Millisort:
An Experiment in Granular Computing

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Massively Parallel Granular Computing

- **Massively parallel computing as an application of granular computing**
  - Split longer time period jobs in finer grain to reduce end-to-end latency
    - Example) *ExCamera*: use 3600x threads to reduce video encoding time (1hr -> 1 sec)
- **Splitting jobs often hurts**
  - Many problems require much coordination among nodes
  - Coordination cost may limit the parallelism
- **Started a case study on distributed sorting problem**
  - Understand the coordination cost and the limit of parallelism
  - Build experiences on minimizing the cost of coordination
  - Serves as an application to drive building granular computing platform

Overview of Millisort

- **Question**: How much can we sort within 1-2 ms given unlimited nodes?
- **Millisort**: a new sorting algorithm tailored for massive parallelism
  - Minimizes overhead of coordinating 1000 nodes.
    - Simplifies coordination metadata that needs to be exchanged.
    - Leaves the metadata distributed in a smaller set of servers (e.g. 100 nodes).
- **Estimated result (no implementation yet)**
  - Using 1024 nodes, sorts 30 million tuples in 1.8 ms. (Single node sorting: 624 ms)

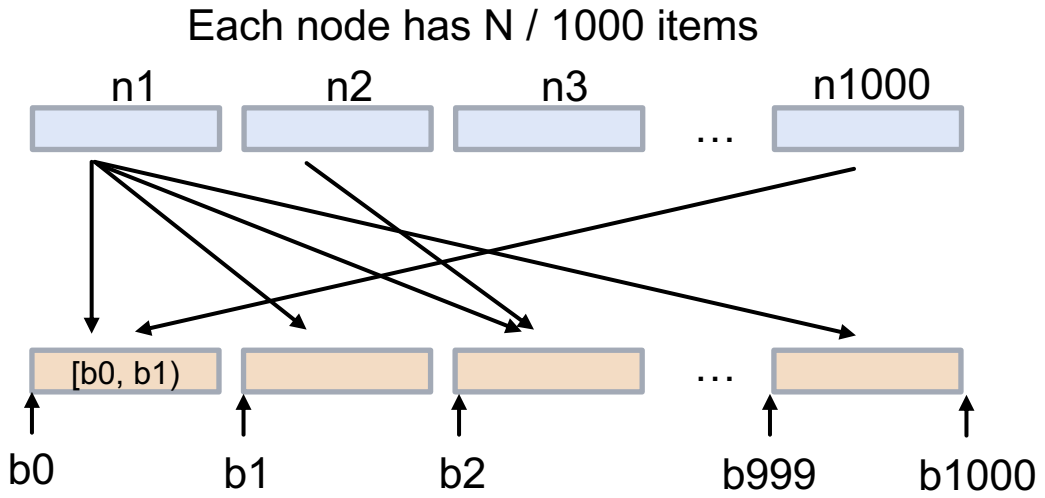
Distributed Sorting Problem

- **Data are already evenly spread over 1000 nodes.**
- **After sorting, the sorted data (almost) evenly distributed to 1000 nodes.**
- **10B keys, 90B value**
- **Given time: 1-2 ms, *which is not very long!***
  - A node can sort ~70,000 tuples (optimized radix sort with 12 cores)
  - Can invoke 200 RPCs sequentially (each RPC takes 5-10 μs)
  - On 40G network, can send 4MB (~40,000 tuples)
  - 10,000 sequential cache misses

Overview of Millisort

A variant of the standard distributed bucket sorting

1. **Local sort**
   Each node sorts its partition
2. **Partitioning**
   Figure out boundaries of sorted buckets
3. **Shuffling**
   Transfer data in each buckets to destinations
4. **Merging**
   Receive locally sorted tuples and merge them as they arrive



Stage 1. Local Sort

- **Each node sort its partition internally**
  - Speeds up later stages significantly
- **Use existing radix sort**
  - With 12 cores, each node can sort 15 ns / item
  - With 1000 nodes (12 cores on each),
    - For 1 ms, we can sort about 67 million tuples (67k per node)

