Embedded Audio

synthesis and processing from cheap to steep

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Interactive Audio in Devices

- Annoyed with the annoying beeps some devices make?

- Let's bring higher quality audio into sketching!
  - Tools to enable this need to be
    - *accessible* to designers
    - *convenient* for users
  - -> Embedded rather than laptop-based

Music Interaction Design: ‘The Fingers’

Example device sketched “the traditional way” (USB interface with laptop generating sound)…

Inspired by Michel Waisvisz ‘The Hands’

Transmits data from MicroNav360 sensors to MaxMSP at 1000 Hz (7ms latency, low jitter)

Simple subtractive synth patch demo that runs in Max/MSP on a laptop

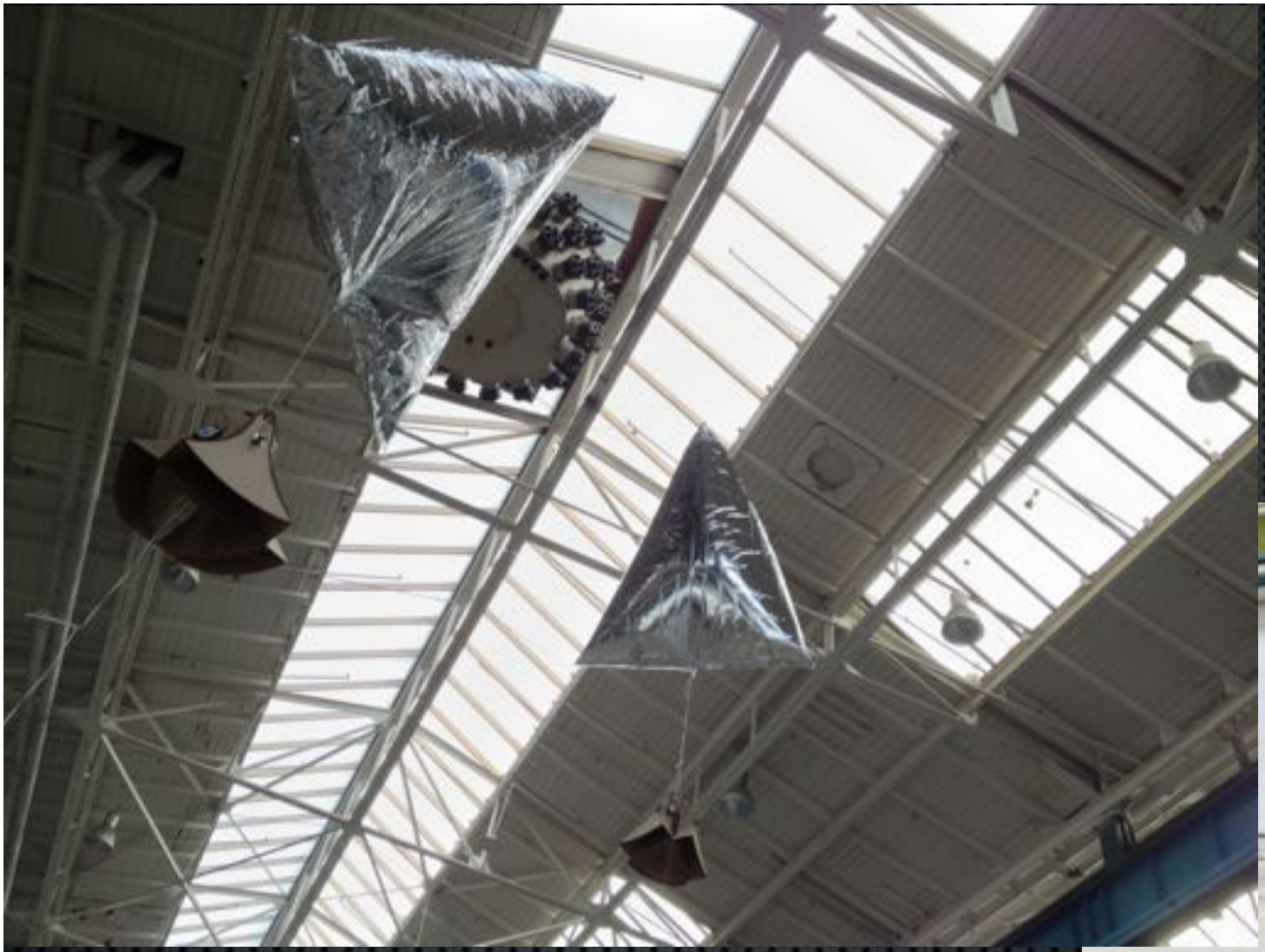
D. Overholt, “The Fingers: a Tribute to The Hands”, Proceedings of the International Computer Music Conference (Montreal, Canada, 16–21 August 2009).

But let's go back and start cheap!

