Vector Load Balancing in Charm++

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Load Balancing

- Load balancing is a hallmark of Charm++
- Performance often limited by maximum load on a PE
- RTS measures load and migrates objects in response
- Dynamic, irregular applications have been able to achieve high performance and scalability because of it

What is Load?

- *Load* is really just a proxy value we use to reason about performance
  - In truth, we want to minimize execution time
  - Unbalanced, fast program > balanced, slow program
- CPU time per object by itself is often a sufficient metric for this value
- However, in the same way measuring cache misses or pipeline stalls improves upon merely profiling, sometimes more detail is helpful

Vector Load Balancing

- Rather than being a single value, *load* is now a vector of multiple values
  - Store vector loads in LBDatabase
  - Pass vector loads to strategies
  - Use vector loads in strategies
- Can be used generically: for various hardware measurements (CPU/GPU/network/memory), discrete parts of an iteration, application specific parameters, etc.

Vector Strategies

- Extra dimensionality makes vector load balancing computationally difficult
- Objects can no longer be totally ordered
- Want to minimize the maximum in each dimension
- NP-complete problem, so only interested in approximations

Vector Strategies

- A simple strategy finds object with global maximum load dimension and places it on PE with minimum load in that dimension
  - Only works well when object has load in only one dimension
- For more realistic cases, have to consider vector holistically

Vector Strategies

- Find object with maximum p-norm and place on PE with minimum p-norm after placement
  - Works well, but computationally expensive
  - PE "weight" varies with object, i.e. $\|(2,0)\|_2 < \|(0,3)\|_2$, but when adding $(3,0)$, $\|(5,0)\|_2 > \|(3,3)\|_2$
- Calculate average load vector in d-space and create a normal hyperplane, then repeatedly allow furthest PE below the hyperplane to choose an object

New Load Balancing APIs - Phase

- Many applications have orthogonal *phases* within an iteration separated by barriers (or weaker sychronization)
- New functions have been added to track phases for load balancing:
  - `void CkMigratable::CkLBSetPhase(int phase)` - Until called again, all automatic LB measurements for calling chare attributed to specified phase
  - `int CkMigratable::CkLBGetPhase()` - Returns current phase

New Load Balancing APIs - Manual

- Added new API for recording vector load data
  - `void CkMigratable::CkLBSetObjTime(LBRealType load, int dimension)` - Sets specified dimension of vector load for calling chare
  - `std::vector<LBRealType> CkMigratable::CkLBGetObjVectorLoad()` - Returns current vector load for calling chare

Using Vector Strategies

- Currently only strategies built on top of TreeLB support vector load balancing
  - TreeLB is new flexible, optimized replacement of CentralLB and HybridLB
  - Eventually all non-distributed strategies should use TreeLB
- If vector loads are detected in the LB database, a vector version of the chosen strategy is automatically used if available

