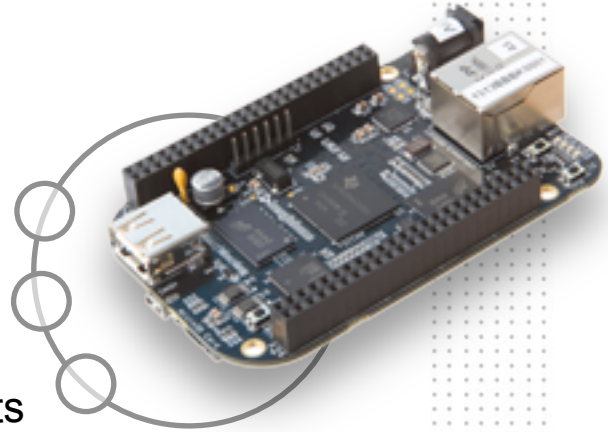
BeagleBone Black – Maker tested, engineer approved

BeagleBone Black

Open-source Linux computer

Everything you need to get started for ~$50

For hobbyists, engineers and students



Jason Kridner

Co-Founder

BeagleBoard.org

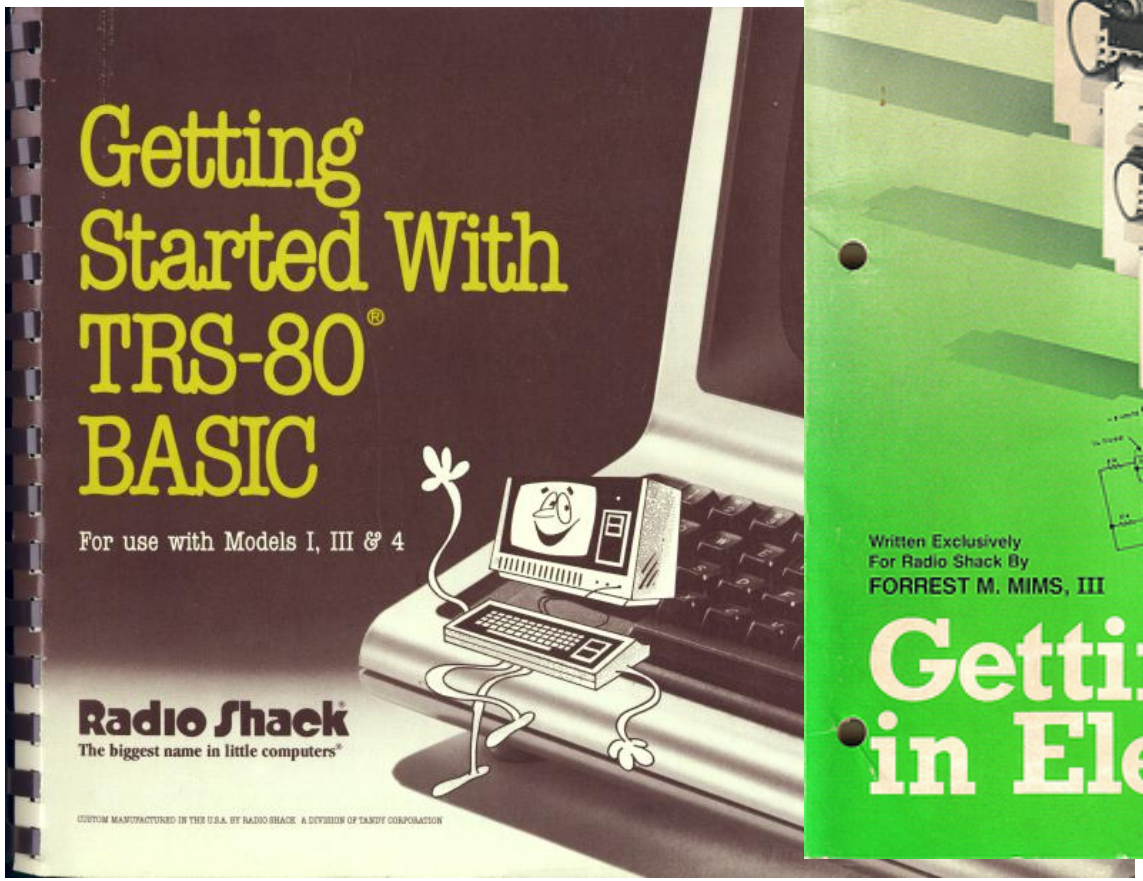
beagleboard.org

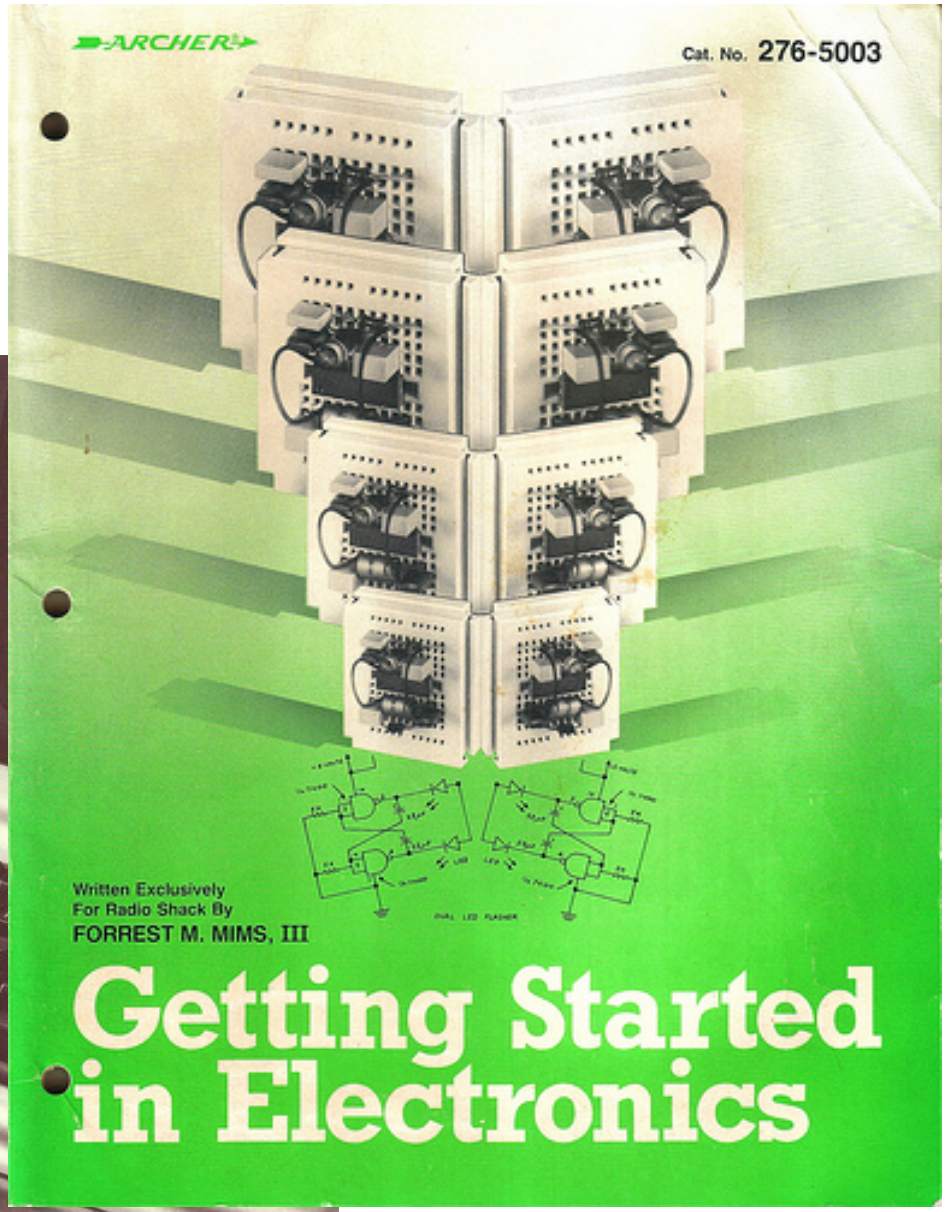
MUG Agenda

- What is open hardware? Why did BeagleBoard.org choose to make BeagleBone Black open hardware? What does this mean to professionals? What does it mean to novices? Jason Kridner, co-founder of BeagleBoard.org, will explore the experiences of makers like David Lang, author of "Zero to Maker", who went from unemployed to running OpenROV, a community and business building open hardware underwater exploration vehicles. Learn about working with local communities and manufacturers to dive into the fun world of connected electronics.

- Jason Kridner is the co-founder of BeagleBoard.org, where he has helped create open source development tools such as BeagleBone Black, BeagleBone, BeagleBoard, and BeagleBoard-xM. Kridner is also a software architecture manager for embedded processors at Texas Instruments (TI).

My History





http://newcome.wordpress.com/2009/12/15/make-electronics-the-new-engineers-notebook/
http://www.sandywalsh.com/2012_07_01_archive.html

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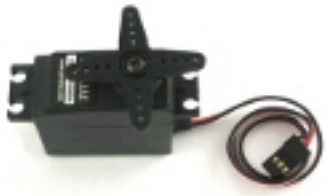
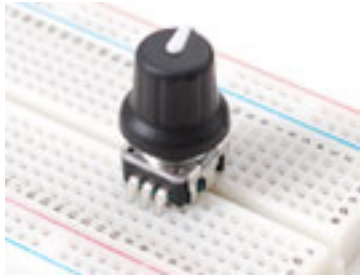
My History

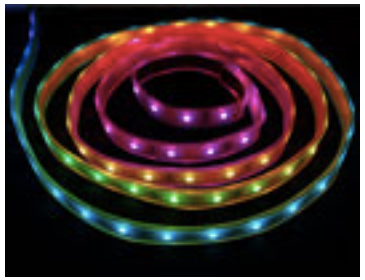
- Over 20 years at Texas Instruments
  - Building and testing boards, chips and software
  - Training people to do my old jobs
- Watching people get frustrated with technology
  - Expectations have changed
- Saw opportunity to share latest mobile technology

Vision for BeagleBoard.org

- Creating with electronics should be as easy as creating a web page





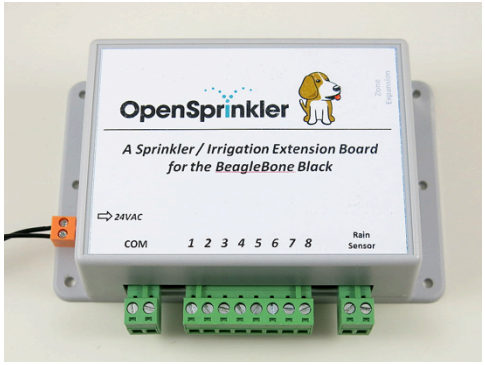


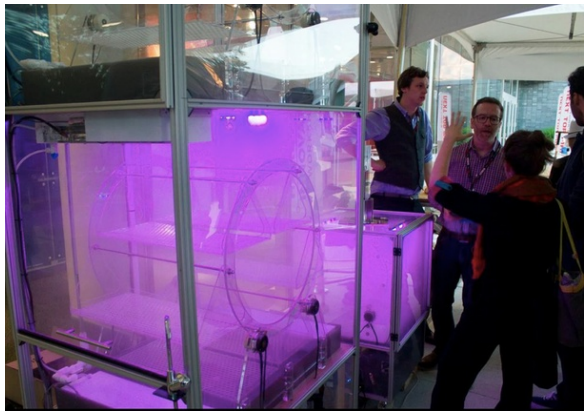
http://www.adafruit.com/

beagleboard.org

Vision for BeagleBoard.org

- Creating with electronics should be as easy as creating a web page
- Appliances are better than applications





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Vision for BeagleBoard.org

- Creating with electronics should be as easy as creating a web page
- Appliances are better than applications
- Open source software and hardware enable
  - Collaboration on the problem
  - Ability to understand and improve the fundamentals

open source hardware

open source

beagleboard.org

BeagleBone Black – an evolution

	BeagleBoard	BeagleBoard-xM	BeagleBone	BeagleBone Black
Board				
Quick summary	The original open hardware, ARM-based development board	All features of the original BeagleBoard with extra memory and extra performance	Low-cost, open-source community platform with plug-in board expansion	Next-generation BeagleBone featuring 1-GHz processor
Memory	256KB L2 cache	512MB DDR2	256MB DDR2	512MB DDR3
Special features	2D/3D graphics accelerator, HDMI, HD video capable, USB powered, C6000 DSP	1-GHz processing power, HDMI, HD video capable, Four- port hub with Ethernet, C6000 DSP	USB-powered, Ethernet, USB JTAG, PRUs	eMMC, HDMI, USB-powered, Ethernet and HDMI interfaces, PRUs
Price ($U.S.)	$129	$149	$89	**$45-$55**

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BeagleBone Black
1 GHz performance, ready to use

Truly flexible open hardware and software development platform

All you need is in the box

Proven ecosystem from prototype to product

BeagleBone Black

- Ready to use: ~$50
- 1 GHz performance and embedded microcontrollers
- On-board HDMI to connect directly to TVs and monitors
- 512MB DDR3-800 RAM
- On-board 4GB flash storage with Debian frees up the microSD card slot
- Support for existing Cape plug-in boards: http://beaglebonecapes.com

Most affordable and proven open hardware Linux platform available

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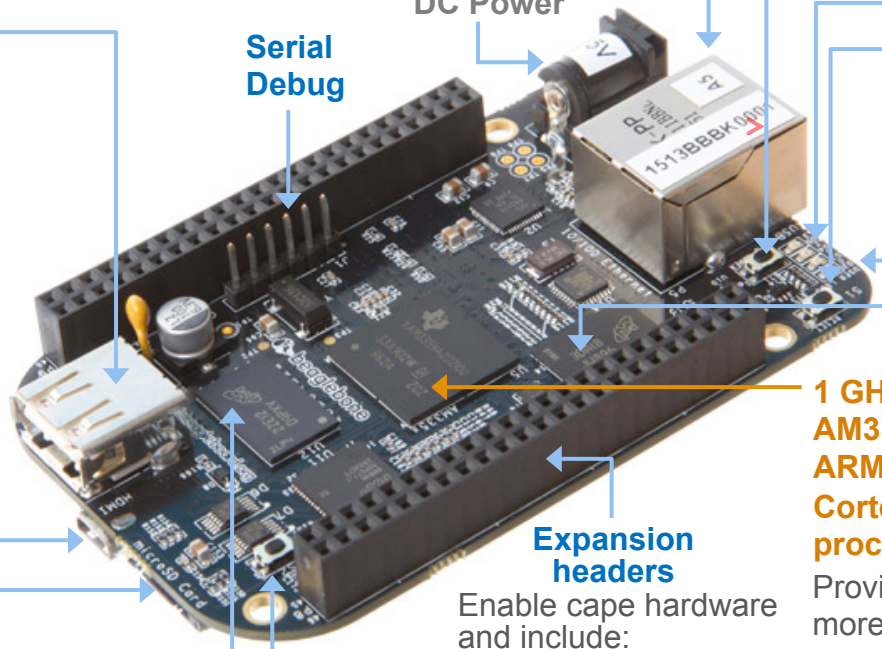
BeagleBone Black board features



10/100 Ethernet

USB Host
Easily connects to almost any everyday device such as mouse or keyboard

microHDMI
Connect directly to monitors and TVs

microSD
Expansion slot for additional storage

512MB DDR3
Faster, lower power RAM for enhanced user-friendly experience

Serial Debug

DC Power

Boot Button

Power Button

LEDS

Reset Button

USB Client
Development interface and directly powers board from PC

4GB on-board storage using eMMC
- Pre-loaded with Debian Linux Distribution
- 8-bit bus accelerates performance
- Frees the microSD slot to be used for additional storage for a less expensive solution than SD cards

1 GHz Sitara AM335x ARM® Cortex™-A8 processor
Provides a more advanced user interface and up to 150% better performance than ARM11

Expansion headers
Enable cape hardware and include:
- 65 digital I/O
- 7 analog
- 4 serial
- 2 SPI
- 2 I2C
- 8 PWMs
- 4 timers
- And much much more!

