	2:06
		dataWrite:	668,850	dataWrite:	668,850
		dataRead:	764,400	dataRead:	1,337,700
		setAddress:	178,360	setAddress:	758,030
10	glcdFillRectangle2-02	Time 4.3.5:	1:04	Time 4.3.5:	2:00
		4.8.1:	1:02	4.8.1:	2:08
		dataWrite:	1,595,000	dataWrite:	1,595,000
		dataRead:	597,400	dataRead:	1,160,000
		setAddress:	43,500	setAddress:	611,900
11	glcdFillRectangle2-03	Time 4.3.5:	1:11	Time 4.3.5:	2:00
		4.8.1:	1:10	4.8.1:	2:07
		dataWrite:	2,000,880	dataWrite:	2,000,880
		dataRead:	508,160	dataRead:	1,000,440
		setAddress:	19,850	setAddress:	516,100
12	glcdFillRectangle2-04	Time 4.3.5:	1:12	Time 4.3.5:	2:00
		4.8.1:	1:10	4.8.1:	2:06
		dataWrite:	1,968,624	dataWrite:	1,968,624
		dataRead:	499,968	dataRead:	984,312
		setAddress:	19,530	setAddress:	507,780
13	glcdPutStr3-01	Time 4.3.5:	0:47	Time 4.3.5:	2:00
		4.8.1:	0:47	4.8.1:	2:07
		dataWrite:	723,240	dataWrite:	723,240
		dataRead:	734,720	dataRead:	1,446,480
		setAddress:	11,480	setAddress:	728,980
14	glcdPutStr3-02	Time 4.3.5:	0:58	Time 4.3.5:	1:59
		4.8.1:	0:58	4.8.1:	2:07
		dataWrite:	1,219,680	dataWrite:	1,219,680
		dataRead:	619,520	dataRead:	1,219,680
		setAddress:	14,520	setAddress:	619,520

Test	Test Name	Emuchron v2.0		Emuchron v1.3	
15	glcdPutStr3-03	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	0:47 0:47 706,800 718,200 11,400	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	1:59 2:07 706,800 1,413,600 712,500
16	glcdPutStr3-04	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	0:54 0:53 1,092,000 666,120 14,560	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:01 2:08 1,092,000 1,310,400 664,300
17	glcdPutStr3-05	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	0:46 0:45 732,816 744,448 11,632	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:00 2:07 732,816 1,465,632 738,632
18	glcdPutStr3v-01	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	1:39 1:50 544,320 164,592 136,080	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:00 2:17 544,320 272,160 244,944
19	glcdPutStr3v-02	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	1:26 1:34 1,364,832 357,456 81,240	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:00 2:15 1,364,832 682,416 406,200
20	glcdPutStr3v-03	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	1:43 1:59 646,016 184,576 115,360	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:01 2:20 646,016 323,008 253,792
21	glcdPutStr3v-04	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	1:24 1:31 1,266,720 340,808 105,560	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:00 2:12 1,266,720 633,360 401,128

Table 26: Performance test run Emuchron v2.0 vs Emuchron v1.3

Some remarks on the test results:

- In v1.3, function `glcdCircle2()` is basically a wrapper on `glcdDot()`. In v2.0 however, code for `glcdCircle2()` is now using the `lcdLine[]` buffer. The logic implemented in the code optimization should lead to a higher performance increase when drawing a smaller circle and drawing a circle of type FULL. Both are confirmed by the actual numbers for test 1 and test 2. Note that the optimized code for `glcdCircle2()` in v2.0, when compared to v1.3, shows a significant reduction in the number of calls to dataRead and especially setAddress. Also note that for test 1 the number of calls to dataWrite has actually increased, which is explained by the fact that in v1.3 circles of type HALF and THIRD require less dots to draw.
- In v1.3, function `glcdLine()` is basically a wrapper on `glcdDot()`. In v2.0 however, code for `glcdLine()` is now using the `lcdLine[]` buffer. Note that the optimized code for `glcdLine()` in v2.0, when compared to v1.3, shows a substantial reduction in the number of calls to dataWrite, dataRead and especially setAddress.
- Function `glcdFillCircle2()` is basically a wrapper on function `glcdFillRectangle2()`. In v2.0 code, `glcdFillCircle2()` optimizes the use of `glcdFillRectangle2()`.

Note that the optimized code for `glcdFillCircle2()` in v2.0, when compared to v1.3, shows a substantial reduction in the number of calls to dataWrite, dataRead and setAddress.
- The performance increase in all `glcdFillRectangle2()` and `glcdPutStr3()` tests is almost completely attributed to the optimization in `glcdBufferRead()`. Note the substantial reduction in the number of calls to dataRead and especially setAddress.
- Compared to the draw performance increase observed in `glcdPutStr3()` tests, the results for the `glcdPutStr3v()` tests appear lower than expected. The relatively low performance gain is explained by the fact that `glcdPutStr3v()` requires less use of the `lcdLine[]` buffer, thereby not profiting that much from the optimization in `glcdBufferRead()`.

