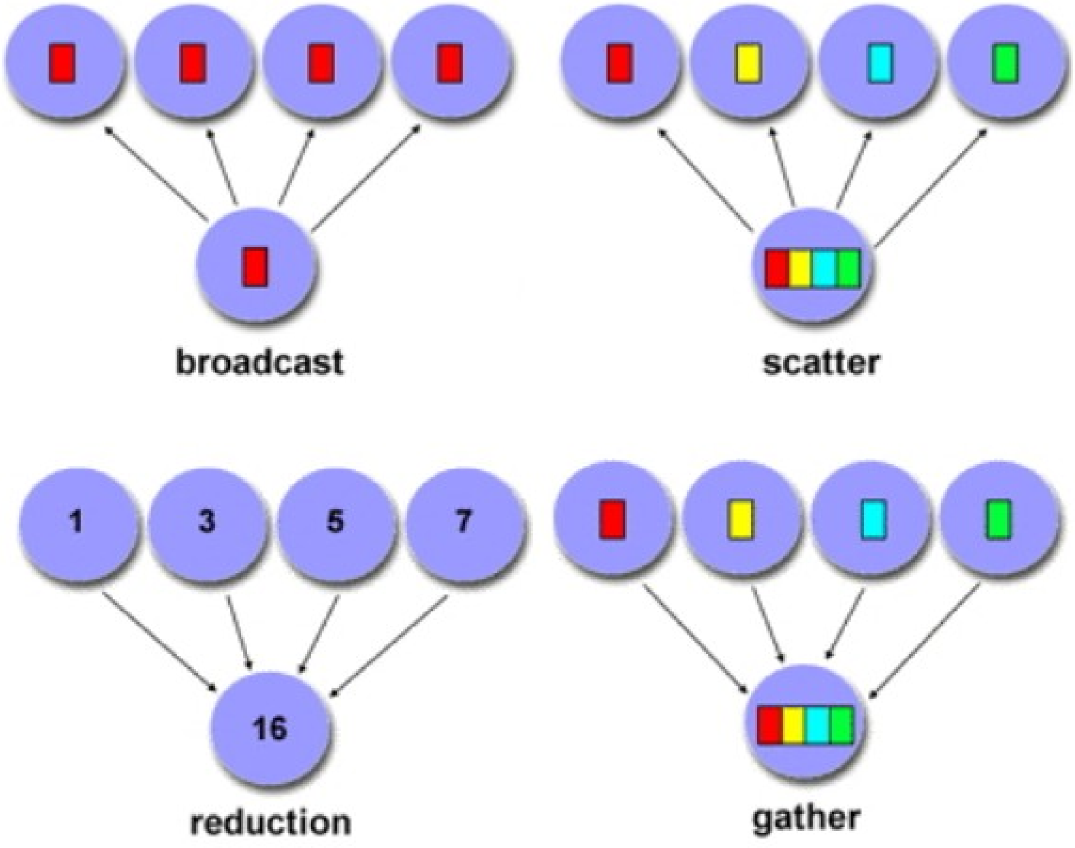
Collectives

- Using combined information from independent nodes



Examples

- How would you realize the following scenarios with MPI collectives?
  - Let each process compute a random number. You want to print the maximum of these numbers to your screen.
  - Each process computes a random number again. Now you want to scale these numbers by their maximum.
  - Let each process compute a random number. You want to print on what processor the maximum value is computed.

Commands Used

- MPI_Bcast, MPI_Reduce, MPI_Gather, MPI_Scatter
- MPI_All_... variants, MPI_....v variants
- MPI_Barrier, MPI_Alltoall, MPI_Scan

Allreduce

- int MPI_Allreduce(const void* sendbuf,

  void* recvbuf, int count, MPI_Datatype datatype,

  MPI_Op op, MPI_Comm comm)

- Semantics:
  - IN sendbuf: starting address of send buffer (choice)
  - OUT recvbuf: starting address of receive buffer (choice)
  - IN count: number of elements in send buffer (non-negative integer)
  - IN datatype: data type of elements of send buffer (handle)
  - IN op: operation (handle)
  - IN comm: communicator (handle)

Example 1

- Each node should generate a single random number
- Use MPI_Allreduce to sum all the numbers then calculate the average
  - Divide by RAND_MAX to normalize between 0 and 1
  - Should be approx 0.5
- The “operation” is MPI_SUM
- The “datatype” is MPI_FLOAT