Money saving extras:
- Power over USB
- Included USB cable
- 4GB on-board storage
- Built-in PRU microcontrollers

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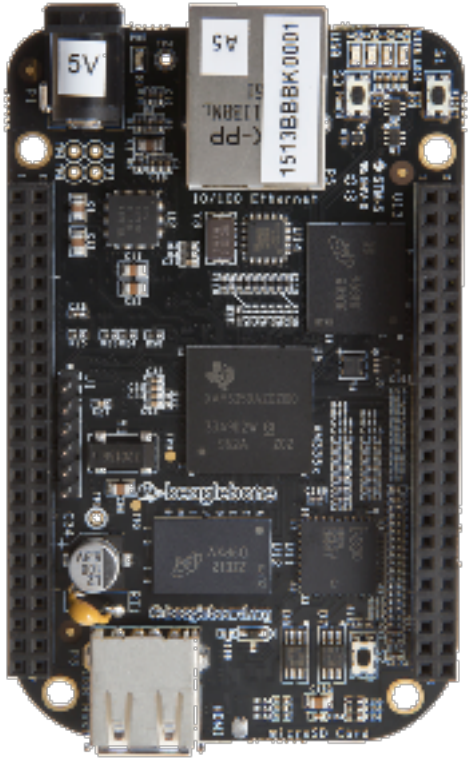
Cape Expansion Headers

DGND	1	2	DGND
VDD_3V3	3	4	VDD_3V3
VDD_5V	5	6	VDD_5V
SYS_5V	7	8	SYS_5V
PWR_BUT	9	10	SYS_RESETn
UART4_RXD	11	12	GPIO_60
UART4_TXD	13	14	EHRPWM1A
GPIO_48	15	16	EHRPWM1B
SPI0_CS0	17	18	SPI0_D1
I2C2_SCL	19	20	I2C2_SDA
SPI0_D0	21	22	SPI0_SCLK
GPIO_49	23	24	UART1_TXD
GPIO_117	25	26	UART1_RXD
GPIO_115	27	28	SPI1_CS0
SPI1_D0	29	30	GPIO_122
SPI1_SCLK	31	32	VDD_ADC
AIN4	33	34	GNDA_ADC
AIN6	35	36	AIN5
AIN2	37	38	AIN3
AIN0	39	40	AIN1
GPIO_20	41	42	ECAPPWM0
DGND	43	44	DGND
DGND	45	46	DGND



LEGEND
Power/Ground/Reset
Available Digital
Available PWM
Shared I2C Bus
Reconfigurable Digital
Analog Inputs (1.8V)

DGND	1	2	DGND
MMC1_DAT6	3	4	MMC1_DAT7
MMC1_DAT2	5	6	MMC1_DAT3
GPIO_66	7	8	GPIO_67
GPIO_69	9	10	GPIO_68
GPIO_45	11	12	GPIO_44
EHRPWM2B	13	14	GPIO_26
GPIO_47	15	16	GPIO_46
GPIO_27	17	18	GPIO_65
EHRPWM2A	19	20	MMC1_CMD
MMC1_CLK	21	22	MMC1_DAT5
MMC1_DAT4	23	24	MMC1_DAT1
MMC1_DAT0	25	26	GPIO_61
LCD_VSYNC	27	28	LCD_PCLK
LCD_HSYNC	29	30	LCD_AC_BIAS
LCD_DATA14	31	32	LCD_DATA15
LCD_DATA13	33	34	LCD_DATA11
LCD_DATA12	35	36	LCD_DATA10
LCD_DATA8	37	38	LCD_DATA9
LCD_DATA6	39	40	LCD_DATA7
LCD_DATA4	41	42	LCD_DATA5
LCD_DATA2	43	44	LCD_DATA3
LCD_DATA0	45	46	LCD_DATA1

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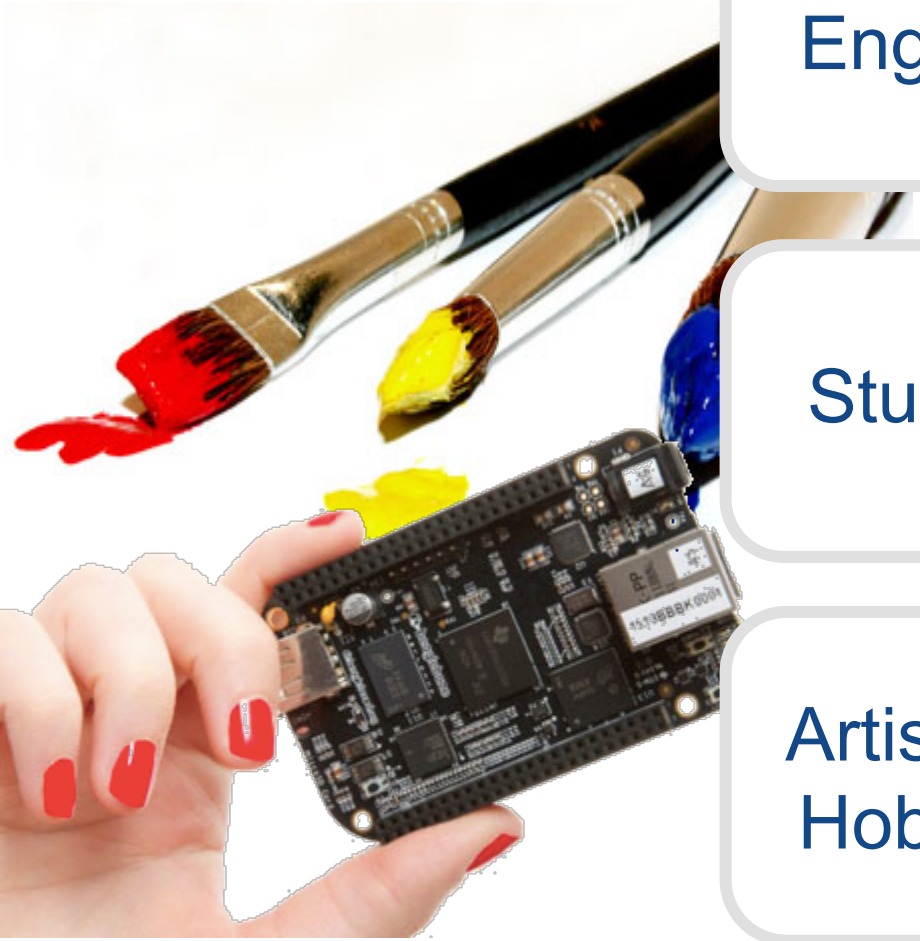
Importance to the hobbyist

- Longevity
- More detailed understanding
- Apply learning across more diverse platforms

Easily transform ideas into usable, unique products

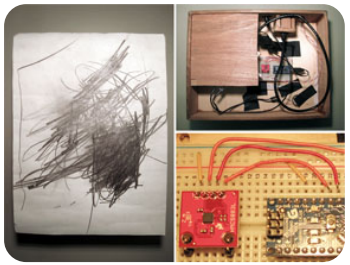


Engineers

Ninja block

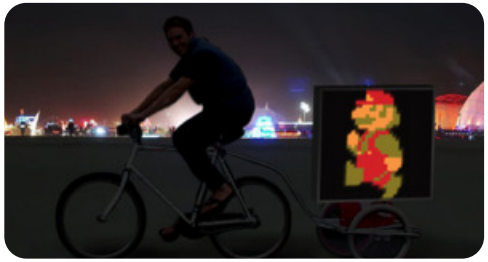
OpenROV

Students



Electroacoustic drawing board

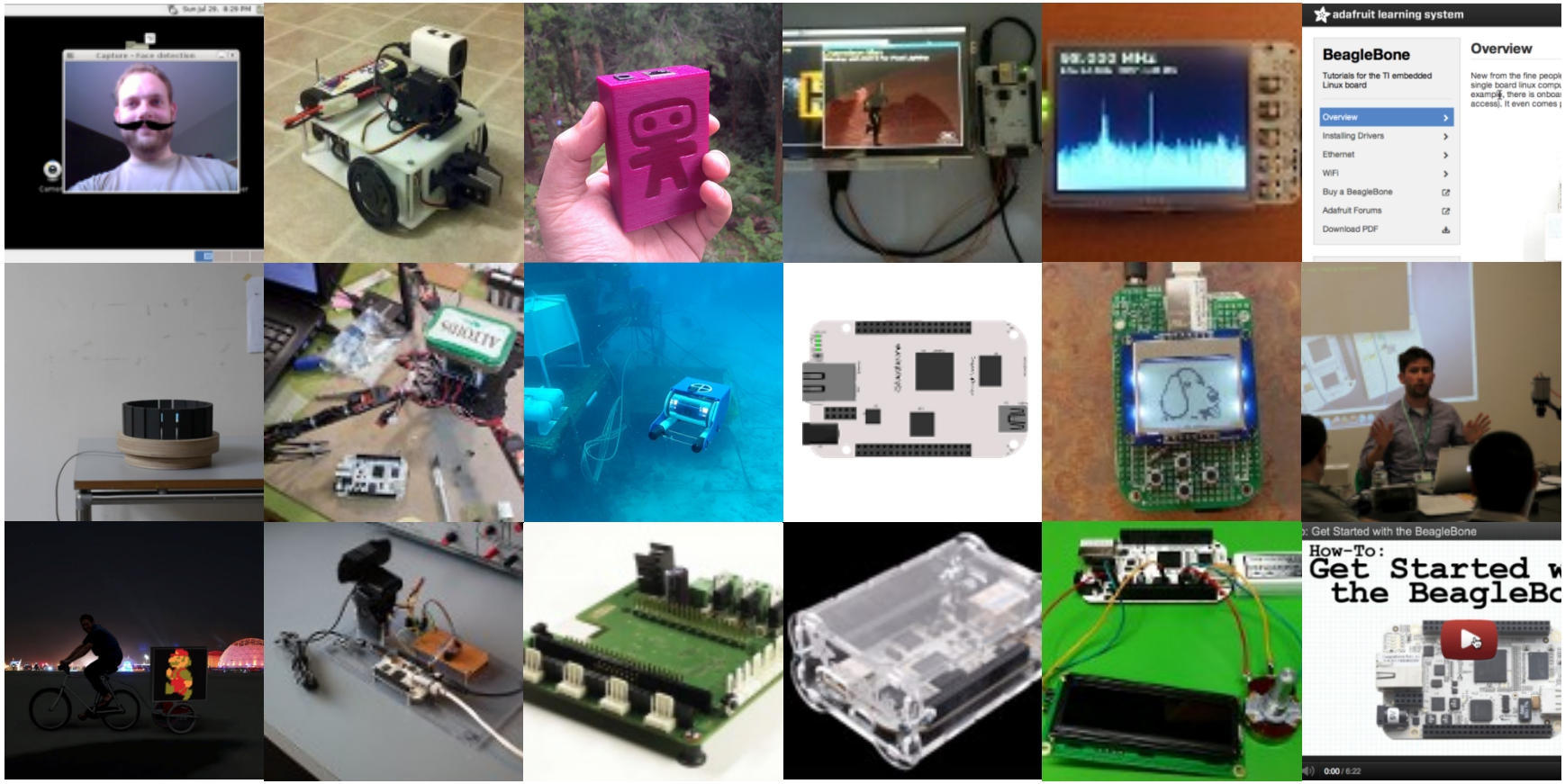
Artists and Hobbyists



Electronic light sculpture

Huge base of existing projects

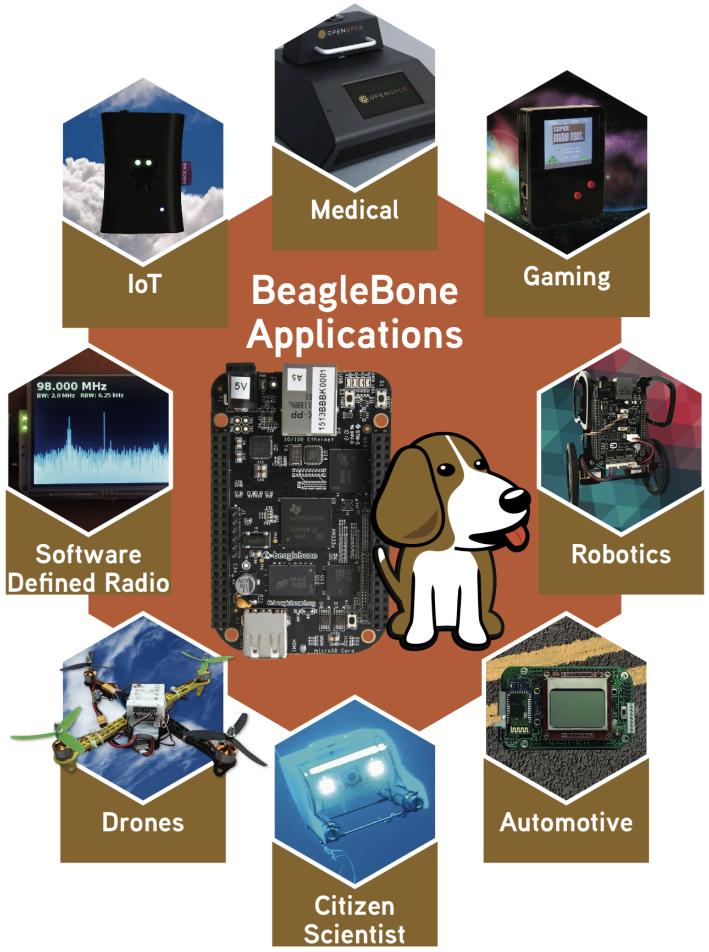
Making it fun and easy to bring ideas to life



http://beagleboard.org/project

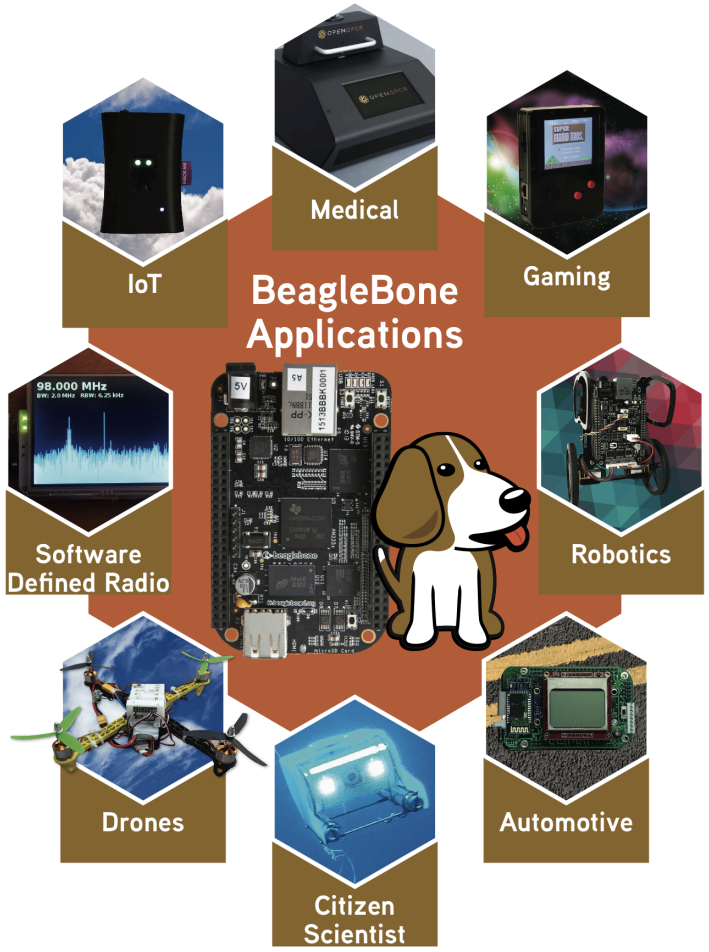
beagleboard.org

BeagleBone used in many applications



- Medical
- Citizen Science
- Home Automation
- Network Security
- Localizing Information
- Assistive Technology
- LEGO Robotics
- Simple Mobile Robots
- Industrial Robots

