Mercury: RPC for High-Performance Computing

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RPC and Exascale Fast-forward

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- Typical HPC workflow:
  1. Compute and produce data
  2. Store data
  3. Analyze data
  4. Visualize data

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  2. Store data (data staging)
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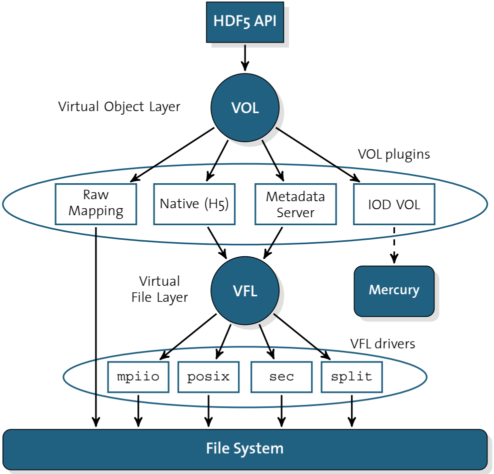
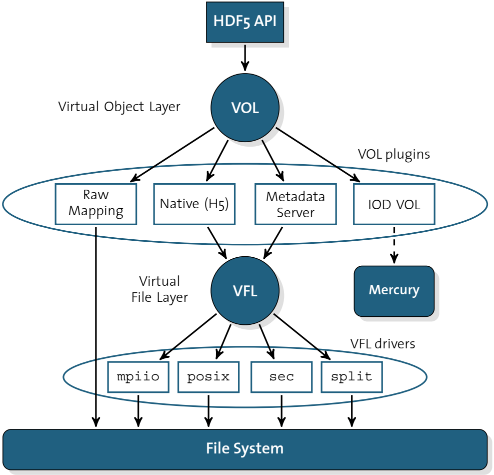
- Distributed workflow with nodes / systems dedicated to specific task
  - Compute nodes with minimal environment
  - I/O / analysis / visualization libraries only available on remote resources
- Transparent solution: Remote Procedure Call (RPC)
  - E.g., store data using HDF5 but re-route I/O calls to I/O nodes

Mercury in HDF5 Stack



Mercury in HDF5 Stack



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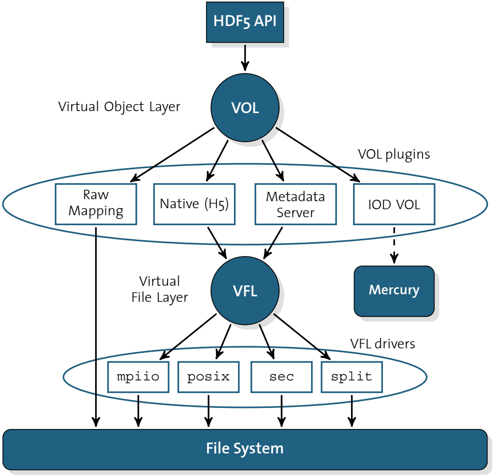

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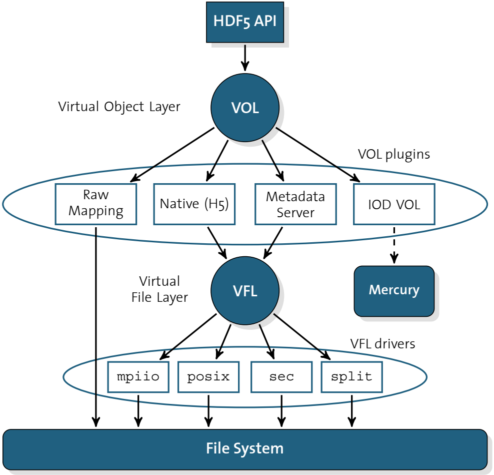

