Tutorial: The Zoltan Toolkit

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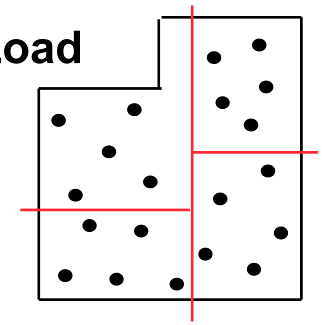
Outline

- High-level view of Zoltan
- Requirements, data models, and interface
- Dynamic Load Balancing and Partitioning
- Matrix Ordering
- Graph Coloring
- Utilities
- Alternate Interfaces
- Future Directions

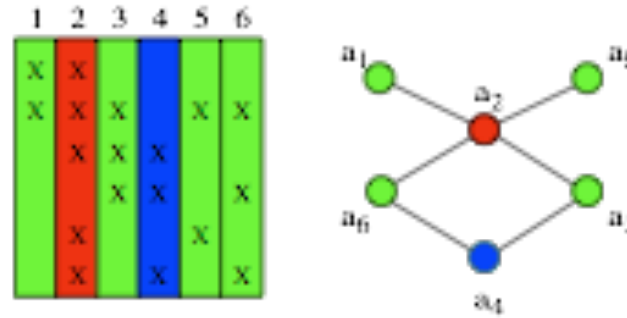
The Zoltan Toolkit

- Library of data management services for unstructured, dynamic and/or adaptive computations.

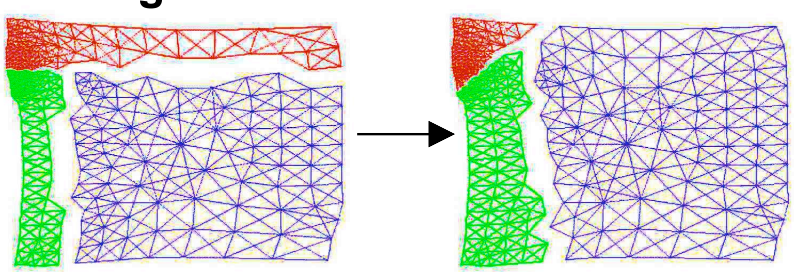
Dynamic Load Balancing



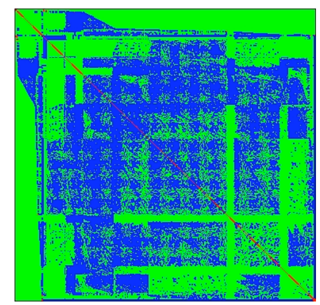
Graph Coloring



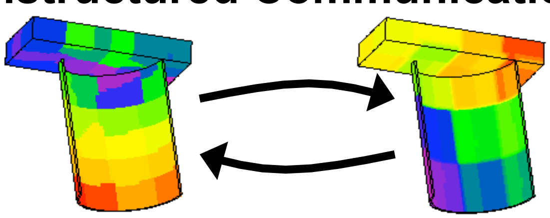
Data Migration



Matrix Ordering



Unstructured Communication



Distributed Data Directories

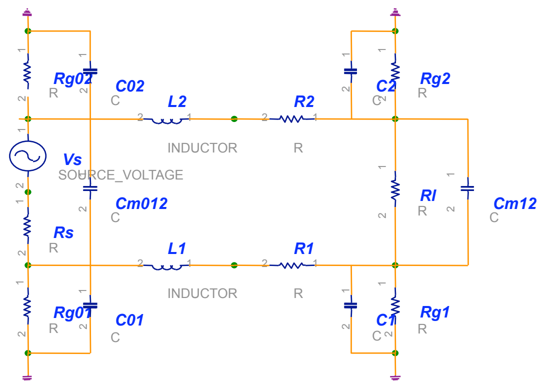
A	B	C	D	E	F	G	H	I
0	1	0	2	1	0	1	2	1

Zoltan System Assumptions

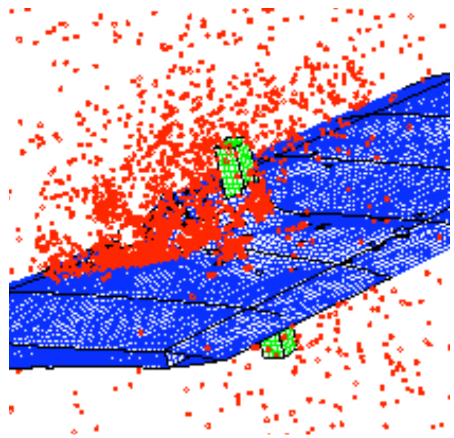
- Assume distributed memory model.
- Data decomposition + "Owner computes":
  - The data is distributed among the processors.
  - The owner performs all computation on its data.
  - Data distribution defines work assignment.
  - Data dependencies among data items owned by different processors incur communication.
- Zoltan is available in Trilinos since version 9.0
- Requirements:
  - MPI
  - C compiler
  - Autotools or CMake.

Zoltan Supports Many Applications

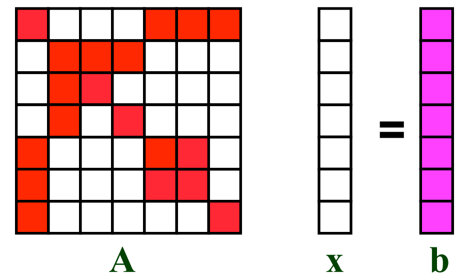
- Different applications, requirements, data structures.



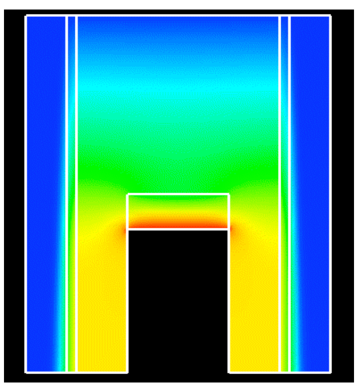
Parallel electronics networks



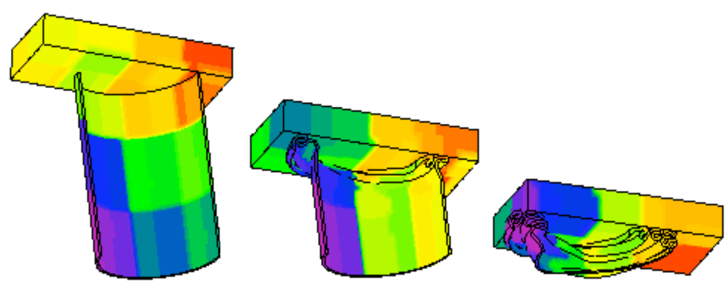
Particle methods



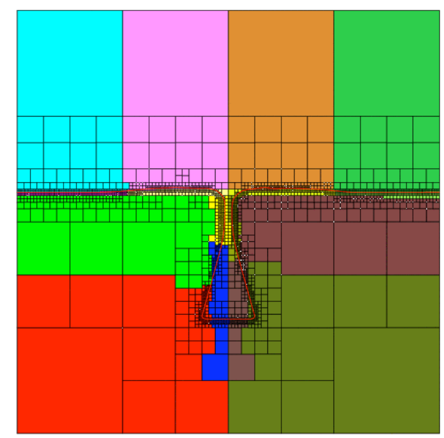
Linear solvers & preconditioners



Multiphysics simulations



Crash simulations



Adaptive mesh refinement

Zoltan Interface Design

- **Common interface to each class of tools.**
- **Tool/method specified with user parameters.**

- **Data-structure neutral design.**
  - **Supports wide range of applications and data structures.**
  - **Imposes no restrictions on application's data structures.**
  - **Application does not have to build Zoltan's data structures.**

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Zoltan Interface

- Simple, easy-to-use interface.
  - Small number of callable Zoltan functions.
  - Callable from C, C++, Fortran.
- Requirement: Unique global IDs for objects to be partitioned/ordered/colored. For example:
  - Global element number.
  - Global matrix row number.
  - (Processor number, local element number)
  - (Processor number, local particle number)

Zoltan Application Interface

- Application interface:
  - Zoltan queries the application for needed info.
    - IDs of objects, coordinates, relationships to other objects.
  - Application provides simple functions to answer queries.
  - Small extra costs in memory and function-call overhead.
- Query mechanism supports…
  - Geometric algorithms
    - Queries for dimensions, coordinates, etc.
  - Hypergraph- and graph-based algorithms
    - Queries for edge lists, edge weights, etc.
  - Tree-based algorithms
    - Queries for parent/child relationships, etc.
- Once query functions are implemented, application can access all Zoltan functionality.
  - Can switch between algorithms by setting parameters.

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Zoltan Application Interface

APPLICATION

Initialize Zoltan
(Zoltan_Initialize, Zoltan_Create)

↓

Select Method and Parameters
(Zoltan_Set_Params)

↓

Register query functions
(Zoltan_Set_Fn)

→

(Re)partition
(Zoltan_LB_Partition)

↓

Move data
(Zoltan_Migrate)

↓

COMPUTE

↓

Clean up
(Zoltan_Destroy)

ZOLTAN

Zoltan_LB_Partition:

- **Call query functions.**
- **Build data structures.**
- **Compute new decomposition.**
- **Return import/export lists.**

Zoltan_Migrate:

- **Call packing query functions for exports.**
- **Send exports.**
- **Receive imports.**
- **Call unpacking query functions for imports.**

Zoltan Query Functions

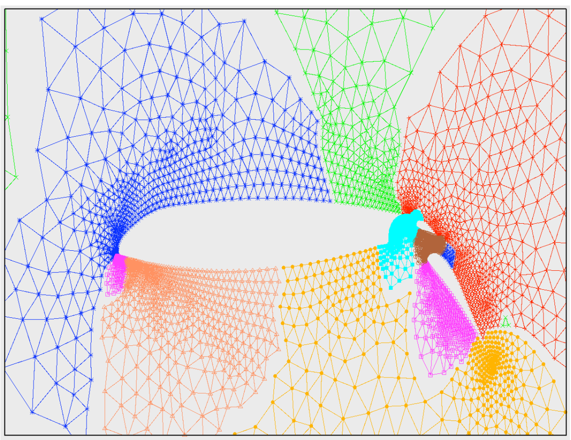
General Query Functions	
`ZOLTAN_NUM_OBJ_FN`	Number of items on processor
`ZOLTAN_OBJ_LIST_FN`	List of item IDs and weights.
Geometric Query Functions	
`ZOLTAN_NUM_GEOM_FN`	Dimensionality of domain.
`ZOLTAN_GEOM_FN`	Coordinates of items.
Hypergraph Query Functions	
`ZOLTAN_HG_SIZE_CS_FN`	Number of hyperedge pins.
`ZOLTAN_HG_CS_FN`	List of hyperedge pins.
`ZOLTAN_HG_SIZE_EDGE_WTS_FN`	Number of hyperedge weights.
`ZOLTAN_HG_EDGE_WTS_FN`	List of hyperedge weights.
Graph Query Functions	
`ZOLTAN_NUM_EDGE_FN`	Number of graph edges.
`ZOLTAN_EDGE_LIST_FN`	List of graph edges and weights.