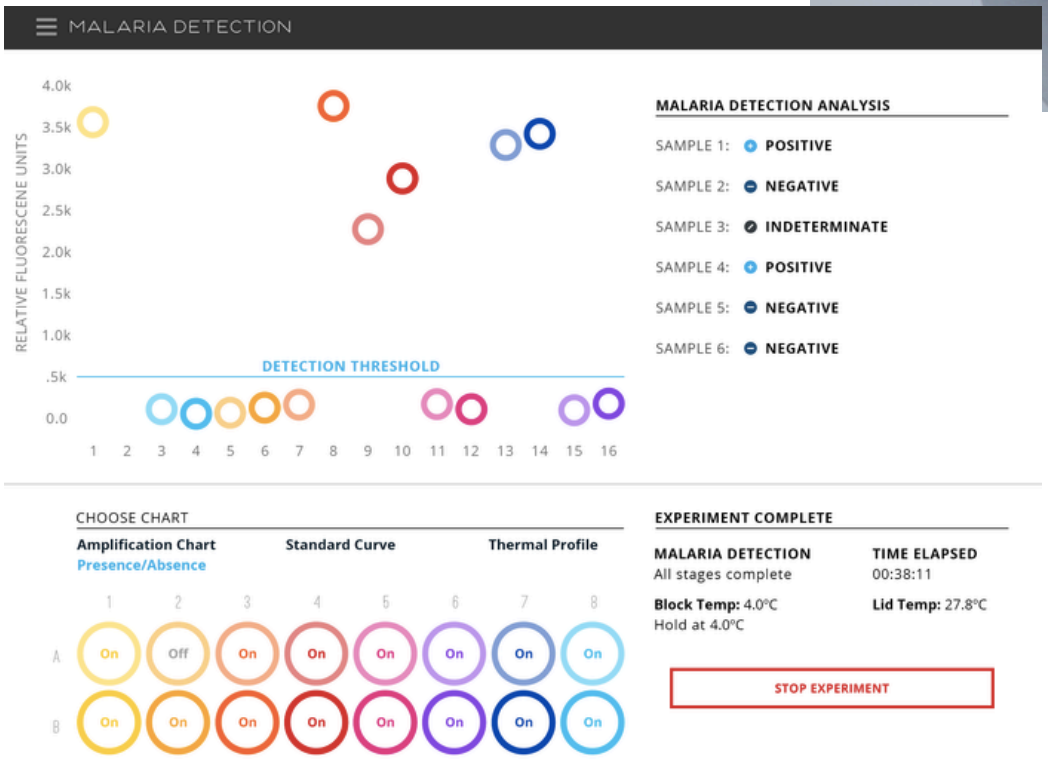
10,000s of developers building connected devices today



- Medical analysis, assistance and information management
- Home information, automation and security systems
- Home and mobile entertainment and educational systems
- New types of communications systems
- Personal robotic devices for cleaning, upkeep and manufacturing
- Remote presence and monitoring
- Automotive information management and control systems
- Personal environmental exploration and monitoring

Open qPCR

DNA Diagnostics for Everyone

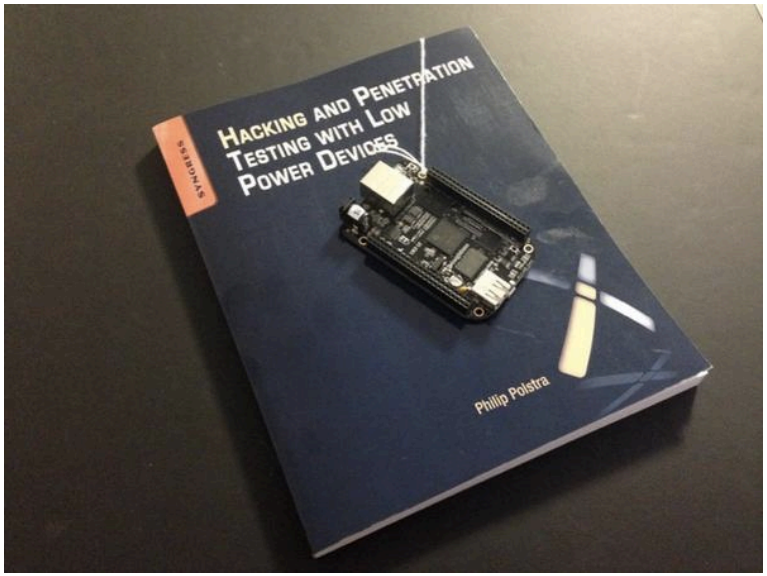


OpenROV

Open source underwater robots for exploration and education

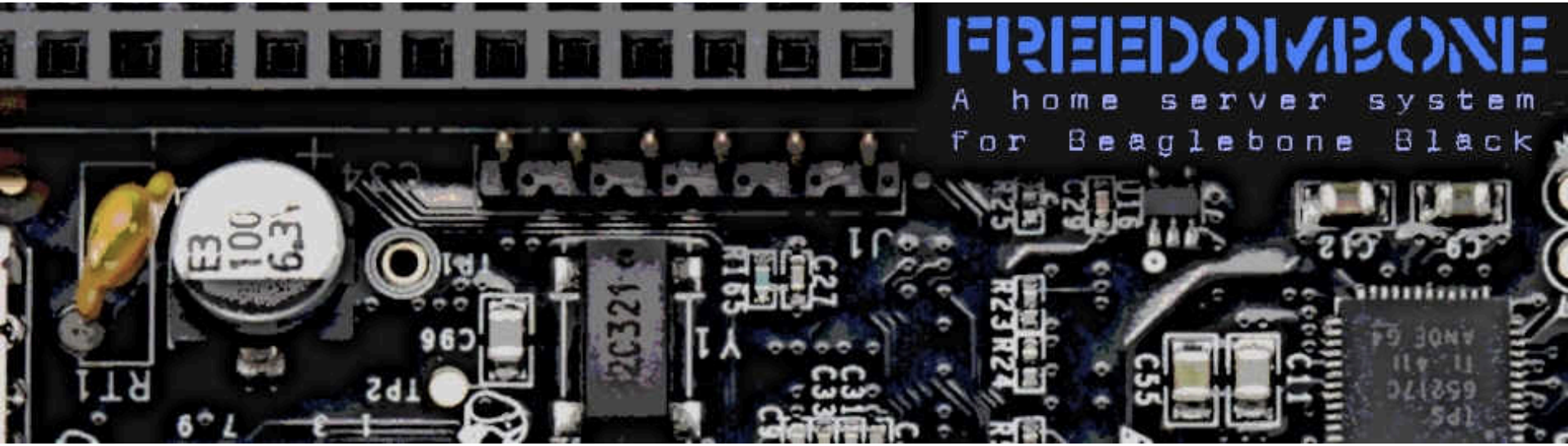
The Deck

Full-featured penetration and forensics testing Linux distribution



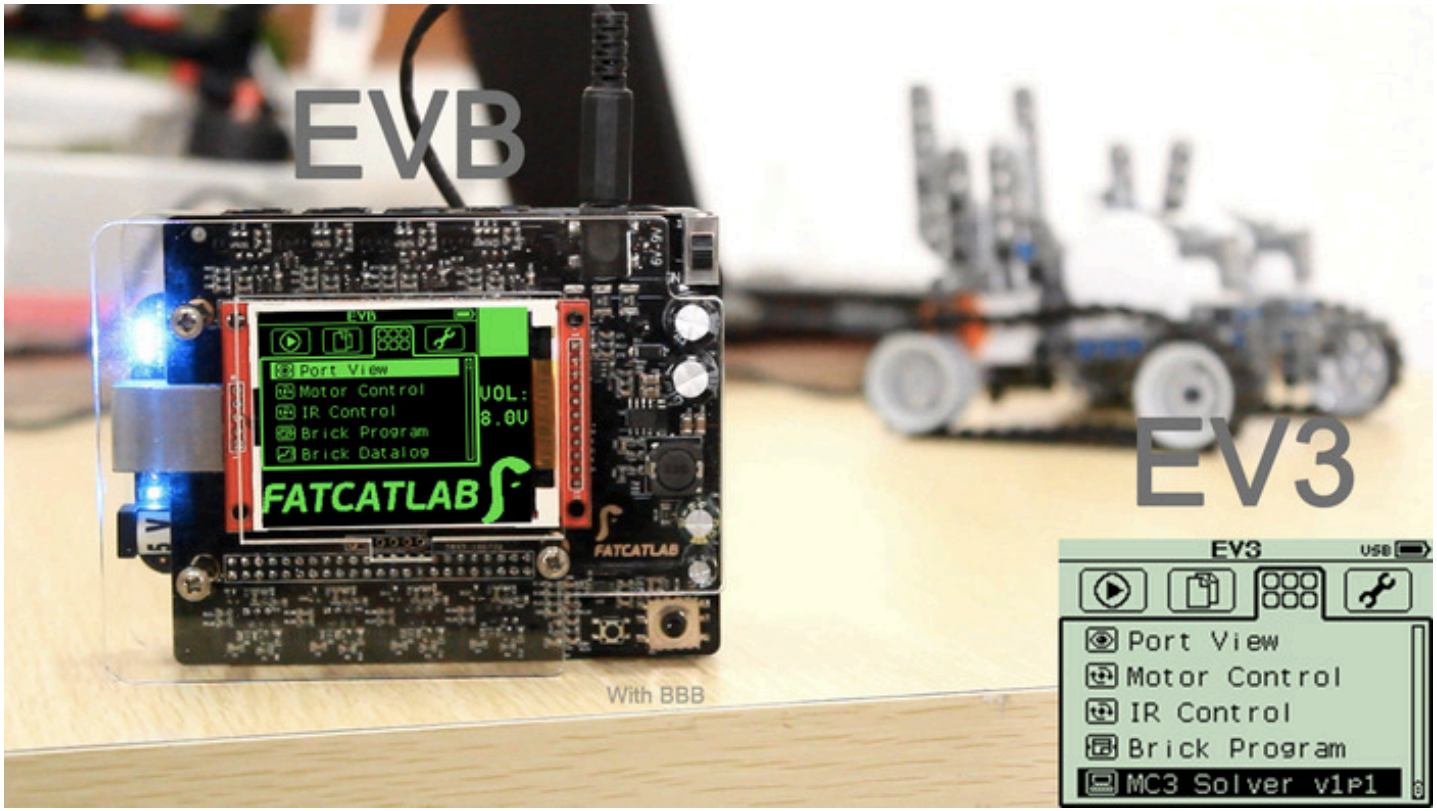
Freedombone

Serve your cloud from your home



EVB

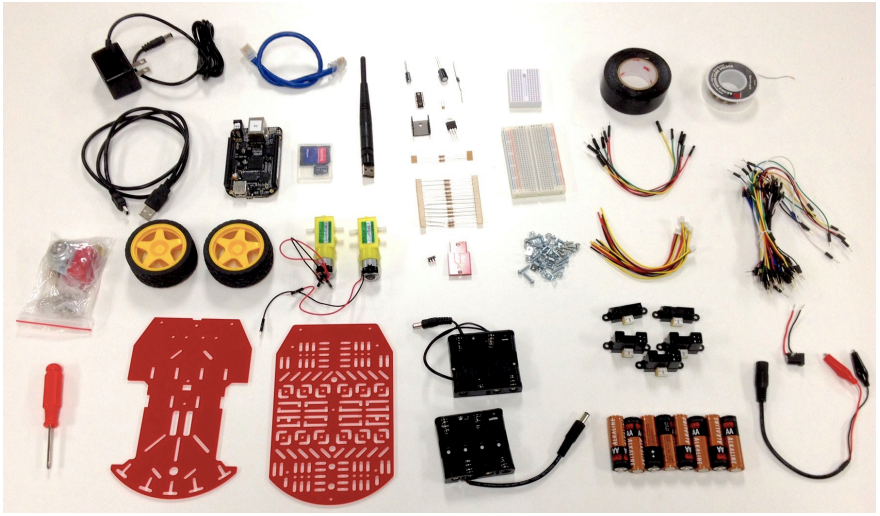
Replace the brain of your LEGO EV3 with BeagleBone Black

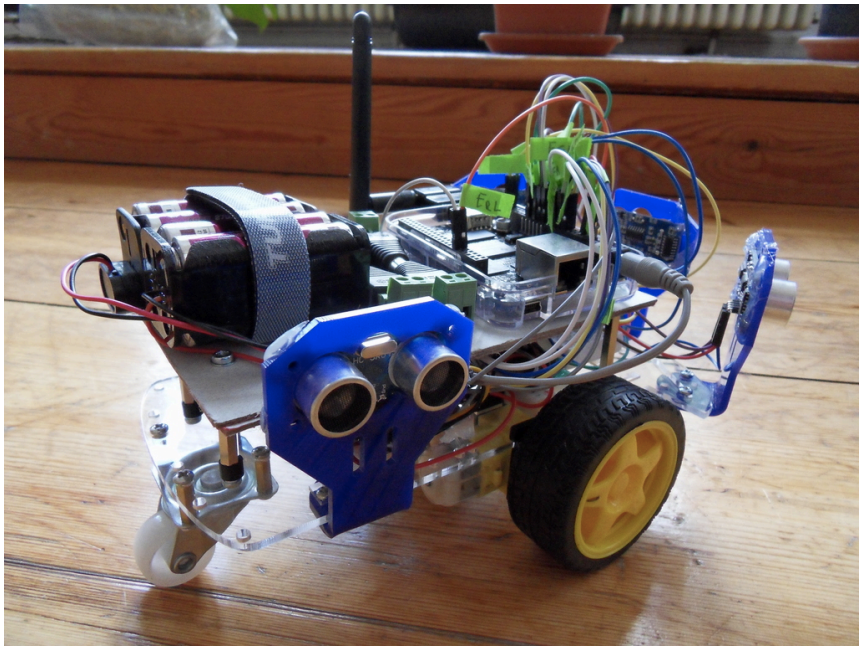


Coursera + O-botics.org

Massively open online course on control of mobile robots

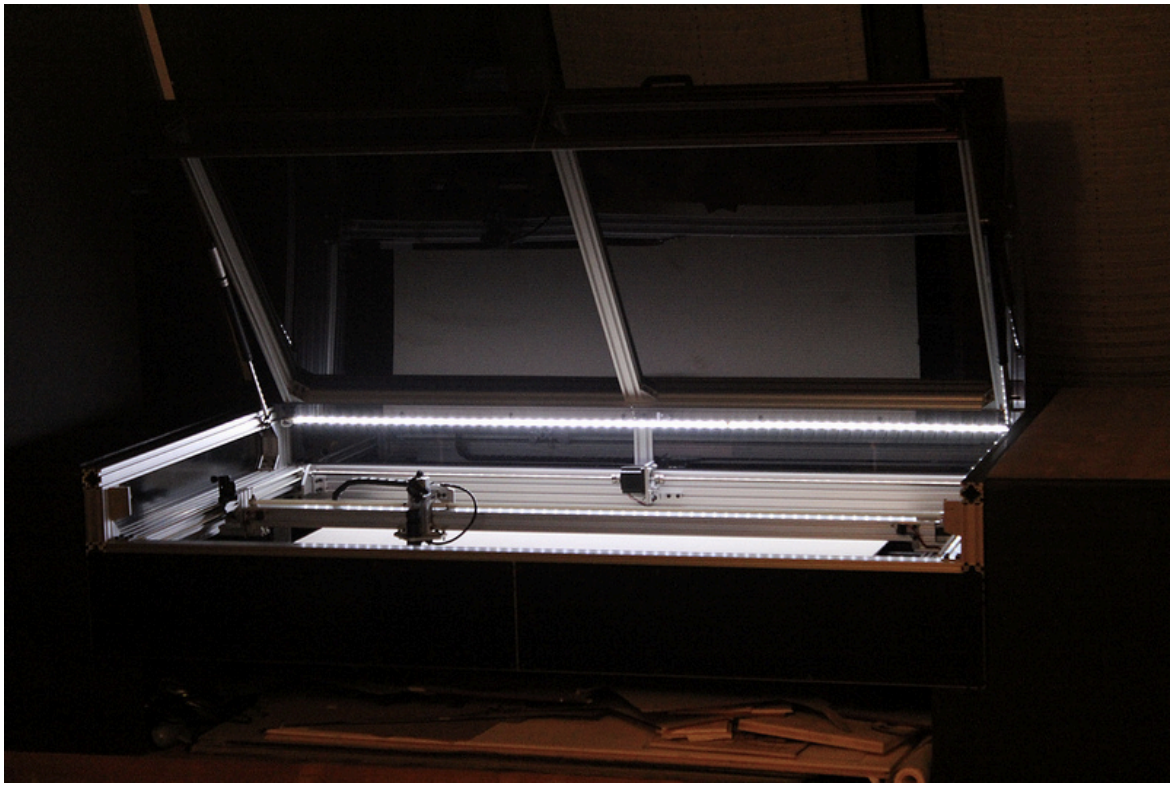
A place where roboticists can collaborate on robot designs, code, electronics, and hardware





