The CASPER Hardware Platform

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Outline

- Radio Telescopes and processing Back-ends:
  - How they have always been done
  - How they should be done

- CASPER System: a pretty good stab at how things should be done
  - Introduction and design philosophy
  - What can it do? What could we (and you!) do with this hardware platform?
  - Components

- Examples Beamforming and Correlation with CASPER System
  - A Packetised Architecture
  - 2PAD Digital Signal Processing
How things used to be done

- Single-dish radio astronomy
- Interferometers
- Aperture arrays

Increasing cost and complexity of antenna technology

Increasingly complex processing back-ends

- A trend, and indeed, a specific design goal is towards placing the complexity in the electronic back-end, with simpler and smaller antenna technologies.
Placing design complexity in the electronics: What could possibly go wrong?

- Delay: hardware development time can spiral out of control.
- Cost (wasn’t this supposed to be an advantage to this approach)?
- Re-inventing everything each time and repeating the entire design cycle.
EVLA Baseline Board*

- PROBLEMS:
  - Takes 5 years to develop and costs millions of dollars.
  - Cost Dominated by NRE because of custom Boards, Backplanes, Protocols
  - Antiquated by the time it’s commissioned into service.

*Carlson, 2006
How things should be done

(An Ideal World Scenario)

- Design re-use:
  - Example: BG/L to BG/P software migration: painless!?
  - Lots of telescopes to be built pre-SKA: ASKAP, MeerKAT, ATA, MWA, LWA, PAST, PAPER, LOFAR, ALMA
  - Not just applicable to software: design re-use is a general engineering principle. I’m going to show you an example of how it may be applied to hardware
  - Unified Language and toolflow (is this possible?)

- Scalable
  - Need to be able to build lots without re-design of the fundamental architecture

- Cost nothing, Consume no power, Infinite computing resource, etc.
CASPER: a pretty good stab at how things should be done

- Centre for Astronomy Signal Processing and Electronics Research @ UC Berkeley
- Radio Astronomy Signal Processing Platform:
  - Fixed Hardware
  - Gateware
  - Open Source software and hardware wherever possible (board schematics available, CASPER library available and modifiable)
- CASPER Toolflow and DSP Library
  - Set of building blocks for Digital Signal Processing tasks and instrument infrastructure.
  - Examples: FFT, Polyphase Filter Bank
Reconfigurable, Scalable Radio Telescope Processors

- How can a processing chip be ‘reconfigurable’ if it is ‘hardware’?

- FPGA – ‘Field Programmable’ Gate Array
  - Switches between fixed silicon building blocks
  - Apply a high voltage to the switch to turn the individual connections either on or off
  - Effectively, any hardware structure can be implemented, as long as it fits on the device
  - New-generation FPGAs also have hard macro cells, like processors and fast multipliers that can also be used in to the design.

- Scalability
  - Network infrastructure
So why don’t we build the whole SKA Aperture Array out of this stuff?

- **Power**
  - Even though (for DSP) FPGA-based systems usually show orders of magnitude better power consumption than your average compute cluster, they’re not as optimal as the SKA would require, and certainly not as power efficient as a custom piece of hardware. Clearly, this topic is open to debate.

- **Cost**
  - FPGAs are not cheap (they’re about the most expensive piece of silicon you can get currently). If we’re making 10^6’s of chips, the cost of initial NRE might be justified.
What’s this best for?

- Digital back ends for Radio instruments with moderate amount of bandwidth and number of antenna elements
- International Collaboration on Packetised Correlator Back-ends:
  - PAPER (Green Bank and Western Australia), ATA (Hat Creek, California), KAT (KAT-7 and MeerKAT in the Karoo), GMRT (India), CARMA (Eastern California), FASR (California) and Medicina (Italy).
  - Now also an alternative 2PAD Beamformer, using the same architectural ‘DNA’ (hardware and gateware) as Correlator-like projects, with some modifications.
CASPER Radio Astronomy Hardware

- ADC boards, FPGA (processing or ‘engine’) boards and commodity Ethernet switches
- Originally designed in Berkeley in the BWRC. Next hardware and toolflow revision a strong collaboration with MeerKAT/ SKA South Africa
iBOB and iADC

- 2 iADC boards per iBOB: dual gigasample Atmel ADCs
  - Other variants available. Newer, higher frequency boards designed for next hardware revision.

- iBOB:
  - Single Xilinx Virtex II FPGA
  - 2 10GbE interfaces.
BEE2

- 5 Xilinx Virtex II FPGAs
- 18 10GbE interfaces
- Runs version of linux (BORPH) on central control FPGA (on the embedded PPC440 processor)

- Inter-chip comms possible, but CASPER recommend that each FPGA be used independently.
10GbE Network Switch

- Fujitsu XG2000C
- 20 ports:
  - 16 copper
  - 4 optical
- Simulink/MATLAB based toolflow
  - ‘Graphical’ programming
- Suite/library of signal processing blocks
Example: Packetised Beamformer Architecture

- All processing performed on reconfigurable hardware (FPGA) boards
- All switching performed with commodity network hardware
Beamforming Engine

- Frequency-domain beamforming allows easier calibration of systems in which we would ideally never touch an individual analogue chain
- Could be either FFT (spatial FFT) or Narrowband Phase-shift beamformer. Initially the latter, possibility of spatial FFT later

Initial application: Alternative signal processing back-end for 2PAD

- However, B-Engine will be a useful addition to CASPER library: future use by other RA projects, especially within the packetised hardware collaboration
- see www.casper.berkeley.edu/wiki/

B-Engine to be part of CASPER 10.1 library
The CASPER correlator is a packetized, scalable design currently using iBOB hardware for the "F engine" and BEE2 hardware for the "X engine".

Used in PAPER (Green Bank and Western Australia), ATA (Hat Creek, California), KAT (KAT-7 and MeerKAT in the Karoo), GMRT (India), CARMA (Eastern California), FASR (California) and Medicina (Italy).
Other examples

- **Spectrometers**
  - Parkes Spectrometer
  - Fly’s Eye Experiment (primarily SETI, but also something useful like transient monitoring)
  - New SETI Spectrometer (multi-iBOB, BEE2 spectrometer)

- **Correlators**
  - Pocket Correlator (single iBOB)
  - Packetised Correlator (scalable, networked system with multiple iBOBs and BEEs or ROACHES)

- **Pulsar Machines**
  - Towards real-time incoherent de-dispersion with fast spectrometers
PFFB response
What to remember from this talk (if anything)

- CASPER is not *just* a friendly cartoon ghost

- It is a system for rapidly building radio astronomy digital back-ends: toolchain, library and hardware

- If you’re staying for the practicals next week, you’re going to be building some radio signal processing systems with this toolchain
Questions
What you’re going to do in the workshop

- Use the CASPER toolflow to build a simple design
- Program it on to some hardware and see it work in real-life (this is very unusual in hardware design generally)