Dependable Multiprocessor (DM) CubeSat Implementation

presented at the

2010 Summer CubeSat Workshop/ Small Satellite Conference

August 8, 2010

Dr. John R. Samson, Jr.
Honeywell Aerospace, Defense and Space
Clearwater, FL
john.r.samson@honeywell.com

Honeywell

Outline

Honeywell

- Objectives
- Brief overview of DM Technology & Status
- DM Small Satellite/CubeSat effort
- Summary & Conclusion
- References

Objectives

Honeywell

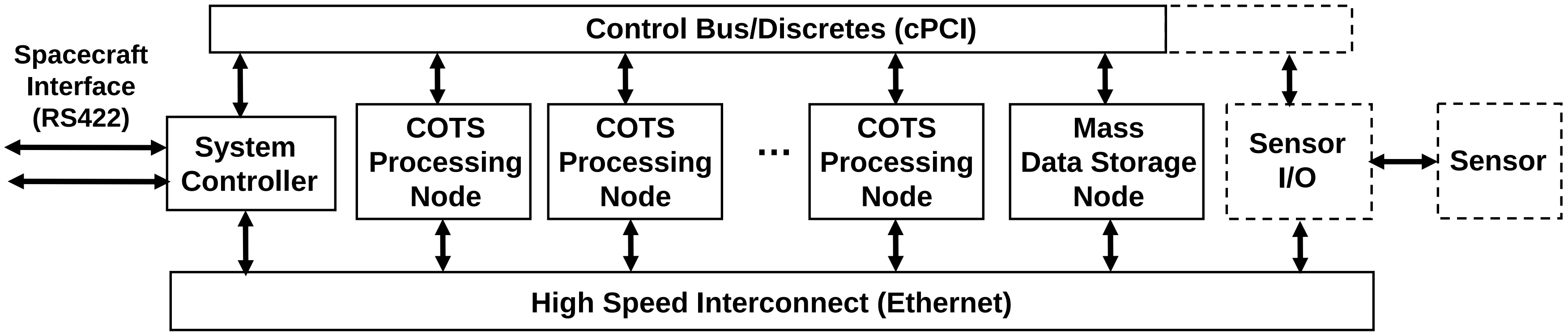
- Introduce DM technology to the Small Satellite/CubeSat community
- Provide overview of the current DM CubeSat effort
- Elicit interest in possible joint DM-CubeSat and/or DM small satellite experiment
  - radiation issues
  - thermal issues
  - structural issues
  - benefits of increased on board processing

Dependable Multiprocessor – What is it?

Honeywell

- cluster of COTS high performance processors
- operated under the control of a reliable system controller and technology- and platform-independent fault tolerant middleware
- flexible
  - user-configurable fault tolerance includes hybrid replication [temporal and spatial self-checking and TMR (Triple Modular Redundancy) for critical functions and ABFT (Algorithm-Based Fault Tolerance)]
- scalable
- easy to use

DM ST8 Flight Experiment System



The platform and technology-independent DM Middleware (DMM) is DM technology; DM technology is <u>not</u> the underlying hardware

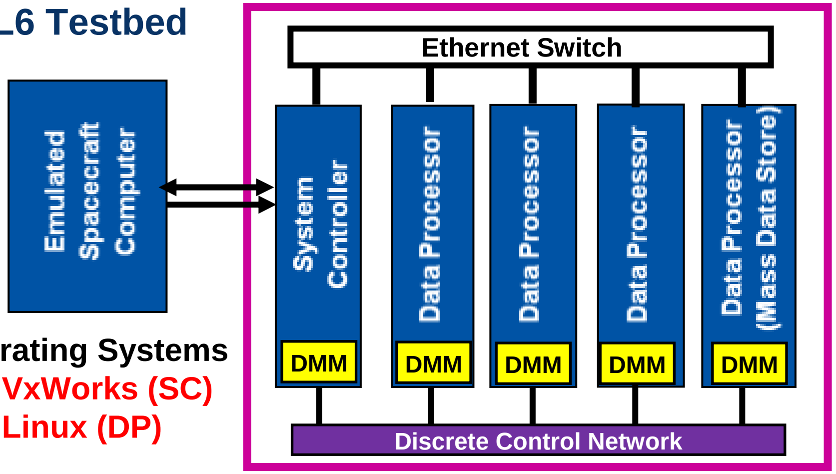
Dependable Multiprocessor (DM): A COTS-Based High-Performance Payload Cluster Computing Platform

Honeywell

What is DM?