Blimps at the Click Festival in Helsingør, Denmark

- Built with ATTinys
(~ $5 each in parts)
- Fast to build, PWM out
(20 mins each incl cones)
- Sequencer onboard
(blimps controlled via IR)

Synthlib written by DZL (similar contributed to Arduino)



http://clickfestival.dk/program-2013%20/
elevatedaudioworkshop

Wavetable synth in C

- Markus Gritsch's open source polyphonic (multi-voice) musical synth on PIC32

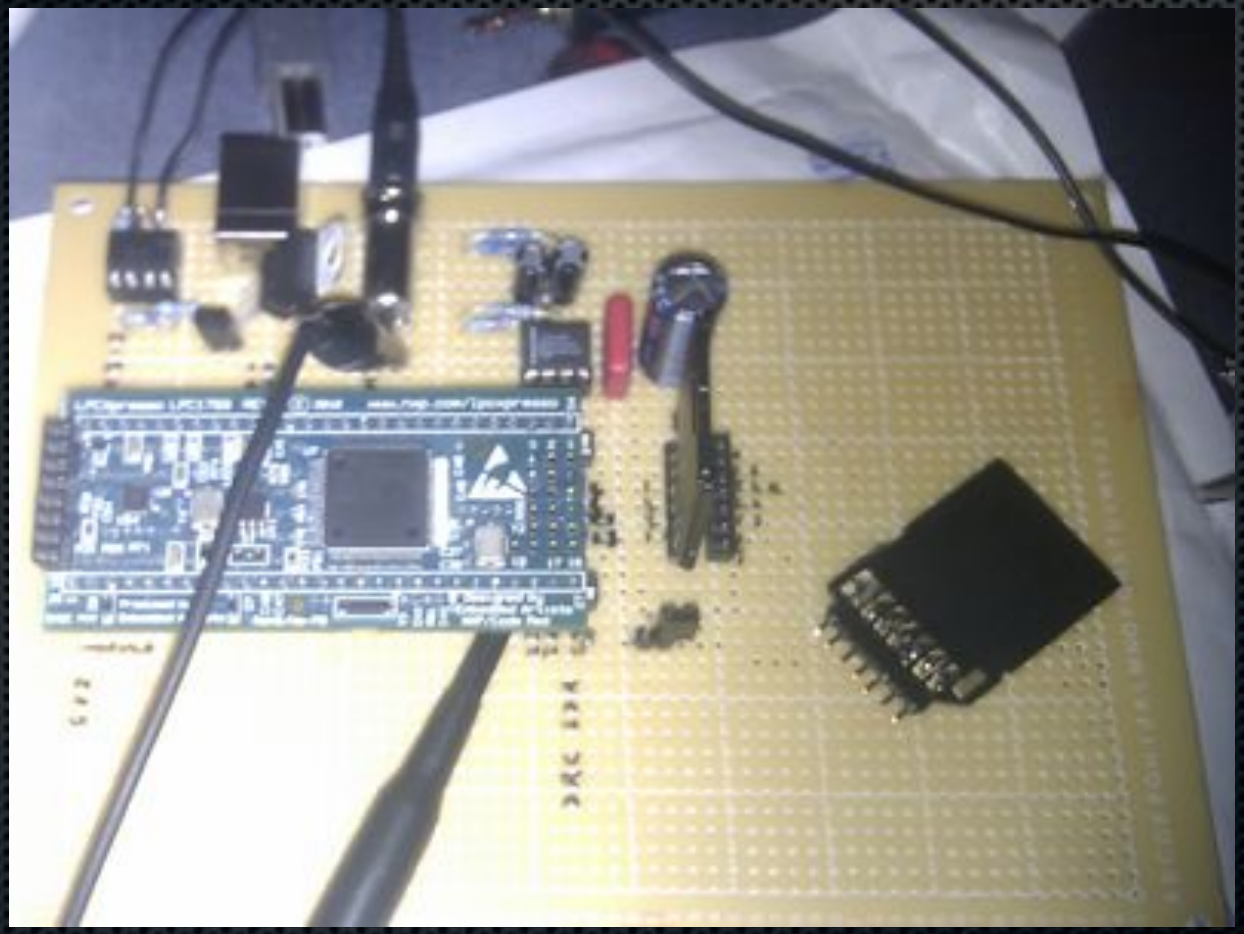
'dead bug' **style, code**
inspired by http://elm-chan.org/

Similar open source project in Arduino language for PIC32 : http://youtu.be/8LdxwfSsjZM

http://hackaday.com/2012/01/17/music-box-is-still-alive-with-wavetable-synthesis/