Lasersaur

Open-source laser cutter for makers and builders



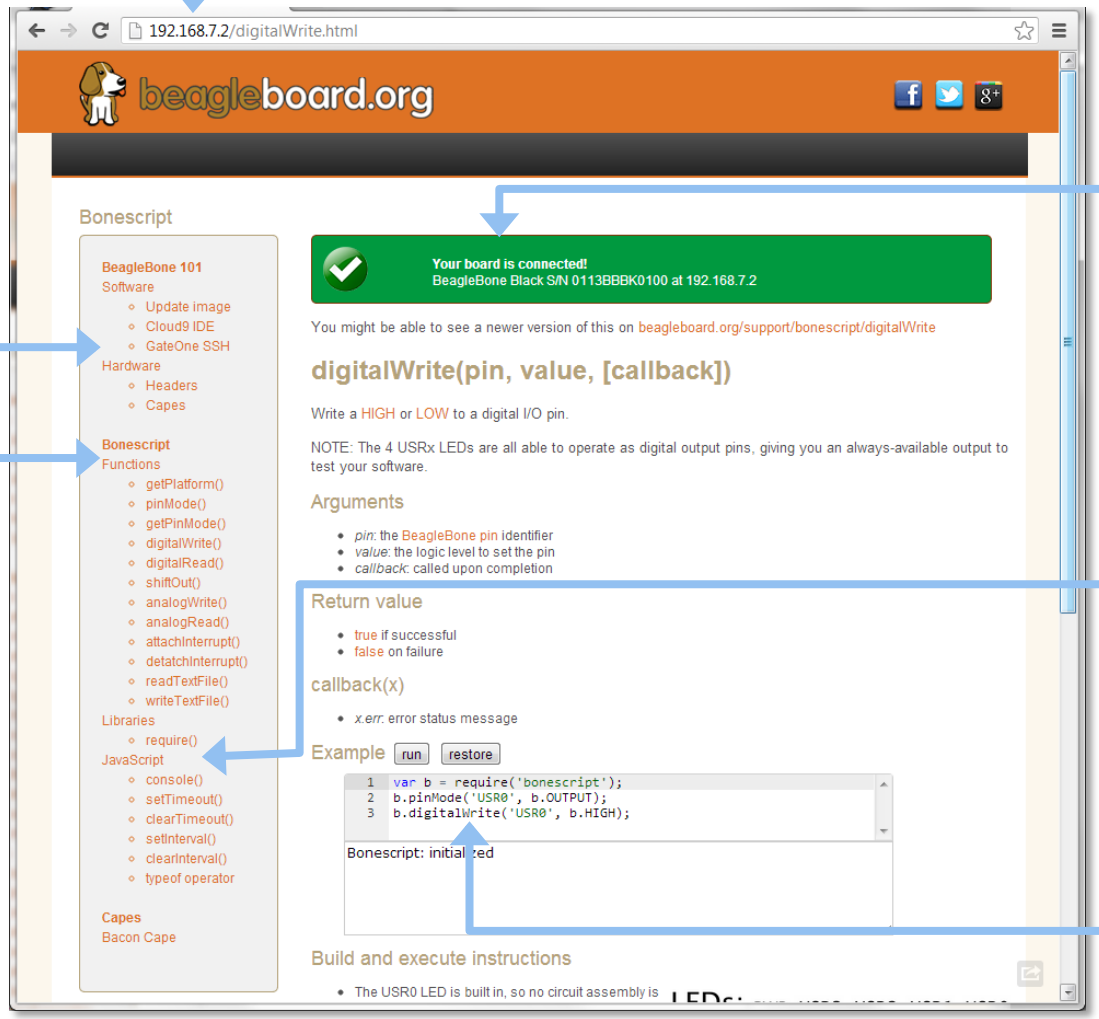
Let’s try it out

BoneScript: Arduino-like simplicity + the power of a 1GHz Linux computer

Browser-based interactive teaching environment
- Zero-install
- Runs directly on BeagleBone Black
- Hides Linux complexity

Power of 1GHz computer on demand
- Networking and USB stacks
- Open-source frameworks available
- Accessible keyboard/mouse/monitor
- Accessible over SSH from PC

BoneScript
- Arduino-like software for easy module interactions



Talks directly to the board
- Programmatic interface into the board

Built on familiar programming environments
- JavaScript
- HTML5
- Node.js

Examples run directly in browser
- Click to run
- Editable in browser
- Experiment to learn
- Copy and paste

BoneScript in the browser

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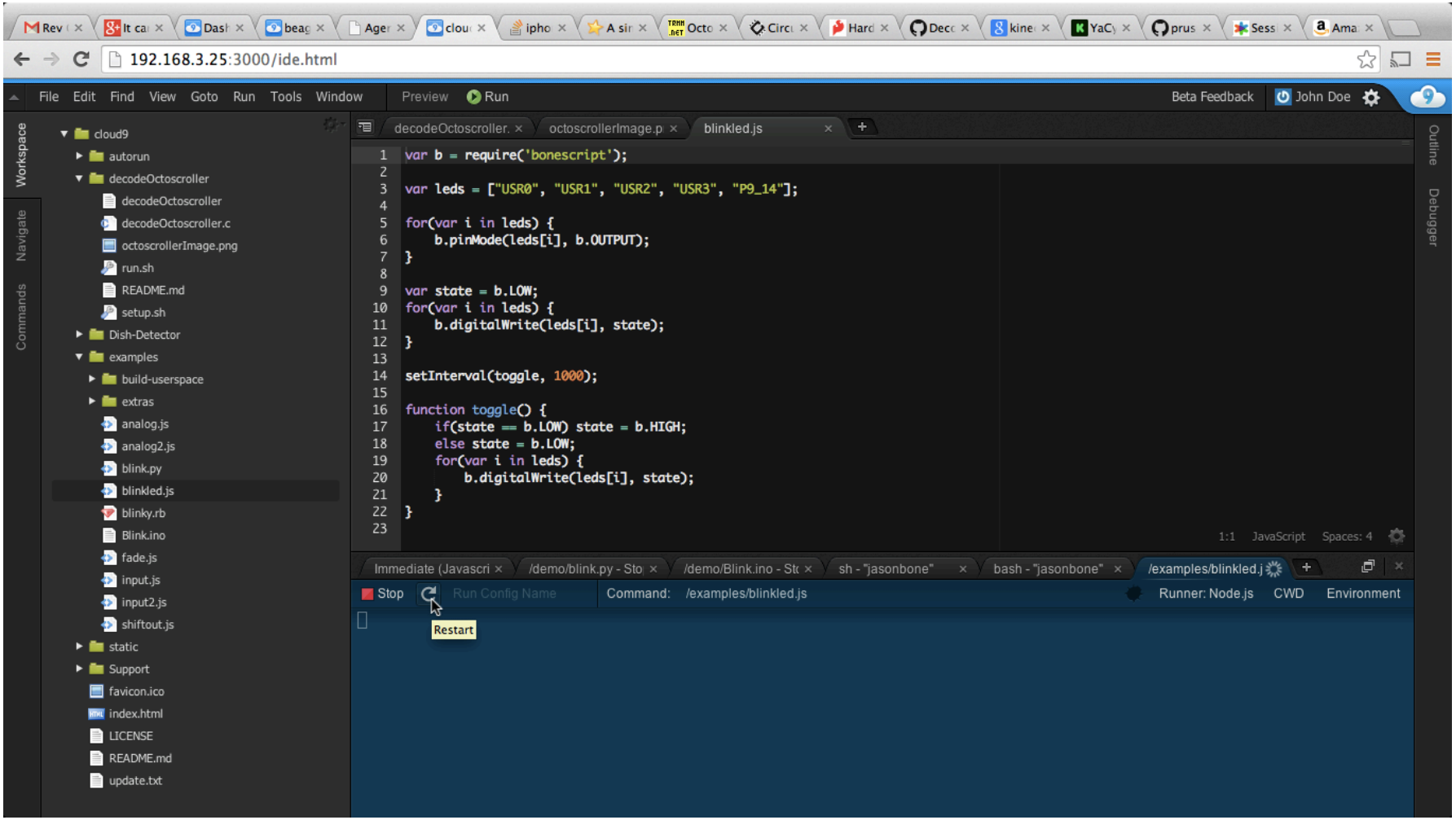
Cloud9 IDE included



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Our challenges and solutions in this lab

- Typical out-of-box is to use USB networking and on-board provided drivers, but we wanted to get out to the Internet quickly
- We know we can connect to “MIT GUEST” WiFi, so we started with an image with all the tools we needed to get on the network
- Typical network supports mDNS on LAN for discovery using “beaglebone.local”, but didn’t prove reliable on our network
- Each board has a unique serial number that is printed on a label on the board and readable using an EEPROM on the board
- Dweet.io is a nice tool to publish data with a simple network operation
- We chose to use Dart, because it’s Brian’s language of choice, to perform the data fetch and publish: https://gist.github.com/jadonk/178f9aa0f96363e4277e
- Flash duplicated using /opt/tools/scripts/eMMC/beaglebone-black-make-microSD-flasher-from-eMMC.sh

Our setup – how to get connected

- Chose to publish using name “beagle-at-mit”
  - http://bit.ly/beagleatmit
  - Search for your serial number in the log and match the ip
- Option #1 - ssh
  - ssh root@10.189.37.24
- Option #2 - Chrome
  - http://10.189.37.24:3000

Some quick interfaces to hack

- LEDs

```
root@beaglebone:~# cd /sys/class/leds/beaglebone\:green\:usr0
root@beaglebone:/sys/class/leds/beaglebone:green:usr0# cat trigger
none nand-disk mmc0 mmc1 timer oneshot [heartbeat] backlight gpio cpu0 default-on transient
root@beaglebone:/sys/class/leds/beaglebone:green:usr0# echo none > trigger
root@beaglebone:/sys/class/leds/beaglebone:green:usr0# echo 1 > brightness
root@beaglebone:/sys/class/leds/beaglebone:green:usr0# echo 0 > brightness
```

- GPIOs

```
root@beaglebone:~# node -pe "require('bonescript').bone.pins.P9_14.gpio"
50
root@beaglebone:~# node -pe "require('bonescript').bone.pins.P9_14.muxRegOffset”
0x048
root@beaglebone:~# cat /sys/kernel/debug/pinctrl/44e10800.pinmux/pins | grep 0848
pin 18 (44e10848) 00000027 pinctrl-single
root@beaglebone:~# node -pe "require('bonescript').getPinMode('P9_14').pullup"
pulldown
root@beaglebone:~# cd /sys/class/gpio
root@beaglebone:/sys/class/gpio# cat gpio50/direction
in
root@beaglebone:/sys/class/gpio# cat gpio50/value
0
```

Some quick interfaces to hack

- LEDs

```
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root@beaglebone:/sys/class/leds/beaglebone:green:usr0# cat trigger
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root@beaglebone:/sys/class/leds/beaglebone:green:usr0# echo 1 > brightness
root@beaglebone:/sys/class/leds/beaglebone:green:usr0# echo 0 > brightness
```
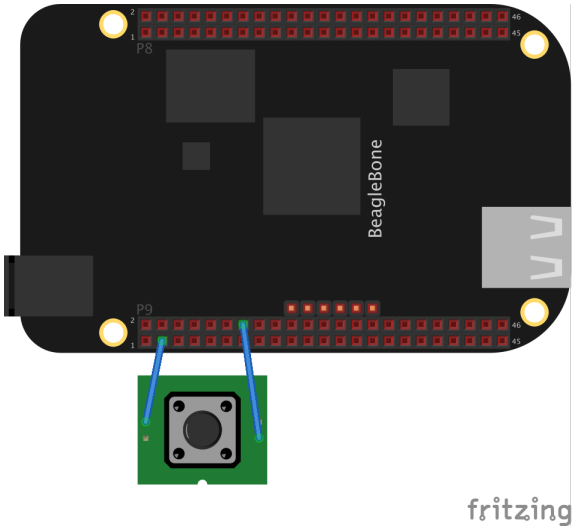
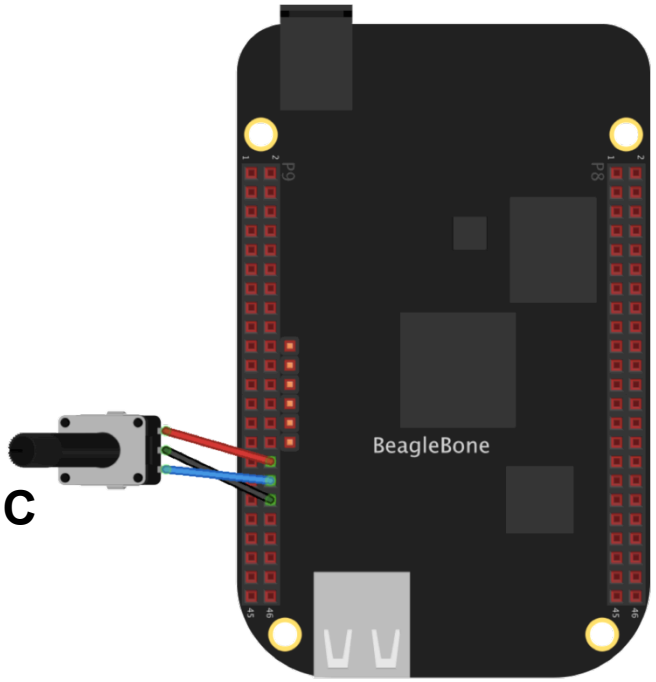