- A high-performance, COTS-based, fault tolerant cluster onboard processing system that can operate in a natural space radiation environment
- High throughput density (>300 MOPS/watt), scalable & software based
- High system availability >0.995
- High probability of timely and correct delivery of data >0.995
- Technology independent system software that manages cluster of high performance COTS processing elements
- Technology independent system software that enhances radiation upset tolerance

TRL6 Testbed



Operating Systems
- VxWorks (SC)
- Linux (DP)

Why is DM important?

- Flying high-performance COTS in space is a long-held NASA and DoD objective
- DM is bringing this objective closer to reality
- Enables heretofore unrealizable levels of onboard data and autonomy processing
- Enables faster, more efficient application development
- Enables users to port applications directly from laboratory to space environment
- DM is a significant paradigm shift
  - provides ~ 10X – 100X throughput density available with current software programmable RHBP & RHBD processors at much lower cost
  - software-based technology allows space to keep pace with terrestrial state-of-the-art COTS

Status?

- Since 2004, NASA NMP ST8 invested >$13M in the development and demonstration of DM technology through TRL6
- Demonstrated DM predictive availability, timely delivery of correctly processed data, and performance models
- Demonstrated ability to meet NASA Level 1 requirements/goals
- Successfully completed system-level radiation testing
- DM project has further developed, refined and demonstrated the process for migrating COTS high performance computing to space
- DM technology has been demonstrated on wide variety of platforms and applications
- DM technology is applicable to wide range of missions
- Seeking a ride to space to achieve TRL7

DM Technology is Ready for a Flight Experiment

Dependable Multiprocessor Technology

Honeywell

Summary of DM technology advance

- Architecture and SW framework that enables COTS-based, high performance, scalable, cluster processing systems to operate in space
  - "SW-based SEU-tolerance enhancement"
- MPI-based for ease of porting applications from lab to space
- Adaptable to environment: radiation, mission, mode
- Validated models that can predict system performance in future missions & environments

Applications of DM technology

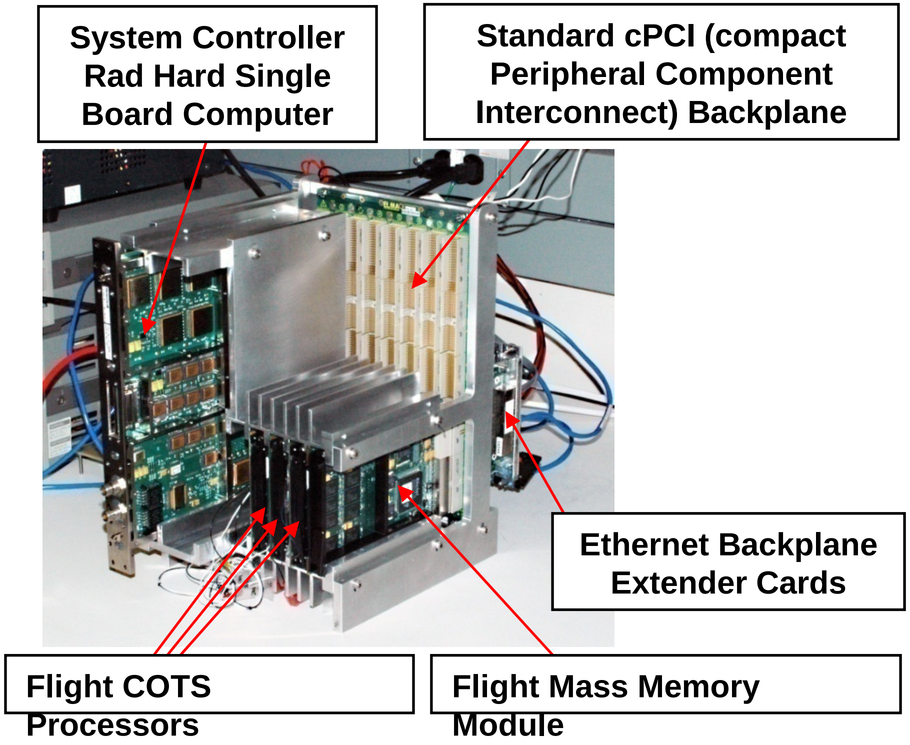
- DM technology is applicable to a wide range of NASA & DoD missions (HSI, HTI, SAR, etc.)
- enables previously unrealizable levels of science and autonomy processing
  - -- NASA science missions
  - -- landers/rovers
  - -- robotic servicing of satellites
  - -- ground/lunar/Mars-based systems
- High Altitude Airships (HAAs)
- Unattended Airborne Vehicles (UAVs)
- Un-tethered Undersea Vehicles (UUVs)
- Stratellites
- Operationally Responsive Space (ORS)
- rad hard space applications