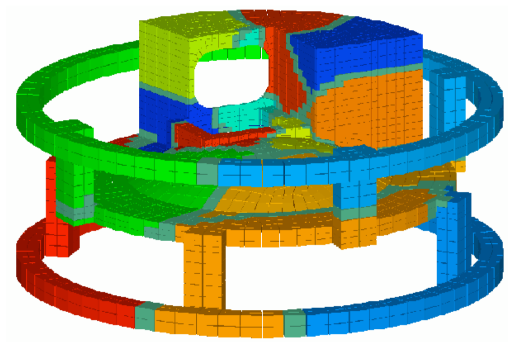
Using Zoltan in Your Application

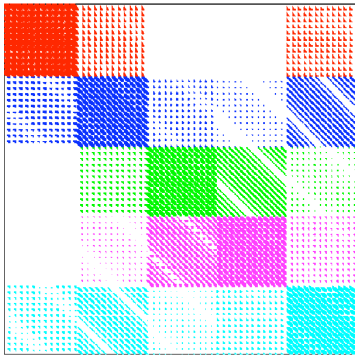
1. Decide what your objects are.
   - Elements? Grid points? Matrix rows? Particles?
2. Decide which tools (partitioning/ordering/coloring/utilities) and class of method (geometric/graph/hypergraph) to use.
3. Download Zoltan.
   - http://www.cs.sandia.gov/Zoltan (or http://trilinos.sandia.gov)
4. Write required query functions for your application.
   - Required functions are listed with each method in Zoltan User's Guide.
5. Call Zoltan from your application.
6. #include "zoltan.h" in files calling Zoltan.
7. Configure and build Zoltan.
8. Compile application; link with libzoltan.a.
   - mpicc application.c -lzoltan

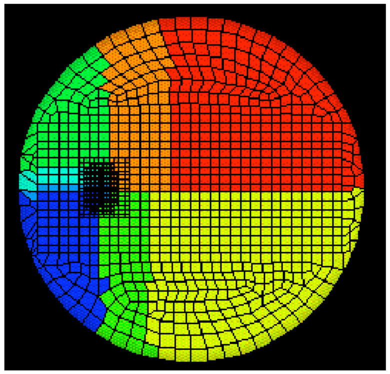
Partitioning and Load Balancing

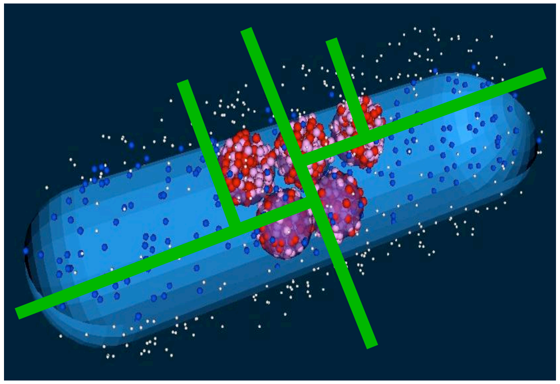
- Assignment of application data to processors for parallel computation.
- Applied to grid points, elements, matrix rows, particles, ….











Partitioning Interface

Zoltan computes the difference (Δ) from current distribution

Choose between:

a) Import lists (data to import from other procs)

b) Export lists (data to export to other procs)

c) Both (the default)

```
err = Zoltan_LB_Partition(zz,
    &changes, /* Flag indicating whether partition changed */
    &numGidEntries, &numLidEntries,
    &numImport, /* objects to be imported to new part */
    &importGlobalGids, &importLocalGids, &importProcs, &importToPart,
    &numExport, /* # objects to be exported from old part */
    &exportGlobalGids, &exportLocalGids, &exportProcs, &exportToPart);
```

Static Partitioning

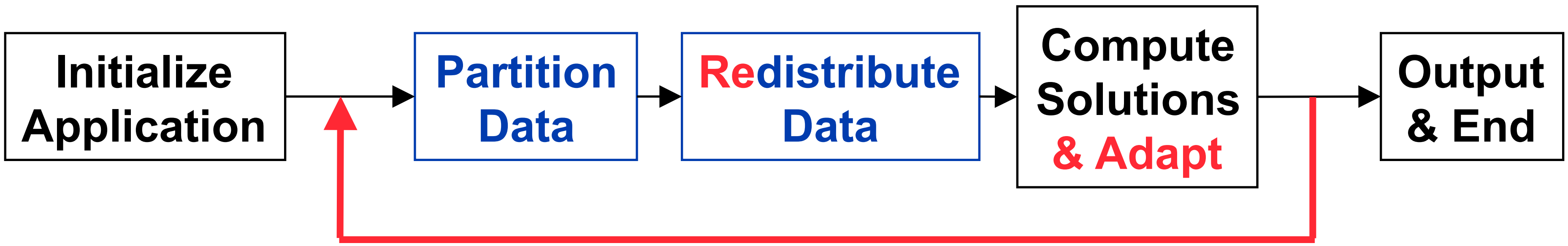
Initialize Application → Partition Data → Distribute Data → Compute Solutions → Output & End

- **Static partitioning in an application:**
  - **Data partition is computed.**
  - **Data are distributed according to partition map.**
  - **Application computes.**

- **Ideal partition:**
  - **Processor idle time is minimized.**
  - **Inter-processor communication costs are kept low.**

- **Zoltan_Set_Param(zz, “LB_APPROACH”, “PARTITION”);**

Dynamic Repartitioning (a.k.a. Dynamic Load Balancing)



- **Dynamic repartitioning (load balancing) in an application:**
  - **Data partition is computed.**
  - **Data are distributed according to partition map.**
  - **Application computes and, perhaps, adapts.**
  - **Process repeats until the application is done.**

- **Ideal partition:**
  - **Processor idle time is minimized.**
  - **Inter-processor communication costs are kept low.**
  - **Cost to redistribute data is also kept low.**

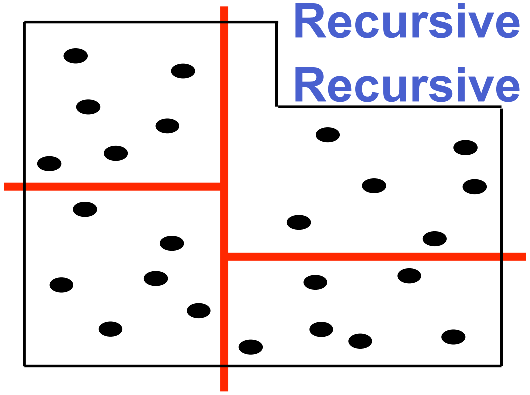
- **Zoltan_Set_Param(zz, “LB_APPROACH”, “REPARTITION”);**

Zoltan Toolkit: Suite of Partitioners

- No single partitioner works best for all applications.
  - Trade-offs:
    - Quality vs. speed.
    - Geometric locality vs. data dependencies.
    - High-data movement costs vs. tolerance for remapping.
- Application developers may not know which partitioner is best for application.
- Zoltan contains suite of partitioning methods.
  - Application changes only one parameter to switch methods.
    - Zoltan_Set_Param(zz, “LB_METHOD”, “new_method_name”);
  - Allows experimentation/comparisons to find most effective partitioner for application.

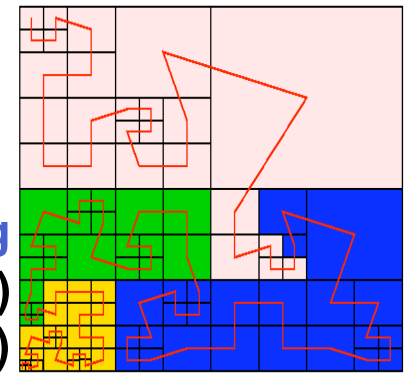
Partitioning Algorithms in the Zoltan Toolkit

Geometric (coordinate-based) methods



Recursive Coordinate Bisection **(Berger, Bokhari)**

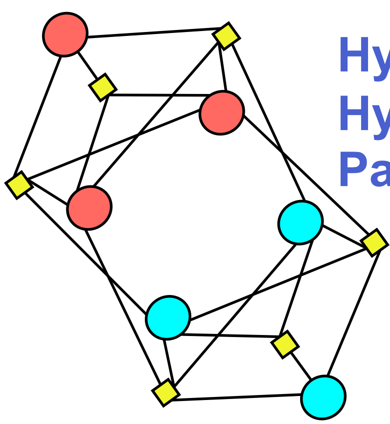
Recursive Inertial Bisection **(Taylor, Nour-Omid)**



