ETH Course 402-0248-00L: Electronics for Physicists II (Digital)

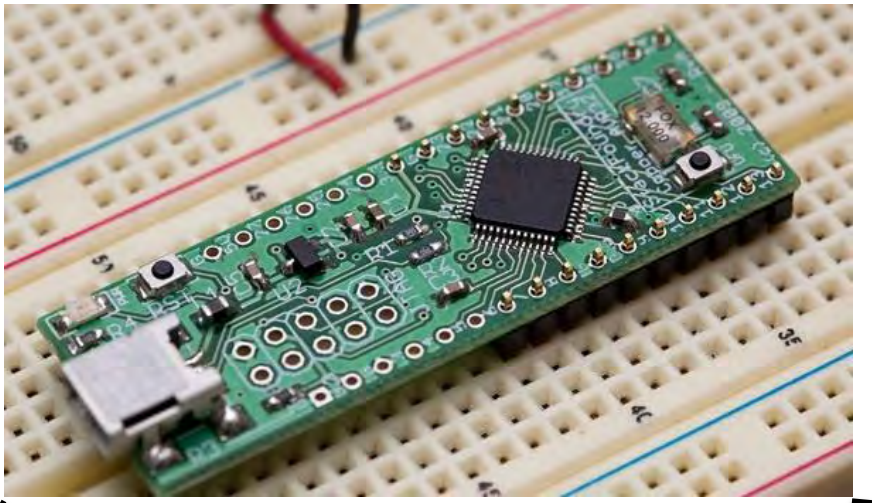
- **Taught by:** Tobi Delbruck
  with help from Daniel Fasnacht and Univ. of Edinburgh
- **Department:** ETH Zurich Department of Physics (D-PHYS)
- **Day/Time:** Weekly on Fridays from 1315 - 1700 in Picaardsaal, ETH Hoenggerberg Campus, HPT Room C103
- **Breaks:** No class in some weeks, check schedule on wiki.
- **Language:** English.
- **Credits:** 4 credit points.
- **Exam**: There is no exam but students must successfully complete the class exercises. Attendance sheet will be used.
- **Class wiki: google** "dig delbruck"

www.ini.uzh.ch/~tobi/wiki/doku.php?id=dig:start

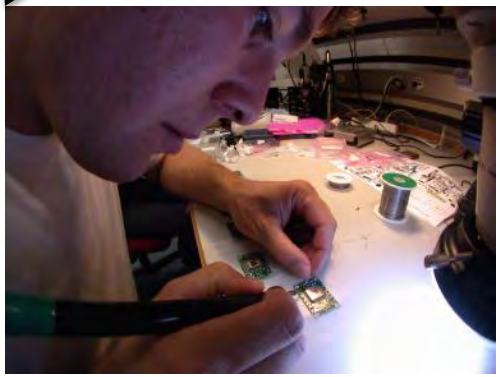
Prerequisites

- **Companion course:** Electronics for Physicists I (Analog), Fall semester, taught by Roland Horisberger.
- The digital course complements the analog course by teaching how to build systems that convert and process analog information.
- You should have had some programming experience, preferably with C. Students (or at least each group of 2-3 students) need a laptop computer, Windows or Linux (but only Windows supported by Tobi). Mac OS can use VM.

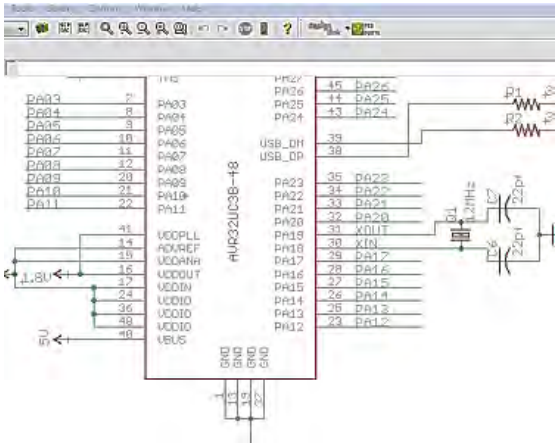
1st half: Embedded systems with microcontrollers