Stage 2. Partitioning

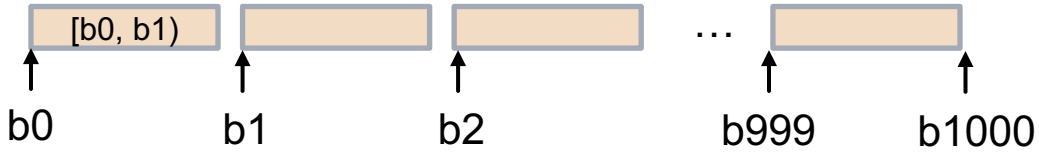
- **Figure out bucket boundaries**
- **Traditional algorithms take too long!**
  - Commonly used algorithm: histogram sampling & splitting
  - Estimated partitioning time for 1000 nodes: 500 ms (21 ms for 256 nodes)
- **Millisort uses a totally new approach.**
  - Guaranteed bound approximate algorithm
    - Largest bucket is twice as large as the perfect distribution
    - For even more distribution, we may use more pivots
  - Estimated partitioning time for **1000** nodes: **~400 µs** (118 µs for 256 nodes)

Stage 2. Partitioning (cont.)

- **For *M* nodes cluster, each partition picks *M* equally spaced pivots**
- **Sort the M^2 pivots all together.**
  - ***This is a non-trivial problem***
  - Strawman: coalesce all M^2 pivots to a machine => too slow.
  - Solution: use the same distributed bucket sorting using fewer nodes.

Network bandwidth on the machine
- 10B key * 1 million pivots = 10MB
- 10MB / 40 Gbit/s => **2 ms**

- **Pick *M* th, 2*M* th, 3*M* th, … , M^2 th pivots. They are the $b_1, b_2, b_3, \dots, b_{1000}$**