Some remarks on the several avr-gcc versions:
- The consistent performance increase of 6% achieved in v2.0 for avr-gcc 4.3.5 by using the 'C' keyword `static` was seen in avr-gcc 4.8.1 as well.
- Compiler avr-gcc 4.3.5 generates larger object code than 4.8.1. However, 4.3.1 still outperforms 4.8.1 in quite a few tests, especially those for `glcdPutStr3v()`.

B.2 Test results Emuchron v2.1 vs v2.0

In Emuchron v2.1 one performance test is added, being test 22. The test is ported back to Emuchron v2.0.

The performance clock firmware is built and tested using two versions of avr-gcc. Find below an overview of version and build sizes.

Version avr-gcc	***Emuchron v2.1 Object size (bytes)***	***Emuchron v2.0 Object size (bytes)***
4.3.5 (Debian 6)	.data: 880 .text: 27,014 **Total: 27,894**	.data: 880 .text: 26,724 **Total: 27,604**
4.8.1 (Debian 8)	.data: 876 .text: 26,168 **Total: 27,044**	.data: 876 .text: 25,878 **Total: 26,754**

Table 27: Performance test firmware Emuchron v2.1 vs Emuchron v2.0

Some remarks on the build statistics:
- The performance test firmware uses code from the analog clock. The analog module is built using the default settings in the Monochron base code.
- The firmware size of the v2.1 build is larger than the v2.0 build. This is caused by the introduction of common function `animAlarmAreaUpdate()` in anim.c [firmware], despite other optimizations focusing on firmware size. However, when multiple clocks are configured that use this common function, the firmware size for v2.1 firmware becomes smaller than a similar build for v2.0. For example, this is the case for the default firmware for v2.1 that is smaller than similar firmware for v2.0.
- The higher the version of avr-gcc, the smaller the total object size. This can be a combination of the compiler becoming more clever at optimizing on object size, as well as size optimizations in the underlying avr-libc library.
- Smaller object code will not imply faster code execution. For this, see below.

Each test in the test plugin is run in both the emulator (to obtain glcd interface statistics) and on Monochron hardware (to obtain runtime statistics). For more information regarding the glcd dataWrite, dataRead and setAddress indicators refer to section 5.8.13.

The performance optimizations implemented in Emuchron v2.1 are twofold:

- Focus is put on optimizing the LCD cursor interface between the low level graphics library in ks0108.c [firmware] and the controller hardware.
  When changing the functional glcd cursor, only the relevant controller (either 0 or 1) is addressed instead of both. Support for auto-incrementing the y-line address for a controller via extra cursor commands in the controller is deprecated. Because of this, the y-line address of the relevant controller will now be modified only when needed.
  These optimizations combined will reduce the number of cursor commands sent to controllers. This will benefit the draw performance of all high-level glcd graphics functions.
- The graphics function `glcdWriteChar()` is optimized by not sending controller startline commands after painting a character. This will benefit the draw performance of `glcdPutStr()`.

Find below a table with the results of the performance tests. The time reported is the time to complete a test in minutes and seconds for each version of avr-gcc.
For details on a specific test refer to the actual code in perftest.c [firmware/clock].

Test	***Test Name***	***Emuchron v2.1***		***Emuchron v2.0***	
1	glcdCircle2-01	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:00 1:51 866,974 1,017,636 264,654	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:16 2:08 866,974 1,017,636 264,654
2	glcdCircle2-02	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:00 1:56 1,120,000 1,360,000 480,000	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:32 2:31 1,120,000 1,360,000 480,000
3	glcdDot-01	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:00 2:05 966,656 1,933,312 1,933,312	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	3:44 4:01 966,656 1,933,312 1,933,312
4	glcdDot-02	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:00 2:05 589,824 2,359,296 1,769,472	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	3:31 3:46 589,824 2,359,296 1,769,472
5	glcdLine-01	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:05 2:04 339,744 1,510,679 377,850	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:24 2:26 341,459 1,604,296 366,594
6	glcdLine-02	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:02 2:02 1,194,596 1,397,500 363,064	Time 4.3.5: 4.8.1: dataWrite: dataRead: setAddress:	2:24 2:26 1,194,596 1,397,500 363,064

