Programming GPGPU with MapReduce

Wenguang CHEN
Tsinghua University
2010/1/15

Program GPU with CUDA

- CUDA is a revolutionary step in GPU programming
  - Much easier than OpenGL ,or other shader languages, such as Cg
- However, it is still not very easy to program with CUDA
  - It is not easy to do any parallel programming

What makes parallel computing so difficult

- Identifying and expressing parallelism
  - Autoparallelizing has been failed so far
- Complex synchronization may be required
  - Data races and deadlocks which are difficult to debug
- Load balance…
- Locality optimization

An ideal parallel programming model

- Portable
- Fast
- Easy to program
- Scalable
- Fault-tolerant
- Automatic load balancing
- Versatile
- …

No Silver Bullet

- If we can not solve the parallel programming in general
  - Can we solve that for a specific domain?
  - Domain specific language(DSL)
    - SQL
    - MAP-Reduce

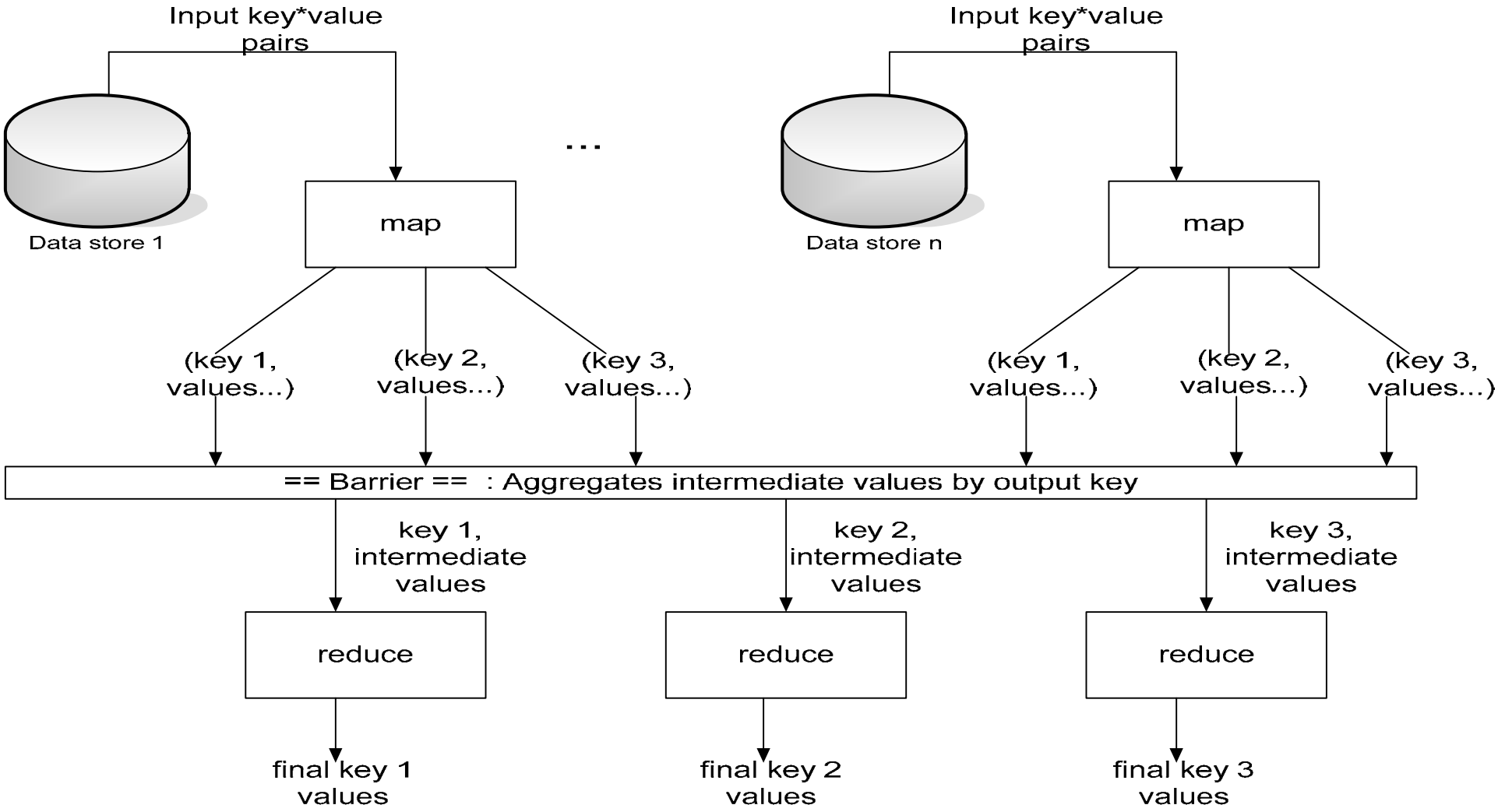
MapReduce Programming Model

- Borrows from functional programming
- Users implement interface of two functions:

```
map  (in_key, in_value)
  -> (out_key, intermediate_value) list
reduce (out_key, intermediate_value list)
 -> out_value list
```

