# Proposal of Interface for Runtime Memory Manipulation of Applications via PGAS-based Communication Library

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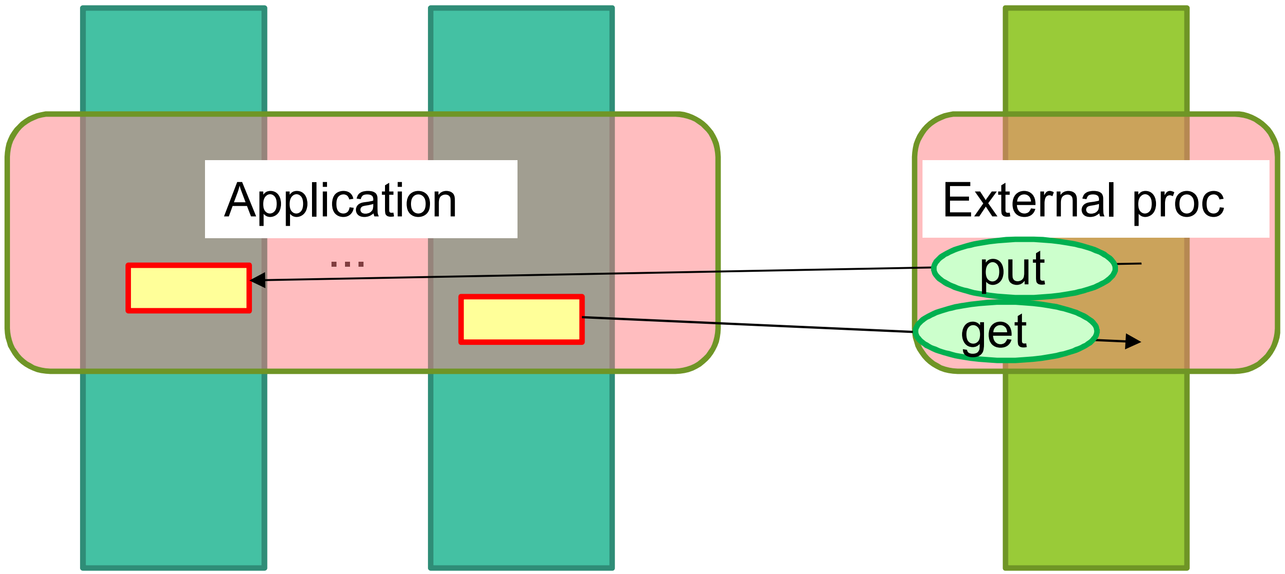
# Background

- PGAS Libraries has become practical candidates as parallel programming tools
  - PGAS-based library
    - OpenSHMEM
    - GASPI
    - Global Arrays
    - ACP
    
    etc.
  - Message-Passing based library
    - MPI RMA
  - Fundamental communication library
    - UCX
    - Portals4
    
    etc.
- One of their most important advantages is asynchronousness

# Proposal of an API for Runtime Memory Manipulation

- Enable asynchronous access to any exposed memory region in an application from outside.
- Empowered by PGAS-based communication library.

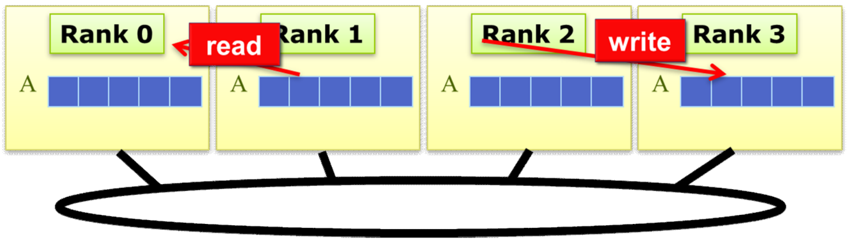


# Outline

- Advantages of Libraries with PGAS Interfaces
- ACP (Advanced Communication Primitives): an Example of PGAS-based Communication Library
- Proposal of OpAS (Open Address Space) Interface
- Sample Implementation of OpAS on ACP

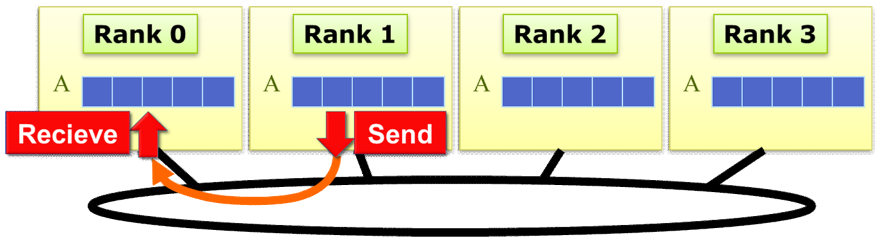
# PGAS vs Message Passing

- PGAS (One-sided communication)
  = Data transfer
  - Lower overhead
  - Lower memory consumption
  - Better overlapping




... assuming RDMA is available

- Message Passing
  = Data transfer
  + Synchronization
  - Usually, easier and more efficient to describe data dependency among processes



# PGAS Language vs PGAS Library

- PGAS languages: UPC, CAF, Xcalable MP, etc.
  - Provides high abstraction of process parallelism
  - Various communication optimizations in compilers are expected
    - Sometimes, they are difficult to apply

- PGAS libraries:
  - Enable detailed control of data transfer and synchronization
  - May show better performance for complicated patterns of communication

# ACP (Advanced Communication Primitives)

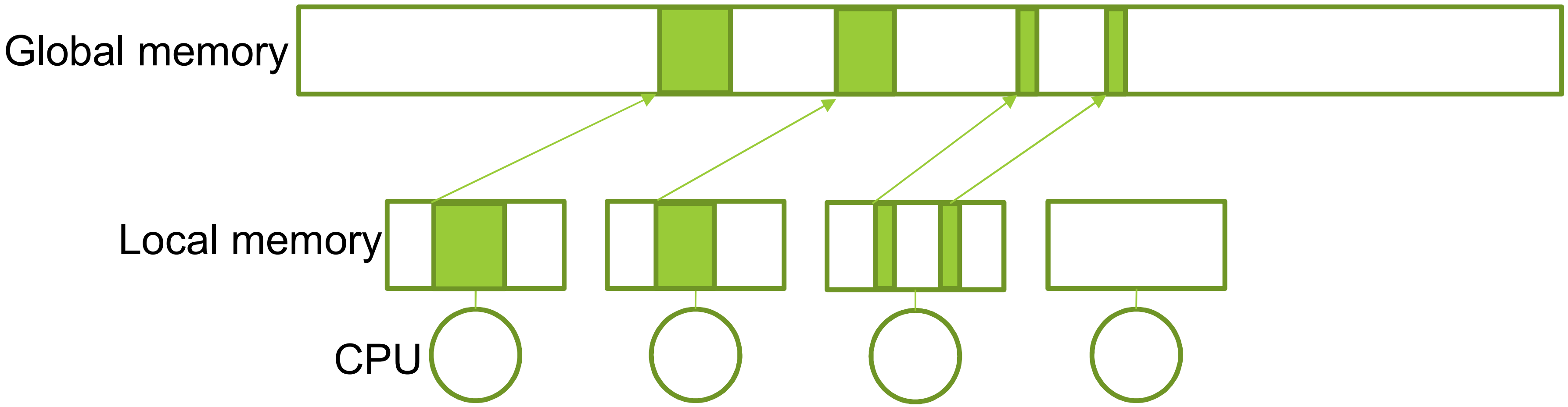
- An example of "PGAS-based" communication library

Use this layer for OpAS

- Basic Layer
  - Provides PGAS interfaces.
    - memory management
    - copy
    - atomic
    - barrier
  - Runs on:
    - IB, Ethernet (UDP), Tofu/Tofu2
- Middle Layer
  - Optional interfaces built on top of Basic Layer:
    - Message Passing
    - Data Structures (List, Vector, Map, etc.)
  - Memory consumptions, such as buffers, are explicit

# Memory Model of ACP

- Local memory:
  - Ordinal address space of each process, managed by OS.
- Global memory:
  - Memory space virtually shared among processes.
    - Any local memory space of any process can be mapped to the global memory via registration.