MIDIbox SD Card Polyphonic Sample Player

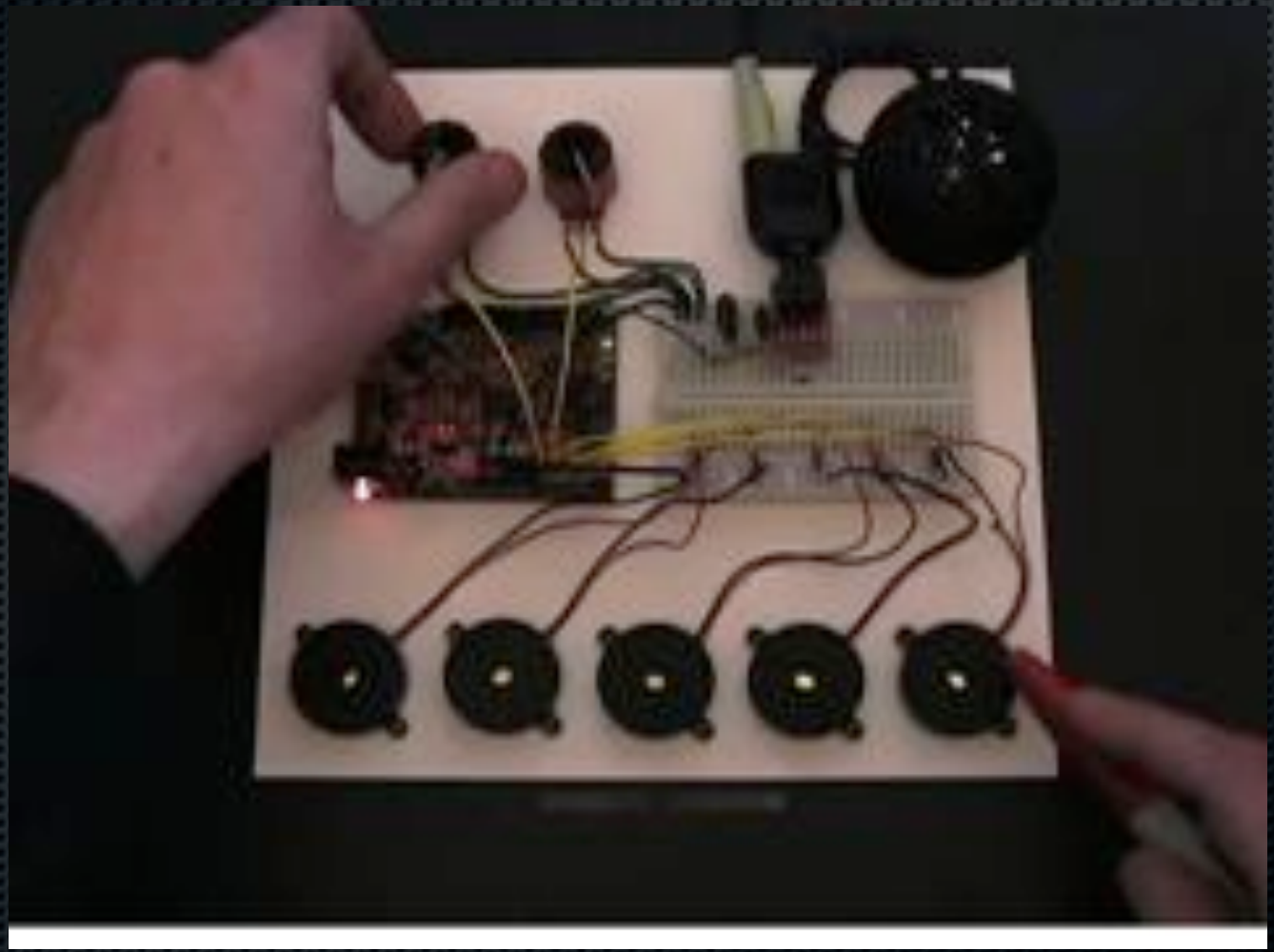
- An open source polyphonic (multi-voice) musical sampler on ARM-Cortex M3 (devboards available for around $20 from Embedded Artists)



http://www.midibox.org/dokuwiki/doku.php?id=midibox_sd_card_sample_player

Interactive sampler

- Philip Burgess' open source polyphonic sample-based synth, with delay effect
  - Arduino-language with a ChipKIT PIC32 board



- http://hackaday.com/2011/06/08/chipkit-sketch-mini-polyphonic-sampling-synth/

Pure Data running on a RPi

- $35, Edgar Berdhal's "Satellite CCRMA" SD-card image has Pd already installed (+ ChucK, SuperCollider, Audacity, etc…)

- Raspbian GUI only via X11 to optimize audio performance

Effects processor with RPi

- Spencer Salazar's "Spectrum Overdrive" is a basic overdrive distortion guitar effects pedal with one twist — it displays a real-time spectrum of the over-driven signal via a small pico-projector

