Applications of Parallel Programming

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Logistics

A2 and A3

- Tests updated should resolve Valgrind issues for Problem 1
- Still no Optional Problem 4
- A3 by Wed

Poll on Final Exam

Poll on Canvas concerning Final Exam

- **Option A:** Mini-exam 4 (10%) + Final Exam (10%)
- ~~Option B: Final Exam Last Day of class (20%)~~

Agenda

- Mon: P2 Prob 1 Review of Fluid Dynamics
- Wed: Applications + Mini-Exam 4

Guest Lecture

Some Applications of Parallel Computing in Fluid Mechanics

Sreevatsa “Sam” Anantharamu, Aerospace Engineering

Final Exam Survey Stats

- Plan on Original Schedule
- Mini-Exam 4 Wed 12/8 on GPUs / CUDA, Fluid Dynamics Application
- Final Exam Mon 12/20 1:30-3:30pm, comprehensive

Attempts: 47 out of 47

As we discussed in lecture some time ago, some students wish to have an adjustment to the Final Exam schedule. Here are two possibilities for this. Please indicate your preference below.

Plan A: Continue according to the original schedule which is

- Mini Exam 4 on Wed 12/8 worth 10% of grade, 35 minute exam
- Review on Wed 12/15 last day of class
- Assignment 2 (MPI/OpenMP) due on 12/15, Assignment 3 (CUDA) due 12/16
- Final Exam on Mon 12/20 worth 10% of grade, 2 hours

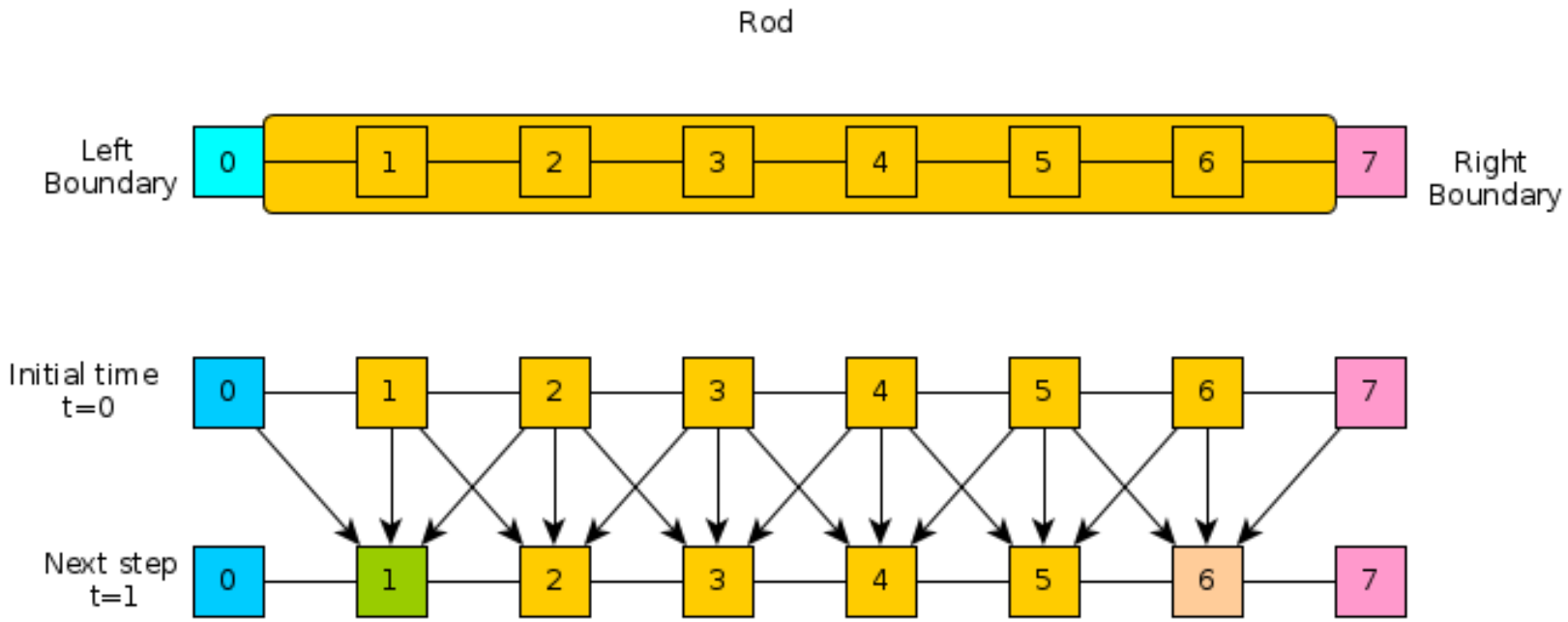
Plan B: Merge Mini-Exam 4 and Final Exam

