Introduction To Writing Signal Processing Applications In Python Using GNURadio

What is it?

What is built with it?

How to build something with it!

Outline

- What is GNURadio
- Building a block
- Connecting Blocks
- Packaging and deploying

What GNURadio Provides

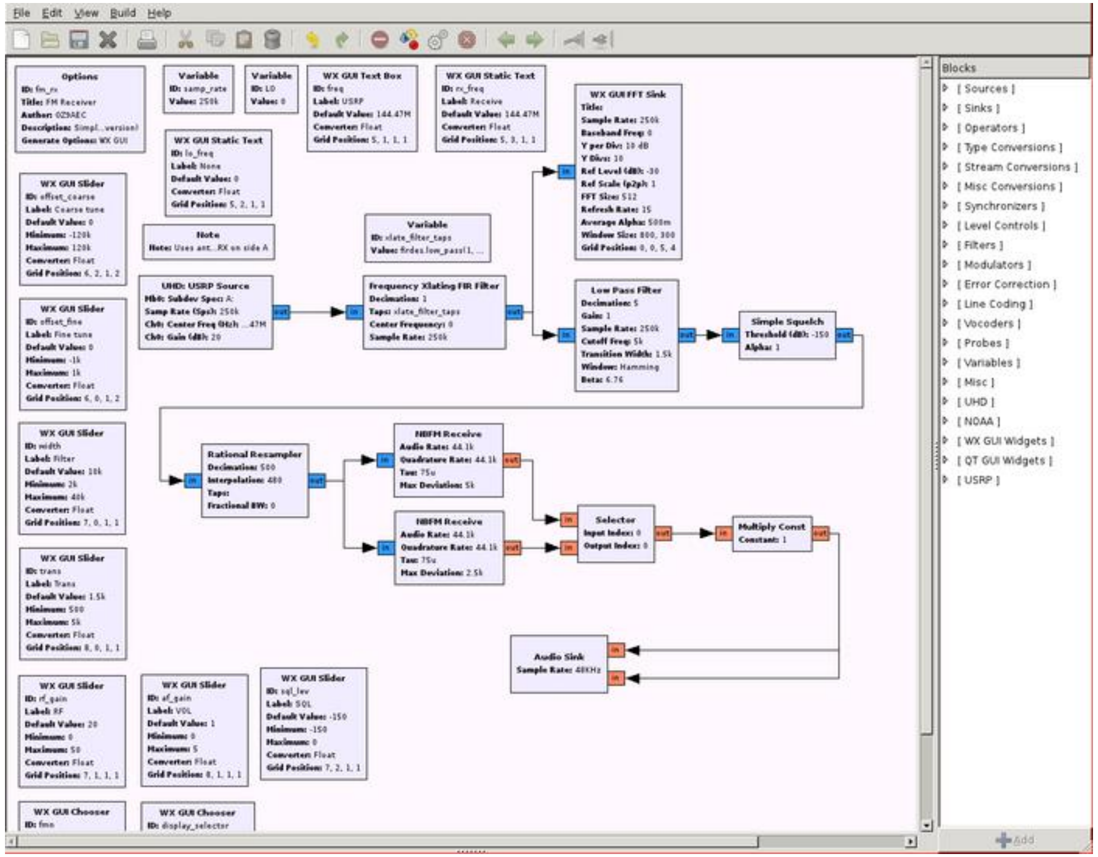
- Framework
  - Currently C++ and Python
- Development tools
  - Tools to packages and interface your code with others
- Scheduler
  - Use all the cores
- Interface and abstraction of hardware
  - Both radio and some acceleration
- Library of DSP
- Graphical interface / GNURadio Companion

What is GNURadio

- Collection of stuff needed for software defined radio
  - Also applies to other signal processing applications
  - Collection of functions and algorithms
  - Standard means of interacting with the outside
  - Many of the things you don’t want to write
- Things build with GNURadio
  - gr-specest
  - gr-lte
  - gr-radar
  - gr-sigmf
  - gr-air-modes
  - gr-limesdr
  - gr-pdu_utils
  - gr-satellites
  - gr-iio
  - gr-doa
  - gr-fosphor

