Supercomputers, Clusters & Hypercomputers (Past, Present Future)

by

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NASA-wide HPC Systems

SGI Altix: 128 Processors
(IA64 - 6 GFLOP/CPU)

Cray X1 : 64 Processors
(Custom - 12 GFLOP/CPU)

+ 128 processor Opteron System

Contents

Past NASA & Langley HPC

Research: Langley, Ames, Glenn (Research)

Ops: JPL, Goddard, Dryden, Johnson, Kennedy, Marshall, MTC

Present Production (Cosmo + Center Clusters)

Research (CiCT + Center Clusters)

Langley Cluster Growth

Estimate by Joseph.H.Morrison@nasa.gov
Chair of Langley Cluster SIG

1200 - 1500 nodes on 2/04
440 nodes added since 6/03
50% increase in nodes/year

for several years

Other NASA Centers: Similar growth?

Why? 3x – 20x less to compute locally
Cost/CPU hour roughly 1/10

Growing HPC Interest at Langley

iNASA
(integrated NASA Architecture for Simulation and Analysis)

- **iNASA initiative will tackle NASA's *hardest Science and Engineering Modeling and Simulation Challenges* enabling unprecedented advances in multi-physics simulations with increased fidelity and resolution.**
  - **In concert with unique data created by science payloads, iNASA will create the capability to model and understand the processes that drive change in the Earth and in the Cosmos**
  - **Will allow, on a day-to-day basis, the capacity and capability to tackle simultaneously, at the limit of our engineering ability, problems that heretofore were untractable except on an episodic/emergency basis**

HPC Across NASA Enterprises

Space Science

Exploration Systems

Earth Science

Biological and Physical Research

Digital Astronaut

Space Flight

Emergency Response

Engineering and Safety

Shuttle Stewardship

Aeronautics

Each mission requires:

- Advanced models
- Model integration
- Efficient codes
- TF/PF Computation
- TB/PB data analysis, exploration, management
- Ensemble Analysis
- Science/engineering environments
- Remote resource access

Exploring Applications on Reconfigurable Hypercomputers

'02 *Creativity & Innovation* *'04*

Computing Without CPUs

***GOAL*: Evaluate FPGA-based Hypercomputers for NASA Scientific Computations**

***TEAM*: Drs. Olaf Storaasli & Jarek Sobieski, Principal Investigators**
Dr. Robert Singleterry, Dave Rutishauser, Joe Rehder, Garry Qualls
Shaun Foley-*MIT*, William Fithian-*Harvard*, Siddhartha Krishnamurthy-*VT*
Cris Kania-*VT*, Patrick Butler-*VT*, Hoy Loper-GS, Neha Dandawate-*UVA*,
Kristin Barr-*JPMorgan*, Robert Lewis-*Morehouse* , Vincent Vance-*VT* *+2 more*

PARTNERS*: *Starbridge Systems*, NSA, USAF, MSFC, *AlphaStar

Langley-Starbridge Systems (SBS) Collaboration

1st SBS Hypercomputers @Langley (β-site: early H/W & S/W)

Langley:

- *application utilities & algorithms*
- *identify bugs, recommend changes & utilities to SBS*
- *coordinate with partners: NSA, USAF, MFSC, VPI*

Starbridge:

- *implement NASA suggestions*

==> **Make FPGAs better tool for NASA applications**

FPGA Computing

Traditional CPU	*FPGA*
: 1 operation/cycle	: inherent
gates & data types	gates & data types
: 99% gates idle/cycle	: Optimizes gates to task
yet all draw power	
: Text	: VIVA Icons & Transports

```
do i = 1, billion
    c= a+b
    end do
```

↑

↘

MFLOPS/250 MHz SGI

GFLOPS/64 MHz FPGA

GFLOPS/10 FPGA board

Algorithms Developed*

: {V}, [M], *$\{V\}^T\{V\}$, [M]x[M],GCD,…*

=> Probability: Combinations/Permutations

=> Transcendentals: sin, log, exp, cosh…

=> Runge-Kutta: CFD, Newmark Beta: CSM

: [A]{x} = {b} - Gauss & Jacobi

: $[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} + NLT = \{P(t)\}$

: digital accuracy

: Analog simulation

avoids Non-Linear Term solution time

* **: Publications Storaasli**

Applications: VIVA Code

Gauss-Jordan $\mathbf{A}x = \mathbf{B}$ Solver

- VIVA code solves *n* equations.

Ex:

$$\begin{aligned} x_0 + x_1 + x_2 &= 0 \\ x_0 - 2x_1 + 2x_2 &= 4 \\ x_0 + 2x_1 - x_2 &= 2 \end{aligned} \quad \Longrightarrow \quad \begin{aligned} x_0 &= 4 \\ x_1 &= -2 \\ x_2 &= -2 \end{aligned}$$

- Run on hypercomputer emulator, then FPGA

Spring-Mass Solver

$\rightarrow f$

Method: 4-stage Runge-Kutta

$$\frac{du}{dt} = f(u,t)$$

$$y(x_0) = y_0$$

$$k_1 = hf(x_n, y_n)$$
$$k_2 = hf(x_n + \tfrac{1}{2}h, y_n + \tfrac{1}{2}k_1)$$
$$k_3 = hf(x_n + \tfrac{1}{2}h, y_n + \tfrac{1}{2}k_2)$$
$$k_4 = hf(x_n + h, y_n + k_3)$$

$$x_{n+1} = x_n + h$$
$$y_{n+1} = y_n + \tfrac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4)$$

Smith Waterman Algorithm
(NCI Compares 2 DNA sequences)

stream of cells*
ref character
iterations, radix
iteration index
system clock
pulse before cells
pulse before search
for each cell
* Keep full for efficiency

newly-computed cell
for next iteration
new cell
for next interation
current row
current column

FPGA SW Performance

7 FPGAs, on HC62, compute SW cells in parallel

(each FPGA computes 64 iterations/cycle)

⇒ 448 parallel SW_Iterations @ 25 Mhz*

⇒ 25M * 448 =

**conservative: may increase clock via VIVA*

VIVA adds on 1 FPGA

Adds-parallel	16	32	128	256	512	640
% FPGA used	1	2	8	16	41	51
Billion Ops	4	8	34	77	154	192

(most CPUs limited to 1-3 ops/cycle)

Summary
NASA exploits HPC mix

- ✓ **Production & Research Computing**
- ✓ **NASA-wide & Center Clusters**
- ✓ **Traditional & "far out" G5s & FPGAs**

HPC future bright at NASA as capability/$ increases

More=> **: Publications Storaasli**