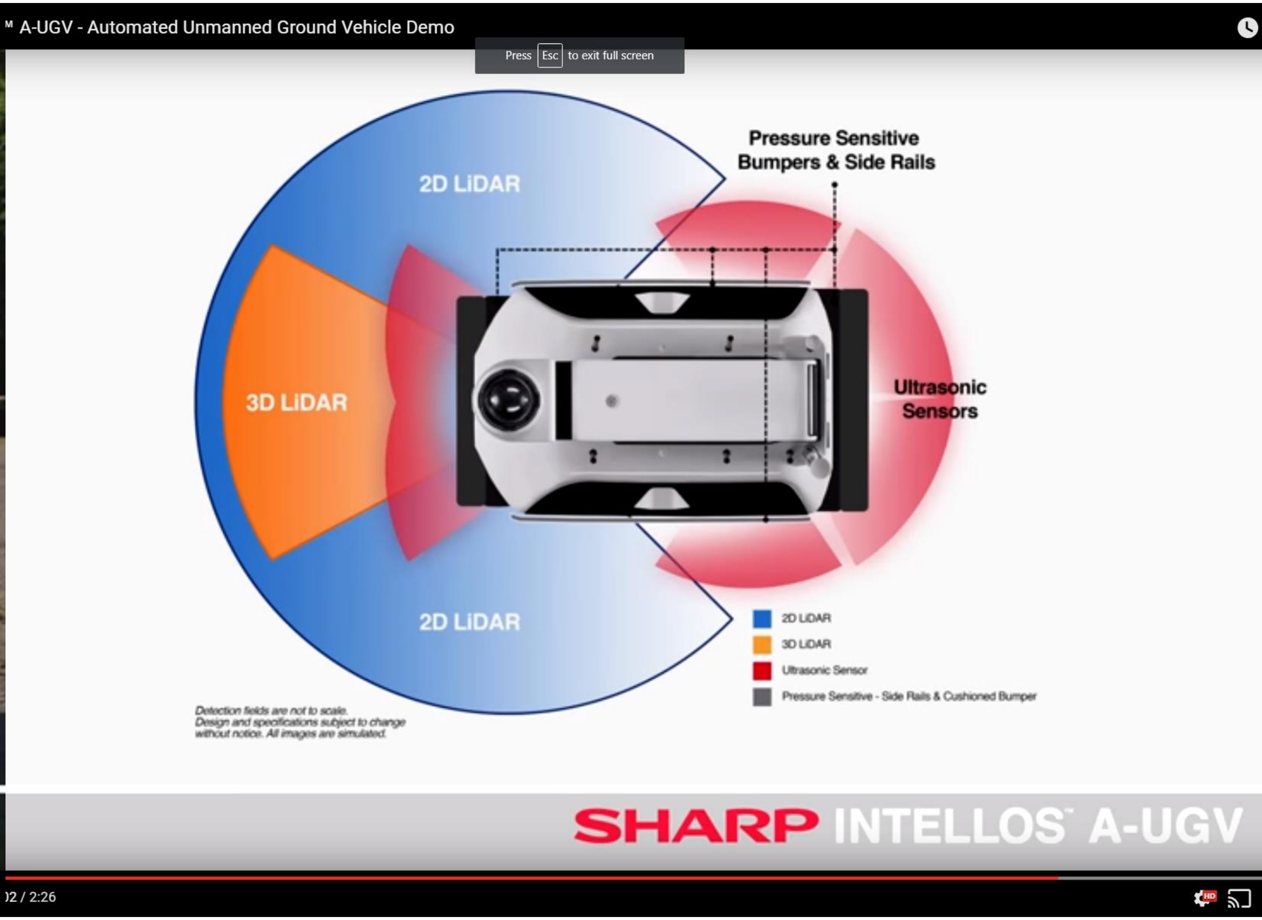
Open Source Software in Robotics and Real-Time Control Systems

Gary Crum at OpenWest 2017

Background and some videos for context

- ASI history with some open source and USU academic roots:
  - asirobots.com
- DARPA: Defense Advanced Research Projects Agency
  - Grand Challenge prize competition in 2004 and 2005
  - Urban Challenge in 2007
  - Robotics Challenge in 2012

product example: Sharp Intellos Automated Unmanned Ground Vehicle



https://www.youtube.com/watch?v=zgEdFkyD9Hg

Introduction

- Robotics and Real-Time Control Systems
  - motors and actuators
  - movement, generally in real world or simulation
  - localization
  - navigation

