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Hybrid Parallel Programming with MPI and PGAS (UPC)

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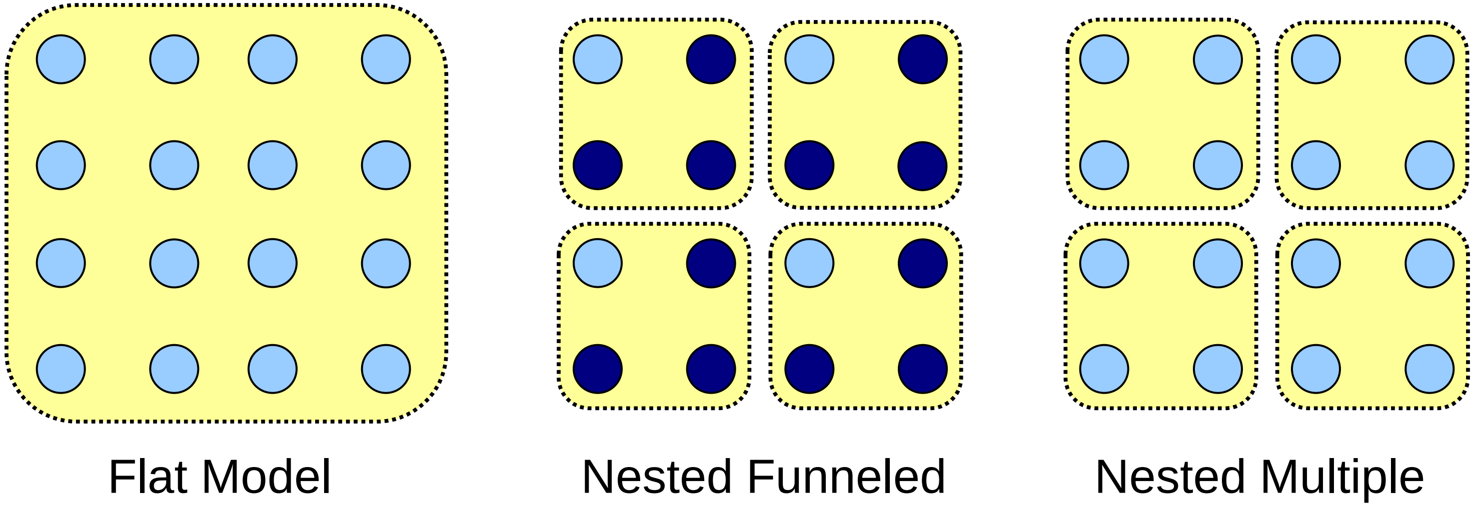
Motivation

- MPI and UPC have their own advantages
  - UPC:
    - Distributed data structures (arrays, trees)
    - Implicit and explicit one-sided communication
      - Good for irregular codes
    - Can support large data sets
      - Multiple virtual address spaces joined together to form a global address space
  - MPI:
    - Groups
    - Topology-aware functionality (e.g., Cart functionality)

Extending MPI to work well with PGAS

- MPI can handle some parts and allow PGAS to do handle others
  - E.g., MPI can handle outer-level coarse-grained parallelism, scalability, fault tolerance and allow PGAS to handle inner-level fine-grained parallelism



Description of Models

- Nested Multiple
  - MPI launches multiple UPC groups of processes
    - Note: Here “one process” refers to all entities that share one virtual address space
  - Each UPC process will have an MPI rank
    - Can make MPI calls
- Nested Funneled
  - MPI launches multiple UPC groups of processes
  - Only one UPC process can make MPI calls
    - Currently not restricted to the “master process” like with threads
  - Applications can extend address space without affecting other internal components

Description of Models (contd.)

- Flat Model
  - Subset of Nested-Multiple
  - … but might be easier to implement

What does MPI need to do?

- Hybrid initialization
  - MPI_Init_hybrid(&argc, &argv, int ranks_per_group)
- When MPI is launched, it needs to know how many processes are being launched
  - Currently we use a flat model
  - If 10 processes are being launched, we know that world size is 10
  - Hybrid launching can be hierarchical
    - 10 processes are launched, each of which might launch 10 other processes → world size can be 100 (in the case of Nested-Multiple)

Other Issues with Interoperability

- No mapping between MPI and UPC ranks
  - Application needs to explicitly figure out
  - Can be done portably with enough number of MPI_Alltoall and Allgather calls
- Communication Deadlock
  - In some cases deadlocks can be avoided by implicit progress done by either MPI or UPC
  - Being handled as ticket #154
    - Might get voted out
    - Application might need to assume the worst case

Other Issues with Interoperability (contd.)

