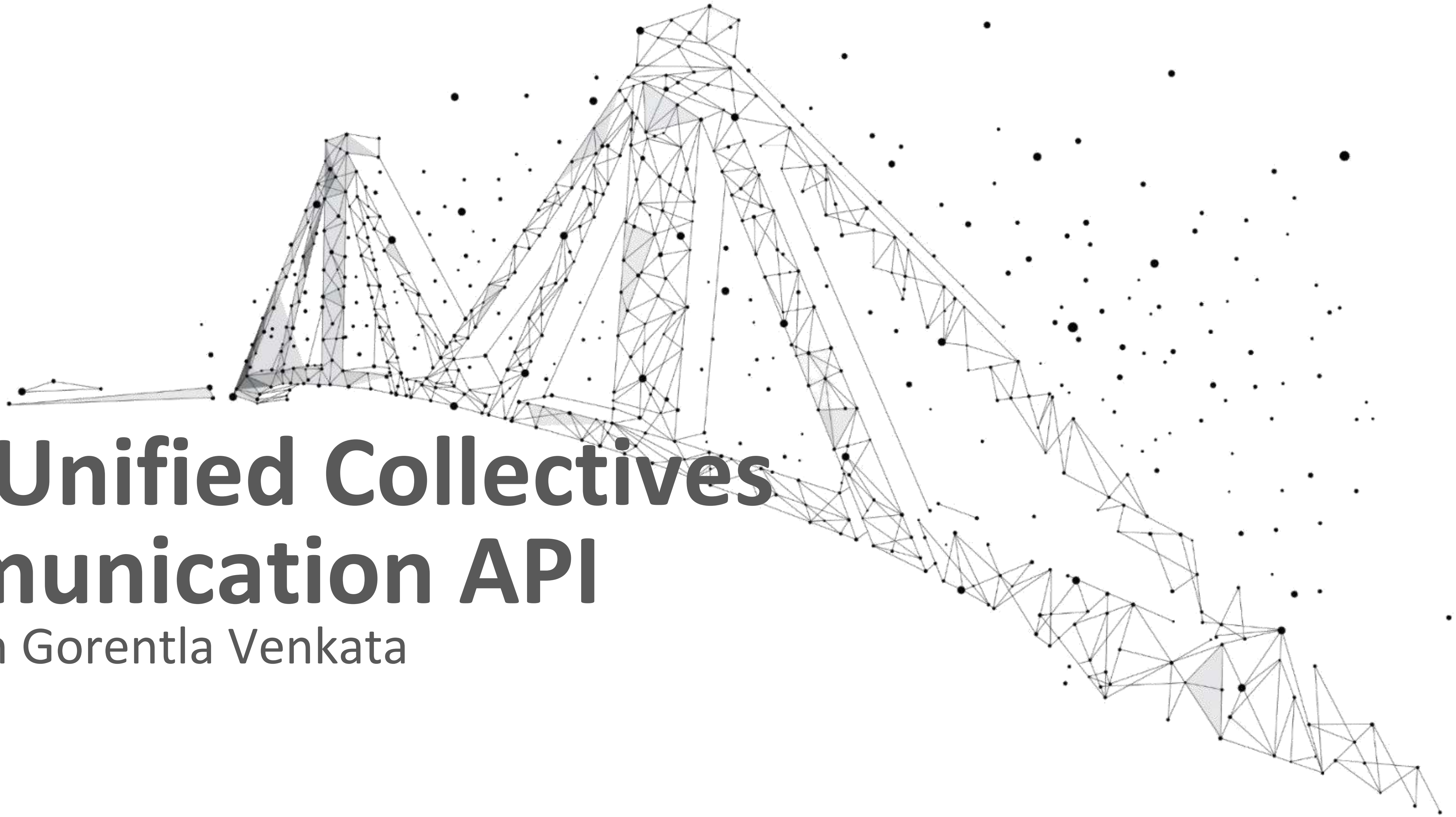

UCC: Unified Collectives Communication API

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How to read this presentation ?

