Processing Radio Astronomy Data from the Arecibo Observatory

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The problem

- One observation session (3 hr) generates about 500 GB (0.5 TB) of data
- Data are very noisy - pulsar signals rarely seen in raw data
- Signals are subject to dispersion - different frequency components arrive at different times.
- Some pulsars are best identified by their periodicity
- Others show up better as single pulses
- Many observations are contaminated by periodic Radio Frequency Interference (RFI)
- Final analysis is done visually -> plots need to be produced automatically

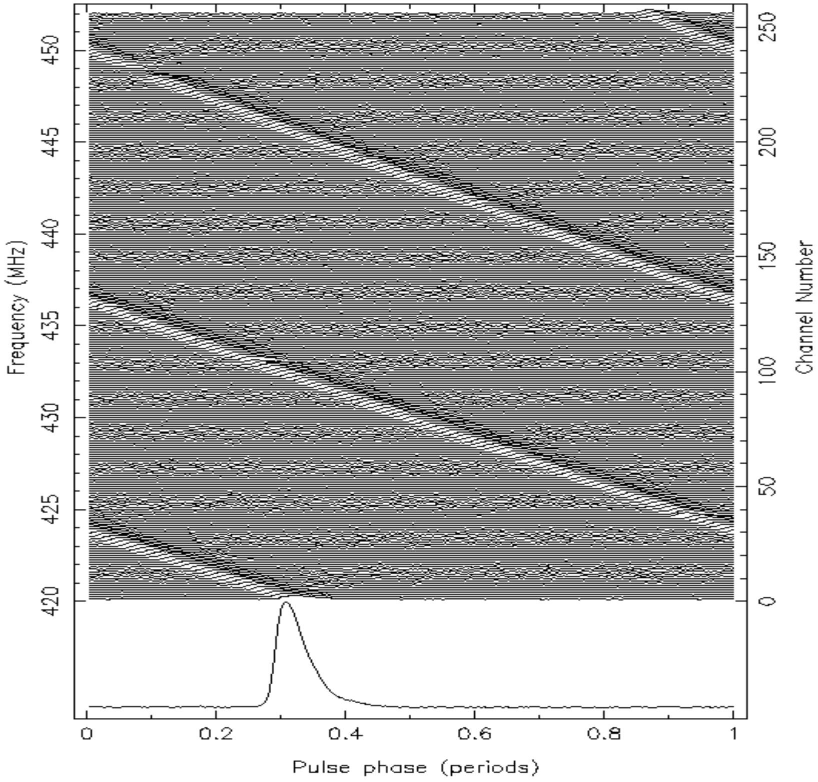
The data

- The telescope has 7 apertures - the signals are stored pairwise interleaved in 4 files.
- Files are limited to 2 GB, so there are 4, 8, or 12 files in a pointing
- Data size for a pointing is typically 4, 8, or 16 GB.
- Raw data are archived in TSM, so they have to be restored before use.
- I typically process a whole day of observations in one batch.

Dispersion

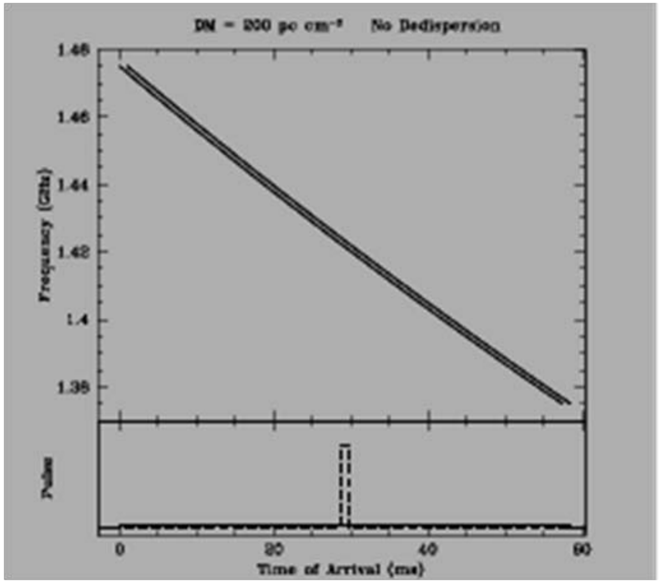
Dynamic spectrum is FFT of raw data.