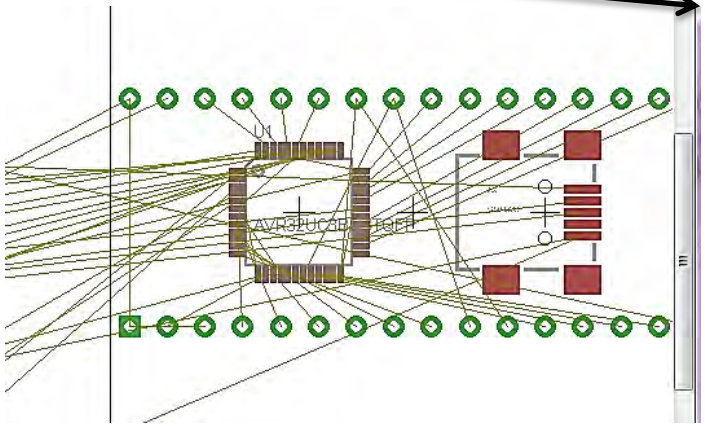


2nd half: Logic design with FPGA



PCB SMD assembly

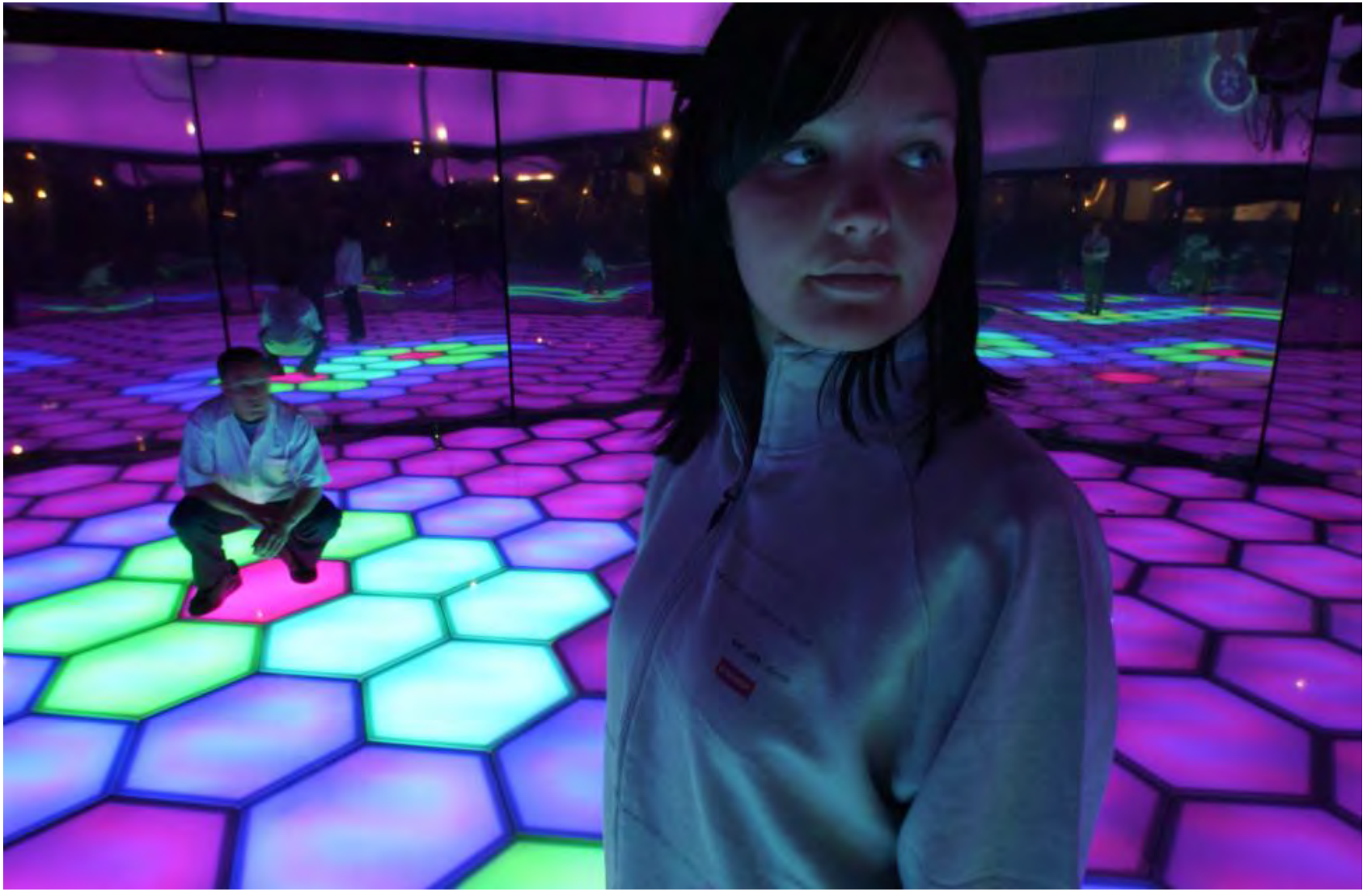




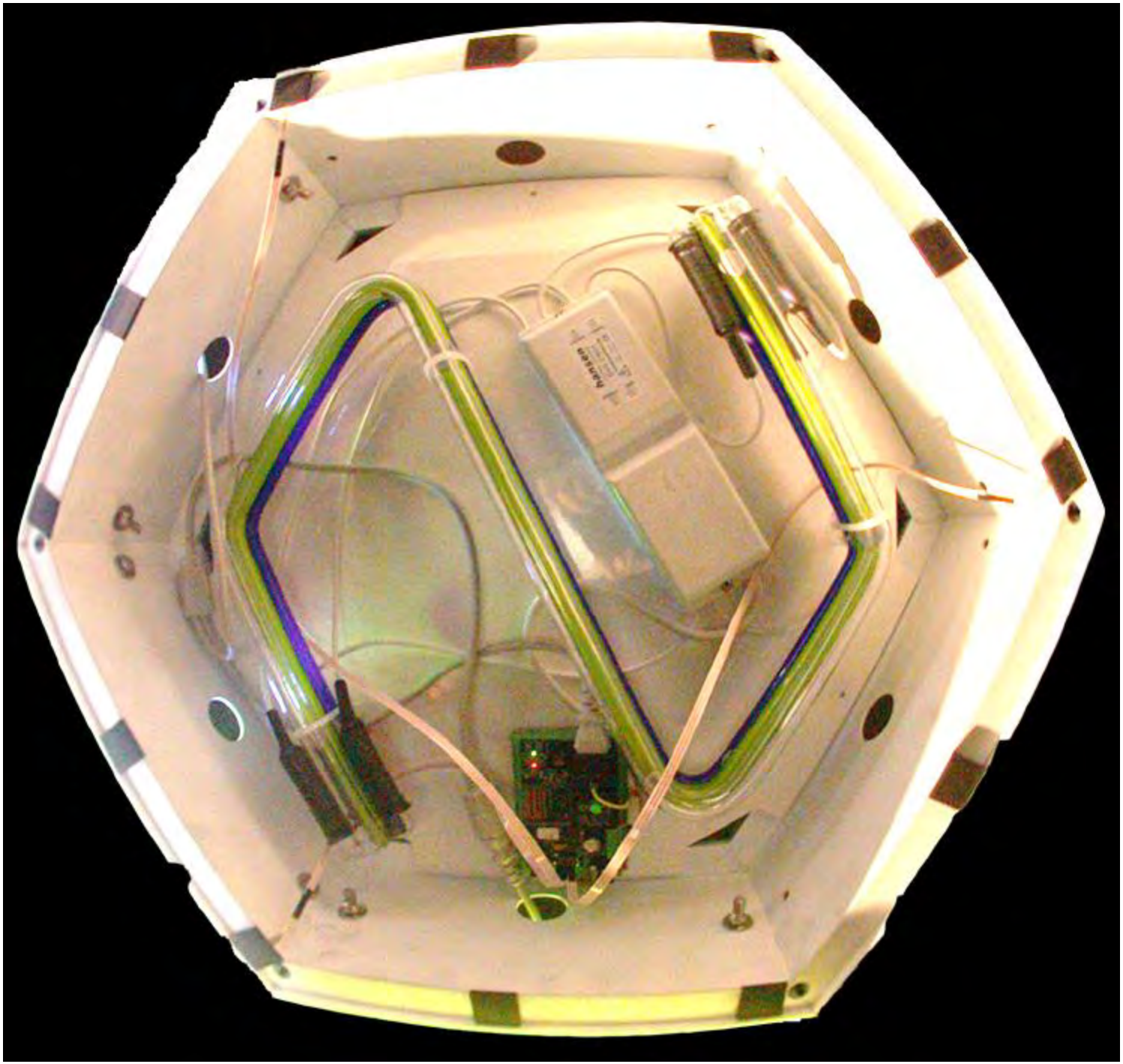
PCB design and layout

Embedded system design example

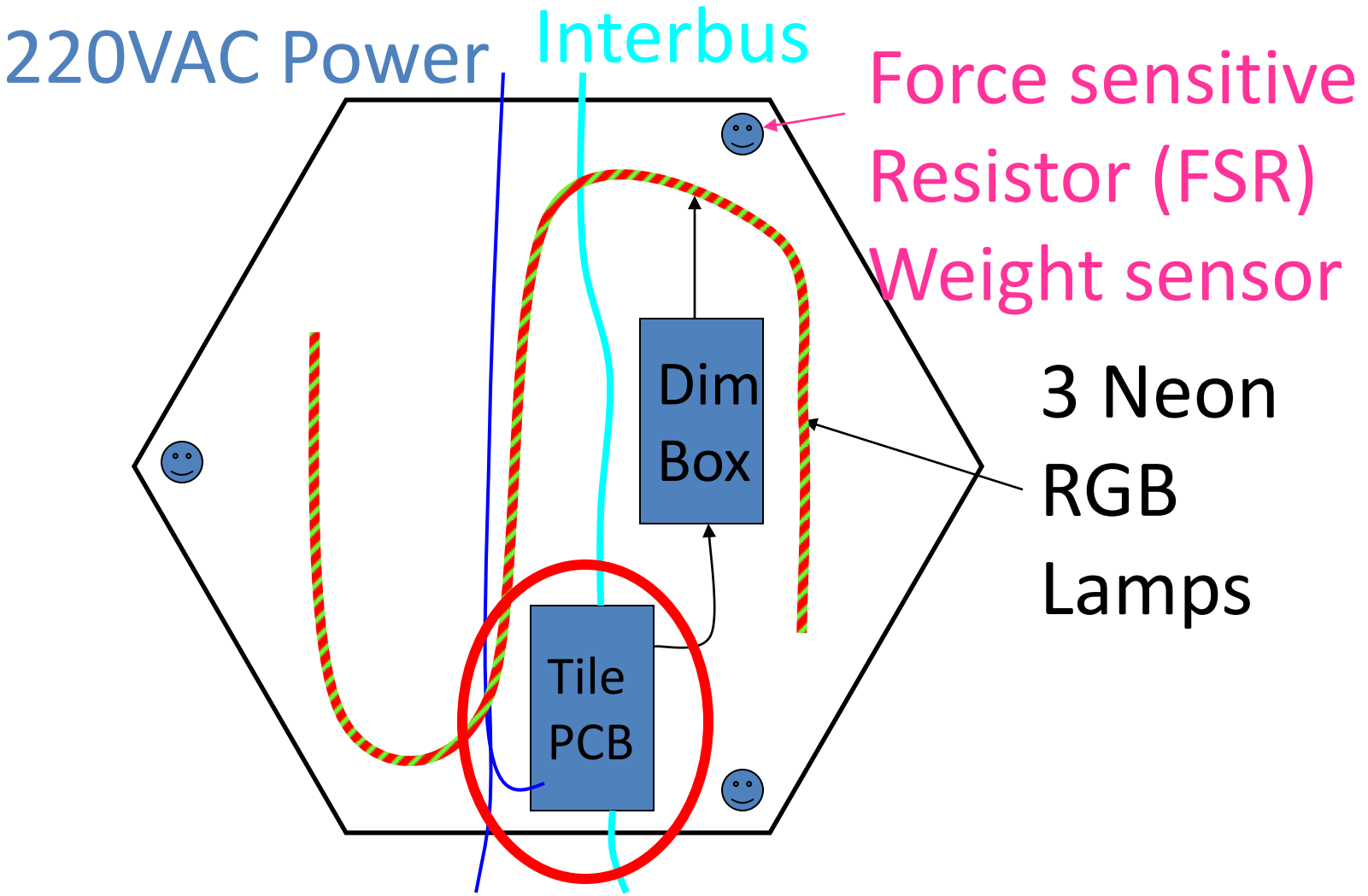
Ada's luminous tactile floor



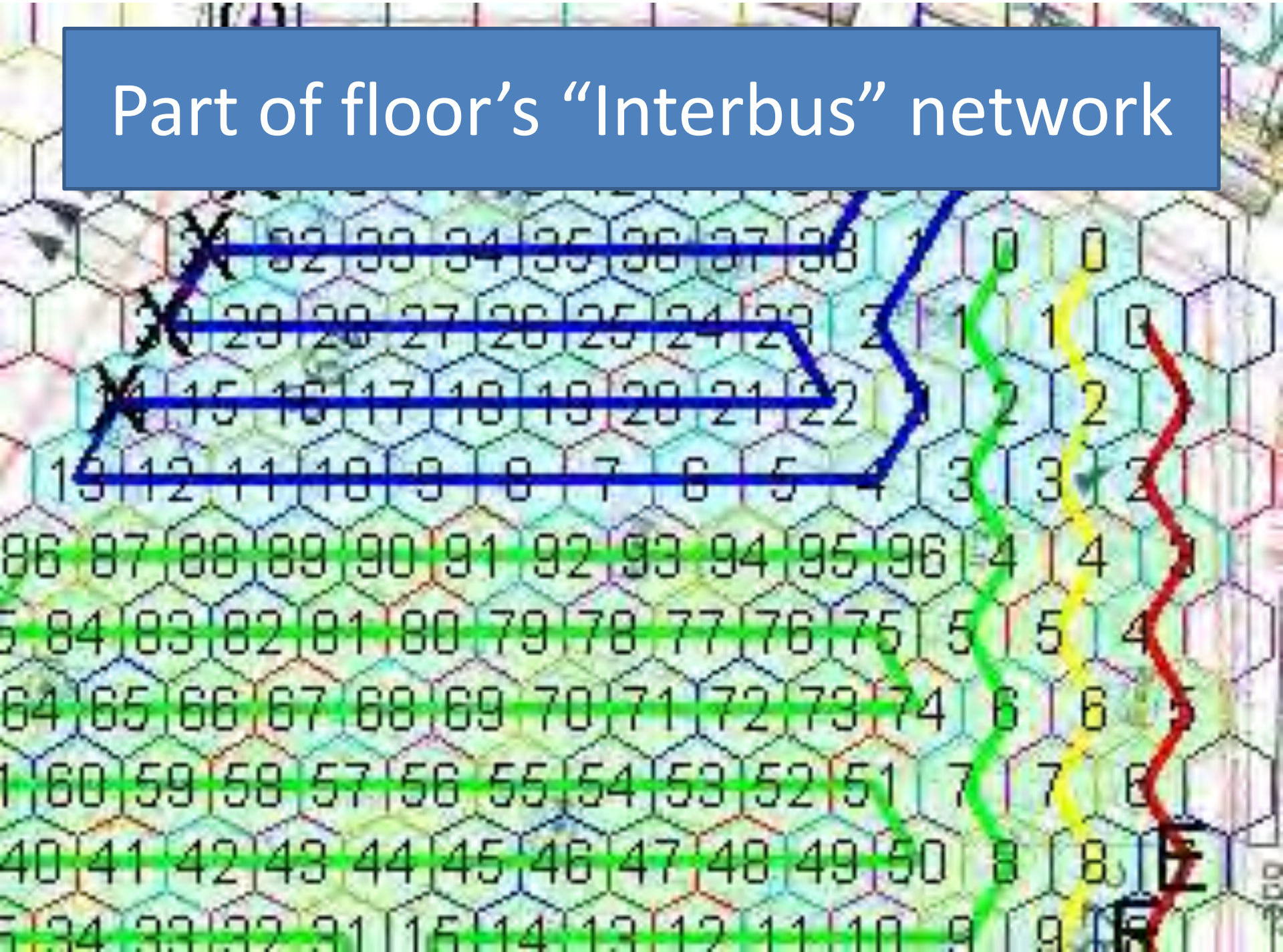
Ada’s luminous tactile floor



