avr-libc Reference Manual

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Contents

1 AVR Libc

The latest version of this document is always available from `http://savannah.nongnu.org/projects/avr-libc/`

The AVR Libc package provides a subset of the standard C library for Atmel AVR 8-bit RISC microcontrollers. In addition, the library provides the basic startup code needed by most applications.

There is a wealth of information in this document which goes beyond simply describing the interfaces and routines provided by the library. We hope that this document provides enough information to get a new AVR developer up to speed quickly using the freely available development tools: binutils, gcc avr-libc and many others.

If you find yourself stuck on a problem which this document doesn't quite address, you may wish to post a message to the avr-gcc mailing list. Most of the developers of the AVR binutils and gcc ports in addition to the devleopers of avr-libc subscribe to the list, so you will usually be able to get your problem resolved. You can subscribe to the list at `http://www.avr1.org/mailman/listinfo/avr-gcc-list/` . Before posting to the list, you might want to try reading the **Frequently Asked Questions**(p. 130) chapter of this document.

Note:

This document is a work in progress. As such, it may contain incorrect information. If you find a mistake, please send an email to `avr-libc-dev@nongnu.org` describing the mistake. Also, send us an email if you find that a specific topic is missing from the document.

1.1 Supported Devices

The following is a list of AVR devices currently supported by the library.

AT90S Type Devices:

- at90s1200 **[1]**(p. 4)
- at90s2313
- at90s2323
- at90s2333
- at90s2343
- at90s4414
- at90s4433
- at90s4434
- at90s8515
- at90c8534
- at90s8535
- at90can128

ATmega Type Devices:

- atmega8
- atmega103
- atmega128
- atmega16
- atmega161
- atmega162
- atmega163
- atmega165
- atmega168

- atmega169
- atmega32
- atmega323
- atmega325
- atmega3250
- atmega48
- atmega64
- atmega645
- atmega6450
- atmega8515
- atmega8535
- atmega88

ATtiny Type Devices:

- attiny11 **[1]**(p. 4)
- attiny12 **[1]**(p. 4)
- attiny13
- attiny15 **[1]**(p. 4)
- attiny22
- attiny26
- attiny28 **[1]**(p. 4)
- attiny2313

Misc Devices:

- at94K **[2]**(p. 4)
- at76c711 **[3]**(p. 4)
- at43usb320
- at43usb355

- at86rf401

Note:

[1] Assembly only. There is no direct support for these devices to be programmed in C since they do not have a RAM based stack. Still, it could be possible to program them in C, see the **FAQ**(p. 150) for an option.

Note:

[2] The at94K devices are a combination of FPGA and AVR microcontroller. [TRoth-2002/11/12: Not sure of the level of support for these. More information would be welcomed.]

Note:

[3] The at76c711 is a USB to fast serial interface bridge chip using an AVR core.

2 avr-libc Module Index

2.1 avr-libc Modules

Here is a list of all modules:

3 avr-libc Directory Hierarchy

3.1 avr-libc Directories

This directory hierarchy is sorted roughly, but not completely, alphabetically:

4 avr-libc Data Structure Index

4.1 avr-libc Data Structures

Here are the data structures with brief descriptions:

5 avr-libc Page Index

5.1 avr-libc Related Pages

Here is a list of all related documentation pages:

6 avr-libc Module Documentation

6.1 Bootloader Support Utilities

6.1.1 Detailed Description

```
#include <avr/io.h>
#include <avr/boot.h>
```

The macros in this module provide a C language interface to the bootloader support functionality of certain AVR processors. These macros are designed to work with all sizes of flash memory.

Note:

Not all AVR processors provide bootloader support. See your processor datasheet to see if it provides bootloader support.

Todo

From email with Marek: On smaller devices (all except ATmega64/128), __SPM_REG is in the I/O space, accessible with the shorter "in" and "out" instructions - since the boot loader has a limited size, this could be an important optimization.

API Usage Example

The following code shows typical usage of the boot API.

```
#include <inttypes.h>
#include <avr/interrupt.h>
#include <avr/pgmspace.h>

void boot_program_page (uint32_t page, uint8_t *buf)
{
    uint16_t i;
    uint8_t sreg;

    // Disable interrupts.

    sreg = SREG;
    cli();

    eeprom_busy_wait ();
```

```
        boot_page_erase (page);
        boot_spm_busy_wait ();      // Wait until the memory is erased.

        for (i=0; i<SPM_PAGESIZE; i+=2)
        {
            // Set up little-endian word.

            uint16_t w = *buf++;
            w += (*buf++) << 8;

            boot_page_fill (page + i, w);
        }

        boot_page_write (page);     // Store buffer in flash page.
        boot_spm_busy_wait();       // Wait until the memory is written.

        // Reenable RWW-section again. We need this if we want to jump back
        // to the application after bootloading.

        boot_rww_enable ();

        // Re-enable interrupts (if they were ever enabled).

        SREG = sreg;
    }
```

Defines

- #define **BOOTLOADER_SECTION** __attribute__ ((section (".bootloader")))
- #define **boot_spm_interrupt_enable**() (__SPM_REG |= (**uint8_t**)_BV(SPMIE))
- #define **boot_spm_interrupt_disable**() (__SPM_REG &= (**uint8_t**)~_BV(SPMIE))
- #define **boot_is_spm_interrupt**() (__SPM_REG & (**uint8_t**)_-BV(SPMIE))
- #define **boot_rww_busy**() (__SPM_REG & (**uint8_t**)_BV(__-COMMON_ASB))
- #define **boot_spm_busy**() (__SPM_REG & (**uint8_t**)_-BV(SPMEN))
- #define **boot_spm_busy_wait**() do{}while(boot_spm_busy())
- #define **boot_page_fill**(address, data) __boot_page_fill_-normal(address, data)
- #define **boot_page_erase**(address) __boot_page_erase_-normal(address)
- #define **boot_page_write**(address) __boot_page_write_-normal(address)
- #define **boot_rww_enable**() __boot_rww_enable()

- #define **boot_lock_bits_set**(lock_bits) __boot_lock_bits_set(lock_bits)
- #define **boot_page_fill_safe**(address, data) __boot_eeprom_spm_safe (boot_page_fill, address, data)
- #define **boot_page_erase_safe**(address, data) __boot_eeprom_spm_safe (boot_page_erase, address, data)
- #define **boot_page_write_safe**(address, data) __boot_eeprom_spm_safe (boot_page_wrte, address, data)
- #define **boot_rww_enable_safe**(address, data) __boot_eeprom_spm_safe (boot_rww_enable, address, data)
- #define **boot_lock_bits_set_safe**(address, data) __boot_eeprom_spm_safe (boot_lock_bits_set, address, data)

6.1.2 Define Documentation

6.1.2.1 #define boot_is_spm_interrupt() (__SPM_REG & (uint8_t)_BV(SPMIE))

Check if the SPM interrupt is enabled.

6.1.2.2 #define boot_lock_bits_set(lock_bits) __boot_lock_bits_set(lock_bits)

Set the bootloader lock bits.

Parameters:

lock_bits A mask of which Boot Loader Lock Bits to set.

Note:

In this context, a 'set bit' will be written to a zero value.

For example, to disallow the SPM instruction from writing to the Boot Loader memory section of flash, you would use this macro as such:

```
boot_lock_bits_set (_BV (BLB12));
```

And to remove any SPM restrictions, you would do this:

```
boot_lock_bits_set (0);
```

6.1.2.3 #define boot_lock_bits_set_safe(address, data) __boot_eeprom_spm_safe (boot_lock_bits_set, address, data)

Same as **boot_lock_bits_set()** (p. 9) except waits for eeprom and spm operations to complete before setting the lock bits.

6.1.2.4 #define boot_page_erase(address) __boot_page_erase_normal(address)

Erase the flash page that contains address.

Note:

address is a byte address in flash, not a word address.

6.1.2.5 #define boot_page_erase_safe(address, data) __boot_eeprom_spm_safe (boot_page_erase, address, data)

Same as **boot_page_erase()**(p. 10) except it waits for eeprom and spm operations to complete before erasing the page.

6.1.2.6 #define boot_page_fill(address, data) __boot_page_fill_normal(address, data)

Fill the bootloader temporary page buffer for flash address with data word.

Note:

The address is a byte address. The data is a word. The AVR writes data to the buffer a word at a time, but addresses the buffer per byte! So, increment your address by 2 between calls, and send 2 data bytes in a word format! The LSB of the data is written to the lower address; the MSB of the data is written to the higher address.

6.1.2.7 #define boot_page_fill_safe(address, data) __boot_eeprom_spm_safe (boot_page_fill, address, data)

Same as **boot_page_fill()**(p. 10) except it waits for eeprom and spm operations to complete before filling the page.

6.1.2.8 #define boot_page_write(address) __boot_page_write_normal(address)

Write the bootloader temporary page buffer to flash page that contains address.

Note:

address is a byte address in flash, not a word address.

6.1.2.9 #define boot_page_write_safe(address, data) __boot_eeprom_spm_safe (boot_page_wrte, address, data)

Same as **boot_page_write()**(p. 10) except it waits for eeprom and spm operations to complete before writing the page.

6.1.2.10 #define boot_rww_busy() (__SPM_REG & (uint8_t)_BV(__COMMON_ASB))

Check if the RWW section is busy.

6.1.2.11 #define boot_rww_enable() __boot_rww_enable()

Enable the Read-While-Write memory section.

6.1.2.12 #define boot_rww_enable_safe(address, data) __boot_eeprom_spm_safe (boot_rww_enable, address, data)

Same as **boot_rww_enable()**(p. 11) except waits for eeprom and spm operations to complete before enabling the RWW mameory.

6.1.2.13 #define boot_spm_busy() (__SPM_REG & (uint8_t)_BV(SPMEN))

Check if the SPM instruction is busy.

6.1.2.14 #define boot_spm_busy_wait() do{}while(boot_spm_busy())

Wait while the SPM instruction is busy.

6.1.2.15 #define boot_spm_interrupt_disable() (__SPM_REG &= (uint8_t)~_BV(SPMIE))

Disable the SPM interrupt.

6.1.2.16 #define boot_spm_interrupt_enable() (__SPM_REG |= (uint8_t)_BV(SPMIE))

Enable the SPM interrupt.

6.1.2.17 #define BOOTLOADER_SECTION __attribute__ ((section (".bootloader")))

Used to declare a function or variable to be placed into a new section called .bootloader. This section and its contents can then be relocated to any address (such as the bootloader NRWW area) at link-time.

6.2 CRC Computations

6.2.1 Detailed Description

```
#include <avr/crc16.h>
```

This header file provides a optimized inline functions for calculating 16 bit cyclic redundancy checks (CRC) using common polynomials.

References:

See the Dallas Semiconductor app note 27 for 8051 assembler example and general CRC optimization suggestions. The table on the last page of the app note is the key to understanding these implementations.

Jack Crenshaw's "Impementing CRCs" article in the January 1992 isue of *Embedded Systems Programming*. This may be difficult to find, but it explains CRC's in very clear and concise terms. Well worth the effort to obtain a copy.

Functions

- static __inline__ **uint16_t _crc16_update** (**uint16_t** __crc, **uint8_t** __data)
- static __inline__ **uint16_t _crc_xmodem_update** (**uint16_t** __crc, **uint8_t** __data)
- static __inline__ **uint16_t _crc_ccitt_update** (**uint16_t** __crc, **uint8_t** __data)

6.2.2 Function Documentation

6.2.2.1 static __inline__ uint16_t _crc16_update (uint16_t *__crc*, uint8_t *__data*) [static]

Optimized CRC-16 calcutation.

Polynomial: x^16 + x^15 + x^2 + 1 (0xa001)

Initial value: 0xffff

This CRC is normally used in disk-drive controllers.

6.2.2.2 static __inline__ uint16_t _crc_ccitt_update (uint16_t __crc, uint8_t __data) [static]

Optimized CRC-CCITT calculation.

Polynomial: x^16 + x^12 + x^5 + 1 (0x8408)

Initial value: 0xffff

This is the CRC used by PPP and IrDA.

See RFC1171 (PPP protocol) and IrDA IrLAP 1.1

Note:

Although the CCITT polynomial is the same as that used by the Xmodem protocol, they are quite different. The difference is in how the bits are shifted through the alorgithm. Xmodem shifts the MSB of the CRC and the input first, while CCITT shifts the LSB of the CRC and the input first.

The following is the equivalent functionality written in C.

```
uint16_t
crc_ccitt_update (uint16_t crc, uint8_t data)
{
    data ^= lo8 (crc);
    data ^= data << 4;

    return ((((uint16_t)data << 8) | hi8 (crc)) ^ (uint8_t)(data >> 4)
            ^ ((uint16_t)data << 3));
}
```

6.2.2.3 static __inline__ uint16_t _crc_xmodem_update (uint16_t __crc, uint8_t __data) [static]

Optimized CRC-XMODEM calculation.

Polynomial: x^16 + x^12 + x^5 + 1 (0x1021)

Initial value: 0x0

This is the CRC used by the Xmodem-CRC protocol.

The following is the equivalent functionality written in C.

```
uint16_t
crc_xmodem_update (uint16_t crc, uint8_t data)
{
    int i;

    crc = crc ^ ((uint16_t)data << 8);
    for (i=0; i<8; i++)
    {
```

```
            if (crc & 0x8000)
                crc = (crc << 1) ^ 0x1021;
            else
                crc <<= 1;
        }

        return crc;
    }
```

6.3 Busy-wait delay loops

6.3.1 Detailed Description

```
#define F_CPU 1000000UL  // 1 MHz
//#define F_CPU 14.7456E6
#include <avr/delay.h>
```

The functions in this header file implement simple delay loops that perform a busy-waiting. They are typically used to facilitate short delays in the program execution. They are implemented as count-down loops with a well-known CPU cycle count per loop iteration. As such, no other processing can occur simultaneously. It should be kept in mind that the functions described here do not disable interrupts.

In general, for long delays, the use of hardware timers is much preferrable, as they free the CPU, and allow for concurrent processing of other events while the timer is running. However, in particular for very short delays, the overhead of setting up a hardware timer is too much compared to the overall delay time.

Two inline functions are provided for the actual delay algorithms.

Two wrapper functions allow the specification of microsecond, and millisecond delays directly, using the application-supplied macro F_CPU as the CPU clock frequency (in Hertz). These functions operate on double typed arguments, however when optimization is turned on, the entire floating-point calculation will be done at compile-time.

Functions

- static __inline__ void **_delay_loop_1** (**uint8_t** __count)
- static __inline__ void **_delay_loop_2** (**uint16_t** __count)
- static __inline__ void **_delay_us** (double __us)
- static __inline__ void **_delay_ms** (double __ms)

6.3.2 Function Documentation

6.3.2.1 static __inline__ void _delay_loop_1 (uint8_t __ *count*) [static]

Delay loop using an 8-bit counter `__count`, so up to 256 iterations are possible. (The value 256 would have to be passed as 0.) The loop executes three CPU cycles per iteration, not including the overhead the compiler needs to setup the counter register.

Thus, at a CPU speed of 1 MHz, delays of up to 768 microseconds can be achieved.

6.3.2.2 static __inline__ void _delay_loop_2 (uint16_t __count) `[static]`

Delay loop using a 16-bit counter `__count`, so up to 65536 iterations are possible. (The value 65536 would have to be passed as 0.) The loop executes four CPU cycles per iteration, not including the overhead the compiler requires to setup the counter register pair.

Thus, at a CPU speed of 1 MHz, delays of up to about 262.1 milliseconds can be achieved.

6.3.2.3 static __inline__ void _delay_ms (double __ms) `[static]`

Perform a delay of `__ms` milliseconds, using **_delay_loop_2()**(p. 15).

The macro F_CPU is supposed to be defined to a constant defining the CPU clock frequency (in Hertz).

The maximal possible delay is 262.14 ms / F_CPU in MHz.

6.3.2.4 static __inline__ void _delay_us (double __us) `[static]`

Perform a delay of `__us` microseconds, using **_delay_loop_1()**(p. 14).

The macro F_CPU is supposed to be defined to a constant defining the CPU clock frequency (in Hertz).

The maximal possible delay is 768 us / F_CPU in MHz.

6.4 EEPROM handling

6.4.1 Detailed Description

```
#include <avr/eeprom.h>
```

This header file declares the interface to some simple library routines suitable for handling the data EEPROM contained in the AVR microcontrollers. The implementation uses a simple polled mode interface. Applications that require interrupt-controlled EEPROM access to ensure that no time will be wasted in spinloops will have to deploy their own implementation.

Note:

All of the read/write functions first make sure the EEPROM is ready to be accessed. Since this may cause long delays if a write operation is still pending, time-critical applications should first poll the EEPROM e. g. using **eeprom_is_ready()**(p. 17) before attempting any actual I/O.

This library will *not* work with the following devices since these devices have the EEPROM IO ports at different locations:

- AT90CAN128
- ATmega48
- ATmega88
- ATmega165
- ATmega168
- ATmega169
- ATmega325
- ATmega3250
- ATmega645
- ATmega6450

avr-libc declarations

- #define **eeprom_is_ready**() bit_is_clear(EECR, EEWE)
- #define **eeprom_busy_wait**() do {} while (!eeprom_is_ready())
- **uint8_t eeprom_read_byte** (const **uint8_t** *addr)
- **uint16_t eeprom_read_word** (const **uint16_t** *addr)
- void **eeprom_read_block** (void *buf, const void *addr, size_t n)
- void **eeprom_write_byte** (**uint8_t** *addr, **uint8_t** val)
- void **eeprom_write_word** (**uint16_t** *addr, **uint16_t** val)
- void **eeprom_write_block** (const void *buf, void *addr, size_t n)

IAR C compatibility defines

- #define **_EEPUT**(addr, val) eeprom_write_byte ((**uint8_t** *)(addr), (**uint8_t**)(val))
- #define **_EEGET**(var, addr) (var) = eeprom_read_byte ((**uint8_t** *)(addr))

6.4.2 Define Documentation

6.4.2.1 #define _EEGET(var, addr) (var) = eeprom_read_byte ((uint8_t *)(addr))

Read a byte from EEPROM.

6.4.2.2 #define _EEPUT(addr, val) eeprom_write_byte ((uint8_t *)(addr), (uint8_t)(val))

Write a byte to EEPROM.

6.4.2.3 #define eeprom_busy_wait() do {} while (!eeprom_is_-ready())

Loops until the eeprom is no longer busy.

Returns:
Nothing.

6.4.2.4 #define eeprom_is_ready() bit_is_clear(EECR, EEWE)

Returns:
1 if EEPROM is ready for a new read/write operation, 0 if not.

6.4.3 Function Documentation

6.4.3.1 void eeprom_read_block (void * *buf*, const void * *addr*, size_t *n*)

Read a block of `n` bytes from EEPROM address `addr` to `buf`.

6.4.3.2 uint8_t eeprom_read_byte (const uint8_t * *addr*)

Read one byte from EEPROM address `addr`.

6.4.3.3 uint16_t eeprom_read_word (const uint16_t * *addr*)

Read one 16-bit word (little endian) from EEPROM address `addr`.

6.4.3.4 void eeprom_write_block (const void * *buf*, void * *addr*, size_t *n*)

Write a block of `n` bytes to EEPROM address `addr` from `buf`.

6.4.3.5 void eeprom_write_byte (uint8_t * *addr*, uint8_t *val*)

Write a byte `val` to EEPROM address `addr`.

6.4.3.6 void eeprom_write_word (uint16_t * *addr*, uint16_t *val*)

Write a word `val` to EEPROM address `addr`.

6.5 AVR device-specific IO definitions

```
#include <avr/io.h>
```

This header file includes the apropriate IO definitions for the device that has been specified by the `-mmcu=` compiler command-line switch. This is done by diverting to the appropriate file `<avr/io`*XXXX*`.h>` which should never be included directly. Some register names common to all AVR devices are defined directly within `<avr/io.h>`, but most of the details come from the respective include file.

Note that this file always includes

```
#include <avr/sfr_defs.h>
```

See **Special function registers**(p. 84) for the details.

Included are definitions of the IO register set and their respective bit values as specified in the Atmel documentation. Note that Atmel is not very consistent in its naming conventions, so even identical functions sometimes get different names on different devices.

Also included are the specific names useable for interrupt function definitions as documented **here**(p. 80).

Finally, the following macros are defined:

- **RAMEND**

  A constant describing the last on-chip RAM location.

- **XRAMEND**

  A constant describing the last possible location in RAM. This is equal to RAMEND for devices that do not allow for external RAM.

- **E2END**

  A constant describing the address of the last EEPROM cell.

- **FLASHEND**

  A constant describing the last byte address in flash ROM.

- **SPM_PAGESIZE**
  For devices with bootloader support, the flash pagesize (in bytes) to be used for the `SPM` instruction.

6.6 Parity bit generation

6.6.1 Detailed Description

```
#include <avr/parity.h>
```

This header file contains optimized assembler code to calculate the parity bit for a byte.

Defines

- #define **parity_even_bit**(val)

6.6.2 Define Documentation

6.6.2.1 #define parity_even_bit(val)

Value:

```
({                              \
        unsigned char __t;                              \
        __asm__ (                                       \
                "mov __tmp_reg__,%0" "\n\t"             \
                "swap %0" "\n\t"                        \
                "eor %0,__tmp_reg__" "\n\t"             \
                "mov __tmp_reg__,%0" "\n\t"             \
                "lsr %0" "\n\t"                         \
                "lsr %0" "\n\t"                         \
                "eor %0,__tmp_reg__"                    \
                : "=r" (__t)                            \
                : "0" ((unsigned char)(val))            \
                : "r0"                                  \
        );                                              \
        (((__t + 1) >> 1) & 1);                         \
 })
```

Returns:

1 if `val` has an odd number of bits set.

6.7 Program Space String Utilities

6.7.1 Detailed Description

```
#include <avr/io.h>
```

```
#include <avr/pgmspace.h>
```

The functions in this module provide interfaces for a program to access data stored in program space (flash memory) of the device. In order to use these functions, the target device must support either the LPM or ELPM instructions.

Note:

These functions are an attempt to provide some compatibility with header files that come with IAR C, to make porting applications between different compilers easier. This is not 100% compatibility though (GCC does not have full support for multiple address spaces yet).

If you are working with strings which are completely based in ram, use the standard string functions described in **Strings**(p. 71).

If possible, put your constant tables in the lower 64K and use **pgm_read_byte_near()**(p. 22) or **pgm_read_word_near()**(p. 23) instead of **pgm_read_byte_far()**(p. 21) or **pgm_read_word_far()**(p. 23) since it is more efficient that way, and you can still use the upper 64K for executable code.

Defines

- #define **PSTR**(s) ({static char __c[] PROGMEM = (s); &__c[0];})
- #define **pgm_read_byte_near**(address_short) __LPM((**uint16_t**)(address_short))
- #define **pgm_read_word_near**(address_short) __LPM_word((**uint16_t**)(address_short))
- #define **pgm_read_dword_near**(address_short) __LPM_dword((**uint16_t**)(address_short))
- #define **pgm_read_byte_far**(address_long) __ELPM((**uint32_t**)(address_long))
- #define **pgm_read_word_far**(address_long) __ELPM_word((**uint32_t**)(address_long))
- #define **pgm_read_dword_far**(address_long) __ELPM_dword((**uint32_t**)(address_long))
- #define **pgm_read_byte**(address_short) pgm_read_byte_near(address_short)
- #define **pgm_read_word**(address_short) pgm_read_word_near(address_short)
- #define **pgm_read_dword**(address_short) pgm_read_dword_near(address_short)
- #define **PGM_P** const prog_char *
- #define **PGM_VOID_P** const prog_void *

Functions

- void * **memcpy_P** (void *, PGM_VOID_P, size_t)
- int **strcasecmp_P** (const char *, PGM_P) __ATTR_PURE__
- char * **strcat_P** (char *, PGM_P)
- int **strcmp_P** (const char *, PGM_P) __ATTR_PURE__
- char * **strcpy_P** (char *, PGM_P)
- size_t **strlcat_P** (char *, PGM_P, size_t)
- size_t **strlcpy_P** (char *, PGM_P, size_t)
- size_t **strlen_P** (PGM_P) __ATTR_CONST__
- int **strncasecmp_P** (const char *, PGM_P, size_t) __ATTR_PURE__
- char * **strncat_P** (char *, PGM_P, size_t)
- int **strncmp_P** (const char *, PGM_P, size_t) __ATTR_PURE__
- char * **strncpy_P** (char *, PGM_P, size_t)
- size_t **strnlen_P** (PGM_P, size_t) __ATTR_CONST__

6.7.2 Define Documentation

6.7.2.1 #define PGM_P const prog_char *

Used to declare a variable that is a pointer to a string in program space.

6.7.2.2 #define pgm_read_byte(address_short) pgm_read_byte_near(address_short)

Read a byte from the program space with a 16-bit (near) address.

Note:
The address is a byte address. The address is in the program space.

6.7.2.3 #define pgm_read_byte_far(address_long) __ELPM((uint32_t)(address_long))

Read a byte from the program space with a 32-bit (far) address.

Note:
The address is a byte address. The address is in the program space.

6.7.2.4 #define pgm_read_byte_near(address_short) __LPM((uint16_t)(address_short))

Read a byte from the program space with a 16-bit (near) address.

Note:
The address is a byte address. The address is in the program space.

6.7.2.5 #define pgm_read_dword(address_short) pgm_read_dword_near(address_short)

Read a double word from the program space with a 16-bit (near) address.

Note:
The address is a byte address. The address is in the program space.

6.7.2.6 #define pgm_read_dword_far(address_long) __ELPM_dword((uint32_t)(address_long))

Read a double word from the program space with a 32-bit (far) address.

Note:
The address is a byte address. The address is in the program space.

6.7.2.7 #define pgm_read_dword_near(address_short) __LPM_dword((uint16_t)(address_short))

Read a double word from the program space with a 16-bit (near) address.

Note:
The address is a byte address. The address is in the program space.

6.7.2.8 #define pgm_read_word(address_short) pgm_read_word_near(address_short)

Read a word from the program space with a 16-bit (near) address.

Note:
The address is a byte address. The address is in the program space.

6.7.2.9 #define pgm_read_word_far(address_long) __ELPM_word((uint32_t)(address_long))

Read a word from the program space with a 32-bit (far) address.

Note:

The address is a byte address. The address is in the program space.

6.7.2.10 #define pgm_read_word_near(address_short) __LPM_word((uint16_t)(address_short))

Read a word from the program space with a 16-bit (near) address.

Note:

The address is a byte address. The address is in the program space.

6.7.2.11 #define PGM_VOID_P const prog_void *

Used to declare a generic pointer to an object in program space.

6.7.2.12 #define PSTR(s) ({static char __c[] PROGMEM = (s); &__c[0];})

Used to declare a static pointer to a string in program space.

6.7.3 Function Documentation

6.7.3.1 void * memcpy_P (void * *dest*, PGM_VOID_P *src*, size_t *n*)

The **memcpy_P()**(p. 23) function is similar to **memcpy()**(p. 73), except the src string resides in program space.

Returns:

The **memcpy_P()**(p. 23) function returns a pointer to dest.

6.7.3.2 int strcasecmp_P (const char * *s1*, PGM_P *s2*)

Compare two strings ignoring case.

The **strcasecmp_P()**(p. 23) function compares the two strings s1 and s2, ignoring the case of the characters.

Parameters:

s1 A pointer to a string in the devices SRAM.

s2 A pointer to a string in the devices Flash.

Returns:

The **strcasecmp_P()**(p. 23) function returns an integer less than, equal to, or greater than zero if s1 is found, respectively, to be less than, to match, or be greater than s2.

6.7.3.3 char * strcat_P (char * *dest*, PGM_P *src*)

The **strcat_P()**(p. 24) function is similar to **strcat()**(p. 74) except that the *src* string must be located in program space (flash).

Returns:

The **strcat()**(p. 74) function returns a pointer to the resulting string *dest*.

6.7.3.4 int strcmp_P (const char * *s1*, PGM_P *s2*)

The **strcmp_P()**(p. 24) function is similar to **strcmp()**(p. 74) except that s2 is pointer to a string in program space.

Returns:

The **strcmp_P()**(p. 24) function returns an integer less than, equal to, or greater than zero if s1 is found, respectively, to be less than, to match, or be greater than s2.

6.7.3.5 char * strcpy_P (char * *dest*, PGM_P *src*)

The **strcpy_P()**(p. 24) function is similar to **strcpy()**(p. 74) except that src is a pointer to a string in program space.

Returns:

The **strcpy_P()**(p. 24) function returns a pointer to the destination string dest.

6.7.3.6 size_t strlcat_P (char * *dst*, PGM_P, size_t *siz*)

Concatenate two strings.

The **strlcat_P()**(p. 24) function is similar to **strlcat()**(p. 75), except that the *src* string must be located in program space (flash).

Appends src to string dst of size siz (unlike **strncat()**(p. 76), siz is the full size of dst, not space left). At most siz-1 characters will be copied. Always NULL terminates (unless siz <= strlen(dst)).

Returns:

The **strlcat_P()**(p. 24) function returns strlen(src) + MIN(siz, strlen(initial dst)). If retval >= siz, truncation occurred.

6.7.3.7 size_t strlcpy_P (char * *dst*, PGM_P, size_t *siz*)

Copy a string from progmem to RAM.

Copy src to string dst of size siz. At most siz-1 characters will be copied. Always NULL terminates (unless siz == 0).

Returns:

The **strlcpy_P()**(p. 25) function returns strlen(src). If retval >= siz, truncation occurred.

6.7.3.8 size_t strlen_P (PGM_P *src*)

The **strlen_P()**(p. 25) function is similar to **strlen()**(p. 75), except that src is a pointer to a string in program space.

Returns:

The **strlen()**(p. 75) function returns the number of characters in src.

6.7.3.9 int strncasecmp_P (const char * *s1*, PGM_P *s2*, size_t *n*)

Compare two strings ignoring case.

The **strncasecmp_P()**(p. 25) function is similar to **strcasecmp_P()**(p. 23), except it only compares the first n characters of s1.

Parameters:

s1 A pointer to a string in the devices SRAM.

s2 A pointer to a string in the devices Flash.

n The maximum number of bytes to compare.

Returns:

The **strcasecmp_P()**(p. 23) function returns an integer less than, equal to, or greater than zero if s1 (or the first n bytes thereof) is found, respectively, to be less than, to match, or be greater than s2.

6.7.3.10 char * strncat_P (char * *dest*, PGM_P *src*, size_t *len*)

Concatenate two strings.

The **strncat_P()**(p. 26) function is similar to **strncat()**(p. 76), except that the *src* string must be located in program space (flash).

Returns:

The **strncat_P()**(p. 26) function returns a pointer to the resulting string dest.

6.7.3.11 int strncmp_P (const char * *s1*, PGM_P *s2*, size_t *n*)

The **strncmp_P()**(p. 26) function is similar to **strcmp_P()**(p. 24) except it only compares the first (at most) n characters of s1 and s2.

Returns:

The **strncmp_P()**(p. 26) function returns an integer less than, equal to, or greater than zero if s1 (or the first n bytes thereof) is found, respectively, to be less than, to match, or be greater than s2.

6.7.3.12 char * strncpy_P (char * *dest*, PGM_P *src*, size_t *n*)

The **strncpy_P()**(p. 26) function is similar to **strcpy_P()**(p. 24) except that not more than n bytes of src are copied. Thus, if there is no null byte among the first n bytes of src, the result will not be null-terminated.

In the case where the length of src is less than that of n, the remainder of dest will be padded with nulls.

Returns:

The **strncpy_P()**(p. 26) function returns a pointer to the destination string dest.

6.7.3.13 size_t strnlen_P (PGM_P *src*, size_t *len*)

Determine the length of a fixed-size string.

The **strnlen_P()**(p. 26) function is similar to **strnlen()**(p. 77), except that `src` is a pointer to a string in program space.

Returns:

The strnlen_P function returns strlen_P(src), if that is less than `len`, or `len` if there is no '\0' character among the first `len` characters pointed to by `src`.

6.8 Additional notes from <avr/sfr_defs.h>

The <avr/sfr_defs.h> file is included by all of the <avr/ioXXXX.h> files, which use macros defined here to make the special function register definitions look like C variables or simple constants, depending on the `_SFR_ASM_COMPAT` define. Some examples from <avr/iom128.h> to show how to define such macros:

```
#define PORTA _SFR_IO8(0x1b)
#define TCNT1 _SFR_IO16(0x2c)
#define PORTF _SFR_MEM8(0x61)
#define TCNT3 _SFR_MEM16(0x88)
```

If `_SFR_ASM_COMPAT` is not defined, C programs can use names like `PORTA` directly in C expressions (also on the left side of assignment operators) and GCC will do the right thing (use short I/O instructions if possible). The `__SFR_OFFSET` definition is not used in any way in this case.

Define `_SFR_ASM_COMPAT` as 1 to make these names work as simple constants (addresses of the I/O registers). This is necessary when included in preprocessed assembler (*.S) source files, so it is done automatically if `__ASSEMBLER__` is defined. By default, all addresses are defined as if they were memory addresses (used in `lds/sts` instructions). To use these addresses in `in/out` instructions, you must subtract 0x20 from them.

For more backwards compatibility, insert the following at the start of your old assembler source file:

```
#define __SFR_OFFSET 0
```

This automatically subtracts 0x20 from I/O space addresses, but it's a hack, so it is recommended to change your source: wrap such addresses in macros defined here, as shown below. After this is done, the `__SFR_OFFSET` definition is no longer necessary and can be removed.

Real example - this code could be used in a boot loader that is portable between devices with `SPMCR` at different addresses.

```
<avr/iom163.h>: #define SPMCR _SFR_IO8(0x37)
<avr/iom128.h>: #define SPMCR _SFR_MEM8(0x68)


#if _SFR_IO_REG_P(SPMCR)
        out     _SFR_IO_ADDR(SPMCR), r24
#else
        sts     _SFR_MEM_ADDR(SPMCR), r24
#endif
```

You can use the `in/out/cbi/sbi/sbic/sbis` instructions, without the `_SFR_IO_REG_P` test, if you know that the register is in the I/O space (as with `SREG`, for example). If it isn't, the assembler will complain (I/O address out of range 0...0x3f), so this should be fairly safe.

If you do not define `__SFR_OFFSET` (so it will be 0x20 by default), all special register addresses are defined as memory addresses (so `SREG` is 0x5f), and (if code size and speed are not important, and you don't like the ugly #if above) you can always use lds/sts to access them. But, this will not work if `__SFR_OFFSET` != 0x20, so use a different macro (defined only if `__SFR_OFFSET` == 0x20) for safety:

```
        sts     _SFR_ADDR(SPMCR), r24
```

In C programs, all 3 combinations of `_SFR_ASM_COMPAT` and `__SFR_OFFSET` are supported - the `_SFR_ADDR(SPMCR)` macro can be used to get the address of the `SPMCR` register (0x57 or 0x68 depending on device).

6.9 Power Management and Sleep Modes

6.9.1 Detailed Description

```
#include <avr/sleep.h>
```

Use of the `SLEEP` instruction can allow your application to reduce it's power comsumption considerably. AVR devices can be put into different sleep modes. Refer to the datasheet for the details relating to the device you are using.

Sleep Functions

- void **set_sleep_mode** (**uint8_t** mode)
- void **sleep_mode** (void)

6.9.2 Function Documentation

6.9.2.1 void set_sleep_mode (uint8_t *mode*)

Select a sleep mode.

6.9.2.2 void sleep_mode (void)

Put the device in sleep mode. How the device is brought out of sleep mode depends on the specific mode selected with the **set_sleep_mode()**(p. 28) function. See the data sheet for your device for more details.

6.10 Watchdog timer handling

6.10.1 Detailed Description

```
#include <avr/wdt.h>
```

This header file declares the interface to some inline macros handling the watchdog timer present in many AVR devices. In order to prevent the watchdog timer configuration from being accidentally altered by a crashing application, a special timed sequence is required in order to change it. The macros within this header file handle the required sequence automatically before changing any value. Interrupts will be disabled during the manipulation.

Note:

Depending on the fuse configuration of the particular device, further restrictions might apply, in particular it might be disallowed to turn off the watchdog timer.

Defines

- #define **wdt_reset**() __asm__ __volatile__ ("wdr")
- #define **wdt_disable**()
- #define **wdt_enable**(timeout) _wdt_write(timeout)
- #define **WDTO_15MS** 0
- #define **WDTO_30MS** 1
- #define **WDTO_60MS** 2
- #define **WDTO_120MS** 3
- #define **WDTO_250MS** 4
- #define **WDTO_500MS** 5
- #define **WDTO_1S** 6
- #define **WDTO_2S** 7

6.10.2 Define Documentation

6.10.2.1 #define wdt_disable()

Value:

```
__asm__ __volatile__ (  \
    "in __tmp_reg__, __SREG__" "\n\t" \
    "out %0, %1" "\n\t" \
    "out %0, __zero_reg__" "\n\t" \
    "out __SREG__,__tmp_reg__" "\n\t" \
    : /* no outputs */ \
    : "I" (_SFR_IO_ADDR(_WD_CONTROL_REG)), \
    "r" ((uint8_t)(_BV(_WD_CHANGE_BIT) | _BV(WDE))) \
```

```
    : "r0" \
)
```

Disable the watchdog timer, if possible. This attempts to turn off the Enable bit in the watchdog control register. See the datasheet for details.