Jeffrey Dean and Sanjay Ghemawat,
MapReduce: Simplified Data Processing on Large Clusters, OSDI'04: Sixth Symposium on Operating System Design and Implementation, San Francisco, CA, December, 2004.

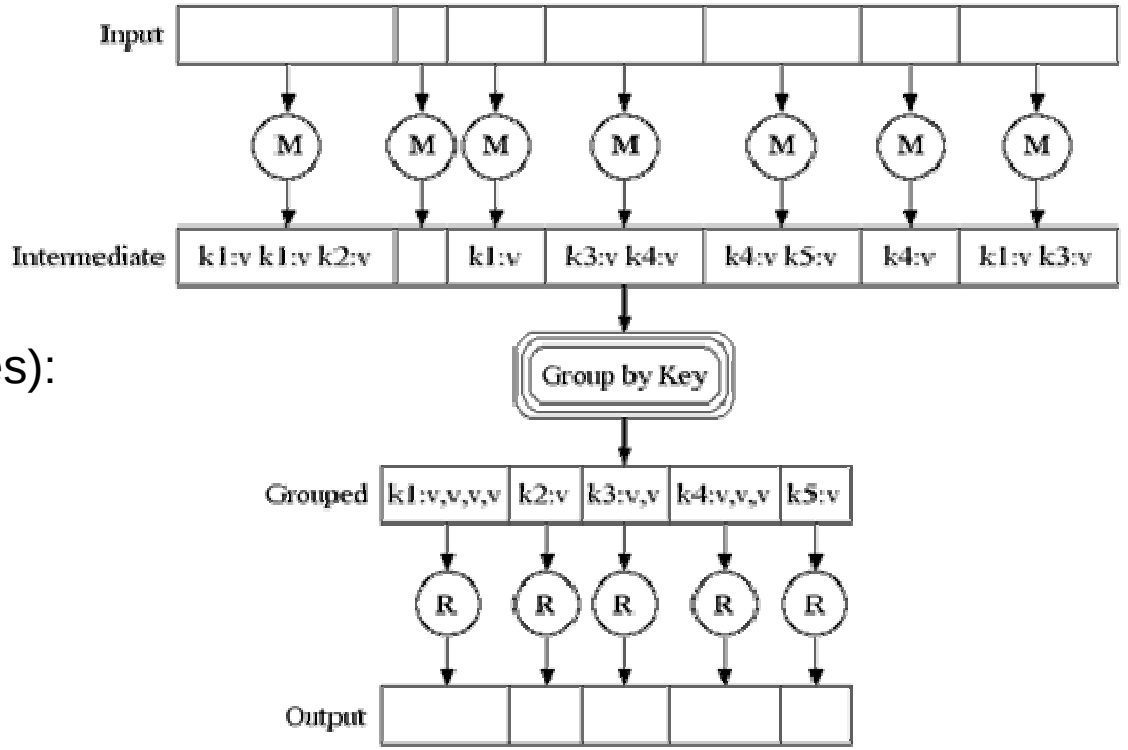
Map-Reduce Architecture



WordCount Program in Map-Reduce

```
map(string key, string val):
    // key: document name
    // value: document content
    for each word  w in value:
        emit_intermediate(w, “1”);

reduce(string key, iterator values):
    // key: a word
    // values: a list of counts
    int result=0;
    for each v in values:
        result+=ParseInt(v);
    emit(AsString(result));
```



