PYNQ™

Python Productivity for Zynq

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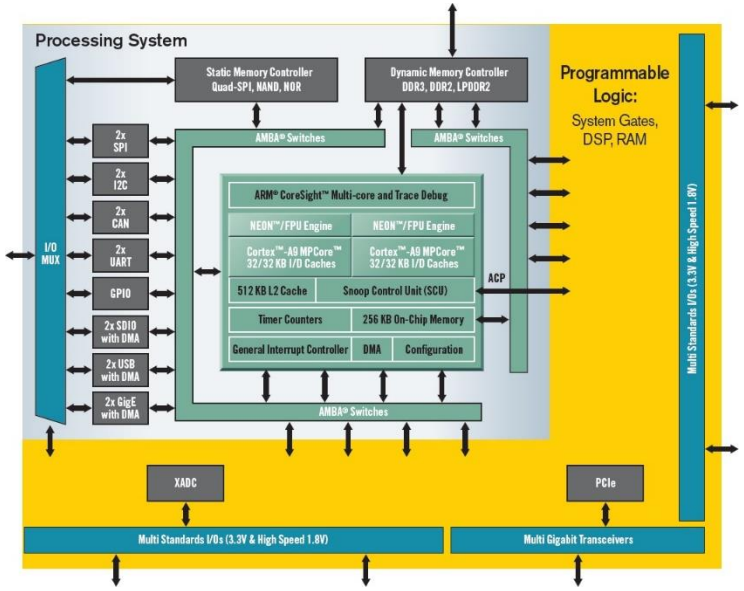
- Zynq & Zynq Ultrascale+
- PYNQ Framework
- Technologies
- Community

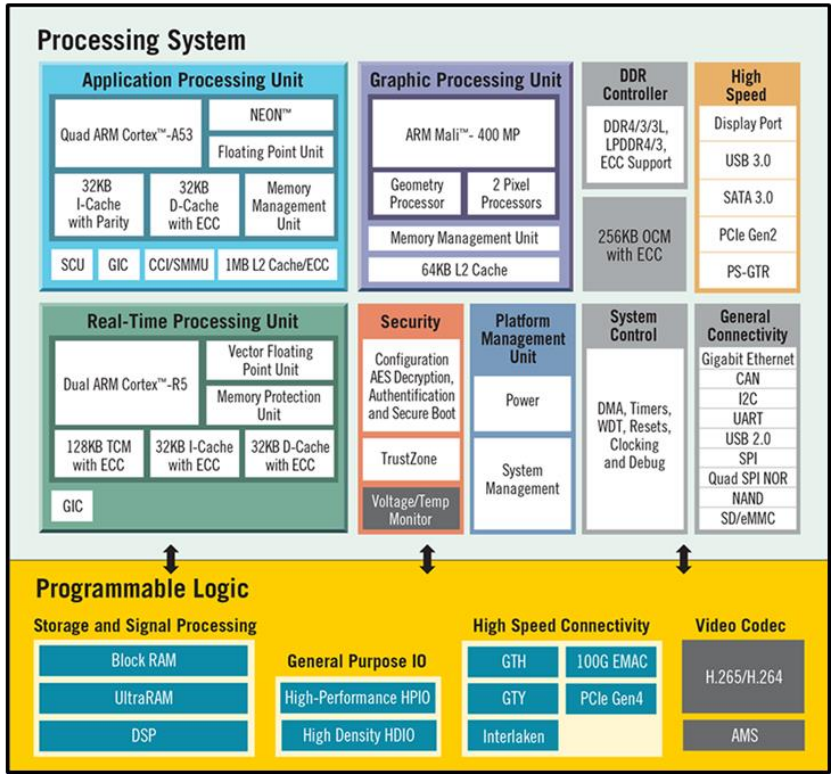
ZYNQ and ZYNQ UltraSCALE+

Best-in-class, SoC and MPSoCs

ZYNQ 7000



ZYNQ UltraSCALE+



FPGAs and tightly-integrated CPUs enable entirely new opportunities

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Zynq applications

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PYNQ Vision

> **Make Zynq so easy-to-use that programmers can access the benefits without learning advanced digital design skills**

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PYNQ framework

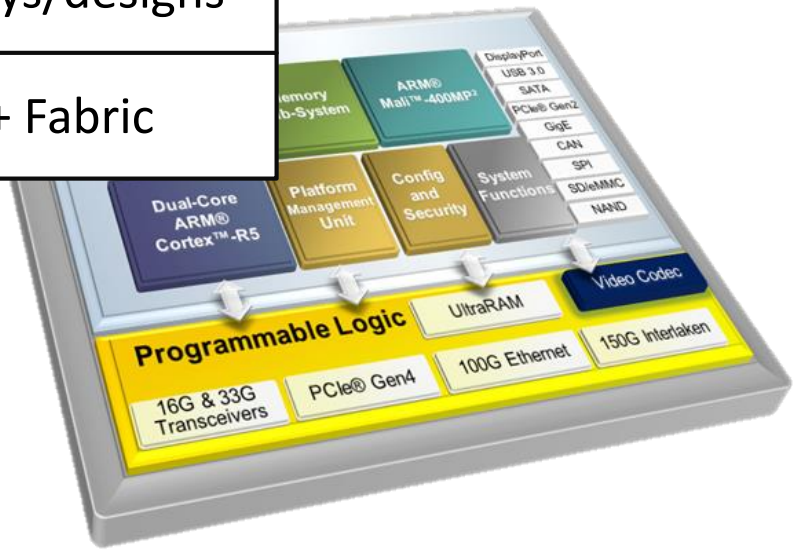
Python Productivity for Zynq

Jupyter notebooks, browser-based interface

PYNQ enables JupyterLab on Zynq and ZU+

Jupyter web server	
IPython kernel	
Ubuntu-based Linux	Overlays/designs
ARM A9 / A53	ZU+ Fabric

Hardware C-drivers wrapped in Python packages



Most competitive, open and advanced GUI

Ubuntu-based Linux versus embedded Linux

Ubuntu-based Linux

Optimized for developer productivity

- All the Linux libraries and drivers you expect
- Pre-built SD card image
- Ubuntu/Debian ecosystem & community
  - >>145,000,000 Google hits

3 orders of magnitude difference

Embedded Linux

Optimized for deployment efficiency

- Selective Linux libraries and drivers
- Commonly delivered in flash memory on board
- PetaLinux ecosystem:
  - >> 143,000 Google hits

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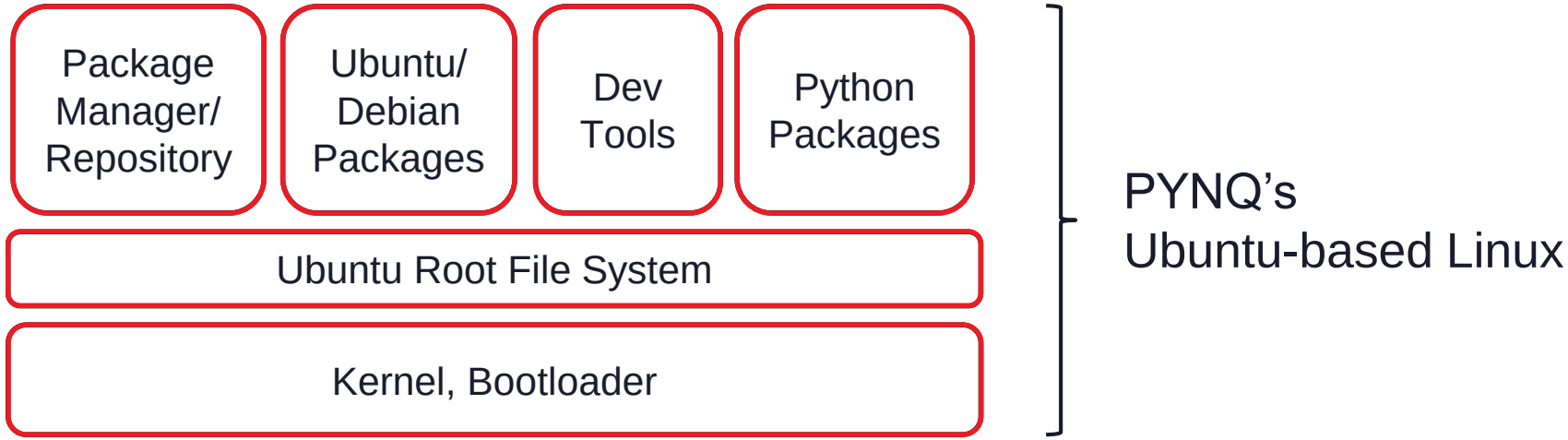
PYNQ's Ubuntu-based Linux

PYNQ uses Ubuntu's:
- Root file system (RFS)
- Package manager (*apt-get*)
- Repositories

PYNQ bundles :
- Development tools
  - Cross-compilers
- Latest Python packages



PYNQ uses the PetaLinux build flow and board support package:
- Access to all Xilinx kernel patches
- Works with any Xilinx supported board
- Configured with additional drivers for PS-PL interfaces