Space Filling Curve Partitioning **(Warren&Salmon, et al.)**

Refinement-tree Partitioning **(Mitchell)**

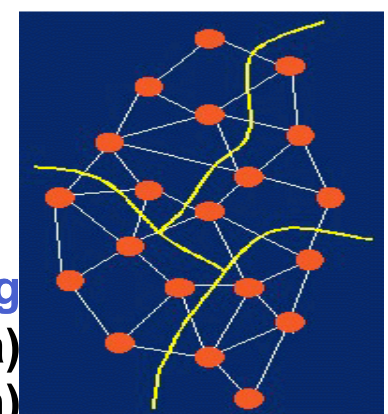
Combinatorial (topology-based) methods



Hypergraph Partitioning

Hypergraph Repartitioning

PaToH **(Catalyurek & Aykanat)**



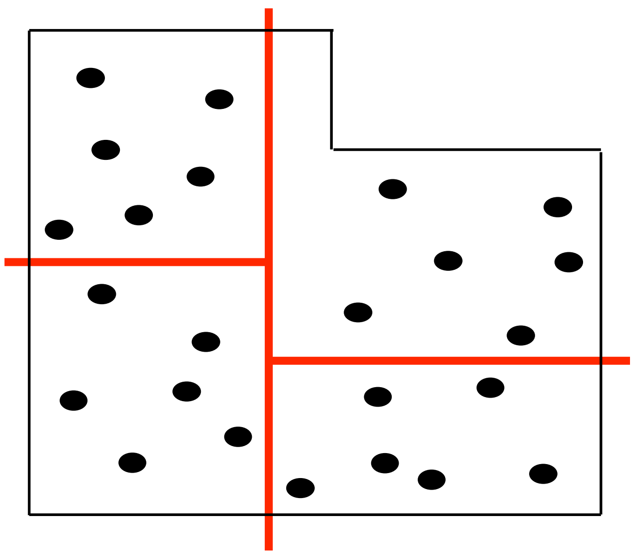
Zoltan Graph Partitioning

ParMETIS **(U. Minnesota)**

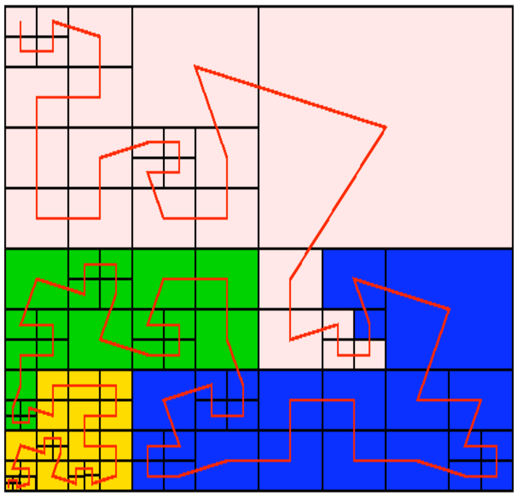
Jostle **(U. Greenwich)**

Geometric Partitioning

- Zoltan_Set_Param(zz, “LB_METHOD”, “RCB”);
  Zoltan_Set_Param(zz, “LB_METHOD”, “RIB”);
  Zoltan_Set_Param(zz, “LB_METHOD”, “HSFC”);
- Partition based on geometric locality.
  - Assign physically close objects to the same processor.



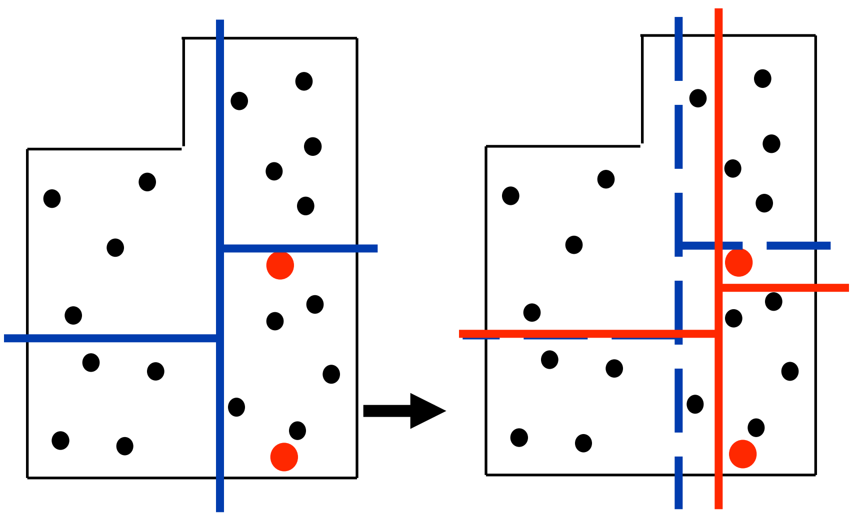
Recursive Coordinate Bisection (RCB)
Berger & Bokhari, 1987



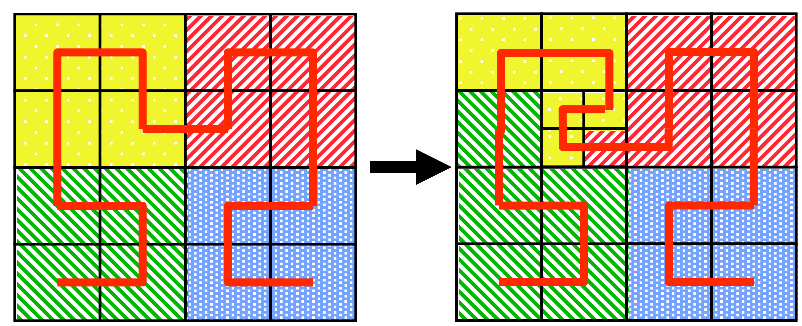
Space Filling Curve Partitioning (HSFC)
Warren & Salmon, 1993;
Pilkington & Baden, 1994; Patra & Oden, 1995

Geometric Repartitioning

- **No explicit control of migration costs, but…**
- **Implicitly achieves low data redistribution costs.**
- **For small changes in data, cuts move only slightly, resulting in little data redistribution.**

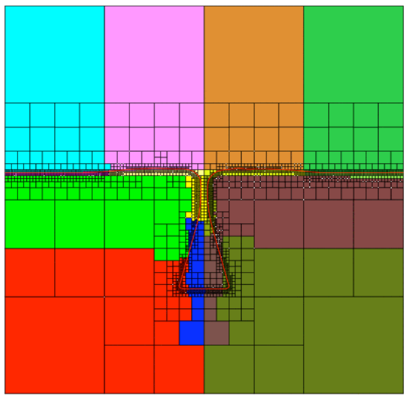


Recursive Coordinate Bisection (RCB)

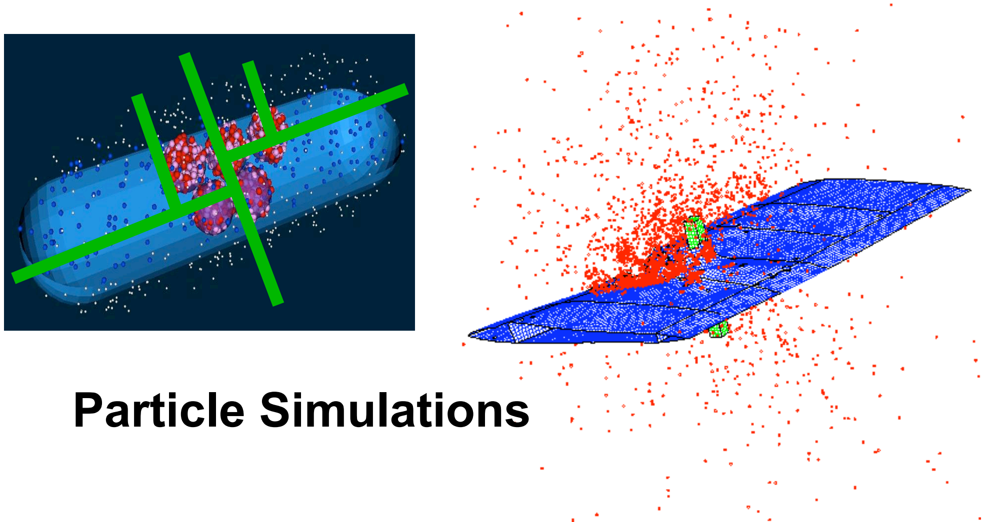


Space Filling Curve Partitioning (HSFC)

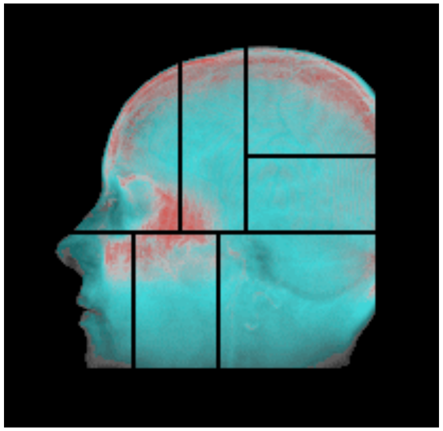
Applications of Geometric Partitioners



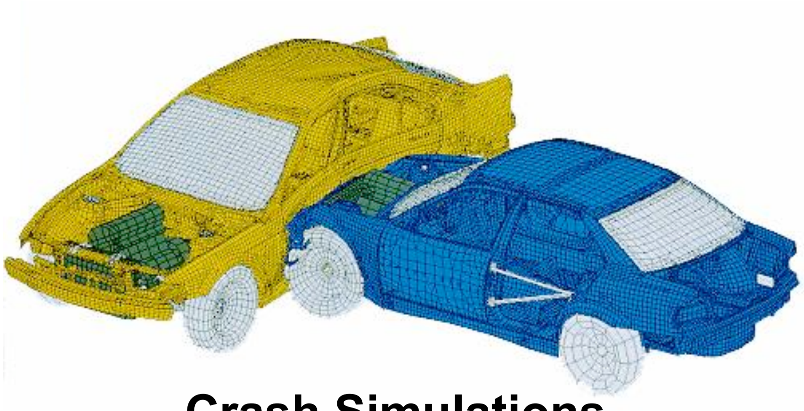
Adaptive Mesh Refinement



Particle Simulations



Parallel Volume Rendering



Crash Simulations
and Contact Detection

Geometric Methods: Advantages and Disadvantages

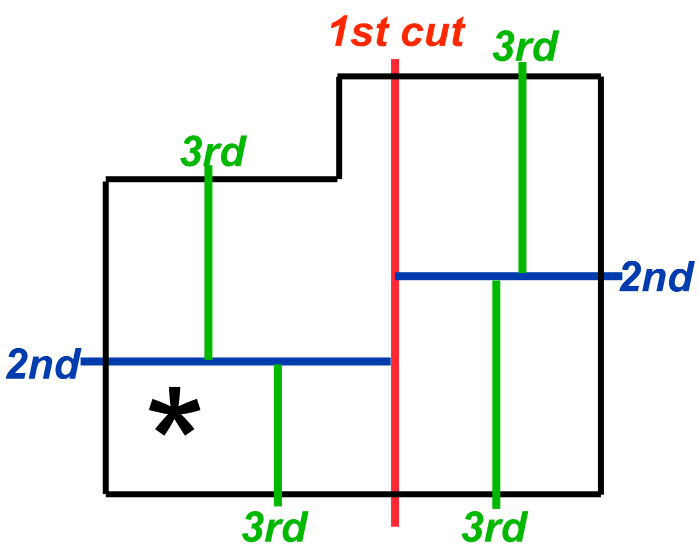
- Advantages:
  - Easiest partitioners to use.
  - Conceptually simple; fast and inexpensive.
  - All processors can inexpensively know entire partition (e.g., for global search in contact detection).
  - No connectivity info needed (e.g., particle methods).
  - Good on specialized geometries.