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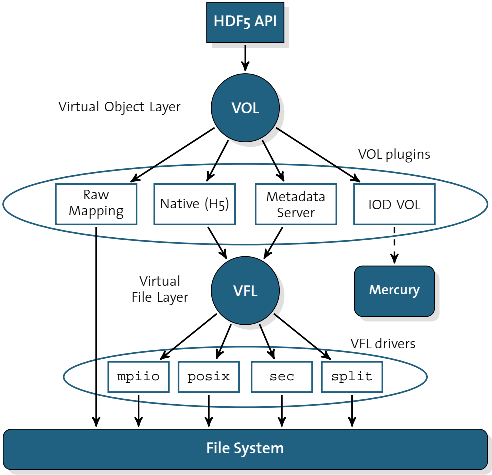


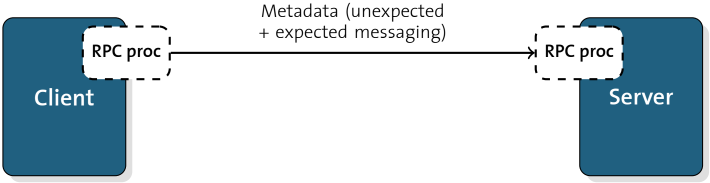
- Mercury must support
  - Non-blocking transfers
  - Large data arguments
  - Native transport protocols

Overview

RPC proc
Client
RPC proc
Server

Overview

- Function arguments / metadata transferred with RPC request
  - Two-sided model with unexpected / expected messaging
  - Message size limited to a few kilobytes



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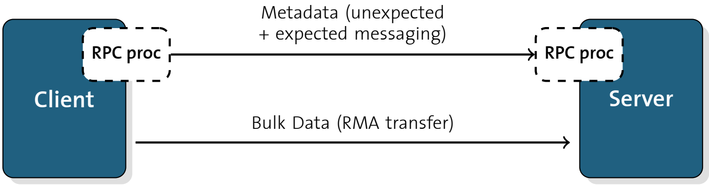

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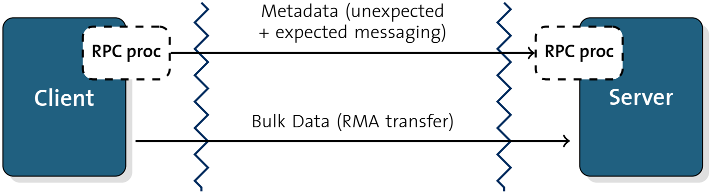
- Network Abstraction Layer
  - Allows definition of multiple network plugins
  - Two functional plugins MPI (MPI2) and BMI but implement one-sided over two-sided
  - More plugins to come



Network Abstraction Layer

Remote Procedure Call

- Mechanism used to send an RPC request

id_1
…
id_N
id_1
…
id_N
Client
Server

Remote Procedure Call

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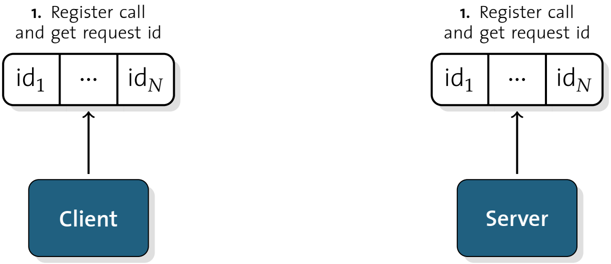

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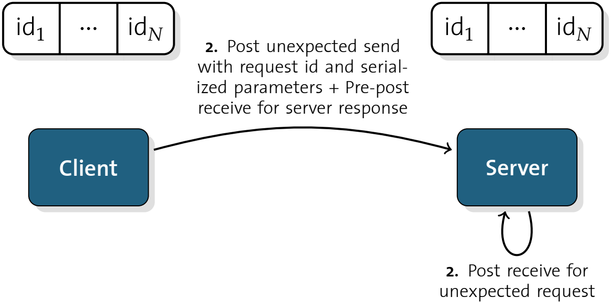


