Overview of Research
Thrust R3

R3 Fundamental Research Topics

R3A Parallel Processing
  • Programming Tools and Systems
  • FPGA Acceleration

R3B Solutionware Development
  • Image and Sensor Data Databases
  • Subsurface Toolboxes

David Kaeli, Northeastern University

NSF Year-2 Site Visit
May 21, 2002
Supporting SSI research leveraging existing computing technologies
Developing new techniques in the areas of parallel processing/embedded and databases to address CenSSIS barriers
Delivering software engineered products to enable IPLUS capabilities
CenSSIS Barriers Addressed by R3 Projects

Barrier 4: Lack of Computationally Efficient, Realistic Models

Barrier 6: Lack of Rapid Processing and Management of Large Image Databases

Barrier 7: Lack of Validated, Integrated Processing and Computational Tools
R3 Year 2 Research Projects

R3A Programming Tools and Systems

- Parallel Programming Tools (G. Krapf (junior), M. Ashouei, W. Meleis, D. Kaeli, K. Tompko, D. Brooks, C. Dimarzio, C. Rappaport, M. El-Shenawee)
- Cluster Development (C. Shaffer (soph), M. Dellaporta and D. Kaeli)

R3A Reconfigurable Embedded Computing

- Vascular Tracing in Embedded Hardware (P. Belanovic, M. Leeser, B. Roysam)
- FPGA Implementation of Backprojection for Rapid Tomographic Imaging (S. Molloy (junior), J. Noseworthy (junior), M. Leeser, E. Miller and Mercury)

R3B Image/Sensor Data Databases and Metadata

- Content Searchable Image and Sensor Data Databases (R. Norum, B. Salzberg, H. Wu, D. Kaeli and E. Miller)

R3B Toolbox Development

- The CenSSIS Tomography Toolbox (P. Edson, J. Black, Y. Wang, E. Yardimci, D. Kaeli, D. Brook, E. Miller and D. Boaz)
## R3 Research Projects - Year 2 Progress

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### Accelerating Modeling and Retinal Tracing Applications

### Relative Contribution to Outcomes

- **Fundamental Science Level**
- **Enabling Technology Level**
- **Engineered System Level**
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**Tomography (MVT) Toolbox and Image DB**

**Relative Contribution to Outcomes**

**Fundamental Science Level**

**Enabling Technology Level**

**Engineered System Level**
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### Relative Contribution to Outcomes

- Fundamental Science Level
- Enabling Technology Level
- Engineering System Level

### Addressing Barriers 4, 6 and 7 Directly

NU, UCinn, RPI, UArk
Year 2 Research Team:

- Geoff Krapf (NU-ECE)
- Craig Shaffer (NU-ECE)
- Maryam Ashouei (NU-ECE)
- Desheng Jiang (NU-ECE)
- David Kaeli (NU-ECE)
- Karen Topko (U. Cinn.)
- Waleed Meleis (NU-ECE)

R1-R2 Collaborators:

- Dana Brooks (NU-ECE)
- Chuck Dimarzio (NU-ECE)
- Magda El-Shenawee (U. Ark.)
- Carey Rappaport (NU-ECE)
Parallel Processing Tools

- Parallelization using MPI - a software pathway to exploiting GRID-level resources (Mariner Center at BU)
- Profile-guided program optimization - reducing computational barriers
- Utilizing MPI-2 to address barriers in I/O performance

Impact on SSI applications:
- Reduced the runtime of a single-body Steepest Descent Fast Multipole Method (SDFMM) application by **74%** on a 32-node Beowulf cluster
  - Hot-path parallelization
  - Data restructuring
- Reduced the runtime of a Monte Carlo scattered light simulation by **98%** on a 16-node SGI Origin 2000
  - Matlab-to-C compilation
  - Hot-path parallelization
Techniques for Parallelizing MATLAB

- Manage completely independent MATLAB processes distributed over different processors
- Message passing within MATLAB (MultiMATLAB)
- MATLAB calls to parallel libraries (multi-threaded LAPACK, PLAPACK)
- Backend compilers can convert MATLAB to C, and automatically inserting MPI calls (RTExpress)

Multiple MATLAB sessions

A Single MATLAB session
Our Approach for Parallelizing MATLAB

1. Convert MATLAB to C using the MATLAB mcc compiler
2. Convert array structs (generated by mcc) to pointer-based structs where needed
3. Profile the C program to capture both data flow and control flow
4. Parallelize the “hot” regions of the application using MPI
State-of-the-art Parallel Processing Tools

CenSSIS Publications:


Other techniques being assessed in this work:
- Globus Toolkit - NSF Middleware Initiative
- MatlabMPI – MIT LL
- RTExpress - Parallelizing compiler for Matlab
- Sparse matrix representations
Cluster Development: The Mercury RACE System