Test	Test Name	Emuchron v2.1	Emuchron v2.0
7	glcdFillCircle2-01	Time 4.3.5: 2:00 4.8.1: 2:03 dataWrite: 1,394,352 dataRead: 815,304 setAddress: 1,030,032	Time 4.3.5: 2:53 4.8.1: 3:02 dataWrite: 1,394,352 dataRead: 815,304 setAddress: 1,030,032
8	glcdFillCircle2-02	Time 4.3.5: 2:00 4.8.1: 2:01 dataWrite: 984,960 dataRead: 1,349,760 setAddress: 1,039,680	Time 4.3.5: 3:00 4.8.1: 3:08 dataWrite: 984,960 dataRead: 1,349,760 setAddress: 1,039,680
9	glcdFillRectangle2-01	Time 4.3.5: 2:01 4.8.1: 1:57 dataWrite: 1,674,330 dataRead: 1,913,520 setAddress: 446,488	Time 4.3.5: 2:30 4.8.1: 2:31 dataWrite: 1,674,330 dataRead: 1,913,520 setAddress: 446,488
10	glcdFillRectangle2-02	Time 4.3.5: 2:00 4.8.1: 1:57 dataWrite: 3,243,900 dataRead: 1,214,988 setAddress: 88,470	Time 4.3.5: 2:10 4.8.1: 2:08 dataWrite: 3,243,900 dataRead: 1,214,988 setAddress: 88,470
11	glcdFillRectangle2-03	Time 4.3.5: 2:01 4.8.1: 1:59 dataWrite: 3,621,744 dataRead: 919,808 setAddress: 35,930	Time 4.3.5: 2:08 4.8.1: 2:06 dataWrite: 3,621,744 dataRead: 919,808 setAddress: 35,930
12	glcdFillRectangle2-04	Time 4.3.5: 2:01 4.8.1: 1:58 dataWrite: 3,538,080 dataRead: 895,560 setAddress: 35,100	Time 4.3.5: 2:08 4.8.1: 2:06 dataWrite: 3,538,080 dataRead: 895,560 setAddress: 35,100
13	glcdPutStr3-01	Time 4.3.5: 2:01 4.8.1: 1:59 dataWrite: 1,956,276 dataRead: 1,987,328 setAddress: 31,052	Time 4.3.5: 2:07 4.8.1: 2:07 dataWrite: 1,956,276 dataRead: 1,987,328 setAddress: 31,052
14	glcdPutStr3-02	Time 4.3.5: 2:01 4.8.1: 1:59 dataWrite: 2,698,920 dataRead: 1,370,880 setAddress: 32,130	Time 4.3.5: 2:09 4.8.1: 2:09 dataWrite: 2,698,920 dataRead: 1,370,880 setAddress: 32,130
15	glcdPutStr3-03	Time 4.3.5: 2:00 4.8.1: 1:59 dataWrite: 1,906,500 dataRead: 1,937,250 setAddress: 30,750	Time 4.3.5: 2:06 4.8.1: 2:06 dataWrite: 1,906,500 dataRead: 1,937,250 setAddress: 30,750
16	glcdPutStr3-04	Time 4.3.5: 2:00 4.8.1: 1:58 dataWrite: 2,570,400 dataRead: 1,567,944 setAddress: 34,272	Time 4.3.5: 2:07 4.8.1: 2:06 dataWrite: 2,570,400 dataRead: 1,567,944 setAddress: 34,272
17	glcdPutStr3-05	Time 4.3.5: 2:00 4.8.1: 1:59 dataWrite: 2,033,136 dataRead: 2,065,408 setAddress: 32,272	Time 4.3.5: 2:07 4.8.1: 2:07 dataWrite: 2,033,136 dataRead: 2,065,408 setAddress: 32,272

Test	Test Name	Emuchron v2.1	Emuchron v2.0
18	glcdPutStr3v-01	Time 4.3.5: 2:00 4.8.1: 2:15 dataWrite: 719,880 dataRead: 217,678 setAddress: 179,970	Time 4.3.5: 2:10 4.8.1: 2:26 dataWrite: 719,880 dataRead: 217,678 setAddress: 179,970
19	glcdPutStr3v-02	Time 4.3.5: 2:00 4.8.1: 2:12 dataWrite: 2,059,344 dataRead: 539,352 setAddress: 122,580	Time 4.3.5: 2:09 4.8.1: 2:24 dataWrite: 2,059,344 dataRead: 539,352 setAddress: 122,580
20	glcdPutStr3v-03	Time 4.3.5: 2:00 4.8.1: 2:19 dataWrite: 805,168 dataRead: 230,048 setAddress: 143,780	Time 4.3.5: 2:08 4.8.1: 2:28 dataWrite: 805,168 dataRead: 230,048 setAddress: 143,780
21	glcdPutStr3v-04	Time 4.3.5: 2:00 4.8.1: 2:10 dataWrite: 1,962,240 dataRead: 527,936 setAddress: 163,520	Time 4.3.5: 2:11 4.8.1: 2:22 dataWrite: 1,962,240 dataRead: 527,936 setAddress: 163,520
22	glcdPutStr-01	Time 4.3.5: 2:00 4.8.1: 1:54 dataWrite: 5,171,040 dataRead: 0 setAddress: 41,040	Time 4.3.5: 2:38 4.8.1: 2:34 dataWrite: 5,171,040 dataRead: 0 setAddress: 41,040