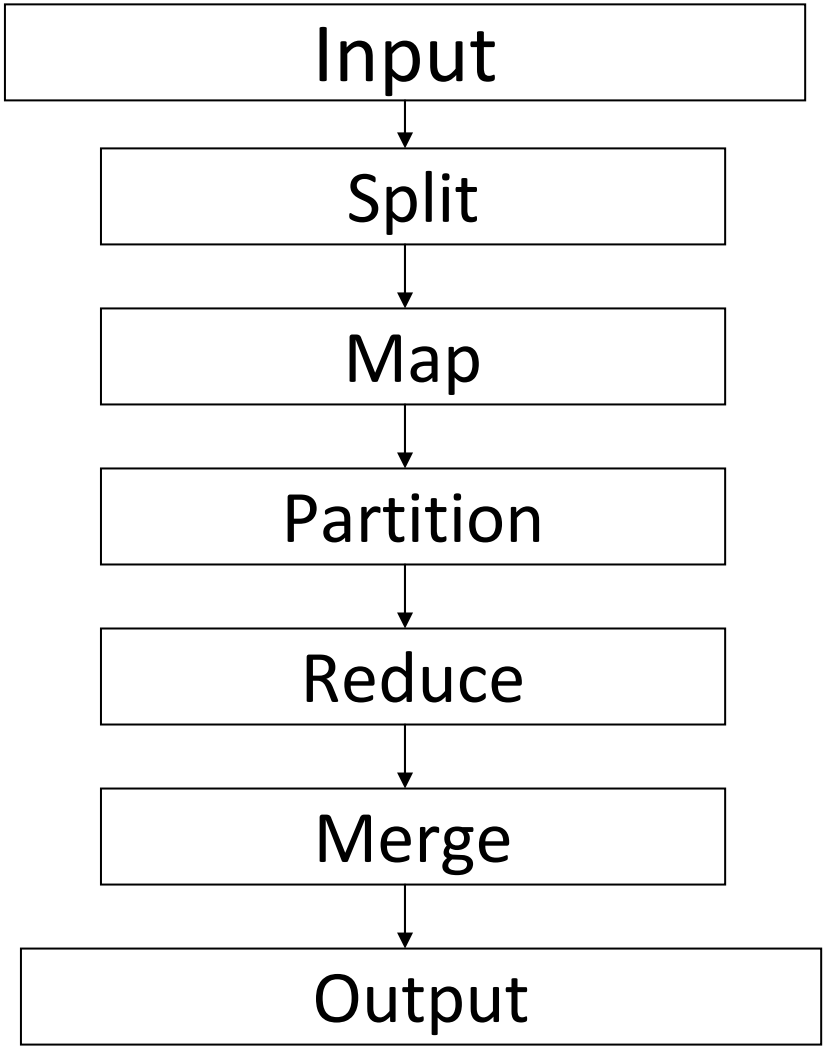
MapReduce is promising

- Easy to use
  - Programmers only need to write sequential code
  - Deal with fault tolerance and load balance automatically which is a very desired feature for large scale computing
- Dominated programming paradigm in Internet companies
- Originally support distributed systems, now ported to GPU, CELL, multi-core
  - Phoenix, Mars, Merge etc.