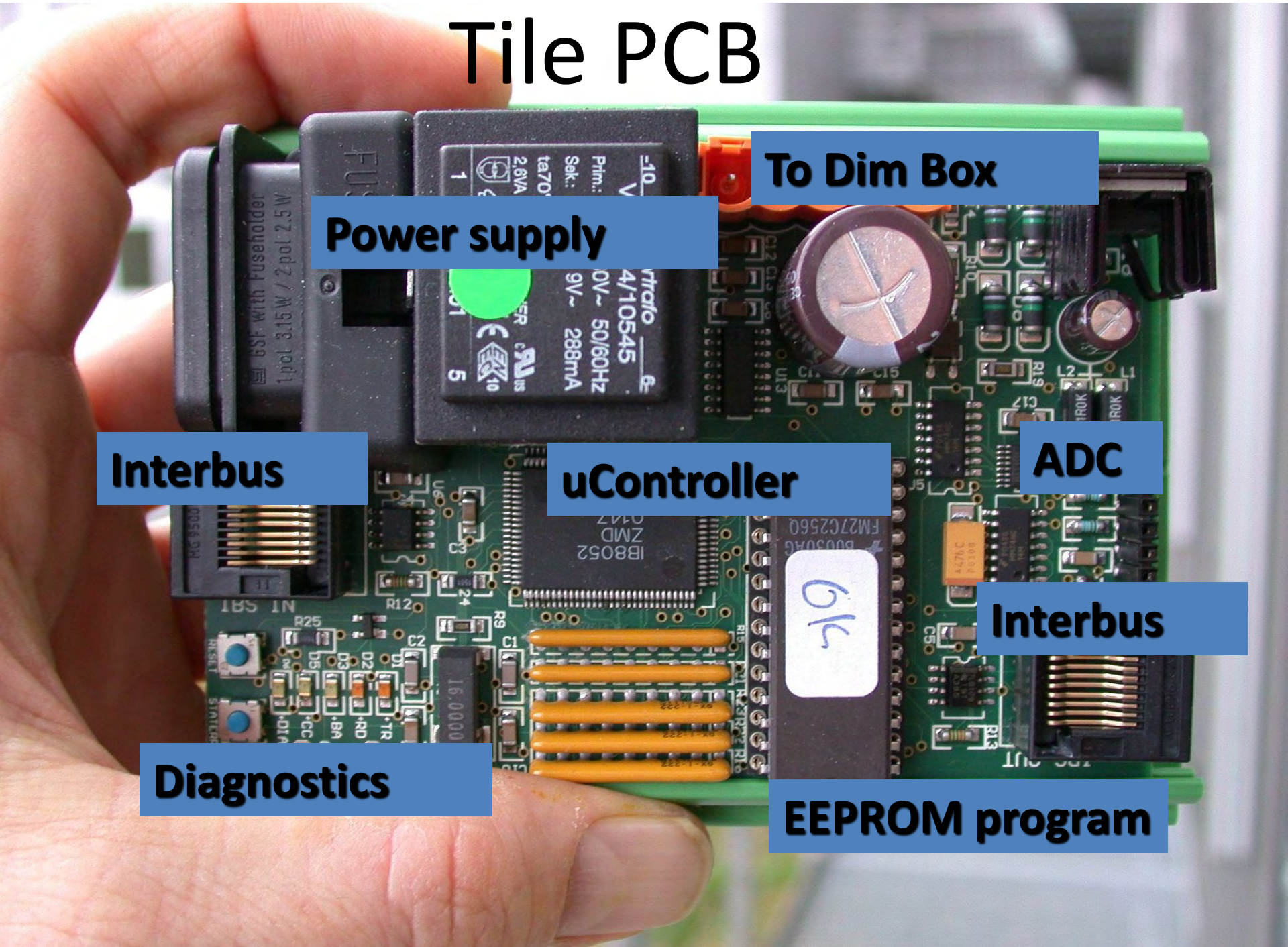
Neon Tile


220VAC Power
Interbus
Force sensitive Resistor (FSR) Weight sensor
Dim Box
3 Neon RGB Lamps
Tile PCB

Part of floor's "Interbus" network



Tile PCB


To Dim Box
Power supply
Interbus
uController
ADC
Interbus
Diagnostics
EEPROM program

PCB assembly

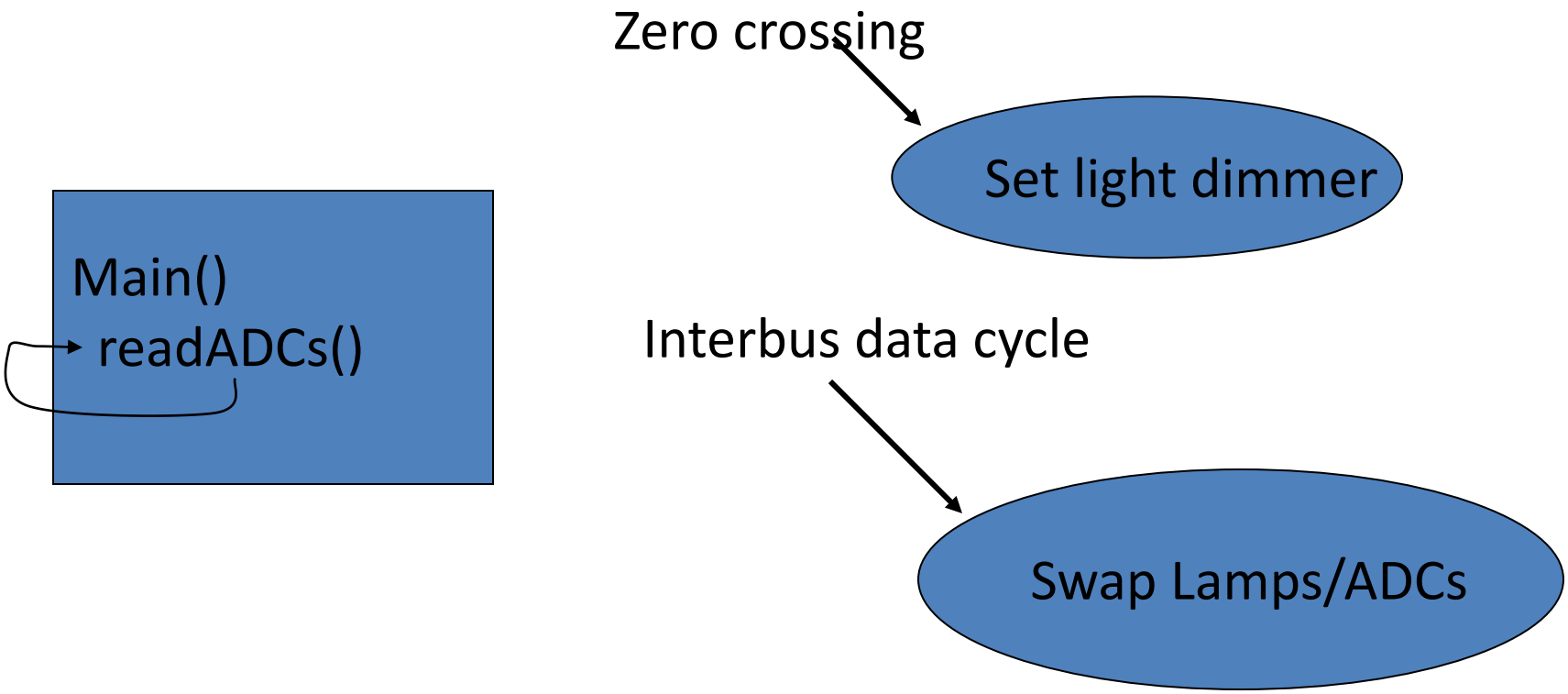
+

=

X 500

Tile Microcontroller Program

Interrupt service routines (ISRs)

