
AmForth Documentation

Release 5.2

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USER'S MANUAL

1.1 User's Manual For Linux

1.1.1 Initial Setup

This guide makes a few assumptions. Your linux should be a fairly recent linux distribution. For this document an Ubuntu 12.04 LTS is used, others should work in a similiar way.

First you'll have to install some packages with the package manager:

- wine (any version)
- ant or make (any version)
- avrdude

They may need quite a lot more packages, install all of them.

Next download the amforth package and un-tar (or unzip) it into a new, empty folder:

```
> pwd
.../amforth
> ls
> tar xvf amforth-x.y.tgz
.. lots of files
> ls
appl core doc examples lib LICENSE.txt readme.txt
tools
> mkdir Atmel
>
```

Now you need access to an installed Atmel Studio 6 installation. Locate the program directory and copy the file `avras2.exe` and the whole `Appnotes2` directory into a newly created directory called `Atmel`:

```
> ls Atmel
avras2.exe Appnotes2/
>
```

The `Appnotes2` directory contains a lot of `inc` files. They are text files. There is no need to convert them from DOS to unix text format. Take them as they are.

1.1.2 Testing

To test if the installation is complete, change into the directory `appl/template`. There run either **make** or **ant** with the target name `template.hex` to test the assembler setup.

```
> make template.hex
wine ../../Atmel/avras2.exe -I ../../Atmel/Appnotes2
-I ../../core -I ../../core/devices/atmega1284p -fI
```

```
-v0 -e template.eep.hex -l template.lst template.asm
>
```

Ant works similar, note the warning at startup, it can safely be ignored:

```
> ant template.hex
Unable to locate tools.jar. Expected to find it in
/usr/lib/jvm/java-6-openjdk-amd64/lib/tools.jar
Buildfile: ....amforth/appl/template/build.xml
```

```
template.hex:
[echo] Producing Hexfiles for atmega128
```

```
BUILD SUCCESSFUL
Total time: 4 seconds
>
```

After this step, there should be a number of new files in the directory:

```
> ls
build.xml          dict_appl.inc  template.asm
template.hex      template.map  dict_appl_core.inc
makefile          template.eep.hex  template.lst  words
```

If something went wrong, read the error messages, fix them and repeat this step until all is well.

1.1.3 Create Your Project

If everything works fine, it is now possible to start your own project. This is as simple as making a copy of the template directory and editing a few files there.

```
> pwd
... amforth/appl
> cp -r template my
> cd my
>
```

Now edit the files `template.asm` and `makefile` (or `build.xml` if you use ant). The file `template.asm` has a lot of settings, to get a quick start only the lines

```
.equ BAUD = 9600
.include "drivers/usart_0.asm"
```

may need to be changed. The baud number should be obvious. The line `usart_x.asm` defines the usart port of the controller on which the command prompt will be available. There are only *real* usart ports available, no USB devices (this may change in future releases..)

In the `makefile` find the lines

```
# set the fuses according to your MCU
LFUSE=0xnn
HFUSE=0xnn
# some MCU have this one, see write-fuses target below
EFUSE=0xnn
```

resp. the `build.xml` for ant:

```
<target name="p1284-8.fuses" description="Set fuses for P1284-8">
  <echo>Writing fuses</echo>
  <avrdude-3fuses
    type="${programmer}"
    mcu="${mcu}"
    efuse="0xff"
    hfuse="0x99"
```



```

        lfuse="0xc6"
    />
</target>

```

and change the fuses to meet your hardware settings. Be careful with these numbers, they can potentially corrupt your controller cpu beyond repair.

The next essential setting is the controller itself

```

# the MCU should be identical to the device
MCU=atmega1284p

```

in the `build.xml` find and change all occurrences that look like

```
mcu="atmega1284p"
```

with the proper name. The mcu names are taken verbatim as file names in the `Atmel/Appnotes2` directory and as directory names in the `core/devices` directory. Case is significant (should be almost always lower case).

With these changes, rebuild the hex files as described above.

1.1.4 Program The Controller

Hardware and System Setup

The last and final step is to transfer the hex files to the controller. The build tools use the program **avrdude**. To get the hex files to the controller a special hardware called *programmer* is needed. There are many different ones available, ranging from simple parallelport tools like the STK200 to expensive tools like the Atmel JTAG ICE MK2. Don't start trying to use exotic tools like ponyser or other self-made el-cheapo tools unless you know what you're doing.

The Atmel tools AVR ISP MK2 and Dragon are not that expensive and work with the USB port of your computer. Linux needs a file named `/etc/udev/rules.d/99-atmel.rules` to make them accessible for users:

```

# Atmel AVR ISP mkII
SUBSYSTEM=="usb", ATTRS{idVendor}=="03eb", ATTRS{idProduct}=="2104", GROUP="users", MODE="0660"
# usbprog bootloader
ATTRS{idVendor}=="1781", ATTRS{idProduct}=="0c62", GROUP="users", MODE="0660"
# USBasp programmer
ATTRS{idVendor}=="16c0", ATTRS{idProduct}=="05dc", GROUP="users", MODE="0660"
# USBtiny programmer
ATTRS{idVendor}=="1781", ATTRS{idProduct}=="0c9f", GROUP="users", MODE="0660"

```

Note, that the correct GROUP name should include one of the groups your linux account is a member of:

```

> id
uid=1000(user) gid=1000(user) groups=1000(user),4(adm),24(cdrom),
    27(sudo),30(dip),46(plugdev),109(lpadmin),124(sambashare),125(libvirt)

```

Here the GROUP name "users" would not work! But "user" or "plugdev" would do. If you do not have a setup like this, only root can access the programmer. If you want to use the parallelport programmer STK200, your account should be a member of the "lp" group (check with `ls -l /dev/parport*`).

Any changes to the rules file are detected almost immediately, there should be no reason to restart any linux program.

Project Setup

If your hardware setup is finished, you need to edit the `makefile` or `build.xml` to reflect the settings. In the `makefile` find and edit the lines

```
USB=-c avr911 -P /dev/ttyUSB3
PP=-c stk200 -P /dev/parport0
JTAG=-c jtag2 -P /dev/ttyUSB2
BURNER=$(USB)
```

The `build.xml` is different. This file uses a property file named `programmer.properties` to set the name and the port of the programmer hardware. The `build.xml` file uses a substring from the label to define the programmer. If you want to use e.g. the AVR Dragon as the programmer, just use the name “dragon” as programmer identifier in your `build.xml`. The `ant` utility will expand this to “`avr.programmer.<label>port`” for the `-P` parameter and “`avr.programmer.<label>`” to the `-c` parameter to generate the right command line for **avrdude** from the property file.

Serial programmers may be difficult while getting the right port name if using RS232-to-USB converters. The mapping may change over time (e.g. every reboot or USB bus reset).

If everything goes ok, the final command **make template** should re-generate the hex files and transfer them to the controller. The default program output should be verbose enough to track any error messages.

1.2 User’s Manual for Windows

by Karl Lunt for amforth v4.2

Document contributed to the amforth project on SourceForge.net.

1.2.1 Introduction

This manual describes the amforth programming language and provides details on how to customize the standard release for use on your target platform. This document focuses on developing amforth applications in the Windows environment, using Atmel’s freeware AVRStudio4. For information on developing amforth applications in the Linux/Unix environment, consult the Web.

amforth is a variant of the `ans94` Forth language, designed for the AVR ATmega family of microcontrollers (MCUs). amforth v2.3 was developed and maintained by Matthias Trute; the amforth project is hosted and maintained on SourceForge.net (<http://sourceforge.net/projects/amforth>).

You create your amforth application by creating a custom template file, (optionally) modifying some of the files included in the distribution set, assembling them with AVRStudio4, then moving the resulting object file into flash in the target hardware. Your amforth application resides in flash, using very little RAM or EEPROM.

amforth is fully interactive. You can connect your target hardware to a serial port on your host PC, run a comm program such as Hyperterm, and develop additional Forth words and applications on the target. Each word you create interactively is also stored in flash and is available following reset or power-cycle of the target. You can select one of your amforth words to be the boot task, which will run automatically on the next reset or power-cycle. You can also write interrupt service routines (ISRs) in amforth for handling low-level, time-critical events.

This manual assumes familiarity with Atmel’s AVRStudio4 development suite (Windows OS); some knowledge of AVR assembly language programming is helpful but not necessary for basic use of the amforth language. You can download the free AVRStudio4 suite from Atmel (http://www.atmel.com/dyn/products/tools_card.asp?tool_id=2725). You can use version 4.2 or higher; note that you need to fill out a fairly simple registration page to complete the download.

This manual also assumes a working knowledge of the Forth programming language. If you are new to Forth, or if you need a quick refresher or a reference page, you can find a full Web version of Leo Brodie’s marvelous book, “Starting Forth,” online at <http://home.iae.nl/users/mhx/sf.html>.

1.2.2 About this document

I created this document to support Matthias’ work on amforth. He has designed an excellent Forth that I enjoy using, but I thought newcomers to amforth could use a bit more detailed explanation on setting up an application.

As my contribution to his amforth project, I'm providing this user's manual.

This document was written using OpenOffice version 3.2.0. You can download a copy of OpenOffice at the project's website: www.openoffice.org

I have contributed this document to Matthias for inclusion in his project, with the hope that others will edit and expand this text, to make amforth even better. If you modify this document, please include this section (with suitable additions) and include my name in the list of contributors.

Karl Lunt, Bothell, WA USA

1.2.3 A quick look inside amforth

amforth v4.2 is available as a single downloadable file (amforth-4.2.zip). Download this file into your working folder (I'll use `c:\projects\amforth-4.2` throughout this document) and unzip them, preserving the subdirectory structure. You should end up with the following subdirectory layout:

```
c:\projects\amforth-4.2\      <-- main directory, holds your project files
                           \appl      <-- holds amforth systems for various MCUs
                           \core      <-- holds source for amforth primitives
                           \doc       <-- holds amforth documentation
                           \examples  <-- holds small projects written in amforth
                           \lib       <-- holds libraries of Forth source files
                           \tools     <-- holds amforth support tools (pd2amforth)
```

You will develop your custom applications by creating simple assembly language source files in the main directory, assembling your source files and the amforth source files with AVRStudio4, then downloading the resulting .hex and .eep files into your target with AVRStudio4.

Note that although you will be creating assembly language source files, the files will be little more than a few macro invocations. Generally, you will not need to know any AVR assembly language to develop your applications.

The following sections describe the various subdirectories and files found in the initial installation of amforth.

core\words subdirectory

The `core\words` subdirectory holds a large collection of amforth words, each defined in a separate .asm file. Each file in this subdirectory is a complete word definition, ready to assemble into the final application. For example, here is the entire contents of `equal.asm`, the source file for the word `=`, which compares two values on the top of the stack and leaves behind a flag that is TRUE if the values match or FALSE if they don't.

```
; ( n1 n2 -- flag ) Compare
; R( -- )
; compares two values
VE_EQUAL:
    .dw $ff01
    .db "=",0
    .dw VE_HEAD
    .set VE_HEAD = VE_EQUAL
XT_EQUAL:
    .dw PFA_EQUAL
PFA_EQUAL:
    ld temp2, Y+
    ld temp3, Y+
    cp tosl, temp2
    cpc tosh, temp3
PFA_EQUALDONE:
    brne PFA_ZERO1
    rjmp PFA_TRUE1
```

This source file gives an excellent view of the layout for each amforth word. It isn't necessary that you understand how a word is laid out inside the dictionary in order to use amforth. However, if you ever need to define your own

amforth words, you will need to follow the layout shown here to make sure your words properly integrate into the dictionary.

core\devices subdirectory

The `core\devices` subdirectory holds several folders, each defining a target MCU. For each target MCU defined, the associated folder holds four files..

The `device.asm` file is intended to be included as part of your application, and provides assembly language definitions for MCU-specific parameters, such as where RAM starts, the number and layout of the interrupt vectors, and where high flash memory starts.

The `<target>.frt` file contains Forth source defining MCU-specific parameters, such as IO register names and addresses. You can use this file when working in Forth on your target system; it is not needed when building an amforth system in AVRStudio4.

The `device.inc` file contains assembler source and is intended to be included as part of any amforth applications you build for the target device. This file creates Forth words in your dictionary that provide access to the MCU registers on your target.

(Comments on `device.py` file are needed.)

If you need to develop support files for a different Atmel MCU, you can copy the existing files for a similar device and use these copies as a starting point for your efforts. Rename the files to match the target MCU, then refer to the appropriate Atmel reference manual to determine the proper values for the various registers and parameters. Where possible, ensure that the assembly language names for the ports match those in the existing `.asm` file. If the names do not match, or if you need to add new names to provide support for a new subsystem (such as the CANBus ports on an AT90CAN128), you may need to edit one or more existing amforth source files.

(Add details on how the `device.py` file is generated.)

core\amforth.asm

`amforth.asm` contains a small amount of assembly language source that: * defines the Forth inner interpreter, * declares the starting address of the Forth kernel, * allocates the memory for the final system, * sets up the small area of EEPROM used by the Forth system, * declares the interrupt service routine (ISR) support, * adds the words to be assembled into low flash memory (`dict_appl.inc`), * adds the words to be assembled into high flash memory (`dict_appl_core.inc`)

The `amforth.asm` included in your original download is essentially complete, in that when assembled it will create most of an amforth system. However, key information about the target hardware is missing and must be supplied by you in what is known as a template file. Details on what this template file contains and how you use the template file to describe your target hardware are contained in a later section.

Note that `amforth.asm` refers to a turnkey application (see `XT_APPLTURNKEY` in the `.eseg` segment). This execution token is assumed to be an amforth word defined somewhere in your application. The default turnkey application, defined in the file `appltturnkey.asm`, provides a typical Forth interactive environment. You can customize `appltturnkey.asm` as needed; see the section below on `appltturnkey.asm`.

core\dict_core.inc

This file lists all amforth words that will be included in that part of amforth's dictionary stored in high flash memory (also known as the bootloader area or NRWW flash). The following excerpt from the standard `dict_core.inc` file shows how the file fits into the amforth system.

```
; this part of the dictionary has to fit into the nrww flash
; section together with the forth inner interpreter
.include "words/int-on.asm"
.include "words/int-off.asm"
.include "words/int-restore.asm"
```

```
.include "words/exit.asm"
.include "words/execute.asm"
.include "words/dobranch.asm"
.include "words/docondbranch.asm"

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
.include "words/doliteral.asm"
.include "words/dovvariable.asm"
.include "words/doconstant.asm"
.include "words/douser.asm"
.include "words/fetch.asm"
.include "words/store.asm"
.include "words/cstore.asm"
.include "words/cfetch.asm"
```

Each line in `dict_core.inc` is either a comment or an *.include* statement that adds an assembly language source file from the `words/` folder. Thus, the words listed in this file and the order in which they appear define the high-memory portion of your amforth project dictionary.

In general, the words in `dict_core.inc` provide flash read and write capability, though other primitives, such as branch operations and the inner interpreter, may also be included. The amforth design puts these flash read/write operations in high flash memory because the AVR MCU does not allow instructions in one area of flash memory to modify that same area of flash memory. Putting the flash read/write primitives in high flash memory allows amforth words in low flash memory to use these primitives to modify the dictionary, which is kept in low flash.

The amount of high flash memory varies based on the type of AVR device. Some small devices may have so little high flash memory that you won't be able to fit all of the words in this file into the available memory. Should this happen, you may be able to move some of the *.include* statements from this file into `dict_minimum.inc` (see below). Note, however, that this must be done carefully, to keep the flash read/write words (at least) in high flash memory.

For nearly all applications, you can simply leave `dict_core.inc` unchanged.

`core\dict_minimum.inc`

This file was called `dict_low.inc` in previous versions of amforth. Like `dict_core.inc`, it contains a series of *.include* statements that add a list of core amforth words to the final system.

The words included in `dict_minimum.inc` are stored in the target system in low flash memory. The entire dictionary in low flash memory that is created when you build an amforth system becomes your application's dictionary. The last word in `dict_minimum.inc` will be the last word created in your application, assuming you don't add any other words as you build your application.

You could, if you chose, edit `dict_minimum.inc` to change the order or content of your application's dictionary. However, this really should be avoided. Instead, use `dict_minimum.inc` as provided and add your own custom *.include* file that defines your application. That file, named `dict_appl.inc`, is discussed below.

1.2.4 Developing your own amforth system

The following sections describe the files you need to create for building your own amforth system. In general, these are the only files you will need to edit during development. You can often find suitable files already in the distribution that can serve as starting points for these files; just copy and edit them to make your own files.

`dict_appl.inc`

The file `dict_appl.inc` is created by you and contains those amforth words that you want to add to your application above and beyond the words added by `dict_minimum.inc` and `dict_core.inc`.

You create your own `dict_appl.inc` file using a standard text editor, such as AVRStudio4's text editor. Here is a simple `dict_appl.inc` file that I use for creating a typical amforth development system. It provides words for printing unsigned numbers, listing the dictionary, and displaying parts of memory.

Here is the `dict_appl.inc` file I created for my sample amforth system.

```
; this dictionary contains optional words
; they may be moved to the core dictionary if needed

.include "dict_minimum.inc"                ; <-- required!
.include "words/fill.asm"
.include "words/d-2star.asm"
.include "words/d-plus.asm"
.include "words/d-minus.asm"
.include "words/d-invert.asm"
.include "words/udot.asm"
.include "words/dot-s.asm"

.include "words/dotstring.asm"
.include "words/squote.asm"

.include "words/words.asm"

.include "words/edefer.asm"
.include "words/rdefer.asm"
.include "words/is.asm"

.include "appltturnkey.asm"
.include "words/int-store.asm"
.include "words/lms.asm"
.include "words/ms.asm"

.include "dict_compiler.inc"
.include "words/show-wordlist.asm"
.include "devices/atmega328p/device.inc"    ; <-- hard-coded path!
.include "dict_usart.inc"
```

Note that the first statement in my file includes the `dict_minimum.inc` file. Note also that I have hard-coded the path to the appropriate `device.inc` file. If you build your application for a different MCU, you will need to adjust this path.

You are free to include whatever words from the `words/` folder you want in your application. Note that if you accidentally include a duplicate word, assembling the resulting application will generate an error; you will need to edit out the duplicate word and reassemble.

`dict_appl_core.inc`

The file `dict_appl.inc` is created by you and contains those amforth words that you want to add to your application above and beyond the words added by `dict_minimum.inc` and `dict_core.inc`. The difference between this file and `dict_appl.inc` above is the words in this file will be written to high flash (the NRWW or bootloader section).

Because of the limited amount of space in the NRWW sections of most ATmega devices, you will want to limit the words in this file to those absolutely required to support amforth. In general, these are words that modify flash, such as `istore.asm`. Below is the `dict_appl_core.inc` file for my sample amforth system.

```
.include "dict_core.inc"                  ; <-- required!
.include "words/estore.asm"
.include "words/efetch.asm"

.include "words/istore.asm"
.include "words/istore_nrww.asm"
.include "words/ifetch.asm"
```

Note that my file starts by including the `dict_core.inc` file. You can add additional words in your `dict_appl_core.inc`, subject to space limitations in your MCU. If you accidentally include words already included by other segments of the amforth system, you will get assembler errors for the duplicates; just remove the duplicates from your `dict_appl_core.inc` file.

appltturnkey.asm

This file is created by you and contains the assembly language source for a turnkey application, as called out in the file `amforth.asm` (see appropriate section above).

The file `appltturnkey.asm` usually contains amforth words, written in assembly language, in the form shown in the `words/` subdirectory description above.

The following sample `appltturnkey.asm` file shows the default turnkey application. This application is suitable for most amforth systems and should be included when you build your system. Here is the `appltturnkey.asm` file for my sample amforth system.

```
; ( -- ) System
; R( -- )
; application specific turnkey action
VE_APPLTURNKEY:
    .dw $ff0b
    .db "appltturnkey",0
    .dw VE_HEAD
    .set VE_HEAD = VE_APPLTURNKEY
XT_APPLTURNKEY:
    .dw DO_COLON
PFA_APPLTURNKEY:
    .dw XT_INITUSER
    .dw XT_USART
    .dw XT_INTON
    .dw XT_CR
    .dw XT_CR
    .dw XT_VER
    .dw XT_CR
    .dw XT_SLITERAL
    .dw 22
    .db "Karl's amForth system "
    .dw XT_ITYPE

    .dw XT_EXIT
```

The above simple application initializes the user area and *USART0*, displays amforth's version information on the serial terminal, displays an extra message proclaiming this as my amforth system, then exits to the main amforth shell.

Note that my custom message ends with a space. I did this so the message had an even number of letters. If the string length is odd, the assembler reports a warning that it had to add a zero-byte to pad out an even number of bytes. (I could have also used the ,0 technique shown in the declaration of the `appltturnkey` string at the top of the file.)

The template file

You define the characteristics of your target hardware and your application in a template file. The template file is an assembly language source file you create with a standard ASCII text editor, such as AVRStudio4's text editor. Although this is called an assembly language source file, you will typically not write any true assembly language instructions. Instead, the contents of your template file will largely consist of *.include* and *.equ* statements.

Here is the template file, `myproj.asm`, for defining my sample amforth system running on an Atmega328P MCU with a clock frequency of 16 MHz.

```
;
; myproj.asm      a simple AVRStudio4 assembly-language project for amforth
;
;
; The order of the entries (esp the include order) must not be
; changed since it is very important that the settings are in the
; right order
;
; first is to include the macros from the amforth
; directory
.include "macros.asm"

; include the amforth device definition file. These
; files include the *def.inc from atmel internally.
.include "devices/atmega328p/device.asm"           ; <-- hard-coded path!

; amforth needs two essential parameters
; cpu clock in hertz, 1MHz is factory default
.equ F_CPU = 16000000

; terminal settings
.set WANT_ISR_RX = 1 ; interrupt driven receive
.set WANT_ISR_TX = 0 ; send slowly but with less code space

; initial baud rate of terminal
.include "drivers/usart_0.asm"
.equ BAUD = 38400

.if WANT_ISR_RX == 1
.set USART_B_VALUE = (1<<TXEN0) | (1<<RXEN0) | (1<<RXCIE0)
.else
.set USART_B_VALUE = (1<<TXEN0) | (1<<RXEN0)
.endif

.equ USART_C_VALUE = (3<<UCSZ00)

.equ TIBSIZE = $64      ; ANS94 needs at least 80 characters per line
.equ APPUSERSIZE = 10   ; size of application specific user area in bytes

; addresses of various data segments
.set here = ramstart      ; start address of HERE, grows upward
.set rstackstart = RAMEND ; start address of return stack, grows downward
.set stackstart = RAMEND - 80 ; start address of data stack, grows downward
.equ amforth_interpreter = max_dict_addr ; the same value as NRWW_START_ADDR
; change only if you know what to you do
.equ NUMWORDLISTS = 8 ; number of word lists in the search order, at least 8

.equ want_fun = 1 ; in case of an error out print an additional line with an caret indicating the

; include the whole source tree.
.include "amforth.asm"
```

Your template file must include the file `macros.asm`, and this should be the first statement (except for comments, of course) in your template file. The file `macros.asm` contains a set of macros specific to amforth, used to simplify the coding of the amforth words and underlying assembly language routines.

Next, your template file should include the `device.asm` file specific to your target hardware. This file is found in the `core\devices\<target>` folder that matches your target hardware. Note that in the above sample, the path to the `device.asm` file is hard-coded in the `.include` statement. If you are using a different MCU, you will need to edit this `.include` statement.

Next, your template file should declare a key equate required by amforth. The equate `F_CPU` defines the oscillator frequency, in Hertz, of your target hardware and is expressed as a long integer. The example shown above shows

the target system uses an 16 MHz clock; `F_CPU` is declared as 16000000.

Next, you need to set a couple of equates defining how your target hardware will use USART0. As shown, my amforth system will use receive interrupts for incoming characters (`WANT_ISR_RX = 1`) but will poll when sending characters (`WANT_ISR_TX = 0`). For your first system, leave these as defined. After you get more skilled in amforth, you can change these equates to tweak performance.

Next, your template file should include the assembly source file supporting the USART you intend to use as a console on your target hardware. The example above uses USART0 and includes the appropriate device include file. The equates `BAUD`, `USART_B_VALUE`, and `USART_C_VALUE` defines the characteristics of the USART that will ultimately serve as the console on your target hardware. You may need to alter these values in your own template file to match your target.

In general, the remaining equate values (*.equ* and *.set*) in the template file will be calculated automatically, based on previously defined values in the Atmel definition files for the various MCUs.

This completes the custom portion of the template file. All that remains is the final include statement, which basically adds all of the words that make up the standard amforth system. Everything you would need to do for the majority of amforth systems can be done with the statements available to you in your template file.

1.2.5 Setting up AVRStudio4

Begin by creating a new assembly-language project in AVRStudio4. For my sample, I named this project `myproj` and created it in the `c:\projects\amforth-4.2` folder.

I then created the four above files in my project folder (the folder holding `myproj.aps`).

Next, I added the path to the `core\` folder to my project. To do this, click on Project/Assembler Options and locate the entry for Additional include path. Enter in this field the full path to the `core` folder; in my case, this path is `C:\projects\amforth-4.2\core`.

This completes setup in AVRStudio4. Pressing F7 assembles the source files and leaves behind two object files. The file `myproj.hex` contains the flash contents for my amforth system and the file `myproj.eep` holds the EEPROM values needed at startup.

I then hooked my programming pod (an AVRISP mkII) to the target board and applied power. I first made sure that the device's fuses were properly set. In particular, I checked that the bootloader area was set to the maximum (2048 words for the ATmega328P), the EESAVE fuse was checked, and the fuse for BOOTRST (jump to bootloader on reset) was NOT checked.

Finally, I downloaded the EEPROM file to the target, followed by downloading the flash file. When I reset the target, the Hyperterm window hooked to the target's serial port showed the expected amforth announcement. My amforth system was up and running!

1.2.6 What could go wrong?

When you build a properly created amforth system, you should not get any errors or warnings. If the assembler complains about not finding included files, double-check the layout of your amforth folder; it should match what I've described at the beginning of this manual. Additionally, make sure you entered the path to your `core\` folder correctly in the Additional include path box when you set up the project's properties.

If the project builds properly but does not provide characters to your serial port when you download your code to the target, double-check that your Hyperterm settings match those in your template file (`myproj.asm` above). Also confirm that you got the MCU frequency correct in your template file. Also double-check that you put the correct hard-coded paths in your template file and in your `dict_appl.inc` file. Also make sure you download BOTH the *.hex* and the *.eep* files for your project, and that you have the EESAVE fuse on your device checked.

1.2.7 An alternative AVRStudio4 setup

The above method uses two hard-coded paths in your source files. This can cause problems if you later try to change processors; it's easy to forget to change one of the hard-coded paths and it can take time to track down the

error.

As an alternative, you can go to Project/Assembler Options and remove the path you added in the Additional include path field. Edit the Additional parameters field to include the following text, all entered on a single line:

```
-I C:\projects\amforth-4.2\core -I C:\projects\amforth-4.2\core\devices\atmega328p
```

Note that the above entry is for my project; adjust as needed for your file paths and target MCU. Be sure to include the single space after each *-I* as shown!

With this change in place, you can now remove the hard-coded paths in your template file and your `dict_appl.inc` file. For example, in my `myproj.asm` template file above, I had the line:

```
.include "devices/atmega328p/device.asm" ; <-- hard-coded path!
```

After adding the above change to the Additional parameters field, this line becomes:

```
.include "device.asm"
```

Make a similar change in `dict_appl.inc` and reassemble.

1.2.8 Revision History

Version	Author	Notes
4.2.0	Karl Lunt	Extensive changes to track amforth v4.2.
4.2.1	Karl Lunt	Minor changes to introduction
4.2.2	Matthias Trute	Reformatted with ReST

1.3 Instructions for Building amforth-5-1 using Atmel Studio 6.1 Components

Author: Craig Lindley Date: November, 2013

1.3.1 Motivation

Building AmForth requires a compatible assembler. Atmel Studio 6.1 for Windows includes `avrasm2.exe` which works great for this process but using Atmel Studio is overkill in my opinion. On my Mac Atmel Studio 6.1 takes forever to load and execute (using the Parallel's Desktop) plus it crashes half the time when I try to make changes to my amforth project's configuration.

I wanted to be able to quickly make changes to AmForth and turn around new hex and eep files for downloading into an Arduino Uno. Note: the technique I discuss here can be used for any Atmel target hardware, not just an Arduino Uno.

1.3.2 Prerequisites

1. Download and installation of the free version of Atmel Studio 6.1 on a Windows computer
2. Being comfortable running a command prompt in the Windows environment

1.3.3 Process

1. Create a project directory into which we are going to copy a bunch of files. I chose `c:\amforth` for my project directory.

2. Copy `avras2.exe` and the complete include directory from `c:\Program Files\Atmel\Atmel Toolchain\AVR Assembler\Native\2.1.39.1005\avrassembler` into the project directory
3. Uncompress and un tar the `amforth-5.1` distribution file (`amforth-5.1.tar.gz`) into the project directory
4. Go into the `amforth-5.1\appl\arduino` directory of the distribution and copy `uno.asm`, `dict_appl_code.inc`, `dict_appl.inc` and the words directory into the project directory.
5. Go into the `amforth-5.1\core\devices` directory and find the directory named with the processor you are going to use (in my case `atmega328p`) and from that directory copy `device.asm` and `device.inc` into the project directory.
6. Create a bat file in the project directory with the following content:

REM batch file for assembling amforth on windows

```
avras2.exe -fI -o uno.hex -e uno.eep -l uno.lst -I .\ -I amforth-5.1\core -I include -v0 uno.asm
```

I named my bat file `make.bat`.