- Presentation introduces the abstraction, concepts, and semantics
  - Interfaces, structures, and library constant details are in the API document
- Focus on the big picture for this presentation
  - Details can be debated
- Do not focus on naming, yet
  - We can change the names later. For example, a ***team*** can be named as ***group*** or ***communicator***

UCC: Unified Collective Communication Library

Proposal : Collective communication operations API that is flexible, complete, and feature-rich for current and emerging programming models and runtimes.

High-level Features

- Blocking and Nonblocking collective operations
- Hierarchical collectives are a first-class citizen
  - Well-established design for achieving performance and scalability
- Hardware collectives are a first-class citizen
  - Well-established model and have demonstrated to achieve performance and scalability
- Flexible resource allocation model
  - Support for lazy, local and global resource allocation decisions
- Support for relaxed ordering model
  - For AI/ML application domains
- Flexible synchronous model
  - Highly synchronized collective operations (MPI model)
  - Less synchronized collective operations (OpenSHMEM and PGAS model)
- Repetitive collective operations (init once and invoke multiple times)
  - AI/ML collective applications, persistent collectives
- Point-to-point operations in the context of group
- Global memory management
  - OpenSHMEM PGAS, MPI, and CORAL2 (RFP)

Key Abstractions : Overview

Design around simple set of key abstractions for flexibility and efficiency

- **Communication (Team) Library:** An abstract object representing the library
- **Communication Context:** Encapsulates local resources and topology for group operations.
- **Team:** Encapsulates global resources and team members for group operations.
- **Endpoints:** Encapsulates the members of the ***team***
- **Collective Operation:** Represents the collective operation
- **Task and task list:** Represents groups of collectives

Key Abstractions

1. Communication (Team) Library
2. Communication Context
3. Teams
4. Endpoints
5. Collective Operation
6. Task and task list

Library : Initialize and finalize

```
ucc_team_lib_init(ucc_lib_team_params_t ucc_params, ucc_team_lib_t *team_lib);

ucc_team_lib_finalize( ucc_team_lib_t team_lib);
```

Semantics:

- Library initialization and finalization allocate and release resources
- All library resources are created and finalized during/after the initialization and finalization calls respectively
  - No operations on the library are valid after the finalize operation
  - No overlapping of Init and finalize call (i.e., Init – Init – Finalize – Finalize on a single thread is invalid behavior)
- The library can be coupled with UCX (UCP context) during initialization
- The library can be customized for a specific programming model

Key Abstractions

1. Communication (Team) Library
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Communication Context (1)

An object to encapsulate local resource and express network parallelism

```
ucc_create_team_context(ucc_team_lib_t comm_lib_context, ucc_team_context_config_t
ctx_config, ucc_team_context_t *comm_context);

ucx_destroy_team_context(ucc_team_context_t team_context);
```

Semantics:

- Context is created by ***ucc _create_team_context(),*** a local operation
- Contexts represents a local resource - threads, injection queue, and/or network parallelism
  - Example: software injection queues (UCP Worker, List of UCP Endpoints), Switch local resources, Hardware injection resources
- Context can be coupled with threads, processes or tasks
  - A single MPI process can have multiple contexts
  - A single thread (pthread or OMP thread) can be coupled with multiple contexts

Communication Context (2)

An object to encapsulate local resource and express network parallelism

```
ucc_create_team_context(ucc_team_lib_t comm_lib_context, ucc_team_context_config_t
ctx_config, ucc_team_context_t *comm_context);

ucx_destroy_team_context(ucc_team_context_t team_context);
```

Semantics:

- Context can be bound to a specific core, socket, or an accelerator
  - Provides an ability to express affinity
- Context can participate in multiple group operations
  - Private context can participate in only one group operation (team)
  - Shared context can participate in multiple group operations
- Multiple contexts per team (from same thread) can be supported
  - Software and hardware collectives

Customizing Context

The usage model, operations supported, thread model, and invocation/completion can be customized.

```
struct ucc_team_context_config {
	ucc_network_ops_t ops;
	ucc_threading_support_t thread_support;
	ucc_team_completion_type_t  completion_type;
	ucc_team_usage_type_t usage;
}
```


Customizing Context: Usage Model

Options:

- UCC as Network Library
  - User implements the collective algorithms and UCC implements the data transfer channels in the context of team
- UCC as Collective library
  - UCC implements the collective algorithms and data transfer channels