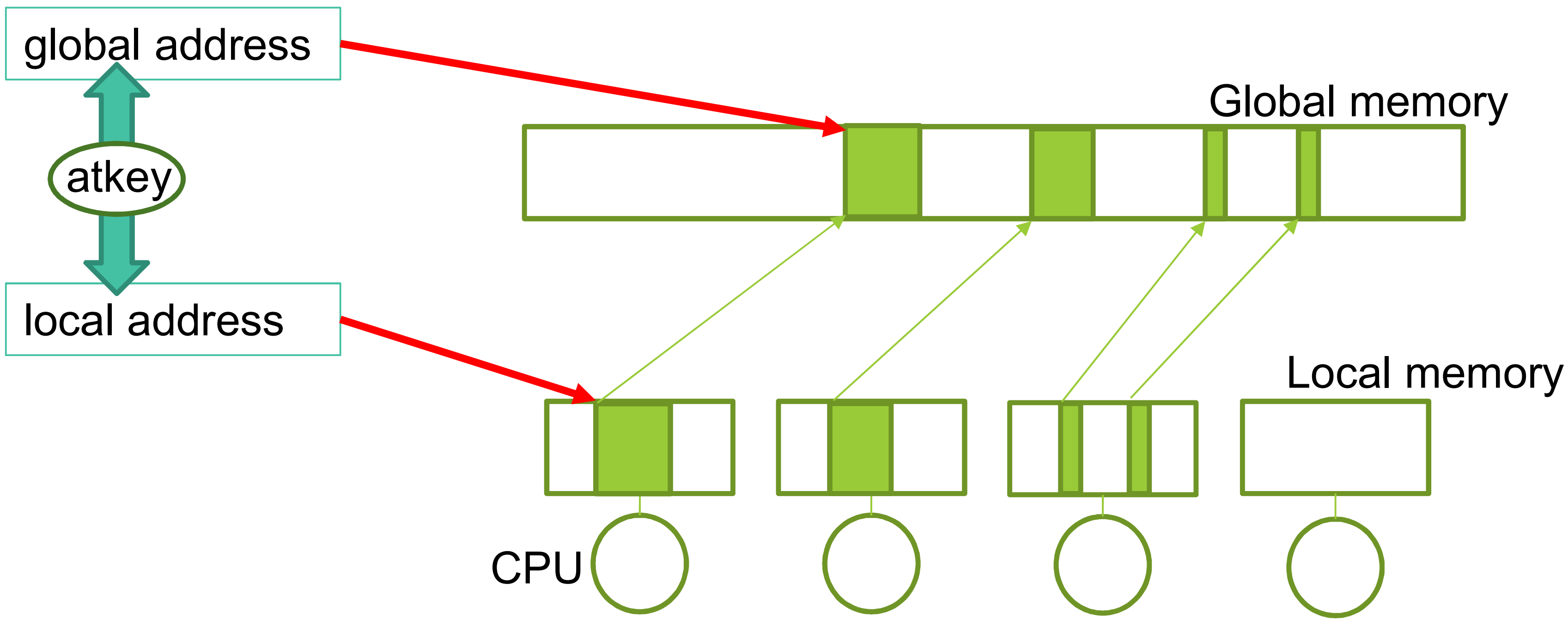


# Fundamental Interfaces of ACP

- Infrastructure
  - initialization / finalization / synchronization / ranks
- Global Memory Management
  - registration / de-registration / query on Global Memory
- Global Memory Access
  - copy / atomic on Global Memory

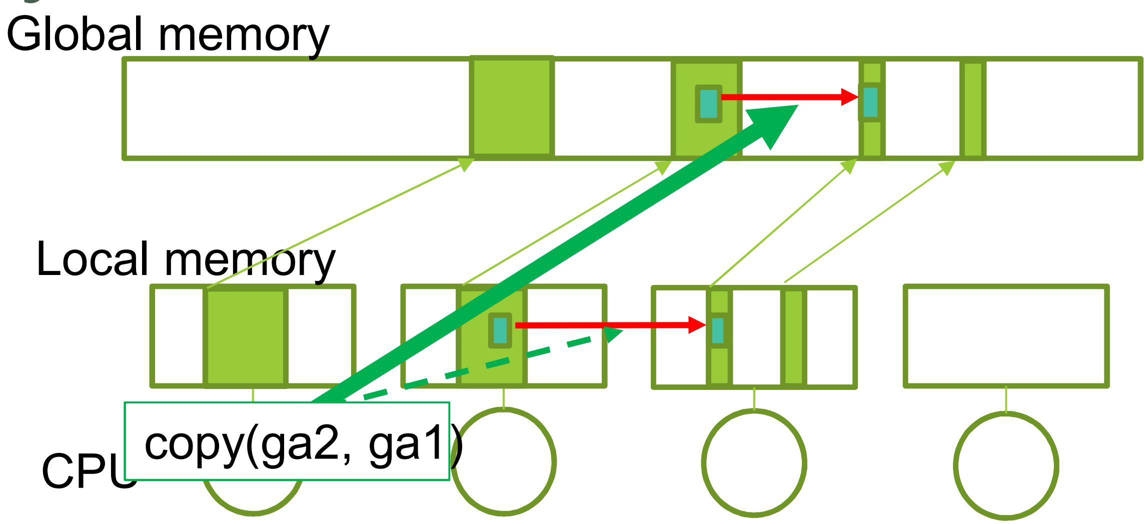
# Global Memory Management

- Registration of Local Memory:
  - Creates an address-translation key (atkey).
- Global address:
  - Queried for the pair of atkey and local address.
- These are "local" operations.

