External Components

Fall 2017

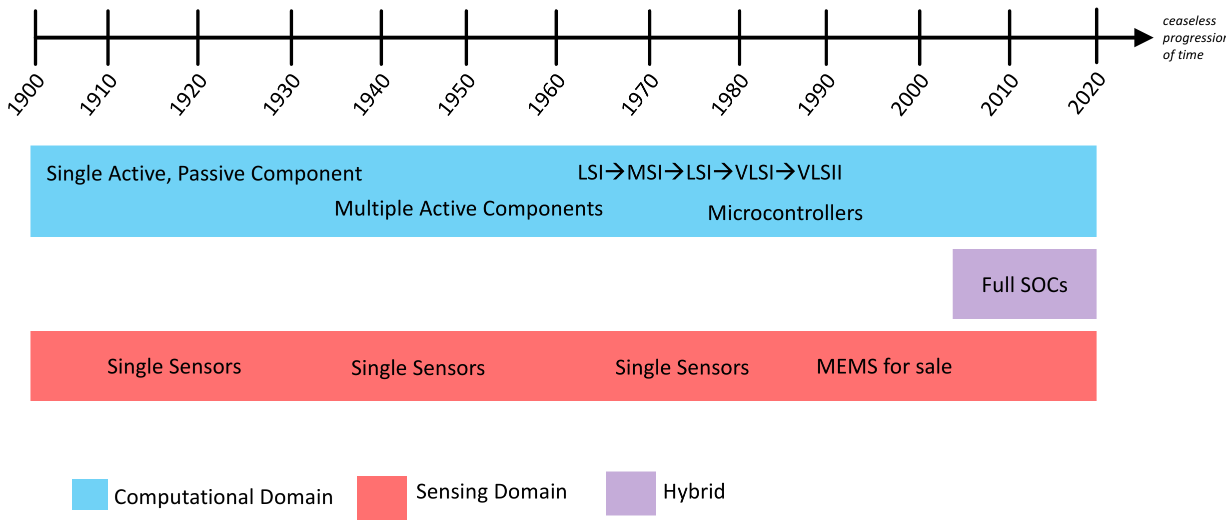
6.111

Where we were…where we're going

- Everyone knows and loves to misquote Moore's Law
- Computational Power has indeed grown exponentially in the last half-century
- Along with that, lurking in the depths, has also been a remarkable development of fully-integrated systems that we've really only started to see break out in the last ~15 years.

https://en.wikipedia.org/wiki/Moore%27s_law

What was the complexity of a single part that you could buy?



Integration Provides Robustness

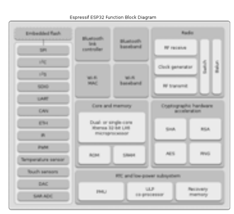
- Much of 20th century focused on integration at the electrical/computational level
- Last few decades saw further integration in with sensors, actuators, communication modules, etc…
- Emergence of real SOCs

German VCL11, 1938: two tubes in one tube!

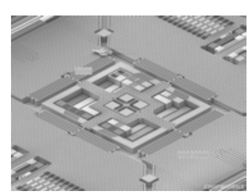
1950s Op Amp from George Philbrick Assoc (Boston)

7400 SSI Integrated Circuit

8080 MCU



ESP32 SOC Functionality Blocks



iPhone 4 (gyro)

http://eecatalog.com/sensors/2012/05/24/mems-trends-smaller-cheaper-everywhere/

Case Study (MEMS SOC): Accelerometers:

1950s Soviet Accelerometer

ADXL335

MMA8452Q

- First MEMS accelerometer: late 70s
- ADXL50: (Analog Devices 1991) (single axis in 25mm^2)
- ADXL335: Analog Out Accelerometer (1998)
  - Voltages for three axes of acceleration
- MMA8452Q: Digital Accelerometer (mid 2000's)
- MPU925X series (or LSM9DS1) series (last few years):
  - 9 DOF (Accel, gyro, compass)
  - Onboard sensor-fusion, orientation integration, DSP engine
  - In-built pedometry, cycle motion detection, etc…

MPU9250

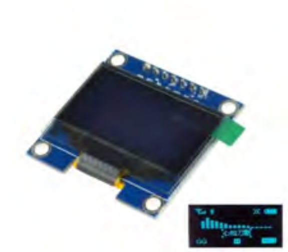
Case Study (Analog): High-voltage Amplification

- APEX PA3440 High-voltage Operational Amplifier:
  - 340 VDC supply limit
  - 120 mA output current
- Where before you needed to design an entire circuit and worry about capacitive loading, death, you now can buy this for $11.00 and drive a Piezo pretty easily

Parts of Interest

Small Displays:

Random TFT off of Amazon



Cheap Monochrome OLED using SPI

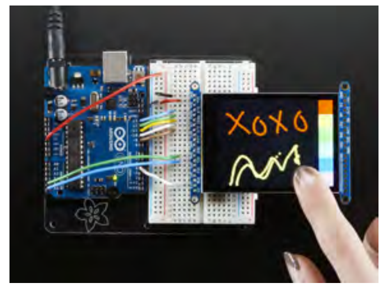
- TFTs Thin-Film Transistors:
  - color
- OLEDs (Organic Light-Emitting Diodes):
  - Faster
  - Better viewing angle, colors, efficiency
- If you want to animate anything, if possible get an SPI interface:
  - i2C is too slow to give sufficiently high speed
- Don't forget computer monitor (is a small display core to your project?)

