Evaluating MapReduce for Multicore and Multiprocessor Systems

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Google's MapReduce

- A general-purpose environment for large-scale data processing
  - Programming model (API) and runtime system for large clusters
  - Functional representation of data parallel tasks

- Easy to use & very successful within Google
  - Indexing system, distributed grep & sort, document clustering, machine learning, statistical machine translation, …

- MapReduce supports
  - Automatic parallelization and distribution
    - Abstracts parallelization, synchronization, and communication issues
  - Fault tolerance
    - Task monitoring and replication
  - I/O scheduling

WordCount Example [OSDI'04]

```
// input: a document
// intermediate output: key=word; value=1
Map(void *input) {                          // Applied to each input element
    for each word w in input
      EmitIntermediate(w, 1);               // <key, val> intermediate pairs
}

// intermediate output: key=word; value=1
// output: key=word; value=occurrences
Reduce(String key, Iterator values) {
    int result = 0;                         // Applied to all pairs with same key
    for each v in values
      result += v;
    Emit(key, result);                      // Final output sorted by key
}
```

The Phoenix System

- Question: is MapReduce applicable to multicore programming?
  - What is the performance?
  - Is the performance scalable & portable?
  - Does it help with locality and fault management?
  - How does it compare to other parallel programming approaches?

- ***Phoenix***: a shared-memory implementation of MapReduce
  - Uses threads instead of cluster nodes for parallelism
  - Communicates through shared memory instead of network messages
    - Works with CMP and SMP systems
  - Current version works with C/C++ and uses P-threads
    - Easy to port to other languages or thread environments

The Phoenix API

- System-defined functions
  - `int phoenix_scheduler (scheduler_args_t *args)`
    - Initializes the runtime system
  - `void emit_intermediate (void *key, void *val, int key_size)`
  - `void emit (void *key, void *val)`

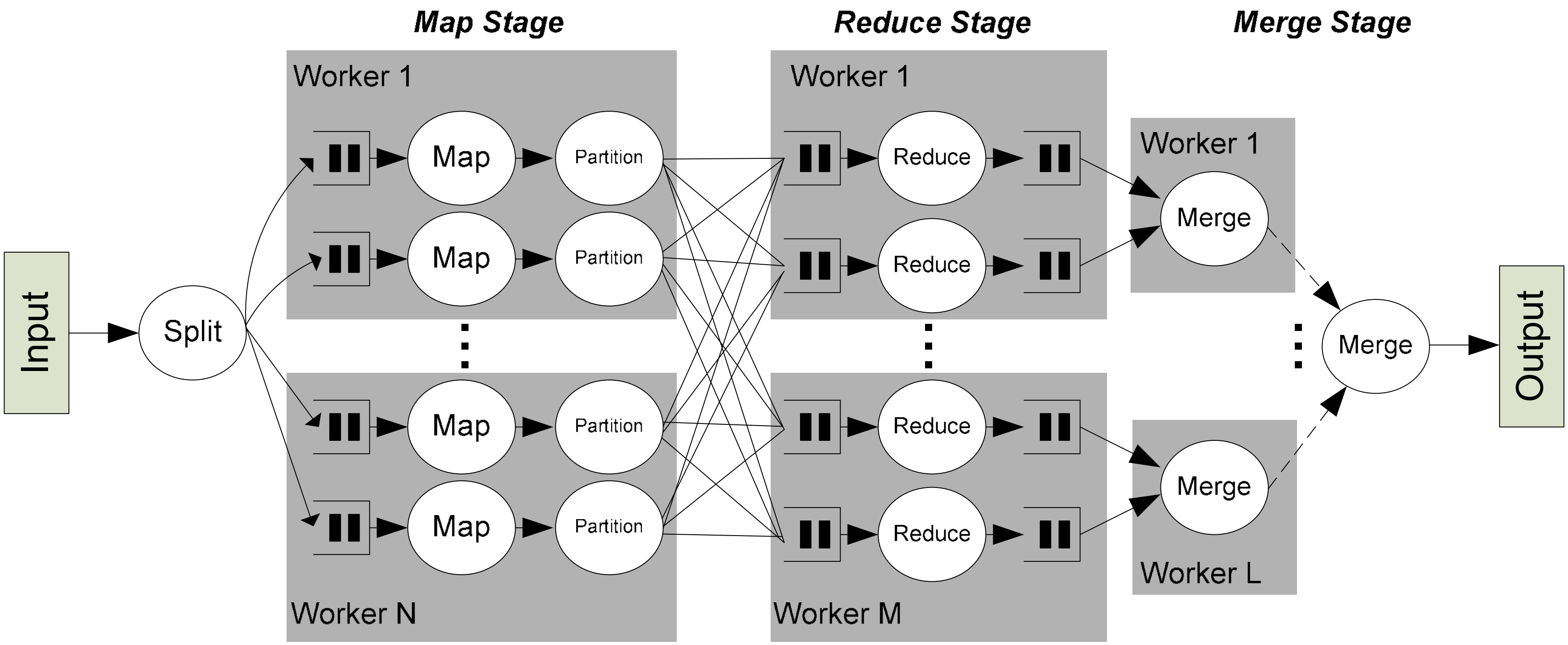
- User-defined functions
  - `void (*map_t) (map_args_t *args)`
    - Map function applied on each input element
  - `void (*reduce_t) (void *key, void **buffer, int count)`
    - Reduce function applied on intermediate pairs with same key
  - `int (*key_cmp_t) (const void *key1, const void *key2)`
    - Function that compares two keys
  - `int (*splitter_t) (void *input, int size, map args t *args)`
    - Splits input data across Map tasks (optional)

