Mercury: RPC for High-Performance Computing

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The HDF Group

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RPC and High-Performance Computing

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Remote Procedure Call (RPC)

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- Already widely used to support distributed services
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- No need for RPC: control flow implicit on all nodes
- A series of SPMD programs sequentially produce & analyze data

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Distributed HPC workflow

- Nodes/systems dedicated to specific task
- Multiple SPMD applications/jobs execute concurrently and interact

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Importance of RPC growing

- Compute nodes with minimal/non-standard environment
- Heterogeneous systems (node-specific resources)
- More “service-oriented” and more complex applications
- Workflows and in-transit instead of sequences of SPMD

Mercury

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Objective

Create a reusable RPC library for use in HPC that can serve as a basis for services such as storage systems, I/O forwarding, analysis frameworks and other forms of inter-application communication

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  - Do not support *efficient* large data transfers or asynchronous calls
  - Mostly built on top of TCP/IP protocols
    - Need support for native transport
    - Need to be easy to port to new systems

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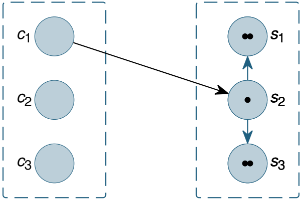
- Similar previous approaches with some differences
  - *I/O Forwarding Scalability Layer* (IOFSL) – ANL
  - *NEtwork Scalable Service Interface* (Nessie) – Sandia
  - Lustre RPC – Intel

Overview

Overview

- Designed to be both easily integrated and extended
  - "Client" / "Server" notions abstracted
    - (Server may also act as a client and vice versa)
  - "Origin" / "Target" used instead

Compute Nodes, origin c_1 has target s_2



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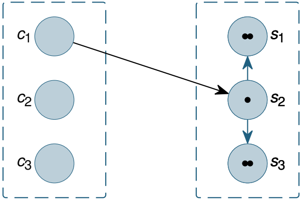

Service Nodes (e.g., storage, visualization, etc), s_1 and s_3 are targets of s_2

- Basis for accessing and enabling resilient services
  - Ability to reclaim resources after failure is imperative

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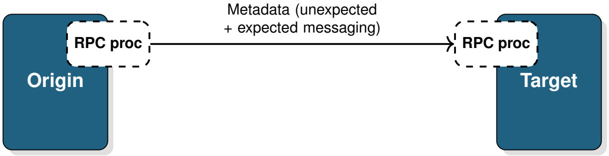
  - Two-sided model with unexpected / expected messaging
  - Message size limited to a few kilobytes (low-latency)



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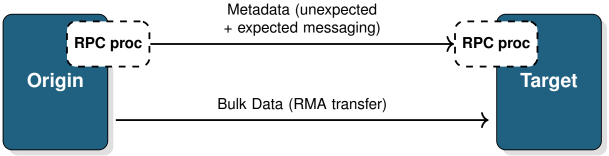

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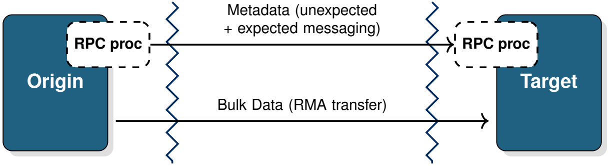
- Network Abstraction Layer
  - Allows definition of multiple network plugins
    - MPI and BMI plugins first plugins
    - Shared-memory plugin (mmap + CMA, supported on Cray w/CLE6)
    - CCI plugin contributed by ORNL
    - Libfabric plugin contributed by Intel (support for Cray GNI)



Network Abstraction Layer

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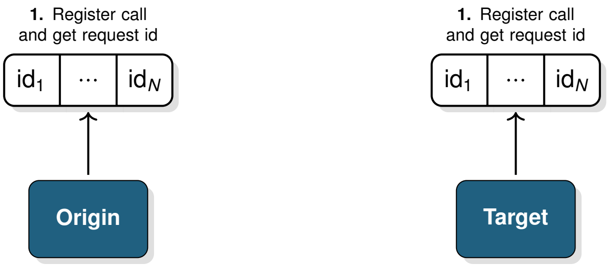