Table 28: Performance test run Emuchron v2.1 vs Emuchron v2.0

Some remarks on the test results:
- Relatively simple controller cursor management optimizations can result in substantial gains in graphics draw performance. The performance of `glcdDot()` is almost doubled while other functions see relevant draw performance improvements. In general, when the setAddress operation is used more often in relation to the use of the dataRead and dataWrite operations, the larger the potential gain in draw performance can be achieved. This is demonstrated by the larger performance increase observed in tests that draw many small objects (example: glcdFillRectangle2-01) compared to tests that draw fewer yet larger objects (example: glcdFillRectangle2-03).
  The performance increase in the `glcdPutStr3v()` tests is lower than may be expected. It is assumed this is caused by the fact that the draw logic in this function is CPU intensive, thereby decreasing the potential impact of the cursor management optimizations.
- As can be seen in the test result of test 22, a very simple optimization in function `glcdWriteChar()` leads to a draw performance increase of roughly 30% in `glcdPutStr()`.

Some remarks on the several avr-gcc versions:
- Similar to the other performance test that was run, avr-gcc 4.3.5 generates larger object code than 4.8.1. However, 4.3.1 still outperforms 4.8.1 in quite a few tests, especially those for `glcdPutStr3v()`.

C Setting up a Monochron terminal profile

In order to be able to use an ncurses terminal in Monochron as an LCD device it is required to create a specific terminal profile. This is a one-time only configuration action. Below are the steps described to create such a terminal profile in respectively Debian 6+7 and Debian 8.

C.1 Setting up a terminal profile in Debian 6 and 7

– Start a terminal and select "Edit→Profiles…".

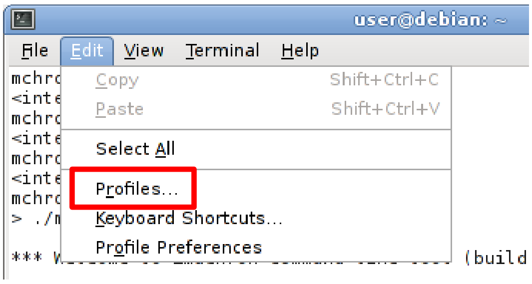


Figure 13: Access terminal profiles

– In the new window that pops up click the 'New' button to create a new profile. See below.

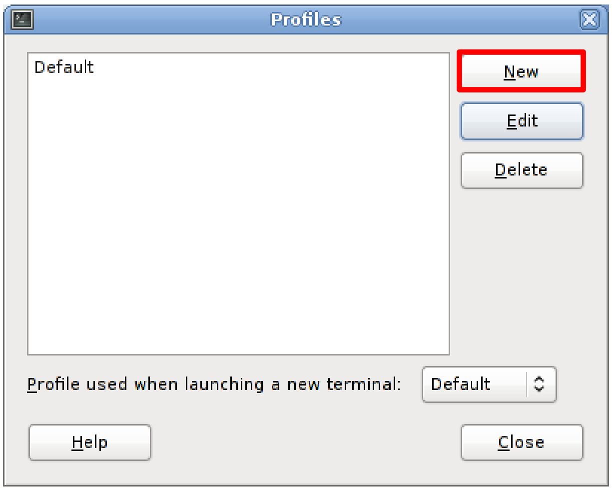


Figure 14: Create new terminal profile

– Name the new profile "Monochron" and select to base it on the 'Default' profile. Click 'Create' to continue.

Figure 15: Create profile 'Monochron'

Now a form is opened with several tabs.
Per tab set the options **exactly** as per screendump and info below.

– Tab 'General'.
Note: The font is 'Monospace' with point size 2. See below. The combination of the font and very small point size allows creating square pixels with a proper size.

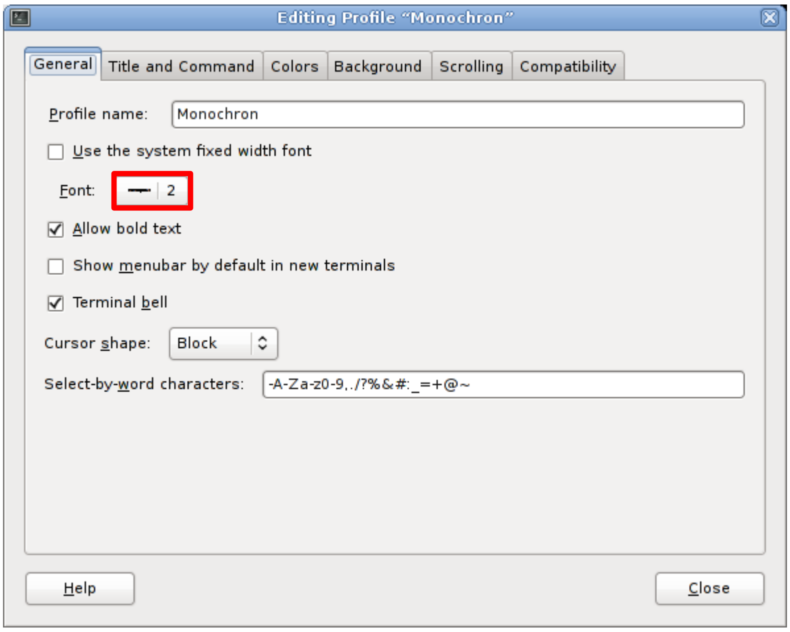


Figure 16: Terminal profile tab 'General'

– Tab 'Title and Command'.
Note: Set the initial title to 'Monochron (ncurses)'. See below.