DM Technology Development Status

- **TRL6 Validated Technology**
  - successful operation validated in a radiation environment
    - -- high performance
    - -- high availability
    - -- high probability of timely and correct delivery of data
    - -- predictive performance models
- **Multiple applications supported**
  - Hyper-Spectral Imaging (HSI)
  - Synthetic Aperture Radar (SAR)
  - multiple astrophysics applications (CRBLASTER, QLWFPC2)
  - FFTs, matrix operations, etc.
- **Easy to Use/Low Overhead**
  - independent 3rd party ports
  - <10% throughput and memory overhead

- **Critical Design Review**
  - ruggedized, conductively-cooled, COTS boards can fly in space

DM TRL6 Flight Experiment Testbed



DM software and COTS technology is ready to fly; only needs to be put in a flight chassis and space qualified

Options for Flying DM Technology Experiment

Honeywell

- Fly existing DM ST8 flight experiment system
- Fly DM hardware and software in a smaller flight chassis
- Fly DM hardware and software in customer-supplied chassis
- Fly DM in conjunction with a real sensor
  - add sensor I/O and software
  - demonstrate faster onboard processing capability and reduced downlink bandwidth
- Port full or partial DMM (Dependable Multiprocessor Middleware) to new platform *
- Others ……

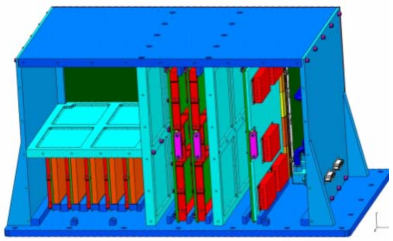
> * Able to use technology-independent DMM on other hardware platforms; currently being considered for a nanosatellite mission^

^Space Experiment Review Board (SERB)-sponsored flight experiment

Dependable Multiprocessor Middleware is Independent of Hardware Platform

Honeywell

6U cPCI Package (Original ST8 Flight Experiment)



Dimensions: 10.6” x 12.2” x 24.0”
(26.9 cm x 30.9 cm x 45.7 cm)
Weight (Mass): ~ 61.05 lbs
(27.8 kg)
Power: ~ 100 Watt (nominal)
~ 120 Watts (max)

System Complement:
- one (1) rad hard System Controller
- three (3) Data Processors
- one (1) Mass Data Storage module
- one (1) Gigabit Ethernet Switch

Chassis oversized relative to the complement of DM hardware due to thermal limitations of the ST8 carrier spacecraft & total solar exposure

~4500 MFLOPS per 7447a DP node
(measured HSI application)

3U cPCI Package

Dimensions : 12.0” x 9.2” x 8.0”
(30.5 cm x 23.4 cm x 20.3 cm)
~ 17.5 lbs w/o circuit boards
~ 26 lbs with circuit boards
~ 70 watts nominal power
~ 100 Watts (max)

System Complement:
- one (1) rad hard System Controller
- three (3) Data Processors
- one (1) Mass Data Storage module
- one (1) Gigabit Ethernet Switch

AiTech COTS chassis flown on ORBITAL EXPRESS flight experiment

~4500 MFLOPS per 7447a DP node
(measured HSI application)

Nanosatellite-Size Package (Preliminary)

Dimensions: ~ 10” x 6” x 6”
(25.4 cm x 15.2 cm x 15.2 cm)
~ 9 lbs (4.08 kg)
~ 25 watts

System Complement:
- 6 COM DP configuration with Rad Hard System Controller and 2 Ethernet switches*

* Based on TRITON-TX51 SIMM COMs for easy visualization and analysis

~1600 MIPS per Cortex-A8 COM node

Gumstix: Small, Light-Weight, Low-Power Processing

Honeywell

Gumstix Processor Module:

58 mm
(~2.28")

17 mm
(~0.67")

~1600 DMIPS
OMAP 3503 Application Processor with ARM Cortex -AP8 CPU
256 MBytes RAM
256 MBytes Flash

Gumstix Tobi-Duo Expansion Board:

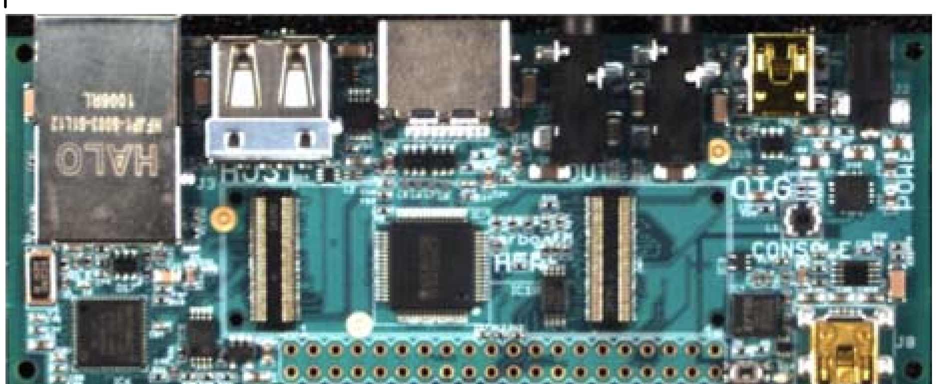
127 mm
(~5.0")

25.4 mm
(~1.0")

Gumstix with
Two (2)10/ 100baseT Ethernet Ports
Power < 2 watts
Mass ~ 0.1lb

Gumstix Tobi Board :

105 mm
(~4.13")



40 mm
(~1.57")

USB Serial Console Port
One (1) 10/ 100baseT Ethernet Port
Two (2) 2-wire serial ports
One (1) 1-wire port
Six (6) PWM lines
I2C port
SPI port
Six (6) A/D inputs
Proc. Cont. Signals

