Center for Adaptive Supercomputing Software - Multithreaded Architectures (CASS-MT)

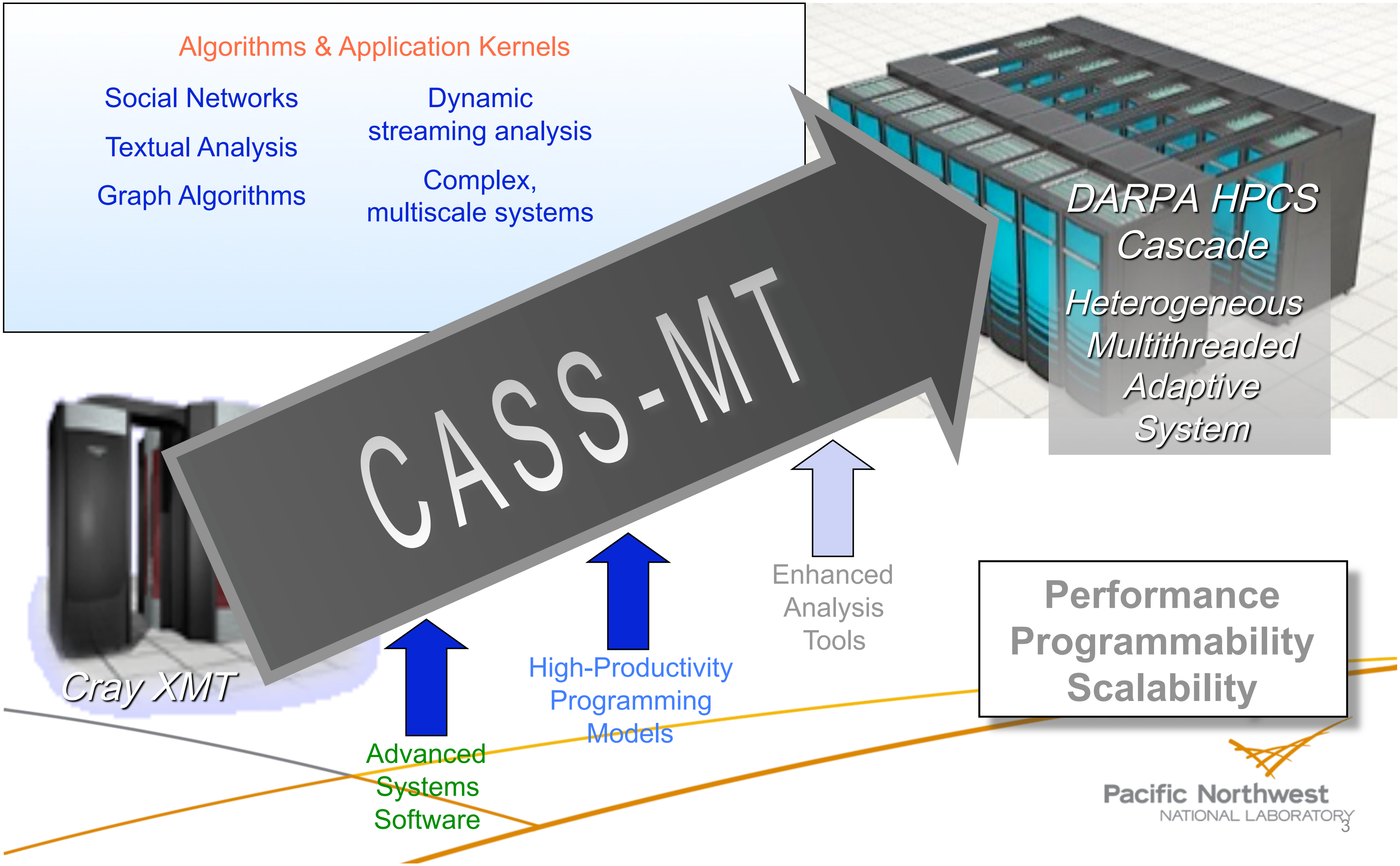
- Partners:
  - Pacific Northwest National Laboratory
  - Cray, Inc.
  - Georgia Institute of Technology
  - Sandia National Laboratories

Vision for CASS-MT

- The Center for Adaptive Supercomputing Software focuses on emerging multithreaded architectures & applications
- Partners:
  - Cray, Inc., Georgia Institute of Technology, Sandia National Laboratories
- Activities:
  - Research on systems software, programming environments & applications
  - Close collaboration with Cray for product feedback & enhancement
  - Provide expertise and help on using XMT systems and porting and optimizing applications
- Outreach:
  - Provide XMT system availability to external & internal researchers
  - Advocacy for emerging multithreaded architectures within the research community: government agencies, industry and academia

CRAY THE SUPERCOMPUTER COMPANY Georgia Tech Sandia National Laboratories Pacific Northwest NATIONAL LABORATORY

Strategy



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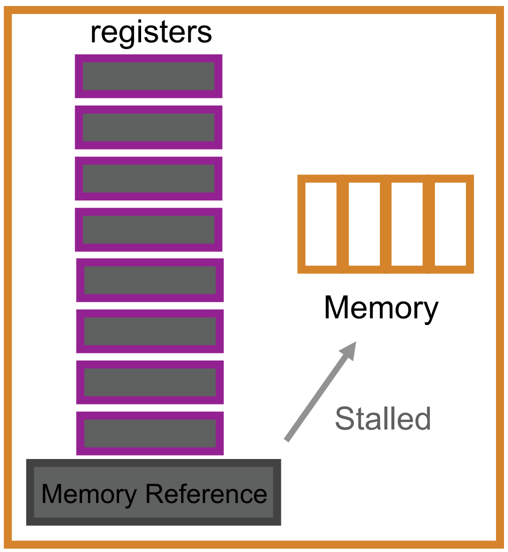
Why multithreading?