6.10.2.2 #define wdt_enable(timeout) _wdt_write(timeout)

Enable the watchdog timer, configuring it for expiry after `timeout` (which is a combination of the `WDP0` through `WDP2` bits to write into the `WDTCR` register; For those devices that have a `WDTCSR` register, it uses the combination of the `WDP0` through `WDP3` bits).

See also the symbolic constants `WDTO_15MS` et al.

6.10.2.3 #define wdt_reset() __asm__ __volatile__ ("wdr")

Reset the watchdog timer. When the watchdog timer is enabled, a call to this instruction is required before the timer expires, otherwise a watchdog-initiated device reset will occur.

6.10.2.4 #define WDTO_120MS 3

See `WDTO_15MS`

6.10.2.5 #define WDTO_15MS 0

Symbolic constants for the watchdog timeout. Since the watchdog timer is based on a free-running RC oscillator, the times are approximate only and apply to a supply voltage of 5 V. At lower supply voltages, the times will increase. For older devices, the times will be as large as three times when operating at Vcc = 3 V, while the newer devices (e. g. ATmega128, ATmega8) only experience a negligible change.

Possible timeout values are: 15 ms, 30 ms, 60 ms, 120 ms, 250 ms, 500 ms, 1 s, 2 s. Symbolic constants are formed by the prefix `WDTO_`, followed by the time.

Example that would select a watchdog timer expiry of approximately 500 ms:

```
wdt_enable(WDTO_500MS);
```

6.10.2.6 #define WDTO_1S 6

See `WDTO_15MS`

6.10.2.7 #define WDTO_250MS 4

See WDTO_15MS

6.10.2.8 #define WDTO_2S 7

See WDTO_15MS

6.10.2.9 #define WDTO_30MS 1

See WDTO_15MS

6.10.2.10 #define WDTO_500MS 5

See WDTO_15MS

6.10.2.11 #define WDTO_60MS 2

WDTO_15MS

6.11 Character Operations

6.11.1 Detailed Description

These functions perform various operations on characters.

```
#include <ctype.h>
```

Character classification routines

These functions perform character classification. They return true or false status depending whether the character passed to the function falls into the function's classification (i.e. **isdigit()**(p. 32) returns true if its argument is any value '0' though '9', inclusive.)

- int **isalnum** (int __c) __ATTR_CONST__
- int **isalpha** (int __c) __ATTR_CONST__
- int **isascii** (int __c) __ATTR_CONST__
- int **isblank** (int __c) __ATTR_CONST__
- int **iscntrl** (int __c) __ATTR_CONST__
- int **isdigit** (int __c) __ATTR_CONST__
- int **isgraph** (int __c) __ATTR_CONST__
- int **islower** (int __c) __ATTR_CONST__
- int **isprint** (int __c) __ATTR_CONST__

- int **ispunct** (int __c) __ATTR_CONST__
- int **isspace** (int __c) __ATTR_CONST__
- int **isupper** (int __c) __ATTR_CONST__
- int **isxdigit** (int __c) __ATTR_CONST__

Character convertion routines

If `c` is not an unsigned char value, or `EOF`, the behaviour of these functions is undefined.

- int **toascii** (int __c) __ATTR_CONST__
- int **tolower** (int __c) __ATTR_CONST__
- int **toupper** (int __c) __ATTR_CONST__

6.11.2 Function Documentation

6.11.2.1 int isalnum (int __ *c*)

Checks for an alphanumeric character. It is equivalent to `(isalpha(c) || isdigit(c))`.

6.11.2.2 int isalpha (int __ *c*)

Checks for an alphabetic character. It is equivalent to `(isupper(c) || islower(c))`.

6.11.2.3 int isascii (int __ *c*)

Checks whether `c` is a 7-bit unsigned char value that fits into the ASCII character set.

6.11.2.4 int isblank (int __ *c*)

Checks for a blank character, that is, a space or a tab.

6.11.2.5 int iscntrl (int __ *c*)

Checks for a control character.

6.11.2.6 int isdigit (int __ *c*)

Checks for a digit (0 through 9).

6.11.2.7 int isgraph (int __c)

Checks for any printable character except space.

6.11.2.8 int islower (int __c)

Checks for a lower-case character.

6.11.2.9 int isprint (int __c)

Checks for any printable character including space.

6.11.2.10 int ispunct (int __c)

Checks for any printable character which is not a space or an alphanumeric character.

6.11.2.11 int isspace (int __c)

Checks for white-space characters. For the avr-libc library, these are: space, form-feed ('\f'), newline ('\n'), carriage return ('\r'), horizontal tab ('\t'), and vertical tab ('\v').

6.11.2.12 int isupper (int __c)

Checks for an uppercase letter.

6.11.2.13 int isxdigit (int __c)

Checks for a hexadecimal digits, i.e. one of 0 1 2 3 4 5 6 7 8 9 a b c d e f A B C D E F.

6.11.2.14 int toascii (int __c)

Converts `c` to a 7-bit unsigned char value that fits into the ASCII character set, by clearing the high-order bits.

Warning:

Many people will be unhappy if you use this function. This function will convert accented letters into random characters.

6.11.2.15 int tolower (int __c)

Converts the letter `c` to lower case, if possible.

6.11.2.16 int toupper (int __ *c*)

Converts the letter `c` to upper case, if possible.

6.12 System Errors (errno)

6.12.1 Detailed Description

```
#include <errno.h>
```

Some functions in the library set the global variable `errno` when an error occurs. The file, <**errno.h**(p. ??)>, provides symbolic names for various error codes.

Warning:

The `errno` global variable is not safe to use in a threaded or multi-task system. A race condition can occur if a task is interrupted between the call which sets `error` and when the task examines `errno`. If another task changes `errno` during this time, the result will be incorrect for the interrupted task.

Defines

- #define **EDOM** 33
- #define **ERANGE** 34

6.12.2 Define Documentation

6.12.2.1 #define EDOM 33

Domain error.

6.12.2.2 #define ERANGE 34

Range error.

6.13 Integer Type conversions

```
#include <inttypes.h>
```

This header file includes the exact-width integer definitions from <**stdint.h**(p. ??)>, and extends them with additional facilities provided by the implementation.

6.14 Mathematics

6.14.1 Detailed Description

```
#include <math.h>
```

This header file declares basic mathematics constants and functions.

Note:

In order to access the functions delcared herein, it is usually also required to additionally link against the library `libm.a`. See also the related **FAQ entry**(p. 132).

Defines

- #define **M_PI** 3.141592653589793238462643
- #define **M_SQRT2** 1.4142135623730950488016887

Functions

- double **cos** (double __x) __ATTR_CONST__
- double **fabs** (double __x) __ATTR_CONST__
- double **fmod** (double __x, double __y) __ATTR_CONST__
- double **modf** (double __value, double *__iptr)
- double **sin** (double __x) __ATTR_CONST__
- double **sqrt** (double __x) __ATTR_CONST__
- double **tan** (double __x) __ATTR_CONST__
- double **floor** (double __x) __ATTR_CONST__
- double **ceil** (double __x) __ATTR_CONST__
- double **frexp** (double __value, int *__exp)
- double **ldexp** (double __x, int __exp) __ATTR_CONST__
- double **exp** (double _x) __ATTR_CONST__
- double **cosh** (double __x) __ATTR_CONST__
- double **sinh** (double __x) __ATTR_CONST__
- double **tanh** (double __x) __ATTR_CONST__
- double **acos** (double __x) __ATTR_CONST__
- double **asin** (double __x) __ATTR_CONST__
- double **atan** (double __x) __ATTR_CONST__
- double **atan2** (double __y, double __x) __ATTR_CONST__
- double **log** (double __x) __ATTR_CONST__
- double **log10** (double __x) __ATTR_CONST__
- double **pow** (double __x, double __y) __ATTR_CONST__
- int **isnan** (double __x) __ATTR_CONST__

- int **isinf** (double __x) __ATTR_CONST__
- double **square** (double __x) __ATTR_CONST__
- double **inverse** (double) __ATTR_CONST__

6.14.2 Define Documentation

6.14.2.1 #define M_PI 3.14159265358979323846264 3

The constant `pi`.

6.14.2.2 #define M_SQRT2 1.4142135623730950488016887

The square root of 2.

6.14.3 Function Documentation

6.14.3.1 double acos (double __x)

The **acos()**(p. 36) function computes the principal value of the arc cosine of `x`. The returned value is in the range [0, pi] radians. A domain error occurs for arguments not in the range [-1, +1].

6.14.3.2 double asin (double __x)

The **asin()**(p. 36) function computes the principal value of the arc sine of `x`. The returned value is in the range [0, pi] radians. A domain error occurs for arguments not in the range [-1, +1].

6.14.3.3 double atan (double __x)

The **atan()**(p. 36) function computes the principal value of the arc tangent of `x`. The returned value is in the range [0, pi] radians. A domain error occurs for arguments not in the range [-1, +1].

6.14.3.4 double atan2 (double __y, double __x)

The **atan2()**(p. 36) function computes the principal value of the arc tangent of `y / x`, using the signs of both arguments to determine the quadrant of the return value. The returned value is in the range [-pi, +pi] radians. If both `x` and `y` are zero, the global variable `errno` is set to `EDOM`.

6.14.3.5 double ceil (double __x)

The **ceil()**(p. 36) function returns the smallest integral value greater than or equal to `x`, expressed as a floating-point number.

6.14.3.6 double cos (double __x)

The **cos()**(p. 37) function returns the cosine of `x`, measured in radians.

6.14.3.7 double cosh (double __x)

The **cosh()**(p. 37) function returns the hyperbolic cosine of `x`.

6.14.3.8 double exp (double _x)

The **exp()**(p. 37) function returns the exponential value of `x`.

6.14.3.9 double fabs (double __x)

The **fabs()**(p. 37) function computes the absolute value of a floating-point number `x`.

6.14.3.10 double floor (double __x)

The **floor()**(p. 37) function returns the largest integral value less than or equal to `x`, expressed as a floating-point number.

6.14.3.11 double fmod (double __x, double __y)

The function **fmod()**(p. 37) returns the floating-point remainder of `x / y`.

6.14.3.12 double frexp (double __value, int * __exp)

The **frexp()**(p. 37) function breaks a floating-point number into a normalized fraction and an integral power of 2. It stores the integer in the `int` object pointed to by `exp`.

The **frexp()**(p. 37) function returns the value `x`, such that `x` is a double with magnitude in the interval [1/2, 1) or zero, and `value` equals `x` times 2 raised to the power `*exp`. If value is zero, both parts of the result are zero.

6.14.3.13 double inverse (double)

The function **inverse()**(p. 37) returns `1 / x`.

Note:

This function does not belong to the C standard definition.

6.14.3.14 int isinf (double __ *x*)

The function **isinf()**(p. 38) returns 1 if the argument x is either positive or negative infinity, otherwise 0.

6.14.3.15 int isnan (double __ *x*)

The function **isnan()**(p. 38) returns 1 if the argument x represents a "not-a-number" (NaN) object, otherwise 0.

6.14.3.16 double ldexp (double __ *x*, int __ *exp*)

The **ldexp()**(p. 38) function multiplies a floating-point number by an integral power of 2.

The **ldexp()**(p. 38) function returns the value of x times 2 raised to the power exp.

If the resultant value would cause an overflow, the global variable errno is set to ERANGE, and the value NaN is returned.

6.14.3.17 double log (double __ *x*)

The **log()**(p. 38) function returns the natural logarithm of argument x.

If the argument is less than or equal 0, a domain error will occur.

6.14.3.18 double log10 (double __ *x*)

The **log10()**(p. 38) function returns the logarithm of argument x to base 10.

If the argument is less than or equal 0, a domain error will occur.

6.14.3.19 double modf (double __ *value*, double * __ *iptr*)

The **modf()**(p. 38) function breaks the argument value into integral and fractional parts, each of which has the same sign as the argument. It stores the integral part as a double in the object pointed to by iptr.

The **modf()**(p. 38) function returns the signed fractional part of value.

6.14.3.20 double pow (double __ *x*, double __ *y*)

The function **pow()**(p. 38) returns the value of x to the exponent y.

6.14.3.21 double sin (double __ *x*)

The **sin()**(p. 38) function returns the sine of x, measured in radians.

6.14.3.22 double sinh (double __x)

The **sinh()**(p. 39) function returns the hyperbolic sine of `x`.

6.14.3.23 double sqrt (double __x)

The **sqrt()**(p. 39) function returns the non-negative square root of `x`.

6.14.3.24 double square (double __x)

The function **square()**(p. 39) returns `x * x`.

Note:

This function does not belong to the C standard definition.

6.14.3.25 double tan (double __x)

The **tan()**(p. 39) function returns the tangent of `x`, measured in radians.

6.14.3.26 double tanh (double __x)

The **tanh()**(p. 39) function returns the hyperbolic tangent of `x`.

6.15 Setjmp and Longjmp

6.15.1 Detailed Description

While the C language has the dreaded `goto` statement, it can only be used to jump to a label in the same (local) function. In order to jump directly to another (non-local) function, the C library provides the **setjmp()**(p. 41) and **longjmp()**(p. 40) functions. **setjmp()**(p. 41) and **longjmp()**(p. 40) are useful for dealing with errors and interrupts encountered in a low-level subroutine of a program.

Note:

setjmp()(p. 41) and **longjmp()**(p. 40) make programs hard to understand and maintain. If possible, an alternative should be used.
longjmp()(p. 40) can destroy changes made to global register variables (see **How to permanently bind a variable to a register?**(p. 132)).

For a very detailed discussion of **setjmp()**(p. 41)/longjmp(), see Chapter 7 of *Advanced Programming in the UNIX Environment*, by W. Richard Stevens.

Example:

```
#include <setjmp.h>

jmp_buf env;

int main (void)
{
    if (setjmp (env))
    {
        ... handle error ...
    }

    while (1)
    {
       ... main processing loop which calls foo() some where ...
    }
}

...

void foo (void)
{
    ... blah, blah, blah ...

    if (err)
    {
        longjmp (env, 1);
    }
}
```

Functions

- int **setjmp** (jmp_buf __jmpb)
- void **longjmp** (jmp_buf __jmpb, int __ret) __ATTR_NORETURN__

6.15.2 Function Documentation

6.15.2.1 void longjmp (jmp_buf __*jmpb*, int __*ret*)

Non-local jump to a saved stack context.

```
#include <setjmp.h>
```

longjmp()(p. 40) restores the environment saved by the last call of **setjmp()**(p. 41) with the corresponding __*jmpb* argument. After **longjmp()**(p. 40) is completed, program execution continues as if the corresponding call of **setjmp()**(p. 41) had just returned the value __*ret*.

Note:

longjmp()(p. 40) cannot cause 0 to be returned. If **longjmp()**(p. 40) is invoked with a second argument of 0, 1 will be returned instead.

Parameters:

__jmpb Information saved by a previous call to **setjmp()**(p. 41).

__ret Value to return to the caller of **setjmp()**(p. 41).

Returns:

This function never returns.

6.15.2.2 int setjmp (jmp_buf *__jmpb*)

Save stack context for non-local goto.

```
#include <setjmp.h>
```

setjmp()(p. 41) saves the stack context/environment in *__jmpb* for later use by **longjmp()**(p. 40). The stack context will be invalidated if the function which called **setjmp()**(p. 41) returns.

Parameters:

__jmpb Variable of type `jmp_buf` which holds the stack information such that the environment can be restored.

Returns:

setjmp()(p. 41) returns 0 if returning directly, and non-zero when returning from **longjmp()**(p. 40) using the saved context.

6.16 Standard Integer Types

6.16.1 Detailed Description

```
#include <stdint.h>
```

Use [u]intN_t if you need exactly N bits.

Since these typedefs are mandated by the C99 standard, they are preferred over rolling your own typedefs.

Note:

If avr-gcc's `-mint8` option is used, no 32-bit types will be available for all versions of GCC below 3.5.

8-bit types.

- typedef signed char **int8_t**
- typedef unsigned char **uint8_t**

16-bit types.

- typedef int **int16_t**
- typedef unsigned int **uint16_t**

32-bit types.

- typedef long **int32_t**
- typedef unsigned long **uint32_t**

64-bit types.

- typedef long long **int64_t**
- typedef unsigned long long **uint64_t**

Pointer types.

These allow you to declare variables of the same size as a pointer.

- typedef **int16_t intptr_t**
- typedef **uint16_t uintptr_t**

6.16.2 Typedef Documentation

6.16.2.1 typedef int int16_t

16-bit signed type.

6.16.2.2 typedef long int32_t

32-bit signed type.

6.16.2.3 typedef long long int64_t

64-bit signed type.

6.16.2.4 typedef signed char int8_t

8-bit signed type.

6.16.2.5 typedef int16_t intptr_t

Signed pointer compatible type.

6.16.2.6 typedef unsigned int uint16_t

16-bit unsigned type.

6.16.2.7 typedef unsigned long uint32_t

32-bit unsigned type.

6.16.2.8 typedef unsigned long long uint64_t

64-bit unsigned type.

6.16.2.9 typedef unsigned char uint8_t

8-bit unsigned type.

6.16.2.10 typedef uint16_t uintptr_t

Unsigned pointer compatible type.

6.17 Standard IO facilities

6.17.1 Detailed Description

```
#include <stdio.h>
```

Warning:

This implementation of the standard IO facilities is new to avr-libc. It is not yet expected to remain stable, so some aspects of the API might change in a future release.

This file declares the standard IO facilities that are implemented in `avr-libc`. Due to the nature of the underlying hardware, only a limited subset of standard IO is implemented. There is no actual file implementation available, so only device IO can be performed. Since there's no operating system, the application needs to provide enough details about their devices in order to make them usable by the standard IO facilities.

Due to space constraints, some functionality has not been implemented at all (like some of the `printf` conversions that have been left out). Nevertheless, potential users of this implementation should be warned: the `printf` and `scanf` families of functions, although usually associated with presumably simple things like the famous "Hello, world!" program, are actually fairly complex which causes their inclusion to eat up a fair amount of code space. Also, they are not fast due to the nature of interpreting the format string at run-time. Whenever possible, resorting to the (sometimes non-standard) predetermined conversion facilities that are offered by avr-libc will usually cost much less in terms of speed and code size.

In order to allow programmers a code size vs. functionality tradeoff, the function **vfprintf()**(p. 52) which is the heart of the printf family can be selected in different flavours using linker options. See the documentation of **vfprintf()**(p. 52) for a detailed description. The same applies to **vfscanf()**(p. 55) and the `scanf` family of functions.

The standard streams `stdin`, `stdout`, and `stderr` are provided, but contrary to the C standard, since avr-libc has no knowledge about applicable devices, these streams are not already pre-initialized at application startup. Also, since there is no notion of "file" whatsoever to avr-libc, there is no function `fopen()` that could be used to associate a stream to some device. (See **note 1**(p. 44).) Instead, the function **fdevopen()**(p. 48) is provided to associate a stream to a device, where the device needs to provide a function to send a character, to receive a character, or both. There is no differentiation between "text" and "binary" streams inside avr-libc. Character `\n` is sent literally down to the device's `put()` function. If the device requires a carriage return (`\r`) character to be sent before the linefeed, its `put()` routine must implement this (see **note 2**(p. 44)).

It should be noted that the automatic conversion of a newline character into a carriage return - newline sequence breaks binary transfers. If binary transfers are desired, no automatic conversion should be performed, but instead any string that aims to issue a CR-LF sequence must use `"\r\n"` explicitly.

For convenience, the first call to **fdevopen()**(p. 48) that opens a stream for reading will cause the resulting stream to be aliased to `stdin`. Likewise, the first call to **fdevopen()**(p. 48) that opens a stream for writing will cause the resulting stream to be aliased to both, `stdout`, and `stderr`. Thus, if the open was done with both, read and write intent, all three standard streams will be identical. Note that these aliases are indistinguishable from each other, thus calling **fclose()**(p. 48) on such a stream will also effectively close all of its aliases (**note 3**(p. 45)).

All the `printf` and `scanf` family functions come in two flavours: the standard name, where the format string is expected to be in SRAM, as well as a version with the suffix "_P" where the format string is expected to reside in the flash ROM. The macro `PSTR` (explained in **Program Space String Utilities**(p. 19)) becomes very handy for declaring these format strings.

Note 1:

It might have been possible to implement a device abstraction that is compatible with `fopen()` but since this would have required to parse a string, and to take all the information needed either out of this string, or out of an additional table that would need to be provided by the application, this approach was not taken.

Note 2:

This basically follows the Unix approach: if a device such as a terminal needs special handling, it is in the domain of the terminal device driver to provide this functionality. Thus, a simple function suitable as `put()` for **fdevopen()**(p. 48) that talks to a UART interface might look like this:

```
int
uart_putchar(char c)
{

  if (c == '\n')
    uart_putchar('\r');
  loop_until_bit_is_set(UCSRA, UDRE);
  UDR = c;
  return 0;
}
```

Note 3:

This implementation has been chosen because the cost of maintaining an alias is considerably smaller than the cost of maintaining full copies of each stream. Yet, providing an implementation that offers the complete set of standard streams was deemed to be useful. Not only that writing **printf()**(p. 51) instead of `fprintf(mystream, ...)` saves typing work, but since avr-gcc needs to resort to pass all arguments of variadic functions on the stack (as opposed to passing them in registers for functions that take a fixed number of parameters), the ability to pass one parameter less by implying `stdin` will also save some execution time.

Defines

- #define **FILE** struct __file
- #define **stdin** (__iob[0])
- #define **stdout** (__iob[1])
- #define **stderr** (__iob[2])
- #define **EOF** (-1)
- #define **putc**(__c, __stream) fputc(__c, __stream)
- #define **putchar**(__c) fputc(__c, stdout)
- #define **getc**(__stream) fgetc(__stream)
- #define **getchar**() fgetc(stdin)

Functions

- int **fclose** (FILE *__stream)
- int **vfprintf** (FILE *__stream, const char *__fmt, va_list __ap)
- int **vfprintf_P** (FILE *__stream, const char *__fmt, va_list __ap)

- int **fputc** (int __c, FILE *__stream)
- int **printf** (const char *__fmt,...)
- int **printf_P** (const char *__fmt,...)
- int **sprintf** (char *__s, const char *__fmt,...)
- int **sprintf_P** (char *__s, const char *__fmt,...)
- int **snprintf** (char *__s, size_t __n, const char *__fmt,...)
- int **snprintf_P** (char *__s, size_t __n, const char *__fmt,...)
- int **vsprintf** (char *__s, const char *__fmt, va_list ap)
- int **vsprintf_P** (char *__s, const char *__fmt, va_list ap)
- int **vsnprintf** (char *__s, size_t __n, const char *__fmt, va_list ap)
- int **vsnprintf_P** (char *__s, size_t __n, const char *__fmt, va_list ap)
- int **fprintf** (FILE *__stream, const char *__fmt,...)
- int **fprintf_P** (FILE *__stream, const char *__fmt,...)
- int **fputs** (const char *__str, FILE *__stream)
- int **fputs_P** (const char *__str, FILE *__stream)
- int **puts** (const char *__str)
- int **puts_P** (const char *__str)
- size_t **fwrite** (const void *__ptr, size_t __size, size_t __nmemb, FILE *__stream)
- int **fgetc** (FILE *__stream)
- int **ungetc** (int __c, FILE *__stream)
- char * **fgets** (char *__str, int __size, FILE *__stream)
- char * **gets** (char *__str)
- size_t **fread** (void *__ptr, size_t __size, size_t __nmemb, FILE *_-_stream)
- void **clearerr** (FILE *__stream)
- int **feof** (FILE *__stream)
- int **ferror** (FILE *__stream)
- int **vfscanf** (FILE *__stream, const char *__fmt, va_list __ap)
- int **vfscanf_P** (FILE *__stream, const char *__fmt, va_list __ap)
- int **fscanf** (FILE *__stream, const char *__fmt,...)
- int **fscanf_P** (FILE *__stream, const char *__fmt,...)
- int **scanf** (const char *__fmt,...)
- int **scanf_P** (const char *__fmt,...)
- int **sscanf** (const char *__buf, const char *__fmt,...)
- int **sscanf_P** (const char *__buf, const char *__fmt,...)
- FILE * **fdevopen** (int(*put)(char), int(*get)(void), int opts __-attribute__((unused)))

6.17.2 Define Documentation

6.17.2.1 #define EOF (-1)

EOF declares the value that is returned by various standard IO functions in case of an error. Since the AVR platform (currently) doesn't contain an abstraction for actual files, its origin as "end of file" is somewhat meaningless here.

6.17.2.2 #define FILE struct __file

FILE is the opaque structure that is passed around between the various standard IO functions.

6.17.2.3 #define getc(__stream) fgetc(__stream)

The macro `getc` used to be a "fast" macro implementation with a functionality identical to **fgetc()**(p. 49). For space constraints, in `avr-libc`, it is just an alias for `fgetc`.

6.17.2.4 #define getchar(void) fgetc(stdin)

The macro `getchar` reads a character from `stdin`. Return values and error handling is identical to **fgetc()**(p. 49).

6.17.2.5 #define putc(__c, __stream) fputc(__c, __stream)

The macro `putc` used to be a "fast" macro implementation with a functionality identical to **fputc()**(p. 50). For space constraints, in `avr-libc`, it is just an alias for `fputc`.

6.17.2.6 #define putchar(__c) fputc(__c, stdout)

The macro `putchar` sends character `c` to `stdout`.

6.17.2.7 #define stderr (__iob[2])

Stream destined for error output. Unless specifically assigned, identical to `stdout`.

If `stderr` should point to another stream, the result of another **fdevopen()**(p. 48) must be explicitly assigned to it without closing the previous `stderr` (since this would also close `stdout`).

6.17.2.8 #define stdin (__iob[0])

Stream that will be used as an input stream by the simplified functions that don't take a `stream` argument.

The first stream opened with read intent using **fdevopen()**(p. 48) will be assigned to `stdin`.

6.17.2.9 #define stdout (__iob[1])

Stream that will be used as an output stream by the simplified functions that don't take a `stream` argument.

The first stream opened with write intent using **fdevopen()**(p. 48) will be assigned to both, `stdin`, and `stderr`.

6.17.3 Function Documentation

6.17.3.1 void clearerr (FILE * __*stream*)

Clear the error and end-of-file flags of `stream`.

6.17.3.2 int fclose (FILE * __*stream*)

This function closes `stream`, and disallows and further IO to and from it.

It currently always returns 0 (for success).

6.17.3.3 FILE* fdevopen (int(*)(char) *put*, int(*)(void) *get*, int opts __*attribute*__ ((unused)))

This function is a replacement for `fopen()`.

It opens a stream for a device where the actual device implementation needs to be provided by the application. If successful, a pointer to the structure for the opened stream is returned. Reasons for a possible failure currently include that neither the `put` nor the `get` argument have been provided, thus attempting to open a stream with no IO intent at all, or that insufficient dynamic memory is available to establish a new stream.

If the `put` function pointer is provided, the stream is opened with write intent. The function passed as `put` shall take one character to write to the device as argument , and shall return 0 if the output was successful, and a nonzero value if the character could not be sent to the device.

If the `get` function pointer is provided, the stream is opened with read intent. The function passed as `get` shall take no arguments, and return one character from the device, passed as an `int` type. If an error occurs when trying to read from the device, it shall return `-1`.

If both functions are provided, the stream is opened with read and write intent.

The first stream opened with read intent is assigned to `stdin`, and the first one opened with write intent is assigned to both, `stdout` and `stderr`.

The third parameter `opts` is currently unused, but reserved for future extensions.

fdevopen()(p. 48) uses **calloc()**(p. 63) (und thus **malloc()**(p. 65)) in order to allocate the storage for the new stream.

6.17.3.4 int feof (FILE * __*stream*)

Test the end-of-file flag of `stream`. This flag can only be cleared by a call to **clearerr()**(p. 48).

Note:

Since there is currently no notion for end-of-file on a device, this function will always return a false value.

6.17.3.5 int ferror (FILE * __*stream*)

Test the error flag of `stream`. This flag can only be cleared by a call to **clearerr()**(p. 48).

6.17.3.6 int fgetc (FILE * __*stream*)

The function `fgetc` reads a character from `stream`. It returns the character, or `EOF` in case end-of-file was encountered or an error occurred. The routines **feof()**(p. 49) or **ferror()**(p. 49) must be used to distinguish between both situations.

6.17.3.7 char* fgets (char * __*str*, int __*size*, FILE * __*stream*)

Read at most `size - 1` bytes from `stream`, until a newline character was encountered, and store the characters in the buffer pointed to by `str`. Unless an error was encountered while reading, the string will then be terminated with a `NUL` character.

If an error was encountered, the function returns NULL and sets the error flag of `stream`, which can be tested using **ferror()**(p. 49). Otherwise, a pointer to the string will be returned.

6.17.3.8 int fprintf (FILE * __*stream*, const char * __*fmt*, ...)

The function `fprintf` performs formatted output to `stream`. See **vfprintf()**(p. 52) for details.

6.17.3.9 int fprintf_P (FILE * __stream, const char * __fmt, ...)

Variant of **fprintf()**(p. 49) that uses a `fmt` string that resides in program memory.

6.17.3.10 int fputc (int __c, FILE * __stream)

The function `fputc` sends the character `c` (though given as type `int`) to `stream`. It returns the character, or `EOF` in case an error occurred.

6.17.3.11 int fputs (const char * __str, FILE * __stream)

Write the string pointed to by `str` to stream `stream`.

Returns 0 on success and EOF on error.

6.17.3.12 int fputs_P (const char * __str, FILE * __stream)

Variant of **fputs()**(p. 50) where `str` resides in program memory.

6.17.3.13 size_t fread (void * __ptr, size_t __size, size_t __nmemb, FILE * __stream)

Read `nmemb` objects, `size` bytes each, from `stream`, to the buffer pointed to by `ptr`.

Returns the number of objects successfully read, i. e. `nmemb` unless an input error occured or end-of-file was encountered. **feof()**(p. 49) and **ferror()**(p. 49) must be used to distinguish between these two conditions.

6.17.3.14 int fscanf (FILE * __stream, const char * __fmt, ...)

The function `fscanf` performs formatted input, reading the input data from `stream`.

See **vfscanf()**(p. 55) for details.

6.17.3.15 int fscanf_P (FILE * __stream, const char * __fmt, ...)

Variant of **fscanf()**(p. 50) using a `fmt` string in program memory.

6.17.3.16 size_t fwrite (const void * __ptr, size_t __size, size_t __nmemb, FILE * __stream)

Write `nmemb` objects, `size` bytes each, to `stream`. The first byte of the first object is referenced by `ptr`.

Returns the number of objects successfully written, i. e. `nmemb` unless an output error occured.

6.17.3.17 char* gets (char * __str)

Similar to **fgets()**(p. 49) except that it will operate on stream `stdin`, and the trailing newline (if any) will not be stored in the string. It is the caller's responsibility to provide enough storage to hold the characters read.

6.17.3.18 int printf (const char * __fmt, ...)

The function `printf` performs formatted output to stream `stderr`. See **vfprintf()**(p. 52) for details.

6.17.3.19 int printf_P (const char * __fmt, ...)

Variant of **printf()**(p. 51) that uses a `fmt` string that resides in program memory.

6.17.3.20 int puts (const char * __str)

Write the string pointed to by `str`, and a trailing newline character, to `stdout`.

6.17.3.21 int puts_P (const char * __str)

Variant of **puts()**(p. 51) where `str` resides in program memory.

6.17.3.22 int scanf (const char * __fmt, ...)

The function `scanf` performs formatted input from stream `stdin`.

See **vfscanf()**(p. 55) for details.

6.17.3.23 int scanf_P (const char * __fmt, ...)

Variant of **scanf()**(p. 51) where `fmt` resides in program memory.

6.17.3.24 int snprintf (char * __s, size_t __n, const char * __fmt, ...)

Like **sprintf()**(p. 52), but instead of assuming `s` to be of infinite size, no more than `n` characters (including the trailing NUL character) will be converted to `s`.

Returns the number of characters that would have been written to `s` if there were enough space.

6.17.3.25 int snprintf_P (char * __s, size_t __n, const char * __fmt, ...)

Variant of **snprintf()**(p. 51) that uses a `fmt` string that resides in program memory.

6.17.3.26 int sprintf (char * __s, const char * __fmt, ...)

Variant of **printf()**(p. 51) that sends the formatted characters to string `s`.

6.17.3.27 int sprintf_P (char * __s, const char * __fmt, ...)

Variant of **sprintf()**(p. 52) that uses a `fmt` string that resides in program memory.

6.17.3.28 int sscanf (const char * __buf, const char * __fmt, ...)

The function `sscanf` performs formatted input, reading the input data from the buffer pointed to by `buf`.

See **vfscanf()**(p. 55) for details.

6.17.3.29 int sscanf_P (const char * __buf, const char * __fmt, ...)

Variant of **sscanf()**(p. 52) using a `fmt` string in program memory.

6.17.3.30 int ungetc (int __c, FILE * __stream)

The **ungetc()**(p. 52) function pushes the character `c` (converted to an unsigned char) back onto the input stream pointed to by `stream`. The pushed-back character will be returned by a subsequent read on the stream.

Currently, only a single character can be pushed back onto the stream.

The **ungetc()**(p. 52) function returns the character pushed back after the conversion, or `EOF` if the operation fails. If the value of the argument `c` character equals `EOF`, the operation will fail and the stream will remain unchanged.

6.17.3.31 int vfprintf (FILE * __stream, const char * __fmt, va_list __ap)

vfprintf is the central facility of the printf family of functions. It outputs values to stream under control of a format string passed in fmt. The actual values to print are passed as a variable argument list ap.

vfprintf returns the number of characters written to stream, or EOF in case of an error. Currently, this will only happen if stream has not been opened with write intent.

The format string is composed of zero or more directives: ordinary characters (not), which are copied unchanged to the output stream; and conversion specifications, each of which results in fetching zero or more subsequent arguments. Each conversion specification is introduced by the character. The arguments must properly correspond (after type promotion) with the conversion specifier. After the , the following appear in sequence:

- Zero or more of the following flags:
  - # The value should be converted to an "alternate form". For c, d, i, s, and u conversions, this option has no effect. For o conversions, the precision of the number is increased to force the first character of the output string to a zero (except if a zero value is printed with an explicit precision of zero). For x and X conversions, a non-zero result has the string '0x' (or '0X' for X conversions) prepended to it.
  - 0 (zero) Zero padding. For all conversions, the converted value is padded on the left with zeros rather than blanks. If a precision is given with a numeric conversion (d, i, o, u, i, x, and X), the 0 flag is ignored.
  - - A negative field width flag; the converted value is to be left adjusted on the field boundary. The converted value is padded on the right with blanks, rather than on the left with blanks or zeros. A - overrides a 0 if both are given.
  - ' ' (space) A blank should be left before a positive number produced by a signed conversion (d, or i).
  - + A sign must always be placed before a number produced by a signed conversion. A + overrides a space if both are used.
- An optional decimal digit string specifying a minimum field width. If the converted value has fewer characters than the field width, it will be padded with spaces on the left (or right, if the left-adjust173 ment flag has been given) to fill out the field width.
- An optional precision, in the form of a period . followed by an optional digit string. If the digit string is omitted, the precision is taken as zero. This gives the minimum number of digits to appear for d, i, o, u, x, and X conversions, or the maximum number of characters to be printed from a string for s conversions.

- An optional `l` length modifier, that specifies that the argument for the d, i, o, u, x, or X conversion is a `"long int"` rather than `int`.
- A character that specifies the type of conversion to be applied.

The conversion specifiers and their meanings are:

- `diouxX` The int (or appropriate variant) argument is converted to signed decimal (d and i), unsigned octal (o), unsigned decimal (u), or unsigned hexadecimal (x and X) notation. The letters "abcdef" are used for x conversions; the letters "ABCDEF" are used for X conversions. The precision, if any, gives the minimum number of digits that must appear; if the converted value requires fewer digits, it is padded on the left with zeros.
- `p` The `void *` argument is taken as an unsigned integer, and converted similarly as a `#x` command would do.
- `c` The `int` argument is converted to an `"unsigned char"`, and the resulting character is written.
- `s` The `"char *"` argument is expected to be a pointer to an array of character type (pointer to a string). Characters from the array are written up to (but not including) a terminating NUL character; if a precision is specified, no more than the number specified are written. If a precision is given, no null character need be present; if the precision is not specified, or is greater than the size of the array, the array must contain a terminating NUL character.
- A is written. No argument is converted. The complete conversion specification is "%%".
- `eE` The double argument is rounded and converted in the format `"[-]d.ddde177dd"` where there is one digit before the decimal-point character and the number of digits after it is equal to the precision; if the precision is missing, it is taken as 6; if the precision is zero, no decimal-point character appears. An *E* conversion uses the letter `'E'` (rather than `'e'`) to introduce the exponent. The exponent always contains two digits; if the value is zero, the exponent is 00.
- `fF` The double argument is rounded and converted to decimal notation in the format `"[-]ddd.ddd"`, where the number of digits after the decimal-point character is equal to the precision specification. If the precision is missing, it is taken as 6; if the precision is explicitly zero, no decimal-point character appears. If a decimal point appears, at least one digit appears before it.
- `gG` The double argument is converted in style `f` or `e` (or `F` or `E` for `G` conversions). The precision specifies the number of significant digits. If

the precision is missing, 6 digits are given; if the precision is zero, it is treated as 1. Style `e` is used if the exponent from its conversion is less than -4 or greater than or equal to the precision. Trailing zeros are removed from the fractional part of the result; a decimal point appears only if it is followed by at least one digit.