- **Broadcast the bucket boundaries < $b_1, b_2, b_3, \dots, b_{1000}$>**

Stage 2.b Sorting M^2 pivots

Sorted *M* (= 1000) **pivots**

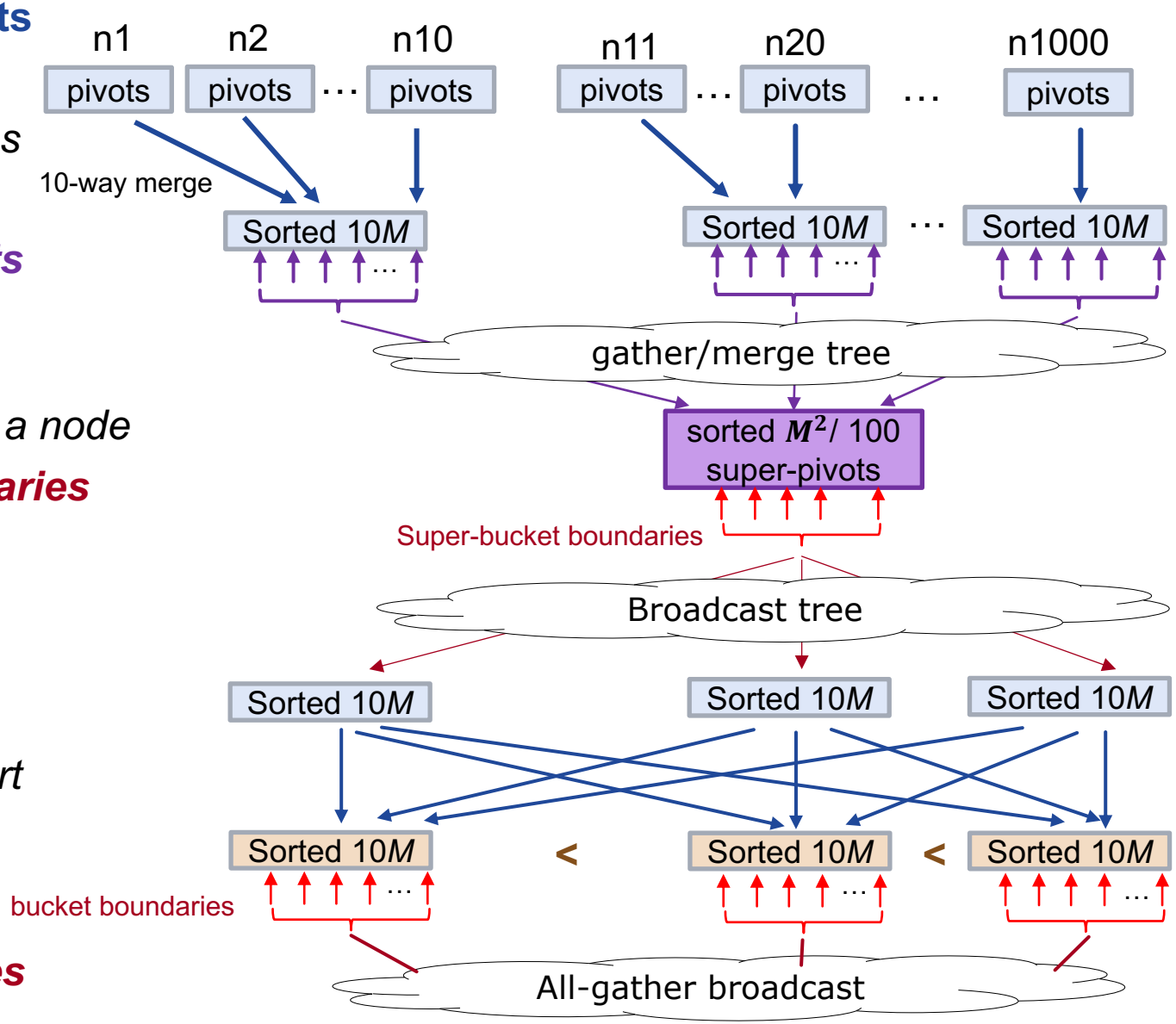
*Coalesce **pivots** to M/10 nodes*

Pick M/10 (= 100) ***super-pivots***

Coalesce all $\frac{M^2}{100}$ ***super-pivots** to a node*
*& select **super bucket boundaries***

*Shuffle all **pivots** & merge sort*

*Broadcast **bucket boundaries***



Estimated Time

	86 µs
	10 µs
	71 µs
	10 µs
	20 µs
	172 µs
	30 µs

Total: 399 µs

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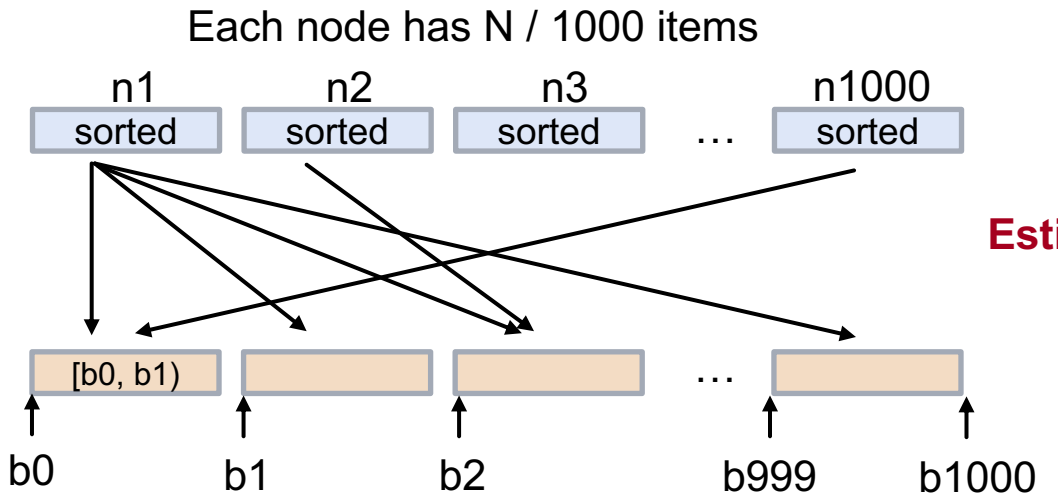