- No Mini-Exam 4
- Review on Mon 12/13
- Final Exam on Wed 12/15 worth 20% of grade, 75 minutes
- Assignments 2 and 3 due on Fri 12/17

Please indicate your preference between these plans.

Plan A: Original Schedule	24 respondents	51 %	
Plan B: Final Exam on last day of class	17 respondents	36 %	
No preference, will do do either	6 respondents	13 %	

Note on A2 Problem 1 Heat



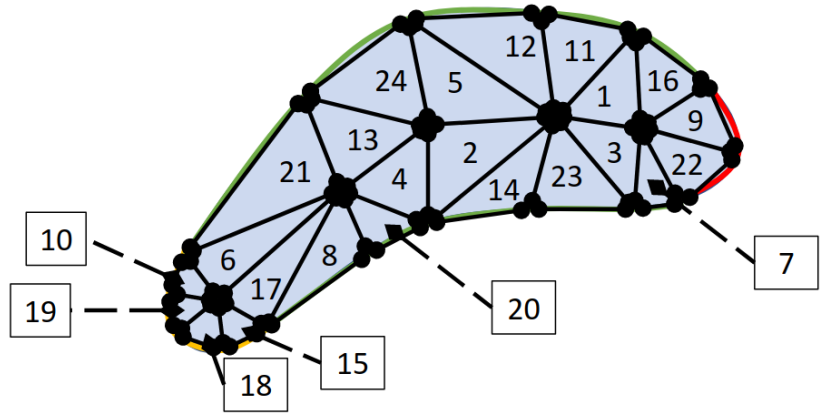
- Assume 4 procs total, Column partition
- Note the need to exchange data between procs
- What MPI calls would be used to exchange
- How does one most efficiently arrange communication?

Avoid "chains" of communication that would block procs for proceeding as quickly as possible.