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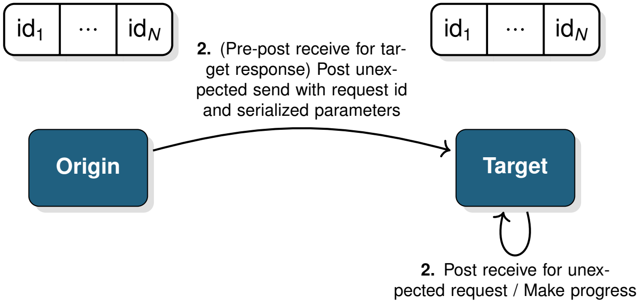

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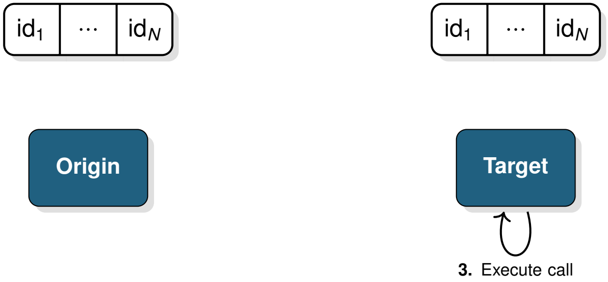

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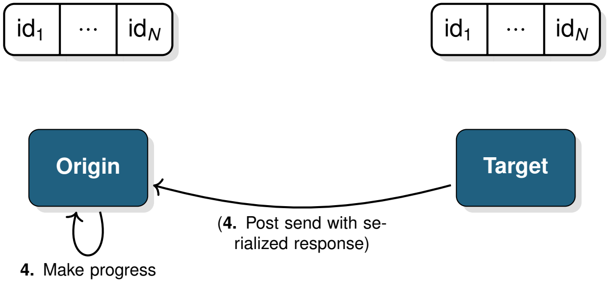
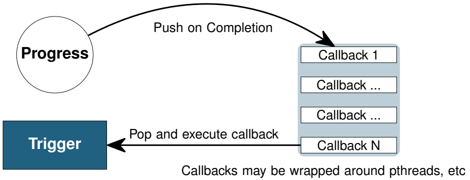


Progress Model

- Callback-based model with completion queue
- Explicit progress with `HG_Progress()` and `HG_Trigger()`
  - Allows user to create workflow
  - No need to have an explicit *wait* call (shim layers possible)
  - Facilitate operation scheduling, multi-threaded execution and cancellation!




```
do {
  unsigned int actual_count = 0;

  do {
    ret = HG_Trigger(context, 0, 1, &actual_count);
  } while ((ret == HG_SUCCESS) && actual_count);

  if (done)
    break;

  ret = HG_Progress(context, HG_MAX_IDLE_TIME);
} while (ret == HG_SUCCESS);
```

Remote Procedure Call: Example

- Origin snippet (Callback model):

```
open_in_t in_struct;

/* Initialize the interface and get target address */
hg_class = HG_Init("ofi+tcp://eth0:22222", HG_FALSE);
hg_context = HG_Context_create(hg_class);
[...]
HG_Addr_lookup_wait(hg_context, target_name, &target_addr);

/* Register RPC call */
rpc_id = MERCURY_REGISTER(hg_class, "open", open_in_t, open_out_t);

/* Set input parameters */
in_struct.in_param0 = in_param0;

/* Create RPC request */
HG_Create(hg_context, target_addr, rpc_id, &hg_handle);

/* Send RPC request */
HG_Forward(hg_handle, rpc_done_cb, &rpc_done_args, &in_struct);

/* Make progress */
[...]
```

Remote Procedure Call: Example

- Origin snippet (next):

```
hg_return_t
rpc_done_cb(const struct hg_cb_info *callback_info)
{
  open_out_t out_struct;

  /* Get output */
  HG_Get_output(callback_info->handle, &out_struct);

  /* Get output parameters */
  ret = out_struct.ret;
  out_param0 = out_struct.out_param0;

  /* Free output */
  HG_Free_output(callback_info->handle, &out_struct);

  return HG_SUCCESS;
}
```

- Cancellation: `HG_Cancel()` on handle
  - Callback still triggered (canceled = completion)

Remote Procedure Call: Example

- Target snippet (main loop):

```
int
main(int argc, void *argv[])
{
   /* Initialize the interface and listen */
   hg_class = HG_Init("ofi+tcp://eth0:22222", HG_TRUE);
   [...]

   /* Register RPC call */
   MERCURY_REGISTER(hg_class, "open", open_in_t, open_out_t, open_rpc_cb);

   /* Make progress */
   [...]

   /* Finalize the interface */
   [...]
}
```

