CHARM++ EXAMPLES

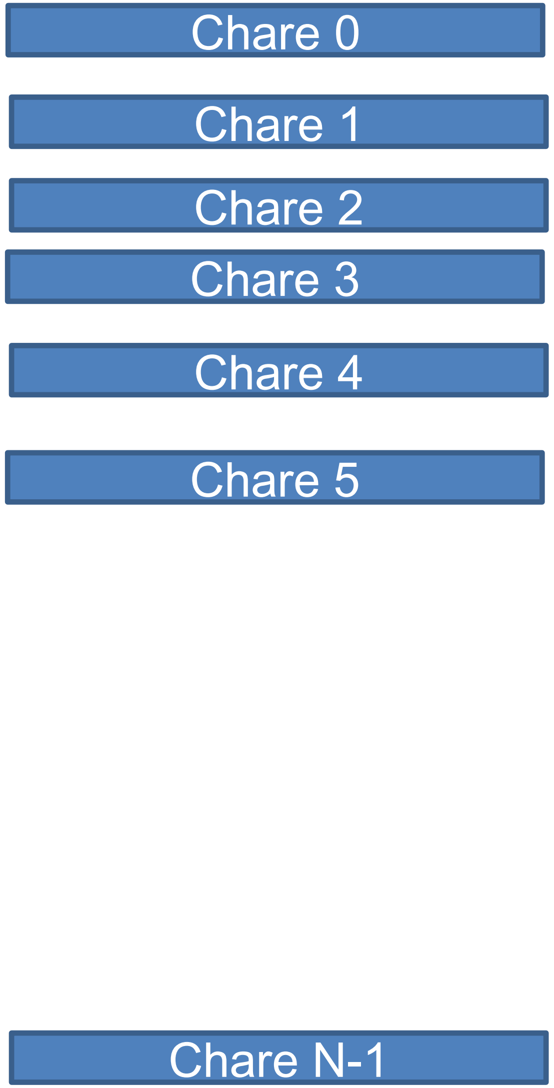
A few examples

- Some with code and some top level designs

1. How to find median of data spread out over a chare array
2. How to send a small number of “wrong” elements to their correct homes in an otherwise sorted array
3. How to sort elements in a chare array:
    1. Using a parallel version of quick sort (may skip)
    2. Using histogram sort

Discussion and Idea for median finding

- N chares in a chare array
- Each containing a set of numbers
- Median:
  - a number X such that about half of all the numbers are smaller than it and half larger
- How to find the median?
- Idea:
  - Main or chare0 makes a guess (how?)
  - Broadcast to everyone
  - Everyone counts smaller/larger
  - Reduce to main
  - Main updates the guess and repeats



Median Example: median.ci

```
mainmodule Median {
  readonly CProxy_Main mainProxy;
  mainchare Main {
    entry Main(CkArgMsg* m);
    entry [reductiontarget] void informRoot(int counts[2]);
    entry void computeMedian(){ … }

  };

  array [1D] Partition {
    entry Partition();
    entry void queryCounts(double median);
  };
};
```

```
entry void computeMedian(){
      while(true){
        serial{ partition_array.queryCounts(median);  }
        when informRoot(int counts[]) serial {
          int nSmaller = counts[0];
          int nLarger = counts[1];
          double error =
                  (double)abs(nSmaller-nLarger)/(nSmaller + nLarger);
          if(error < 0.01){
            CkPrintf("\nMedian = %lf (in %d iterations)\n", median, iter);
            CkExit(); }
          if(nSmaller > nLarger)
            max_range = median;
          else
            min_range = median;
          median = (min_range+max_range)/2;
          iter++;
      }
    }
  }
```

Median Example: median.C I

```
#include "Median.decl.h”
/*readonly*/ CProxy_Main mainProxy;
/*readonly*/ int K;

class Main: public CBase_Main { Main_SDAG_CODE
private:
  CProxy_Partition partition_array;
  double median, min_range, max_range;
  int iter;
public:
  Main(CkArgMsg* m) {
    iter = 0, min_range = 0.0, max_range = 1.0;
    K = atoi(m->argv[2]);
    median = atof(m->argv[3]);  // initial guess provided on command line
    mainProxy = thisProxy;
    partition_array = CProxy_Partition::ckNew(atoi(m->argv[1]));
    mainProxy.computeMedian();
  }
};
```