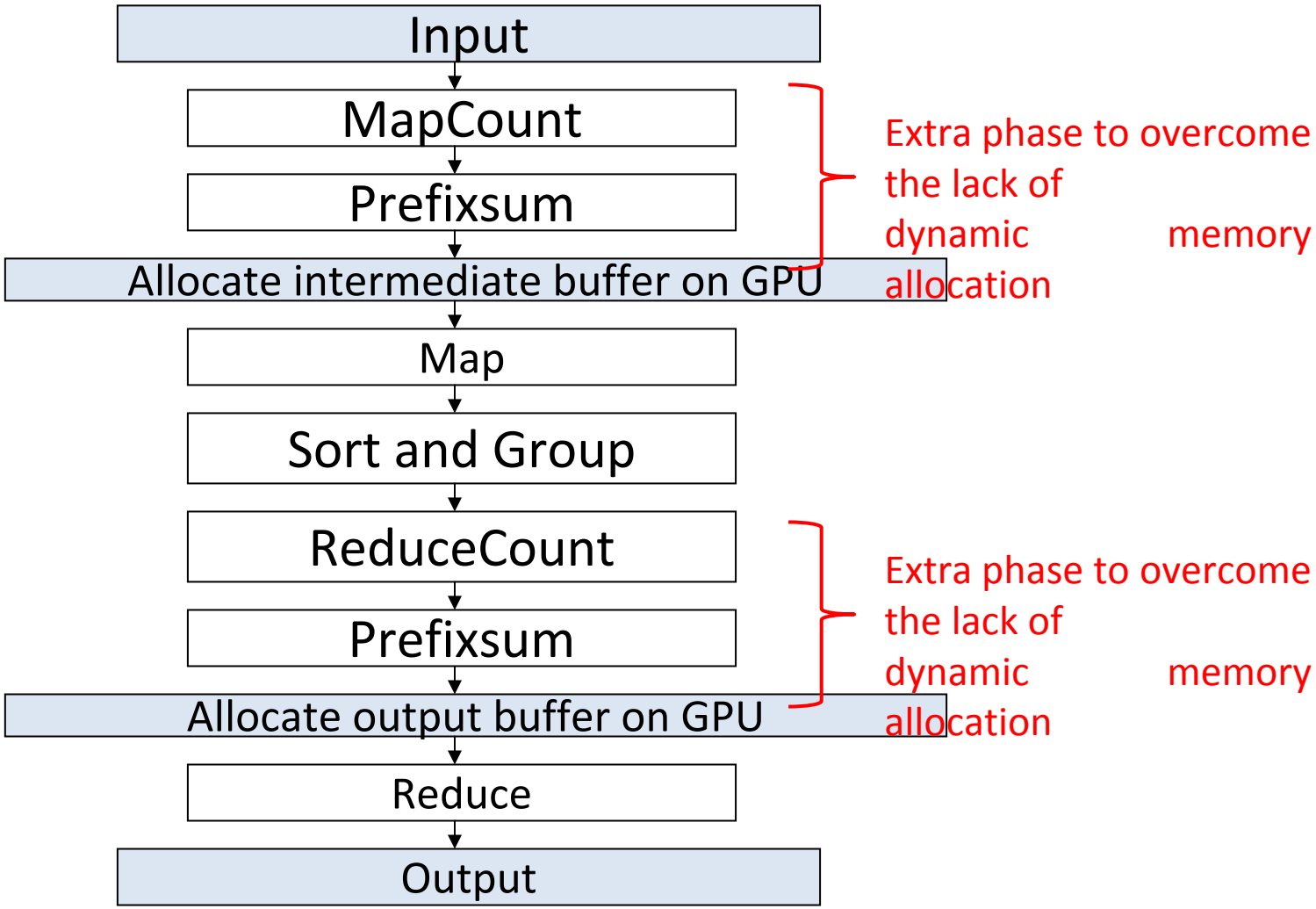
However, there are many dialects of MapReduce

- Because of limited features provided by different architectures
- nVidia GPU as an example
  - No “host” function support
  - No dynamic memory allocation
  - Complex memory hierarchy make it difficult to tune performance

MapReduce on Multi-core CPU (Phoenix [HPCA'07])



MapReduce on GPU (Mars[PACT'08])



Program Example

- Word Count (Phoenix Implementation)

```
…
  for (i = 0; i < args->length; i++)
  {
    curr_ltr = toupper(data[i]);
    switch (state)
    {
    case IN_WORD:
      data[i] = curr_ltr;
      if ((curr_ltr < 'A' || curr_ltr > 'Z') && curr_ltr != '\'‘)    {
        data[i] = 0;
        emit_intermediate(curr_start, (void *)1, &data[i] - curr_start + 1);
        state = NOT_IN_WORD;
      }
    break;
…
```