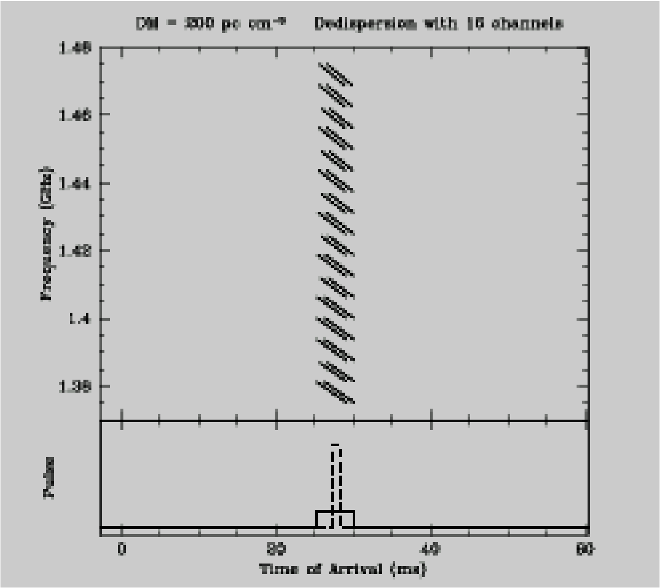
See that phase of pulses changes with frequency - this is due to dispersion



Dedispersion

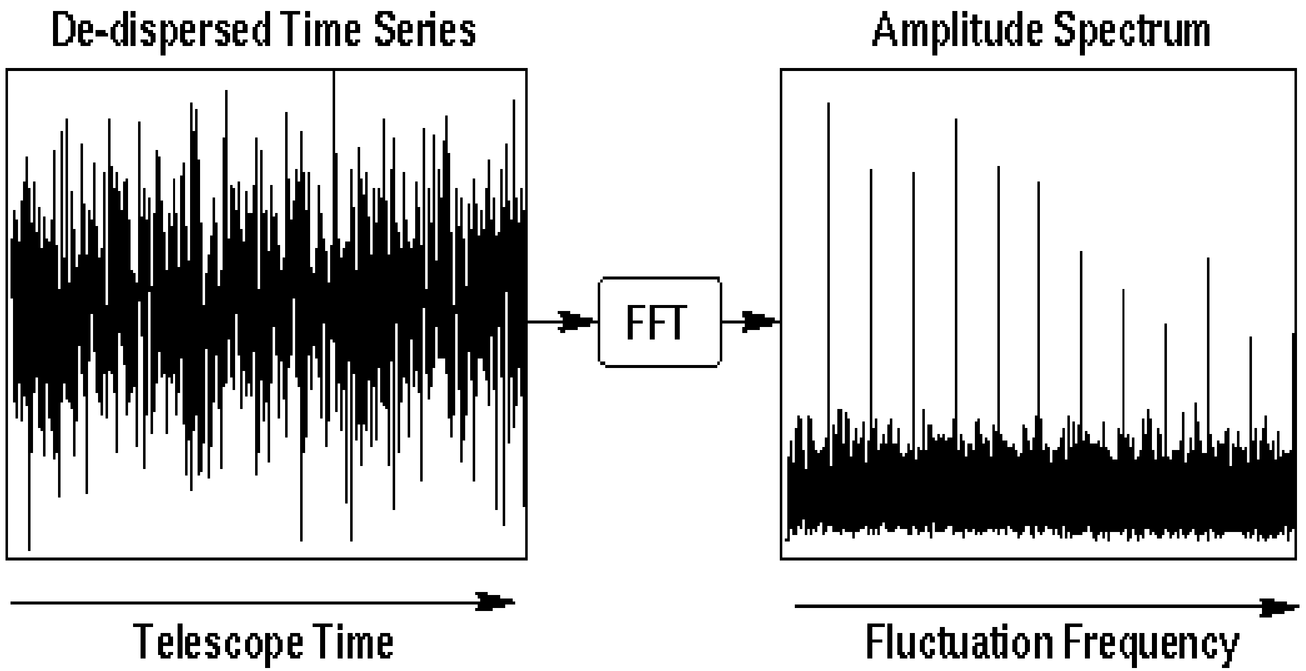
- Time of Arrival of frequency channels are adjusted according to a postulated dispersion measure. In our processing we use 1272 different values.



