Zero copy serialization using RMA in the Hpx distributed task-based runtime

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ABSTRACT

Increasing layers of abstraction between user code and the hardware on which it runs can lead to reduced performance unless careful attention is paid to how data is transferred between the layers of the software stack. For distributed HPC applications, those layers include the network interface where data must be passed from the user’s code and explicitly copied from one node to another. Message passing incurs relatively high latencies (compared to local copies) from the transmission of data across the network and also from the injection and retrieval of messages into and out of the network drivers which may be exacerbated by unwanted copies of data being made at different levels of the stack. As memory bandwidth is becoming one of the limiting factors in scalability of codes within a node, and latencies of messaging between nodes, it is important to reduce both memory transfers and latencies wherever possible. In this paper we show how the distributed asynchronous task-based runtime, HPX, has been developed to allow zero-copy transfers of data between arguments in user defined remote function invocations and demonstrate the performance of our network layer in a state-of-the-art astrophysics code.

KEYWORDS

Distributed, Task-based, Asynchronous, Runtime, Network, Serialization

1. INTRODUCTION

The HPX runtime system for parallelism and concurrency (Kaiser et al. 2014) is a C++ library that implements asynchronous execution of task (graphs) using futures as synchronization primitives and extends the C++ API with distributed operations using an Active Global Address Space (Kaiser et al. 2015). Asynchronous task launching is performed using an async function that is templated over the function type and over a variadic arguments list; this powerful construct allows the user to define any function - with *any number of arguments* - and invoke it asynchronously, returning a future. The C++ standard introduced this function in C++11 as a means of introducing concurrency into the language; when this feature is extended to allow arbitrary function invocations on remote compute nodes as well as the local node, it introduces the need to serialize the arguments into a buffer (marshalling) for transmission and then deserialize them on reception and pass the function arguments onwards to the call being made. When the arguments are small (in terms of bytes of memory required to represent them), then the arguments can be copied into a memory buffer and transmitted as one using an eager protocol, but when the arguments are larger, performance improves when using remote memory access (RMA) operations (using a rendezvous protocol) between nodes to avoid copies and reduce latency – this technique is employed by nearly all HPC message passing systems such as MPI/MVAPICH (W. Huang 2007), PGAS models like UPC (El-Ghazawi et al. 2003), Legion (Bauer et al. 2012)..

In addition to implementing the serialization of arguments and RMA transfer between nodes, HPX is a multithreaded task based runtime that makes use of lightweight threads for fast context switching when suspending (or ending) one task and resuming (or starting) another, this means that our implementation must be thread safe and in order to be used in HPC applications must give high performance.

1. Related work

There are three areas of research that this work overlaps with, serialization, message passing, and runtime systems – these areas are too large to cover fully in the space provided and we must therefore highlight only those aspects that differ significantly from existing work.

There exist a large number of serialization libraries that are used for RPC purposes (as well as for persisting the state of objects to the filesystem or a database), they can be separated broadly into categories as follows

* Auto generated data requiring an intermediate description and/or pre-processor
* Auto generated but not requiring additional description/compiler
* Manually generated and possibly not strongly typed

Where auto generated means that code necessary to transfer parameters (either streamed/copied/placed) for functions can be generated by using either the native compiler for the system – or the compiler accompanied by an additional preprocessing/compilation step using a tool to transform a user supplied description of structures/data to be transmitted. The principal advantage of using an intermediate description of structures is that serialization between different languages (Java/Python/C++/&etc.) can be handled by the preprocessing step since it can generate different import/export code for each language. A secondary advantage is that it can produce very fast serialization code as the user has supplied types and sizes to the preprocessor that makes it easier for the final compilation step to do the right thing. Serializers that fall into this category include Google’s protobuf (Google & Varda 2017) and Flatbuffers, Apache thrift (Agarwal et al. 2007) and the charm++ Pack/Unpack (PUP) framework (Kale & Krishnan 1993). The principal disadvantage of these libraries is that they require the user to instrument any datatypes that they need to send/receive and/or run a preprocessing step over them before use. In projects that have a limited number of fixed messages/structures/records/types (or vocabulary) this is not a significant workload, but in a runtime system where the user may invoke arbitrary functions with arbitrary parameters, this places an unacceptable burden on the developer, particularly so for projects in their development phase where type can be changing rapidly.

Notable libraries that do not require an intermediate description include the boost serialization library (Boost 1998-2017), the boost MPI library, Cereal (Grant & Voorhies 2017). These libraries have the advantage of not requiring additional preprocessing steps and instead require the user to provide a (frequently trivial) serialization function for custom types that usually follows the pattern

Listing 1: Structure of a typical serialization function, an archive object is given a size and binary data, the type of the structure being serialized allow the compiler to instantiate the correct specialization (here string<Char>)

template **<**typename Char**>**

void serialize**(**output\_archive **&** ar**,** const std**::**string**<**Char**>** **&** s**,** unsigned**)**

**{**

std**::**uint64\_t size **=** s**.**size**();**

ar **<<** size**;**

save\_binary**(**ar**,** s**.**data**(),** s**.**size**()** **\*** **sizeof(**Char**));**

**}**

Built in types usually have serialization functions provided either as part of the language distribution or the serialization library provides them.