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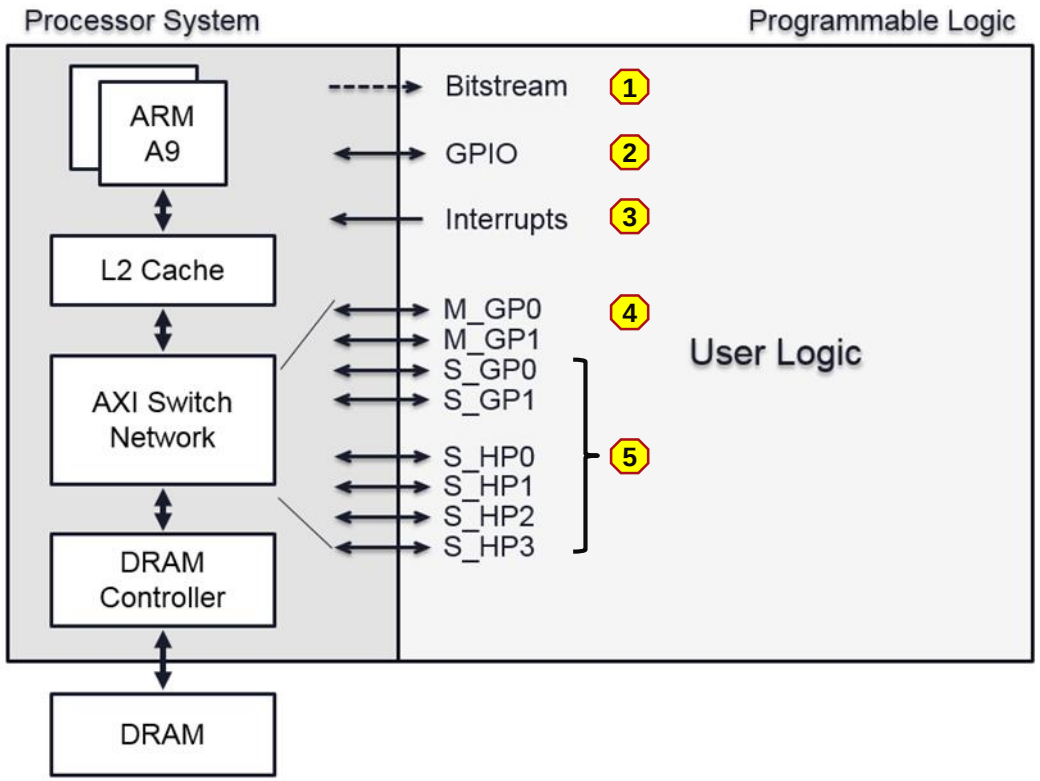
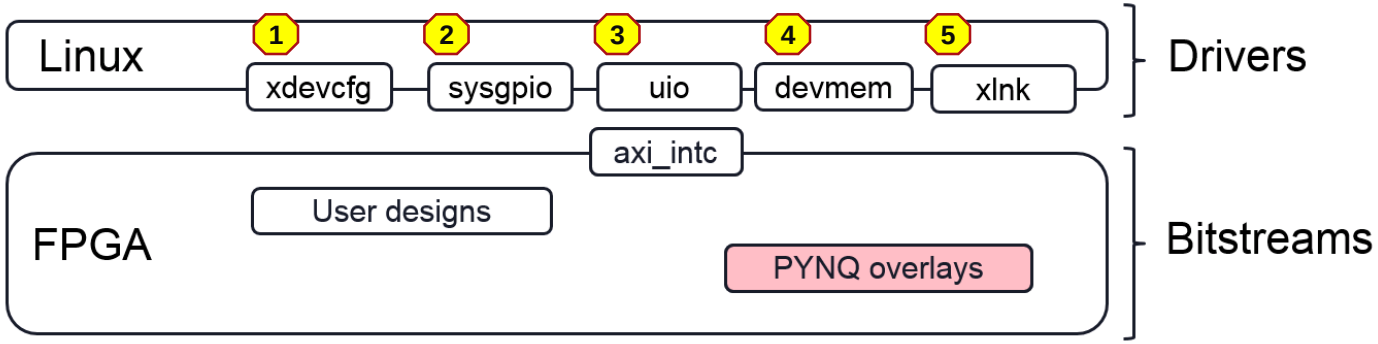
PYNQ provides Linux Drivers for PS-PL Interfaces …

wrapped in Python Libraries

Zynq





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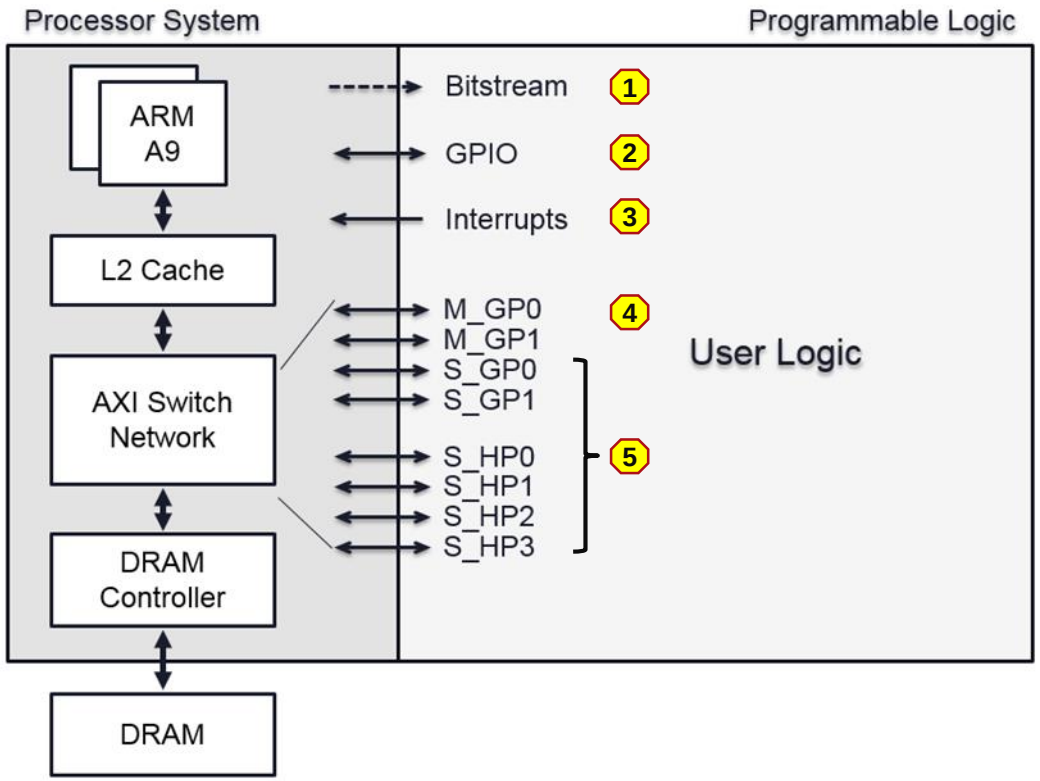
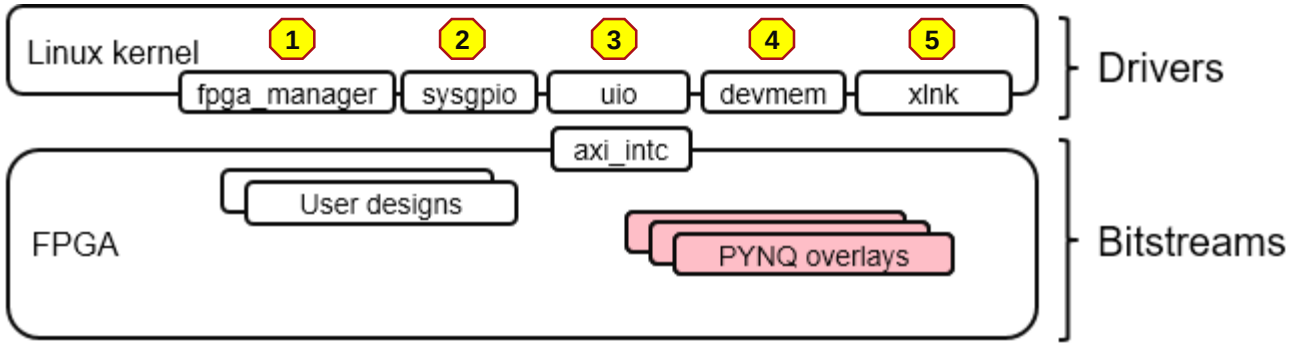
PYNQ provides Linux Drivers for PS-PL Interfaces … wrapped in Python Libraries