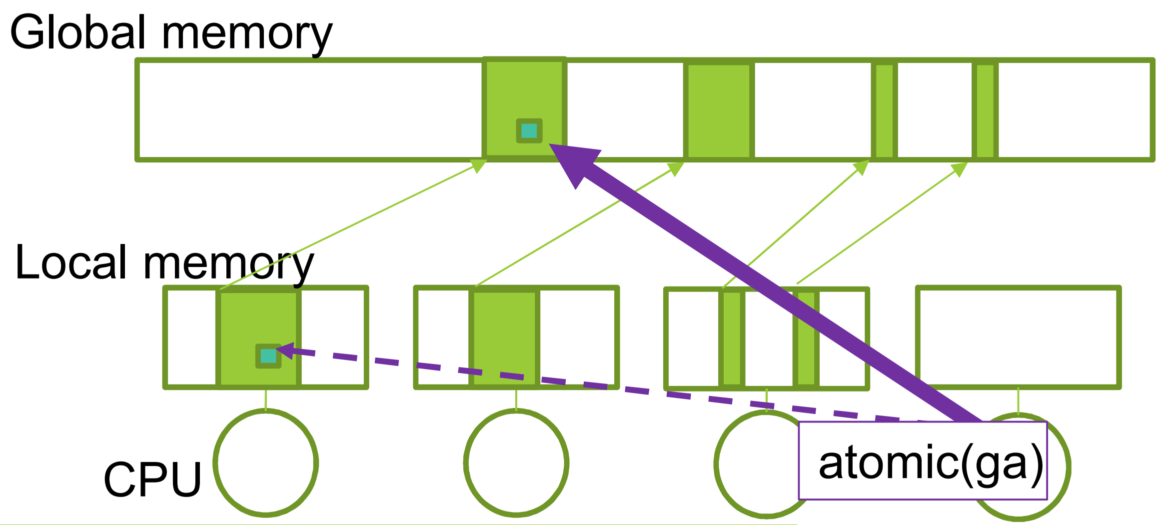


# Global Memory Access

- Copy operation
  - Not Get / Put
  - Why?
    Because this is global memory



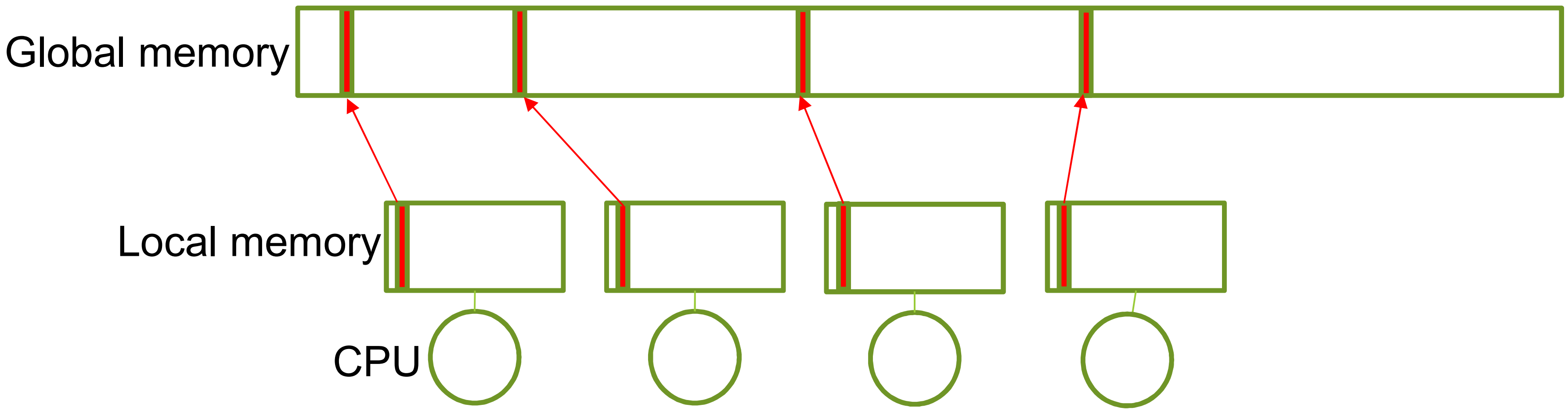

- Atomic operation




How to exchange "global addresses"?

# Starter Memory

- A special memory region of each process that is registered at the initialization.
  - Global address of starter of any process can be queried directly.
  - Mainly used for exchanging global addresses.



# Details of Global Memory Access

- Non-blocking:
  - Wait with handle.
- 'Order' argument:
  - Handle of a previous operation to wait.
    - Used for describing algorithms of patterned communications.

```
acp_handle_t acp_copy (acp_ga_t dst, acp_ga_t src, size_t size,
  acp_handle_t order)
```

- In-order completion:
  - Completion of one operation guarantees completions of all preceding operations.

# Evaluation of Memory Consumption

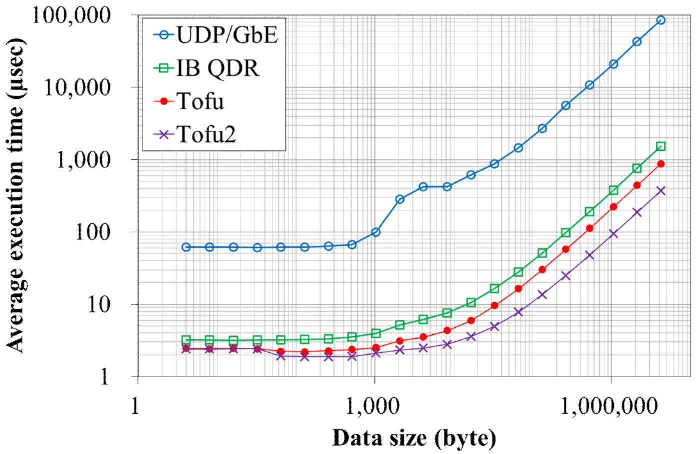
- Estimated memory consumption per process of ACP with 1M procs:

| InfiniBand | Tofu | UDP |
|---|---|---|
| 369MB / process | 67MB / process | 34MB / process |

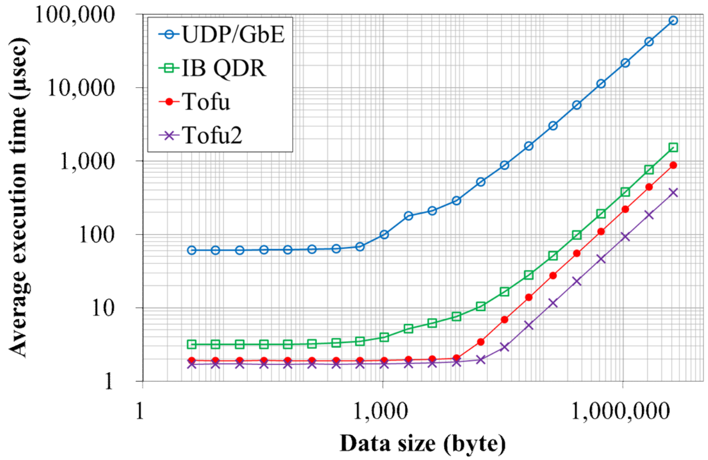
  - may require 10GB for message passing with 10KB buffer / proc

# Fundamental Performance of ACP

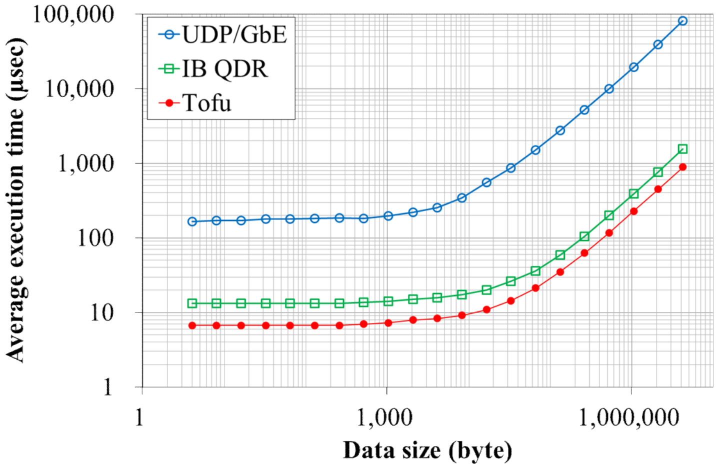
## Local to Remote (Put)