The third category that requires manually generating serialization functions includes the MPI library itself and the HPC RPC framework Mercury (Soumagne et al. 2013). With MPI, one can build custom datatypes to represent aggregates of other types and then pass these to the network for transmission, with Mercury one can do the same, but in addition each element may be designated either as a bulk data type or a normal argument. The user must register the function signature and provide a registered memory handle to each bulk data item so that the serialization of arguments can be done using an eager protocol to transfer bulk data handles, followed by a rendezvous phase where each of the bulk arguments is retrieved using an RMA fetch from the remote node. In this respect, Mercury performs essentially the same operation as the zero copy infrastructure in HPX, however, HPX being based a C++ solution (rather than C) automates a large part of the function and argument registration to greatly simplify the process and place the burden of work on the compiler instead of the user.

1. serialization

2.1 Serialization of arguments

To solve the problem of serialization and zero-copy of arguments, HPX uses a chunk-based archive format that differs from ‘flat’ archives, consider the following function invocation

Sdfdsfds

Figure 1: The archive is split into chunks, index chunks hold streamed binary data, pointer chunks only hold a pointer and size of the out-of-band data.

**Index**

**chunk**

**RMA**

**chunk**

**Pointer**

**chunk**

**Index**

**chunk**

**Pointer**

**chunk**

The HPX runtime

In standard C++, a std::async function call is spawned on a new thread of execution (or via a thread pool, depending upon implementation),

allowing concurrent execution of tasks in different threads and also enabling parallelism of algorithms by providing a mechanism whereby they may be broken into sub-tasks and executed on different threads.

The HPX library provides an implementation of hpx::async that conforms to the std::async API but uses thread pools and a lightweight threading model for tasks that does not require a kernel level context switch when changing the thread of executing from one task to another. HPX supports distributed execution of tasks via async calls by allowing them to be executed on remote localities (nodes) which, in turn, requires that the user supplied arguments to remotely invoked functions (or RPCs - Remote Procedure Calls) must be transmitted across the network, a process usually known as serialization

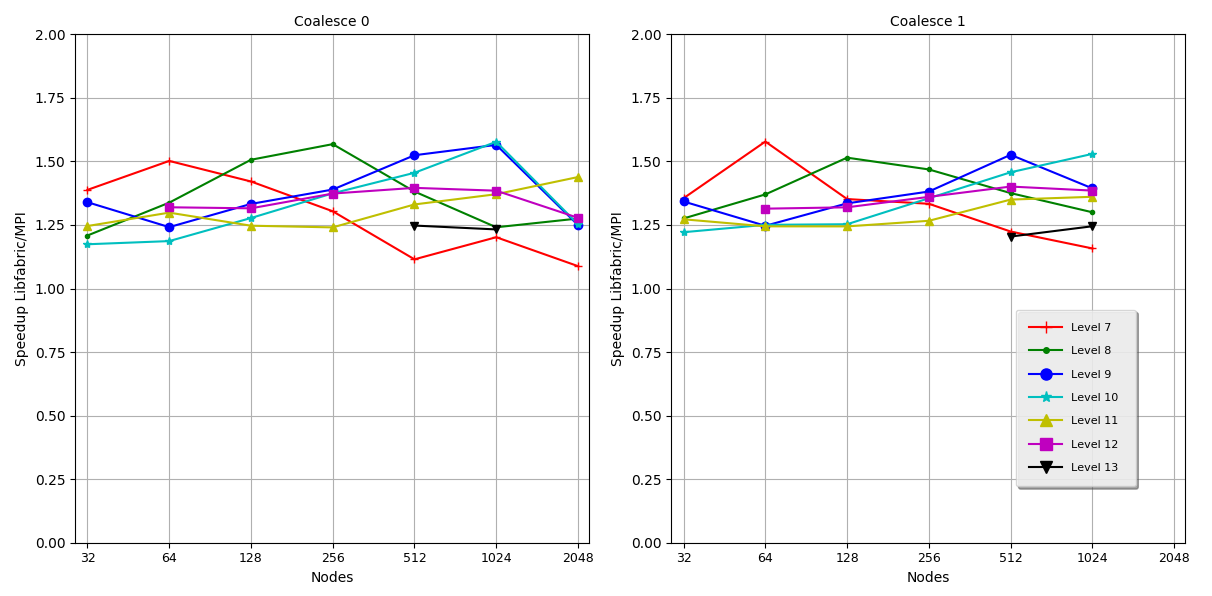
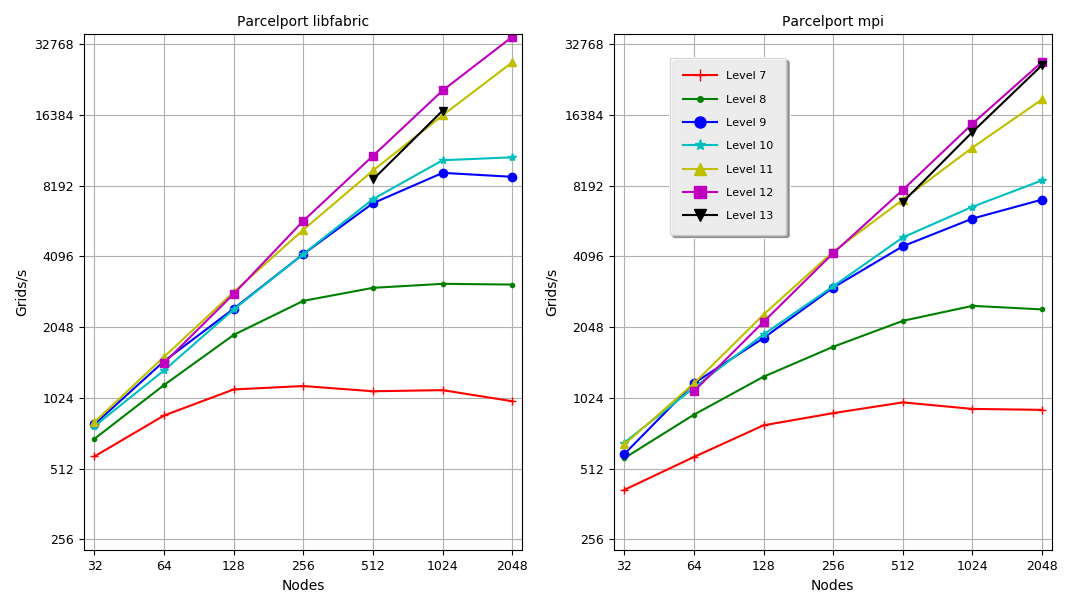
Qthreads (Wheeler et al. 2008)