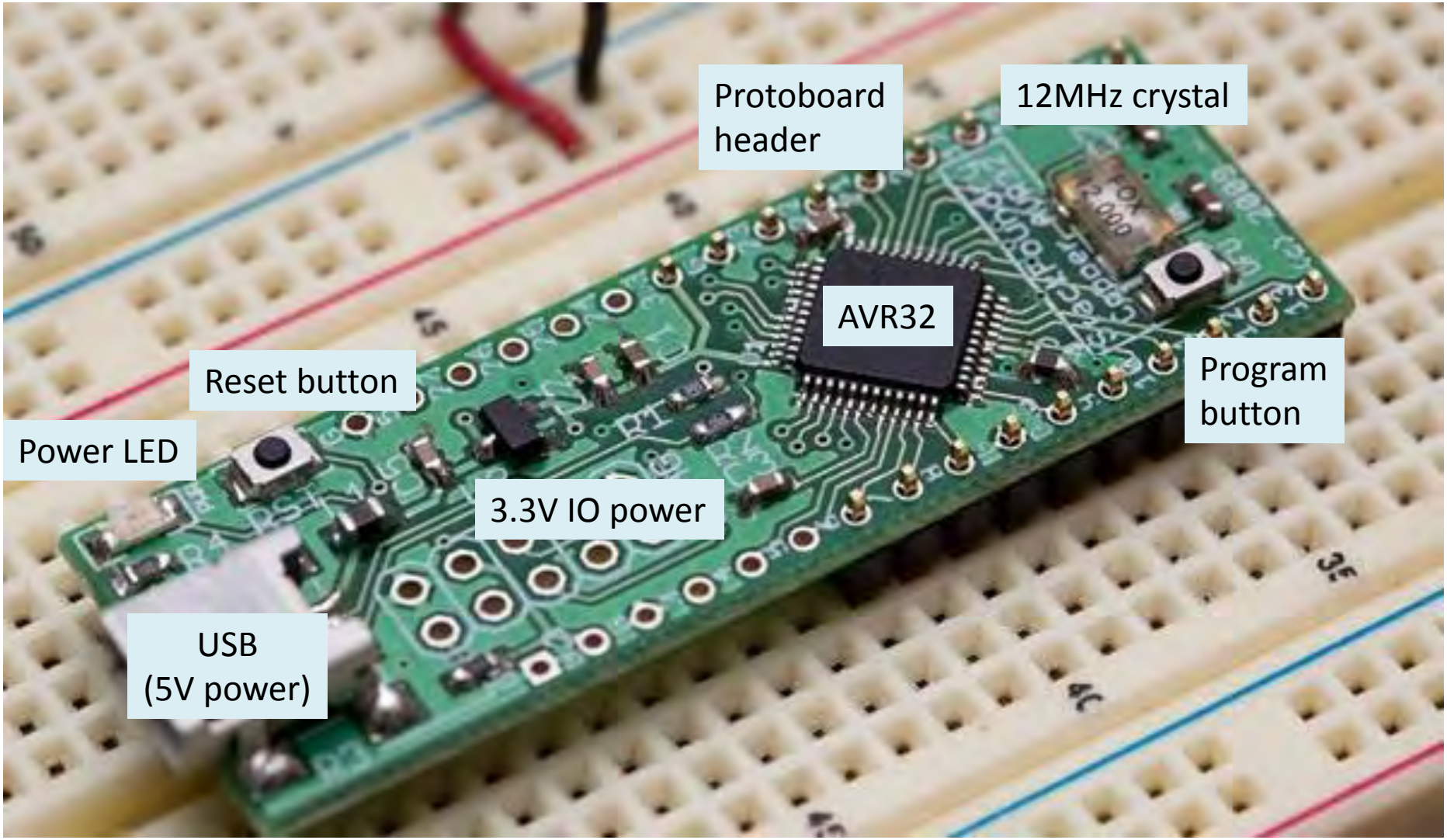


1000 lines C/assembler code running on 8052 derivative
Two demo tiles have been running continuously for >5 years!

The AVR32 AT32UC3B1256

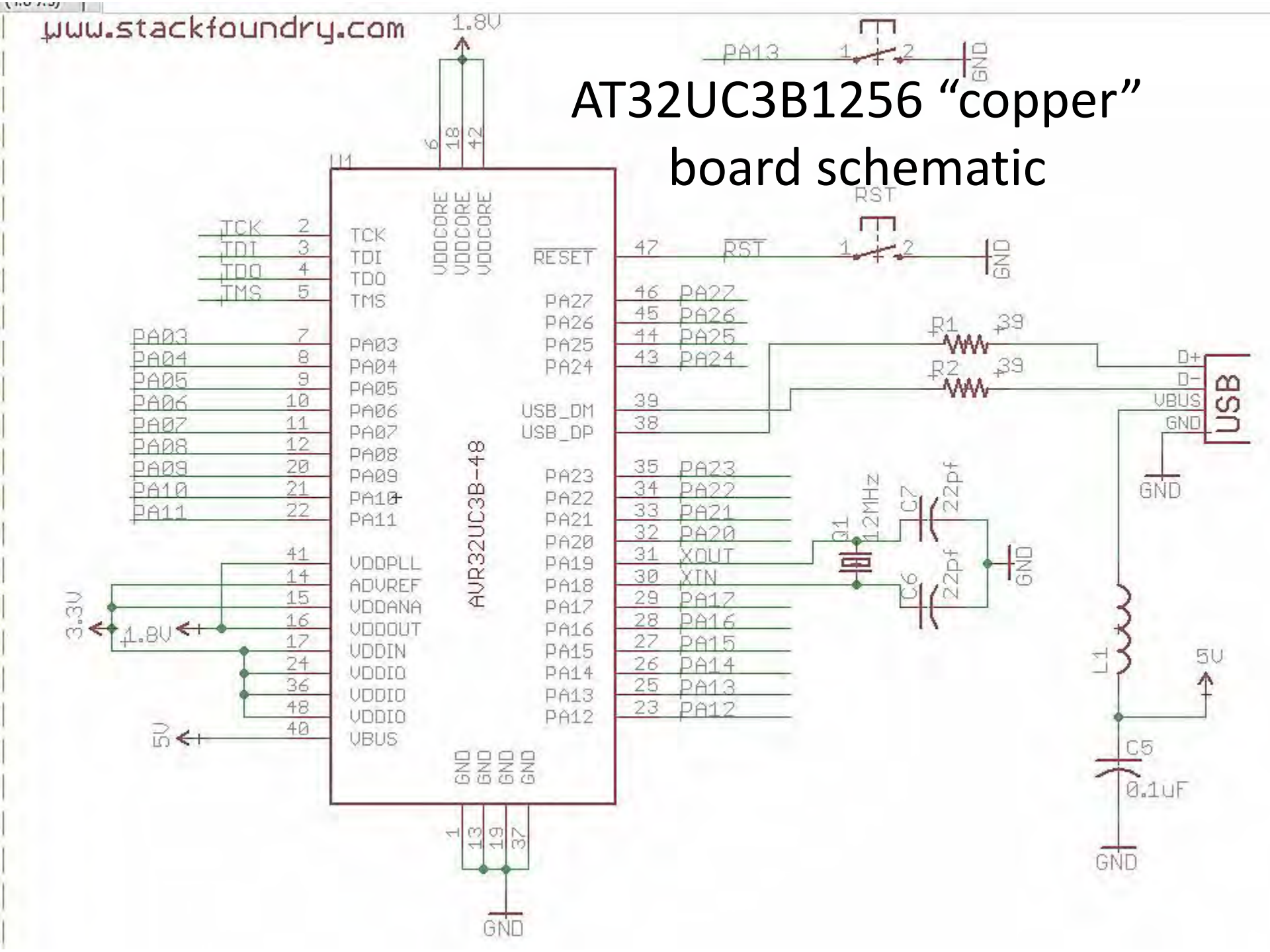
- AT = Atmel: Big microcontroller company
- 32 = 32 bit architecture
- UC3 = Atmel microcontroller family
- B = more powerful and expensive variant ($7 each @25 units)
- 1 = revision
- 256 = 256kB internal high speed flash memory (32kB single cycle SRAM)