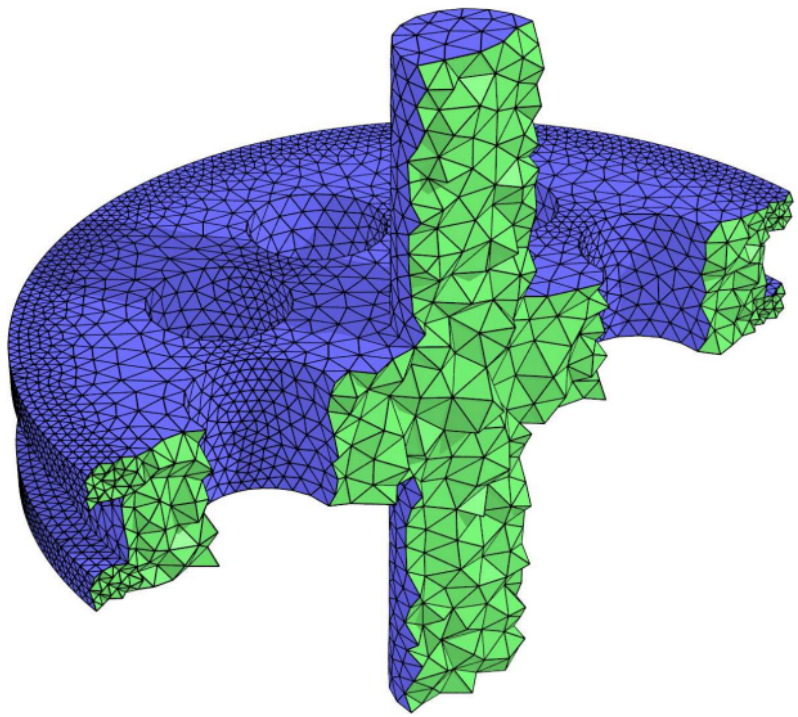
Reviewing Fluid Dynamics: Meshes

Divide the domain into triangles; the set of triangles is called a mesh/grid

Done long in advance of running any simulations



Source: Some applications of parallel computing in fluid mechanics by Sreevatsa Anantharamu

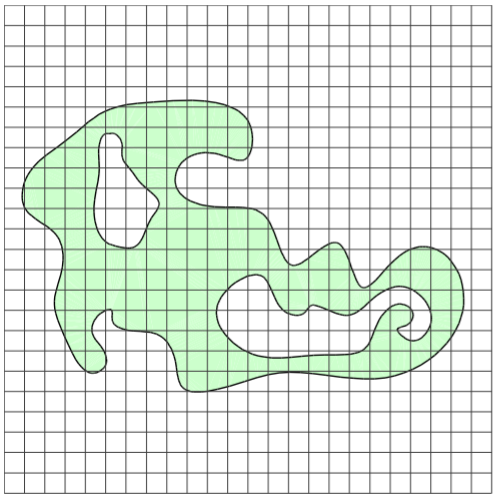


Source: Mesh Generation for Implicit Geometries by Per-Olof Persson (Thesis)

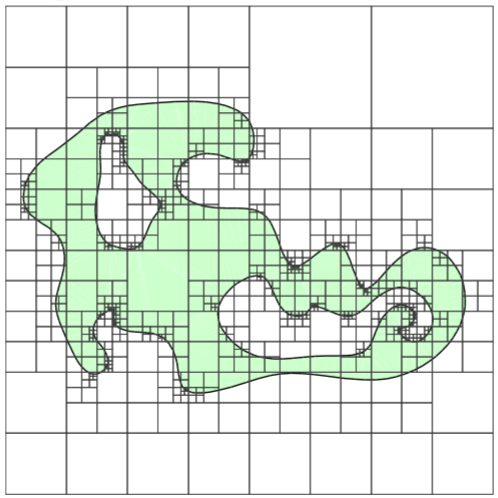
Reviewing Fluid Dynamics: Mesh Generation