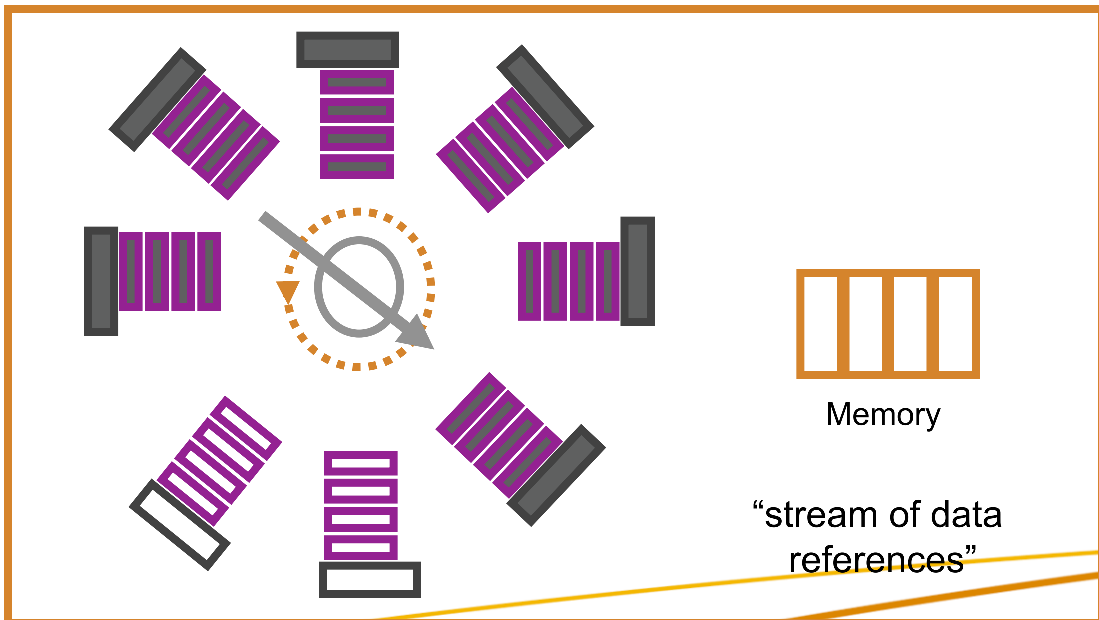
- Increasing gap between memory and processor speed
  - Causing many applications to become memory-bound
  - Mainstream processors utilize cache hierarchy
  - Caches not effective for **highly irregular, data-intensive applications**
- Multithreaded architectures provide an alternative
  - Switch computation context to hide memory latency
  - Enable parallel execution of non-traditional applications
  - Highly suitable for **large-scale, data-driven knowledge discovery**
- Example architectures:
  - Cray MTA-2 and XMT
  - Sun Niagara 1 and 2

Multithreading Advantage

- Quickly assimilates and processes data that is widely dispersed and therefore unsuitable for caches
- Many threads per processor core
- Thread-level context switch at every instruction cycle



Industry Standard Processor



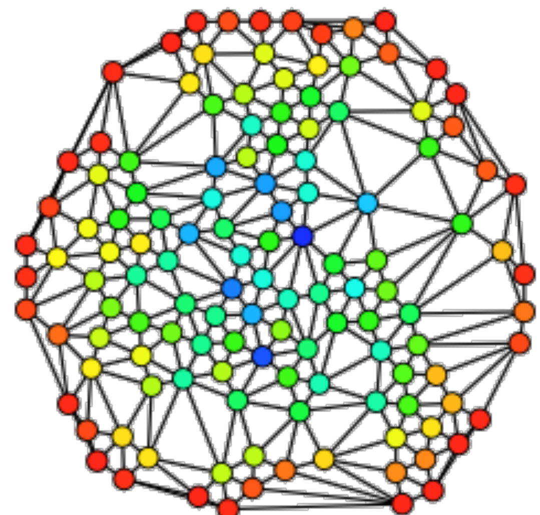
Representation of Cray’s Threadstorm Processor

Research Areas

- Algorithms & Application Kernels
  - Advanced Social Network Analysis
  - Statistical Textual Document Analysis
  - Dynamic Network Analysis
  - Sparse Graph network-of-networks Algorithms
  - Contingency Analysis
- Advanced Systems Software
  - An Efficient XMT Database System
- High-productivity Programming Models
  - Compiler and runtime enhancements
  - Hybrid Computing in Chapel

Advanced Social Network Analysis (Georgia Tech)

- Goal: design of novel EXASCALE multithreaded algorithms for processing large-scale dynamic interaction networks
- New multithreaded algorithms that can analyze billion entity graphs for
  - Graph traversal and shortest paths
  - Connectivity in dynamic networks
  - Centrality
  - Community Identification



- Target Applications:
  - Intelligence and Surveillance
  - Systems Biology: epidemiology, protein function prediction
  - Internet Algorithms
- We are extending the SNAP graph analysis framework to design scalable graph analytical algorithms for the Cray XMT multithreaded architecture.

