CSCI 5451: Introduction to Parallel Computing

Lecture 14/15: MPI Examples (cont'd)

computer science
& engineering

Announcements (10/20)

- HW 2 released (due Nov 2)
  - Canvas
  - Currently uploaded to course site
  - Canvas autograder currently running
  - No hidden tests
- Group Formation due yesterday → Sunday, Oct 19 (Canvas)

Lecture Overview

- MPI Examples (Whiteboard walkthrough)
  - **2-D Matrix-Vector Multiplication**
  - Djikstra's Single Source Shortest Path
  - Sample Sort

2-D Matrix-Vector Multiplication

```
void MatrixVectorMultiply_2D(int n, double *a, double *b, double *x, MPI_Comm comm)
{
    int ROW = 0, COL = 1;
    int i, j, nlocal;
    double *px;
    int npes, dims[2], periods[2], keep_dims[2];
    int myrank, my2drank, mycoords[2];
    int other_rank, coords[2];
    MPI_Status status;
    MPI_Comm comm_2d, comm_row, comm_col;

    MPI_Comm_size(comm, &npes);
    MPI_Comm_rank(comm, &myrank);

    dims[ROW] = dims[COL] = sqrt(npes);
    nlocal = n / dims[ROW];
    px = malloc(nlocal * sizeof(double));
```

```
periods[ROW] = periods[COL] = 1;
MPI_Cart_create(MPI_COMM_WORLD, 2, dims, periods, 1, &comm_2d);
MPI_Comm_rank(comm_2d, &my2drank);
MPI_Cart_coords(comm_2d, my2drank, 2, mycoords);

keep_dims[ROW] = 0; keep_dims[COL] = 1;
MPI_Cart_sub(comm_2d, keep_dims, &comm_row);

keep_dims[ROW] = 1; keep_dims[COL] = 0;
MPI_Cart_sub(comm_2d, keep_dims, &comm_col);

if (mycoords[COL] == 0 && mycoords[ROW] != 0) {
   coords[ROW] = mycoords[ROW];
   coords[COL] = mycoords[ROW];
   MPI_Cart_rank(comm_2d, coords, &other_rank);
   MPI_Send(b, nlocal, MPI_DOUBLE, other_rank, 1, comm_2d);
}

if (mycoords[ROW] == mycoords[COL] && mycoords[ROW] != 0) {
   coords[ROW] = mycoords[ROW];
   coords[COL] = 0;
   MPI_Cart_rank(comm_2d, coords, &other_rank);
   MPI_Recv(b, nlocal, MPI_DOUBLE, other_rank, 1, comm_2d, &status);
}
```

2-D Matrix-Vector Multiplication

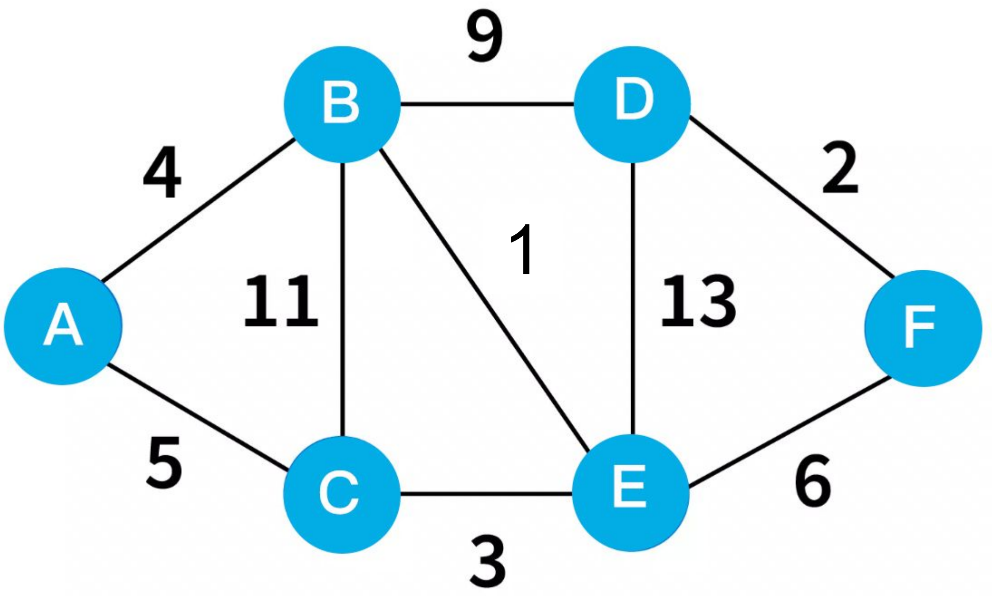
```
    coords[0] = mycoords[COL];
    MPI_Cart_rank(comm_col, coords, &other_rank);
    MPI_Bcast(b, nlocal, MPI_DOUBLE, other_rank, comm_col);

    for (i = 0; i < nlocal; i++) {
        px[i] = 0.0;
        for (j = 0; j < nlocal; j++)
            px[i] += a[i * nlocal + j] * b[j];
    }

    coords[0] = 0;
    MPI_Cart_rank(comm_row, coords, &other_rank);
    MPI_Reduce(px, x, nlocal, MPI_DOUBLE, MPI_SUM, other_rank, comm_row);

    MPI_Comm_free(&comm_2d);
    MPI_Comm_free(&comm_row);
    MPI_Comm_free(&comm_col);
    free(px);
}
```