Mesh generation has many styles / techniques, can be is own (parallel) problem

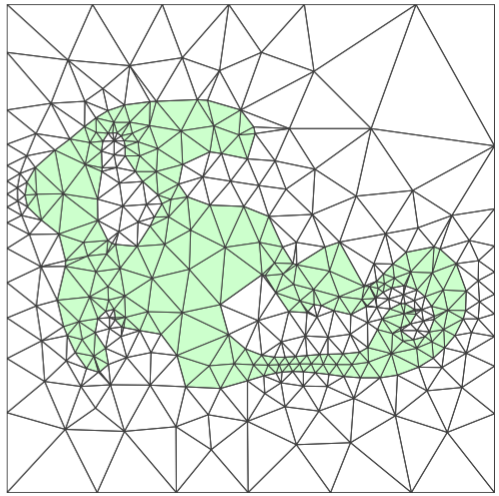
Cartesian



Quadtree/Octree



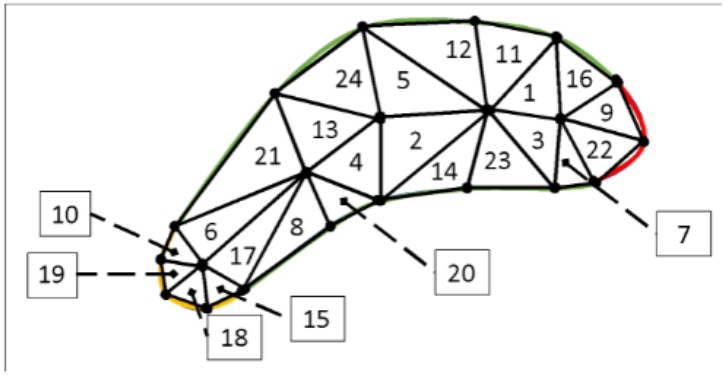
Unstructured



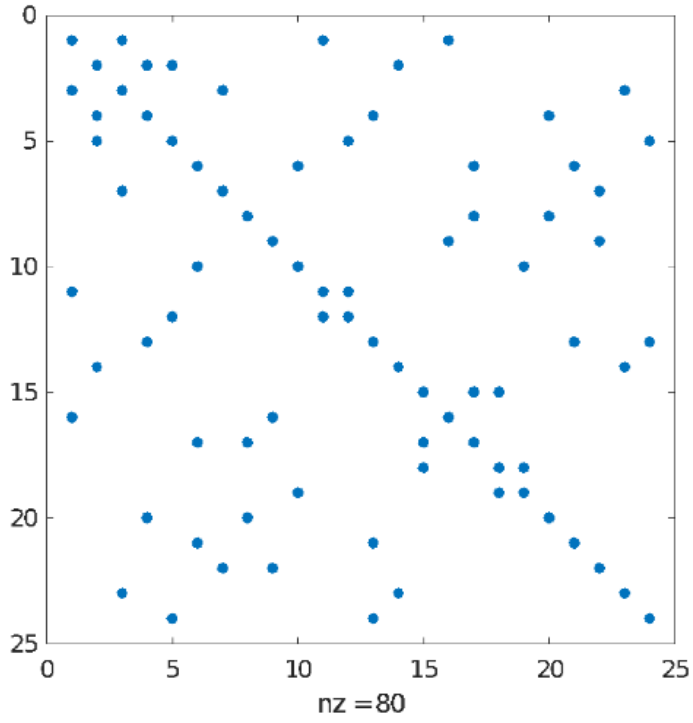
Exercise: Mesh to Matrix

After creating a mesh, Sam alluded to getting a sparse matrix from it.

1. What is this matrix?
2. Why is it sparse?
3. What relation does it have to the Heat problem we have studied several times?
4. What would the matrix for the Heat problem look like?
5. Sam described it as an "unstructured" sparse matrix. What does this mean?



Mesh



Sparsity pattern of A

Answers: Mesh to Matrix

1. What is this matrix?
   Matrix of neighbors: which triangles share a face with others.

2. Why is it sparse?
   Not all triangles share faces. Each triangle only has 3 faces so has at most 3 neighbors.

3. What relation does it have to the Heat problem we have studied several times?
   The heat problem also defined neighbors which dictated heat transfer. Each element in the rod had 2 neighbors (left and right).

Answers: Mesh to Matrix

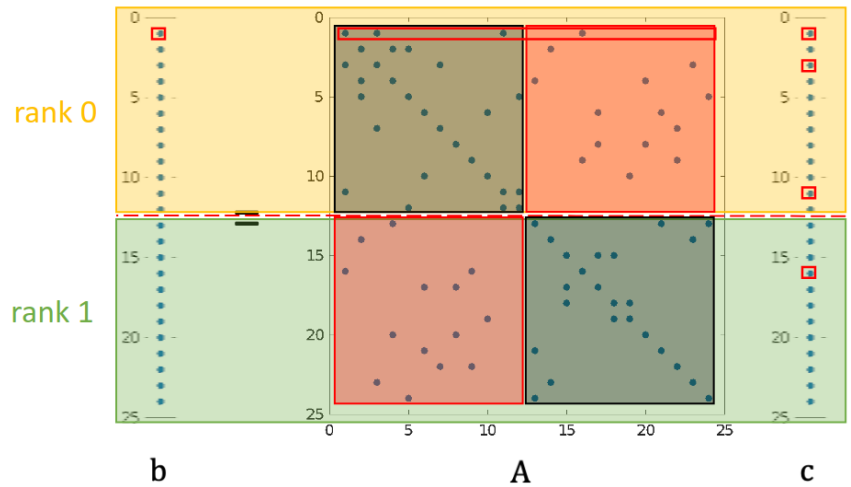
4. What would the matrix for the Heat problem look like?
   Tri-diagonal: element i has neighbors $i-1$ and $i+1$.