Simple & narrow API. Similar to Google's API

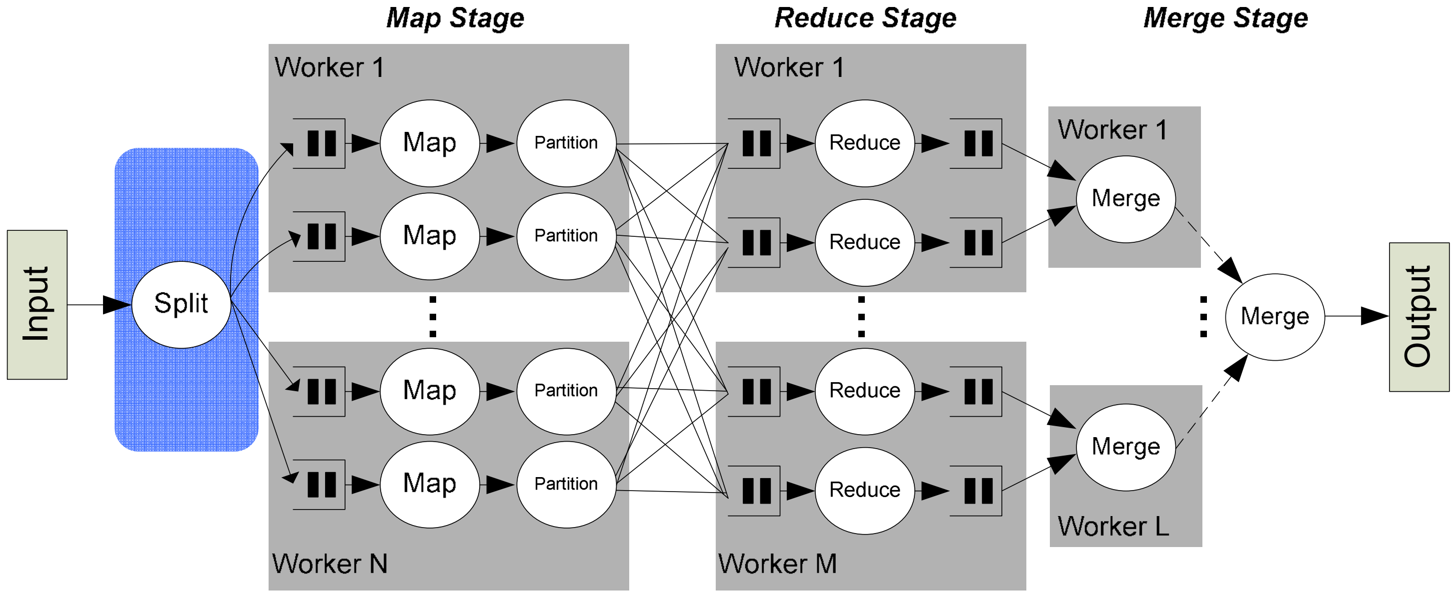
The Phoenix Runtime

- Orchestrates program execution across multiple threads
  - Initiates and terminates threads (workers)
  - Assigns map & reduce tasks to workers
  - Handles buffer allocation and communication
- Key runtime features
  - Dynamic scheduling of tasks for load balancing
  - Communication through pointer exchange (when possible)
  - Locality optimization through granularity adjustment
  - Support for failure recovery
- Details of parallel execution are hidden from programmer
  - Low-level threading, communication, scheduling, …

Phoenix Execution Overview