- GPIOs

```
root@beaglebone:~# config-pin overlay cape-universaln
Loading cape-universaln overlay
root@beaglebone:~# config-pin p9.14 gpio_pd
root@beaglebone:~# config-pin -q p9.14
P9_14 Mode: gpio_pd Direction: in Value: 0
root@beaglebone:~# cd /sys/class/gpio
root@beaglebone:/sys/class/gpio# cat gpio50/direction
in
root@beaglebone:/sys/class/gpio# cat gpio50/value
0
```



Hacking with the ADC

- Don't forget it is only **1.8V** --- use that voltage divider stuff David was showing you or you'll ***damage your board***!!!
- The overlay will load an ADC driver



- Steps

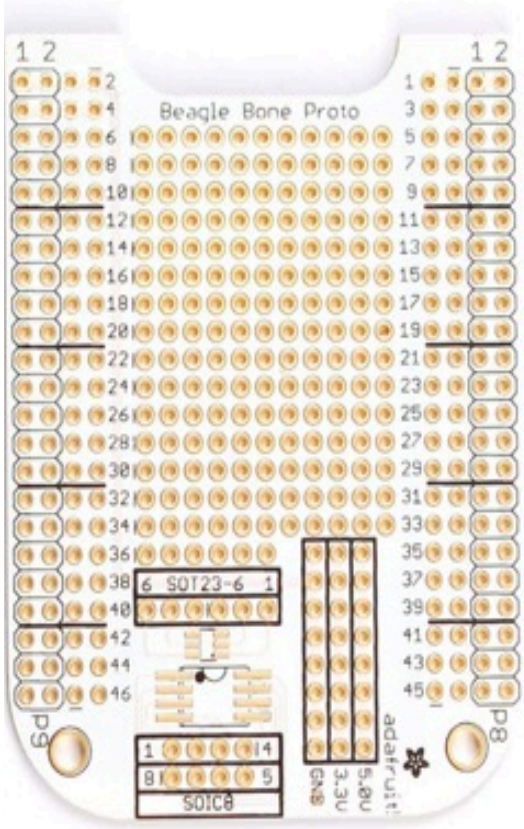
root@beaglebone:~# **config-pin overlay BB-ADC**
Loading BB-ADC overlay
root@beaglebone:~# **config-pin -q p9.36**
Pin is not modifyable: P9_36 AIN5
root@beaglebone:~# **cd /sys/bus/iio/devices/iio\:device0**
root@beaglebone:/sys/bus/iio/devices/iio:device0# **cat in_voltage5_raw**
1850

BeagleBone Black vs. Raspberry PI

- Made from an industrial control processor
- Out-of-box experience (as you've seen)
- Capes
- Programmable Real-time Units (PRUs)
- Open hardware
- (there are more, but we'll discuss these first)

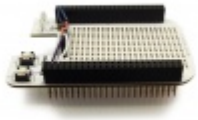
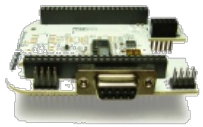
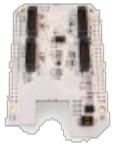
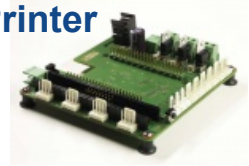
BeagleBone Capes
http://beaglebonecapes.com

- Just another word for a daughterboard
- Many have a cape-like formfactor
- Up to 4 stacked, depending on resources used
- Most are open hardware



beagleboard.org

Capes easily expand BeagleBone capability

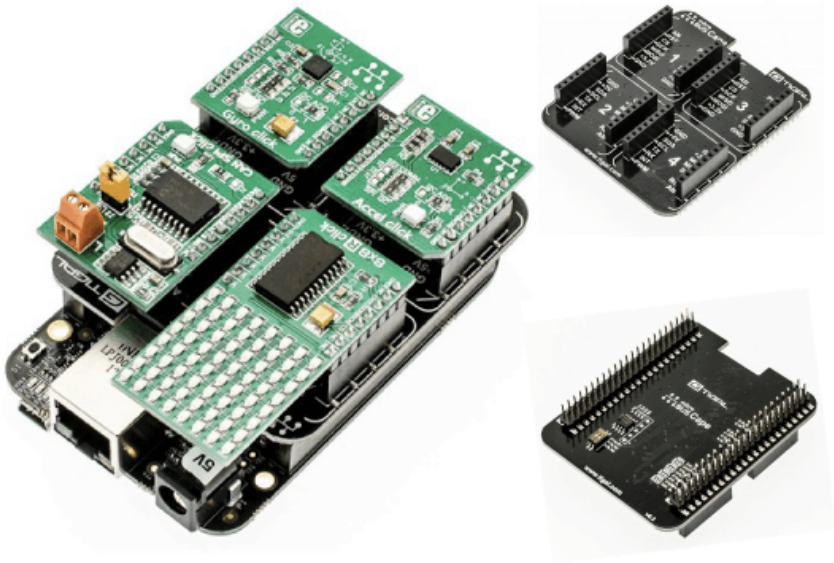
Breadboard 	**Breakout**	**LCD** 7", 4.3" or 3.5"	**DVI-D**	**CANBus**
RS232	**RS485**	**VGA**	**Battery**	**Profibus** 
Proto	**RF-CC1101** CC2500 CC2530 	**Weather**	**Camera**	**CAN**
DVI-D w/ Audio	**Audio**	**BeBoPr 3D Printer** 	**Radar**	**LVDS**

http://beaglebonecapes.com

beagleboard.org

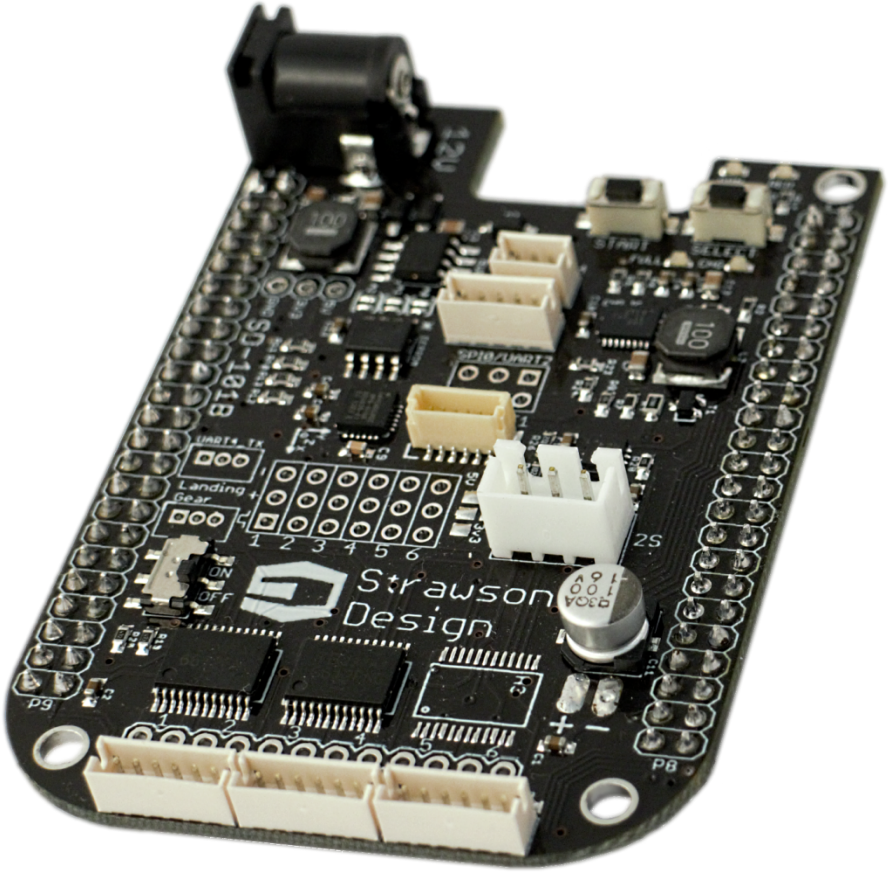
Tigal Mikrobus Cape and Click Boards

- One Cape to Rule them All
- Four Adaptable Capes in One
- Over 70 Click Boards Available and Counting



Novus Robotics Cape

STRAWSON DESIGN



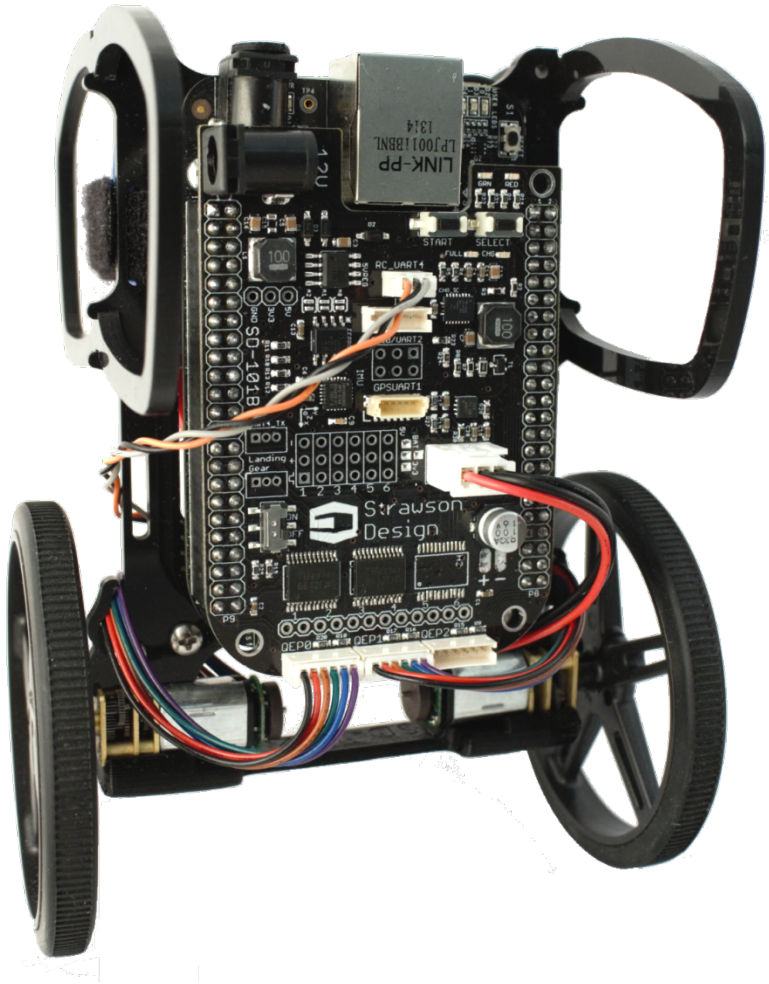
Bringing the power of the BeagleBone Black to your robotics project has never been easier.

- 2S LiPo Charger and Balancer
- 9-Axis IMU
- Drive 6 DC Motors
- Plug and Play Connections for
  - GPS
  - I2C
  - UART
  - Hobby Servos
  - Brushless ESCs
  - Spektrum RC Radio
- Open Source Libraries, Sample Code, and detailed documentation.

beagleboard.org

BeagleMIP

UCSD



- Self-Balancing robot powered by the BeagleBone Black and the Novus Robotics Cape
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- Developed at the University of California, San Diego to Teach Advanced Digital Control Systems

beagleboard.org

BeagleQuad

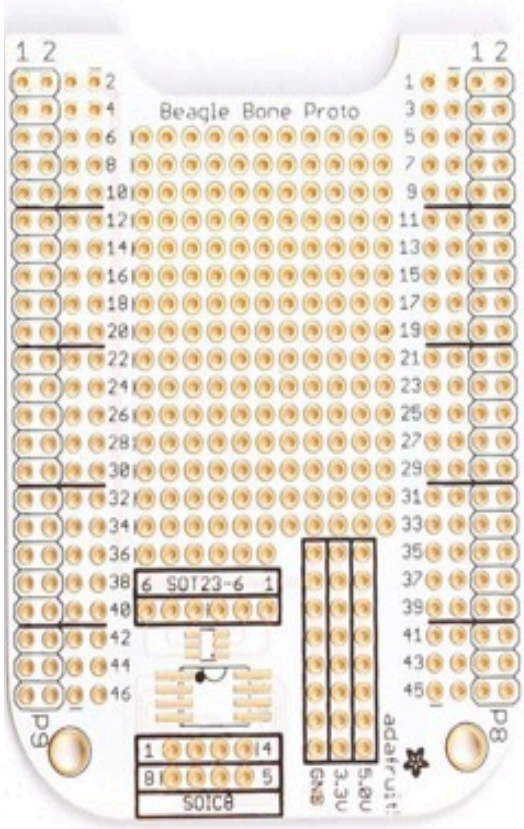
UCSD

The new ***Novus Robotics Cape*** sends your ***BeagleBone Black*** projects to the sky!

beagleboard.org

BeagleBone Capes
http://beaglebonecapes.com

- Just another word for a daughterboard
- Many have a cape-like formfactor
- Up to 4 stacked, depending on resources used
- Most are open hardware



beagleboard.org

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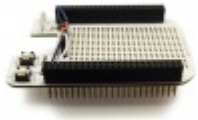
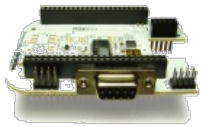
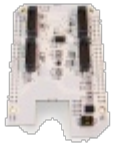
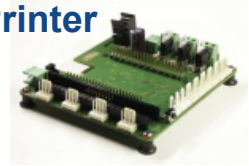
Breadboard 	**Breakout**	**LCD** 7", 4.3" or 3.5"	**DVI-D**	**CANBus**
RS232	**RS485**	**VGA**	**Battery**	**Profibus** 
Proto	**RF-CC1101** CC2500 CC2530 	**Weather**	**Camera**	**CAN**
DVI-D w/ Audio	**Audio**	**BeBoPr 3D Printer** 	**Radar**	**LVDS**

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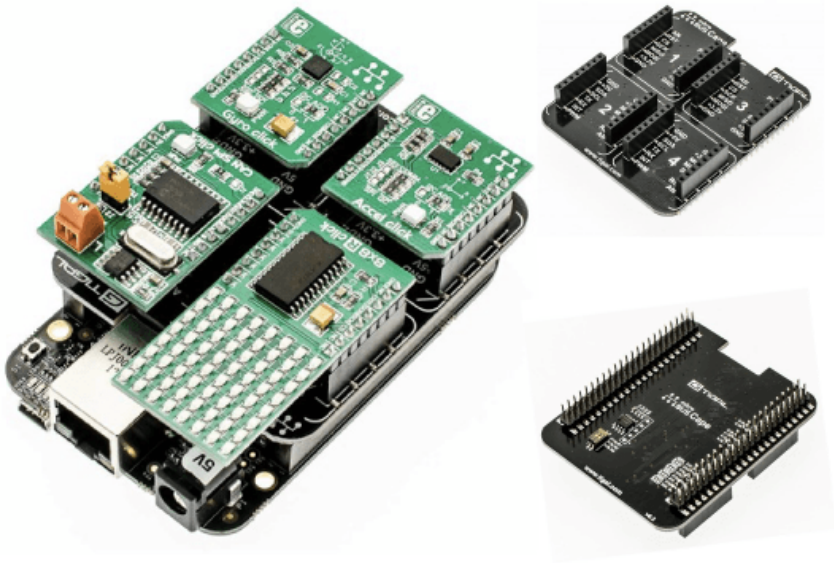