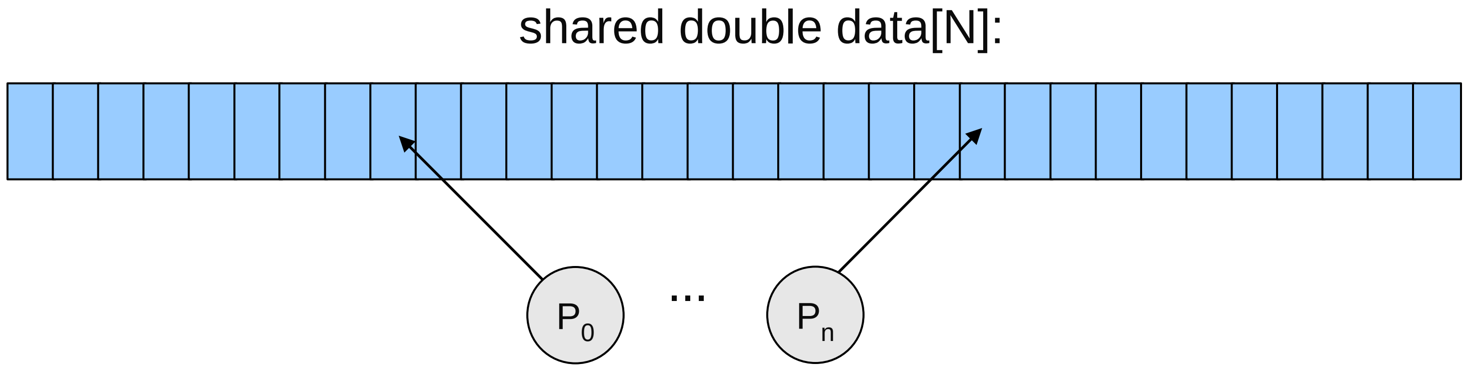
- There is no sharing of MPI and UPC objects
  - MPI does not know how to send data from “global address spaces”
    - User has to provide the data in its virtual address space
  - UPC cannot perform RMA into MPI windows

Implementation in MPICH2

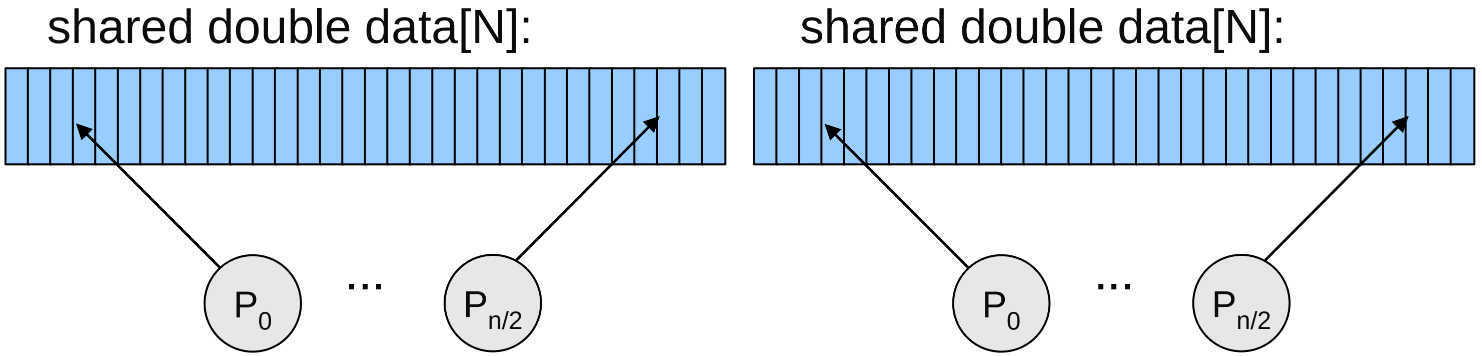
- Rough implementation available
  - Will be corrected once the details are finalized