SLAC'S 55-cell Linear Accelerator with couplers: One-dimensional RCB partition reduced runtime up to 68% on 512 processor IBM SP3. (Wolf, Ko)

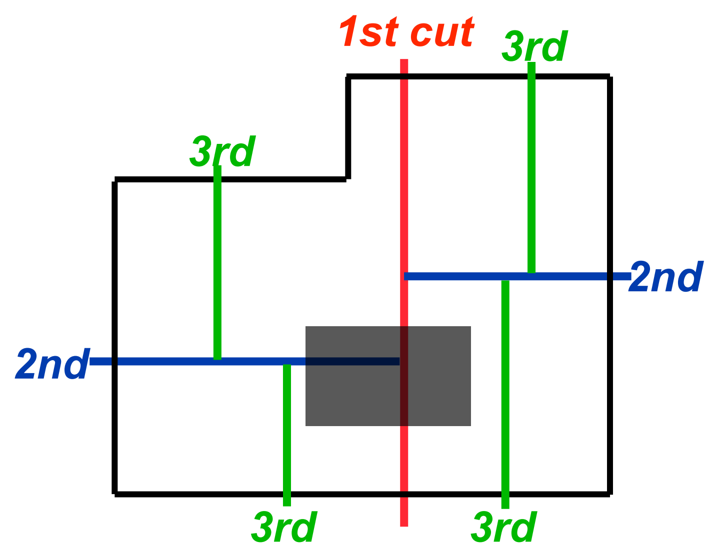
- Disadvantages:
  - No explicit control of communication costs.
  - Mediocre partition quality.
  - Can generate disconnected subdomains for complex geometries.
  - Need coordinate information.

Auxiliary Capabilities for Geometric Methods

- Zoltan can store cuts from RCB, RIB, and HSFC inexpensively in each processor.
  – Zoltan_Set_Param(zz, “KEEP_CUTS”, “1”);
- Enables parallel geometric search without communication.
  – Useful for contact detection, particle methods, rendering.



Determine the part/processor owning region with a given point.
Zoltan_LB_Point_PP_Assign



Determine all parts/processors overlapping a given region.
Zoltan_LB_Box_PP_Assign

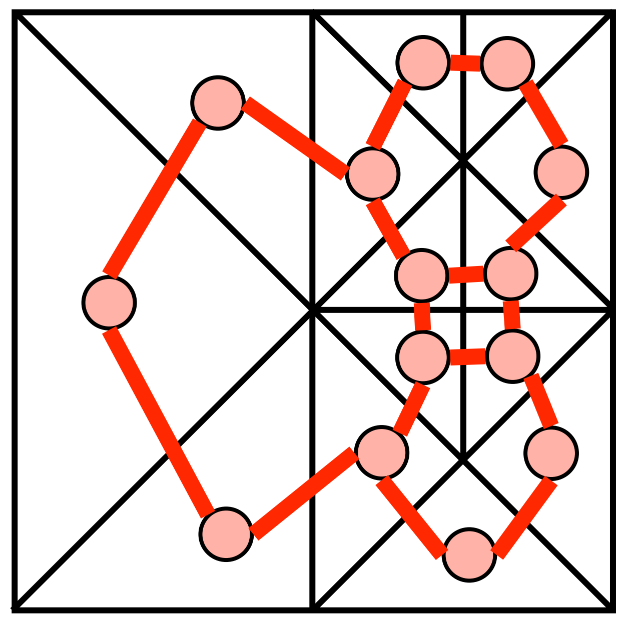
For geometric partitioning (RCB, RIB, HSFC), use …

General Query Functions	
`ZOLTAN_NUM_OBJ_FN`	Number of items on processor
`ZOLTAN_OBJ_LIST_FN`	List of item IDs and weights.
Geometric Query Functions	
`ZOLTAN_NUM_GEOM_FN`	Dimensionality of domain.
`ZOLTAN_GEOM_FN`	Coordinates of items.
Hypergraph Query Functions	
`ZOLTAN_HG_SIZE_CS_FN`	Number of hyperedge pins.
`ZOLTAN_HG_CS_FN`	List of hyperedge pins.
`ZOLTAN_HG_SIZE_EDGE_WTS_FN`	Number of hyperedge weights.
`ZOLTAN_HG_EDGE_WTS_FN`	List of hyperedge weights.
Graph Query Functions	
`ZOLTAN_NUM_EDGE_FN`	Number of graph edges.
`ZOLTAN_EDGE_LIST_FN`	List of graph edges and weights.

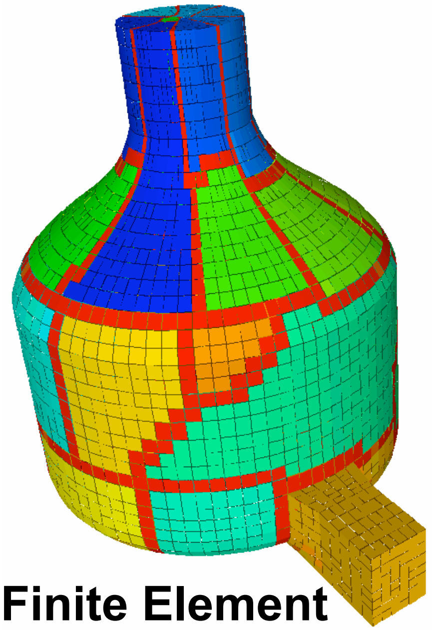
Graph Partitioning

- Zoltan_Set_Param(zz, “LB_METHOD”, “GRAPH”);
- Zoltan_Set_Param(zz, “GRAPH_PACKAGE”, “ZOLTAN”); or
  Zoltan_Set_Param(zz, “GRAPH_PACKAGE”, “PARMETIS”); or
  Zoltan_Set_Param(zz, “GRAPH_PACKAGE”, “SCOTCH”);

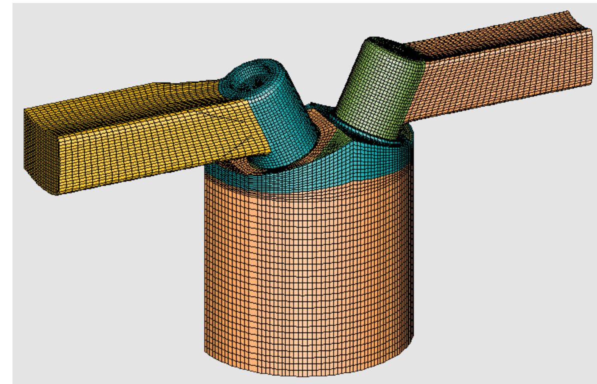
- Kernighan, Lin, Schweikert, Fiduccia, Mattheyes, Simon, Hendrickson, Leland, Kumar, Karypis, et al.
- Represent problem as a weighted graph.
  - Vertices = objects to be partitioned.
  - Edges = dependencies between two objects.
  - Weights = work load or amount of dependency.
- Partition graph so that …
  - Parts have equal vertex weight.
  - Weight of edges cut by part boundaries is small.



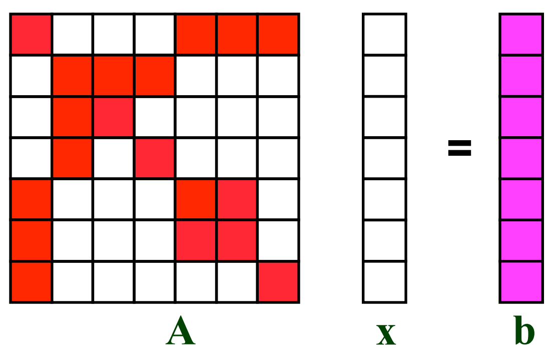
Applications using Graph Partitioning



Finite Element Analysis



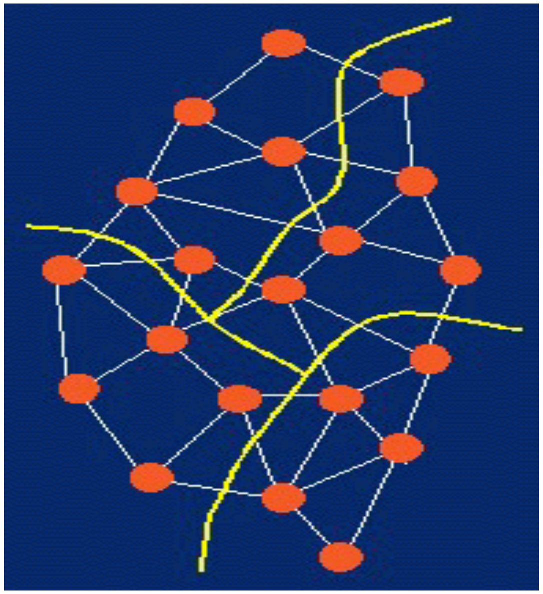
Multiphysics and multiphase simulations



Linear solvers & preconditioners
(square, structurally symmetric systems)

Graph Partitioning: Advantages and Disadvantages

- Advantages:
  - Highly successful model for mesh-based PDE problems.
  - Explicit control of communication volume gives higher partition quality than geometric methods.
  - Excellent software available.
    - Serial: Chaco (SNL)
Jostle (U. Greenwich)
METIS (U. Minn.)
Party (U. Paderborn)
Scotch (U. Bordeaux)
    - Parallel: Zoltan (SNL)
ParMETIS (U. Minn.)
PJostle (U. Greenwich)
PTScotch (U. Bordeaux)



- Disadvantages:
  - More expensive than geometric methods.
  - Edge-cut model only approximates communication volume.

For graph partitioning, coloring & ordering, use …

General Query Functions	
`ZOLTAN_NUM_OBJ_FN`	Number of items on processor
`ZOLTAN_OBJ_LIST_FN`	List of item IDs and weights.
Geometric Query Functions	
`ZOLTAN_NUM_GEOM_FN`	Dimensionality of domain.
`ZOLTAN_GEOM_FN`	Coordinates of items.
Hypergraph Query Functions	
`ZOLTAN_HG_SIZE_CS_FN`	Number of hyperedge pins.
`ZOLTAN_HG_CS_FN`	List of hyperedge pins.
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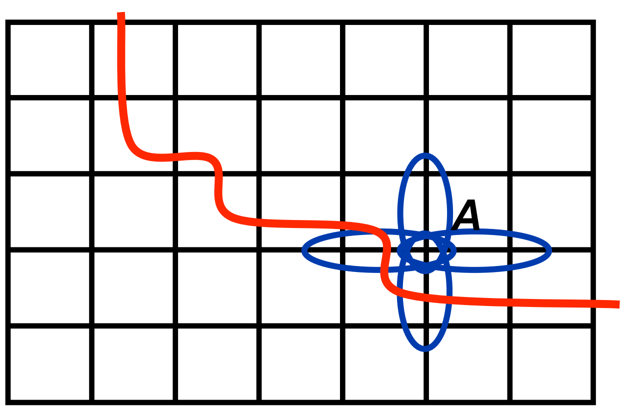
`ZOLTAN_HG_EDGE_WTS_FN`	List of hyperedge weights.
Graph Query Functions	
`ZOLTAN_NUM_EDGE_FN`	Number of graph edges.
`ZOLTAN_EDGE_LIST_FN`	List of graph edges and weights.

