ACM/CS 114
Parallel algorithms for scientific applications

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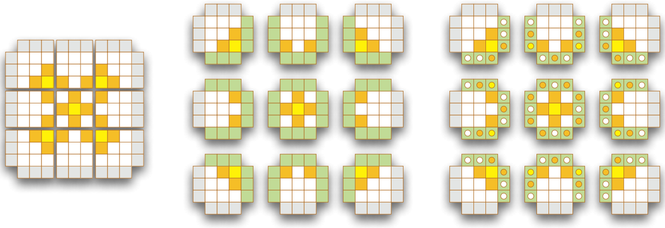
Parallelization with MPI

- the MPI implementation will require careful data management
  - we must partition the mesh among processes
  - each process work on its own subgrid
    - it will allocate its own memory, for both actual data and the guard zones
    - it must locate its patch in physical space
  - communication is required every iteration
    - so that neighbors can synchronize their boundaries
    - think of the synchronization as a kind of boundary condition!
  - parallel convergence testing involves a collective operation



A little bit of help

- MPI supports this common use case through a Cartesian *virtual topology*
  - a special communicator with a map from a *d*-dimensional virtual process grid to the normal linear process ranks
  - and local operations that enable you to discover the ranks of your virtual neighbors
  - there is even a special form of send/receive so that you don't have to worry about contention and race conditions during the boundary synchronization
- to create a Cartesian communicator

```
int MPI_Cart_create(MPI_Comm oldcomm,
      int ndims, int* layout, int* periods, int reorder, MPI_Comm* newcomm)
```

- to find out the coordinates of a process in the virtual grid given its rank

```
int MPI_Cart_coords(MPI_Comm cartesian,
      int rank, int ndims, int* coords);
```

- you can also find out the ranks of your neighbors

```
int MPI_Cart_shift(MPI_Comm cartesian,
      int dimension, int shift, int* origin, int* neighbor);
```

The MPI driver, part 1

```
int main(int argc, char* argv[]) {
   int status;
   // initialize mpi
   status = MPI_Init(&argc, &argv);
   if (status) {
      throw("error in MPI_Init");
   }
   // get my rank in the world communicator
   int worldRank, worldSize;
   MPI_Comm_rank(MPI_COMM_WORLD, &worldRank);
   MPI_Comm_size(MPI_COMM_WORLD, &worldSize);
   size_t processors = static_cast<size_t>(std::sqrt(worldSize));

   // default values for our user configurable settings
   size_t n = 9; // points per processor
   size_t threads = 1;
   double tolerance = 1.0e-3;

   // read the command line
   int command;
   while ((command = getopt(argc, argv, "n:e:t:")) != -1) {
      switch (command) {
      // get the convergence tolerance
      case 'e':
         tolerance = atof(optarg);
         break;
      // get the grid size
      case 'n':
         n = (size_t) atof(optarg);
         break;
      // get the number of threads
      case 't':
         threads = (size_t) atoi(optarg);
         break;
      }
   }
```

The MPI driver, part 2

```
   // print out the chosen options
   if (worldRank == 0) {
      for (int arg = 0; arg < argc; ++arg) {
         std::cout << argv[arg] << " ";
      }
      std::cout
         << std::endl
         << "  grid size: " << n << std::endl
         << "    workers: " << threads << std::endl
         << "  tolerance: " << tolerance << std::endl;
   }

   // instantiate a problem
   Example problem("cliche", 1.0, processors, n);

   // instantiate a solver
   Jacobi solver(tolerance, threads);
   // solve
   solver.solve(problem);
   // save the results
   Visualizer vis;
   vis.csv(problem);

   // initialize mpi
   status = MPI_Finalize();
   if (status) {
      throw("error in MPI_Finalize");
   }

   // all done
   return 0;
}
```

The Jacobi declaration

```
class acm114::laplace::Jacobi : public acm114::laplace::Solver {
   // interface
public:
   virtual void solve(Problem &);

   // meta methods
public:
   inline Jacobi(double tolerance, size_t workers);
   virtual ~Jacobi();

   // data members
private:
   double _tolerance;
   size_t _workers;

   // disable these
private:
   Jacobi(const Jacobi &);
   const Jacobi & operator= (const Jacobi &);
};
```

The Problem declaration

```
class acm114::laplace::Problem {
   //typedefs
public:
   typedef std::string string_t;
   // interface
public:
   string_t name() const;
   inline MPI_Comm communicator() const;
   inline int rank() const;
   // access to my grid
   inline Grid & solution();
   inline const Grid & solution() const;
   // interface used by the solver
   virtual void initialize();
   virtual void applyBoundaryConditions() = 0;
   // meta methods
public:
   Problem(string_t name, double interval, int processors, size_t points);
   virtual ˜Problem();
   // data members
protected:
   string_t _name;
   double _delta, _x0, _y0;
   int _rank, _size, _processors;
   int _place[2];
   MPI_Comm _cartesian;
   Grid _solution;
   // disable these
private:
   Problem(const Problem &);
   const Problem & operator= (const Problem &);
};
```

The `Problem` constructor

```
Problem::Problem(
   string_t name, double interval, int processors, size_t points) :
   _name(name),
   _delta(interval/((points-2)*processors+1)),
   _x0(0.0), _y0(0.0),
   _rank(0), _size(0), _processors(processors), _place(),
   _cartesian(),
   _solution(points) {

   // build the intended layout
   int layout[] = { processors, processors };
   // find my rank in the world communicator
   int worldRank;
   MPI_Comm_rank(MPI_COMM_WORLD, &worldRank);
   // build a Cartesian communicator
   int periods[] = { 0, 0 };
   MPI_Cart_create(MPI_COMM_WORLD, 2, &layout[0], periods, 1, &_cartesian);
   // check whether i can paritcipate
   if (_cartesian != MPI_COMM_NULL) {
      // get my rank in the cartesian communicator
      MPI_Comm_rank(_cartesian, &_rank);
      MPI_Comm_size(_cartesian, &_size);
      // get my logical position on the process grid
      MPI_Cart_coords(_cartesian, _rank, 2, &_place[0]);
      // now compute my offset in physical space
      _x0 = 0.0 + (points-2)*_place[0]*_delta;
      _y0 = 0.0 + (points-2)*_place[1]*_delta;
   } else {
      // i was left out because the total number of processors is not a square
      std::cout
         << "world rank " << worldRank << ": not a member of the cartesian communicator "
         << std::endl;
   }
}
```

The `Example` declaration

```
class acm114::laplace::Example : public acm114::laplace::Problem {
   // interface
public:
   virtual void applyBoundaryConditions();

   // meta methods
public:
   inline Example(
      string_t name, double interval, int processors, size_t points);
   virtual ˜Example();

   // disable these
private:
   Example(const Example &);
   const Example & operator= (const Example &);
};
```