Legion-based Scientific Data Analytics on Heterogeneous Processors

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- Examples
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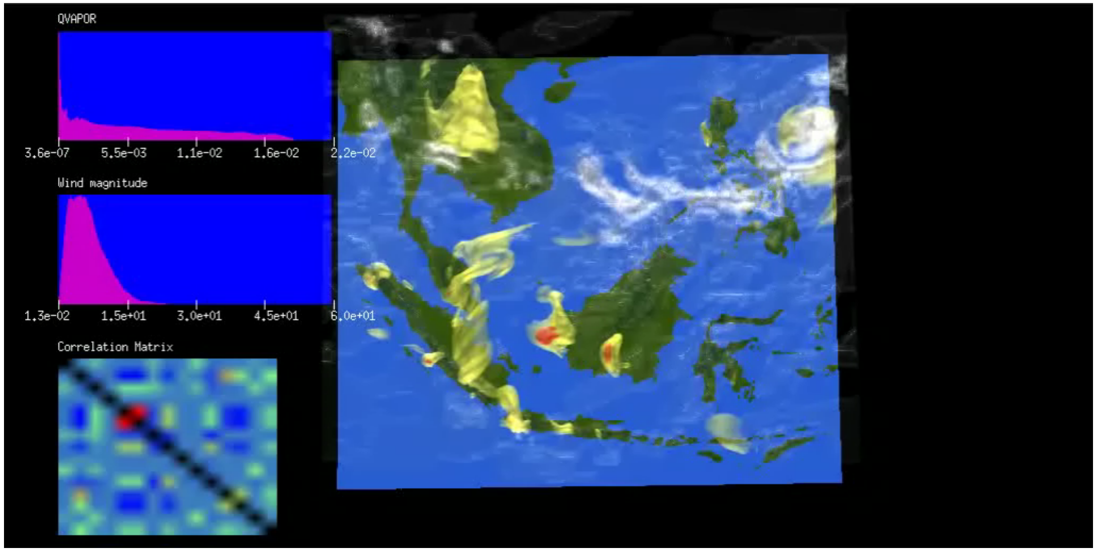
Motivation



– A scientific analytics workflow consists of **multiple operations** that intrinsically incur different **communication** or **data movement** requirements between compute nodes

Motivation

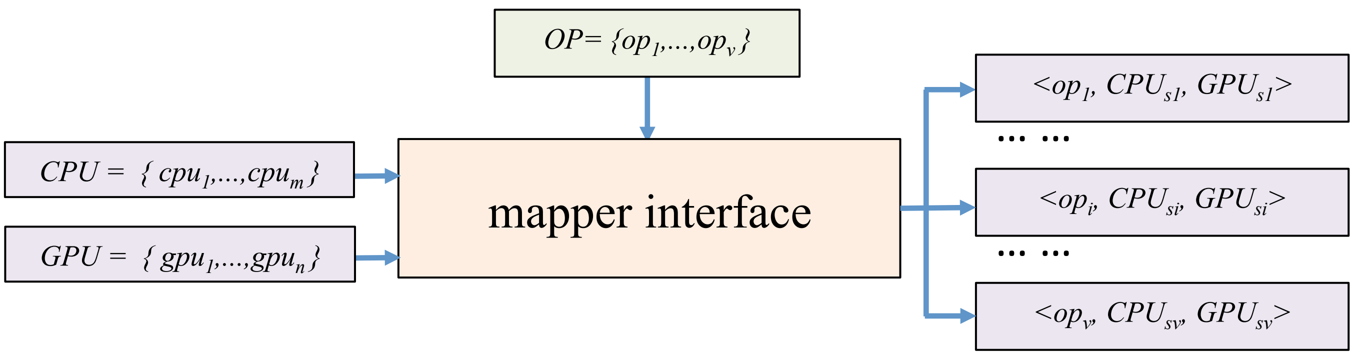
- Legion : programming model + runtime system
  - Describe hierarchical organizations of both data and computation at an abstract level
- Legion assists a programmer in solving the common programming burdens
  - Discover/verify the correctness of parallel execution
  - Manage communication
- At a high level, mapping a Legion program needs making two kinds of decisions
  - For each task, select a processor on which to run the task by the **mapping interface**
  - For each **logical region**, a task needs to select a memory in which to create and use a physical instance of the logical region