Zynq





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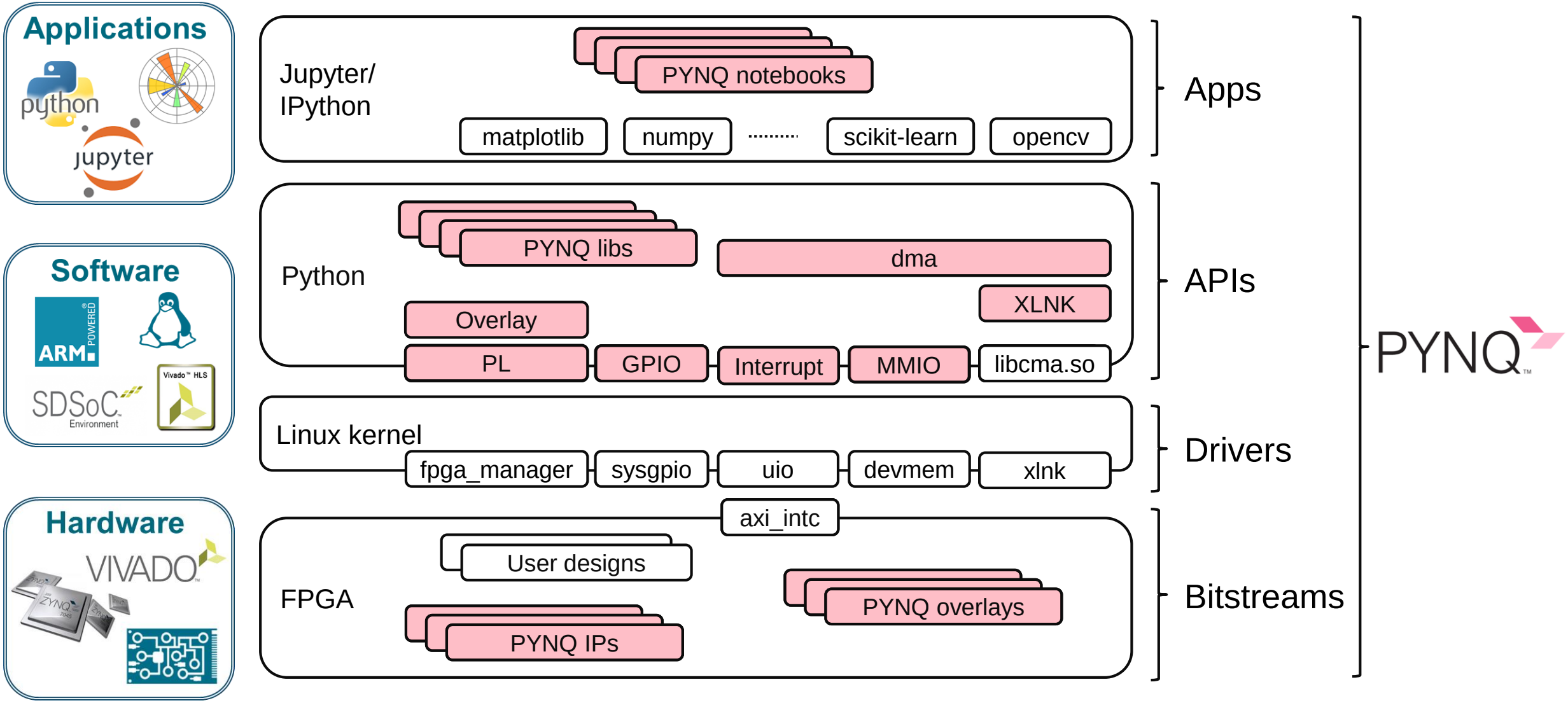
PYNQ is a Framework



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Vivado Design Metadata available from Python

- **PYNQ passes the Vivado metadata file to the target platform**
  - Initially Vivado TCL file
  - Now moving to Hardware Handoff (HWH) file

- **It then parses the Vivado metadata file to:**
  - Set Zynq clock frequencies automatically
  - Assign memory-map attributes for every IP
  - Assign default MMIO drivers to IP, when no drivers are specified

- **Creates a Python dictionary for the IP in the bitstream from the metadata file**
  - Enables bitstream metadata to be queried and modified in Python at runtime

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Hybrid Packages

- **New *hybrid packages* are created by extending Python packages with additional files:**
  - Design Bitstream
  - Design metadata file
  - C drivers
  - Jupyter notebooks

- **Hybrid packages enable software-style packaging and distribution of designs**

- **Use the Python package installer, `PIP` to install a hybrid package just like any regular Python (software only) package**
  - Delivers package's files to target board

- **Uses Python standard `setup.py` script for installation**

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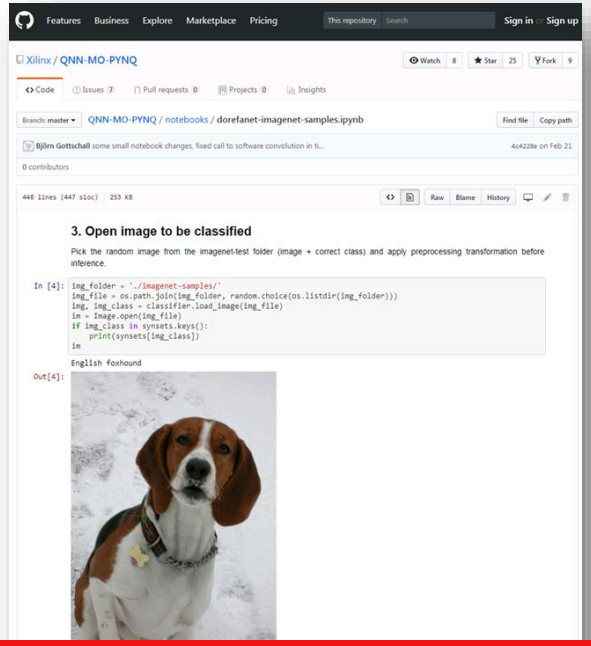
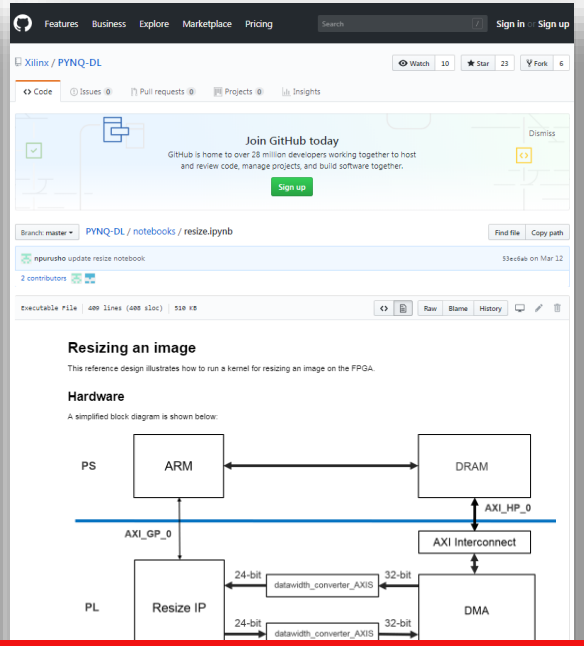
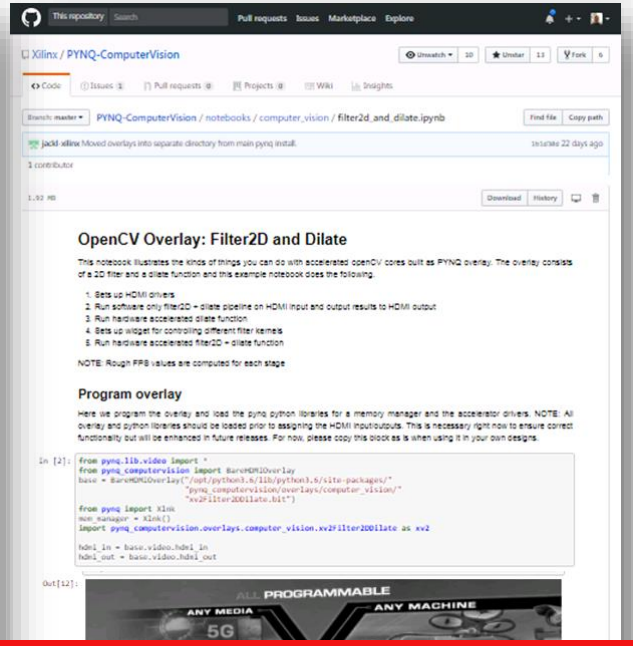
Software-style Packaging & Distribution of Designs

Enabled by new *hybrid packages*







Download a design from GitHub with a single Python command:

```
pip3.6 install git+https://github.com/Xilinx/pynqDL.git
```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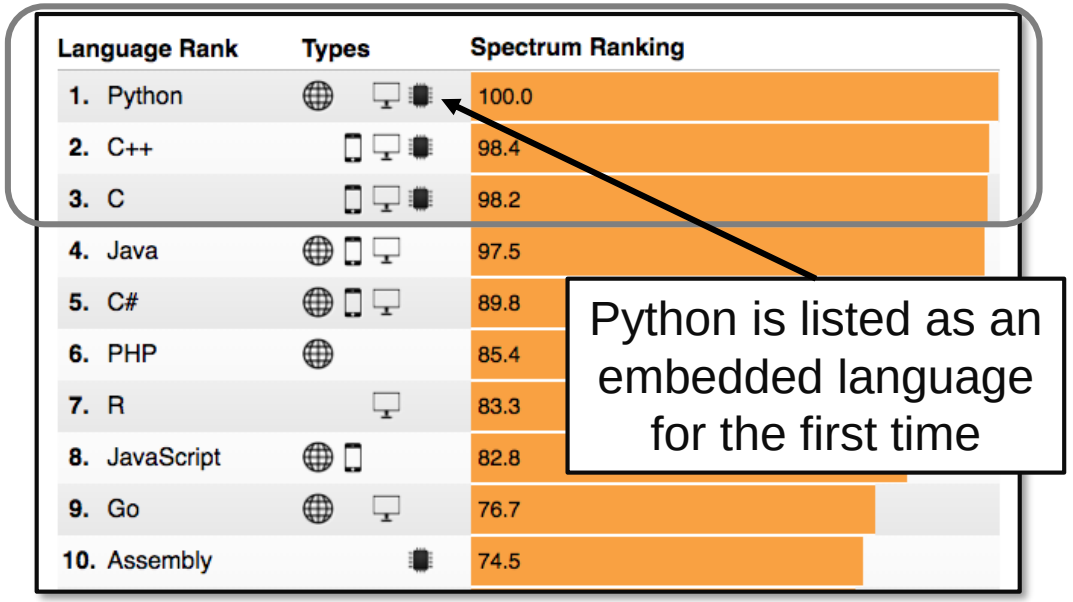
PYNQ enabling technologies

