Takyon

Heterogeneous Communication API
For eHPC (embedded High Performance Computing)

https://github.com/michaelboth/Takyon

Michael Both: Mar 1, 2023

What is Takyon?

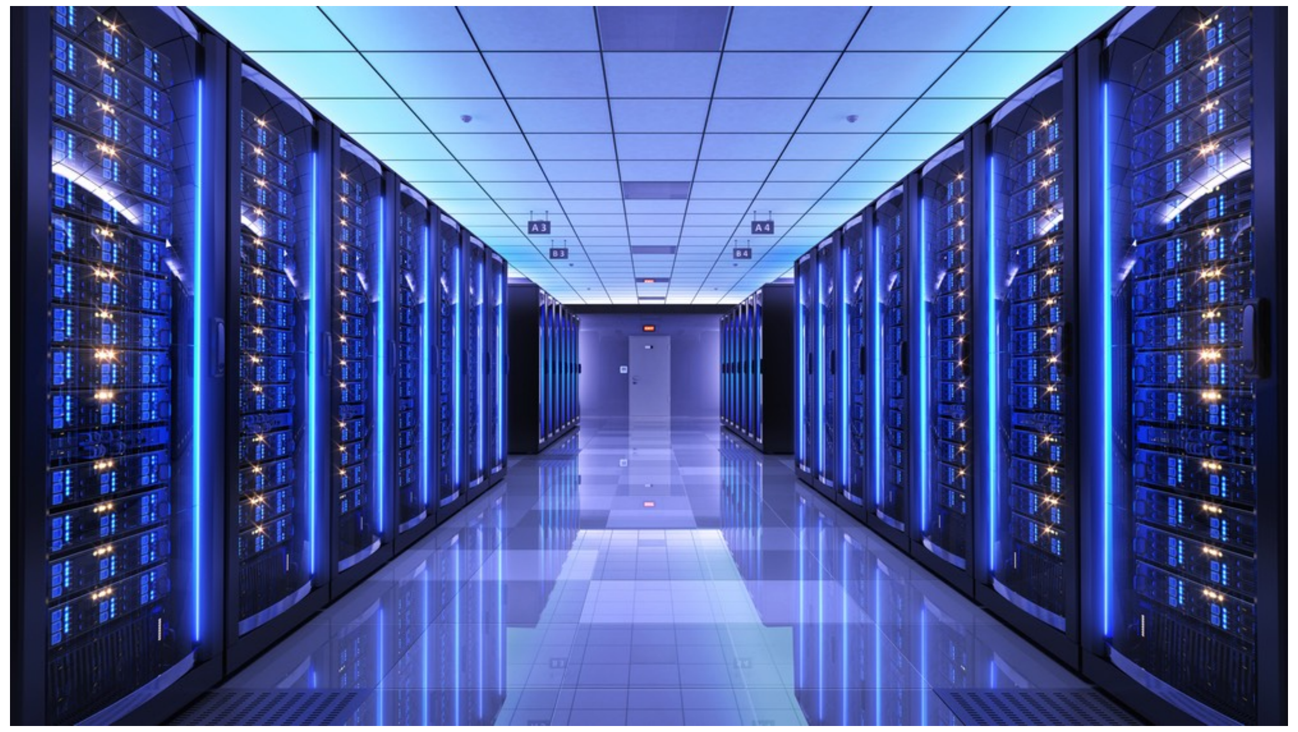
It’s a modern message passing communication API focused on eHPC (e.g. edge computing)

- Reliable and unreliable (unicast & multicast) communication
- Most interconnects: e.g. RDMA, sockets
- Any locality: inter-processor, inter-process, inter-thread
- Two-sided (send/recv), and one-sided (read/write)
- Blocking and non-blocking transfers
- Fault tolerant capable (via timeouts, disconnect detection, dynamic path creation)
- Most memory types: e.g. CPU, GPU

Takyon’s Intended Audience

Small heterogeneous systems (eHPC, edge computing, SWaP limited environments, etc)

Large homogeneous systems, with highly collective needs are better suited by MPI or libFabric