## Remote to Local (Get)

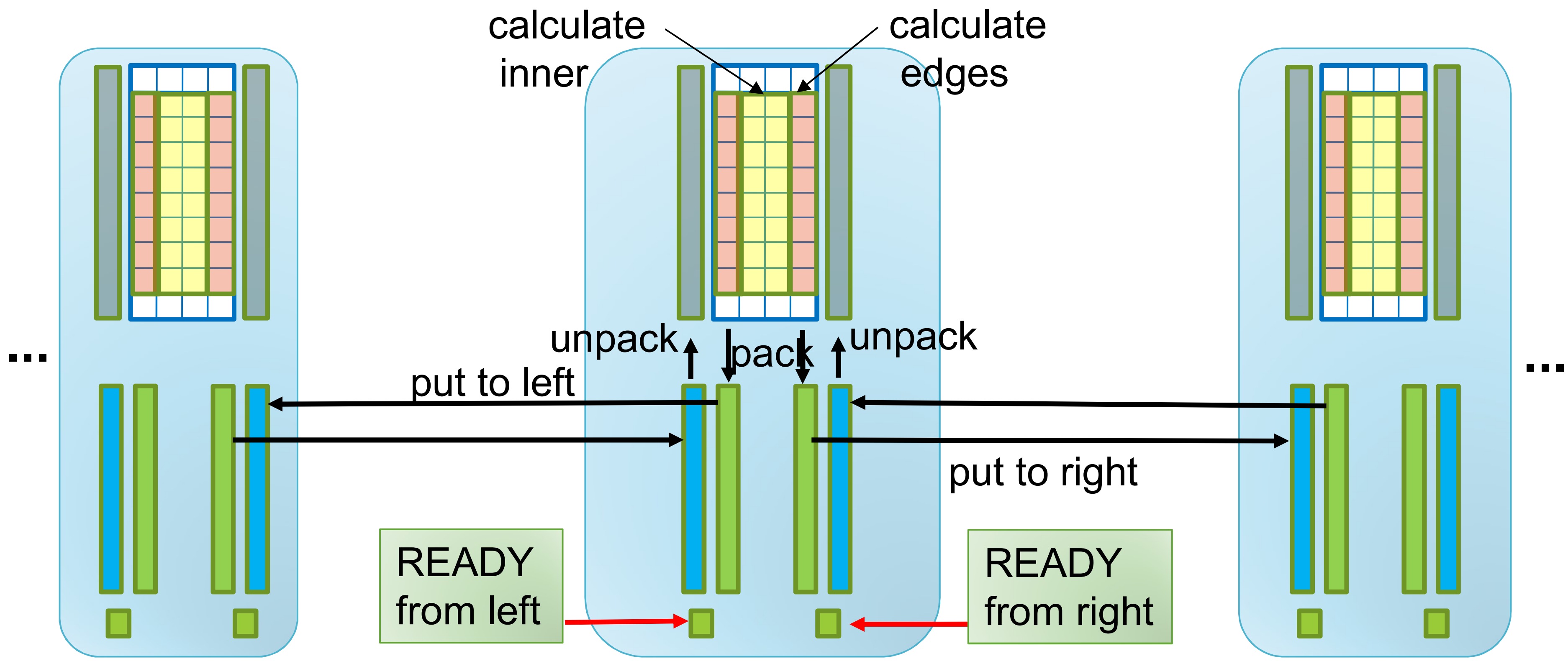



## Remote to Remote



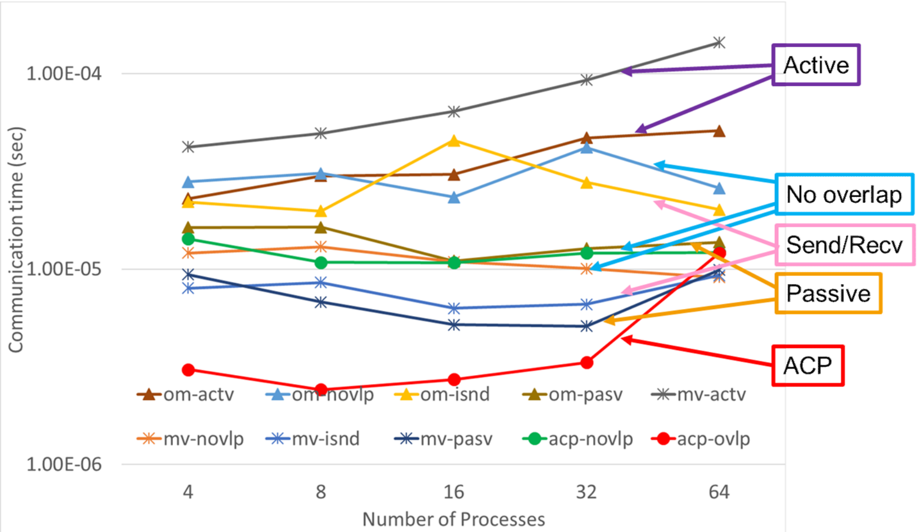
# Effect of Overlap with ACP

- Code: 2D stencil with 1D decomposition
  - One-sided version uses "ready flag" for consistency



# Communication Time of Stencil

- MPI: Message Passing (isnd) and RMA (actv/pasv) of Open MPI 2.0.0rc3 (om) and MVAPICH2 2.2rc1 (mv)
- ACP: Non-overlap (novlp) and Overlap (ovlp)

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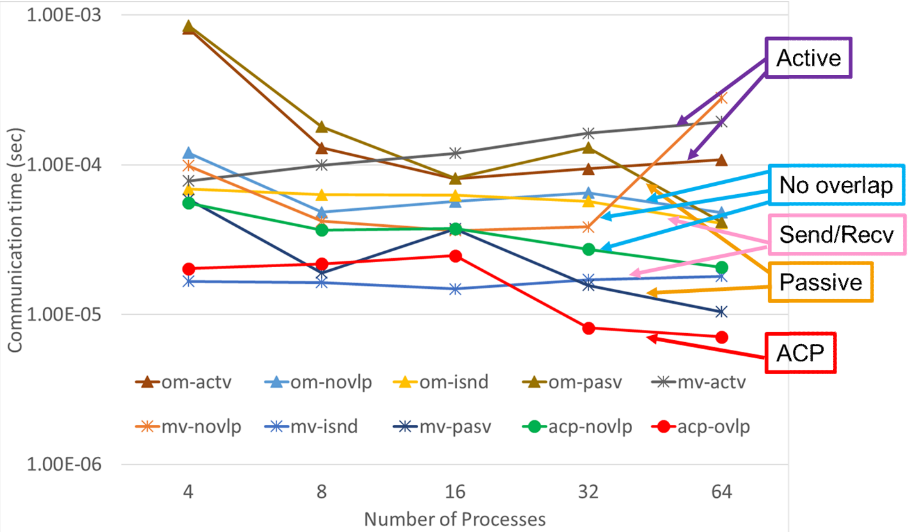


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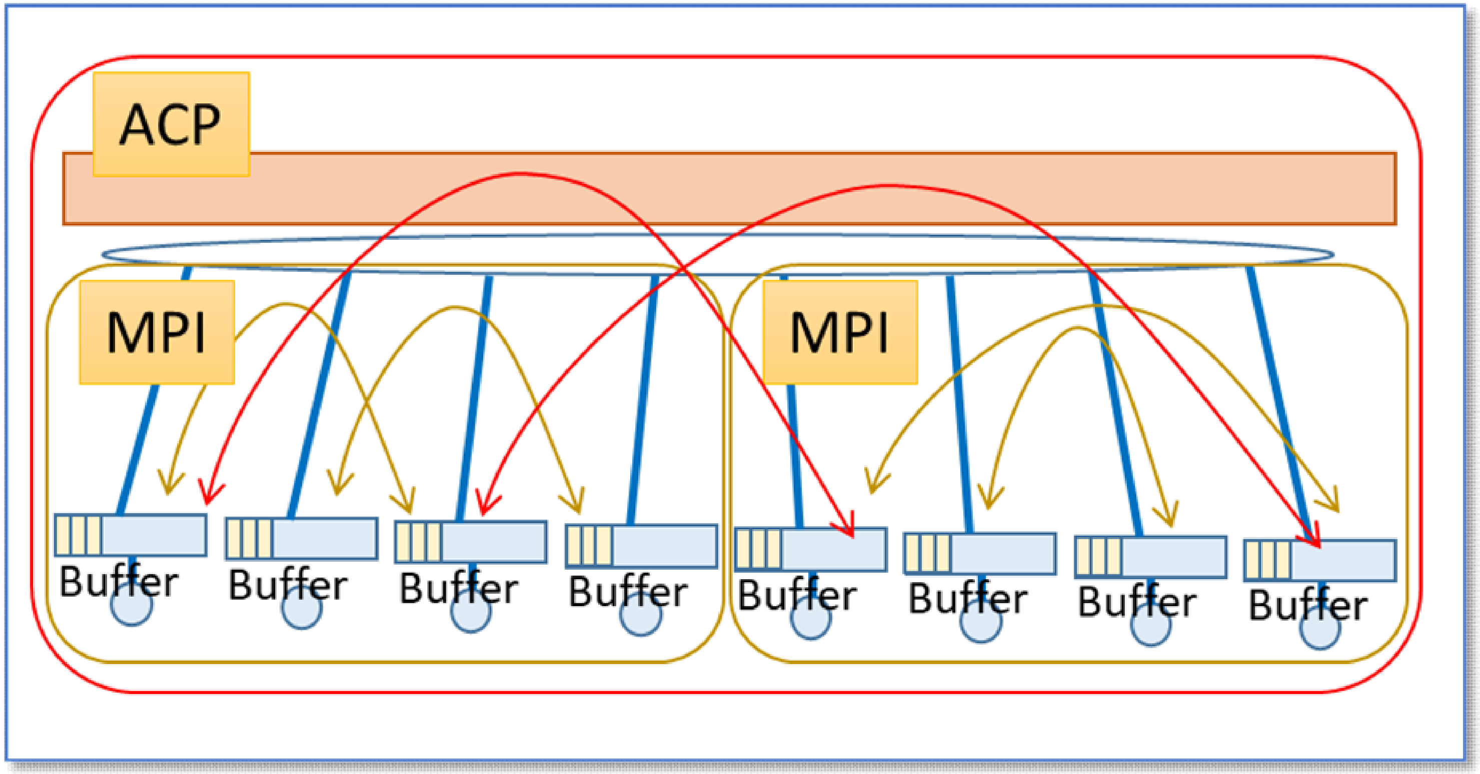
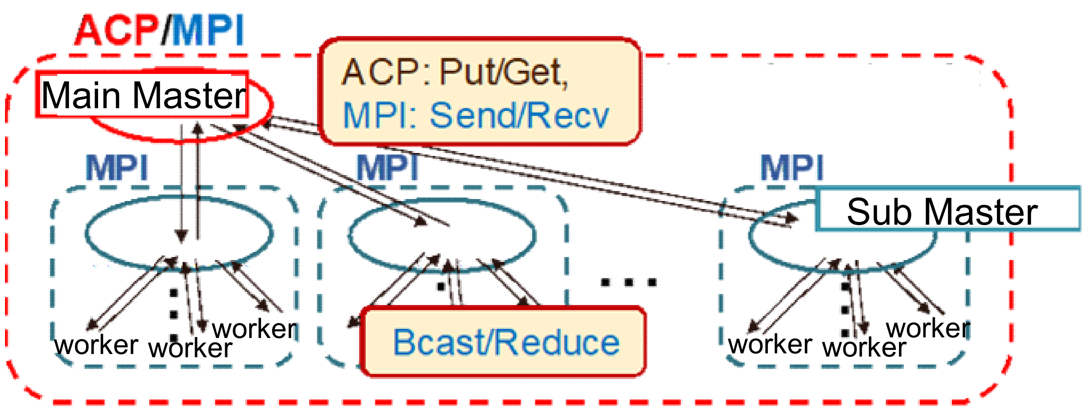
# ACP + MPI