Python is increasingly the Language of Choice

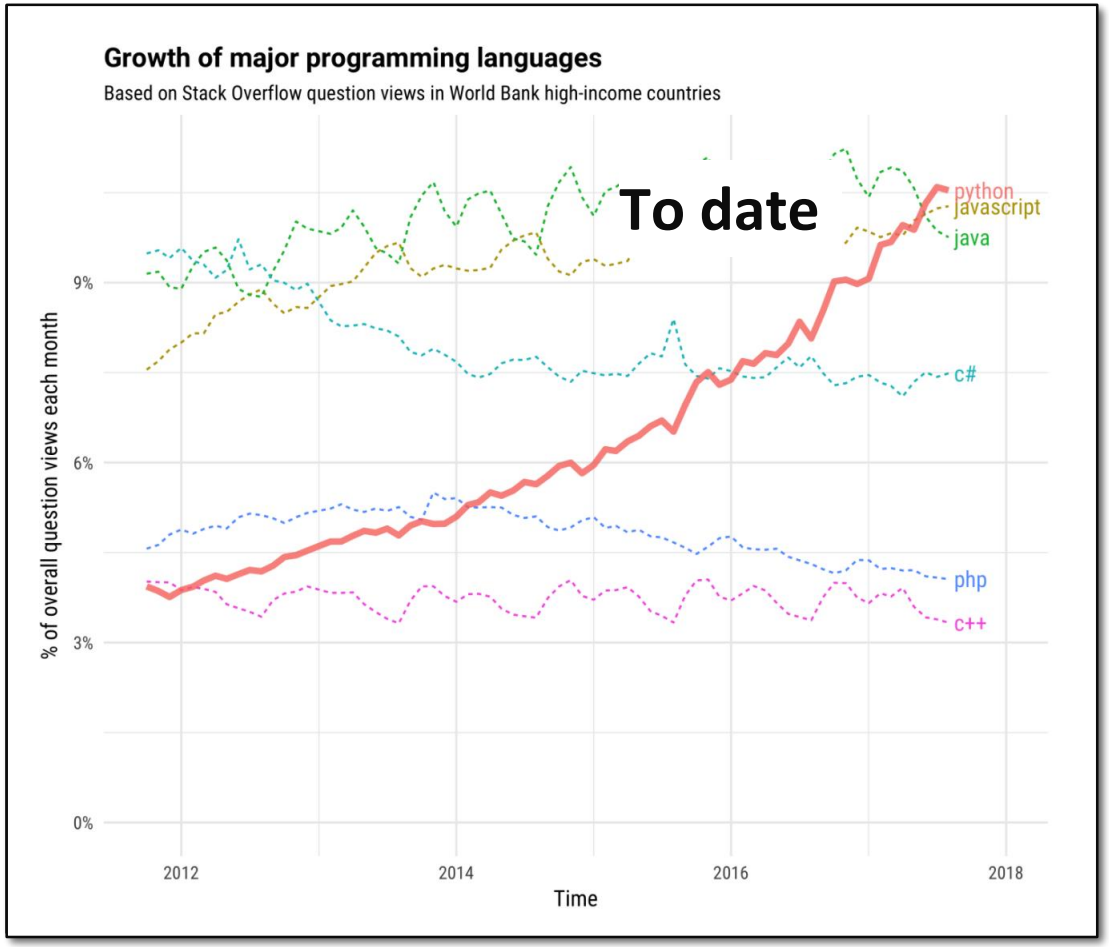
Top Programming Languages,
IEEE Spectrum, July'18



Language Rank	Types	Spectrum Ranking
1. Python		100.0
2. C++		98.4
3. C		98.2
4. Java		97.5
5. C#		89.8
6. PHP		85.4
7. R		83.3
8. JavaScript		82.8
9. Go		76.7
10. Assembly		74.5

Python is listed as an embedded language for the first time

https://spectrum.ieee.org/at-work/innovation/the-2018-top-programming-languages



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Python is the fastest growing language: driven by data science, AI, ML and academia

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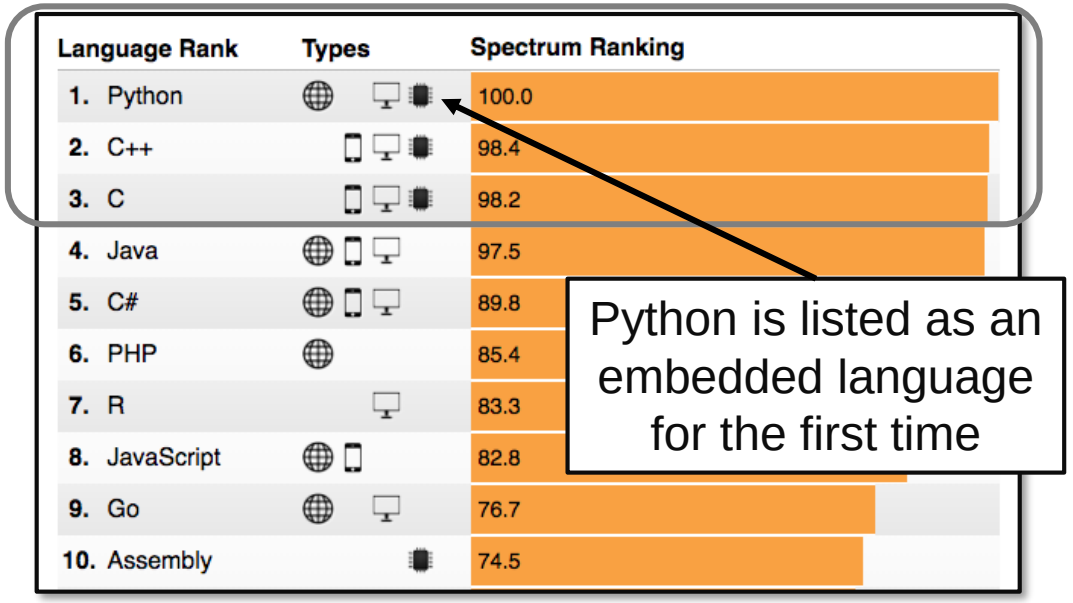

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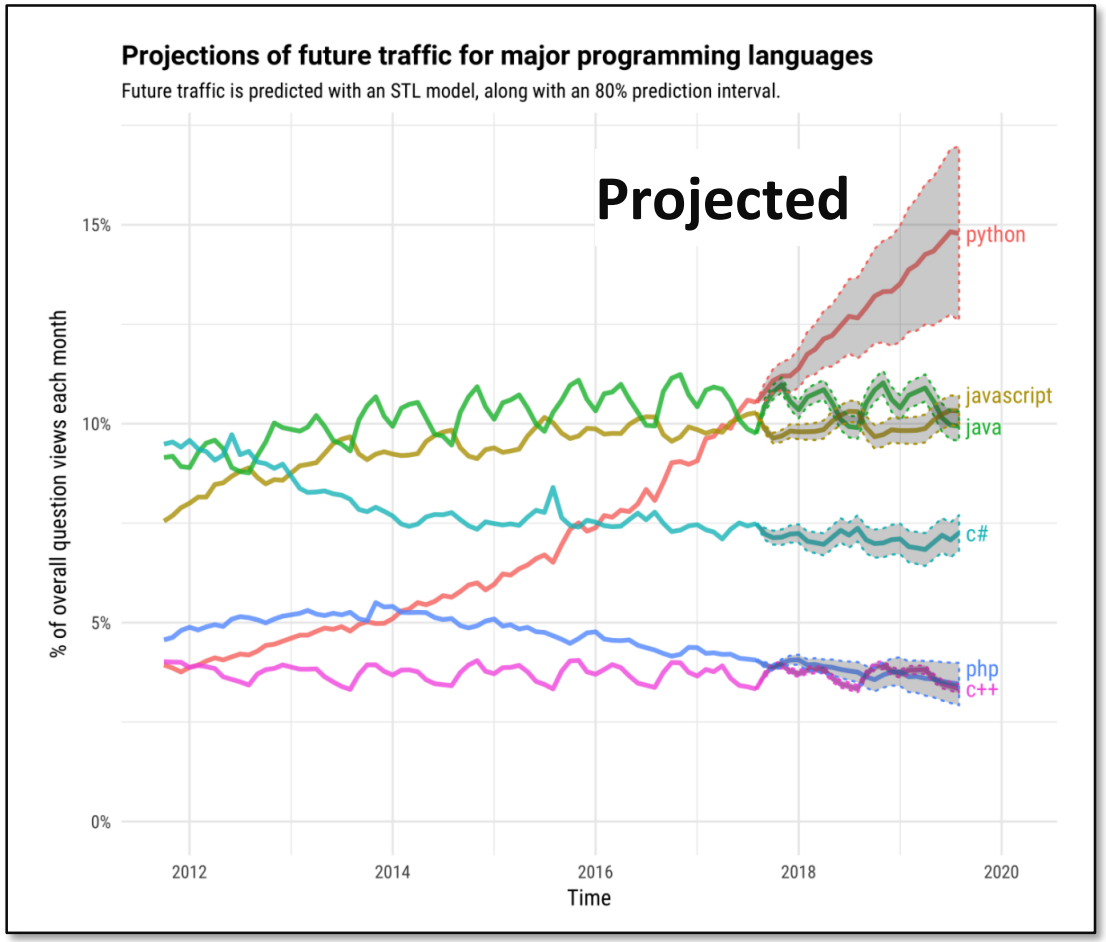

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Python is the fastest growing language: driven by data science, AI, ML and academia

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Ecosystem advantage: there's a Python library for that…

200,00+ projects	1.6M+ releases	2.4M+ files	390,000+ users

python™ Package Index

The Python Package Index (PyPI) is a repository of software for the Python programming language.

PyPI helps you find and install software developed and shared by the Python community. Learn about installing packages.