When you have completed these steps you should have a directory structure as follows:

```
c:\amforth          - your project directory
  amforth-5.1       - the uncompressed and untarred amforth-5.1 distribution
    appl
    core
    doc
    . . .
    include         - copied from c:\Program Files\Atmel\AtmelToolchain\AVR Assembler\Native\2.
    words
    applturnkey.asm
    avras2.exe       - copied from c:\Program Files\Atmel\AtmelToolchain\AVR Assembler\Native\2.
    device.asm
    device.inc
    dict_appl.inc
    dict_appl_core.inc
    make.bat
```

If all is well, change directory to your project directory and type `make` from a command prompt. In less than a second you will have the new `amforth` files (hex file and eep file) for programming into your target hardware. You could now uninstall Atmel Studio if you want as it is no longer required.

Making changes to `amforth` is now very easy and turn around is very fast.

FAQ

2.1 Where do I find more information?

There are 2 documentation files: a *User's Manual* written by Karl Lunt and a more *Technical Guide*.

More can be found in the [Mailinglist archive](#)

2.2 How do I start with amforth?

First: You will have to build your own amforth first. To do this you really want to make copy of the `appl/template` directory and edit the files in it to fit your environment: controller type, cpu frequency, serial port settings etc. The files are well documented. Once the assembler produces two hex files and no errors (warnings should not come up either) you can proceed. If you are using the Atmel studio, make sure that the project settings include the generation of the eep files. This settings may be disabled by default.

Second you need a programmer to transfer the hex files you generated to the controller. The only programmers that can be used are those that can work on bare (micro controller) systems: ISP (e.g. the Atmel AVRISPmk2 or stk200 or ponyser), JTAG (e.g. the AVR Dragon), High Voltage programming (rarely used) or DebugWire (same: rarely used). Programming tools that relies on a boot loader on the micro-controller itself can not load amforth (the reasons are explained in the *Technical Guide*).

The program to talk with the programmer is avrdude. It is a swiss army knife like tool, that works for almost all devices on all operating systems (Linux, Windows, MacOS and few more). The [Makefiles](#) / [ANT](#) files use it. Other programs (just like the famous Atmel Studio) are never used by me, you are on your own.

After you transferred “burned” both hex files (one for the flash memory, one for the EEPROM memory), you can begin working with amforth on the serial connection.

2.3 How do I use amforth interactively?

At the command prompt you can enter any command and can explore the controller. To simply add two numbers just do the following:

```
> 24 42 + .  
66 ok  
>
```

To get the content of an IO register just use the memory mapped address (the example reads the 16bit return stack pointer which the just the normal mcu stack pointer):

```
> $5d @ .  
1101 ok  
> rpe @ .
```

```
1101 ok
>
```

8bit registers just use the `c@` command instead of the `@`. Writing to any address is just as simple:

```
> 17 pad !
ok
> pad @ .
17 ok
>
```

2.4 There are no hexfiles in the distribution archive!

Hex-files are very specific to the hardware, even the change of the oscillator frequency needs a rebuild. And every processor wants its own settings. There would be far too many different hex-files. For some targets a hex-file is provided (e.g AVR Butterfly).

2.5 I get no serial prompt!

You need to program two hex files, one for the flash memory and one for the EEPROM. The makefiles do that already automatically.

Next check are the frequency settings. Atmegs need a configuration (fuse setting) to use an external clock source. By default they run with an unstabilized 1MHz internal clock source, which is not well suited for serial communication. Check the datasheet of your controller to find the correct fuse settings, they are different for different atmegs and very sensitive, be absolutly careful! Rebuilt the hex files with the proper frequency (F_CPU setting).

Finally check the terminal settings: default are 9600 8N1, no flow control. If your terminal has different settings, change them.

Finally check the hardware. You may add a LED (or a scope) to the TX pin to check wether the controller sends out the boot message upon reset. Plug off all programmers (they may keep the RESET pin).

Check the mailing list archive for other hints or (finally) ask there for help.

2.6 What do all the words do?

amforth tries to implement the ans94 dialect of forth. The last public version is available at (e.g.) [Taygeta Archive](#)

2.7 Can I embed amforth into other programs?

Embedding amforth into other programs (e.g. written in C) is almost impossible. Amforth is designed to run stand-alone and does not follow any conventions that may be used on other systems.

2.8 Can I use code written in C (or any other language) with/in amforth?

Short answer: no.

2.9 How do I send forth code to the system?

Basically send them as ascii text via the terminal line. A command line like:

```
> ascii-xfr -s -c 10 -l 100 devices/atmega32.frt > /dev/ttyS0
```

can be used. amforth does not currently support any kind of flow control. Any transfer has to be slow enough to not overrun the buffers. A more sophisticated approach is described in *Use of the amforth-shell.py utility*

2.10 I found a bug

Too bad. Please send all information to the [Mailling List](#)

2.11 Does amforth run on hardware xy?

amforth is targeted to Atmel AVR Atmega controllers. It does not and never will run on Attiny controllers or on completely different architectures like PIC or 8051 etc. Work is currently under way to fully support Atmels ATXMega's.

2.12 What about the fuses?

Just set them to the factory defaults and adjust the oscillator settings only. amforth uses the self programming capabilities so if any boot loader works, amforth should do so. Make sure that the boot loader size is as large as the NRWW flash size, otherwise the flash write operation may fail silently and crash your system completely.

2.13 What about boot loaders?

amforth overwrites them, they are no longer existent. And this can only be changed for boot loaders with an application usable API to use the flash self programming feature. There are none currently available. With such an API the only word that's need to be rewritten is `!i`.

2.14 What do I need for linux?

The linux assembler avra comes without the controller definition files. They need to be copied from the Atmel AVR Studio. Please use the version 1 of the files from the `AvrAssembler/appnotes` directory. The Makefiles in the applications expect the files in the directory `~/lib/avra`. Please note that these files are horribly outdated and do not cover all controller types. For those controllers you need the Atmel AVR Assembler version2. See next note.

2.15 How do I use Atmel's assembler with linux?

First you need a working setup of a recent wine. Then put the `avrasm2.exe` and the `Appnotes` directory somewhere on your system. Then edit the `makefile` to look similar too:

```
AVRDUDE=/usr/local/bin/avrdude
PP=-c stk200 -P /dev/parport0
JTAG=-c jtag1 -P /dev/ttyUSB2
```

```
AVRASM=wine ~/projects/avr/AvrAssembler2/avrasm2.exe
AVRASMOPTS=-fI -I ~/projects/avr/AvrAssembler2/Appnotes -e $@.eep -l $@.lst -m $@.map

p8.hex: *.asm words/*.asm devices/*.asm
    $(AVRASM) $(AVRASMOPTS) p8.asm

p8: p8.hex
    $(AVRDUDE) $(PP) -p atmega644 -e -U flash:w:p8.hex:i -U eeprom:w:p8.hex.eep:i
```

please note that the file names are slightly different from the avra generated code. Good luck.

2.16 What resources are available in my own assembly words?

You can use any resource if you take care. There are some things you need to obey: Never use the T flag in the machine status register SREG. Only the CPU registers named temp0..temp5 are save to use without the need of restoration. Any other register change may be harmful.

TECHNICAL GUIDE

3.1 First Steps

The first steps require an ATmega micro controller with an RS232 connection to an PC or a terminal like the VT100 or similar hardware. A customization may change these requirements.

3.1.1 User Interface

amforth has a simple user interface. Connect your system to a serial terminal (or a PC) and you get, after pressing the enter key, the forth prompt >

```
> cold
amforth 5.0 ATmega16 8000 kHz
> words
nr> n>r (i!) !i @i @e !e nip not s>d up! up@ ...
>
```

3.2 Hardware

3.2.1 Controller

amforth is designed to run on AVR Atmega micro controllers. It requires ca 8KB flash memory for the basic system and can address 128KB of flash memory.

The ATtiny micro controllers and a few ATmega types lack the minimum flash capacity. The ATtiny's some machine instructions as well.

3.2.2 Bootloader Support

Most bootloaders will not work with amforth since they do not provide an application programming interface to rewrite a single flash cell. The default setup will thus replace any bootloader found with some core routines.

It is possible to change the word `!i` to use an API and work with existing bootloaders. `!i` is a deferred word that can be re-targeted to more advanced words that may do address range checks, write success checks or simply turn on/off LEDs to visualize the flash programming.

3.2.3 Fuses

Amforth uses the self programming feature of the ATmega micro controllers to work with the dictionary. It is ok to use the factory default settings plus the changes for the oscillator settings. It is recommended to use a higher CPU frequency to meet the timing requirements of the serial terminal.

Fuses are the main cause for problems with the flash write operations. If the `!i` operation fails, make sure that the code for it is within the boot loader section. It is recommended to make the bootloader section as large as the NRWW section, otherwise the basic machine instruction `spm` may fail silently and the controller becomes unresponsive.

3.2.4 External Modules

Most external modules are accessed with library modules.

3.3 Source Organization

3.3.1 Overview

amforth is written using the standard Atmel AVR 8 bit assembly language. That does not mean that every word is actually written in assembly language however. Most of the words are written in forth itself, but are precompiled into the assembler syntax. This solves the chicken-and-egg problem: how to compile the compiler words.

The source code can be processed with both the AVR Studio and the Linux `avr` assembler `avra`.

amforth consists of a great number of small source files. Nearly all words are coded in their own source files. These files are organized with include files, named after the pattern `dict*.inc`.

The include hierarchy is as follows: Top level is the application specific file (`template.asm`). It included the file `core/amforth.asm` only. This file includes the two files from the application directory: `dict_appl.inc` for the low address words (RWW space) and the file `dict_appl_core.inc` for the high address space words (NRWW). These two include files use other `dict*` files and direct words definition files. Any cross-references are solved by the assembler. The user needs to take care that the highest used address is within the flash address range, an assembler error message is generated in that case.

Currently the following pre defined `dict` files exist:

3.3.2 Source Filenames

Filename	Purpose	Placement
<code>dict_minimum.inc</code>	All basic words beyond the primitives.	Usually included via <code>dict_appl.inc</code> and placed in the RWW section. If possible put it into the NRWW section however.
<code>dict_mcu.inc</code>	Micro controller specific primitives.	It can be placed everywhere. Usually in <code>dict_appl_core.inc</code> .
<code>dict_core.inc</code>	All essential primitives.	Always near the inner interpreter (NRWW, <code>dict_appl_core.inc</code>).
<code>dict_compiler.inc</code>	All Compiler words.	Usually part of the <code>dict_appl.inc</code> .
<code>dict_vm.inc</code>	Not-Yet proposed additional VM registers A and B	Usually part of the <code>dict_appl.inc</code> .
<code>dict_wl.inc</code>	words dealing with word lists.	Usually part of the <code>dict_appl.inc</code>

The order in which the files are included defines the search order and there location within the flash memory. Most words can be moved from one include file to another to optimize the flash usage.

There are additional files: `amforth.asm` and `macros.asm`. The first one is the master file and the only one the application needs to include. The file `macros.asm` contains some useful assembler macros that make the source code easier to read. `user.inc` contains the layout of the system user area.

3.3.3 Core system

The file `amforth.asm` is the core of amforth. Here is the startup code for the micro controller, and the forth inner interpreter with the interrupt service routine. It includes the dictionary files.

3.3.4 Dictionary files

The dictionary files have two tasks: First they include the word definition files. Second, they determine each word's location in the resulting flash layout.

There are a few words left out from the dictionary lists. These words are either not always needed or are some variants of existing words or simply cannot be included in the core system due to size limitations in the NRW section with smaller atmegs. They are usually included by the application specific include file(s).

`dict_core.inc`

The file `dict_core.inc` contains all words for the NRW flash section, Since the word `!i` cannot write to this address range, no new words can be compiled to this section at runtime. Thus it is advisable to include as many words as possible in `dict_core.inc` if the amount of writable dictionary space is an issue. As a helper the file `dict_appl_core.inc` can be used to place application specific words in the core area.

`dict_minimum.inc`

A useful forth system needs in addition to the above at least the file `dict_minimum.inc`, which includes the forth interpreter words.

`dict_compiler.inc`

An almost complete forth system with a compiler gives the third include file: `dict_compiler.inc`.

`dict_appl.inc` and `dict_appl_core.inc`

Some words have their source files within the `core/words` directory but have to be included via the `dict_appl.inc` or `dict_appl_core.inc` files. These words may provide the hardware dependencies to access the amforth system. The serial line terminal is an example.

3.3.5 Device Settings

Every Atmega has its own specific settings. They are based on the official include files provided by Atmel and define the important settings for the serial IO port (which port and which parameters), the interrupt vectors and some macros.

Adapting another ATmega micro controller is as easy as copy and edit an existing file from a similar type.

The last definition is a string with the device name in clear text. This string is used within the word **VER**.

3.3.6 Application Code

Every build of amforth needs an application. There are a few sample applications, which can be used either directly (AVR Butterfly) or serve as a source for inspiration (template application).

The structure is basically always the same. First the file `macros.asm` has to be included. After that some definitions need to be done: The size of the Forth buffers, the CPU frequency, initial terminal settings etc. Then the device specific part needs to be included and as the last step the amforth core is included.

For a comfortable development cycle the use of a build utility such as **make** or **ant** is recommended. The assembler needs a few settings and the proper order of the include directories.

3.4 Architecture

3.4.1 Overview

amforth is a 16 bit Forth implementing the indirect threading model. The flash memory contains the whole dictionary. A few EEPROM cells are used to hold initial values and the dictionary pointers. The RAM contains buffers, variables and the stacks.

The compiler is a classic compiler without any optimization support.

amforth uses all of the CPU registers to hold vital data: The data stack pointer, the instruction pointer, the user pointer, and the Top-Of-Stack cell. The hardware stack is used as the return stack. Some registers are used for temporary data in primitives.

3.4.2 CPU – Forth VM Mapping

The Forth VM has a few registers that need to be mapped to the microcontroller registers. The mapping has been extended over time and may cover all available registers. The actual coverage depends on the amount of additional packages. The default settings are shown in the table *Register Mapping*.

Register Mapping

Forth Register	ATmega Register(s)
W: Working Register	R22:R23
IP: Instruction Pointer	XH:XL (R27:R26)
RSP: Return Stack Pointer	SPH:SPL
PSP: Parameter Stack Pointer	YH:YL (R29:R28)
UP: User Pointer	R4:R5
TOS: Top Of Stack	R24:R25
X: temporary register	ZH:ZL (R31:R30)

Extended Forth VM Register Mapping

Forth Register	ATmega Register(s)
A: Index and Scratch Register	R6:R7
B: Index and Scratch Register	R8:R9

In addition the register pair R0:R1 is used internally e.g. to hold the the result of multiply operations. The register pair R2:R3 is used as the zero value in many words. These registers must never be changed.

The registers from R10 to R13 are currently unused, but may be used for the VM extended registers X and Y sometimes. The registers R14 to R21 are used as temporary registers and can be used freely within one module as temp0 to temp7.

The forth core uses the T Flag in the machine status register SREG for signalling an interrupt. Any other code must not change that bit.

3.4.3 Core System

Threading Model

AmForth implements the classic indirect threaded variant of forth. The registers and their mappings are shown in table *Register Mapping*.

Inner Interpreter

For the indirect threading model an inner interpreter is needed. The inner interpreter does the interrupt handling too. It repeatedly reads the cell, the **IP** points to, takes this number as the address for the next code segment and jumps to that code. It is expected that this code segment does a jump back to the inner interpreter (**NEXT**). The **IP** is incremented by 1 just before the jumps are done to get the next cell.

```
Check_Interrupt
W  <- [IP]      ; read at IP
IP <- IP+1      ; advance IP
X  <- [W]       ; EXECUTE phase, W points to execution token
JMP [X]         ; read execution token and execute its code
```

NEXT

The **NEXT** routine is the core of the inner interpreter. It does the mapping between the execution tokens and the corresponding machine code. It consists of 4 steps which are executed for every forth word.

The first step is to check whether an interrupt needs to be handled. It is done by looking at the **T** flag in the machine status register. If it is set, the code jumps to the interrupt handling part.

The next step is to read the cell the **IP** points to and stores this value in the **W** register. For a **COLON** word **W** contains the address of the code field.

The 3rd step is to increase the **IP** register by 1.

The 4th step is the **EXECUTE** step.

EXECUTE

This operation is the **JUMP**. It reads the content of the cell the **W** register points to. The result is stored in the scratch pad register **X**. The data in **X** is the address of the machine code to be executed in the last step. This step is used by the forth command **EXECUTE** too. The forth command does not get the address of the next destination from the current **IP** but from the data stack.

This last step finally jumps to the machine code pointed to by the **X** scratch pad register.

DO COLON

DO COLON (aka **NEST**) is the subroutine call. It pushes the **IP** onto the return stack. It then increments **W** by one flash cell, so that it points to the body of the (colon) word, and sets **IP** to that value. Then it continues with **NEXT**, which begins executing the words in the body of the (parent) colon word. Note that **W** points to the execution token of the current word, so **W+1** points to the parameter field (body) of the forth word.

```
push IP
IP <- W+1
JMP NEXT
```

EXIT

The code for EXIT (aka UNNEST) is the return from a subroutine. It is defined in the forth word **EXIT** in the dictionary. It reads the **IP** from the return stack and jumps to NEXT. The return stack pointer is incremented by 2 (1 flash cell).

```
pop IP
JMP NEXT
```

3.4.4 Text Interpreter

The interpreter is a line based command interpreter. It based upon **REFILL** to acquire the next line of characters, located at a position **SOURCE** points to. While processing the line, the pointer **>IN** is adjusted accordingly. Both words **REFILL** and **SOURCE** are USER based deferred words which allows to use any input source on a thread specific level. The interpreter itself does not use any static buffers or variables (**>IN** is a USER variable as well).

A given string is handled by **INTERPRET** which splits it into whitespace delimited words. Every word is processed using a list of recognizers. Processing ends either when the string end is reached or an exception occurs.

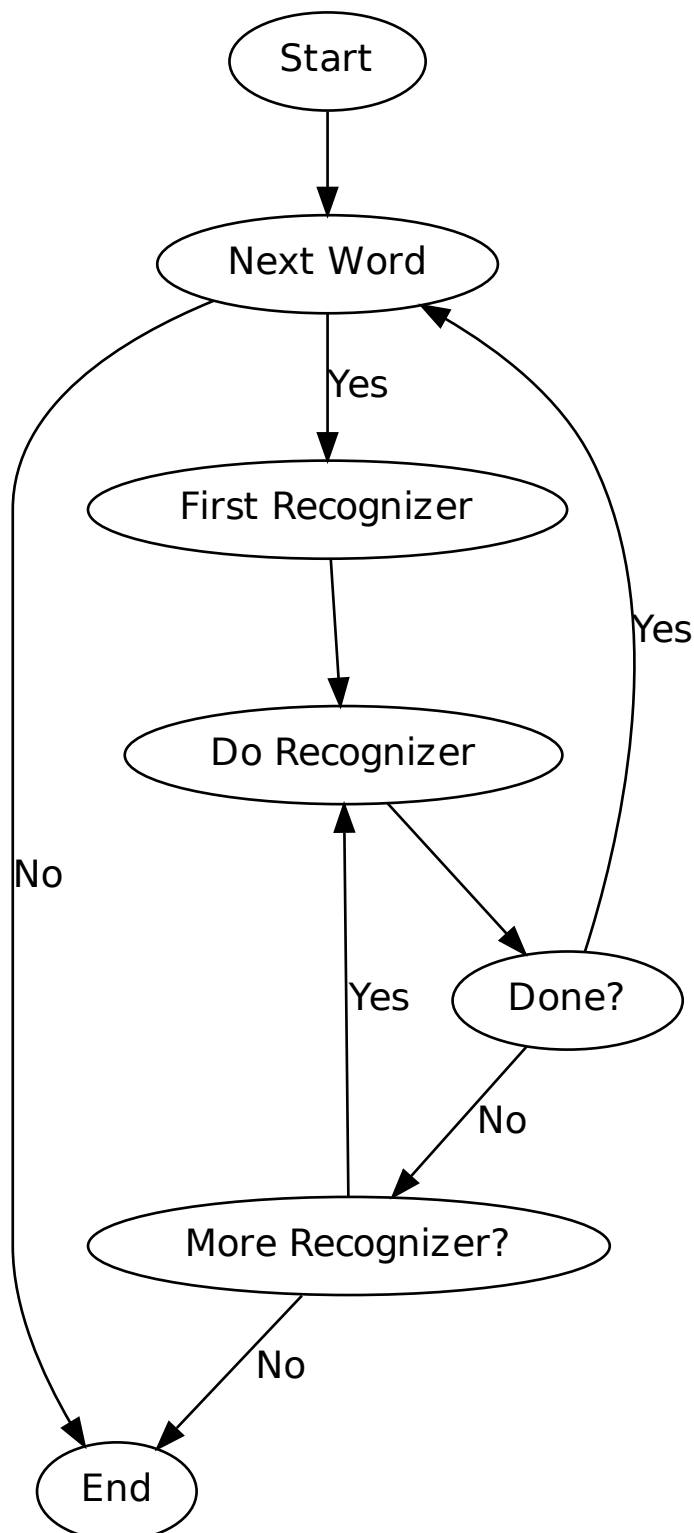
SOURCE and REFILL

SOURCE provides an addr/len string pair that does not change during processing. The task of **REFILL** is to fill the string buffer, **SOURCE** points to when finished.

There is one default input source: The terminal input buffer. This buffer gets filled with **REFILL-TIB** that reads from the serial input buffers (**KEY**). **SOURCE** points to the Terminal Input Buffer itself. Another input source are plain strings, used by **EVALUATE**.

Recognizer

The text interpreter does only split the source into single, whitespace separated words. For each word, a list of specialized actions is used to analyse and operate on the particular word.



A recognizer gets the string information of the current word. If the word can be processed, the recognizer is responsible to do so. A word from the dictionary has to be either executed or compiled, a number as well. A recognizer must not change the word buffer content. Finally the recognizer returns a flag to the interpreter which signals success or not. This flag

is consumed, any other stack change is kept.

Three recognizers are defined: Dictionary lookup **rec-find**, integer number conversion **rec-intnum** and a not-found dummy **rec-notfound**. The first two take care of the interpreter state and either leave more than the flag (e.g. the number entered) or compile the information to the dictionary.

The not-found recognizer prints the word and throws an exception -13 which can be caught.

The list of the recognizers is kept in the EEPROM, the maximum size of the entries is a compile time setting (currently 6 slot are available).

Example

A recognizer gets the address/len pair of a word in RAM and leaves at least the flag for the interpreter. If any data is to be left on the stack (e.g. numeric values) it has to be beneath the flag.

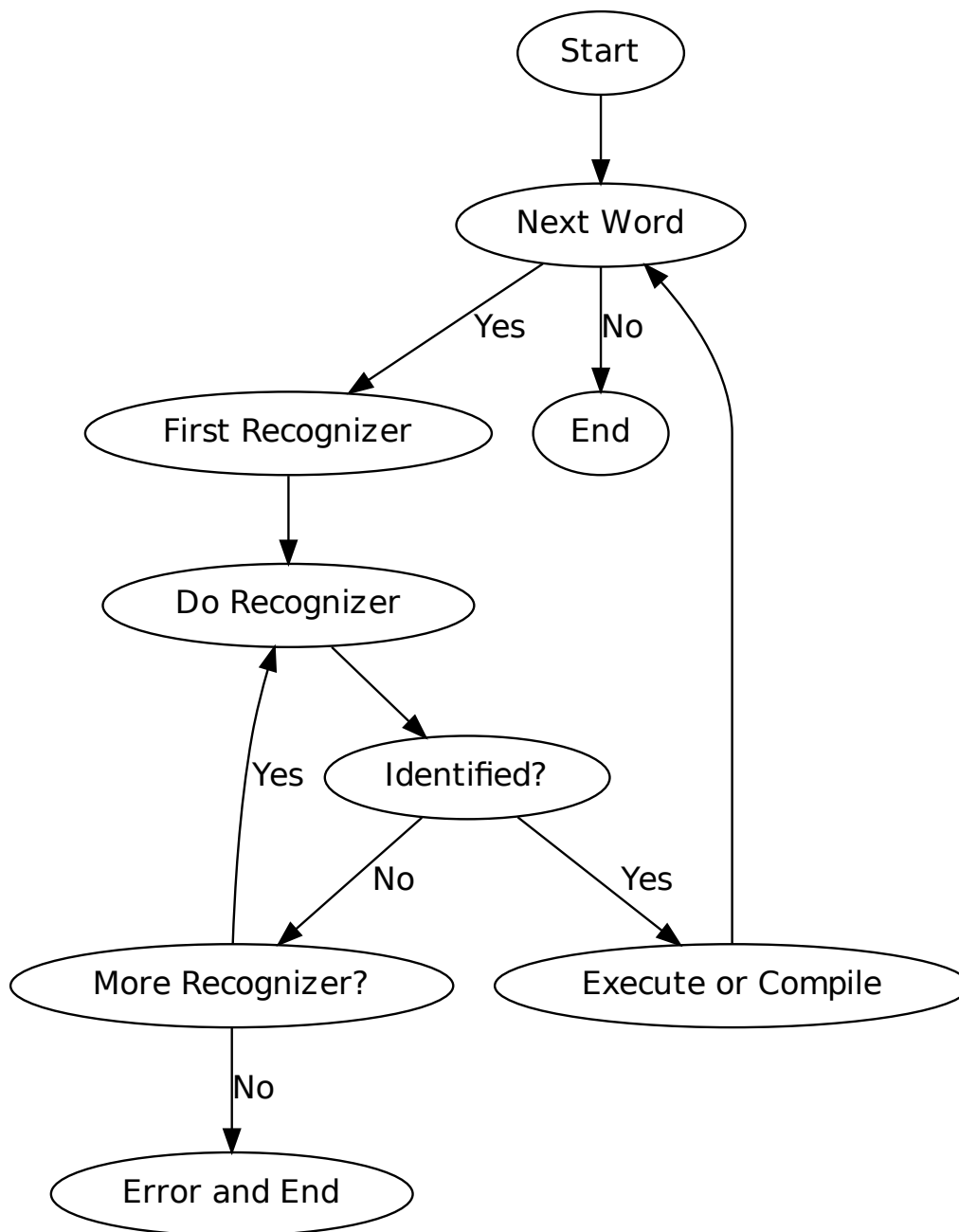
The small example illustrates the integration of the floating point library for amforth. It is based upon a conversion word **>float** which takes a string and tries to convert it into a float. The word **fliteral** compiles a floating point number into the dictionary.

```
: rec-float  \ \ addr len -- (f/) -1 | 0
>float
if state @ if postpone fliteral then -1 else 0
then ;
```

The recognizer first tries to convert the string to a number. If that fails, the flag from the **>float** is essentially duplicated and the recognizer is left. If the conversion succeeded, the floating point number is on the data stack. The recognizer now checks whether the number needs to be compiled or not. In any case the success flag is returned.

New Recognizer

In its current state, a recognizer not only parses and identified the word, but has to take care of the interpreter state and various other things (e.g. being postponed or not). This makes a single recognizer more complex and duplicates some code blocks (state smartness). To improve this situation, are more complex picture may be used in future versions:



With this structure the text interpreter is the only one that takes care of the state and acts on the execution tokens accordingly. The final goal is to get a system, that can be used in other forth's as well.

3.4.5 Stacks

Data Stack

The data stack uses the CPU register pair **YH:YL** as its data pointer. The Top-Of-Stack element (TOS) is in a register pair. Compared to a straight forward implementation this approach saves code space and gives higher execution speed (approx 10-20%). Saving even more stack elements does not really provide a greater benefit

(much more code and only little speed enhancements).

The data stack starts at a configurable distance below the return stack (RAMEND) and grows downward.

Return Stack

The Return Stack is the hardware stack of the controller. It is managed with push/pop assembler instructions. The default return stack starts at RAMEND and grows downward.

3.4.6 Interrupts

Amforth routes the low level interrupts into the forth inner interpreter. The inner interpreter switches the execution to a predefined word if an interrupt occurs. When that word finishes execution, the interrupted word is continued. The interrupt handlers are completely normal forth colon words without any stack effect. They do not get interrupted themselves.

The processing of interrupts takes place in two steps: The first one is the low level part. It is called whenever an interrupt occurs. The code is the same for all interrupts. It takes the number of the interrupt from its vector address and stores this in a RAM cell. Then the low level ISR sets the **T** flag in the status register of the controller and returns with **RET**.

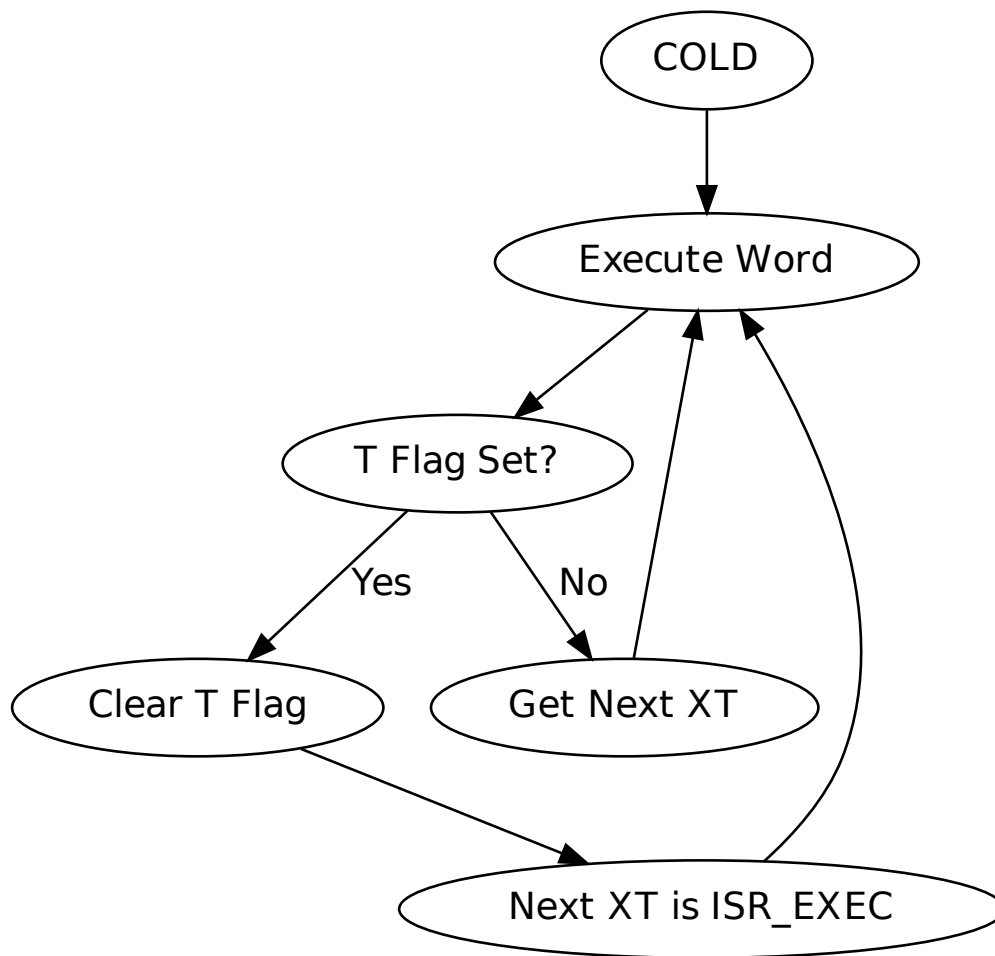
The second step does the inner interpreter. It checks the T-flag every time it is entered and, if it is set, it switches to interrupt handling at forth level. This approach has a penalty of 1 CPU cycle for checking and skipping the branch instruction to the isr forth code if no interrupt occurred.