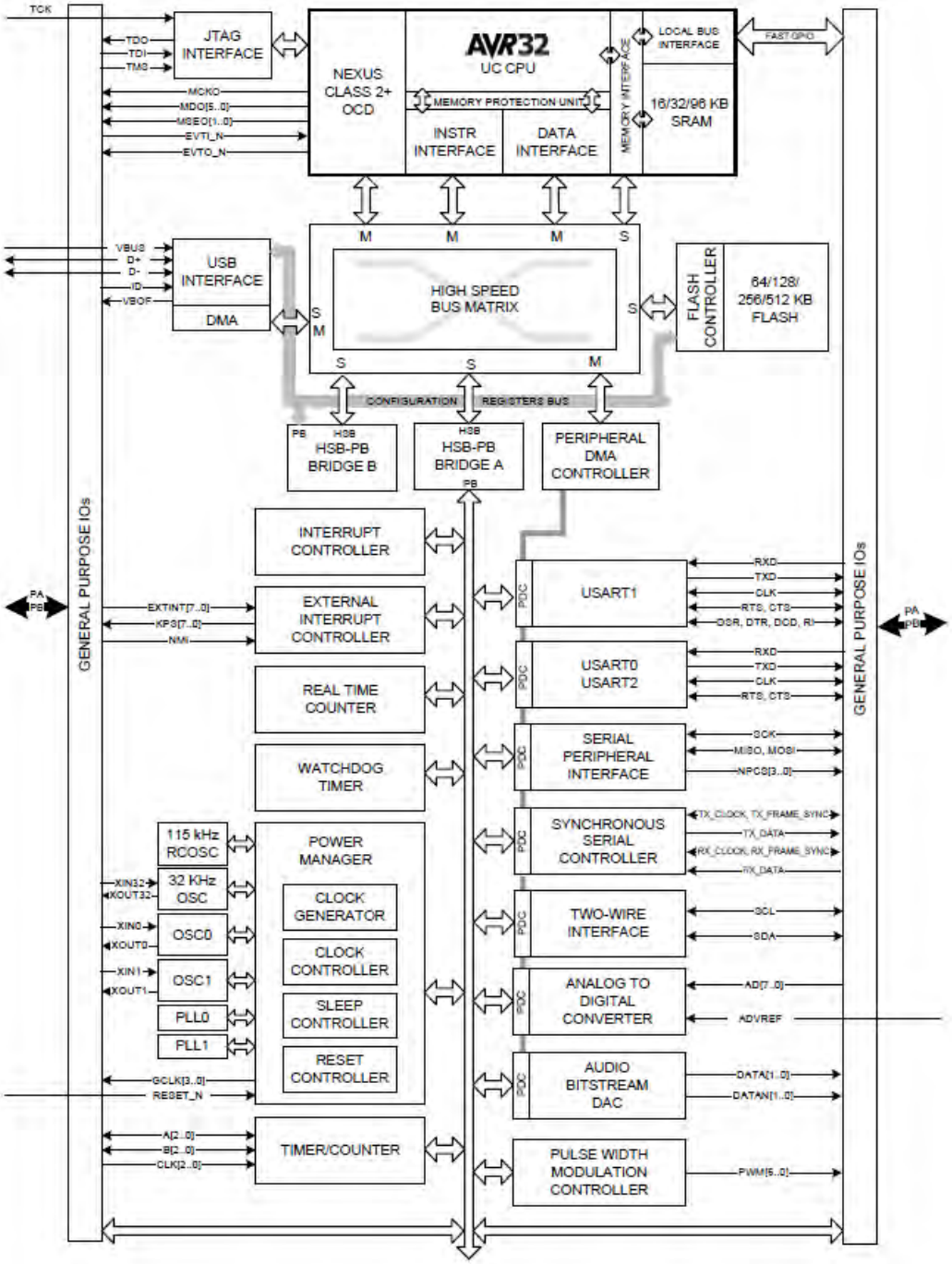
The “bronze” board



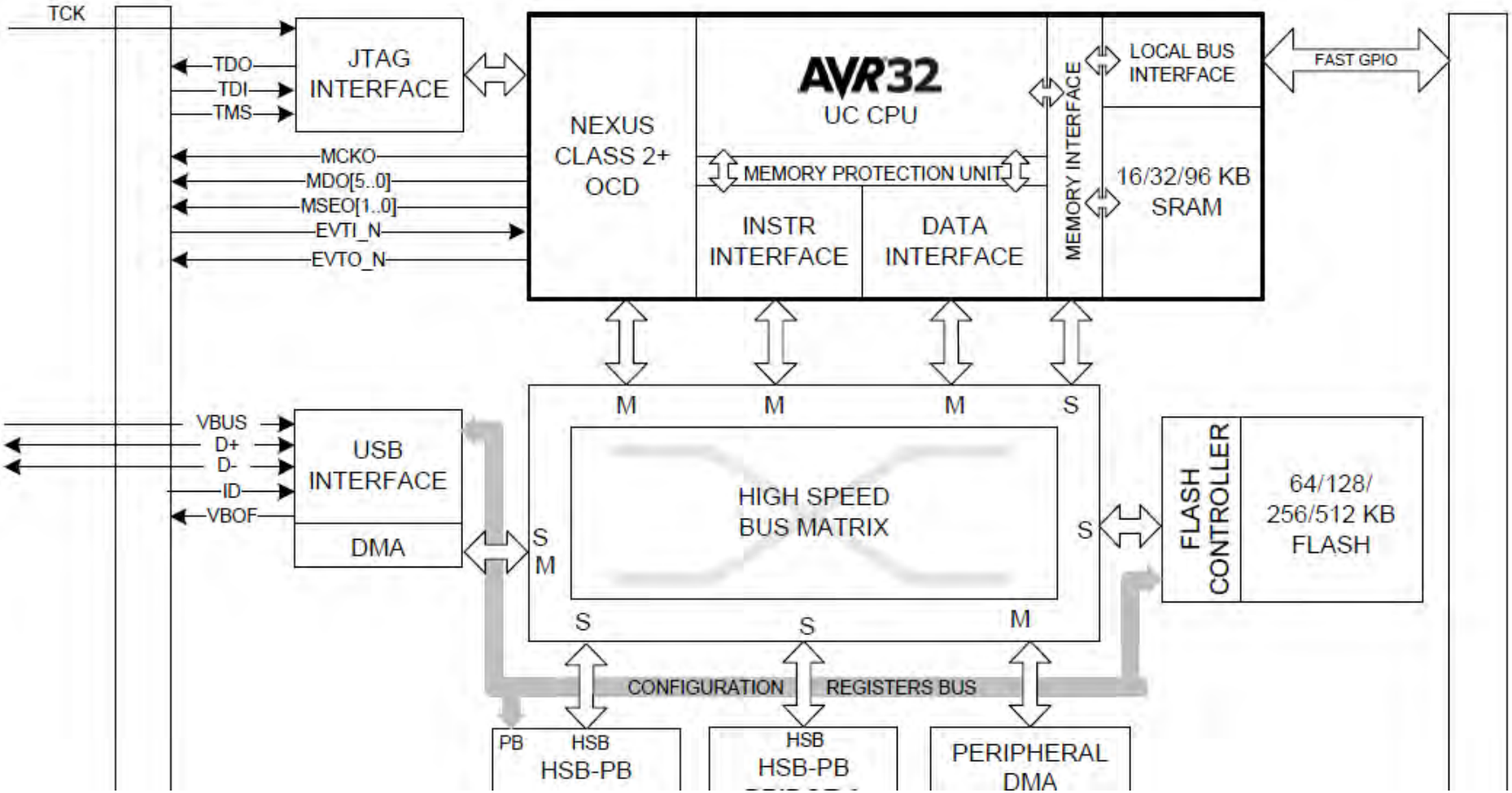
AVR32 capabilities

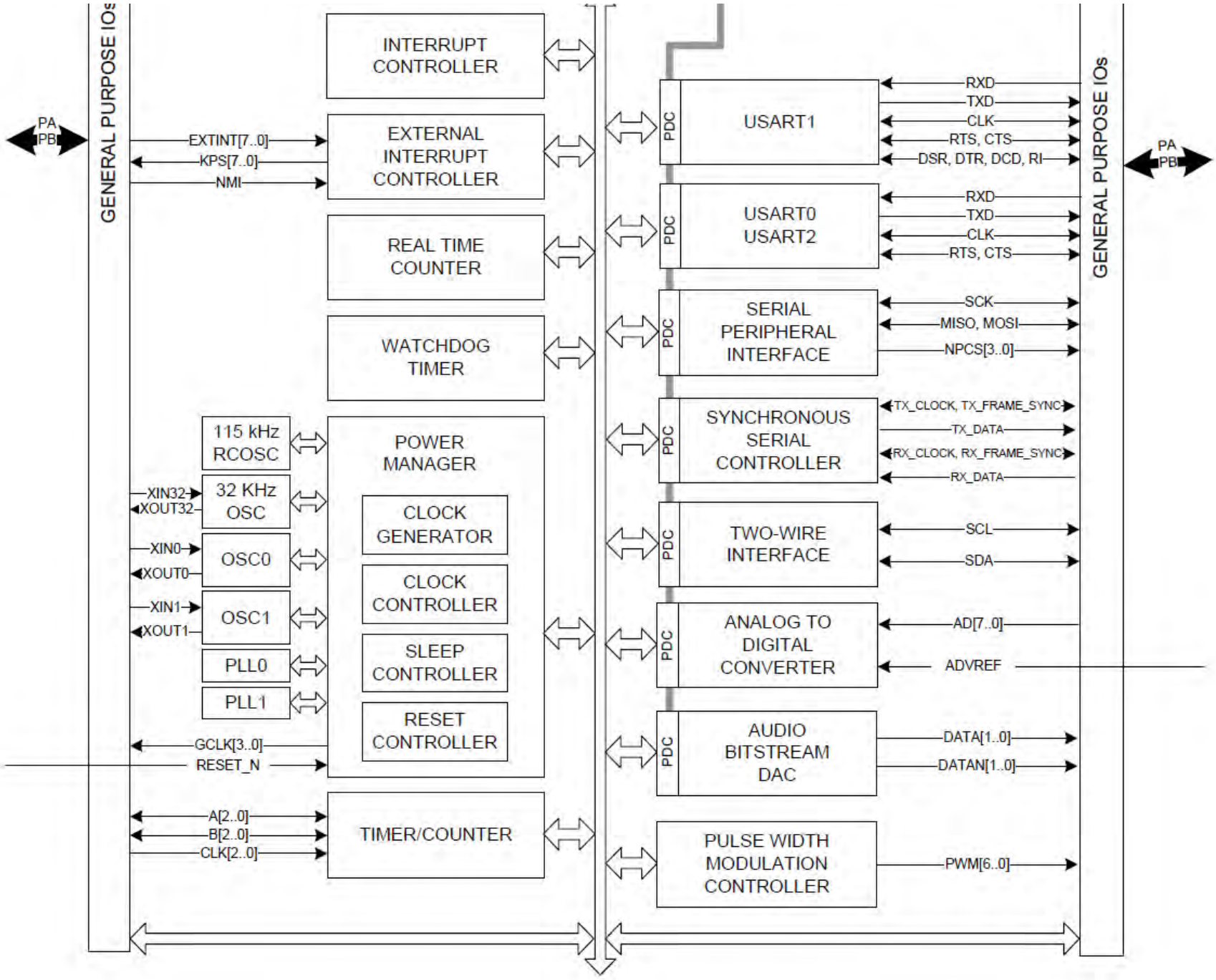
- **System Functions**
  - **Power and Clock Manager**
  - **Two Multipurpose Oscillators**
  - **Watchdog Timer, Real-Time Clock Timer**
- **Interrupt Controller**
  - **Auto-vectored Low Latency Interrupt Service with Programmable Priority**
- **Universal Serial Bus (USB)**
  - **Device 2.0 Full Speed (12Mbps~1MBps)**
- **One Three-Channel 16-bit Timer/Counter (TC)**
- **One 7-Channel 20-bit Pulse Width Modulation Controller (PWM)**
- **Three Universal Synchronous/Asynchronous Receiver/Transmitters (USART)**
- **One Master/Slave Serial Peripheral Interfaces (SPI) with Chip Select Signals**
- **One 8-channel 10-bit Analog-To-Digital Converter, 384ks/s**
- **16-bit Stereo Audio Bitstream DAC**


www.stackfoundry.com
AT32UC3B1256 “copper” board schematic
AVR32UC3B-48
U1
1.8V
3.3V
5V
GND
RST
PA13
TCK
TDI
TDO
TMS
PA03
PA04
PA05
PA06
PA07
PA08
PA09
PA10
PA11
PA27
PA26
PA25
PA24
PA23
PA22
PA21
PA20
PA19
PA18
PA17
PA16
PA15
PA14
PA13
PA12
USB_DM
USB_DP
VBUS
R1
R2
39
D+
D-
USB
Q1
12MHz
C7
C6
22pf
XOUT
XIN
L1
C5
0.1uF