Package authors use PyPI to distribute their software. Learn how to package your Python code for PyPI.

https://pypi.org retrieved 19 Apr 2019

CPython is written in C … and most popular C/C++ frameworks have Python libraries

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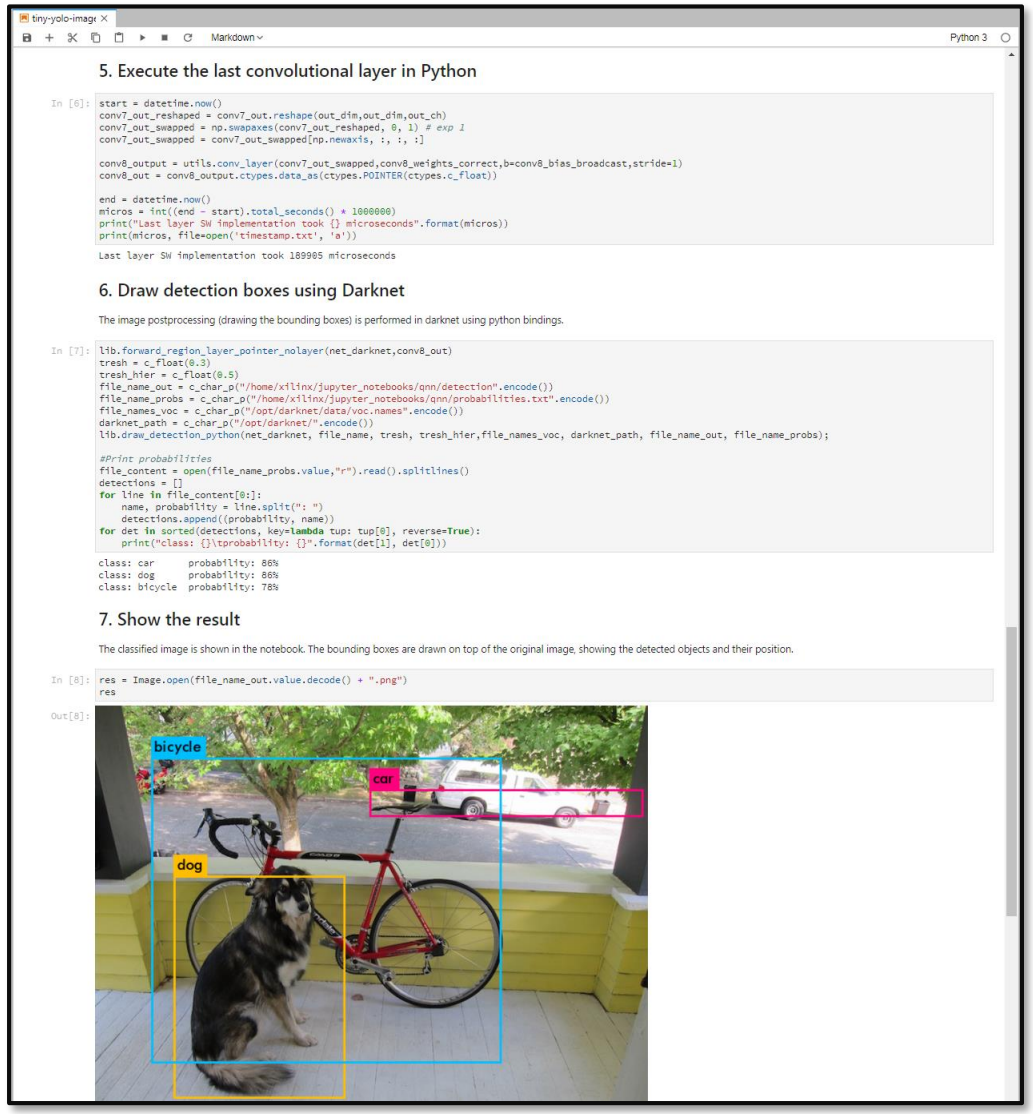
Jupyter Notebooks … the engine of data science



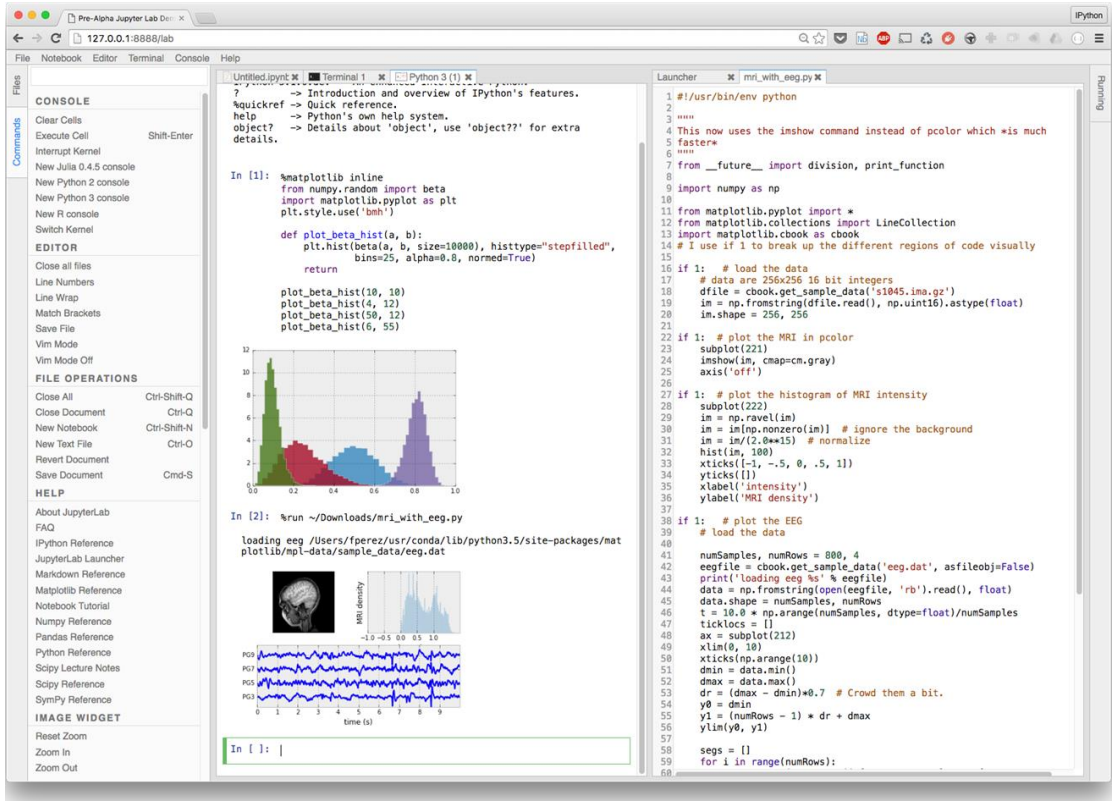
Open source browser-based, executable documents

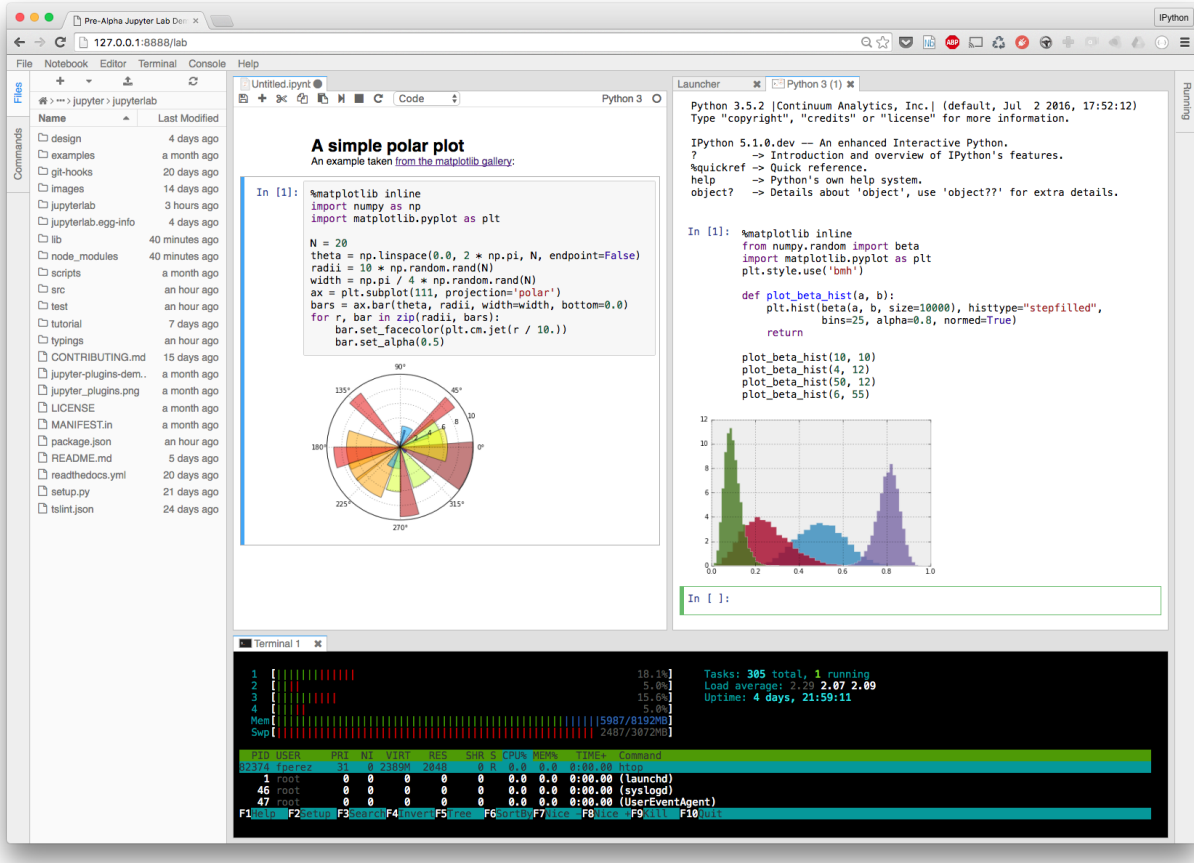
Live code, text, multimedia, graphics, equations, widgets …