Program Example

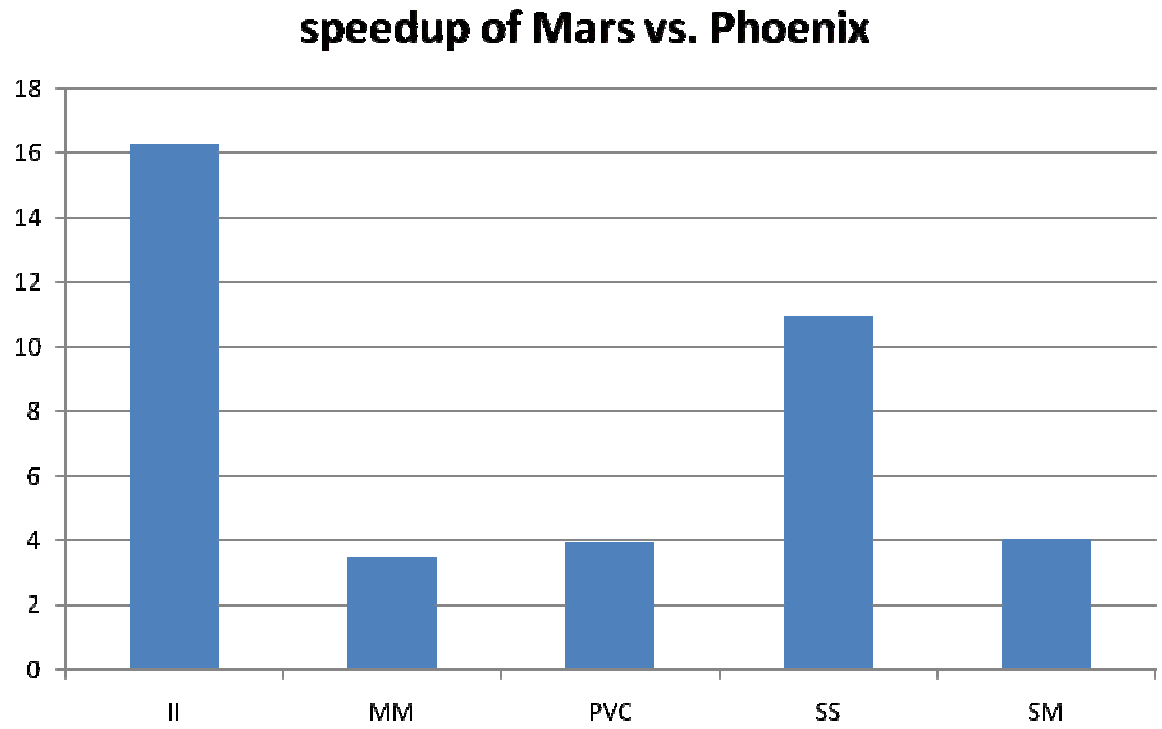
- Word Count (Mars Implementation)

```
__device__ void GPU_MAP_COUNT_FUNC
     //(void *key, void *val, int keySize, int valSize)
{
….
 do  {
….
   if (*line != ' ‘)   line++;
   else {
         line++;
         GPU_EMIT_INTER_COUNT_FUNC(
                              wordSize-1, sizeof(int));
         while (*line == ' ‘)   {
            line++;
         }
         wordSize = 0;
   }
 } while (*line != '\n');
…
}
```

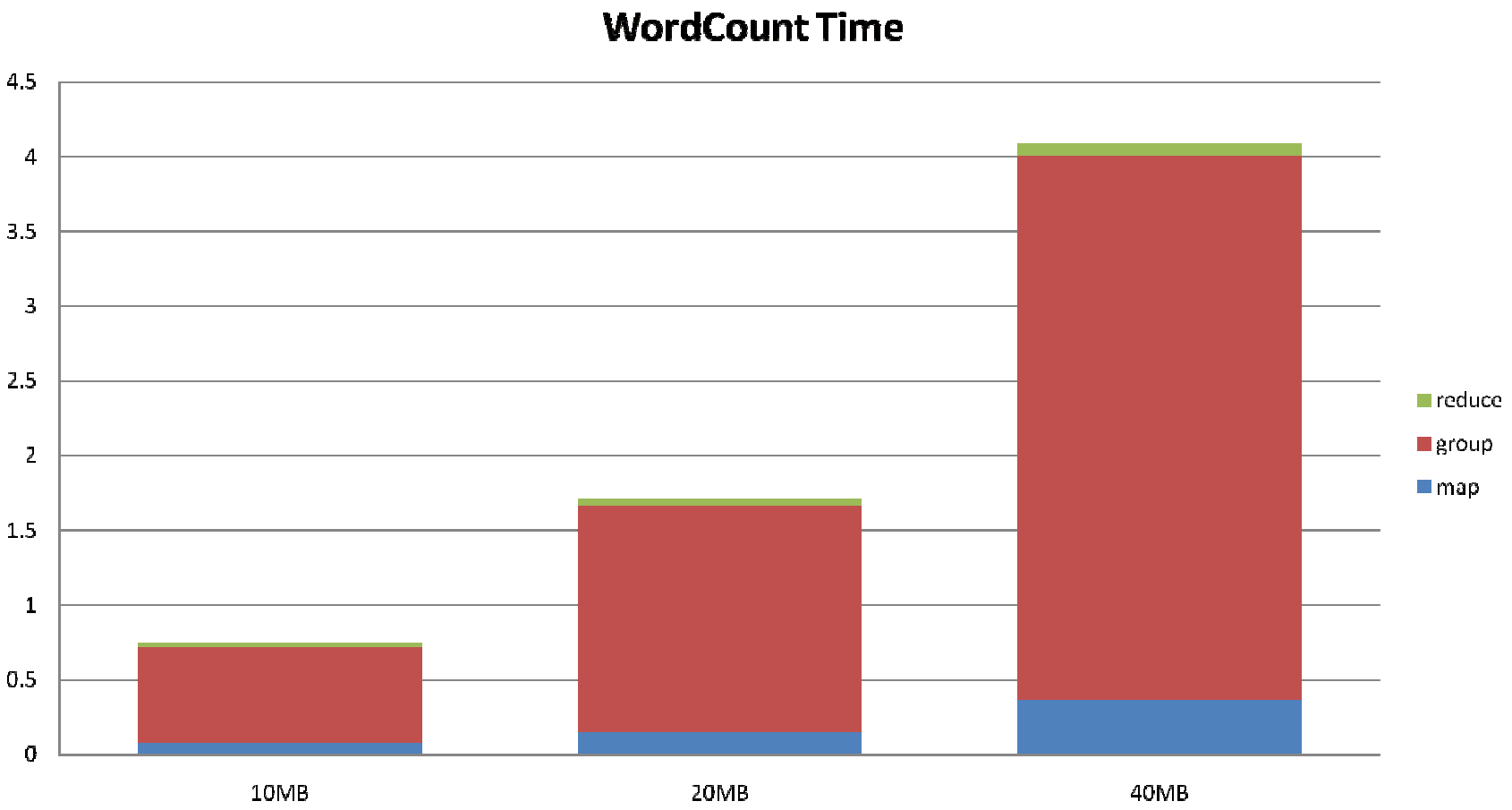
```
__device__ void GPU_MAP_FUNC//(void
*key,
                  void val, int keySize, int valSize)
{
….
 do  {
….
   if (*line != ' ‘)   line++;
   else {
         line++;
         GPU_EMIT_INTER_FUNC(word,
               &wordSize, wordSize-1, sizeof(int));
         while (*line == ' ‘)   {
            line++;
         }
         wordSize = 0;
   }
 } while (*line != '\n');
…
}
```