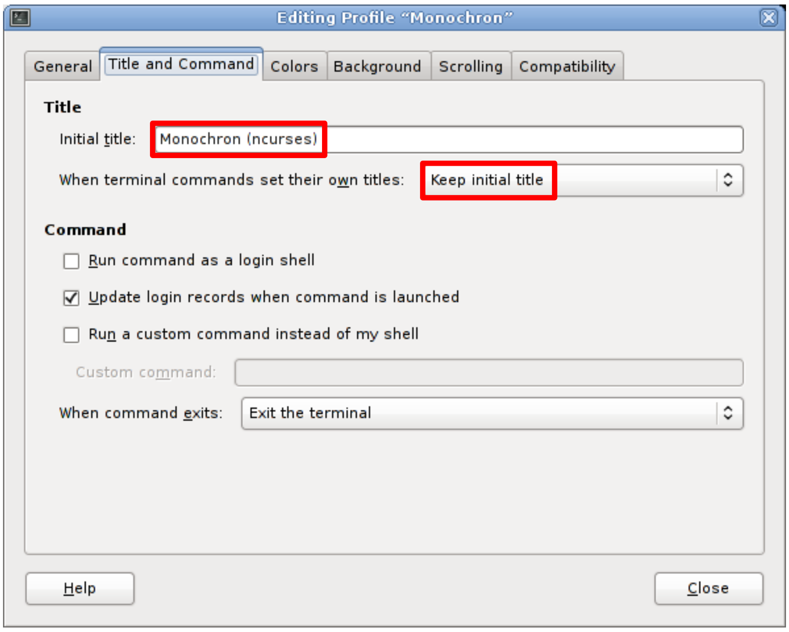


Figure 17: Terminal profile tab 'Title and Command'

– Tab 'Colors'.

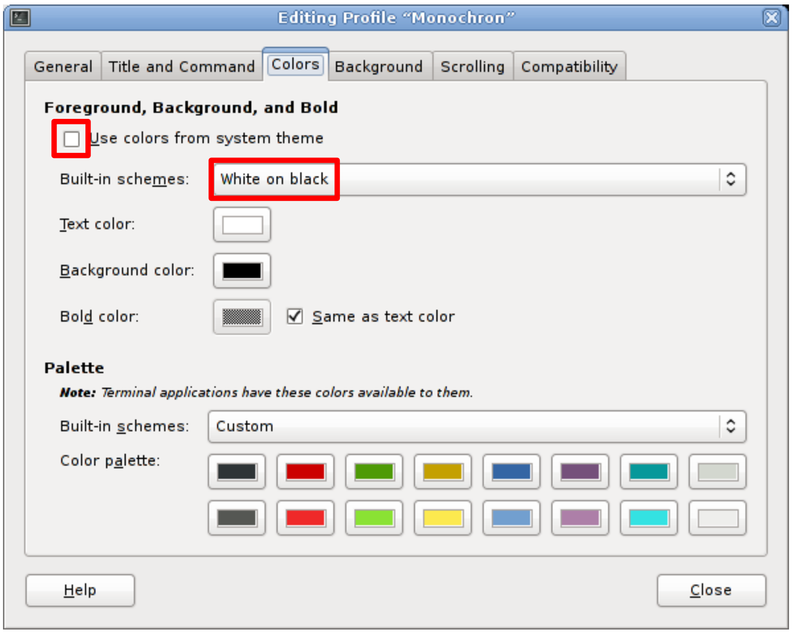


Figure 18: Terminal profile tab 'Colors'

– Tab 'Background'.