Input Data Splitting



- ❑ Divides input data to chunks for map tasks
  - Small chunk → map overhead; large chunk → locality issues
- ❑ Phoenix: chunk size determined by cache size for locality
  - Or programmer provides custom splitter

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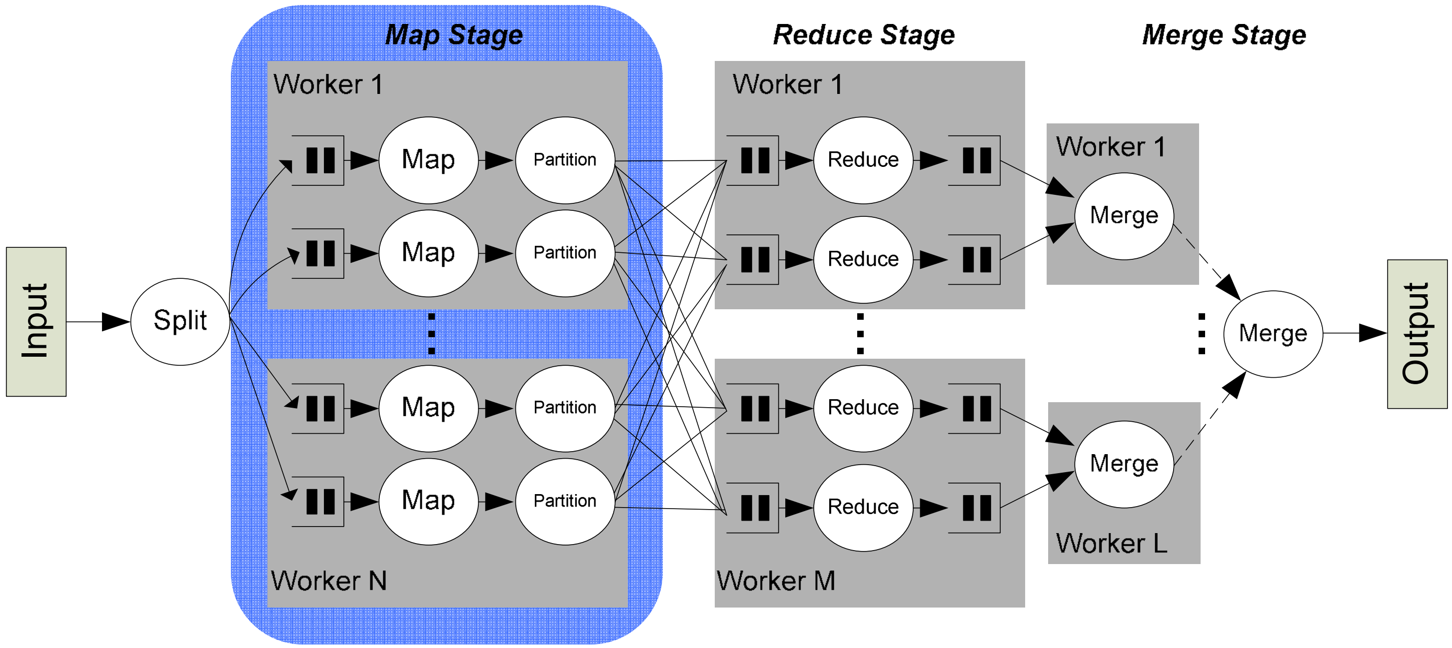
Map Stage



- ❑ Each task applies map function to an input chunk
  - Phoenix: typically 100s of tasks multiplexed to available workers
  - No reduce tasks are started before map tasks complete
- ❑ Intermediate pairs partitioned to reduce queues based on keys
  - Partitioning can introduce significant overhead!