- `S` Similar to the `s` format, except the pointer is expected to point to a program-memory (ROM) string instead of a RAM string.

In no case does a non-existent or small field width cause truncation of a numeric field; if the result of a conversion is wider than the field width, the field is expanded to contain the conversion result.

Since the full implementation of all the mentioned features becomes fairly large, three different flavours of **vfprintf()**(p. 52) can be selected using linker options. The default **vfprintf()**(p. 52) implements all the mentioned functionality except floating point conversions. A minimized version of **vfprintf()**(p. 52) is available that only implements the very basic integer and string conversion facilities, but none of the additional options that can be specified using conversion flags (these flags are parsed correctly from the format specification, but then simply ignored). This version can be requested using the following **compiler options**(p. 190):

```
-Wl,-u,vfprintf -lprintf_min
```

If the full functionality including the floating point conversions is required, the following options should be used:

```
-Wl,-u,vfprintf -lprintf_flt -lm
```

Limitations:

- The specified width and precision can be at most 127.
- For floating-point conversions, trailing digits will be lost if a number close to DBL_MAX is converted with a precision > 0.

6.17.3.32 int vfprintf_P (FILE * __*stream*, const char * __*fmt*, va_list __*ap*)

Variant of **vfprintf()**(p. 52) that uses a `fmt` string that resides in program memory.

6.17.3.33 int vfscanf (FILE * __*stream*, const char * __*fmt*, va_list __*ap*)

Formatted input. This function is the heart of the `scanf` family of functions.

Characters are read from `stream` and processed in a way described by `fmt`. Conversion results will be assigned to the parameters passed via `ap`.

The format string `fmt` is scanned for conversion specifications. Anything that doesn't comprise a conversion specification is taken as text that is matched literally against the input. White space in the format string will match any white space in the data (including none), all other characters match only itself. Processing is aborted as soon as the data and format string no longer match, or there is an error or end-of-file condition on `stream`.

Most conversions skip leading white space before starting the actual conversion.

Conversions are introduced with the character . Possible options can follow the :

- a * indicating that the conversion should be performed but the conversion result is to be discarded; no parameters will be processed from `ap`,
- the character `h` indicating that the argument is a pointer to `short int` (rather than `int`),
- the character `l` indicating that the argument is a pointer to `long int` (rather than `int`, for integer type conversions), or a pointer to `double` (for floating point conversions).

In addition, a maximal field width may be specified as a nonzero positive decimal integer, which will restrict the conversion to at most this many characters from the input stream. This field width is limited to at most 127 characters which is also the default value (except for the `c` conversion that defaults to 1).

The following conversion flags are supported:

- Matches a literal character. This is not a conversion.
- `d` Matches an optionally signed decimal integer; the next pointer must be a pointer to `int`.
- `i` Matches an optionally signed integer; the next pointer must be a pointer to `int`. The integer is read in base 16 if it begins with **0x** or **0X**, in base 8 if it begins with **0**, and in base 10 otherwise. Only characters that correspond to the base are used.
- `o` Matches an octal integer; the next pointer must be a pointer to `unsigned int`.
- `u` Matches an optionally signed decimal integer; the next pointer must be a pointer to `unsigned int`.
- `x` Matches an optionally signed hexadecimal integer; the next pointer must be a pointer to `unsigned int`.

- `f` Matches an optionally signed floating-point number; the next pointer must be a pointer to `float`.
- `e, g, E, G` Equivalent to `f`.
- `s` Matches a sequence of non-white-space characters; the next pointer must be a pointer to `char`, and the array must be large enough to accept all the sequence and the terminating `NUL` character. The input string stops at white space or at the maximum field width, whichever occurs first.
- `c` Matches a sequence of width count characters (default 1); the next pointer must be a pointer to `char`, and there must be enough room for all the characters (no terminating `NUL` is added). The usual skip of leading white space is suppressed. To skip white space first, use an explicit space in the format.
- [Matches a nonempty sequence of characters from the specified set of accepted characters; the next pointer must be a pointer to `char`, and there must be enough room for all the characters in the string, plus a terminating `NUL` character. The usual skip of leading white space is suppressed. The string is to be made up of characters in (or not in) a particular set; the set is defined by the characters between the open bracket [character and a close bracket] character. The set excludes those characters if the first character after the open bracket is a circumflex ^. To include a close bracket in the set, make it the first character after the open bracket or the circumflex; any other position will end the set. The hyphen character `-` is also special; when placed between two other characters, it adds all intervening characters to the set. To include a hyphen, make it the last character before the final close bracket. For instance, `[^]0-9-]` means the set of *everything except close bracket, zero through nine, and hyphen*. The string ends with the appearance of a character not in the (or, with a circumflex, in) set or when the field width runs out.
- `p` Matches a pointer value (as printed by `p` in **printf()**(p. 51)); the next pointer must be a pointer to `void`.
- `n` Nothing is expected; instead, the number of characters consumed thus far from the input is stored through the next pointer, which must be a pointer to `int`. This is not a conversion, although it can be suppressed with the $*$ flag.

These functions return the number of input items assigned, which can be fewer than provided for, or even zero, in the event of a matching failure. Zero indicates that, while there was input available, no conversions were assigned; typically this is due to an invalid input character, such as an alphabetic character for a `d` conversion. The value `EOF` is returned if an input failure occurs before any conversion such as an end-of-file occurs. If an error or end-of-file occurs after conversion has begun, the number of conversions which were successfully completed is returned.

By default, all the conversions described above are available except the floating-point conversions, and the `[` conversion. These conversions will be available in the extended version provided by the library `libscanf_flt.a`. Note that either of these conversions requires the availability of a buffer that needs to be obtained at run-time using **malloc()**(p. 65). If this buffer cannot be obtained, the operation is aborted, returning the value `EOF`. To link a program against the extended version, use the following compiler flags in the link stage:

```
-Wl,-u,vfscanf -lscanf_flt -lm
```

A third version is available for environments that are tight on space. This version is provided in the library `libscanf_min.a`, and can be requested using the following options in the link stage:

```
-Wl,-u,vfscanf -lscanf_min -lm
```

In addition to the restrictions of the standard version, this version implements no field width specification, no conversion assignment suppression flag (`*`), no `n` specification, and no general format character matching at all. All characters in `fmt` that do not comprise a conversion specification will simply be ignored, including white space (that is normally used to consume *any* amount of white space in the input stream). However, the usual skip of initial white space in the formats that support it is implemented.

6.17.3.34 int vfscanf_P (FILE * __*stream*, const char * __*fmt*, va_list __*ap*)

Variant of **vfscanf()**(p. 55) using a `fmt` string in program memory.

6.17.3.35 int vsnprintf (char * __*s*, size_t __*n*, const char * __*fmt*, va_list *ap*)

Like **vsprintf()**(p. 59), but instead of assuming `s` to be of infinite size, no more than `n` characters (including the trailing NUL character) will be converted to `s`.

Returns the number of characters that would have been written to `s` if there were enough space.

6.17.3.36 int vsnprintf_P (char * __*s*, size_t __*n*, const char * __*fmt*, va_list *ap*)

Variant of **vsnprintf()**(p. 58) that uses a `fmt` string that resides in program memory.

6.17.3.37 int vsprintf (char * __s, const char * __fmt, va_list ap)

Like **sprintf()**(p. 52) but takes a variable argument list for the arguments.

6.17.3.38 int vsprintf_P (char * __s, const char * __fmt, va_list ap)

Variant of **vsprintf()**(p. 59) that uses a `fmt` string that resides in program memory.

6.18 General utilities

6.18.1 Detailed Description

```
#include <stdlib.h>
```

This file declares some basic C macros and functions as defined by the ISO standard, plus some AVR-specific extensions.

Data Structures

- struct **div_t**
- struct **ldiv_t**

Non-standard (i.e. non-ISO C) functions.

- #define **RANDOM_MAX** 0x7FFFFFFF
- char * **itoa** (int __val, char *__s, int __radix)
- char * **ltoa** (long int __val, char *__s, int __radix)
- char * **utoa** (unsigned int __val, char *__s, int __radix)
- char * **ultoa** (unsigned long int __val, char *__s, int __radix)
- long **random** (void)
- void **srandom** (unsigned long __seed)
- long **random_r** (unsigned long *ctx)

Conversion functions for double arguments.

Note that these functions are not located in the default library, `libc.a`, but in the mathematical library, `libm.a`. So when linking the application, the `-lm` option needs to be specified.

- #define **DTOSTR_ALWAYS_SIGN** 0x01

- #define **DTOSTR_PLUS_SIGN** 0x02
- #define **DTOSTR_UPPERCASE** 0x04
- char * **dtostre** (double __val, char *__s, unsigned char __prec, unsigned char __flags)
- char * **dtostrf** (double __val, char __width, char __prec, char *__s)

Defines

- #define **RAND_MAX** 0x7FFF

Typedefs

- typedef int(* **__compar_fn_t**)(const void *, const void *)

Functions

- __inline__ void **abort** (void) __ATTR_NORETURN__
- int **abs** (int __i) __ATTR_CONST__
- long **labs** (long __i) __ATTR_CONST__
- void * **bsearch** (const void *__key, const void *__base, size_t __nmemb, size_t __size, int(*__compar)(const void *, const void *))
- **div_t div** (int __num, int __denom) __asm__("__divmodhi4") __ATTR_CONST__
- **ldiv_t ldiv** (long __num, long __denom) __asm__("__divmodsi4") __ATTR_CONST__
- void **qsort** (void *__base, size_t __nmemb, size_t __size, **__compar_fn_t** __compar)
- long **strtol** (const char *__nptr, char **__endptr, int __base)
- unsigned long **strtoul** (const char *__nptr, char **__endptr, int __base)
- __inline__ long **atol** (const char *__nptr) __ATTR_PURE__
- __inline__ int **atoi** (const char *__nptr) __ATTR_PURE__
- void **exit** (int __status) __ATTR_NORETURN__
- void * **malloc** (size_t __size) __ATTR_MALLOC__
- void **free** (void *__ptr)
- void * **calloc** (size_t __nele, size_t __size) __ATTR_MALLOC__
- void * **realloc** (void *__ptr, size_t __size) __ATTR_MALLOC__
- double **strtod** (const char *__nptr, char **__endptr)
- double **atof** (const char *__nptr)
- int **rand** (void)
- void **srand** (unsigned int __seed)
- int **rand_r** (unsigned long *ctx)

Variables

- size_t **__malloc_margin**
- char * **__malloc_heap_start**
- char * **__malloc_heap_end**

6.18.2 Define Documentation

6.18.2.1 #define DTOSTR_ALWAYS_SIGN 0x01

Bit value that can be passed in `flags` to **dtostre()**(p. 63).

6.18.2.2 #define DTOSTR_PLUS_SIGN 0x02

Bit value that can be passed in `flags` to **dtostre()**(p. 63).

6.18.2.3 #define DTOSTR_UPPERCASE 0x04

Bit value that can be passed in `flags` to **dtostre()**(p. 63).

6.18.2.4 #define RAND_MAX 0x7FFF

Highest number that can be generated by **rand()**(p. 66).

6.18.2.5 #define RANDOM_MAX 0x7FFFFFFF

Highest number that can be generated by **random()**(p. 66).

6.18.3 Typedef Documentation

6.18.3.1 typedef int(* __compar_fn_t)(const void *, const void *)

Comparision function type for **qsort()**(p. 66), just for convenience.

6.18.4 Function Documentation

6.18.4.1 __inline__ void abort (void)

The **abort()**(p. 61) function causes abnormal program termination to occur. In the limited AVR environment, execution is effectively halted by entering an infinite loop.

6.18.4.2 int abs (int __ *i*)

The **abs()**(p. 62) function computes the absolute value of the integer `i`.

Note:

The **abs()**(p. 62) and **labs()**(p. 65) functions are builtins of gcc.

6.18.4.3 double atof (const char * __ *nptr*)

The **atof()**(p. 62) function converts the initial portion of the string pointed to by `nptr` to double representation.

It is equivalent to calling

```
strtod(nptr, (char **)NULL);
```

6.18.4.4 int atoi (const char * *string*)

Convert a string to an integer.

The **atoi()**(p. 62) function converts the initial portion of the string pointed to by `nptr` to integer representation.

It is equivalent to:

```
(int)strtol(nptr, (char **)NULL, 10);
```

except that **atoi()**(p. 62) does not detect errors.

6.18.4.5 long int atol (const char * *string*)

Convert a string to a long integer.

The **atol()**(p. 62) function converts the initial portion of the string pointed to by `stringp` to integer representation.

It is equivalent to:

```
strtol(nptr, (char **)NULL, 10);
```

except that **atol()**(p. 62) does not detect errors.

6.18.4.6 void* bsearch (const void * __ *key*, const void * __ *base*, size_t __ *nmemb*, size_t __ *size*, int(*)(const void *, const void *) __ *compar*)

The **bsearch()**(p. 62) function searches an array of nmemb objects, the initial member of which is pointed to by base, for a member that matches the object pointed to by key. The size of each member of the array is specified by size.

The contents of the array should be in ascending sorted order according to the comparison function referenced by compar. The compar routine is expected to have two arguments which point to the key object and to an array member, in that order, and should return an integer less than, equal to, or greater than zero if the key object is found, respectively, to be less than, to match, or be greater than the array member.

The **bsearch()**(p. 62) function returns a pointer to a matching member of the array, or a null pointer if no match is found. If two members compare as equal, which member is matched is unspecified.

6.18.4.7 void* calloc (size_t __ *nele*, size_t __ *size*)

Allocate nele elements of size each. Identical to calling **malloc()**(p. 65) using nele * size as argument, except the allocated memory will be cleared to zero.

6.18.4.8 div_t div (int __ *num*, int __ *denom*)

The **div()**(p. 63) function computes the value num/denom and returns the quotient and remainder in a structure named **div_t**(p. 122) that contains two int members named quot and rem.

6.18.4.9 char* dtostre (double __ *val*, char * __ *s*, unsigned char __ *prec*, unsigned char __ *flags*)

The **dtostre()**(p. 63) function converts the double value passed in val into an ASCII representation that will be stored under s. The caller is responsible for providing sufficient storage in s.

Conversion is done in the format "[-]d.ddde177dd" where there is one digit before the decimal-point character and the number of digits after it is equal to the precision prec; if the precision is zero, no decimal-point character appears. If flags has the DTOSTRE_UPPERCASE bit set, the letter 'E' (rather than 'e') will be used to introduce the exponent. The exponent always contains two digits; if the value is zero, the exponent is "00".

If flags has the DTOSTRE_ALWAYS_SIGN bit set, a space character will be placed into the leading position for positive numbers.

If flags has the DTOSTRE_PLUS_SIGN bit set, a plus sign will be used instead of a space character in this case.

The **dtostre()**(p. 63) function returns the pointer to the converted string s.

6.18.4.10 char* dtostrf (double __val, char __width, char __prec, char * __s)

The **dtostrf()**(p. 64) function converts the double value passed in `val` into an ASCII representationthat will be stored under `s`. The caller is responsible for providing sufficient storage in `s`.

Conversion is done in the format `"[-]d.ddd"`. The minimum field width of the output string (including the `'.'` and the possible sign for negative values) is given in `width`, and `prec` determines the number of digits after the decimal sign.

The **dtostrf()**(p. 64) function returns the pointer to the converted string `s`.

6.18.4.11 void exit (int __status)

The **exit()**(p. 64) function terminates the application. Since there is no environment to return to, `status` is ignored, and code execution will eventually reach an infinite loop, thereby effectively halting all code processing.

In a C++ context, global destructors will be called before halting execution.

6.18.4.12 void free (void * __ptr)

The **free()**(p. 64) function causes the allocated memory referenced by `ptr` to be made available for future allocations. If `ptr` is NULL, no action occurs.

6.18.4.13 char* itoa (int __val, char * __s, int __radix)

Convert an integer to a string.

The function **itoa()**(p. 64) converts the integer value from `val` into an ASCII representation that will be stored under `s`. The caller is responsible for providing sufficient storage in `s`.

Note:

The minimal size of the buffer `s` depends on the choice of radix. For example, if the radix is 2 (binary), you need to supply a buffer with a minimal length of 8 * sizeof (int) + 1 characters, i.e. one character for each bit plus one for the string terminator. Using a larger radix will require a smaller minimal buffer size.

Warning:

If the buffer is too small, you risk a buffer overflow.

Conversion is done using the `radix` as base, which may be a number between 2 (binary conversion) and up to 36. If `radix` is greater than 10, the next digit after `'9'` will be the letter `'a'`.

If radix is 10 and val is negative, a minus sign will be prepended.

The **itoa()**(p. 64) function returns the pointer passed as `s`.

6.18.4.14 long labs (long __ *i*)

The **labs()**(p. 65) function computes the absolute value of the long integer `i`.

Note:

The **abs()**(p. 62) and **labs()**(p. 65) functions are builtins of gcc.

6.18.4.15 ldiv_t ldiv (long __ *num*, long __ *denom*)

The **ldiv()**(p. 65) function computes the value `num/denom` and returns the quotient and remainder in a structure named **ldiv_t**(p. 123) that contains two long integer members named `quot` and `rem`.

6.18.4.16 char* ltoa (long int __ *val*, char * __ *s*, int __ *radix*)

Convert a long integer to a string.

The function **ltoa()**(p. 65) converts the long integer value from `val` into an ASCII representation that will be stored under `s`. The caller is responsible for providing sufficient storage in `s`.

Note:

The minimal size of the buffer `s` depends on the choice of radix. For example, if the radix is 2 (binary), you need to supply a buffer with a minimal length of 8 * sizeof (long int) + 1 characters, i.e. one character for each bit plus one for the string terminator. Using a larger radix will require a smaller minimal buffer size.

Warning:

If the buffer is too small, you risk a buffer overflow.

Conversion is done using the `radix` as base, which may be a number between 2 (binary conversion) and up to 36. If `radix` is greater than 10, the next digit after `'9'` will be the letter `'a'`.

If radix is 10 and val is negative, a minus sign will be prepended.

The **ltoa()**(p. 65) function returns the pointer passed as `s`.

6.18.4.17 void* malloc (size_t __ *size*)

The **malloc()**(p. 65) function allocates `size` bytes of memory. If **malloc()**(p. 65) fails, a NULL pointer is returned.

Note that **malloc()**(p. 65) does *not* initialize the returned memory to zero bytes.

See the chapter about **malloc() usage**(p. 164) for implementation details.

6.18.4.18 void qsort (void * __ *base*, size_t __ *nmemb*, size_t __ *size*, __compar_fn_t __ *compar*)

The **qsort()**(p. 66) function is a modified partition-exchange sort, or quicksort.

The **qsort()**(p. 66) function sorts an array of `nmemb` objects, the initial member of which is pointed to by `base`. The size of each object is specified by `size`. The contents of the array base are sorted in ascending order according to a comparison function pointed to by `compar`, which requires two arguments pointing to the objects being compared.

The comparison function must return an integer less than, equal to, or greater than zero if the first argument is considered to be respectively less than, equal to, or greater than the second.

6.18.4.19 int rand (void)

The **rand()**(p. 66) function computes a sequence of pseudo-random integers in the range of 0 to `RAND_MAX` (as defined by the header file <**stdlib.h**(p. ??)>).

The **srand()**(p. 67) function sets its argument `seed` as the seed for a new sequence of pseudo-random numbers to be returned by **rand()**(p. 66). These sequences are repeatable by calling **srand()**(p. 67) with the same seed value.

If no seed value is provided, the functions are automatically seeded with a value of 1.

In compliance with the C standard, these functions operate on `int` arguments. Since the underlying algorithm already uses 32-bit calculations, this causes a loss of precision. See **random()**(p. 66) for an alternate set of functions that retains full 32-bit precision.

6.18.4.20 int rand_r (unsigned long * *ctx*)

Variant of **rand()**(p. 66) that stores the context in the user-supplied variable located at `ctx` instead of a static library variable so the function becomes reentrant.

6.18.4.21 long random (void)

The **random()**(p. 66) function computes a sequence of pseudo-random integers in the range of 0 to `RANDOM_MAX` (as defined by the header file

<**stdlib.h**(p. ??)>).

The **srandom()**(p. 67) function sets its argument `seed` as the seed for a new sequence of pseudo-random numbers to be returned by **rand()**(p. 66). These sequences are repeatable by calling **srandom()**(p. 67) with the same seed value.

If no seed value is provided, the functions are automatically seeded with a value of 1.

6.18.4.22 long random_r (unsigned long * *ctx*)

Variant of **random()**(p. 66) that stores the context in the user-supplied variable located at `ctx` instead of a static library variable so the function becomes re-entrant.

6.18.4.23 void* realloc (void * *__ptr*, size_t *__size*)

The **realloc()**(p. 67) function tries to change the size of the region allocated at `ptr` to the new `size` value. It returns a pointer to the new region. The returned pointer might be the same as the old pointer, or a pointer to a completely different region.

The contents of the returned region up to either the old or the new size value (whatever is less) will be identical to the contents of the old region, even in case a new region had to be allocated.

It is acceptable to pass `ptr` as NULL, in which case **realloc()**(p. 67) will behave identical to **malloc()**(p. 65).

If the new memory cannot be allocated, **realloc()**(p. 67) returns NULL, and the region at `ptr` will not be changed.

6.18.4.24 void srand (unsigned int *__seed*)

Pseudo-random number generator seeding; see **rand()**(p. 66).

6.18.4.25 void srandom (unsigned long *__seed*)

Pseudo-random number generator seeding; see **random()**(p. 66).

6.18.4.26 double strtod (const char * *__nptr*, char ** *__endptr*)

The **strtod()**(p. 67) function converts the initial portion of the string pointed to by `nptr` to double representation.

The expected form of the string is an optional plus (`'+'`) or minus sign (`'-'`) followed by a sequence of digits optionally containing a decimal-point character, optionally followed by an exponent. An exponent consists of an `'E'` or `'e'`, followed by an optional plus or minus sign, followed by a sequence of digits.

Leading white-space characters in the string are skipped.

The **strtod()**(p. 67) function returns the converted value, if any.

If `endptr` is not `NULL`, a pointer to the character after the last character used in the conversion is stored in the location referenced by `endptr`.

If no conversion is performed, zero is returned and the value of `nptr` is stored in the location referenced by `endptr`.

If the correct value would cause overflow, plus or minus `HUGE_VAL` is returned (according to the sign of the value), and `ERANGE` is stored in `errno`. If the correct value would cause underflow, zero is returned and `ERANGE` is stored in `errno`.

FIXME: HUGE_VAL needs to be defined somewhere. The bit pattern is 0x7fffffff, but what number would this be?

6.18.4.27 long strtol (const char * __ *nptr*, char ** __ *endptr*, int __ *base*)

The **strtol()**(p. 68) function converts the string in `nptr` to a long value. The conversion is done according to the given base, which must be between 2 and 36 inclusive, or be the special value 0.

The string may begin with an arbitrary amount of white space (as determined by **isspace()**(p. 33)) followed by a single optional `'+'` or `'-'` sign. If `base` is zero or 16, the string may then include a `"0x"` prefix, and the number will be read in base 16; otherwise, a zero base is taken as 10 (decimal) unless the next character is `'0'`, in which case it is taken as 8 (octal).

The remainder of the string is converted to a long value in the obvious manner, stopping at the first character which is not a valid digit in the given base. (In bases above 10, the letter `'A'` in either upper or lower case represents 10, `'B'` represents 11, and so forth, with `'Z'` representing 35.)

If `endptr` is not NULL, **strtol()**(p. 68) stores the address of the first invalid character in `*endptr`. If there were no digits at all, however, **strtol()**(p. 68) stores the original value of `nptr` in `endptr`. (Thus, if `*nptr` is not `'\0'` but `**endptr` is `'\0'` on return, the entire string was valid.)

The **strtol()**(p. 68) function returns the result of the conversion, unless the value would underflow or overflow. If no conversion could be performed, 0 is returned. If an overflow or underflow occurs, `errno` is set to **ERANGE**(p. 34) and the function return value is clamped to `LONG_MIN` or `LONG_MAX`, respectively.

6.18.4.28 unsigned long strtoul (const char * __nptr, char ** __endptr, int __base)

The **strtoul()**(p. 69) function converts the string in `nptr` to an unsigned long value. The conversion is done according to the given base, which must be between 2 and 36 inclusive, or be the special value 0.

The string may begin with an arbitrary amount of white space (as determined by **isspace()**(p. 33)) followed by a single optional `'+'` or `'-'` sign. If `base` is zero or 16, the string may then include a `"0x"` prefix, and the number will be read in base 16; otherwise, a zero base is taken as 10 (decimal) unless the next character is `'0'`, in which case it is taken as 8 (octal).

The remainder of the string is converted to an unsigned long value in the obvious manner, stopping at the first character which is not a valid digit in the given base. (In bases above 10, the letter `'A'` in either upper or lower case represents 10, `'B'` represents 11, and so forth, with `'Z'` representing 35.)

If `endptr` is not NULL, **strtoul()**(p. 69) stores the address of the first invalid character in `*endptr`. If there were no digits at all, however, **strtoul()**(p. 69) stores the original value of `nptr` in `endptr`. (Thus, if `*nptr` is not `'\0'` but `**endptr` is `'\0'` on return, the entire string was valid.)

The **strtoul()**(p. 69) function return either the result of the conversion or, if there was a leading minus sign, the negation of the result of the conversion, unless the original (non-negated) value would overflow; in the latter case, **strtoul()**(p. 69) returns ULONG_MAX, and `errno` is set to **ERANGE**(p. 34). If no conversion could be performed, 0 is returned.

6.18.4.29 char* ultoa (unsigned long int __val, char * __s, int __radix)

Convert an unsigned long integer to a string.

The function **ultoa()**(p. 69) converts the unsigned long integer value from `val` into an ASCII representation that will be stored under `s`. The caller is responsible for providing sufficient storage in `s`.

Note:

The minimal size of the buffer `s` depends on the choice of radix. For example, if the radix is 2 (binary), you need to supply a buffer with a minimal length of 8 * sizeof (unsigned long int) + 1 characters, i.e. one character for each bit plus one for the string terminator. Using a larger radix will require a smaller minimal buffer size.

Warning:

If the buffer is too small, you risk a buffer overflow.

Conversion is done using the `radix` as base, which may be a number between

2 (binary conversion) and up to 36. If radix is greater than 10, the next digit after '9' will be the letter 'a'.

The **ultoa()**(p. 69) function returns the pointer passed as s.

6.18.4.30 char* utoa (unsigned int __ *val*, char * __ *s*, int __ *radix*)

Convert an unsigned integer to a string.

The function **utoa()**(p. 70) converts the unsigned integer value from val into an ASCII representation that will be stored under s. The caller is responsible for providing sufficient storage in s.

Note:

The minimal size of the buffer s depends on the choice of radix. For example, if the radix is 2 (binary), you need to supply a buffer with a minimal length of 8 * sizeof (unsigned int) + 1 characters, i.e. one character for each bit plus one for the string terminator. Using a larger radix will require a smaller minimal buffer size.

Warning:

If the buffer is too small, you risk a buffer overflow.

Conversion is done using the radix as base, which may be a number between 2 (binary conversion) and up to 36. If radix is greater than 10, the next digit after '9' will be the letter 'a'.

The **utoa()**(p. 70) function returns the pointer passed as s.

6.18.5 Variable Documentation

6.18.5.1 char* __malloc_heap_end

malloc()(p. 65) **tunable**(p. 166).

6.18.5.2 char* __malloc_heap_start

malloc()(p. 65) **tunable**(p. 166).

6.18.5.3 size_t __malloc_margin

malloc()(p. 65) **tunable**(p. 166).

6.19 Strings

6.19.1 Detailed Description

```
#include <string.h>
```

The string functions perform string operations on NULL terminated strings.

Note:

If the strings you are working on resident in program space (flash), you will need to use the string functions described in **Program Space String Utilities**(p. 19).

Functions

- void * **memccpy** (void *, const void *, int, size_t)
- void * **memchr** (const void *, int, size_t) __ATTR_PURE__
- int **memcmp** (const void *, const void *, size_t) __ATTR_PURE__
- void * **memcpy** (void *, const void *, size_t)
- void * **memmove** (void *, const void *, size_t)
- void * **memset** (void *, int, size_t)
- int **strcasecmp** (const char *, const char *) __ATTR_PURE__
- char * **strcat** (char *, const char *)
- char * **strchr** (const char *, int) __ATTR_PURE__
- int **strcmp** (const char *, const char *) __ATTR_PURE__
- char * **strcpy** (char *, const char *)
- size_t **strlcat** (char *, const char *, size_t)
- size_t **strlcpy** (char *, const char *, size_t)
- size_t **strlen** (const char *) __ATTR_PURE__
- char * **strlwr** (char *)
- int **strncasecmp** (const char *, const char *, size_t) __ATTR_PURE__
- char * **strncat** (char *, const char *, size_t)
- int **strncmp** (const char *, const char *, size_t) __ATTR_PURE__
- char * **strncpy** (char *, const char *, size_t)
- size_t **strnlen** (const char *, size_t) __ATTR_PURE__
- char * **strrchr** (const char *, int) __ATTR_PURE__
- char * **strrev** (char *)
- char * **strsep** (char **, const char *)
- char * **strstr** (const char *, const char *) __ATTR_PURE__
- char * **strtok_r** (char *, const char *, char **)
- char * **strupr** (char *)

6.19.2 Function Documentation

6.19.2.1 void * memccpy (void * *dest*, const void * *src*, int *val*, size_t *len*)

Copy memory area.

The **memccpy()**(p. 72) function copies no more than len bytes from memory area src to memory area dest, stopping when the character val is found.

Returns:

The **memccpy()**(p. 72) function returns a pointer to the next character in dest after val, or NULL if val was not found in the first len characters of src.

6.19.2.2 void * memchr (const void * *src*, int *val*, size_t *len*)

Scan memory for a character.

The **memchr()**(p. 72) function scans the first len bytes of the memory area pointed to by src for the character val. The first byte to match val (interpreted as an unsigned character) stops the operation.

Returns:

The **memchr()**(p. 72) function returns a pointer to the matching byte or NULL if the character does not occur in the given memory area.

6.19.2.3 int memcmp (const void * *s1*, const void * *s2*, size_t *len*)

Compare memory areas.

The **memcmp()**(p. 72) function compares the first len bytes of the memory areas s1 and s2. The comparision is performed using unsigned char operations.

Returns:

The **memcmp()**(p. 72) function returns an integer less than, equal to, or greater than zero if the first len bytes of s1 is found, respectively, to be less than, to match, or be greater than the first len bytes of s2.

Note:

Be sure to store the result in a 16 bit variable since you may get incorrect results if you use an unsigned char or char due to truncation.

Warning:

This function is not -mint8 compatible, although if you only care about testing for equality, this function should be safe to use.

6.19.2.4 void * memcpy (void * *dest*, const void * *src*, size_t *len*)

Copy a memory area.

The **memcpy()**(p. 73) function copies len bytes from memory area src to memory area dest. The memory areas may not overlap. Use **memmove()**(p. 73) if the memory areas do overlap.

Returns:

The **memcpy()**(p. 73) function returns a pointer to dest.

6.19.2.5 void * memmove (void * *dest*, const void * *src*, size_t *len*)

Copy memory area.

The **memmove()**(p. 73) function copies len bytes from memory area src to memory area dest. The memory areas may overlap.

Returns:

The **memmove()**(p. 73) function returns a pointer to dest.

6.19.2.6 void * memset (void * *dest*, int *val*, size_t *len*)

Fill memory with a constant byte.

The **memset()**(p. 73) function fills the first len bytes of the memory area pointed to by dest with the constant byte val.

Returns:

The **memset()**(p. 73) function returns a pointer to the memory area dest.

6.19.2.7 int strcasecmp (const char * *s1*, const char * *s2*)

Compare two strings ignoring case.

The **strcasecmp()**(p. 73) function compares the two strings s1 and s2, ignoring the case of the characters.

Returns:

The **strcasecmp()**(p. 73) function returns an integer less than, equal to, or greater than zero if s1 is found, respectively, to be less than, to match, or be greater than s2.

6.19.2.8 char * strcat (char * *dest*, const char * *src*)

Concatenate two strings.

The **strcat()**(p. 74) function appends the src string to the dest string overwriting the '\0' character at the end of dest, and then adds a terminating '\0' character. The strings may not overlap, and the dest string must have enough space for the result.

Returns:

The **strcat()**(p. 74) function returns a pointer to the resulting string dest.

6.19.2.9 char * strchr (const char * *src*, int *val*)

Locate character in string.

The **strchr()**(p. 74) function returns a pointer to the first occurrence of the character val in the string src.

Here "character" means "byte" - these functions do not work with wide or multi-byte characters.

Returns:

The **strchr()**(p. 74) function returns a pointer to the matched character or NULL if the character is not found.

6.19.2.10 int strcmp (const char * *s1*, const char * *s2*)

Compare two strings.

The **strcmp()**(p. 74) function compares the two strings s1 and s2.

Returns:

The **strcmp()**(p. 74) function returns an integer less than, equal to, or greater than zero if s1 is found, respectively, to be less than, to match, or be greater than s2.

6.19.2.11 char * strcpy (char * *dest*, const char * *src*)

Copy a string.

The **strcpy()**(p. 74) function copies the string pointed to by src (including the terminating '\0' character) to the array pointed to by dest. The strings may not overlap, and the destination string dest must be large enough to receive the copy.

Returns:

The **strcpy()**(p. 74) function returns a pointer to the destination string dest.

Note:

If the destination string of a **strcpy()**(p. 74) is not large enough (that is, if the programmer was stupid/lazy, and failed to check the size before copying) then anything might happen. Overflowing fixed length strings is a favourite cracker technique.

6.19.2.12 size_t strlcat (char * *dst*, const char * *src*, size_t *siz*)

Concatenate two strings.

Appends src to string dst of size siz (unlike **strncat()**(p. 76), siz is the full size of dst, not space left). At most siz-1 characters will be copied. Always NULL terminates (unless siz <= strlen(dst)).

Returns:

The **strlcat()**(p. 75) function returns strlen(src) + MIN(siz, strlen(initial dst)). If retval >= siz, truncation occurred.

6.19.2.13 size_t strlcpy (char * *dst*, const char * *src*, size_t *siz*)

Copy a string.

Copy src to string dst of size siz. At most siz-1 characters will be copied. Always NULL terminates (unless siz == 0).

Returns:

The **strlcpy()**(p. 75) function returns strlen(src). If retval >= siz, truncation occurred.

6.19.2.14 size_t strlen (const char * *src*)

Calculate the length of a string.

The **strlen()**(p. 75) function calculates the length of the string src, not including the terminating '\0' character.

Returns:

The **strlen()**(p. 75) function returns the number of characters in src.

6.19.2.15 char * strlwr (char * *string*)

Convert a string to lower case.

The **strlwr()**(p. 76) function will convert a string to lower case. Only the upper case alphabetic characters [A .. Z] are converted. Non-alphabetic characters will not be changed.

Returns:
The **strlwr()**(p. 76) function returns a pointer to the converted string.

6.19.2.16 int strncasecmp (const char * *s1*, const char * *s2*, size_t *len*)

Compare two strings ignoring case.

The **strncasecmp()**(p. 76) function is similar to **strcasecmp()**(p. 73), except it only compares the first n characters of s1.

Returns:
The **strncasecmp()**(p. 76) function returns an integer less than, equal to, or greater than zero if s1 (or the first n bytes thereof) is found, respectively, to be less than, to match, or be greater than s2.

6.19.2.17 char * strncat (char * *dest*, const char * *src*, size_t *len*)

Concatenate two strings.

The **strncat()**(p. 76) function is similar to **strcat()**(p. 74), except that only the first n characters of src are appended to dest.

Returns:
The **strncat()**(p. 76) function returns a pointer to the resulting string dest.

6.19.2.18 int strncmp (const char * *s1*, const char * *s2*, size_t *len*)

Compare two strings.

The **strncmp()**(p. 76) function is similar to **strcmp()**(p. 74), except it only compares the first (at most) n characters of s1 and s2.

Returns:
The **strncmp()**(p. 76) function returns an integer less than, equal to, or greater than zero if s1 (or the first n bytes thereof) is found, respectively, to be less than, to match, or be greater than s2.

6.19.2.19 char * strncpy (char * *dest*, const char * *src*, size_t *len*)

Copy a string.

The **strncpy()**(p. 77) function is similar to **strcpy()**(p. 74), except that not more than n bytes of src are copied. Thus, if there is no null byte among the first n bytes of src, the result will not be null-terminated.