1.7 million notebooks on GitHub

Taught to 1,000+ Berkeley data science students

JupyterLab: web-based IDE incl. Notebooks





Jupyter Notebook is now one of many plug-ins within the JupyterLab integrated development environment

JupyterLab - an open-source, extensible IDE in a browser

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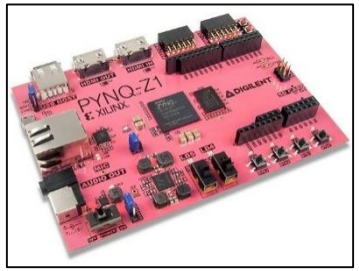
PYNQ enabled boards

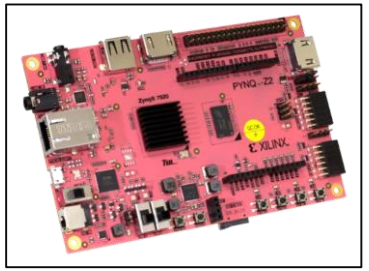
PYNQ-enabled boards

ZYNQ™ ZYNQ® MPSoC ZYNQ® RFSoC

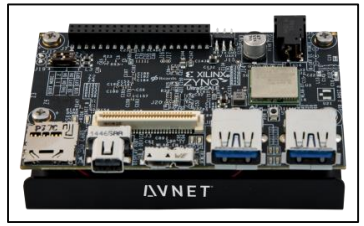
- **Python productivity for <u>Zynq</u>**
  - Open source
  - Build image for other Zynq boards
- **Downloadable SD card image**
  - Zynq 7000
    - PYNQ-Z1 (Digilent)
    - PYNQ-Z2 (TUL)
  - Zynq MPSoC
    - Ultra96 (Avnet)
    - ZCU104 (Xilinx)
  - Zynq RFSoC
    - ZCU111 RFSoC (Xilinx)



PYNQ-Z1

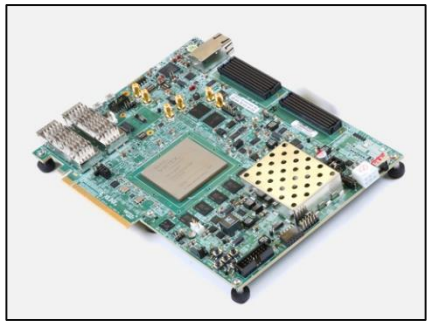


PYNQ-Z2



Ultra96

ZCU104



ZCU111

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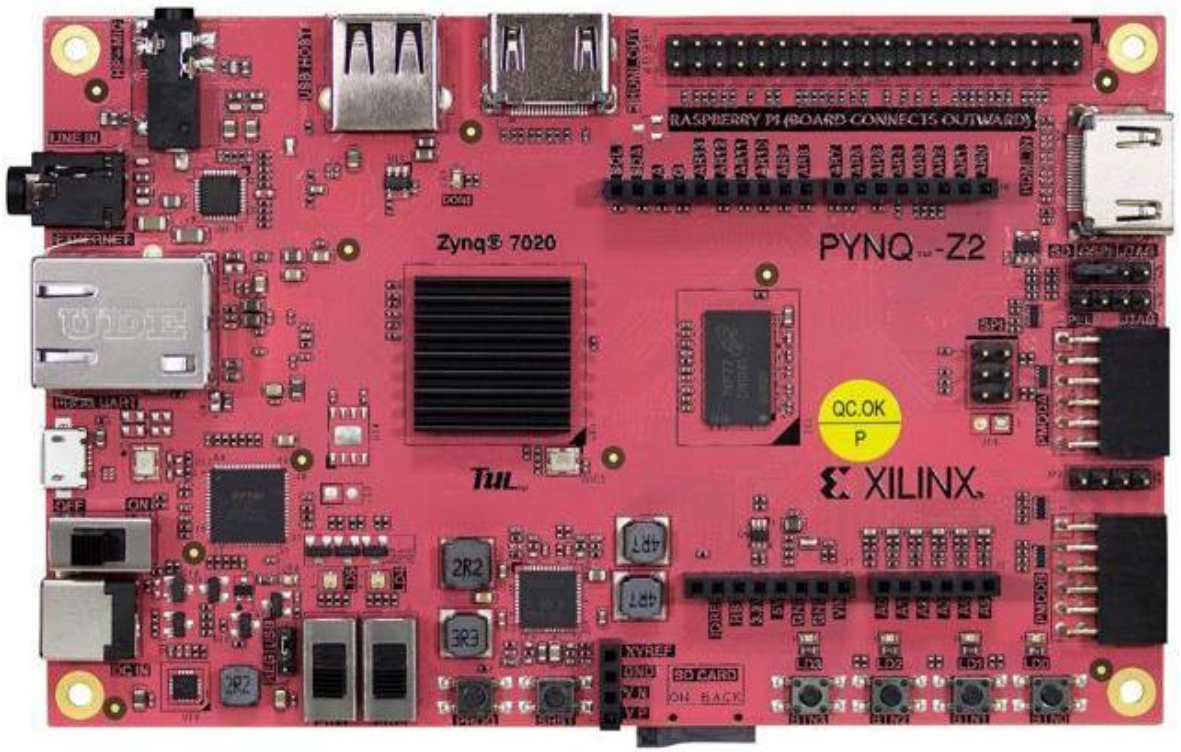
New PYNQ-Z2 Board



$119/€119 or equivalent

- New PYNQ reference platform
- New stereo audio with on-board codec
- New Raspberry Pi connector
- Open source design
- Z2 manufactured in Taiwan by TUL
- Distributed globally by Premier Farnell
- Also Newegg in US
- Academic discounts & donations available

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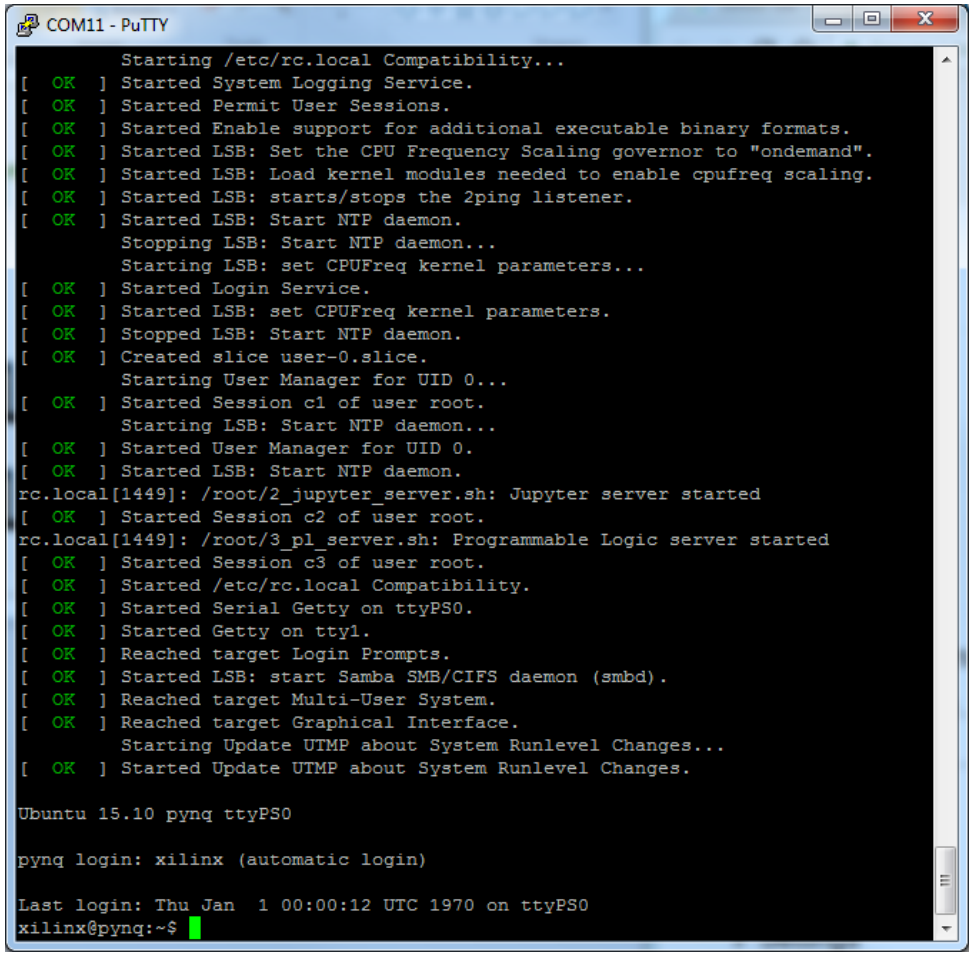
Benefits of PYNQ

Start using PYNQ out-of-the-box



- **PYNQ delivered as downloadable SD card image**
  - Linux preconfigured
- **Additional packages and drivers pre-installed**
  - USB peripheral drivers: webcams, wifi modules …
- **PYNQ is for Zynq**
  - PYNQ image is portable to other Zynq boards