If an interrupt is detected, the forth VM clears the T-flag and continues with the word **ISR-EXEC**. This word reads the currently active interrupt number and calls the associated execution token. When this word is finished, the word **ISR-END** is called. This word clears the interrupt flag for the controller (**RETI**).

This interrupt processing has two advantages: There are no lost interrupts (the controller itself disables interrupts within interrupts and re-transmits newly discovered interrupts afterwards) and it is possible to use standard forth words to deal with any kind of interrupts.

Interrupts from some hardware sources (e.g. the usart) need to be cleared from the Interrupt Service Routine. If this is not done within the ISR, the interrupt is re-triggered immediately after the ISR returned control.

The downside is a relatively long latency since the the forth VM has to be synchronized with the interrupt handling code in order to use normal colon words as ISR. This penalty is usually small since only words in assembly can cause the delay.

**See Also:**

Interrupt Service Routines Interrupt Critical Section

3.4.7 Multitasking

amforth does not implement multitasking directly. It provides the basic functionality however. Within IO words the deferred word **PAUSE** is called whenever possible. This word is initialized to do nothing (**NOOP**).

3.4.8 Exceptions

Amforth uses and supports exceptions as specified in the ANS wordset. It provides the **CATCH** and **THROW** commands. The outermost catch frame is located at the interpreter level in the word **QUIT**. If an exception with a negative value is caught, **QUIT** will print a message with this number and re-start itself. Positive values silently restart **QUIT**.

The next table lists the exceptions, amforth may throw itself.

Exception	Meaning	Used in
-1	silent abort	ABORT
-2	abort with message	ABORT"
-4	stack underflow	?STACK
-13	undefined word	rec-notfound, tick
-16	Invalid word	(create)
-50	search order	previous

3.4.9 User Area

The User Area is a special RAM storage area. It contains the USER variables and the User deferred definitions. Access is based upon the value of the user pointer UP. It can be changed with the word **UP!** and read with **UP@** . The UP itself is stored in a register pair.

The size of the user area is determined by the size the system itself uses plus a configurable number at compile time. For self defined tasks this user supplied number can be changed for task local variables.

The first USER area is located at the first data address (usually RAMSTART).

Address offset (bytes)	Purpose
0	Multitasker Status
2	Multitasker Follower
4	RP0
6	SP0
8	SP (used by multitasker)
10	HANDLER (exception handling)
12	BASE (number conversion)
14	EMIT (deferred)
16	EMIT? (deferred)
18	KEY (deferred)
20	KEY? (deferred)
22	SOURCE (deferred)
24	>IN
26	REFILL (deferred)

The User Area is used to provide task local information. Without an active multitasker it contains the starting values for the stackpointers, the deferred words for terminal IO, the BASE variable and the exception handler.

The multitasker uses the first 2 cells to store the status and the link to the next entry in the task list. In that situation the user area is/can be seen as the task control block.

Beginning with release 3.7 the USER area has been split into two parts. The first one called system user area contains all the variables described above. The second one is the application user area that contains all variables defined with the USER command. The default application user area is empty and by default of size zero.

3.4.10 Word Lists and Environment Queries

Word lists and environment queries are implemented using the same structure. The word list identifier is a EEPROM address that holds the name field address of the first word in the word list.

Environment queries are normal colon words. They are called within **environment?** and leave there results at the data stack.

find-name (und **find** for counted strings) uses an array of word list identifiers to search for the word. This list can be accessed with **get-order** as well.

Wordlist Header

Wordlists are implemented as a single linked list. The list entry consists of 4 elements:

- Name Field (NF) (variable length, at least 2 flash cells).
- Link Field (LF) (1 flash cell), points to the NFA of the next element.
- Execution Token (XT) (1 flash cell)
- Parameter Field (Body) (variable length)

The wording is some mixture of old style fig-forth and the more modern variants. The order makes it possible to implement the list iterators (**search-wordlist** and **show-wordlist**) in a straight forward way.

The name field itself is a structure containing the flags, the length information in the first flash cell and the characters of the word name in a packed format afterwards.

The anchor of any wordlist points to the name field address of the first element. The last element has a zero link field content. The lists are created from lower addresses to higher ones, the links go from higher addresses backwards to lower ones.

3.4.11 Memories

Flash

The flash memory is divided into 4 sections. The first section, starting at address 0, contains the interrupt vector table for the low level interrupt handling and a character string with the name of the controller in plain text.

The 2nd section contains the low level interrupt handling routines. The interrupt handler is very closely tied to the inner interpreter. It is located near the first section to use the faster relative jump instructions.

The 3rd section is the first part of the dictionary. Nearly all colon words are located here. New words are appended to this section. This section is filled with FFFF cells when flashing the controller initially. The current write pointer is the DP pointer.

The last section is identical to the boot loader section of the ATmegs. It is also known as the NRWW area. Here is the heart of amforth: The inner interpreter and most of the words coded in assembly language.

FLASH Structure Overview

The reason for this split is a technical one: to work with a dictionary in flash the controller needs to write to the flash. The ATmega architecture provides a mechanism called self-programming by using a special instruction and a rather complex algorithm. This instruction only works in the boot loader/NRWW section. amforth uses this instruction in the word I!. Due to the fact that the self programming is a lot more than only a simple instruction, amforth needs most of the forth core system to achieve it. A side effect is that amforth cannot co-exist with classic boot loaders. If a particular boot loader provides an API to enable applications to call the flash write operation, amforth can be restructured to use it. Currently only very few and seldom used boot loaders exist that enable this feature.

Atmegs can have more than 64 KB Flash. This requires more than a 16 bit address, which is more than the cell size. For one type of those bigger atmegs there will be an solution with 16 bit cell size: Atmega128 Controllers. They can use the whole address range with an interpretation trick: The flash addresses are in fact not byte addresses but word addresses. Since amforth does not deal with bytes but cells it is possible to use the whole address range with a 16 bit cell. The Atmegs with 128 KBytes Flash operate slightly slower since the address interpretation needs more code to access the flash (both read and write). The source code uses assembly macros to hide the differences.

An alternative approach to place the elements in the flash shows picture . Here all code goes into the RWW section. This layout definitely needs a routine in the NRWW section that provides a cell level flash write functionality. The usual boot loaders do not have such an runtime accessible API, only the DFU boot loader from atmel found on some USB enabled controllers does.

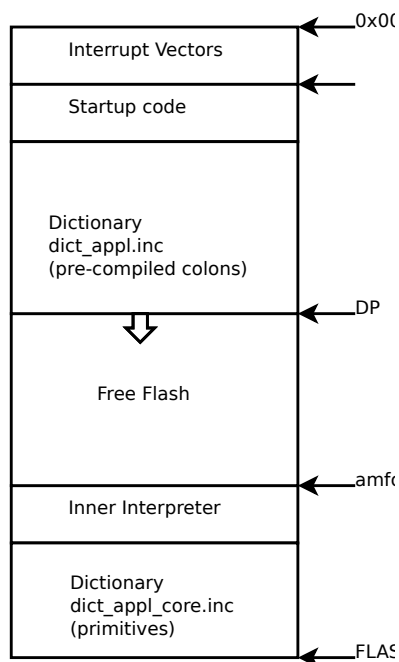


Figure 3.1: Default Flash Structure

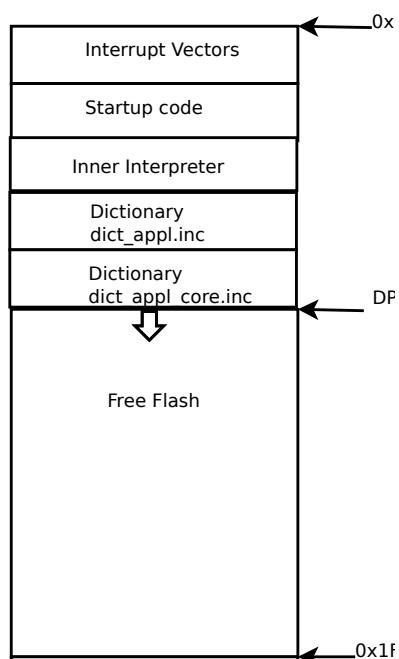


Figure 3.2: Alternative Flash Structure

Alternative FLASH Structure

The unused flash area beyond 0x1FFFF is not directly accessible for amforth. It could be used as a block device.

Flash Write

The word performing the actual flash write operation is **!** (i-store). This word takes the value and the address of a single cell to be written to flash from the data stack. The address is a word address, not a byte address!

The flash write strategy follows Atmel's appnotes. The first step is turning off all interrupts. Then the affected flash page is read into the flash page buffer. While doing the copying a check is performed whether a flash erase cycle is needed. The flash erase can be avoided if no bit is turned from 0 to 1. Only if a bit is switched from 0 to 1 must a flash page erase operation be done. In the fourth step the new flash data is written and the flash is set back to normal operation and the interrupt flag is restored. The whole process takes a few milliseconds.

This write strategy ensures that the flash has minimal flash erase cycles while extending the dictionary. In addition it keeps the forth system simple since it does not need to deal with page sizes or RAM based buffers for dictionary operations.

3.4.12 EEPROM

The built-in EEPROM contains vital dictionary pointer and other persistent data. They need only a few EEPROM cells. The remaining space is available for user programs. The easiest way to use the EEPROM is a **VALUE**. There intended design pattern (read often, write seldom) is like that for the typical EEPROM usage. More information about values can be found in the recipe *Values*.

Another use for EEPROM cells is to hold execution tokens. The default system uses this for the turnkey vector. This is an EEPROM variable that reads and executes the XT at runtime. It is based on the DEFER/IS standard. To define a deferred word in the EEPROM use the Edefer definition word. The standard word IS is used to put a new XT into it.

Low level space management is done through the the EDP variable. This is not a forth value but a EEPROM based variable. To read the current value an **@e** operation must be used, changes are written back with **!e**. It contains the highest EEPROM address currently allocated. The name is based on the DP variable, which points to the highest dictionary address.

3.4.13 RAM

The RAM address space is divided into three sections: the first 32 addresses are the CPU registers. Above come the IO registers and extended IO registers and finally the RAM itself.

amforth needs very little RAM space for its internal data structures. The biggest part are the buffers for the terminal IO. In general RAM is managed with the words **VARIABLE** and **ALLOT**.

Forth defines a few transient buffer regions for various purposes. The most important is PAD, the scratch buffer. It is located 100 bytes above the current HERE and goes to upper addresses. The Pictured Numeric Output is just at PAD and grows downward. The word WORD uses the area above HERE as it's buffer to store the just recognized word from SOURCE.

Ram Structure shows an RAM layout that can be used on systems without external RAM. All elements are located within the internal memory pool.

Another layout, that makes the external RAM easily available is shown in *Alternative RAM Structure*. Here are the stacks at the beginning of the internal RAM and the data space region. All other buffers grow directly into the external data space. From an application point of view there is not difference but a speed penalty when working with external RAM instead of internal.

With amforth all three sections can be accessed using their RAM addresses. That makes it quite easy to work with words like **C@**. The word **!** implements a LSB byte order: The lower part of the cell is stored at the lower address.

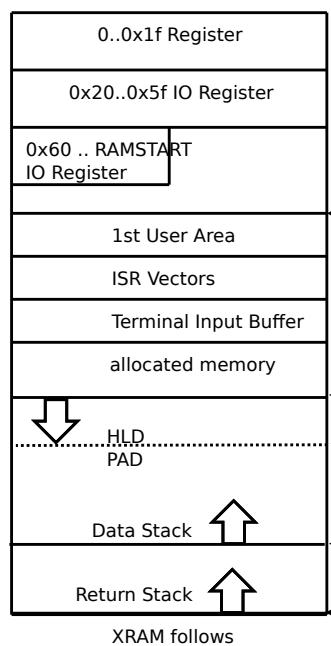


Figure 3.3: Ram Structure

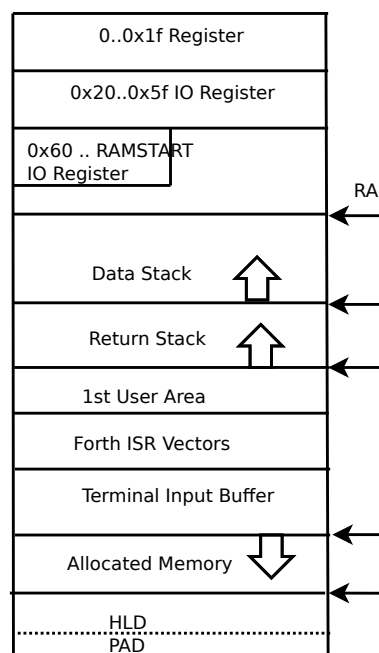


Figure 3.4: Alternative RAM Structure

For the RAM there is the word **Rdefer** which defines a deferred word, placed in RAM. As a special case there is the word **Udefer**, which sets up a deferred word in the user area. To put an XT into them the word **IS** is used. This word is smart enough to distinguish between the various Xdefer definitions.

3.4.14 DOES>

DOES> is used to change the runtime action of a word that **create** has already defined.

Its working is described best using a simple example: defining a constant. The standard word **constant** does exactly the same.

```
> : con create , does> @i ;
ok
> 42 con answer
ok
> answer .
42 ok
```

The first command creates a new command **con**. With it a new word gets defined, in this example **answer**. **con** calls **create**, that parses the source buffer and creates a wordlist entry **answer**. After that, within **con** the top-of-stack element (42) is compiled into the newly defined word. The **does>** changes the runtime of the newly defined word **answer** to the code that follows **does>**.

does> is an immediate word. That means, it is not compiled into the new word (**con**) but executed. This compile time action creates a small data structure similar to the wordlist entry for a noname: word. The address of this data structure is an execution token. This execution token replaces the standard XT that **create** has already written for words that are defined using **con**. This leads inevitably to a flash erase cycle.

3.5 Implementation

3.5.1 Dictionary Management

The dictionary can be seen from several points of view. One is the split into two memory regions: NRWW and RWW flash. This is the hardware view. NRWW flash cannot be read during a flash write operation, NRWW means Non-Read-While-Write. This makes it impossible to change there anything at runtime. On the other hand is this the place, where code resides that can change the RWW (Read-While-Write) part of the flash. For AmForth, the command **!i** does this work: It changes a single flash cell in the RWW section of the flash. This command hides all actions that are necessary to achieve this.

The NRWW section is usually large enough to hold the interpreter core and most (if not all) words coded in assembly (not to be confused with the words that are hand-assembled into a execution token list) too. Having all of them within a rather small memory region makes it possible to use the short-ranged and fast relative jumps instead of slower full-range jumps necessary for RWW entries.

Another point of view to the dictionary is the memory allocation. The key for it is the dictionary pointer **dp**. It is a EEPROM based VALUE that stores the address of the first unused flash cell. With this pointer it is easy to allocate or free flash space at the end of the allocated area. It is not possible to maintain “holes” in the address range. To append a single number to the dictionary, the command **,** is used. It writes the data and increases the DP pointer accordingly:

```
\ ( n -- )
: , dp !i dp 1+ to dp ;
```

To free a flash region, the DP pointer can be set to any value, but a lot of care has to be taken, that all other system data is still consistent with it.

The next view point to the dictionary are the wordlists. A wordlist is a single linked, searchable list of entries. All wordlists create the forth dictionary. A wordlist is identified by its **wid**, an EEPROM address, that contains the address of the first entry. The entries themselves contain a pointer to the next entry or ZERO to indicate End-Of-List. When a new entry is added to a list it will be the first one of this wordlist afterwards.

A new wordlist is easily created: Simply reserve an EEPROM cell and initialize its content with 0:

```
: wordlist ( -- wid )
  edp 0 over !e
  dup cell+ to edp ;
```

This `wid` is used to create new entries. The basic procedure to do it is **create**:

```
: create
  (create) reveal
  postpone (constant) ;
```

(create) parses the current source to get a space delimited string. The next step is to determine, into which wordlists the new entry will be placed and finally, the new entry is created, but it is still invisible:

```
: (create)
  parse-name
  wlscope
  dup >r
  header
  r> smudge 2! ;
```

The **header** command starts a new dictionary entry. The first action is to copy the string from RAM to the flash. The second task is to create the link for the wordlist management

```
: header
  dp >r
  \ copy the string from RAM to flash
  r> @e ,
  \ minor housekeeping
;
```

`smudge` is the address of a 4 byte RAM location, that buffers the access information. Why not not all words are immediately visible is something, that the forth standard requires. The command **reveal** un-hides the new entry by adjusting the content of the wordlist identifier to the address of the new entry:

```
: reveal
  smudge @ ?dup if \ check if valid data
    smudge 2+ @ !e \ update the wid
    0 smudge ! \ invalidate
  then ;
```

The command **wlscope** can be used to change the wordlist that gets the new entry. It is a deferred word that defaults to **get-current**.

The last command **postpone (constant)** writes the runtime action, the execution token (XT) into the newly created word. The XT is the address of executable machine code that the forth inner interpreter calls (see *Inner Interpreter*). The machine code for **(constant)** puts the address of the flash cell that follows the XT on the data stack.

3.5.2 Compiler

The Amforth Compiler is based upon immediate words. They are always executed, regardless of the value in the `state` variable. All non-immediate words get compiled verbatim with their respective execution token. It is simply appended to the current DP location.

Immediate words are usually executed (unless some special action such as **postpone** is applied). The immediate words do usually generate some data or compile it to the dictionary. They are not compiled with their execution token.

There are no optimization steps involved. The XT are written immediately into the dictionary (flash).

3.5.3 Control Structures

The inner interpreter, the forth virtual machine, can, just like a real CPU, only execute words, one after the next. This linear control flow is usually not sufficient to do real work. The Forth VM needs to be redirected to other places instead of the next one, often depending on runtime decisions.

Since Edsger Dijkstra the structured programming is the preferred way to do it. AmForth provides all kinds of them: sequences, selections and repetitions. Sequences are the simple, linear execution of consecutive words. Selections provide a conditional jump over code segments. They are usually implemented with the **if** command. Multiple selections can be made with **case**. Repetitions can be unlimited or limited. Limited Repetitions can use flags and counter/limits to leave the loop.

There is also support for out-of-band control flow: Exceptions. They provide some kind of emergency exits to solve hard problems. They can be caught at any level up to the outer text interpreter. It will print a message on the command terminal and will wait for commands.

Building Blocks

All control structures can be implemented using jumps and conditional jumps. Every control operation results in either a forward or a backward jump. Thus 6 building blocks are needed to create them all: **(branch)**, **(0branch)**, **>mark**, **<mark**, **>resolve** and **<resolve**. None of them are directly accessible however. Most of these words are used in pairs. The data stack is used as the control flow stack. At runtime the top-of-stack element is the flag. All words are used in immediate words. They are executed at compile time and produce code for the runtime action.

(branch) is a unconditional jump. It reads the flash cell after the command and takes it as the jump destination. Jumps can be at any distance in any direction. **(0branch)** reads the Top-Of-Stack element and jumps if it is zero (e.g. logically FALSE). If it is non-zero, the jump is not made and execution continues with the next XT in the dictionary. In this case, the branch destination field is ignored. These two words are implemented in assembly. A equivalent forth implementation would be

```
: (branch) r> 1+ @i >r ;
: (0branch) if (branch) else r> 1+ >r then ;
```

Note the chicken-and-egg problem with the conditional branch operation.

The **mark** words put the jump destination onto the data stack. This information is used by the **resolve** words to actually complete the operation. The **<mark** additionally reserves one flash cell. The **<resolve** stores the information for the backward jump at the current location of the dictionary pointer, the **>resolve** places the information at the place the **>mark** has reserved and completes the forward jump. Every mark needs to be paired with the *right* resolve.

```
: >mark dp -1 , ;
: >resolve ?stack dp swap !i ;

: <mark dp ;
: <resolve ?stack , ;
```

The place holder -1 in **>mark** prevents a flash erase cycle when the jump is resolved using the **!i** in **>resolve**. The **?stack** checks for the existence of a data stack entry, not for a plausible value. If the data stack is empty, an exception -4 is thrown.

```
: ?stack depth 0< if -4 throw then ;
```

Highlevel Structures

The building blocks described above create the standard control structures: conditional execution and various loop constructs.

Conditional Execution

The conditional execution compiles a forward jump to another location. The jump destination is resolved with **then**. An **else** terminates the first jump and starts a new one for the final **then**. This way an alternate code block is executed at runtime depending on the flag given to the **if**.

```
: if postpone (0branch) >mark ; immediate
: else postpone (branch) >mark swap >resolve ; immediate
: then >resolve ; immediate
```

There is a rarely used variant of the **if** command, that compiles an unconditional forward branch: **ahead**. It needs to be paired with a **then** to resolve the branch destination too. An **else** would not make any sense, but is syntactically ok.

```
: ahead postpone (branch) >mark ; immediate
```

There are more variants of multiple selections possible. The **case** structure is based upon nested **if**'s. Computed goto's can be implemented with jump tables which execution tokens as code blocks. Examples are in the **lib** directory.

Conditional Loops

The loop commands create a structure for repeated execution of code blocks. A loop starts with a **begin** to which the program flow can jump back any time.

```
: begin <mark ; immediate
```

The first group of loop command are created with **again** and **until**. They basically differ from each with the branch command they compile:

```
: until postpone (0branch) <resolve ; immediate
: again postpone (branch) <resolve ; immediate
```

The other loop construct starts with **begin** too. The control flow is further organized with **while** and **repeat**. **while** checks whether a flag is true and leaves the loop while **repeat** unconditionally repeats it.

```
: while postpone (0branch) >mark swap ; immediate
: repeat again >resolve ; immediate
```

Counted Loops

Counted loops need to store the starting address and the address of the last word of the loop body. The first one is needed to jump back if the counter has not yet reached its limit. The forward jump is made in **leave** to unconditionally exit the loop body.

```
: do postpone (do) >mark <mark ; immediate
: loop postpone (loop) <resolve >resolve ; immediate
```

The other loop commands **?do** and **+loop** are almost identical to their respective counterparts, they compile only a different runtime action to their goals.

The runtime action of **do** (the **(do)**) puts three information onto the return stack: The loop counter, the loop limit and the destination address for the **leave**. The first two parameters are taken from the data stack at runtime, the leave-address comes from the compiler (from the **>mark**).

The runtime of **loop** (the **(loop)**) checks the limits and with **0branch** decides whether to repeat the loop body with the next loop counter value or to exit the loop body. If the loop has terminated, it cleans up the return stack. The **+loop** works almost identically, except that it reads the loop counter increment from the data stack.

The access to the loop counters within the loops is done with **i** and **j**. Since the return stack is used to manage the loop runtime, it is necessary to clean it up. This is done with either **unloop** or **leave**. Note that **unloop** does not leave the loop!

3.6 Standard Wordlists

3.6.1 ANS94 Words

amforth is close to the ANS94 Forth standard. The main difference comes from the fact that the AVR ATmegas use a Harvard architecture (separate code and data address space) that amforth does not hide. amforth gives full and unmodified access to the whole address space.

amforth implements most or all words from the ANS word sets CORE, CORE EXT, EXCEPTION and DOUBLE NUMBERS. A loadable floating point library that contains the basic routines is available. Words from the word sets LOCALS and FILE-ACCESS are dropped completely. The others are partially implemented.

Core and Core EXT

All words from the CORE word set are available. CORE EXT drops the words **C"**, **CONVERT**, **EXPECT**, **SPAN**, and **ROLL**.

Loop counters are checked on signed compares.

Block

amforth has limited block support with I2C/TWI serial eeprom chips with 2 byte addresses.

Double Number

Double cell numbers work as expected. Not all words are implemented. Entering them directly using the dot-notation work for dots at the end of the number, not if the dot is somewhere within it.

Exception

Exceptions are fully supported. The words **ABORT** and **ABORT"** use them internally.

The **THROW** codes -1, -2 and -13 work as specified.

The implementation is based upon a variable **HANDLER** which holds the current return stack pointer position. This variable is a **USER** variable.

Facility

The basic system uses the **KEY?** and **EMIT?** words as deferred words in the **USER** area.

The word **MS** is implemented with the word **1MS** which busy waits almost exactly 1 millisecond. The calculation is based upon the frequency specified at compile time.

The words **TIME&DATE**, **EKEY**, **EKEY>CHAR** are not implemented.

To control a VT100 terminal the words **AT-XY** and **PAGE** are written in forth code. They emit the ANSI control codes according to the VT100 terminal codes.

File Access

amforth does not have filesystem support. It does not contain any words from this word set.

Floating Point

amforth has a loadable floating point library. It contains the basic words to deal with single precision floats. The floats are managed on the standard data stack. After loading the library floats can be entered directly at the command prompt. Some speed sensitive words are available as assembly code as well.

Locals

amforth does not currently support locals.

Memory Allocation

amforth does not support the words from the memory allocation word set.

Programming Tools

Variants of the words **.S**, **?** and **DUMP** are implemented or can easily be done. The word **SEE** is available as well. **STATE** works as specified.

The word **WORDS** does not sort the word list and does not take care of screen sizes.

The words **;CODE** and **ASSEMBLER** are not supported. amforth has a loadable assembler which can be used with the words **CODE** and **END-CODE**.

The control stack commands **CS-ROLL**, and **CS-PICK** are not implemented. The compiler words operate with the more traditional **MARK / RESOLVE** word pairs.

FORGET is not implemented since it would be nearly impossible to reset the search order word list with reasonable efforts. The better way is using **MARKER** from the library.

An **EDITOR** is not implemented.

[IF], **[ELSE]** and **[THEN]** are not implemented.

Word Lists and Search Order

Amforth supports the ANS Search Order word list. A word list consist of a linked list of words in the dictionary. There are no limits on the number of word lists defined. Only the length of the active search order is limited: There can be up to 8 entries at any given moment. This limit can be changed at compile time in the application definition file.

Internally the word list identifier is the address where the word list start address is stored in the EEPROM. Creating a new word list means to allocate a new EEPROM cell. Since the ANS standard does not give named word list there is library code available that uses the old fashioned vocabulary.

Strings

SLITERAL, **CMOVE>**, **CMOVE**, **COMPARE>**, and **/STRING** are implemented.

-TRAILING, **BLANK**, and **SEARCH** are not implemented.

3.6.2 Forth 200x

amforth provides the **defer/is**, **buffer:** and the **structure** extensions from the forth 200x standards.

Defer and IS

defer give the possibility of vectored execution. Amforth has 3 different kind of such vectors, varying in how they are stored: EEPROM, RAM or the USER area. The EEPROM makes it possible to save the settings permanently, the RAM enables frequent changes. Finally the user area is for multitasking.

Buffer:

The buffer allocates a named memory (RAM) region. It is superior to the usual `create foo xx allot` since amforth has a non-unified memory model and the code snippet does not the same as an unified memory model forth (with the dictionary being at the same memory as the `allot` command works).

Structures

3.6.3 Amforth

COLD

The startup code is in the file `cold.asm`. It gets called directly from the address 0 vector.

This assembly part of the startup code creates the basic runtime environment to start the virtual forth machine. It sets up the stack pointers and the user pointer and places the forth instruction pointer on the word `WARM`. Then it boots the forth virtual machine by jumping to the inner interpreter.

The start addresses of the stacks are placed to the user area for later use as well.

WARM

The word `WARM` is the high level part of the forth VM initialization. When called from within forth it is the equivalent to a `RESET`. `WARM` initializes the `PAUSE` deferred word to do nothing, calls the application defined `TURNKEY` action and finally hands over to `QUIT`.

TURNKEY

The `turnkey` is a EEPROM deferred word that points to an application specific startup word.

Its main task is to initialize the character IO to enable the forth interpreter to interact with the command prompt. The examples shipped with amforth do this by “opening” the serial port, switching to decimal number conversion and setting up the character IO deferred words (`KEY`, `EMIT` etc).

QUIT

`QUIT` initializes both data and return stack pointers by reading them from the user area and enters the traditional `ACCEPT – INTERPRET` loop that never ends. It provides the topmost exception catcher as well. Depending on the exception thrown, it prints an error message and restarts itself.

MCU Access

amforth provides wrapper words for the micro controller instructions **SLEEP** and **WDR** (watch dog reset). To work properly, the MCU needs more configuration. amforth itself does not call these words.

Assembler

Lubos Pekny has written an assembler for amforth. To support it, amforth provides the two words **CODE** and **END-CODE**. The first creates a dictionary entry and sets the code field to the data field address. The interpreter will thus jump directly into the data field assuming some machine code there. The word **END-CODE** places a JUMP NEXT into the data field. This finishes the machine instruction execution and jumps back to the forth interpreter.