In the case where the length of src is less than that of n, the remainder of dest will be padded with nulls.

Returns:

The **strncpy()**(p. 77) function returns a pointer to the destination string dest.

6.19.2.20 size_t strnlen (const char * *src*, size_t *len*)

Determine the length of a fixed-size string.

The strnlen function returns the number of characters in the string pointed to by src, not including the terminating '\0' character, but at most len. In doing this, strnlen looks only at the first len characters at src and never beyond src+len.

Returns:

The strnlen function returns strlen(src), if that is less than len, or len if there is no '\0' character among the first len characters pointed to by src.

6.19.2.21 char * strrchr (const char * *src*, int *val*)

Locate character in string.

The **strrchr()**(p. 77) function returns a pointer to the last occurrence of the character val in the string src.

Here "character" means "byte" - these functions do not work with wide or multi-byte characters.

Returns:

The **strrchr()**(p. 77) function returns a pointer to the matched character or NULL if the character is not found.

6.19.2.22 char * strrev (char * *string*)

Reverse a string.

The **strrev()**(p. 77) function reverses the order of the string.

Returns:

The **strrev()**(p. 77) function returns a pointer to the beginning of the reversed string.

6.19.2.23 char * strsep (char ** *string*, const char * *delim*)

Parse a string into tokens.

The **strsep()**(p. 78) function locates, in the string referenced by *string, the first occurrence of any character in the string delim (or the terminating '\0' character) and replaces it with a '\0'. The location of the next character after the delimiter character (or NULL, if the end of the string was reached) is stored in *string. An "empty" field, i.e. one caused by two adjacent delimiter characters, can be detected by comparing the location referenced by the pointer returned in *string to '\0'.

Returns:

The **strtok_r()**(p. 78) function returns a pointer to the original value of *string. If *stringp is initially NULL, **strsep()**(p. 78) returns NULL.

6.19.2.24 char * strstr (const char * *s1*, const char * *s2*)

Locate a substring.

The **strstr()**(p. 78) function finds the first occurrence of the substring `s2` in the string `s1`. The terminating '\0' characters are not compared.

Returns:

The **strstr()**(p. 78) function returns a pointer to the beginning of the substring, or NULL if the substring is not found. If s2 points to a string of zero length, the function returns s1.

6.19.2.25 char * strtok_r (char * *string*, const char * *delim*, char ** *last*)

Parses the string s into tokens.

strtok_r parses the string s into tokens. The first call to strtok_r should have string as its first argument. Subsequent calls should have the first argument set to NULL. If a token ends with a delimiter, this delimiting character is overwritten with a '\0' and a pointer to the next character is saved for the next call to strtok_r. The delimiter string delim may be different for each call. last is a user allocated char* pointer. It must be the same while parsing the same string. strtok_r is a reentrant version of strtok().

Returns:

The **strtok_r()**(p. 78) function returns a pointer to the next token or NULL when no more tokens are found.

6.19.2.26 char * strupr (char * *string*)

Convert a string to upper case.

The **strupr()**(p. 79) function will convert a string to upper case. Only the lower case alphabetic characters [a .. z] are converted. Non-alphabetic characters will not be changed.

Returns:

The **strupr()**(p. 79) function returns a pointer to the converted string. The pointer is the same as that passed in since the operation is perform in place.

6.20 Interrupts and Signals

6.20.1 Detailed Description

Note:

This discussion of interrupts and signals was taken from Rich Neswold's document. See **Acknowledgments**(p. 123).

It's nearly impossible to find compilers that agree on how to handle interrupt code. Since the C language tries to stay away from machine dependent details, each compiler writer is forced to design their method of support.

In the AVR-GCC environment, the vector table is predefined to point to interrupt routines with predetermined names. By using the appropriate name, your routine will be called when the corresponding interrupt occurs. The device library provides a set of default interrupt routines, which will get used if you don't define your own.

Patching into the vector table is only one part of the problem. The compiler uses, by convention, a set of registers when it's normally executing compiler-generated code. It's important that these registers, as well as the status register, get saved and restored. The extra code needed to do this is enabled by tagging the interrupt function with `__attribute__((interrupt))`.

These details seem to make interrupt routines a little messy, but all these details are handled by the Interrupt API. An interrupt routine is defined with one of two macros, **INTERRUPT()**(p. 83) and **SIGNAL()**(p. 84). These macros register and mark the routine as an interrupt handler for the specified peripheral. The following is an example definition of a handler for the ADC interrupt.

```
#include <avr/signal.h>
```

```
INTERRUPT(SIG_ADC)
{
    // user code here
}
```

Refer to the chapter explaining **assembler programming**(p. 128) for an explanation about interrupt routines written solely in assembler language.

If an unexpected interrupt occurs (interrupt is enabled and no handler is installed, which usually indicates a bug), then the default action is to reset the device by jumping to the reset vector. You can override this by supplying a function named `__vector_default` which should be defined with either **SIGNAL()**(p. 84) or **INTERRUPT()**(p. 83) as such.

```
#include <avr/signal.h>

SIGNAL(__vector_default)
{
    // user code here
}
```

The interrupt is chosen by supplying one of the symbols in following table. Note that every AVR device has a different interrupt vector table so some signals might not be available. Check the data sheet for the device you are using.

[FIXME: Fill in the blanks! Gotta read those durn data sheets ;-)]

Note:

The **SIGNAL()**(p. 84) and **INTERRUPT()**(p. 83) macros currently cannot spell-check the argument passed to them. Thus, by misspelling one of the names below in a call to **SIGNAL()**(p. 84) or **INTERRUPT()**(p. 83), a function will be created that, while possibly being usable as an interrupt function, is not actually wired into the interrupt vector table. No warning will be given about this situation.

Signal Name	**Description**
SIG_2WIRE_SERIAL	2-wire serial interface (aka. I178C [tm])
SIG_ADC	ADC Conversion complete
SIG_COMPARATOR	Analog Comparator Interrupt
SIG_EEPROM_READY	Eeprom ready
SIG_FPGA_INTERRUPT0	
SIG_FPGA_INTERRUPT1	
SIG_FPGA_INTERRUPT2	
SIG_FPGA_INTERRUPT3	
SIG_FPGA_INTERRUPT4	
SIG_FPGA_INTERRUPT5	
SIG_FPGA_INTERRUPT6	
SIG_FPGA_INTERRUPT7	
SIG_FPGA_INTERRUPT8	

Signal Name	Description
SIG_FPGA_INTERRUPT9	
SIG_FPGA_INTERRUPT10	
SIG_FPGA_INTERRUPT11	
SIG_FPGA_INTERRUPT12	
SIG_FPGA_INTERRUPT13	
SIG_FPGA_INTERRUPT14	
SIG_FPGA_INTERRUPT15	
SIG_INPUT_CAPTURE1	Input Capture1 Interrupt
SIG_INPUT_CAPTURE3	Input Capture3 Interrupt
SIG_INTERRUPT0	External Interrupt0
SIG_INTERRUPT1	External Interrupt1
SIG_INTERRUPT2	External Interrupt2
SIG_INTERRUPT3	External Interrupt3
SIG_INTERRUPT4	External Interrupt4
SIG_INTERRUPT5	External Interrupt5
SIG_INTERRUPT6	External Interrupt6
SIG_INTERRUPT7	External Interrupt7
SIG_OUTPUT_COMPARE0	Output Compare0 Interrupt
SIG_OUTPUT_COMPARE1A	Output Compare1(A) Interrupt
SIG_OUTPUT_COMPARE1B	Output Compare1(B) Interrupt
SIG_OUTPUT_COMPARE1C	Output Compare1(C) Interrupt
SIG_OUTPUT_COMPARE2	Output Compare2 Interrupt
SIG_OUTPUT_COMPARE3A	Output Compare3(A) Interrupt
SIG_OUTPUT_COMPARE3B	Output Compare3(B) Interrupt
SIG_OUTPUT_COMPARE3C	Output Compare3(C) Interrupt
SIG_OVERFLOW0	Overflow0 Interrupt
SIG_OVERFLOW1	Overflow1 Interrupt
SIG_OVERFLOW2	Overflow2 Interrupt
SIG_OVERFLOW3	Overflow3 Interrupt
SIG_PIN	
SIG_PIN_CHANGE0	
SIG_PIN_CHANGE1	
SIG_RDMAC	
SIG_SPI	SPI Interrupt
SIG_SPM_READY	Store program memory ready
SIG_SUSPEND_RESUME	
SIG_TDMAC	
SIG_UART0	
SIG_UART0_DATA	UART(0) Data Register Empty Interrupt
SIG_UART0_RECV	UART(0) Receive Complete Interrupt
SIG_UART0_TRANS	UART(0) Transmit Complete Interrupt
SIG_UART1	
SIG_UART1_DATA	UART(1) Data Register Empty Interrupt
SIG_UART1_RECV	UART(1) Receive Complete Interrupt
SIG_UART1_TRANS	UART(1) Transmit Complete Interrupt
SIG_UART_DATA	UART Data Register Empty Interrupt
SIG_UART_RECV	UART Receive Complete Interrupt
SIG_UART_TRANS	UART Transmit Complete Interrupt
SIG_USART0_DATA	USART(0) Data Register Empty Interrupt
SIG_USART0_RECV	USART(0) Receive Complete Interrupt
SIG_USART0_TRANS	USART(0) Transmit Complete Interrupt
SIG_USART1_DATA	USART(1) Data Register Empty Interrupt
SIG_USART1_RECV	USART(1) Receive Complete Interrupt
SIG_USART1_TRANS	USART(1) Transmit Complete Interrupt

Signal Name	Description
SIG_USB_HW	

Global manipulation of the interrupt flag

The global interrupt flag is maintained in the I bit of the status register (SREG).

- #define **sei**() __asm__ __volatile__ ("sei" ::)
- #define **cli**() __asm__ __volatile__ ("cli" ::)

Allowing specific system-wide interrupts

In addition to globally enabling interrupts, each device's particular interrupt needs to be enabled separately if interrupts for this device are desired. While some devices maintain their interrupt enable bit inside the device's register set, external and timer interrupts have system-wide configuration registers.

Example:

```
// Enable timer 1 overflow interrupts.
timer_enable_int(_BV(TOIE1));

// Do some work...

// Disable all timer interrupts.
timer_enable_int(0);
```

Note:

Be careful when you use these functions. If you already have a different interrupt enabled, you could inadvertantly disable it by enabling another intterupt.

- #define **enable_external_int**(mask) (__EICR = mask)
- static __inline__ void **timer_enable_int** (unsigned char ints)

Macros for writing interrupt handler functions

- #define **SIGNAL**(signame)
- #define **INTERRUPT**(signame)
- #define **EMPTY_INTERRUPT**(signame)

6.20.2 Define Documentation

6.20.2.1 #define cli() __asm__ __volatile__ ("cli" ::)

```
#include <avr/interrupt.h>
```

Disables all interrupts by clearing the global interrupt mask. This function actually compiles into a single line of assembly, so there is no function call overhead.

6.20.2.2 #define EMPTY_INTERRUPT(signame)

Value:

```
void signame (void) __attribute__ ((naked));    \
void signame (void) { __asm__ __volatile__ ("reti" ::); }
```

```
#include <avr/signal.h>
```

Defines an empty interrupt handler function. This will not generate any prolog or epilog code and will only return from the ISR. Do not define a function body as this will define it for you. Example:

```
 EMPTY_INTERRUPT(SIG_ADC);
```

6.20.2.3 #define enable_external_int(mask) (__EICR = mask)

```
#include <avr/interrupt.h>
```

This macro gives access to the `GIMSK` register (or `EIMSK` register if using an AVR Mega device or `GICR` register for others). Although this macro is essentially the same as assigning to the register, it does adapt slightly to the type of device being used. This macro is unavailable if none of the registers listed above are defined.

6.20.2.4 #define INTERRUPT(signame)

Value:

```
void signame (void) __attribute__ ((interrupt));        \
void signame (void)
```

```
#include <avr/signal.h>
```

Introduces an interrupt handler function that runs with global interrupts initially enabled. This allows interrupt handlers to be interrupted.

6.20.2.5 #define sei() __asm__ __volatile__ ("sei" ::)

```
#include <avr/interrupt.h>
```

Enables interrupts by clearing the global interrupt mask. This function actually compiles into a single line of assembly, so there is no function call overhead.

6.20.2.6 #define SIGNAL(signame)

Value:

```
void signame (void) __attribute__ ((signal));          \
void signame (void)
```

```
#include <avr/signal.h>
```

Introduces an interrupt handler function that runs with global interrupts initially disabled.

6.20.3 Function Documentation

6.20.3.1 static __inline__ void timer_enable_int (unsigned char *ints*) `[static]`

```
#include <avr/interrupt.h>
```

This function modifies the `timsk` register. The value you pass via `ints` is device specific.

6.21 Special function registers

6.21.1 Detailed Description

When working with microcontrollers, many of the tasks usually consist of controlling the peripherals that are connected to the device, respectively programming the subsystems that are contained in the controller (which by itself communicate with the circuitry connected to the controller).

The AVR series of microcontrollers offers two different paradigms to perform this task. There's a separate IO address space available (as it is known from some high-level CISC CPUs) that can be addressed with specific IO instructions that are applicable to some or all of the IO address space (`in`, `out`, `sbi` etc.). The entire IO address space is also made available as *memory-mapped IO*, i. e. it can be accessed using all the MCU instructions that are applicable to normal data memory. The IO register space is mapped into the data memory address space with an offset of 0x20 since the bottom of this space is reserved for direct access to the MCU registers. (Actual SRAM is available only behind the IO register area, starting at either address 0x60, or 0x100 depending on the device.)

AVR Libc supports both these paradigms. While by default, the implementation uses memory-mapped IO access, this is hidden from the programmer. So the programmer can access IO registers either with a special function like `outb()`:

```
#include <avr/io.h>

outb(PORTA, 0x33);
```

or they can assign a value directly to the symbolic address:

```
PORTA = 0x33;
```

The compiler's choice of which method to use when actually accessing the IO port is completely independent of the way the programmer chooses to write the code. So even if the programmer uses the memory-mapped paradigm and writes

```
PORTA |= 0x40;
```

the compiler can optimize this into the use of an `sbi` instruction (of course, provided the target address is within the allowable range for this instruction, and the right-hand side of the expression is a constant value known at compile-time).

The advantage of using the memory-mapped paradigm in C programs is that it makes the programs more portable to other C compilers for the AVR platform. Some people might also feel that this is more readable. For example, the following two statements would be equivalent:

```
outb(DDRD, inb(DDRD) & ~LCDBITS);
DDRD &= ~LCDBITS;
```

The generated code is identical for both. Whitout optimization, the compiler strictly generates code following the memory-mapped paradigm, while with optimization turned on, code is generated using the (faster and smaller) `in/out` MCU instructions.

Note that special care must be taken when accessing some of the 16-bit timer IO registers where access from both the main program and within an interrupt context can happen. See **Why do some 16-bit timer registers sometimes get trashed?**(p. 136).

Modules

- **Additional notes from <avr/sfr_defs.h>**

Bit manipulation

- #define **_BV**(bit) (1 << (bit))

IO register bit manipulation

- #define **bit_is_set**(sfr, bit) (_SFR_BYTE(sfr) & _BV(bit))
- #define **bit_is_clear**(sfr, bit) (!(_SFR_BYTE(sfr) & _BV(bit)))
- #define **loop_until_bit_is_set**(sfr, bit) do { } while (bit_is_clear(sfr, bit))
- #define **loop_until_bit_is_clear**(sfr, bit) do { } while (bit_is_set(sfr, bit))

6.21.2 Define Documentation

6.21.2.1 #define _BV(bit) (1 << (bit))

```
#include <avr/io.h>
```

Converts a bit number into a byte value.

Note:

The bit shift is performed by the compiler which then inserts the result into the code. Thus, there is no run-time overhead when using **_BV()**(p. 86).

6.21.2.2 #define bit_is_clear(sfr, bit) (!(_SFR_BYTE(sfr) & _BV(bit)))

```
#include <avr/io.h>
```

Test whether bit `bit` in IO register `sfr` is clear. This will return non-zero if the bit is clear, and a 0 if the bit is set.

6.21.2.3 #define bit_is_set(sfr, bit) (_SFR_BYTE(sfr) & _BV(bit))

```
#include <avr/io.h>
```

Test whether bit `bit` in IO register `sfr` is set. This will return a 0 if the bit is clear, and non-zero if the bit is set.

6.21.2.4 #define loop_until_bit_is_clear(sfr, bit) do { } while (bit_is_set(sfr, bit))

```
#include <avr/io.h>
```

Wait until bit `bit` in IO register `sfr` is clear.

6.21.2.5 #define loop_until_bit_is_set(sfr, bit) do { } while (bit_is_clear(sfr, bit))

```
#include <avr/io.h>
```

Wait until bit `bit` in IO register `sfr` is set.

6.22 Demo projects

6.22.1 Detailed Description

Various small demo projects are provided to illustrate several aspects of using the opensource utilities for the AVR controller series. It should be kept in mind that these demos serve mainly educational purposes, and are normally not directly suitable for use in any production environment. Usually, they have been kept as simple as sufficient to demonstrate one particular feature.

The **simple project**(p. 87) is somewhat like the "Hello world!" application for a microcontroller, about the most simple project that can be done. It is explained in good detail, to allow the reader to understand the basic concepts behind using the tools on an AVR microcontroller.

The **Example using the two-wire interface (TWI)**(p. 100) project explains the use of the two-wire hardware interface (also known as "I2C") that is present on many AVR controllers.

Modules

- **A simple project**
- **Example using the two-wire interface (TWI)**

6.23 A simple project

At this point, you should have the GNU tools configured, built, and installed on your system. In this chapter, we present a simple example of using the GNU tools in an AVR project. After reading this chapter, you should have a better feel as to how the tools are used and how a `Makefile` can be configured.

6.23.1 The Project

This project will use the pulse-width modulator (PWM) to ramp an LED on and off every two seconds. An AT90S2313 processor will be used as the controller. The circuit for this demonstration is shown in the **schematic diagram**(p. 88). If you have a development kit, you should be able to use it, rather than build the circuit, for this project.

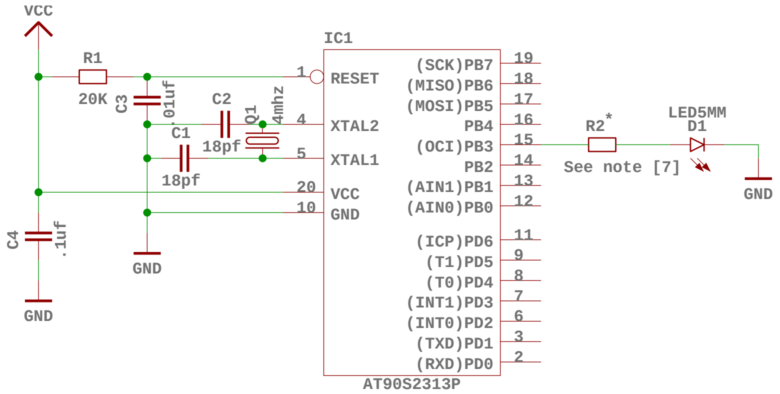

Figure 1: Schematic of circuit for demo project

The source code is given in **demo.c**(p. 89). For the sake of this example, create a file called **demo.c**(p. **??**) containing this source code. Some of the more important parts of the code are:

Note [1]:
The PWM is being used in 10-bit mode, so we need a 16-bit variable to remember the current value.

Note [2]:
SIGNAL()(p. 84) is a macro that marks the function as an interrupt routine. In this case, the function will get called when the timer overflows. Setting up interrupts is explained in greater detail in **Interrupts and Signals**(p. 79).

Note [3]:
This section determines the new value of the PWM.

Note [4]:
Here's where the newly computed value is loaded into the PWM register. Since we are in an interrupt routine, it is safe to use a 16-bit assignment to the register. Outside of an interrupt, the assignment should only be

performed with interrupts disabled if there's a chance that an interrupt routine could also access this register (or another register that uses TEMP), see the appropriate **FAQ entry**(p. 136).

Note [5]:
This routine gets called after a reset. It initializes the PWM and enables interrupts.

Note [6]:
The main loop of the program does nothing – all the work is done by the interrupt routine! If this was a real product, we'd probably put a SLEEP instruction in this loop to conserve power.

Note [7]:
Early AVR devices saturate their outputs at rather low currents when sourcing current, so the LED can be connected directly, the resulting current through the LED will be about 15 mA. For modern parts (at least for the ATmega 128), however Atmel has drastically increased the IO source capability, so when operating at 5 V Vcc, R2 is needed. Its value should be about 150 Ohms. When operating the circuit at 3 V, it can still be omitted though.

6.23.2 The Source Code

```
/*
 * ----------------------------------------------------------------------------
 * "THE BEER-WARE LICENSE" (Revision 42):
 * <joerg@FreeBSD.ORG> wrote this file.  As long as you retain this notice you
 * can do whatever you want with this stuff. If we meet some day, and you think
 * this stuff is worth it, you can buy me a beer in return.        Joerg Wunsch
 * ----------------------------------------------------------------------------
 *
 * Simple AVR demonstration.  Controls a LED that can be directly
 * connected from OC1/OC1A to GND.  The brightness of the LED is
 * controlled with the PWM.  After each period of the PWM, the PWM
 * value is either incremented or decremented, that's all.
 *
 * $Id: demo.c,v 1.4.2.1 2005/04/09 14:55:28 joerg_wunsch Exp $
 */

#include <inttypes.h>
#include <avr/io.h>
#include <avr/interrupt.h>
#include <avr/signal.h>

#if defined(__AVR_AT90S2313__)
#  define OC1 PB3
#  define OCR OCR1
#  define DDROC DDRB
#elif defined(__AVR_AT90S2333__) || defined(__AVR_AT90S4433__)
```

```
#  define OC1 PB1
#  define DDROC DDRB
#  define OCR OCR1
#elif defined(__AVR_AT90S4414__) || defined(__AVR_AT90S8515__) || \
      defined(__AVR_AT90S4434__) || defined(__AVR_AT90S8535__) || \
      defined(__AVR_ATmega163__)
#  define OC1 PD5
#  define DDROC DDRD
#  define OCR OCR1A
#elif defined(__AVR_ATmega8__)
#  define OC1 PB1
#  define DDROC DDRB
#  define OCR OCR1A
#  define PWM10 WGM10
#  define PWM11 WGM11
#elif defined(__AVR_ATmega32__) || defined(__AVR_ATmega16__)
#  define OC1 PD5
#  define DDROC DDRD
#  define OCR OCR1A
#  define PWM10 WGM10
#  define PWM11 WGM11
#elif defined(__AVR_ATmega64__) || defined(__AVR_ATmega128__)
#  define OC1 PB5
#  define DDROC DDRB
#  define OCR OCR1A
#  define PWM10 WGM10
#  define PWM11 WGM11
#else
#  error "Don't know what kind of MCU you are compiling for"
#endif

#if defined(COM11)
#  define XCOM11 COM11
#elif defined(COM1A1)
#  define XCOM11 COM1A1
#else
#  error "need either COM1A1 or COM11"
#endif

enum { UP, DOWN };

volatile uint16_t pwm; /* Note [1] */
volatile uint8_t direction;

SIGNAL (SIG_OVERFLOW1) /* Note [2] */
{
    switch (direction) /* Note [3] */
    {
        case UP:
            if (++pwm == 1023)
                direction = DOWN;
            break;

        case DOWN:
            if (--pwm == 0)
                direction = UP;
            break;
```

```
    }

    OCR = pwm; /* Note [4] */
}

void
ioinit (void) /* Note [5] */
{
    /* tmr1 is 10-bit PWM */
    TCCR1A = _BV (PWM10) | _BV (PWM11) | _BV (XCOM11);

    /* tmr1 running on full MCU clock */
    TCCR1B = _BV (CS10);

    /* set PWM value to 0 */
    OCR = 0;

    /* enable OC1 and PB2 as output */
    DDROC = _BV (OC1);

    timer_enable_int (_BV (TOIE1));

    /* enable interrupts */
    sei ();
}

int
main (void)
{
    ioinit ();

    /* loop forever, the interrupts are doing the rest */

    for (;;) /* Note [6] */
        ;

    return (0);
}
```

6.23.3 Compiling and Linking

This first thing that needs to be done is compile the source. When compiling, the compiler needs to know the processor type so the `-mmcu` option is specified. The `-Os` option will tell the compiler to optimize the code for efficient space usage (at the possible expense of code execution speed). The `-g` is used to embed debug info. The debug info is useful for disassemblies and doesn't end up in the .hex files, so I usually specify it. Finally, the `-c` tells the compiler to compile and stop – don't link. This demo is small enough that we could compile and link in one step. However, real-world projects will have several modules and will typically need to break up the building of the project into several compiles and one link.

```
$ avr-gcc -g -Os -mmcu=at90s2333 -c demo.c
```

The compilation will create a `demo.o` file. Next we link it into a binary called `demo.elf`.

```
$ avr-gcc -g -mmcu=at90s2333 -o demo.elf demo.o
```

It is important to specify the MCU type when linking. The compiler uses the `-mmcu` option to choose start-up files and run-time libraries that get linked together. If this option isn't specified, the compiler defaults to the 8515 processor environment, which is most certainly what you didn't want.

6.23.4 Examining the Object File

Now we have a binary file. Can we do anything useful with it (besides put it into the processor?) The GNU Binutils suite is made up of many useful tools for manipulating object files that get generated. One tool is `avr-objdump`, which takes information from the object file and displays it in many useful ways. Typing the command by itself will cause it to list out its options.

For instance, to get a feel of the application's size, the `-h` option can be used. The output of this option shows how much space is used in each of the sections (the .stab and .stabstr sections hold the debugging information and won't make it into the ROM file).

An even more useful option is `-S`. This option disassembles the binary file and intersperses the source code in the output! This method is much better, in my opinion, than using the `-S` with the compiler because this listing includes routines from the libraries and the vector table contents. Also, all the "fix-ups" have been satisfied. In other words, the listing generated by this option reflects the actual code that the processor will run.

```
$ avr-objdump -h -S demo.elf > demo.lst
```

Here's the output as saved in the `demo.lst` file:

```
demo.elf:     file format elf32-avr

Sections:
Idx Name          Size      VMA       LMA       File off  Algn
  0 .text         000000cc  00000000  00000000  00000094  2**0
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
  1 .data         00000000  00800060  000000cc  00000160  2**0
                  CONTENTS, ALLOC, LOAD, DATA
  2 .bss          00000003  00800060  00800060  00000160  2**0
                  ALLOC
  3 .noinit       00000000  00800063  00800063  00000160  2**0
                  CONTENTS
  4 .eeprom       00000000  00810000  00810000  00000160  2**0
                  CONTENTS
```

```
  5 .stab         000005d0  00000000  00000000  00000160  2**2
                  CONTENTS, READONLY, DEBUGGING
  6 .stabstr      000005c2  00000000  00000000  00000730  2**0
                  CONTENTS, READONLY, DEBUGGING
Disassembly of section .text:

00000000 <__vectors>:
   0: 0a c0       rjmp .+20      ; 0x16 <__ctors_end>
   2: 63 c0       rjmp .+198     ; 0xca <__bad_interrupt>
   4: 62 c0       rjmp .+196     ; 0xca <__bad_interrupt>
   6: 61 c0       rjmp .+194     ; 0xca <__bad_interrupt>
   8: 60 c0       rjmp .+192     ; 0xca <__bad_interrupt>
   a: 5f c0       rjmp .+190     ; 0xca <__bad_interrupt>
   c: 5e c0       rjmp .+188     ; 0xca <__bad_interrupt>
   e: 5d c0       rjmp .+186     ; 0xca <__bad_interrupt>
  10: 07 c0       rjmp .+14      ; 0x20 <__vector_8>
  12: 5b c0       rjmp .+182     ; 0xca <__bad_interrupt>
  14: 5a c0       rjmp .+180     ; 0xca <__bad_interrupt>

00000016 <__ctors_end>:
  16: 11 24       eor r1, r1
  18: 1f be       out 0x3f, r1 ; 63
  1a: cf ed       ldi r28, 0xDF ; 223
  1c: cd bf       out 0x3d, r28 ; 61
  1e: 4f c0       rjmp .+158     ; 0xbe <main>

00000020 <__vector_8>:
volatile uint16_t pwm; /* Note [1] */
volatile uint8_t direction;

SIGNAL (SIG_OVERFLOW1) /* Note [2] */
{
  20: 1f 92       push r1
  22: 0f 92       push r0
  24: 0f b6       in r0, 0x3f ; 63
  26: 0f 92       push r0
  28: 11 24       eor r1, r1
  2a: 2f 93       push r18
  2c: 8f 93       push r24
  2e: 9f 93       push r25
    switch (direction) /* Note [3] */
  30: 80 91 60 00  lds r24, 0x0060
  34: 99 27       eor r25, r25
  36: 00 97       sbiw r24, 0x00 ; 0
  38: 19 f0       breq .+6       ; 0x40 <__SREG__+0x1>
  3a: 01 97       sbiw r24, 0x01 ; 1
  3c: 31 f5       brne .+76      ; 0x8a <__SREG__+0x4b>
  3e: 14 c0       rjmp .+40      ; 0x68 <__SREG__+0x29>
    {
        case UP:
            if (++pwm == 1023)
  40: 80 91 61 00  lds r24, 0x0061
  44: 90 91 62 00  lds r25, 0x0062
  48: 01 96       adiw r24, 0x01 ; 1
  4a: 90 93 62 00  sts 0x0062, r25
  4e: 80 93 61 00  sts 0x0061, r24
  52: 80 91 61 00  lds r24, 0x0061
```

```
  56: 90 91 62 00  lds r25, 0x0062
  5a: 8f 5f        subi r24, 0xFF ; 255
  5c: 93 40        sbci r25, 0x03 ; 3
  5e: a9 f4        brne .+42      ; 0x8a <__SREG__+0x4b>
                direction = DOWN;
  60: 81 e0        ldi r24, 0x01 ; 1
  62: 80 93 60 00  sts 0x0060, r24
  66: 11 c0        rjmp .+34      ; 0x8a <__SREG__+0x4b>
            break;

        case DOWN:
            if (--pwm == 0)
  68: 80 91 61 00  lds r24, 0x0061
  6c: 90 91 62 00  lds r25, 0x0062
  70: 01 97        sbiw r24, 0x01 ; 1
  72: 90 93 62 00  sts 0x0062, r25
  76: 80 93 61 00  sts 0x0061, r24
  7a: 80 91 61 00  lds r24, 0x0061
  7e: 90 91 62 00  lds r25, 0x0062
  82: 89 2b        or r24, r25
  84: 11 f4        brne .+4       ; 0x8a <__SREG__+0x4b>
                direction = UP;
  86: 10 92 60 00  sts 0x0060, r1
            break;
    }

    OCR = pwm; /* Note [4] */
  8a: 80 91 61 00  lds r24, 0x0061
  8e: 90 91 62 00  lds r25, 0x0062
  92: 9b bd        out 0x2b, r25 ; 43
  94: 8a bd        out 0x2a, r24 ; 42
  96: 9f 91        pop r25
  98: 8f 91        pop r24
  9a: 2f 91        pop r18
  9c: 0f 90        pop r0
  9e: 0f be        out 0x3f, r0 ; 63
  a0: 0f 90        pop r0
  a2: 1f 90        pop r1
  a4: 18 95        reti

000000a6 <ioinit>:
}

void
ioinit (void) /* Note [5] */
{
    /* tmr1 is 10-bit PWM */
    TCCR1A = _BV (PWM10) | _BV (PWM11) | _BV (XCOM11);
  a6: 83 e8        ldi r24, 0x83 ; 131
  a8: 8f bd        out 0x2f, r24 ; 47

    /* tmr1 running on full MCU clock */
    TCCR1B = _BV (CS10);
  aa: 81 e0        ldi r24, 0x01 ; 1
  ac: 8e bd        out 0x2e, r24 ; 46

    /* set PWM value to 0 */
```

```
    OCR = 0;
  ae: 1b bc        out 0x2b, r1 ; 43
  b0: 1a bc        out 0x2a, r1 ; 42

    /* enable OC1 and PB2 as output */
    DDROC = _BV (OC1);
  b2: 82 e0        ldi r24, 0x02 ; 2
  b4: 87 bb        out 0x17, r24 ; 23

static __inline__ void timer_enable_int (unsigned char ints)
{
#ifdef TIMSK
    TIMSK = ints;
  b6: 84 e0        ldi r24, 0x04 ; 4
  b8: 89 bf        out 0x39, r24 ; 57

    timer_enable_int (_BV (TOIE1));

    /* enable interrupts */
    sei ();
  ba: 78 94        sei
  bc: 08 95        ret

000000be <main>:
}

int
main (void)
{
  be: cf ed        ldi r28, 0xDF ; 223
  c0: d0 e0        ldi r29, 0x00 ; 0
  c2: de bf        out 0x3e, r29 ; 62
  c4: cd bf        out 0x3d, r28 ; 61
    ioinit ();
  c6: ef df        rcall .-34      ; 0xa6 <ioinit>
  c8: ff cf        rjmp .-2       ; 0xc8 <main+0xa>

000000ca <__bad_interrupt>:
  ca: 9a cf        rjmp .-204     ; 0x0 <__heap_end>
```

6.23.5 Linker Map Files

`avr-objdump` is very useful, but sometimes it's necessary to see information about the link that can only be generated by the linker. A map file contains this information. A map file is useful for monitoring the sizes of your code and data. It also shows where modules are loaded and which modules were loaded from libraries. It is yet another view of your application. To get a map file, I usually add **-Wl,-Map,demo.map** to my link command. Relink the application using the following command to generate `demo.map` (a portion of which is shown below).

```
    $ avr-gcc -g -mmcu=at90s2313 -Wl,-Map,demo.map -o demo.elf demo.o
```

Some points of interest in the `demo.map` file are:

```
.rela.plt
 *(.rela.plt)

.text           0x00000000       0xcc
 *(.vectors)
 .vectors       0x00000000       0x16 ../../../build/crt1/crts2313.o
                0x00000000               __vectors
                0x00000000               __vector_default
                0x00000016               __ctors_start = .
```

The .text segment (where program instructions are stored) starts at location 0x0.

```
 *(.fini2)
 *(.fini1)
 *(.fini0)
                0x000000cc               _etext = .

.data           0x00800060        0x0 load address 0x000000cc
                0x00800060               PROVIDE (__data_start, .)
 *(.data)
 *(.gnu.linkonce.d*)
                0x00800060               . = ALIGN (0x2)
                0x00800060               _edata = .
                0x00800060               PROVIDE (__data_end, .)

.bss            0x00800060        0x3
                0x00800060               PROVIDE (__bss_start, .)
 *(.bss)
 *(COMMON)
 COMMON         0x00800060        0x3 demo.o
                0x00800060               direction
                0x00800061               pwm
                0x00800063               PROVIDE (__bss_end, .)
                0x000000cc               __data_load_start = LOADADDR (.data)
                0x000000cc               __data_load_end = (__data_load_start + SIZEOF (.data))

.noinit         0x00800063        0x0
                0x00800063               PROVIDE (__noinit_start, .)
 *(.noinit*)
                0x00800063               PROVIDE (__noinit_end, .)
                0x00800063               _end = .
                0x00800063               PROVIDE (__heap_start, .)

.eeprom         0x00810000        0x0
 *(.eeprom*)
                0x00810000               __eeprom_end = .
```

The last address in the .text segment is location `0xf2` (denoted by `_etext`), so the instructions use up 242 bytes of FLASH.

The .data segment (where initialized static variables are stored) starts at location `0x60`, which is the first address after the register bank on a 2313 processor.

The next available address in the .data segment is also location `0x60`, so the application has no initialized data.

The .bss segment (where uninitialized data is stored) starts at location `0x60`.

The next available address in the .bss segment is location 0x63, so the application uses 3 bytes of uninitialized data.

The .eeprom segment (where EEPROM variables are stored) starts at location 0x0.

The next available address in the .eeprom segment is also location 0x0, so there aren't any EEPROM variables.

6.23.6 Intel Hex Files

We have a binary of the application, but how do we get it into the processor? Most (if not all) programmers will not accept a GNU executable as an input file, so we need to do a little more processing. The next step is to extract portions of the binary and save the information into .hex files. The GNU utility that does this is called `avr-objcopy`.