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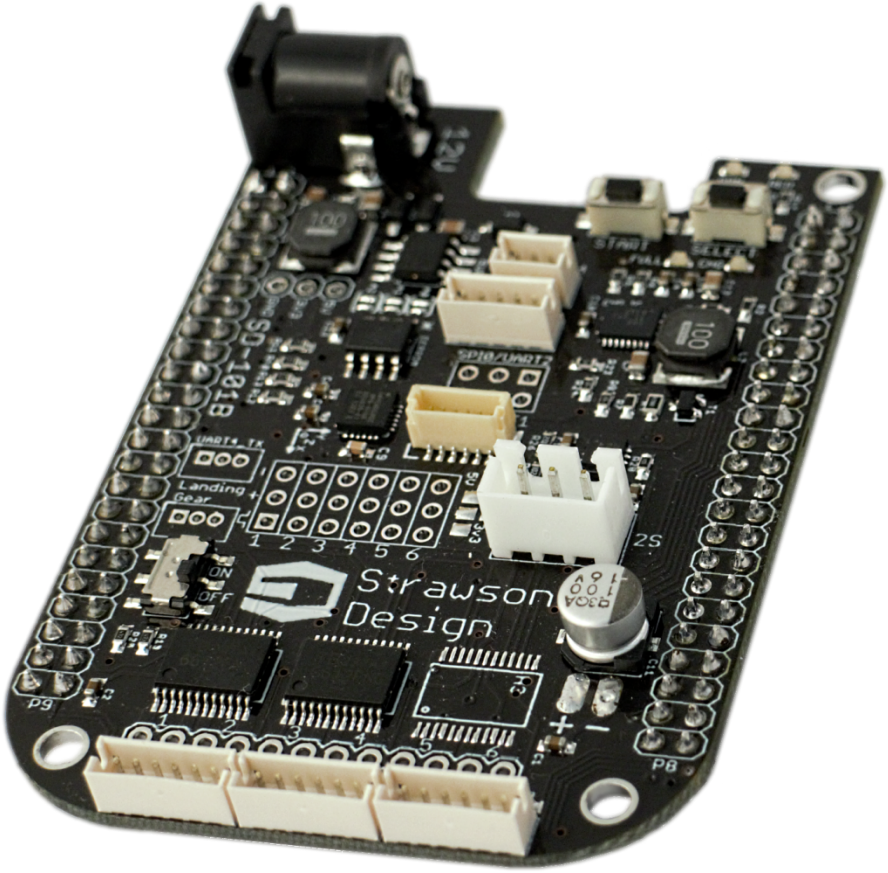

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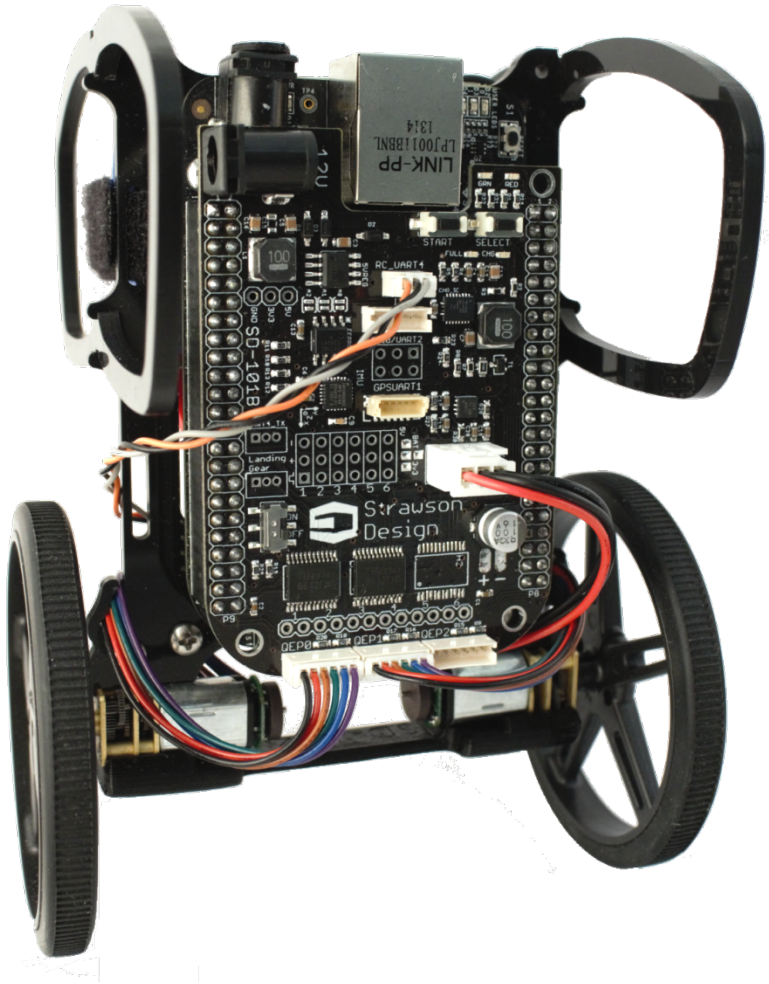

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beagleboard.org

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UCSD

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beagleboard.org

True open-source hardware and software

Development Unchained

open source hardware

open source™

You can get the chips, the docs and the software!

Open source gives people the freedom to control their technology while sharing knowledge and encouraging commerce through the open exchange of designs and code

Open Source Hardware Principles

- Design publicly available for study, modification, distribution, making, and selling the design or hardware based on that design
- Source available in format for making modifications to it
- Ideally, open source hardware uses readily-available components and materials, standard processes, open infrastructure, unrestricted content, and open-source design tools to maximize the ability of individuals to make and use hardware
- Open source hardware gives people the freedom to control their technology while sharing knowledge and encouraging commerce through the open exchange of designs

http://www.oshwa.org/

Lessons from open source software

- Discover and address security and other flaws
- Alter to suit user wishes
- Use as basis for a new product

http://arstechnica.com/information-technology/2013/10/arduino-creator-explains-why-open-source-matters-in-hardware-too/

Mapping this to hardware

- "Because open hardware platforms become the platform where people start to develop their own products," Banzi told Ars.
- "For us, it's important that people can prototype on the BeagleBone [a similar product] or the Arduino, and if they decide to make a product out of it, they can go and buy the processors and use our design as a starting point and make their own product out of it."

http://arstechnica.com/information-technology/2013/10/arduino-creator-explains-why-open-source-matters-in-hardware-too/

BeagleBone Black Terms and Conditions

- Use design materials as you see fit, just don't blame
- No viral requirements unless you republish the materials
  - Materials licensed as CC-BY-SA
- Materials don't include the BeagleBoard.org logo, for which we expect a license
- Use of boards with BeagleBoard.org logo in commercial projects is discouraged
  - No enforcement, just a request
  - Interferes with planning parts and meeting individual user demand
  - Design may be adjusted to better suite community needs

http://elinux.org/Beagleboard:BeagleBoneBlack#Terms_of_Use

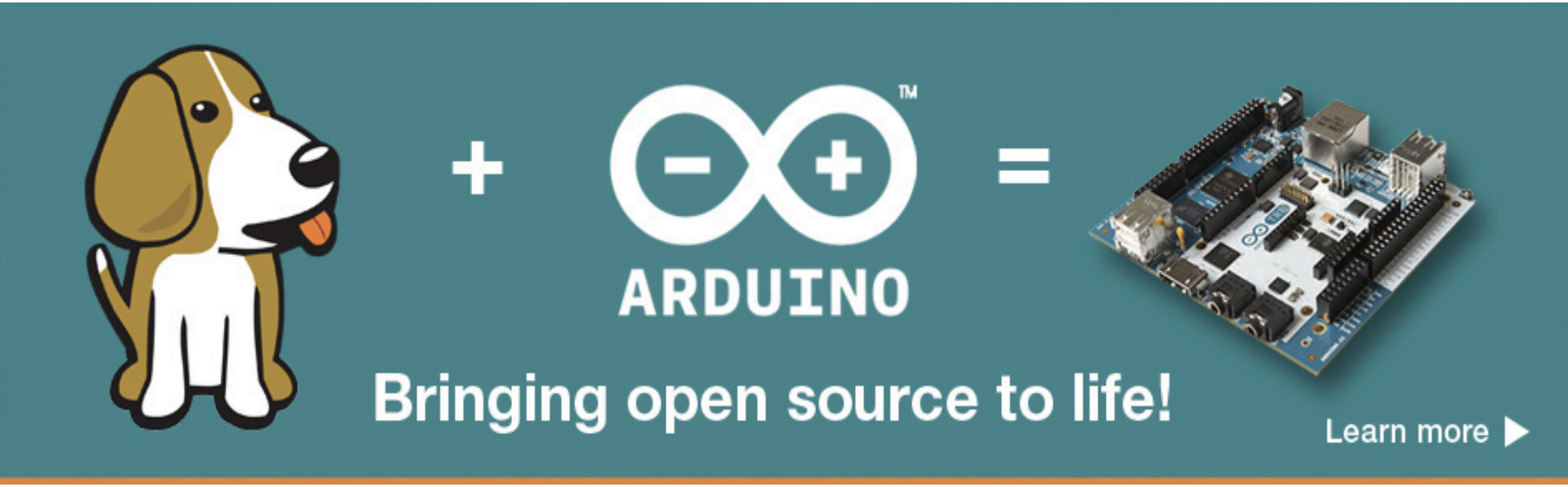
OSHWA checklist

- Comply with definition
- Allow study, modify, distribute, make and sell
- CC documentation w/o NC or ND
- OSHWA logo
- Own logos and trademarks
- Source file format
- Source files online
- Source files findable
- Able to copy
- Free
- Images in documentation
- Emotionally prepared
- Documentation of limits of openness

Importance to the hobbyist

- Longevity
- More detailed understanding
- Apply learning across more diverse platforms

Arduino Tre

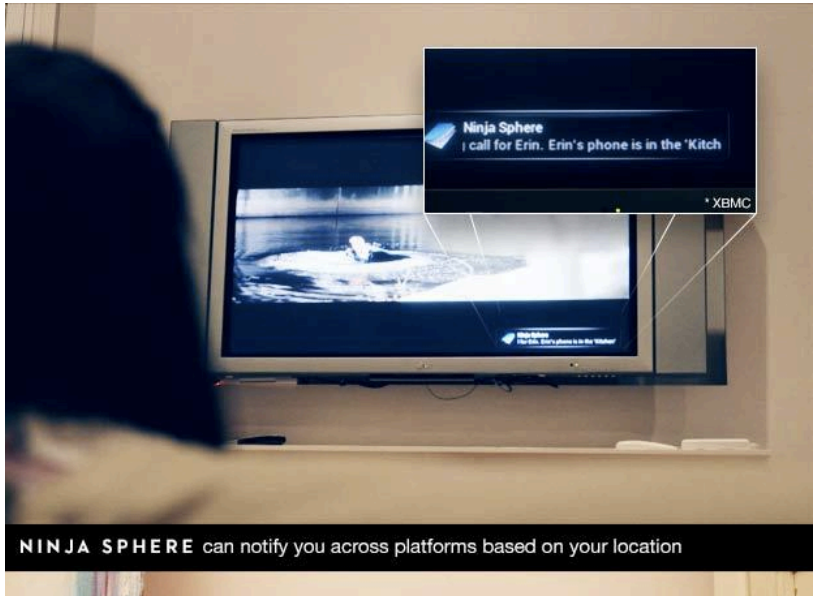


http://beagleboard.org/blog/2014-05-13-arduino-tre-developer-program/

beagleboard.org

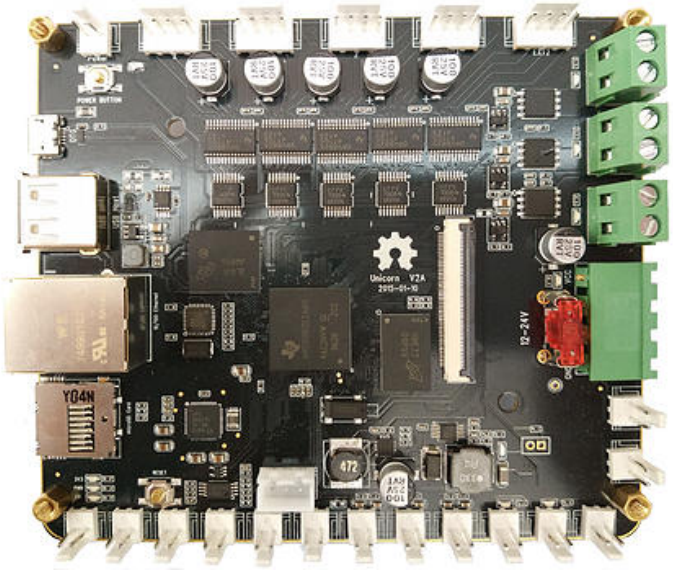
Ninja Sphere

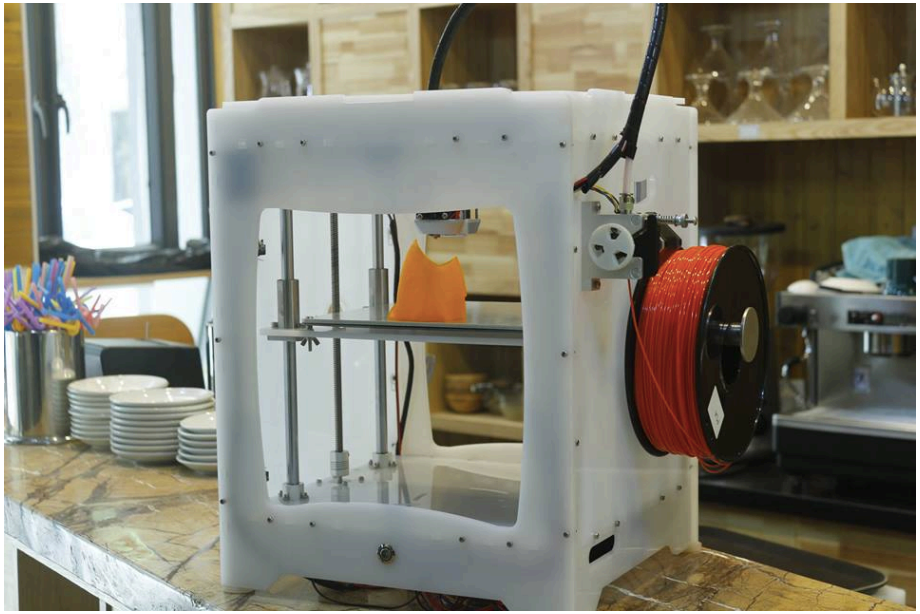
Next generation control of your environment



FastBotBBP

Next generation 3D printer controller





PROGRAMMABLE REAL-TIME UNITS

beagleboard.org

PRU: Programmable Real-time Unit

Architecture

- Two 32-bit RISC cores for real-time functions each running at 200MHz
- 8KB IRAM, 8KB DRAM, 12KB Shared RAM
- **Single-cycle execution**
- **Direct I/O interface sampling at ~5ns**
- Logic, Control and arithmetic instructions
- 32-bit MULT and Interrupt controller
- Efficient bit/byte/word manipulations

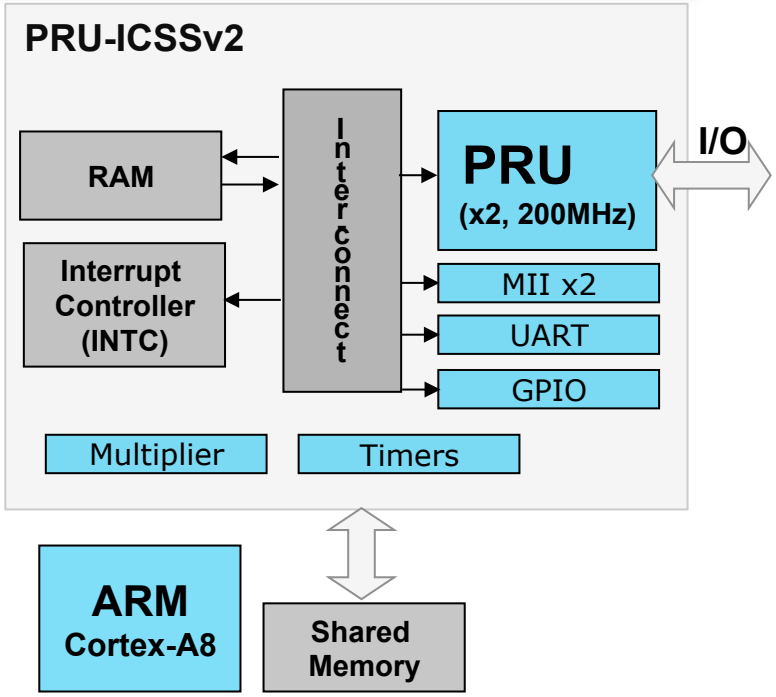
Capabilities

- Implement **Real-time communication interfaces** : PROFIBUS, EtherCAT, PROFINET & Ethernet/IP
- Implement **custom IP** (such as EnDAT 2.2, SINC3 decimation, PWMs, DP Memory, Manchester Coding, 9 bit UART or a Backplane bus)