- Following slides: Examples of open source software packages

Prime example: operating systems

- UNIX -> Linux, very open
  - increasingly useful for deterministic real-time systems such as robotics

- Arduino: minimal, free and open, bare-metal runtime software

- VxWorks
- INTEGRITY
- µC/OS-II

- ROS: Robot Operating System

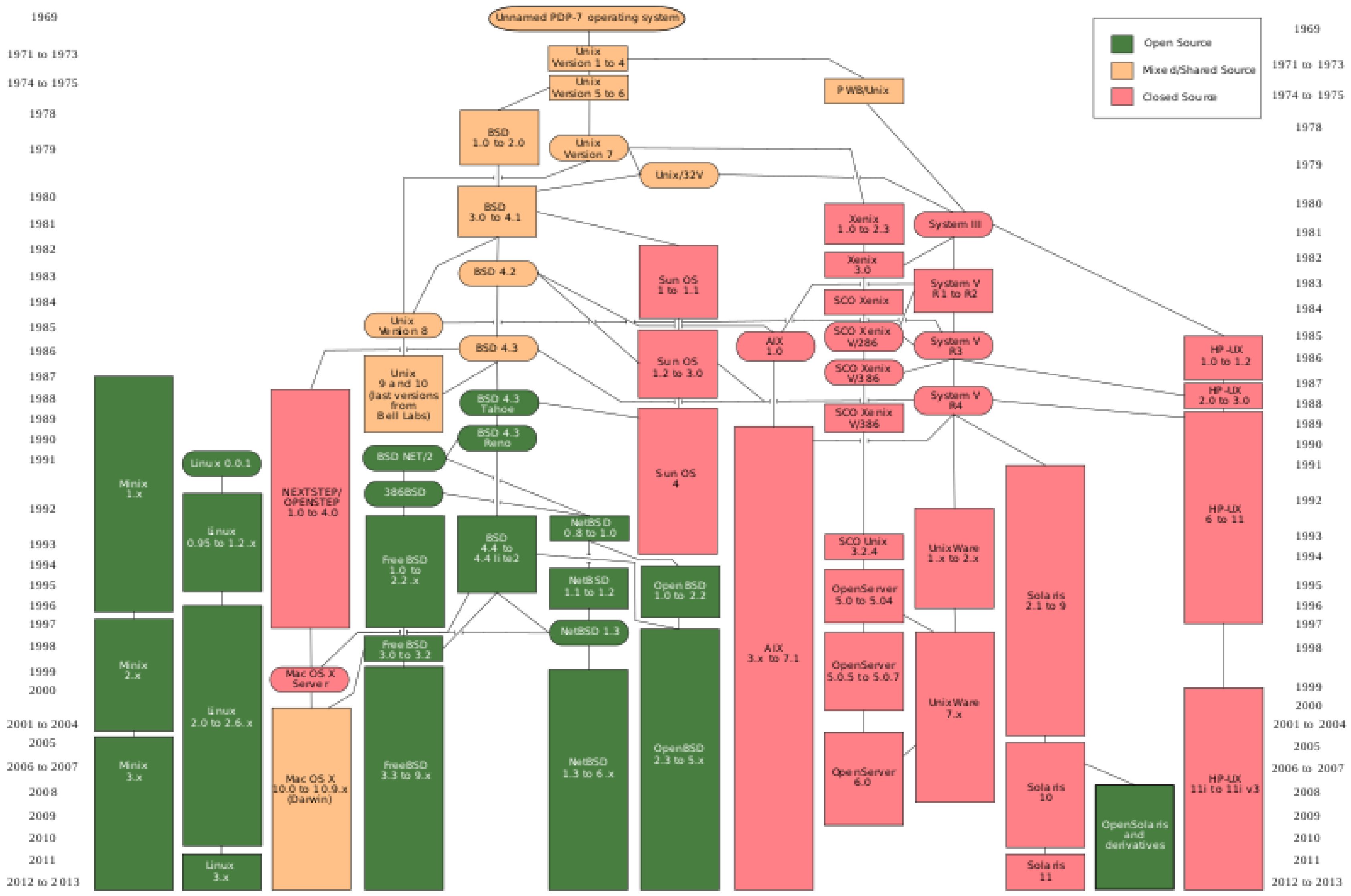
Operating System characteristics

- Management of hardware resources
  - memory, storage
  - I/O to devices, such as digital and analog I/O
  - task/process/thread scheduling
- Communication and networking interfaces
  - TCP/IP on Ethernet and RF, e.g. WiFi
  - CAN: Controller Area Network
  - I2C, RS-232, RS-485
- Application Binary Interface and loading
  - init, system
- Shell command interpreter, bash, and tools such as ps: process status