The ROM contents can be pulled from our project's binary and put into the file demo.hex using the following command:

```
$ avr-objcopy -j .text -j .data -O ihex demo.elf demo.hex
```

The resulting `demo.hex` file contains:

```
:100000000AC063C062C061C060C05FC05EC05DC046
:1000100007C05BC05AC011241FBECFEDCDBF4FC07B
:100020001F920F920FB60F9211242F938F939F93CD
:10003000809160009927009719F0019731F514C05D
:10004000809161009091620001969093620080938C
:1000500061008091610090916200 8F5F9340A9F4EC
:1000600081E08093600011C08091610090916200F6
:100070000197909362008093610080916100909115C
:10008000620089 2B11F41092600080916100 9091C0
:100090006200 9BBD8ABD9F918F912F910F900FBEE3
:1000A0000F901F90189583E88FBD81E08EBD1BBC1B
:1000B0001ABC82E087BB84E089BF78940895CFEDB5
:0C00C000D0E0DEBFCDBFEFDFFFCF9ACF56
:00000001FF
```

The `-j` option indicates that we want the information from the .text and .data segment extracted. If we specify the EEPROM segment, we can generate a .hex file that can be used to program the EEPROM:

```
$ avr-objcopy -j .eeprom --change-section-lma .eeprom=0 -O ihex demo.elf demo_eeprom.hex
```

The resulting demo_eeprom.hex file contains:

```
:00000001FF
```

which is an empty .hex file (which is expected, since we didn't define any EEPROM variables).

6.23.7 Make Build the Project

Rather than type these commands over and over, they can all be placed in a make file. To build the demo project using make, save the following in a file called Makefile.

Note:

This Makefile can only be used as input for the GNU version of make.

```
PRG            = demo
OBJ            = demo.o
MCU_TARGET     = atmega8
OPTIMIZE       = -O2

DEFS           =
LIBS           =

# You should not have to change anything below here.

CC             = avr-gcc

# Override is only needed by avr-lib build system.

override CFLAGS        = -g -Wall $(OPTIMIZE) -mmcu=$(MCU_TARGET) $(DEFS)
override LDFLAGS       = -Wl,-Map,$(PRG).map

OBJCOPY        = avr-objcopy
OBJDUMP        = avr-objdump

all: $(PRG).elf lst text eeprom

$(PRG).elf: $(OBJ)
	$(CC) $(CFLAGS) $(LDFLAGS) -o $@ $^ $(LIBS)

clean:
	rm -rf *.o $(PRG).elf *.eps *.png *.pdf *.bak
	rm -rf *.lst *.map $(EXTRA_CLEAN_FILES)

lst:  $(PRG).lst

%.lst: %.elf
	$(OBJDUMP) -h -S $< > $@

# Rules for building the .text rom images
```

```
text: hex bin srec

hex:  $(PRG).hex
bin:  $(PRG).bin
srec: $(PRG).srec

%.hex: %.elf
	$(OBJCOPY) -j .text -j .data -O ihex $< $@

%.srec: %.elf
	$(OBJCOPY) -j .text -j .data -O srec $< $@

%.bin: %.elf
	$(OBJCOPY) -j .text -j .data -O binary $< $@

# Rules for building the .eeprom rom images

eeprom: ehex ebin esrec

ehex:  $(PRG)_eeprom.hex
ebin:  $(PRG)_eeprom.bin
esrec: $(PRG)_eeprom.srec

%_eeprom.hex: %.elf
	$(OBJCOPY) -j .eeprom --change-section-lma .eeprom=0 -O ihex $< $@

%_eeprom.srec: %.elf
	$(OBJCOPY) -j .eeprom --change-section-lma .eeprom=0 -O srec $< $@

%_eeprom.bin: %.elf
	$(OBJCOPY) -j .eeprom --change-section-lma .eeprom=0 -O binary $< $@

# Every thing below here is used by avr-libc's build system and can be ignored
# by the casual user.

FIG2DEV                 = fig2dev
EXTRA_CLEAN_FILES       = *.hex *.bin *.srec

dox: eps png pdf

eps: $(PRG).eps
png: $(PRG).png
pdf: $(PRG).pdf

%.eps: %.fig
	$(FIG2DEV) -L eps $< $@

%.pdf: %.fig
	$(FIG2DEV) -L pdf $< $@

%.png: %.fig
	$(FIG2DEV) -L png $< $@
```

6.24 Example using the two-wire interface (TWI)

Some newer devices of the ATmega series contain builtin support for interfacing the microcontroller to a two-wire bus, called TWI. This is essentially the same called I2C by Philips, but that term is avoided in Atmel's documentation due to patenting issues.

For the original Philips documentation, see

`http://www.semiconductors.philips.com/buses/i2c/index.html`

6.24.1 Introduction into TWI

The two-wire interface consists of two signal lines named *SDA* (serial data) and *SCL* (serial clock) (plus a ground line, of course). All devices participating in the bus are connected together, using open-drain driver circuitry, so the wires must be terminated using appropriate pullup resistors. The pullups must be small enough to recharge the line capacity in short enough time compared to the desired maximal clock frequency, yet large enough so all drivers will not be overloaded. There are formulas in the datasheet that help selecting the pullups.

Devices can either act as a master to the bus (i. e., they initiate a transfer), or as a slave (they only act when being called by a master). The bus is multi-master capable, and a particular device implementation can act as either master or slave at different times. Devices are addressed using a 7-bit address (coordinated by Philips) transfered as the first byte after the so-called start condition. The LSB of that byte is R/∼W, i. e. it determines whether the request to the slave is to read or write data during the next cycles. (There is also an option to have devices using 10-bit addresses but that is not covered by this example.)

6.24.2 The TWI example project

The ATmega TWI hardware supports both, master and slave operation. This example will only demonstrate how to use an AVR microcontroller as TWI master. The implementation is kept simple in order to concentrate on the steps that are required to talk to a TWI slave, so all processing is done in polled-mode, waiting for the TWI interface to indicate that the next processing step is due (by setting the TWINT interrupt bit). If it is desired to have the entire TWI communication happen in "background", all this can be implemented in an interrupt-controlled way, where only the start condition needs to be triggered from outside the interrupt routine.

There is a variety of slave devices available that can be connected to a TWI bus. For the purpose of this example, an EEPROM device out of the industry-standard **24C*xx*** series has been chosen (where *xx* can be one of **01**, **02**, **04**, **08**, or **16**) which are available from various vendors. The choice was almost arbitrary, mainly triggered by the fact that an EEPROM device is being talked to in both directions, reading and writing the slave device, so the example will demonstrate the details of both.

Usually, there is probably not much need to add more EEPROM to an ATmega system that way: the smallest possible AVR device that offers hardware TWI support is the ATmega8 which comes with 512 bytes of EEPROM, which is equivalent to an 24C04 device. The ATmega128 already comes with twice as much EEPROM as the 24C16 would offer. One exception might be to use an externally connected EEPROM device that is removable; e. g. SDRAM PC memory comes with an integrated TWI EEPROM that carries the RAM configuration information.

6.24.3 The Source Code

```
/*
 * ----------------------------------------------------------------------------
 * "THE BEER-WARE LICENSE" (Revision 42):
 * <joerg@FreeBSD.ORG> wrote this file.  As long as you retain this notice you
 * can do whatever you want with this stuff. If we meet some day, and you think
 * this stuff is worth it, you can buy me a beer in return.        Joerg Wunsch
 * ----------------------------------------------------------------------------
 */

/* $Id: twitest.c,v 1.2.2.2 2005/02/07 22:47:46 arcanum Exp $ */

/*
 * Simple demo program that talks to a 24Cxx IšC EEPROM using the
 * builtin TWI interface of an ATmega device.
 */

#include <inttypes.h>
#include <stdio.h>
#include <stdlib.h>

#include <avr/io.h>
#include <compat/twi.h>         /* Note [1] */

#define DEBUG 1

/*
 * System clock in Hz.
 */
#define F_CPU 14745600UL        /* Note [2] */

/*
 * Compatibility defines.  This should work on ATmega8, ATmega16,
 * ATmega163, ATmega323 and ATmega128 (IOW: on all devices that
 * provide a builtin TWI interface).
 *
 * On the 128, it defaults to USART 1.
 */
#ifndef UCSRB
# ifdef UCSR1A          /* ATmega128 */
```

```
#  define UCSRA UCSR1A
#  define UCSRB UCSR1B
#  define UBRR UBRR1L
#  define UDR UDR1
# else /* ATmega8 */
#  define UCSRA USR
#  define UCSRB UCR
# endif
#endif
#ifndef UBRR
#  define UBRR UBRRL
#endif

/*
 * Note [3]
 * TWI address for 24Cxx EEPROM:
 *
 * 1 0 1 0 E2 E1 E0 R/~W        24C01/24C02
 * 1 0 1 0 E2 E1 A8 R/~W        24C04
 * 1 0 1 0 E2 A9 A8 R/~W        24C08
 * 1 0 1 0 A10 A9 A8 R/~W       24C16
 */
#define TWI_SLA_24CXX   0xa0    /* E2 E1 E0 = 0 0 0 */

/*
 * Maximal number of iterations to wait for a device to respond for a
 * selection.  Should be large enough to allow for a pending write to
 * complete, but low enough to properly abort an infinite loop in case
 * a slave is broken or not present at all.  With 100 kHz TWI clock,
 * transfering the start condition and SLA+R/W packet takes about 10
 * ţs.  The longest write period is supposed to not exceed ~ 10 ms.
 * Thus, normal operation should not require more than 100 iterations
 * to get the device to respond to a selection.
 */
#define MAX_ITER        200

/*
 * Number of bytes that can be written in a row, see comments for
 * ee24xx_write_page() below.  Some vendor's devices would accept 16,
 * but 8 seems to be the lowest common denominator.
 *
 * Note that the page size must be a power of two, this simplifies the
 * page boundary calculations below.
 */
#define PAGE_SIZE 8

/*
 * Saved TWI status register, for error messages only.  We need to
 * save it in a variable, since the datasheet only guarantees the TWSR
 * register to have valid contents while the TWINT bit in TWCR is set.
 */
uint8_t twst;

/*
 * Do all the startup-time peripheral initializations: UART (for our
 * debug/test output), and TWI clock.
 */
```

```
void
ioinit(void)
{

#if F_CPU <= 1000000UL
  /*
   * Note [4]
   * Slow system clock, double Baud rate to improve rate error.
   */
  UCSRA = _BV(U2X);
  UBRR = (F_CPU / (8 * 9600UL)) - 1; /* 9600 Bd */
#else
  UBRR = (F_CPU / (16 * 9600UL)) - 1; /* 9600 Bd */
#endif
  UCSRB = _BV(TXEN);            /* tx enable */

  /* initialize TWI clock: 100 kHz clock, TWPS = 0 => prescaler = 1 */
#if defined(TWPS0)
  /* has prescaler (mega128 & newer) */
  TWSR = 0;
#endif

#if F_CPU < 3600000UL
  TWBR = 10;                    /* smallest TWBR value, see note [5] */
#else
  TWBR = (F_CPU / 100000UL - 16) / 2;
#endif
}

/*
 * Note [6]
 * Send character c down the UART Tx, wait until tx holding register
 * is empty.
 */
int
uart_putchar(char c)
{

  if (c == '\n')
    uart_putchar('\r');
  loop_until_bit_is_set(UCSRA, UDRE);
  UDR = c;
  return 0;
}

/*
 * Note [7]
 *
 * Read "len" bytes from EEPROM starting at "eeaddr" into "buf".
 *
 * This requires two bus cycles: during the first cycle, the device
 * will be selected (master transmitter mode), and the address
 * transfered.  Address bits exceeding 256 are transfered in the
 * E2/E1/E0 bits (subaddress bits) of the device selector.
 *
 * The second bus cycle will reselect the device (repeated start
 * condition, going into master receiver mode), and transfer the data
```

```
 * from the device to the TWI master.  Multiple bytes can be
 * transfered by ACKing the client's transfer.  The last transfer will
 * be NACKed, which the client will take as an indication to not
 * initiate further transfers.
 */
int
ee24xx_read_bytes(uint16_t eeaddr, int len, uint8_t *buf)
{
  uint8_t sla, twcr, n = 0;
  int rv = 0;

  /* patch high bits of EEPROM address into SLA */
  sla = TWI_SLA_24CXX | (((eeaddr >> 8) & 0x07) << 1);

  /*
   * Note [8]
   * First cycle: master transmitter mode
   */
  restart:
  if (n++ >= MAX_ITER)
    return -1;
  begin:

  TWCR = _BV(TWINT) | _BV(TWSTA) | _BV(TWEN); /* send start condition */
  while ((TWCR & _BV(TWINT)) == 0) ; /* wait for transmission */
  switch ((twst = TW_STATUS))
    {
    case TW_REP_START:          /* OK, but should not happen */
    case TW_START:
      break;

    case TW_MT_ARB_LOST:        /* Note [9] */
      goto begin;

    default:
      return -1;                /* error: not in start condition */
                                /* NB: do /not/ send stop condition */
    }

  /* Note [10] */
  /* send SLA+W */
  TWDR = sla | TW_WRITE;
  TWCR = _BV(TWINT) | _BV(TWEN); /* clear interrupt to start transmission */
  while ((TWCR & _BV(TWINT)) == 0) ; /* wait for transmission */
  switch ((twst = TW_STATUS))
    {
    case TW_MT_SLA_ACK:
      break;

    case TW_MT_SLA_NACK:        /* nack during select: device busy writing */
                                /* Note [11] */
      goto restart;

    case TW_MT_ARB_LOST:        /* re-arbitrate */
      goto begin;

    default:
```

```
      goto error;               /* must send stop condition */
    }

  TWDR = eeaddr;                /* low 8 bits of addr */
  TWCR = _BV(TWINT) | _BV(TWEN); /* clear interrupt to start transmission */
  while ((TWCR & _BV(TWINT)) == 0) ; /* wait for transmission */
  switch ((twst = TW_STATUS))
    {
    case TW_MT_DATA_ACK:
      break;

    case TW_MT_DATA_NACK:
      goto quit;

    case TW_MT_ARB_LOST:
      goto begin;

    default:
      goto error;               /* must send stop condition */
    }

  /*
   * Note [12]
   * Next cycle(s): master receiver mode
   */
  TWCR = _BV(TWINT) | _BV(TWSTA) | _BV(TWEN); /* send (rep.) start condition */
  while ((TWCR & _BV(TWINT)) == 0) ; /* wait for transmission */
  switch ((twst = TW_STATUS))
    {
    case TW_START:              /* OK, but should not happen */
    case TW_REP_START:
      break;

    case TW_MT_ARB_LOST:
      goto begin;

    default:
      goto error;
    }

  /* send SLA+R */
  TWDR = sla | TW_READ;
  TWCR = _BV(TWINT) | _BV(TWEN); /* clear interrupt to start transmission */
  while ((TWCR & _BV(TWINT)) == 0) ; /* wait for transmission */
  switch ((twst = TW_STATUS))
    {
    case TW_MR_SLA_ACK:
      break;

    case TW_MR_SLA_NACK:
      goto quit;

    case TW_MR_ARB_LOST:
      goto begin;

    default:
      goto error;
```

```
    }

  for (twcr = _BV(TWINT) | _BV(TWEN) | _BV(TWEA) /* Note [13] */;
       len > 0;
       len--)
    {
      if (len == 1)
        twcr = _BV(TWINT) | _BV(TWEN); /* send NAK this time */
      TWCR = twcr;              /* clear int to start transmission */
      while ((TWCR & _BV(TWINT)) == 0) ; /* wait for transmission */
      switch ((twst = TW_STATUS))
        {
        case TW_MR_DATA_NACK:
          len = 0;              /* force end of loop */
          /* FALLTHROUGH */
        case TW_MR_DATA_ACK:
          *buf++ = TWDR;
          rv++;
          break;

        default:
          goto error;
        }
    }
  quit:
  /* Note [14] */
  TWCR = _BV(TWINT) | _BV(TWSTO) | _BV(TWEN); /* send stop condition */

  return rv;

  error:
  rv = -1;
  goto quit;
}

/*
 * Write "len" bytes into EEPROM starting at "eeaddr" from "buf".
 *
 * This is a bit simpler than the previous function since both, the
 * address and the data bytes will be transfered in master transmitter
 * mode, thus no reselection of the device is necessary.  However, the
 * EEPROMs are only capable of writing one "page" simultaneously, so
 * care must be taken to not cross a page boundary within one write
 * cycle.  The amount of data one page consists of varies from
 * manufacturer to manufacturer: some vendors only use 8-byte pages
 * for the smaller devices, and 16-byte pages for the larger devices,
 * while other vendors generally use 16-byte pages.  We thus use the
 * smallest common denominator of 8 bytes per page, declared by the
 * macro PAGE_SIZE above.
 *
 * The function simply returns after writing one page, returning the
 * actual number of data byte written.  It is up to the caller to
 * re-invoke it in order to write further data.
 */
int
ee24xx_write_page(uint16_t eeaddr, int len, uint8_t *buf)
{
```

```
uint8_t sla, n = 0;
int rv = 0;
uint16_t endaddr;

if (eeaddr + len < (eeaddr | (PAGE_SIZE - 1)))
  endaddr = eeaddr + len;
else
  endaddr = (eeaddr | (PAGE_SIZE - 1)) + 1;
len = endaddr - eeaddr;

/* patch high bits of EEPROM address into SLA */
sla = TWI_SLA_24CXX | (((eeaddr >> 8) & 0x07) << 1);

restart:
if (n++ >= MAX_ITER)
  return -1;
begin:

/* Note [15] */
TWCR = _BV(TWINT) | _BV(TWSTA) | _BV(TWEN); /* send start condition */
while ((TWCR & _BV(TWINT)) == 0) ; /* wait for transmission */
switch ((twst = TW_STATUS))
  {
  case TW_REP_START:          /* OK, but should not happen */
  case TW_START:
    break;

  case TW_MT_ARB_LOST:
    goto begin;

  default:
    return -1;                /* error: not in start condition */
                              /* NB: do /not/ send stop condition */
  }

/* send SLA+W */
TWDR = sla | TW_WRITE;
TWCR = _BV(TWINT) | _BV(TWEN); /* clear interrupt to start transmission */
while ((TWCR & _BV(TWINT)) == 0) ; /* wait for transmission */
switch ((twst = TW_STATUS))
  {
  case TW_MT_SLA_ACK:
    break;

  case TW_MT_SLA_NACK:        /* nack during select: device busy writing */
    goto restart;

  case TW_MT_ARB_LOST:        /* re-arbitrate */
    goto begin;

  default:
    goto error;               /* must send stop condition */
  }

TWDR = eeaddr;                /* low 8 bits of addr */
TWCR = _BV(TWINT) | _BV(TWEN); /* clear interrupt to start transmission */
while ((TWCR & _BV(TWINT)) == 0) ; /* wait for transmission */
```

```
  switch ((twst = TW_STATUS))
    {
    case TW_MT_DATA_ACK:
      break;

    case TW_MT_DATA_NACK:
      goto quit;

    case TW_MT_ARB_LOST:
      goto begin;

    default:
      goto error;               /* must send stop condition */
    }

  for (; len > 0; len--)
    {
      TWDR = *buf++;
      TWCR = _BV(TWINT) | _BV(TWEN); /* start transmission */
      while ((TWCR & _BV(TWINT)) == 0) ; /* wait for transmission */
      switch ((twst = TW_STATUS))
        {
        case TW_MT_DATA_NACK:
          goto error;           /* device write protected -- Note [16] */

        case TW_MT_DATA_ACK:
          rv++;
          break;

        default:
          goto error;
        }
    }
  quit:
  TWCR = _BV(TWINT) | _BV(TWSTO) | _BV(TWEN); /* send stop condition */

  return rv;

  error:
  rv = -1;
  goto quit;
}

/*
 * Wrapper around ee24xx_write_page() that repeats calling this
 * function until either an error has been returned, or all bytes
 * have been written.
 */
int
ee24xx_write_bytes(uint16_t eeaddr, int len, uint8_t *buf)
{
  int rv, total;

  total = 0;
  do
    {
#if DEBUG
```

```
      printf("Calling ee24xx_write_page(%d, %d, %p)",
             eeaddr, len, buf);
#endif
      rv = ee24xx_write_page(eeaddr, len, buf);
#if DEBUG
      printf(" => %d\n", rv);
#endif
      if (rv == -1)
        return -1;
      eeaddr += rv;
      len -= rv;
      buf += rv;
      total += rv;
    }
  while (len > 0);

  return total;
}

void
error(void)
{

  printf("error: TWI status %#x\n", twst);
  exit(0);
}

void
main(void)
{
  uint16_t a;
  int rv;
  uint8_t b[16];
  uint8_t x;

  ioinit();

  fdevopen(uart_putchar, NULL, 0);

  for (a = 0; a < 256;)
    {
      printf("%#04x: ", a);
      rv = ee24xx_read_bytes(a, 16, b);
      if (rv <= 0)
        error();
      if (rv < 16)
        printf("warning: short read %d\n", rv);
      a += rv;
      for (x = 0; x < rv; x++)
        printf("%02x ", b[x]);
      putchar('\n');
    }
#define EE_WRITE(addr, str) ee24xx_write_bytes(addr, sizeof(str)-1, str)
  rv = EE_WRITE(55, "The quick brown fox jumps over the lazy dog.");
  if (rv < 0)
    error();
  printf("Wrote %d bytes.\n", rv);
```

```
  for (a = 0; a < 256;)
    {
      printf("%#04x: ", a);
      rv = ee24xx_read_bytes(a, 16, b);
      if (rv <= 0)
        error();
      if (rv < 16)
        printf("warning: short read %d\n", rv);
      a += rv;
      for (x = 0; x < rv; x++)
        printf("%02x ", b[x]);
      putchar('\n');
    }

  printf("done.\n");

}
```

Note [1]

The header file <compat/twi.h> contains some macro definitions for symbolic constants used in the TWI status register. These definitions match the names used in the Atmel datasheet except that all names have been prefixed with `TW_`.

Note [2]

The clock is used in timer calculations done by the compiler, for the UART baud rate and the TWI clock rate.

Note [3]

The address assigned for the 24Cxx EEPROM consists of 1010 in the upper four bits. The following three bits are normally available as slave sub-addresses, allowing to operate more than one device of the same type on a single bus, where the actual subaddress used for each device is configured by hardware strapping. However, since the next data packet following the device selection only allows for 8 bits that are used as an EEPROM address, devices that require more than 8 address bits (24C04 and above) "steal" subaddress bits and use them for the EEPROM cell address bits 9 to 11 as required. This example simply assumes all subaddress bits are 0 for the smaller devices, so the E0, E1, and E2 inputs of the 24Cxx must be grounded.

Note [4]

For slow clocks, enable the 2 x U[S]ART clock multiplier, to improve the baud rate error. This will allow a 9600 Bd communication using the standard 1 MHz calibrated RC oscillator. See also the Baud rate tables in the datasheets.

Note [5]

The datasheet explains why a minimum TWBR value of 10 should be maintained when running in master mode. Thus, for system clocks below 3.6 MHz, we cannot run the bus at the intented clock rate of 100 kHz but have to slow down accordingly.

Note [6]

This function is used by the standard output facilities that are utilized in this example for debugging and demonstration purposes.

Note [7]

In order to shorten the data to be sent over the TWI bus, the 24Cxx EEPROMs support multiple data bytes transfered within a single request, maintaining an internal address counter that is updated after each data byte transfered successfully. When reading data, one request can read the entire device memory if desired (the counter would wrap around and start back from 0 when reaching the end of the device).

Note [8]

When reading the EEPROM, a first device selection must be made with write intent (R/∼W bit set to 0 indicating a write operation) in order to transfer the EEPROM address to start reading from. This is called *master transmitter mode*. Each completion of a particular step in TWI communication is indicated by an asserted TWINT bit in TWCR. (An interrupt would be generated if allowed.) After performing any actions that are needed for the next communication step, the interrupt condition must be manually cleared by *setting* the TWINT bit. Unlike with many other interrupt sources, this would even be required when using a true interrupt routine, since as soon as TWINT is re-asserted, the next bus transaction will start.

Note [9]

Since the TWI bus is multi-master capable, there is potential for a bus contention when one master starts to access the bus. Normally, the TWI bus interface unit will detect this situation, and will not initiate a start condition while the bus is busy. However, in case two masters were starting at exactly the same time, the way bus arbitration works, there is always a chance that one master could lose arbitration of the bus during any transmit operation. A master that has lost arbitration is required by the protocol to immediately cease talking on the bus; in particular it must not initiate a stop condition in order to not corrupt the ongoing transfer from the active master. In this example, upon detecting a lost arbitration condition, the entire transfer is going to be restarted. This will cause a new start condition to be initiated, which will normally be delayed until the currently active master has released the bus.

Note [10]

Next, the device slave is going to be reselected (using a so-called repeated start condition which is meant to guarantee that the bus arbitration will remain at the current master) using the same slave address (SLA), but this time with read intent (R/~W bit set to 1) in order to request the device slave to start transfering data from the slave to the master in the next packet.

Note [11]

If the EEPROM device is still busy writing one or more cells after a previous write request, it will simply leave its bus interface drivers at high impedance, and does not respond to a selection in any way at all. The master selecting the device will see the high level at SDA after transfering the SLA+R/W packet as a NACK to its selection request. Thus, the select process is simply started over (effectively causing a *repeated start condition*), until the device will eventually respond. This polling procedure is recommended in the 24Cxx datasheet in order to minimize the busy wait time when writing. Note that in case a device is broken and never responds to a selection (e. g. since it is no longer present at all), this will cause an infinite loop. Thus the maximal number of iterations made until the device is declared to be not responding at all, and an error is returned, will be limited to MAX_ITER.

Note [12]

This is called *master receiver mode*: the bus master still supplies the SCL clock, but the device slave drives the SDA line with the appropriate data. After 8 data bits, the master responds with an ACK bit (SDA driven low) in order to request another data transfer from the slave, or it can leave the SDA line high (NACK), indicating to the slave that it is going to stop the transfer now. Assertion of ACK is handled by setting the TWEA bit in TWCR when starting the current transfer.

Note [13]

The control word sent out in order to initiate the transfer of the next data packet is initially set up to assert the TWEA bit. During the last loop iteration, TWEA is de-asserted so the client will get informed that no further transfer is desired.

Note [14]

Except in the case of lost arbitration, all bus transactions must properly be terminated by the master initiating a stop condition.

Note [15]

Writing to the EEPROM device is simpler than reading, since only a master transmitter mode transfer is needed. Note that the first packet after the SLA+W selection is always considered to be the EEPROM address for the next operation. (This packet is exactly the same as the one above sent before starting to read the device.) In case a master transmitter mode transfer is going to send more than one data packet, all following packets will be considered data bytes to write at the indicated address. The internal address pointer will be incremented after each write operation.

Note [16]

24Cxx devices can become write-protected by strapping their ~WC pin to logic high. (Leaving it unconnected is explicitly allowed, and constitutes logic low level, i. e. no write protection.) In case of a write protected device, all data transfer attempts will be NACKed by the device. Note that some devices might not implement this.

7 avr-libc Directory Documentation

7.1 /junk/AVR/avr-libc-1.2/include/avr/ Directory Reference

Files

- file **boot.h**
- file **crc16.h**
- file **delay.h**
- file **eeprom.h**
- file **interrupt.h**
- file **io.h**
- file **io1200.h**
- file **io2313.h**
- file **io2323.h**
- file **io2333.h**
- file **io2343.h**
- file **io43u32x.h**
- file **io43u35x.h**
- file **io4414.h**
- file **io4433.h**
- file **io4434.h**
- file **io76c711.h**
- file **io8515.h**
- file **io8534.h**
- file **io8535.h**
- file **io86r401.h**
- file **ioat94k.h**
- file **iocan128.h**
- file **iom103.h**
- file **iom128.h**
- file **iom16.h**
- file **iom161.h**
- file **iom162.h**
- file **iom163.h**
- file **iom165.h**
- file **iom168.h**
- file **iom169.h**
- file **iom32.h**
- file **iom323.h**
- file **iom325.h**
- file **iom3250.h**

- file **iom48.h**
- file **iom64.h**
- file **iom645.h**
- file **iom6450.h**
- file **iom8.h**
- file **iom8515.h**
- file **iom8535.h**
- file **iom88.h**
- file **iomx8.h**
- file **iotn11.h**
- file **iotn12.h**
- file **iotn13.h**
- file **iotn15.h**
- file **iotn22.h**
- file **iotn2313.h**
- file **iotn26.h**
- file **iotn28.h**
- file **parity.h**
- file **pgmspace.h**
- file **portpins.h**
- file **sfr_defs.h**
- file **signal.h**
- file **sleep.h**
- file **wdt.h**

7.2 /junk/AVR/avr-libc-1.2/include/compat/ Directory Reference

Files

- file **ina90.h**
- file **twi.h**

7.3 /junk/AVR/avr-libc-1.2/doc/examples/demo/ Directory Reference

Files

- file **demo.c**

7.4 /junk/AVR/avr-libc-1.2/doc/ Directory Reference

Directories

- directory **examples**

7.5 /junk/AVR/avr-libc-1.2/doc/examples/ Directory Reference

Directories

- directory **demo**
- directory **twitest**

Files

- file **avr-recv.c**
- file **io.c**
- file **printf.h**
- file **progmem.c**
- file **signal.c**

7.6 /junk/AVR/avr-libc-1.2/libm/fplib/ Directory Reference

Files

- file **acos.S**
- file **addsf3.S**
- file **addsf3x.S**
- file **asin.S**
- file **atan.S**
- file **atan2.S**
- file **ceil.S**
- file **cos.S**
- file **cosh.S**
- file **divsf3.S**
- file **divsf3x.S**
- file **dtostre.S**
- file **dtostrf.S**
- file **exp.S**
- file **fixsfsi.S**

- file **floatsisf.S**
- file **floor.S**
- file **fmod.S**
- file **fp_cmp.S**
- file **fp_cosinus.S**
- file **fp_flashconst.S**
- file **fp_merge.S**
- file **fp_nan.S**
- file **fp_powerseries.S**
- file **fp_split.S**
- file **fp_zero.S**
- file **frexp.S**
- file **isinfnan.S**
- file **ldexp.S**
- file **log.S**
- file **log10.S**
- file **modf.S**
- file **mulsf3.S**
- file **mulsf3x.S**
- file **negsf2.S**
- file **pow.S**
- file **sin.S**
- file **sinh.S**
- file **sqrt.S**
- file **strtod.S**
- file **tan.S**
- file **tanh.S**

7.7 /junk/AVR/avr-libc-1.2/include/ Directory Reference

Directories

- directory **avr**
- directory **compat**

Files

- file **ctype.h**
- file **errno.h**
- file **inttypes.h**
- file **math.h**

- file **setjmp.h**
- file **stdint.h**
- file **stdio.h**
- file **stdlib.h**
- file **string.h**

7.8 /junk/AVR/avr-libc-1.2/libc/ Directory Reference

Directories

- directory **misc**
- directory **pmstring**
- directory **stdio**
- directory **stdlib**
- directory **string**

7.9 /junk/AVR/avr-libc-1.2/libm/ Directory Reference

Directories

- directory **fplib**

7.10 /junk/AVR/avr-libc-1.2/libc/misc/ Directory Reference

Files

- file **ee_rb.S**
- file **ee_rblk.S**
- file **ee_rw.S**
- file **ee_wb.S**
- file **ee_wblk.S**
- file **ee_ww.S**
- file **eeprom.S**
- file **itoa.S**
- file **ltoa.S**
- file **mul10.S**
- file **mulsi10.S**
- file **ultoa.S**
- file **utoa.S**

7.11 /junk/AVR/avr-libc-1.2/libc/pmstring/ Directory Reference

Files

- file **memcpy_P.S**
- file **strcasecmp_P.S**
- file **strcat_P.S**
- file **strcmp_P.S**
- file **strcpy_P.S**
- file **strlcat_P.S**
- file **strlcpy_P.S**
- file **strlen_P.S**
- file **strncasecmp_P.S**
- file **strncat_P.S**
- file **strncmp_P.S**
- file **strncpy_P.S**
- file **strnlen_P.S**

7.12 /junk/AVR/avr-libc-1.2/libc/stdio/ Directory Reference

Files

- file **clearerr.c**
- file **fclose.c**
- file **fdevopen.c**
- file **feof.c**
- file **ferror.c**
- file **fgetc.c**
- file **fgets.c**
- file **fprintf.c**
- file **fprintf_p.c**
- file **fputc.c**
- file **fputs.c**
- file **fputs_p.c**
- file **fread.c**
- file **fscanf.c**
- file **fscanf_p.c**
- file **fwrite.c**
- file **getc.S**
- file **getchar.c**
- file **gets.c**

- file **printf.c**
- file **printf_p.c**
- file **putc.S**
- file **putchar.c**
- file **puts.c**
- file **puts_p.c**
- file **scanf.c**
- file **scanf_p.c**
- file **snprintf.c**
- file **snprintf_p.c**
- file **sprintf.c**
- file **sprintf_p.c**
- file **sscanf.c**
- file **sscanf_p.c**
- file **stdio_private.h**
- file **ungetc.c**
- file **vfprintf.c**
- file **vfprintf_p.c**
- file **vfscanf.c**
- file **vfscanf_p.c**
- file **vsnprintf.c**
- file **vsnprintf_p.c**
- file **vsprintf.c**
- file **vsprintf_p.c**

7.13 /junk/AVR/avr-libc-1.2/libc/stdlib/ Directory Reference

Files

- file **abort.c**
- file **abort.S**
- file **abs.c**
- file **atoi.c**
- file **atoi.S**
- file **atol.c**
- file **atol.S**
- file **bsearch.c**
- file **calloc.c**
- file **ctype.S**
- file **div.S**
- file **errno.c**

- file **exit.S**
- file **labs.c**
- file **ldiv.S**
- file **malloc.c**
- file **qsort.c**
- file **rand.c**
- file **random.c**
- file **realloc.c**
- file **setjmp.S**
- file **stdlib_private.h**
- file **strtol.c**
- file **strtoul.c**

7.14 /junk/AVR/avr-libc-1.2/libc/string/ Directory Reference

Files

- file **memccpy.S**
- file **memchr.S**
- file **memcmp.S**
- file **memcpy.S**
- file **memmove.S**
- file **memset.S**
- file **strcasecmp.S**
- file **strcat.S**
- file **strchr.S**
- file **strcmp.S**
- file **strcpy.S**
- file **strlcat.c**
- file **strlcat.S**
- file **strlcpy.c**
- file **strlcpy.S**
- file **strlen.S**
- file **strlwr.S**
- file **strncasecmp.S**
- file **strncat.S**
- file **strncmp.S**
- file **strncpy.S**
- file **strnlen.S**
- file **strrchr.S**
- file **strrev.S**

- file **strsep.S**
- file **strstr.S**
- file **strtok_r.S**
- file **strupr.S**

7.15 /junk/AVR/avr-libc-1.2/doc/examples/twitest/ Directory Reference

Files

- file **twitest.c**

8 avr-libc Data Structure Documentation

8.1 div_t Struct Reference

8.1.1 Detailed Description

Result type for function **div()**(p. 63).

Data Fields

- int **quot**
- int **rem**

8.1.2 Field Documentation

8.1.2.1 int div_t::quot

The Quotient.

8.1.2.2 int div_t::rem

The Remainder.

The documentation for this struct was generated from the following file:

- stdlib.h

8.2 ldiv_t Struct Reference

8.2.1 Detailed Description

Result type for function **ldiv()**(p. 65).

Data Fields

- long **quot**
- long **rem**

8.2.2 Field Documentation

8.2.2.1 long ldiv_t::quot

The Quotient.

8.2.2.2 long ldiv_t::rem

The Remainder.

The documentation for this struct was generated from the following file:

- stdlib.h

9 avr-libc Page Documentation

9.1 Acknowledgments

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- The GCC Team, which produced a very capable set of development tools for an amazing number of platforms and processors.
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- And lastly, all the users who use the software. If nobody used the software, we would probably not be very motivated to continue to develop it. Keep those bug reports coming. ;-)

9.2 avr-libc and assembler programs

9.2.1 Introduction

There might be several reasons to write code for AVR microcontrollers using plain assembler source code. Among them are:

- Code for devices that do not have RAM and are thus not supported by the C compiler.
- Code for very time-critical applications.
- Special tweaks that cannot be done in C.

Usually, all but the first could probably be done easily using the **inline assembler**(p. 152) facility of the compiler.

Although avr-libc is primarily targeted to support programming AVR microcontrollers using the C (and C++) language, there's limited support for direct assembler usage as well. The benefits of it are:

- Use of the C preprocessor and thus the ability to use the same symbolic constants that are available to C programs, as well as a flexible macro concept that can use any valid C identifier as a macro (whereas the assembler's macro concept is basically targeted to use a macro in place of an assembler instruction).
- Use of the runtime framework like automatically assigning interrupt vectors. For devices that have RAM, **initializing the RAM variables**(p. 174) can also be utilized.

9.2.2 Invoking the compiler

For the purpose described in this document, the assembler and linker are usually not invoked manually, but rather using the C compiler frontend (`avr-gcc`) that in turn will call the assembler and linker as required.

This approach has the following advantages:

- There is basically only one program to be called directly, `avr-gcc`, regardless of the actual source language used.
- The invokation of the C preprocessor will be automatic, and will include the appropriate options to locate required include files in the filesystem.
- The invokation of the linker will be automatic, and will include the appropriate options to locate additional libraries as well as the application start-up code (`crt`*XXX*`.o`) and linker script.

Note that the invokation of the C preprocessor will be automatic when the filename provided for the assembler file ends in .S (the capital letter "s"). This would even apply to operating systems that use case-insensitive filesystems since the actual decision is made based on the case of the filename suffix given on the command-line, not based on the actual filename from the file system.