TCK
TDO
TDI
TMS
JTAG INTERFACE
MCKO
MDO[5..0]
MSEO[1..0]
EVTI_N
EVTO_N
NEXUS CLASS 2+ OCD
AVR32
UC CPU
MEMORY PROTECTION UNIT
INSTR INTERFACE
DATA INTERFACE
MEMORY INTERFACE
LOCAL BUS INTERFACE
FAST GPIO
16/32/96 KB SRAM
VBUS
D+
D-
ID
VBOF
USB INTERFACE
DMA
M
M
M
S
HIGH SPEED BUS MATRIX
S
M
S
S
M
FLASH CONTROLLER
64/128/ 256/512 KB FLASH
CONFIGURATION
REGISTERS BUS
PB
HSB
HSB-PB BRIDGE B
HSB
HSB-PB BRIDGE A
PB
PERIPHERAL DMA CONTROLLER
GENERAL PURPOSE IOs
PA
PB
INTERRUPT CONTROLLER
EXTINT[7..0]
KPS[7..0]
NMI
EXTERNAL INTERRUPT CONTROLLER
REAL TIME COUNTER
WATCHDOG TIMER
115 kHz RCOSC
XIN32
XOUT32
32 kHz OSC
XIN0
XOUT0
OSC0
XIN1
XOUT1
OSC1
PLL0
PLL1
POWER MANAGER
CLOCK GENERATOR
CLOCK CONTROLLER
SLEEP CONTROLLER
RESET CONTROLLER
GCLK[3..0]
RESET_N
A[2..0]
B[2..0]
CLK[2..0]
TIMER/COUNTER
PDC
USART1
RXD
TXD
CLK
RTS, CTS
DSR, DTR, DCD, RI
USART0
USART2
SERIAL PERIPHERAL INTERFACE
SCK
MISO, MOSI
NPCS[3..0]
SYNCHRONOUS SERIAL CONTROLLER
TX_CLOCK, TX_FRAME_SYNC
TX_DATA
RX_CLOCK, RX_FRAME_SYNC
RX_DATA
TWO-WIRE INTERFACE
SCL
SDA
ANALOG TO DIGITAL CONVERTER
AD[7..0]
ADVREF
AUDIO BITSTREAM DAC
DATA[1..0]
DATAN[1..0]
PULSE WIDTH MODULATION CONTROLLER
PWM[5..0]

AVR32


TCK
TDO
TDI
TMS
JTAG INTERFACE
MCKO
MDO[5..0]
MSEO[1..0]
EVTI_N
EVTO_N
NEXUS CLASS 2+ OCD
AVR32
UC CPU
MEMORY PROTECTION UNIT
INSTR INTERFACE
DATA INTERFACE
MEMORY INTERFACE
LOCAL BUS INTERFACE
FAST GPIO
16/32/96 KB SRAM
M
M
M
S
VBUS
D+
D-
ID
VBOF
USB INTERFACE
DMA
S
M
HIGH SPEED BUS MATRIX
S
S
S
M
FLASH CONTROLLER
64/128/ 256/512 KB FLASH
CONFIGURATION
REGISTERS BUS
PB
HSB
HSB-PB
HSB
HSB-PB
PERIPHERAL DMA

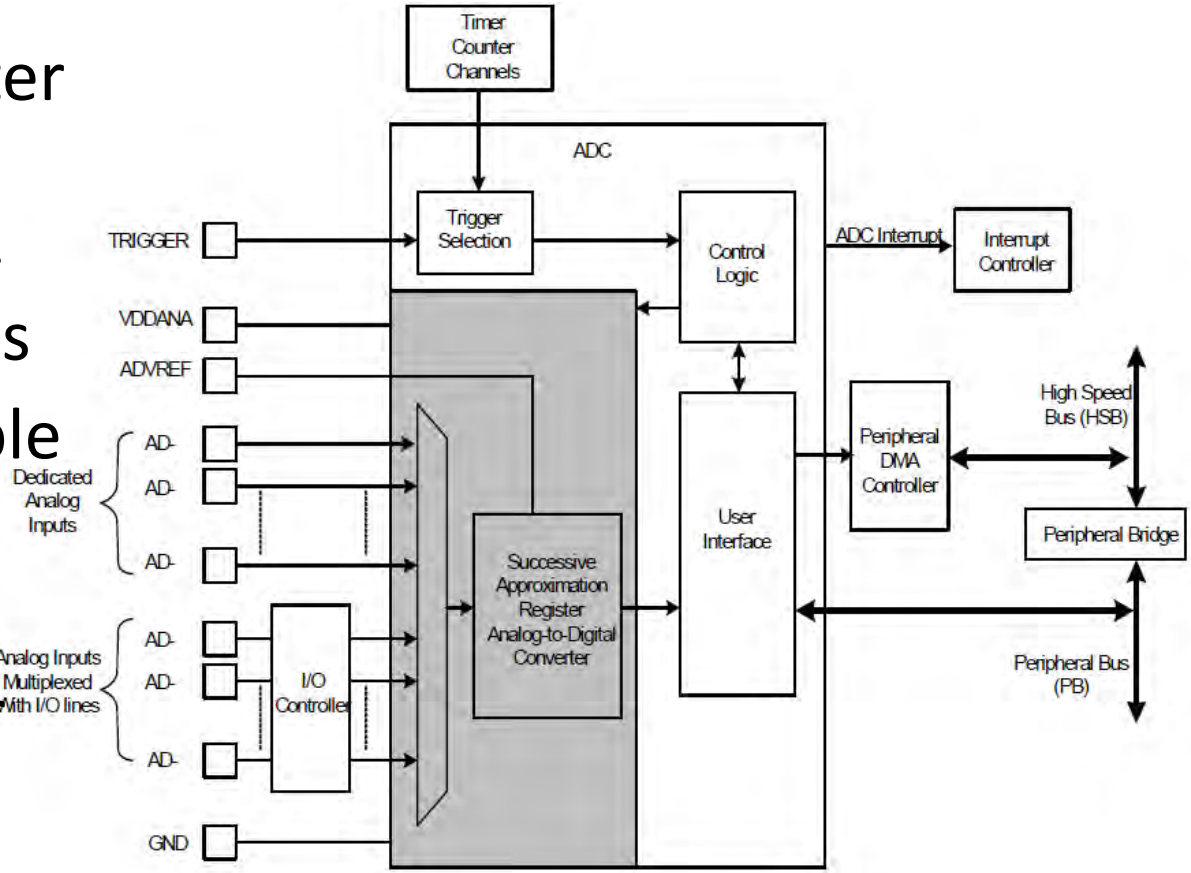

GENERAL PURPOSE IOs
PA
PB
INTERRUPT CONTROLLER
EXTERNAL INTERRUPT CONTROLLER
EXTINT[7..0]
KPS[7..0]
NMI
REAL TIME COUNTER
WATCHDOG TIMER
POWER MANAGER
115 kHz RCOSC
32 KHz OSC
XIN32
XOUT32
OSC0
XIN0
XOUT0
OSC1
XIN1
XOUT1
PLL0
PLL1
CLOCK GENERATOR
CLOCK CONTROLLER
SLEEP CONTROLLER
RESET CONTROLLER
GCLK[3..0]
RESET_N
TIMER/COUNTER
A[2..0]
B[2..0]
CLK[2..0]
PDC
USART1
RXD
TXD
CLK
RTS, CTS
DSR, DTR, DCD, RI
USART0
USART2
SERIAL PERIPHERAL INTERFACE
SCK
MISO, MOSI
NPCS[3..0]
SYNCHRONOUS SERIAL CONTROLLER
TX_CLOCK, TX_FRAME_SYNC
TX_DATA
RX_CLOCK, RX_FRAME_SYNC
RX_DATA
TWO-WIRE INTERFACE
SCL
SDA
ANALOG TO DIGITAL CONVERTER
AD[7..0]
ADVREF
AUDIO BITSTREAM DAC
DATA[1..0]
DATAN[1..0]
PULSE WIDTH MODULATION CONTROLLER
PWM[6..0]

AVR32 datasheet – ~700 pages

- Intro/Core features: 200pp
- Peripherals: 400pp (e.g. USB 180pp, GPIO 19pp)
- Electrical characteristics: 20pp

AVR32 Analog to Digital converter

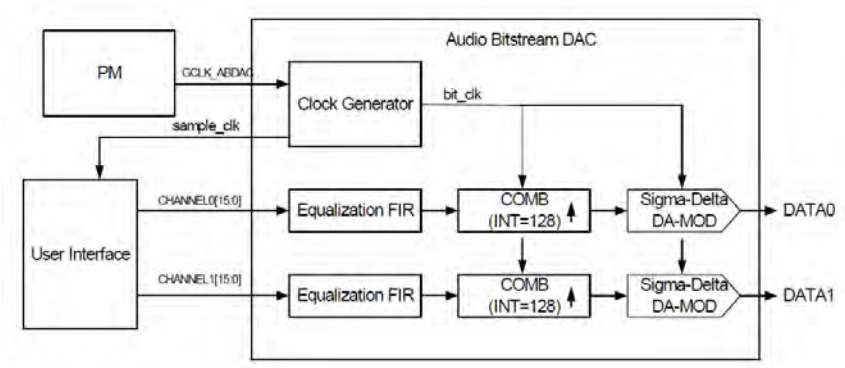
- 10-bit Successive approximation register (SAR) type
- 6 multiplexed single-ended input channels
- Max combined sample rate 384ks/s
- External trigger
- Hardware sequencer
- Peripheral DMA



Audio stereo bitstream DAC

The Audio Bitstream DAC converts a 16-bit sample value to a digital bitstream with an average value proportional to the sample value