Graphical interface / GNURadio Companion

- Most recognized feature of GNURadio
    - Maybe least useful
        - Just an opinion
- Provides graphical means of connection operations
    - Color shows type
- Makes descriptive graphics
- Not used in talk



Options
ID: fm_rx
Title: FM Receiver
Author: OZ9AEC
Description: Simpl...version)
Generate Options: WX GUI

Variable
ID: samp_rate
Value: 250k

Variable
ID: LO
Value: 0

WX GUI Text Box
ID: freq
Label: USRP
Default Value: 144.47M
Converter: Float
Grid Position: 5, 1, 1, 1

WX GUI Static Text
ID: rx_freq
Label: Receive
Default Value: 144.47M
Converter: Float
Grid Position: 5, 3, 1, 1

WX GUI Static Text
ID: lo_freq
Label: None
Default Value: 0
Converter: Float
Grid Position: 5, 2, 1, 1

WX GUI FFT Sink
Title:
Sample Rate: 250k
Baseband Freq: 0
Y per Div: 10 dB
Y Divs: 10
Ref Level (dB): -30
Ref Scale (p2p): 1
FFT Size: 512
Refresh Rate: 15
Average Alpha: 500m
Window Size: 800, 300
Grid Position: 0, 0, 5, 4

WX GUI Slider
ID: offset_coarse
Label: Coarse tune
Default Value: 0
Minimum: -120k
Maximum: 120k
Converter: Float
Grid Position: 6, 2, 1, 2

Note
Note: Uses ant...RX on side A

Variable
ID: xlate_filter_taps
Value: firdes.low_pass(1, ...

UHD: USRP Source
Mb0: Subdev Spec: A:
Samp Rate (Sps): 250k
Ch0: Center Freq (Hz): ...47M
Ch0: Gain (dB): 20

Frequency Xlating FIR Filter
Decimation: 1
Taps: xlate_filter_taps
Center Frequency: 0
Sample Rate: 250k

Low Pass Filter
Decimation: 5
Gain: 1
Sample Rate: 250k
Cutoff Freq: 5k
Transition Width: 1.5k
Window: Hamming
Beta: 6.76

Simple Squelch
Threshold (dB): -150
Alpha: 1

WX GUI Slider
ID: offset_fine
Label: Fine tune
Default Value: 0
Minimum: -1k
Maximum: 1k
Converter: Float
Grid Position: 6, 0, 1, 2

WX GUI Slider
ID: width
Label: Filter
Default Value: 10k
Minimum: 2k
Maximum: 40k
Converter: Float
Grid Position: 7, 0, 1, 1

Rational Resampler
Decimation: 500
Interpolation: 480
Taps:
Fractional BW: 0

NBFM Receive
Audio Rate: 44.1k
Quadrature Rate: 44.1k
Tau: 75u
Max Deviation: 5k

NBFM Receive
Audio Rate: 44.1k
Quadrature Rate: 44.1k
Tau: 75u
Max Deviation: 2.5k

Selector
Input Index: 0
Output Index: 0

Multiply Const
Constant: 1

WX GUI Slider
ID: trans
Label: Trans
Default Value: 1.5k
Minimum: 500
Maximum: 5k
Converter: Float
Grid Position: 8, 0, 1, 1

Audio Sink
Sample Rate: 48KHz

WX GUI Slider
ID: rf_gain
Label: RF
Default Value: 20
Minimum: 0
Maximum: 50
Converter: Float
Grid Position: 7, 1, 1, 1

WX GUI Slider
ID: af_gain
Label: VOL
Default Value: 1
Minimum: 0
Maximum: 5
Converter: Float
Grid Position: 8, 1, 1, 1

WX GUI Slider
ID: sql_lev
Label: SQL
Default Value: -150
Minimum: -150
Maximum: 0
Converter: Float
Grid Position: 7, 2, 1, 1