Median Example: median.C II

```
class Partition: public CBase_Partition {
 public:
  double *numbers;

  Partition(int guess) {
   numbers = new double[K];
   srand48(time(NULL));
   for(int i=0;i<K;i++)
    numbers[i] = drand48();
  }
  void queryCounts(double median){...}
};

#include "Median.def.h"
```

```
void queryCounts(double median){
 int counts[2]; counts[0] = counts[1] = 0;
 for(int i=0;i<K;i++){
   if(numbers[i]<median)
         counts[0]++; // # smaller than median
   else
         counts[1]++; // # larger than median
  }
 contribute(2*sizeof(int), counts, CkReduction::sum_int,
 CkCallback(CkReductionTarget(Main, informRoot), mainProxy));
 }
```

Relaxing an assumption

- We assumed in the above code:
  - The main chare knows the smallest and largest possible values
  - Under what conditions is that valid or efficient?

- How can we relax that assumption?
- Discuss

Improving Our Median Program further

- How can we improve its efficiency?
- What are the costs?
  - Discuss
  - Number of rounds
  - Cost of each round

Improving Our Median Program further

- How can we improve its efficiency?
- What are the costs?
- For each probe, the queryCounts method has to loop through the entire array
  - What if we pre-sort the array?
  - What if we partially sort the array (and keep improving it at every probe)
- How to improve the initial guess?
  - So as to reduce the number of broadcast-reduction iterations
- How to get more information with each reduction?
  - After all the cost of reduction doesn't change much if we reduce a small vector instead of just 2 counts
  - Histogramming

A somewhat related problem

- Consider a situation in which a chare array is sorted
  - Values are between 0 and M, long integers
  - Without worrying too much about data balance
  - The data distribution is uniform, so, we decide that chare I will hold values between (I*M/P, (I+1)*M/P -1)
    - Where P is the number of chares in the array
- Now, each chare generates a few new items
  - Their value may be anywhere in the range 0..M
  - Let us assume the “few” is really small, like 5 or 10
  - And P is large (say > 10,000)
  - Also, the total data on each chare is large.. But that’s immaterial
- How can we send them to their correct home places?

Send a few stragglers home

- Easy enough:
- Just send a message for each new value to its home
  - (it is easy to calculate home)
  - Optimize: don’t send message to yourself
  - Optimize?: combine messages going to the same processor?
    - Rare so we will ignore for now
- The problem?
  - How do we know when we are done
  - So, each chare can start the next phase of computation, for example

Quiescence Detection

- In Charm++, ***quiescence*** is defined as the state in which no processor is executing any entry method, no messages are awaiting processing, and there are no messages in-flight
- Charm++ provides a method to detect quiescence:
- From any chare, invoke *CkStartQD(callback);*
- The system is always doing the background bookkeeping so it can detect quiescence
  - The call just starts a low-overhead distributed algorithm to detect the condition
  - It runs concurrently with your application
  - So, call CkStartQD as late as possible to reduce the overhead

Quiescence Detection applied to stragglers

- For our problem,
  - we can have one of the chares (say with index 0) call CkStartQD after it has done its sending
  - With a callback that broadcasts to every chare in the array that quiescence has been attained
  - This means all the stragglers have reached their home

Histogram sort

- Idea: extend the median finding algorithm
- If we have P chares, we need to find P-1 separator keys
  - I.e. values that act as (or define) boundaries between chares
  - Such that everyone has an (approximately) equal number of values
- We can
  - make a guess (called a probe)
  - Collect a histogram (counts)
  - Correct the guesses and prepeat
- When adequate separators are identified:
  - Everyone sends the data to where it belongs
  - Use quiescence detection to make sure all the data is received
  - Sort locally

Histogram sort: interesting optimizations

- Some optimizations to this algorithm exploit charm++’s message driven execution
- E.g. Some chares’ separators may be found early on:
  - Everyone can start sending their values in parallel with histogramming for other chares
- Histogramming and initial local sorting may be overlapped
- Histogram may be decomposed into multiple portions
  - So that it can be pipelined
  - While root is preparing the next guess for one ection, the other section is doing it distributed histogramming

See paper by Vipul Harsh: https://charm.cs.illinois.edu/papers/19-02