Alternatively, the language can explicitly be specified using the `-x assembler-with-cpp` option.

9.2.3 Example program

The following annotated example features a simple 100 kHz square wave generator using an AT90S1200 clocked with a 10.7 MHz crystal. Pin PD6 will be used for the square wave output.

```
#include <avr/io.h>             ; Note [1]

work    =       16              ; Note [2]
tmp     =       17

inttmp  =       19

intsav  =       0

SQUARE  =       PD6             ; Note [3]

                                ; Note [4]:
tmconst= 10700000 / 200000      ; 100 kHz => 200000 edges/s
fuzz=   8                       ; # clocks in ISR until TCNT0 is set

        .section .text

        .global main                            ; Note [5]
main:
        rcall   ioinit
1:
        rjmp    1b                              ; Note [6]

        .global SIG_OVERFLOW0                   ; Note [7]
SIG_OVERFLOW0:
        ldi     inttmp, 256 - tmconst + fuzz
        out     _SFR_IO_ADDR(TCNT0), inttmp     ; Note [8]

        in      intsav, _SFR_IO_ADDR(SREG)      ; Note [9]

        sbic    _SFR_IO_ADDR(PORTD), SQUARE
        rjmp    1f
        sbi     _SFR_IO_ADDR(PORTD), SQUARE
        rjmp    2f
1:      cbi     _SFR_IO_ADDR(PORTD), SQUARE
2:

        out     _SFR_IO_ADDR(SREG), intsav
        reti

ioinit:
        sbi     _SFR_IO_ADDR(DDRD), SQUARE

        ldi     work, _BV(TOIE0)
        out     _SFR_IO_ADDR(TIMSK), work

        ldi     work, _BV(CS00)         ; tmr0:  CK/1
        out     _SFR_IO_ADDR(TCCR0), work

        ldi     work, 256 - tmconst
        out     _SFR_IO_ADDR(TCNT0), work

        sei

        ret

        .global __vector_default                ; Note [10]
```

```
__vector_default:
        reti

        .end
```

Note [1]

As in C programs, this includes the central processor-specific file containing the IO port definitions for the device. Note that not all include files can be included into assembler sources.

Note [2]

Assignment of registers to symbolic names used locally. Another option would be to use a C preprocessor macro instead:

```
#define work 16
```

Note [3]

Our bit number for the square wave output. Note that the right-hand side consists of a CPP macro which will be substituted by its value (6 in this case) before actually being passed to the assembler.

Note [4]

The assembler uses integer operations in the host-defined integer size (32 bits or longer) when evaluating expressions. This is in contrast to the C compiler that uses the C type `int` by default in order to calculate constant integer expressions.

In order to get a 100 kHz output, we need to toggle the PD6 line 200000 times per second. Since we use timer 0 without any prescaling options in order to get the desired frequency and accuracy, we already run into serious timing considerations: while accepting and processing the timer overflow interrupt, the timer already continues to count. When pre-loading the `TCCNT0` register, we therefore have to account for the number of clock cycles required for interrupt acknowledge and for the instructions to reload `TCCNT0` (4 clock cycles for interrupt acknowledge, 2 cycles for the jump from the interrupt vector, 2 cycles for the 2 instructions that reload `TCCNT0`). This is what the constant `fuzz` is for.

Note [5]

External functions need to be declared to be .global. `main` is the application entry point that will be jumped to from the ininitalization routine in `crts1200.o`.

Note [6]

The main loop is just a single jump back to itself. Square wave generation itself is completely handled by the timer 0 overflow interrupt service. A `sleep` instruction (using idle mode) could be used as well, but probably would not conserve much energy anyway since the interrupt service is executed quite frequently.

Note [7]

Interrupt functions can get the **usual names**(p. 80) that are also available to C programs. The linker will then put them into the appropriate interrupt vector slots. Note that they must be declared .global in order to be acceptable for this purpose. This will only work if <`avr/io.h`> has been included. Note that the assembler or linker have no chance to check the correct spelling of an interrupt function, so it should be double-checked. (When analyzing the resulting object file using `avr-objdump` or `avr-nm`, a name like `__vector_N` should appear, with *N* being a small integer number.)

Note [8]

As explained in the section about **special function registers**(p. 27), the actual IO port address should be obtained using the macro `_SFR_IO_ADDR`. (The AT90S1200 does not have RAM thus the memory-mapped approach to access the IO registers is not available. It would be slower than using `in` / `out` instructions anyway.)

Since the operation to reload `TCCNT0` is time-critical, it is even performed before saving `SREG`. Obviously, this requires that the instructions involved would not change any of the flag bits in `SREG`.

Note [9]

Interrupt routines must not clobber the global CPU state. Thus, it is usually necessary to save at least the state of the flag bits in `SREG`. (Note that this serves as an example here only since actually, all the following instructions would not modify `SREG` either, but that's not commonly the case.)

Also, it must be made sure that registers used inside the interrupt routine do not conflict with those used outside. In the case of a RAM-less device like the

AT90S1200, this can only be done by agreeing on a set of registers to be used exclusively inside the interrupt routine; there would not be any other chance to "save" a register anywhere.

If the interrupt routine is to be linked together with C modules, care must be taken to follow the **register usage guidelines**(p. 142) imposed by the C compiler. Also, any register modified inside the interrupt sevice needs to be saved, usually on the stack.

Note [10]

As explained in **Interrupts and Signals**(p. 79), a global "catch-all" interrupt handler that gets all unassigned interrupt vectors can be installed using the name `__vector_default`. This must be .global, and obviously, should end in a `reti` instruction. (By default, a jump to location 0 would be implied instead.)

9.2.4 Pseudo-ops and operators

The available pseudo-ops in the assembler are described in the GNU assembler (gas) manual. The manual can be found online as part of the current binutils release under `http://sources.redhat.com/binutils/`.

As gas comes from a Unix origin, its pseudo-op and overall assembler syntax is slightly different than the one being used by other assemblers. Numeric constants follow the C notation (prefix `0x` for hexadecimal constants), expressions use a C-like syntax.

Some common pseudo-ops include:

- .byte allocates single byte constants
- .ascii allocates a non-terminated string of characters
- .asciz allocates a \0-terminated string of characters (C string)
- .data switches to the .data section (initialized RAM variables)
- .text switches to the .text section (code and ROM constants)
- .set declares a symbol as a constant expression (identical to .equ)
- .global (or .globl) declares a public symbol that is visible to the linker (e. g. function entry point, global variable)

- .extern declares a symbol to be externally defined; this is effectively a comment only, as gas treats all undefined symbols it encounters as globally undefined anyway

Note that .org is available in gas as well, but is a fairly pointless pseudo-op in an assembler environment that uses relocatable object files, as it is the linker that determines the final position of some object in ROM or RAM.

Along with the architecture-independent standard operators, there are some AVR-specific operators available which are unfortunately not yet described in the official documentation. The most notable operators are:

- `lo8` Takes the least significant 8 bits of a 16-bit integer
- `hi8` Takes the most significant 8 bits of a 16-bit integer
- `pm` Takes a program-memory (ROM) address, and converts it into a RAM address. This implies a division by 2 as the AVR handles ROM addresses as 16-bit words (e.g. in an `IJMP` or `ICALL` instruction), and can also handle relocatable symbols on the right-hand side.

Example:

```
ldi r24, lo8(pm(somefunc))
ldi r25, hi8(pm(somefunc))
call something
```

This passes the address of function `somefunc` as the first parameter to function `something`.

9.3 Frequently Asked Questions

9.3.1 FAQ Index

9.3.2 My program doesn't recognize a variable updated within an interrupt routine

When using the optimizer, in a loop like the following one:

```
uint8_t flag;
...

        while (flag == 0) {
                ...
        }
```

the compiler will typically optimize the access to `flag` completely away, since its code path analysis shows that nothing inside the loop could change the value of `flag` anyway. To tell the compiler that this variable could be changed outside the scope of its code path analysis (e. g. from within an interrupt routine), the variable needs to be declared like:

```
volatile uint8_t flag;
```

Back to **FAQ Index**(p. 130).

9.3.3 I get "undefined reference to..." for functions like "sin()"

In order to access the mathematical functions that are declared in <**math.h**(p. ??)>, the linker needs to be told to also link the mathematical library, `libm.a`.

Typically, system libraries like `libm.a` are given to the final C compiler command line that performs the linking step by adding a flag `-lm` at the end. (That is, the initial *lib* and the filename suffix from the library are written immediately after a *-l* flag. So for a `libfoo.a` library, `-lfoo` needs to be provided.) This will make the linker search the library in a path known to the system.

An alternative would be to specify the full path to the `libm.a` file at the same place on the command line, i. e. *after* all the object files (`*.o`). However, since this requires knowledge of where the build system will exactly find those library files, this is deprecated for system libraries.

Back to **FAQ Index**(p. 130).

9.3.4 How to permanently bind a variable to a register?

This can be done with

```
register unsigned char counter asm("r3");
```

See **C Names Used in Assembler Code**(p. 163) for more details.

Back to **FAQ Index**(p. 130).

9.3.5 How to modify MCUCR or WDTCR early?

The method of early initialization (MCUCR, WDTCR or anything else) is different (and more flexible) in the current version. Basically, write a small assembler file which looks like this:

```
;; begin xram.S

#include <avr/io.h>

        .section .init1,"ax",@progbits

        ldi r16,_BV(SRE) | _BV(SRW)
        out _SFR_IO_ADDR(MCUCR),r16

;; end xram.S
```

Assemble it, link the resulting `xram.o` with other files in your program, and this piece of code will be inserted in initialization code, which is run right after reset. See the linker script for comments about the new `.init`*N* sections (which one to use, etc.).

The advantage of this method is that you can insert any initialization code you want (just remember that this is very early startup – no stack and no `__zero_reg__` yet), and no program memory space is wasted if this feature is not used.

There should be no need to modify linker scripts anymore, except for some very special cases. It is best to leave `__stack` at its default value (end of internal SRAM – faster, and required on some devices like ATmega161 because of errata), and add `-Wl,-Tdata,0x801100` to start the data section above the stack.

For more information on using sections, including how to use them from C code, see **Memory Sections**(p. 173). Note that in C code, any such function would preferrably be placed into section .init3 as the code in .init2 ensures the internal register `__zero_reg__` is already cleared.

Back to **FAQ Index**(p. 130).

9.3.6 What is all this _BV() stuff about?

When performing low-level output work, which is a very central point in microcontroller programming, it is quite common that a particular bit needs to be set or cleared in some IO register. While the device documentation provides mnemonic names for the various bits in the IO registers, and the **AVR device-specific IO definitions**(p. 18) reflect these names in definitions for numerical constants, a way is needed to convert a bit number (usually within a byte register) into a byte value that can be assigned directly to the register. However, sometimes the direct bit numbers are needed as well (e. g. in an `SBI()` instruction), so the definitions cannot usefully be made as byte values in the first place.

So in order to access a particular bit number as a byte value, use the **_BV()**(p. 86) macro. Of course, the implementation of this macro is just the usual bit shift (which is done by the compiler anyway, thus doesn't impose any run-time penalty), so the following applies:

```
_BV(3) => 1 << 3 => 0x08
```

However, using the macro often makes the program better readable.

"BV" stands for "bit value", in case someone might ask you. :-)

Example: clock timer 2 with full IO clock (`CS2`x = 0b001), toggle OC2 output on compare match (`COM2`x = 0b01), and clear timer on compare match (`CTC2` = 1). Make OC2 (`PD7`) an output.

```
TCCR2 = _BV(COM20)|_BV(CTC2)|_BV(CS20);
DDRD = _BV(PD7);
```

Back to **FAQ Index**(p. 130).

9.3.7 Can I use C++ on the AVR?

Basically yes, C++ is supported (assuming your compiler has been configured and compiled to support it, of course). Source files ending in .cc, .cpp or .C will automatically cause the compiler frontend to invoke the C++ compiler. Alternatively, the C++ compiler could be explicitly called by the name `avr-c++`.

However, there's currently no support for `libstdc++`, the standard support library needed for a complete C++ implementation. This imposes a number of restrictions on the C++ programs that can be compiled. Among them are:

- Obviously, none of the C++ related standard functions, classes, and template classes are available.
- The operators `new` and `delete` are not implemented, attempting to use them will cause the linker to complain about undefined external references. (This could perhaps be fixed.)

- Some of the supplied include files are not C++ safe, i. e. they need to be wrapped into

  ```
  extern "C" { . . . }
  ```

  (This could certainly be fixed, too.)

- Exceptions are not supported. Since exceptions are enabled by default in the C++ frontend, they explicitly need to be turned off using `-fno-exceptions` in the compiler options. Failing this, the linker will complain about an undefined external reference to `__gxx_personality_sj0`.

Constructors and destructors *are* supported though, including global ones.

When programming C++ in space- and runtime-sensitive environments like microcontrollers, extra care should be taken to avoid unwanted side effects of the C++ calling conventions like implied copy constructors that could be called upon function invocation etc. These things could easily add up into a considerable amount of time and program memory wasted. Thus, casual inspection of the generated assembler code (using the `-S` compiler option) seems to be warranted.

Back to **FAQ Index**(p. 130).

9.3.8 Shouldn't I initialize all my variables?

Global and static variables are guaranteed to be initialized to 0 by the C standard. `avr-gcc` does this by placing the appropriate code into section .init4 (see **The .initN Sections**(p. 174)). With respect to the standard, this sentence is somewhat simplified (because the standard allows for machines where the actual bit pattern used differs from all bits being 0), but for the AVR target, in general, all integer-type variables are set to 0, all pointers to a NULL pointer, and all floating-point variables to 0.0.

As long as these variables are not initialized (i. e. they don't have an equal sign and an initialization expression to the right within the definition of the variable), they go into the **.bss**(p. 173) section of the file. This section simply records the size of the variable, but otherwise doesn't consume space, neither within the object file nor within flash memory. (Of course, being a variable, it will consume space in the target's SRAM.)

In contrast, global and static variables that have an initializer go into the **.data**(p. 173) section of the file. This will cause them to consume space in the object file (in order to record the initializing value), *and* in the flash ROM of the target device. The latter is needed since the flash ROM is the only way that the compiler can tell the target device the value this variable is going to be initialized to.

Now if some programmer "wants to make doubly sure" their variables really get a 0 at program startup, and adds an initializer just containing 0 on the right-hand side, they waste space. While this waste of space applies to virtually any platform C is implemented on, it's usually not noticeable on larger machines like PCs, while the waste of flash ROM storage can be very painful on a small microcontroller like the AVR.

So in general, variables should only be explicitly initialized if the initial value is non-zero.

Back to **FAQ Index**(p. 130).

9.3.9 Why do some 16-bit timer registers sometimes get trashed?

Some of the timer-related 16-bit IO registers use a temporary register (called TEMP in the Atmel datasheet) to guarantee an atomic access to the register despite the fact that two separate 8-bit IO transfers are required to actually move the data. Typically, this includes access to the current timer/counter value register (`TCNT`*n*), the input capture register (`ICR`*n*), and write access to the output compare registers (`OCR`*nM*). Refer to the actual datasheet for each device's set of registers that involves the TEMP register.

When accessing one of the registers that use TEMP from the main application, and possibly any other one from within an interrupt routine, care must be taken that no access from within an interrupt context could clobber the TEMP register data of an in-progress transaction that has just started elsewhere.

To protect interrupt routines against other interrupt routines, it's usually best to use the **SIGNAL()**(p. 84) macro when declaring the interrupt function, and to ensure that interrupts are still disabled when accessing those 16-bit timer registers.

Within the main program, access to those registers could be encapsulated in calls to the **cli()**(p. 82) and **sei()**(p. 84) macros. If the status of the global interrupt flag before accessing one of those registers is uncertain, something like the following example code can be used.

```
uint16_t
read_timer1(void)
{
        uint8_t sreg;
        uint16_t val;

        sreg = SREG;
        cli();
        val = TCNT1;
        SREG = sreg;
```

```
        return val;
}
```

Back to **FAQ Index**(p. 130).

9.3.10 How do I use a #define'd constant in an asm statement?

So you tried this:

```
asm volatile("sbi 0x18,0x07;");
```

Which works. When you do the same thing but replace the address of the port by its macro name, like this:

```
asm volatile("sbi PORTB,0x07;");
```

you get a compilation error: `"Error:  constant value required"`.

`PORTB` is a precompiler definition included in the processor specific file included in `avr/io.h`. As you may know, the precompiler will not touch strings and `PORTB`, instead of `0x18`, gets passed to the assembler. One way to avoid this problem is:

```
asm volatile("sbi %0, 0x07" : "I" (_SFR_IO_ADDR(PORTB)):);
```

Note:

For C programs, rather use the standard C bit operators instead, so the above would be expressed as `PORTB |= (1 << 7)`. The optimizer will take care to transform this into a single SBI instruction, assuming the operands allow for this.

Back to **FAQ Index**(p. 130).

9.3.11 Why does the PC randomly jump around when single-stepping through my program in avr-gdb?

When compiling a program with both optimization (`-O`) and debug information (`-g`) which is fortunately possible in `avr-gcc`, the code watched in the debugger is optimized code. While it is not guaranteed, very often this code runs with the exact same optimizations as it would run without the `-g` switch.

This can have unwanted side effects. Since the compiler is free to reorder code execution as long as the semantics do not change, code is often rearranged in order to make it possible to use a single branch instruction for conditional operations. Branch instructions can only cover a short range for the target PC (-63 through +64 words from the current PC). If a branch instruction cannot be used directly, the compiler needs to work around it by combining a skip instruction together with a relative jump (`rjmp`) instruction, which will need one additional word of ROM.

Another side effect of optimzation is that variable usage is restricted to the area of code where it is actually used. So if a variable was placed in a register at the beginning of some function, this same register can be re-used later on if the compiler notices that the first variable is no longer used inside that function, even though the variable is still in lexical scope. When trying to examine the variable in `avr-gdb`, the displayed result will then look garbled.

So in order to avoid these side effects, optimization can be turned off while debugging. However, some of these optimizations might also have the side effect of uncovering bugs that would otherwise not be obvious, so it must be noted that turning off optimization can easily change the bug pattern. In most cases, you are better off leaving optimizations enabled while debugging.

Back to **FAQ Index**(p. 130).

9.3.12 How do I trace an assembler file in avr-gdb?

When using the `-g` compiler option, `avr-gcc` only generates line number and other debug information for C (and C++) files that pass the compiler. Functions that don't have line number information will be completely skipped by a single `step` command in `gdb`. This includes functions linked from a standard library, but by default also functions defined in an assembler source file, since the `-g` compiler switch does not apply to the assembler.

So in order to debug an assembler input file (possibly one that has to be passed through the C preprocessor), it's the assembler that needs to be told to include line-number information into the output file. (Other debug information like data types and variable allocation cannot be generated, since unlike a compiler, the assembler basically doesn't know about this.) This is done using the (GNU) assembler option `-gstabs`.

Example:

```
$ avr-as -mmcu=atmega128 --gstabs -o foo.o foo.s
```

When the assembler is not called directly but through the C compiler frontend (either implicitly by passing a source file ending in .S, or explicitly using `-x assembler-with-cpp`), the compiler frontend needs to be told to pass the `-gstabs` option down to the assembler. This is done using `-Wa,-gstabs`. Please take care to *only* pass this option when compiling an assembler input file. Otherwise, the assembler code that results from the C compilation stage will also get line number information, which confuses the debugger.

Note:

You can also use `-Wa,-gstabs` since the compiler will add the extra '-' for you.

Example:

```
$ EXTRA_OPTS="-Wall -mmcu=atmega128 -x assembler-with-cpp"
$ avr-gcc -Wa,--gstabs ${EXTRA_OPTS} -c -o foo.o foo.S
```

Also note that the debugger might get confused when entering a piece of code that has a non-local label before, since it then takes this label as the name of a new function that appears to have been entered. Thus, the best practice to avoid this confusion is to only use non-local labels when declaring a new function, and restrict anything else to local labels. Local labels consist just of a number only. References to these labels consist of the number, followed by the letter **b** for a backward reference, or **f** for a forward reference. These local labels may be re-used within the source file, references will pick the closest label with the same number and given direction.

Example:

```
myfunc: push    r16
        push    r17
        push    r18
        push    YL
        push    YH
        ...
        eor     r16, r16        ; start loop
        ldi     YL, lo8(sometable)
        ldi     YH, hi8(sometable)
        rjmp    2f              ; jump to loop test at end
1:      ld      r17, Y+         ; loop continues here
        ...
        breq    1f              ; return from myfunc prematurely
        ...
        inc     r16
2:      cmp     r16, r18
        brlo    1b              ; jump back to top of loop

1:      pop     YH
        pop     YL
        pop     r18
        pop     r17
        pop     r16
        ret
```

Back to **FAQ Index**(p. 130).

9.3.13 How do I pass an IO port as a parameter to a function?

Consider this example code:

```
#include <inttypes.h>
#include <avr/io.h>

void
set_bits_func_wrong (volatile uint8_t port, uint8_t mask)
{
    port |= mask;
}

void
set_bits_func_correct (volatile uint8_t *port, uint8_t mask)
{
    *port |= mask;
}

#define set_bits_macro(port,mask) ((port) |= (mask))

int main (void)
{
    set_bits_func_wrong (PORTB, 0xaa);
    set_bits_func_correct (&PORTB, 0x55);
    set_bits_macro (PORTB, 0xf0);

    return (0);
}
```

The first function will generate object code which is not even close to what is intended. The major problem arises when the function is called. When the compiler sees this call, it will actually pass the value of the PORTB register (using an IN instruction), instead of passing the address of PORTB (e.g. memory mapped io addr of 0x38, io port 0x18 for the mega128). This is seen clearly when looking at the disassembly of the call:

```
    set_bits_func_wrong (PORTB, 0xaa);
 10a:   6a ea           ldi     r22, 0xAA       ; 170
 10c:   88 b3           in      r24, 0x18       ; 24
 10e:   0e 94 65 00     call    0xca
```

So, the function, once called, only sees the value of the port register and knows nothing about which port it came from. At this point, whatever object code is generated for the function by the compiler is irrelevant. The interested reader can examine the full disassembly to see that the function's body is completely fubar.

The second function shows how to pass (by reference) the memory mapped address of the io port to the function so that you can read and write to it in the function. Here's the object code generated for the function call:

```
    set_bits_func_correct (&PORTB, 0x55);
 112:   65 e5           ldi     r22, 0x55       ; 85
 114:   88 e3           ldi     r24, 0x38       ; 56
 116:   90 e0           ldi     r25, 0x00       ; 0
 118:   0e 94 7c 00     call    0xf8
```

You can clearly see that `0x0038` is correctly passed for the address of the io port. Looking at the disassembled object code for the body of the function, we can see that the function is indeed performing the operation we intended:

```
void
set_bits_func_correct (volatile uint8_t *port, uint8_t mask)
{
  f8:   fc 01           movw    r30, r24
    *port |= mask;
  fa:   80 81           ld      r24, Z
  fc:   86 2b           or      r24, r22
  fe:   80 83           st      Z, r24
}
 100:   08 95           ret
```

Notice that we are accessing the io port via the `LD` and `ST` instructions.

The `port` parameter must be volatile to avoid a compiler warning.

Note:

Because of the nature of the `IN` and `OUT` assembly instructions, they can not be used inside the function when passing the port in this way. Readers interested in the details should consult the *Instruction Set* data sheet.

Finally we come to the macro version of the operation. In this contrived example, the macro is the most efficient method with respect to both execution speed and code size:

```
    set_bits_macro (PORTB, 0xf0);
 11c:   88 b3           in      r24, 0x18       ; 24
 11e:   80 6f           ori     r24, 0xF0       ; 240
 120:   88 bb           out     0x18, r24       ; 24
```

Of course, in a real application, you might be doing a lot more in your function which uses a passed by reference io port address and thus the use of a function over a macro could save you some code space, but still at a cost of execution speed.

Care should be taken when such an indirect port access is going to one of the 16-bit IO registers where the order of write access is critical (like some timer registers). All versions of avr-gcc up to 3.3 will generate instructions that use the wrong access order in this situation (since with normal memory operands where the order doesn't matter, this sometimes yields shorter code).

See `http://mail.nongnu.org/archive/html/avr-libc-dev/2003-01/msg00044.html` for a possible workaround.

avr-gcc versions after 3.3 have been fixed in a way where this optimization will be disabled if the respective pointer variable is declared to be `volatile`, so the correct behaviour for 16-bit IO ports can be forced that way.

Back to **FAQ Index**(p. 130).

9.3.14 What registers are used by the C compiler?

- **Data types:**

  `char` is 8 bits, `int` is 16 bits, `long` is 32 bits, `long` long is 64 bits, `float` and `double` are 32 bits (this is the only supported floating point format), pointers are 16 bits (function pointers are word addresses, to allow addressing the whole 128K program memory space on the ATmega devices with > 64 KB of flash ROM). There is a `-mint8` option (see **Options for the C compiler avr-gcc**(p. 186)) to make `int` 8 bits, but that is not supported by avr-libc and violates C standards (`int` *must* be at least 16 bits). It may be removed in a future release.

- **Call-used registers (r18-r27, r30-r31):**

  May be allocated by gcc for local data. You *may* use them freely in assembler subroutines. Calling C subroutines can clobber any of them - the caller is responsible for saving and restoring.

- **Call-saved registers (r2-r17, r28-r29):**

  May be allocated by gcc for local data. Calling C subroutines leaves them unchanged. Assembler subroutines are responsible for saving and restoring these registers, if changed. r29:r28 (Y pointer) is used as a frame pointer (points to local data on stack) if necessary.

- **Fixed registers (r0, r1):**

  Never allocated by gcc for local data, but often used for fixed purposes:

r0 - temporary register, can be clobbered by any C code (except interrupt handlers which save it), *may* be used to remember something for a while within one piece of assembler code

r1 - assumed to be always zero in any C code, *may* be used to remember something for a while within one piece of assembler code, but *must* then be cleared after use (`clr r1`). This includes any use of the `[f]mul[s[u]]` instructions, which return their result in r1:r0. Interrupt handlers save and clear r1 on entry, and restore r1 on exit (in case it was non-zero).

- **Function call conventions:**

  Arguments - allocated left to right, r25 to r8. All arguments are aligned to start in even-numbered registers (odd-sized arguments, including `char`, have one free register above them). This allows making better use of the `movw` instruction on the enhanced core.

If too many, those that don't fit are passed on the stack.

Return values: 8-bit in r24 (not r25!), 16-bit in r25:r24, up to 32 bits in r22-r25, up to 64 bits in r18-r25. 8-bit return values are zero/sign-extended to 16 bits by the caller (`unsigned char` is more efficient than `signed char` - just `clr r25`). Arguments to functions with variable argument lists (printf etc.) are all passed on stack, and `char` is extended to `int`.

Warning:

There was no such alignment before 2000-07-01, including the old patches for gcc-2.95.2. Check your old assembler subroutines, and adjust them accordingly.

Back to **FAQ Index**(p. 130).

9.3.15 How do I put an array of strings completely in ROM?

There are times when you may need an array of strings which will never be modified. In this case, you don't want to waste ram storing the constant strings. The most obvious (and incorrect) thing to do is this:

```
#include <avr/pgmspace.h>

PGM_P array[2] PROGMEM = {
    "Foo",
    "Bar"
};

int main (void)
{
    char buf[32];
    strcpy_P (buf, array[1]);
    return 0;
}
```

The result is not want you want though. What you end up with is the array stored in ROM, while the individual strings end up in RAM (in the .data section).

To work around this, you need to do something like this:

```
#include <avr/pgmspace.h>

const char foo[] PROGMEM = "Foo";
const char bar[] PROGMEM = "Bar";

PGM_P array[2] PROGMEM = {
    foo,
    bar
};

int main (void)
```

```
{
    char buf[32];
    PGM_P p;
    int i;

    memcpy_P(&p, &array[i], sizeof(PGM_P));
    strcpy_P(buf, p);
    return 0;
}
```

Looking at the disassembly of the resulting object file we see that array is in flash as such:

```
00000026 <array>:
  26:   2e 00           .word   0x002e  ; ????
  28:   2a 00           .word   0x002a  ; ????

0000002a <bar>:
  2a:   42 61 72 00                                         Bar.

0000002e <foo>:
  2e:   46 6f 6f 00                                         Foo.
```

`foo` is at addr 0x002e.

`bar` is at addr 0x002a.

`array` is at addr 0x0026.

Then in main we see this:

```
    memcpy_P(&p, &array[i], sizeof(PGM_P));
  70:   66 0f           add     r22, r22
  72:   77 1f           adc     r23, r23
  74:   6a 5d           subi    r22, 0xDA       ; 218
  76:   7f 4f           sbci    r23, 0xFF       ; 255
  78:   42 e0           ldi     r20, 0x02       ; 2
  7a:   50 e0           ldi     r21, 0x00       ; 0
  7c:   ce 01           movw    r24, r28
  7e:   81 96           adiw    r24, 0x21       ; 33
  80:   08 d0           rcall   .+16            ; 0x92
```

This code reads the pointer to the desired string from the ROM table `array` into a register pair.

The value of `i` (in r22:r23) is doubled to accomodate for the word offset required to access array[], then the address of array (0x26) is added, by subtracting the negated address (0xffda). The address of variable `p` is computed by adding its offset within the stack frame (33) to the Y pointer register, and **memcpy_P** is called.

```
    strcpy_P(buf, p);
```

```
 82:   69 a1          ldd     r22, Y+33       ; 0x21
 84:   7a a1          ldd     r23, Y+34       ; 0x22
 86:   ce 01          movw    r24, r28
 88:   01 96          adiw    r24, 0x01       ; 1
 8a:   0c d0          rcall   .+24            ; 0xa4
```

This will finally copy the ROM string into the local buffer `buf`.

Variable `p` (located at Y+33) is read, and passed together with the address of buf (Y+1) to **strcpy_P**. This will copy the string from ROM to `buf`.

Note that when using a compile-time constant index, omitting the first step (reading the pointer from ROM via **memcpy_P**) usually remains unnoticed, since the compiler would then optimize the code for accessing `array` at compile-time.

Back to **FAQ Index**(p. 130).

9.3.16 How to use external RAM?

Well, there is no universal answer to this question; it depends on what the external RAM is going to be used for.

Basically, the bit `SRE` (SRAM enable) in the `MCUCR` register needs to be set in order to enable the external memory interface. Depending on the device to be used, and the application details, further registers affecting the external memory operation like `XMCRA` and `XMCRB`, and/or further bits in `MCUCR` might be configured. Refer to the datasheet for details.

If the external RAM is going to be used to store the variables from the C program (i. e., the .data and/or .bss segment) in that memory area, it is essential to set up the external memory interface early during the **device initialization**(p. 174) so the initialization of these variable will take place. Refer to **How to modify MCUCR or WDTCR early?**(p. 133) for a description how to do this using few lines of assembler code, or to the chapter about memory sections for an **example written in C**(p. 177).

The explanation of **malloc()**(p. 65) contains a **discussion**(p. 166) about the use of internal RAM vs. external RAM in particular with respect to the various possible locations of the *heap* (area reserved for **malloc()**(p. 65)). It also explains the linker command-line options that are required to move the memory regions away from their respective standard locations in internal RAM.

Finally, if the application simply wants to use the additional RAM for private data storage kept outside the domain of the C compiler (e. g. through a `char *` variable initialized directly to a particular address), it would be sufficient to defer the initialization of the external RAM interface to the beginning of **main()**, so no tweaking of the .init3 section is necessary. The same applies if only the heap is going to be located there, since the application start-up code does not affect the heap.

It is not recommended to locate the stack in external RAM. In general, accessing external RAM is slower than internal RAM, and errata of some AVR devices even prevent this configuration from working properly at all.

Back to **FAQ Index**(p. 130).

9.3.17 Which -O flag to use?

There's a common misconception that larger numbers behind the `-O` option might automatically cause "better" optimization. First, there's no universal definition for "better", with optimization often being a speed vs. code size tradeoff. See the **detailed discussion**(p. 189) for which option affects which part of the code generation.

A test case was run on an ATmega128 to judge the effect of compiling the library itself using different optimization levels. The following table lists the results. The test case consisted of around 2 KB of strings to sort. Test #1 used **qsort()**(p. 66) using the standard library **strcmp()**(p. 74), test #2 used a function that sorted the strings by their size (thus had two calls to **strlen()**(p. 75) per invocation).

When comparing the resulting code size, it should be noted that a floating point version of fvprintf() was linked into the binary (in order to print out the time elapsed) which is entirely not affected by the different optimization levels, and added about 2.5 KB to the code.

Optimization flags	**Size of .text**	**Time for test #1**	**Time for test #2**
-O3	6898	903 μs	19.7 ms
-O2	6666	972 μs	20.1 ms
-Os	6618	955 μs	20.1 ms
-Os -mcall-prologues	6474	972 μs	20.1 ms

(The difference between 955 μs and 972 μs was just a single timer-tick, so take this with a grain of salt.)

So generally, it seems `-Os -mcall-prologues` is the most universal "best" optimization level. Only applications that need to get the last few percent of speed benefit from using `-O3`.

Back to **FAQ Index**(p. 130).

9.3.18 How do I relocate code to a fixed address?

First, the code should be put into a new **named section**(p. 173). This is done with a section attribute:

```
__attribute__ ((section (".bootloader")))
```

In this example, .bootloader is the name of the new section. This attribute needs to be placed after the prototype of any function to force the function into the new section.

```
void boot(void) __attribute__ ((section (".bootloader")));
```

To relocate the section to a fixed address the linker flag `-section-start` is used. This option can be passed to the linker using the **-Wl compiler option**(p. 190):

```
-Wl,--section-start=.bootloader=0x1E000
```

The name after section-start is the name of the section to be relocated. The number after the section name is the beginning address of the named section.

Back to **FAQ Index**(p. 130).

9.3.19 My UART is generating nonsense! My ATmega128 keeps crashing! Port F is completely broken!

Well, certain odd problems arise out of the situation that the AVR devices as shipped by Atmel often come with a default fuse bit configuration that doesn't match the user's expectations. Here is a list of things to care for:

- All devices that have an internal RC oscillator ship with the fuse enabled that causes the device to run off this oscillator, instead of an external crystal. This often remains unnoticed until the first attempt is made to use something critical in timing, like UART communication.
- The ATmega128 ships with the fuse enabled that turns this device into ATmega103 compatibility mode. This means that some ports are not fully usable, and in particular that the internal SRAM is located at lower addresses. Since by default, the stack is located at the top of internal SRAM, a program compiled for an ATmega128 running on such a device will immediately crash upon the first function call (or rather, upon the first function return).
- Devices with a JTAG interface have the `JTAGEN` fuse programmed by default. This will make the respective port pins that are used for the JTAG interface unavailable for regular IO.

Back to **FAQ Index**(p. 130).

9.3.20 Why do all my "foo...bar" strings eat up the SRAM?

By default, all strings are handled as all other initialized variables: they occupy RAM (even though the compiler might warn you when it detects write attempts to these RAM locations), and occupy the same amount of flash ROM so they can be initialized to the actual string by startup code. The compiler can optimize multiple identical strings into a single one, but obviously only for one compilation unit (i. e., a single C source file).

That way, any string literal will be a valid argument to any C function that expects a `const char *` argument.

Of course, this is going to waste a lot of SRAM. In **Program Space String Utilities**(p. 19), a method is described how such constant data can be moved out to flash ROM. However, a constant string located in flash ROM is no longer a valid argument to pass to a function that expects a `const char *`-type string, since the AVR processor needs the special instruction `LPM` to access these strings. Thus, separate functions are needed that take this into account. Many of the standard C library functions have equivalents available where one of the string arguments can be located in flash ROM. Private functions in the applications need to handle this, too. For example, the following can be used to implement simple debugging messages that will be sent through a UART:

```
#include <inttypes.h>
#include <avr/io.h>
#include <avr/pgmspace.h>

int
uart_putchar(char c)
{
  if (c == '\n')
    uart_putchar('\r');
  loop_until_bit_is_set(USR, UDRE);
  UDR = c;
  return 0; /* so it could be used for fdevopen(), too */
}

void
debug_P(const char *addr)
{
  char c;

  while ((c = pgm_read_byte(addr++)))
    uart_putchar(c);
}

int
main(void)
{
  ioinit(); /* initialize UART, ... */
  debug_P(PSTR("foo was here\n"));
  return 0;
}
```

Note:

By convention, the suffix **_P** to the function name is used as an indication that this function is going to accept a "program-space string". Note also the use of the **PSTR()**(p. 23) macro.

Back to **FAQ Index**(p. 130).

9.3.21 Why does the compiler compile an 8-bit operation that uses bitwise operators into a 16-bit operation in assembly?

Bitwise operations in Standard C will automatically promote their operands to an int, which is (by default) 16 bits in avr-gcc.

To work around this use typecasts on the operands, including literals, to declare that the values are to be 8 bit operands.

This may be especially important when clearing a bit:

```
var &= ~mask;  /* wrong way! */
```

The bitwise "not" operator (~) will also promote the value in `mask` to an int. To keep it an 8-bit value, typecast before the "not" operator:

```
var &= (unsigned char)~mask;
```

Back to **FAQ Index**(p. 130).