$$T = \begin{pmatrix} a_1 & b_1 & & & \\ c_1 & a_2 & b_2 & & \\ & c_2 & \ddots & \ddots & \\ & & \ddots & \ddots & b_{n-1} \\ & & & c_{n-1} & a_n \end{pmatrix}$$

5. Sam described it as an "unstructured" sparse matrix. What does this mean?
   For an arbitrary mesh, the neighbor matrix does not follow a regular pattern like in the Heat problem. Element 4 has neighbors 2, 13, 20; no pattern for the neighbors.

Exercise: Sparse Matrix Vector Multiply

- Sam indicated a Sparse Matrix/Vector multiply is a central operation for the simulation
- Advocated using a simple Row Partition scheme for the matrix, input vector, output vector



Questions

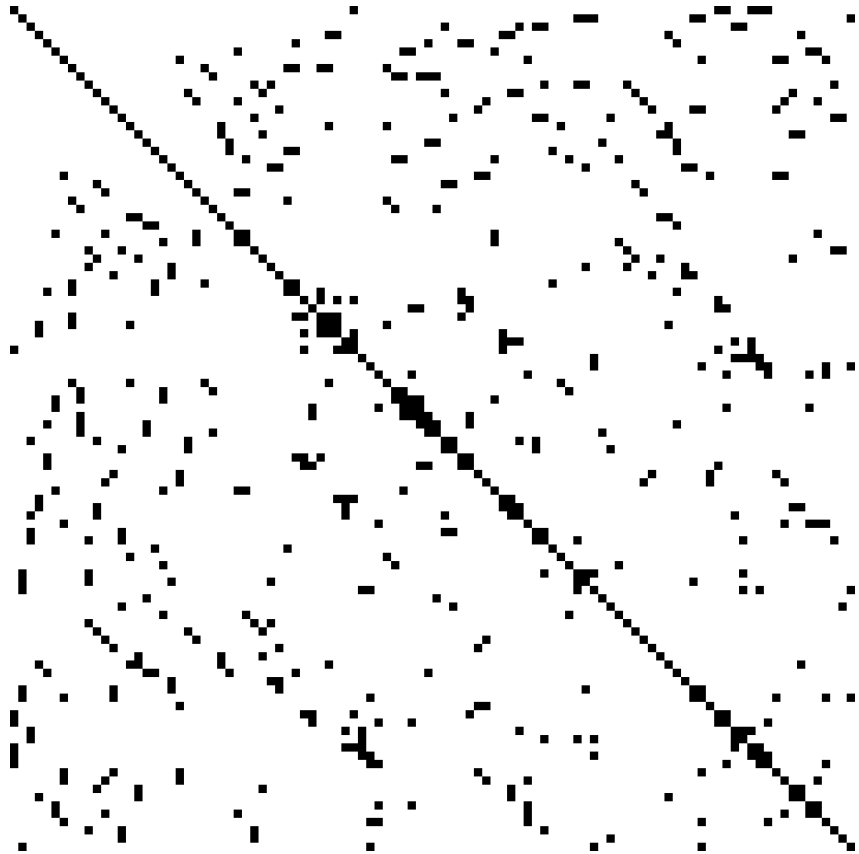
1. What need for communication does this incur?
2. Why is this situation more complex than our work on Page Rank: give 2 reasons?