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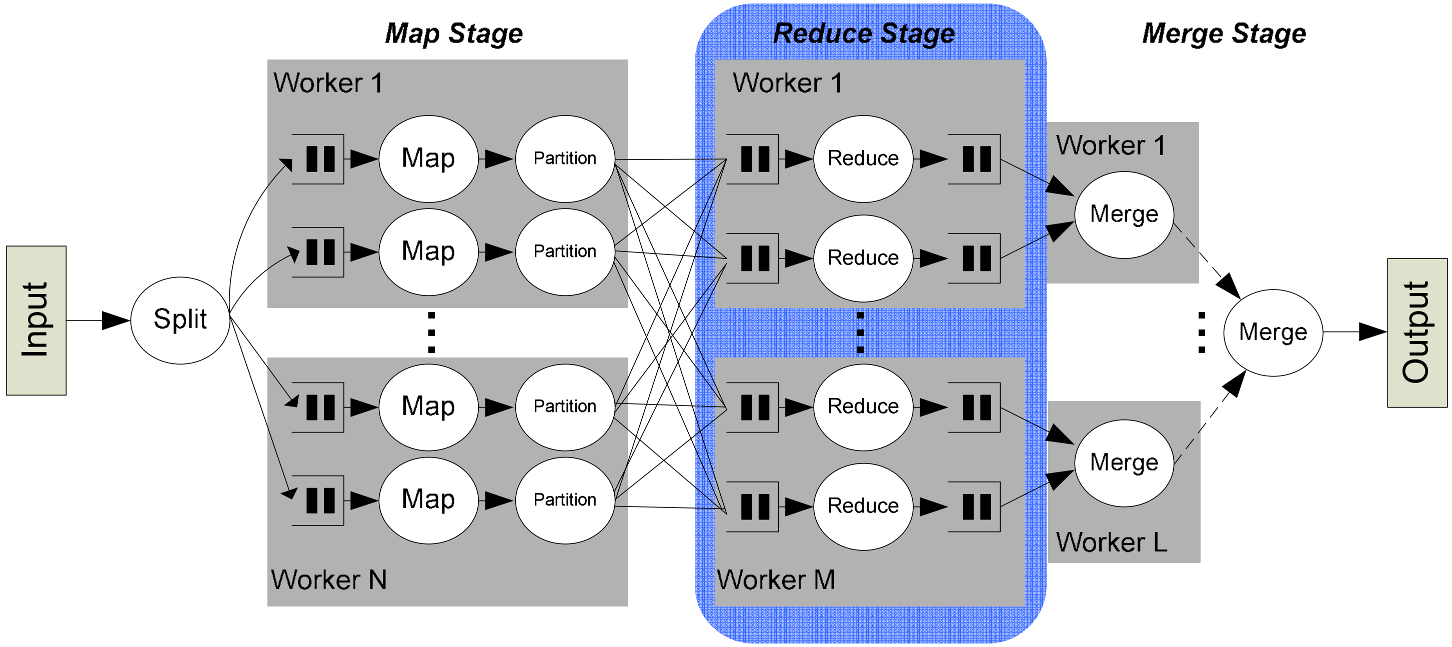
Reduce Stage



- Each task processes a key set from the reduce queues
  - Dynamic scheduling used for reduce tasks as well
- A poor partition function can lead to significant imbalance
  - Default partition function based on key hashing
  - Programmer can provide custom partition function