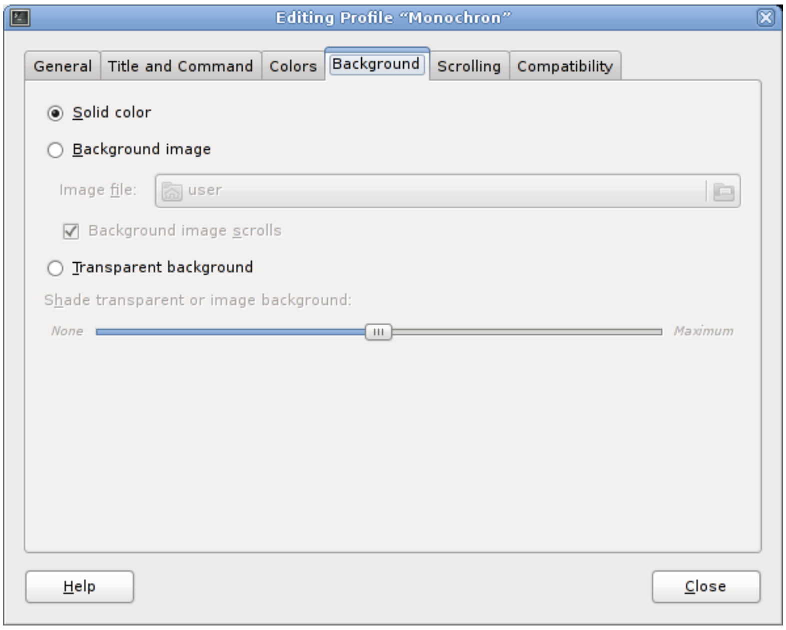


Figure 19: Terminal profile tab 'Background'

– Tab 'Scrolling'.

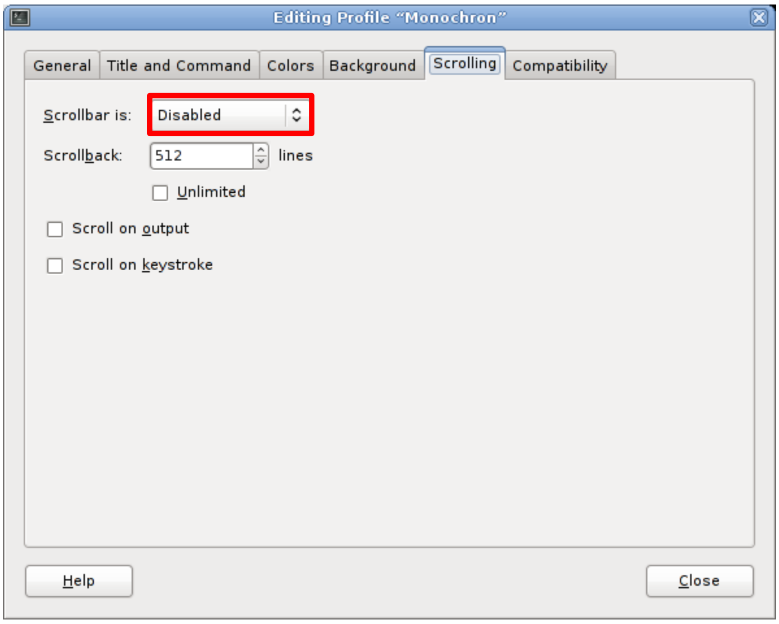


Figure 20: Terminal profile tab 'Scrolling'

– Tab 'Compatibility'.

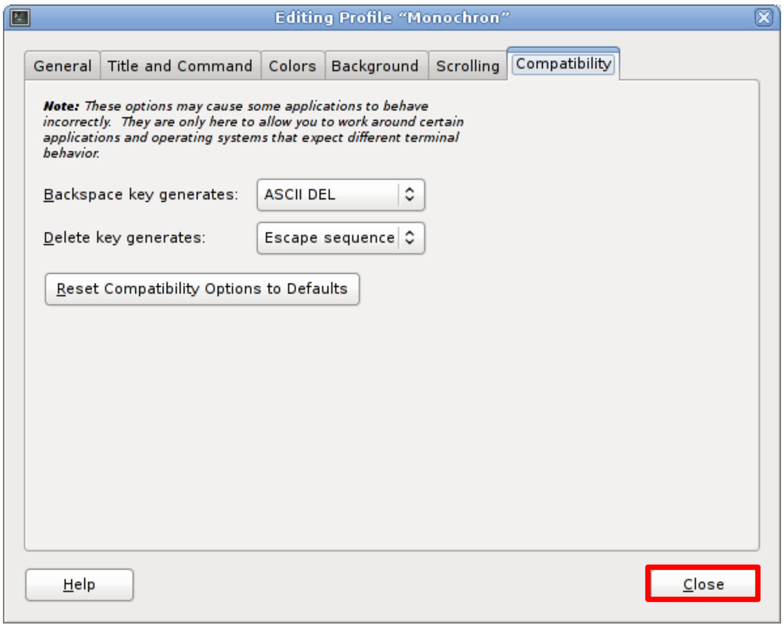


Figure 21: Terminal profile tab 'Compatibility'

As a final step click 'Close' to complete the setup of the Monochron terminal profile.

C.2 Setting up a terminal profile in Debian 8

– Start a terminal and select "Edit→Preferences".

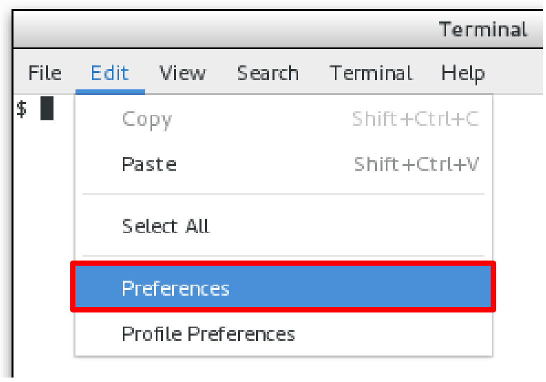


Figure 22: Access terminal profiles

– In the new window that pops up go to tab 'Profiles' and click the 'Clone' button to create a new profile based on the default. See below.