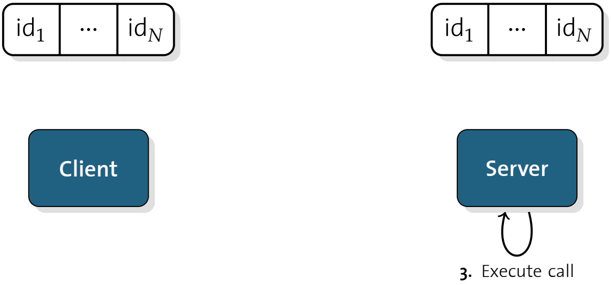
id_1 … id_N
id_1 … id_N
Client
Server

2. Post unexpected send with request id and serialized parameters + Pre-post receive for server response

2. Post receive for unexpected request

Remote Procedure Call

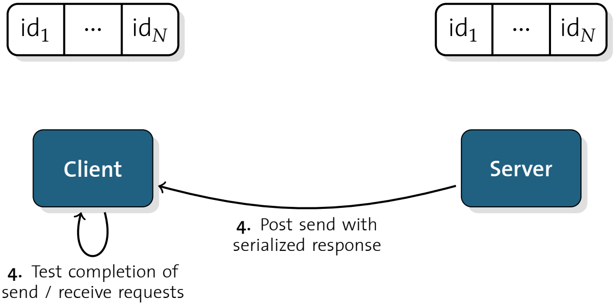
- Mechanism used to send an RPC request



id_1 | ⋯ | id_N
id_1 | ⋯ | id_N
Client
Server
3. Execute call

Remote Procedure Call

- Mechanism used to send an RPC request



id_1 | ⋯ | id_N
id_1 | ⋯ | id_N
Client
Server
4. Post send with serialized response
4. Test completion of send / receive requests

Remote Procedure Call: Example

- Client snippet:

```
open_in_t in_struct;
open_out_t out_struct;

/* Initialize the interface */
[...]
NA_Addr_lookup(network_class, server_name, &server_addr);

/* Register RPC call */
rpc_id = HG_REGISTER(”open”, open_in_t, open_out_t);

/* Fill input parameters */
[...]
in_struct.in_param0 = in_param0;

/* Send RPC request */
HG_Forward(server_addr, rpc_id, &in_struct, &out_struct,
    &rpc_request);

/* Wait for completion */
HG_Wait(rpc_request, HG_MAX_IDLE_TIME, HG_STATUS_IGNORE);

/* Get output parameters */
[...]
out_param0 = out_struct.out_param0;
```

Remote Procedure Call: Example

- Server snippet (main loop):

```
int main(int argc, void *argv[])
{
  /* Initialize the interface */
  [...]

  /* Register RPC call */
  HG_HANDLER_REGISTER(”open”, open_rpc, open_in_t, open_out_t);

  /* Process RPC calls */
  while (!finalized) {
    HG_Handler_process(timeout, HG_STATUS_IGNORE);
  }

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

Remote Procedure Call: Example

- Server snippet (RPC callback):

```
int open_rpc(hg_handle_t handle)
{
  open_in_t in_struct;
  open_out_t out_struct;

  /* Get input parameters and bulk handle */
  HG_Handler_get_input(handle, &in_struct);
  [...]
  in_param0 = in_struct.in_param0;

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

  /* Fill output structure */
  open_out_struct.out_param0 = out_param0;

  /* Send response back */
  HG_Handler_start_output(handle, &out_struct);