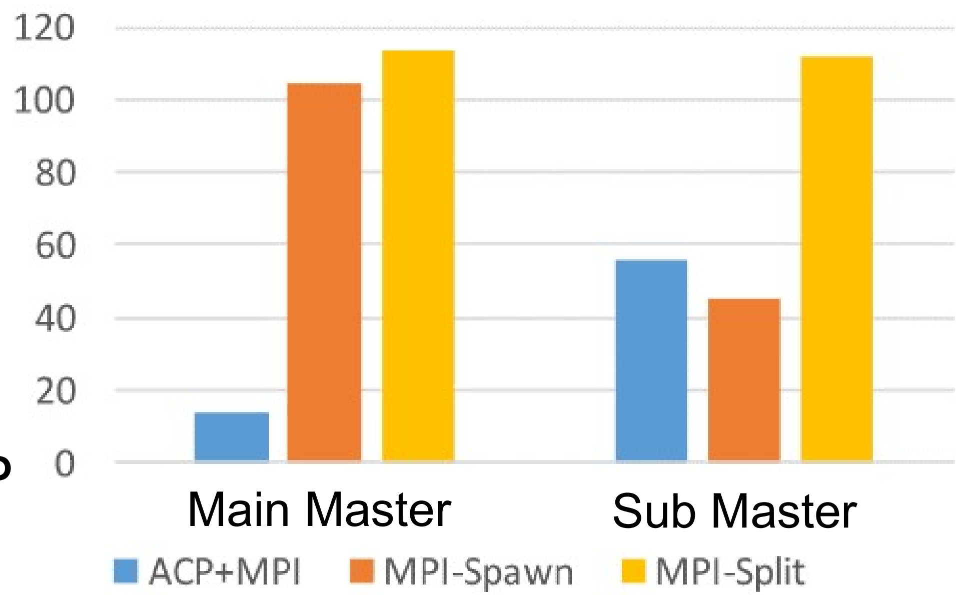
- ACP can be used to connect multiple MPI codes
  => enables memory-efficient MPI
  with smaller communicator



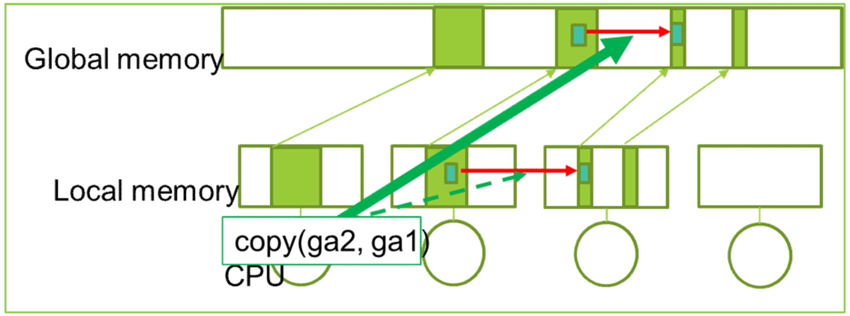
# Memory Consumption of ACP + MPI

- Sample code:
  - Hierarchical master-worker
    - Main Master / Sub Master / Worker
- Compare
  - ACP + MPI
  - MPI-Spawn
    - with MPI_Comm_spawn()
  - MPI-Split
    - with MPI_Comm_split()
- Largest memory consumption:
  MPI-Split > MPI-Spawn > ACP



# Short Summary of ACP

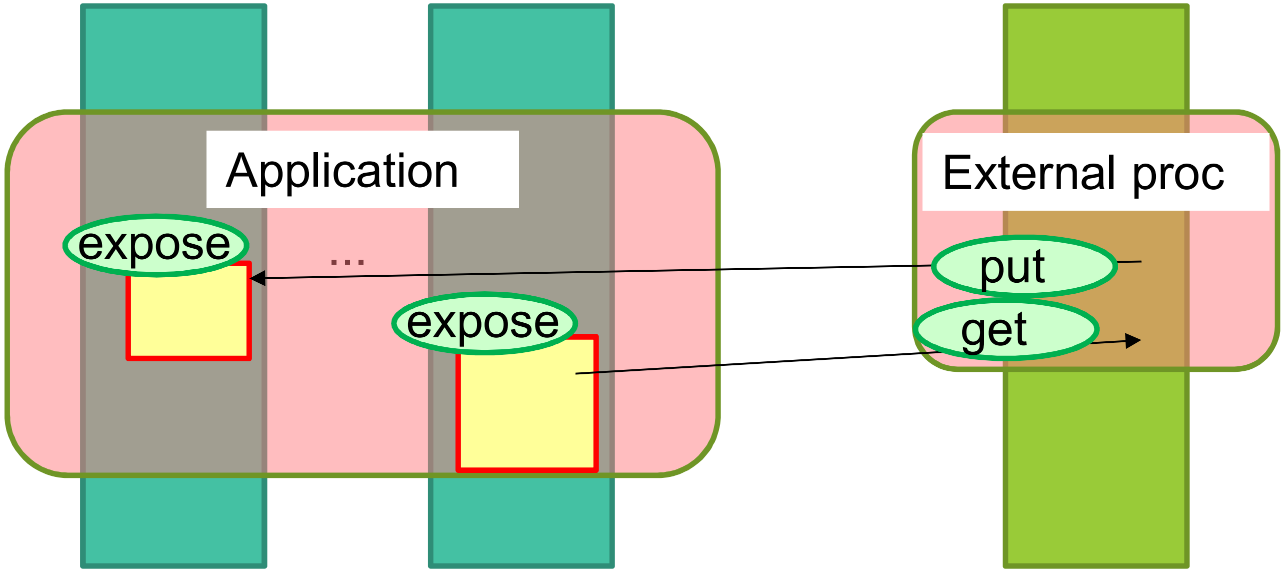



- Memory registration is **flexible and local**
  - Any region can be registered at any time without synchronization
- Global addresses can be exchanged via **starter memories**
- **copy and atomic** operations within global memory
- **orders** can be used to express dependencies
- **ACP + MPI**

# Introduction of OpAS (Open Address Space) Interface

- Leverage "asynchronous", "flexible" and "ACP+MPI" features of ACP.
  - Enable asynchronous access to any exposed memory region in an application from outside.