Color OLED from Adafruit

Touch Screens

- Resistive:
  - Accessed using analog measurements (sometimes digital readout)
  - Usually only one point of contact allowed
  - Generally suck..those early android tablets with them were borderline unusable
- Capacitive:
  - Accessed via i2c, SPI registers
  - More advanced chipsets have in-built gesture detection (swipes, etc..) in addition to touch-points
  - Actually work

Random-resistive
Touchscreen from Amazon



FT6X06-family based touchscreen

Environmental Sensors

- Lots of single-chip environmental sensors available:
  - UV
  - Temp/Pressure/Humidty
  - Smoke
  - Gasses
  - Particulate Matter

- Single-chip spectrometers…probably overkill for us (do RGB extraction from camera pixels), but want to show it since it is cool
- Hamamatsu C12880MA
- ($400, but we can dream)

CCS811 Gas sensor
BME280 pressure/temp/humidity

GUVA-S12SD UV Sensor

MiCS-6814 (all in one device!):

Detectable gases

• Carbon monoxide	CO	1 – 1000ppm
• Nitrogen dioxide	NO_2	0.05 – 10ppm
• Ethanol	C_2H_5OH	10 – 500ppm
• Hydrogen	H_2	1 – 1000ppm
• Ammonia	NH_3	1 – 500ppm
• Methane	CH_4	>1000ppm
• Propane	C_3H_8	>1000ppm
• Iso-butane	C_4H_{10}	>1000ppm

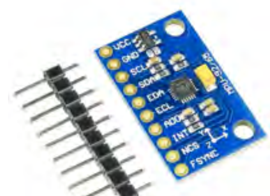
https://www.tindie.com/products/onehorse/air-quality-sensors/

C12880MA

Accelerometers/IMUs

- Both digital and analog models available. Really cheap
- Orientation (using gravity and compass) Determination
- Relative Motion Determination

ADXL335



MPU9250

Time-of-Flight Sensors

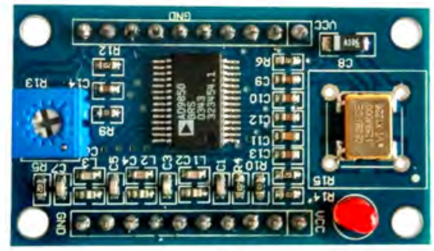
- Cheap, shorter-range LiDAR (couple meters max)
- VL53L0X by STMicro
- ST has the big patents in this field
- Used currently in proximity detection on phones, etc…
- ~$10.00
- ~1 cm resolution (10 picosecond difference in light return)

VL53L0X

Breakout from Pololu

DDS Modules

- Function Generators on a chip
- AD9850 DDS: Direct Digital Synthesis:
- Can create sine waves, square waves from 0 to 40MHz via digital control very quickly
- Phase-shift control as well!
- AD9833: Slightly different version of AD9850, SPI controlled, capable of 0.004 Hz resolution from 0 to 500 kHz with right settings/0.1 Hz resolution up to 40 MHz



AD9850 Dev Board

AD9833 Dev Board

Cameras

- OV7670 ish Series:
  - There should be some basic modules that already work with this
- Other variants exist OV2640, *should* be able to go faster…looking at communication with it now.
- Tons of others

OV7670

MT9M001
Infrared Camera

OV2640
(w SPI interface)

Raw OV2640
(should be able to get 60fps out of this with subsampling)

Specialty Imagers

- Line Scan Devices:
  - 128 x 1 pixel array
- Motion/Thermal Detection Devices

Line Scan Camera

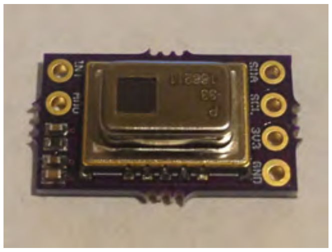
https://www.tindie.com/products/AP_tech/tsl1401cl-linescan-camera-/

TPiS 1S 1385 / 5029

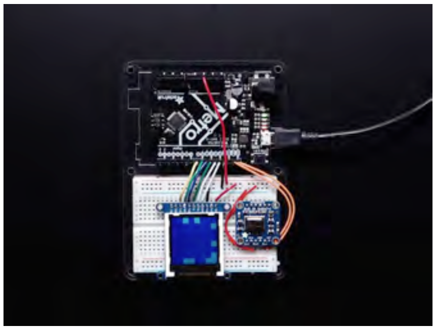
https://www.tindie.com/products/onehorse/calipile-tpis1s1385-presence-and-motion-detector/