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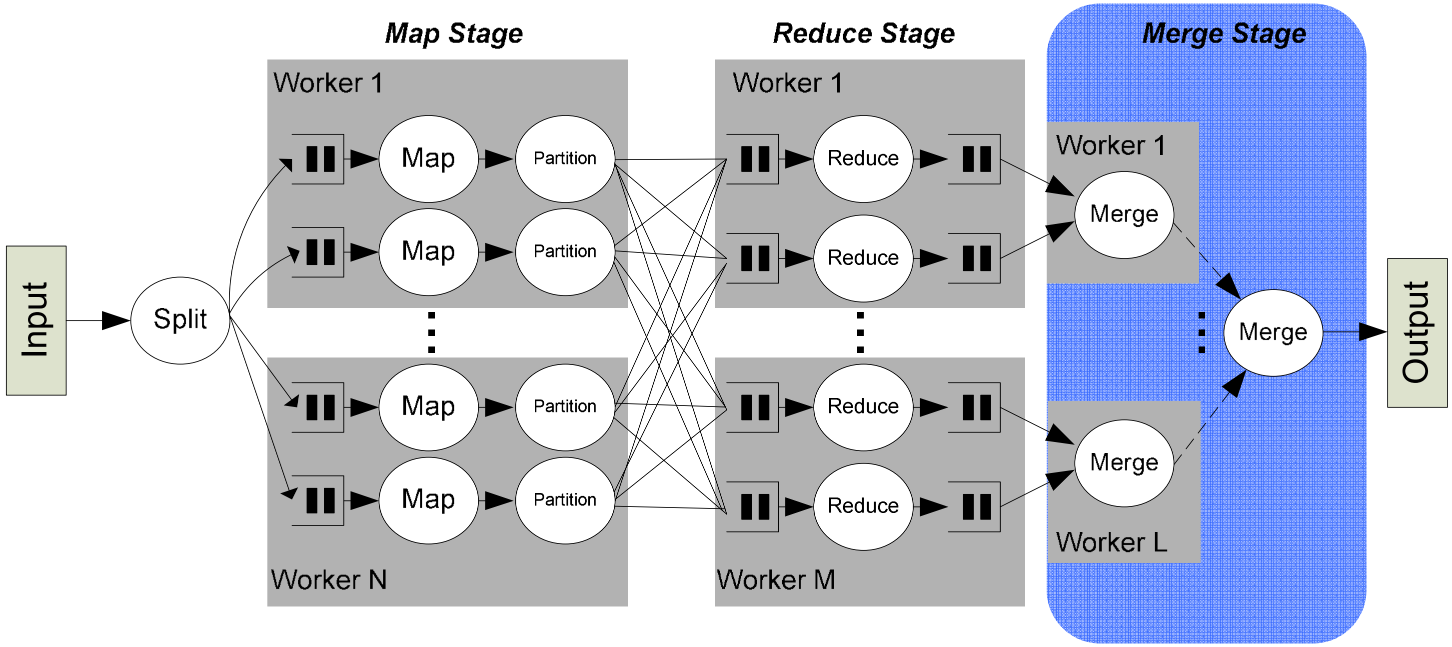
Merge Stage



- ❑ Combines reduce output queues to single sorted output
  - May be unnecessary for some applications
  - But merge time tends to be small compared to map/reduce time
- ❑ Phoenix: binary merging of reduce queues into single queue
  - Overhead increases with number of reduce tasks

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Potential Performance Detractors

- Significant detractors
  - **Partitioning overhead**: communication and grouping requirements
  - **Model overhead**: particularly due to calls to emit/emit_intermediate
  - **Key management**: some apps do not naturally associate keys with data
  - **Repeated Map/Reduce invocations**: necessary for some apps
- Practically insignificant issues
  - **Final merging & sorting**: insignificant compared to other tasks
  - **Buffer management**: extensive (re-)use of pre-allocated buffers
  - **Reduce imbalance**: handled through dynamic scheduling
  - **Serialized input splitting**: most map tasks involve non-trivial work

Phoenix Fault Tolerance

- Focus: transient or permanent errors in workers
- Error detection: worker time-out
  - Execution time of similar tasks used as yardstick
- Error recovery
  - Restart or potentially re-assign affected tasks
  - Handle input/output buffer management
- Future work
  - Fault tolerance for the scheduler
  - Error detection and isolation through worker sandboxing