Random Access Benchmark

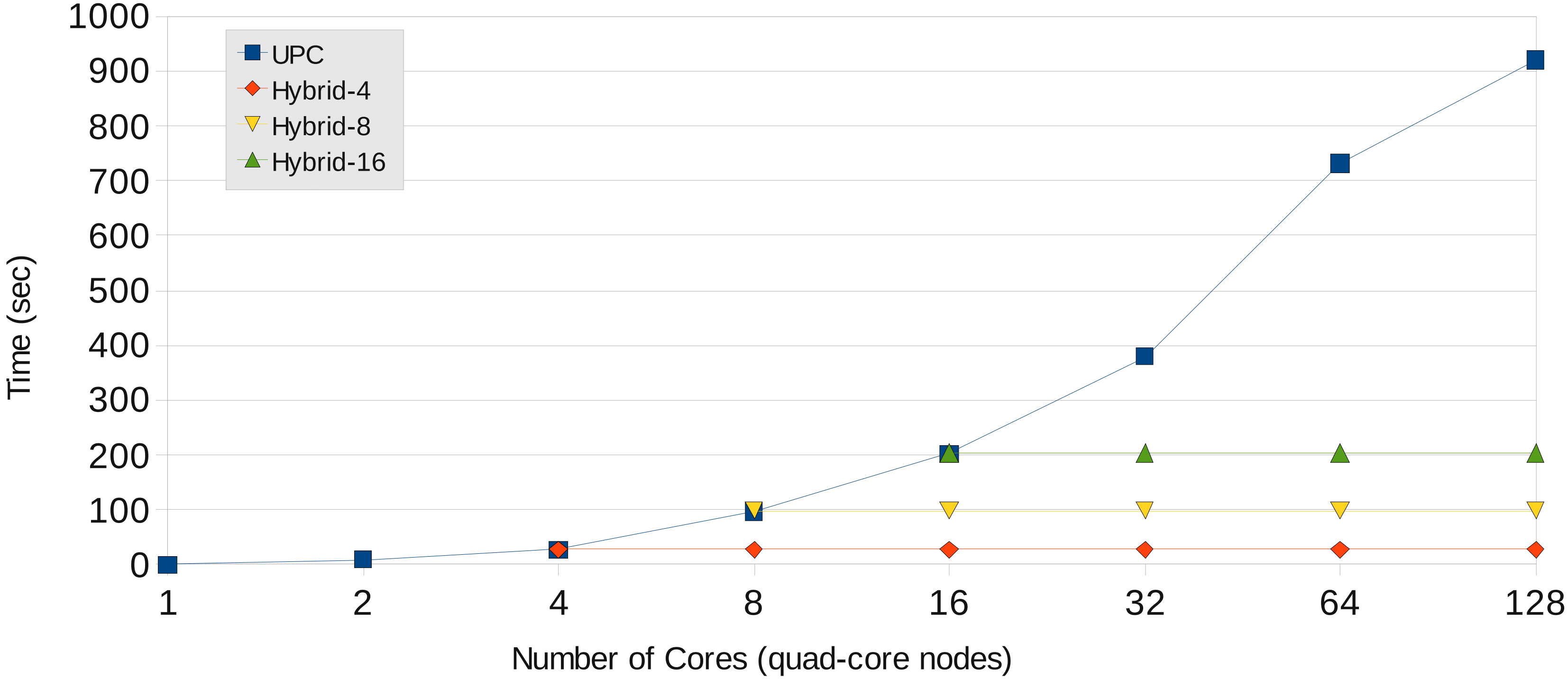
- UPC: Threads access random elements of distributed shared array