AMG8833
Thermal Imager

- 8x8 thermal sensor array
- Effectively a Low-res camera that works off of thermal intensity
- $40 currently

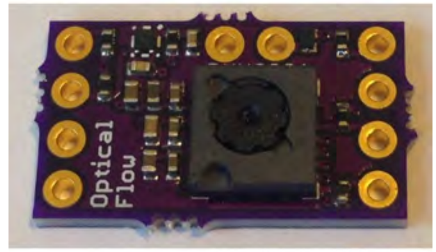


AMG8833
(from tindie)



Optical Flow Sensors

- Basically like long-range optical mice
  - (many feet with a lens)
- PWM3901 is a good one, uses SPI communication and can make/give measurements at ~100 Hz
- Great because they provide an convenient means of dead reckoning with sub-inch resolution which cannot be fixed using IMU math or current GPS



https://www.tindie.com/products/onehorse/pmw3901-optical-flow-sensor/

Board with combined PMW3901 and VL53L0X (optical flow and distance)

Wireless Communication

- Bluetooth: HC05 modules are designed to take in/put out UART (serial like from Lab02B) and chipset handles conversions (good up to ~50 ft or more with LOS)
- Infrared is reliable over short distances…(need LOS)
- Nordic Semiconductors makes some devices that have flooded the market with their own brand of 2.4GHz brand communication (popular from Arduino community)

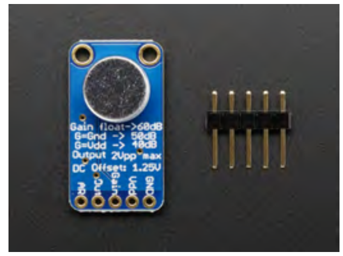
HC-04/5/6 Bluetooth series

Infrared TX/RX pairs (from Lab 5)

NRF24L01

Microphones

- Electret and MEMS capacitive microphones are standard now
- Either use analog out OR models that digitize on-chip (usually convert into I2S which is a standard audio-information digital communication protocol…we'll discuss next Tuesday)



Electret with selectable gain (Adafruit)

ICS43434 Digital Output Microphone (Invensense), uses i2s protocol

https://www.tindie.com/products/onehorse/ics43434-i2s-digital-microphone/

Audio Out

- Analog or i2s amplifiers, DACs, etc… are available.
- Most DACs have i2s inputs, and many modern electronic devices convert audio information immediately to/from i2s
- If you're considering an audio project might be a neat protocol to look into (although the AC97-setup on the older labkits works well too) (Vivado has an i2s core)

MAX98357A-based board from Adafruit: 3W Class D audio amp i2s input

Computer Interfacing

- We've already explored this in Lab 2B with USB-to-RS232 interfacing
- Nexys4 supports USB slave mode (haven't tested drivers yet)
- Also have a collection of FTDI converters (convert USB to/from UART (serial-readable)
- **Use tools like these to help put test cases, example data, record outputs, etc…**

FTDI converter
(Broken out USB to UART)

Things to Consider

- Level Shifting?:
  - Nexys4 DDR runs at 3.3V
  - Some sensors run at 5V
  - Others run at 2.7V
  - Check! May need to use level shifters and these add their own delay/skew to signals so be aware with high-speed data transfers
- When buying, check the datasheets. For every well-documented version of something there are "clones"/variants/obscure chipsets that are also sold and are often cheaper.
- Your project should be complex but do you want to focus on the complexity of a sensor or a protocol or a higher level?
- FPGAs are neat* to develop with because there's generally not a **`do_everything()`** like you'll see when working in regular Arduino-family devices. Make lemons into lemonades…more opportunity to read data sheets,

*also frustrating

Random Project Ideas (What I'd do if I were young)

Margaret Hamilton,
Director of Software Engineering
Apollo Program, 1967

- Rebuild Apollo Guidance Computer (AGC):
  - Source code here: https://qz.com/726338/the-code-that-took-america-to-the-moon-was-just-published-to-github-and-its-like-a-1960s-time-capsule/
  - Schematics here: http://klabs.org/history/ech/agc_schematics
  - Real one was implemented using nothing but 3-input NOR Gates !
- Implement a Neural-Net/Some kind of Assisted/Unassisted learning:
  - FPGAs have benefit of parallelizability
  - Some decent repos out there to get started/serve as inspiration
  - Classify some things without the crutch of TensorFlow, numpy, etc…
- Noise-Cancellation using DSP:
  - Don't need to rely on feedback only of to get 6dB of suppression
  - FFTs and cut out the noise