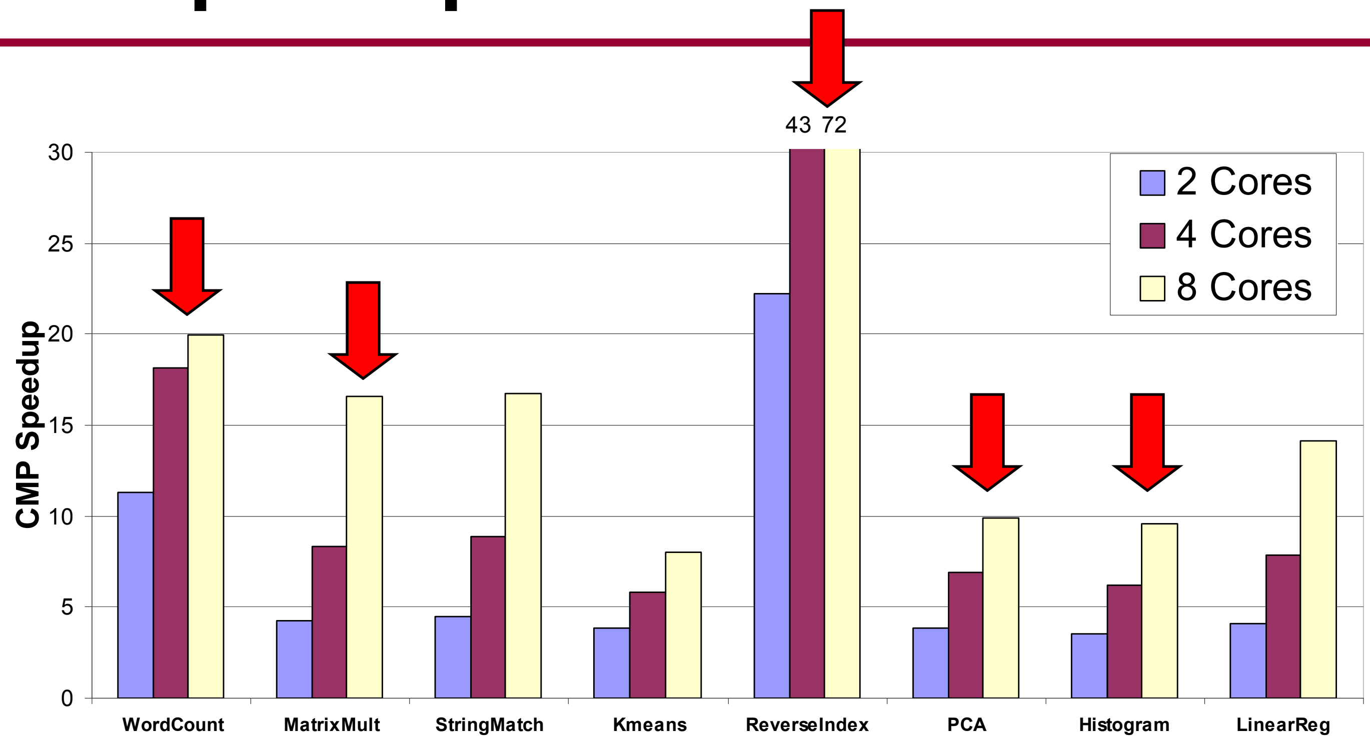
Evaluation Methodology

- Shared-memory systems
  - CMP: Niagara-based Sun Fire T1200 (8 CPUs, 4 threads/CPU)
  - SMP: Sun Ultra E6000 (24 CPUs)
    - SMP results similar to CMP → portable performance
    - See paper for details
- 8 applications
  - Domains: enterprise, scientific, consumer
  - Three code versions: sequential, MapReduce (Phoenix), P-threads
    - Optimized independently
- Experiments
  - **Talk**: performance & scalability, Phoenix Vs. P-threads
  - **See paper for**: dependency to data-set size, dependency to input task granularity, (soft & hard) fault injection experiment

Applications

- **Word count** – determine frequency of words in documents
- **String match** – search file with keys for an encrypted word
- **Reverse Index** – build reverse index for links in HTML files
- **Linear regression** – find the best fit line for a set of points
- **Matrix multiply** – dense integer matrix multiplication
  - MapReduce version introduces coarse-grain coordinate variables
- **Kmeans** – clustering algorithm for 3D data points
  - Multiple MapReduce invocation with translation step
- **PCA** – principal component analysis on a matrix
  - MapReduce version introduces coordinate variables
- **Histogram** – frequency of RGB components in images
  - There is no need for keys in original algorithm