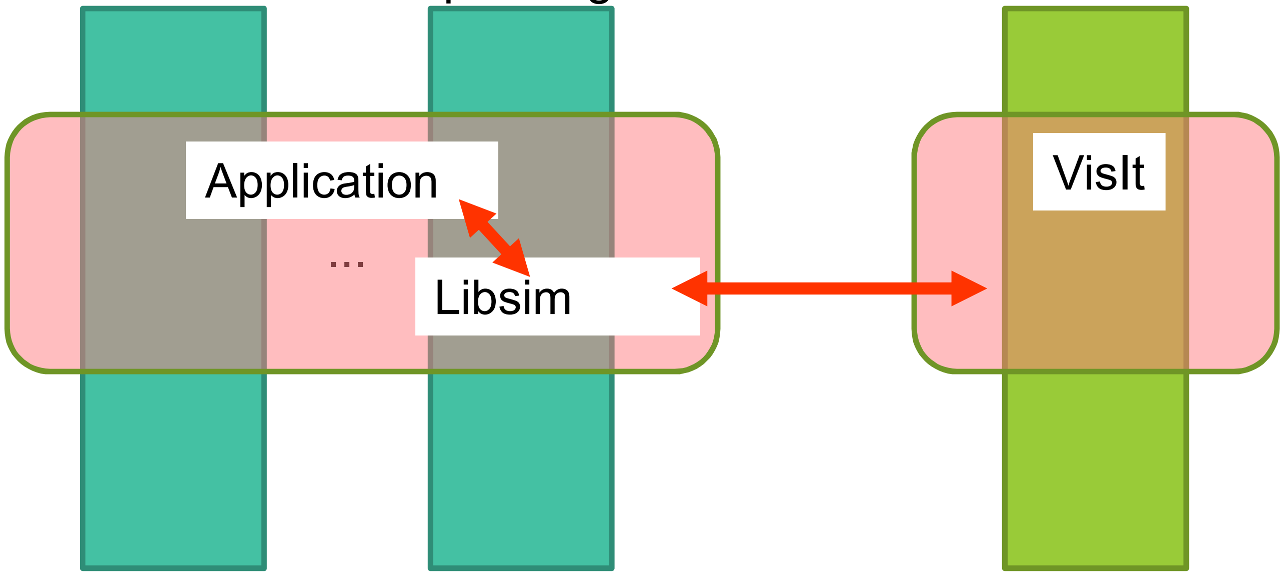
- Possible usage:
  - In-situ visualization, Runtime manipulation, Debug, etc.



# Similar Approach

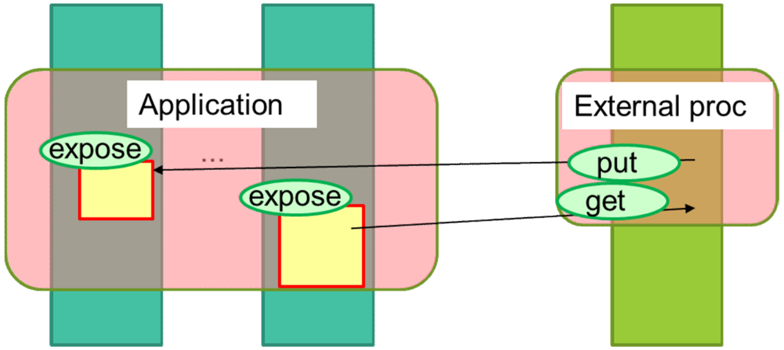
- Libsim of VisIt
  - Library for In-situ visualization
  - Instructs simulations to communicate with the visualizer (VisIt)
    - Wait for connections
    - Provide information about internal data structure
    - Handle commands from VisIt
    - Notify VisIt that the time step changed

    etc.

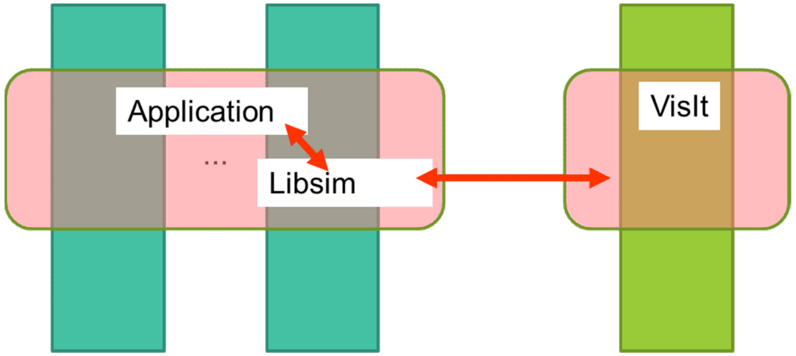


# OpAS vs Libsim

- OpAS is more primitive
  - Able to (or Need to) write detailed interactions between the application and the external process.
  - Provide opportunity for other style of interactions
    - Completely independent access from the external process.
      = Less overhead and modification on applications.
      - Ex) Expose once, and do nothing afterwards.



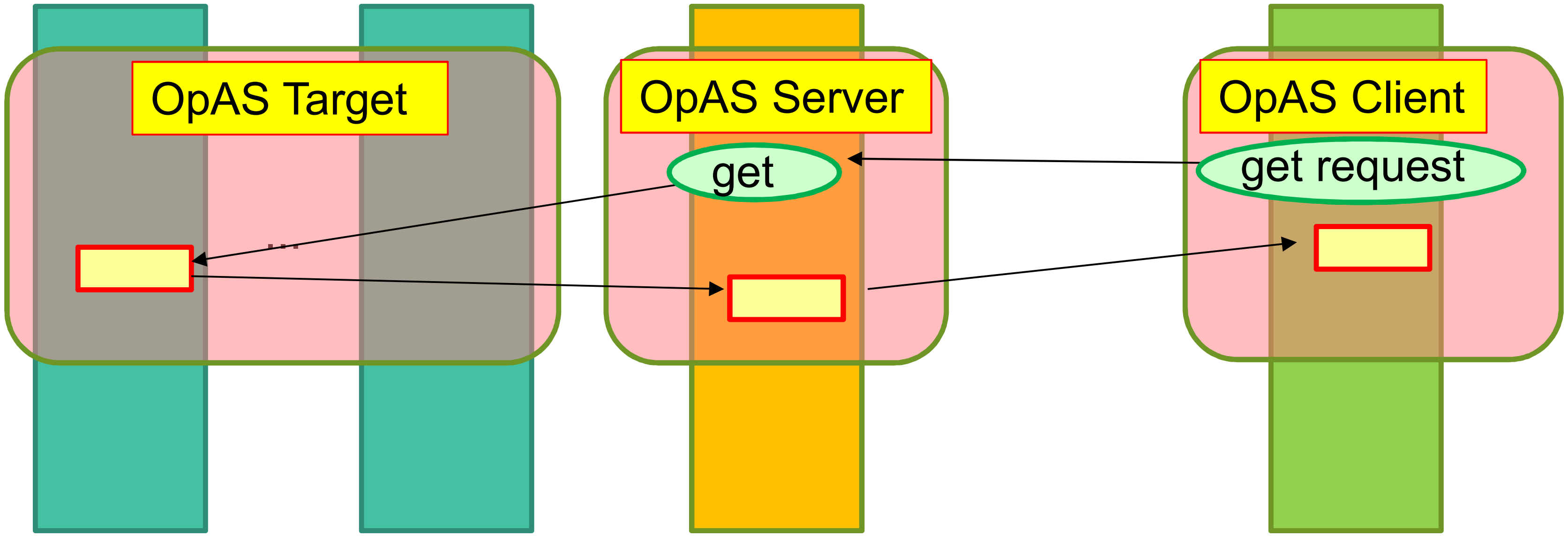

OpAS




Libsim

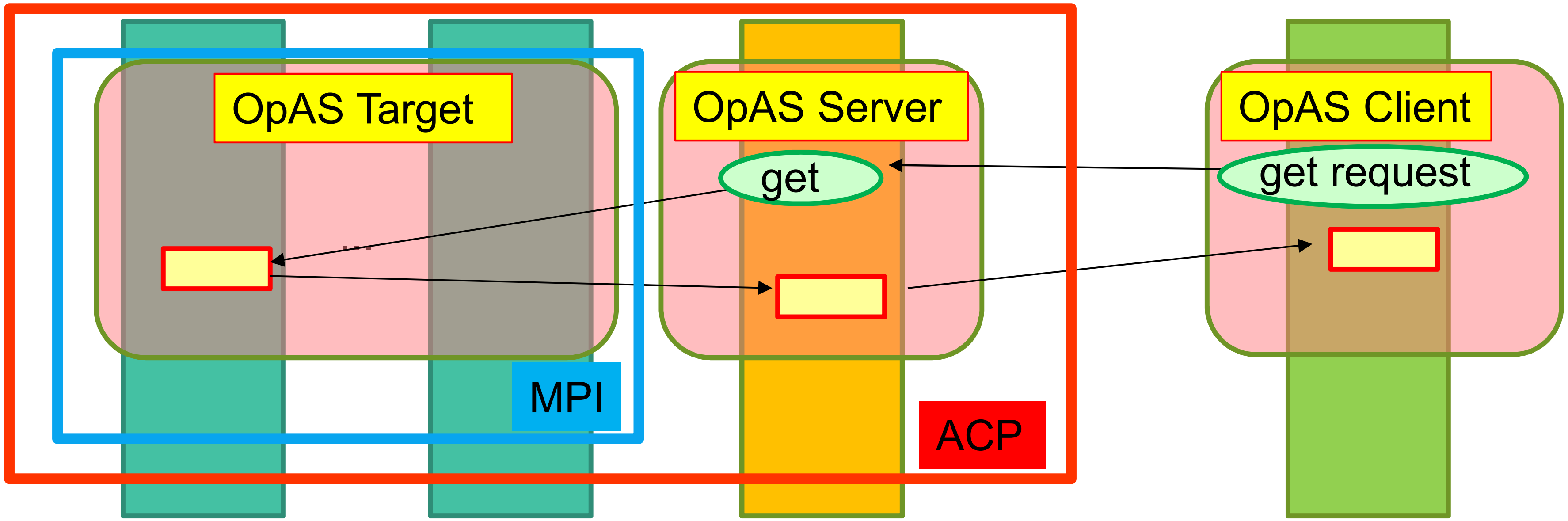
# Structure of OpAS

- OpAS Target
  = Application
- OpAS Server
  = Connecter between an application and an external process
- OpAS Client
  = External process interacts with the application