9.3.22 How to detect RAM memory and variable overlap problems?

You can simply run `avr-nm` on your output (ELF) file. Run it with the `-n` option, and it will sort the symbols numerically (by default, they are sorted alphabetically).

Look for the symbol `_end`, that's the first address in RAM that is not allocated by a variable. (avr-gcc internally adds 0x800000 to all data/bss variable addresses, so please ignore this offset.) Then, the run-time initialization code initializes the stack pointer (by default) to point to the last avaialable address in (internal) SRAM. Thus, the region between `_end` and the end of SRAM is what is available for stack. (If your application uses **malloc()**(p. 65), which e. g. also can happen inside **printf()**(p. 51), the heap for dynamic memory is also located there. See **Using malloc()**(p. 164).)

The amount of stack required for your application cannot be determined that easily. For example, if you recursively call a function and forget to break that recursion, the amount of stack required is infinite. :-) You can look at the generated assembler code (`avr-gcc ... -S`), there's a comment in each generated assembler file that tells you the frame size for each generated function. That's the amount of stack required for this function, you have to add up that for all functions where you know that the calls could be nested.

Back to **FAQ Index**(p. 130).

9.3.23 Is it really impossible to program the ATtinyXX in C?

While some small AVRs are not directly supported by the C compiler since they do not have a RAM-based stack (and some do not even have RAM at all), it is possible anyway to use the general-purpose registers as a RAM replacement since they are mapped into the data memory region.

Bruce D. Lightner wrote an excellent description of how to do this, and offers this together with a toolkit on his web page:

`http://lightner.net/avr/ATtinyAvrGcc.html`

Back to **FAQ Index**(p. 130).

9.3.24 What is this "clock skew detected" messsage?

It's a known problem of the MS-DOS FAT file system. Since the FAT file system has only a granularity of 2 seconds for maintaining a file's timestamp, and it seems that some MS-DOS derivative (Win9x) perhaps rounds up the current time to the next second when calculating the timestamp of an updated file in case the current time cannot be represented in FAT's terms, this causes a situation where `make` sees a "file coming from the future".

Since all make decisions are based on file timestamps, and their dependencies, make warns about this situation.

Solution: don't use inferior file systems / operating systems. Neither Unix file systems nor HPFS (aka NTFS) do experience that problem.

Workaround: after saving the file, wait a second before starting `make`. Or simply ignore the warning. If you are paranoid, execute a `make clean all` to make sure everything gets rebuilt.

In networked environments where the files are accessed from a file server, this message can also happen if the file server's clock differs too much from the network client's clock. In this case, the solution is to use a proper time keeping protocol on both systems, like NTP. As a workaround, synchronize the client's clock frequently with the server's clock.

Back to **FAQ Index**(p. 130).

9.3.25 Why are (many) interrupt flags cleared by writing a logical 1?

Usually, each interrupt has its own interrupt flag bit in some control register, indicating the specified interrupt condition has been met by representing a logical 1 in the respective bit position. When working with interrupt handlers, this interrupt flag bit usually gets cleared automatically in the course of processing the interrupt, sometimes by just calling the handler at all, sometimes (e. g. for the U[S]ART) by reading a particular hardware register that will normally happen anyway when processing the interrupt.

From the hardware's point of view, an interrupt is asserted as long as the respective bit is set, while global interrupts are enabled. Thus, it is essential to have the bit cleared before interrupts get re-enabled again (which usually happens when returning from an interrupt handler).

Only few subsystems require an explicit action to clear the interrupt request when using interrupt handlers. (The notable exception is the TWI interface, where clearing the interrupt indicates to proceed with the TWI bus hardware handshake, so it's never done automatically.)

However, if no normal interrupt handlers are to be used, or in order to make extra sure any pending interrupt gets cleared before re-activating global interrupts (e. g. an external edge-triggered one), it can be necessary to explicitly clear the respective hardware interrupt bit by software. This is usually done by writing a logical 1 into this bit position. This seems to be illogical at first, the bit position already carries a logical 1 when reading it, so why does writing a logical 1 to it *clear* the interrupt bit?

The solution is simple: writing a logical 1 to it requires only a single `OUT` instruction, and it is clear that only this single interrupt request bit will be cleared. There is no need to perform a read-modify-write cycle (like, an `SBI` instruction), since all bits in these control registers are interrupt bits, and writing a logical 0 to the remaining bits (as it is done by the simple `OUT` instruction) will not alter them, so there is no risk of any race condition that might accidentally clear another interrupt request bit. So instead of writing

```
TIFR |= _BV(TOV0); /* wrong! */
```

simply use

```
TIFR = _BV(TOV0);
```

Back to **FAQ Index**(p. 130).

9.3.26 Why have "programmed" fuses the bit value 0?

Basically, fuses are just a bit in a special EEPROM area. For technical reasons, erased E[E]PROM cells have all bits set to the value 1, so unprogrammed fuses also have a logical 1. Conversely, programmed fuse cells read out as bit value 0.

Back to **FAQ Index**(p. 130).

9.3.27 Which AVR-specific assembler operators are available?

See **Pseudo-ops and operators**(p. 129).

Back to **FAQ Index**(p. 130).

9.4 Inline Asm

AVR-GCC

Inline Assembler Cookbook

About this Document

The GNU C compiler for Atmel AVR RISC processors offers, to embed assembly language code into C programs. This cool feature may be used for manually optimizing time critical parts of the software or to use specific processor instruction, which are not available in the C language.

Because of a lack of documentation, especially for the AVR version of the compiler, it may take some time to figure out the implementation details by studying the compiler and assembler source code. There are also a few sample programs available in the net. Hopefully this document will help to increase their number.

It's assumed, that you are familiar with writing AVR assembler programs, because this is not an AVR assembler programming tutorial. It's not a C language tutorial either.

Note that this document does not cover file written completely in assembler language, refer to **avr-libc and assembler programs**(p. 124) for this.

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This document describes version 3.3 of the compiler. There may be some parts, which hadn't been completely understood by the author himself and not all samples had been tested so far. Because the author is German and not familiar with the English language, there are definitely some typos and syntax errors in the text. As a programmer the author knows, that a wrong documentation sometimes might be worse than none. Anyway, he decided to offer his little knowledge to the public, in the hope to get enough response to improve this document. Feel free to contact the author via e-mail. For the latest release check `http://www.ethernut.de/`.

Herne, 17th of May 2002 Harald Kipp harald.kipp-at-egnite.de

Note:

As of 26th of July 2002, this document has been merged into the documentation for avr-libc. The latest version is now available at `http://savannah.nongnu.org/projects/avr-libc/`.

9.4.1 GCC asm Statement

Let's start with a simple example of reading a value from port D:

```
asm("in %0, %1" : "=r" (value) : "I" (_SFR_IO_ADDR(PORTD)) );
```

Each `asm` statement is devided by colons into (up to) four parts:

1. The assembler instructions, defined as a single string constant:

   ```
   "in %0, %1"
   ```

2. A list of output operands, separated by commas. Our example uses just one:

   ```
   "=r" (value)
   ```

3. A comma separated list of input operands. Again our example uses one operand only:

   ```
   "I" (_SFR_IO_ADDR(PORTD))
   ```

4. Clobbered registers, left empty in our example.

You can write assembler instructions in much the same way as you would write assembler programs. However, registers and constants are used in a different way if they refer to expressions of your C program. The connection between registers and C operands is specified in the second and third part of the `asm` instruction, the list of input and output operands, respectively. The general form is

```
asm(code : output operand list : input operand list [: clobber list]);
```

In the code section, operands are referenced by a percent sign followed by a single digit. `0` refers to the first `1` to the second operand and so forth. From the above example:

`0` refers to `"=r" (value)` and

`1` refers to `"I" (_SFR_IO_ADDR(PORTD))`.

This may still look a little odd now, but the syntax of an operand list will be explained soon. Let us first examine the part of a compiler listing which may have been generated from our example:

```
        lds r24,value
/* #APP */
        in r24, 12
/* #NOAPP */
        sts value,r24
```

The comments have been added by the compiler to inform the assembler that the included code was not generated by the compilation of C statements, but by inline assembler statements. The compiler selected register `r24` for storage of the value read from `PORTD`. The compiler could have selected any other register, though. It may not explicitely load or store the value and it may even decide not to include your assembler code at all. All these decisions are part of the compiler's optimization strategy. For example, if you never use the variable value in the remaining part of the C program, the compiler will most likely remove your code unless you switched off optimization. To avoid this, you can add the volatile attribute to the `asm` statement:

```
asm volatile("in %0, %1" : "=r" (value) : "I" (_SFR_IO_ADDR(PORTD)));
```

The last part of the `asm` instruction, the clobber list, is mainly used to tell the compiler about modifications done by the assembler code. This part may be omitted, all other parts are required, but may be left empty. If your assembler routine won't use any input or output operand, two colons must still follow the assembler code string. A good example is a simple statement to disable interrupts:

```
asm volatile("cli"::);
```

9.4.2 Assembler Code

You can use the same assembler instruction mnemonics as you'd use with any other AVR assembler. And you can write as many assembler statements into one code string as you like and your flash memory is able to hold.

Note:

The available assembler directives vary from one assembler to another.

To make it more readable, you should put each statement on a seperate line:

```
asm volatile("nop\n\t"
             "nop\n\t"
             "nop\n\t"
             "nop\n\t"
             ::);
```

The linefeed and tab characters will make the assembler listing generated by the compiler more readable. It may look a bit odd for the first time, but that's the way the compiler creates it's own assembler code.

You may also make use of some special registers.

Symbol	Register
`__SREG__`	Status register at address 0x3F
`__SP_H__`	Stack pointer high byte at address 0x3E
`__SP_L__`	Stack pointer low byte at address 0x3D
`__tmp_reg__`	Register r0, used for temporary storage
`__zero_reg__`	Register r1, always zero

Register `r0` may be freely used by your assembler code and need not be restored at the end of your code. It's a good idea to use `__tmp_reg__` and `__zero_reg__` instead of `r0` or `r1`, just in case a new compiler version changes the register usage definitions.

9.4.3 Input and Output Operands

Each input and output operand is described by a constraint string followed by a C expression in parantheses. `AVR-GCC` 3.3 knows the following constraint characters:

Note:

The most up-to-date and detailed information on contraints for the avr can be found in the gcc manual.

The `x` register is `r27:r26`, the `y` register is `r29:r28`, and the `z` register is `r31:r30`

Constraint	Used for	Range
a	Simple upper registers	r16 to r23
b	Base pointer registers pairs	y, z
d	Upper register	r16 to r31
e	Pointer register pairs	x, y, z
G	Floating point constant	0.0
I	6-bit positive integer constant	0 to 63
J	6-bit negative integer constant	-63 to 0
K	Integer constant	2
L	Integer constant	0
l	Lower registers	r0 to r15
M	8-bit integer constant	0 to 255
N	Integer constant	-1
O	Integer constant	8, 16, 24
P	Integer constant	1
q	Stack pointer register	SPH:SPL
r	Any register	r0 to r31
t	Temporary register	r0
w	Special upper register pairs	r24, r26, r28, r30
x	Pointer register pair X	x (r27:r26)
y	Pointer register pair Y	y (r29:r28)
z	Pointer register pair Z	z (r31:r30)

These definitions seem not to fit properly to the AVR instruction set. The author's assumption is, that this part of the compiler has never been really finished in this version, but that assumption may be wrong. The selection of the proper contraint depends on the range of the constants or registers, which must be acceptable to the AVR instruction they are used with. The C compiler doesn't check any line of your assembler code. But it is able to check the constraint against your C expression. However, if you specify the wrong constraints, then the compiler may silently pass wrong code to the assembler. And, of course, the assembler will fail with some cryptic output or internal errors. For example, if you specify the constraint `"r"` and you are using this register with an `"ori"` instruction in your assembler code, then the compiler may select any register. This will fail, if the compiler chooses `r2` to `r15`. (It will never choose `r0` or `r1`, because these are uses for special purposes.) That's why the correct constraint in that case is `"d"`. On the other hand, if you use the constraint `"M"`, the compiler will make sure that you don't pass anything else but an 8-bit value. Later on we will see how to pass multibyte expression results to the assembler code.

The following table shows all AVR assembler mnemonics which require operands, and the related contraints. Because of the improper constraint definitions in version 3.3, they aren't strict enough. There is, for example, no constraint, which restricts integer constants to the range 0 to 7 for bit set and bit clear operations.

Mnemonic	**Constraints**		**Mnemonic**	**Constraints**
adc	r,r		add	r,r
adiw	w,I		and	r,r
andi	d,M		asr	r
bclr	I		bld	r,I
brbc	I,label		brbs	I,label
bset	I		bst	r,I
cbi	I,I		cbr	d,I
com	r		cp	r,r
cpc	r,r		cpi	d,M
cpse	r,r		dec	r
elpm	t,z		eor	r,r
in	r,I		inc	r
ld	r,e		ldd	r,b
ldi	d,M		lds	r,label
lpm	t,z		lsl	r
lsr	r		mov	r,r
movw	r,r		mul	r,r
neg	r		or	r,r
ori	d,M		out	I,r
pop	r		push	r
rol	r		ror	r
sbc	r,r		sbci	d,M
sbi	I,I		sbic	I,I
sbiw	w,I		sbr	d,M
sbrc	r,I		sbrs	r,I
ser	d		st	e,r
std	b,r		sts	label,r
sub	r,r		subi	d,M
swap	r			

Constraint characters may be prepended by a single constraint modifier. Contraints without a modifier specify read-only operands. Modifiers are:

Modifier	**Specifies**
=	Write-only operand, usually used for all output operands.
+	Read-write operand (not supported by inline assembler)
&	Register should be used for output only

Output operands must be write-only and the C expression result must be an lvalue, which means that the operands must be valid on the left side of assignments. Note, that the compiler will not check if the operands are of reasonable type for the kind of operation used in the assembler instructions.

Input operands are, you guessed it, read-only. But what if you need the same operand for input and output? As stated above, read-write operands are not supported in inline assembler code. But there is another solution. For input operators it is possible to use a single digit in the constraint string. Using digit n tells the compiler to use the same register as for the n-th operand, starting with zero. Here is an example:

```
asm volatile("swap %0" : "=r" (value) : "0" (value));
```

This statement will swap the nibbles of an 8-bit variable named value. Constraint `"0"` tells the compiler, to use the same input register as for the first operand. Note however, that this doesn't automatically imply the reverse case. The compiler may choose the same registers for input and output, even if not told to do so. This is not a problem in most cases, but may be fatal if the output operator is modified by the assembler code before the input operator is used. In the situation where your code depends on different registers used for input and output operands, you must add the `&` constraint modifier to your output operand. The following example demonstrates this problem:

```
asm volatile("in %0,%1"    "\n\t"
             "out %1, %2"  "\n\t"
             : "=&r" (input)
             : "I" (_SFR_IO_ADDR(port)), "r" (output)
            );
```

In this example an input value is read from a port and then an output value is written to the same port. If the compiler would have choosen the same register for input and output, then the output value would have been destroyed on the first assembler instruction. Fortunately, this example uses the `&` constraint modifier to instruct the compiler not to select any register for the output value, which is used for any of the input operands. Back to swapping. Here is the code to swap high and low byte of a 16-bit value:

```
asm volatile("mov __tmp_reg__, %A0" "\n\t"
             "mov %A0, %B0"         "\n\t"
             "mov %B0, __tmp_reg__" "\n\t"
             : "=r" (value)
             : "0" (value)
            );
```

First you will notice the usage of register `__tmp_reg__`, which we listed among other special registers in the **Assembler Code**(p. 154) section. You can use this register without saving its contents. Completely new are those letters A and B in %A0 and %B0. In fact they refer to two different 8-bit registers, both containing a part of value.

Another example to swap bytes of a 32-bit value:

```
asm volatile("mov __tmp_reg__, %A0" "\n\t"
             "mov %A0, %D0"         "\n\t"
             "mov %D0, __tmp_reg__" "\n\t"
             "mov __tmp_reg__, %B0" "\n\t"
             "mov %B0, %C0"         "\n\t"
             "mov %C0, __tmp_reg__" "\n\t"
             : "=r" (value)
             : "0" (value)
            );
```

If operands do not fit into a single register, the compiler will automatically assign enough registers to hold the entire operand. In the assembler code you use %A0 to refer to the lowest byte of the first operand, %A1 to the lowest byte of the second operand and so on. The next byte of the first operand will be %B0, the next byte %C0 and so on.

This also implies, that it is often neccessary to cast the type of an input operand to the desired size.

A final problem may arise while using pointer register pairs. If you define an input operand

```
"e" (ptr)
```

and the compiler selects register Z (r30:r31), then

%A0 refers to r30 and

%B0 refers to r31.

But both versions will fail during the assembly stage of the compiler, if you explicitely need Z, like in

```
ld r24,Z
```

If you write

```
ld r24, %a0
```

with a lower case a following the percent sign, then the compiler will create the proper assembler line.

9.4.4 Clobbers

As stated previously, the last part of the asm statement, the list of clobbers, may be omitted, including the colon seperator. However, if you are using registers, which had not been passed as operands, you need to inform the compiler about this. The following example will do an atomic increment. It increments an 8-bit value pointed to by a pointer variable in one go, without being interrupted by an interrupt routine or another thread in a multithreaded environment. Note, that we must use a pointer, because the incremented value needs to be stored before interrupts are enabled.

```
asm volatile(
    "cli"               "\n\t"
    "ld r24, %a0"       "\n\t"
    "inc r24"           "\n\t"
    "st %a0, r24"       "\n\t"
    "sei"               "\n\t"
    :
    : "e" (ptr)
    : "r24"
);
```

The compiler might produce the following code:

```
    cli
    ld r24, Z
    inc r24
    st Z, r24
    sei
```

One easy solution to avoid clobbering register r24 is, to make use of the special temporary register __tmp_reg__ defined by the compiler.

```
asm volatile(
    "cli"                       "\n\t"
    "ld __tmp_reg__, %a0"       "\n\t"
    "inc __tmp_reg__"           "\n\t"
    "st %a0, __tmp_reg__"       "\n\t"
    "sei"                       "\n\t"
    :
    : "e" (ptr)
);
```

The compiler is prepared to reload this register next time it uses it. Another problem with the above code is, that it should not be called in code sections, where interrupts are disabled and should be kept disabled, because it will enable interrupts at the end. We may store the current status, but then we need another register. Again we can solve this without clobbering a fixed, but let the compiler select it. This could be done with the help of a local C variable.

```
{
    uint8_t s;
    asm volatile(
        "in %0, __SREG__"           "\n\t"
        "cli"                       "\n\t"
        "ld __tmp_reg__, %a1"       "\n\t"
        "inc __tmp_reg__"           "\n\t"
        "st %a1, __tmp_reg__"       "\n\t"
        "out __SREG__, %0"          "\n\t"
        : "=&r" (s)
        : "e" (ptr)
    );
}
```

Now every thing seems correct, but it isn't really. The assembler code modifies the variable, that `ptr` points to. The compiler will not recognize this and may keep its value in any of the other registers. Not only does the compiler work with the wrong value, but the assembler code does too. The C program may have modified the value too, but the compiler didn't update the memory location for optimization reasons. The worst thing you can do in this case is:

```
{
    uint8_t s;
    asm volatile(
        "in %0, __SREG__"           "\n\t"
        "cli"                       "\n\t"
        "ld __tmp_reg__, %a1"       "\n\t"
        "inc __tmp_reg__"           "\n\t"
        "st %a1, __tmp_reg__"       "\n\t"
        "out __SREG__, %0"          "\n\t"
        : "=&r" (s)
        : "e" (ptr)
        : "memory"
    );
}
```

The special clobber "memory" informs the compiler that the assembler code may modify any memory location. It forces the compiler to update all variables for which the contents are currently held in a register before executing the assembler code. And of course, everything has to be reloaded again after this code.

In most situations, a much better solution would be to declare the pointer destination itself volatile:

```
volatile uint8_t *ptr;
```

This way, the compiler expects the value pointed to by `ptr` to be changed and will load it whenever used and store it whenever modified.

Situations in which you need clobbers are very rare. In most cases there will be better ways. Clobbered registers will force the compiler to store their values before and reload them after your assembler code. Avoiding clobbers gives the compiler more freedom while optimizing your code.

9.4.5 Assembler Macros

In order to reuse your assembler language parts, it is useful to define them as macros and put them into include files. AVR Libc comes with a bunch of them, which could be found in the directory `avr/include`. Using such include files may produce compiler warnings, if they are used in modules, which are compiled in strict ANSI mode. To avoid that, you can write `__asm__` instead of `asm` and `__volatile__` instead of `volatile`. These are equivalent aliases.

Another problem with reused macros arises if you are using labels. In such cases you may make use of the special pattern `=`, which is replaced by a unique number on each `asm` statement. The following code had been taken from `avr/include/iomacros.h`:

```
#define loop_until_bit_is_clear(port,bit)  \
        __asm__ __volatile__ (             \
        "L_%=: " "sbic %0, %1" "\n\t"      \
                 "rjmp L_%="               \
                 : /* no outputs */        \
                 : "I" (_SFR_IO_ADDR(port)),  \
                   "I" (bit)    \
        )
```

When used for the first time, `L_%=` may be translated to `L_1404`, the next usage might create `L_1405` or whatever. In any case, the labels became unique too.

Another option is to use Unix-assembler style numeric labels. They are explained in **How do I trace an assembler file in avr-gdb?**(p. 138). The above example would then look like:

```
#define loop_until_bit_is_clear(port,bit)  \
        __asm__ __volatile__ (             \
        "1: " "sbic %0, %1" "\n\t"      \
                 "rjmp 1b"               \
                 : /* no outputs */        \
                 : "I" (_SFR_IO_ADDR(port)),  \
                   "I" (bit)    \
        )
```

9.4.6 C Stub Functions

Macro definitions will include the same assembler code whenever they are referenced. This may not be acceptable for larger routines. In this case you may define a C stub function, containing nothing other than your assembler code.

```
void delay(uint8_t ms)
{
    uint16_t cnt;
    asm volatile (
        "\n"
        "L_dl1%=:" "\n\t"
        "mov %A0, %A2" "\n\t"
        "mov %B0, %B2" "\n"
        "L_dl2%=:" "\n\t"
        "sbiw %A0, 1" "\n\t"
        "brne L_dl2%=" "\n\t"
        "dec %1" "\n\t"
        "brne L_dl1%=" "\n\t"
        : "=&w" (cnt)
        : "r" (ms), "r" (delay_count)
        );
}
```

The purpose of this function is to delay the program execution by a specified number of milliseconds using a counting loop. The global 16 bit variable delay_-count must contain the CPU clock frequency in Hertz divided by 4000 and must have been set before calling this routine for the first time. As described in the **clobber**(p. 160) section, the routine uses a local variable to hold a temporary value.

Another use for a local variable is a return value. The following function returns a 16 bit value read from two successive port addresses.

```
uint16_t inw(uint8_t port)
{
    uint16_t result;
    asm volatile (
        "in %A0,%1" "\n\t"
        "in %B0,(%1) + 1"
        : "=r" (result)
        : "I" (_SFR_IO_ADDR(port))
        );
    return result;
}
```

Note:

inw() is supplied by avr-libc.

9.4.7 C Names Used in Assembler Code

By default `AVR-GCC` uses the same symbolic names of functions or variables in C and assembler code. You can specify a different name for the assembler code by using a special form of the `asm` statement:

```
unsigned long value asm("clock") = 3686400;
```

This statement instructs the compiler to use the symbol name clock rather than value. This makes sense only for external or static variables, because local variables do not have symbolic names in the assembler code. However, local variables may be held in registers.

With `AVR-GCC` you can specify the use of a specific register:

```
void Count(void)
{
    register unsigned char counter asm("r3");

    ... some code...
    asm volatile("clr r3");
    ... more code...
}
```

The assembler instruction, `"clr r3"`, will clear the variable counter. `AVR-GCC` will not completely reserve the specified register. If the optimizer recognizes that the variable will not be referenced any longer, the register may be re-used. But the compiler is not able to check wether this register usage conflicts with any predefined register. If you reserve too many registers in this way, the compiler may even run out of registers during code generation.

In order to change the name of a function, you need a prototype declaration, because the compiler will not accept the `asm` keyword in the function definition:

```
extern long Calc(void) asm ("CALCULATE");
```

Calling the function `Calc()` will create assembler instructions to call the function `CALCULATE`.

9.4.8 Links

For a more thorough discussion of inline assembly usage, see the gcc user manual. The latest version of the gcc manual is always available here: `http://gcc.gnu.org/onlinedocs/`

9.5 Using malloc()

9.5.1 Introduction

On a simple device like a microcontroller, implementing dynamic memory allocation is quite a challenge.

Many of the devices that are possible targets of avr-libc have a minimal amount of RAM. The smallest parts supported by the C environment come with 128 bytes of RAM. This needs to be shared between initialized and uninitialized variables (**sections**(p. 173) .data and .bss), the dynamic memory allocator, and the stack that is used for calling subroutines and storing local (automatic) variables.

Also, unlike larger architectures, there is no hardware-supported memory management which could help in separating the mentioned RAM regions from being overwritten by each other.

The standard RAM layout is to place .data variables first, from the beginning of the internal RAM, followed by .bss. The stack is started from the top of internal RAM, growing downwards. The so-called "heap" available for the dynamic memory allocator will be placed beyond the end of .bss. Thus, there's no risk that dynamic memory will ever collide with the RAM variables (unless there were bugs in the implementation of the allocator). There is still a risk that the heap and stack could collide if there are large requirements for either dynamic memory or stack space. The former can even happen if the allocations aren't all that large but dynamic memory allocations get fragmented over time such that new requests don't quite fit into the "holes" of previously freed regions. Large stack space requirements can arise in a C function containing large and/or numerous local variables or when recursively calling function.

Note:

The pictures shown in this document represent typical situations where the RAM locations refer to an ATmega128. The memory addresses used are not displayed in a linear scale.

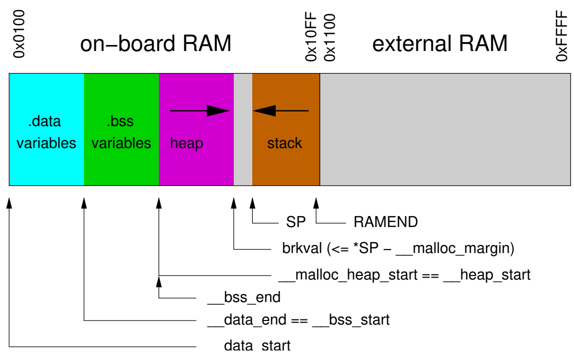

Figure 2: RAM map of a device with internal RAM

Finally, there's a challenge to make the memory allocator simple enough so the code size requirements will remain low, yet powerful enough to avoid unnecessary memory fragmentation and to get it all done with reasonably few CPU cycles since microcontrollers aren't only often low on space, but also run at much lower speeds than the typical PC these days.

The memory allocator implemented in avr-libc tries to cope with all of these constraints, and offers some tuning options that can be used if there are more resources available than in the default configuration.

9.5.2 Internal vs. external RAM

Obviously, the constraints are much harder to satisfy in the default configuration where only internal RAM is available. Extreme care must be taken to avoid a stack-heap collision, both by making sure functions aren't nesting too deeply, and don't require too much stack space for local variables, as well as by being cautious with allocating too much dynamic memory.

If external RAM is available, it is strongly recommended to move the heap into the external RAM, regardless of whether or not the variables from the .data and .bss sections are also going to be located there. The stack should always be kept in internal RAM. Some devices even require this, and in general, internal RAM can be accessed faster since no extra wait states are required. When using dynamic memory allocation and stack and heap are separated in distinct memory areas, this is the safest way to avoid a stack-heap collision.

9.5.3 Tunables for malloc()

There are a number of variables that can be tuned to adapt the behavior of **malloc()**(p. 65) to the expected requirements and constraints of the application. Any changes to these tunables should be made before the very first call to **malloc()**(p. 65). Note that some library functions might also use dynamic memory (notably those from the **Standard IO facilities**(p. 43)), so make sure the changes will be done early enough in the startup sequence.

The variables `__malloc_heap_start` and `__malloc_heap_end` can be used to restrict the **malloc()**(p. 65) function to a certain memory region. These variables are statically initialized to point to `__heap_start` and `__heap_end`, respectively, where `__heap_start` is filled in by the linker to point just beyond .bss, and `__heap_end` is set to 0 which makes **malloc()**(p. 65) assume the heap is below the stack.

If the heap is going to be moved to external RAM, `__malloc_heap_end` *must* be adjusted accordingly. This can either be done at run-time, by writing directly to this variable, or it can be done automatically at link-time, by adjusting the value of the symbol `__heap_end`.

The following example shows a linker command to relocate the entire .data and .bss segments, and the heap to location 0x1100 in external RAM. The heap will extend up to address 0xffff.

```
avr-gcc ... -Wl,-Tdata=0x801100,--defsym=__heap_end=0x80ffff ...
```

Note:

See **explanation**(p. 174) for offset 0x800000. See the chapter about **using gcc**(p. 190) for the `-Wl` options.

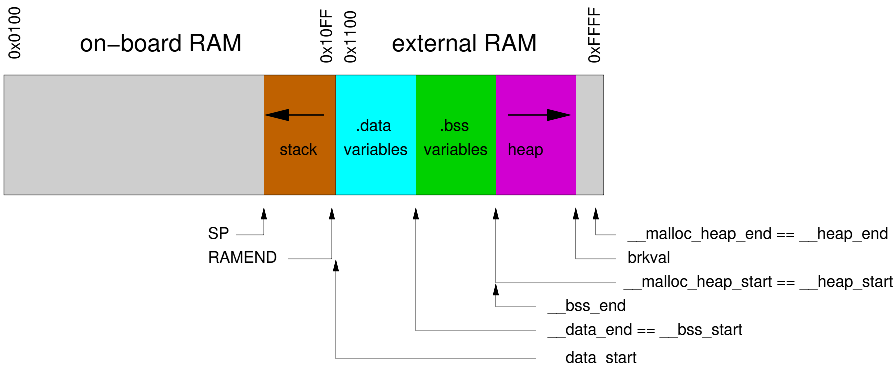

Figure 3: Internal RAM: stack only, external RAM: variables and heap

If dynamic memory should be placed in external RAM, while keeping the variables in internal RAM, something like the following could be used. Note that for demonstration purposes, the assignment of the various regions has not been made adjacent in this example, so there are "holes" below and above the heap in external RAM that remain completely unaccessible by regular variables or dynamic memory allocations (shown in light bisque color in the picture below).

```
avr-gcc ... -Wl,--defsym=__heap_start=0x802000,--defsym=__heap_end=0x803fff ...
```

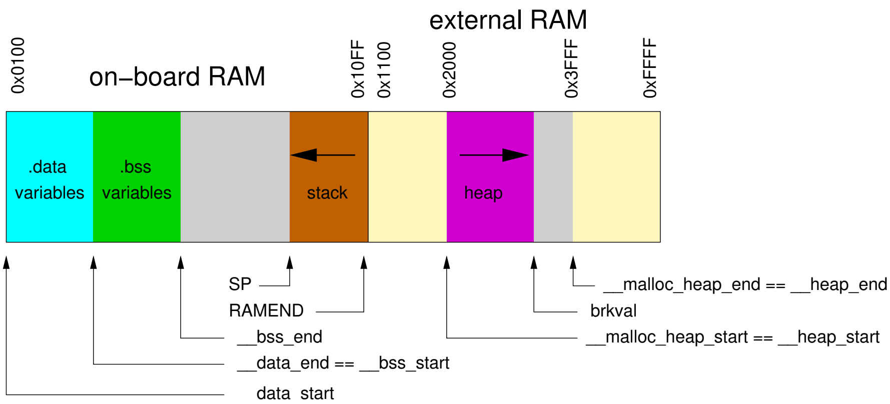

Figure 4: Internal RAM: variables and stack, external RAM: heap

If `__malloc_heap_end` is 0, the allocator attempts to detect the bottom of stack in order to prevent a stack-heap collision when extending the actual size of the heap to gain more space for dynamic memory. It will not try to go beyond the current stack limit, decreased by `__malloc_margin` bytes. Thus, all possible stack frames of interrupt routines that could interrupt the current function, plus all further nested function calls must not require more stack space, or they will risk colliding with the data segment.

The default value of `__malloc_margin` is set to 32.

9.5.4 Implementation details

Dynamic memory allocation requests will be returned with a two-byte header prepended that records the size of the allocation. This is later used by **free()**(p. 64). The returned address points just beyond that header. Thus, if the application accidentally writes before the returned memory region, the internal consistency of the memory allocator is compromised.

The implementation maintains a simple freelist that accounts for memory blocks that have been returned in previous calls to **free()**(p. 64). Note that all of this memory is considered to be successfully added to the heap already, so no further checks against stack-heap collisions are done when recycling memory from the freelist.

The freelist itself is not maintained as a separate data structure, but rather by modifying the contents of the freed memory to contain pointers chaining the pieces together. That way, no additional memory is reqired to maintain this list except for a variable that keeps track of the lowest memory segment available for reallocation. Since both, a chain pointer and the size of the chunk need to be recorded in each chunk, the minimum chunk size on the freelist is four bytes.

When allocating memory, first the freelist is walked to see if it could satisfy the request. If there's a chunk available on the freelist that will fit the request exactly, it will be taken, disconnected from the freelist, and returned to the caller. If no exact match could be found, the closest match that would just satisfy the request will be used. The chunk will normally be split up into one to be returned to the caller, and another (smaller) one that will remain on the freelist. In case this chunk was only up to two bytes larger than the request, the request will simply be altered internally to also account for these additional bytes since no separate freelist entry could be split off in that case.

If nothing could be found on the freelist, heap extension is attempted. This is where `__malloc_margin` will be considered if the heap is operating below the stack, or where `__malloc_heap_end` will be verified otherwise.

If the remaining memory is insufficient to satisfy the request, `NULL` will eventually be returned to the caller.

When calling **free()**(p. 64), a new freelist entry will be prepared. An attempt is then made to aggregate the new entry with possible adjacent entries, yielding a single larger entry available for further allocations. That way, the potential for heap fragmentation is hopefully reduced.

A call to **realloc()**(p. 67) first determines whether the operation is about to grow or shrink the current allocation. When shrinking, the case is easy: the existing chunk is split, and the tail of the region that is no longer to be used is passed to the standard **free()**(p. 64) function for insertion into the freelist. Checks are first made whether the tail chunk is large enough to hold a chunk of its own at all, otherwise **realloc()**(p. 67) will simply do nothing, and return the original region.

When growing the region, it is first checked whether the existing allocation can be extended in-place. If so, this is done, and the original pointer is returned without copying any data contents. As a side-effect, this check will also record the size of the largest chunk on the freelist.

If the region cannot be extended in-place, but the old chunk is at the top of heap, and the above freelist walk did not reveal a large enough chunk on the freelist to satisfy the new request, an attempt is made to quickly extend this topmost chunk (and thus the heap), so no need arises to copy over the existing data. If there's no more space available in the heap (same check is done as in **malloc()**(p. 65)), the entire request will fail.

Otherwise, **malloc()**(p. 65) will be called with the new request size, the existing data will be copied over, and **free()**(p. 64) will be called on the old region.

9.6 Release Numbering and Methodology

9.6.1 Release Version Numbering Scheme

9.6.1.1 Stable Versions A stable release will always have a minor number that is an even number. This implies that you should be able to upgrade to a new version of the library with the same major and minor numbers without fear that any of the APIs have changed. The only changes that should be made to a stable branch are bug fixes and under some circumstances, additional functionality (e.g. adding support for a new device).

If major version number has changed, this implies that the required versions of gcc and binutils have changed. Consult the README file in the toplevel directory of the AVR Libc source for which versions are required.

9.6.1.2 Development Versions The major version number of a development series is always the same as the last stable release.

The minor version number of a development series is always an odd number and is 1 more than the last stable release.

The patch version number of a development series is always 0 until a new branch is cut at which point the patch number is changed to 90 to denote the branch is approaching a release and the date appended to the version to denote that it is still in development.

All versions in development in cvs will also always have the date appended as a fourth version number. The format of the date will be YYYYMMDD.

So, the development version number will look like this:

```
1.1.0.20030825
```

While a pre-release version number on a branch (destined to become either 1.2 or 2.0) will look like this:

```
1.1.90.20030828
```

9.6.2 Releasing AVR Libc

The information in this section is only relevant to AVR Libc developers and can be ignored by end users.

Note:

In what follows, I assume you know how to use cvs and how to checkout multiple source trees in a single directory without having them clobber each other. If you don't know how to do this, you probably shouldn't be making releases or cutting branches.

9.6.2.1 Creating a cvs branch The following steps should be taken to cut a branch in cvs:

1. Check out a fresh source tree from cvs HEAD.
2. Update the NEWS file with pending release number and commit to cvs HEAD:

   Change "Changes since avr-libc-<last_release>:" to "Changes in avr-libc-<this_relelase>:".
3. Set the branch-point tag (setting <major> and <minor> accordingly):

   'cvs tag avr-libc-<major>_<minor>-branchpoint'
4. Create the branch:

   'cvs tag -b avr-lib-<major>_<minor>-branch'

5. Update the package version in configure.in and commit configure.in to cvs HEAD:

   Change minor number to next odd value.