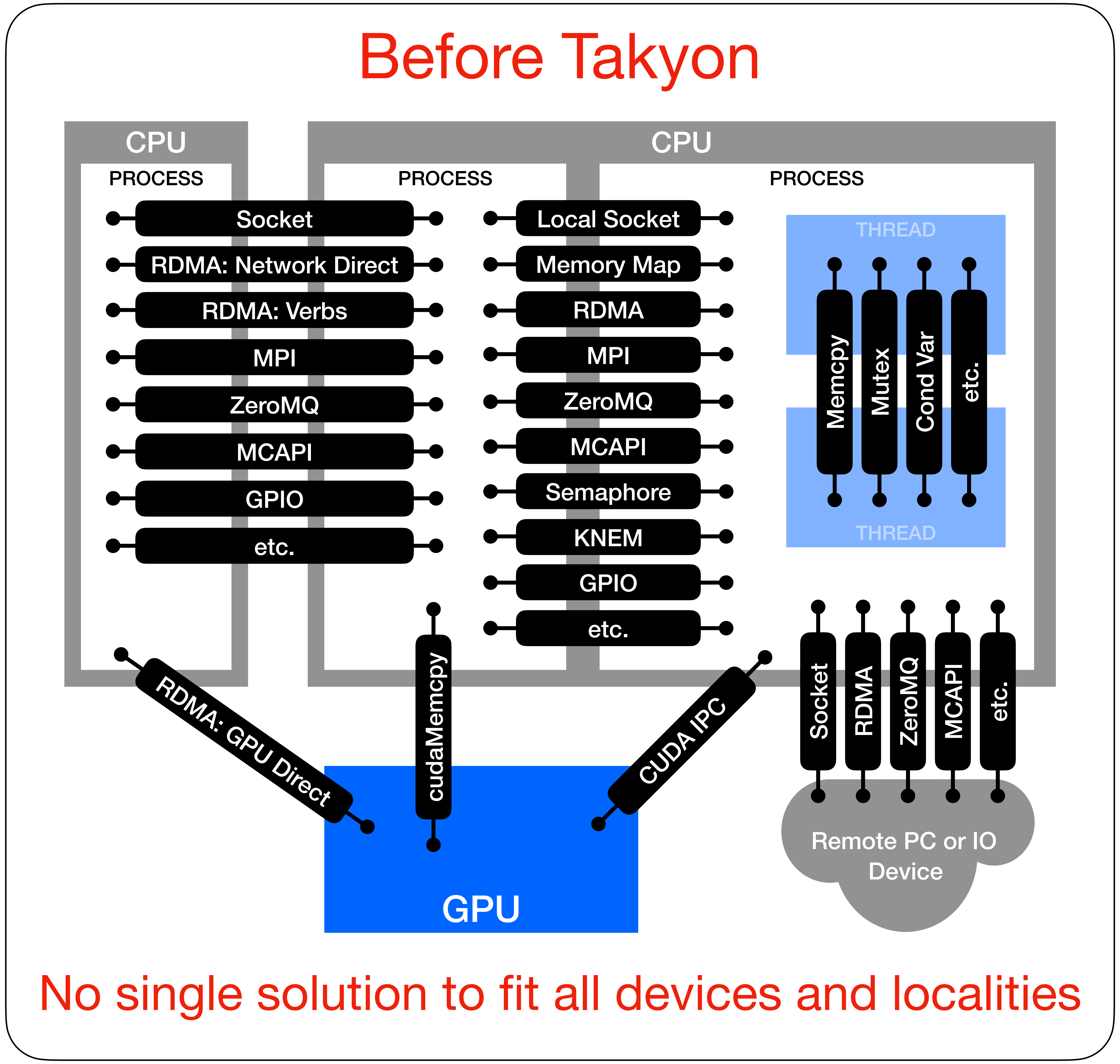
Why Introduce Another Communication API?

Takyon is an evolution that solves four major communication issues at once:

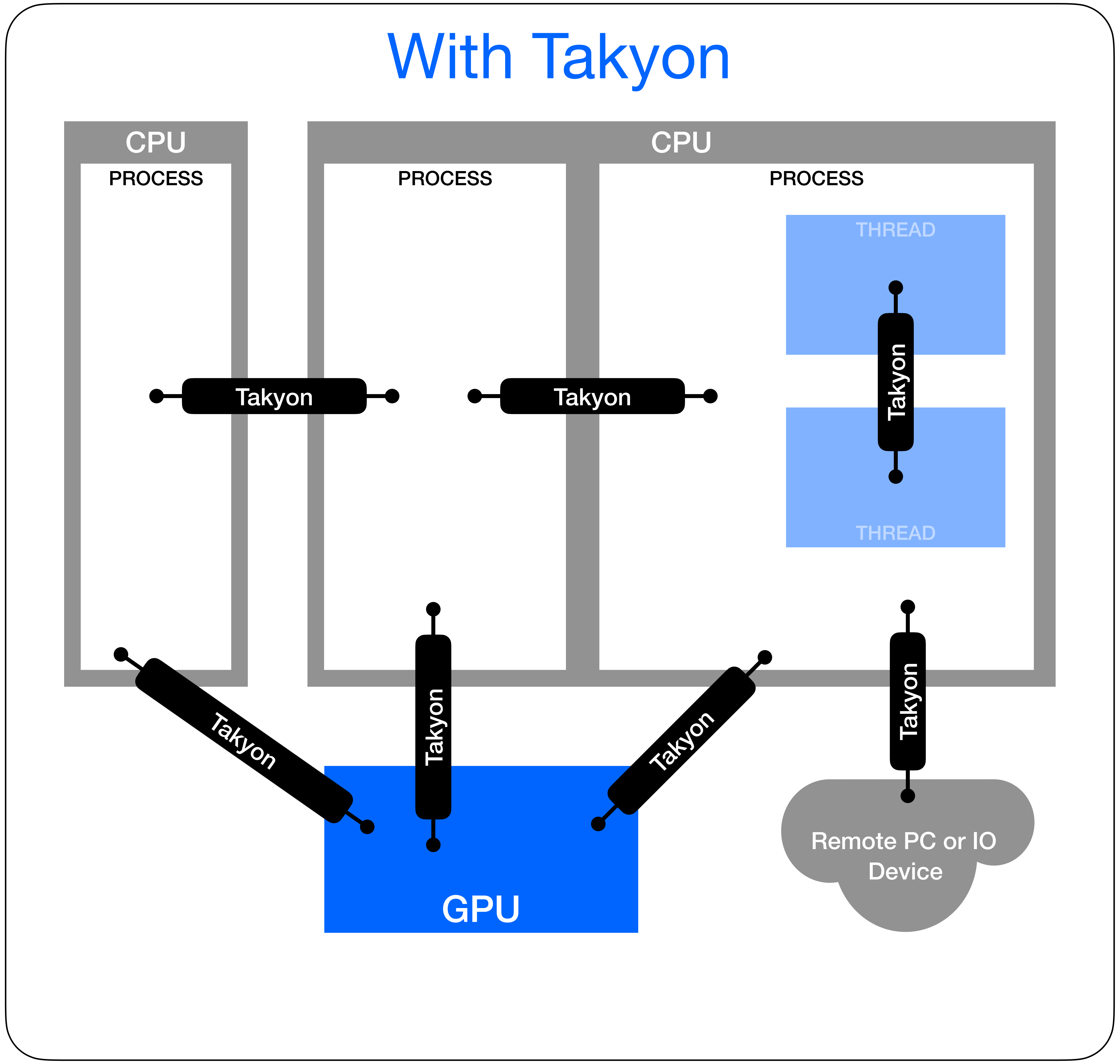
- One API for all device/interconnect variations
- Supports all common communication features
- Simple and intuitive: 8 functions and 8 data structures
- Best possible performance: throughput, latency, and determinism