Answers: Sparse Matrix Vector Multiply

1. What need for communication does this incur?
   Procs do not have the entire RHS vector; must communicate with other procs to multiply it. Other procs must know who will ask for data from them.
2. Why is this situation more complex than our work on Page Rank: give 2 reasons?
   - 2.1 *Pagerank was dense so the data communicated were just blocks of dense arrays. In sparse problems must communicate in a format like Compressed Sparse Row (CSR).*
   - 2.2 *We assumed whole RHS vector fits on procs so no need to communicate before multiplying: all procs had their entire own copy.*

Exercise: Distribution of Sparse Matrices

- Given a square sparse matrix with N rows
- Have a parallel computer with P procs
- Will partition RHS vector as well
- Which proc should get which rows (matrix/RHS vector)?
- What criteria should be used to dictate partitioning?



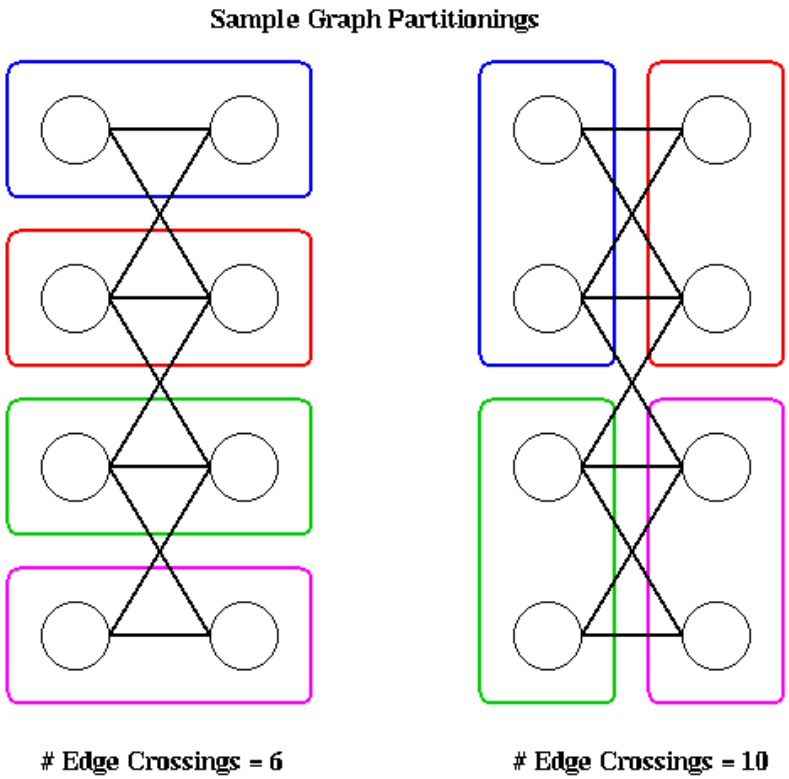
Answers: Distribution of Sparse Matrices

- Want to minimize communication between procs
- If Element 4 has neighbors 2, 13, 20, put rows 2,4,13,20 on same processor
- Leads to a classic NP-Hard problem: **Graph Partitioning**

  In mathematics, a graph partition is the reduction of a graph to a smaller graph by partitioning its set of nodes into mutually exclusive groups. Edges of the original graph that cross between the groups will produce edges in the partitioned graph. If the number of resulting edges is small compared to the original graph, then the partitioned graph may be better suited for analysis and problem-solving than the original.

  – *Wikipedia: Graph Partitioning*

Graph Partitioning



Source: CS267 Lectures 11 and 12 Note by James Demmel, Berkeley

- Graph partitioning seeks a "reduced" graph where multiple vertices are merged into a single vertex group
- Edges within group cost nothing - on same processor
- Seek to minimize edges between groups, the **Cut** of the partition
- Widely used approach is METIS (serial) and ParMETIS (parallel) by our own George Karypis and Vipin Kumar