Our Contribution

- Investigate the feasibility of using **Legion** to perform analytics for **large-scale** scientific data on **heterogeneous** processors
- Help users **simplify** programming on the **data partition**, **data organization**, and **data movement** for distributed-memory heterogeneous architectures
- Facilitate a simultaneous execution of **multiple analytics operations** on modern and future supercomputers
- Demonstrate the **scalability** and the **usability** of our approach using several representative analytics operations on a heterogeneous supercomputer

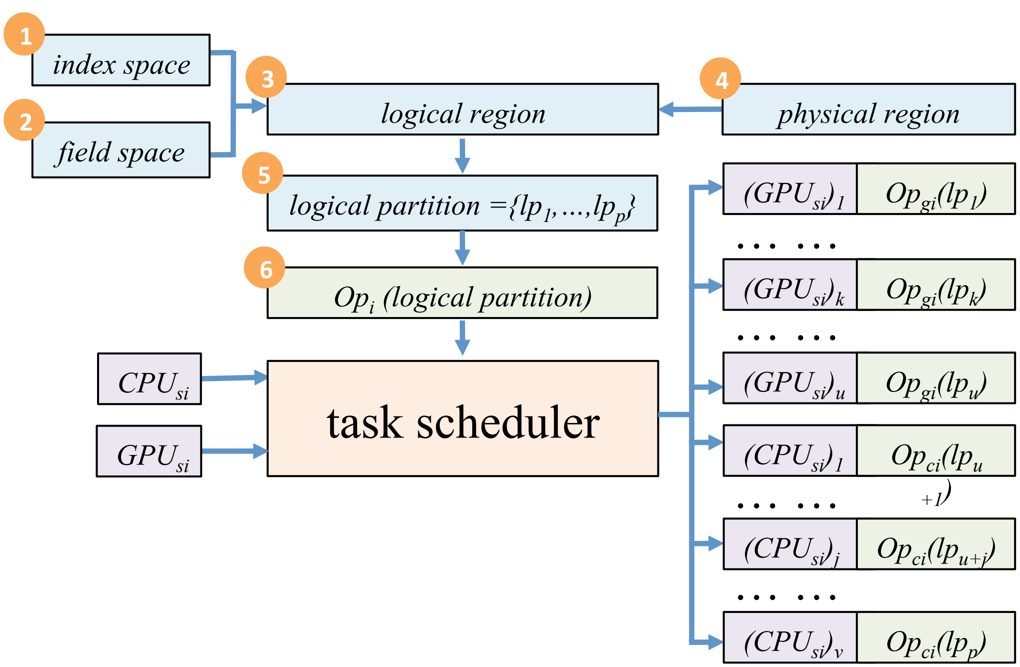
Mapper Interface

- We design a custom mapper based on Legion’s mapper interface
  - Map operations onto target processors
  - Specify which memories are used to host the physical instances of the logical regions requested by such operations



Region Construction and Task Scheduling

- Main steps of the process of our approach
  - Make an operation *opi* processed on heterogeneous processors



1. Construct an index space of the logical region for the input data of each operation.
2. Construct a field space of the logical region, and allocate the field space for each portion of data.
3. Create a logical region using the index space and the field space defined in the previous two steps.
4. Create a corresponding physical region to hold the physical instances (i.e., the real values for the input data).
5. Use coloring to partition a logical region (colorings are objects that describe an intended partition of an index space).
6. Execute operations on GPUs and CPUs according to the previous mapper interface we designed.