The next four slides provide details on the above

One API for all Device/Interconnect Variations



No single solution to fit all devices and localities



Supports all Common Communication Features

Feature	Sockets and similar: MCAPI, ZeroMQ	RDMA: Verbs and Network Direct	OFA’s libFabric	MPI	Takyon
Reliable and Unreliable	✅	✅	✅		✅
Communication to external apps, sensors, and other IO devices	✅	✅	?		✅
Fault tolerant hooks (timeouts, disconnect detection, path creation)	✅	✅	?		✅
Deterministic: avoids implicit communication and allocations	✅	✅	✅		✅
Includes Inter-thread communication			✅		✅
Non blocking transfers		✅	✅	✅	✅
One way read/write/atomcis: no involvement from remote endpoint		✅	✅	✅	✅
GPU support		✅	✅	✅	✅
Multiple memory blocks per message		✅	?	✅	✅
Memory pre-registered before transfer		✅	✅	Partial	✅
Zero copy and one-way (i.e. no implicit round trip)		✅	?		✅
32bit piggy back message with main message		✅	?		✅

Simple and Intuitive

API	Function Count	Typical Drawbacks
Sockets	~20	Lots of options, confusing terms
RDMA (OFA Verbs, Network Direct)	~100	Overwhelming learning curve, experts are rare
OFA's libFabrics	~100	Overwhelming learning curve, experts are rare
MPI	~300	Large learning curve for various transfer models, limited to reliable communication, 'mpirun' is not portable and can be difficult to tune
Takyon	8	Simple API, intuitive terms and concepts

Takyon eHPC audience is likely focused on something other than communication, such as radar processing, and won't have the time for a high learning curve

Best Possible Performance

Latency, Throughput, and Determinism

- Zero-copy, and one-way (no round trips!)
  - Achieved by:
    - Pre-registering (is time consuming) transport memory when the path is created
    - Pre-post receive requests
      - Creates a holding place for data to arrive later asynchronously in the background
      - This makes sure there is no delay or implicit buffering needed when sending
- Non-Blocking
  - Offload transfers to a DMA to allow for efficient concurrent processing and IO

Not all interconnects support the above, but Takyon's abstraction does not inhibit or degrade the interconnects that do support the above.

Takyon API: 8 Functions

Function	Description
takyonCreate()	Create one endpoint of a communication path
takyonDestroy()	Destroy the endpoint
takyonSend()	Start sending a message If the communication does not support non-blocking then this will block
takyonIsSent()	Check if send is complete, up to a specified timeout period.
takyonPostRecvs()	If supported, pre-post a list of recv requests before the sender starts sending Provides memory buckets for receiving messages asynchronously
takyonIsRecved()	Check if a message has arrived, up to a specified timeout period.
takyonOneSided()	Start a one sided message transfer (read, write, atomics)
takyonIsOneSidedDone()	Check if one-sided transfer is complete, up to a specified timeout period.

Two-sided functions

One-sided functions

Not all interconnects support the above; e.g. sockets don’t support one-sided or posting receives

Takyon Provider: Defines the Interconnect

All providers are defined in a text string passed to takyonCreate()

Locality	Examples
Inter-Thread	"**InterThread** -pathID=<non_negative_integer>"
Inter-Process	"**InterProcess** -pathID=<non_negative_integer>” “**SocketTcp** -local -pathID=<non_negative_integer>"
Inter-Processor	"**SocketTcp** -client -remoteIP=<ip_addr> -port=<number>” "**SocketTcp** -server -localIP=<ip_addr>|Any -port=<number> [-reuse]” "**SocketUdpSend** -multicast -localIP=<ip_addr> -groupIP=<multicast_ip> -port=<number> [-noLoopback] [-TTL=<time_to_live>]" "**SocketUdpRecv** -multicast -localIP=<ip_addr> -groupIP=<multicast_ip> -port=<number> [-reuse] [-rcvbuf=<bytes>]” “**RdmaRC** -client -remoteIP=<ip_addr> -port=<number> -rdmaDevice=<name> -rdmaPort=<number>” “**RdmaRC** -server -localIP=<ip_addr>|Any -port=<number> [-reuse] -rdmaDevice=<name> -rdmaPort=<number>” “**RdmaUC** -client -remoteIP=<ip_addr> -port=<number> -rdmaDevice=<name> -rdmaPort=<number>” “**RdmaUC** -server -localIP=<ip_addr>|Any -port=<number> [-reuse] -rdmaDevice=<name> -rdmaPort=<number>” “**RdmaUDMulticastSend** -localIP=<ip_addr> -groupIP=<multicast_ip>” “**RdmaUDMulticastRecv** -localIP=<ip_addr> -groupIP=<multicast_ip>”

No limit to the Takyon Provider possibilities: GPIO, sensors, FPGAs, etc.