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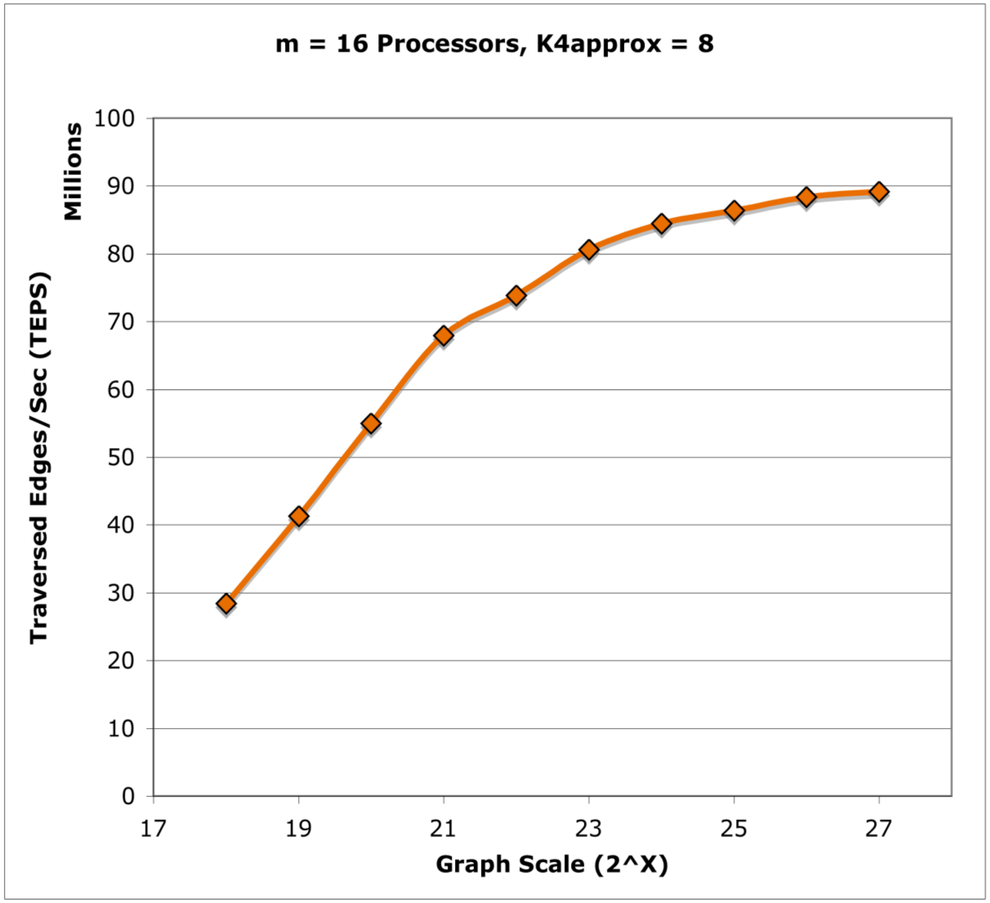
Case Study: DARPA HPCS SSCA2 Graph Analytics Benchmark on Cray XMT

- The DARPA HPCS SSCA2 benchmark is representative of irregular, predominantly integer-based computations in complex network analysis
- Compute-intensive kernel: Betweenness Centrality
- Input: Synthetic complex network (power-law degree distribution, low diameter) with 135 million vertices and **1.05 billion edges**
- Performance on 16 Cray XMT processors: approx **90 million TEPS** (Traversed Edges Per Second)



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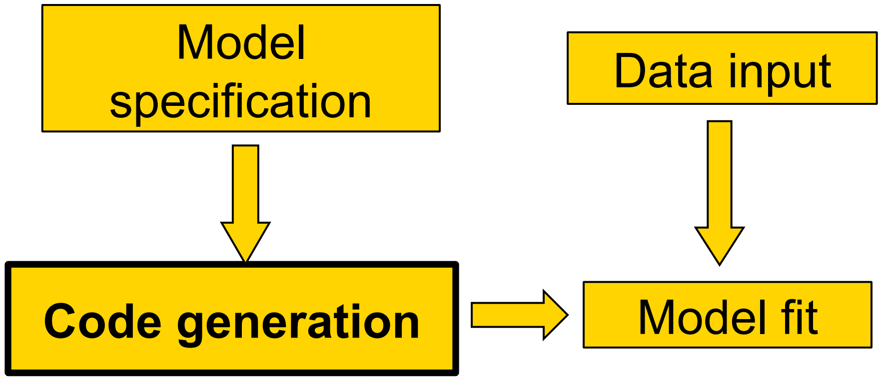
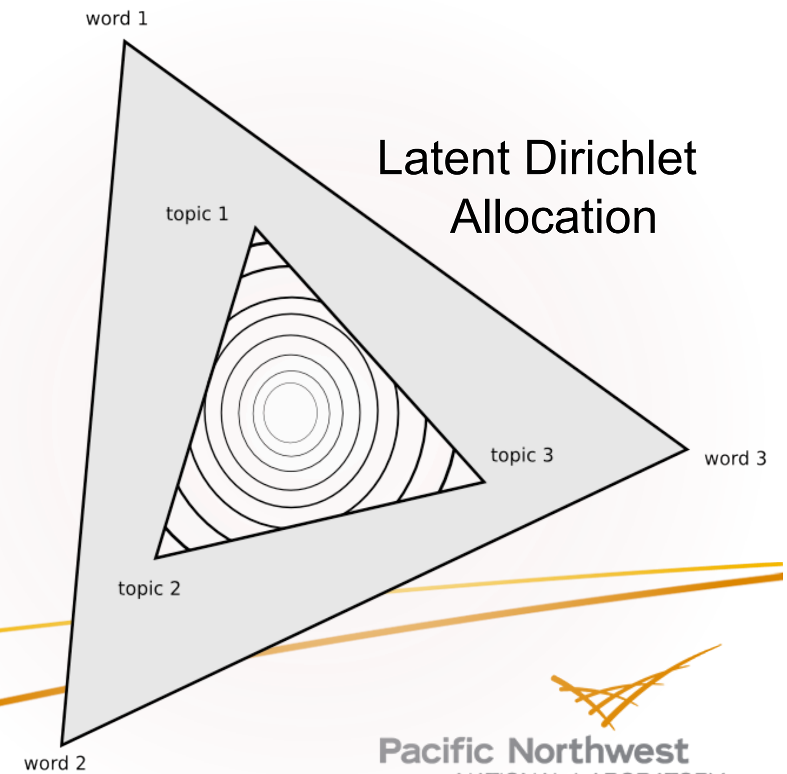
Statistical Textual Document Analysis