Listing 1
REGISTERING TASKS IN THE MAIN FUNCTION

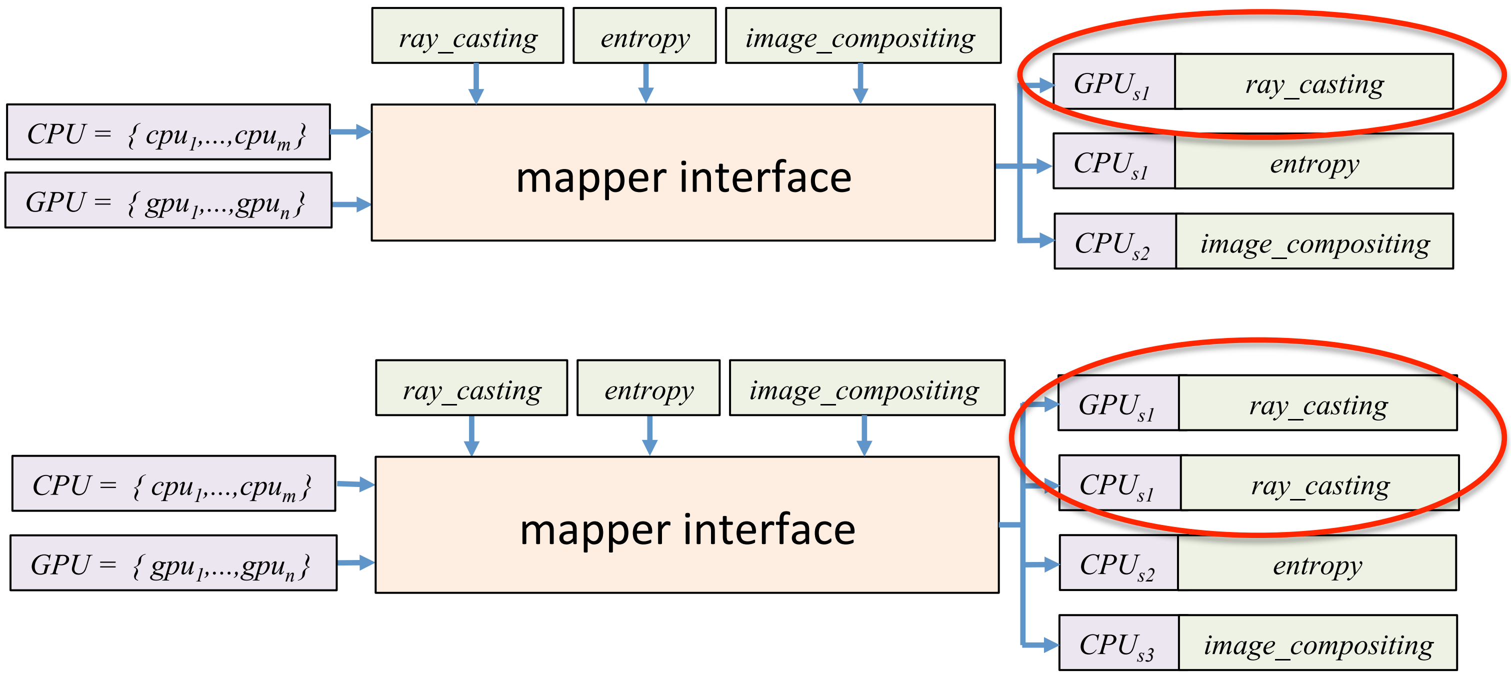
```
int main(int argc,char* argv[]){
  HighLevelRuntime::set_top_level_task_id
                        (TOP_LEVEL_TASK_ID);
  HighLevelRuntime::register_legion_task<top_level_task>
        (TOP_LEVEL_TASK_ID,
        Processor::LOC_PROC, true/*single*/, false/*index*/,
        AUTO_GENERATE_ID, TaskConfigOptions(),
              "top_level");
  TaskHelper::register_gpu_variants<op_gi>();
  TaskHelper::register_cpu_variants<op_ci>();
}
//TaskHelper namespace
namespace TaskHelper {
  template<typename T>
  FutureMap dispatch_task(T &launcher, Context ctx,
        HighLevelRuntime *runtime){
    FutureMap fm = runtime->execute_index_space(ctx,
          launcher);
    return fm;
  }
  //CPU implementation of the operation
  template<typename T>
  void base_cpu_wrapper(const Task *task,
                         const std::vector<PhysicalRegion>
                               &regions,
                         Context ctx, HighLevelRuntime
                               *runtime){
    T::cpu_base_impl(task, task->local_args, regions, ctx,
          runtime);
  }
```