- Hybrid: Array is replicated on every group

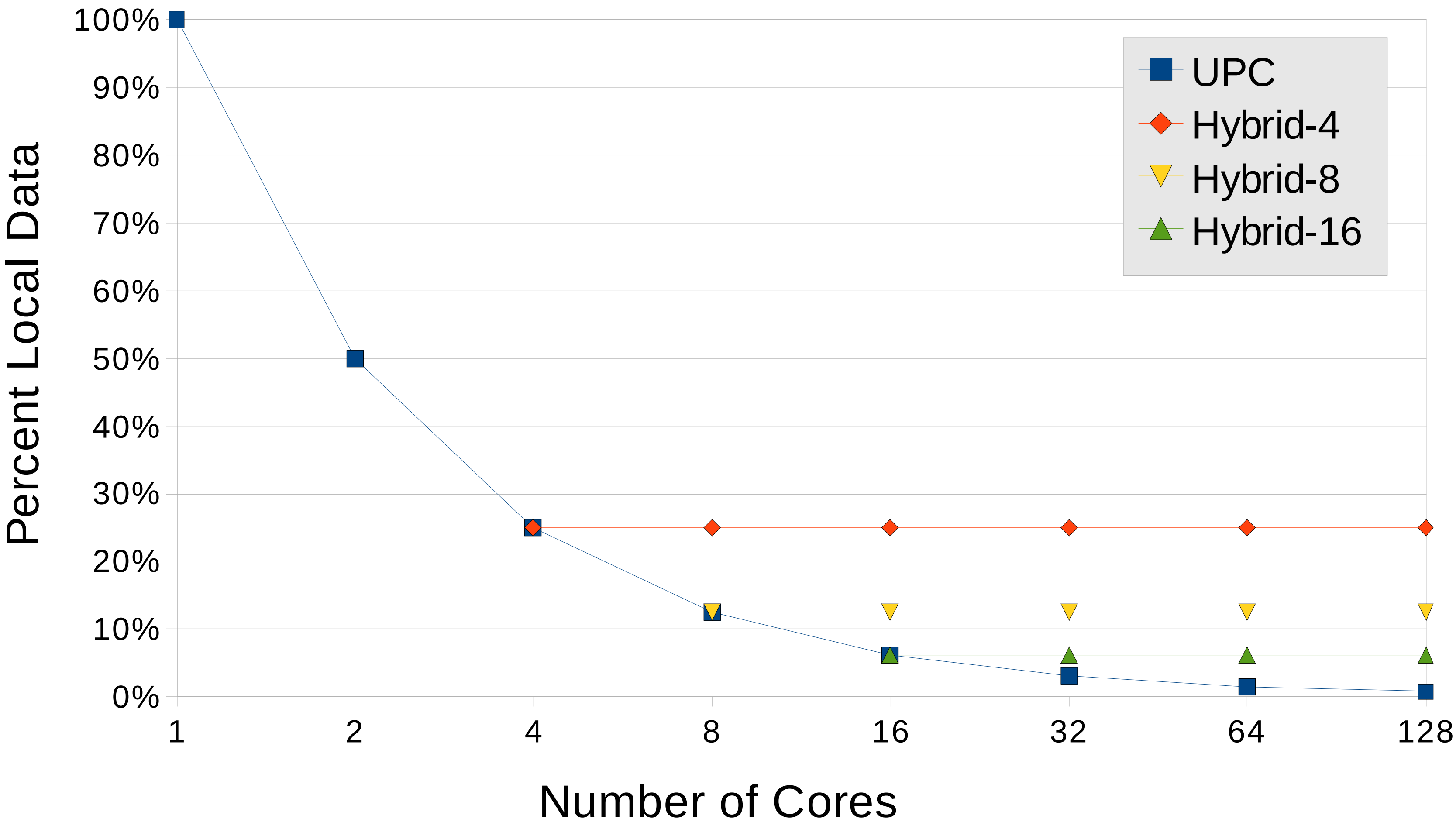


Impact of Data Locality on Performance



- Each process performs 1,000,000 random accesses
- Weak scaling ideal: Flat line

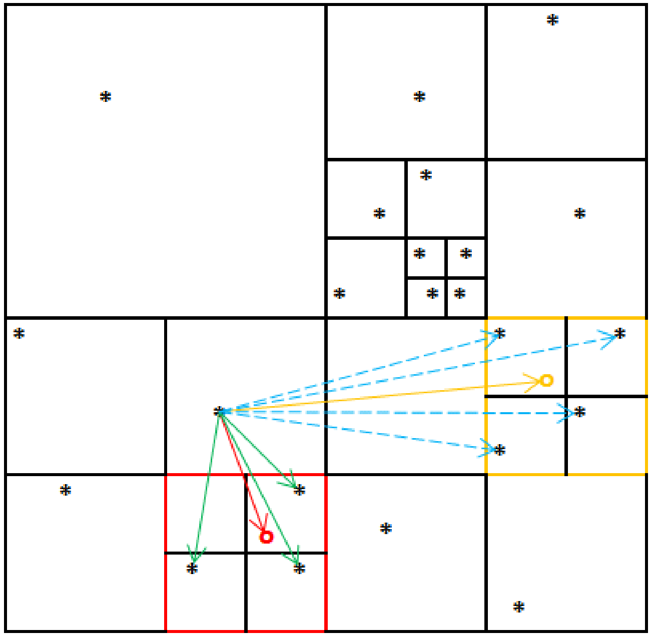
Percentage Local References



Barnes-Hut n-Body Cosmological Simulation

- Simulates gravitational interactions of a system of *n* bodies
- Represents 3-d space using an oct-tree
- Summarize distant interactions using center of mass

```
for i in 1..t_max
    t <- new octree()

    forall b in bodies
        insert(t, b)

    summarize_subtrees(t)

    forall b in bodies
        compute_forces(b, t)

    forall b in bodies
        advance(b)
```