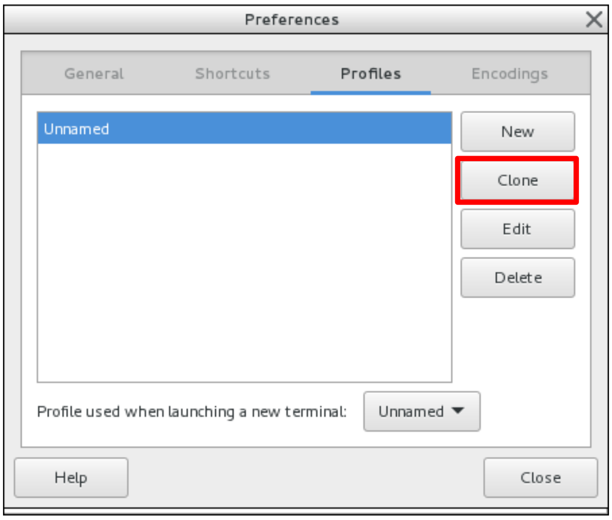


Figure 23: Create new terminal profile

Now a form is opened with several tabs.
Per tab set the options **exactly** as per screendump and info below.

– Tab 'General'.
  Name the profile 'Monochron'.
  Note: At the bottom select font 'Monospace Regular' with point size 2. The combination of the font and very small point size allows creating square pixels with a proper size.

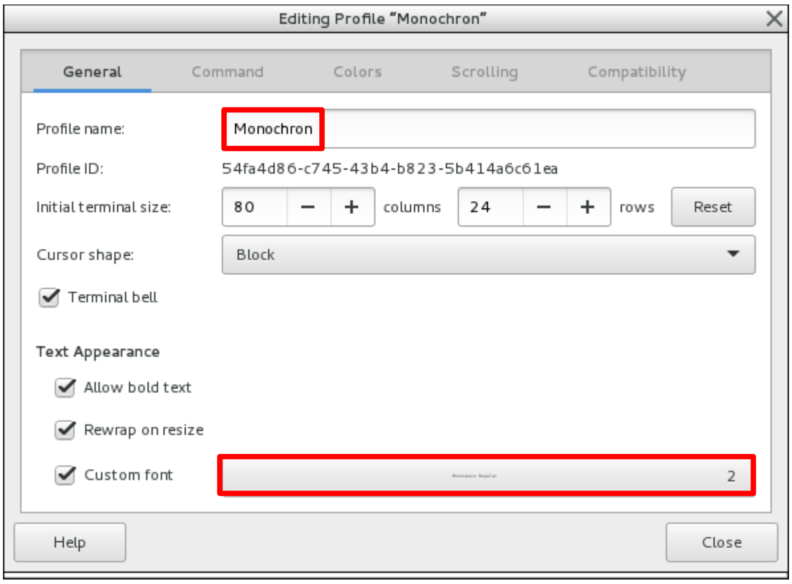


Figure 24: Terminal profile tab 'General'

– Tab 'Command'.

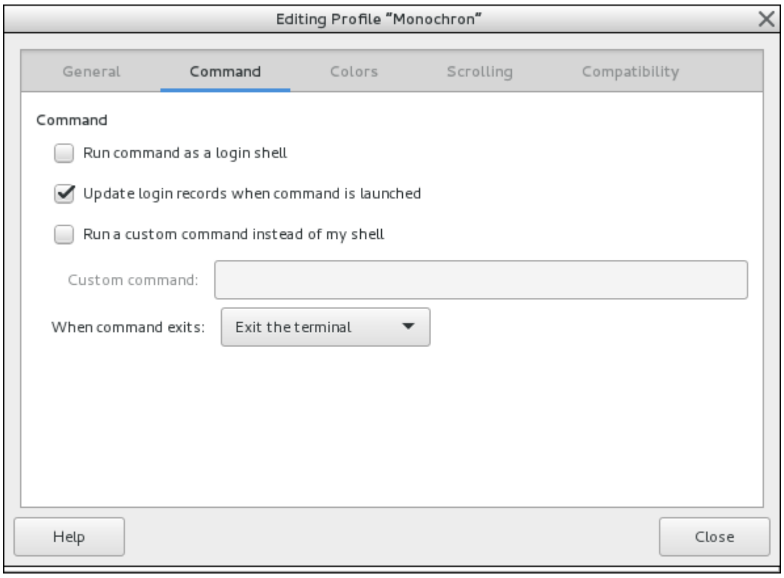


Figure 25: Terminal profile tab ' Command'

– Tab 'Colors'.