  return HG_SUCCESS;
}
```

Bulk Data Transfers

- Mechanism used to transfer bulk data
  - Transfer controlled by server
  - Memory buffer abstracted by memory handle
  - Client memory handle must be serialized and sent to the server

Client

Server

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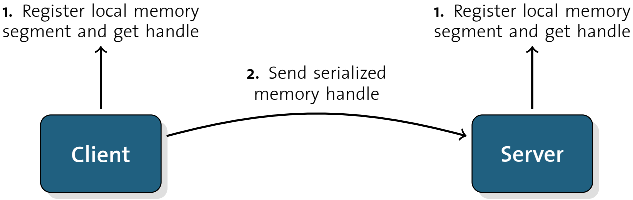
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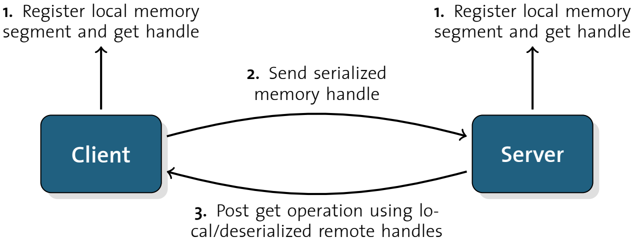

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3. Post get operation using local/deserialized remote handles

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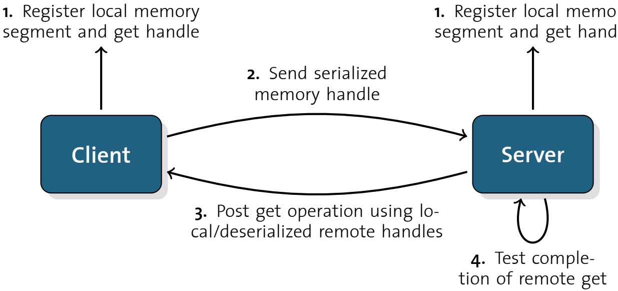

1. Register local memory segment and get handle

1. Register local memory segment and get handle

2. Send serialized memory handle

Client

Server

3. Post get operation using local/deserialized remote handles

4. Test completion of remote get

Bulk Data Transfers: Example

- Client snippet (contiguous):

```
/* Initialize the interface */
[...]
/* Register RPC call */
rpc_id = HG_REGISTER(”write”, write_in_t, write_out_t);

/* Create bulk handle */
HG_Bulk_handle_create(buf, buf_size,
    HG_BULK_READ_ONLY, &bulk_handle);

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

/* Send RPC request */
HG_Forward(server_addr, rpc_id, &in_struct, &out_struct,
    &rpc_request);

/* Wait for completion */
HG_Wait(rpc_request, HG_MAX_IDLE_TIME, HG_STATUS_IGNORE);
```

Bulk Data Transfers: Example

- Server snippet (RPC callback):

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

/* Get size of data and allocate buffer */
nbytes = HG_Bulk_handle_get_size(bulk_handle);
buf = malloc(nbytes);

/* Create block handle to read data */
HG_Bulk_block_handle_create(buf, nbytes,
    HG_BULK_READWRITE, &bulk_block_handle);

/* Start reading bulk data  */
HG_Bulk_read_all(client_addr, bulk_handle,
    bulk_block_handle, &bulk_request);

/* Wait for completion */
HG_Bulk_wait(bulk_request,
    HG_MAX_IDLE_TIME, HG_STATUS_IGNORE);
```

Non-contiguous Bulk Data Transfers

- Non contiguous memory is registered through bulk data interface…

```
int HG_Bulk_handle_create_segments(
        hg_bulk_segment_t *bulk_segments,
        size_t segment_count,
        unsigned long flags,
        hg_bulk_t *handle);
```

- …which maps to network abstraction layer if plugin supports it…

```
int NA_Mem_register_segments(na_class_t *network_class,
        na_segment_t *segments,
        na_size_t segment_count,
        unsigned long flags,
        na_mem_handle_t *mem_handle);
```

- …otherwise several `na_mem_handle_t` created and `hg_bulk_t` may therefore have a variable size
    - If serialized `hg_bulk_t` too large, use bulk data API to register memory and pull memory descriptors from server

Non-contiguous Bulk Data Transfers: API

- Non-blocking read

```
int HG_Bulk_read(na_addr_t addr,
        hg_bulk_t bulk_handle,
        size_t bulk_offset,
        hg_bulk_block_t block_handle,
        size_t block_offset,
        size_t block_size,
        hg_bulk_request_t *bulk_request);
```

- Non-blocking write

```
int HG_Bulk_write(na_addr_t addr,
        hg_bulk_t bulk_handle,
        size_t bulk_offset,
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        size_t block_size,
        hg_bulk_request_t *bulk_request);
```