DM 3U CubeSat Concept with Rad Hard Controller*

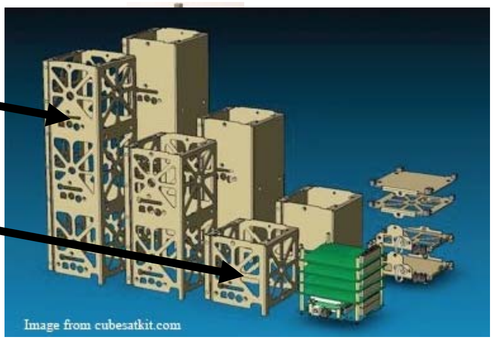
Honeywell

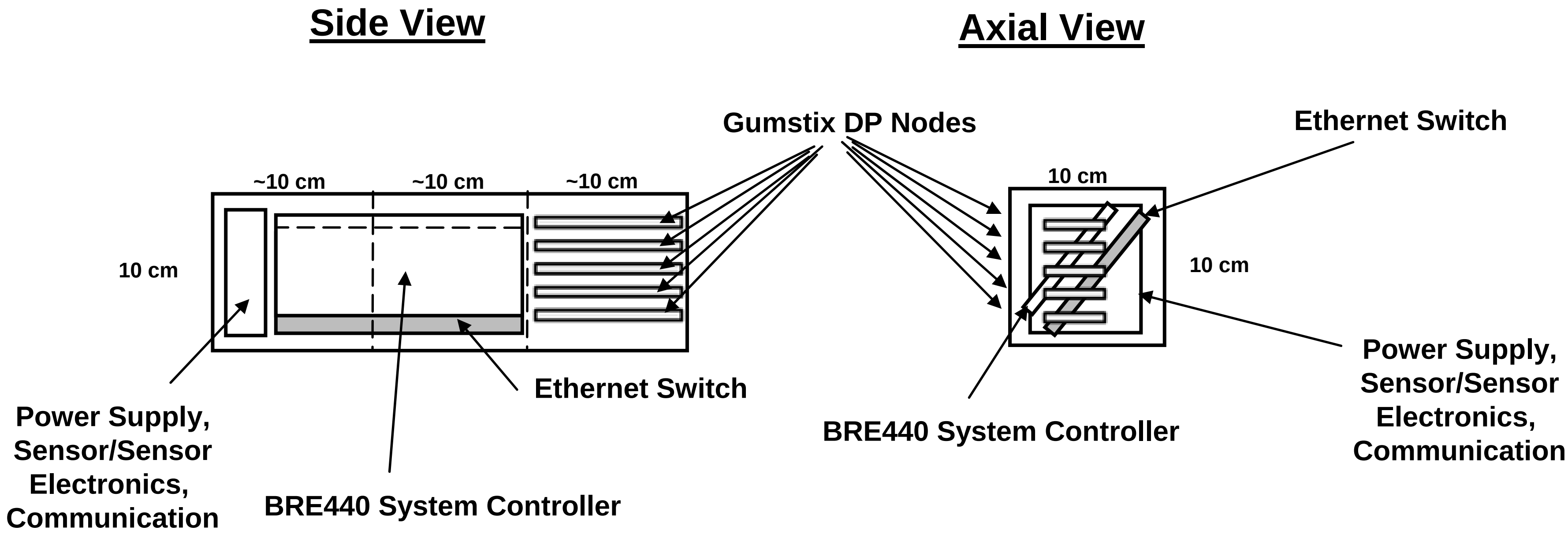
Original Concept

3U CubeSat size: 10 cm x 10 cm x 34 cm

1U CubeSat size: 10 cm x 10 cm x 10 cm

BRE440 Rad Hard Controller is 10 cm x 16 cm
(needs to be mounted on an angle)