Use cases:

- Require collective algorithms and implementation for collective communication
  - Programming models using UCX for point-to-point communication
- Require a thin abstraction over hardware collective primitives
  - Collective libraries that have explored and implemented collective algorithms
- Require a thin abstraction over point-to-point operations and need group abstractions
  - OpenSHMEM contexts
  - MPI Windows

Customizing Context: Operations Supported

Helps with transport selection, resource allocation, and management

Options:

- Only Point-to-point operations
  - Enables creation of resources for only RMA and Point-to-point operations
- Only Collective operations
  - Enables creation of resources for only collective operations
- No communication operation
  - Enables creation of group but no resources are allocated for collectives or RMA/P2P operations
  - Use case: Required for symmetric memory APIs, Memory allocation routines in OpenSHMEM
- Both Point-to-point and collective communication operations are supported

Customizing Context : Threads and Contexts

Provides well-defined interaction between the threads and local resources

- Provide options for performance, flexibility and resource usage
- Sharing of resources between Teams

Options:

- SINGLE
  - The context is accessed by a single thread
  - The context participates in a single Team
    - So resources are exclusive to one Team
  - The libraries can implement it as a lock-free implementation

- SHARED
  - The context is accessed by multiple threads
  - The context can participate in multiple teams
    - Resources are shared by multiple teams
  - The library is required to protect critical sections

Customizing Context: Invocation and Completion

Options:

- Blocking: All operations on the context are blocking
- Non-blocking: All operations on the context are non-blocking operations
- Split-phase: One outstanding operation at a time, however, completion can be delayed
- Default: Both blocking and non-blocking operations can be posted

Use cases:

- OpenSHMEM only supports blocking operations.
- Support for split-phase barriers
- Support for persistent collective semantics

Key Abstractions

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Team: Membership

Who manages the participation in the group?

User Managed

- The user manages who participates in the team
  - The user provides an OOB collective operation to exchange ***context*** among the members
  - The members join the collective operation
  - The scope of the team is defined by the OOB collectives
    - For example, if the OOB is defined over shared memory, the team is created over shared memory.
    - **"UCC_TEAM_WORLD"** is created by using PMIx collectives as OOB collectives

Library managed:

- The library (UCC) manages the membership
  - UCC performs and implement a collective operation to determine the participation

Team: Operations for creating teams

```
ucc_team_create_post(
        ucc_team_context_t  team_context, ucc_team_config_t comm_config, oob_collectives_t
oob_collectives, ucc_team_ep_t *my_ep, ucc_team_t *new_team);

ucc_team_create_wait();
```

Semantics:

- Created by processes, threads or tasks by calling ***ucc_team_create_post()***
  - A collective operation but no explicit synchronization among the processes or threads
- Non-blocking operation and only one active call at any given instance.
- Each process or thread passes local resource object ***(context)***
  - Achieve global agreement during the create operation
- Passing NULL as OOB will result in creating a "world" team

- Create global resources for group communication buffers
  - Synchronization buffers for one-sided collectives
  - Temporary buffers for reduction operations
  - Scratch buffers for non-blocking operations
  - Create connections if required
  - Filter the available operations and algorithms

Team : Customizing team

```
struct ucc_team_config_t {
        ucc_post_ordering ordering;
        uint64_t num_outstanding_collectives;
        ucc_team_completion_type_t  comple
        tion_type;
        ucc_collective_sync_type_t sync;
        ucc_ep_range_contig ep_range;
        ucc_dt_type_t datatype;
        ucc_mem_params_t mem_params;
        }
```

Semantics:

- Ordering : All team members must invoke collective in the same order?
  - Yes for MPI and No for TensorFlow and Persistent collectives
- Outstanding collectives
  - Can help with resource management
- Blocking/Non-blocking
  - A ***team*** can be customized to be either blocking or non-blocking
- Should Endpoints in a contiguous range ?
- Datatype
  - Can be customized for contiguous, strided, or non-contiguous datatypes
- Synchronization Model
  - On_Entry, On_Exit, or On_Both – this helps with global resource allocation