Operating System licensing and openness

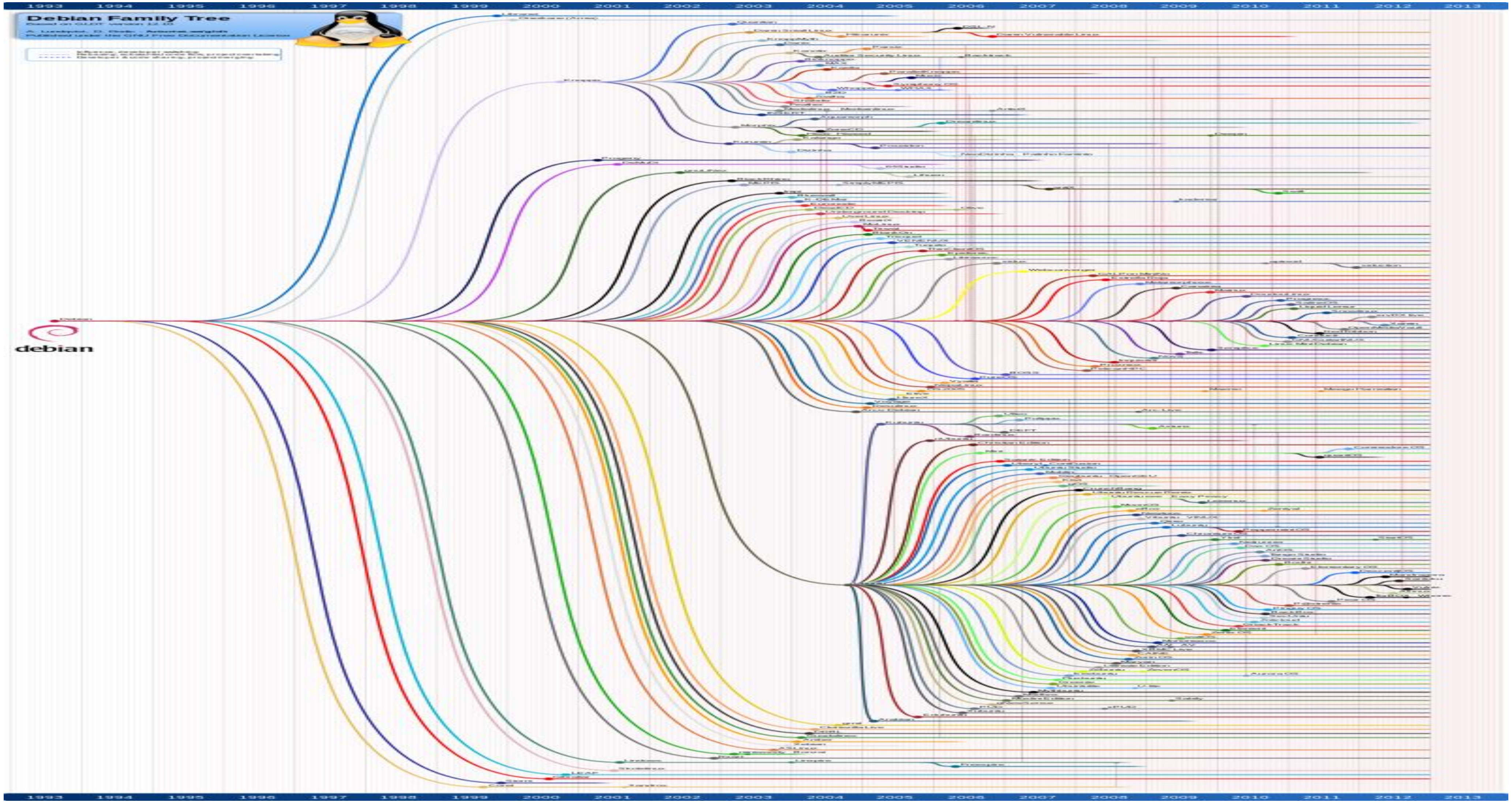
- Linux (e.g. kernel) is GPL
  - GPL: GNU General Public License
  - GNU: GNU’s Not UNIX
- Some operating systems are open source, but not free
  - e.g. µC/OS-II
- Some operating systems are closed source
  - INTEGRITY
  - VxWorks
- Some operating systems have open source components
  - Apple macos and iOS, with Darwin kernel and BSD UNIX libraries and tools