Non-contiguous Bulk Data Transfers: Example

- Client snippet:

```
/* Initialize the interface */
[...]
/* Register RPC call */
rpc_id = HG_REGISTER(”write”, write_in_t, write_out_t);

/* Provide data layout information */
for (i = 0; i < BULK_NX ; i++) {
  segments[i].address = buf[i];
  segments[i].size = BULK_NY * sizeof(int);
}

/* Create bulk handle with segment info */
HG_Bulk_handle_create_segments(segments, BULK_NX,
    HG_BULK_READ_ONLY, &bulk_handle);

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

/* Send RPC request */
HG_Forward(server_addr, rpc_id, &in_struct, &out_struct,
    &rpc_request);
```

Non-contiguous Bulk Data Transfers: Example

- Server snippet:

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HG_Handler_get_input(handle, &in_struct);
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/* Start reading bulk data  */
HG_Bulk_read_all(client_addr, bulk_handle,
    bulk_block_handle, &bulk_request);

/* Wait for completion */
HG_Bulk_wait(bulk_request,
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Data buffer (nbytes)

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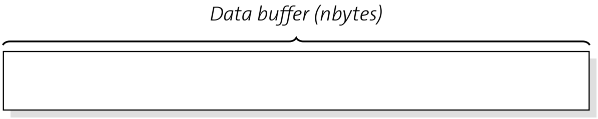

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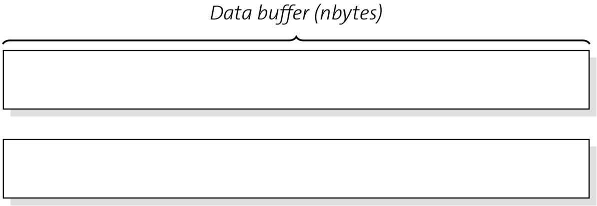

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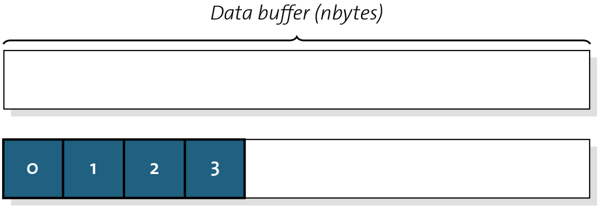

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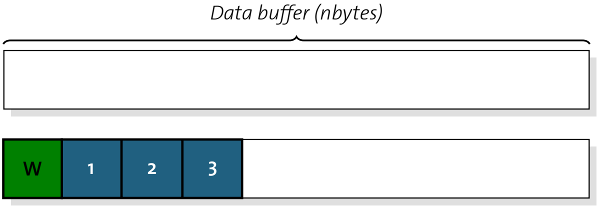

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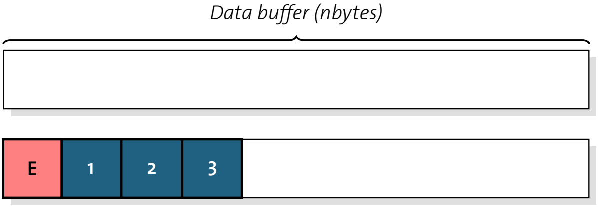

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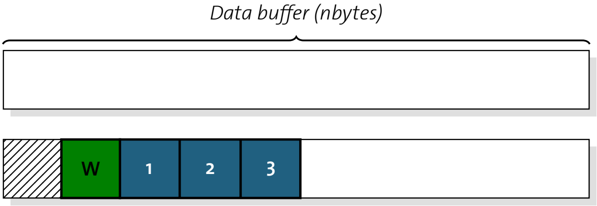

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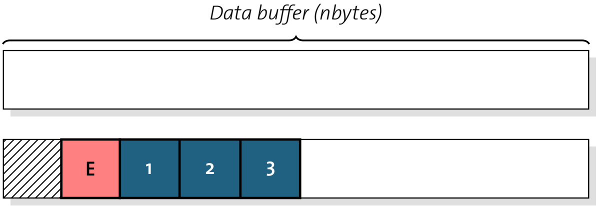