Memories

Atmega micro controller have three different types of memory. RAM, EEPROM and Flash. The words **@** and **!** work on the RAM address space (which includes IO Ports and the CPU register), the words **@e** and **!e** operate on the EEPROM and **@i** and **!i** deal with the flash memory. All these words transfer one cell (2 bytes) between the memory and the data stack. The address is always the native address of the target storage: byte-based for EEPROM and RAM, word-based for flash. Therefore the flash addresses 64 KWords or 128 KBytes address space.

External RAM shares the normal RAM address space after initialization (which can be done in the turnkey action). It is accessible without further changes.

For RAM only there is the special word pair **c@/c!** which operate with the lower half of a stack cell. The upper byte is either ignored or set to 0 (zero).

All other types of external memory need special handling, which may be masked with the block word set.

Input Output

amforth uses character terminal IO. A serial console is used. All IO is based upon the standard words **EMIT/EMIT?** and **KEY/KEY?**. Additionally the word **/KEY** is used to signal the sender to stop. All these words are deferred words in the USER area and can be changed with the **IS** command.

The predefined words use an interrupt driven IO with a buffer for input and output. They do not implement a handshake procedure (XON/XOFF or CTS/RTS). The default terminal device is selected at compile time.

These basic words include a call to the **PAUSE** command to enable the use of multitasking.

Other IO depend on the hardware connected to the micro controller. Code exists to use LCD and TV devices. CAN, USB or I2C are possible as well. Another use of the redirect feature is the following: consider some input data in external EEPROM (or SD-Cards). To read it, the words **KEY** and **KEY?** can be redirected to fetch the data from them.

Strings

Strings can be stored in two areas: RAM and FLASH. It is not possible to distinguish between the storage areas based on the addresses found on the data stack, it's up to the developer to keep track.

Strings are stored as counted strings with a 16 bit counter value (1 flash cell) Strings in flash are compressed: two consecutive characters (bytes) are placed into one flash cell. The standard word **S"** copies the string from the RAM into flash using the word **S,**.

3.7 Tools

3.7.1 Host

There are a few number of tools on the host side (PC) that are specifically written to support amforth. They are written in script languages like Perl and python and should work on all major operating systems. They are not needed to use amforth but may be useful.

Part description Converter

The **pd2amforth.pl** script reads a part description file in XML format (comes with the Atmel Studio package) and produces the controller specific `devices/controllername/*` files.

Documentation

The tool **makerefcard** reads the assembly files from the **words** subdirectory and creates a reference card. The resulting LaTeX file needs to be processed with **latex** to generate a nice looking overview of all words available in the amforth core system.

The command **make-htmlwords** creates the linked overview of all words on the amforth homepage.

Uploader

To transfer forth code to the micro controller some precautions need to be taken. During a flash write operation all interrupts are turned off. This may lead to lost characters on the serial line. One solution is to send very slowly and hope that the receiver gets all characters. A better solution is to send a character and wait for the echo from the controller. This may sound awfully slow at the glance but it turned out to be a fast and reliable strategy.

An example for the first strategy can be used with the program **ascii-xfer**. Calling it with the command line parameters

```
$ ascii-xfer -s -c $delayChar -l $delayLine file > $tty
```

will work but the upload of longer files needs a very long time: `$delayChar` can be 1 or 2 ms, `$delayLine` around 800 ms.

Uploader++

The powerful Python script **amforth-shell.py** is using echo to regulate uploading. It recognizes Forth comments, single and multi line, and skips uploading them. The shell also features automatic file inclusion via `#include filename.frt` meta commands and, what can save a lot of dictionary space and clutter, it does constant substitution for the AVR register names and the project's own definitions (via a locally provided `appl_defs.frt` file). The shell has much more to offer, please read its script.

3.7.2 Controller

There are a few tools that may be useful on the controller. They are implemented as loadable forth code that may affect internal data and work flows in a non-portable way. In particular are available a profiler (counting calls to words), a call tracer (printing a stack trace while executing the words), a timing utility (**benchme**), a few memory dump tools and a **see** that may be useful to revert the compilation process (gets some forth code from compiled words).

See Also:

Profiler Debug Shell Watcher Tracer

COOKBOOK

The Cookbook is a collection of small and not so small recipes. Every recipe is intended to deal with exactly one task. It is a living document, so expect changes at any time.

4.1 Popular Boards

4.1.1 Arduino Hello World

The example for the blinking LED works on every arduino with a LED attached to Digital-13. It is tested on a arduino mega.

What does the code do? It lets the LED blink and gives some hints for using and enjoying amforth.

First: A few constants:

```
> $25 constant PORTB
> $24 constant DDRB
```

The sign > is the command prompt, if you see it, you can enter any commands. You'll never enter that character yourselves. A command line can be up to 80 characters long, if you need a longer one, you'll need to change the sources and reflash the system.

The arduino uses its own numbering schema for pins, but for now we use the atmega one: digital-13 is the same as bit 7 of PORT-B. Port B has 8 pins and three registers, we need only two of them: The Data Direction Register (DDR) and the PORT (Output) Register. The third register is used for reading from the port (PIN).

To quickly test the hardware enter the following commands:

```
> $80 DDRB c! $80 PORTB c! <enter>
```

The led turns on. With:

```
> 0 PORTB c!
```

the led turns off. You can repeat these commands and watch the LED.

The next step is to define some commands and use them. And add some more features that make life easier.

Forth usually uses many small words which do exactly one thing. When entering forth commands take care that every word is separated by at least one space. In forth almost every character can be used as part of a command name.

The first command in this example sets up the Data Direction Register to make the LED Port an output pin. In arduino sketch it would be:

```
void setup() {
  pinMode(13, OUTPUT);
}
```

The same in Forth is:

```
: led-init  $80 DDRB c! ;
```

By entering the command line the interpreter will learn a new command: **led-init**. This command can be called immediately after the command prompt says OK. And it can be used in further command definitions.

It writes the 8-bit number 128 (hex 80) to the register DDRB (hex 24) as defined above. This makes the 7th bit of PORTB an Output pin.

Calling our newly defined word does not change anything visible. But with the next word, the LED will turn on:

```
: led-on  $80 PORTB c! ;
```

Here the 7th bit will be set to 1, and that makes the led to be connected to VCC (5V) and it will turn on (the LED is connected to ground already).

If the led-on command does not turn on the LED just call the **led-init** command (again). The led-init is needed after an reset or power cycle as well.

Now that the led is active, we want a command to turn it off. One solution is to repeat the command from above: **0 PORTB c!**. Smarter is a new command word:

```
: led-off  0 PORTB c! ;
```

You can now use the newly defined commands to turn the led on and off:

```
> led-on led-off led-on led-off
```

(since there is no timing involved yet, you may not even see the led glow)

Our next word will simplify this, saves many keystrokes, and gives the real blink experience:

```
: led-blink led-on 500 ms led-off 500 ms ;
```

Calling this command will turn the led on, waits half a second, turn it off again and waits again half a second before returning to the command prompt.

With a command line like:

```
> led-blink led-blink led-blink
```

The led will blink for a few seconds.

To make it blink “forever”, the next word is helpful

```
: blink-forever
  ." press any key to stop "
  begin
    led-blink
    key?
  until
  key drop \ we do not want to keep this key stroke
;
```

This word prints some text (“press any key to stop”) and starts a loop. This loop lets the led blink one and checks for a keystroke. If no key is pressed, the loops is repeated. If a key is pressed, the loop is terminated. The last two commands are housekeeping: read the key pressed and forget it. Otherwise the key pressed would be the first character of the next command line.

The advantage of defining many words is that you can test them immediately. Thus any further code can rely on words already being tested and that makes debugging a lot easier. The drawback of that many words? You need some more code space for the names of the commands. There is no speed penalty.

4.1.2 Arduino Analog

Accessing the Analog ports for reading needs the files `lib/bitnames.frt` for basic routines, the file `appl/arduino/blocks/ports-arduinotype.frt` for the actual ports and `appl/arduino/blocks/wiring_analog.frt` for the code to do the work. After loading the files, the Analog Conversion Module has to be initialized with the **adc.init**. This has to be done after a reset and power cycle as well.

Now it is time to connect some hardware to one of the ports labeled *Analog In*. Once this is done, some simple commands will work:

```
> analog.1 adc.get u.
67 ok
>
```

The ADC on the ATmega has a resolution of 10 bits, thus a number between 0 and 1023 can be expected as the result.

Note that the ADC module needs some time between two conversion. If you do it too fast, expect malfunctions or even crashes. A simple **50 ms** circumvent most problems.

```
\ continuously read the adc port
\ and print the new value if it
\ has changed considerably since last round
\ note the 50ms delay to keep things
\ run smoothly. A key press will
\ return to the command prompt
: analog-test
  0
  begin
    ( -- old )
    analog.1 adc.get ( -- old new )
    swap over        ( -- new old new )
    - abs 6 >        ( -- new f )
    50 ms            ( wait...)
    if dup u. then   ( -- new )
      key?           ( -- new f )
  until
  key drop
drop ;
```

4.1.3 AVR Butterfly

The Butterfly Demo board from Atmel uses an Atmega169 controller. It uses the internal 8MHz oscillator which can be calibrated with the external 32kHz quartz.

amforth uses the serial connection (3pin connection on the left side) as it's terminal.

amforth *completely* replaces the flash content. It overwrites the bootloader. You definitely need ISP or JTAG to upload amforth to the controller. Afterwards the serial programming does not work anymore. You've been warned!

A lot of useful code and examples how to use the various parts of the butterfly can be found at the wiki of the German FIG Forth e.V. at www.forth-ev.de/wiki/doku.php/projects:avr:hilfsmittel. Basic Knowledge of the German language is required.

The 32 kHz external quartz can be used to generate a timer tick. The following definition may help:

```
\ implement a timer with the 32kHz oscillator
decimal
\ timer/counter subsystem
182 constant ASSR
\ timer/counter2
```

```
179 constant OCR2A
178 constant TCNT2
176 constant TCCR2A
112 constant TIMSK2
75 constant GPIOR2
55 constant TIFR2
4  constant OC2addr
5  constant OVF2addr

variable tick

\ increment the tick variable
: timer2isr ( -- )
  1 tick +!
;

\ initialize and start the timer.
: +32kHz ( -- )
  \ Set timer 2 to asynchronous mode (32.768KHz crystal)
  1 3 lshift ASSR c!
  \ Start with prescaler 128
  1 0 lshift
  1 2 lshift or TCCR2A c!
  \ Wait until timer 2's external 32.768KHz crystal is stable
  begin
    ASSR c@
    1 2 lshift \ TCN2UB
    1 0 lshift or \ TCR2UB
    1 1 lshift or \ OCR2UB
    and
  until
  0 tick !
  \ use overflow interrupt
  ['] timer2isr OVF2addr int!
  1 TIMSK2 c!
;

: -32kHz
  \ Turn off interrupt
  0 TIMSK2 c!
  \ Turn off timer 2 asynchronous mode
  ASSR c@
  1 3 lshift invert and ASSR c!
;
```

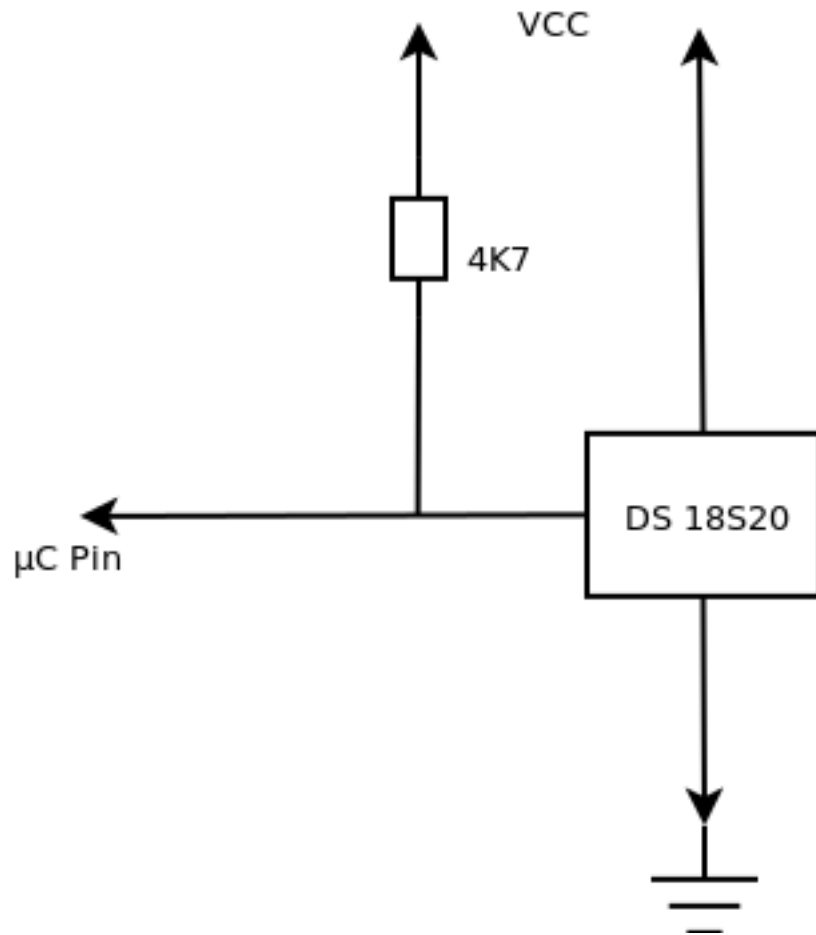
4.2 Hardware Modules

4.2.1 Dallas 1-Wire Devices

Dallas 1-Wire devices use 1 wire (besides ground level) to connect a peripheral device with the hostmaster. A common use case are the temperature sensors DS18[SIB]20. The communication protocol between the device and the micro controller is simple but at some points very timing sensible.

The typical wiring is shown in the picture. The pull up resistor is recommended as well as the connection to VCC.

This recipe is based upon work from Brad Rodriguez for the 4€4th project. He split the 1-wire module into two parts: a bit level layer for all the dirty, time critical work with only 2 small assembly words, and all other stuff in portable forth code. Despite the fact, that he uses another controller type, the forth code remained almost the same.



To use the 1-wire module new AmForth hexfiles have to be created with the file `drivers/1wire.asm` included into your project master file (e.g. `template.asm`) All configuration is done with 2 constants that are set in the same file. They define, which pin is connected to the 1-wire bus. There are no defaults

```

; Port and Pin for the 1-wire bus.
.equ OW_BIT=4
.equ OW_PORT=PORTE

.include "drivers/1wire.asm"

```

After burning the new system into the controller, two new words are available: **1w.reset** and **1w.slot**. The **1w.reset** reinitializes the 1-wire bus and gives a flag, whether at least one device is present or not. It would not make much sense to continue, if no device is recognized.

```

: 1wirejob ... 1w.reset if
  do-the-job
then ... ;

```

The **1w.slot** writes the LSB to the 1-wire bus and reads one bit back, if a 1 was written. It turns off all interrupts for approx 60 microseconds to achieve the correct timing. The lower byte of the TOS is rotated so repeated calls to **1w.slot** can transfer all bits of a bytes without further code. It is probably the smartest word of the whole package.

```

: 1w.touch ( c1 -- c2 )
  1w.slot 1w.slot 1w.slot 1w.slot
  1w.slot 1w.slot 1w.slot 1w.slot ;

: 1w.put ( c -- ) 1w.touch drop ;
: 1w.get ( -- c ) $ff 1w.touch ;

```

1-Wire Tools

The first useful tool is the low level **1w.reset**. It checks whether at least one 1-wire device is present and working or not. Other useful tools are in the file `1wire.frt`. They perform a ROM search to print all ROM id's of the connected devices.

```
(ATmega1280)> hex 1w.showids  
  
10 11 E5 68 2 8 0 2A  
28 4C 75 CC 2 0 0 CD  
ok  
(ATmega1280)>
```

Code specialized for temperature sensors is in the file `1wire-temp.frt`. Keep in mind, that at least 2 different sensor types are available with different result encoding's. The code is not currently capable to take care of the differences.

```
> hex create sensor2 28 , 4C , 75 , CC , 2 , 0 , 0 , CD ,  
ok  
> decimal sensor2 1w.convert 750 ms sensor2 readtemp temp>pad pad count type  
18.0 ok  
>
```

Possible Improvements

The module opens the door to the 1-wire world. It is by far not complete or finished. Some things could (or should?) be done better. Feel free to improve them and share them, please.

4.2.2 Digital Ports

Atmegas have digital ports each with 8 individual pins. They that can be configured as input and output pins. To make an easy use of them, amforth has a small library `bitnames.frt` in the lib directory.

With this library, you can give any pin a name and can manipulate it afterwards regardless of others.

```
PORTB 1 portpin: led
```

Output pins

The simplest hardware is a LED connected to one pin. The following sequence initializes the pin and turns the LED on:

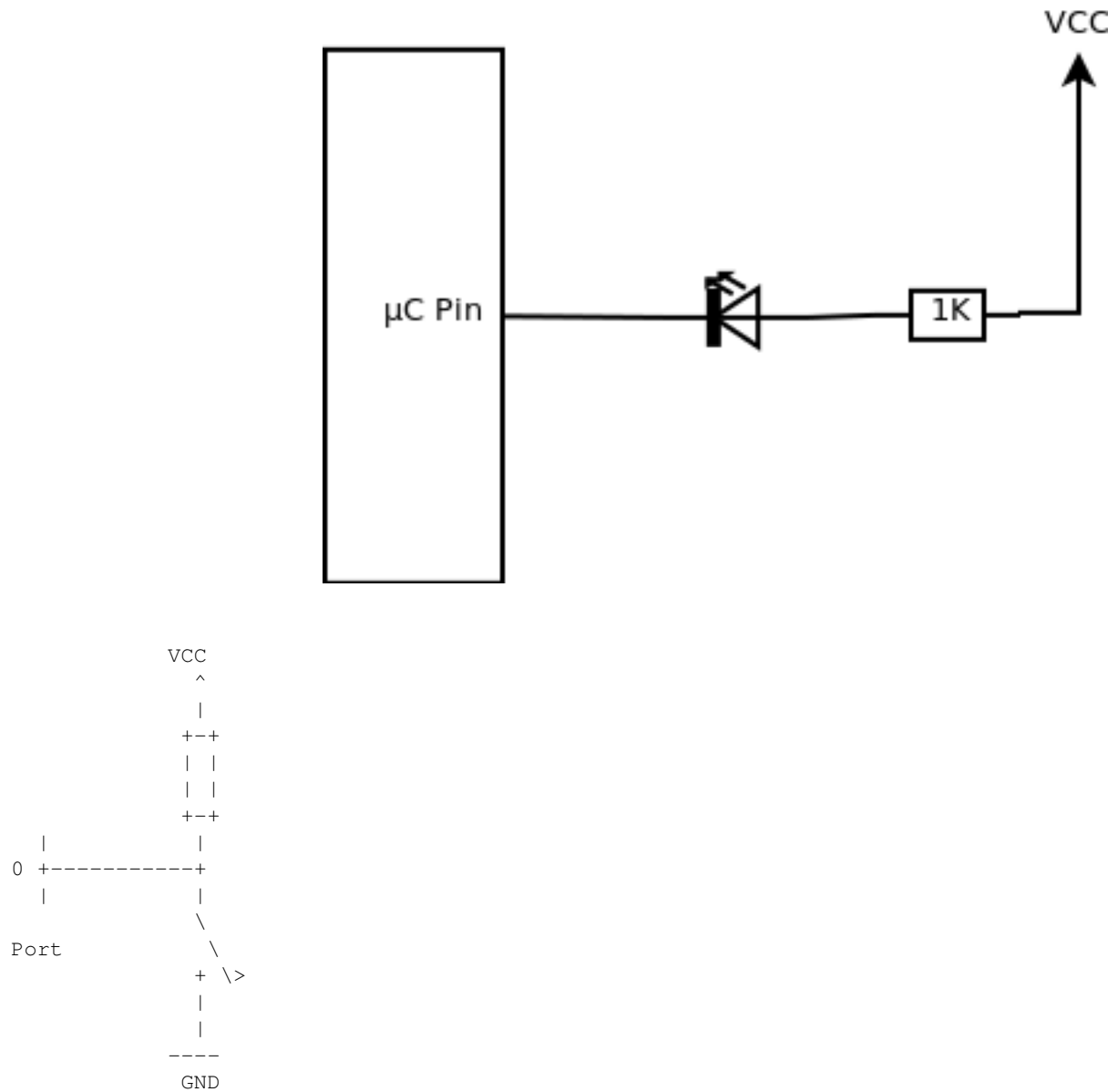
```
> PORTB 1 portpin: led  
ok  
> led is_output  
ok  
> led low
```

To turn it off, simply execute

```
> led high
```

Input pins

Input pins are used to get the voltage state: High or Low. A simple hardware would be as follows:



The resistor is not really needed, the pin can be configured to use an internal resistor.

```
> PORTB 0 portpin: mykey
ok
> mykey is_input
ok
> mykey pin_pullup_on
```

If the key is not pressed, the resistor (either the internal pull up or the external resistor) drives the voltage to high. If you read the pin, you will get a 1 in this example:

```
> mykey pin@ .
1 ok
```

if the key gets pressed, it will connect the controller pin with ground level, giving a 0

```
> mykey pin@ .
0 ok
```

4.2.3 EEPROM

This recipe is about the internal EEPROM storage of the atmega's. It does not deal with external devices such as I2C or SPI EEPROM chips.

The EEPROM contains usually 512 to 2048 bytes, depending on the actual controller type. The address range goes from zero (0) upwards and is independent of the other memory regions flash and RAM. The address unit is the byte, just like RAM. There is no alignment involved.

The usage pattern of the EEPROM is `write seldom read often`, which is slightly different from flash (write almost never, read very often) and RAM (read and write more than often). Any data written to EEPROM is kept over reset and power off.

built in's

The basic words to access EEPROM are `@e` and `!e`. They operate with the standard 2 bytes forth cells to read and write data. There is no byte-level access.

```
2 @e u.  
64 82 !e
```

Amforth uses EEPROM internally already. To keep track of the free memory area the command `edp` gives the first free EEPROM address.

```
> edp u.  
82 ok  
>
```

The following commands manage EEPROM space: `Edefer` and `value`. `value` is works according to the ANS94 standard.

```
> 1 value one  
ok  
> one u.  
1 ok  
> 17 to one  
ok  
> one u.  
17 ok  
>
```

The `Edefer` word defines a word that, when called executes another word by its execution token. Amforth uses this technique to implement the `turnkey` action.

```
> Edefer foo  
ok  
> ' ver is foo  
ok  
> foo  
amforth 5.0 ATmega32 ok  
> ' words is foo  
ok  
> foo  
foo one is pick nip ...  
>
```

your own stuff

To use EEPROM storage without `value` or `Edefer`, the command `edp` is the building block. It is the pointer to the first unused byte in the EEPROM. It is itself a `value` that can be adjusted with `to` to allocate (or free) address space.

```
> : Ealloc edp swap over + to edp ;
ok
> edp u. 17 Ealloc edp u.
84 101 ok
> value my-eprom
ok
> my-eprom u.
84 ok
>
```

The `Ealloc (n -)` in the example leaves the start address of the allocated area on the stack. It is later stored in the newly defined value `my-eprom`.

Adjusting `edp` as described above is consistent with later use of `value` and `Edefer`.

Arrays

Arrays can be placed in EEPROM as well

```
> : Ebuffer: edp value Ealloc ; ( n -- ) ( similar to buffer: from forth200x)
ok
> 42 Ebuffer: my-array
ok
> : my-array-@ cells my-array + @e ;
ok
> : my-array-! cells my-array + !e ;
ok
>
```

The recipe Using Arrays may give further ideas.

4.2.4 Efficient Bit Manipulation

Idea and Implementation: Enoch

Some Atmegas have a number of General Purpose IO Registers. They are not connected to any hardware but can be used with special instructions. They are executed in one CPU cycle and have the additional advantage to be interrupt safe.

This solution differs from the bitnames approach in that it does not operate on addresses but creates new commands that do so.

```
PORTA 0 port:hi! relay_on
PORTA 0 port:lo! relay_off
```

A bitname solution would look like

```
PORTA 0 portpin: relay
: relay_on relay high ;
: relay_off relay low ;
```

The implementation of the first solution generates highly optimized machine code. The bitname solution is more generic but significantly slower and is not interrupt safe.

```
: port:hi ( portadr bitno -- ) \ SBI
    swap $20 - 3 lshift or $9A00 or code , end-code
;

: port:lo ( portadr bitno -- ) \ CBI
    swap $20 - 3 lshift or $9800 or code , end-code
;
```

Additionally some range checks should be applied to make sure that the instruction does actually work as it should be

```
: _bitio
  dup $1F U> if &-9 throw then
  over $7 U> if &-9 throw then
;

: port:hi ( portadr bitno -- ) \ SBI
  swap $20 - _bitio
  3 lshift or $9A00 or
  code , end-code
;

: port:lo ( portadr bitno -- ) \ CBI
  swap $20 - _bitio
  3 lshift or $9800 or
  code , end-code
;
```

4.2.5 Interrupt Service Routines

The interrupt forth word is simply a colon word. It is executed within the context of the current user area and stack frame. It must not have any stack effect outside the word. Using `throw` is not recommended since it will affect the user area of the interrupted task.

```
\ TIMER_0 example
\
\ requires
\ in application master file
\   .set WANT_TIMER_COUNTER_0 = 1
\ from device.frt
\   TIMER0_OVFAddr
\ provides
\ timer0.tick      -- increasing ticker
\
\ older mcu's may need
\   TCCR0 constant TCCR0B
\   TIMSK constant TIMSK0

variable timer0.tick

: timer0.isr
  1 timer0.tick +!
;

: timer0.init ( preload -- )
  0 timer0.tick !
  TCNT0 c! \ preload
  ['] timer0.isr TIMER0_OVFAddr int!
;

\ some settings for 8bit timer to
\ get 1ms ticks
\ f_cpu prescaler preload
\ 16MHz 64 6
\ 8MHz 64 131

: timer0.start
  0 timer0.tick !
  %00000011 TCCR0B c! \ prescaler 64
  %00000001 TIMSK0 c! \ enable overflow interrupt
```

```
;
: timer0.stop
  %00000000 TCCR0B c! \ stop timer
  %00000000 TIMSK0 c! \ stop interrupt
;
```

All interrupts are available for forth interrupts. Versions earlier than 4.4 have the limitation that hardware interrupt conditions could not be cleared.

`int!` (and friends) uses the interrupt address from the data sheet as an index, but points to a different address in RAM.

Interrupts are processed in two stages. First stage is a simple low-level processing routine.

1. The low-level interrupt routine stores the index of the interrupt in a RAM cell (not directly accessible from amforth).
2. Sets the T-flag in the status register to signal the inner interpreter that an interrupt needs attention.

The inner interpreter checks *every* time it is entered the T-flag. If it is set (1) the interrupt processing routine is activated. It reads the number of the interrupt and calculates the index into the RAM based interrupt vector table. This table is identical to the atmega interrupt table in the flash except that it holds the XT of the forth words that will be started for the interrupt.

4.2.6 Interrupt Critical Section

There are situations where no interrupts should be allowed. These code segments are usually named critical sections.

```
: bar ." bar" int? . ;
: baz ." baz" int? . ;
: qux ." qux" int? . ;

: foo \ prints bar-1 baz0 qux-1.
  bar
  critical[
    \ nothing will disturb us here
    baz
  ]critical \ now interrupts or other things may happen again
  qux ;
```

If the standard interrupt enabled system setup is used, calling **foo** should print `bar-1 baz0 qux-1`. **baz** can call words that use the `critical[]` word pair itself.

To temporarily turn off interrupts, the current state has to be stored. Since the critical section could be nested, a global variable is not the best solution. The following code example stores the information on the return stack. This requires some stack shuffling since a colon word is usually not allowed to manipulate the return stack outside of its own scope. This is the reason, why the critical section must be paired within one definition afterwards. Otherwise the return stack will have data that crashes the system.

```
\ global interrupt enable state as forth flag
: int? ( -- f )
  SREG c@ SREG_I and 0> \ use the amforth-shell for the constants
;

: critical[ \ ( -- ) R( XT -- f XT )
  r> int? >r >r \ keep the current state
  -int
;

: ]critical \ ( -- ) R( f XT -- XT )
```

```
r> r> if +int then >r \ will crash if not matched
;
```

A possible modification is to add the PAUSE vector as well and turn off the cooperative multitasker during the critical section.

```
: critical[ \ ( -- ) R( XT -- n*f XT )
  r>
  int? >r \ get the global interrupt flag
  ['] pause defer@ >r \ get current multitasker
  >r \ restore the returnstack
  -int single
;

:]critical \ ( -- ) R( n*f XT -- XT )
  r>
  r> ['] pause defer! \ restore multitasker
  r> if +int then \ restore global interrupt flag
  >r \ will crash if not matched
;
```

4.2.7 Timer

The timer library in the `lib/hardware` directory consists basically of two parts: an access module and a generic module that depends on one of the access modules.

The access module (in `timer0.frt` and `timer1.frt`) encapsulate the access to the selected timer. It uses interrupts to create a millisecond counter for common usage. This millisecond counter is a single cell variable that gets continuously incremented and wraps around every 65,5 seconds.

The generic routines rely on this counter. A timer is simply a single cell number that is either the starting value of the millisecond counter (e.g. for **elapsed**) or the stop value (**after**).

To get a timer get the current value of the tick. With that number you can call **elapsed** to get the number of milliseconds since start. To check whether a timer is expired you need to calculate the end time by adding the time span to the current tick value. The word **expired?** compares the current tick value with that calculated time and leaves a flag.

The words are multitasker friendly (by calling **pause** whenever useful. The words provided so far are

- **expired? (t – flag)** checks whether a timers has expired. calls **pause** internally.
- **elapsed (t – n)** gets the number of milliseconds since the timer has started.
- **ms (u –)** alternative implementation of standard word **ms**
- **after (XT u –)** waits u milliseconds and executes XT afterwards.
- **every (XT n –)** executes XT every n milliseconds. The XT has the stack effect (– f) for f beeing a flag indicating whether or not terminating the every loop.