UNIX evolution including Linux kernel



Debian Linux family tree

https://upload.wikimedia.org/wikipedia/commons/1/1b/Linux_Distribution_Timeline.svg



Development tools

- Closely tied to operating systems
- GNU Compiler Kit
- LLVM/Clang
- Modern C++
- Python
    - modern
    - free, open source
    - runs on inexpensive hardware
    - interpreted
    - many libraries
        - SciPy.org
    - cross-platform
    - core language of ROS: Robot Operating System

ROS: Robot Operating System

- Framework, especially for robotics communication
- uses publish/subscribe design pattern
- introduces useful concepts, abstraction and clean implementation
- nodes
- topics
- tf: transforms
- talker/listener nodes
- I/O drivers for motors, actuators, sensors including LIDAR

More on ROS: ROS packages incl. localization

- GPS input, NMEA 0183 parsing
  - NMEA: National Maritime Electronics Association
    messages such as $GPGGA output by GPS/GNSS receivers

  - can provide accuracy within +/- 1cm when used with
    RTK: Real-Time Kinematics, differential corrections using
    RTCM: Radio Technical Commission for Maritime services
    NTRIP: Networked Transport of RTCM via Internet Protocol
    CORS: Continuously Operating Reference Station

More on ROS: higher-level ROS packages

- AMCL - Adaptive Monte Carlo Localization, 2D
  - http://wiki.ros.org/amcl
- gmapping - OpenSlam Gmapping
  - SLAM: Simultaneous Localization and Mapping
- loam_velodyne
  - LOAM: Laser Odometry and Mapping
  - BSD license, comes from CMU
- drivers for wheel encoders and odometry

Example: Gazebo: http://gazebosim.org

- from OSRF: Open Source Robotics Foundation
- Gazebo is Robot Simulator with 3D vizualization and robot model
- includes images, video, 3D point clouds, maps

Example: Open Source math libraries and tools

- Eigen: C++ template library for linear algebra
- Eigen is implemented in .hpp files
- modern alternative to classic LAPACK: Linear Algebra Package

```
#include <iostream>
#include <Eigen/Dense>
using Eigen::MatrixXd;
int main()
{
  MatrixXd m(2,2);
  m(0,0) = 3;
  m(1,0) = 2.5;
  m(0,1) = -1;
  m(1,1) = m(1,0) + m(0,1);
  std::cout << m << std::endl;
}
```

Example: Open Source math libraries and tools

- GNU Octave, a scientific programming language with GUI
  - much like Matlab, not including Simulink
  - also good for data analysis and plotting
  - can solve nonlinear differential equations
- DLIB, http://dlib.net/, machine learning and data analysis library

Example: OpenCL: Open Computing Language

- standard for parallel programming, heterogeneous systems
- from non-profit technology consortium Khronos Group
- includes code for making use of multiprocessing capability of multiple hardware implementations including:
  - Intel CPUs and GPUs
  - NVIDIA GPUs: Graphics Processing Units
  - FPGAs: Field-Programmable Gate Arrays