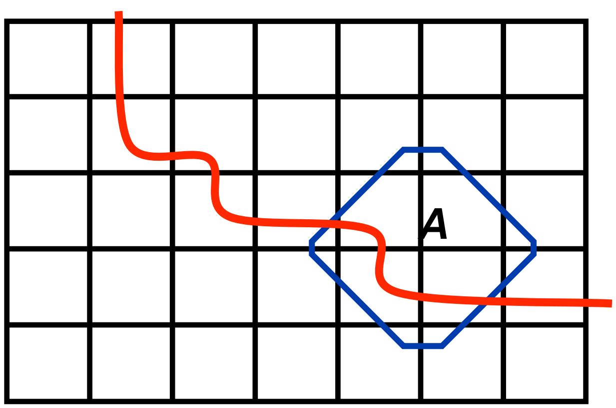
Hypergraph Partitioning

- Zoltan_Set_Param(zz, “LB_METHOD”, “HYPERGRAPH”);
- Zoltan_Set_Param(zz, “HYPERGRAPH_PACKAGE”, “ZOLTAN”); or Zoltan_Set_Param(zz, “HYPERGRAPH_PACKAGE”, “PATOH”);

- Alpert, Kahng, Hauck, Borriello, Çatalyürek, Aykanat, Karypis, et al.
- Hypergraph model:
  - Vertices = objects to be partitioned.
  - Hyperedges = dependencies between two or more objects.
- Partitioning goal: Assign equal vertex weight while minimizing hyperedge cut weight.



Graph Partitioning Model



Hypergraph Partitioning Model

Hypergraph Repartitioning

- Augment hypergraph with data redistribution costs.
  - Account for data's current processor assignments.
  - Weight dependencies by their size and frequency of use.
- Partitioning then tries to minimize total communication volume:

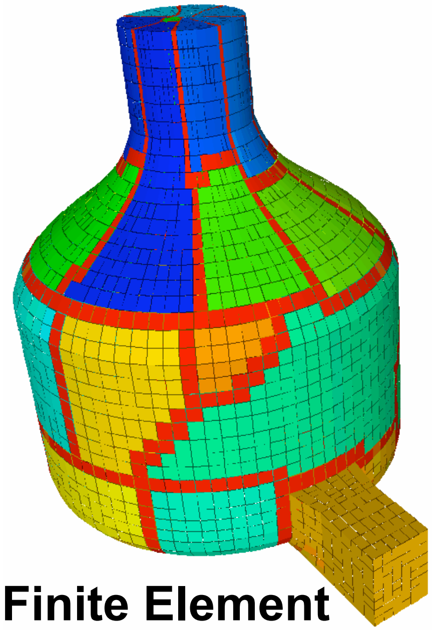
  Data redistribution volume

  + Application communication volume

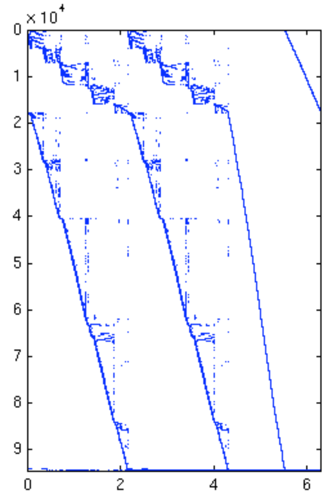
  Total communication volume
- Data redistribution volume: callback returns data sizes.
  - Zoltan_Set_Fn(zz, ZOLTAN_OBJ_SIZE_MULTI_FN_TYPE, myObjSizeFn, 0);
- Application communication volume = Hyperedge cuts * Number of times the communication is done between repartitionings.
  - Zoltan_Set_Param(zz, "PHG_REPART_MULTIPLIER", "100");

Best Algorithms Paper Award at IPDPS07
"Hypergraph-based Dynamic Load Balancing for Adaptive Scientific Computations"
Çatalyürek, Boman, Devine, Bozdag, Heaphy, & Riesen

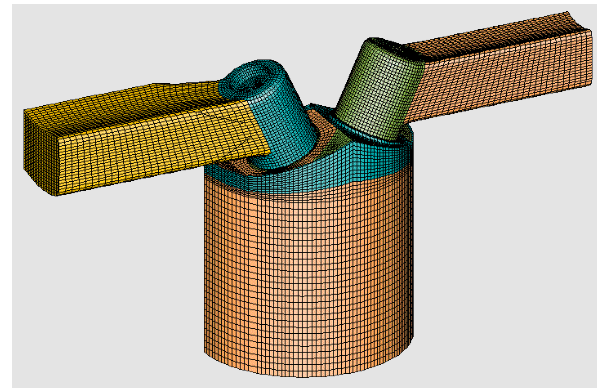
Hypergraph Applications



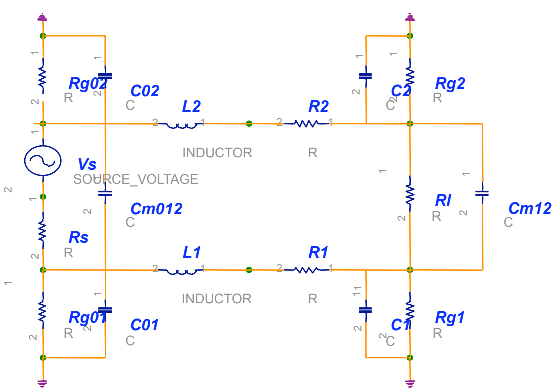
Finite Element Analysis



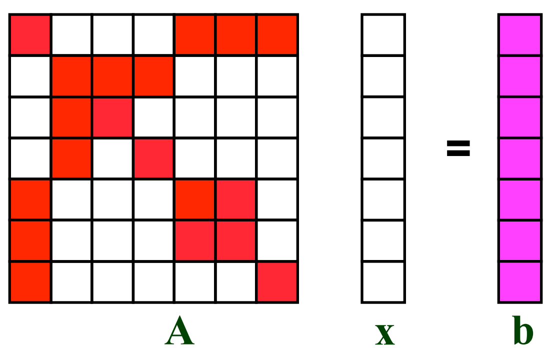
Linear programming for sensor placement



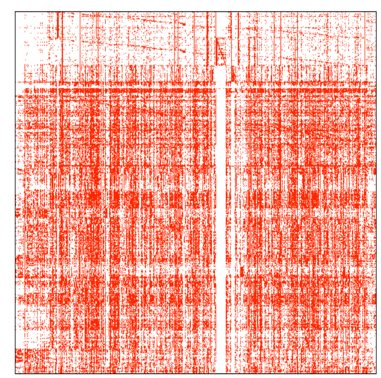
Multiphysics and multiphase simulations



Circuit Simulations



Linear solvers & preconditioners
(no restrictions on matrix structure)



Data Mining

Hypergraph Partitioning: Advantages and Disadvantages

- **Advantages:**
  - Communication volume reduced 30-38% on average over graph partitioning (Catalyurek & Aykanat).
    - 5-15% reduction for mesh-based applications.
  - More accurate communication model than graph partitioning.
    - Better representation of highly connected and/or non-homogeneous systems.
  - Greater applicability than graph model.
    - Can represent rectangular systems and non-symmetric dependencies.
- **Disadvantages:**
  - Usually more expensive than graph partitioning.

For hypergraph partitioning and repartitioning, use …

General Query Functions	
`ZOLTAN_NUM_OBJ_FN`	Number of items on processor
`ZOLTAN_OBJ_LIST_FN`	List of item IDs and weights.
Geometric Query Functions	
`ZOLTAN_NUM_GEOM_FN`	Dimensionality of domain.
`ZOLTAN_GEOM_FN`	Coordinates of items.
Hypergraph Query Functions	
`ZOLTAN_HG_SIZE_CS_FN`	Number of hyperedge pins.
`ZOLTAN_HG_CS_FN`	List of hyperedge pins.
`ZOLTAN_HG_SIZE_EDGE_WTS_FN`	Number of hyperedge weights.
`ZOLTAN_HG_EDGE_WTS_FN`	List of hyperedge weights.
Graph Query Functions	
`ZOLTAN_NUM_EDGE_FN`	Number of graph edges.
`ZOLTAN_EDGE_LIST_FN`	List of graph edges and weights.

Or can use graph queries to build hypergraph.

General Query Functions	
ZOLTAN_NUM_OBJ_FN	Number of items on processor
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Geometric Query Functions	
ZOLTAN_NUM_GEOM_FN	Dimensionality of domain.
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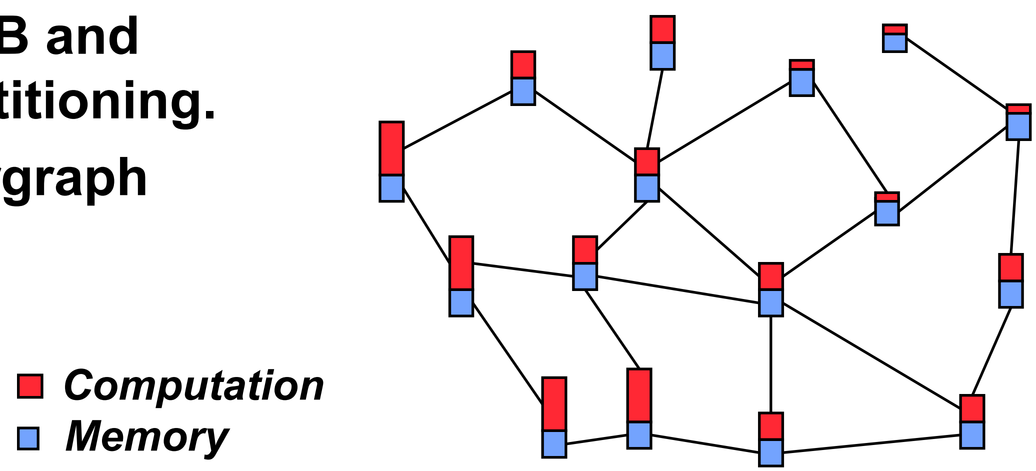
Graph Query Functions	
ZOLTAN_NUM_EDGE_FN	Number of graph edges.
ZOLTAN_EDGE_LIST_FN	List of graph edges and weights.