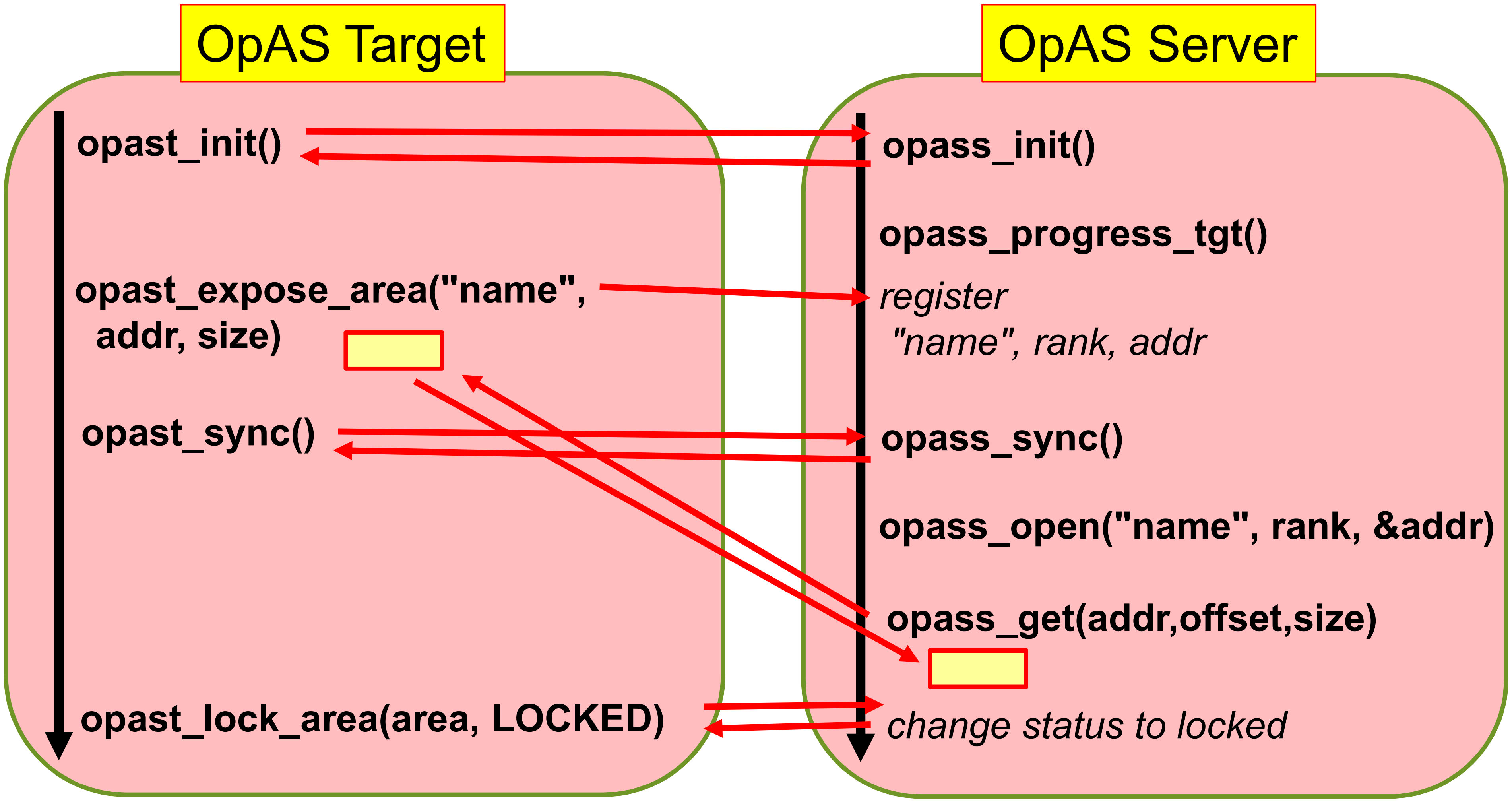


# OpAS on ACP

- Invoke OpAS Target and OpAS Server by ACP+MPI
- OpAS Client connects to the server, at anytime.
  - Maybe via TCP/UDP
- Discuss about implementations of Target and Server in this talk.



# Example of flows between Target and Server

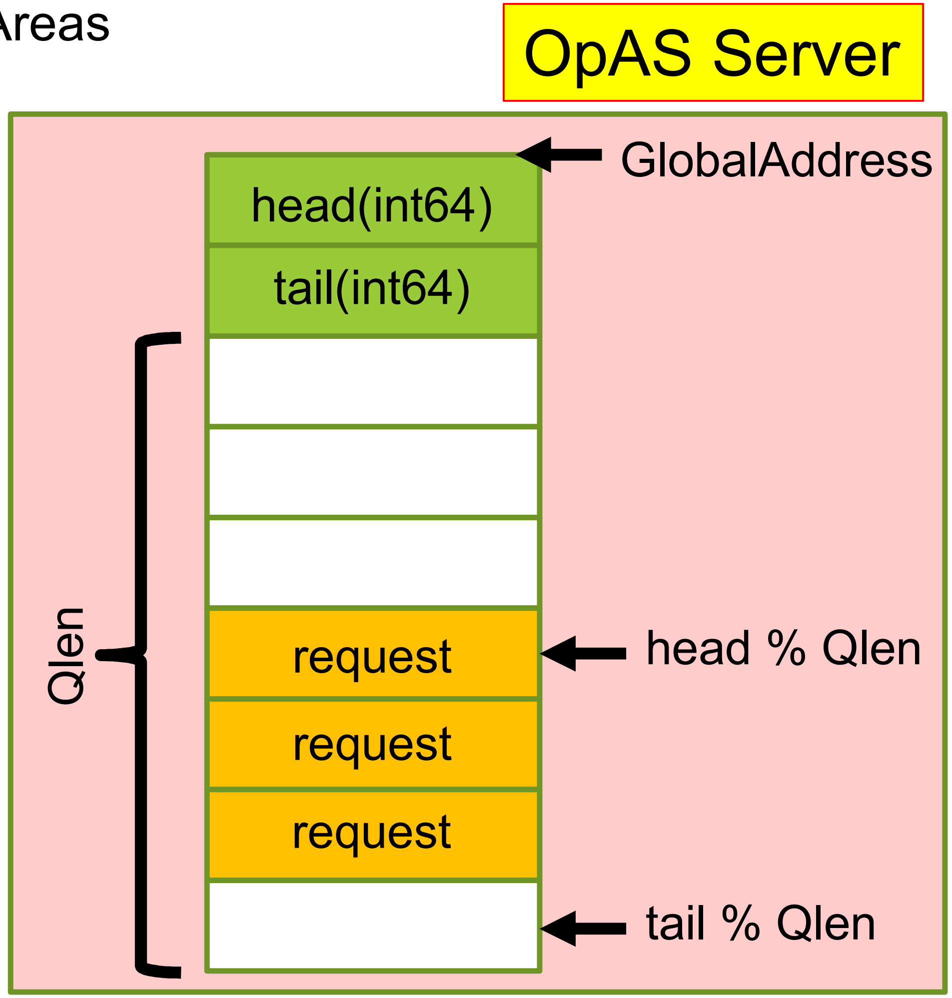


# Implementation

- Request Queue on Server
- Exposing Area
  - Target Side
  - Server Side
- Access to the Area
- Lock / Unlock Area