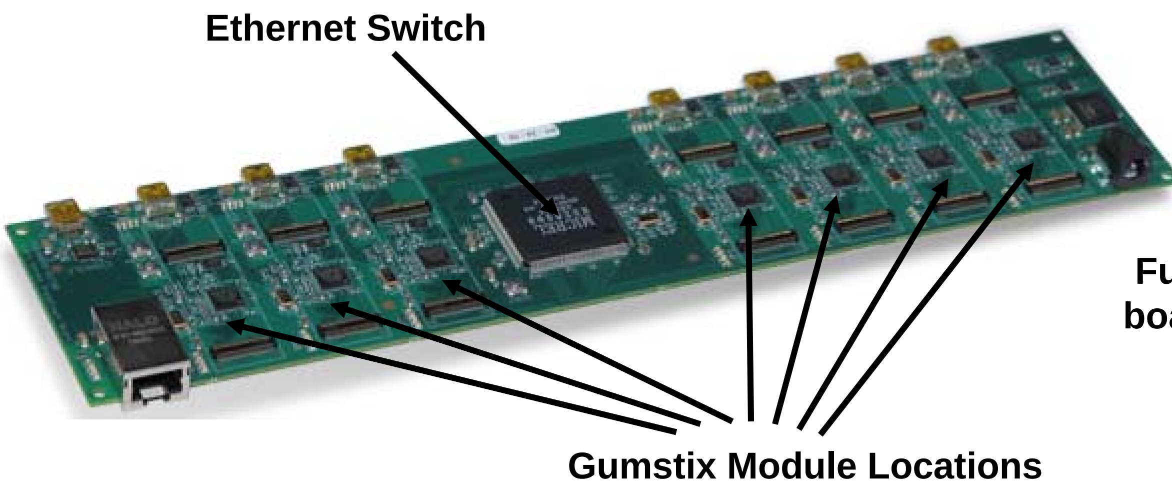


*** Using COTS parts**

Gumstix “Stage Coach” Expansion Board Product

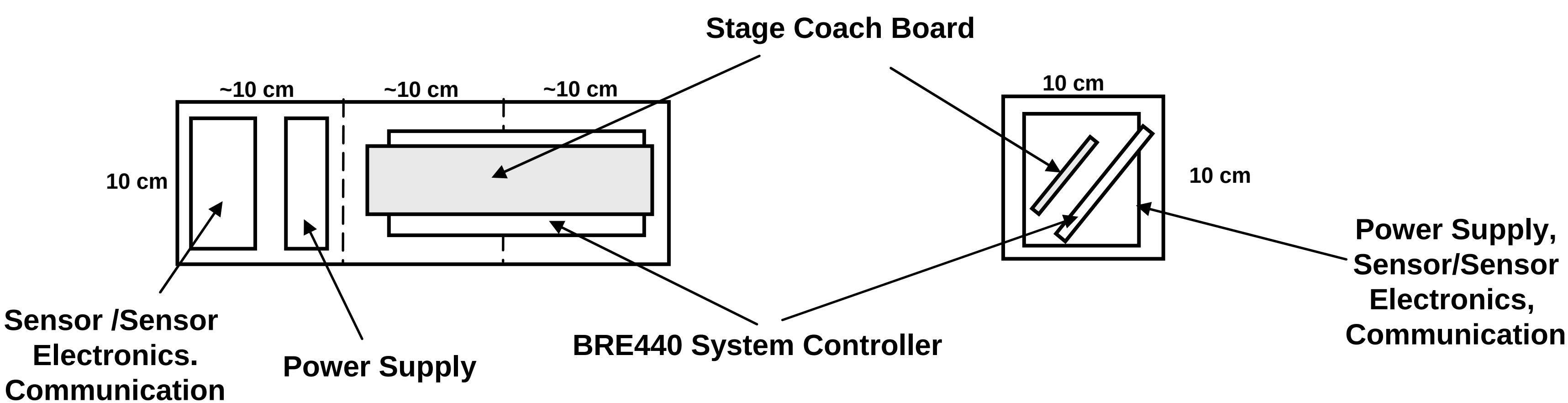
Honeywell

Gumstix Cluster: 7 Gumstix Modules on “Stage Coach” Expansion Board



Fully populated board < 20 Watts

CubeSat Side View | **CubeSat Axial View**



Summary of DM CubeSat Effort To Date

Honeywell

- DM-based CubeSat feasibility study
  - size, weight, power, mechanical (structural & thermal), radiation
- Performed atmospheric neutron testing of Gumstix module and two (2) Ethernet devices at LANL
  - results directly applicable to high altitude UAV and High Altitude Airship (HAA) applications
  - results extrapolated to space applications
  - future radiation tests planned (including proton and heavy ion testing)
- DMM (Dependable Multiprocessor Middleware) ported to Gumstix module
  - biggest issue to address was the Big Endian/Little Endian conversion for the ARM processor
  - applications running on Gumstix module under DMM control
- In the process of building a Gumstix-based DM cluster
  - 4 – 6 nodes running parallel applications with BRE440 system controller
- Investigating other "COMs" for Nano-Sats and Cubesats

Summary & Conclusion

Honeywell

- DM technology is the Dependable Multiprocessor Middleware (DMM)
  - DMM is platform- and technology-independent
  - DMM has been successfully and easily ported to many different processors and Operating Systems
    - now includes ARMs
    - includes state-of-the-art multi-core processors
    - working on future tiled architectures, e.g., Tilera Tile64 and MAESTRO
      - at Honeywell and at the NSF Center for Reconfigurable High-performance Computing (CHREC) at the University of Florida
- Processing technologies used in space applications no longer need to be 2 - 3 generations behind state-of-the-art terrestrial processing technologies
- DM technology is definitely applicable to CubeSat and Small Satellites
  - more onboard processing within size, weight, power, and cost constraints
    - more science/more autonomy
    - faster onboard processing, faster frame processing
    - reduced downlink bandwidth requirements
    - processed data/information directly to the user
- DM can incorporate new techniques/technologies to overcome performance gaps with regards to throughput, power, mass, radiation, & cost
- NASA, the DM project, and Honeywell are interested in exploring collaborative CubeSat and Small Satellite opportunities

Acknowledgements

Honeywell

- The Dependable Multiprocessor* effort was funded under NASA NMP ST8 contract NMO-710209
- The DM CubeSat effort to date has been carried out on Honeywell internal investment
- The author wishes to acknowledge the contributions of DM team members at Honeywell Defense & Space Systems in Clearwater, FL, the High-performance Computing and Simulation Laboratory at the University of Florida, and JPL

For more information contact:

Dr. John R. Samson, Jr.
Honeywell Defense & Space,
Clearwater, FL
john.r.samson@honeywell.com
(727) 539 – 2449

* The Dependable Multiprocessor (DM) project was originally known as the Environmentally-Adaptive Fault-Tolerant Computer (EAFTC) project

Recent References

Honeywell

[1] Samson, Jr., John R., Grobelny, Eric M., Clark, M., Driesse-Bunn, S., Van Portfliet, S., "NMP ST8 Dependable Multiprocessor: Technology and Technology Validation Overview," Proceedings of the 48th AIAA Aerospace Sciences Meeting Conference, Orlando, FL, January 4-8, 2010.

[2] Grobelny, Eric M., Samson, J., Clark, M., Driesse-Bunn, S., Van Portfliet, S., "NMP ST8 Dependable Multiprocessor: Technology Validation Approach and Results," Proceedings of the 48th AIAA Aerospace Sciences Meeting Conference, Orlando, FL, January 4-8, 2010.

[3] Samson, Jr., John R., Grobelny, Eric M., Driesse-Bunn, S., Clark, M., Van Portfliet, S., "Post-TRL6 Dependable Multiprocessor Technology Developments," Proceedings of the 2010 IEEE Aerospace Conference, Big Sky, MT, March 7-12, 2010.

[4] Samson, Jr., John R., and Grobelny, E., "NMP ST8 Dependable Multiprocessor: TRL6 Validation – Preliminary Results," Proceedings of the 2009 IEEE Aerospace Conference, Big Sky, MT, March 8-13, 2009.