Real-Time Pulsar Timing
Signal Processing on GPUs

Plan :
Pulsar Timing
Instrumentations

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Pulsars

A highly magnetized neutron star producing two beams acting like a cosmic lighthouse.

Pulsars are highly stable clocks, suffering from dispersion.

Most fast and stable pulsars are used to test Gravitation theories and to probe the Cosmological Gravitational Wave background.
Dispersion by the ISM

CSER workshop, Sept 30, 2009, Cape Town, SA

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**Pulsar timing**

A huge computing power is required to coherent dedisperse over a large bandwidth. The coherent dedispersion removes the **dispersion effect** of the interstellar medium directly on recorded voltages.

- **Rotation axis**
- **Neutron star**
- **Radio beam**
- **Telescope**
- **Receiver**
- **Reference clock**
- **Mean pulse profile**
- **TOA**
- **De-dispersion & on-line folding**

(Lorimer & Kramer, 2004)
a large radiotelescope: Nançay

a 100m dish equivalent telescope
2 receivers 1.1-1.8 and 1.7-3.5GHz
Tsys 35K  efficiency 1.4K.Jy
Five stable pulsars timed at Nançay

- **PSR J1600-3053**
  - rms 576ns

- **PSR J1713+0747**
  - rms 350ns

- **PSR J1744-1134**
  - rms 343ns

- **PSR J1909-3744**
  - rms 109ns

- **PSR B1937+21**
  - rms 387ns
a bit of history...

1988  swept LO (co 8MHz)  
~ 0.5μs uncertainty on PSR B1937+21

1996  filterbank NBPP (inco 120MHz)  
      Navy Berkeley Pulsar Processor

2004  coherent dedispersor BON (co 64-128MHz)  
      Berkeley Orleans Nancay

2008  GPU coherent BON (co 128MHz)

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BON: a coherent dedispersion with a cluster of CPUs

Serendip5

64 bi-Athlon 1.2GHz
Gigabit fiber network
installed in 2001
Upgrade of the BON dedispersor

in 2008, it was time to think about the upgrade of the 7 years old cluster and of the 4 years old instrumentation...

following preliminary tests by Paul Demorest, UC Berkeley, in 2007, we tried different types of processors in addition to standard CPUs: the GPUs with the Nvidia 8800GTX for example (G80 family)
Tests of different engines

so, we tested two types of processors in addition to standard CPUs: the IBM Cell (PlayStation3) and the Nvidia 8800GTX

**PS3** is really good but very limited by the only Gigabit link it has (15-20MHz bandwidth)

**Nvidia 8800GTX** is fairly good and less limited by the PCIe bus (few Gbs easily)
A GPU-based pulsar instrumentation developed at Nançay

1 motherboard
   Supermicro X7DWA-N
2 CPUs
   quad-core Xeon
   E5420 (2.5GHz, 12MB cache)
4 GB main memory
2 PCI-CDa DMA interface (for EDT)
2 GeForce 8800GTX
and water cooling

+ CUDA libraries + CUFFT

This 5k€ system is able to remove the dispersion effect of the interstellar medium directly on recorded voltages over a 128MHz bandwidth (the data rate is 2x 2Gbs)
Architecture

data from the telescope

1Gbs

dataserver EDT + 2NICs

Eth 2x1Gbs

1Gbs 1Gbs

superdataserver 2EDT + 2GPUs

SERENDIP5 spectrometer
2 cplx pol over 128MHz
32x4MHz channels

SERENDIP5 spectrometer
2 cplx pol over 128MHz
32x4MHz channels

dataserver EDT + 2NICs

dataserver EDT + 2NICs

dataserver EDT + 2NICs

SWITCH Gigabit Cisco 6009 (32Gbs)

NODE bi–pro Athlon 1.2GHz

CLUSTER

NODE bi–pro Athlon 1.2GHz

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INPUT at 2Gb/s from Serendip5 spectrometer

the data path

OUTPUT on disk 100kB/s

Apr 2008, prototype without water cooling
monitoring the system...

A/C failure

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probably still the only ones to do GPU dedispersion...

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Real-time Pulsar Timing signal processing on GPUs
the next coherent pulsar dedispersor at Nançay will have a 400MHz bandwidth

iBOB tests conducted on Sept 2008 with P. McMahon

800MHz clock

10GbE Gore cable

PC + 10GbE card (+ GPU)

10GbE Gore cable

800MHz clock

PC + 10GbE card (+ GPU)
Early 2010: a 400MHz coherent pulsar dedispersor

~ 2012-2013

direct sampling of the receivers outputs?

UNIBOARD collaboration with PRISME Univ Orléans (PhD)
(http://www.radionet-eu.org/uniboard)
GT280 is 2.5-3 times faster than the 8800GTX for dedispersion (FFT, chirp_mult, FFT⁻¹)
Folding in the GPU

we developed kernel code to do the **folding** within the GPU and tested it...

we are now working on the **re-ordering** of data received from a PFB (a matrix transposition)
Conclusion

we guess GPUs are a good alternative
to do coherent dedispersion of pulsars

they are inexpensive at \( \sim 300\text{€} \) each

the GT200 generation is able to process
more than 100MHz bw each

properly coded, GPUs can do all the job:
re-ordering data, dedispersing, folding
(maybe doing everything for bw 100MHz)