Sandia National Laboratories

Multi-criteria Load-balancing

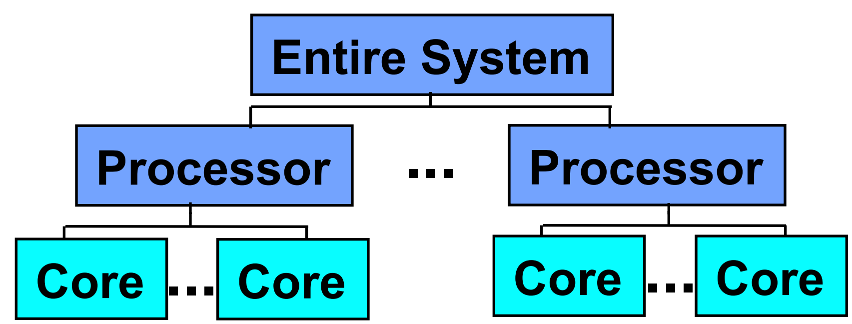
- Multiple constraints or objectives
  - Compute a single partition that is good with respect to multiple factors.
    - Balance both computation and memory.
    - Balance meshes in loosely coupled physics.
    - Balance multi-phase simulations.
  - Extend algorithms to multiple weights
    - Difficult. No guarantee good solution exists.
- Zoltan_Set_Param(zz, "OBJ_WEIGHT_DIM", "2");
  - Available in RCB, RIB and ParMETIS graph partitioning.
  - In progress in Hypergraph partitioning.



Heterogeneous Architectures

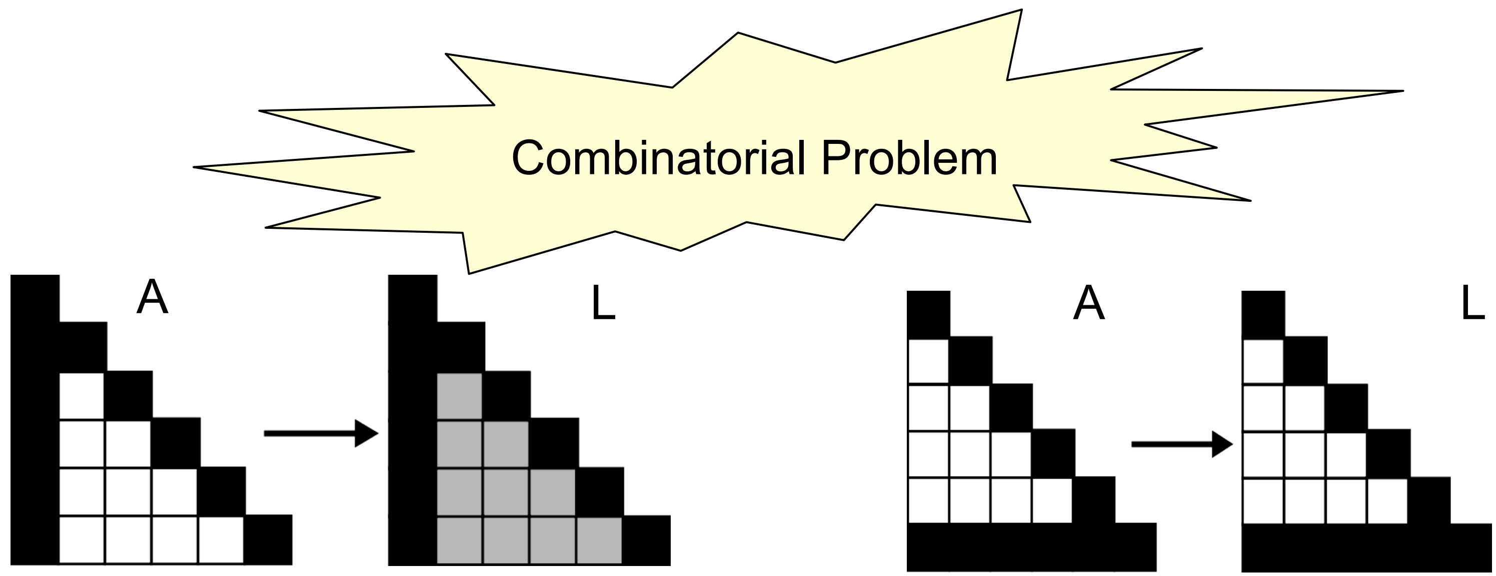
- Clusters may have different types of processors.
- Assign "capacity" weights to processors.
  - E.g., Compute power (speed).
  - Zoltan_LB_Set_Part_Sizes(…);
    - Note: Can use this function to specify part sizes for any purpose.
- Balance with respect to processor capacity.

- Hierarchical partitioning: Allows different partitioners at different architecture levels.
  - Zoltan_Set_Param(zz, "LB_METHOD", "HIER");
  - Requires three additional callbacks to describe architecture hierarchy.
    - ZOLTAN_HIER_NUM_LEVELS_FN
    - ZOLTAN_HIER_PARTITION_FN
    - ZOLTAN_HIER_METHOD_FN



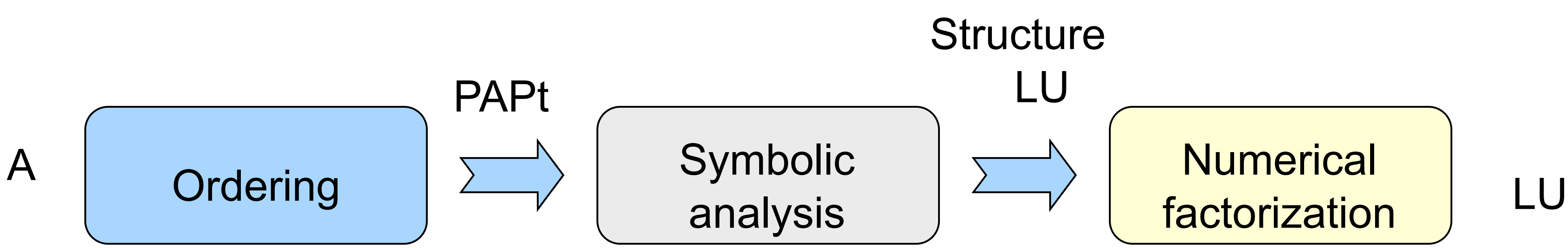
Sparse Matrix Ordering problem

- **When solving sparse linear systems with direct methods, nonzero terms are created during the factorization process (A→LU or LDL^t or LL^t)**
- **Fill-in depends on the order of the unknowns.**
  - **Need to provide fill-reducing ordering**



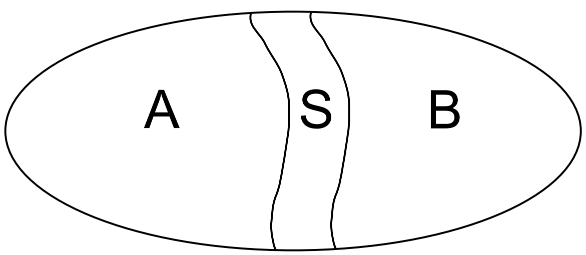
Sparse LU (or Cholesky) factorization framework

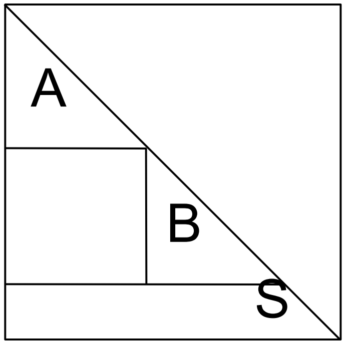
- 3 essential steps to factorize A in LU:
  - Order A:
    - Ordering
    - minimize the fill-in in L and U
  - Compute the structure of L and U:
    - Symbolic factorization
    - Schedule the numerical factorization
  - Compute the values of L and U:
    - Numerical factorization

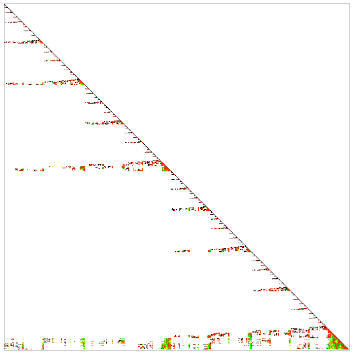


Nested dissection

- **Principle [George 1973]**
  - **Find a vertex separator *S* in graph.**
  - **Order vertices of *S* with highest available indices.**
  - **Recursively apply the algorithm to the two separated subgraphs *A* and *B.***

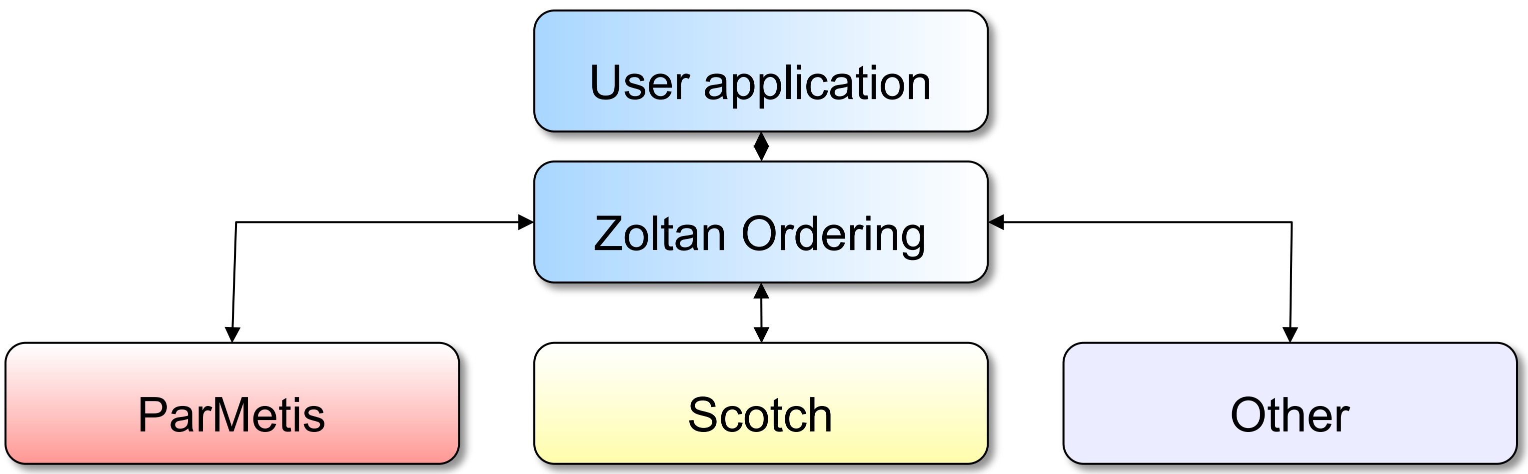






Matrix Ordering with Zoltan

- Computed by third party libraries:
  - ParMetis (U. Minnesota)
  - Scotch (INRIA Bordeaux)
  - Easy to add another
- The calls to third party libraries are transparent to the user, thus Zoltan's calls can be a standard way to compute ordering