Lecture Overview

- MPI Examples (Whiteboard walkthrough)
  - 2-D Matrix-Vector Multiplication
  - **Djikstra's Single Source Shortest Path**
  - Sample Sort

Djikstra's Single-Source Shortest Path (Review)

- Find the shortest path from a single node in a graph to all other nodes in a graph
- Serial Example Walkthrough (Starting from *A*)



Djikstra’s Single-Source Shortest Path

```
void SingleSource(int n, int source, int *wgt, int *lengths, MPI_Comm comm)
{
    int i, j;
    int nlocal;      /* The number of vertices stored locally */
    int *marker;     /* Used to mark the vertices belonging to Vo */
    int firstvtx;    /* The index number of the first vertex that is stored locally */
    int lastvtx;     /* The index number of the last vertex that is stored locally */
    int u, udist;
    int lminpair[2], gminpair[2];
    int npes, myrank;
    MPI_Status status;

    MPI_Comm_size(comm, &npes);
    MPI_Comm_rank(comm, &myrank);

    nlocal = n / npes;
    firstvtx = myrank * nlocal;
    lastvtx = firstvtx + nlocal - 1;
```

Djikstra’s Single-Source Shortest Path

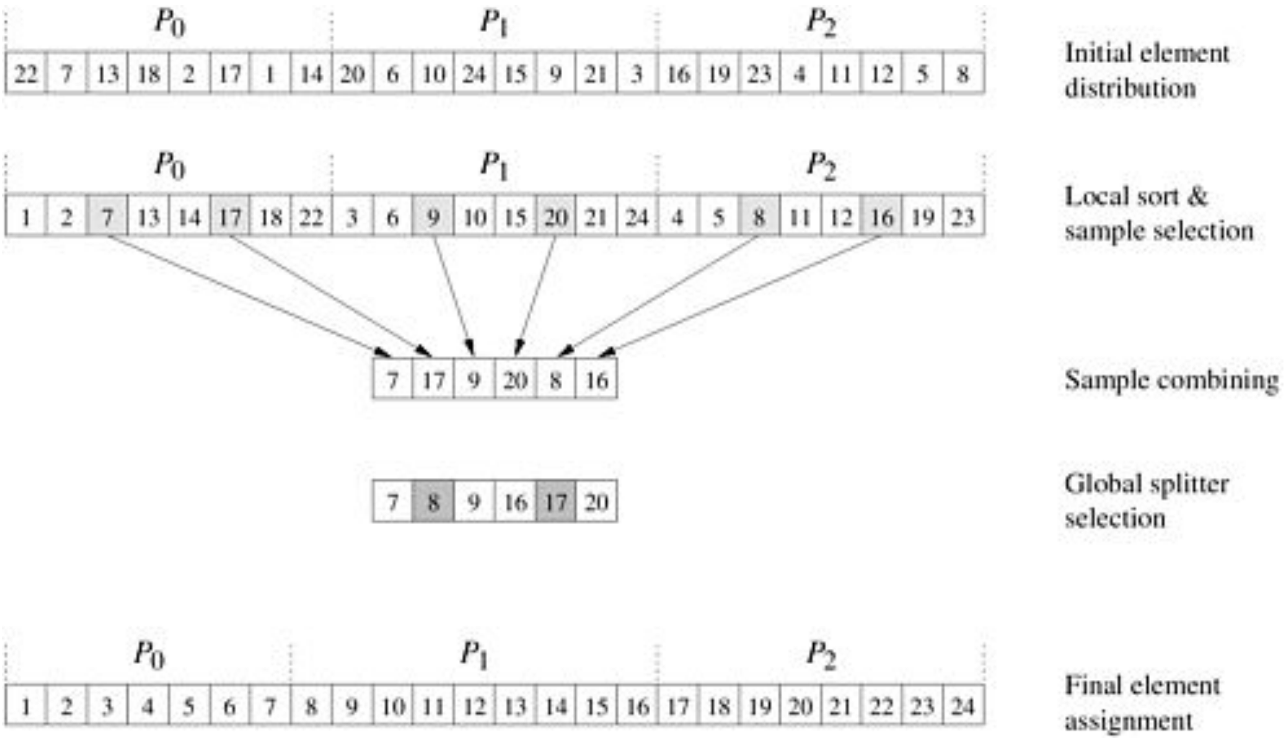
```
/* Set the initial distances from source to all the other vertices */
for (j = 0; j < nlocal; j++)
    lengths[j] = wgt[source * nlocal + j];

/* This array is used to indicate if the shortest path to a vertex has been found */
marker = (int *)malloc(nlocal * sizeof(int));
for (j = 0; j < nlocal; j++)
    marker[j] = 1;

/* The process that stores the source vertex marks it as seen */
if (source >= firstvtx && source <= lastvtx)
    marker[source - firstvtx] = 0;
```

```
    /* The main loop of Dijkstra's algorithm */
    for (i = 1; i < n; i++) {
      /* Step 1: Find the local vertex at the smallest distance from source */
      lminpair[0] = MAXINT; /* architecture dependent large number */
      lminpair[1] = -1;

      for (j = 0; j < nlocal; j++) {
        if (marker[j] && lengths[j] < lminpair[0]) {
          lminpair[0] = lengths[j];
          lminpair[1] = firstvtx + j;
        }
      }

      /* Step 2: Compute the global minimum vertex and insert it into Vc */
      MPI_Allreduce(lminpair, gminpair, 1, MPI_2INT, MPI_MINLOC, comm);
      udist = gminpair[0];
      u = gminpair[1];

      /* The process that stores the minimum vertex marks it as seen */
      if (u == lminpair[1])
        marker[u - firstvtx] = 0;

      /* Step 3: Update the distances given that u got inserted */
      for (j = 0; j < nlocal; j++) {
        if (marker[j] && udist + wgt[u * nlocal + j] < lengths[j])
          lengths[j] = udist + wgt[u * nlocal + j];
      }
    }
    free(marker);
}
```