Estimated Time
~1 ms

Expected Performance

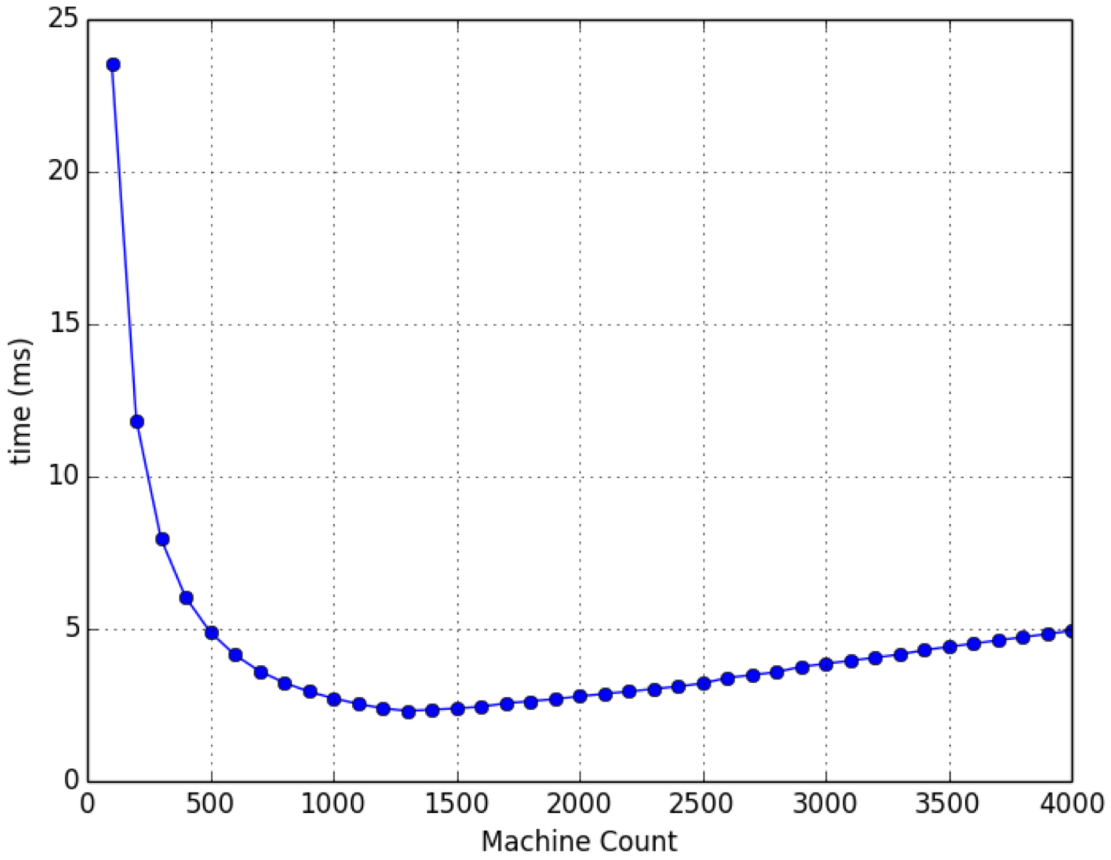
- **Built performance estimator for Millisort** (real implementation is in progress)
- **Anticipated cluster configurations**
  - > 1000 nodes (10 cores / node)
  - 40 Gbits/s full-bisection networking
  - 30 GB/sec peak memory bandwidth
  - 0.3 µs to send message, 0.7 µs to receive message
- **Sorting problem**
  - 50 million tuples are evenly distributed to 1000 machines
  - Each tuple: 10B key, 90B value ➔ Total data size: 5 GB (5 MB per node)
- **Estimated time to sort**
  - Single machine radix sort: ~1 sec
  - Millisort on 1000 machines: **2.7 ms** (1 ms of local radix sort + 0.5 ms of partitioning + 1.2 ms of shuffling)