An usage example is the *Loop With Timeout*. It is used as an replacement for **begin**, and takes an number as the amount of milliseconds the loop has to finish, otherwise an exception is thrown.

4.2.8 TWI/I2C

SCL Clock Calculator

Most client devices want a clock speed of 100 kHz or 400 kHz. The bitrate register should be well above 10 if the controller is the bus master. The calculation formula

$$twiclock = \frac{cpuclock}{16 + 2 * bitrateregister * 4^{prescaler}}$$

The next table shows the resulting twi clocks for a 8MHz device clock

prescaler	bitrate register (may be any value between 0 and 255)						
	8	16	32	64	128	255	
0	333.333	250.000	166.667	100.000	55.556	29.412	15.209
1	166.667	100.000	55.556	29.412	15.152	7.692	3.891
2	55.556	29.412	15.152	7.692	3.876	1.946	978
3	15.152	7.692	3.876	1.946	975	488	245

4.2.9 Usart Settings

There is some confusion concerning how usart settings should be made.

During assembly, the typical error message looks like

```
atmega16.asm(26): warning: Use of undefined or forward referenced symbol 'TXEN0' in .equ/.set
```

The symbol naming is based upon Atmel's naming conventions. If the controller has only one usart module, it is named either `usart` or `usart0`. Newer Atmegas use the 0 regardless of the real number of usart modules, older ones omit the 0 completely. You definitely have to check the datasheet.

The following controllers use the old schema, they need the `usart` file:

```
8515def.inc:.equ    RXEN    = 4 ; Receiver Enable
8535def.inc:.equ    RXEN    = 4 ; Receiver Enable
m103def.inc:.equ    RXEN    = 4 ; Receiver Enable
m163def.inc:.equ    RXEN    = 4 ; Receiver Enable
m16Adef.inc:.equ    RXEN    = 4 ; Receiver Enable
m16def.inc:.equ    RXEN    = 4 ; Receiver Enable
m323def.inc:.equ    RXEN    = 4 ; Receiver Enable
m32Adef.inc:.equ    RXEN    = 4 ; Receiver Enable
m32def.inc:.equ    RXEN    = 4 ; Receiver Enable
m8515def.inc:.equ    RXEN    = 4 ; Receiver Enable
m8535def.inc:.equ    RXEN    = 4 ; Receiver Enable
m8Adef.inc:.equ    RXEN    = 4 ; Receiver Enable
m8def.inc:.equ    RXEN    = 4 ; Receiver Enable
pwm216def.inc:.equ    RXEN    = 4 ; Receiver Enable
pwm2Bdef.inc:.equ    RXEN    = 4 ; Receiver Enable
pwm2def.inc:.equ    RXEN    = 4 ; Receiver Enable
pwm316def.inc:.equ    RXEN    = 4 ; Receiver Enable
pwm3Bdef.inc:.equ    RXEN    = 4 ; Receiver Enable
pwm3def.inc:.equ    RXEN    = 4 ; Receiver Enable
```

All others use a number.

A simple approach that works in most cases is as follows: delete/change all occurrences of the 0 character in the following excerpt from your version of the `template.asm` file.

```
.include "drivers/usart_0.asm"
```

Please note, that the file is named `drivers/usart.asm` not `drivers/usart_.asm`.

Similar changes are needed for the other usart modules (e.g. `usart3`).

4.2.10 Watchdog

The watchdog is a build-in module present in all atmega controllers. It triggers a reset if for a predefined period of time nothing is done to prevent it.

The controller has a special machine instruction for the watchdog reset called `wdr`. Amforth has a wrapper forth word with the same name after including the file `core/words/wdr.asm`.

This word needs to be called often enough to keep the watchdog from resetting the controller. For a system that basically waits at the command prompt the `pause` command could be sufficient:

```
> ' wdr is pause
```

Another potential place for adding a `wdr` is the inner interpreter by either changing `amforth-interpreter.asm` or the `core/words/exit.asm`. Adding the (machine) `wdr` instruction there makes sure that the watchdog is reset as long as the inner interpreter works.

Initialization

Early atmega variants need to initialize the watchdog every time after a reset, newer ones keep it active even over resets. This may cause troubles since the WDR needs to be called much earlier for these controllers. One solution is to place the WDR activation at the beginning of the turnkey actions.

Acknowledgements

This recipe is based upon work by David Wallis.

4.3 General Code Examples

4.3.1 Defining and using Arrays

The traditional approach is the following:

```
create my-array 42 cells allot
```

This creates the dictionary entry named `my-array` and allocates 42 cells in RAM. BUT: the `my-array` dictionary entry is not connected to the allocated RAM. The correct solution is:

```
variable my-array 42 cells allot
```

This makes the dictionary entry named `my-array`, sets up the link to the RAM address and allocates an *additional* amount of 42 cells in RAM.

Forth 200x introduced a new word named `Buffer:`. With it the above code turns into

```
43 buffer: my-array
```

please note the different sizes! The `buffer:`-implementation allocates the exact number of bytes whereas the `variable` version adds the given size parameter to the 1 cell it allocates anyways.

The use of the array is quite simple:

```
: my-array-@ cells my-array + @ ;  
: my-array-! cells my-array + ! ;
```

Arrays of structures

This example uses structures. Structures can be used after including of the `structures.frt` file. First a hash data structure consisting of two elements is defined. This structure is used to create an array of a few elements afterwards.

```
begin-structure hash  
  field: hash.key  
  field: hash.value  
end-structure
```



```

\ inspired by CELLS
\ ( n -- size )
\ calculates the size of n items of the
\ type hash
: hash-cells hash * ;

\ define a hash-array
: hash:
  hash-cells buffer:
  does>
    swap hash-cells +
;

```

The helper word `hash-cells` calculates the size of the data structure in terms of bytes, just like the standard word `cells` does it.

Now we're using the words (using the `amforth-shell`). First define an array of 4 hash pairs. After that store a key/value pair at a particular position and retrieve it again later.

```

(ATmega16)> 4 hash: my-hash
ok
(ATmega16)> 42 3 my-hash hash.key !
ok
(ATmega16)> 4711 3 my-hash hash.value !
ok
(ATmega16)> 3 my-hash hash.key @ .
42 ok
(ATmega16)> 3 my-hash hash.value @ .
4711 ok
(ATmega16)>

```

If you place the data structure in a different memory (e.g. the EEPROM) adapt the code accordingly. `buffer:` needs to be replaced with a similar allocation word and `@/!` with the proper memory access words. Remember, memory is not always 2 bytes per cell.

See Also:

Structures

4.3.2 Using `create/does>`

A subtle error will be made with the following code

```
: const create , does> @ ;
```

This code does *not* work as expected. The value compiled with `,` is compiled into the dictionary, which is read using the `@i` word. The correct code is

```
: const create , does> @i ;
```

Similarly the sequence

```
: world create ( sizeinformation ) allot
does> ( size is on stack) ... ;
```

does not work. It needs to be changed to

```
: world variable ( sizeinformation) allot
does> @i ( sizeinformation is now on stack) ... ;
;
```

4.3.3 Deferred Words

Deferred words a technique that allows to change the behaviour of a word at runtime. This is done by storing an execution token under a certain name that is executed whenever that name is called. The stack effect is entirely that of the stored execution token code. The basic specification is at www.forth200x.org/deferred.html which is a must-read now.

AmForth has 3 different variants of **defer** which differ in the place, where the execution is stored: **Edefer** stores in EEPROM, **Rdefer** stores in RAM and `:command Udefer` stores in the USER area. The definition of a deferred word does not set a useful execution token. Using a deferred word without giving it a XT will crash the system. After the definition of the words, the further handling is always the same: **IS** stores the execution token into the deferred word. Further the standard words **defer@** and **defer!** read and write the execution token regardless of the exact storage location.

AmForth uses the deferred words technique already internally:

- **turnkey** is an EEPROM based deferred word that is executed from **QUIT** usually during startup and reset.
- the words **key**, **key?**, **emit**, and **emit?** are USER deferred words for low level terminal IO.
- **refill** and **source** are USER deferred words used by the forth interpreter to get the next command line.
- **pause** is a RAM based deferred word that is called whenever a task switch can be done.
- **!i** does the actual flash write of a single cell. It is intended for *Unbreakable AmForth*

Since there is no standard defer word, the programmer has to take care where to store the execution tokens. An EEPROM locations is available at startup without further initialization. A USER based deferred word can be targeted to different words in a multitasking environment and finally a RAM based deferred word can be changed frequently. To get a standard however, the following definition may be helpful:

```
> Edefer defer      \ keeps the assignment during resets
ok
> ' Rdefer is defer \ assignment not lost after reset
ok
>
```

4.3.4 Disabling the terminal command echo

Sometimes it may be desirable to turn off the echo function in **accept** when entering commands. One solution to do it is to temporarily redirect the **emit** to do nothing.

```
variable tmpemit
: -emit ['] emit defer@ tmpemit !
      ['] drop is emit ;
: +emit tmpemit @ is emit ;

> 1 2 3
ok
> .s
  0 809 3
  1 80B 2
  2 80D 1
ok
> -emit .s +emit
ok
>
```

Alternately the definition

```
: +emit tmpemit @ ['] emit defer! ;
```

could be used as well.

4.3.5 Defining and using Macros

Macros are small code snippets that do not represent a colon word for itself but the code is used verbatim in other definitions. To use them, include the file `lib/macro.frt` (requires `evaluate.frt` and amforth version 4.7ff)

```
> macro square " dup *"
ok
> : foo 5 square . ;
ok
> foo
25 ok
```

square can be called just like a word definition as well.

```
> 6 square .
36 ok
>
```

There is only one drawback: the macro string cannot contain the delimiting character itself. You're free to choose any character however

```
> macro square2 _ dup *_
ok
> 5 square2 .
25 ok
>
```

4.3.6 Multitasking

Multitasking is a way to execute separate chunks of program code (tasks) apparently simultaneous on a single CPU. Of course, the separate tasks will run one after another. If the CPU can switch between them fast enough, separate tasks may appear to execute in parallel.

Multitasking in amforth is achieved as *cooperative multitasking*¹: In every task the programmer defines places, where control is given up, such that the next task can run. The tasks current state is stored in a piece of memory called the task control block (TCB). TCBs are organized in a simple, linked list and are visited in round-robin fashion.

What is a Task?

Every task owns a piece of RAM, where it finds a set of runtime information (user area) and where it has its own space for the data and return stacks. This space is called a *task control block (TCB)*. It is referred to by the *task id* or *tid*, which happens to be the start address of the TCB by convention[#]_

The runtime information includes:

- status, whether the task is *awake* or *sleeping*
- follower, points to the next task in the list
- where do the stacks start and how many entries are currently on them
- the current value of **base**
- pointers to deferred words such as **key**, **emit** and the like
- the content of the stacks is not regarded part of the task control block. They can be located anywhere as long as their location is known. They do belong to the task, however.

Viewed from afar, a task is just a piece of RAM holding a small set of important information.

¹ as opposed to preemptive multitasking

Switching Tasks

To switch execution from one task to the next, the following things need to happen somehow:

- store the relevant bits of the current runtime in the task control block (stack pointers, mainly)
- look up the next task's control block
- switch the userarea-pointer to that control block
- unfold the same bits, which were stored before giving up control, back into the runtime
- resume execution at the next instruction of the new task

So the problem is mainly an exercise in saving and restoring all relevant information.

Using the Multitasker

Problem

Simultaneous execution of several blocks of code (tasks) is desired on a single CPU.

Solution

Include the file `lib/multitask.frt` in your programm, define separate tasks as separate words. The start of everything needs a little extra code (see `starttasker`). This solution is working together with `turnkey`.

Sample Program

The following example creates two tasks:

1. the command loop keeps running
2. increment a Counter N, write its value to PORTB. The intention is to make connected LEDs blink.

```
\ run_multitask -- tested with amforth-4.7, atmega-32

$38 constant PORTB
$37 constant DDRB
include lib/multitask.frt
\ load the multitasker
: ms ( n -- ) 0 ?do pause 1ms loop ; \ call pause on wait
variable N
: init
  $ff PORTB c!
  \ portB: all pins high
  $ff DDRB c!
  \ all pins output
  0 N !
;
: run-demo
  \ --- task 2 ---
  begin
    N @ invert PORTB c!
    1 N +!
    &500 ms
  again
;
$20 $20 0 task: task_demo
\ create task, allot tcb + stack space
: start-demo
  task_demo tcb>tid activate
```

```

    \ words after this line are run in new task
run-demo
;
: starttasker
  task_demo task-init
  \ create TCB in RAM
  start-demo
  \ activate tasks job
  onlytask
  task_demo tcb>tid alsotask
  multi
;
: run-turnkey
  \ make cmd loop task-1
  \ start task-2
  \ activate multitaskingMultitasking
  appltturnkey
  init
  starttasker
;
' run-turnkey is turnkey
\ make run-turnkey start on power up

```

When the program is started, LEDs connected to PORTB will blink. However, the prompt is presented as well and commands will be handled.

```

> run-turnkey
amforth 4.7 ATmega32
ok
> tasks
149
running
309
running
Multitasker is running ok
> N @ .
199 ok
>

```

Discussion

The two tasks will happily run along provided, that both tasks call **pause** regularly. This call is built into the command loop already. It is possible to call **run-turnkey** as **turnkey**. The program will survive a power cycle, because task: stores the necessary information in flash memory:

1. the address of the task control block
2. the start of the data stack (sp0)
3. the start of the return stack (rp0)

The sizes of the stacks are not explicitly stored. They can be inferred from the knowledge that all space is allocated as one chunk. However, amforth does not protect the stack from overflows. Exceeding the allocated stack space does cause unexpected crashes of your program (see below at **task:**).

task-init prepares the task control block located in RAM. It erases any previous content, stores the addresses of the stacks, the top-of-stack address for the data stack, base, and the status of the task (sleeping). start-demo adds the calls to the tasks body into the TCB and stack space. task: will use three entries from the stack.

1. additional size of the user area in this task. This space can be used to create user-variables, which belong to this task only.
2. size of the task's return stack

3. size of the task's data stack. Both stack sizes may be as small as \$20 bytes. However, programs exceeding a certain complexity may experience inexplicable crashes. If the program works in the foreground but not as a task, increasing the stack sizes may help. Please note that calling **ms**, which in turn calls **lms** will not produce accurate time intervals any more, depending on how much time is spent in the other tasks. One might argue that the startup sequence (**starttasker**) is way too long and should not be handled by the programmer. On the other hand, full control over the startup might be useful in unforeseen ways.

Multitasker: The Gory Details

amforth ships the file `lib/multitask.frt` featuring a multitasker based on code by Brad Eckert.

Task Control Block

The layout of the task control block is fixed. Technically it is located at the start of the so called *User Area*. The first 6 entries (status ... handler) are not intended for changes by the programmer. The next 6 entries (base ... /key) are commonly changed by the programmer. If more space for user variables is desired, the user area needs to be increased specifically. When defining user variables, the offset of that variable from the start of the user area needs to be specified. It is the programmers duty to keep track of how many entries have been used.

Also as a consequence the **tid** of a task holds the start address of the user area for that task. Its value is copied into the user pointer upon task switch. The user pointer is fetched and stored with **up@** and **up!**, respectively (see definition of **wake** below).

Two offsets into the TCB are defined as user variables. They produce the address of **TCB[0]** and **TCB[2]** respectively, correctly using the current TCB's address.

```
decimal
0 user status
2 user follower
```

After that two noname: words are defined. These words will not have a header in the vocabulary, their execution tokens (xts) are stored in the constants **pass** and **wake**. Their values will be stored in the status field (**TCB[0]**).

```
:noname ( 'status1 -- 'status2 )
  cell+ @ dup @ 1+ >r
; constant pass
:noname ( 'status1 -- )
  up! sp @ sp! rp!
; constant wakeMultitasking
```

Switching Multitasking on and off

To switch between tasks the deferred word **pause** is used. Normally, **pause** does nothing. Therefore turning multitasking off is simple:

```
\ stop multitasking
: single ( -- )
  ['] noop is pause
;
```

A new word **multitaskpause** is defined, which will switch from this to the next task.

```
\ switch to the next task in the list
: multitaskpause ( -- )
  rp@ sp@ sp ! follower @ dup @ 1+ >r
;
\ start multitasking
: multi ( -- )
```

```
['] multitaskpause is pause
;
```

multitaskpause looks short and innocent, but a little explanation is called for:

```
rp@      \ -- rp          | fetch the current return stack pointer
sp@      \ -- rp sp       | fetch the current data stack pointer TOS
sp       \ -- rp sp tcb[sp] | get the addr of user variable to store TOS
!        \ -- rp          | store, TCB[8] := TOS
follower \ -- rp tcb[2]    | get the address of TCB[2]
@        \ -- rp tid'      | fetch it's content, tid of the next task
dup @    \ -- rp tid' status' | fetch status of the next task (xt)
1+       \ -- rp tid' pfa   | xt \Verb|>body|
>r       \ -- rp tid'      | put pfa of pass or wake on the returnstack
```

When multitaskpause exits, the interpreter finds the xt of wake or pass on the return stack and will continue execution there.

If status was pass, the next task is sleeping, so we need to look for the next next task:

```
      \ -- rp tid'          | these are still on the stack
cell+ \ -- rp tid'[2]      | point to follower
@     \ -- rp tid''        | get the tid of the next next task
dup   \ -- rp tid'' tid''   |
@     \ -- rp tid'' status'' | fetch status of next next task (xt)
1+    \ -- rp tid'' pfa     | xt of >body
>r    \ -- rp tid''        | put xt of next next tasks status on return stack
```

This is repeated until an awake task is found. If status was wake, the next task should be running, so we need to unfold it:

```
      \ -- rp tid' these are still on the stack
up! \ -- rp make user pointer point to tid'
```

This was the magic line. Now the stacks are different stacks! We left the old task's data stack behind with rp on top. Now we look at the new task's stack and find rp' of that task on top of it.

```
sp \ -- rp'
   \ -- rp' tid'[sp] get addr of TOS locationMultitasking
@  \ -- rp' sp' retrieve stack pointer of now current task
sp! \ -- rp'      store it in (activate) stack pointer
rp! \ --          store rp' of this task in current rp
```

Switching multitasking on is simply pointing pause to multitaskpause. The inner workings are far from obvious, but they have been proven to work.

Handling tasks

We need a few words to change the status of tasks:

```
: stop
: task-sleep
: task-awake ( -- )
  pass status ! pause ; \ sleep current task
  ( tid -- ) pass swap ! ;
  \ sleep another task
  ( tid -- ) wake swap ! ;
  \ wake another task
```

A little more tricky is setting up a piece of code to be run in a task. **activate** will be used in a snippet similar to this.

```
: run-demo ( interesting work here ... ) ;
$20 $20 0 task: task_demo
\ create task, allot tcb + stack space
: start-demo
  task_demo tcb>tid activate
  \ words after this line are run in new task
  run-demo
;
```

activate will store the xt of **run-demo** on the return stack belonging to the TCB. It will also save the address of top of return stack on top of the data stack belonging to the same TCB, and the address of TOS in the field TCB[sp]. This particular order of information is expected by **wake**.

```
: cell- negate cell+ negate ;
\ continue the code as a task in a predefined tcb
: activate ( tid -- )
  dup
  6 + @ cell-
  over
  4 + @ cell- ( -- tid sp rp )
  \ point to RP0 SP0
  r> over 1+ !
  ( save entry at rp ) \ skip all after ACTIVATE
  over !
  ( save rp at sp )
  \ save stack context for WAKE
  over 8 + !
  ( save sp in tos )
  task-awake
;
```

onlytask initializes the linked list with the current task only. It copies the tid of the current task into the field TCB[follower] to create a circular list.

```
\ initialize the multitasker with the current task only
: onlytask ( -- )
  wake status !
  \ own status is running
  up@ follower ! \ point to myself
;
```

alsotask links a new task given by its tid into the list behind the current task.

```
: alsotask ( tid -- )
  ['] pause defer@ >r \ stop multitasking
  single
  follower @ ( -- tid f)
  over      ( -- tid f tid )
  follower ! ( -- tid f )
  swap cell+ ( -- f tid-f )
  !
  r> is pause \ restore multitasking
;
```

And then there is **tasks** to print the tid of every task in the list and its state to the serial console. It will also report, whether the multitasker is switched on or not. If you uncomment the three commented lines, then the values of top-of-stack and start-of-stack for the data and return stacks are also printed out. This might be useful for debugging.

```
: tasks ( -- )
  status ( -- tid ) \ starting value
  dup
  begin
    ( -- tid1 ctid )
```



```

dup u. ( -- tid1 ctid )
dup @ ( -- tid1 ctid status )
dup wake = if ." running" drop else
  pass = if ." sleeping" else
    abort" unknown" then
  then
  \      dup 4 + @ ." rp0=" dup u. cell- @ ." TOR=" u.
  \      dup 6 + @ ." sp0=" dup u. cell- @ ." TOS=" u.
  \      dup 8 + @ ." sp=" u. cr
  cell+ @ ( -- tid1 next-tid )
  over over =      ( -- f flag)
until
drop drop
." Multitasker is "
['] pause defer@ ['] noop = if ." not " then
." running"
;

```

Creating a TCB

So there is only one thing left to do, namely create space for a TCB and the stacks.

```

: task: ( C: dstacksize rstacksize add.usersize "name"-- )
  ( R: -- addr )
  create here ,
    \ store address of TCB
    ( add.usersize ) &24 + allot \ default user area size
    \ allocate stacks
    ( rstacksize ) allot here , \ store sp0
    ( dstacksize ) allot here , \ store rp0Multitasking
    1 allot \ keep here away, amforth specific
  does>
  \ leave flash addr on stack
;

: tcb>tid ( f -- tid )      @i ;
: tcb>sp0 ( f -- sp0 ) 1+ @i ;
: tcb>rp0 ( f -- rp0 ) 2 + @i ;
: tcb>size ( f -- size )
  dup tcb>tid swap tcb>rp0 1+ swap -
;

```

task: allots memory for the task control block and its associated stacks. The sizes of the stacks are taken from the data stack. The start of the data stack (SP0) is stored in TCB[6], the start of the return stack (RP0) is stored in TCB[4]. Then new tid is moved from the return stack to the data stack. The task is marked as sleeping and one more byte is allot'ed to keep here out of the way. This is an implementation feature of amforth. Also please note that stacks are growing downwards. **task-init** initializes a TCB and copies the information stored in flash into their correct locations.

```

: task-init ( f -- )
  dup tcb>tid over tcb>size 0 fill \ clear RAM for tcb and stacks
  \ fixme: possibly use init-user?
  dup tcb>sp0 over tcb>tid &6 + !
  \ store sp0 in tid[6]
  dup tcb>sp0 cell- over tcb>tid &8 + ! \ store sp0-- in tid[8], tos
  dup tcb>rp0 over tcb>tid &4 + !
  \ store rp0 in tid[4]
  &10 over tcb>tid &12 + !
  \ store base in tid[12]
  tcb>tid task-sleep
  \ store 'pass' in tid[0]

```

;

Versions of `lib/multitask.frt` prior to amforth-4.7 are broken in that there is no permanent storage as described above. These versions of the multitasker work, but they do not survive a power cycle.

4.3.7 Saving Power

The Atmegas have a number of power saving options. All of them are available with the `sleep` instruction. Amforth has a wrapper word with the same name which works on newer atmegas only. You can simply include the file `words/sleep.asm` into your `dict_appl.inc` file and try assembling. If it does not produce an error, the `sleep` instruction can be used.

The next step is a system that uses interrupt driven terminal IO and possibly other interrupt sources. This makes it possible to include the `sleep` call into the `pause` deferred word.

```
: mypause 0 sleep ; ' mypause is pause
```

The exact meaning of the parameter (0) should be checked with the data sheet. Also make sure, that the interrupts are working properly. Otherwise the controller will sleep until the reset button is pressed..

4.3.8 Redirect IO

The IO system consists of 4 words: **EMIT**, **EMIT?**, **KEY** and **KEY?**. They are deferred words, e.g. they can be changed at runtime.

Output

Amforth has many words like `.` and `type` to write information. All these words do not do the output work actually, they call `emit` for each and every single character.

```
: morse-emit ( c -- )
  ... \ some code to let a buzzer beep for the character c
;
' morse-emit is emit
\ now everything gets mersed out. even the prompt
\ unless your morse-emit does not call the previous
\ emit nothing will be displayd
s" let it beep" type
```

The same technique may be used for e.g. a 44780 LCD. The new code has to take care of everything like scrolling etc as well.

To complete the picture, another word `emit?` should be redefined. It is called in front of `<emit>` to check whether the output is possible. If no such check is necessary or possible, just do an `' true is emit?`

Unless you do not change the turnkey action as well, everything gets reset to serial IO whenever you call `WARM`.

Input

Input is based upon single characters. The command **key?** checks whether an unread character is available and **key** fetches it. To read an user supplied buffer, the command **accept** can be used. It reads until either the buffer is filled or an end-of-line character is found (caridge return and/or line feed).

Depending on the input source, different strategies may be used. The simplest way is to poll the input device frequently and hope that no character is lost. More sophisticated is the use of interrupts. They can be called at any time and almost guarantee that no characters will be lost. The interrupt usually fills an internal small buffer **key** and **key?** can deal with.

```

: ps2-key-isr ( -- )
  \ get the most recent key stroke
  \ place the key-event in a queue
;
: ps2-key? ( -- f )
  \ check the input queue, return true if
  \ a key-event is unread
;
: ps2-key ( -- c )
  \ read and unqueue the oldest key-event from the
  \ queue.
;
\ the next word changes the terminal input to
\ the PS2 based system. This cannot be done interactively!
: ps2-init ( -- )
  \ initialize ps2-key-isr
  ['] ps2-key? is key?
  ['] ps2-key is key
;

```

There are some notes that may affect your program

- If a multitasker is used take care to include calls to `pause` in your `key?` and `emit?` definitions.
- It is not uncommon that `key` calls `key?` in a loop until a character is available.
- AmForth uses one of the following words depending on two WANT settings. They default in `macros.asm` to `WANT_RX_ISR=1` and `WANT_TX_ISR=0`.

WANT_RX_ISR		WANT_TX_ISR	
0	1	0	1
rx-poll and rx?-poll	rx-isr and rx?-isr	tx-poll and tx?-poll	tx-isr and tx?-isr

- All IO words with more complexity (e.g. `type` or `accept`) call any of the 4 deferred words. There is no need to change them.
- Amforth uses the control characters for the line editing (e.g. backspace, TAB, CR/LF). Characters are 8 bit numbers (ASCII). Multibyte-Characters are not currently supported.

See Also:

Disabling the terminal command echo

4.3.9 Reason For Reset

If the controller constantly resets and prints only (part of) the version string, it could be really nice to know why it behaves that way. The controller itself stores the reset reason in the machine control register, which gets unfortunately overwritten real soon. amforth reads its content upon startup into an unused register for later usage however.

Adding the following few lines to the `appltturnkey.asm` file prints the numeric information at every reset

```

; print the numeric reason for reset
; forth code: 10 c@ . cr
.dw XT_DOLITERAL
.dw 10
.dw XT_CFETCH
.dw XT_DOT
.dw XT_CR

```

The following screen shows the program output after power on reset (4), pressing the reset button (2) and an ordinary call to `cold`:

```
-- power on --
> 4
amforth 4.7 ATmega328P 16000 kHz
-- pressing reset button --
> 2
amforth 4.7 ATmega328P 16000 kHz
> cold
0
amforth 4.7 ATmega328P 16000 kHz
>
```

The exact meaning of the numbers is available by reading the respective controller data sheet (8 usually means watch dog reset).

4.3.10 Simple Strings

On the command line, strings are part of the current SOURCE buffer. Their content is usually lost, when SOURCE gets REFILL'ed. The command

```
> s" hi there" type
  hi there ok
>
```

works fine. If you split the commands into two lines like

```
> s" hi there"
  ok
> type
  ei there ok
>
```

it will print the last character of type and the remaining characters from the previous command line. If a string has to be used later on, it needs to be moved to another buffer within the same command line or accept is used to enter the string into some other buffer (see below for an example).

```
> s" hi there" pad swap cmove> \ length information gets lost
  ok
> pad 7 type
  hi ther ok
>
```

In colon definitions, s'' does something completely different: It copies the whole string from the **SOURCE** buffer to flash (into the dictionary) and at runtime provides the flash address and length of the string. This data can be used with e.g. **ITYPE**.

```
\ allocate RAM for the string content.
20 buffer: namestring
variable age

\ enter string and print them
: input ( buf-addr buf-len prompt-addr prompt-len -- buf-addr buf-len )
  cr itype over swap accept ;

: getname ( -- addr len )
  namestring 20
  s" Who are you? " input ; \ [1]
: getage
  0. \ [2]
  pad 3 \ [3]
  s" How old are you? " input
  >number 2drop d>s \ [4]
  age ! ;;
```

```

: .name      ( addr len -- ) type ;
: .age       ( -- ) age @ u. ;

: .hallo     cr ." Nice to meet you"
  .age ."   year old "
  .name      \ [5]
  ." ." cr ;

\ putting it all together
: ask       getname getage .hallo ;

```

Running the command ask gives the following session

```

> ask

Who are you? Hannu

How old are you? 23

Nice to meet you 23 year old Hannu.
ok
>

```

Notes

1. **s** compiles a string into flash. The compiled string gets a runtime that leaves the address/length pair of the compiled string *and* skips its content for further program execution.
2. Places a double cell zero value onto the stack to be used at >number.
3. **pad** is a commonly used temporary storage pool. It is not used by the system itself. Its location is relative to HERE, so every change to HERE will move PAD as well.
4. >number is a standard word that converts a string to a number. To get the actual age (assuming a reasonable value) the **2drop** removes some returned data. Finally the double cell age is converted to single cell and stored at the variable age.
5. **getname** leaves the actual length of the name string on the stack. This length information is not stored elsewhere. .name removes this information so you cannot reconstruct this data.

```

> : label: create s, , does> ;
ok
> 42 s" hello" label: example
ok
> example icount itype
hello ok
> example icount 2/ 1+ + @i .
42 ok
>

```

s, copies a string from RAM to flash, increasing the DP. The storage format follows the counted string schema: first cell is the length information, followed by the characters, 2 per flash cell. A zero byte is appended if necessary to fill the last flash cell. It is an internal factor of s.