Ordering interface in Zoltan

- Compute ordering with one function: Zoltan_Order
- Output provided:
  - New order of the unknowns (direct permutation)
  - Access to elimination tree, “block” view of the ordering
    - Suitable for parallel symbolic factorization
- Ordering can also be used through Isorropia for Trilinos User:
  - Direct support for Epetra matrices

Zoltan Graph Coloring

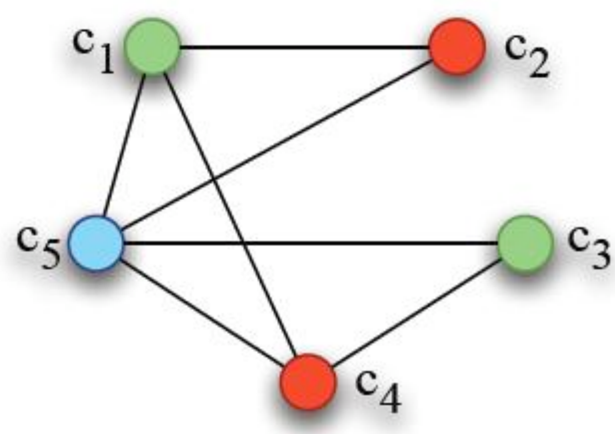
- **Parallel distance-1 and distance-2 graph coloring.**
- **Graph built using same application interface and code as graph partitioners.**
- **Generic coloring interface; easy to add new coloring algorithms.**
- **Algorithms**
  - **Distance-1 coloring: Bozdag, Gebremedhin, Manne, Boman, Catalyurek, *EuroPar'05, JPDC'08*.**
  - **Distance-2 coloring: Bozdag, Catalyurek, Gebremedhin, Manne, Boman, Ozguner, *HPCC'05, SISC'08* (in submission).**

Distance-1 Graph Coloring

- **Problem (NP-hard)**

  Color the vertices of a graph with as few colors as possible such that no two adjacent vertices receive the same color.

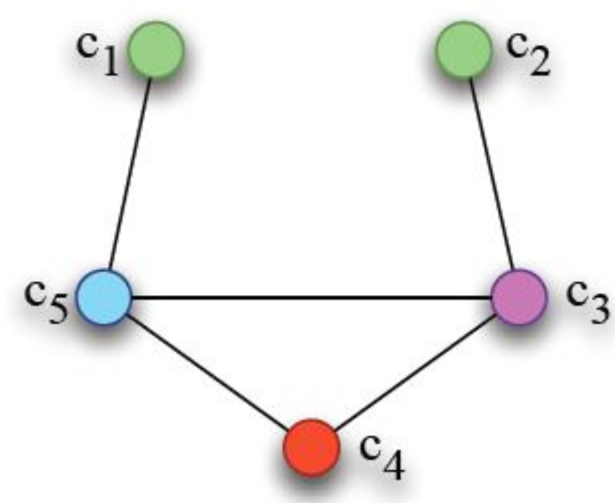
- **Applications**
  - **Iterative solution of sparse linear systems**
  - **Preconditioners**
  - **Sparse tiling**
  - **Eigenvalue computation**
  - **Parallel graph partitioning**



Distance-2 Graph Coloring

- **Problem (NP-hard)**
  Color the vertices of a graph with as few colors as possible such that a pair of vertices connected by a path on two or less edges receives different colors.

- **Applications**
  - **Derivative matrix computation in numerical optimization**
  - **Channel assignment**
  - **Facility location**
- **Related problems**
  - **Partial distance-2 coloring**
  - **Star coloring**



Coloring Interface in Zoltan

- Both distance-1 and distance-2 coloring routines can be invoked by Zoltan_Color function.
- The colors assigned to the objects are returned in an array.

For graph partitioning, coloring & ordering, use …

General Query Functions	
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ZOLTAN_OBJ_LIST_FN	**List of item IDs and weights.**
Geometric Query Functions	
ZOLTAN_NUM_GEOM_FN	**Dimensionality of domain.**
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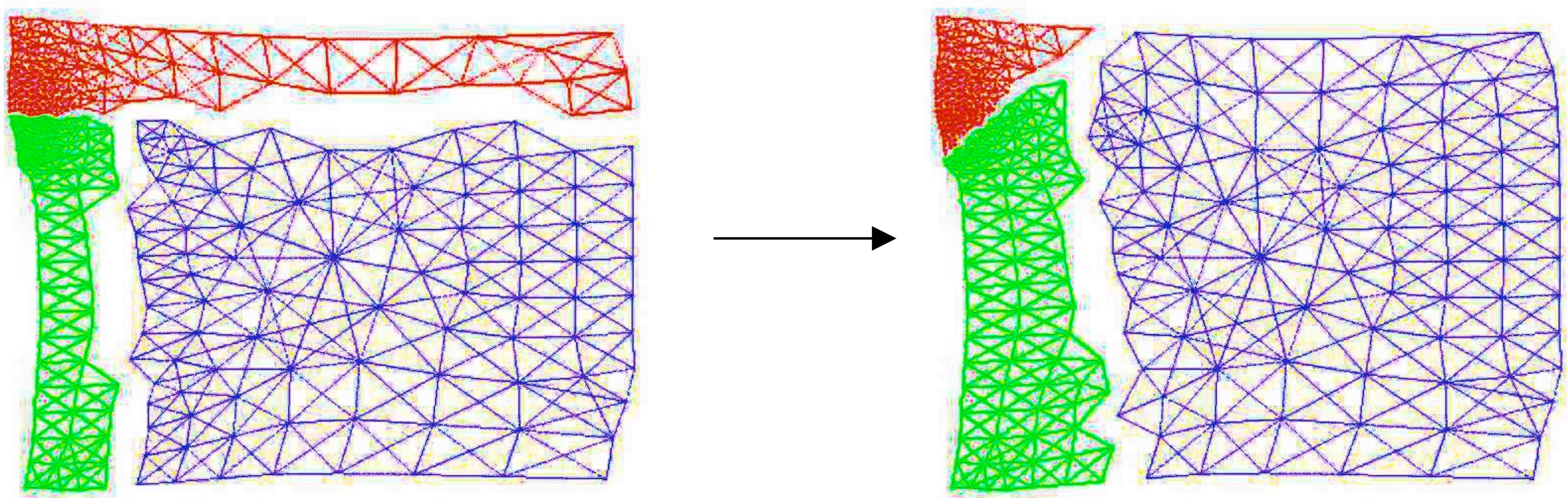
ZOLTAN_HG_SIZE_CS_FN	**Number of hyperedge pins.**
ZOLTAN_HG_CS_FN	**List of hyperedge pins.**
ZOLTAN_HG_SIZE_EDGE_WTS_FN	**Number of hyperedge weights.**
ZOLTAN_HG_EDGE_WTS_FN	**List of hyperedge weights.**
Graph Query Functions	
ZOLTAN_NUM_EDGE_FN	**Number of graph edges.**
ZOLTAN_EDGE_LIST_FN	**List of graph edges and weights.**

Other Zoltan Functionality

- Tools needed when doing dynamic load balancing:
  - Data Migration
  - Unstructured Communication Primitives
  - Distributed Data Directories
- All functionalities are described in Zoltan User's Guide.
  - http://www.cs.sandia.gov/Zoltan/ug_html/ug.html

Zoltan Data Migration Tools

- **After partition is computed, data must be moved to new decomposition.**
  - **Depends strongly on application data structures.**
  - **Complicated communication patterns.**
- **Zoltan can help!**
  - **Application supplies query functions to pack/unpack data.**
  - **Zoltan does all communication to new processors.**



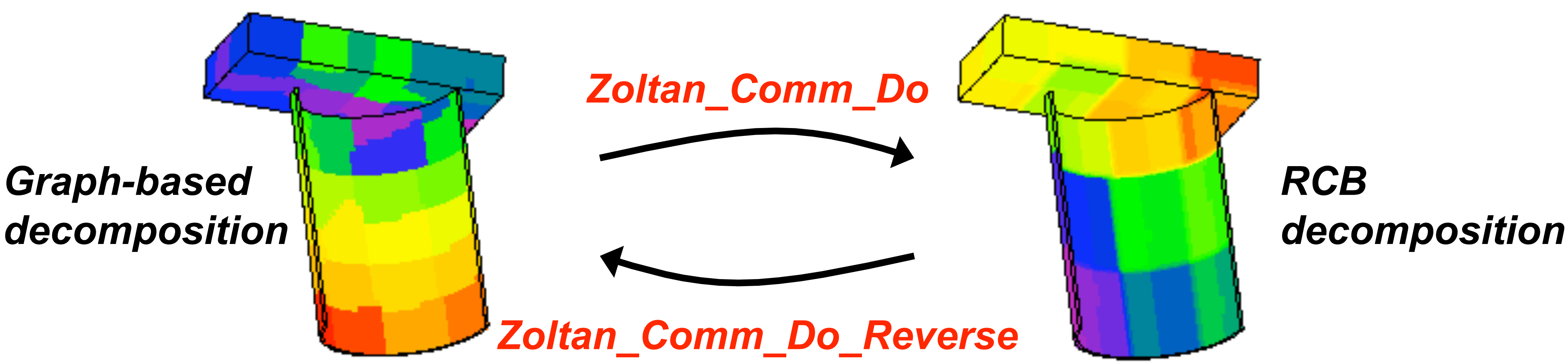
Using Zoltan's Data Migration Tools

- Required migration query functions:
  - ZOLTAN_OBJ_SIZE_MULTI_FN:
    - Returns size of data (in bytes) for each object to be exported to a new processor.
  - ZOLTAN_PACK_MULTI_FN:
    - Remove data from application data structure on old processor;
    - Copy data to Zoltan communication buffer.
  - ZOLTAN_UNPACK_MULTI_FN:
    - Copy data from Zoltan communication buffer into data structure on new processor.

-
```
int Zoltan_Migrate(struct Zoltan_Struct *zz,
        int num_import, ZOLTAN_ID_PTR import_global_ids,
        ZOLTAN_ID_PTR import_local_ids, int *import_procs,
        int *import_to_part,
        int num_export, ZOLTAN_ID_PTR export_global_ids,
        ZOLTAN_ID_PTR export_local_ids, int *export_procs,
        int *export_to_part);
```

