MxN Data Redistribution for Coupling Disparate Parallel Components

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Coupled Multi-Physics Simulations

• Improved Fidelity from Live Coupling
  ⇒ Dynamic Feedback versus Static Boundaries
  ⇒ More Accurate Overall System Modeling

• Capitalize on Domain Expertise
  ⇒ Combine “Best” Interdisciplinary Software

• Mechanism for Next-Generation Collaboration

• Applications of Coupling:
  ⇒ Climate, Fusion, Biology, Numerical, Visualization
What’s the Catch?

• Independently Developed Models Use:
  ⇒ Different Meshes and Time Scales
  ⇒ Different Programming Models and Languages
  ⇒ Different Data Structures and Decompositions

• Coupling Therefore Requires:
  ⇒ Spatial and Temporal Interpolation
  ⇒ Language Interoperability & Component Tools
  ⇒ Parallel Data Exchange and Redistribution
    • Synchronization, Communication Schedules
The “Basic” Problem:
MxN Parallel Data Exchange
MxN Layered Structure

- High-Level MxN Run-Time Library
- MxN Data Exchange and Synchronization
- Parallel Data Mapping and Communication
- Data Decomposition Specification
- Data Distribution System
- Local Data
The Common Component Architecture (CCA)

- Component-Based Software Engineering
  ⇒ Manage Complexity of Scientific Simulation Software
- Successful in Business ~ Corba, DCOM, EJB
  ⇒ Add Performance, Languages, Science Data Models, and MxN Parallel Data Redistribution!
- National Forum (Open) / DOE SciDAC Center

http://www.cca-forum.org/
Why Components?

The task of the software development team is to engineer the illusion of simplicity [Booch].
Why Components?

• Well-Defined Abstract Interfaces
  ⇒ No “Cheating” Allowed…
  • Hides Implementation Details (Separated Name Spaces)
  • Combine Multiple Implementations in Same Code
  ⇒ Note: Cost of Standardization Efforts…

• Eases Code Re-use, Enables Swapping
  ⇒ Simple Wrappers, Bridge Language Gaps
  ⇒ “Port” Abstraction Enables Intelligent Proxies…

The task of the software development team is to engineer the illusion of simplicity [Booch].
MxN Interface

Parallel Data Exchange Operations

⇒ Describe and “Register” Data/Decompositions
⇒ Map Data Elements ~ “Communication Schedules”
⇒ Build Synchronized MxN “Connections”
⇒ Initiate Data Transfers Asynchronously: “dataReady()”

Generalizes Existing Tools:
⇒ CUMULVS, PAWS, Meta-Chaos

Several interface evolutions (ongoing…)
⇒ Reconciling appropriate level of detail & flexibility
MxN “Explicit” Component Solution

• Port-based direct invocation of MxN methods
  ⇒ Most general solution, but…
  ⇒ More challenging to the end-user scientist.
    • “Assembly language” level interface…
    • Preliminary platform for experimentation

• Several implementations have evolved…
  ⇒ Using generalized DistArrayDescriptor
  ⇒ Basic inter-framework capabilities
  ⇒ Visualization, Coupling
Future Work ~ “Implicit” Solutions

- Need simpler, high-level interfaces
  ⇒ For the non-expert… even automated handling
- Targeting built-in framework services
  ⇒ Capture method invocations via port indirection
  ⇒ Implicitly apply MxN functions to reconcile parallel data arguments & returned results
- Increases framework complexity
  ⇒ Use pluggable service registration!
  ⇒ Requires additional method specifications…
Parallel Remote Method Invocation (PRMI)

- Next step beyond “simple” data exchange…
  - Method itself has parallel context
  - Specification of semantics and policies is key!
- Preliminary PRMI progress:
  - PAWS prototype and early policy identification
    - Invocation scheduling, marshalling arguments & results
  - 2nd SCIRun prototype explores method specification
    - SIDL extensions for “independent” and “collective” methods
    - With sub-grouping, generalizes PRMI invocation semantics
- Still much research ahead…
  - Transport mechanisms (SOAP, etc)
  - Parallel data argument & results meta-data specification…
Distributed MxN Data Scenarios

• Incompatible with Parallel MxN
  ⇒ No co-location components
  ⇒ Different connection semantics

• Distributed-Parallel Framework
  ⇒ Experimental ~ “DCA” (Indiana)
  ⇒ Process Participation & Synch
    • MPI Communicator Groups
  ⇒ Manual Argument Redistribution
    • Who dictates layout reconciliation?
      → Caller or Callee…?

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MxN and Climate (MCT / ESMF)

• Climate-specific coupling models & technology
  ⇒ Amenable to generalized MxN specification
  ⇒ Two-way integration underway…
    • Re-package MCT/ESMF as CCA components
    • Build MxN component on top of MCT/ESMF

• Ongoing reconciliation of terms and concepts
  ⇒ Between MxN and MCT, and CCSM and ESMF…

• Componentization of CCSM models
  ⇒ Atmosphere, ocean, sea-ice, land-surface, river-runoff, plus flux couplers…
Scalable Visualization Cache Architecture

- Increasingly Massive Scientific Data Sets
  ⇒ Too Large to Fully Explore / Visualize Interactively
- Modular, Layered Viz Cache Framework
  ⇒ Parallel Storage, Analysis & Reduction Per Layer
  ⇒ Independent Memory & Disk Cache Per Layer
  ⇒ Navigate & Zoom Through Hierarchy

SDM & ASPECT
Data Reduction

CCA / MxN
CUMULVS

Terabyte+ Data
Reorganized Data For Viz
100s of GBs
10s of GBs
100s of MBs
Parallel Rendering
Display

R3() R2() R1() R0()
“Real” Model Coupling…

• MxN parallel data redistribution is just the beginning of real model coupling…

• Need interpolation and data translation
  ⇒ Spatial ~ different meshes & coordinate spaces
  ⇒ Temporal ~ different time frames / rates
  ⇒ Flux Conservation
  ⇒ Units Conversion

• Must explore composing “filters” with MxN
  ⇒ Pipeline efficiency and compound “Quality of Service”
MxN Summary

- Stable MxN specification and component solutions
  ⇒ Next step ~ implicit framework services
- Parallel Remote Method Invocation (PRMI)
  ⇒ Initial semantics being defined, much to do…
- Distributed MxN Framework Experiments (DCA)
  ⇒ Culminating Generalization of Parallel/Distributed…
- Tip of the iceberg for production model coupling
  ⇒ Need development of suite of interpolation “filters”…

http://www.csm.ornl.gov/cca/mxn/