WX GUI Chooser
ID: fmn

WX GUI Chooser
ID: display_selector

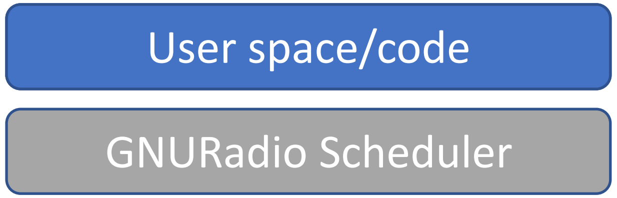
Library of DSP

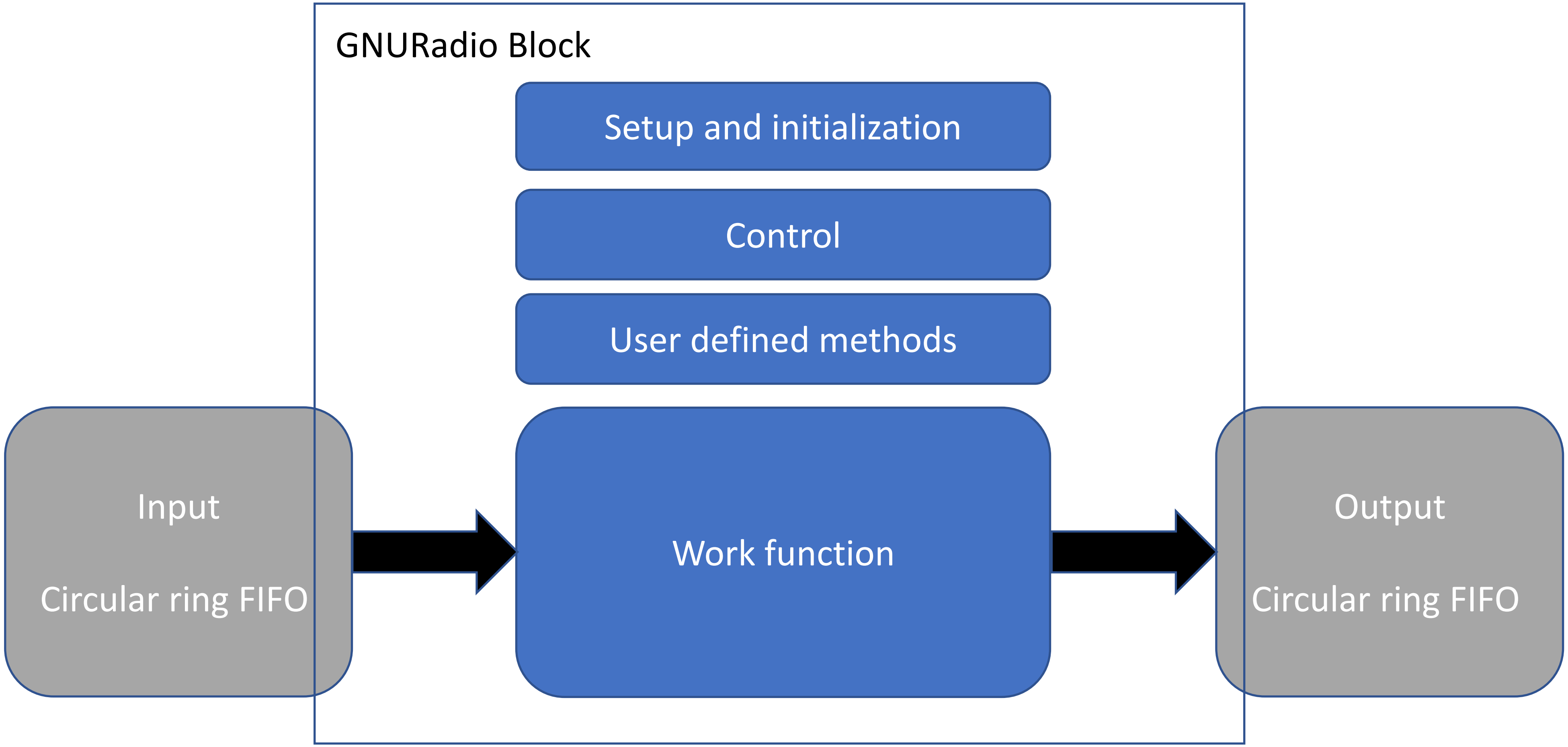
- Gr-filter
  - Filter stuff
- Gr-digital
  - Modulation, demodulation
- Gr-analog
  - AGC, AM, FM...
- Gr-fec
  - Error correction
- Gr-vocoder
  - Vocoders
- Gr-channel
  - Channel simulation
- Gr-fft
  - FFT
- Volk
  - Vector optimized library of kernels

