From Uni-Core to Many-Core, the Splendor of DAS-1 to 4

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Overview

- my experience with DAS-1
- my experience with DAS-2
- my experience with DAS-3
- my experience with DAS-4
Volkskrant, 17-8-'01
Solving the Game of Awari
Solving The Game of Awari

- popular African board game
- rules:
  - sow stones
  - capture stones
  - winner: >24 stones
- solve:
  - assume optimal play
  - minimax
  - determine score of 889,063,398,406 positions
Solving The Game of Awari

- compute database
  - entry = board score
  - partitioned
- upgraded DAS-2@VU memory
  - 2 bits/entry → DRAM
  - 7 bits/entry → disk
- retrograde analysis
  - remote lookup
  - move computation
  - never wait!
Solving The Game of Awari

- 72 DAS-2 nodes: 51 hours
  - 1 DAS-4 node: 12 hours ...
- result: draw
- web server (5 disks)
- “1 of the 250 Milestones in the History of Mathematics” [C.A. Pickover, the Math book]
Volkskrant, 17-8-'01
The LOFAR Radio Telescope

- largest low-frequency telescope
- distributed sensor network
  - ~85,000 receivers
LOFAR SuperTerp
LOFAR: A **Software Telescope**

- different observation modes require **flexibility**
  - standard imaging
  - pulsar survey
  - known pulsar
  - epoch of re-ionization
  - transients
  - ultra-high energy particles
  - ...
- digitally steered
- concurrent observations
- Blue Gene supercomputer
- real time
LOFAR Data Processing

stations in the field

Blue Gene/P supercomputer
LOFAR Central Processing

- complex software
- several pipelines
- 85-96% efficiency!
- use DAS to develop new functionality
What's Next?  
the Square Kilometre Array

- world-wide effort
- unprecedented size
- South Africa + Australia
  - 2016–2019: 10% SKA
  - 2020–2023: 100% SKA
- exascale computing; petascale I/O
  - $O(10^4)–O(10^5) > \text{LOFAR}$
- many challenges!
research challenges of the SKA

2012–2017

31,9 M€ project
  (Min. EL&I, prov. Drenthe)

use DAS-4

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<th>algorithms &amp; machines</th>
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<td>real-time communication</td>
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Many-Core Research

- accelerators for (radio-astronomical) signal processing
  - GPUs, Xeon Phi, BG/Q, FPGAs, ...
- fundamental understanding of accelerators
  - which properties make architecture (in)efficient?
  - I/O-compute balance?
  - energy efficiency?
  - programmability?
  - architecture-(in)dependent optimizations?
  - devise new algorithms?
  - generic approach to program accelerators, or ad-hoc?
- applications:
  1) LOFAR, AARTFAAC, ...
  2) SKA
Blue Gene/P Algorithms $\rightarrow$ GPUs

- port to GPUs
  1) LOFAR BG/P replacement
  2) code base for accelerator research
- prototype on DAS-4
Implemented Kernels
Compute Performance

![Compute Performance Graph]

- **FIR filter**
- **FFT**
- **Delay/correlator**
- **Beam former (6x3, local)**
- **Beam former (16x1, global)**
- **Transpose**
- **Inv. FIR filter**
- **Inv. FFT**
- **Trigger**

**GHLOPS**

- **HD6970 (max)**
- **HD6970 (min)**
- **HD7970 (max)**
- **HD7970 (min)**
- **GTX580 (max)**
- **GTX580 (min)**
- **GTX680 (max)**
- **GTX680 (min)**
- **K10 (max)**
- **K10 (min)**
AARTFAAC

- all-sky monitor
  - transients
  - 1 image/s
- correlate 288 LOFAR superterp dipoles
  - use LOFAR correlator on DAS-4
  - world record \#individual receivers! (41,616 pairs)
  - 21 nodes; 3x slower than real time
- now developing real-time GPU correlator
  - eventually: FPGAs
correlate 288 dual-pol receivers

AMD FirePro S10000:
😊 computations extremely fast
😢 has driver issues
Creation of Sky Images on GPUs
Imaging

- correlator output $\rightarrow$ sky image
  - convolve correlations and add to grid
    - lots of memory I/O!
  - 2D FFT $\rightarrow$ sky image
Previous GPU Work

- MWA (Edgar et. al. [CFC'11])
- van Amesfoort et. al. [CF'09]
- Humphreys & Cornwell [SKA'11]

- estimated performance on GTX-680
- ~3% of peak
Why Is This An Issue?

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<td>LOFAR (2012)</td>
<td>~30</td>
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<tr>
<td>10% SKA (2016)</td>
<td>~30,000</td>
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<tr>
<td>Full SKA (2020)</td>
<td>~1,000,000</td>
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cannot afford 3% efficiency
New GPU Imaging Algorithm

- reduces memory I/O
- unintuitive
- ~10x faster [ICS'12]
Our OpenCL Work
OpenCL vs. CUDA

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**OpenCL advantages**
- vendor independent
- runtime compilation
- CPU: C++ exceptions
- GPU: swizzling

**disadvantages**
- poor library support
- cannot use all GPU features
- **NVIDIA dropped OpenCL support!!!**
OpenCL on Top of CUDA RTS

- fool CUDA RTS
- CPU: implement our own “platform” (ICD)
  - OpenCL library calls ➜ CUDA library calls
  - limited subset (proof of concept)
- GPU: use OpenCL ➜ PTX compiler (clc/clang/llvm)
  - efficient
  - does not support full language
- advantages:
  - can use visual profiler
  - use cuFFT etc.
  - more RTS control
OpenCL on Top of CUDA RTS
Current/Future Work on DAS-4

- accelerator research
- OpenCL on FPGAs
  - Altera
- OpenCL on top of CUDA
- LOFAR Blue Gene/P correlator port → GPU cluster
  - + AARTFAAC correlator
  - + new observation modes
- ...

Conclusions

- solved Awari
- use DAS-4 for (accelerator) research
  - correlator etc.; imaging
  - LOFAR, AARTFAAC, SKA
- DAS increasingly important!
Job Openings!

- www.dome-exascale.nl ➔ careers
- www.astron.nl ➔ careers ➔ jobs