Customizing Team: Synchronizing Model

- **NO_SYNC_ON_Entry:** No synchronization on entry
  - On entry each process can start the collective irrespective of other processes entered the collective or not
  - Data readiness is ensured by the programming model user (not programming model itself)
  - Use case : OpenSHMEM / UPC

- **NO_SYNC_ON _Exit:** No synchronization on exit
  - On exit each process can exit the collective irrespective of other processes completed or not
    - Provides guarantees about local completeness, not global state
  - Use case/ Motivation: Broadcast, OpenSHMEM / UPC

- **NO_SYNC:** No synchronization on entry or exit
  - Data readiness is ensured by the User
  - Global completion guarantees are to be learned by the user
  - Use case : OpenSHMEM/UPC

- **Default:** Synchronization on both entry and exit to the collective
  - Data readiness is ensured by the programming model and provides global state on completion

Team : Query Operations

```
ucc_get_team_attribs(ucc_team_t ucc_team, ucc_team_attrib_t *team_atrib)
ucc_get_team_size(ucc_team_t ucc_team);
ucc_get_team_my_ep(ucc_team_t ucc_team, ucc_team_ep_t *ep);
ucc_get_team_all_eps(ucc_team_t ucc_team, ucc_team_ep_t *ep, uint64_t num_eps);
```

- All attributes of the ***team*** are available via ***ucc_team_attrib_t***
  - Size, ordering, sync type, completion semantics, datatype, endpoints, and memory handles
- Interfaces for some common attributes
  - Size and Endpoints

Team : Splitting teams

Supporting split operations in lower libraries will enable resource sharing between parent and child teams

```
ucc_team_create_from_parent( ucc_team_ep my_ep,  int color,  ucc_team_t parent_team,
ucc_team_t *new_ucc_team);
```

Semantics:

- Split
  - Collective operation over the parent team
  - Collective operations over the child team or can be a local operation (interface in the later slides)
- Provides flexible way to create a team
  - Supports regular as well as irregular team creation
- Inherits configuration from the parent team
- Thread model: One active split operation per process

Key Abstractions

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Endpoint

An integer that represents the network address and/or team member

```
ucc_create_team_from_ep_list(ucc_team_t parent_ucc_team, ucc_team_ep *ep, uint64_t num_eps, ucc_team_t *new_team);

ucc_create_team_from_ep_stride(ucc_team_t parent_ucc_team, uint64_t start_ep, uint64_t stride, uint64_t num_eps, ucc_team_t *new_team);

ucc_team_add_endpoint(ucc_team_t parent_ucc_team,  ucc_team_context_t *team_context, ucc_team_ep ep, ucc_team_t *new_team);
```

Use case:

- Team creation only with a collective operation on the newly created team
- Light-weight team creation by passing the list of endpoints
  - Enables lazy resource allocation
- Support spawn semantics .i.e., supports adding an endpoint to the team

Key Abstractions

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Collective Operations : Building blocks (1)

```
ucc_collective_init( ucc_coll_op_args coll_args, ucc_team_t team, ucc_coll_op_h *coll_handle);
ucc_collective_init_and_post( ucc_coll_op_args coll_args, ucc_team_t team, ucc_coll_req
*request, ucc_coll_op_h *coll_handle);

int ucx_collective_post(ucc_coll_op_h coll_handle, ucc_coll_req *request)
int ucx_collective_test(ucc_coll_req request);
int ucx_collective_wait(ucc_coll_req request);
int ucx_collective_finalize(ucc_coll_req request);
```

Collective Operations : Building blocks (2)

Semantics:

- Collective operations : ***ucc_collective_init(…)*** and ***ucc_collective_init_and_post(…)***
- Local operations: ***ucc_collective_post, test, wait, finalize***
- Initialize with ***ucc_collective_init(…)***
  - Initializes the resources required for a particular collective operation, but does not post the operation
- Completion
  - The ***test*** routine provides the status, and ***wait*** routine can be used to complete the operation
- Finalize
  - Releases the resources for the collective operation represented by the request
  - The post, test, and wait operations are invalid after finalize