- Bring high-productivity, high-performance modeling capability to domain specialists
- Start with a declarative, high-level specification of a hierarchical Bayesian model
- Generate optimized parallel C code by exploiting model structure at code generation time
- Initially focus on Latent Dirichlet Allocation, a popular text analysis model
- Use table lookup approach and leverage available memory subsystem specifications to optimize numeric functions
  - **20x speedup for log(x)**



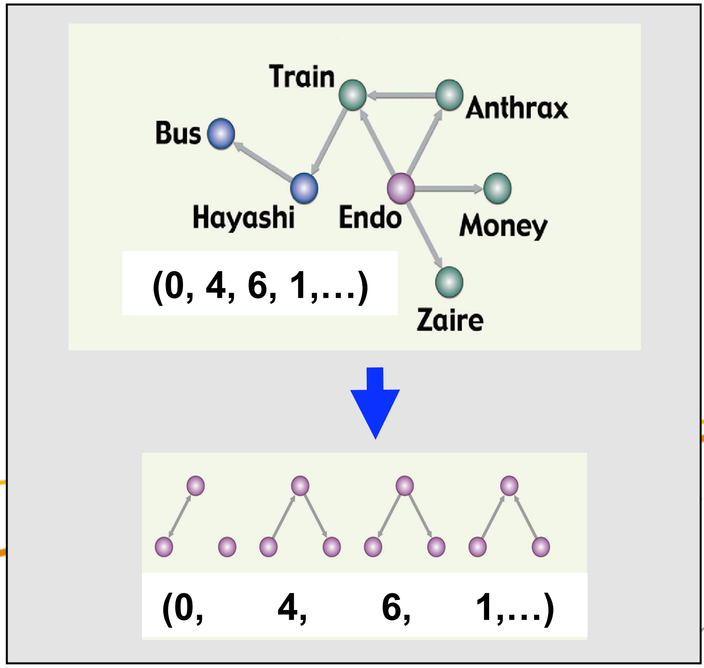


Dynamic Network Analysis

- Dynamic networks (DNs) represent dynamic (often time dependent) systems and processes in which nodes and edges may appear and disappear, loads and bandwidths may fluctuate, and services and contents may move across nodes
- DNs are often large-scale with multiple types of nodes and links
- Algorithms are computationally complex and employ graph data structures; they are typically irregular applications with random memory access patterns
- DNs link to dynamic and/or real-time data sources – require high performance I/O to handle high volumes of dynamic data
- Objective is to port and implement specific classes of DN algorithms (dynamic social and Bayesian networks) on Cray XMT to test and evaluate XMT unique capabilities.

Dynamic Social Network Analysis - Triadic and Quadratic Analysis

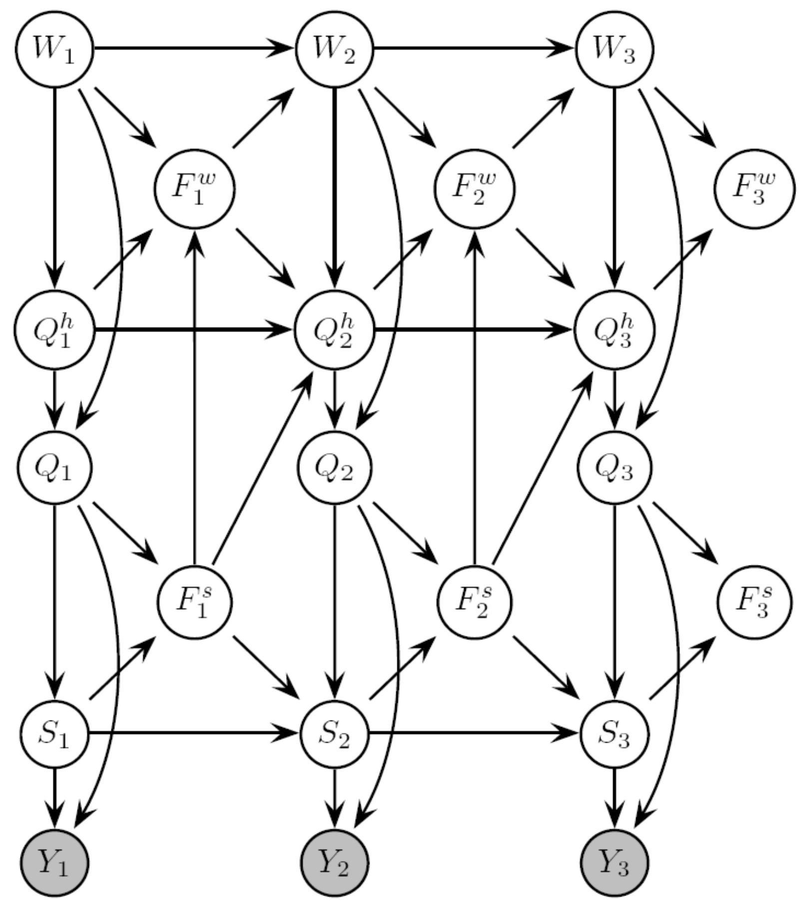
- Extend triadic and quadratic analysis algorithms to support dynamic networks
- Computes triad or quad censuses for network at frame or time step
- Examine transitions of triads or quads across frames to determine network behavior
- Complexity: Triads - $O(n^3)$, Quads - $O(n^4)$
- Applications: social networks, link analysis, computer networks



Dynamic Network Analysis (cont.)