Continued List 1

```
//GPU implementation of the operation
template<typename T>
void base_gpu_wrapper(const Task *task,
                       const std::vector<PhysicalRegion>
                              &regions,
  T::gpu_base_impl(task, task->local_args, regions, ctx,
         runtime);
}
//register tasks on CPUs
template<typename T>
void register_cpu_variants(void){
  HighLevelRuntime::register_legion_task<base_cpu_wrapper<T>
         >(T::TASK_ID, Processor::LOC_PROC,
         false/*single*/, true/*index*/, CPU_LEAF_VARIANT,
         TaskConfigOptions(T::CPU_BASE_LEAF),
         T::TASK_NAME);
}
//register tasks on GPUs
template<typename T>
void register_gpu_variants(void){
  HighLevelRuntime::register_legion_task<base_gpu_wrapper<T>
         >(T::TASK_ID, Processor::TOC_PROC,
         false/*single*/, true/*index*/, GPU_LEAF_VARIANT,
         TaskConfigOptions(T::GPU_BASE_LEAF),
         T::TASK_NAME);
}
};
```

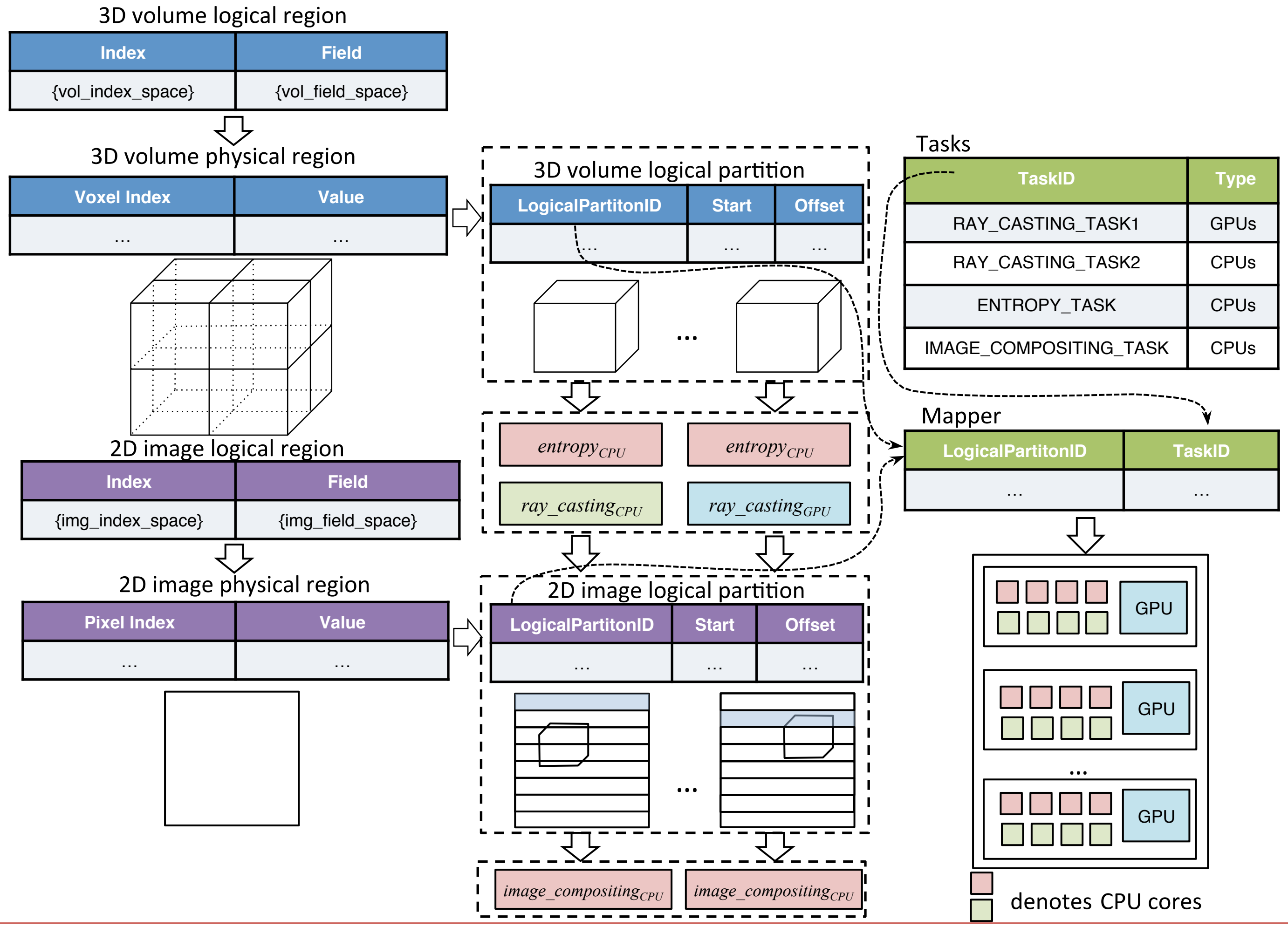
Examples

- **Sort-last** parallel volume rendering with entropy analysis
  - Mapper interface



Examples

- **Sort-last** parallel volume rendering with entropy analysis
  - Region construction and task scheduling



Examples

- **Sort-first** parallel volume rendering with entropy analysis
  - Mapper interface
    - Ray casting task(GPUs)
    - Entropy task(CPUs)
  - Region construction and task scheduling
    - **Divide the 2D image** into uniform 2D grids