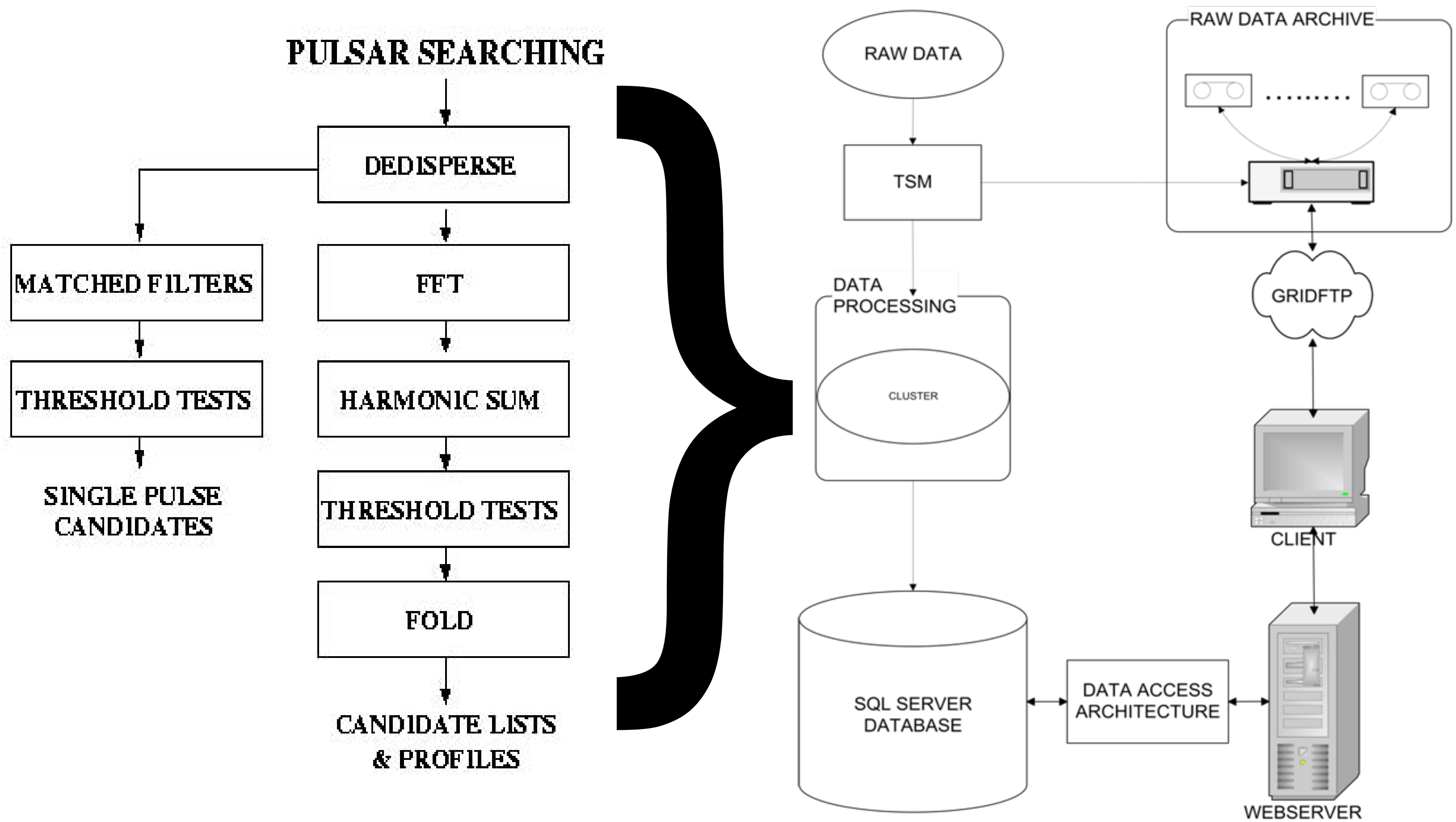


Periodicity search

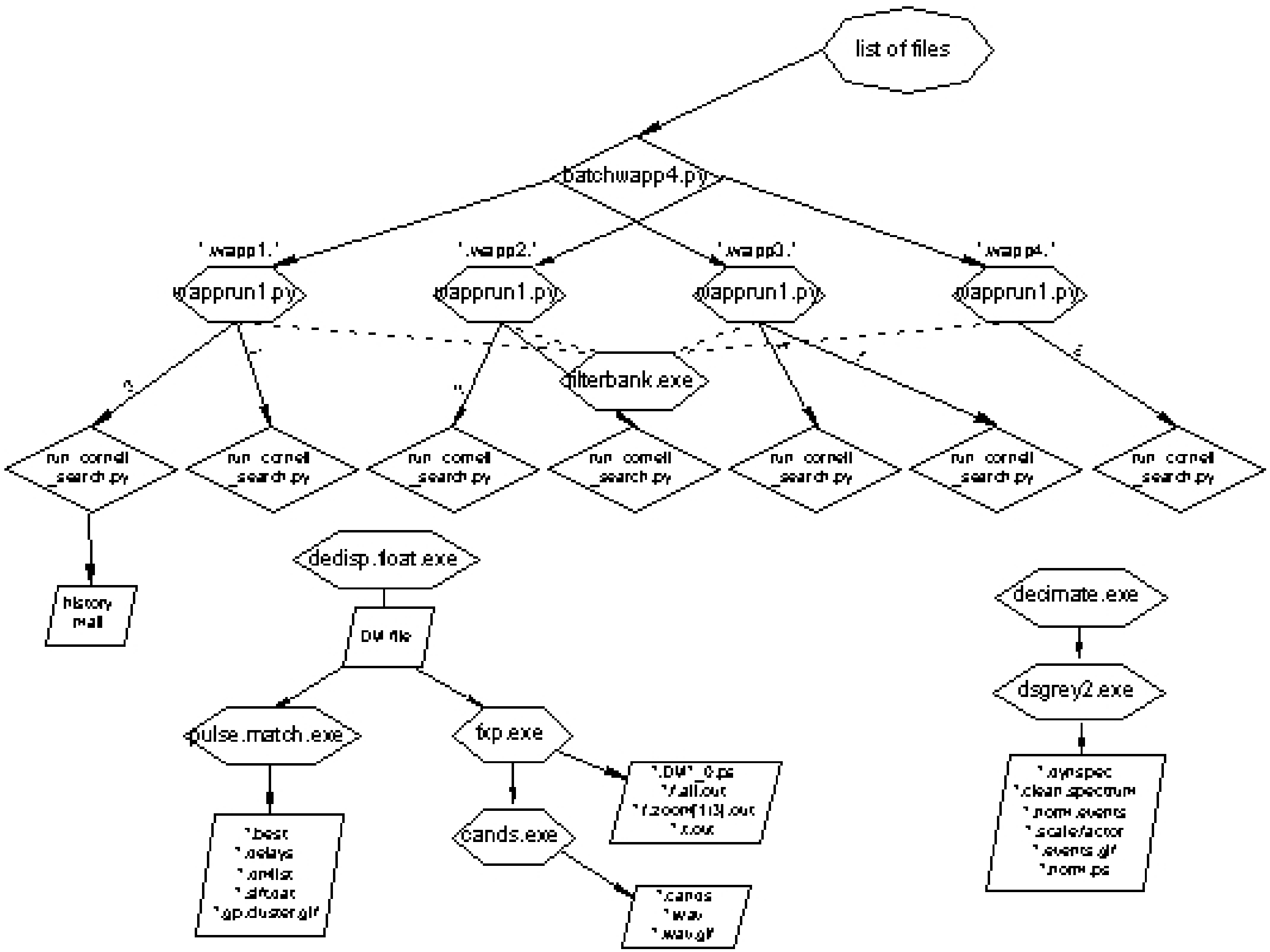
- A sequence of sharp pulses will have many harmonics.



Processing pipeline



Pipeline detail



Assembling the Pipeline

- Used Python
  - Cross-platform
  - Available as built-in on linux systems
  - Xml configuration file for pipeline management
  - Easily fork new processes
  - Manage pipes

Configuration file

```
<?xml version="1.0" encoding="iso-8859-1"?>
<marshal>
  <dictionary id="i2">
    <string>band_norm</string>
    <string></string>
    <string>base_dir</string>
    <string>/home/gfs01/jaz4/Arecibo/pulsar.search.code.2004</string>
    <string>bin_dir</string>
    <string>lambda d: "%s/bin/%s" % (d["base_dir"], d["ostype"])</string>
    <string>bins_input</string>
    <int>6500</int>
    <string>do_dedisp</string>
    <bool>True</bool>
  </dictionary>
</marshal>
```

Usage

```
import ffxml, ldict
parfile = open(process_dir+os.sep+'defpar.xml')
parmdict = ffxml.load(parfile)
parfile.close()
pm.update(parmdict)
```

Subprocesses

```
from subprocess import *

    outname = "run.out.%s.%d" % (wappno, i)
    fd.append(open(outname, 'w'))
    if beam<7 or pm["do_dedisp"] or pm["do_dynspec"]:
        beamproc.append(Popen([sys.executable,
pm.workdir+os.sep+'run_cornell_search.py',
pm.filename,ntimesamples_s], stdout=fd[i],stderr=PIPE))
.......
for i in [0, 1]:
    sys.stderr.write(beamproc[i].communicate()[1])
```