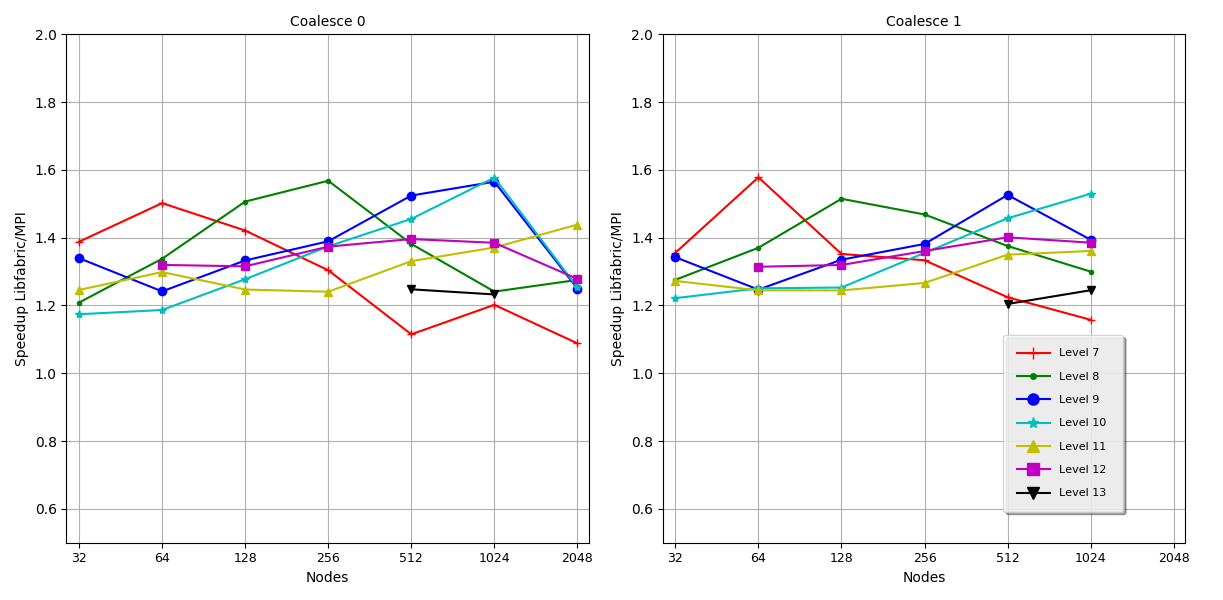
Charm++ (Kale & Krishnan 1993)

Libfabric (Choi et al. 2015)

Figure 2: Comparison of serialization libraries. In general, the larger the size, the faster the time, HPX produces small archives (because pointer chunks are skipped) and achieves good speed for the same reason.

1. Results

Figure 3: Comparison of the number of AMR blocks processed per second for different levels of refinement when using the libfabrics and MPI parcelports with OctoTiger.

Figure 4: The speedup obtained using the Libfabric parcelport compared to the MPI one, (left) results obtained when no parcel coalescing is enabled, (right) results with coalescing. Note that some points are missing as not all combinations of parameter were tested. The coalescing produces a slight reduction in the variance of results.

1. INTRODUCTION

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Clearly explain the nature of the problem, previous work, purpose, and contribution of the paper.

(Kaiser et al. 2015)

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1. CONCLUSION

Clearly indicate advantages, limitations and possible applications.

ACKNOWLEDGEMENT

A brief acknowledgement section may be included here.

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