    - Each processor is responsible for the rendering of an image portion
    - **No need to divide the 3D volume data**
    - **No need image compositing**

- The sort-first and sort-last algorithms have **differences on data partitioning and distribution requirements**, but our solution provides a **simple** and **feasible** way to incorporate different operations in a unified framework using logical regions

Experiments and Results

- Conduct experiments on Titan, a Cray XK7 supercomputer located at the Oak Ridge Leadership Computing Facility
  - Each node of Titan contains one 16-core AMD Opteron **CPU** and a NVIDIA Tesla K20 **GPU**
- Test sort-first and sort-last parallel rendering
- Conduct scalability comparisons using a combustion dataset with the resolution of 1600x1375x430
- Test between 1 to 256 processors with two output image resolutions of 1024^2 and 2048^2

Experiments and Results

- The overview time breakdown, **data partition time**, **rendering time**, and **data movement time** on a different total number of nodes for sort-first rendering and sort-last rendering

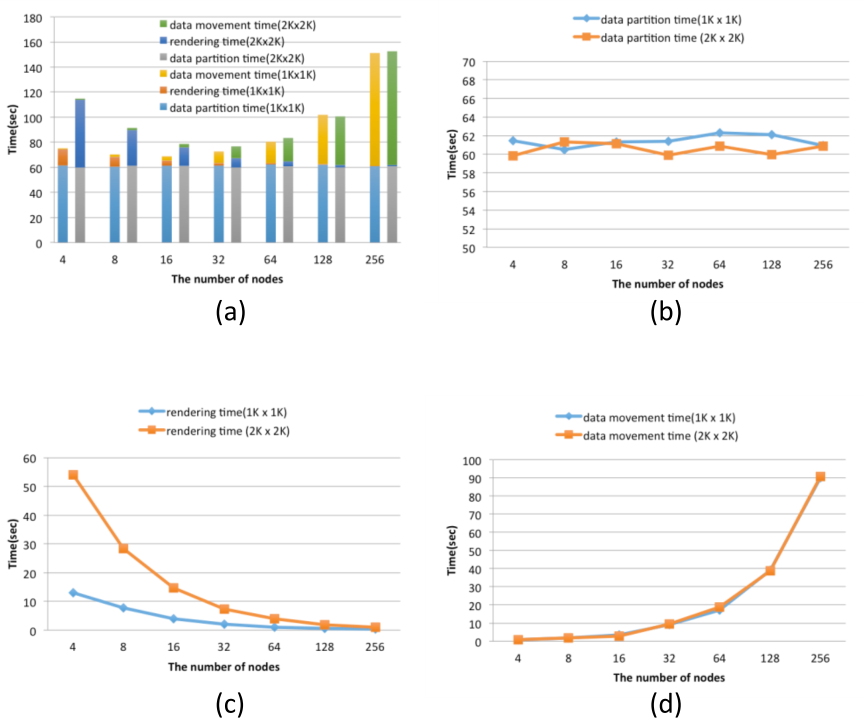


Fig. 1: (a): the time breakdown of sort-first parallel volume rendering for different number of nodes. (b): the data partition time. (c): the rendering time. (d): the data movement time. Two output image resolutions, 1024^2 and 2048^2, are used.