Advantages

- Completely programmable & Flexible
- Reduce system cost & complexity

AM335x SoC: ARM + PRU



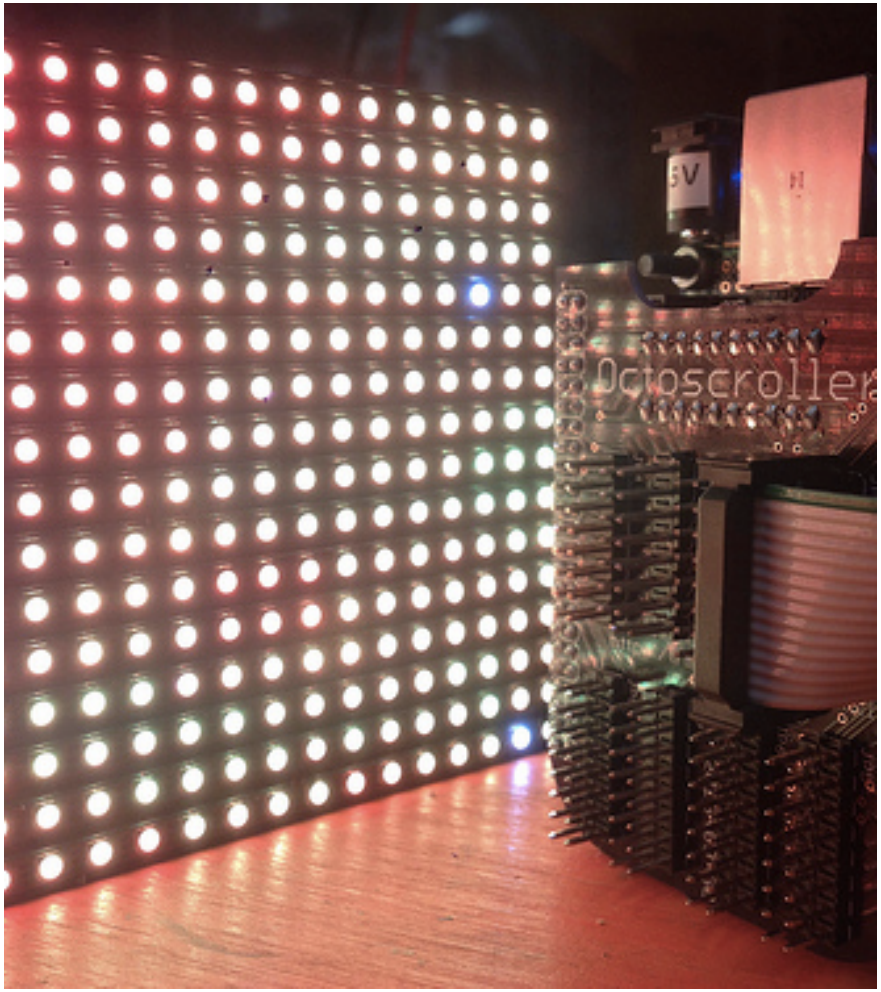
beagleboard.org

Community support of PRU

- GCC compiler - https://github.com/dinuxbg/gnupru
- Updates to assembler/examples - https://github.com/beagleboard/am335x_pru_package
- Lots of examples - http://processors.wiki.ti.com/index.php/PRU_Projects
  - PRU Speak interpreter – https://github.com/jadonk/pruspeak
  - 100MHz 14-channel logic analyzer – http://beaglelogic.net
- Driving cottage industries
  - LED lighting, machinekit (3D printing, CNC, ...), ...

LEDscape and Octoscroller

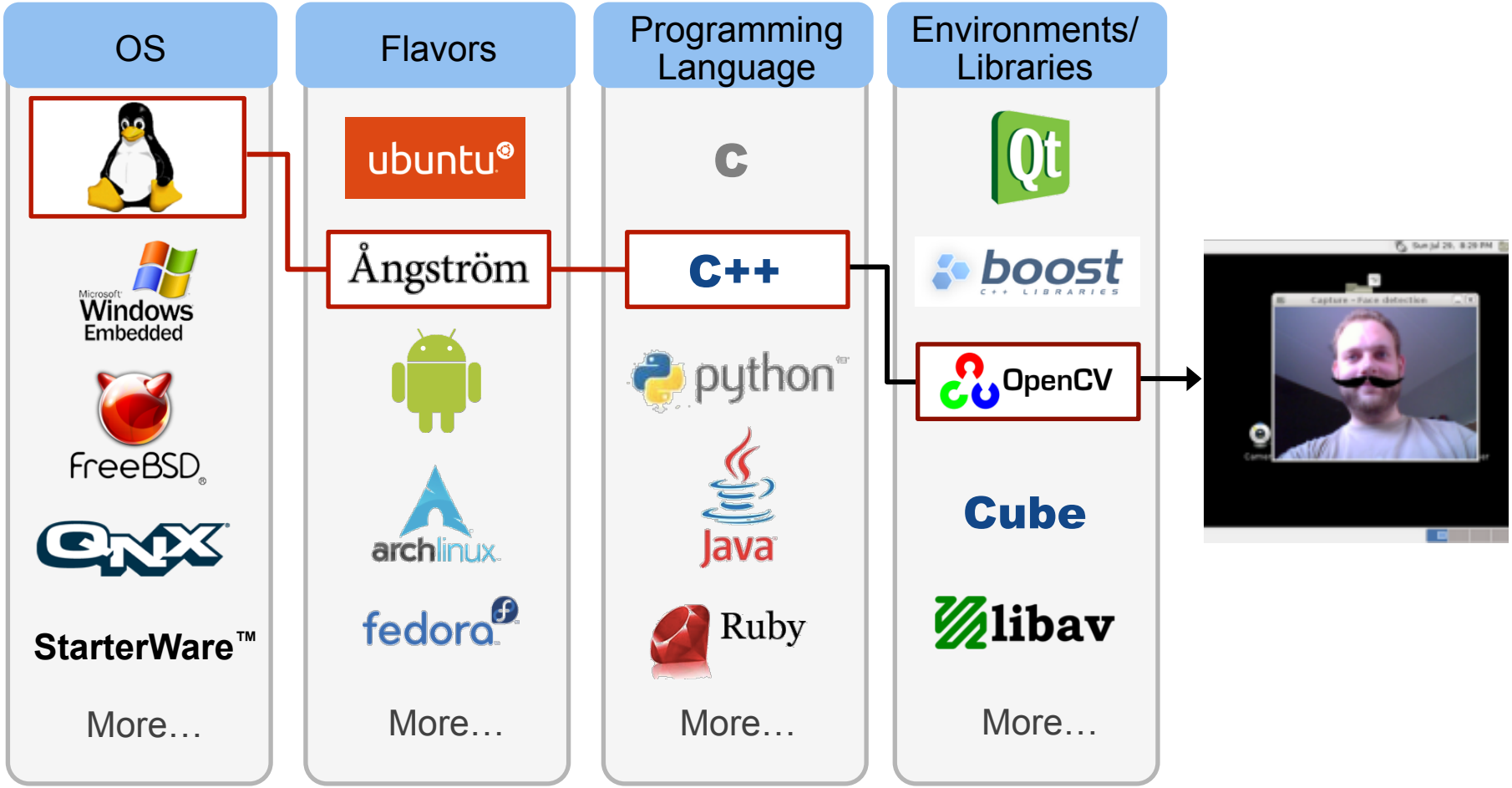
- Works with Adafruit 32x16 LED panels
- 12-bit color supported through PRU-based pulse-width modulation
- Open source software and hardware
- Content delivered using network packets (Python)
- Supports 64 panels each



The community software experience

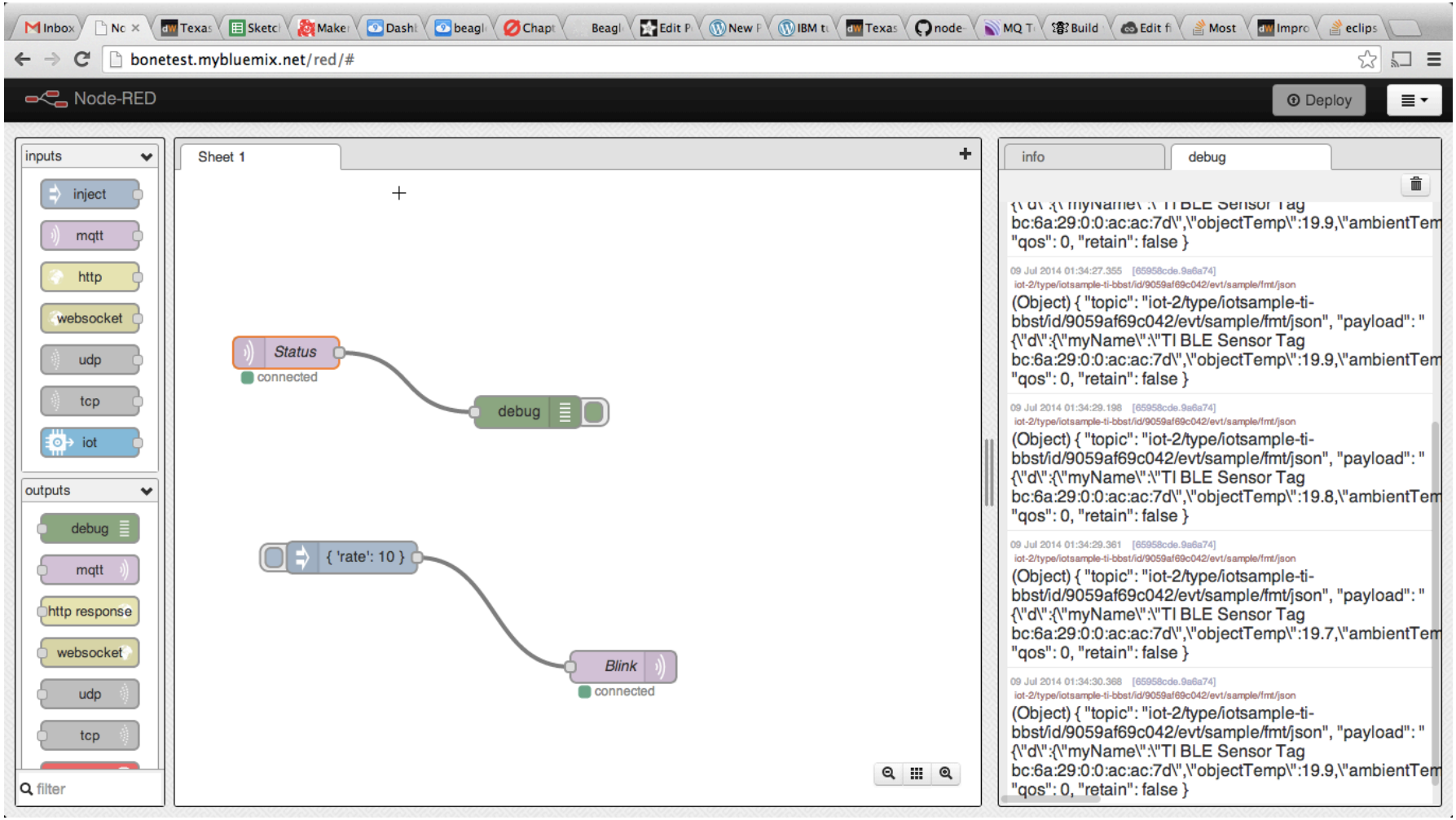
Reaching a new class of developer

Endless software opportunities

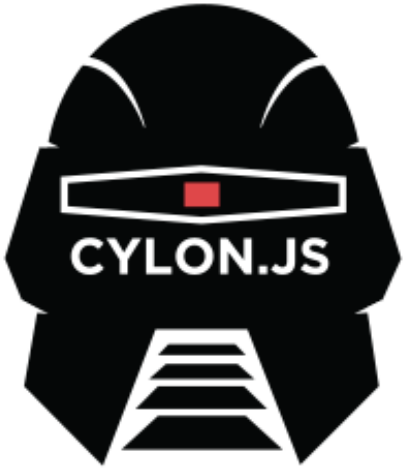


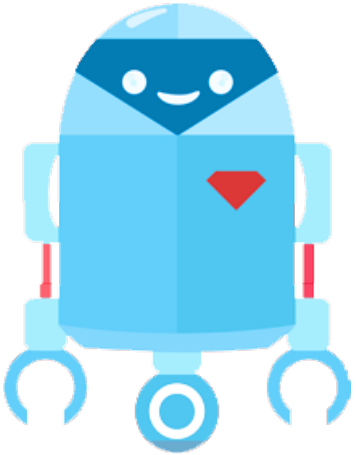
Open industry development platform enabling a full range of software

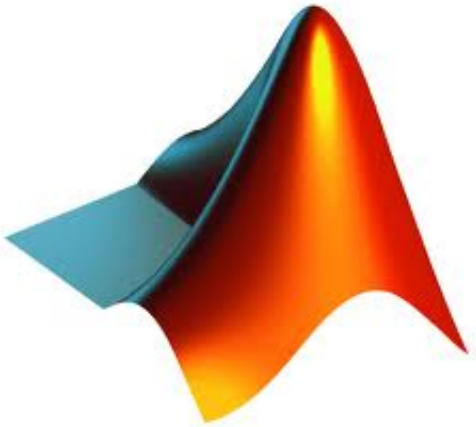
Node-RED by IBM

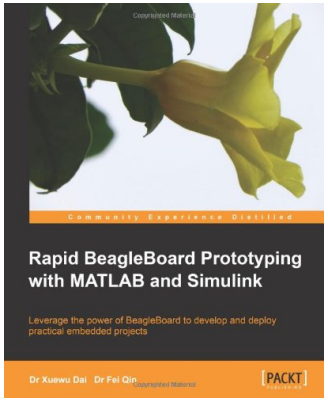


Supported by many frameworks









beagleboard.org

IoT software/network platform providers

- Weaved
- PubNub
- Dweet.io (Bug Labs)
- AllJoyn (alliance)
- Many, many more coming – starting passing these on to Nick Lethaby

Snappy Ubuntu Core

What do we need to have Apps Everywhere?

Apps need to run securely, be easily remotely upgradeable & run on a small OS.

SECURE

Malicious code can not affect other apps or the OS. Secret services should not have backdoors.

EFFICIENT

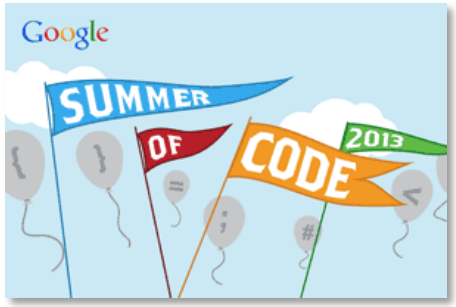
The OS needs to be small to fit in many devices. The OS should be extendible to support for all type of extensions.