Remote Procedure Call: Example

- Target snippet (RPC callback):

```
hg_return_t
open_rpc_cb(hg_handle_t handle)
{
  open_in_t in_struct;
  open_out_t out_struct;

  /* Get input */
  HG_Get_input(handle, &in_struct);
  in_param0 = in_struct.in_param0;

  /* Execute call */
  out_param0 = open(in_param0, ...);

  /* Set output */
  open_out_struct.out_param0 = out_param0;

  /* Send response back to origin */
  HG_Respond(handle, NULL, NULL, &out_struct);

  /* Free input and destroy handle */
  HG_Free_input(handle, &in_struct);
  HG_Destroy(handle);

  return HG_SUCCESS;
}
```

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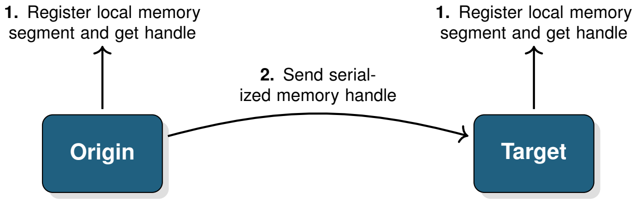

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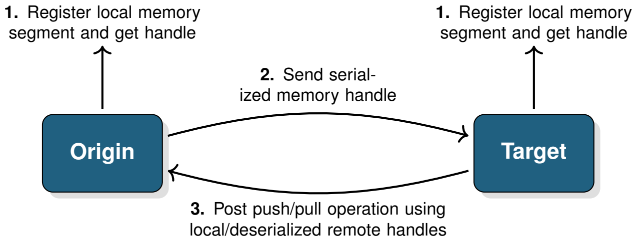

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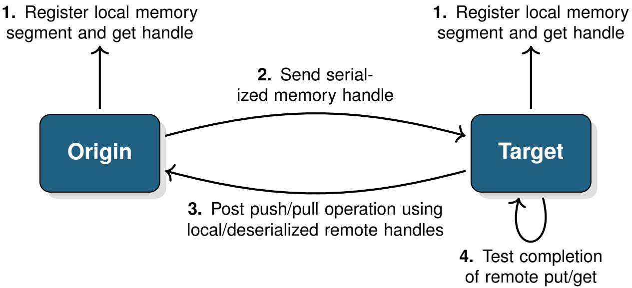

Bulk Data Transfers: Example

- Origin snippet (contiguous):

```
/* Initialize the interface and get target address */
[...]

/* Create bulk handle (only change) */
HG_Bulk_create(hg_info->hg_bulk_class, 1, &buf, &buf_size, HG_BULK_READ_ONLY, &
    bulk_handle);

/* Attach bulk handle to input parameters */
[...]
in_struct.bulk_handle = bulk_handle;

/* Create RPC request */
HG_Create(hg_context, target_addr, rpc_id, &hg_handle);

/* Send RPC request */
HG_Forward(hg_handle, rpc_done_cb, &rpc_done_args, &in_struct);

/* Make progress */
[...]
```

Bulk Data Transfers: Example

- Target snippet (RPC callback):

```
/* Get input parameters and bulk handle */
HG_Get_input(handle, &in_struct);
[...]
origin_bulk_handle = in_struct.bulk_handle;

/* Get size of data and allocate buffer */
nbytes = HG_Bulk_get_size(bulk_handle);

/* Create block handle to read data */
HG_Bulk_create(hg_info->hg_bulk_class, 1, NULL, &nbytes,
  HG_BULK_READWRITE, &local_bulk_handle);

/* Start pulling bulk data (execute call / send response in callback) */
HG_Bulk_transfer(hg_info->bulk_context, bulk_transfer_cb,
  bulk_args, HG_BULK_PULL, hg_info->addr, origin_bulk_handle, 0,
  local_bulk_handle, 0, nbytes, HG_OP_ID_IGNORE);
```

Non-contiguous Bulk Data Transfers

- Non contiguous memory is registered through bulk data interface...

```
hg_return_t HG_Bulk_create(
    hg_bulk_class_t *hg_bulk_class,
    hg_size_t count,
    void **buf_ptrs,
    const hg_size_t *buf_sizes,
    hg_uint8_t flags,
    hg_bulk_t *handle
    );
```

- ...and allows for scatter/gather memory transfers using virtual memory offsets and length
- Origin unaware of target memory layout

