Software Defined Printed Circuit Boards

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EECS UC Berkeley

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- introduction
- JITPCB
- course info

Software Defined Printed Circuit Boards
"Circuit Board Design for Programmers"

Prof Jonathan Bachrach with Richard Lin @ EECS

Do you want to

make this

on this

```
val led_rows = Vector<Layout>()
for j in 0 to 8 do :
  val led_row = Vector<Layout>()
  for i in 0 to 8 do :
    val name = symbol_join(["led_" i "x" j])
    val led = bool_out(name, PullUpLED))
    append(led_row, Space(V2f(12.0, 12.0), led))
  append(led_rows, HBox(led_row))
val sliders = [slider(0), slider(1)]
val lay = HBox([VBox(join(sliders, Fill())),
                HSpace(2.0), VBox(led_rows)])
val sob = SOB(lay)
```

in code?

Have you ever wanted to design a circuit board but were intimidated?
Have you been frustrated by the tedium of circuit design apps?
Are you a programmer and want circuit board design to be like software design?
Do you want to design boards at the speed of rapid fabrication?

Well this class is for you...

CS194/294-126
upper div / grad / studio / project class

Fall 2016, TuTh 10-11:30a, Jacobs 220
4 Units: 3 hr lecture and 3+ hrs lab time / week.

`http://www-inst.eecs.berkeley.edu/~cs194-126`

"making the easy things easy and the hardware things software"

Industrial Revolution of Personalized Fabrication

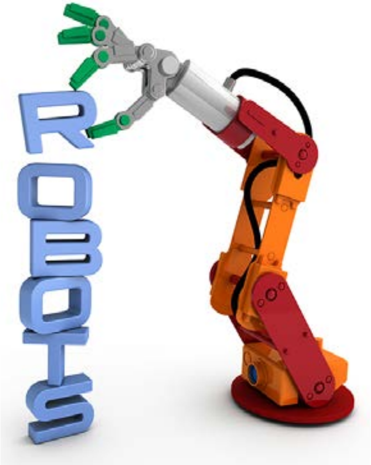
- cheap fabbing – 3D Printers + laser cutters + milling machines
- cheap and available parts – sparkfun, adafruit, seeed studio, ...
- standard interfaces – arduino, mbed, etc
- collective development – makerspaces

The Economist

Motivation

IoT

good work labs



Robotics

Utah Valley University

Problem

Current Design Flows are

- time consuming
- inaccessibly complicated
- not reusable

Situation:

- idle printers
- domain experts without access to fabrication

- High level design with software generators
- Use software to define hardware and software

Because

- highly parametric
- massive reuse
- abstract away low-level details
- easy design space exploration
- extreme integration across EE and CS (and ME)

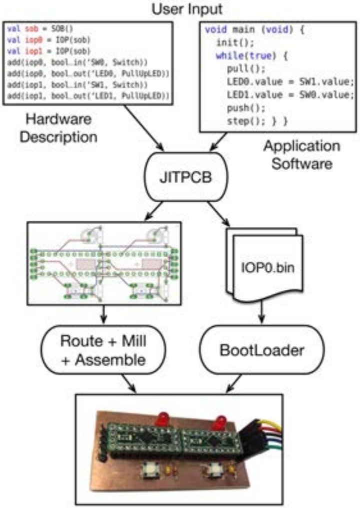
Declaratively design embedded systems

Inputs

- list of peripherals
- application in C++

Outputs

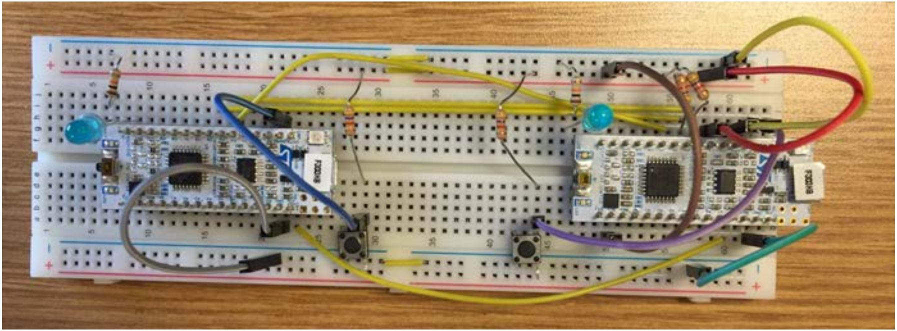
- (multiple) board files
- compiled firmware
- networking layer