Mars Speedup over CPU

- Speedup of Mars vs. Phoenix, according to Mars paper



Grouping Performance is Important

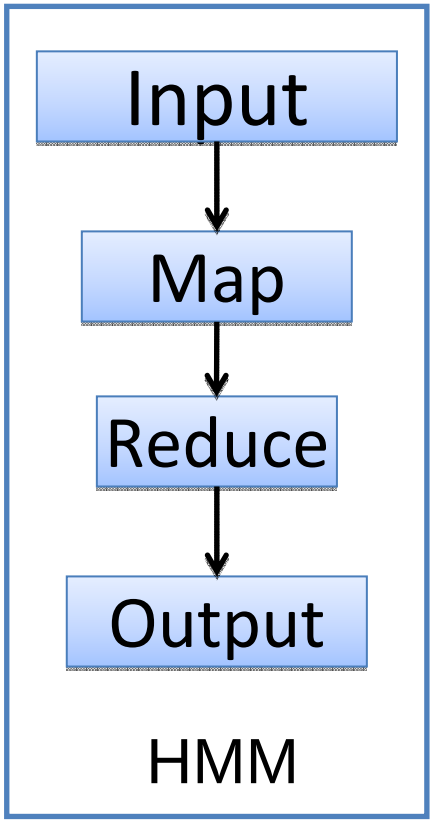


Execution time of WordCount using Mars

Mars: Using Bitonic Sort

- High complexity
  - O(n(logn)^2)
- Unnecessary:
  - The order of the intermediate key/value pairs is usually not desired, as in the case of WordCount, PageViewCount, etc…

HMM: Efficient MapReduce Framework for GPU



- Goals
  - Better portability of Map-Reduce on GPU
  - Better Performance
- Two key ideas:
  - Lightweight memory allocator
  - Uses hash table to group key/values instead of sorting

Dynamic Memory Allocation on GPU

- Observations:
  - No need for free()
    - Memory can be freed at once at the end of a phase
  - Small, regular size allocations
    - Key/value lists are usually small (<=32byte)

Dynamic Memory Allocation --Problems

- Correctness
  - Two threads should not get the same memory address
- Performance
  - Contention
    - Thousands, even millions of thread allocating simultaneously (HMM uses 256*256 threads by default)
  - Long latency
    - The latency of accessing a global address takes 400 cycles