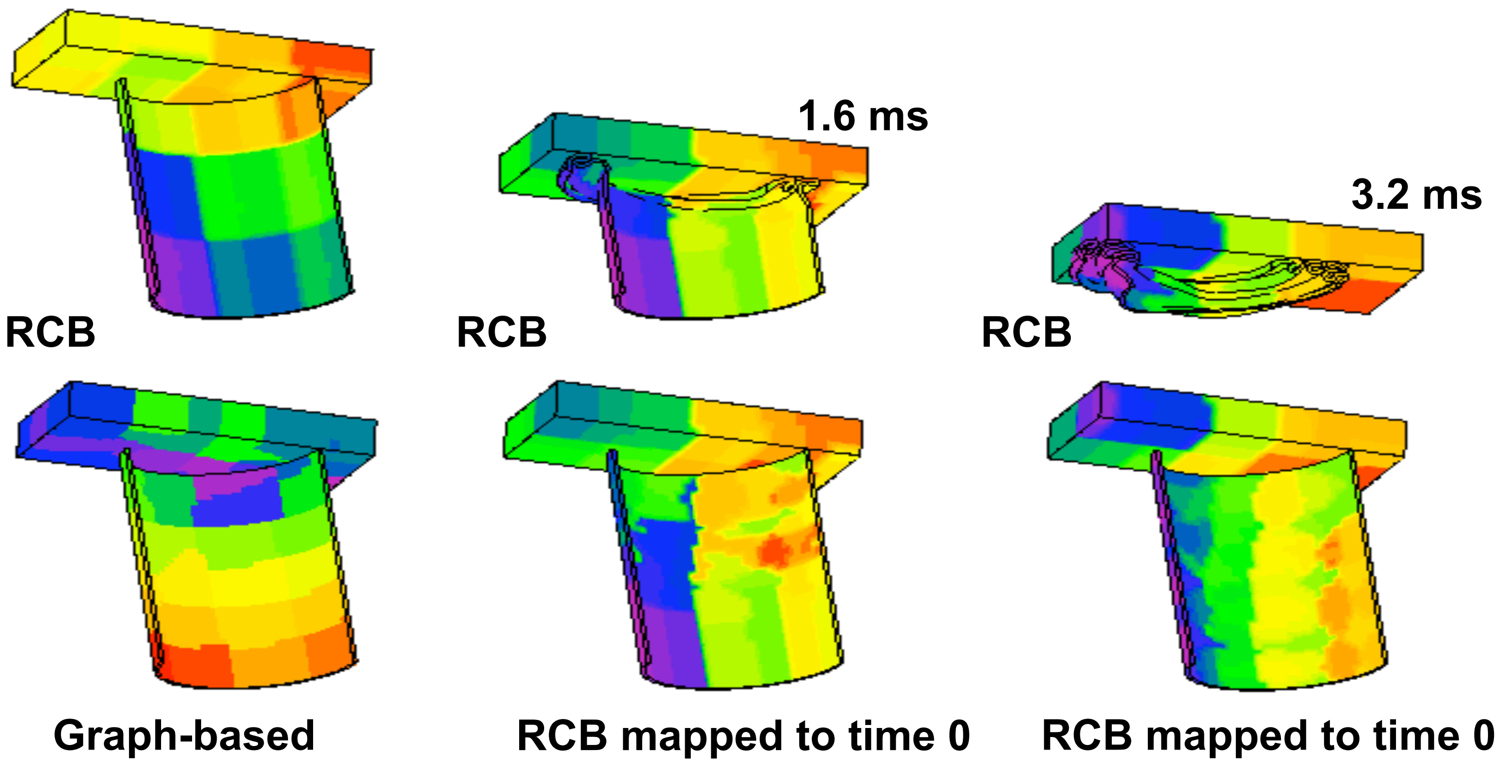
Zoltan Unstructured Communication Package

- Simple primitives for efficient irregular communication.
  - Zoltan_Comm_Create: Generates communication plan.
    - Processors and amount of data to send and receive.
  - Zoltan_Comm_Do: Send data using plan.
    - Can reuse plan. (Same plan, different data.)
  - Zoltan_Comm_Do_Reverse: Inverse communication.
- Used for most communication in Zoltan.



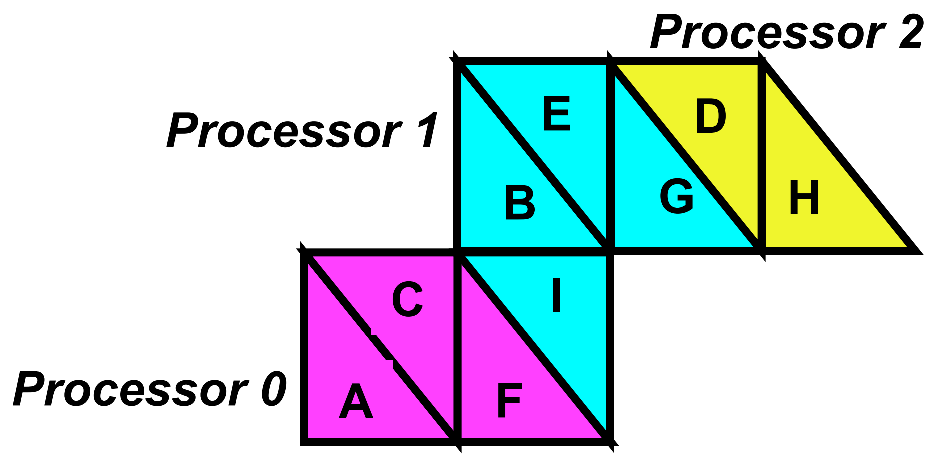
Example Application: Crash Simulations

- **Multiphase simulation:**
  - Graph-based decomposition of elements for finite element calculation.
  - Dynamic geometric decomposition of surfaces for contact detection.
  - Migration tools and Unstructured Communication package map between decompositions.



Zoltan Distributed Data Directory

- Helps applications locate off-processor data.
- Rendezvous algorithm (Pinar, 2001).
  - Directory distributed in known way (hashing) across processors.
  - Requests for object location sent to processor storing the object's directory entry.



Processor 0

Directory Index →	A	B	C
Location →	0	1	0

Processor 1

Directory Index →	D	E	F
Location →	2	1	0

Processor 2

Directory Index →	G	H	I
Location →	1	2	1

Alternate Interfaces to Zoltan

- **C, C++ and F90 interfaces in Zoltan.**
- **Matrix-based interface in Trilinos.**
- **Mesh-based interface in ITAPS.**

Isorropia: Trilinos Interface to Zoltan

- Trilinos Toolkit (M. Heroux, SNL, PI): Packages for …
  - Parallel matrix and vector classes (Epetra)
  - Linear, nonlinear and eigen solvers
  - Preconditioners
  - Matrix partitioning (Isorropia)
  - Time integration, discretizations, inline meshing, ….
- Epetra provides parallel matrix and vector classes.
- Isorropia uses Zoltan to repartition Epetra objects.
  - B = Isorropia::Epetra::createBalancedCopy(A, params); or
  - Partitioner, redistributor, and cost-evaluator classes.
- Trilinos v9.0 includes:
  - Zoltan in the Trilinos distribution and build environment.
  - Isorropia interfaces to matrix ordering and coloring.

(Member of SciDAC2 TOPS CET)

ITAPS Dynamic Services: Mesh-based Interface to Zoltan

- Interoperable Technologies for Advanced Petascale Simulations (L. Diachin, LLNL, PI)
  - SciDAC2 CET.
- ITAPS Goals:
  - Develop the next generation of meshing and geometry tools for petascale computing.
    - E.g., adaptive mesh refinement, shape optimization.
  - Improve applications' ability to use these tools.
    - "Standardization" of mesh interfaces.
- Dynamic Services toolkit:
  - ITAPS-compliant mesh interface to Zoltan tools.
  - Integration with ITAPS iMeshP parallel mesh interface to be released FY09.

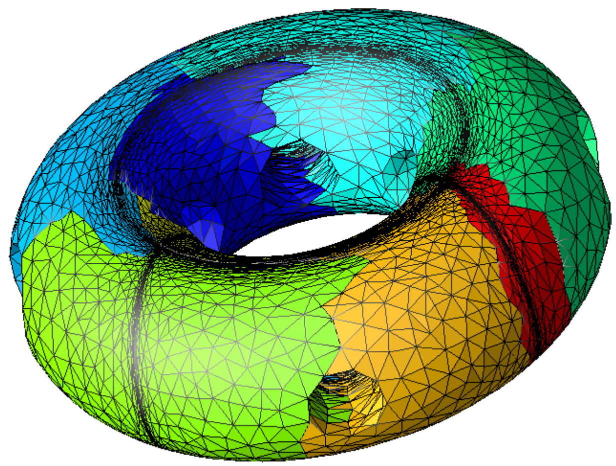


Image courtesy of M. Shephard, RPI

Current Work

- Two-dimensional matrix partitioning.
- Performance improvements for hypergraph partitioning.
- Multi-criteria hypergraph partitioning.
- May be available in Trilinos 10:
  - Non-symmetric matrix ordering.
  - Other coloring problems: partial distance 2, …

For More Information...

- Zoltan Home Page
  - http://www.cs.sandia.gov/Zoltan
  - User's and Developer's Guides
  - Tutorial: "Getting Started with Zoltan: A Short Tutorial"
  - Download Zoltan software under GNU LGPL.
- Trilinos Home Page
  - http://trilinos.sandia.gov
- ITAPS Home Page
  - http://www.itaps.org
- CSCAPES Home Page
  - http://www.cscapes.org
- Email:
  - zoltan-dev@software.sandia.gov
  - kddevin@sandia.gov