JITPCB
IROS 2016
JONATHAN BACHRACH
DAVID BIANCOLIN
AUSTIN BUCHAN
DUNCAN HALDANE
RICHARD LIN

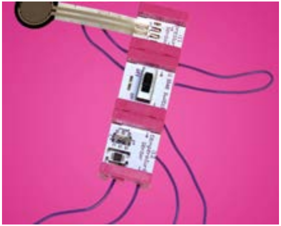
Current Breadboard Prototyping

- ungainly format
- fragile
- manual and error prone efforts – pin conflicts
- doesn't scale



Current Modular Circuit Prototyping

- modular spaghetti and expense
- arduino frankenboards – why have interfaces? supports modules
- no perfect premade modules
- still manual and error prone efforts – pin conflicts
- doesn't scale



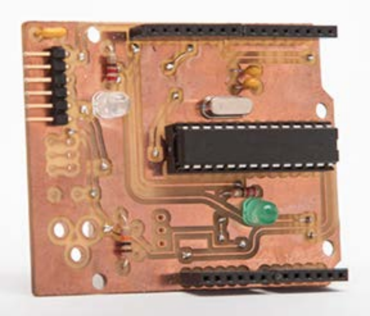
lilbits

gadgeteer

arduino

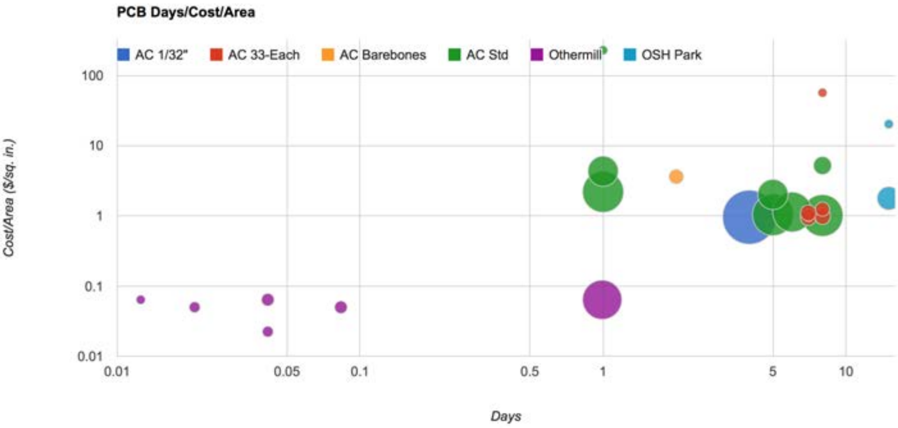
- CAD is tedious and only WYSIWYG
- fabrication is slow and expensive

- JIT manufacturing – mills blank copper boards while you wait
- produces structurally sound electronics in desired form factors
- relatively inexpensive (approx $3000 for mill and $5 for boards)
- 20 in^2 / hour
- 1 or 2 layers and no solder mask for now
- still requires labor intensive Eagle design



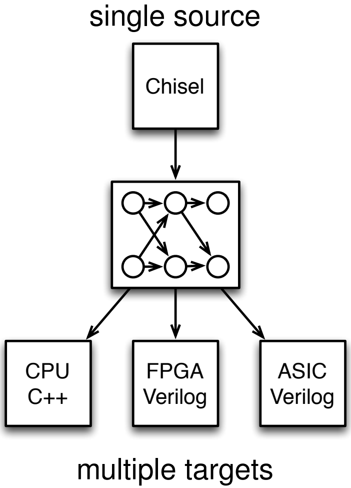
OtherMill vs Alternatives (or MCB vs PCB)

- othermill is an order of magnitude lower cost and time



Chisel is ...