Dynamic Memory Allocation -- Solutions

- Correctness
  - use atomic operation

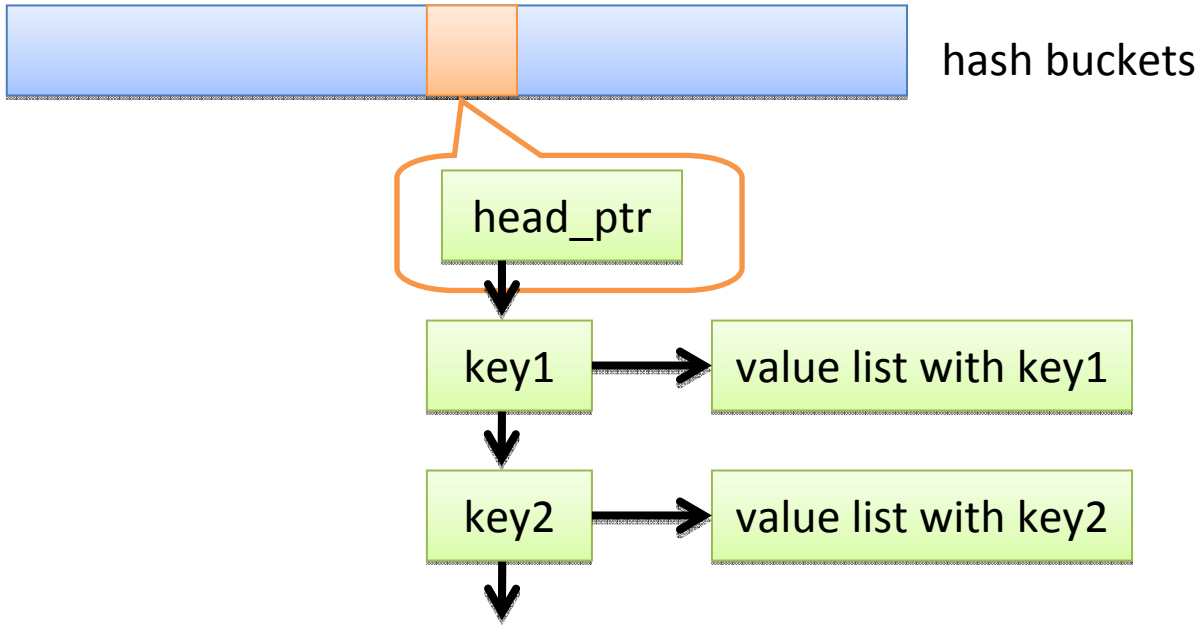
    *unsigned atomicAdd(unsigned * addr, unsigned inc)*

```
char * memory_ptr;    // the pointer to the free memory space
void * malloc_from_memory_pool ( int size ){
   return (char *)atomicAdd( (int*)&memory_ptr, size );
}
```

- Performance
  - take advantage of the fast *shared memory*

Grouping with Hash Table

- Low complexity:
  - O (n)
- Closed hashing, enabled with dynamic memory allocator



Problems

- Data race when different threads try to insert into the same value list
  - need a thread-safe list implementation
- The value lists and the value list nodes should be dynamically allocated
  - fortunately, we have the memory allocator

Dealing with Data Races

- No lock on GPU, but there is atomic CAS provided:
  - atomicCAS(addr, old_val, new_val)
    - If *addr==old_val, then *addr=new_val. The compare and store are executed atomically. The return value is *addr before the operation.
  - atomicCAS can be used to implement efficient lock-free data structures, such as linked list

```
// inserting a new node into a list
Node * new_node=get_new_node();
While(1){
   Node * local_copy_of_list_head=list_head;
   new_node->next=local_copy_of_list_head;
   if(atomicCAS(&list_head, local_copy_of_list_head, new_node)==local_copy_of_list_head)
      break;
}
```