Dynamic Bayesian Networks (DBNs)

- Bayesian networks (BNs) are represented as directed acyclic graphs with nodes corresponding to random variables and edges corresponding to conditional independencies between variables
- DBNs model stochastic evolution of set of variables often over time
- With DBNs, discrete time is introduced and conditional distributions are related to parent variable values of the previous time point
- Standard BN requirement for graph acyclicity is often relaxed for DBNs
- Inferencing and learning in DBNs are NP-hard
- Applications: speech recognition, bionetwork analysis, social networks, computer networks



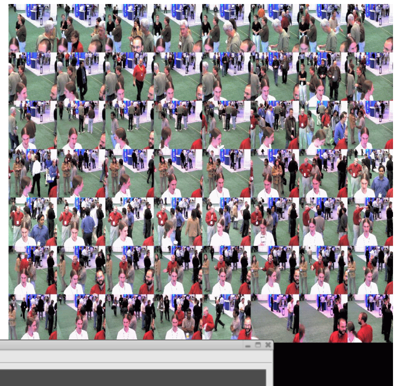
Sparse Graph Network-of-Networks Algorithms

- Our focus is to provide better solutions for the analyst to one of the most challenging problems in the intelligence analysis community: how to distill massive amounts of data (e.g., multiple live-streams of data or large databases) into reduced forms that can feed into a decision matrix and then be presented to an analyst or decision maker

- One of the core technologies of this data reduction process is sparse graph network-of-networks methods.
- Fortunately, the intelligence community is not left to totally solve these types of problems by themselves because sparse graph problems arise in many application areas, including: image processing, informatics, simulation/ modeling, decision making analysis, battlefield analysis, etc.
- The important concept is that there are algorithmic kernels that are common between theses applications. (Examples include: S-T connectivity, sub-graph isomorphism, connected components, BFS searching and sparse matrix vector multiplication).
- Defining these computational kernels in light of new multi-threaded and special purpose computers can provide big performance, power, and scalability benefits, which will translate for the analyst (and soldier) into better, smaller, and real-time reductions in data volume.

Application to Video Analysis

SC05 Videos



Streaming video

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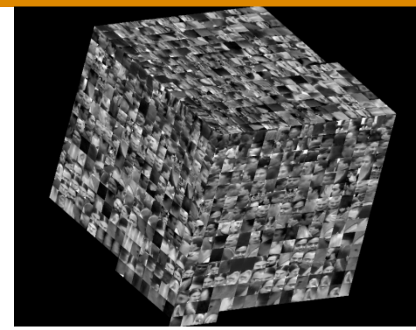
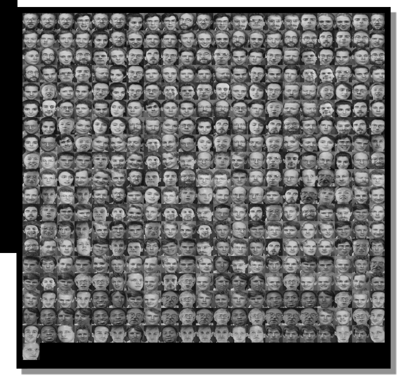
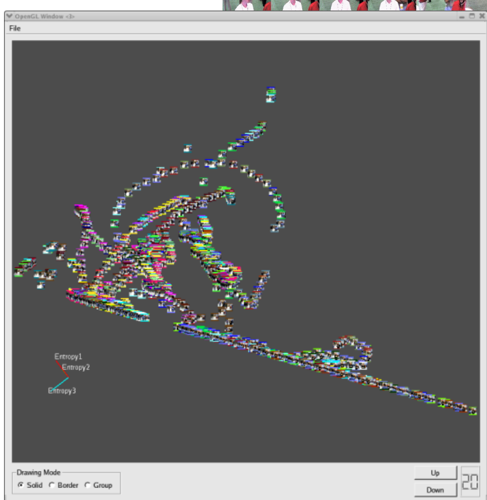
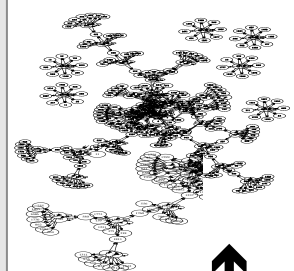
Face database



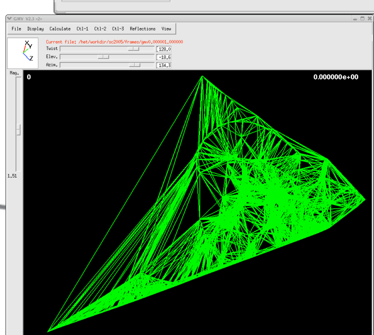


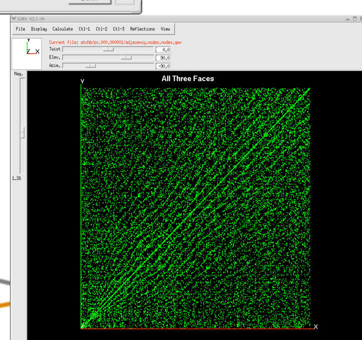


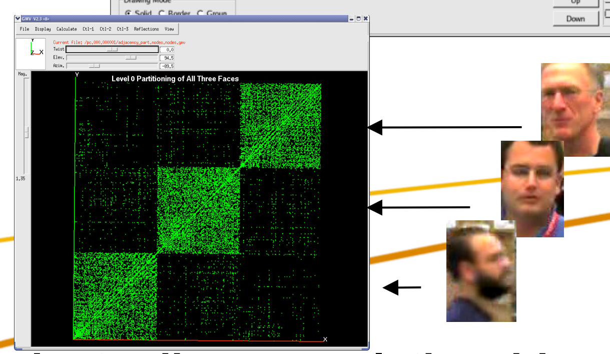
Building Social Network Graphs From Face Data and Face DB



Social Network







Partitioning face based graphs to discover relationships

Advanced Contingency Analysis

- **Fast contingency selection**
  - Graph centrality applied to **power grid** topology to identify non-critical elements
  - Massive number sorting to identify high-index contingency cases
- **Contingency post-processing to convert large amounts of data to actionable information**
  - User-friendly visualization
  - Graph trending
  - Interactive graphing
- **Expected Outcomes**
  - An advanced tool for contingency analysis to support the operation of the nation’s critical infrastructures, e.g. power grids
  - Analysis capabilities through generic implementation of algorithms on Cray XMT Threadstorm processors, applicable to other problems

Advanced Contingency Analysis (cont.)