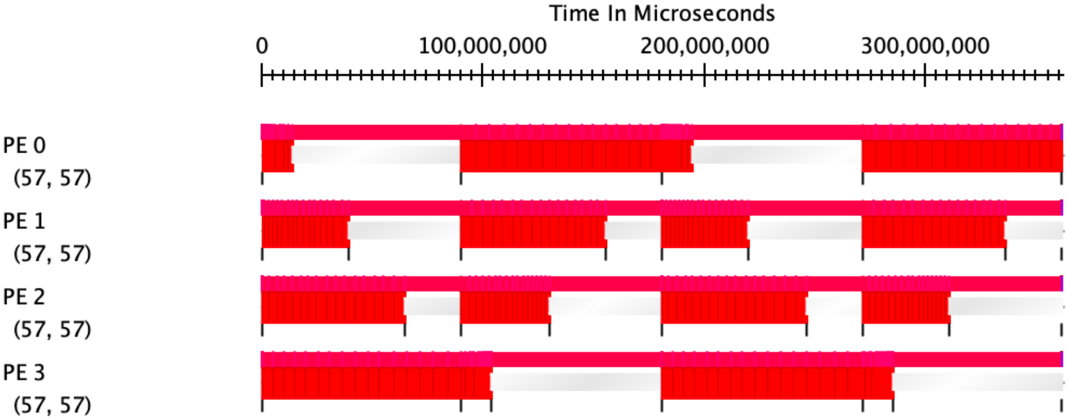
Writing Vector Strategies

- Objects and PEs are templated on dimension, replicated in a `static constexpr` field for external access
- A specific dimension of Object or PE load is accessible with `LBRealType getLoad(int dimension)`
- Template specialization allows LB author to handle vector and non-vector cases

Writing Vector Strategies

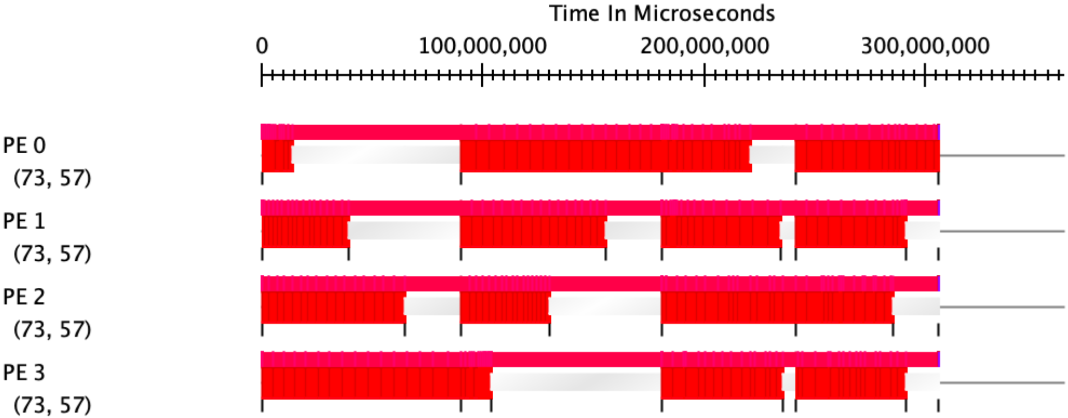
```
template <typename O, typename P, typename S>
class Example : public Strategy<O, P, S> {
  public:
  void solve(std::vector<O>& objs, std::vector<P>& procs,
             S& solution, bool objsSorted) {
    // vector implementation
  }
};

template <typename P, typename S>
class Example<Obj<1>, P, S> : public Strategy<Obj<1>, P, S> {
  public:
  void solve(std::vector<Obj<1>>& objs, std::vector<P>& procs,
             S& solution, bool objsSorted) {
    // scalar implementation
  }
};
```