Credit: Lonestar Benchmarks (Pingali et al)

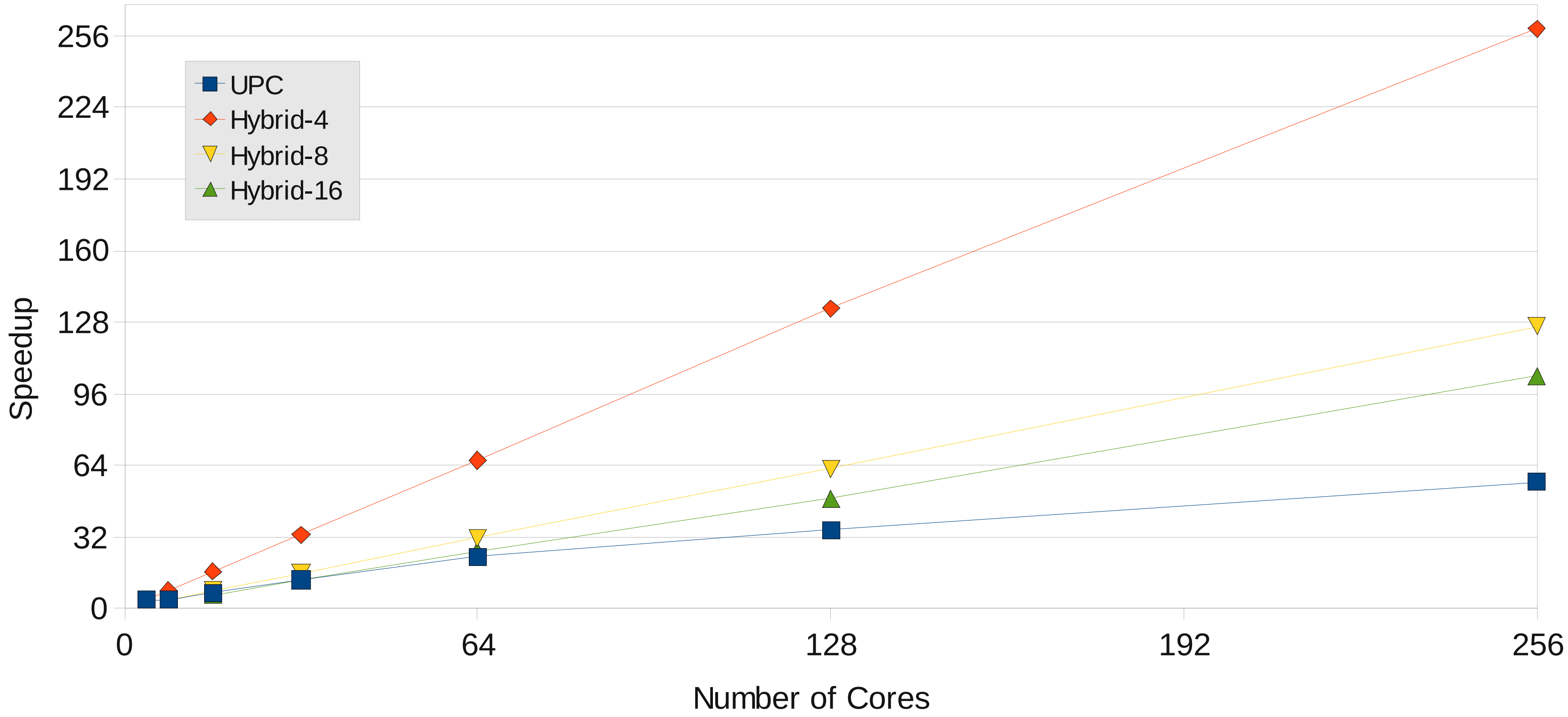
Hybrid Barnes Algorithm

```
for i in 1..t_max
   t <- new octree()

   forall b in bodies
      insert(t, b)

   summarize_subtrees(t)
   our_bodies <- partion(group id, bodies)

   forall b in our_bodies
      compute_forces(b, t)

   forall b in bodies
      advance(b)

   Allgather(bodies)
```

Tree is distributed across group

Smaller distribution improves O(our_bodies) tree traversals

Barnes Force Computation



- Strong scaling: 100,000 body system