8 - node PPC 750’s
Raceway backplane
MC/OS
PAS
VSIPL
Ultra10 hosted
web-accessible
Cluster Development: 
*The Gigabit Cluster*

8 - node Gigabit Cluster

- 1.2 GHZ P3
- 1.5 GB dram
- 45 GB disk

10/100/1000 switched ethernet

RedHat Linux 7.2

MATLAB

MPI-2
Reconfigurable Hardware for Accelerated Vessel Enhancement in Retinal Fundus Images

Research Team
- Miriam Leeser - NU-ECE
- Pavle Belanovic - NU-ECE
- Badri Roysam - RPI-ECSE
- Kenneth Fritzsche - RPI-ECSE

What does the algorithm do?
- Retinal vascular tracing; detection of blood vessels in images of the retina
- Utilizes a matched filter to find blood vessels and traces out structure

Where is the algorithm used?
- Processing live video of the patient retina during laser retinal surgery.
- Data are 1024x1024 images at 30 frames/sec
- Highlighting the vascular structure helps the surgeon avoid damage
Why do we need to accelerate it?

- Current implementation: software on a general-purpose processor
- It takes about 400ms to process one 1024x1024 image
- To reach 30 frames/sec, the algorithm must be accelerated at least 12 times

Solution: Reconfigurable Hardware
The Firebird reconfigurable computing engine from Annapolis Micro Systems
- 1 Xilinx VIRTEX E (XCV2000E) FPGA
- 5 Memory banks (4 x 64-bit, 1 x 32-bit)
- 5.4 Gbytes/sec of memory bandwidth
- 66Mhz/64-bit PCI interface to host
Year 2 Progress

- Partitioned the algorithm: template response calculations in hardware
- Determined mapping of templates onto the pixel neighborhood
- Designed, simulated and synthesized modules for:
  - partial template response,
  - template response,
  - comparison of template responses, and
  - full datapath

Year 3 Plan

- Integration of the hardware implementation into the algorithm (20x speedup anticipated)
- Processing of retina images and live video
- Apply similar techniques to identify sub-skin tumors in tissue (MGH)
R3 Undergraduate Involvement

- Craig Shaffer - (NSF - REU, IUROP - Mercury)
- Geoff Krapf - (NSF - REU)
- Seth Molloy - (IUROP - Mercury)
- Josh Noseworthy - (IUROP - Mercury)

Creating unique undergraduate research experiences for our students

www.cesssis.neu.edu/Industry/IUROP/
## Proposed Changes in Emphasis for Year Three Research Program

### Important Outcomes

### CenSSIS Research Areas

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<th>Thrust R1 SOA Advances</th>
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<th>Thrust R3 SOA Advances</th>
<th>Usable Validating “BEDs”</th>
<th>Solutionware Products</th>
<th>Unifying Framework Demos</th>
<th>Advances in Solving Real World Problems</th>
<th>1st Generation I-PLUS Process</th>
<th>Multi-Sensor Instrument Demos</th>
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### Libraries of VHDL and parallelized SSI applications

Δ = +1

### Relative Contribution to Outcomes

- Fundamental Science Level
- Enabling Technology Level
- Engineered System Level

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Libraries of VHDL and parallelized SSI applications

Δ = +1
## Proposed Changes in Emphasis for Year Three Research Program

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### Relative Contribution to Outcomes

- **Fundamental Science Level**
- **Enabling Technology Level**
- **Engineered System Level**

**Delta = +1**

*Retinal scanning testbed demo*
CenSSIS Solutionware Year 2 Goals

**Toolbox Development**

- Support the development of CenSSIS Solutionware that demonstrates our “Diverse Problems - Similar Solutions” model
- Deliver a software-engineered Tomography MVT Toolbox, developed in OOMATLAB
- Identify new Toolbox candidates for Year 3
- Establish software development and testing standards for CenSSIS

**Image and Sensor Data Database**

- Develop an web-accessible image database for CenSSIS that enables efficient searching and querying of images, metadata and image content
- Develop image feature tagging capabilities
CenSSIS Subsurface Toolboxes

Year 2 Research Team:

- Patrick Edson (MathWorks)
- Jennifer Black (NU-ECE)
- Yijian Wang (NU-ECE)
- David Kaeli (NU-ECE)
- Dana Brooks (NU-ECE)
- Eric Miller (NU-ECE)

Collaborators:

- David Boaz (MGH)

New members in Year 3:

- Chris Carothers (RPI-CS)
- Badri Roysam (RPI-ECSE)
- Luis Jimenez (UPRM-ECE)
CenSSIS Toolbox Development