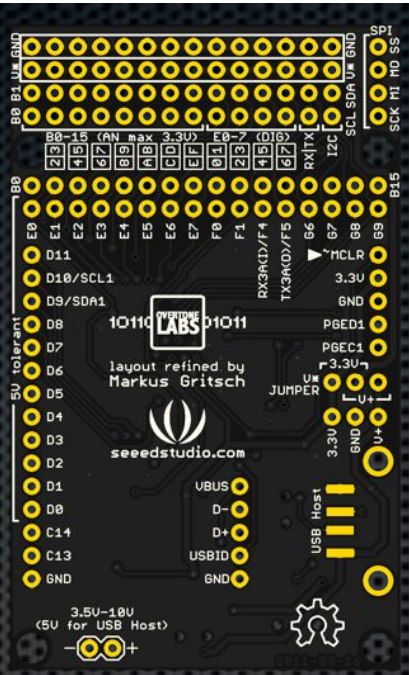
Android / iOS options

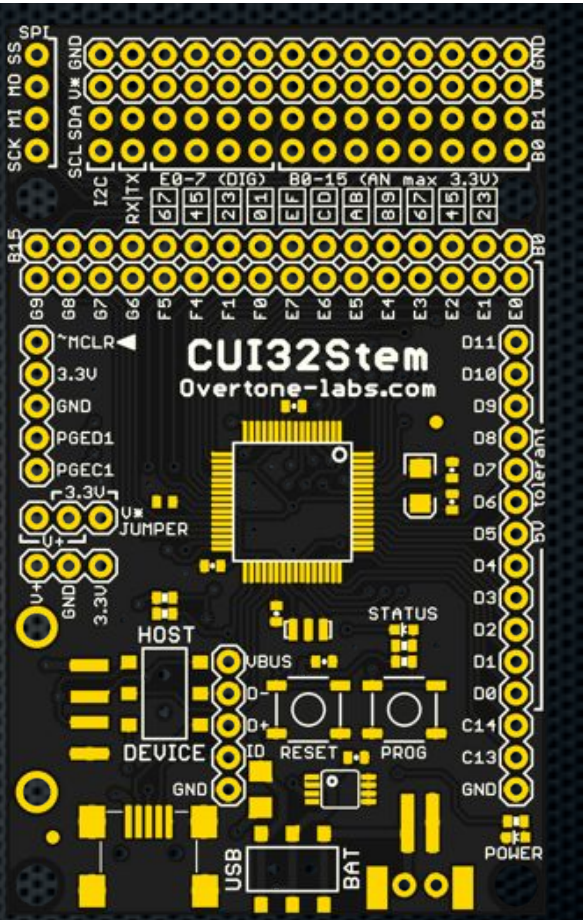
- Steep ($$?)
  - Well, some Android ‘TV-sticks’ are not so expensive, but generally phone/tablet options are much more costly
    - Download free apps like MobMuPlat (Mobile Music Platform) that enables Pd patches to run on iOS…
    - Compile libPD for Android or iOS, SuperCollider, etc.
  - Powerful compared to many embedded options (but still smaller than a laptop)
    - Note: Android currently (still!) has latency problems…

OK, that was cheap-> steep

- Now a bit about the CUI32Stem board + wireless…
  - Teaching approach: start with BASIC, move on when needed

CUI32Stem (YADB)





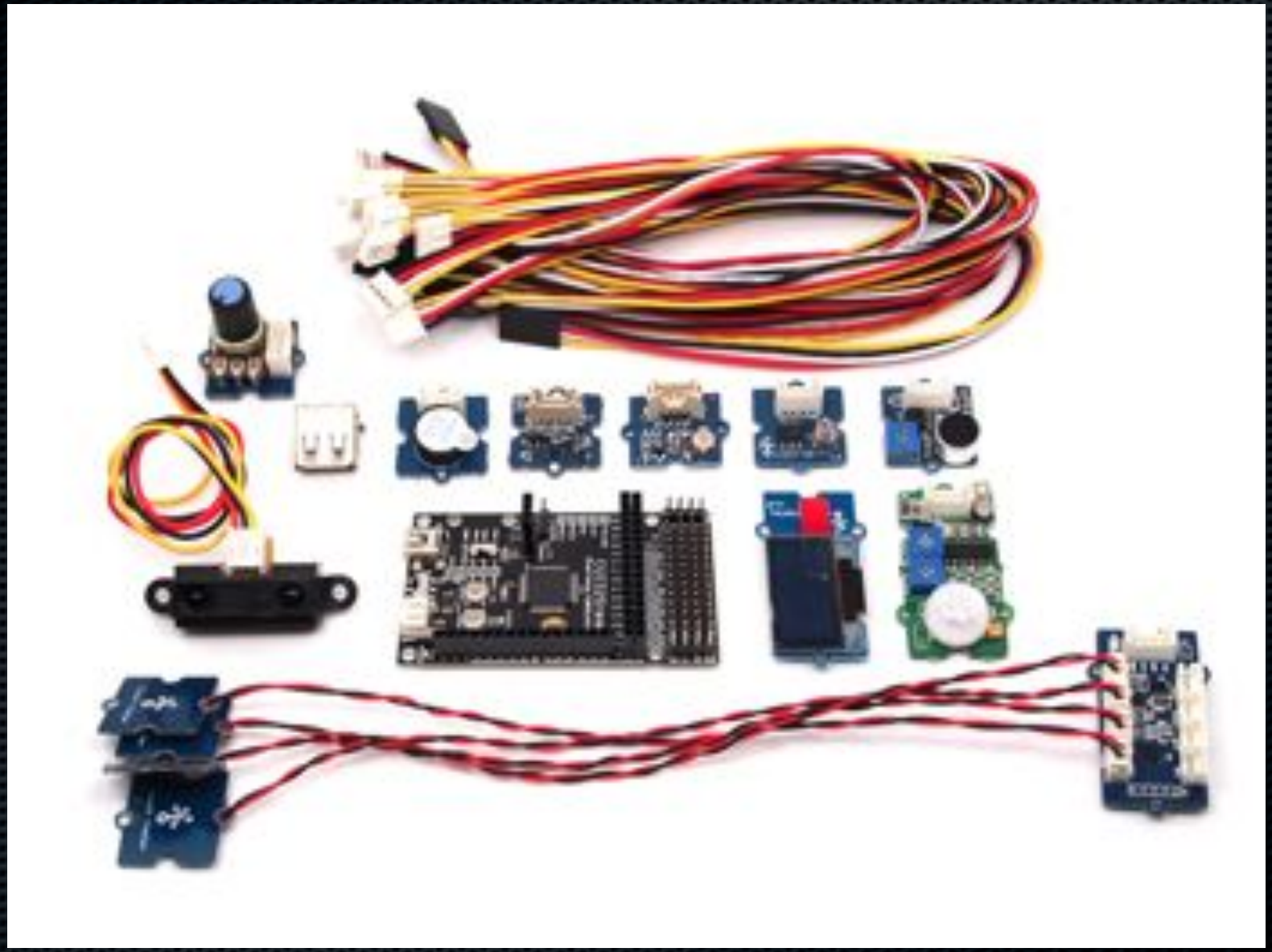
- $30, is this somewhat ‘steep’ now?
  - Continuation of past research…
  - Make it as simple as possible to sketch prototypes
    - Integration with GROVE system of sensors/actuators
    - Focus on making it easy for beginners + versatile for advanced users