Example: OpenCV:
Open Source Computer Vision Library

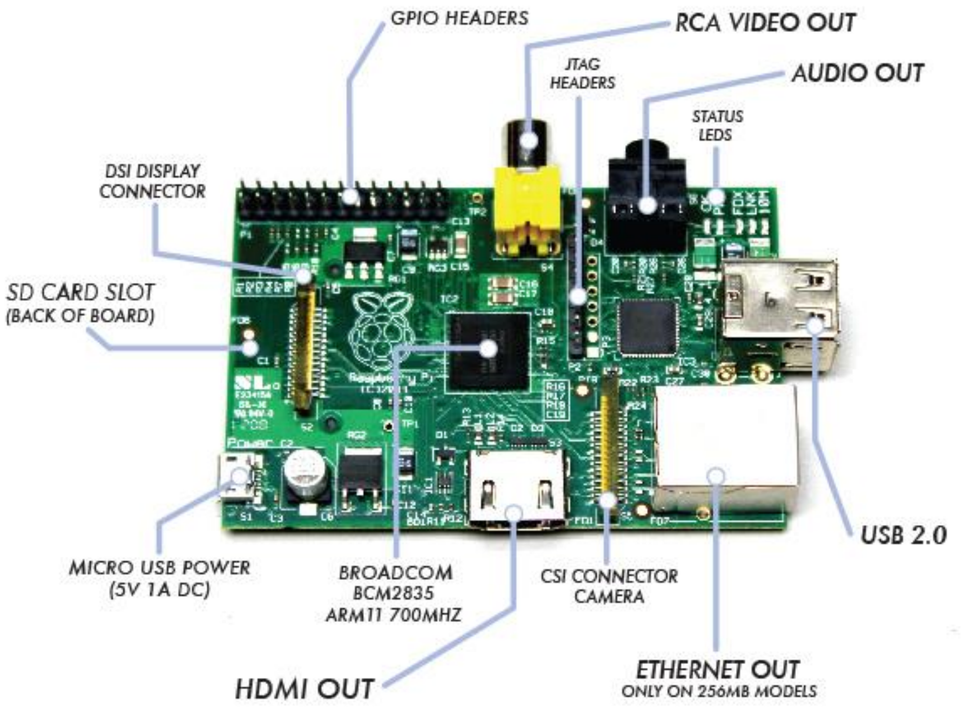
- library available under BSD license
- includes C++, C, Python and Java interface
- on Windows, Linux, macos, iOS and Android
- efficient, uses OpenCL
- for image processing
- used by some ROS code such as IAI Kinect library

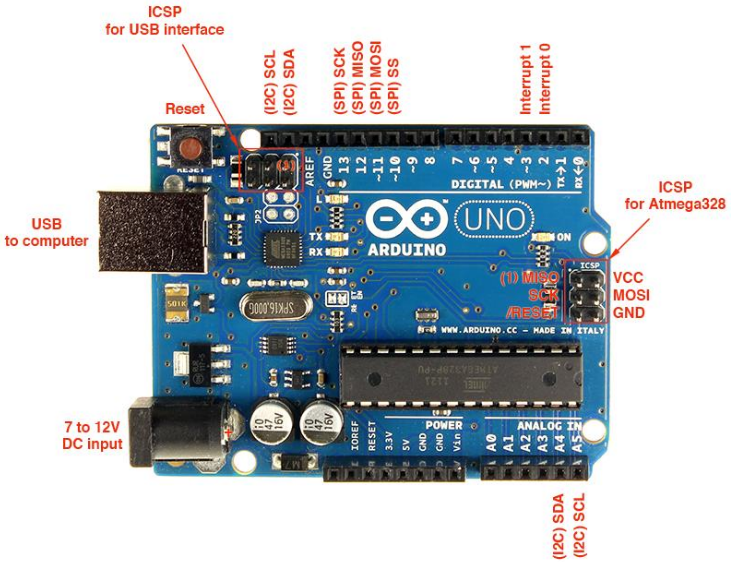
Example: other Deep Learning implementations

- TensorFlow: open-source software library for Machine Intelligence
  - originated by Google, but made open and independent
- Keras: Deep Learning library for Python
  - can be used as simplified interface to TensorFlow
- Deep Learning can be used for image and object recognition

Example: Raspberry Pi and Arduino platforms

- Open, low-cost and easy with free examples,
- setting precedent and example, copied by others including low price
- Some packages can be partially open but have key closed components





Raspberry Pi 3 specifications

System-on-chip used	Broadcom BCM2837
CPU	1.2 GHz 64/32-bit quad-core ARM Cortex-A53
Memory	1 GB LPDDR2 RAM at 900 MHz[2]
Storage	MicroSDHC slot
Graphics	Broadcom VideoCore IV at higher clock frequencies (300 MHz & 400 MHz) than previous that run at 250 MHz
Power	10.0 W (2 A)
Website	raspberrypi.org

Other examples from you? How about:

- Robotics competitions such as VEX and FIRST.
- ArduPilot for flying robots
- MIT Scratch
- Arduino and Pi robotics platforms including motors and wheels
- Academic projects, sometimes open at least for more academic use
  - example is CVXGEN: Convex problem solver, code generator from Stanford
    - used for NASA Mars landing code as well as by SpaceX for rocket landings

Any similar experience and interests?

Questions?

CrumResearch@gmail.com
Tel. 801-449-1426