This recipe is based upon ideas from Hannu Vuolasaho and Michael Kalus.

4.3.11 Structures

Structures are used to keep complex data in one place. Classical use cases are records.

To use structures, load the file lib/forth200x/structure.frt into the controller. It has no further dependencies.

```
\ simple test example for forth200x structures
\ define a new data structure named list.

begin-structure list
  field: l.p \ previous
  field: l.n \ next
  field: l.d \ data
end-structure

\ create an instance of the datastructure list
\ named listroot

list buffer: listroot

\ access an element from the instance
$55aa listroot l.d !

\ place a structure at a special place
begin-structure atmega-port
  cfield: PIN
  cfield: DDR
  cfield: PORT
end-structure

\ Atmegas have 3 addresses per port, use
\ the lowest one here
$39 constant PORT-A

\ set all pins to output
$ff PORT-A DDR c!
```

The example shows a few aspects that should be known:

- field names are global entries in the dictionary, one should choose good names for them. Names like `a` are a no-go. One possibility is the schema `structure-name->fieldname`
- structures keep definitions in flash, the data goes to RAM.

The package works with amforth version 4.0 and newer.

See Also:

Defining and using Arrays

4.3.12 Loop With Timeout

Many low level routines require to wait for a specific condition come true: A transmission is finished, a flag is set etc. Most of the time these action do work fine. But sometimes, the check loop does not terminate for some (usually stupid) reason and the program essentially crashed.

```
\ wait for twi finish
: twi.wait ( -- )
begin
  TWCR c@ 80 and
until
;
```

To circumvent such unwanted endless loops, a timeout is often a solution. This ensures that the loop will be left, regardless what happens. This recipe is based upon the timer module from the `lib/hardware` directory, that provides a millisecond tick that can be used for timeouts as well.

A timeout loop is basically a modified begin that takes a runtime parameter: the maximum allowed time for a particular loop. The loop terminator (again, until, etc) is left unchanged. If the loop terminates properly, the

timeout is ignored, otherwise an *exception* is thrown. It is up to the programmer to catch that exception. If it is not caught, the forth interpreter will do it and returns to the command prompt.

```
\ timeout-begin is a potentially endless loop
\ that terminates after a predefined timeout

\ in the case of a timeout an exception is thrown
variable alarmtime
: (init-alarm)
  @tick + alarmtime !
;

: (check-alarm)
  alarmtime @ expired? if -512 throw then
;

: timeout-begin
  postpone (init-alarm)
  postpone begin
  postpone (check-alarm)
; immediate
```

Since the alarm checks are simple, some precautions should be obeyed:

- The timer gives a millisecond resolution.
- The longest timeout period is 65.535 seconds (slightly more than a minute).
- **The timeout-loop cannot be nested. If you want to use it in a multitasking environment, change the variable to a user.**
- Don't forget to initialize and start the timer.

```
\ testcase. timeout after 100ms
: foo
  100 timeout-begin
    noop
  again
;
```

4.3.13 Turnkey applications

Turnkey application automatically execute a word upon startup. The default turnkey action establishes the serial line communication and prints the welcome messages (version number, cpu name, frequency). When the turnkey action finishes, the control is handed over to the amforth interpreter loop, which never finishes.

Turnkey itself is a deferred word. That means that it can be changed by applying a new execution to it. Whether the turnkey action leaves data on the stack is up to the application needs. Turnkey is called with an empty data stack.

```
: myinit ( -- )
  \ some code
;

\ save the xt of myinit into turnkey vector (an eeprom variable)
' myinit is turnkey
```

Special care must be taken if the turnkey action should not be replaced but appended. To achieve this, the current turnkey action has to be stored elsewhere and this execution must be called inside the new turnkey command.

```
variable oldturnkey
' turnkey defer@ oldturnkey !
: myturnkey
  oldturnkey @ execute
```

```
my_own_turnkey_actions
;
' myturnkey is turnkey
```

Be aware that the initialization sequence must not be repeated, this will create an endless loop by calling the turnkey action inside itself.

4.3.14 Use of the amforth-shell.py utility

The amforth-shell.py from Keith Amidon may simplify the interaction with amforth and the forth code management while uploading projects.

It is a python2 script that runs fine on Linux, other platforms may work as well. The tool takes care of the correct transfer of the source code and will optionally pre-process the sources: e.g. replace the register names with their numeric values. This saves valuable flash (dictionary) space since most of these registers are used only once.

```
mt@ayla:~/amforth$ cat tools/test.frt
\ this is a test
INT1Addr .
ver 1000 ms cr
1000 ms
ver cr ver
1000 ms
mt@ayla:alias|grep amforth-shell
alias u0=' $HOME/amforth/tools/amforth-shell.py -p /dev/ttyUSB0 --no-error-on-output'
mt@ayla:~/amforth$ u0 test.frt
|I=mcudef
|I=using device.py for atmega1280
|F=....test.frt
|C| 1|\ this is a test
|S| 2|INT1Addr .
|O| 2|4
|S| 3|ver 1000 ms cr
|O| 3|amforth 4.9 ATmega1280
|S| 4|1000 ms
|S| 5|ver cr ver
|O| 5|amforth 4.9 ATmega1280
|O| 5|amforth 4.9 ATmega1280
```

Note the replacement of the INT1Addr with 4 in line 2. This is done by using the device.py file from the core/devices/atmega1280p directory which is automagically identified and loaded at startup. And second note, that the file is found automatically in the subdirectory tools.

The amforth-shell.py utility has a lot of more features: an interactive command prompt with dynamic command completion and command history (stored across multiple invocations), a lot of runtime checks and so on. To enter an interactive session, just call it with the port name

```
mt@ayla:~/amforth$ u0 -i
|I=Entering amforth interactive interpreter
|I=using device.py for atmega1280
(ATmega1280)> # (and pressing TAB twice)
#                #directive      #exit          #quote-char-word  #tib
#update-cpu      #edit          #ignore-error   #s                 #timeout
#update-words    #cd            #error-on-output #include           #string-start
#timeout-next
(ATmega1280)> #
```

Note that not all words displayed here are actual commands on the controller itself. The terminal provides commands itself, they start with a # (hash mark).

To locate the files, the utility checks the current work directory or, if set, the directories from the environment variable AMFORTH_LIB. Be careful when using a directory with many files, the startup may take a long time

due to the directory tree scanning.

```
mt@ayla:~/amforth$ grep AMFORTH ~/.profile
AMFORTH=~/amforth
AMFORTH_LIB=$AMFORTH/lib:$AMFORTH/examples
export AMFORTH_LIB
mt@ayla:~/amforth$
```

4.4 Programming and Debugging

4.4.1 Forth Assembler

Amforth is written in assembly language. Writing assembly words usually requires a rebuild of the hex files and flashing them to the controller. Lubos Pekny developed an assembler that runs within amforth and does not require a change of the amforth sources. Its syntax is a mixture of the standard Atmel assembly and forth. The mnemonics are close to Atmel's. The forth influence leads to a postfix notation and that the words that do the actual code generation end with a comma.

Start

To use it, load the file `lib/assembler.frt` and its dependencies into a running amforth. The assembler uses word lists to organize itself. The assembler supports all common mnemonics regardless of the controller type.

The assembler words are in a separate word list. To activate it, the following sequence is typically used:

```
forth only also assembler
```

This resets the word list order and adds the assembler word list. After successfully compiling the assembler word, the word list can be removed with `previous`.

Simple Example

The example uses the assembler for words that could easily be written in plain forth. Nevertheless an implementation in assembler is done. The code itself is taken from a posting on Roboforum.RU

```
$2F constant tccr1a
$2E constant tccr1b

\ stop timer1
\ : t1> 0 TCCR1 c! ;
code t1>
    tccr1b R2 out,
end-code

\ start timer1 @ normal mode, prescaler=8 ( 1us counter @8MHz )
\ : <t1 2 TCCR1 ! ;
code <t1
    R17    2    ldi,
    tccr1a R2   out,
    tccr1b R17 out,
end-code
```

The new words can be used just like a ordinary forth words.

```
\ stop timer1 & zero counter
: <t1> t1> 0 dup TCNT1H c! TCNT1L c! ;

\ show t1 counter
: .t1
```

```
TCNT1L c@ TCNT1H c@ 8 lshift + dup
." (0x" .x ." )" bl emit u. ." us"

TIFR dup c@ $4 and dup      \ test TOV1 flag
if bl emit ." overrun"
    over c@ or swap c!      \ clear TOV1 by writing '1'
else drop drop then cr
;

\ timing test using timer1, xt - executable address
: ?us <t1> <t1> execute t1> .t1 ; ( *x xt -- *y )
```

4.4.2 Build Timestamp

AmForth has a version number, that can be read with an environment query:

```
> s" version" environment? drop .
50 ok
> s" version" environment search-wordlist drop .
50 ok
>
```

In addition to this information (esp for those who use the newest revision from the source repository) the built timestamp maybe useful as well. To get it, AmForth needs to be compiled with the file words/built.asm included. Calling it prints the date and time the hexfile was generated in the current terminal.

```
> built
Nov 22 2012 23:12:94 ok
>
```

The assembly code uses some avr asm specific macros, the string length information is hardcoded.

```
; ( -- ) System
; R( -- )
; prints the date and time the hex file was generated
VE_BUILT:
    .dw $ff05
    .db "built",0
    .dw VE_HEAD
    .set VE_HEAD = VE_BUILT
XT_BUILT:
    .dw DO_COLON
PFA_BUILT:
    .dw XT_DOSLITERAL
    .dw 11
    .db __DATE__ ; generated from assembler
    .dw XT_ITYPE
    .dw XT_SPACE
    .dw XT_DOSLITERAL
    .dw 8
    .db __TIME__ ; generated from assembler
    .dw XT_ITYPE
    .dw XT_EXIT
```

Subversion Revision Number

If you are using the subversion sandbox from the sourceforge repository, the following solution from Enoch provides the subversion revision number.

His solutions extends the Makefile to generate a small forth snippet that contains the information as a string.

```

AMFORTH := ../amforth/trunk
CORE := $(AMFORTH)/core
DEVICE := $(CORE)/devices/$(MCU)

SVNVERSION := `svnversion -n $(AMFORTH) `

$(TARGET).hex: $(TARGET).asm *.inc words/*.asm $(CORE)/*.asm $(CORE)/words/*.asm
$(DEVICE)/*.asm
    $(XASM) -I $(CORE) -o $(TARGET).hex -e $(TARGET).eep -l $(TARGET).lst $(TARGET).asm
    echo ": svnversion ." r$(SVNVERSION) ";" >svnversion.frt

```

Running make creates the file `svnversion.frt` in the current directory that contains the output of the `svnversion -n` command. Uploading this file creates the forth command `_svnversion_` that prints it in the terminal.

```

\ #include svnversion.frt

: myturnkey
\ snip
  applturnkey
  space svnversion
;

' myturnkey is turnkey

\      The result:
\      ~~~~~~

amforth 4.9 AT90CAN128 r1306M

```

GIT Branch Name

Adding the name of the current GIT branch is slightly more complex. The first step is creating a template file as `appl/words/git-info.tmpl`. This file will be transformed into an assembly file with some search-replace actions during this copy.

```

; ( -- ) System
; R( -- )
; GIT Info
VE_GITINFO:
  .dw $ff08
  .db "git-info"
  .dw VE_HEAD
  .set VE_HEAD = VE_GITINFO
XT_GITINFO:
  .dw DO_COLON
PFA_GITINFO:
  .dw XT_DOSLITERAL
  .dw @BRLen@
  .db "@BRNAME@"
  .dw XT_ITYPE
  .dw XT_EXIT

```

The next step is to add the file `words/git-info.asm` to the list of included files (e.g. `dict_appl.inc`). The final step is to add a rule to the build tool. In this example, ant is used, so edit the `build.xml` file in the project application directory as follows:

```

<!-- change existing rules -->
<target name="uno.hex"
  depends="git-info"
  description="Hexfiles for ...."/>

```

```
<!-- add to build.xml -->
<macrodef name="git-branch">
  <attribute name="output" />
  <sequential>

    <exec executable="git" outputproperty="branch" >
      <arg value="status"/>
      <arg value="--short"/>
      <arg value="-b"/>
      <arg value="-u"/>
      <arg value="all"/>
      <arg value="--porcelain"/>
      <env key="LANG" value="C"/>
    </exec>
    <property name="@{output}" value="{branch}"/>
  </sequential>
</macrodef>

<target name="git-info">
  <git-branch output="branch" />
  <length property="length" string="{branch}"/>
  <copy tofile="words/git-info.asm" file="words/git-info.tmpl" overwrite="true">
    <filterset>
      <filter token="BRLen" value="{length}"/>
      <filter token="BRNAME" value="{branch}"/>
    </filterset>
  </copy>

</target>
```

With these settings, a new command is available **git-info**. It prints the current branch name in the terminal:

```
> git-info
## master ok
>
```

Its easy to add this command to the **appltturnkey** actions as well.

4.4.3 Ctrl-C

To interrupt a running system at any time and reset it to the prompt a keyboard command ctrl-c is often used. AmForth can honour such a keystroke as well. To achieve it, a small code change needs to be applied and a new hex file pair has to be flashed to the controller.

The code change affects the interrupt usart handler (`drivers/usart-rx-isr.asm`). Here add the 4 lines 5-8:

```
1  lds xh, USART_DATA
2  ; optional: check for certain character(s) (e.g. CTRL-C)
3  ; and trigger a soft interrupt instead of storing the
4  ; charater into the input queue.
5  cpi xh, 3
6  brne usart_rx_store
7  jmp 0
8  usart_rx_store:
9  lds xl, usart_rx_in
```

With this change, whenever the keyboard sends the ascii code 3 (for ctrl-c) it is caught immediately and a soft reset is made. it requires that the `WANT_ISR_RX` option is set to 1.

4.4.4 Customize AmForth

Customization takes place when you create the hex files. It requires to edit files and re-generate them using the assembler.

All customization is done in the application master file. A good starting point is `template/template.asm`. If you change any other file, good luck. You can look for these options in the code however.

Application / Board specific

Every application is unique. Thus you need to create your own amforth specific to your intended environment. There is no generic image that works everywhere.

First make a copy of the `appl/template` directory (myapp in this example).

```
mt@ayla:~/amforth/appl$ cp -r template myapp
```

Next edit the `template.asm` in the mayapp directory. You may want to rename the file later. There are only a few lines that need your attention.

```
; include the amforth device definition file. These
; files include the *def.inc from atmel internally.
.include "device.asm"
```

This line is tricky. It uses the generated include file but does not specify the controller type itself. The magic is in the list of `INCLUDE` directory that is defined in the Makefile. Alternatively change the line to

```
.include "devices/atmega1280/device.asm"
```

please use the same directory name from the `pd2amforth` run above. The downside of using the controller-dependent directory name instead of some makefile variables is that you have to keep the definition of the controller type in sync in `two` files. The makefile always need the information for the programmer.

The next essential information is the frequency your controller uses. It is necessary (at least) to calculate the proper usart settings and to get the right delay in the forth word `ms`.

```
; amforth needs two essential parameters
; cpu clock in hertz, 1MHz is factory default
.equ F_CPU = 16000000
```

The last setting is the command terminal for the prompt. There are a few predefined settings. Unfortunately Atmel has changed the wording over time. In most cases make sure that the number in the `_0` reflects the number in the `RXEN0` definitions and the final 0 in the `UCSZ00`. Elder controllers do not have a number suffix, just delete it (atmega32 may serve as an example for it).

```
; initial baud rate of terminal
.include "drivers/usart_0.asm"
.equ BAUD = 9600
.equ USART_B_VALUE = (1<&lt;TXEN0) | (1<&lt;RXEN0) | (1<&lt;RXCIE0)
.equ USART_C_VALUE = (3<&lt;UCSZ00)
```

The next file to edit is the Makefile (or the `build.xml` if you want to use the ant utility). First set the right controller type:

```
# the MCU should be identical to the device
# setting in template.asm, it set
MCU=atmega1280
```

The last change is the placement of the `avrasm2.exe` and the `Appnotes2` directory.

```
# directories
DIR_ATMEL=../../Atmel
```

To flash the controller, the program **avrdude** is used. Depending on your programmer, define the BURNER variable as well:

```
# programmers / flags
USB=-c avr911 -P /dev/ttyUSB3
PP=-c stk200 -P /dev/parport0
JTAG=-c jtag2 -P /dev/ttyUSB2
BURNER=$(USB)
AVRDUDE=avrdude
AVRDUDE_FLAGS=-q $(BURNER) -p $(MCU)
```

All other settings can be kept for now. Just run make and look for errors.

WANT - Options

WANT Options are used to select certain features. There is always a default value in place (0).

The files `core/devices/$MCU/device.asm` contain among other things a complete list of WANT Options that can be used to include device specific Names into the dictionary.

```
.set WANT_AD_CONVERTER = 0
.set WANT_ANALOG_COMPARATOR = 0
.set WANT_BOOT_LOAD = 0
.set WANT_CPU = 0
....
```

Changing these options to 1 includes the matching sections from `device.inc` into the generated dictionary. The same effect could be achieved by selectively send the `device.frt` file sections.

Another such option is the WANT_IGNORECASE option. If it is set to 1, the amforth dictionary lookup routine is extended to handle upper and lower case words the same. This makes `foo` and `FOO` the same. This is a dictionary wide setting, valid for both pre-defined and self-defined words.

The 3rd group switches the USART terminal communication between interrupt and poll based routines:

```
.set WANT_ISR_TX = 0
.set WANT_ISR_RX = 1
```

Settings the value of 1 select the interrupt based routines, otherwise the poll driven routines are used. It is recommended to leave the options as they are set.

See Also:

Redirect IO

4.4.5 Debug Shell

A debugger is a tool to check data at runtime. For amforth there is no single tool for that purpose. There are a *Tracer* and a *Profiler* available. They modify the code generation to achieve their goals. The debugshell presented here is called at explicit breakpoints to stop the execution of the current word and gives an independent command prompt to execute arbitrary commands.

This debugshell core can be modified and expanded in many ways. One example is the Watcher Utility for memory access.

Core

The debug shell core is quite small. Only 3 lines of code:

```
82 buffer: debugbuf
: (?) cr ." debug> " debugbuf dup 80 accept ;
: ?? begin (?) dup while (evaluate) repeat 2drop ;
```

Technically it is an isolated command shell activated at any time. With this debugger you can place the command `??` anywhere in your code and you'll get the `debug>` prompt whenever execution reaches it.

Extensions

The first extension is to have an on-off feature of the debugger. This can be achieved by an global flag or using deferred words:

```
0 value debug?
\ re-defines the ?? command and uses the old one
\ internally
: ?? debug? if ?? then ;
```

assigning a non-zero value to `debug?` (true to `debug?`) will activate the debug prompt. Note that the debug flag is stored in EEPROM und the settings survive a reset.

Another on-off implementation uses the deferred word technique.

```
Edefer breakpoint
' ?? is breakpoint
\ ' noop is breakpoint
```

Here you use the command `breakpoint` in your code instead of the basic `??` command.

```
: foo bar breakpoint baz ;
```

Note that the deferred vector is stored in EEPROM and the settings survive a reset.

The third extension uses interrupts. Since amforth executes them as ordinary forth code it is possible to assign any interrupt source to the `??` command (0 is an example interrupt number)

```
> ' ?? 0 int!
> 0 int-trap
```

```
debug> rp@ hex .
82D
debug>
ok
>
```

When you use an external interrupt via a simple key you get the debug prompt whenever you press it. If you configure and enable the external interrupt of course. Note that in this case the debug prompt is executed in the interrupt mode of the controller, you have to use the polling implementation of the usart receive module.

4.4.6 Dump Utilities

Stack Dumps

Stack dumps can be generated with the command `.s`. The standard does not specify, how the output has to formatted. The built-in command is for core development. This means that numbers are printed as unsigned (hex is highly recommended) and the TOS is on the left hand side. This makes it easy to get the most important information easily and the numbers are quickly found in memory dumps and the assembler LST and MAP files.

The output looks like:

```
> -1 -2 -3 .s
65533 65534 65535 ok
> hex .s
FFFD FFFE FFFF ok
>
```

Most other forth's and the various books use another stack dump format. It uses signed numbers and places the TOS on the right side. This can be achieved with the following definition, kindly provided by Enoch on the mailing list:

```
: .s ( -- ) \ stack picture listing order
  depth
  begin dup while dup pick . 1- repeat
  drop
;
```

The output looks like:

```
> -1 -2 -3 .s
-1 -2 -3 ok
>
```

Other stack dumps are as follows. They are kindly provided by Erich:

```
\ variations on dot-s
\ dot-s, one way, signed output:
: ds sp@ sp0 1 cells - do i @ . -2 +loop ;

\ dot-s, one way, unsigned output:
: uds sp@ sp0 1 cells - do i @ u. -2 +loop ;

\ dot-s, the other way (reverse?), signed output:
: rs sp@ sp0 swap do i @ . 2 +loop ;

\ dot-s, the other way, unsigned output:
: urs sp@ sp0 swap do i @ u. 2 +loop ;

\ dot-s, verbose, as it used to be in earlier versions of amforth:
: dsv depth dup 0 do i u. dup i -
  cells sp0 swap - dup u. @ . cr loop ;
: uds depth dup 0 do i u. dup i -
  cells sp0 swap - dup u. @ u. cr loop ;
```

Memory Dumps

Atmegas have three different memory address spaces. Each region has its own dump utility

dump Standard Memory. Every Address unit has 8 bits.

```
> $180 $20 dump

0180 36 30 31 33 33 02 87 75 F4 6D 74 26 8F 63 A3 CD 601CD..u.mt&.c..
0190 44 AB FC D7 3D DA D7 16 59 EB 3F AF 76 F2 27 3F D...=...Y.?.v.'?
ok
```

edump EEPROM. Similar to RAM, every address unit has 8 bits, but since it used on a cell (16 bits) basis, the display uses this number width:

```
> 0 $30 edump

0000 - FFFF 0EA3 0121 0052 OCC7 3B65 0019 0B2B ....!.R...e;...+.
0010 - 0014 0014 0E66 0001 0014 FFFF FFFF FFFF ....f.....
0020 - FFFF FFFF FFFF FFFF 0000 0000 085F 080F ....._...
ok
```

idump Flash. Unlike the other memories, flash has 16 bits per address unit:

```
> $dc0 $20 idump

0DC0 - 3830 0DC5 38D0 3837 002E 381A FF05 322E 08...878...8...2
```



```

ODC8 - 6568 0078 0DAB 3800 3B23 02D5 02DD 02DD    hex....8#;.....
ODD0 - 02FF 0430 381A FF05 342E 6568 0078 0DC6    ..0..8...4hex...
ODD8 - 3800 3B23 02D5 02DD 02DD 02DD 02DD 02FF    .8#;.....
ok

```

4.4.7 Un-Doing Definitions

During development and testing it is often desirable to start over again and forget everything. Traditional forth's have the word **FORGET**. Amforth uses another, more modern approach: **marker**.

marker needs planning. Before use, include the *file:dict_wl.inc* into your list of include packages to generate the hex files. Next two forth source files need to be uploaded to the controller: *lib/ans94/core/postpone.frt* and *lib/ans94/core-ext/marker.frt* (in that order). If you encounter errors that the word *set-current* is not defined, you forgot to include the *dict_wl.inc*.

Now the command **marker** is used to create a named snapshot of the current memory state to that you can return to any time afterwards. This includes all definitions and wordlists defined after the snapshot is taken. They get completely deleted and the occupied memories (flash, ram, eeprom) are available again.

```

> marker empty
ok
> : foo ." foo" ;
ok
> foo
foo ok
> empty
ok
> foo
foo ?? -13 3
> empty
empty ?? -13 5
>

```

Note that the snapshot itself is gone as well. If you want it again, just re-create it.

4.4.8 Port Code From C

There is a lot of C code out there. And there is no easy way to use it in AmForth. This recipe gives some hints for porting C code. A lot of more examples can be found at [Rosetta Code](#).

Register Names and Bits

AmForth provides the same register names as C. All addresses are memory mapped. Many registers are split into bitgroups, that got names as well. In C these names are usually bitnumbers, AmForth uses the bitmaps as specified in the Atmel resource files.

Single bits are straight forward:

```

C:
TIMSK0 |= (1<<OCIE0); /* set the bit */
TIMSK0 &= ~(1<<OCIE0); /* clear the bit */
AmForth:
\ set the bit
: or! dup c@ rot or swap c! ;
OCIE0 TIMSK0 or!

\ clear the bit
: and! dup c@ rot and swap c! ;
OCIE0 invert TIMSK0 and!

```

Control Structures

The control structures are basically all the same. The differences are subtle and usually small. Conditional Execution

```
C:
    if(flag) { foo(); } else { bar(); }
```

```
AmForth:
    flag if foo else bar then
```

Counted Loops

```
C:
    for(i=0;i<10;i++) {
        foo();
    }
```

```
AmForth:
    10 0 do foo loop
```

If the loop increment is not 1, Forth uses the word `+loop` instead of `loop`:

```
C:
    for(i=0;i<10;i+2) {
        foo();
    }
```

```
AmForth:
    10 0 do foo 2 +loop
```

4.4.9 Profiler

Sometimes it is useful to watch a word working. The Tracer gives many informations, which may be confusing or un-usable at all. The number of calls of a given word can be more instructive. This is the time for the profiler utility.

```
variable profiling?
: profile:on -1 profiling? ! ;
: profile:off 0 profiling? ! ;

: profiler profiling? @ if 1 swap +! else drop then ;
\ re-define colon
: : :
    here 2 allot postpone literal postpone profiler
;

\ get the address of the profiling data.
: xt>prf ( xt -- addr )
    cell+ @i
;
```

After loading it into the controller, every colon word gets a counter (1 cell) which is incremented every time the word is called. Since this cell can be used like any variable, it can be reset any time as well.

```
> : foo 1 ;
ok
> profiler:on
ok
> ' foo xt>prf @ .
0 ok
> foo
ok
> ' foo xt>prf @ .
```

```

1 ok
> 0 ' foo xt>prf !
ok
>

```

4.4.10 Efficient RAM Usage

RAM is probably the scarcest resource of an atmega. To make the best of it, some additional words may be helpful.

cvariable

cvariable acts like **variable** but does not allocate a cell (2 bytes) but only 1 byte of RAM. Access to it is limited to **c@** and **c!**. To indicate the size, one may want to use the [Hungarian Notation](#).

There are a few possible implementations. One uses carnal knowledge of the inner workings, the other one relies on the fact that 1 cell is 2 bytes RAM in amforth.

```

: cvariable
  here constant 1 allot ; \ carnal knowledge

\ just a variable, but gives one byte RAM back to pool
\ : cvariable variable -1 allot ;

```

Use of such small variables is just like other ones:

```

answer cvariable \ allocates 1 byte only!
42 answer c!
answer c@ .

\ troublesome
answer @ . \ undetermined
4242 answer ! \ destroys other data

```

See Also:

Defining and using Arrays and the *cvalue* section in *Values*

4.4.11 Tracer

Sometimes it is useful to watch a word working. A simple trace utility that prints the name of the word and the stack content at the beginning helps to get important information.

```

\ flag to dynamically turn trace output
\ on and off
variable tracing?
: trace:on -1 tracing? ! ;
: trace:off 0 tracing? ! ;
: tracer tracing? @ if cr itype cr .s else drop drop then ;

\ save the name of the word for use in tracer
: : >in @ >r : r> >in !
  parse-name postpone sliteral postpone tracer
;

```

After loading these few lines into the controller, every word being defined afterwards prints it's name and the stack content at runtime.

```

> : foo 1 ;
ok
> : bar 2 foo ;

```

```
ok
> : baz 3 bar ;
ok
> trace:on
ok
> baz

baz

bar
0 2221 3

foo
0 2219 2
1 2221 3
ok
> .s
0 2217 1
1 2219 2
2 2221 3
ok
> trace:off
ok
> baz
ok
>
```

It requires amforth version 4.7 and up. (sliteral is missing in earlier versions).

This tracer is based on posts from Emma Ledwidge and Gerry in the usenet group comp.lang.forth in January 2012.

4.4.12 Upgrade AmForth

You may want to upgrade AmForth if you encounter a bug that is fixed in a later revision or want to make use of a certain new feature. In this recipe I assume that you use the standard filesystem layout.

The first step is to unpack the new release archive into a new directory. Do not try to overwrite an existing installation. The 2nd step is a full copy of the `Atmel/` directory from your existing installation into the new tree. This copy has to include the `Appnotes*` directories and the `avrasm32.exe` file from Atmel. These files are verbatim copies from an Atmel AVR Studio installation and are not included into the AmForth distribution (guess why).

The next step is to make sure, that the template sample application can be compiled without problems. If you encounter any error, fix it first. If everything went well, you can copy your application directory from the old tree into the new directory tree and carefully re-apply all changes that the template application has got since you started your own application. The major source for information is the change log on the [AmForth Webpage](#) and the [Source Code Repository](#).

4.4.13 Unbreakable AmForth

This recipe gives some hints how to protect AmForth from being (partially) destroyed and to be able to recover from accidents without re-flashing the system.

Flash protection

The first line should be a flash protection. It prevents the `!` to write to places where it should not. This can be done by creating a new word, that does some bounds checking and does the final write command only if everything is ok.

```
\ write protect everything up to this command
: save-!i [ dp 12 + ] literal over <
  if (!i-nrww) else -20 throw then ;
' save-!i is !i
```

After these few lines, all flash up to this definition is now write-protected. All forbidden access will generate an exception. The offset added makes sure that our new command protects itself as well.