Collective Operations : How to build various collectives ?

```
ucc_collective_init( ucc_coll_op_args *coll_args, ucc_team_t team, ucc_coll_op_h *coll_handle);
ucc_collective_init_and_post( ucc_coll_op_args *coll_args, ucc_team_t team, ucc_coll_req *request,
ucc_coll_op_h *coll_handle);

int ucx_collective_post(ucc_coll_op_h *coll_handle, ucc_coll_req *request)
int ucx_collective_test(ucc_coll_req request);
int ucx_collective_wait(ucc_coll_req request);
int ucx_collective_finalize(ucc_coll_req request);
int ucx_collective_req_status(ucc_coll_req request);
```

- Nonblocking and blocking collectives:
  - Can be implemented with Init_and_post and wait+finalize
- Persistent Collectives:
  - Can be implemented using the building blocks - init, post, test, wait, finalize
- Split-Phase
  - Can be implemented with Init_and_post and wait+finalize

Customizing Collective Operation (1)

```
typedef struct ucc_collective_op_arguments
{
        ucc_collective_type coll_type;
        ucc_coll_buffer_info_t buffer_info;
        ucc_collective_sync_type_t sync_type;
        ucc_reduction_op reduction_info;
        ucc_error_type_t error_type;
        ucc_coll_tag_t coll_id;
        ucc_team_endpoint_t root;
} ucc_coll_op_args;
```

- Collective type, buffer information, and reduction info
  - Customize the operation
- Synchronization type
  - Same sync_type as context_config / comm_config.
  - Valid to use the default (all synchronization) even when context and config are configured as on_entry, on_exit, or on_both but not vice versa
- Collective Tag
  - For unordered collectives
- Root endpoint for root-based operations

Customizing Collective Operation (2)

Operation and Reduction Types

```
enum ucc_collective_type {
        Barrier,
        Alltoall,
        Alltoallv,
        Broadcast,
        Gather,
        Allgather,
        Reduce,
        Allreduce,
        Scatter,
        FAN_IN,
        FAN_OUT
}
```

```
enum ucc_reduction_op {
        OP_MAX,
        OP_MIN,
        OP_SUM,
        OP_PROD,
        OP_AND,
        OP_OR,
        OP_XOR,
        OP_MAXLOC,
        OP_MINLOC
}
```

Customizing Collective Operation (3)

Buffer Information

```
typedef struct ucc_coll_buffer_info {
        void *src_buffer;
        size_t src_len;
        void *dest_buffer;
        size_t dest_len,
        int64 flags, /* in-buffer */
} ucc_coll_buffer_info_t
```

- src_buffer, src_len, dest_buffer, and dest_len standard semantics
- Flags
  - Persistent
  - Symmetric
  - In-buffer

Customizing Collective Operation (3)

Error Types

```
enum ucc_error_type {
        LOCAL=0,
        GLOBAL=1,
}
```

- **Local:**
  - There is no agreement on the errors reported to the members
  - If agreement is needed, it is the user responsibility to achieve it
- **Global:**
  - All members return the same error

Customize Context or Team or Collective Operation?

This is a philosophical question as it varies with the programming environment. So, some guidelines

- Make a local decision, when you can.
  - This reduces the number of global decisions, hence fewer collectives during initialization
  - Can change the decision with less cost. i.e., no collective required
- Provide mechanism to modify local decision during the global agreement process
- Provide mechanism to modify the local decision or global decision during the invocation time

Key Abstractions

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Collective Groups

Collective groups are a group of ordered or un-ordered collective operations

Use Case:

- Collective groups enable the implementation of hierarchical collectives
  - It is well established that by tailoring the algorithm and customizing the implementation to various communication mechanisms in the system can achieve higher performance and scalability