Lecture Overview

- MPI Examples (Whiteboard walkthrough)
  - 2-D Matrix-Vector Multiplication
  - Djikstra’s Single Source Shortest Path
  - **Sample Sort**

Sample Sort


P0 P1 P2
22 7 13 18 2 17 1 14 20 6 10 24 15 9 21 3 16 19 23 4 11 12 5 8
Initial element distribution
P0 P1 P2
1 2 7 13 14 17 18 22 3 6 9 10 15 20 21 24 4 5 8 11 12 16 19 23
Local sort & sample selection
7 17 9 20 8 16
Sample combining
7 8 9 16 17 20
Global splitter selection
P0 P1 P2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Final element assignment

Sample Sort

```
int *SampleSort(int n, int *elmnts, int *nsorted, MPI_Comm comm)
{
    int i, j, nlocal, npes, myrank;
    int *sorted_elmnts, *splitters, *allpicks;
    int *scounts, *sdispls, *rcounts, *rdispls;

    /* Get communicator-related information */
    MPI_Comm_size(comm, &npes);
    MPI_Comm_rank(comm, &myrank);

    nlocal = n / npes;

    /* Allocate memory for the arrays that will store the splitters */
    splitters = (int *)malloc(npes * sizeof(int));
    allpicks = (int *)malloc(npes * (npes - 1) * sizeof(int));

    /* Sort local array */
    qsort(elmnts, nlocal, sizeof(int), IncOrder);
```

Sample Sort

```
/* Select local npes-1 equally spaced elements */
for (i = 1; i < npes; i++)
    splitters[i - 1] = elmnts[i * nlocal / npes];

/* Gather the samples in the processors */
MPI_Allgather(splitters, npes - 1, MPI_INT, allpicks, npes - 1, MPI_INT, comm);

/* Sort these samples */
qsort(allpicks, npes * (npes - 1), sizeof(int), IncOrder);

/* Select splitters */
for (i = 1; i < npes; i++)
    splitters[i - 1] = allpicks[i * npes - (int)ceil((double)npes/2)];
splitters[npes - 1] = MAXINT;

/* Compute the number of elements that belong to each bucket */
scounts = (int *)malloc(npes * sizeof(int));
for (i = 0; i < npes; i++)
    scounts[i] = 0;
for (j = i = 0; i < nlocal; i++) {
    if (elmnts[i] < splitters[j])
        scounts[j]++;
    else
        scounts[++j]++;
}
```

Sample Sort

```
/* Determine starting locations of each bucket's elements */
   sdispls = (int *)malloc(npes * sizeof(int));
   sdispls[0] = 0;
   for (i = 1; i < npes; i++)
      sdispls[i] = sdispls[i - 1] + scounts[i - 1];

   /* Inform all processes about receive counts */
   rcounts = (int *)malloc(npes * sizeof(int));
   MPI_Alltoall(scounts, 1, MPI_INT, rcounts, 1, MPI_INT, comm);

   /* Compute receive displacements */
   rdispls = (int *)malloc(npes * sizeof(int));
   rdispls[0] = 0;
   for (i = 1; i < npes; i++)
      rdispls[i] = rdispls[i - 1] + rcounts[i - 1];

   *nsorted = rdispls[npes - 1] + rcounts[npes - 1];
   sorted_elmnts = (int *)malloc((*nsorted) * sizeof(int));

   /* Exchange elements between processors */
   MPI_Alltoallv(elmnts, scounts, sdispls, MPI_INT,
              sorted_elmnts, rcounts, rdispls, MPI_INT, comm);

   /* Final local sort */
   qsort(sorted_elmnts, *nsorted, sizeof(int), IncOrder);
```

Sample Sort

```
    free(splitters);
    free(allpicks);
    free(scounts);
    free(sdispls);
    free(rcounts);
    free(rdispls);

    return sorted_elmnts;
}
```