Start using Zynq out of the box ✓

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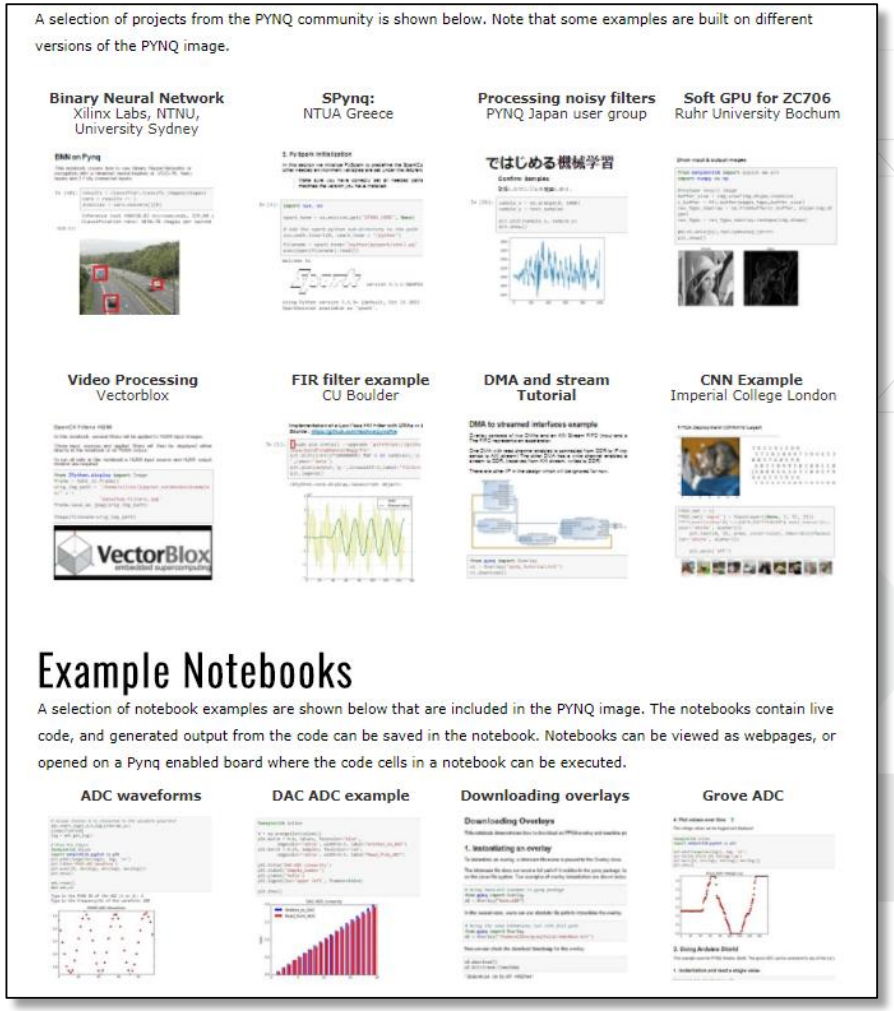
Desktop Linux

- **Network/Internet access**
  - “apt-get” to install packages from Ubuntu universe
  - Samba(Network drive)
  - Web services
- **Git directly on board**
- **Compilers and other development tools**
  - Gcc,, MicroBlaze, RISC-V ….
- **Python packages**
  - “pip install”
  - PYNQ Community examples



Simplify downloading bitstreams to PL

- **PYNQ 'Overlay' class**
  - Simplifies downloading bitstream
  - two lines of code
  - No Xilinx tools required
- **Maintain many bitstreams on the SD card**
  - E.g. multiple different demos
- **Can execute Python in browser, or from command line**

```
from pynq import Overlay

ol = Overlay('gray.bit')
```

Simply and fast way to configure Programmable Logic ✓

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Simplify IP debug and prototyping

- **Debug of IP typically uses C/C++**
- **SDK tools used to:**
  - Compile test application
  - Download application to board
  - Step through code
- **PYNQ MMIO class allows peek/poke of IP registers from Python**
  - Python executes directly on the board
  - No offline compilation, download loop
  - No SDK tools

C code – compile, debug from host

```c
/*****************************************************************************/
* This function does a selftest on the IIC device and XIic driver as an
* example.
* @param    DeviceId is the XPAR_<IIC_instance>_DEVICE_ID value from
*           xparameters.h.
*****************************************************************************/
int IicSelfTestExample(u16 DeviceId)
{
    Status = XIic_CfgInitialize(&Iic, ConfigPtr, ConfigPtr->BaseAddress);
    if (Status != XST_SUCCESS) {
        return XST_FAILURE;
    }

    /* Perform a self-test to ensure that the hardware was built */

    Status = XIic_SelfTest(&Iic);
    if (Status != XST_SUCCESS) {
        return XST_FAILURE;
    }
```

Python executes directly on target

```python
from pynq import MMIO

# Map registers to MMIO instance
my_ip = MMIO(my_ip_addr, LENGTH)

# Write 0x1 to start IP
my_ip.write(CONTROL_REGISTER, 0x1)
# Check status register
my_ip.read(STATUS_REGISTER)
```

Rapid testing and prototyping ✓

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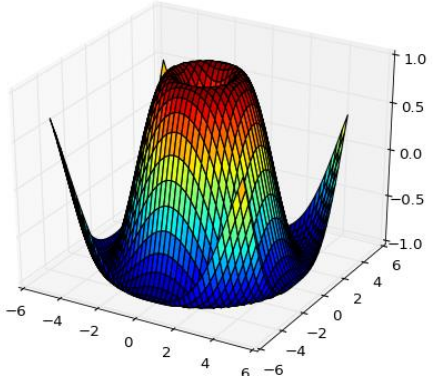
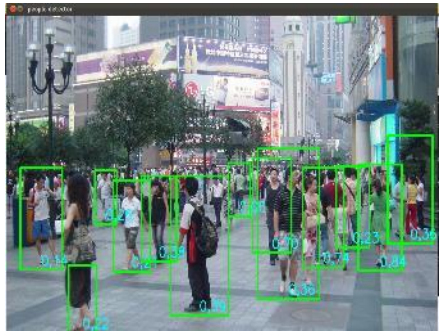
Python packages for data analysis and visualisation



Matplotlib



OpenCV

- **Take advantage of Python for data analysis and processing**
  - NumPy
    - Scientific computing package for Python
  - Matplotlib
    - Python 2D plotting library
  - Pandas
    - Data analysis tools for Python
  - OpenCV
    - Computer Vision and machine learning software

Optimized open-source software libraries ✓

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Example

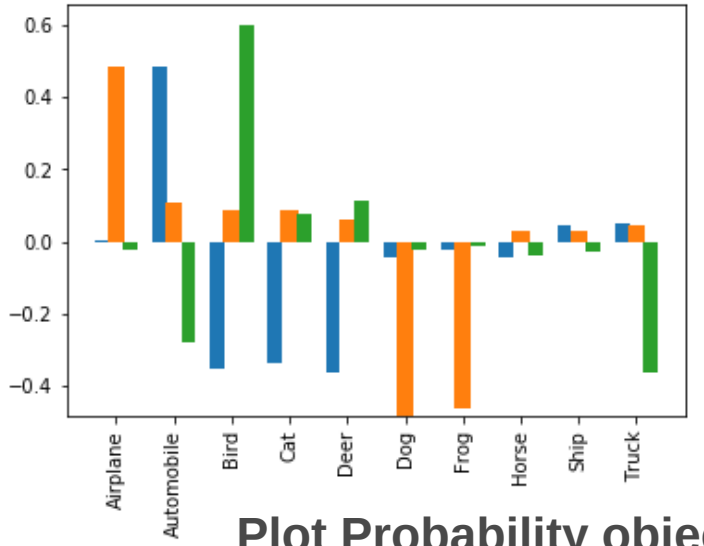
6. Detailed Classification Information

In addition to highest ranked class, it is possible to get the ra
couple of images of a car, an airplane, and a bird and place

In [8]: from IPython.display import display

Probability object belongs to class

```
%matplotlib inline
import matplotlib.pyplot as plt

x_pos = np.arange(len(car_class))
fig, ax = plt.subplots()
ax.bar(x_pos - 0.25, (car_class/255)-1, 0.25)
ax.bar(x_pos, (air_class/255)-1, 0.3)
ax.bar(x_pos + 0.25, (bird_class/255)-1, 0.25)
ax.set_xticklabels(classifier.bnn.classes, rotation='vertical')
ax.set_xticks(x_pos)
ax.set
plt.show()
```