Let's Build a Block

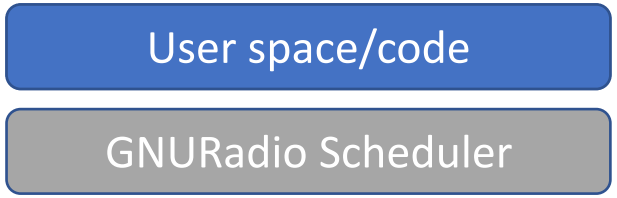
Think of some piece of code you want in a block

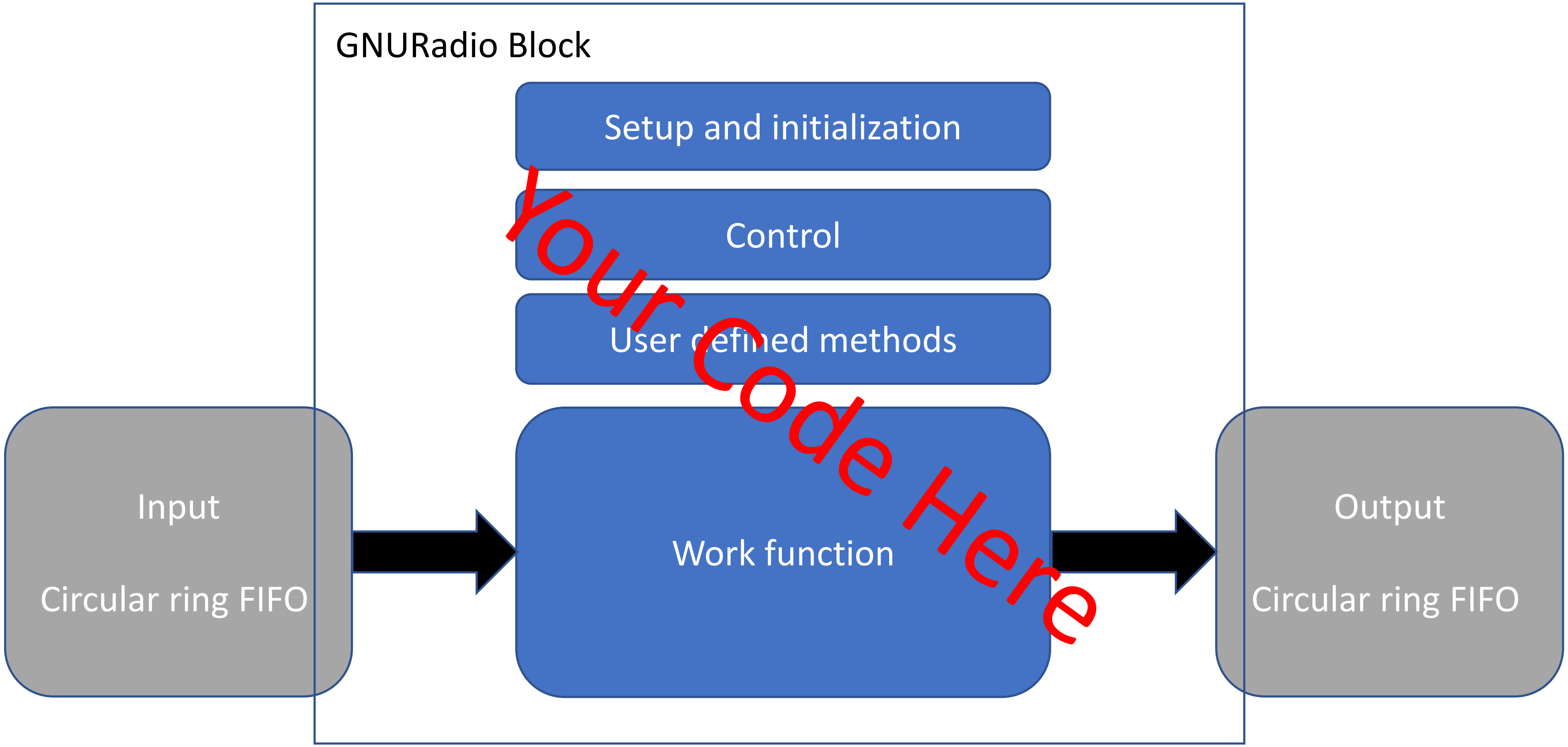
What is a block





What is a block



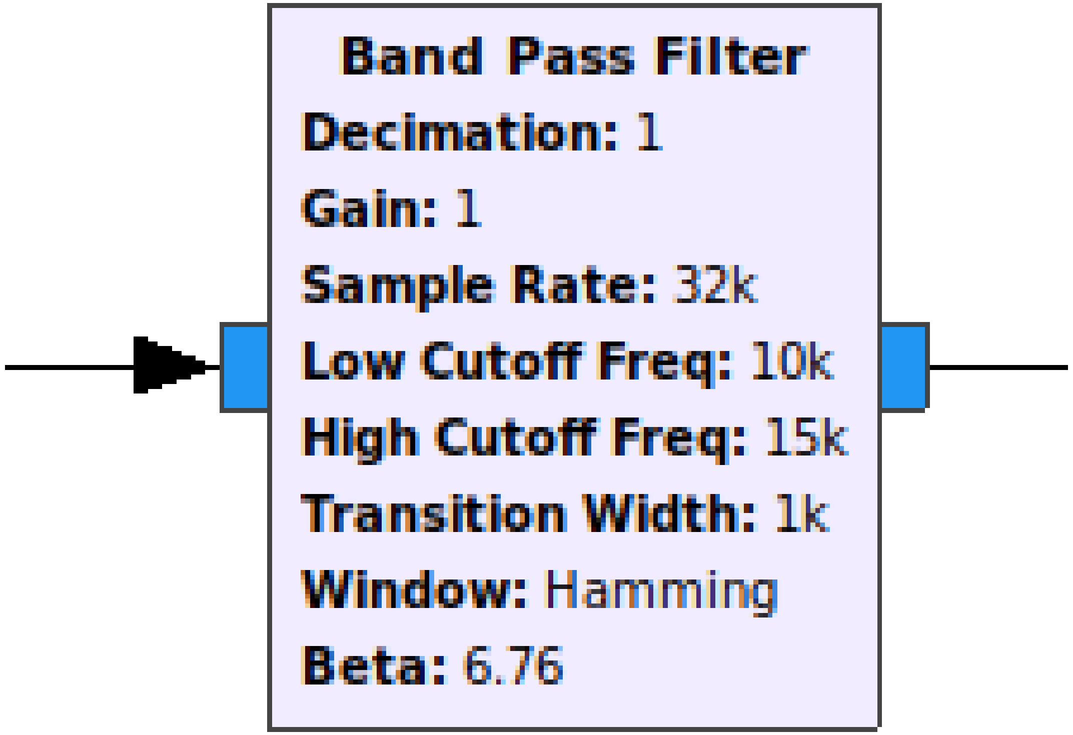


Types of blocks

- Sync
  - Synchronous, one in one out
- Source
  - Where the data comes from
- Sink
  - Where the data goes
- Interpolator
  - One in many out
- Tagged stream
  - Labeled in labeled out
- General
  - Something in maybe something else out
- Decimator
  - Many in one out
- Hier
  - Blocks in blocks