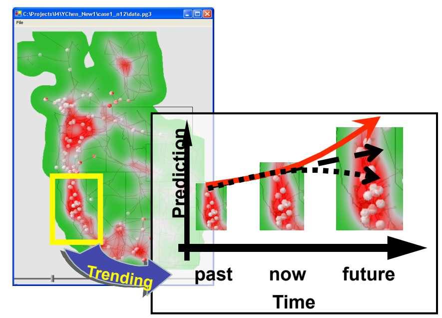
Industry Need: Multi-failure (N-x) contingency analysis

Issue: Massive number of cases | Massive amount of data

Need: **Smart case selection** | **Operator-oriented data processing**

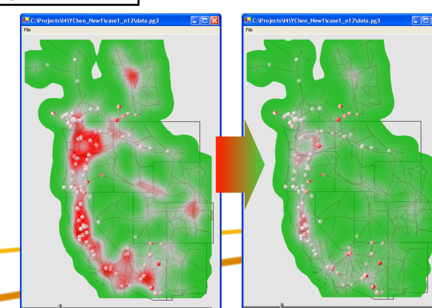
Our Solution:

10^Z cases → 10^Y cases → 10^X cases → Contingency Analysis → Data



Our Tasks:

- **Graph Theory**
- **Contingency Index Sorting**
- **Visual Analytics & Graph Trending**
- **Interactive Graphing**



Expected Outcomes:

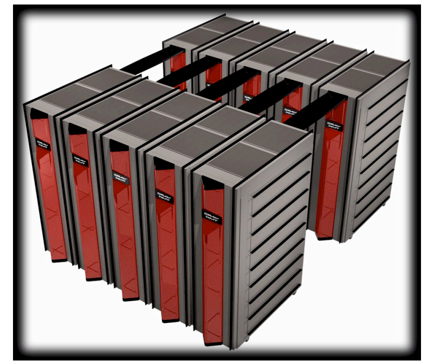
- An advanced tool for contingency analysis to support the operation of the nation's critical infrastructures, e.g. power grids
- Analysis capabilities through generic implementation of algorithms on Cray XMT ThreadStorm processors, applicable to other problems

An Efficient XMT Database System (Sandia/ Cray)

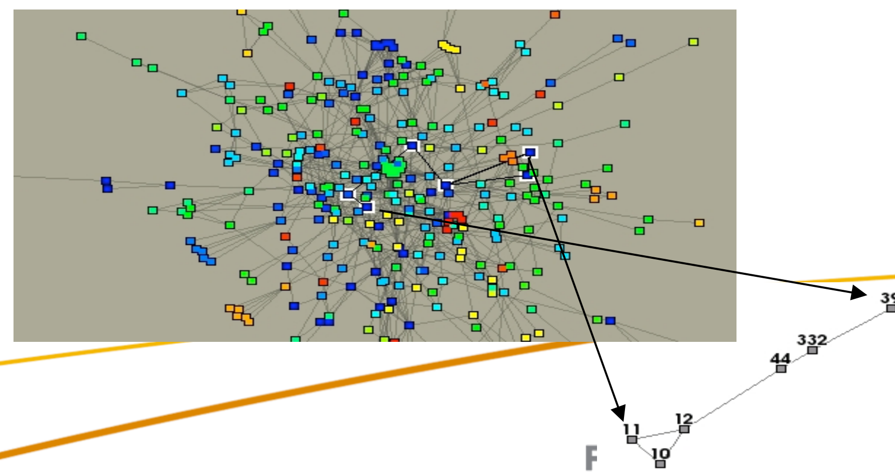
- Simple attribute queries are easy to parallelize, but not complex data analysis algorithms
  - E.g. bio-informatics, homeland security, infrastructure modeling, etc.
    - Networks and graphs are central to these applications
  - Performance is limited by latency of complex memory access patterns
- The XMT has the potential to provide transformative capabilities for such problems
  - Handful of XMT processors can solve some analysis problems as fast as 32,000 BlueGene processors!
- Goal: Create a system for data analysis on XMT
  - Key missing piece is data management engine

XMT Data Management

- We are creating an in-memory data system for the XMT
  - Exploit large shared address space and latency tolerance