EASY

Creating, upgrading and rollback of apps should be easy. Programmers package their software and users get it minutes later.

Changing the world through education and open source

demystifying technology

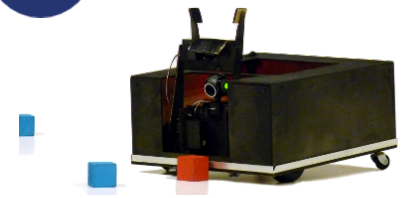


BeagleBoard.org is a mentor helping students write code for open source projects

Crafting Electronics Systems with BeagleBone and BeagleBone Black, includes tutorials

Derek Molloy video training series

STUDENT ROBOTICS



Held at the University of Southampton, teams design, build and test their robots, and compete against other teams

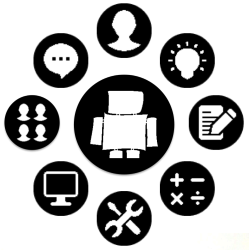
ECE497 Contributions and Project Status

ROSE-HULMAN INSTITUTE OF TECHNOLOGY Embedded Linux Class by *Mark A. Yoder*

beagleboard.org

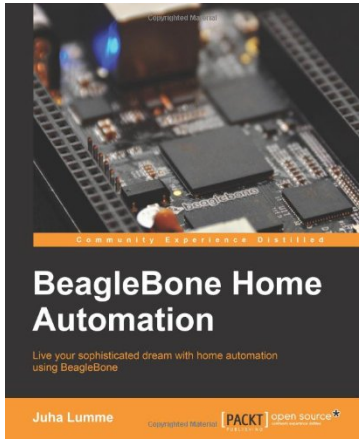
Quickbot course on mobile robots

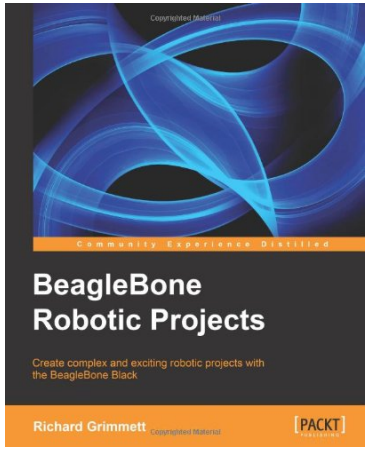
- http://o-botics.org/
  - A place where roboticists can collaborate on robot designs, code, electronics, and hardware
- Build a robot from scratch using components from Sparkfun
- Learn about mobile robotics theory

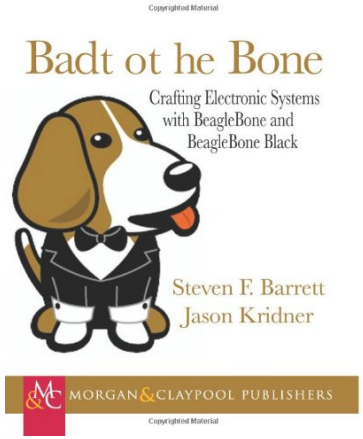


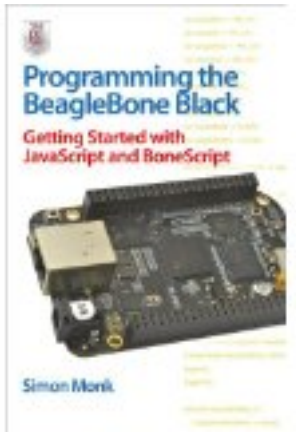
Georgia Tech

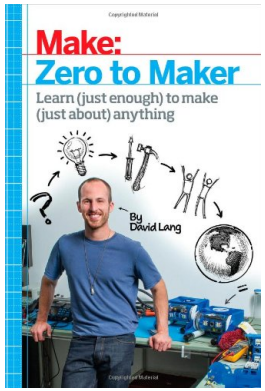
Some BeagleBoard.org related books

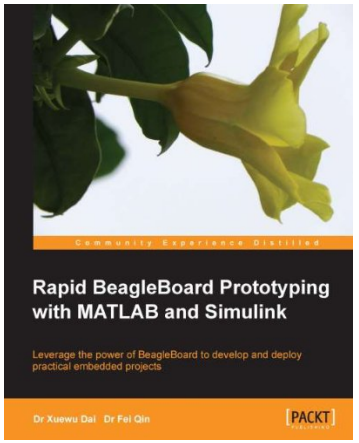






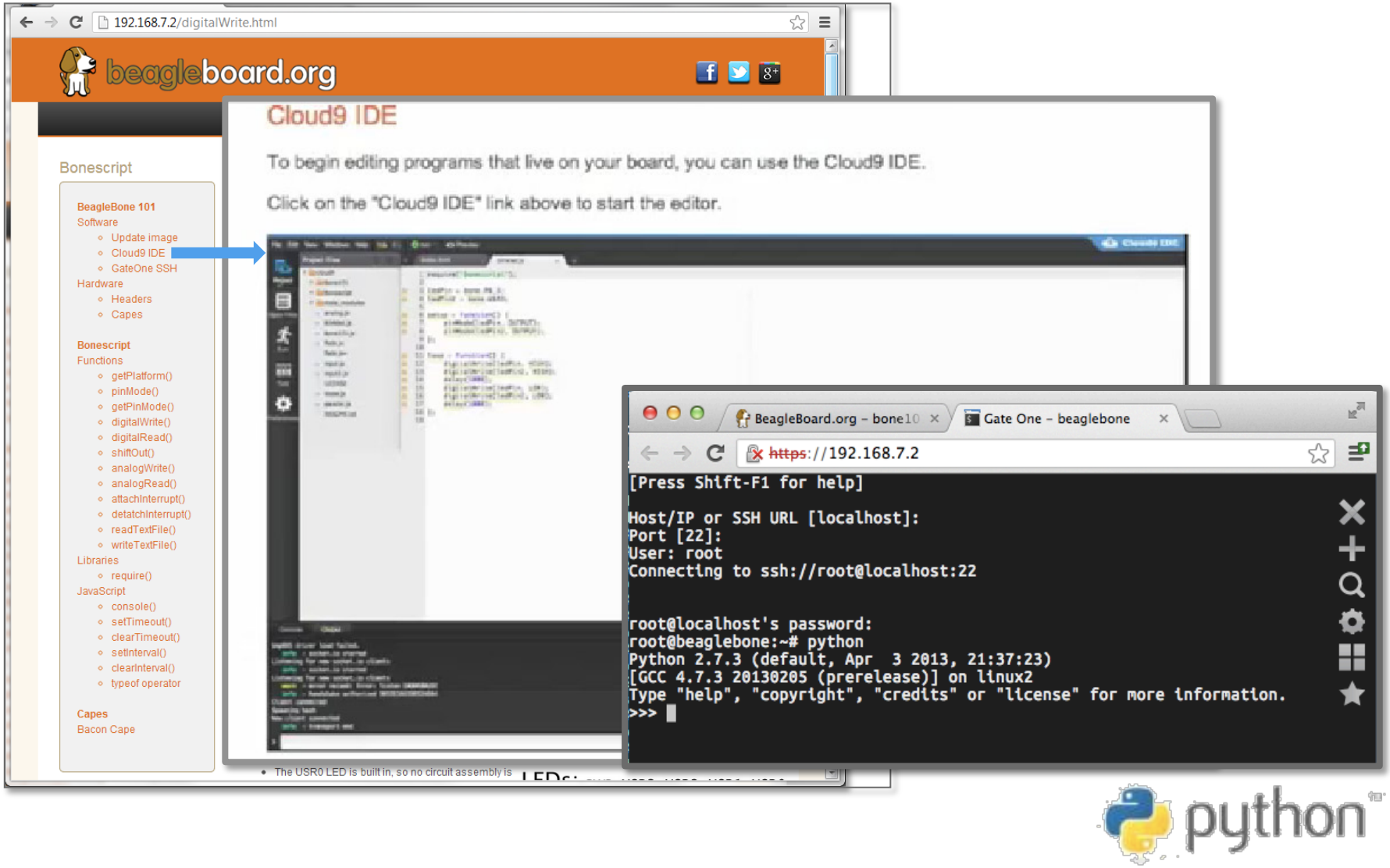






BACKUP

On-board Development Options



python

beagleboard.org

Junk slides

beagleboard.org

Extended Linux ecosystem for BeagleBone Black

Global community of respected, well-established companies providing products and services for Sitara™ processors that can be used on BeagleBone Black

- Turnkey products and services
- System modules
- Embedded software
- Development tools
- Engineering services

Select partners delivered added efficiencies through the Open Embedded-Core-based build system:

- Leverage the well defined foundational layers of Yocto
- Access OE-Core file system
- Effectively tailor software distributions to the requirements of a particular application

yocto PROJECT PARTICIPANT

Ångström

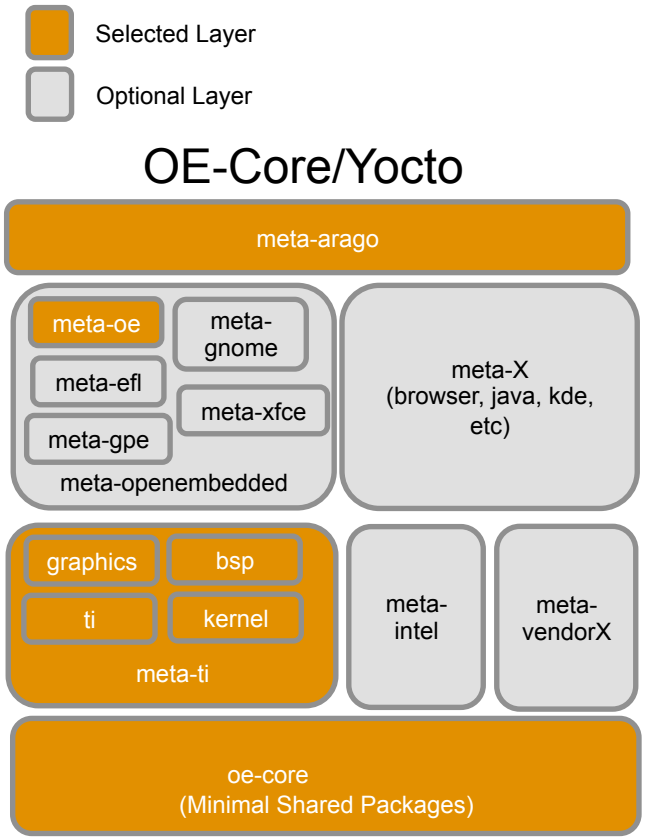
gumstix dream, design, deliver

WIND RIVER

montavista

openembedded

mentor embedded

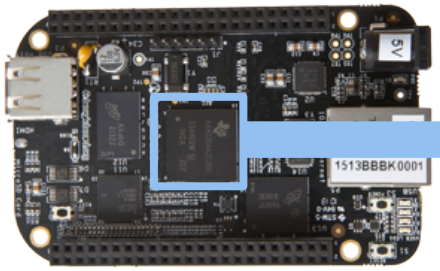


beagleboard.org

How do you get it

beagleboard.org/buy

1GHz performance, lots of peripherals, Ubuntu, Linux and Android, oh my!



1GHz performance enables:

- ARMv7 instruction set
- 2.0 DMIPS/MHz

45nm

- ARM® Cortex A8 Up to 1 GHz*
- 32K/32K L1
- 256K L2 w/ECC
- 64K RAM
- 64KB L3 Shared RAM
- LPDDR1/DDR2/DDR3/ DDR3L
- Graphics AccelerationPac SGX530
- LCD Controller
  - 24bit LCD Cont.
  - Touch Screen Controller(1)
- PRU
  - Industrial Communication Subsystem EtherCAT®, PROFINET®, EtherNET/IP™
- Security AccelerationPac Crypto

System Services

EDMA | JTAG/ETB | Timers x8 | WDT | RTC | 12-bit ADC(1)

Connectivity and IOs

- EMAC 2-port w/ Switch 10/100/1G w/1588
- USB2 OTG +PHY x2
- CAN x2
- eCAP/ eQEP x3
- HDQ
- PWM x3
- SPI x2
- I2C x3
- McASP x2
- GPIO
- UART x6
- NAND /NOR (16bit ECC)
- MMC/ SD/SDIO x3

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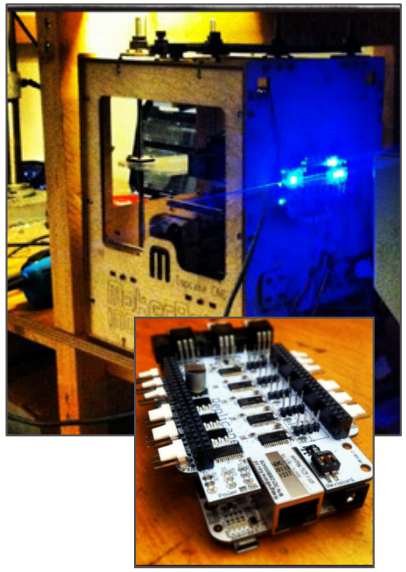
Innovating just got easier

Engineer

Replicape
3D Printer Cape



Open-source 3D printer used in professional prototyping

Artist

BeagleBone DMX Cape

Interactive light show covering a city block, utilizes PRU

Student

University of Texas Sr Design Project

Guitar amplifier with digital effects

Hacker

World's coolest dad

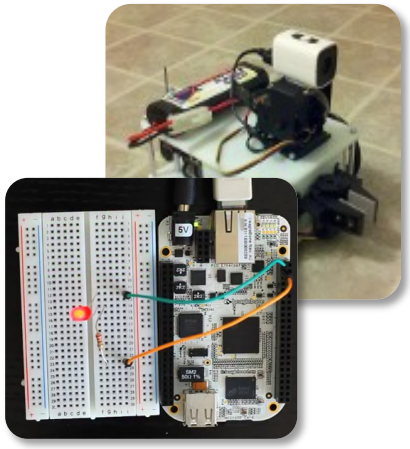
Ironman Halloween costume with repulsor sound effect and sensor/light/audio control

Support from Boot to Angry Birds to Robots

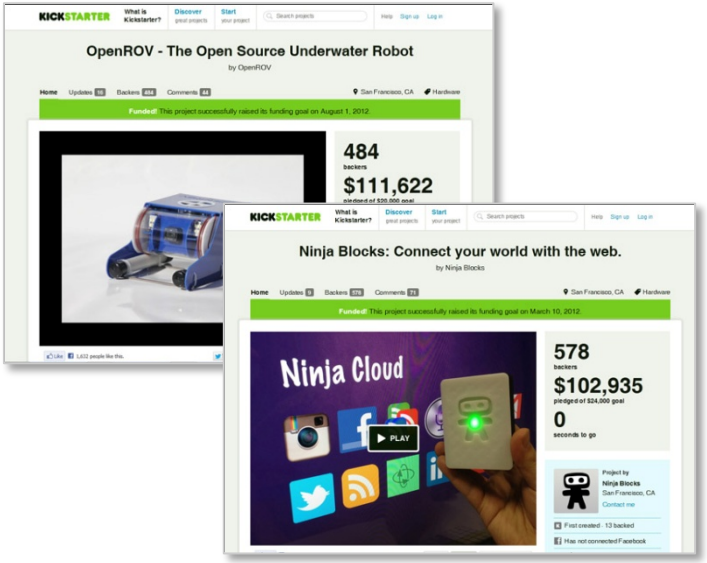
beagleboard.org – an affordable education platform

Artists | Hackers | Students | Engineers

- Access to free documentation and free code examples



- Ability to collaborate on new ideas through open blogs, wikis and web sites



- Access to production ready hardware
- Mainline kernel support for Ubuntu, Android, Fedora and others
- Allows experienced users to get prototype and get to market faster