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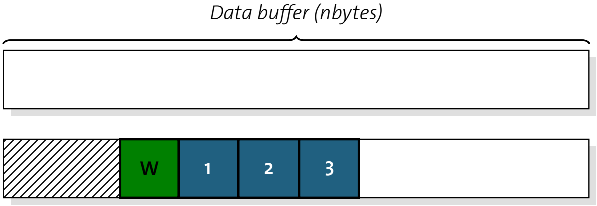

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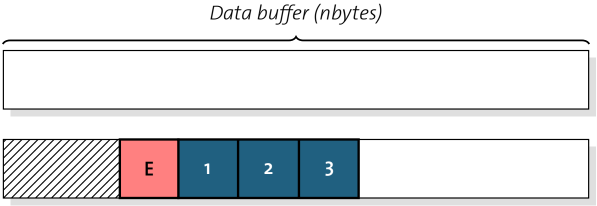

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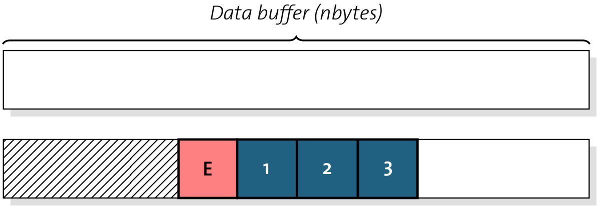

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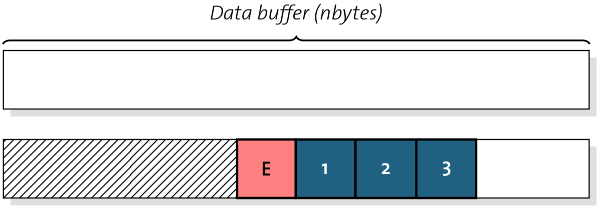

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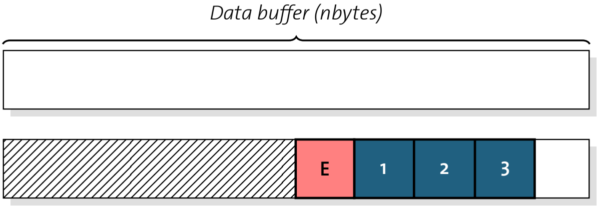

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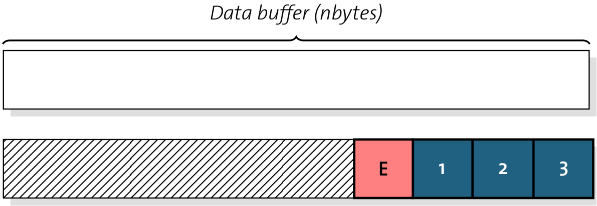

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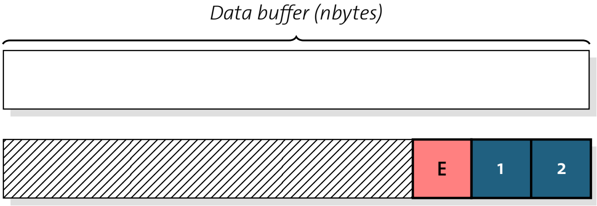

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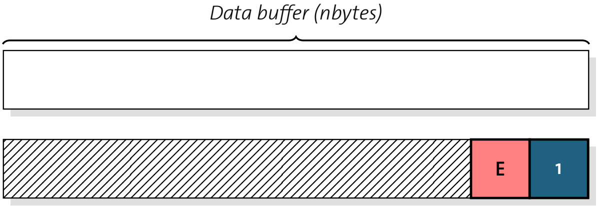

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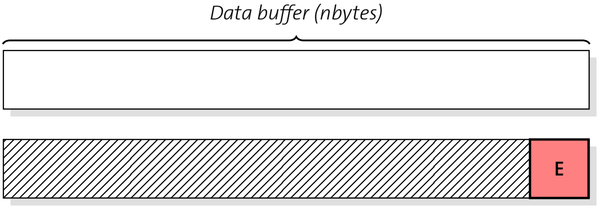