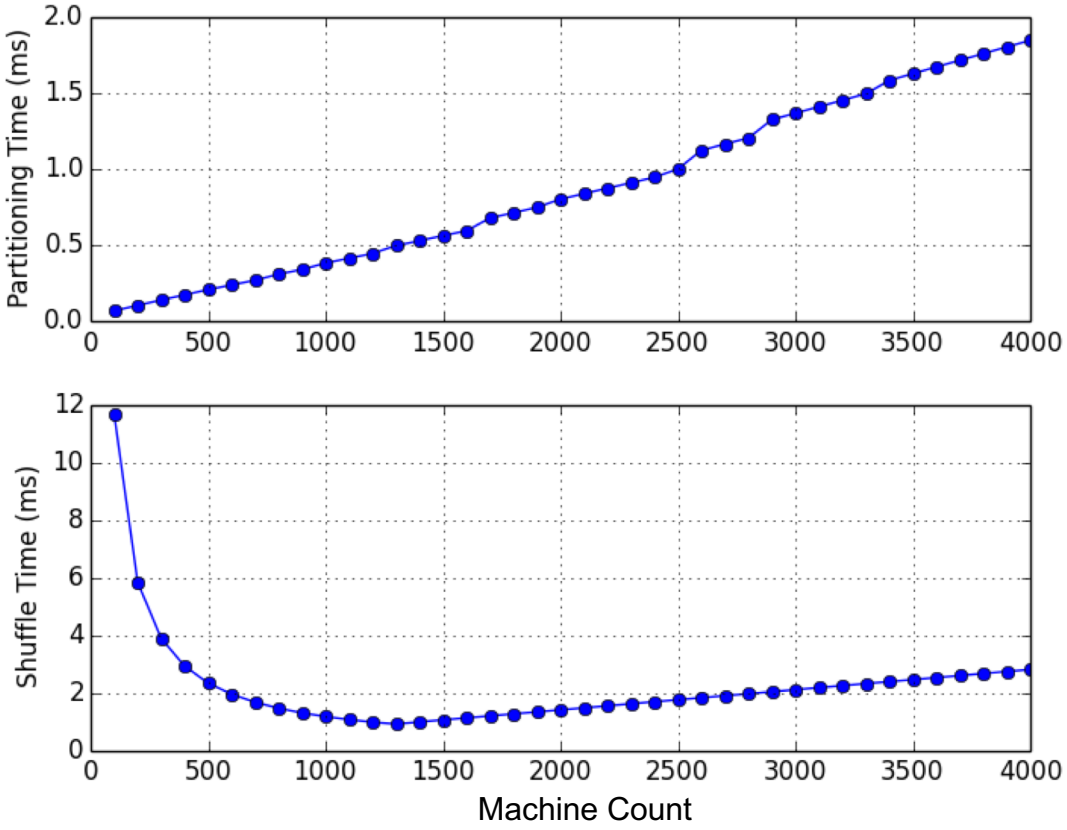
fundamental cost of sorting

fundamental cost of distribution

Estimated Sort Time by Machine Count

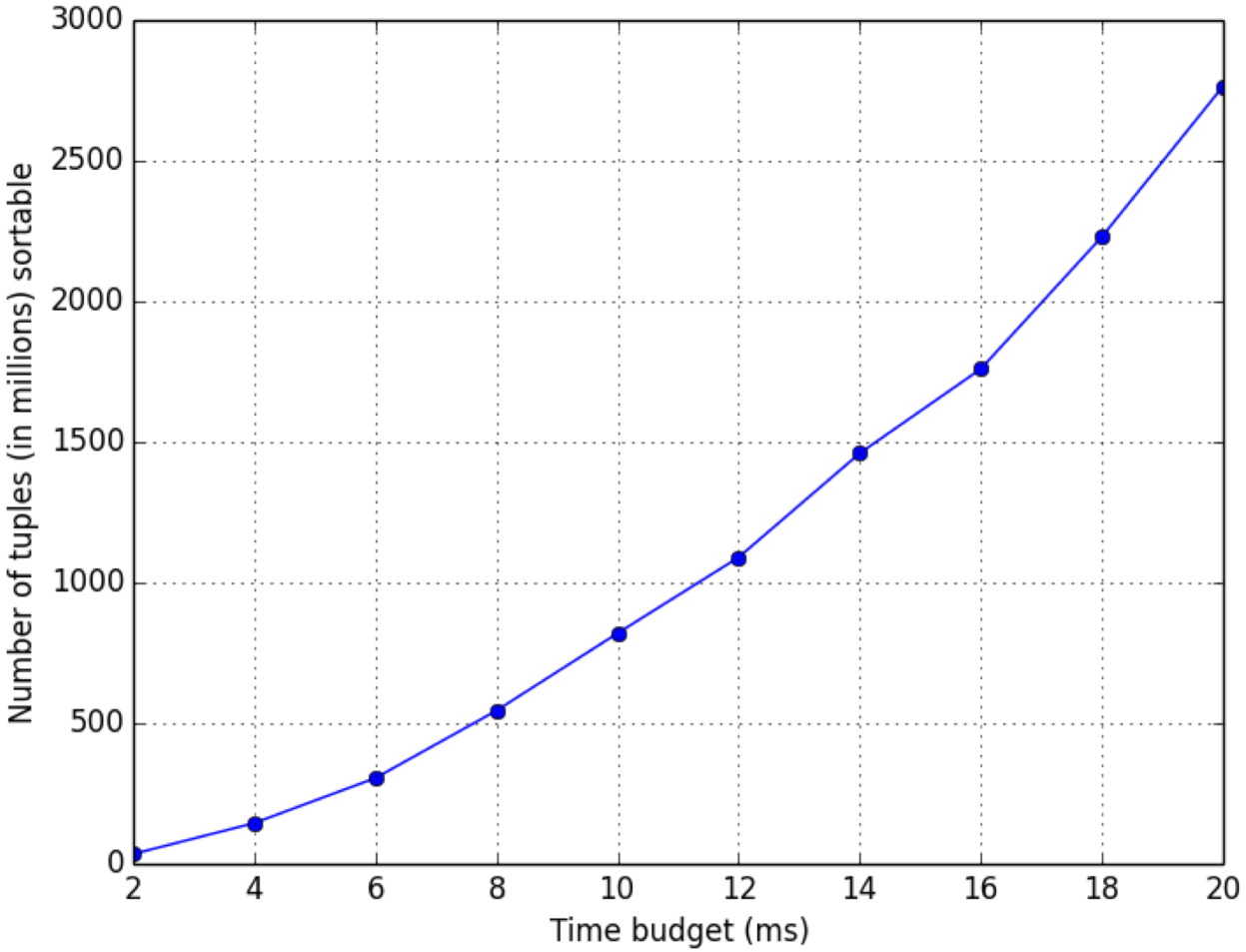
- **50 million tuples, 10B key, 90B value**