Managing pipes - 1

Connect to named pipe:

```
while True:
    try:
        if os.name is 'nt':
            WaitNamedPipe(pipename, 0)
        else:
            sinfo = os.stat(pipename)
        print "Named pipe %s found" % pipename
        break
    except:
        time.sleep(1)
fdpipe = os.open(pipename, os.O_RDONLY)
```

Managing pipes - 2

```
if do_dedisp and do_dynspec:
    (dyinr, dyinw) = os.pipe()
    fbpipe = os.fdopen(fdpipe, "rb", 65536)
    dyin = os.fdopen(dyinr, "rb", 65536)
    dypipe = os.fdopen(dyinw, "wb", 65536)
    (deinr, deinw) = os.pipe()
    dein = os.fdopen(deinr, "rb", 65536)
    depipe = os.fdopen(deinw, "wb", 65536)
elif do_dedisp:
    dein = os.fdopen(fdpipe, "rb", 65536)
elif do_dynspec:
    dyin = os.fdopen(fdpipe, "rb", 65536)
```

Manage pipes - 3

```
if do_dynspec:
    decimate = Popen([pm["sigproc_bin"]+os.sep+'decimate', '-c', nfdecimate_s, '-t', ntdecimate_s, '-headerless'], stdin=dyin, stdout=PIPE, stderr=decimerr)
    reader = Popen([pm["sigproc_bin"]+os.sep+'reader', '-noindex'], stdin=decimate.stdout, stdout=fileout, stderr=readerr)

if do_dedisp:
    dedisp = Popen([pm['dedisp_bin']+os.sep+'dedisp.float', '-c', nchans_s, '-s', sample_time_s, '-b', bins_input_s, '-f', frequency_s, '-w', bandwidth_s, '-d', ntimesamples, '-o', 'f', '-n', nsubbands_s, '-t', dedisp_type, '-z', tree_shift_s, unflip, band_norm], stdin=dein, stdout=dedispout, stderr=dedisperr)
```

Manage pipes - run

```
if do_dedisp and do_dynspec:
  buff2=[]
  while True:
      buff = fbpipe.read(65536)
      if len(buff) > 0:
          buff2.append(buff)
          if len(buff2) >= 64:
              dypipe.write(''.join(buff2))
              depipe.write(''.join(buff2))
              buff2=[]
          continue
      dypipe.write(''.join(buff2))
      depipe.write(''.join(buff2))
      break
  dypipe.close()
  depipe.close()
```

Here we use python to push the data from one pipe to the others.

Exploit multiple cores

- OpenMP
  - Insert directives
- Pthreads (or Windows Threads)
  - Use separate threads for I/O
  - Manage threads with semaphores (or Windows events)

OpenMP

```
#pragma omp parallel for private(delayp, outputp, datap, nf, nt)
  for(idm=0; idm<ndm; idm++) {
    delayp = &delays[idm][ns*m];
    outputp = &output[idm][done-tstart];
    for(nf=0;nf<m;nf++) {
      datap = &ddata[nf][delayp[nf]];
      for(nt=tstart;nt<n;nt++) {
        outputp[nt] += datap[nt];
      }
    }
  }
```

I/O Threads

```
void *iothread(void *dummy) {
  int bytes_out_reqt,jt,outpt=0,offsett=0;
  jt = (int)dummy;
  bytes_out_reqt=bytes_out_block;
  while (1) {
    pthread_mutex_lock(&doIO[outpt]);
    pthread_mutex_lock(&IOdone[outpt]);
    offsett+=bytes_out_reqt;
#pragma omp parallel for private(jt)
    for (jt=0; jt<n_dm_channels_per_subband; jt++) {
      bytes_out = pwrite(out[n_subbands-1], output[outpt][jt], bytes_out_reqt, *ovl[n_subbands-1][jt]);
      *ovl[n_subbands-1][jt] = jt*file_size + offsett;}
    IOdon[outpt]=1;
    pthread_mutex_unlock(&IOdone[outpt]);
    outpt = (++outpt)%2;
  }
}
```

Output buffers

In order to make use of a write thread, there must be two output buffers - while one is being filled, the other is being written - and *vice versa*.

Mutex *doIO* is locked until a buffer is full; output thread waits for it be unlocked. When a buffer is filled by main thread, it unlocks *doIO* so that write thread can go ahead with writing it.

A second mutex *IOdone* is locked by the write thread while it is writing and unlocked when it is done. The main thread doesn't start filling a buffer unless it can lock (and immediately unlock) that mutex.

Conclusion

- Arecibo Data Processing on Ranger:
  - Multicore processors
  - Large, fast scratch space