Transport Memory

Takyon does NOT allocate transport memory (this is intentional)

Transport memory may need to be shared between communication paths (Takyon or 3rd party) and other processing APIs and IO devices

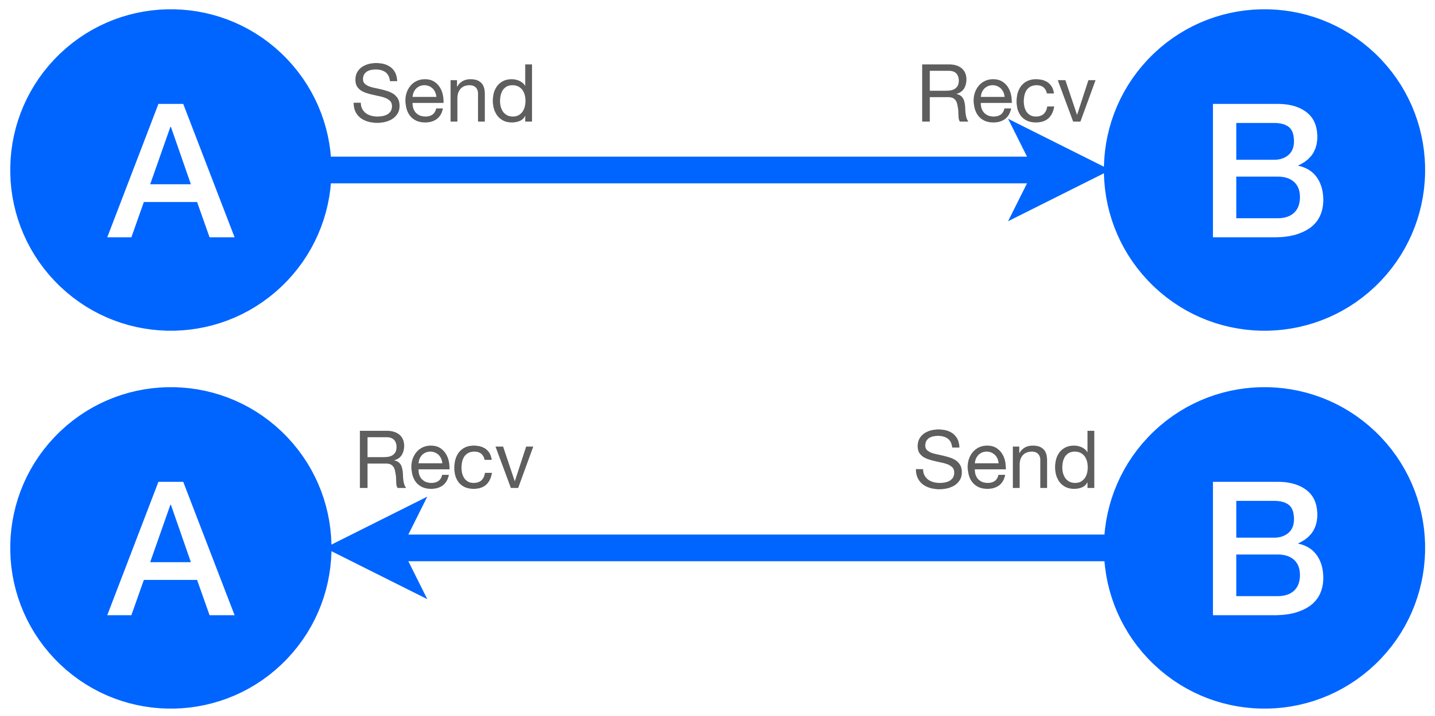
Therefore it is logical to have the application organize all transport memory