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  - Serialization / deserialization of parameters
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- Single include header file shared between origin and target
- Make use of BOOST preprocessor for macro definition
  - Generate serialization / deserialization functions and structure that contains parameters

Macros: Serialization / Deserialization


```
MERCURY_GEN_PROC(
    struct_type_name,
    fields
)
```

Macro

```
MERCURY_GEN_PROC(
    open_in_t,
    ((hg_string_t)(path))
    ((int32_t)(flags))
    ((uint32_t)(mode))
)
```

Generates proc and struct →

Generated Code

```
/* Define open_in_t */
typedef struct {
    hg_string_t path;
    int32_t flags;
    uint32_t mode;
} open_in_t;

/* Define hg_proc_open_in_t */
static inline hg_return_t
hg_proc_open_in_t(hg_proc_t proc, void *data)
{
    hg_return_t ret = HG_SUCCESS;
    open_in_t *struct_data = (open_in_t *) data;

    ret = hg_proc_hg_string_t(proc, &struct_data->path);
    if (ret != HG_SUCCESS) {
        HG_LOG_ERROR("Proc error");
        ret = HG_FAIL;
        return ret;
    }

    ret = hg_proc_int32_t(proc, &struct_data->flags);
    if (ret != HG_SUCCESS) {
        HG_LOG_ERROR("Proc error");
        ret = HG_FAIL;
        return ret;
    }

    ret = hg_proc_uint32_t(proc, &struct_data->mode);
    if (ret != HG_SUCCESS) {
        HG_LOG_ERROR("Proc error");
        ret = HG_FAIL;
        return ret;
    }

    return ret;
}
```

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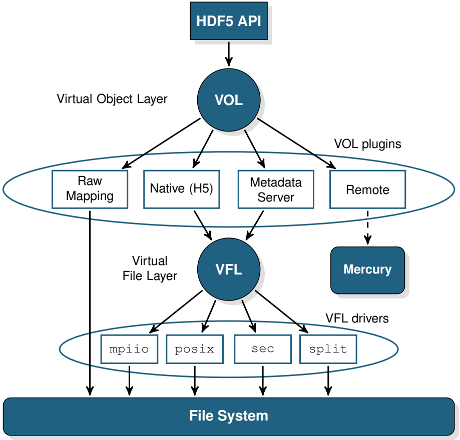
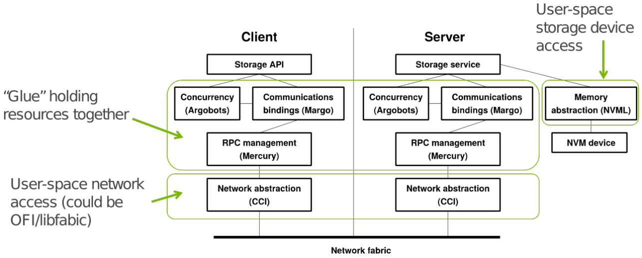
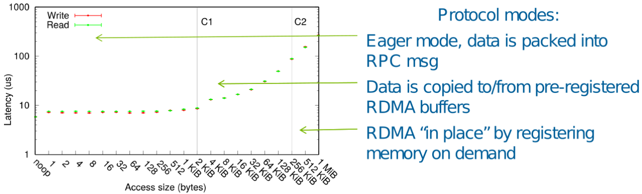


Other projects that already use Mercury

- Mochi (ANL) – – – – – >
- DAOS (Intel)
- DeltaFS (CMU)
- PDC (LBNL)
- MDHIM? / Legion? (LANL)





Current and Future Work

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- Support cancel operations of ongoing RPC calls done
- Shared-memory plugin and multi-progress done

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- Support cancel operations of ongoing RPC calls done
- Shared-memory plugin and multi-progress done
- Transparent Shared-memory selection ongoing
- Libfabric plugin and DRC support (auth keys) ongoing
- Group membership and Publish/subscribe model ongoing

Where to go next

- Mercury project page
  - http://mercury-hpc.github.io/
  - https://www.mcs.anl.gov/research/projects/mochi/tutorials/
  - https://github.com/mercury-hpc
  - Download / Documentation / Source / Mailing-lists
- Current and previous contributors (non exhaustive): Phil Carns (ANL), Rob Ross (ANL), Scott Atchley (ORNL), Chuck Cranor (CMU), Xuezhao Liu (Intel), Quincey Koziol, Mohamad Chaarawi, John Jenkins, Dries Kimpe
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