- Best of hardware and software design ideas
- Embedded within Scala language to leverage mindshare and language design
- Not Scala -> Verilog
- Algebraic construction and wiring
- Hierarchical, object oriented, and functional construction
- Abstract data types and interfaces
- Bulk connections
- Multiple targets
  - Simulation and synthesis
  - Memory IP is target-specific



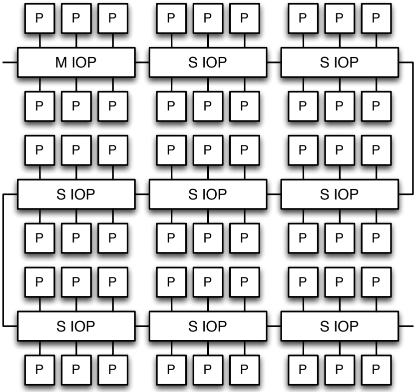
- SOB architecture
- stanza
- hardware description
- software model

Template

- Peripherals
- IO processors
  - one master and rest slaves
  - peripherals attach to pins
- Network

Benefits

- Modular and Scalable
- Easier SW and Routing



Stanza* Essence

- best of scripting and production languages
  - easy to understand and powerful to use
  - gradual types -> easy parameteric types
- simple orthogonal concepts
  - functions, objects, pipes, and namespace separated
  - use concepts in unlimited ways – serendipity
  - entire language including optimizing native compiler in 20K LOC
- powerful macros for conventional syntax
  - almost entire stanza syntax written as macros
  - better DSL hosting language

* developed by Patrick Li @ EECS Berkeley

Stanza by Contrast

- like Python but
  - types and on and on and on ...
- like Scala but
  - thinner – native compiler + runtime in 20K LOC
  - simpler – fewer base concepts
  - more separated – orthogonal functions / objects
- like Clojure but
  - conventional syntax – love the parens but ...
  - thinner – native
  - more powerful macro system – not just name macros
- like Dylan but
  - improved gradual types – parameteric types
  - better multimethod namespaces – fewer name clashes
  - more powerful macros – syntax written in it
  - has pipes – generalized control flow mechanism

- components
- modules
- layout
- autorouter

Component Descriptions:

```
defcomponent LED ("LED", "LED5MM") :
  pad A
  pad K

defcomponent Resistor ("RCL", "0204/7") :
  pad 1
  pad 2
```

Module Description:

```
defmodule PullUpLED () <: Module:
  ;; interface
  inherit gnd
  inherit v3
  sig io
  ;; subcomponents
  mod l   : LED("red")
  mod r   : Resistor("1k")
  ;; netlists
  sig up  = [r.1, l.A]
  sig v3  = [r.2]
  sig gnd = []
  sig io  = [l.K]
  ;; layout
  lay HBox([Rot(r,90), Rot(led,90)], 1.0)
```

- mBED
- drivers
- virtualized peripherals – RPC calls
- bootloader

- C++ Object Oriented Library for Embedded
- ARM consortium and works across chips / boards
- Standard and nicely designed

```
I2C master(SDA_PIN, SCL_PIN);
master.frequency(I2C_FREQ);
master.read(SLAVE_ADDR,(char*)&SW1_dat,1);
master.write(SLAVE_ADDR,(const char*)&LED1_dat,4);
```

```
DigitalIn SW0_dev(PTB1);
PwmOut LED0_dev(PTB10);
```

Peripheral Interface (Stanza):

```
defn bool_out (name:Symbol, hw:Symbol -> PeripheralModule) :
  Peripheral(name, "BoolOut", hw,
    [Pin(‘DigitalOut, pad#io)],
    [Port("value", IntType(0))])
```

Peripheral Interface (C++):

```
// Automatically generated Peripheral and Master class
class BoolOutPeriph : public Peripheral {
  public:
    int value;
};
class BoolOutPeriphMaster : public BoolOutPeriph {
  // Initialize and synchrnonize local class variables
  // to Slave instantiations over network
};

// User completed Slave functionality class
class BoolOutPeriphSlave : public BoolOutPeriph {
  public:
    BoolOutDevice(PinName pin) : dout_pin(pin) { }
    void step(void): { dout_pin.write(value); }
  protected:
    DigitalOutPin dout_pin;
};
```