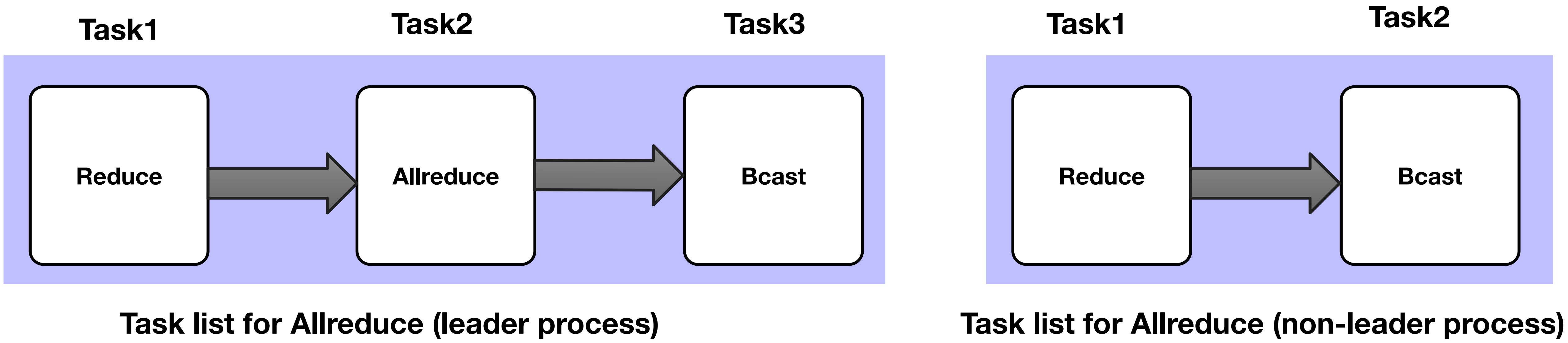
How to express groups of collectives?

- Triggered Operations
  - o Pros: Hardware Support
  - o Cons: Expressing
- Collective Schedules as DAGs
  - o Pros: Highly Expressible (parallelism, dependencies)
  - o Cons: Leveraging hardware trigger mechanism is tricky
- Chained/List Collective Operations
  - o Pros: Easy to program and implement
  - o Cons: Expressing parallelism can be a bit awkward

Collective Groups: Task and Task List

Collective groups are a group of ordered or un-ordered collective operations

- **Task:** Represents a collective operation and its corresponding team
- **Task List:** Represents a collective operation group executed either in order or unordered



Collective Groups

Operations to create and execute tasks

```
ucc_create_coll_task(ucc_coll_op_args_t args, ucc_team_t team, ucc_coll_task_t *task);
ucc_create_task_list(int num_tasks, bool ordered, ucc_coll_task_t tasks[], ucc_coll_task_list
*task_list);
ucc_schedule_task_list(int priority, ucc_coll_task_t task_list, ucc_task_execution_t *active_list);
ucc_complete_tasks(ucc_execution_t active_graph);
```

Semantics:

- All task operations are local
- *ucc_create_coll_task()* creates a task from collective arguments and team
- *ucc_create_task_list()* creates either an ordered or unordered list of tasks
- *ucc_schedule_task_list()* schedules the tasks to be executed either parallel(unordered) or serial(if ordered)
  - All members of the team in the task are expected to execute the same collective operation; otherwise, the operation is undefined.
  - All task executions are non-blocking and asynchronous
- *ucc_complete_tasks()* completes the execution of tasks in the task_list

Key Abstractions

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Global memory management

```
ucc_global_mem_alloc(ucc_team_t team, size_t size, ucc_mem_constraints constraints,
ucc_mem_hints hints, ucc_global_mem_t *mem_handle);

ucc_global_mem_free(ucc_global_mem_t mem_handle, ucc_team_t team)

ucc_global_mem_get_attrib(ucc_global_mem_t mem, ucc_global_mem_attrib *attributes);
```

Semantics:

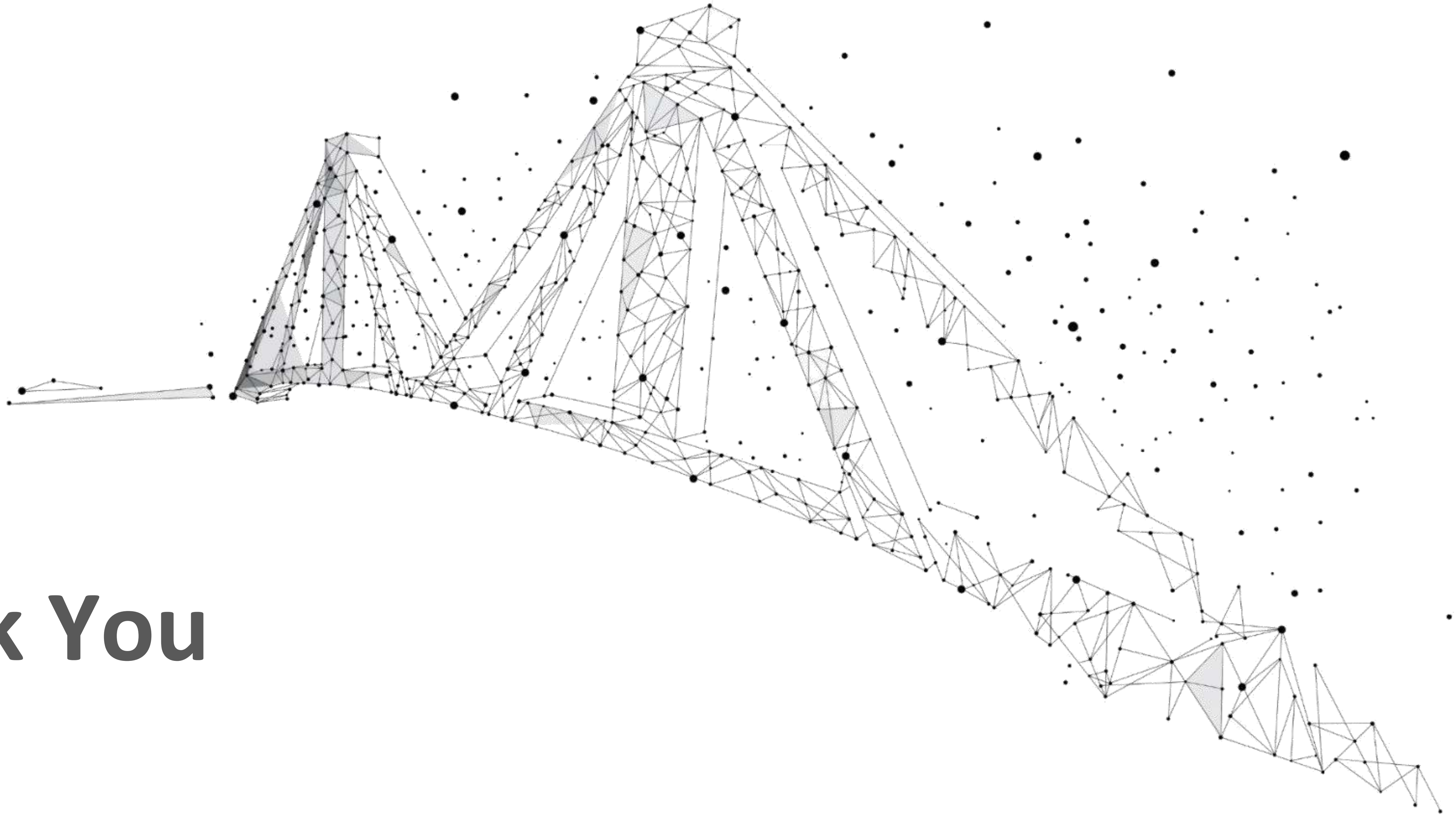
- Manages memory on each of member of the ***team***
- The constraints argument control the semantics
  - Example – symmetric, alignment
- The hints provide information about usage (think about mbind)
  - Memory policy – local, shared,
  - Usage - atomics, counters, small message, large message, MPI windows

Use cases:

- OpenSHMEM heaps, MPI Windows, PGAS models, and requirement for some RFPs (for example CORAL2)
- Internal for collectives – sync buffers, temporary work buffers

A Collective Communication API in UCF should support

- A wider variety of programming models
  - MPI is important for HPC
  - Other programming models are important and will grow in importance
- Hardware collectives should be a first-class citizen
  - Mellanox and other vendors already support hardware collectives
- Hierarchies should be a first-class citizen
  - It is well-established that hierarchical collectives achieve higher performance and scalability
  - UCC API should support abstractions to build hierarchies
- Enable flexible resource allocation
  - Lazy resource allocation
  - Local and global decisions
- Iterative collectives should be supported
  - Build once and invoke multiple times.
- Support for various synchronization models
  - Both strict and relaxed synchronization models should be supported
- Support for P2P operations and global memory allocation operations



Thank You