The code in the NRWW section (file:dict_appl_core.inc) is already write protected, the controller itself makes sure of that. A write attempt to this locations does not generate an exception, it will be ignored silently.

EEPROM protection

Protect the EEPROM is more difficult. AmForth rewrites a few cells during normal development, which makes a simple write protection as described for the flash rather useless. Furthermore AmForth uses the EEPROM content at very early stages in the boot process. Any safety action needs thus be hard-coded in **warm** and it will need a trigger to start the EEPROM recovery. This could be a check for some data or a hardware based information.

As long as the command prompt works, the data that got saved by a **marker** definition is sufficient to reset to a working system.

4.4.14 Values

The standard VALUE gives access to memory content like a variable does. The difference between these two is that a value gives a actual data whereas a variable leaves the address of the data on the stack. The place, where a value stores the data is usually not known. There is only one way to change it: use of **TO**.

```
> 42 value answer
ok
> answer .
42 ok
> 4711 to answer
ok
> answer .
4711
>
```

This resembles the intended usage pattern for EEPROM: Write seldom, read often.

The forth standard defines a few value types: **2VALUE** for double cell data, **FVALUE** for floating point numbers and the single cell sized **VALUE** itself. They all use the same **TO** command to change their content. This requires a non-trivial implementation to achieve it. Amforth uses a simple data structure for each value in the dictionary (flash). The first element contains the address of the actual data. This first field is followed by 2 execution tokens (XT) for the read and write operations. This makes the runtime operations fairly easy. The read operation (the 2nd element in the data structure) is called with the address of the 1st element. It is expected that the read operation leaves the data on the data stack. Similiar the write operation. The **TO** command simply executes the write execution token (the 3rd element).

This generic approach allows not only single cell data in EEPROM but any data everywhere. The following examples illustrate this with an implementation of a value that stores a single byte in RAM and a cached version of the standard EEPROM value. They have in common that calling their names give the data and applying **TO** to them stores new data.

cvalue

Cvalues store a single byte in RAM. The first element in the value data structure in the dictionary is the address of the RAM byte. The defining word allocates it. Like any other RAM based data its content is not preserved over resets and restarts.

```
\ two helper functions, not called directly
: c@v @i c@ ;
: c!v @i c! ;

: cvalue ( n "name" -- )
  (value)          \ create a new wordlist entry
  here ,           \ the address of the RAM memory
  postpone c@v     \ method for the read operation
  postpone c!v     \ method for the write (TO) operation
  here c!          \ initialize the RAM content
  1 allot          \ formally allocate the RAM byte
;

```

Using this new value is straight forward:

```
> 42 cvalue answer
ok
> answer .
42 ok
> 17 to answer
ok
> answer .
17 ok
>

```

After its definition the new size restricted value is used like any other value. To read it, simply call its name. To write to it, use the TO command. As a bonus, all operations are save against overflows:

```
> $dead to answer
ok
> hex answer .
AD ok
>

```

cached Value

A cached value is a value that stores the data in EEPROM but tolerates heavy write access by using a RAM cell as a cache. This RAM cell gets all write operations. The eeprom is not written until an explicit flush is performed. At startup the cache needs to be warmed, this is not done automatically.

```
\ 2 is a magic number
: @cache 2 + @i @ ;
: !cache 2 + @i ! ;

\ cache related words
: flush-cache 1+ dup 2 + @i @ swap @i !e ;
: warm-cache 1+ dup @i @e swap 2 + @i ! ;

: cache-value
  (value)          \ create the vocabulary entry
  dup edp dup , dup cell+ to edp !e \ allocate an EEPROM cell.
  postpone @cache  \ XT for the read method
  postpone !cache  \ XT for the write methon
  here 2 ( 1 cell ) allot dup , ! \ allocate a RAM cell and initialize it
;

```

The following example session creates a cached value and demonstrates the content of the two memory's during normal execution.

```
> edp \ keep the eeprom address for later direct access
ok
> 42 cache-value c-dp

```

```

ok
> 17 to c-dp
ok
> c-dp . dup @e .
\ RAM and EEPROM contents are different!
17 42 ok
> ' c-dp flush-cache
ok
> c-dp . dup @e .
17 17 ok
>

```

Note that there is a difference in programming style between the load/store and the additional warm/flush operations. The latter use a code sequence like

```
' value method
```

instead of the standard TO schema

```
method value
```

It's fairly simple to achieve the TO schema for the other commands as well, but since this requires a parsing word (which is state smart too) the forth gurus consider this suboptimal. A second argument against may be the growing acceptance of the OO notation `object method` with `object` being kind of an address.

```

: flush
  ' state @ if
    postpone literal postpone flush-cache
  else
    flush-cache
  then
; immediate

```

Note: This recipe requires amforth version 5.2 and newer.

4.4.15 Walking Wordlists

Wordlists are the building block of the dictionary. A wordlist is a single linked list of entries. Entries are compiled colon words, assembly words or data structures created with `create`. The link chain ends when the next pointer is zero. A wordlist grows usually upward in the flash memory, while the links point downwards.

The anchor of a wordlist is stored in an EEPROM cell, which address is the wordlist identifier.

Walking a wordlist requires the following steps

1. get the WID (e.g. environment)
2. read the starting address from the EEPROM (line 2) It is the name field address of the first word.
3. start the loop until zero is reached (lines 4+5)
4. keep the vital iterator data (line 6)
5. do some work with the entry, consuming the NFA-copy from the previous line (line 7)
6. go to the next entry (line 8)
7. repeat the loop body

The implementation of the word **show-wordlist** may illustrate this:

```

1 : show-wordlist ( wid -- )
2   @e
3   begin

```

```
4      ?dup
5  while
6      dup
7      icount $ff and itype space
8      nfa>lfa @i
9  repeat
10 ;
```

The sequence `$ff and` masks the entry flags (e.g. immediate) and extracts the actual string length for use with the following `itype`.

Way easier is using the `traverse-wordlist` available since amforth version 5.2. With it, the above changes to

```
\ print the name of a single wordlist entry
: show-word ( nt -- flag )
  name>string itype space
  true \ see spec of traverse-wordlist

: show-wordlist ( wid -- )
  ['] show-word swap traverse-wordlist
;
```

4.4.16 Watcher

A Watcher is a tool that monitors the access to a memory region. If a predefined memory location is accessed (read, written to or both) something is done in addition. In its simplest case, a message is printed.

The next few code lines use a single watch address. Any access to it is trapped and calls the Debug Shell.

```
\ core routines
variable watch-addr
defer watch-action
\ redefine memory access words
: ! dup watch-addr @ = if watch-action then ! ;
: c@ dup watch-addr @ = if watch-action then c@ ;
: c! dup watch-addr @ = if watch-action then c! ;
\ this one is the last one
: @ dup watch-addr @ = if watch-action then @ ;
\ simply use the debugshell
' ?? is watch-action

\ possible modifications
\ use an address range
\ use a list of addresses (address ranges)
```

After loading these lines, any word that uses memory access words will be watched for access to a particular address. If it is accessed, the debug shell will come up for further work.

REFERENCE CARD

5.1 General

AmForth is a 16bit ITC forth. It is almost compatible with the forth standards from 1994 and 200x. It runs on the bare metal controller with no further dependencies. The interpreter operates on whitespace delimited words. The compiler is a single pass compiler that writes directly to the flash based dictionary.

There are three distinct address spaces for flash, eeprom and RAM. Flash is addressed word wise (16 bits per address unit), RAM and EEPROM is accessed byte wise (8bits per address unit). The standard return stack has 40 cells, the data stack is limited by the available RAM size.

Numbers can be prefixed by \$ to indicate hexadecimal, % for binary and # for decimal numbers. A trailing dot is used for double cell numbers.

Words not found here are not part of the compileable core system. Their forth sources are in the `/lib` directory, usually named after the word name: e.g. **2dup** is defined in a file named `2dup.frt`.

5.2 Arithmetics

- **1-** ($n1 - n2$) optimized decrement
- **1+** ($n1 \text{lu}1 - n2 \text{lu}2$) optimized increment
- **2/** ($n1 - n2$) arithmetic shift right
- **2*** ($n1 - n2$) arithmetic shift left, filling with zero
- **abs** ($n1 - u1$) get the absolute value
- **><** ($n1 - n2$) exchange the bytes of the TOS
- **cell+** ($a\text{-addr}1 - a\text{-addr}2$) add the size of an address-unit to $a\text{-addr}1$
- **cells** ($n1 - n2$) $n2$ is the size in address units of $n1$ cells
- **d2/** ($d1 - d2$) shift a double cell value right
- **d2*** ($d1 - d2$) shift a double cell left
- **dabs** ($d - ud$) double cell absolute value
- **dinvert** ($d1 - d2$) invert all bits in the double cell value
- **d-** ($d1\ d2 - d3$) subtract $d2$ from $d1$
- **dnegate** ($d1 - d2$) double cell negation
- **d+** ($d1\ d2 - d3$) add 2 double cell values
- **invert** ($n1 - n2$) 1-complement of TOS
- **log2** ($n1 - n2$) logarithm to base 2 or highest set bitnumber

- **lshift** (n1 n2 – n3) logically shift n1 left n2 times
- **-** (n1lu1 n2lu2 – n3lu3) subtract n2 from n1
- **mod** (n1 n2 – n3) divide n1 by n2 giving the remainder n3
- **m*** (n1 n2 – d) multiply 2 cells to a double cell
- **+** (n1 n2 – n3) add n1 and n2
- **+#** (n a-addr –) add n to content of RAM address a-addr
- **popcnt** (n1 – n2) count the Number of 1 bits (population count)
- **rshift** (n1 n2 – n3) shift n1 n2-times logically right
- **/** (n1 n2 – n3) divide n1 by n2. giving the quotient
- **/mod** (n1 n2 – rem quot) signed division n1/n2 with remainder and quotient
- ***** (n1 n2 – n3) multiply routine
- ***/** (n1 n2 n3 – n4) signed multiply and division with double precision intermediate
- ***/mod** (n1 n2 n3 – rem quot) signed multiply n1 * n2 and division with n3 with double precision intermediate and remainder
- **true** (– -1) leaves the value -1 (true) on TOS
- **ud/mod** (d1 n – rem ud2) unsigned double cell division with remainder
- **um/mod** (ud u2 – rem quot) unsigned division ud / u2 with remainder
- **um*** (u1 u2 – d) multiply 2 unsigned cells to a double cell
- **u/mod** (u1 u2 – rem quot) unsigned division with remainder
- **0** (– 0) place a value 0 on TOS

5.3 Character IO

- **bl** (– 32) put ascii code of the blank to the stack
- **cr** (–) cause subsequent output appear at the beginning of the next line
- **emit** (c –) fetch the emit vector and execute it. should emit a character from TOS
- **emit?** (– f) fetch emit? vector and execute it. should return the ready-to-send condition
- **key** (– c) fetch key vector and execute it, should leave a single character on TOS
- **key?** (– f) fetch key? vector and execute it. should turn on key sender, if it is disabled/stopped
- **space** (–) emits a space (bl)
- **spaces** (n –) emits n space(s) (bl)
- **type** (addr n –) print a RAM based string

5.4 Compare

- **d=** (n1 n2 – flag) compares two double cell values
- **d>** (d1 d2 – flag) compares two double cell values (signed)
- **d0>** (d – flag) compares if a double double cell number is greater 0
- **d<** (d1 d2 – flag) checks whether d1 is less than d2
- **d0<** (d – flag) compares if a double double cell number is less than 0

- **=** (n1 n2 – flag) compares two values for equality
- **0=** (n – flag) compare with 0 (zero)
- **>** (n1 n2 – flag) flag is true if n1 is greater than n2
- **0>** (n1 – flag) true if n1 is greater than 0
- **0<** (n1 – flag) compare with zero
- **max** (n1 n2 – n1ln2) compare two values, leave the bigger one
- **min** (n1 n2 – n1ln2) compare two values leave the smaller one
- **<>** (n1 n2 – flag) true if n1 is not equal to n2
- **0<>** (n – flag) true if n is not zero
- **u>** (u1 u2 – flag) true if u1 > u2 (unsigned)
- **u>=** (u1 u2 – flag) compare two unsigned numbers, returns true flag if u1 is greater then or equal to u2
- **u<** (u1 u2 – flag) true if u1 < u2 (unsigned)
- **u<=** (u1 u2 – flag) compare two unsigned numbers, returns true flag if u1 is less then or equal to u2
- **within** (n min max – f) check if n is within min..max

5.5 Compiler

- **2literal** (– x1 x2) (C: x1 x2 –) compile a cell pair literal in colon definitions
- **again** (–) (C: dest –) compile a jump back to dest
- **ahead** (f –) (C: – orig) do a unconditional branch
- **** (“ccc<eol>” –) everything up to the end of the current line is a comment
- **begin** (–) (C: – dest) put the next location for a transfer of control onto the control flow stack
- **[]** (– xt) (C: “<space>name” –) what ‘ does in the interpreter mode, do in colon definitions
- **code** (–) (C: cchar –) create named entry in the dictionary, XT is the data field
- **:** (–) (C: “<spaces>name” –) create a named entry in the dictionary, XT is DO_COLON
- **:noname** (– xt) create an unnamed entry in the dictionary, XT is DO_COLON
- **constant** (– x) (C: x “<spaces>name” –) create a constant in the dictionary
- **do** (n1 n2 –) (R: – loop-sys) (C: – do-sys) start do .. [+] loop
- **(create)** (–) (C: “<spaces>name” –) parse the input and create an empty vocabulary entry without XT and data field (PF)
- **does>** (i*x – j*y) (R: nest-sys1 –) (C: colon-sys1 – colon-sys2) organize the XT replacement to call other colon code
- **.’** (–) (C: “ccc<quote>” –) compiles string into dictionary to be printed at runtime
- **Edefer** (c<name> –) creates a defer vector which is kept in eeprom.
- **else** (C: orig1 – orig2) (C: orig1 – orig2) resolve the forward reference and place a new unresolved forward reference
- **end-code** (–) finish a code definition
- **exit** (–) (R: nest-sys –) end of current colon word
- **header** (addr len wid – nfa) creates the vocabulary header without XT and data field (PF) in the wordlist wid

- **i** (- n) (R: loop-sys – loop-sys) current loop counter
- **if** (f –) (C: – orig) start conditional branch
- **immediate** (–) set immediate flag for the most recent word definition
- **j** (- n) (R: loop-sys1 loop-sys2 – loop-sys1 loop-sys2) loop counter of outer loop
- **[** (–) enter interpreter mode
- **leave** (–) (R: loop-sys –) immediatly leave the current DO..LOOP
- **literal** (- n) (C: n –) compile a literal in colon defintions
- **loop** (R: loop-sys –) (R: loop-sys –) (C: do-sys –) compile (loop) and resolve the backward branch
- **(** (“ccc<paren>” –) skip everything up to the closing bracket on the same line
- **+loop** (n –) (R: loop-sys – loop-sysl) (C: do-sys –) compile (+loop) and resolve branches
- **?do** (n1lu1 n2lu2 –) (C: – do-sys) start a ?do .. [+]loop control structure
- **]** (–) enter compiler mode
- **Rdefer** (c<name> –) creates a RAM based defer vector
- **recurse** (–) compile the XT of the word currently being defined into the dictionary
- **repeat** (–) (C: orig dest –) continue execution at dest, resolve orig
- **s,** (addr len –) compiles a string from RAM to Flash
- **;** (–) finish colon defintion, compiles (exit) and returns to interpret state
- **s’** (– addr len) (C: <cchar> –) compiles a string to flash, at runtime leaves (– flash-addr count) on stack
- **then** (–) (C: orig –) finish if
- **unloop** (–) (R: loop-sys –) remove loop-sys, exit the loop and continue execution after it
- **until** (f –) (C: dest –) finish begin with conditional branch, leaves the loop if true flag at runtime
- **user** (n cchar –) create a dictionary entry for a user variable at offset n
- **value** (n <name> –) create a dictionary entry for a value and allocate 1 cell in EEPROM.
- **value** (n <name> –) create a dictionary entry for a value and allocate 1 cell in EEPROM.
- **value** (n <name> –) create a dictionary entry for a value and allocate 1 cell in EEPROM.
- **variable** (cchar –) create a dictionary entry for a variable and allocate 1 cell RAM
- **while** (f –) (C: dest – orig dest) at runtime skip until repeat if non-true
- **wscope** (addr len – addr’ len’ wid) dynamically place a word in a wordlist. The word name may be changed.

5.6 Conversion

- **d>s** (d1 – n1) shrink double cell value to single cell.
- **s>d** (n1 – d1) extend (signed) single cell value to double cell

5.7 Dictionary

- **:command:**“ (n –) compile 16 bit into flash at DP
- **compile** (–) read the following cell from the dictionary and append it to the current dictionary position.

- **create** (– a-addr) (C: “<spaces>name” –) create a dictionary header. XT is (constant), with the address of the data field of name
- **reveal** (–) makes an entry in a wordlist visible, if not already done.
- ‘ (“<spaces>name” – XT) search dictionary for name, return XT or throw an exception -13

5.8 Environment

- **/hold** (– hldsize) size of the pictured numeric output buffer in bytes
- **/pad** (– padsize) Size of the PAD buffer in bytes
- **/user** (– usersize) size of the USER area in bytes
- **wordlists** (– n) maximum number of wordlists in the dictionary search order
- **cpu** (– faddr len) flash address of the CPU identification string
- **forth-name** (– faddr len) flash address of the amforth name string
- **version** (– n) version number of amforth
- **mcu-info** (– faddr len) flash address of some CPU specific parameters

5.9 Exceptions

- **abort** (i*x –) (R: j*y –) send an exception -1
- **abort’** (i*x x1 – | i*x) (R: j*y – | j*y) (C: “ccc<quote>” –) check flag. If true display the parsed text and throw exception -2
- **catch** (i*x xt – j*x 0 | i*x n) execute XT and check for exceptions.
- **handler** (– a-addr) USER variable used by catch/throw
- **throw** (n –) throw an exception

5.10 Extended VM

- **a@** (– n2) Read memory pointed to by register A (Extended VM)
- **a@-** (– n) Read memory pointed to by register A, decrement A by 1 cell (Extended VM)
- **a@+** (– n) Read memory pointed to by register A, increment A by 1 cell (Extended VM)
- **a!** (n –) Write memory pointed to by register A (Extended VM)
- **a!-** (– n2) Write memory pointed to by register A, decrement A by 1 cell (Extended VM)
- **a!+** (– n2) Write memory pointed to by register A, increment A by 1 cell (Extended VM)
- **a>** (n1 – n2) read the A register (Extended VM)
- **b@** (– n2) Read memory pointed to by register B (Extended VM)
- **b@-** (– n) Read memory pointed to by register B, decrement B by 1 cell (Extended VM)
- **b@+** (– n) Read memory pointed to by register B, increment B by 1 cell (Extended VM)
- **b!** (n –) Write memory pointed to by register B (Extended VM)
- **b!-** (– n2) Write memory pointed to by register B, decrement B by 1 cell (Extended VM)
- **b!+** (– n2) Write memory pointed to by register B, increment B by 1 cell (Extended VM)

- **b>** (n1 – n2) read the B register (Extended VM)
- **na@** (n1 – n2) Read memory pointed to by register A plus offset (Extended VM)
- **na!** (n offs –) Write memory pointed to by register A plus offset (Extended VM)
- **nb@** (n1 – n2) Read memory pointed to by register B plus offset (Extended VM)
- **nb!** (n offs –) Write memory pointed to by register B plus offset (Extended VM)
- **>a** (n –) Write to A register (Extended VM)
- **>b** (n –) Write to B register (Extended VM)

5.11 Interpreter

- **get-recognizer** (– recn .. rec0 n) Get the current recognizer list
- **rec-find** (addr len – f) recognizer searching the dictionary
- **rec-intnum** (addr len – f) recognizer for integer numbers
- **rec-notfound** (addr len –) recognizer for NOT FOUND
- **set-recognizer** (recn .. rec0 n –) replace the recognizer list

5.12 Interrupt

- **int@** (i – xt) fetches XT from interrupt vector i
- **-int** (–) turns off all interrupts
- **+int** (–) turns on all interrupts
- **int!** (xt i –) stores XT as interrupt vector i
- **int-trap** (i –) trigger an interrupt
- **#int** (– n) number of interrupt vectors (0 based)

5.13 Logic

- **and** (n1 n2 – n3) bitwise and
- **negate** (n1 – n2) 2-complement
- **not** (flag – flag') identical to 0=
- **or** (n1 n2 – n3) logical or
- **xor** (n1 n2 – n3) exclusive or

5.14 MCU

- **!@spi** (n1 – n2) SPI exchange of 2 bytes, high byte first
- **bm-clear** (bitmask byte-addr –) clear bits set in bitmask on byte at addr
- **bm-set** (bitmask byte-addr –) set bits from bitmask on byte at addr
- **bm-toggle** (bitmask byte-addr –) toggle bits set in bitmask on byte at addr
- **rx?-isr** (– f) check if unread characters are in the input queue using interrupt driver

- **rx?-poll** (– f) check if a character can be appended to output queue using register poll
- **rx-isr** (– c) get 1 character from input queue, wait if needed using interrupt driver
- **rx-poll** (c –) wait for one character and read it from the terminal connection using register poll
- **c!@spi** (txbyte – rxbyte) SPI exchange of 1 byte
- **tx?-isr** (– f) check if a character can be appended to output queue.
- **tx?-poll** (– f) check if a character can be send using register poll
- **tx-isr** (c –) put 1 character into output queue, wait if needed, enable UDRIE interrupt
- **tx-poll** (c –) check availability and send one character to the terminal using register poll
- **ubrr** (– v) returns usart UBRR settings
- **+usart** (–) initialize usart
- **+usartx** (–) initialize the atxmega usart (ATXmega)
- **wdr** (–) calls the MCU watch dog reset instruction
- **x-rx?-poll** (– f) check if a character can read from the terminal (Poll, ATXmega)
- **x-rx-poll** (– c) wait for and get one character from the terminal (Poll, ATXmega)
- **x-tx?-poll** (– f) check if a character can be sent (Poll, ATXmega)
- **x-tx-poll** (c –) wait for the terminal becomes ready and put 1 character to it (Poll, ATXmega)

5.15 Memory

- **c@** (a-addr - c1) fetch a single byte from memory mapped locations
- **cmove** (addr-from addr-to n –) copy data in RAM, from lower to higher addresses
- **cmove>** (addr-from addr-to n –) copy data in RAM from higher to lower addresses.
- **c!** (c a-addr –) store a single byte to RAM address
- **(!i-nrww)** (n f-addr –) writes n to flash memory using assembly code (code to be placed in boot loader section)
- **(!i-nvm)** (n f-addr –) writes n to flash at f-addr using NVM (ATXmega)
- **@** (a-addr – n) read 1 cell from RAM address
- **@e** (e-addr - n) read 1 cell from eeprom
- **@e** (e-addr - n) read 1 cell from eeprom using NVM (ATXmega)
- **@i** (f-addr – n1) read 1 cell from flash
- **@u** (a-addr – n) read 1 cell from RAM address
- **fill** (a-addr u c –) fill u bytes memory beginning at a-addr with character c
- **!** (n addr –) write n to RAM memory at addr, low byte first
- **!e** (n e-addr –) write n (2bytes) to eeprom address
- **!e** (n e-addr –) write n (2bytes) to eeprom address using nvm (atxmega)
- **!i** (n addr –) Deferred action to write a single 16bit cell to flash
- **!u** (n addr –) write n to RAM memory at addr, low byte first

5.16 Multitasking

- **cas** (new old addr – f) Atomic Compare and Swap: store new at addr and set f to true if contents of addr is equal to old.
- **pause** (–) Fetch pause vector and execute it. may make a context/task switch

5.17 Numeric IO

- **base** (– a-addr) location of the cell containing the number conversion radix
- **bin** (–) set base for number conversion to 2
- **d.** (d –) singed PNO with double cell numbers
- **d.r** (d w –) singed PNO with double cell numbers, right aligned in width w
- **decimal** (–) set base for numeric conversion to 10
- **digit?** (c – (number!)) tries to convert a character to a number, set flag accordingly
- **.** (n –) singed PNO with single cell numbers
- **.r** (n w –) singed PNO with single cell numbers, right aligned in width w
- **hex** (–) set base for number conversion to 16
- **hld** (– addr) pointer to current write position in the Pictured Numeric Output buffer
- **hold** (c –) prepend character to pictured numeric output buffer
- **<#** (–) initialize the pictured numeric output conversion process
- **number** (addr len – [nld size] f) convert a string at addr to a number
- **#** (d1 – d2) pictured numeric output: convert one digit
- **#>** (d1 – addr count) Pictured Numeric Output: convert PNO buffer into an string
- **#s** (d – 0) pictured numeric output: convert all digits until 0 (zero) is reached
- **sign** (n –) place a - in HLD if n is negative
- **>number** (ud1 c-addr1 u1 – ud2 c-addr2 u2) convert a string to a number c-addr2/u2 is the unconverted string
- **ud.** (ud –) unsigned PNO with double cell numbers
- **ud.r** (ud w –) unsigned PNO with double cell numbers, right aligned in width w
- **u.** (u –) unsigned PNO with single cell numbers
- **u.r** (u w –) unsigned PNO with single cells numbers, right aligned in width w
- **u0.r** (ud n –) Print n digits, fill in preceeding zeros if needed

5.18 R(–)

- **built** (–) prints the date and time the hex file was generated

5.19 Search Order

- **also** (–) Duplicate first entry in the current search order list
- **definitions** (–) Make the compilation word list the same as the current first word list in the search order.
- **forth** (–) replace the search order list with the system default list
- **forth-wordlist** (– wid) get the system default word list
- **get-current** (– wid) get the wid of the current compilation word list
- **get-order** (– widn .. wid0 n) Get the current search order word list
- **(marker)** (–) Duplicate first entry in the current search order list
- **only** (–) replace the order list with the system default list
- **order** (–) print the wids of the current word list and the search order
- **previous** (–) remove the first entry in the search order list
- **search-wordlist** (c-addr len wid – [0] | [xt [-1|1]]) searches the word list wid for the word at c-addr/len
- **search-wordlist** (c-addr len wid – [0] | [xt [-1|1]]) searches the word list wid for the word at c-addr/len
- **set-current** (wid –) set current word list to the given word list wid
- **set-order** (widn .. wid0 n –) replace the search order list
- **wordlist** (– wid) create a new, empty wordlist

5.20 Stack

- **2drop** (x1 x2 –) Remove the 2 top elements
- **2dup** (x1 x2 – x1 x2 x1 x2) Duplicate the 2 top elements
- **2r>** (– x1 x2) (R: x1 x2 –) move DTOR to TOS
- **2swap** (x1 x2 x3 x4 – x3 x4 x1 x2) Exchange the two top cell pairs
- **2>r** (x1 x2 –) (R: – x1 x2) move DTOS to TOR
- **depth** (– n) number of single-cell values contained in the data stack before n was placed on the stack.
- **drop** (n –) drop TOS
- **dup** (n – n n) duplicate TOS
- **nip** (n1 n2 – n2) Remove Second of Stack
- **nr>** (– xn .. x0 n) (R: xn .. x0 n –) move n items from return stack to data stack
- **n>r** (xn .. x0 n –) (R: – xn .. x0 n) move n items from data stack to return stack
- **over** (x1 x2 – x1 x2 x1) Place a copy of x1 on top of the stack
- **pick** (xu ... x1 x0 u – xu ... x1 x0 xu) access the stack as an array and fetch the u-th element as new TOS
- **?dup** (n1 – [n1 n1] | 0) duplicate TOS if non-zero
- **rot** (n1 n2 n3 – n2 n3 n1) rotate the three top level cells
- **rp0** (– addr) start address of return stack
- **rp@** (– n) current return stack pointer address
- **rp!** (addr –) (R: – x*y) set return stack pointer
- **r@** (– n) (R: n – n) fetch content of TOR

- **r>** (- n) (R: n -) move TOR to TOS
- **sp** (- addr) address of user variable to store top-of-stack for inactive tasks
- **sp** (- addr) address of user variable to store top-of-stack for inactive tasks
- **sp** (- addr) address of user variable to store top-of-stack for inactive tasks
- **sp0** (- addr) start address of the data stack
- **sp@** (- addr) current data stack pointer
- **sp!** (addr - i*x) set data stack pointer to addr
- **swap** (n1 n2 - n2 n1) swaps the two top level stack cells
- **>r** (n -) (R: - n) move TOS to TOR

5.21 String

- **compare** (r-addr r-len f-addr f-len - f) compares two strings in RAM
- **count** (c-addr1 - c-addr2 len) convert addr of counted string to address of the first character and length of the string
- **cscan** (addr1 n1 c - addr1 n2) Scan string at addr1/n1 for the first occurrence of c, leaving addr1/n2, char at n2 is first non-c character
- **cskip** (addr1 n1 c - addr2 n2) skips leading occurrences in string at addr1/n1 leaving addr2/n2 pointing to the 1st non-c character
- **parse** (char "ccc<char>" - c-addr u) in input buffer parse ccc delimited string by the delimiter char.
- **parse-name** ("<name>" - c-addr u) In the SOURCE buffer parse whitespace delimited string. Returns string address within SOURCE.
- **place** (addr1 len1 addr2 -) copy string as counted string
- **/string** (addr1 u1 n - addr2 u2) adjust string from addr1 to addr1+n, reduce length from u1 to u2 by n
- **sliteral** (C: addr len -) (C: addr len -) compiles a string to flash, at runtime leaves (- flash-addr count) on stack
- **tolower** (C - c) if C is an uppercase letter convert it to lowercase
- **toupper** (c - C) if c is a lowercase letter convert it to uppercase