- CPU (local or memory map)
- GPU (CUDA)
- Sensor/FPGA/etc. memory

And then provide pointers to the TakyonBuffer structure and other 3rd party APIs

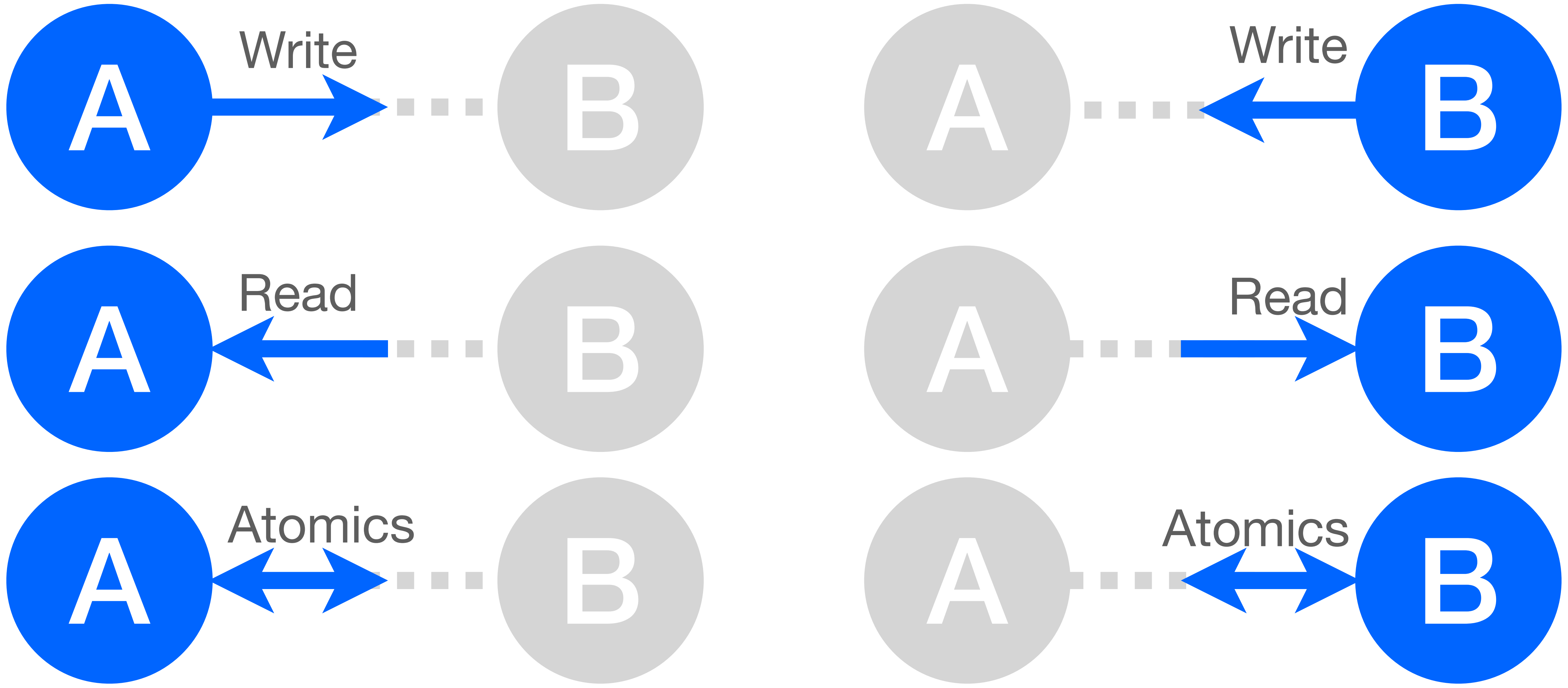
Two-Sided versus One-Sided Transfers

Two-Sided



- Both endpoints are involved with a coordinated send() and recv()
- Unicast and Multicast are two-sided

One-Sided

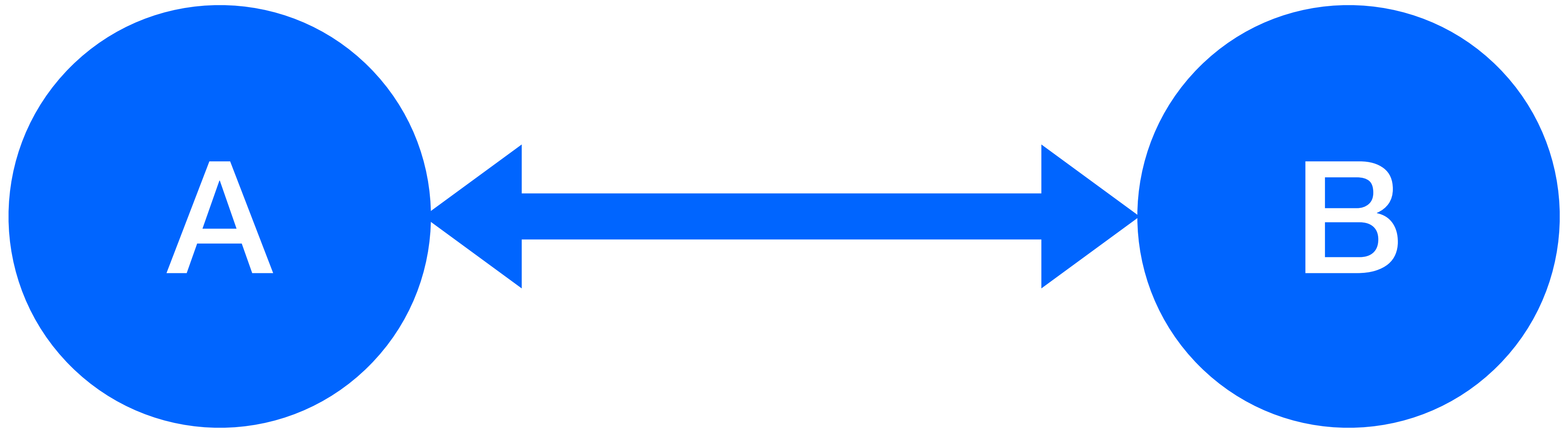


- Only one endpoint is involved with the transfer
- Can support read, write, and atomics