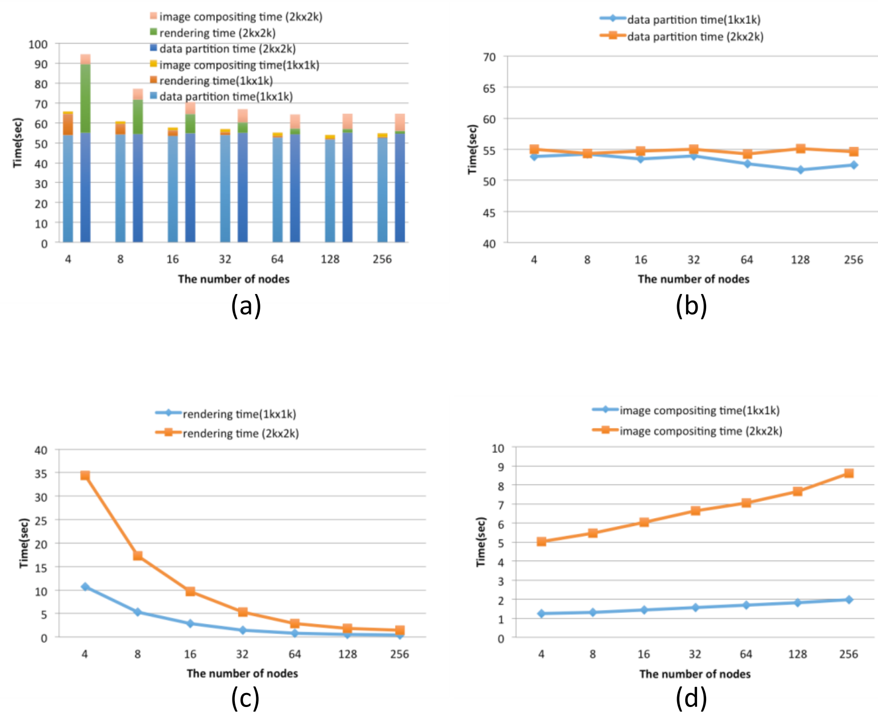


Fig. 2: (a): the time breakdown of sort-last parallel volume rendering for different number of nodes. (b): the data partition time. (c): the rendering time. (d): the image compositing time. Two output image resolutions, 1024^2 and 2048^2, are used.

Experiments and Results

- Interactive rendering time and data movement time of sort-first parallel rendering for 64 nodes with image resolution of 1024^2