CMP Speedup



- Good scalability across all applications
  - Absolute speedup depends on importance of various detractors
  - Note for CMP: 1 core = 4 threads (4 workers)
- Improved locality leads to significant improvements for some apps
- At high core counts: some bandwidth saturation or load imbalance

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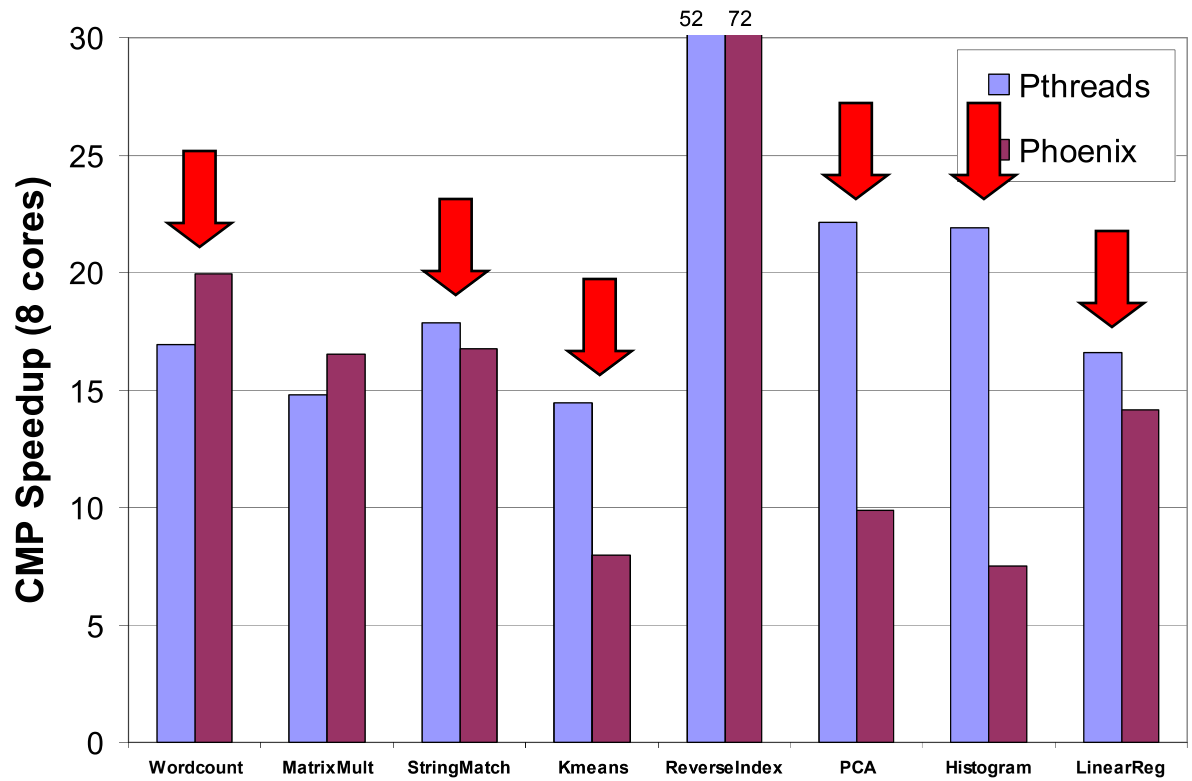
Phoenix Vs. P-threads



- ❑ Phoenix equal to P-threads if algorithm matches MapReduce model
  - Note that P-threads' low-level API is more flexible
- ❑ Anecdote: we looked at Phoenix behavior to tune some Pthreads codes
- ❑ P-threads is better for algorithms that do not fit MapReduce model
  - Does not use keys, requires multiple MapReduce iterations, …

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Conclusions

- Phoenix: a shared-memory implementation of MapReduce
  - MapReduce API and runtime system for C/C++
    - Uses threads instead of cluster nodes for parallelism
    - Communicates through shared memory instead of network messages
    - Dynamic scheduling, locality management, fault recovery, …
  - Scalable & portable performance, compares well to P-threads

- Future work
  - Improve queue structures
  - Automatic configuration detection
  - Better fault detection
  - Experiment with more systems & apps

Questions?

- Want a copy of Phoenix?
  - Will post the source code at ***http://csl.stanford.edu/~christos***