Some Takyon Providers only allow one or the other

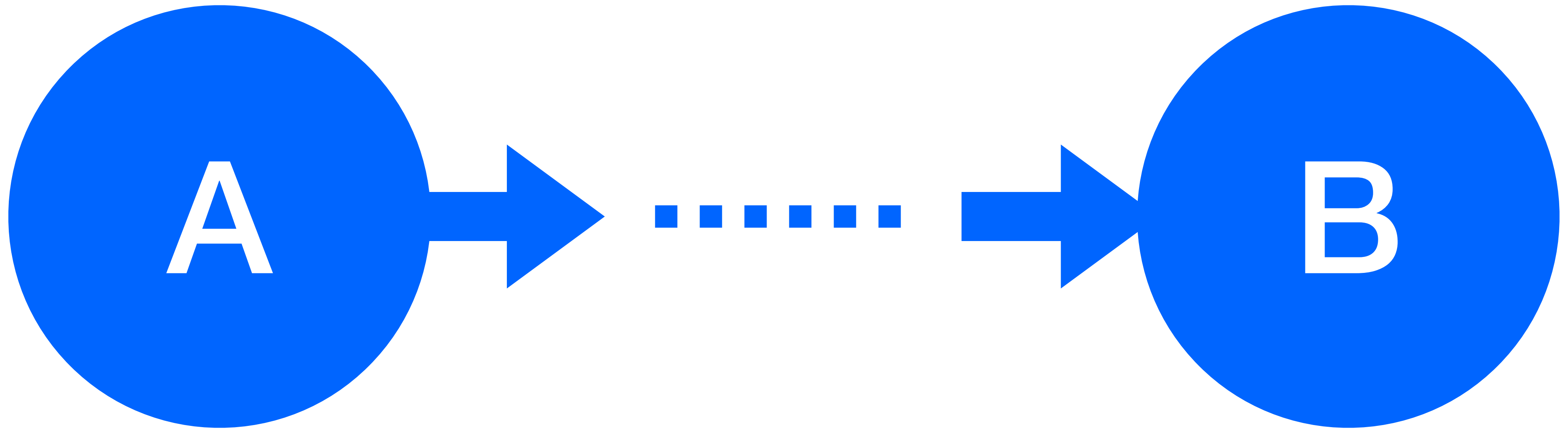
Takyon Supports Reliable and Unreliable Transfers

Reliable



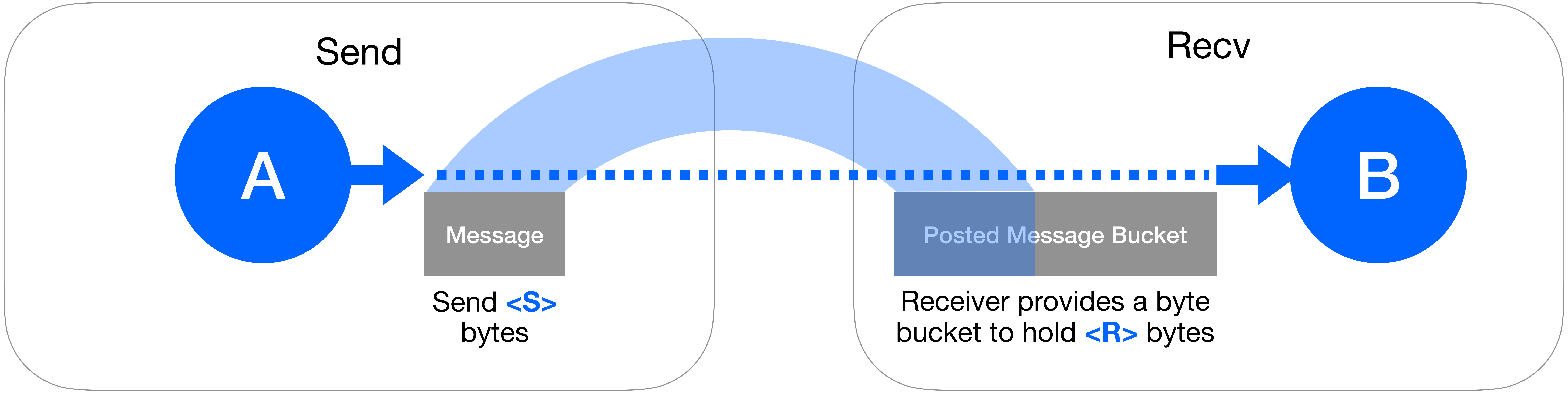
- **Every byte matters**
- Can support very large messages
- E.g. Distributed computation

Unreliable



- **Messages may drop, come out of order, or be duplicated**
- Unicast and multicast
- Usually small messages
- E.g. audio, video, lidar, radar

Two-Sided (Send/Recv) Semantics: Message Size



sizeof(<S>) <= sizeof(<R>)

I.e. sent messages can be smaller than what takyon's recv request provided as a byte bucket

Two-Sided (Send/Recv) Semantics: Message Order

Rule 1: The order of arriving messages is based on one of:

- If the Provider is ‘reliable’ then the messages will arrive in the same order as sent
- If the Provider is ‘unreliable’ then the messages may:
  - Arrive in a different order than sent
  - Be dropped and lost forever
  - Be a duplicate of a previously arrived message

Rule 2: The arrived message is put into the recv buffer based on:

- If takyonPostRecvs() IS supported: the order of received messages is defined by the order of posting recv requests
- If takyonPostRecvs() NOT supported: the order of received messages is defined by the order of calling takyonIsRecved()

Blocking versus Non-Blocking Transfers

Interconnects that can support non-blocking usually have a DMA engine

Blocking

CPU does transfer

takyonSend() - Send message and block until message is sent. Memory buffer can be updated when this call is complete.

takyonIsRecved() - Wait for a message to arrive. Memory buffer won't be overwritten until reused by subsequent call this this function.

takyonOneSided() - Transfer message and block until complete. Memory buffer can be updated when this call is complete.