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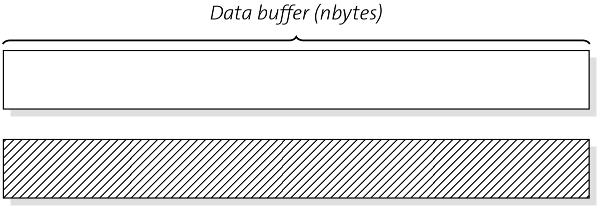

Fine-grained Transfers: Example

- Server snippet (part 1):

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

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

/* Initialize pipeline and start reads */
for (p = 0; p < PIPELINE_SIZE; p++) {
  size_t offset = p * PIPELINE_BUFFER_SIZE;
  buf[p] = malloc(PIPELINE_BUFFER_SIZE);

  /* Create block handle to read data */
  HG_Bulk_block_handle_create(buf[p],
    PIPELINE_BUFFER_SIZE, HG_BULK_READWRITE,
    &bulk_block_handle[p]);

  /* Start read of data chunk */
  HG_Bulk_read(client_addr, bulk_handle,
    offset, bulk_block_handle[p], 0,
    PIPELINE_BUFFER_SIZE, &bulk_request[p]);
}
```

Fine-grained Transfers: Example

- Server snippet (part 2):

```
while (nbytes_read != nbytes) {
  for (p = 0; p < PIPELINE_SIZE; p++) {
    size_t offset = start_offset + p * PIPELINE_BUFFER_SIZE;
    /* Wait for data chunk */
    HG_Bulk_wait(bulk_request[p],
      HG_MAX_IDLE_TIME, HG_STATUS_IGNORE);
    nbytes_read += PIPELINE_BUFFER_SIZE;

    /* Do work (write data chunk) */
    write(buf[p], offset, PIPELINE_BUFFER_SIZE);

    /* Start another read */
    offset += PIPELINE_BUFFER_SIZE * PIPELINE_SIZE;
    if (offset < nbytes) {
      HG_Bulk_read(client_addr, bulk_handle, offset,
        bulk_block_handle[p], 0, PIPELINE_BUFFER_SIZE,
        &bulk_request[p]);
    } else {
      /* Start read with remaining piece */
    }
  }
  start_offset += PIPELINE_BUFFER_SIZE * PIPELINE_SIZE;
}
```

Macros

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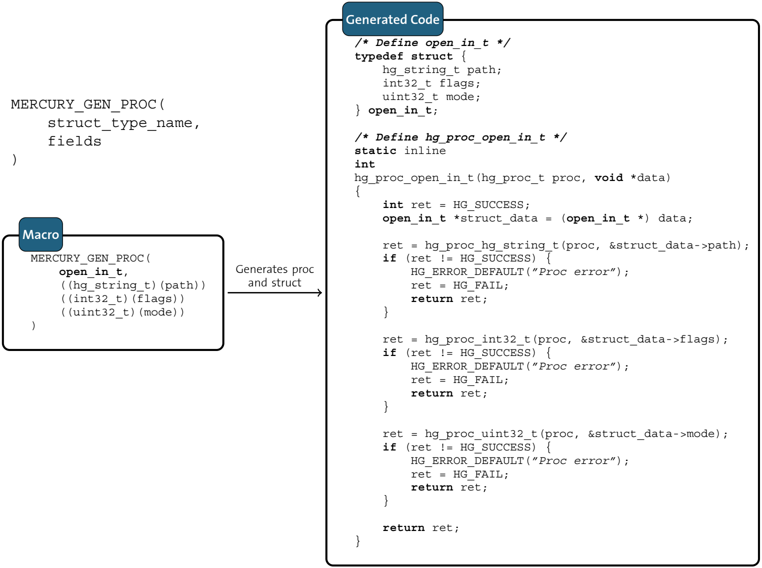
  - Generate synchronous RPC stub

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))
)
```