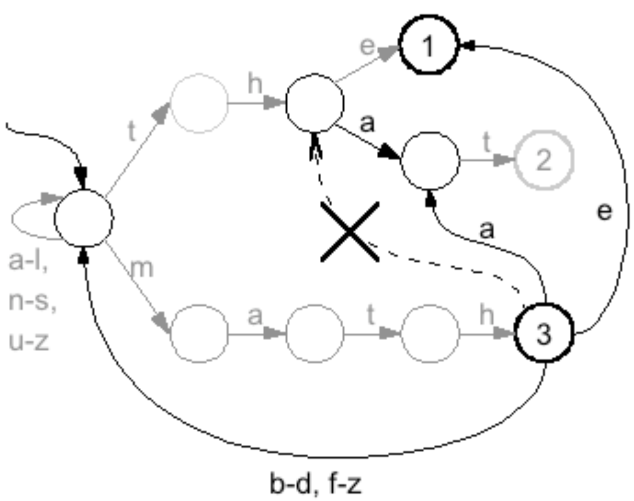


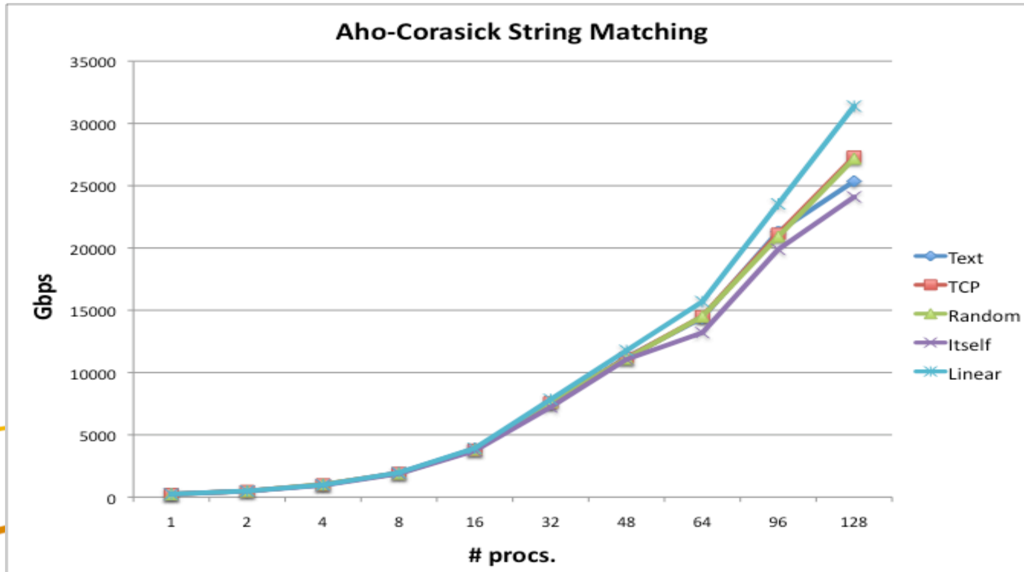
- Key tasks
  - Design data structures for complex data
  - Devise efficient multithreaded algorithms
  - Improve XMT's I/O capabilities
  - Interface with advanced graph analysis tools like Sandia's Multithreaded Graph Library



High-Performance String Matching on the Cray XMT

- Fast, scalable string matching is at the base of modern cybersecurity applications
  - Deep packet inspection for malware
- Performance has to be consistent and content independent
  - At the same system should be flexible and programmable
  - Prevent content-based attacks
- Excellent scalability and performance on the XMT





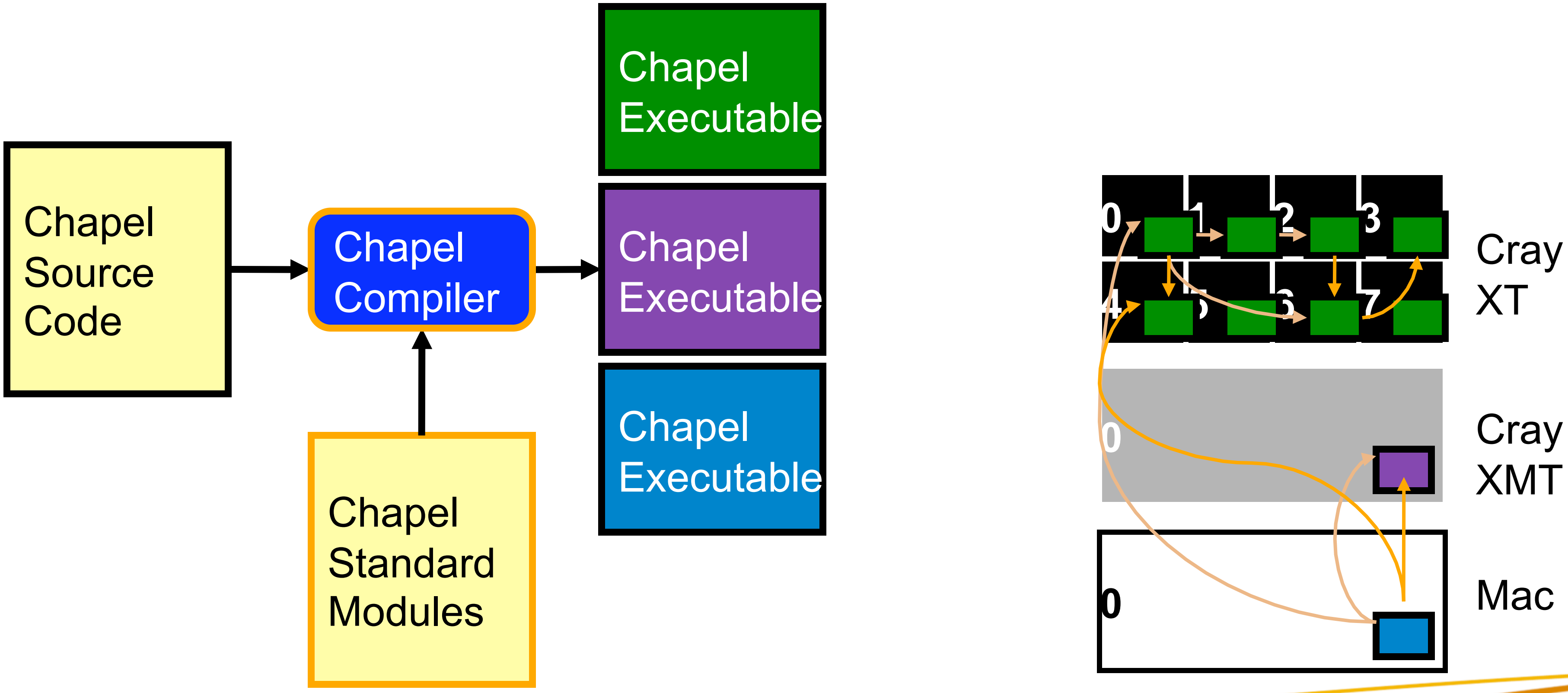
Chapel

Chapel: a new parallel language being developed by Cray Inc.