Non-Blocking

DMA does transfer in the background

takyonSend() - start two-sided transfer

Don't modify message at this point

takyonIsSent() - block until sent

If not called before message arrives, message will be dropped (unreliable), or cause a failure (reliable)

takyonPostRecvs() - provides a place to recv data ahead of time

takyonIsRecved() - block until message arrives

Process the message before re-posting to avoid overwriting data from a newly arriving message

takyonOneSided() - start one-sided transfer

Don't modify message at this point

takyonIsOneSidedDone() - block until transferred

Non-Blocking Notifications and Fences

Send and one-sided completion notifications

- The application can decided if a completion notification should be used or not:

```
TakyonSendRequest.use_is_sent_notification = false;      // Don't call takyonIsSent()
TakyonOneSidedRequest.use_is_done_notification = false;  // Don't call takyonIsOneSidedDone()
```

- Since transfers are processed in order, can used a subsequent transfer to see of if previous un-signaled transfer completed. Improves latency and throughput.

Fences

- Forces preceding non-blocking transfers (send, read, write, atomics), where notification is turned off, to complete before the new transfer starts

```
TakyonSendRequest.submit_fence = true;
TakyonOneSidedRequest.submit_fence = true;
```

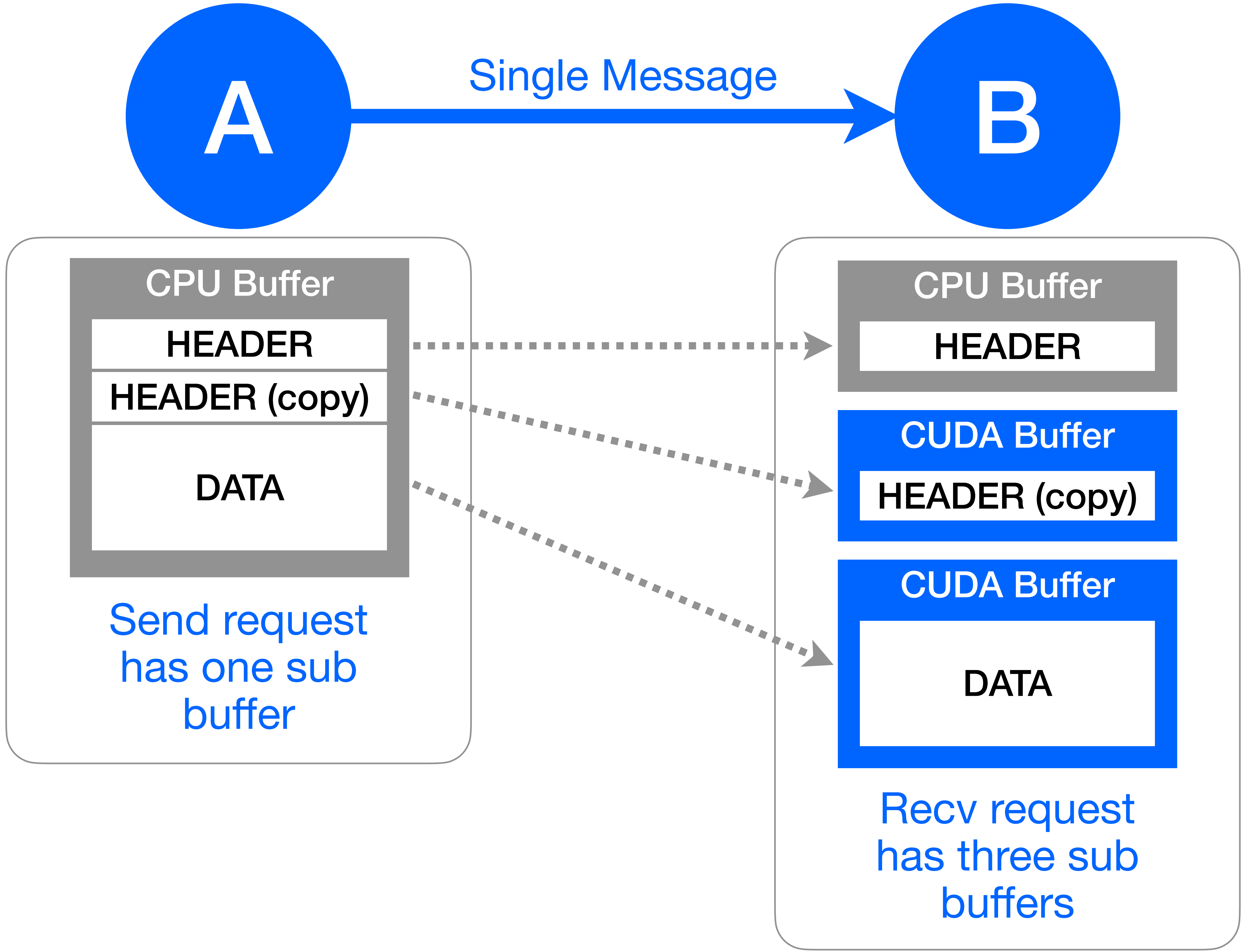
- This is typically only needed if a preceding 'read' or 'atomic' operation is invoked (changes local memory) just before sending the results of the preceding operations