Example 2

- If one has two (large) vectors x and y, such that each processor stores a “block” of each, compute the inner product of the two vectors
- Recall, <x,y> (inner product) is:
  - $$x \cdot y = \sum_{i=1}^{n} x_i \cdot y_i$$
- Method: Do the “local” inner product and Allreduce with the MPI_SUM op

Some necessities of C

- No more “new” command for arrays :(
- Instead, we call malloc directly!
  - void* malloc(size_t)
  - Returns an address
  - Recall void ptrs can be cast to whatever they need to be (but be careful!)
- Typical strategy: malloc(num * sizeof(type))
- Note: collectives are **blocking**!
  - Have to wait if some processes aren’t there yet

Example 3

- All processes generate 500k random doubles between 0 and 1
- Calculate the average, but use MPI_IN_PLACE, which overwrites the input data with the result
  - Saves half the memory!
  - Only need to calculate the average on one node
  - Can be cast and stored as a variable

More MPI Operators

MPI type	meaning	applies to
MPI_MAX	maximum	integer, floating point
MPI_MIN	minimum	
MPI_SUM	sum	integer, floating point, complex, multilanguage types
MPI_PROD	product	
MPI_LAND	logical and	C integer, logical
MPI_LOR	logical or	
MPI_LXOR	logical xor	
MPI_BAND	bitwise and	integer, byte, multilanguage types
MPI_BOR	bitwise or	
MPI_BXOR	bitwise xor	
MPI_MAXLOC	max value and location	*MPI_DOUBLE_INT* and such
MPI_MINLOC	min value and location	

- Can also create your own!
  - MPI_Op_create(MPI_User_function * func, int commute, MPI_Op * op);

Rooted Collectives

- We can designate one process with “root” status, giving higher priority and extra responsibility
- Usage example: instead of using Allreduce, we can reduce to a single root node instead
  - Fewer communications
  - Less memory overhead
    - Non-roots can use null receive buffer
  - Need to broadcast results

MPI_Reduce

- int MPI_Reduce(

  const void* sendbuf, void* recvbuf, int count, MPI_Datatype datatype,

  MPI_Op op, int root, MPI_Comm comm)
- Note that root is designated by its rank among the communicator
- Can also be done in place

Example 4

- Each process generates its own random number
- Reduce to a root, process 0, which reports the max of all the numbers
- Include output from all processes to check correctness

Broadcasting

- MP_Bcast(void* buffer, int count, MPI_Datatype t, int root, MPI_Comm c)
- Keep in mind buffer is an address
  - So will be &value for an int, etc.
  - But will be arrName for an array
- Result is that all non-roots get a copy of the root node's "buffer" variable
  - Space must be pre-allocated (maybe need a broadcast beforehand)!

Example: Matrices

- Recall that for matrices A and B of sizes n-by-k and k-by-m, respectively, their product, A*B is defined as the n-by-m matrix C such that

$$C_{i,j} = \sum_{\ell=1}^{k} A_{i,\ell} \cdot B_{\ell,j}$$

That is, the (i,j) entry of C is the inner (or dot) product of the ith row of A with the jth column of B.

Matrix Multiplication

- Question: how to distribute the matrix product? Options? What collectives are needed?
- Basic task: given a matrix A, find another matrix, called A^{-1}, so that $A * A^{-1}$ is a square matrix with 1’s on the main diagonal and 0’s everywhere else (i.e. the identity matrix)

Example from Numerical Linear Algebra

Exercise 3.6. The *Gauss-Jordan algorithm* for solving a linear system with a matrix A (or computing its inverse) runs as follows:

for pivot $k = 1, \ldots, n$
  let the vector of scalings $\ell_i^{(k)} = A_{ik}/A_{kk}$
  for row $r \neq k$
    for column $c = 1, \ldots, n$
      $A_{rc} \leftarrow A_{rc} - \ell_r^{(k)} A_{rc}$

where we ignore the update of the righthand side, or the formation of the inverse. Let a matrix be distributed with each process storing one column. Implement the Gauss-Jordan algorithm as a series of broadcasts: in iteration k process k computes and broadcasts the scaling vector $\{\ell_i^{(k)}\}_i$. Replicate the right-hand side on all processors.