SOB Programming

- program logic agnostic to device placement
  - user defines init and main on master
  - transform input to output data through net addressable registers
- generate HW + SW together
  - HW IDs
  - device / data layout
- use RPC for remote control/status registers
- bootloader loads code on i2c according to ids

```c
#include "master.h"

void main (void) {
  init();   // init user code / drivers
  for (;;) {
    motor0.torque = f(motor0.pos, ...);
    motor1.torque = g(motor1.pos, ...);
    step(); // step drivers
} }
```

master.h (CPU16.h)

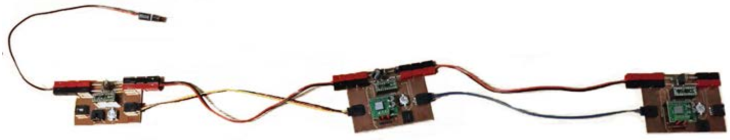
```
MotorMaster motor0, motor1;
void pull(void) { ... } ... void push(void) { ... }
```

CPU18.h

```
MotorSlave motor0(pin3, ...);
void pull(void) { ... } ... void push(void) { ... }
```

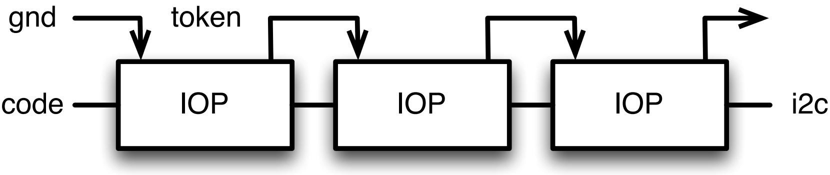
CPU20.h

```
MotorSlave motor1(pin3, ...);
void pull(void) { ... } ... void push(void) { ... }
```

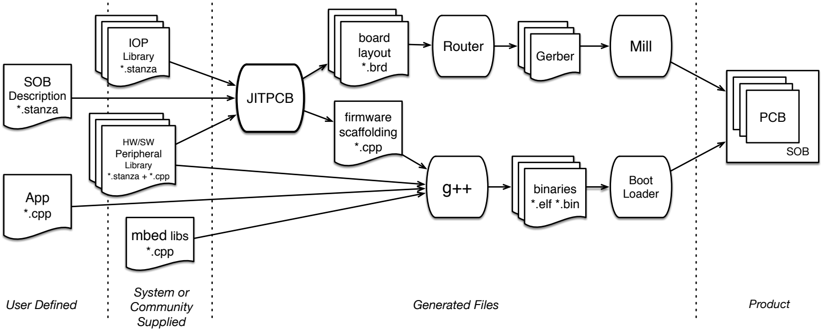


Bootloader

- programmed over I2C
- code organized by IO processor from low to high with cpu-id.elf
- token passed down i2c bus programming processors in order
- IOP with token gets programmed

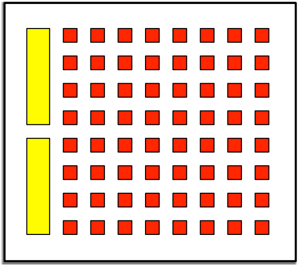


Entire JITPCB Workflow

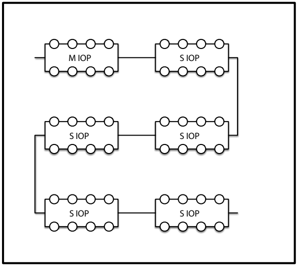


Results

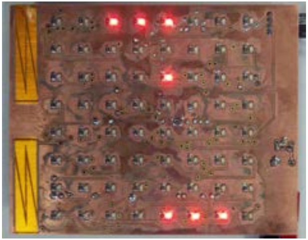
- pong
- robot arm
- mobile robot



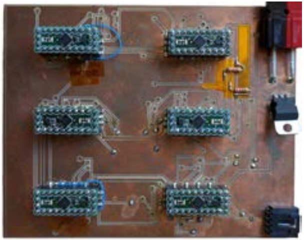
Peripheral layout.