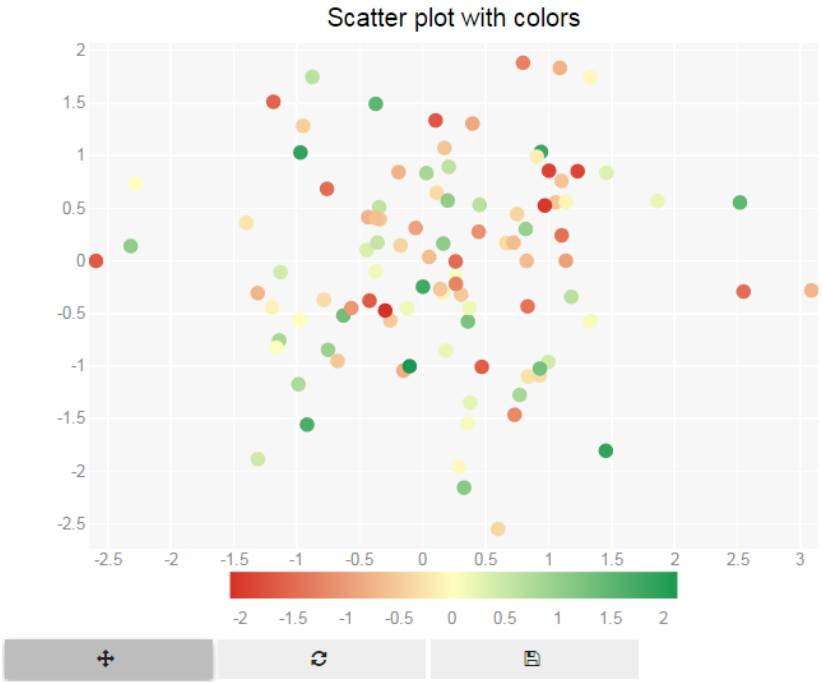


Car
Plane
Bird

Plot Probability object belongs to class

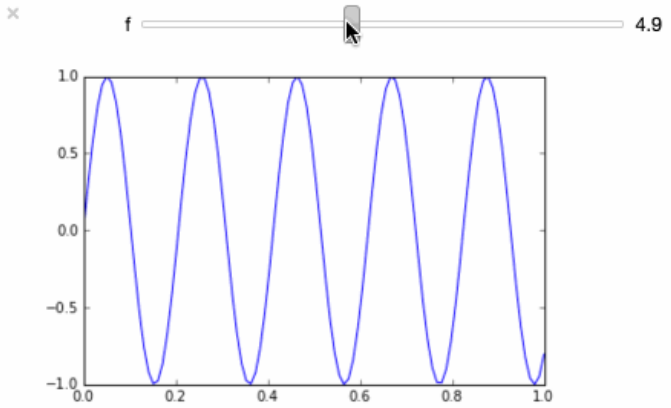
```
oseconds
 images per second
69 163 244 249 244 267 268]

oseconds
 images per second
277 277 271 132 137 262 263 266]

oseconds
 images per second
274 284 249 252 245 248 163]
```

Take advantage of interactive widgets



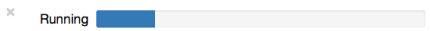
http://jupyter.org/widgets.html

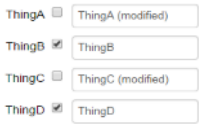
```
In [22]: from IPython.html.widgets import *
         t = arange(0.0, 1.0, 0.01)

         def pltsin(f):
             plt.plot(x,sin(2*pi*t*f))
             plt.show()

         interact(pltsin, f=(1,10,0.1))
```

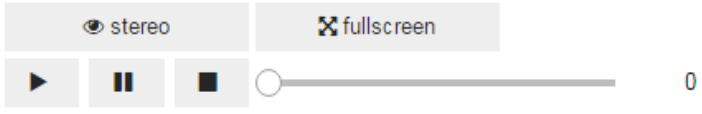


https://blog.dominodatalab.com/interactive-dashboards-in-jupyter/

```
In [7]: p2 = IntProgress(max=56)
        p2.value += 10
        p2.description = 'Running'
        display(p2)
```







Add intuitive graphical interfaces ✓

Why PYNQ is a Game-changer!

- **PYNQ makes Zynq/ZynqU+ accessible to non-traditional customers**

- **PYNQ delivers open source benefits**
  - Huge ecosystem
  - Extensive knowledge base
  - Amazing community support

- **PYNQ enables highly-productive …**
  - Prototyping
  - Debug
  - Verification
  - Evaluation

- **PYNQ powers awesome demonstrators**

- **PYNQ documentation flows are amazing**
  - Capture your own work
  - Capture work you want to re-use

- **PYNQ designs can be …**
  - Packaged, published and distributed

  just like software

- **"PYNQ makes FPGAs FUN again!",**
  J. Gray, Xilinx Power User

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Community

PYNQ: PYTHON PRODUCTIVITY ON ZYNQ

Home | Get Started | PYNQ-Z1 Bo

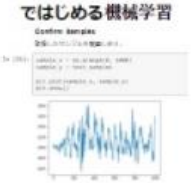
Community Projects

A selection of projects from the PYNQ community is shown below. Note that some examples are built on different versions of the PYNQ image.

Binary Neural Network
Xilinx Labs, NTNU, University Sydney

SPynq:
NTUA Greece

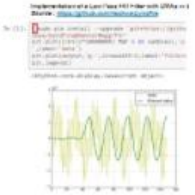
Processing noisy filters
PYNQ Japan user group



Soft GPU for ZC706
Ruhr University Bochum

Video Processing
Vectorblox

FIR filter example
CU Boulder



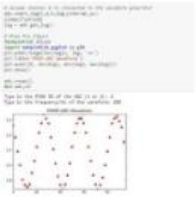
DMA and stream Tutorial

CNN Example
Imperial College London

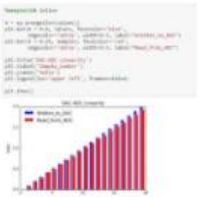
Example Notebooks

A selection of notebook examples are shown below that are included in the PYNQ image. The notebooks contain live code, and generated output from the code can be saved in the notebook. Notebooks can be viewed as webpages, or opened on a Pynq enabled board where the code cells in a notebook can be executed.

ADC waveforms

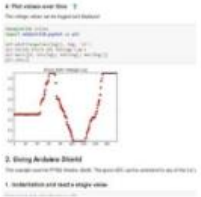


DAC ADC example



Downloading overlays

Grove ADC



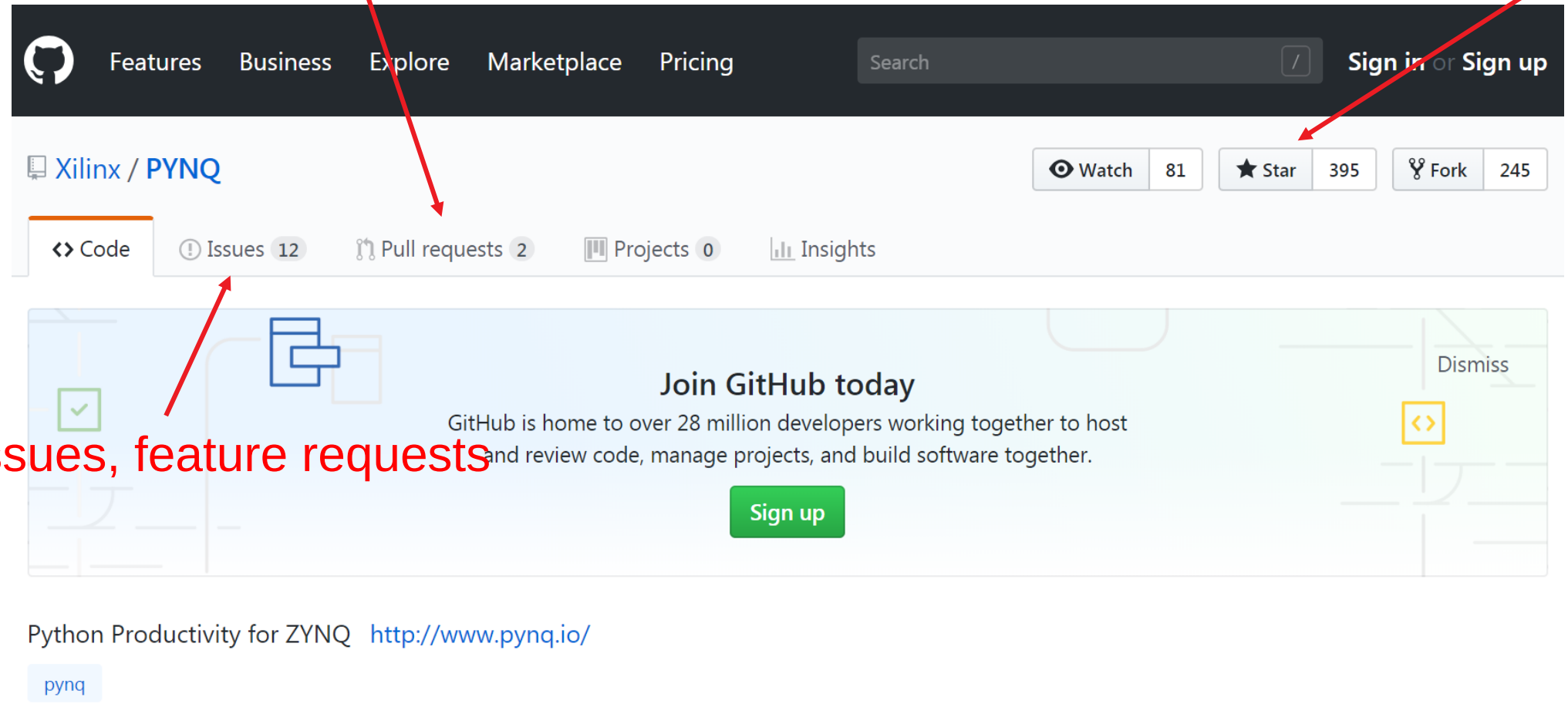
Selection of projects and notebooks

XILINX

All Feedback helps

Contribute

If you like it, star it!



Issues, feature requests

XILINX

Summary

PYNQ™

- PYNQ is Python productivity for Zynq
- Everything runs on Zynq, access via a browser
- Support for Zynq Ultrascale+
- Overlays are hardware libraries and enable software developers to use Zynq
- Provides a rapid prototyping framework for hardware developers

pynq.io

pynq.readthedocs.org

github.com/Xilinx/PYNQ

tul.com.tw/ProductsPYNQ-Z2.html

pynq.io/support

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PYNQ