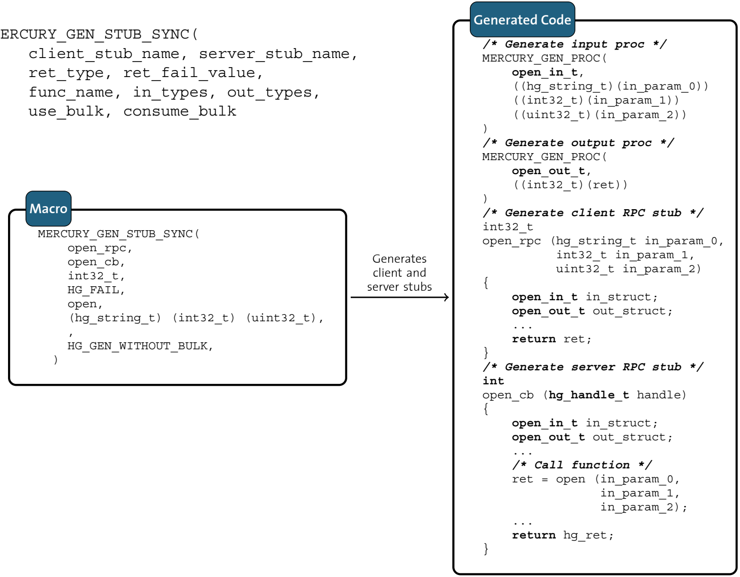
Generates proc and struct →

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
int
hg_proc_open_in_t(hg_proc_t proc, void *data)
{
    int 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_ERROR_DEFAULT("Proc error");
        ret = HG_FAIL;
        return ret;
    }

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

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

    return ret;
}
```

Macros: RPC Stubs

```
MERCURY_GEN_STUB_SYNC(
    client_stub_name, server_stub_name,
    ret_type, ret_fail_value,
    func_name, in_types, out_types,
    use_bulk, consume_bulk
)
```



Macro

```
MERCURY_GEN_STUB_SYNC(
    open_rpc,
    open_cb,
    int32_t,
    HG_FAIL,
    open,
    (hg_string_t) (int32_t) (uint32_t),
    ,
    HG_GEN_WITHOUT_BULK,
  )
```

Generates
client and
server stubs

Generated Code

```
/* Generate input proc */
MERCURY_GEN_PROC(
    open_in_t,
    ((hg_string_t)(in_param_0))
    ((int32_t)(in_param_1))
    ((uint32_t)(in_param_2))
)
/* Generate output proc */
MERCURY_GEN_PROC(
    open_out_t,
    ((int32_t)(ret))
)
/* Generate client RPC stub */
int32_t
open_rpc (hg_string_t in_param_0,
          int32_t in_param_1,
          uint32_t in_param_2)
{
    open_in_t in_struct;
    open_out_t out_struct;
    ...
    return ret;
}
/* Generate server RPC stub */
int
open_cb (hg_handle_t handle)
{
    open_in_t in_struct;
    open_out_t out_struct;
    ...
    /* Call function */
    ret = open (in_param_0,
                in_param_1,
                in_param_2);
    ...
    return hg_ret;
}
```

Future Work

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  - Apply to HDF5 VFD
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- Support cancel operations of ongoing RPC calls

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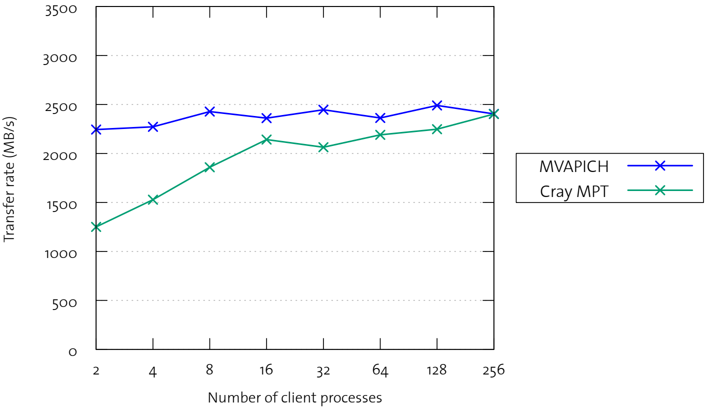

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Questions

- Mercury project page:
  - `http://trac.mcs.anl.gov/projects/mercury`