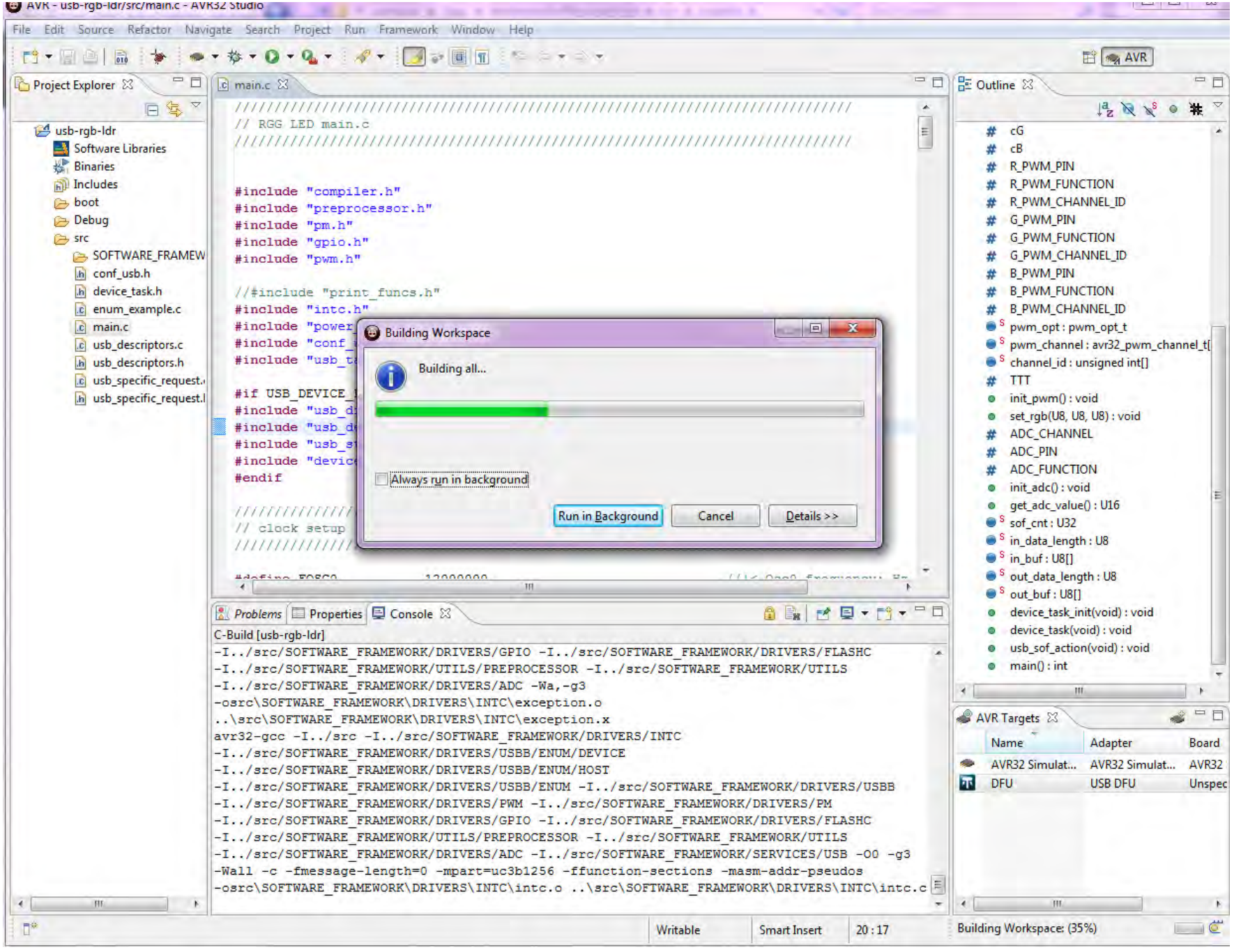
- **Oversampled D/A conversion architecture**
  - **Oversampling ratio fixed 128x**
  - **FIR equalization filter**
  - **Digital interpolation filter: Comb4**
  - **3rd Order Sigma-Delta D/A converters**
- **Digital bitstream outputs**
- **Parallel interface**
- **Connected to DMA Controller for background transfer without CPU intervention**



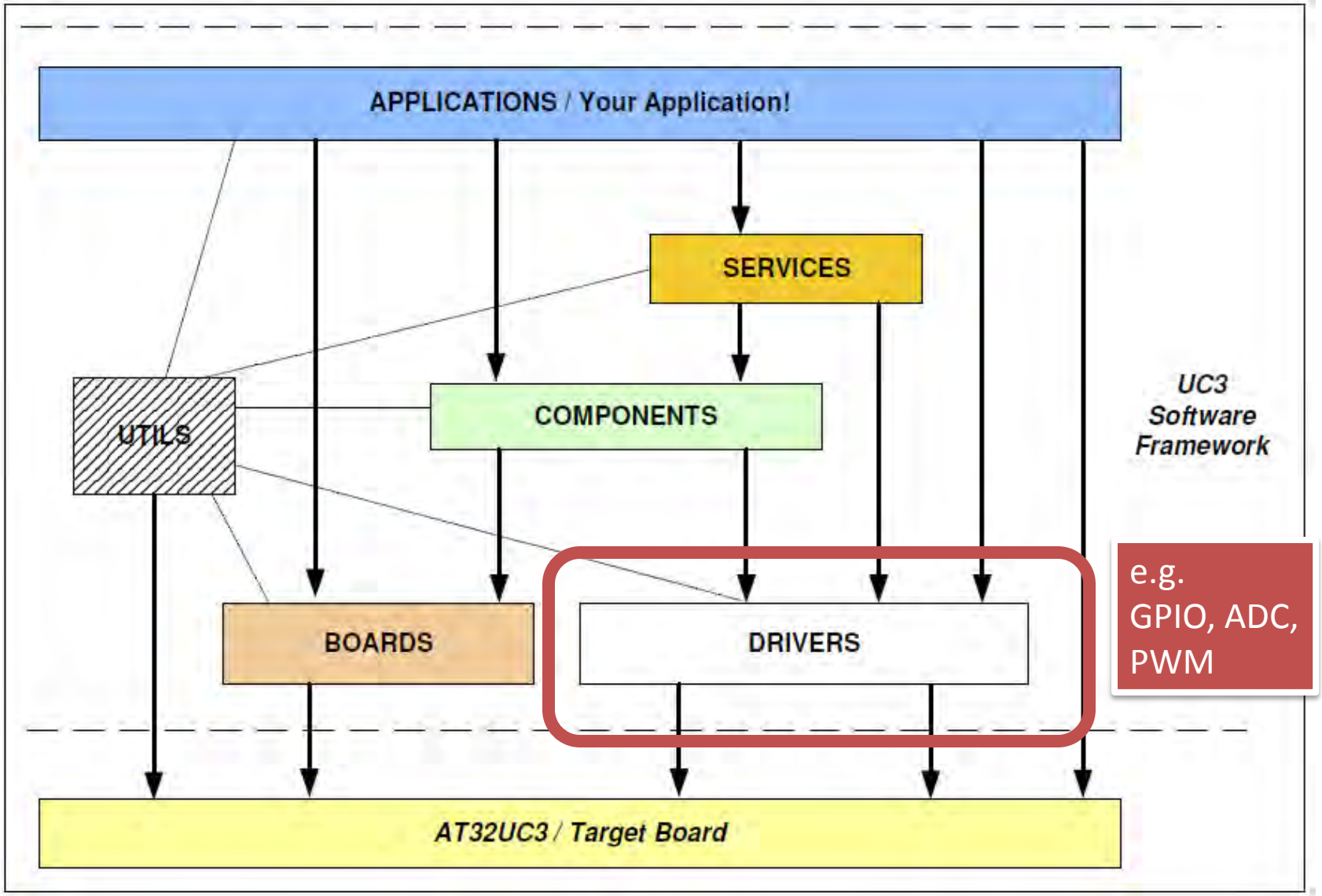
AVR32 Studio

- Eclipse IDE
- gcc ‘tool chain’
- Integrated DFU

IDE=Integrated Development Environment; DFU=Device Firmware Update; gcc=Gnu C-Compiler


AVR - usb-rgb-ldr/src/main.c - AVR32 Studio
File Edit Source Refactor Navigate Search Project Run Framework Window Help
AVR
Project Explorer
usb-rgb-ldr
Software Libraries
Binaries
Includes
boot
Debug
src
SOFTWARE_FRAMEW
conf_usb.h
device_task.h
enum_example.c
main.c
usb_descriptors.c
usb_descriptors.h
usb_specific_request.
usb_specific_request.
main.c
// RGG LED main.c
#include "compiler.h"
#include "preprocessor.h"
#include "pm.h"
#include "gpio.h"
#include "pwm.h"
//#include "print_funcs.h"
#include "intc.h"
#include "power
#include "conf_
#include "usb_t
#if USB_DEVICE_
#include "usb_d
#include "usb_d
#include "usb_s
#include "devic
#endif
// clock setup
Building Workspace
Building all...
Always run in background
Run in Background
Cancel
Details >>
Outline
cG
cB
R_PWM_PIN
R_PWM_FUNCTION
R_PWM_CHANNEL_ID
G_PWM_PIN
G_PWM_FUNCTION
G_PWM_CHANNEL_ID
B_PWM_PIN
B_PWM_FUNCTION
B_PWM_CHANNEL_ID
pwm_opt : pwm_opt_t
pwm_channel : avr32_pwm_channel_t[
channel_id : unsigned int[]
TTT
init_pwm() : void
set_rgb(U8, U8, U8) : void
ADC_CHANNEL
ADC_PIN
ADC_FUNCTION
init_adc() : void
get_adc_value() : U16
sof_cnt : U32
in_data_length : U8
in_buf : U8[]
out_data_length : U8
out_buf : U8[]
device_task_init(void) : void
device_task(void) : void
usb_sof_action(void) : void
main() : int
Problems
Properties
Console
C-Build [usb-rgb-ldr]
-I../src/SOFTWARE_FRAMEWORK/DRIVERS/GPIO -I../src/SOFTWARE_FRAMEWORK/DRIVERS/FLASHC
-I../src/SOFTWARE_FRAMEWORK/UTILS/PREPROCESSOR -I../src/SOFTWARE_FRAMEWORK/UTILS
-I../src/SOFTWARE_FRAMEWORK/DRIVERS/ADC -Wa,-g3
-osrc\SOFTWARE_FRAMEWORK\DRIVERS\INTC\exception.o
..\src\SOFTWARE_FRAMEWORK\DRIVERS\INTC\exception.x
avr32-gcc -I../src -I../src/SOFTWARE_FRAMEWORK/DRIVERS/INTC
-I../src/SOFTWARE_FRAMEWORK/DRIVERS/USBB/ENUM/DEVICE
-I../src/SOFTWARE_FRAMEWORK/DRIVERS/USBB/ENUM/HOST
-I../src/SOFTWARE_FRAMEWORK/DRIVERS/USBB/ENUM -I../src/SOFTWARE_FRAMEWORK/DRIVERS/USBB
-I../src/SOFTWARE_FRAMEWORK/DRIVERS/PWM -I../src/SOFTWARE_FRAMEWORK/DRIVERS/PM
-I../src/SOFTWARE_FRAMEWORK/DRIVERS/GPIO -I../src/SOFTWARE_FRAMEWORK/DRIVERS/FLASHC
-I../src/SOFTWARE_FRAMEWORK/UTILS/PREPROCESSOR -I../src/SOFTWARE_FRAMEWORK/UTILS
-I../src/SOFTWARE_FRAMEWORK/DRIVERS/ADC -I../src/SOFTWARE_FRAMEWORK/SERVICES/USB -O0 -g3
-Wall -c -fmessage-length=0 -mpart=uc3b1256 -ffunction-sections -masm-addr-pseudos
-osrc\SOFTWARE_FRAMEWORK\DRIVERS\INTC\intc.o ..\src\SOFTWARE_FRAMEWORK\DRIVERS\INTC\intc.c
AVR Targets
Name
Adapter
Board
AVR32 Simulat...
AVR32 Simulat...
AVR32
DFU
USB DFU
Unspec
Writable
Smart Insert
20 : 17
Building Workspace: (35%)