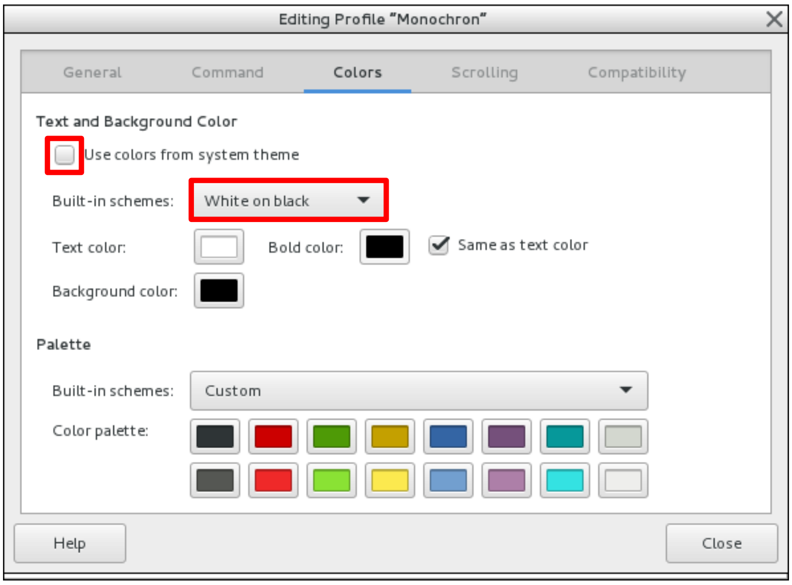


Figure 26: Terminal profile tab 'Colors'

– Tab 'Scrolling'.

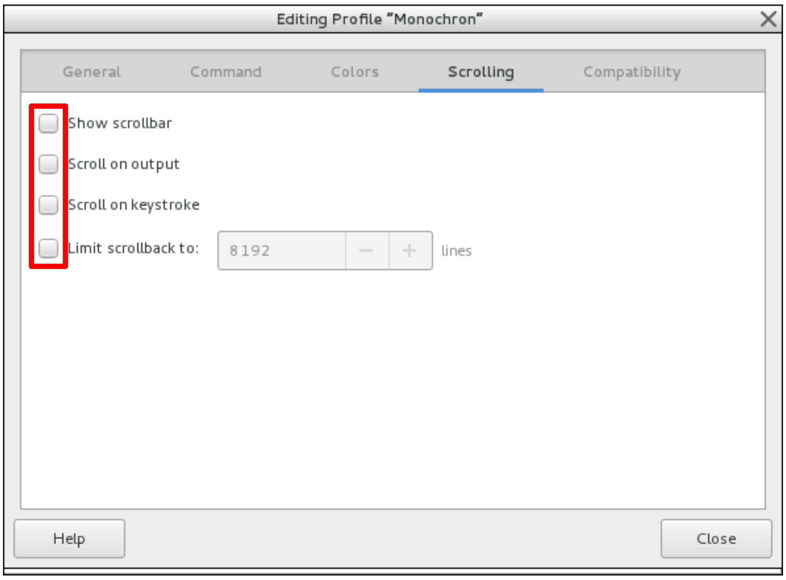


Figure 27: Terminal profile tab 'Scrolling'

– Tab 'Compatibility'.

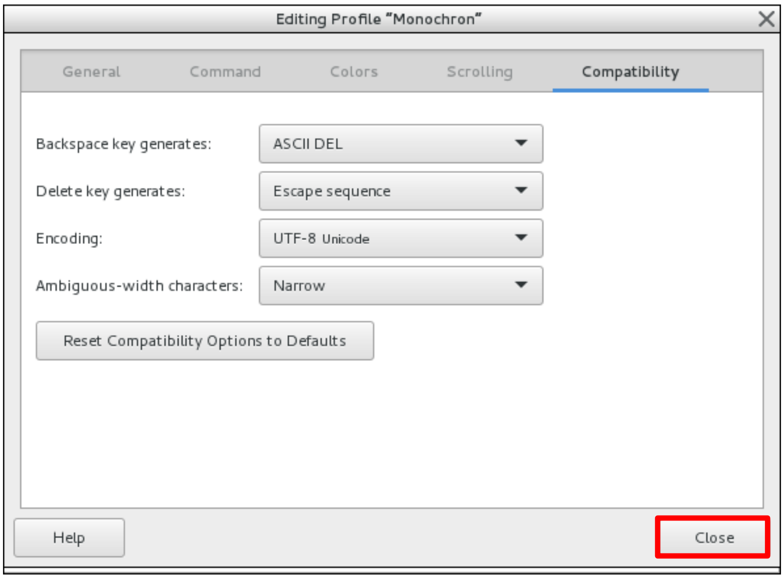


Figure 28: Terminal profile tab 'Compatibility'

As a final step click 'Close' to complete the setup of the Monochron terminal profile.