What does a block need

- What does a block needs
  - Setup
    - constructor or __init__
  - Work
    - Code to do the task
  - Schedule
    - For data in how much comes out
- Inherits from base class
- Not needed but nice to have
  - Graphical description for GRC
    - Was XML, +3.8.0 uses YAML
  - Works with tags
  - Unit testing and profiling
  - Version control



Band Pass Filter

Decimation: 1

Gain: 1

Sample Rate: 32k

Low Cutoff Freq: 10k

High Cutoff Freq: 15k

Transition Width: 1k

Window: Hamming

Beta: 6.76

Example Empty Block

```
form gnuradio import gr

class MyBlock(gr.sync_block):
    def __init__(self, *args, **kwargs):
         gr.sync_block.__init__(self,
             in_sig=[complex],
             out_sig=[complex])
         # Add constructor stuff
    def work(self, input_items, output_items):
        in0 = input_items[0]
        out = output_items[0]
        out[:] = in0
        # Add signal processing
        Return len(out)
```

Constructor and Initializer

- Builds the block
- Inherits from one of the block types
    - Source, Sink, Sync, Interpolator, Decimator, Tagged stream, Hier
    - Must call parent constructor/initializer
- Executes once
    - Contains user's setup code

```
def __init__(self, *args,
**kwargs):
        gr.sync_block.__init__(self,
            in_sig=[complex],
            out_sig=[complex])
        # Add constructor stuff
```

Work Function

- Where the work happens
- Executes are on each buffered chuck of data
  - Called multiple times
- Maps buffers as input arguments
  - input_items, output_items
  - Each input is a list of buffers
  - Python buffer protocol
  - Numpy array
- Returns the number of items written to the output buffer

```
def work(self, input_items, output_items):
        in0 = input_items[0]
        out = output_items[0]
        out[:] = in0
        return len(out)
```

Building with Blocks

Assembling your application with blocks

Top block

- Provides common interface to a signal processing chain
  - How the schedular interacts with your code
- Contains all the blocks
- Distributes across multiple processes and cores
- Graphical tools produce sub-class of top block

- Implementation uses inheritance
- Provides methods
  - Start
    - Gets the data moving
  - Run
    - Gets the data moving and waits for it to finish
  - Wait
    - Waits for it to finish
  - Stop
    - Stops the movement of data

Connecting the blocks

```
class FlowGraph(gr.top_block):
  def __init__(self):
    gr.top_block.__init__(self, name="Flow graph")
    # Creating the blocks
    self.block1 = Block1(...)
    self.block2 = Block2(...)
    # Connecting the blocks
    self.connect((self.block1, 0), (self.block2, 0))
    # Connect takes 2 tuples of the block instance and the number
```

Note on Types and Vectors

- Types
  - Complex float 32
  - Float 32
  - Int 32
  - Short 16
  - int 8
- Vectors
  - Vectors of samples

- Currently no explicit support for heterogenous types or structures
  - easily be worked around

Starting and Stopping the Process

- Starting the top block
  - Start method
    - None blocking
  - Run method
    - Blocking

- Stopping the top block
  - Call the stop method on the top block
  - Blocks work functions returns a negative number
  - Raise an exception

Questions ?

Comments

Concerns

Complaints

Accusations

Allegations

The End

Thank you for your time

Missing from this talk

- Reconfiguration
- Packaging and deployment
- Tagged streams
- Polymorphic types
- Vectors
- Libraries of existing components
- MAC Layer
- Proper unit testing
- GRC and GUI
- Messaging
- C++
- Building useful things
- Hardware
- Simulation

Packaging everything into an OOT

Out Of Tree package

What is OOT

- Standard way of packaging code
  - Directory structure
- Build tools
  - Cmake, make
- Testing tools
  - Ctest, python nose, CppUnit
- Install tools
  - Make install

Build, Test, Install, Deploy, Reuse

- Build
  - $ mkdir ./build
  - $ cd ./build
  - $ cmake ../
  - $ make
- Test
  - $ make test
- Install
  - $ make install

Graphical part

- GNURadio 3.8 forward
  - YAML file describing
    - Input and output ports
    - Graphical appearance
    - Construction arguments
    - Documentation
- GNURadio 3.7
  - XML

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