IOP layout.

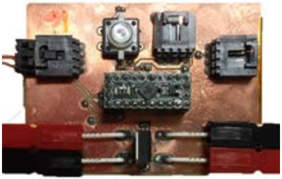


Board front.

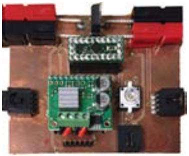


Board back.

Arm mechanism.

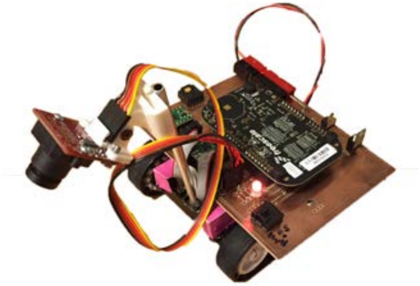


Master board.

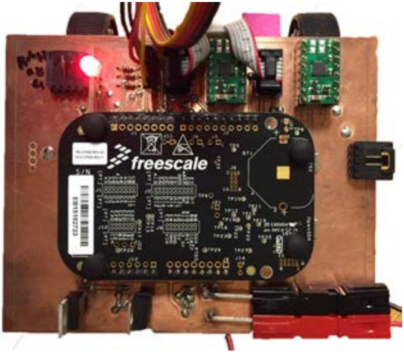


Motor board.

System of three boards.

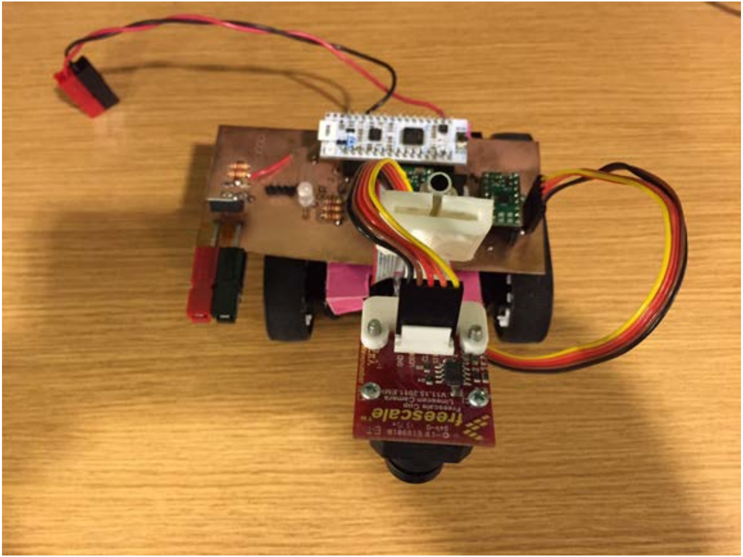


Mobile Robot.



Board detail.

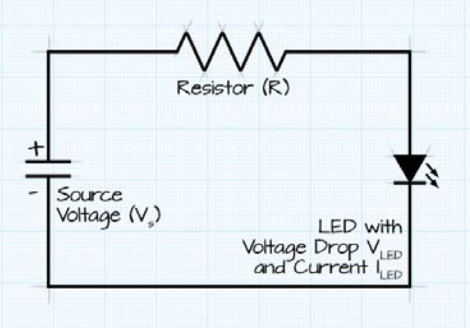
Mobile Robot with Nucleo



- physically sound
- automatic pin assignment
- scalable

Solver

- voltage + resistance + current annotations
- solve for missing quantities
- check for correct wiring
- solve for power supply



- Fabricated: The New World of 3D Printing, by Hod Lipson, Melba Kurman
- Makers: The New Industrial Revolution, by Chris Anderson
- Makers, by Cory Doctorow
- The Third Industrial Revolution, The Economist
- JITPCB, by Jonathan Bachrach, David Biancolin, Austin Buchan, Duncan Haldane, Richard Lin