AVR32 Software Framework



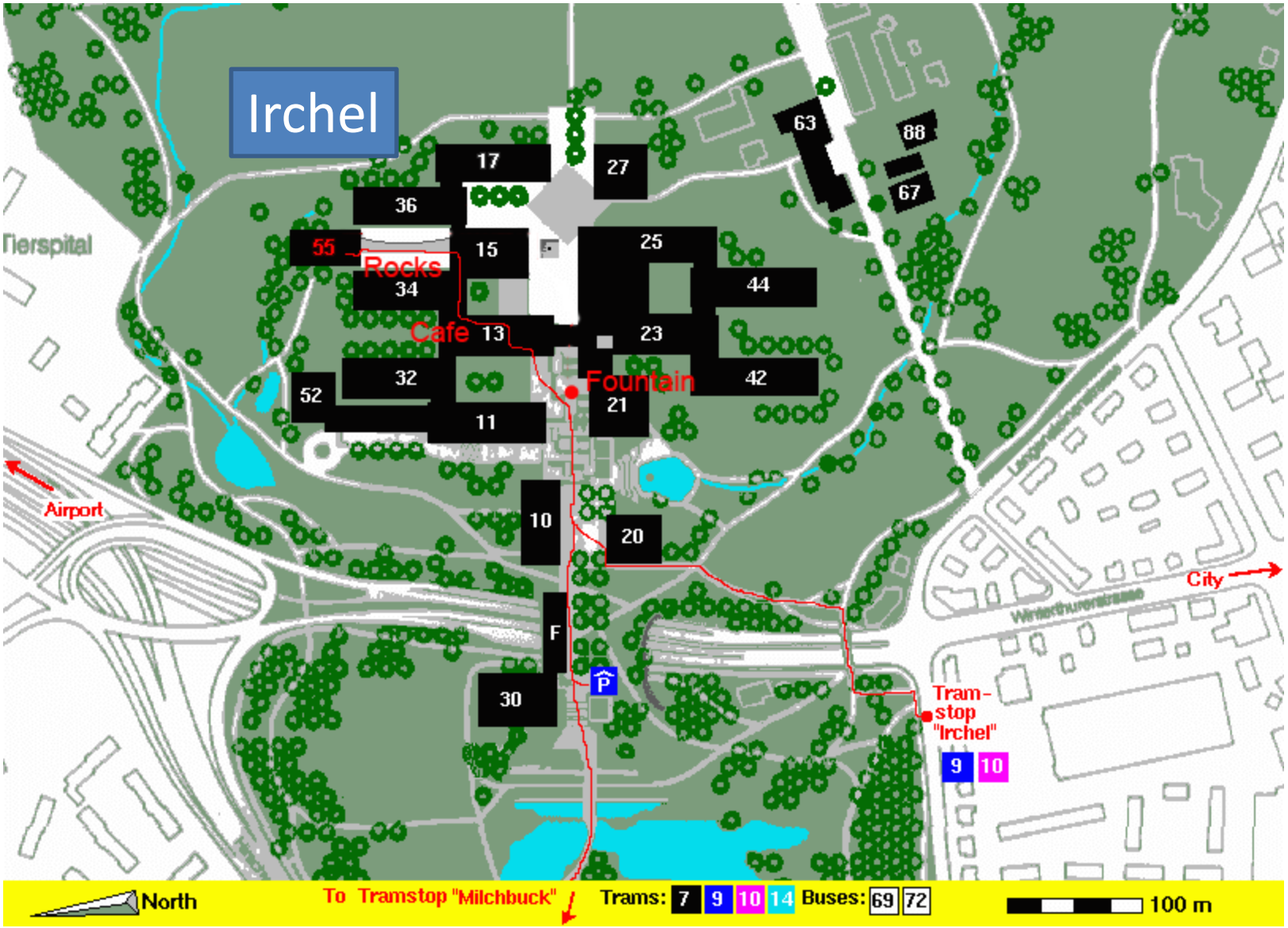
Exercise 1

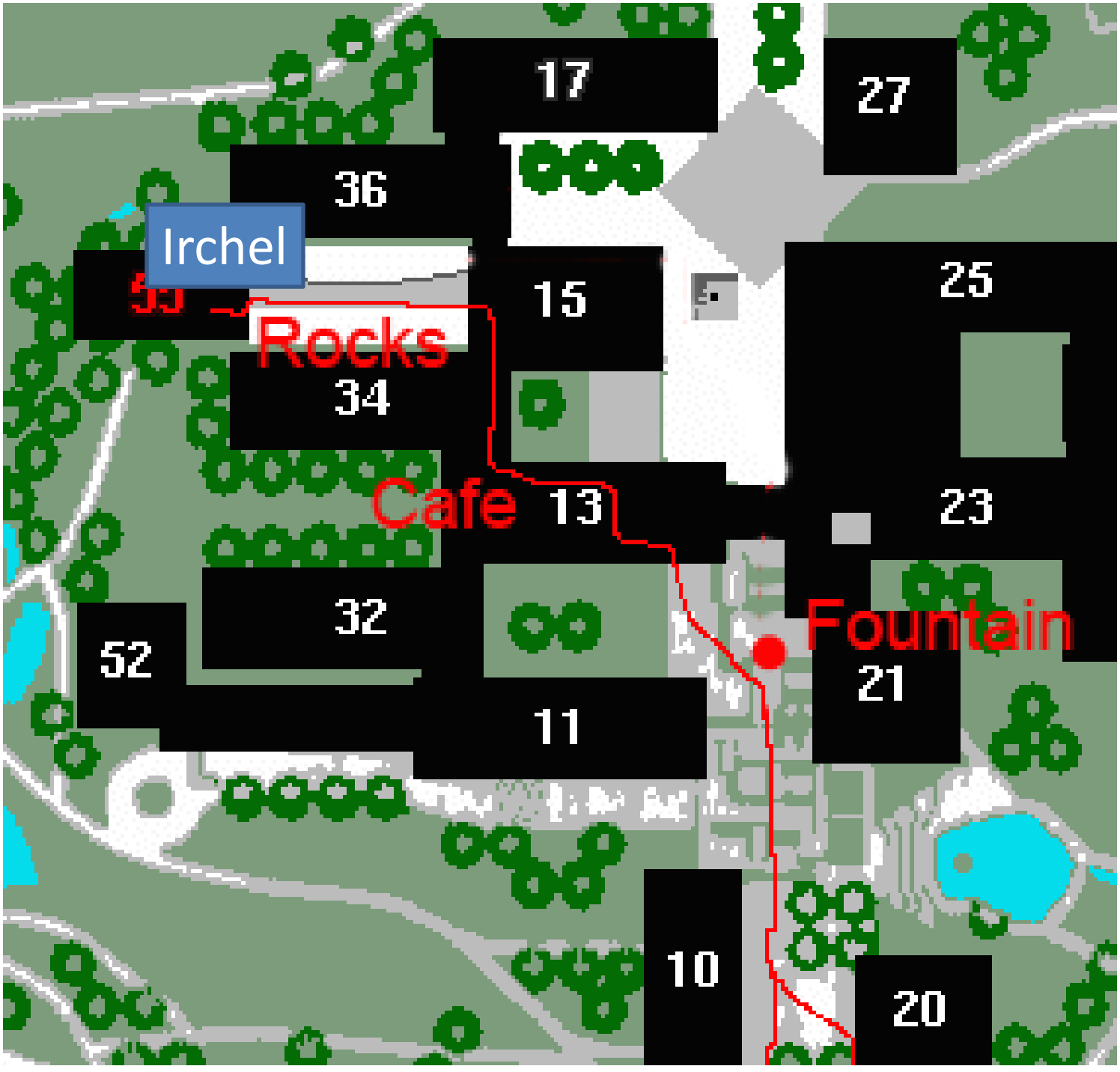
- Installing and running AVR32 tools.
- Importing Daniel's usb-rgb-ldr* example project.
- Installing libusb USB driver and 'copper' board.
- Programming sample copper board with usb-rgb-ldr.
- Installing python and pyusb.
- Running usb-rgb-ldr on copper board with LDR and RGB LEDs added.
- Arranging time for soldering your own copper or 'bronze' board.
- Exercise 2: probably debugging and repairing your own copper board, adding RGB LED and LDR

* LDR=Light dependent resistor, RGB LED=Red/Green/Blue Light Emitting Diode

Surface mount soldering exercise

Finding INI=Inst. of Neuroinformatics




17
27
36
Irchel
15
25
Rocks
34
Cafe
13
23
32
Fountain
52
21
11
10
20