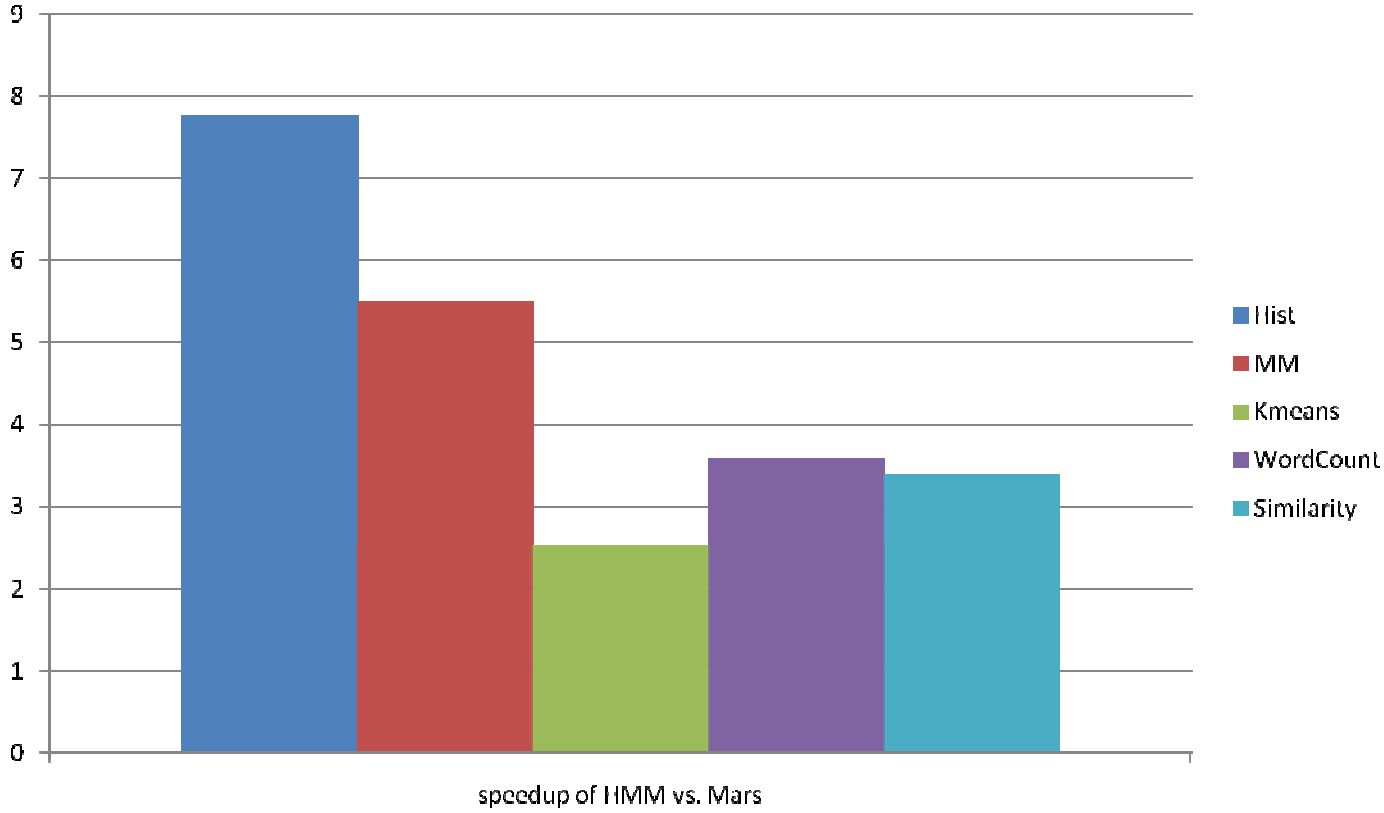
Benchmark Applications

Name	Description	Dataset
Hist	**Histogram: generates the histogram of frequencies of pixel values in the red, green and blue channels of a bitmap picture**	9MB file, 10 pixels/map
MM	**Dense Matrix Multiplication: A*B=C, where A, B are N*N matrices**	N=2048
SS	**Similarity Score: calculates the similarity between a set of documents, given their vector representation**	2048 documents, dim=128
WC	**Word Count: count the number of times each word occurs in a file**	40MB
Kmeans	**K-means: K-means clustering algorithm**	8000 points, 200 clusters, vector dim=40

Benchmarks – under construction

- PLSA: Probabilistic Latent Semantic Analysis
- N-Body: N-body simulation
- Inverted Index
- Linear Regression

Speedup of HMM vs. Mars



speedup of HMM vs. Mars on:
Histogram, MatrixMultiplication, Kmeans, WordCount, and SimilarityScore

Open Source

- You are welcome to try HMM and give us your feedback!
  - http://sourceforge.net/projects/mapp/

Conclusion

- Map-Reduce is a promising high level parallel programming model for GPU
  - Easy to write
  - Fault-tolerant and load balancing
  - Scalable to multiple cards
  - Portable(ongoing)

Thanks!