CUI32Stem - versatility

Programmable in **BASIC, Arduino or C-languages** for versatility (enabled by a multi-platform bootloader)…

- **BASIC language**: StickOS operating system is included, with an on-chip BASIC compiler, line editor, debugger, profiler, and in-line help system to create new firmware programs, save them and run them (IDE = any terminal emulator).
- **Arduino language**: Code can be compiled and run on the CUI32Stem using MPIDE - Multi-Platform Integrated Development Environment, a spin-off of the official Arduino IDE (may become part of the official distribution eventually)…
- **C-language**: MPLAB-X (IDE runs on Windows, Linux, and MacOS), many example projects included in the “Microchip Application Libraries”, such as USB-soundcard, USB-MIDI, USB-HID, etc…

CUI32Stem Grove Dash Kit

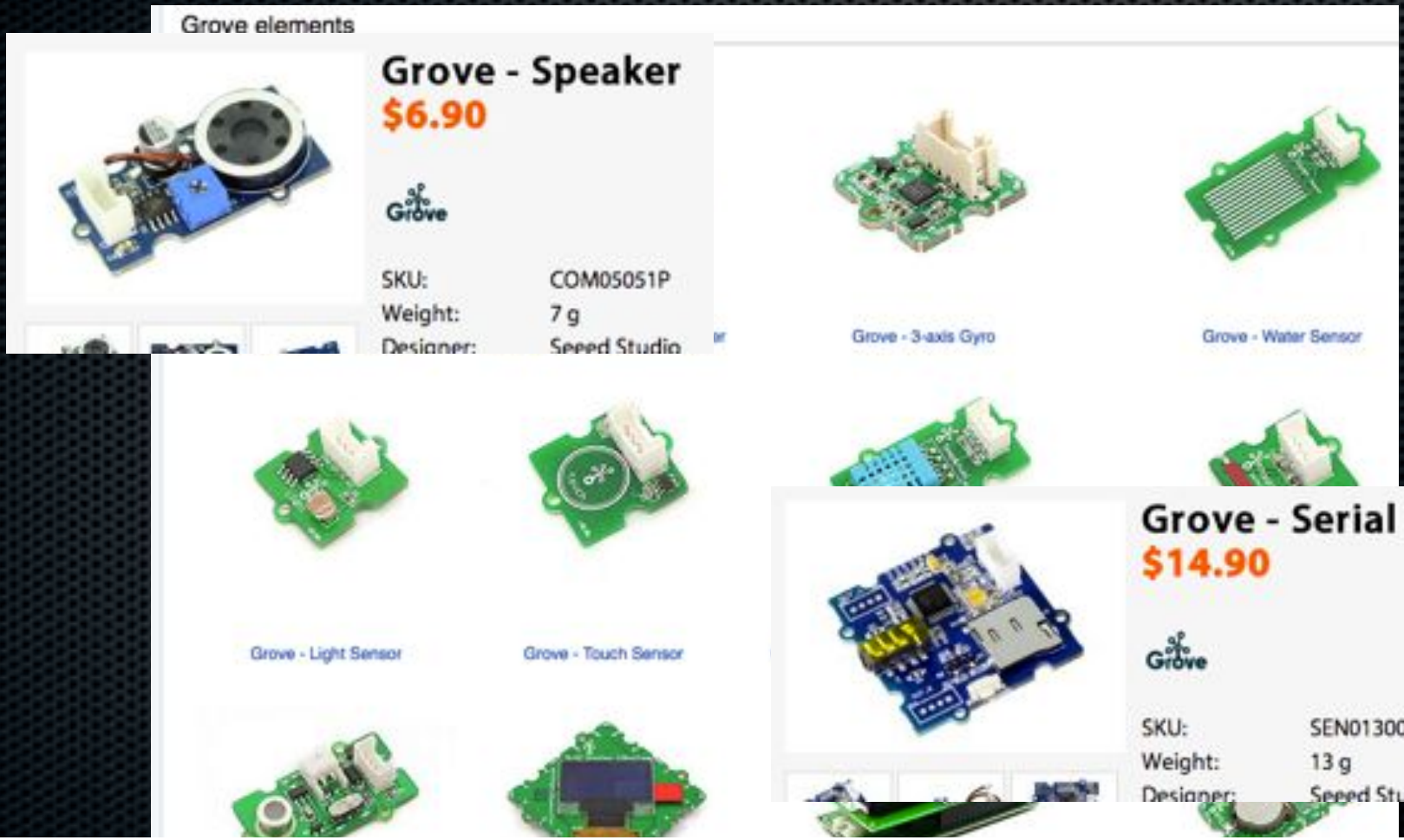


(~$100)

Individual Grove Elements

Arduinos connect via shield (as you probably knew already):

- http://www.seeedstudio.com/wiki/GROVE_System



StickOS overview...

- While C-language or Arduino-language are better suited for high-performance audio applications, StickOS is better suited for some prototyping:
- StickOS BASIC Features - StickOS was created by Rich Testardi
  - access all on-chip peripheral modules: ADC, PWM, TIMERS, UARTS, I2C, SPI, etc...
  - trace or single-step program execution
  - use profiling to see where the program is spending its time
  - use breakpoints, assertions, and watchpoints
  - use live variable (and pin) manipulation and examination while the program is stopped
- StickOS is more approachable, transparent, and forgiving than many other environments
  - Nonetheless, even casual users will learn the same fundamental concepts that are used by career microcontroller experts (but without the career investment).

StickOS Quick Reference (v1.90)

http://www.cpustick.com

Commands

<Ctrl-C>	stop running program
auto [line]	automatically number program lines
clear [**flash**]	clear ram [and flash] variables
cls	clear terminal screen
cont [line]	continue program from stop
delete [[line][-[line]]|subname]	delete program lines
dir	list saved programs
edit line	edit program line
help [topic]	online help
list [[line][-[line]]|subname]	list program lines