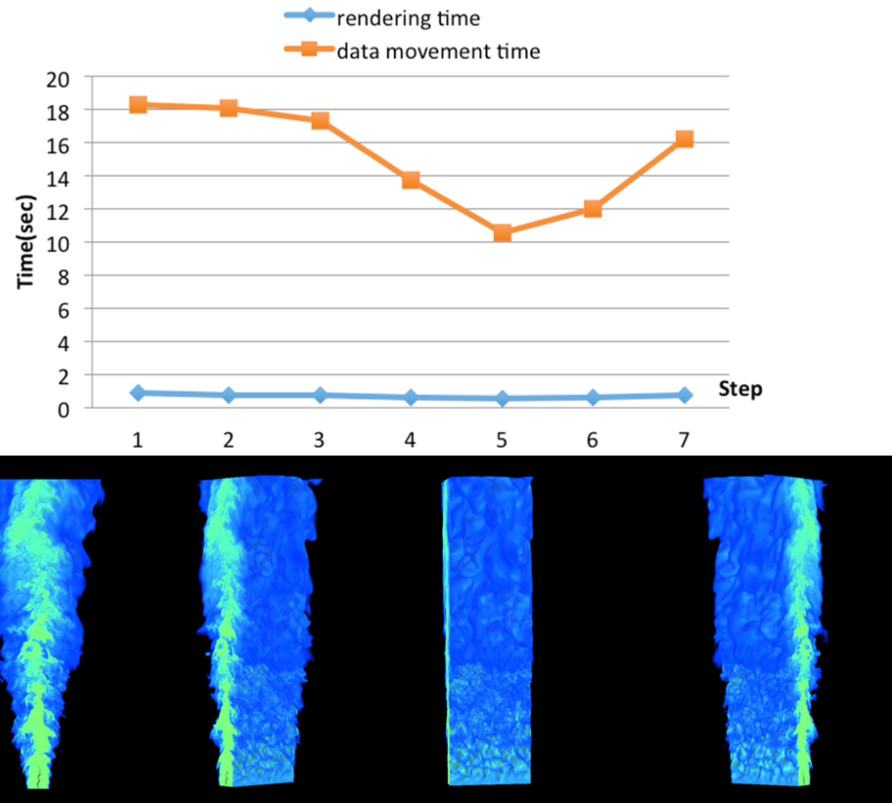


Fig. 3: The rendering time and data movement time of sort-first rendering for 64 nodes from multiple view angles. The output image resolution is 1024^2.

Experiments and Results

- The rendering time results of sort-first and sort-last parallel rendering on any number of nodes from 1 to 256 with image resolution of 1024^2

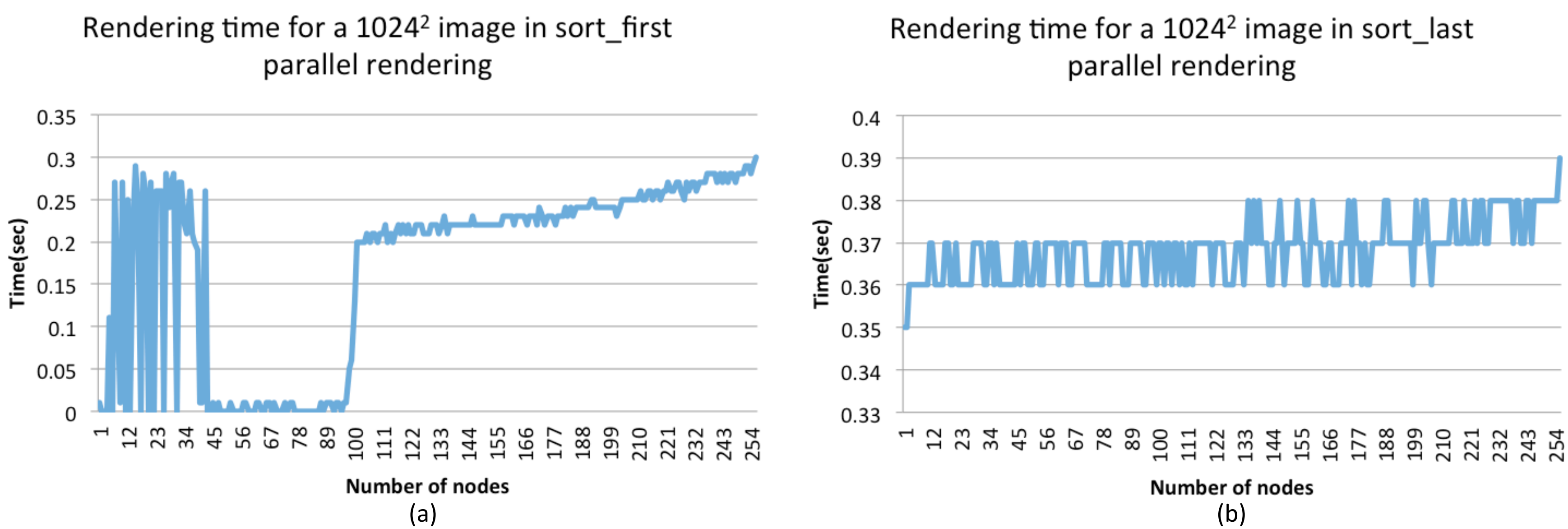


Fig. 4: The time results of sort-first (a) and sort-last (b) parallel rendering on any number of nodes from 1 to 256. The output image resolution is 1024^2.