# Request Queue on Server

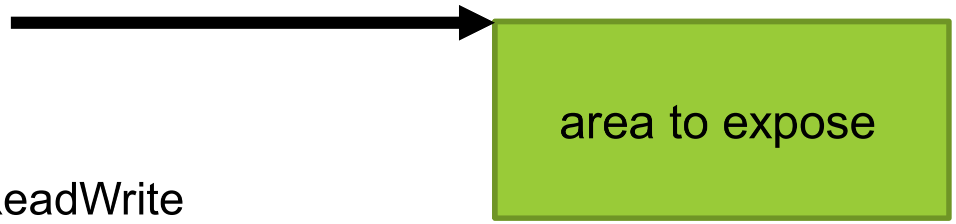
- Used for accepting requests from targets
  - Exposing, Locking and Unlocking Areas
- Prepared at opas{s|t}_init()
  - Malloc, ACP Register
  - Distribute GA via Starter Memory
- Pushed from Target
  - ACP Atomic Add to Tail
  - ACP Copy request to Tail % Qlen
- Handled at Server
  in opass_progress()
  - Handle request at Head % Qlen
  - Head++



# Exposing Area: Target Side

```
opast_area_t opast_expose_area(
              char *name, void *addr, size_t size, int stat)
```

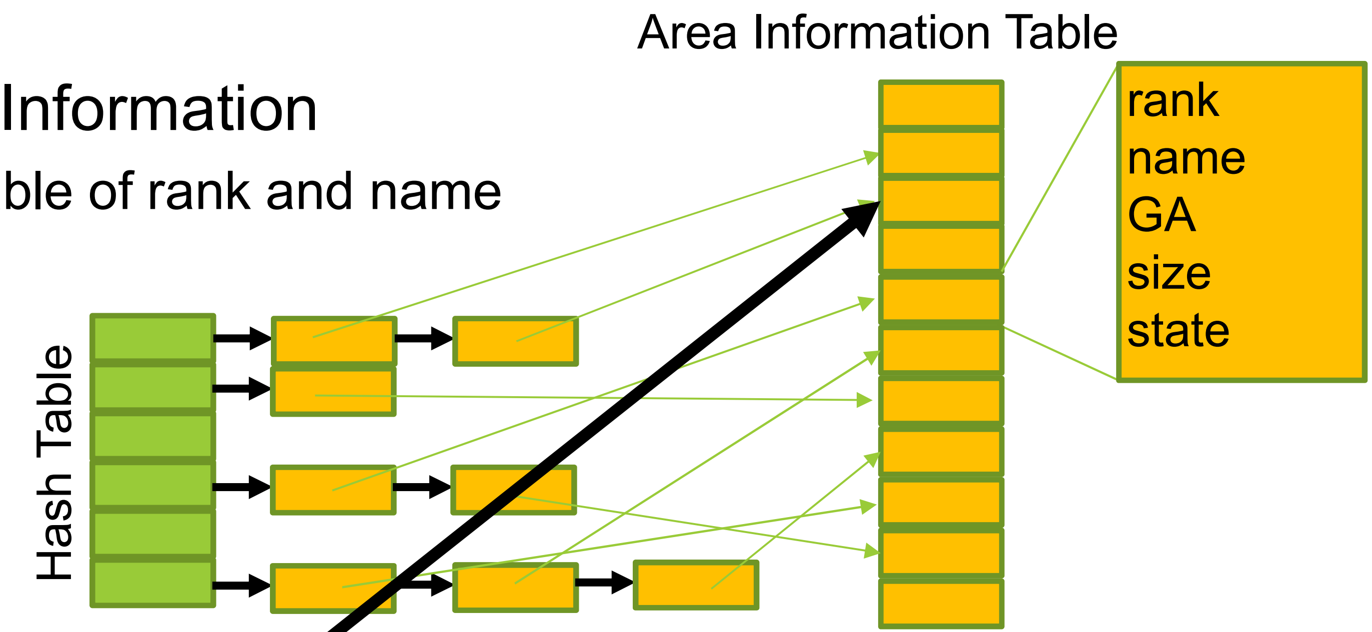
- ACP Register area
- Push exposure request to the request queue in OpAS Server
  - Rank
  - Global Address
  - Size
  - State
    - ReadOnly or ReadWrite
  - Name
    - ACP Copied separately via Starter Memory because length is unlimited.




- Wait for completion
  - Check a Flag to be updated by the server
  - Also get the index of the Area Information Table in the Server via Starter Memory

# Exposing Area: Server Side

- In response to the exposure request from Target
- Store Area Information
  - Via hash table of rank and name




- Send Ack to Target
  - Modify the Flag
  - Also notify **index** of the area in the table via Starter Memory

# Access to the Area from Server

- Open Area

```
opass_area_t opass_open_area(int rank, char *name)
```

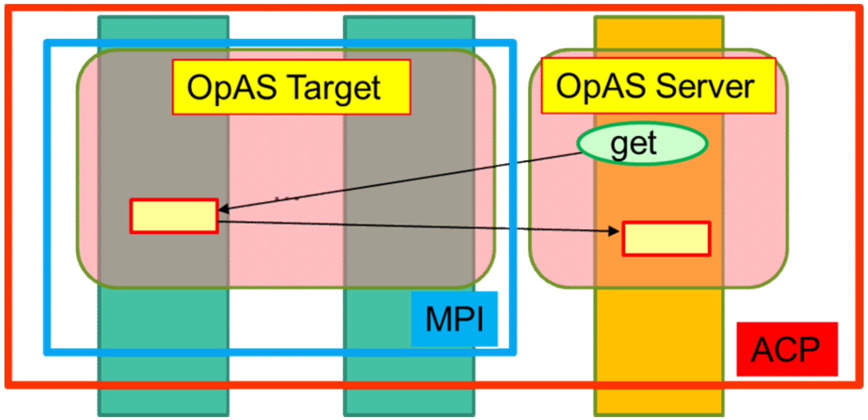
  - Return Information of the Area of the Rank and Name

- Make access

  Ex) Get

```
int opass_get(opass_area_t area, size_t offset,
              size_t size, void *addr)
```

  - Check state
    - Return if not permitted
  - Check offset
  - ACP Copy from Target
    - Pipelined with local buffers



# Lock / Unlock Area

- Target
  - Request Lock / Unlock
    with the index of the area information table to the Server
  - Wait for Ack from the Server

- Server
  - Handle the request in opass_progress() function
  - Change the state of the area to Locked / Unlocked
  - Send Ack to the Target

# Evaluation

- Environment
  - Hardware: ITO System in Kyushu University, Japan
    - Intel Xeon Gold 3.0 GHz cluster
    - InfiniBand EDR
  - Software:
    - Open MPI 3.0.0 for Targets
    - ACP 3.0.0 for Targets-Server
  - Target: 4 processes (2 procs / node)
- Measurement
  - Exposure (at Target)
  - Lock (at Target)
  - Get (at Server)

# Performance

Latency of Exposure

| Processes | Latency (us) |
|---|---|
| 1 | 75 |
| 2 | 80 |
| 3 | 90 |
| 4 | 127 |

Latency of Lock

| Processes | Latency (us) |
|---|---|
| 1 | 60 |
| 2 | 76 |
| 3 | 110 |
| 4 | 148 |

Latency and Bandwidth of Get

| Size | Latency (us) | Bandwidth (MB/sec) |
|---|---|---|
| 4B | 5 | 0.2 |
| 4KB | 67 | 150 |
| 4MB | 734 | 1,428 |

# Conclusion

- Proposed OpAS (Open Address Space),
  an interface for runtime access to the memory of applications

- Now we are working for :
  - in-situ visualization
  - runtime manipulation
  - debugging

- Github repository will be prepared, soon
  - ACP is available from
    https://github.com/project-ace/ACP

# Acknowledgement


- ACP Library was developed in ACE Project supported by JST CREST
  - Members:
    - Kyushu Univ.
      T. Nanri, H. Honda, R. Susukita, T. Kobayashi and Y. Morie
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