CenSSIS Applications written in MATLAB, C, C++, Java, MPI, VHDL and Verilog

- Identify classes of CenSSIS algorithms that can be more generally specified to extend applications to multiple research domains
- Utilize Software Engineering principles to produce reusable and extensible software toolboxes
  - Object-oriented design principles used
  - Exploratory Software Development Model
  - Library and revision control to support IPLUS infrastructure
The CenSSIS Multi-View Tomography (MVT) Toolbox

3 Packages
8166 lines of OOMATLAB
22 MATLAB classes/126 methods
Generic noise classes

Tomography
Reconstruction
Diffuse Optical Tomography

DOT
EIT
ERT
Matlab 6
Year 3 Goals for Toolbox Development

- Release Tomography (MVT) Toolbox as part of the MathWorks Connections program
- Evaluate the level of effort needed to address diverse problems using the Tomography Toolbox to address problems in EIT and ERT (INEEL)
- Extend our model to three new Toolbox efforts:
  - Registration (LPM) Toolbox - RPI and WHOI
  - Hyperspectral (MSD) Toolbox - UPRM
  - Data Modeling Toolbox - NU
The CenSSIS Image and Sensor Data Database

Year 2 Research Team:

- David Kaeli (NU-ECE)
- Eric Miller (NU-ECE)
- Huanmei Wu (NU-CCS)
- Betty Salzberg (NU-CCS)
- Becky Norum (NU-CenSSIS)

Collaborators:

- Patrick Muraca (Clinomics)
- Hanu Singh (WHOI)

New Members in Year 3:

- Manuel Rodriguez (UPRM-ECE)
Deliver an web-accessible database for CenSSIS that enables efficient searching and querying of images, sensor data, metadata and image content

Database Characteristics:
- Relational complex queries (Oracle8i)
- Data security, reliability and layered user privileges
- Efficient search and query of image content and metadata
- Content-based image tagging using XML adopting MPEG-7 standards
- Easy upload and registration of user images and metadata
- Indexing algorithms (2D, 3D and 4D) and partitioning of the database for better performance
- Explore object relational technology to handle collections

Goals for Year 2
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# R3 Research Projects - Year 3 Plans

## CenSSIS Research Areas

<table>
<thead>
<tr>
<th>Research Area</th>
<th>Important Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R1A Nonlinear and Dual Wave Probes</strong></td>
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<tr>
<td><strong>R1B Effective Forward Models</strong></td>
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<td><strong>R3B Solutionware Tools</strong></td>
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<tr>
<td>Initial TestBED Facilities</td>
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<tr>
<td>Bio, Med, Soil, SeaBEDs</td>
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<td>I-PLUS Development</td>
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<tr>
<td>Bio, Med, Soil, Sea (Real Problems)</td>
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### Modeling Toolbox
- >500 Datasets Online, 3D and 4D indexing, 3 new CenSSIS Toolboxes

### Relative Contribution to Outcomes
- Fundamental Science Level
- Enabling Technology Level
- Engineered System Level
## Proposed Changes in Emphasis for Year Three Research Program

### CenSSIS Research Areas

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### Important Outcomes

|------------------------|------------------------|------------------------|------------------------|--------------------------|----------------------------------------|-------------------------------|-------------------------------|--------------------------------|

### Relative Contribution to Outcomes

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### New Toolboxes, 3-D Fusion Microscope Database Support

Δ = +1

Δ = +1
Clinomics BioSciences
- Microarray provider
- Joint SBIR submissions

Mercury Computer
- Profile-guided compilation - DARPA proposal
- Back projection acceleration with FPGAs
- IUROPs

Integrated Sensors
- RTExpress - parallel MATLAB

MathWorks
- Leadership role in Solutionware development
- Object-oriented MATLAB training

Future partners
- EMC - storage array proposal to the NSF-MRI program
R3 Education Plan

- **Year 2**
  - Industrial/Research Meeting featured a workshop on Computer-aided Medical Image Analysis
  - RTExpress courses on-site to support the CenSSIS computing community

- **Year 3**
  - Development of CenSSIS Software Engineering class under development, centered around OO MATLAB and C++
  - Online tutorial for CenSSIS database users will be available in 2Q02
  - Short course on MATLAB parallelization strategies will be provided at next industry meeting
R3 Research Thrust Summary

- Providing both SSI-related computing research expertise and supporting CenSSIS infrastructure needs
- Addressing key research barriers in computational efficiency, embedded computing and image/sensor data management
- Will play a key role in laying the foundation for IPLUS products
  - Subsurface Toolboxes
  - Image/Sensor Data Databases
  - Parallel Computing Solutions