Themes:

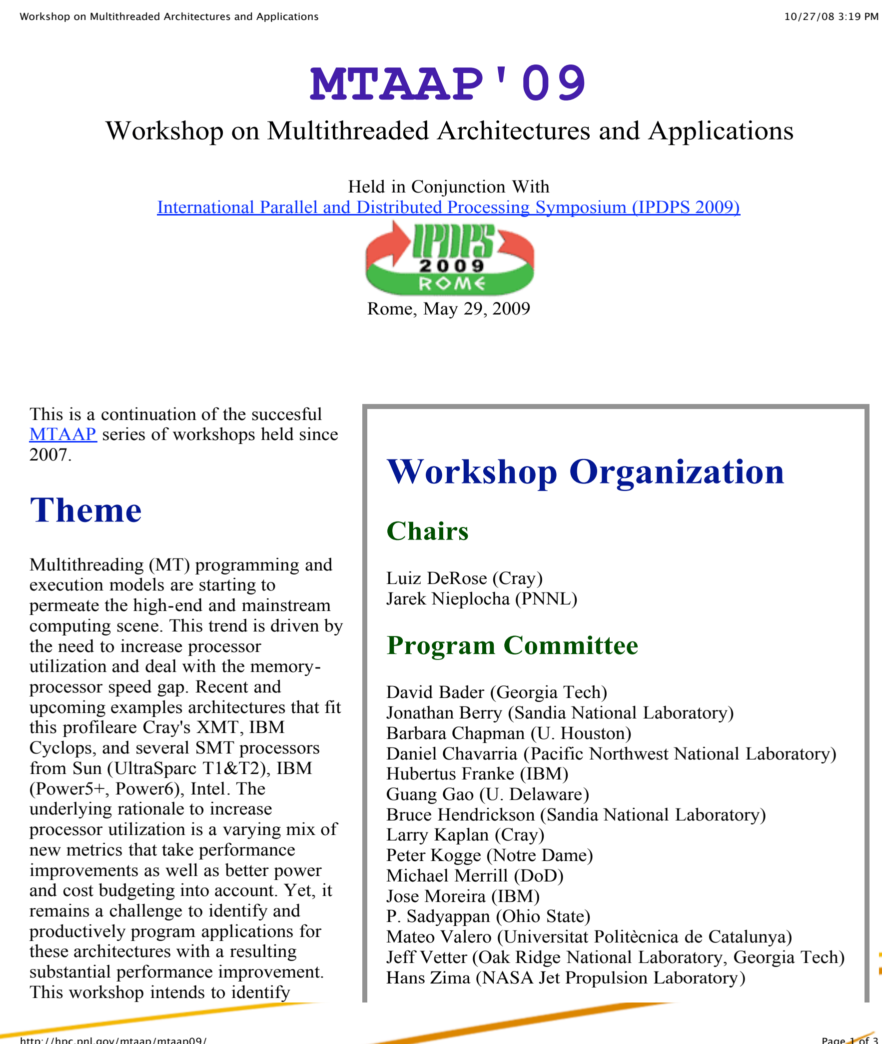
- **general parallel programming**
  - data-, task-, and nested parallelism
  - express general levels of software parallelism
  - target general levels of hardware parallelism
- ***global-view* arrays and control flow**
- ***multiresolution* design**
- **control of locality**
- **reduce gap between mainstream & parallel languages**

Compilation of Hybrid Chapel Programs



Advocacy for Multithreaded Architectures

- Advocate multithreaded architectures
  - Workshops (MTAAP’09, part of IEEE IPDPS’09)
  - Summer school
- Provide access to the XMT to researchers from other labs, government agencies, and academia
- Share expertise and help with porting and tuning of applications
- **SC’08 BOF 11/18/08 3:00 – 4:30 PM Courtyard by Marriott Hotel**



Workshop on Multithreaded Architectures and Applications 10/27/08 3:19 PM

MTAAP'09

Workshop on Multithreaded Architectures and Applications

Held in Conjunction With
International Parallel and Distributed Processing Symposium (IPDPS 2009)

IPDPS 2009 ROME

Rome, May 29, 2009

This is a continuation of the succesful MTAAP series of workshops held since 2007.

Theme

Multithreading (MT) programming and execution models are starting to permeate the high-end and mainstream computing scene. This trend is driven by the need to increase processor utilization and deal with the memory-processor speed gap. Recent and upcoming examples architectures that fit this profileare Cray's XMT, IBM Cyclops, and several SMT processors from Sun (UltraSparc T1&T2), IBM (Power5+, Power6), Intel. The underlying rationale to increase processor utilization is a varying mix of new metrics that take performance improvements as well as better power and cost budgeting into account. Yet, it remains a challenge to identify and productively program applications for these architectures with a resulting substantial performance improvement. This workshop intends to identify

Workshop Organization

Chairs

Luiz DeRose (Cray)
Jarek Nieplocha (PNNL)

Program Committee

David Bader (Georgia Tech)
Jonathan Berry (Sandia National Laboratory)
Barbara Chapman (U. Houston)
Daniel Chavarria (Pacific Northwest National Laboratory)
Hubertus Franke (IBM)
Guang Gao (U. Delaware)
Bruce Hendrickson (Sandia National Laboratory)
Larry Kaplan (Cray)
Peter Kogge (Notre Dame)
Michael Merrill (DoD)
Jose Moreira (IBM)
P. Sadyappan (Ohio State)
Mateo Valero (Universitat Politècnica de Catalunya)
Jeff Vetter (Oak Ridge National Laboratory, Georgia Tech)
Hans Zima (NASA Jet Propulsion Laboratory)

http://hpc.pnl.gov/mtaap/mtaap09/ Page 1 of 3