Experiments and Results

- Legion job stealing scheduling performance
  - CPU ray casting time is 1.347 seconds(5%)
  - CPU entropy time is 0.936 second
  - GPU ray casting time is 2.833 seconds (95%)
- Given that each node has a 16-core CPU, we tested different ratios between ray casting and entropy operations

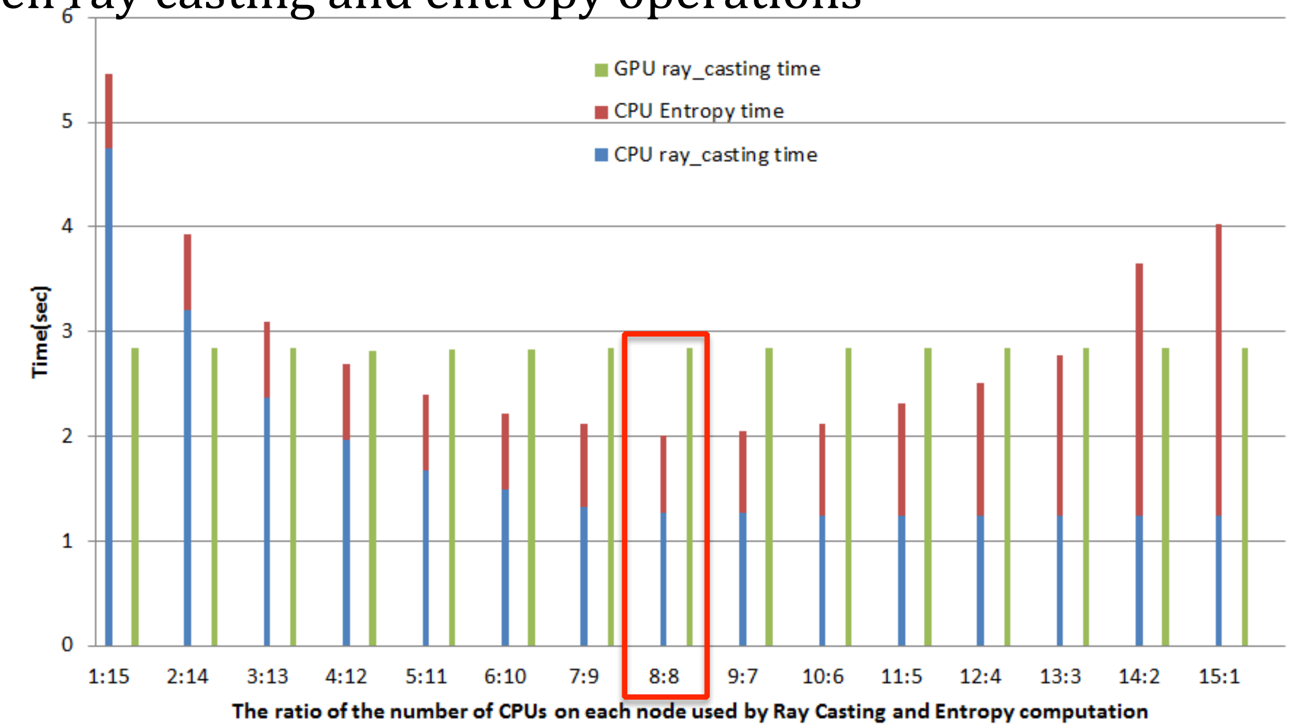


Fig. 5: The time results of ray casting and entropy analysis with various ratios on allocation. The output image resolution is 1024^2.

Conclusion

- A study for conducting scientific data analytics on **distributed heterogeneous** architectures by leveraging the **Legion** programming model and runtime system
- Consider both **scalability** and **usability** in our design
- Facilitate complex analytics operations with **completely different data partitioning** and **distribution** requirements in a nearly **unified** manner
- Perform operations across **CPUs** and **GPUs** and **balance** workload by automatic or manual scheduling strategies

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Thank You!