load name	load saved program
memory	print memory usage
new	erase code ram and flash memories
profile [[line][-[line]]|subname]	display profile info
purge name	purge saved program
renumber [line]	renumber program lines (and save)
reset	reset the MCU!
run [line]	run program
save [name|**library***]	save code ram to flash memory
subs	* list sub names
undo	undo code changes since last save
upgrade	upgrade StickOS firmware!
uptime	print time since last reset

Modes

analog [millivolts]	set analog voltage scale
autorun [**on**|**off**]	autorun mode (on reset)
baud [rate]	UART transport baud rate (on reset)
echo [**on**|**off**]	terminal echo mode
indent [**on**|**off**]	listing indent mode
ipaddress [**dhcp**|ipaddress]	set/display ip address (on reset)
keychars [keychars]	set/display keypad scan chars
nodeid [nodeid|**none**]	set/display zigflea nodeid
numbers [**on**|**off**]	listing line numbers mode
pins [assign [pinname|**none**]]	set/display pin assignments
prompt [**on**|**off**]	terminal prompt mode
servo [Hz]	set/display servo Hz (on reset)
step [**on**|**off**]	debugger single-step mode
trace [**on**|**off**]	debugger trace mode
usbboot [**on**|**off**]	set/display USB host mode (on reset)
watchsmart [**on**|**off**]	low-overhead watchpoint mode

General Statements

line	delete program line
line statement // comment*	enter program line
variable[$] = expression, ...	** assign variable
? [**dec**|**hex**|**raw**] expression, ...[;]	** print strings/expressions
assert expression	break if expression is false
data n [, ...]	read-only data
dim variable[$][[n]] [**as** ...], ...	dimension variables
end	end program
halt	loop forever
input [**dec**|**hex**|**raw**] variable[$], ...	input data
label label	read/data label
lcd pos, [**dec**|**hex**|**raw**] expression, ...	* display results on lcd
let variable[$] = expression, ...	assign variable
print [**dec**|**hex**|**raw**] expression, ...[;]	print strings/expressions
read variable [, ...]	read data into variables
rem remark	remark
restore [label]	restore data pointer
sleep expression [**s**|**ms**|**us**]	delay program execution
stop	insert breakpoint in code
vprint var[$] = [**dec**|**hex**|**raw**] expr, ...	print to variable