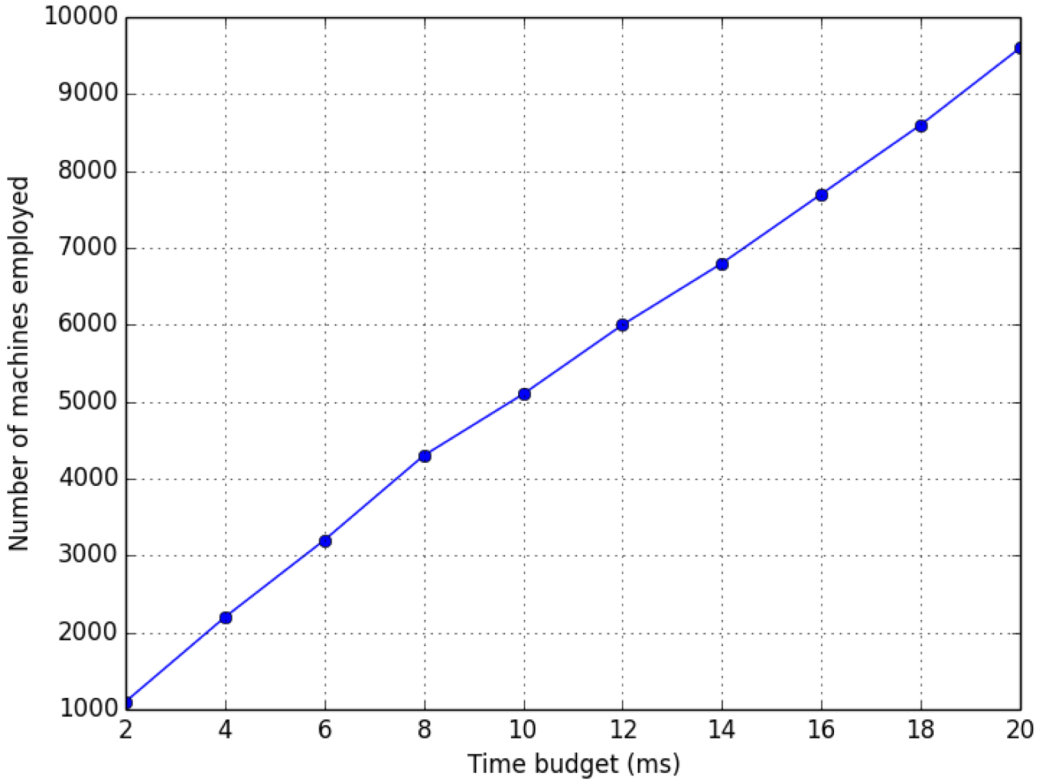




How many can you sort with infinite resources?

- **Infinite # of nodes available**





Conclusion

- **Sorting is a hard problem to use massively distributed computing**
- **Millisort hints the cost of distribution in granular computing**
  - Building experiences on minimizing the coordination cost
  - A specific case to understand coordination cost and the limit of parallelism
  - Reusable components
    - Multicast-style communications (broadcast, gather/merge, all-gather)
    - Performance simulator
- **Still at an early stage**
  - What we have: algorithm, cost model
  - Hope to finish implementation this summer to verify
- **Hope to see**
  - System challenges to be solved to execute operations in tight latency budgets
  - New platform/programming model to run/develop Millisort efficiently