5.22 System

- **accept** (addr +n1 - +n2) receive a string of at most n1 characters at addr until n2 characters are received or cr/lf detected.
- **allot** (n -) allocate or release memory in RAM
- **cold** (-) start up amforth.
- **defer@** (xt1 - xt2) returns the XT associated with the given XT
- **defer!** (xt1 xt2 -) stores xt1 as the xt to be executed when xt2 is called
- **(value)** (- n) runtime of value
- **execute** (xt -) execute XT
- **f_cpu** (- d) put the cpu frequency in Hz on stack
- **f_cpu** (- d) put the cpu frequency in Hz on stack

- **f_cpu** (- d) put the cpu frequency in Hz on stack
- **interpret** (-) (R: i*x - j*x) interpret input word by word.
- **is** (xt1 c<char> -) stores xt into defer or compiles code to do so at runtime
- **nfa>lfa** (nfa - lfa) get the link field address from the name field address
- **?execute** (xt|0 -) execute XT if non-zero
- **quit** (-) main loop of amforth. accept - interpret in an endless loop
- **refill** (- f) refills the input buffer
- **refill-tib** (- f) refills the input buffer
- **source** (- addr n) address and current length of the input buffer
- **source-tib** (- addr n) address and current length of the input buffer
- **warm** (nx* -) (R: ny* -) initialize amforth further. executes turnkey operation and go to quit

5.23 System Value

- **dp** (- f-addr) address of the next free dictionary cell
- **edp** (- e-addr) address of the next free address in eeprom
- **ee-user** (- v) address of the default user area content in eeprom
- **environment** (- wid) word list identifier of the environmental search list
- **here** (- addr) address of the next free data space (RAM) cell
- **turnkey** (- n*y) Deferred action during startup/reset

5.24 System Variable

- **>in** (- a-addr) pointer to current read position in input buffer
- **latest** (- addr) system LATEST
- **#tib** (- addr) variable holding the number of characters in TIB
- **pad** (- a-addr) Address of the temporary scratch buffer.
- **state** (- addr) system state
- **tib** (- addr) terminal input buffer address
- **up@** (- addr) get user area pointer
- **up!** (addr -) set user area pointer

5.25 Time

- **1ms** (-) busy waits (almost) exactly 1 millisecond
- **ms** (n -) busy waits the specified amount of milliseconds

5.26 Tools

- **[char]** (- c) (C: “<space>name” -) skip leading space delimites, place the first character of the word on the stack
- **[compile]** (- c) (C: “<space>name” -) skip leading space delimites, place the first COMPILERacter of the word on the stack
- **char** (“<spaces>name” - c) copy the first character of the next word onto the stack
- **.s** (-) stack dump
- **ee>ram** (e-addr r-addr len -) copy len cells from eeprom to ram
- **@e[]** (ee-addr - itemn .. item0 n) Get an array from EEPROM
- **find** (addr - addr 0 | xt -1 | xt 1) search wordlists for entry taken as counted string from addr
- **find-name** (addr len - 0 | xt -1 | xt 1) search wordlists for the name from string addr/len
- **icompare** (r-addr r-len f-addr f-len - f) compares string in RAM with string in flash
- **icount** (addr - addr+1 n) get count information out of a counted string in flash
- **init-user** (-) setup the default user area from eeprom
- **itype** (addr n -) reads string from flash and prints it
- **noop** (-) do nothing
- **?stack** (-) check stack underflow, throw exception -4
- **show-wordlist** (wid -) prints the name of the words in a wordlist
- **show-wordlist** (wid -) prints the name of the words in a wordlist
- **!e[]** (recn .. rec0 n ee-addr -) Write a list to EEPROM
- **to** (n <name> -) store the TOS to the named value (eeprom cell)
- **unused** (- n) Amount of available RAM (incl. PAD)
- **ver** (-) print the version string
- **word** (c - addr) skip leading delimiter character and parse SOURCE until the next delimiter. copy the word to HERE
- **words** (-) prints a list of all (visible) words in the dictionary

5.27 Tools Ext (2012)

- **name>string** (nt - addr len) get a (flash) string from a name token nt
- **traverse-wordlist** (i*x xt wid - j*x) call the xt for every member of the wordlist wid until xt returns false

HISTORY

6.1 5.4.2013: release 5.1

- core: Automatic scoping of words. A system hook can be used to use a different wordlist than CURRENT to place a new word in. Thanks to Enoch for the idea and the code.
- lib: very flexible CRC8 checksum generator and checker. Thanks to Enoch.
- recipes: *Interrupt Critical Section*, *Unbreakable AmForth*, *Efficient Bit Manipulation*, *Dump Utilities*, *Ctrl-C* Thanks to Enoch and the others on the mailing list for code and inspiration.
- core: **-int** does no longer leave the SREG register. It only turns off the global interrupt flag. Thanks to Enoch.
- lib: major 1-wire enhancements: CRC checks and a better naming convention for all words. Thanks to Erich for help and substantial contributions.
- appl: added the Arduino Leonardo. avrdude needs a small patch to write properly the eeprom on the Atmega32U4.
- core: New **popcnt** (n – m) counts the *Hamming Weight* of the given number.
- core: renamed **baud** to **ubrr**.
- core: **nfa>lfa** is a factor in a number of words. It generates the link field address from a given name field address.
- doc: Farewell docbook XML, welcome reST. All documentation will be written in *reStructured Text*.
- lib: Simple Quotations. Their typical use case is

```
: foo ... [: bar baz ;] ... ;
```

which is equivalent to

```
:noname bar baz ; Constant#temp#  
: foo ... #temp# ...;
```

6.2 27.12.2012: release 5.0

- lib: Access to *Dallas 1-Wire Devices*. Based on code and ideas by Bradford J. Rodriguez for the *4€4th project*.
- lib: many Arduino ports have more than one purpose. The forth200x *Synonym* gives them useful alias names.
- Arduino: Added definitions for all ports based upon *Digital Ports*.
- recipes: There are now more than 30 *Cookbook* in the cookbook: many debug tools, loop with timeout, porting from C, and interrupts to mention some of them.

- core: autogenerate **sleep** depending on register availability. **sleep** on an Atmega32 is very different from an Atmega328p. The parameters for calling it at the forth level are the same however. The include list for the assembler is expanded with `core/<device>/` to find the right `sleep.asm` file.
- core: rudimentary error checks in the compiler: There has to be branch destination on the stack. If there is nothing, a stack underflow exception gets thrown.

```
> : ?do i . loop ;
?? -4 14
> : t2 ?do i . loop ;
ok
>
```

- core: Number sign may follow the number base prefix as specified in [Forth200x Number Prefix](#). Added the character # as prefix for decimal as well.
- core: fixed a regression in **toupper** caused by making **within** standards compliant. Thanks to Arthur for the fix. **[compile]** fixed as well.

6.3 27.7.2012: release 4.9

- core: initialisation of the USER area is now done in WARM. please check your TURNKEY to remove the call to it. Thanks to Erich for pointing to.
- core: regenerated the devices files with the part description files from studio v6. added bitnames to the forth and python modules (later to be used with the shell).
- tools: completely new shell program with cool upload features from Keith: [amforth-shell](#) It has command completion, full command history, automatic controller identification with all register names and much more. Updated the *Use of the amforth-shell.py utility* for this task
- lib: re-arranged source files, improved timer modules.
- lib: **case** did not work at all. Thanks to Jan for telling.
- core: the new variable **latest** has the XT of the currently being defined colon word.
- core: **unused** should tell the free amount of memory in the area **here** points to: RAM. Thanks to Carsten for the hint.
- core: introducing an environment query for basic controller information: memory sizes, max dictionary address: **mcu-info**. The structure itself is not yet finalized. See at the end of a `core/<device>/device.asm` file for details.
- tools: The upload utilities were unable to process absolute filenames (those beginning with a /) Thanks to Carsten for the fix.

6.4 26.3.2012: release 4.8

- core: fixed a bug in **na@** and **nb@** (extended VM registers).
- core: redesigned **to** for use in LOCALs and RAM-based values.
- core: **.s** is stripped down to a single line output of the stack content only. Looks better in the call tracer and is more like other forth's.
- core: small atxmega updates. Unfortunately avrdude cannot flash the boot loader section as expected.
- core: optional Unified memory address space. **@** and **!** use the range from 0 to RAMEND as RAM, from RAMEND+1 upwards the next addresses from EEPROM, until EEPROMEND is reached and the remaining addresses from flash.

- core: **environment?** can now be used in colon definitions. changed into loadable forth source instead of compile-time assembly.
- core: **itype** now sends proper (e.g. single byte) characters to **emit**.
- core: **type** is made more robust against **emit** errors.
- lib: **macro** and a *Defining and using Macros* recipe for using them.
- *Profiler* to count the number of calls.
- lib: **evaluate** for both RAM and Flash based strings.

6.5 4.2.2012: release 4.7

- recipes: *Multitasking*, *Reason For Reset* and *Tracer*
- core: new words from the STRINGS word set: **sliteral** and **compare**. Latter is a simplified version of the ANS94 spec: max 255 chars, (in)equality tests only.
- core: **source**, **refill** are now deferred words, based on the USER area. **>in** likewise. Based on ideas from *Strong Forth*.
- core: **/key** removed, it can be implemented by changing **refill**.
- lib: The multitasker could not work after power cycles. Thanks to Erich for fixing.

6.6 6.10.2011: release 4.6

- core: **words** shows the *first* entry in the search order list as specified by DPANS94.
- lib: new word **m*/** (d1 n1 n2 – d2), uses a triple cell intermediate for d1*n1.
- lib: new words **bm-set**, **bm-clear** and **bm-toggle** that efficiently change bits in RAM byte addresses. e.g. :command: ‘ %0010 here bm-toggle ‘ changes bit 2 in the RAM location at **here**.
- lib: renamed **spirw** to **c!@spi**, new word **!@spi** exchanges two bytes via SPI. Follows remotly the memory access word naming conventions.

6.7 29.6.2011: release 4.5

- arduino: re-arranged word placing to maximize usable flash (at least on a duemilanove device, the bigger variants like the sanguino and mega* still have room for improvement). The target mega is now called mega128.
- lib: `lib/buffer.frt` implements **buffer:**.
- doc: improved refcard. Thanks to Erich for input and patches.
- core: changed API of the Recognizer to the final addr/len pairs. Do not use counted strings any longer!
- core: new words **find-name** and **parse-name** follow *Forth 200x* and operate on the current input buffer, **word** is no longer used internally. Lots of internal code simplifications.
- core: **(create)** throws exception -16 if no name is given.
- core: exception -42 is really -4 (stack underflow).
- core: **digit?** again. Stack effect now compatible to gforth: (**char** – **n true | false**). Current setting of **base** is now taken internally.

6.8 24.5.2011: release 4.4

- examples: added a game of life and a queens puzzle solver.
- core: restructure of the RAM usage. You need to remove the **.set here = ...** line from your application definition file (template.asm).
- core: turn **cold** into the main initialization word and **warm** into some high level initialization.
- doc: updated Technical Documentation of Recognizers and Interrupt Processing. Reformatted the *Reference Card* to a more compact style.
- core: added **n>r** and **nr>** from *Forth 200x*.
- core: Redesign of Interrupt Handling. ISR Routines are still normal Colon Words and can deal with every kind of interrupts. There are no lost interrupts any longer. Based on Ideas from Wojciech (Tracker ID 2781547) and AI (mailling list).
- appl: Fixed a regression in the floating point library due to changes in **number** in post 4.0 releases. **>float** can now be used as the main part of a recognizer.
- core: added a compile time option WANT_IGNORECASE to make amforth case-insensitive, disabled by default.

6.9 1.5.2011: release 4.3

- core: **u>** had wrong stack effect in case of true result.
- core: **int-trap** triggers an interrupt from software.
- core: **/user** environment query gives the size of the USER area
- core: **sleep** takes the sleep mode as parameter.
- ex: added timer-interrupt.frt as an example for using interrupts with forth.
- pub: Erich has presented amforth at the Fosdem 2011 Slides and Proceedings (published with permission). Thanks Erich!
- core: simplified **get/set-order** with a changed eeprom content.
- doc: new user guide version from Karl (for version 4.2).
- core: renamed **e@/e!** to **@e!/e** to comply with the memory access wordset from forth200x, same with **i@/i!**.
- core: documentation fixes in many files: *Reference Card*.
- core: re-design of the (outer) interpreter using recognizers (dynamically extend the interpreter to deal with new semantics. Defined **get/set-recognizer** similar to **get/set-order**.

6.10 19.9.2010: release 4.2

- core: fixed a regression for **i!** which made **marker** useless (among other oddities). Thanks to Marcin for the fix
- core: currently defined colon words are invisible until the final **;**.
- applications: Leon contributed a IEEE754 floating point library in plain forth, Pito translated some basic words into assembly for speed.

6.11 2.9.2010: release 4.1

- core: new words **2>r**, **2r>** and **2literal**.
- core: converted most of the atmega part definition files with the pd2amforth utility. Please report any success / failure.
- doc: set the fuses to make the bootloader size as large as the NRWW size.
- core: abort assembling if flash usage is above limits.
- core: allow double cell numbers in colon definitions. Thanks to Pito for reporting the bug.

6.12 1.7.2010: release 4.0

- tools: amforth-upload.py optionally loads a device specific module and replaces register definitions with their values prior to sent the code to the controller. The device modules are auto-generated from the part description files.
- core: ANS94 mention that HERE points to the data (RAM) region. Re-introduced DP as the dictionary (Flash) pointer. **HEAP** is gone. Migrate old HEAP to HERE and old HERE to DP.
- core: save and clear the initial value of the MCU Status Register at address 10.
- tools: pd2amforth is now capable to generate the device definition files. It is no longer necessary to edit them manually.
- core: finally separated the terminal IO settings from the device definition files.
- core: optionally set WANT_SPI (or any other IO Module) to include the register definition names at build time.
- core: massively restructured the devices/ filesystem entry. Change your application files to include device.asm instead of the device name. Set the include directory to the proper subdirectory under core/devices as well.
- core: dynamically calculate the free space. Do not use all of it however, the data stack may grow.

s" /pad" **environment?**

- core: Simplified the Pictured Numeric Output words. They now use the memory area below **pad** (which is 100 bytes above HEAP) as the buffer region.
- appl: added the arduino board with some example codes. Currently with the Mega (Atmega1280), Duemilanove (Atmega328) and Sanguino (Atmega644p) controller types.

6.13 25.5.2010: release 3.9

- web: updated the Howto page to demonstrate *Redirect IO*.
- core: The Atmega2561 now fully works (incl the compiler).
- core, appl: Andy Kirby donated the device files and a full implementation for Arduino Mega with the Atmega1280.
- core: CPU Name, Forthname and Version strings can be accessed as environment queries.

6.14 25.4.2010: release 3.8

- core: turned **i!** into a deferred word.

- core: fix for **icompare** to make it work with all addr/len strings. Bug found and fixed by Michael and Adolf.
- core: re-implemented the **i!** in (mostly) assembly language to ease integration into bootloaders.
- core: factor the three prompts into compile time changable words.
- appl: the `dict_minimum.inc` und `dict_core.inc` files need to be included within the application defition files.
- core: **pad** is no longer used by amforth itself.
- core: reorder internal code in **interpret** to get rid of **0=** calls.

6.15 24.1.2010: release 3.7

- core: atxmega 128 support (no compiler yet).
- core: new word **>number. number** accepts trailing (!) dots to enter double cell numbers.
- lib: enhanced multitasker with turnkey support. Thanks to Erich Wälde for in depth debugging and testing.
- lib: new word **anew** drops word definitions if already defined, starts a new generation.
- core: USER area is now split into system and application user areas, system user area is pre-set from EEPROM.
- new: source repository [Incubator](#) for not-yet-ready-but-interesting projects, volunteers welcome.

6.16 1.10.2009: release 3.6

- core: new word **environment**. It provides the environment wordlist identifier, thus make it possible to create own environment queries as standard words.
- core: new word **d=**.
- core: amforth runs partially on an atmega2561 and atxmega's, there is still no working flash store word (**i!**) therefore only the interpreter is available yet.
- core: moved the usart init values to appl section.
- core: added a poll-only receive word, selectable at compile time. Disable the rx interrupt to use it.

6.17 1.9.2009: release 3.5

- core: re-structure the usart code, added a non-interrupt based transmit word (TX), selectable at compile time.
- lib: added **xt>nfa** that goes from the XT to the name field address.
- core: bugfix **recurse**.
- core: restructured EEPROM, never depend on fixed addresses for system values.
- core: added a `dict_wl.inc` file with most of the non-core wordlist commands.

6.18 11.4.2009: release 3.4

- core: renamed the words for the serial terminal to be more generic since they can deal with any serial port, not only the first one.

- lib: dropped **forget** since it cannot work with multiple wordlists, fixed **marker**.
- core: changed again **digit?** stack effect (and fixed a little bug).
- core: **number** honors a leading &, \$ or % sign to temporarily switch to DECIMAL, HEX or BIN base resp. Thanks to Michael Kalus for factoring the code.

6.19 22.2.2009: release 3.3

- core: faster **noop**.
- added ANS94 search order wordlist.
- core: **within** had problems with signed boundaries, literal numbers are processed faster (again).
- core: improved **digit?** and **number**. They now report errors on invalid characters at the wrong position. The following strings are no longer valid numbers: -1 or 0@ (in base hex).
- core: **-1 spaces** now prints nothing, Fix from Lothar Schmidt.
- core: **(loop)** (runtime of loop) now checks for equality only, as specified in ANS94.

6.20 10.1.2009: release 3.2

- core: bugfix for trailing 0x00 byte during **itype**.
- core: enable use of other usart port than 0.
- pc-host: Ken Staton wrote a nice pc based terminal with upload functionality.
- core: New controllers: ATmega328P and ATmega640.
- core: changed **digit** to **digit?** found in many other forth's.
- core: new word **within**.
- core: split application dictionary definition into 2 parts, one for the lower flash, one for the upper (NRWW) flash. Both can be empty, but need to exists.
- core: changed some names for internal constants (baudrate -> BAUD) and registers (EEPE vs EEWE).
- core: new directory `drivers/` for low level driver functions. Currently only the generic ISR and the USART0 interrupt handler.

6.21 10.11.2008: release 3.1

- core: **icompare** now has a similiar stack effect as **compare**.
- core: new word: **environment?**. Supports **/hold** query.
- core: Strings in flash (incl. names in the dictionary) contain now 16bit length information, previously only 8 bit.

6.22 17.10.2008: release 3.0

- core: **s''** new with interpreter semantics.

```
s" hello world" type`
```

works at the command prompt. The compiled version is

```
: hw s" hello world" itype ;
```

- core: Placement of Stacks is now an application setting. See example apps.
- core: added VM register A and B. See [Stephen Pelc' Slides](#) for details. Uses Atmega Register R6:R7, R8:R9 resp.
- core: added **cmove** as a primitive.
- core: **f_cpu** used the old (pre-2.7) stack order for double cell values.
- lib: moved some definitions to more appropriate files.

6.23 1.8.2008: release 2.9

- core: **heap**, **here** and **edp** are now VALUES. **dp** is gone (use **here**)
- lib: more VT100 sequences.
- core: The TIB location and size are accessible with the VALUES **TIB** and **TIBSIZE**.
- core: fixed TIBSIZE default configuration.
- lib: created math.frt, contains among others the standard words **sm/rem**, **fm/mod**.
- Alexander Guy fixed a bug in **u*/mod**.
- Bernard Mentink adapted Julian Noble's Finite State Machine code.
- applications: Lubos Pekny designed a smart computer with a 4line character LCD and a PS/2 keyboard. Details are in the [Application Repository](#), a video is [available](#) as well.

6.24 27.6.2008: release 2.8

- core: Lubos Pekny found that **-jtag** sometimes used the wrong mcu register.
- core: Bernard Mentink wrote a Atmega128 device file, Thanks alot.
- core: Atmega88 & Atmega168 work too.
- core: Fixed regression for atmega128.
- core: Moved serial interface words to application dictionary (not every amforth installation may have a serial terminal).
- library: Updated assembler from Lubos Pekny.
- examples: sieve benchmark, optimized for 1K RAM.

6.25 5.4.2007: release 2.7

- core, lib and sample applications are now in one package.
- restructured repository layout. Now the trunk has most of the sources.
- core: re-arranged the register mapping.
- core: **m*** was in fact **um***.
- core: double cell numbers changed stack order: TOS is now the most significant cell.
- library: new: assembler written by Lubos Pekny, www.forth.cz. Thank you!
- examples: PWM example from Bruce Wolk. TWI/I2C EEPROM access

6.26 27.1.2008: release 2.6

- core: new defining words **code** and **end-code**. **code** starts a new dictionary header with the XT set to the data field. The 2nd one appends the **jmp NEXT** call into the dictionary.
- core: removed the pre-assembled **case** / **endcase** words. Added them as forth library.
- core: new words **-jtag** (turns off JTAG at runtime) and **-wdt** (turns off watch dog timer at runtime). They need to be implemented as primitives due to timing requirements.
- core: **quit**: Keep **base** when handling an exception.
- library: TWI/I2C EEPROM Support.

6.27 6.12.2007: release 2.5

- Bug: **hex 8000** . froze the controller. Now it prints -8000. Thanks to Lubos for the hint.
- Moved init of **base** from **quit** to **cold**. **turnkey** be used to change it permanently. Thanks to Lubos for the hint.
- nice looking dumper words for RAM/EEPROM/FLASH, dropped idump.asm.
- Extended Upload utility (`tools/amforth-upload.py`) from piix: include files using following syntax:

```
\ demo file
#include ans94/marker.frt
marker empty
```

- usart transmit (**tx0**) made more robust.
- User Area restructured for the new multitasker.
- added documentation: Karl's *User's Manual* and a *Technical Guide*.

6.28 11.10.2007: release 2.4

- Added AT90CAN128. Other Atmega128 style controllers should work too.
- lot of fine tuning.
- dropped the assembler device init portion.
- New file: `dict_compiler.inc`. Without these words the forth system is (more or less) a pure interactive system without extensibility.
- new words **[char]**, **fill**.
- re-arranged usart code. fixed bug when usart baud rate calculation leads to values greater 255.
- renamed **/int** to **-int** and **int** to **+int**, it's more forthish ;=)

6.29 29.7.2007: release 2.3

- new words **spaces** and **place**.
- Improved **if!**.
- bugfixing runtime parts of **do/loop** and co.
- re-coded **find** and **icompare** for better readability.

- eliminated code duplets in some primitives.
- moved usart init from **cold** to application specific turn key action. Added error checking in receive module.

6.30 17.6.2007: release 2.2

- new download section: application
- optional dictionary is now part of the application, therefore renamed to dict_appl.
- new words: **leave** and **?do**.

6.31 22.5.2007 release 2.1

- changed stack effect for **#** to ansi (from single cell value to double cell). Double cell values do not work (yet).
- introduced **deferred** words instead of tick-variables. Works for EEPROM based vectors (turnkey), RAM based (**pause**) and User based (**emit** etc) vectors.
- new words: **wdr** (Watchdog reset), **d>** and **d<** (double cell compare).

6.32 2.5.2007 release 2.0

- internal restructure of targets.
- new words: **u>** and **u<**.
- bugfixing interrupts.
- new word: **log2** logarithm to base 2, or the number of the highest 1 bit.
- fixed wrong addresses for usart-io (esp. butterfly)

6.33 25.4.2007 release 1.9

- renamed dict_low.asm to dict_minimal.asm.
- new word **parse** (c – addr len) parses **source** for char delimited strings.
- new word **sleep** (–) puts the controller into (previously defined) sleep mode.
- new words **s”** (– addr len) parses TIB for ” character and compiles it into flash, **s**, (addr len –) does the real copying of the string into flash at **here** together with the invisible word (**sliteral**) (– flash-addr len).
- bugfix: **f_cpu** had wrong word order. Use **swap** as a temporary work around.
- re-wrote initialisation of usart0 (baud –) to forth code. Startup speed is taken from (eeprom) VALUE **baud0**.

6.34 10.4.2007 release 1.8

- interrupt handling redesigned. Now every interrupt (except those for usart0) can be used. **intcounter** is gone. New words are **int@**, **int!** and **#int**.
- double and mixed cell arithmetics.
- bugfix: proper initialization of data stack pointer. Thanks to Maciej Witkowiak.

- move TOS into register pair.

6.35 3.4.2007 release 1.7

- new word: **f_cpu** sets a double cell value with the cpu clock rate.
- **hld** is now at **pad** to save RAM.
- **pad** did return some compile-time stochastic value‘
- lots of internal changes.
- optional dictionary: **d-**, **d+**, **s>d** and **d>s**.

6.36 25.3.2007 release 1.6

- split `blocks/ans.frt` into pieces.
- **sign** no longer inserts a space for non-negative values.
- new word: **/key**. It is vectorized via **‘/key** and gets called by **accept** to signal the sender to stop transmission. See `blocks/xonxoff.frt` for example usage.
- replaces **up** with **up@** and **up!**.
- new word: **j** (- n).
- new word: **?execute** (xt!0 -) if non-zero execute the XT.
- The Atmega644 works fine :=) but needs the Atmel assembler (see [FAQ](#)) :=(
- Bugfix: **+**! did a + only.
- Bugfix: too many spaces in **.** (dot).
- give user variables **rp** and **sp** a name.

6.37 14.3.2007 release 1.5

- changed: **itype** and (new) **icount** refactored by Michael Kalus. These words now have similiar stack effects as there RAM counterparts.
- changed: **.** now operates on signed values.
- new word: **u/mod** is basically the former **/mod**.
- new word: **u.** to display unsigned values.
- fixed bug in **/mod** for values less -FF (hex).
- **create** left the address of the XT insted of the PFA. Fixed.
- deleted word: **idump**. It is now in the file `blocks/misc.frt`.
- new word: **:noname** (- xt) creates headerless entry in the dictionary.
- new word: **cold** as main entry point. It executes the turnkey action. **abort** & co do not trigger the turnkey action.

6.38 5.3.2007 release 1.4

- **pad** is now in the **unused** (according to **heap**) ram. That may help **word** to store longer strings.
- new word: **unused** (- n) gives the number of unused flash cells in the dictionary.
- **/mod** (and **/** and **mod**) now honor signed numbers, division is symmetric.
- new word: **abort**
- **quit** now aborts on every caught exception.
- **quit** no longer prints anything, **ver** is now a turnkey action.
- new optional dictionary, included at compiletime. Contains now **case** & Co and some **d-** words for double cell arithmetics.

6.39 24.2.2007 release 1.3

- bug: **digit** did not work properly
- bug: **<**: equal is not less
- interrupts are processed faster
- Interrupt counter are now only 1 byte long (access with **c@**)
- change: **allot** works now for ram not for flash
- added/corrected stack comments
- bug: **create** leaves flash address insted of first cell content
- change: **.s** nicer for empty stack
- internal: **i!** internally completly turns off interrupts
- bug: **abort** now works again, error was in **quit**
- bug: **while** and **repeat** changed stack effects
- bug: **r@** now works correctly
- new word: **immediate**
- removed words: **forget**, **postpone** (these and many more are now in the **blocks/ans.frt** library)
- bug: if **'** (tick) does not find the word, it now throws the exception -13 Many thanks to Ulrich Hoffmann for providing feedback and corrections!

6.40 3.2.2007 release 1.2

- anyone missed **emit**??.
- increased user area to 24 bytes (12 cells). Fixed a overlap between **handler** and **emit** ff.
- AVR *AVR Butterfly* works (again). Many thanks to the *German FIG* for donating one.
- internal changes for multitarget development (for the AREXX asuro minirobot).

6.41 20.1.2007 release 1.1

- **emit**, **key** and **key?** are now vectored via **user** based variables.
- **forget** frees most of the flash space too
- internal go back for **i!** to previous code
- Code for Atmega8 was broken due to nrww flash overflow (found by Milan Horkel)
- Bugfix: backspace key in **accept** now stops at beginning of line (found by Milan Horkel)

6.42 4.1.2007 release 1.0

- new immediate word: **[']**
- new word **user** defines user variables
- new controller: atmega169 (Atmel Butterfly)
- renamed **eheap** to **edp**.

6.43 17.12.2006 release 0.9

- interrupts in high level forth colon words (INT0 and INT1 for now).
- new word: **noop** a colon word for doing nothing.
- **number** respects minus sign
- changed **turnkey** into **'turnkey**. The "turn-off" value is now 0 (zero)
- new words: **pause** and **'pause**. **pause** will execute the XT stored in **'pause** (a RAM cell) when non zero
- **handler** (used by **catch** and **throw**) is a USER variable.

6.44 7.12.2006 release 0.8

- new words: **create**, **does>**, **up**, **0**
- Support for user variable, turned **base**, **rp0** and **sp0** into user variables
- words like **(do)** which should not be called by user are now invisible to save nrww flash space
- bugfix for negative increment for **+loop**.

6.45 24.11.2006 release 0.7

- new word: **turnkey**: executed whenever **quit** starts.
- numbers may contain lower case characters (if **base** permits)
- bugfixing **case** & co.
- **number** emits -13 if an invalid character is found
- renamed **vheader** to **(create)**
- **abort** re-initializes both stacks
- made backslash **** immediate

6.46 20.11.2006 release 0.6

- backspace now works in **accept**
- **depth** based on **sp0/sp@**
- “unused” control characters are treated as spaces
- bugfixes for **(loop)** and **(+lopp)**.
- New words: **1ms** busy waits 1 millisecond

6.47 13.11.2006 release 0.5

- definition files for varios atmega types
- core wordlist should be complete
- internal cleanups and bugfixes

6.48 5.11.2006 release 0.4

- start using **catch/throw**
- Atmega8 works fine
- few new words (**case**, comments)
- nicer prompt

6.49 31.10.2006 release 0.3

- New website
- Atmega16 works fine
- Bugfixing, true flag always 0xffff

6.50 27.10.2006 release 0.2

- Compiler works
- Many new wrds

6.51 16.10.2006 release 0.1

- first public release
- interpreter over serial terminal