Block Statements

```
if expression then
[elseif expression then]
[else]
endif

for variable = expression to expression [step expression]
  [break|continue] [n]]
next

while expression do
  [break|continue] [n]]
endwhile

do
  [break|continue] [n]]
until expression

gosub subname [expression, ...]

sub subname [param, ...]
  [return]
endsub
```

Device Statements

timers:

configure timer n **for** n [**s**|**ms**|**us**]	
on timer n **do** statement	
off timer n	disable timer interrupt
mask timer n	mask/hold timer interrupt
unmask timer n	unmask timer interrupt

uarts:

configure uart n **for** n **baud** n **data** \ [**even**|**odd**|**no**] **parity** [**loopback**]	
on uart n [**input**|**output**] **do** statement	
off uart n [input|output]	disable uart interrupt
mask uart n [input|output]	mask/hold uart interrupt
unmask uart n [input|output]	unmask uart interrupt
uart n [**read**|**write**] variable, ...	perform uart I/O

i2c:

i2c start addr	master i2c I/O
i2c [**read**|**write**] variable, ...	
i2c stop	

spi:

spi variable [, ...]	master spi I/O

watchpoints:

on expression **do** statement	
off expression	disable expr watchpoint
mask expression	mask/hold expr watchpoint
unmask expression	unmask expr watchpoint

ZigFlea

<Ctrl-D>	disconnect from remote node
connect nodeid	connect to remote node via zigflea

remote node variables:

```
dim varremote[[n]] as remote on nodeid nodeid
```

+ = v1.82 and later; ** = v1.90 and later; note that as of v1.88, the units of servo output pins was changed from (mostly) milliseconds (ms) to microseconds (us)

Expressions

the following operators are supported as in C, in order of decreasing precedence:

n	decimal constant
0xn	hexadecimal constant
'c'	character constant
variable	simple variable
variable[expression]	array variable element
variable$	length of array or string
( )	grouping
! ~	logical not, bitwise not
* / %	times, divide, mod
+ -	plus, minus
>> <<	shift right, left
<= < >= >	inequalities
== !=	equal, not equal
| ^ &	(bitwise or, xor, and
|| ^^ &&	logical or, xor, and

Strings

v$ is a nul-terminated view into a byte array v[]

string statements:

```
dim, input, let, print, vprint
if expression relation expression then
while expression relation expression do
until expression relation expression
```

string expressions:

"[literal]"	literal string
variable$	variable string
variable$[start|length]	variable substring
+	concatenates strings

string relations:

<= < >= >	inequalities
== !=	equal, not equal
~ !~	contains, does not contain

Variables

all variables must be dimensioned!
variables dimensioned in a sub are local to that sub
simple variables are passed to sub params by reference
array variable indices start at 0
v is the same as v[0], except for input/print/i2c/spi statements

ram variables:

```
dim var[$][[n]]
dim var[[n]] as [byte|short]
```

flash parameter variables:

```
dim varflash[[n]] as flash
```

pin alias variables:

```
dim varpin[[n]] as pin pinname for \
    [digital|analog|servo|frequency|uart] \
      [input|output] \
        [debounced] [inverted] [open_drain]
```

absolute variables:

```
dim varabs[[n]] at address addr
dim varabs[[n]] as [byte|short] at address addr
```

system variables (read-only):

```
analog+  getchar   keychar*  msecs  nodeid
random** seconds   ticks   ticks_per_msec
```

Pins

Use the "**help pins**" command to see MCU-specific pin names and capabilities; use the "**pins**" command to set/display pin assignments

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Using StickOS for simple I/O

- interfacing the CUI32 with desktop / laptop for sound generation…
  - In C (MPLAB-X), HID / USB-audio, USB-MIDI, etc. are possible, but for simple ‘serial’ data StickOS is easiest.

```
150 dim c as pin an14 for analog input
160 dim p as pin an15 for analog input
170 configure timer 0 for 10 ms
180 on timer 0 do print "A",a,b,c,d,e,
190 while 1 do
200 endwhile
```

In ↑

Out->

Sketching embedded interaction

Inspiration: “Knock Clock”, a screen-less clock by CIID students

Knock Clock – in StickOS BASIC

```
 10 dim mins, secs, counter
 20 dim timeTrigger as pin re7 for digital input debounced
 30 rem --- re7 is the PROG switch on the CUI32
 40 dim timeTeller as pin re0 for digital output
 50 rem --- re0 is the STATUS LED on the CUI32

 60 let mins = 0, secs = 0
 70 rem --- setting the current time above

 80 configure timer 0 for 1 s
 90 on timer 0 do gosub timeKeeper

100 while 1 do
110   if timeTrigger==0 then
120     for counter = 0 to mins-1
130       let timeTeller = 0
140       sleep 100 ms
150       let timeTeller = 1
160       sleep 400 ms
170     next
180     sleep 800 ms
190     for counter = 0 to secs-1
200       let timeTeller = 0
210       sleep 100 ms
220       let timeTeller = 1
230       sleep 200 ms
240     next
250   endif
260 endwhile
```

```
270 sub timeKeeper
280   let secs = secs+1
290   if secs>60 then
300     let mins = mins+1
310     let secs = 0
320   endif
330 endsub
```