6. Update the NEWS file and commit to cvs HEAD:

   Add "Changes since avr-libc-<this_release>:"

7. Check out a new tree for the branch:

   'cvs co -r avr-lib-<major>_<minor>-branch'

8. Update the package version in configure.in and commit configure.in to cvs branch:

   Change the patch number to 90 to denote that this now a branch leading up to a release. Be sure to leave the <date> part of the version.

9. Bring the build system up to date by running reconf and doconf.

10. Perform a 'make distcheck' and make sure it succeeds. This will create the snapshot source tarball. This should be considered the first release candidate.

11. Upload the snapshot tarball to savannah.

12. Announce the branch and the branch tag to the avr-libc-dev list so other developers can checkout the branch.

Note:

CVS tags do not allow the use of periods ('.').

9.6.2.2 Making a release A stable release will only be done on a branch, not from the cvs HEAD.

The following steps should be taken when making a release:

1. Make sure the source tree you are working from is on the correct branch:

   'cvs update -r avr-lib-<major>_<minor>-branch'

2. Update the package version in configure.in and commit it to cvs.

3. Update the gnu tool chain version requirements in the README and commit to cvs.

4. Update the ChangeLog file to note the release and commit to cvs on the branch:

   Add "Released avr-libc-<this_release>."

5. Bring the build system up to date by running reconf and doconf.

6. Perform a 'make distcheck' and make sure it succeeds. This will create the source tarball.
7. Tag the release (_<patch> is not given if this is the first release on this branch):

   'cvs tag avr-lib-<major>_<minor>_<patch>-release'
8. Upload the tarball to savannah.
9. Generate the latest documentation and upload to savannah.
10. Announce the release.

The following hypothetical diagram should help clarify version and branch relationships.

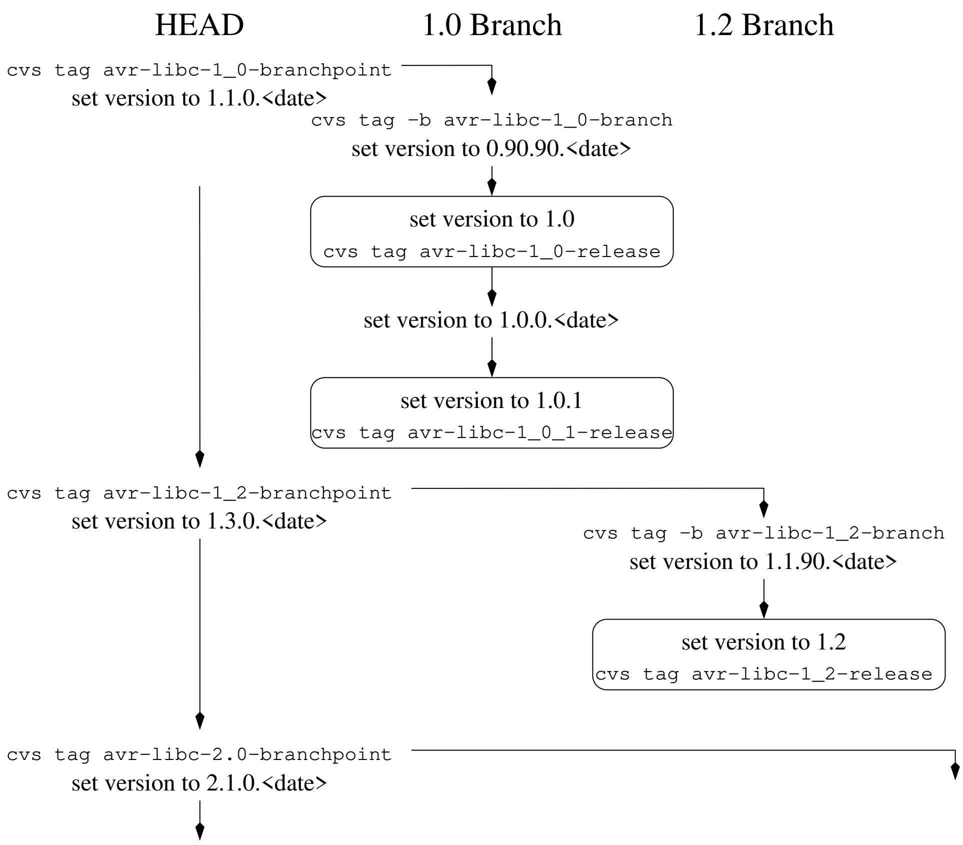

Figure 5: Release tree

9.7 Memory Sections

Remarks:
Need to list all the sections which are available to the avr.

Weak Bindings
FIXME: need to discuss the .weak directive.

The following describes the various sections available.

9.7.1 The .text Section

The .text section contains the actual machine instructions which make up your program. This section is further subdivided by the .initN and .finiN sections dicussed below.

Note:
The `avr-size` program (part of binutils), coming from a Unix background, doesn't account for the .data initialization space added to the .text section, so in order to know how much flash the final program will consume, one needs to add the values for both, .text and .data (but not .bss), while the amount of pre-allocated SRAM is the sum of .data and .bss.

9.7.2 The .data Section

This section contains static data which was defined in your code. Things like the following would end up in .data:

```
char err_str[] = "Your program has died a horrible death!";

struct point pt = { 1, 1 };
```

It is possible to tell the linker the SRAM address of the beginning of the .data section. This is accomplished by adding `-Wl,-Tdata,`*`addr`* to the `avr-gcc` command used to the link your program. Not that `addr` must be offset by adding 0x800000 the to real SRAM address so that the linker knows that the address is in the SRAM memory space. Thus, if you want the .data section to start at 0x1100, pass 0x801100 at the address to the linker. [offset **explained**(p. 174)]

Note:
When using **malloc()**(p. 65) in the application (which could even happen inside library calls), **additional adjustments**(p. 166) are required.

9.7.3 The .bss Section

Uninitialized global or static variables end up in the .bss section.

9.7.4 The .eeprom Section

This is where eeprom variables are stored.

9.7.5 The .noinit Section

This sections is a part of the .bss section. What makes the .noinit section special is that variables which are defined as such:

```
int foo __attribute__ ((section (".noinit")));
```

will not be initialized to zero during startup as would normal .bss data.

Only uninitialized variables can be placed in the .noinit section. Thus, the following code will cause `avr-gcc` to issue an error:

```
int bar __attribute__ ((section (".noinit"))) = 0xaa;
```

It is possible to tell the linker explicitly where to place the .noinit section by adding `-Wl,-section-start=.noinit=0x802000` to the `avr-gcc` command line at the linking stage. For example, suppose you wish to place the .noinit section at SRAM address 0x2000:

```
$ avr-gcc ... -Wl,--section-start=.noinit=0x802000 ...
```

Note:

Because of the Harvard architecture of the AVR devices, you must manually add 0x800000 to the address you pass to the linker as the start of the section. Otherwise, the linker thinks you want to put the .noinit section into the .text section instead of .data/.bss and will complain.

Alternatively, you can write your own linker script to automate this. [FIXME: need an example or ref to dox for writing linker scripts.]

9.7.6 The .initN Sections

These sections are used to define the startup code from reset up through the start of main(). These all are subparts of the **.text section**(p. 173).

The purpose of these sections is to allow for more specific placement of code within your program.

Note:

Sometimes, it is convenient to think of the .initN and .finiN sections as functions, but in reality they are just symbolic names which tell the linker where to stick a chunk of code which is *not* a function. Notice that the examples for **asm**(p. 176) and **C**(p. 177) can not be called as functions and should not be jumped into.

The **.initN** sections are executed in order from 0 to 9.

.init0:
Weakly bound to __init(). If user defines __init(), it will be jumped into immediately after a reset.

.init1:
Unused. User definable.

.init2:
In C programs, weakly bound to initialize the stack, and to clear __zero_reg__ (r1).

.init3:
Unused. User definable.

.init4:

Copies the .data section from flash to SRAM. Also sets up and zeros out the .bss section. In Unix-like targets, .data is normally initialized by the OS directly from the executable file. Since this is impossible in an MCU environment, `avr-gcc` instead takes care of appending the .data variables after .text in the flash ROM image. .init4 then defines the code (weakly bound) which takes care of copying the contents of .data from the flash to SRAM.

.init5:
Unused. User definable.

.init6:
Unused for C programs, but used for constructors in C++ programs.

.init7:
Unused. User definable.

.init8:
Unused. User definable.

.init9:
Jumps into main().

9.7.7 The .finiN Sections

These sections are used to define the exit code executed after return from main() or a call to **exit()**(p. 64). These all are subparts of the **.text section**(p. 173).

The **.finiN** sections are executed in descending order from 9 to 0.

.finit9:
Unused. User definable. This is effectively where _exit() starts.

.fini8:
Unused. User definable.

.fini7:
Unused. User definable.

.fini6:
Unused for C programs, but used for destructors in C++ programs.

.fini5:
Unused. User definable.

.fini4:
Unused. User definable.

.fini3:
Unused. User definable.

.fini2:
Unused. User definable.

.fini1:
Unused. User definable.

.fini0:
Goes into an infinite loop after program termination and completion of any _exit() code (execution of code in the .fini9 -> .fini1 sections).

9.7.8 Using Sections in Assembler Code

Example:

```
#include <avr/io.h>

        .section .init1,"ax",@progbits
        ldi       r0, 0xff
        out       _SFR_IO_ADDR(PORTB), r0
        out       _SFR_IO_ADDR(DDRB), r0
```

Note:

The `,"ax",@progbits` tells the assembler that the section is allocatable ("a"), executable ("x") and contains data ("@progbits"). For more detailed information on the .section directive, see the gas user manual.

9.7.9 Using Sections in C Code

Example:

```
#include <avr/io.h>

void my_init_portb (void) __attribute__ ((naked)) \
    __attribute__ ((section (".init1")));

void
my_init_portb (void)
{
        PORTB = 0xff;
        DDRB = 0xff;
}
```

9.8 Installing the GNU Tool Chain

Note:

This discussion was taken directly from Rich Neswold's document. (See **Acknowledgments**(p. 123)).

This discussion is Unix specific. [FIXME: troth/2002-08-13: we need a volunteer to add windows specific notes to these instructions.]

This chapter shows how to build and install a complete development environment for the AVR processors using the GNU toolset.

The default behaviour for most of these tools is to install every thing under the `/usr/local` directory. In order to keep the AVR tools separate from the base system, it is usually better to install everything into `/usr/local/avr`. If the `/usr/local/avr` directory does not exist, you should create it before trying to install anything. You will need `root` access to install there. If you don't have root access to the system, you can alternatively install in your home directory, for example, in `$HOME/local/avr`. Where you install is a completely arbitrary decision, but should be consistent for all the tools.

You specify the installation directory by using the `-prefix=dir` option with the `configure` script. It is important to install all the AVR tools in the same directory or some of the tools will not work correctly. To ensure consistency and simplify the discussion, we will use `$PREFIX` to refer to whatever directory you wish to install in. You can set this as an environment variable if you wish as such (using a Bourne-like shell):

```
$ PREFIX=$HOME/local/avr
$ export PREFIX
```

Note:

Be sure that you have your `PATH` environment variable set to search the directory you install everything in *before* you start installing anything. For example, if you use `-prefix=$PREFIX`, you must have `$PREFIX/bin` in your exported `PATH`. As such:

```
$ PATH=$PATH:$PREFIX/bin
$ export PATH
```

Warning:

If you have `CC` set to anything other than `avr-gcc` in your environment, this will cause the configure script to fail. It is best to not have `CC` set at all.

Note:

It is usually the best to use the latest released version of each of the tools.

9.8.1 Required Tools

- **GNU Binutils**

  `http://sources.redhat.com/binutils/`

  Installation(p. 179)

- **GCC**

  `http://gcc.gnu.org/`

  Installation(p. 180)

- **AVR Libc**

  `http://savannah.gnu.org/projects/avr-libc/`

  Installation(p. 181)

9.8.2 Optional Tools

You can develop programs for AVR devices without the following tools. They may or may not be of use for you.

- **uisp**

  `http://savannah.gnu.org/projects/uisp/`

  Installation(p. 182)

- **avrdude**
  http://savannah.nongnu.org/projects/avrdude/
  Installation(p. 182)
  Usage Notes(p. 184)

- **GDB**
  http://sources.redhat.com/gdb/
  Installation(p. 182)

- **Simulavr**
  http://savannah.gnu.org/projects/simulavr/
  Installation(p. 183)

- **AVaRice**
  http://avarice.sourceforge.net/
  Installation(p. 183)

9.8.3 GNU Binutils for the AVR target

The **binutils** package provides all the low-level utilities needed in building and manipulating object files. Once installed, your environment will have an AVR assembler (`avr-as`), linker (`avr-ld`), and librarian (`avr-ar` and `avr-ranlib`). In addition, you get tools which extract data from object files (`avr-objcopy`), dissassemble object file information (`avr-objdump`), and strip information from object files (`avr-strip`). Before we can build the C compiler, these tools need to be in place.

Download and unpack the source files:

```
$ bunzip2 -c binutils-<version>.tar.bz2 | tar xf -
$ cd binutils-<version>
```

Note:
Replace

with the version of the package you downloaded.

Note:
If you obtained a gzip compressed file (.gz), use `gunzip` instead of `bunzip2`.

It is usually a good idea to configure and build **binutils** in a subdirectory so as not to pollute the source with the compiled files. This is recommended by the **binutils** developers.

```
$ mkdir obj-avr
$ cd obj-avr
```

The next step is to configure and build the tools. This is done by supplying arguments to the `configure` script that enable the AVR-specific options.

```
$ ../configure --prefix=$PREFIX --target=avr --disable-nls
```

If you don't specify the `-prefix` option, the tools will get installed in the `/usr/local` hierarchy (i.e. the binaries will get installed in `/usr/local/bin`, the info pages get installed in `/usr/local/info`, etc.) Since these tools are changing frequently, It is preferrable to put them in a location that is easily removed.

When `configure` is run, it generates a lot of messages while it determines what is available on your operating system. When it finishes, it will have created several `Makefile`s that are custom tailored to your platform. At this point, you can build the project.

```
$ make
```

Note:

BSD users should note that the project's `Makefile` uses GNU `make` syntax. This means FreeBSD users may need to build the tools by using `gmake`.

If the tools compiled cleanly, you're ready to install them. If you specified a destination that isn't owned by your account, you'll need `root` access to install them. To install:

```
$ make install
```

You should now have the programs from binutils installed into `$PREFIX/bin`. Don't forget to **set your PATH**(p. 178) environment variable before going to build avr-gcc.

9.8.4 GCC for the AVR target

Warning:

You **must** install **avr-binutils**(p. 179) and make sure your **path is set**(p. 178) properly before installing avr-gcc.

The steps to build `avr-gcc` are essentially same as for **binutils**(p. 179):

```
$ bunzip2 -c gcc-<version>.tar.bz2 | tar xf -
$ cd gcc-<version>
```

```
$ mkdir obj-avr
$ cd obj-avr
$ ../configure --prefix=$PREFIX --target=avr --enable-languages=c,c++ \
    --disable-nls
$ make
$ make install
```

To save your self some download time, you can alternatively download only the `gcc-core-<version>.tar.bz2` and `gcc-c++-<version>.tar.bz2` parts of the gcc. Also, if you don't need C++ support, you only need the core part and should only enable the C language support.

Note:

Early versions of these tools did not support C++.
The stdc++ libs are not included with C++ for AVR due to the size limitations of the devices.

9.8.5 AVR Libc

Warning:

You **must** install **avr-binutils**(p. 179), **avr-gcc**(p. 180) and make sure your **path is set**(p. 178) properly before installing avr-libc.

Note:

If you have obtained the latest avr-libc from cvs, you will have to run the `reconf` script before using either of the build methods described below.

To build and install avr-libc:

```
$ gunzip -c avr-libc-<version>.tar.gz
$ cd avr-libc-<version>
$ ./doconf
$ ./domake
$ cd build
$ make install
```

Note:

The `doconf` script will automatically use the `$PREFIX` environment variable if you have set and exported it.

Alternatively, you could do this (shown for consistency with `binutils` and `gcc`):

```
$ gunzip -c avr-libc-<version>.tar.gz | tar xf -
$ cd avr-libc-<version>
$ mkdir obj-avr
$ cd obj-avr
$ ../configure --prefix=$PREFIX
$ make
$ make install
```

9.8.6 UISP

Uisp also uses the `configure` system, so to build and install:

```
$ gunzip -c uisp-<version>.tar.gz | tar xf -
$ cd uisp-<version>
$ mkdir obj-avr
$ cd obj-avr
$ ../configure --prefix=$PREFIX
$ make
$ make install
```

9.8.7 Avrdude

Note:

It has been ported to windows (via cygwin) and linux. Other unix systems should be trivial to port to.

avrdude is part of the FreeBSD ports system. To install it, simply do the following:

```
# cd /usr/ports/devel/avrdude
# make install
```

Note:

Installation into the default location usually requires root permissions. However, running the program only requires access permissions to the appropriate `ppi(4)` device.

Building and installing on other systems should use the `configure` system, as such:

```
$ gunzip -c avrdude-<version>.tar.gz | tar xf -
$ cd avrdude-<version>
$ mkdir obj-avr
$ cd obj-avr
$ ../configure --prefix=$PREFIX
$ make
$ make install
```

9.8.8 GDB for the AVR target

Gdb also uses the `configure` system, so to build and install:

```
$ bunzip2 -c gdb-<version>.tar.bz2 | tar xf -
$ cd gdb-<version>
$ mkdir obj-avr
```

```
$ cd obj-avr
$ ../configure --prefix=$PREFIX --target=avr
$ make
$ make install
```

Note:

If you are planning on using `avr-gdb`, you will probably want to install either **simulavr**(p. 183) or **avarice**(p. 183) since avr-gdb needs one of these to run as a a remote target backend.

9.8.9 Simulavr

Simulavr also uses the `configure` system, so to build and install:

```
$ gunzip -c simulavr-<version>.tar.gz | tar xf -
$ cd simulavr-<version>
$ mkdir obj-avr
$ cd obj-avr
$ ../configure --prefix=$PREFIX
$ make
$ make install
```

Note:

You might want to have already installed **avr-binutils**(p. 179), **avr-gcc**(p. 180) and **avr-libc**(p. 181) if you want to have the test programs built in the simulavr source.

9.8.10 AVaRice

Note:

These install notes are not applicable to avarice-1.5 or older. You probably don't want to use anything that old anyways since there have been many improvements and bug fixes since the 1.5 release.

AVaRice also uses the `configure` system, so to build and install:

```
$ gunzip -c avarice-<version>.tar.gz | tar xf -
$ cd avarice-<version>
$ mkdir obj-avr
$ cd obj-avr
$ ../configure --prefix=$PREFIX
$ make
$ make install
```

Note:

AVaRice uses the bfd library for accessing various binary file formats. You may need to tell the configure script where to find the lib and headers for the link to work. This is usually done by invoking the configure script like this (Replace <`hdr_path`> with the path to the `bfd.h` file on your system. Replace <`lib_path`> with the path to `libbfd.a` on your system.):

```
$ CPPFLAGS=-I<hdr_path> LDFLAGS=-L<lib_path> ../configure --prefix=$PREFIX
```

9.9 Using the avrdude program

Note:

This section was contributed by Brian Dean [`bsd@bsdhome.com`].

The avrdude program was previously called avrprog. The name was changed to avoid confusion with the avrprog program that Atmel ships with AvrStudio.

`avrdude` is a program that is used to update or read the flash and EEPROM memories of Atmel AVR microcontrollers on FreeBSD Unix. It supports the Atmel serial programming protocol using the PC's parallel port and can upload either a raw binary file or an Intel Hex format file. It can also be used in an interactive mode to individually update EEPROM cells, fuse bits, and/or lock bits (if their access is supported by the Atmel serial programming protocol.) The main flash instruction memory of the AVR can also be programmed in interactive mode, however this is not very useful because one can only turn bits off. The only way to turn flash bits on is to erase the entire memory (using `avrdude`'s `-e` option).

`avrdude` is part of the FreeBSD ports system. To install it, simply do the following:

```
# cd /usr/ports/devel/avrdude
# make install
```

Once installed, `avrdude` can program processors using the contents of the .hex file specified on the command line. In this example, the file `main.hex` is burned into the flash memory:

```
# avrdude -p 2313 -e -m flash -i main.hex

avrdude: AVR device initialized and ready to accept instructions

avrdude: Device signature = 0x1e9101

avrdude: erasing chip
avrdude: done.
avrdude: reading input file "main.hex"
avrdude: input file main.hex auto detected as Intel Hex

avrdude: writing flash:
1749 0x00
avrdude: 1750 bytes of flash written
```

```
avrdude: verifying flash memory against main.hex:
avrdude: reading on-chip flash data:
1749  0x00
avrdude: verifying ...
avrdude: 1750 bytes of flash verified

avrdude done.  Thank you.
```

The -p 2313 option lets avrdude know that we are operating on an AT90S2313 chip. This option specifies the device id and is matched up with the device of the same id in avrdude's configuration file (/usr/local/etc/avrdude.conf). To list valid parts, specify the -v option. The -e option instructs avrdude to perform a chip-erase before programming; this is almost always necessary before programming the flash. The -m flash option indicates that we want to upload data into the flash memory, while -i main.hex specifies the name of the input file.

The EEPROM is uploaded in the same way, the only difference is that you would use -m eeprom instead of -m flash.

To use interactive mode, use the -t option:

```
# avrdude -p 2313 -t
avrdude: AVR device initialized and ready to accept instructions
avrdude: Device signature = 0x1e9101
avrdude>

The '?' command displays a list of valid
commands:

avrdude> ?
>>> ?
Valid commands:

  dump   : dump memory  : dump <memtype> <addr> <N-Bytes>
  read   : alias for dump
  write  : write memory : write <memtype> <addr> <b1> <b2> ... <bN>
  erase  : perform a chip erase
  sig    : display device signature bytes
  part   : display the current part information
  send   : send a raw command : send <b1> <b2> <b3> <b4>
  help   : help
  ?      : help
  quit   : quit

Use the 'part' command to display valid memory types for use with the
'dump' and 'write' commands.

avrdude>
```

9.10 Using the GNU tools

This is a short summary of the AVR-specific aspects of using the GNU tools. Normally, the generic documentation of these tools is fairly large and maintained in `texinfo` files. Command-line options are explained in detail in the manual page.

9.10.1 Options for the C compiler avr-gcc

9.10.1.1 Machine-specific options for the AVR The following machine-specific options are recognized by the C compiler frontend.

- `-mmcu=`*architecture*

Compile code for *architecture*. Currently known architectures are

avr1	Simple CPU core, only assembler support
avr2	"Classic" CPU core, up to 8 KB of ROM
avr3	"Classic" CPU core, more than 8 KB of ROM
avr4	"Enhanced" CPU core, up to 8 KB of ROM
avr5	"Enhanced" CPU core, more than 8 KB of ROM

By default, code is generated for the avr2 architecture.

Note that when only using `-mmcu=`*architecture* but no `-mmcu=`*MCU type*, including the file <`avr/io.h`> cannot work since it cannot decide which device's definitions to select.

- `-mmcu=`*MCU type*

The following MCU types are currently understood by avr-gcc. The table matches them against the corresponding avr-gcc architecture name, and shows the preprocessor symbol declared by the `-mmcu` option.

Architecture	MCU name	Macro
avr1	at90s1200	__AVR_AT90S1200__
avr1	attiny11	__AVR_ATtiny11__
avr1	attiny12	__AVR_ATtiny12__
avr1	attiny15	__AVR_ATtiny15__
avr1	attiny28	__AVR_ATtiny28__

Architecture	MCU name	Macro
avr2	at90s2313	__AVR_AT90S2313__
avr2	at90s2323	__AVR_AT90S2323__
avr2	at90s2333	__AVR_AT90S2333__
avr2	at90s2343	__AVR_AT90S2343__
avr2	attiny22	__AVR_ATtiny22__
avr2	attiny26	__AVR_ATtiny26__
avr2	at90s4414	__AVR_AT90S4414__
avr2	at90s4433	__AVR_AT90S4433__
avr2	at90s4434	__AVR_AT90S4434__
avr2	at90s8515	__AVR_AT90S8515__
avr2	at90c8534	__AVR_AT90C8534__
avr2	at90s8535	__AVR_AT90S8535__
avr2	at86rf401	__AVR_AT86RF401__
avr2	attiny13	__AVR_ATtiny13__
avr2	attiny2313	__AVR_ATtiny2313__
avr3	atmega103	__AVR_ATmega103__
avr3	atmega603	__AVR_ATmega603__
avr3	at43usb320	__AVR_AT43USB320__
avr3	at43usb355	__AVR_AT43USB355__
avr3	at76c711	__AVR_AT76C711__
avr4	atmega48	__AVR_ATmega48__
avr4	atmega8	__AVR_ATmega8__
avr4	atmega8515	__AVR_ATmega8515__
avr4	atmega8535	__AVR_ATmega8535__
avr4	atmega88	__AVR_ATmega88__
avr5	at90can128	__AVR_AT90CAN128__
avr5	atmega128	__AVR_ATmega128__
avr5	atmega16	__AVR_ATmega16__
avr5	atmega161	__AVR_ATmega161__
avr5	atmega162	__AVR_ATmega162__
avr5	atmega163	__AVR_ATmega163__
avr5	atmega165	__AVR_ATmega165__
avr5	atmega168	__AVR_ATmega168__
avr5	atmega169	__AVR_ATmega169__
avr5	atmega32	__AVR_ATmega32__
avr5	atmega323	__AVR_ATmega323__
avr5	atmega325	__AVR_ATmega325__
avr5	atmega3250	__AVR_ATmega3250__
avr5	atmega64	__AVR_ATmega64__
avr5	atmega645	__AVR_ATmega645__
avr5	atmega6450	__AVR_ATmega6450__
avr5	at94k	__AVR_AT94K__

- -morder1
- -morder2

Change the order of register assignment. The default is

r24, r25, r18, r19, r20, r21, r22, r23, r30, r31, r26, r27, r28, r29, r17, r16, r15, r14, r13, r12, r11, r10, r9, r8, r7, r6, r5, r4, r3, r2, r0, r1

Order 1 uses

r18, r19, r20, r21, r22, r23, r24, r25, r30, r31, r26, r27, r28, r29, r17, r16, r15, r14, r13, r12, r11, r10, r9, r8, r7, r6, r5, r4, r3, r2, r0, r1

Order 2 uses

r25, r24, r23, r22, r21, r20, r19, r18, r30, r31, r26, r27, r28, r29, r17, r16, r15, r14, r13, r12, r11, r10, r9, r8, r7, r6, r5, r4, r3, r2, r1, r0

- -mint8

Assume `int` to be an 8-bit integer. Note that this is not really supported by `avr-libc`, so it should normally not be used. The default is to use 16-bit integers.

- -mno-interrupts

Generates code that changes the stack pointer without disabling interrupts. Normally, the state of the status register `SREG` is saved in a temporary register, interrupts are disabled while changing the stack pointer, and `SREG` is restored.

- -mcall-prologues

Use subroutines for function prologue/epilogue. For complex functions that use many registers (that needs to be saved/restored on function entry/exit), this saves some space at the cost of a slightly increased execution time.

- -minit-stack=*nnnn*

Set the initial stack pointer to *nnnn*. By default, the stack pointer is initialized to the symbol `__stack`, which is set to `RAMEND` by the run-time initialization code.

- -mtiny-stack

Change only the low 8 bits of the stack pointer.

- `-mno-tablejump`

Do not generate tablejump instructions. By default, jump tables can be used to optimize `switch` statements. When turned off, sequences of compare statements are used instead. Jump tables are usually faster to execute on average, but in particular for `switch` statements where most of the jumps would go to the default label, they might waste a bit of flash memory.

- `-mshort-calls`

Use `rjmp/rcall` (limited range) on >8K devices. On `avr2` and `avr4` architectures (less than 8 KB or flash memory), this is always the case. On `avr3` and `avr5` architectures, calls and jumps to targets outside the current function will by default use `jmp/call` instructions that can cover the entire address range, but that require more flash ROM and execution time.

- `-mrtl`

Dump the internal compilation result called "RTL" into comments in the generated assembler code. Used for debugging avr-gcc.

- `-msize`

Dump the address, size, and relative cost of each statement into comments in the generated assembler code. Used for debugging avr-gcc.

- `-mdeb`

Generate lots of debugging information to `stderr`.

9.10.1.2 Selected general compiler options The following general gcc options might be of some interest to AVR users.

- `-O`*n*

Optimization level n. Increasing n is meant to optimize more, an optimization level of 0 means no optimization at all, which is the default if no `-O` option is present. The special option `-Os` is meant to turn on all `-O2` optimizations that are not expected to increase code size.

Note that at `-O3`, gcc attempts to inline all "simple" functions. For the AVR target, this will normally constitute a large pessimization due to the code increasement. The only other optimization turned on with `-O3` is `-frename-registers`, which could rather be enabled manually instead.

A simple `-O` option is equivalent to `-O1`.

Note also that turning off all optimizations will prevent some warnings from being issued since the generation of those warnings depends on code analysis steps that are only performed when optimizing (unreachable code, unused variables).

See also the **appropriate FAQ entry**(p. 137) for issues regarding debugging optimized code.

- `-Wa,`*assembler-options*
- `-Wl,`*linker-options*

Pass the listed options to the assembler, or linker, respectively.

- `-g`

Generate debugging information that can be used by avr-gdb.

- `-ffreestanding`

Assume a "freestanding" environment as per the C standard. This turns off automatic builtin functions (though they can still be reached by prepending `__builtin_` to the actual function name). It also makes the compiler not complain when `main()` is declared with a `void` return type which makes some sense in a microcontroller environment where the application cannot meaningfully provide a return value to its environment (in most cases, `main()` won't even return anyway). However, this also turns off all optimizations normally done by the compiler which assume that functions known by a certain name behave as described by the standard. E. g., applying the function **strlen()**(p. 75) to a literal string will normally cause the compiler to immediately replace that call by the actual length of the string, while with `-ffreestanding`, it will always call **strlen()**(p. 75) at run-time.

- `-funsigned-char`

Make any unqualfied `char` type an unsigned char. Without this option, they default to a signed char.

- `-funsigned-bitfields`

Make any unqualified bitfield type unsigned. By default, they are signed.

- `-fshort-enums`

Allocate to an `enum` type only as many bytes as it needs for the declared range of possible values. Specifically, the enum type will be equivalent to the smallest integer type which has enough room.

- `-fpack-struct`

Pack all structure members together without holes.

9.10.2 Options for the assembler avr-as

9.10.2.1 Machine-specific assembler options

- `-mmcu=`*architecture*
- `-mmcu=`*MCU name*

avr-as understands the same `-mmcu=` options as **avr-gcc**(p. 186). By default, avr2 is assumed, but this can be altered by using the appropriate .arch pseudo-instruction inside the assembler source file.

- `-mall-opcodes`

Turns off opcode checking for the actual MCU type, and allows any possible AVR opcode to be assembled.

- `-mno-skip-bug`

Don't emit a warning when trying to skip a 2-word instruction with a `CPSE/SBIC/SBIS/SBRC/SBRS` instruction. Early AVR devices suffered from a hardware bug where these instructions could not be properly skipped.

- `-mno-wrap`

For `RJMP/RCALL` instructions, don't allow the target address to wrap around for devices that have more than 8 KB of memory.

- `-gstabs`

Generate .stabs debugging symbols for assembler source lines. This enables avr-gdb to trace through assembler source files. This option *must not* be used when assembling sources that have been generated by the C compiler; these files already contain the appropriate line number information from the C source files.

- -a[cdhlmns=*file*]

Turn on the assembler listing. The sub-options are:

- c omit false conditionals
- d omit debugging directives
- h include high-level source
- l include assembly
- m include macro expansions
- n omit forms processing
- s include symbols
- =*file* set the name of the listing file

The various sub-options can be combined into a single -a option list; =*file* must be the last one in that case.

9.10.2.2 Examples for assembler options passed through the C compiler

Remember that assembler options can be passed from the C compiler frontend using -Wa (see **above**(p. 190)), so in order to include the C source code into the assembler listing in file foo.lst, when compiling foo.c, the following compiler command-line can be used:

```
$ avr-gcc -c -O foo.c -o foo.o -Wa,-ahls=foo.lst
```

In order to pass an assembler file through the C preprocessor first, and have the assembler generate line number debugging information for it, the following command can be used:

```
$ avr-gcc -c -x assembler-with-cpp -o foo.o foo.S -Wa,--gstabs
```

Note that on Unix systems that have case-distinguishing file systems, specifying a file name with the suffix .S (upper-case letter S) will make the compiler automatically assume -x assembler-with-cpp, while using .s would pass the file directly to the assembler (no preprocessing done).

9.10.3 Controlling the linker avr-ld

9.10.3.1 Selected linker options While there are no machine-specific options for avr-ld, a number of the standard options might be of interest to AVR users.

- `-l`*name*

Locate the archive library named `lib`*name*`.a`, and use it to resolve currently unresolved symbols from it. The library is searched along a path that consists of builtin pathname entries that have been specified at compile time (e. g. `/usr/local/avr/lib` on Unix systems), possibly extended by pathname entries as specified by `-L` options (that must precede the `-l` options on the command-line).

- `-L`*path*

Additional location to look for archive libraries requested by `-l` options.

- `-defsym` *symbol=expr*

Define a global symbol *symbol* using *expr* as the value.

- `-M`

Print a linker map to `stdout`.

- `-Map` *mapfile*

Print a linker map to *mapfile*.

- `-cref`

Output a cross reference table to the map file (in case `-Map` is also present), or to `stdout`.

- `-section-start` *sectionname=org*

Start section *sectionname* at absolute address *org*.

- `-Tbss` *org*

- `-Tdata` *org*
- `-Ttext` *org*

Start the `bss`, `data`, or `text` section at *org*, respectively.

- `-T` *scriptfile*

Use *scriptfile* as the linker script, replacing the default linker script. Default linker scripts are stored in a system-specific location (e. g. under `/usr/local/avr/lib/ldscripts` on Unix systems), and consist of the AVR architecture name (avr2 through avr5) with the suffix .x appended. They describe how the various **memory sections**(p. 173) will be linked together.

9.10.3.2 Passing linker options from the C compiler By default, all unknown non-option arguments on the avr-gcc command-line (i. e., all filename arguments that don't have a suffix that is handled by avr-gcc) are passed straight to the linker. Thus, all files ending in .o (object files) and .a (object libraries) are provided to the linker.

System libraries are usually not passed by their explicit filename but rather using the `-l` option which uses an abbreviated form of the archive filename (see above). avr-libc ships two system libraries, `libc.a`, and `libm.a`. While the standard library `libc.a` will always be searched for unresolved references when the linker is started using the C compiler frontend (i. e., there's always at least one implied `-lc` option), the mathematics library `libm.a` needs to be explicitly requested using `-lm`. See also the **entry in the FAQ**(p. 132) explaining this.

Conventionally, Makefiles use the `make` macro `LDLIBS` to keep track of `-l` (and possibly `-L`) options that should only be appended to the C compiler command-line when linking the final binary. In contrast, the macro `LDFLAGS` is used to store other command-line options to the C compiler that should be passed as options during the linking stage. The difference is that options are placed early on the command-line, while libraries are put at the end since they are to be used to resolve global symbols that are still unresolved at this point.

Specific linker flags can be passed from the C compiler command-line using the `-Wl` compiler option, see **above**(p. 190). This option requires that there be no spaces in the appended linker option, while some of the linker options above (like `-Map` or `-defsym`) would require a space. In these situations, the space can be replaced by an equal sign as well. For example, the following command-line can be used to compile `foo.c` into an executable, and also produce a link map that contains a cross-reference list in the file `foo.map`:

```
$ avr-gcc -O -o foo.out -Wl,-Map=foo.map -Wl,--cref foo.c
```

Alternatively, a comma as a placeholder will be replaced by a space before passing the option to the linker. So for a device with external SRAM, the following command-line would cause the linker to place the data segment at address 0x2000 in the SRAM:

```
$ avr-gcc -mmcu=atmega128 -o foo.out -Wl,-Tdata,0x802000
```

See the explanation of the **data section**(p. 173) for why 0x800000 needs to be added to the actual value. Note that unless a `-minit-stack` option has been given when compiling the C source file that contains the function `main()`, the stack will still remain in internal RAM, through the symbol `__stack` that is provided by the run-time startup code. This is probably a good idea anyway (since internal RAM access is faster), and even required for some early devices that had hardware bugs preventing them from using a stack in external RAM. Note also that the heap for **malloc()**(p. 65) will still be placed after all the variables in the data section, so in this situation, no stack/heap collision can occur.

9.11 Todo List

Group avr_boot(p. 7) From email with Marek: On smaller devices (all except ATmega64/128), __SPM_REG is in the I/O space, accessible with the shorter "in" and "out" instructions - since the boot loader has a limited size, this could be an important optimization.

Index