Single Message, Multiple Sub Buffers

Multiple sub buffers may allow for highly organized and optimized processing

Hypothetical Example:

- It’s common for GPUs to do heavy processing and CPU does light book keeping, but both need to know the attributes of the data



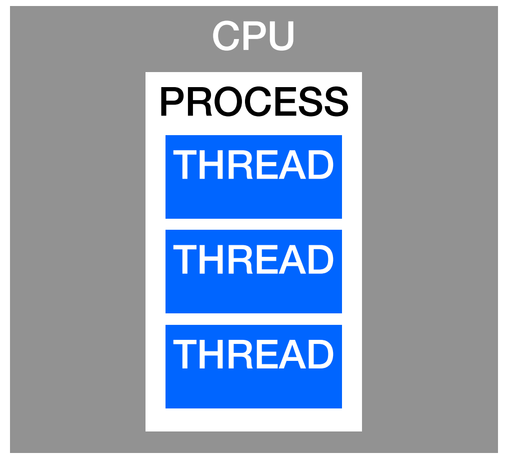
Some providers only allow one sub buffer per message

Fault Tolerant Communication

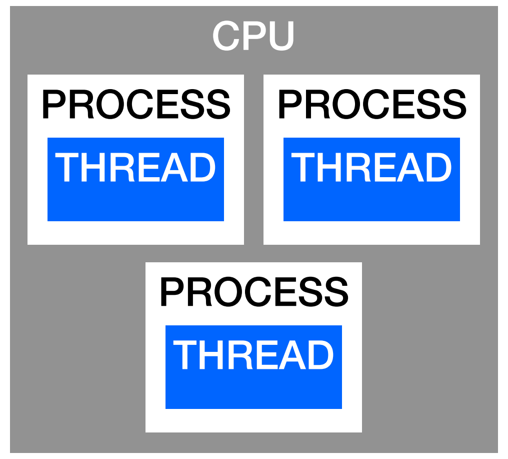
- Detecting degraded communication
  - Disconnect detected (e.g. network is down); i.e. Takyon function return false
  - Timeout (the transfer is not occurring in a reasonable amount of time)
- Handle a degraded communication path
  - Used dynamic path destruction/creation, without effecting other existing paths
  - Some other application defined alternative
- Notes about being fault tolerant
  - Communication API should provided the hooks for fault tolerance
  - Only the app can know what to do when communication degrades
  - Communication paths should be independent (Want to avoid "One light goes out they all go out")

Takyon is not fault tolerant (by design), but does provide fault tolerant hooks

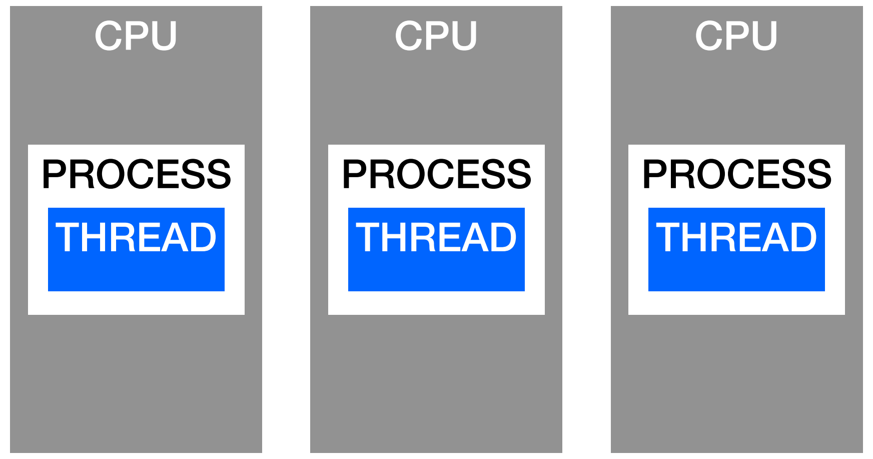
Accelerate Development by Locality Staging



1. Start with one process and multiple threads
   - While dataflow is being developed, only need to run a single executable
   - Easier to debug crashes or validate memory leaks/overwrites (e.g. valgrind)



2. Move to multiple processes on one CPU
   - Simple way to validate the migration of dataflow, without jumping to multi-processors



3. Move to multiple processors
   - Migration should be simple
   - Can now test for deployment performance

All Takyon examples support this

Looking to the Future

Posible Enhancements

- Strided Transfers
  - Currently avoiding this since common interconnects don't support this
- Publish/Subscribe
  - A potential replacement for the overly complex DDS
  - Could have simplified participants, publishers, subscribers, and QoS
  - Make messages opaque and private (removes need for DDS's intermediate language)
- Collectives: barrier, scatter, gather, all-to-all, reduce, etc.
  - Already done as a separate API with Takyon 1.x, and may be converted to Takyon 2.x
  - Create a complimenting GUI to build and maintain the collective groups visually

CHALLENGE: Is Takyon missing a key feature?

Ultimate Goal: Open Standard

KHRONOS® GROUP

CONNECTING SOFTWARE TO SILICON

The creation of Takyon inspired a Khronos exploratory group that hinted that the industry is in need of an eHPC Heterogeneous Communication API

It's difficult to find experts who can contribute. Join the next stage of the Khronos Exploratory Group to help determine industry interest

https://www.khronos.org/exploratory/heterogeneous-communication/