Vector LB Performance - AMPI



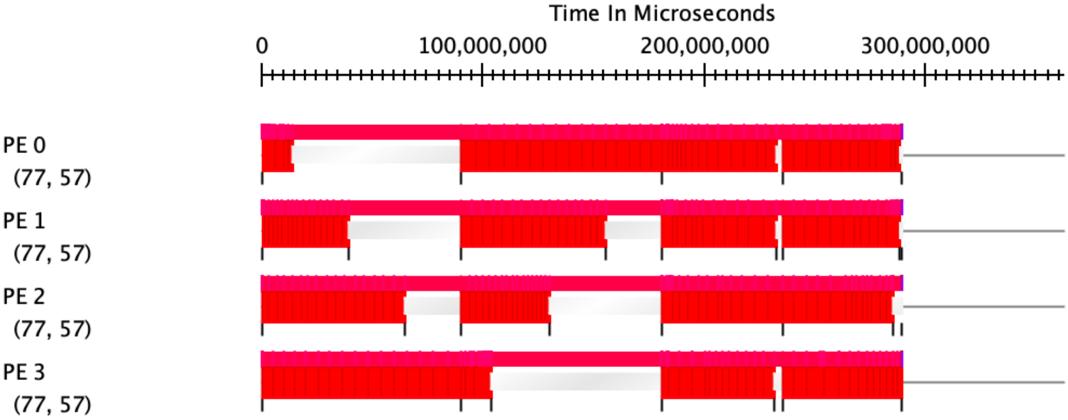
AMPI - No Load Balancing

Vector LB Performance - AMPI



AMPI - Regular Load Balancing

Vector LB Performance - AMPI



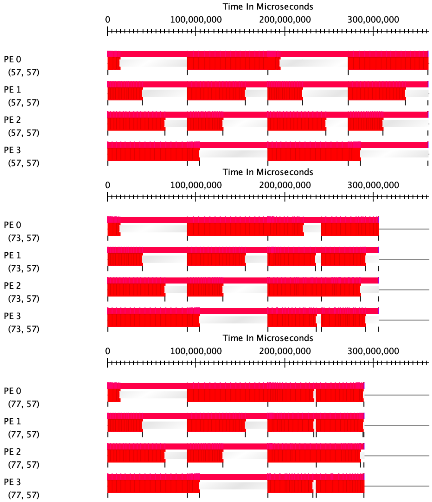
AMPI - Vector Load Balancing

Vector LB Performance - AMPI

LB Off

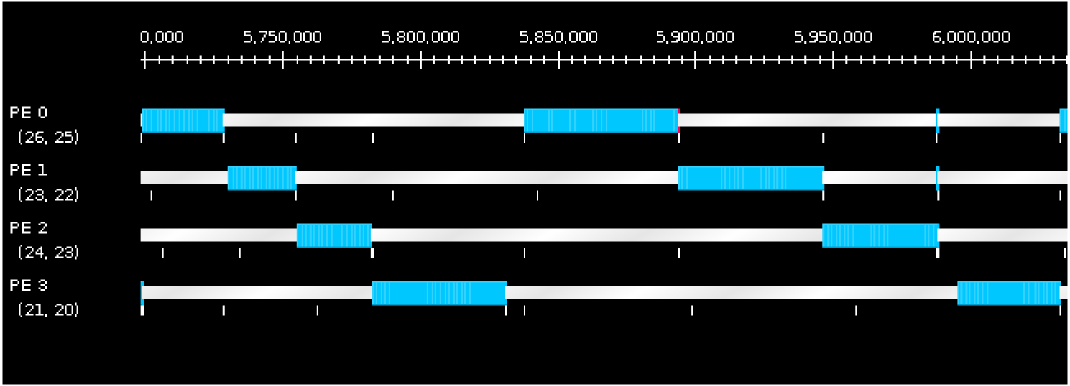
Phase Unaware (1.44x speedup)

Phase Aware (1.67x speedup)

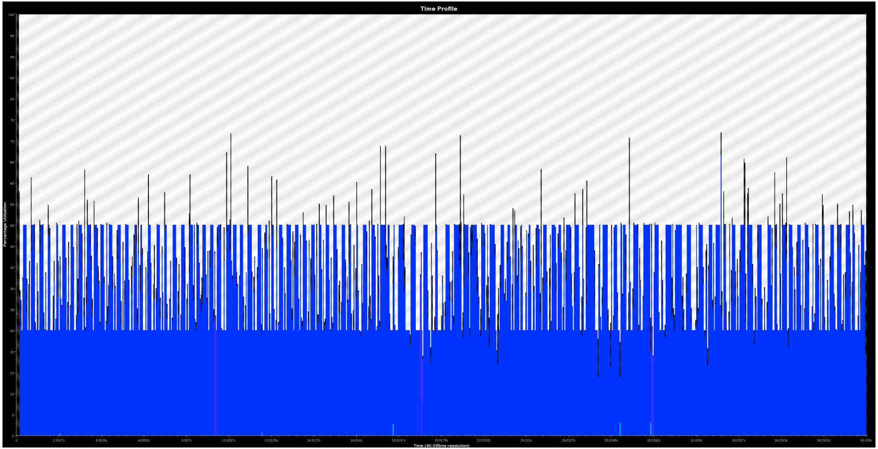


Vector LB Performance

Timeline of phase-based application:

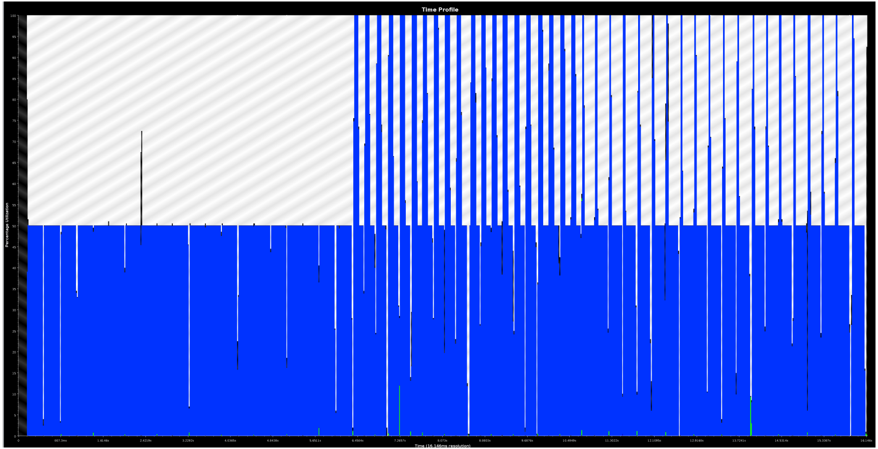


Vector LB Performance



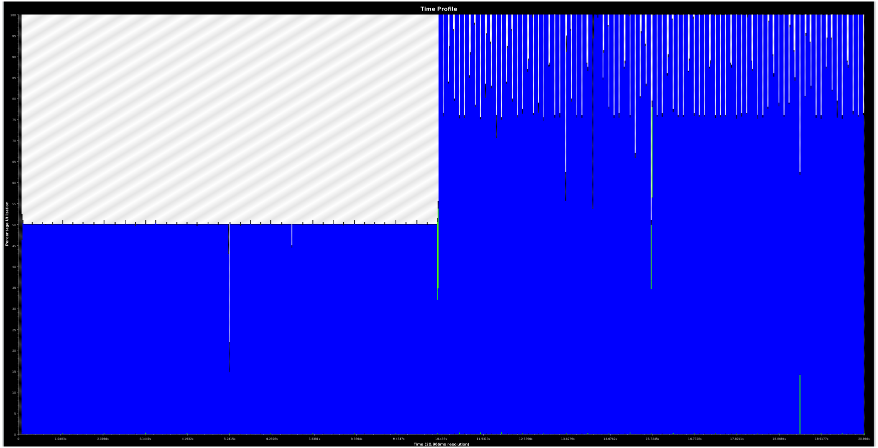
No LB

Vector LB Performance



(non-vector) GreedyLB

Vector LB Performance



Vector Greedy

Applications

- ChaNGa
  - Working, but no performance results at scale yet
  - Time spent in each rung of multi-stepping corresponds to dimension in vector
- NAMD
  - In process of making vector of CPU and GPU load
- Please contact me if you think your application would benefit!

Future Vector LB Work

- Performance is still an issue, so optimizations needed
  - Discretization, clustering, space-partitioning, etc. should go a long way
- Exploit distribution of load per-dimension
- Integrate HAPI into load measurement to automatically record accelerator load
- Add support for constraint based objective functions for cache/memory balancing

Conclusions

- Applications often have scope for improved load balance
- As programming techniques and hardware become more complex, this scope will likely increase
- Providing more detailed load data via Vector LB has been shown to improve decision quality over traditional LB in testing