Wireless - motivation

- Urban Musical Game has been created by researchers in the Real-Time Musical Interactions team at IRCAM

Wireless : Bluetooth & Nordic

- Latency: 10s of milliseconds? nRF possibly faster…
- Max 7 slaves paired with 1 master with Bluetooth
- Bluetooth re-pairing can be annoying…

nRF24L01+
$1.00 each!

- BlueSMiRF Gold, $65
- GROVE Serial Bluetooth, $20
- Dealextreme/E-bay, $6
- Bluegiga modules, $?

- 100 meter range
- 10 meter range
- 10 meter range
- 10 meter range

Note: Bluetooth 4.0 is only connectivity option for iOS devices (without joining Apple's MFi program)

Wireless options: ZigFlea

- StickOS implements a subset of the ZigBee protocol (ZigFlea does not do node-hopping). Example:

```
On a CUI32Stem set to nodeid 1, which has a knob connected to an0:

10 dim potentiometer as pin an0 for analog input
20 dim led as remote on nodeid 2
30 while 1 do
40   let led = potentiometer
50   sleep 100 ms
60 endwhile

On a CUI32Stem set to nodeid 2, which has an LED connected to rd0:

10 dim led as pin rd0 for analog output
20 while 1 do
30 endwhile
```

ZigFlea
$9.90

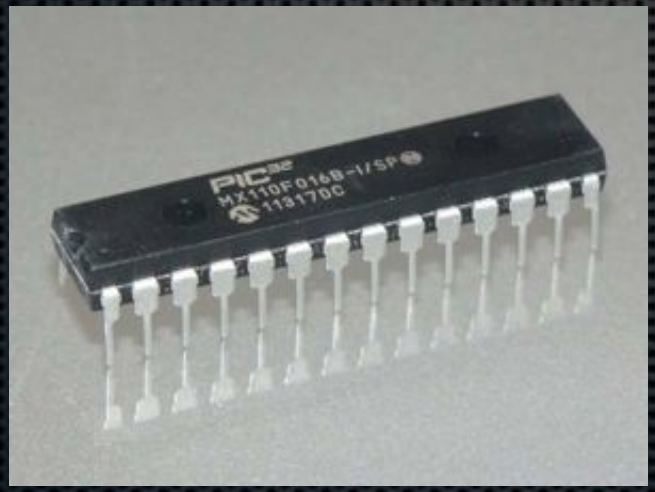
SKU:	PIC04111P
Weight:	6 g
Designer:	Seeed Studi

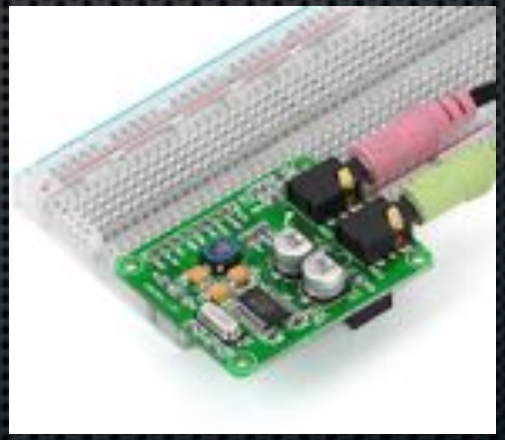
Wireless options: Wi-Fi

- Wi-Fi allows the CUI32Stem to send raw UDP and/or TCP-based OSC packets, and communicate easily with any software that supports Open Sound Control
- Can be used directly with any iOS or Android device, without having to use a laptop as a ‘bridge’
- “WiFly” or Xbee Wi-Fi modules can broadcast ‘adhoc’ base-stations or join existing networks
  - can use telnet to connect to CUI32Stem and remotely program it

Future Directions

- Considering high-quality 16/24-bit audio CODEC as an extension for the CUI32Stem, or with a DIP-package PIC32 (these include I2S support, instead of relying on the PWM 'hack' for audio output)…
  - This is my personal focus - other platforms need high quality audio sketching capabilities, too! I'd love to hear from all of you about past approaches you've used, or any related upcoming plans…





<- MikroElektronika's Audio Codec Board

Related: Audio Codec Shield http://www.openmusiclabs.com/projects/codec-shield/

Next year we'll all be sound designers?

- No matter what the platform you're using (Arduino Due, ???), let's pursue adding higher quality sound to our sketching platforms…
  - A lot of you probably already are there (e.g., CIID's 'motors &music' board includes a 12-bit DAC), but…

Embedded Audio
synthesis and processing from cheap to steep

Thanks!

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