Single-sided PGAS Communications Libraries

Overview of PGAS approaches

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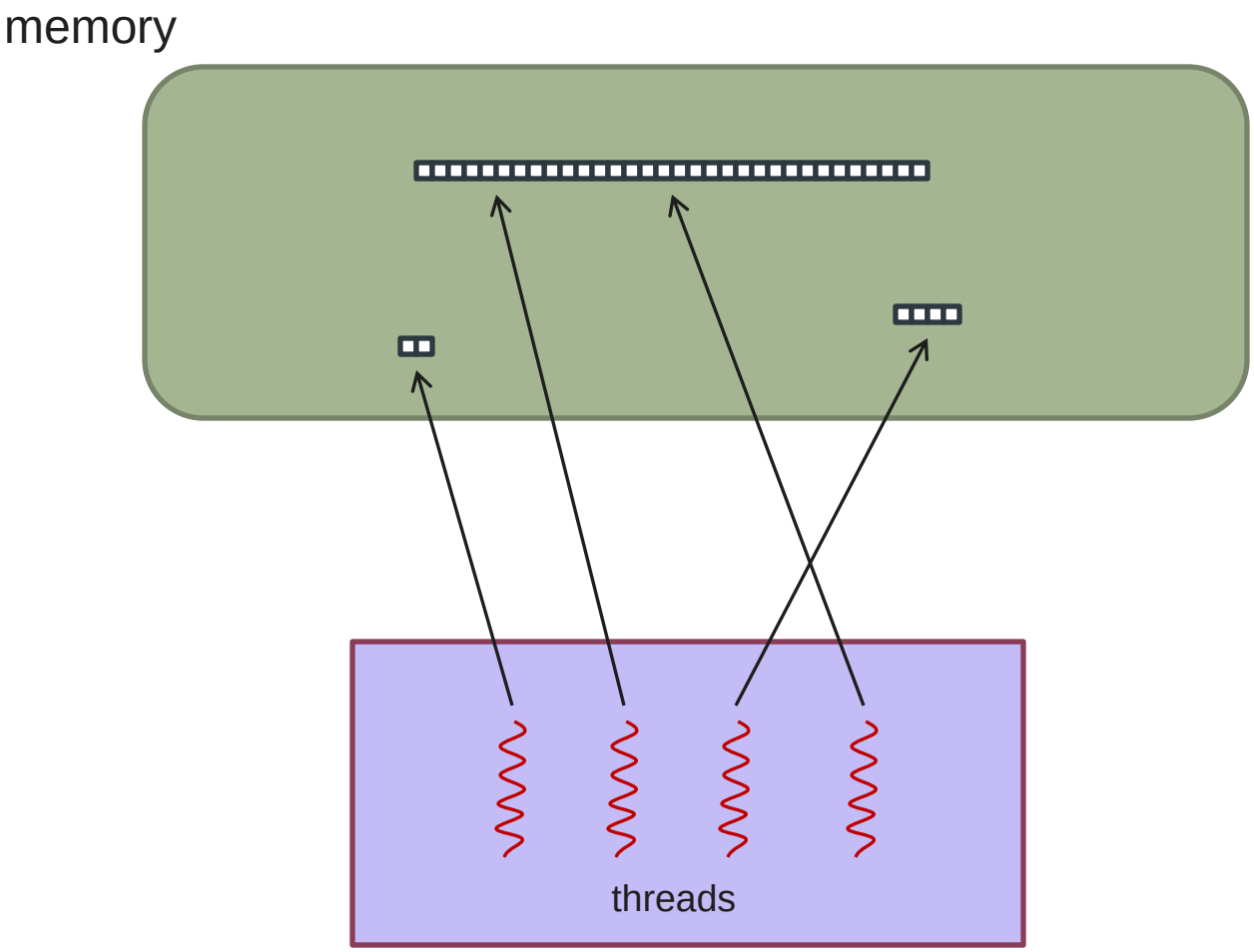
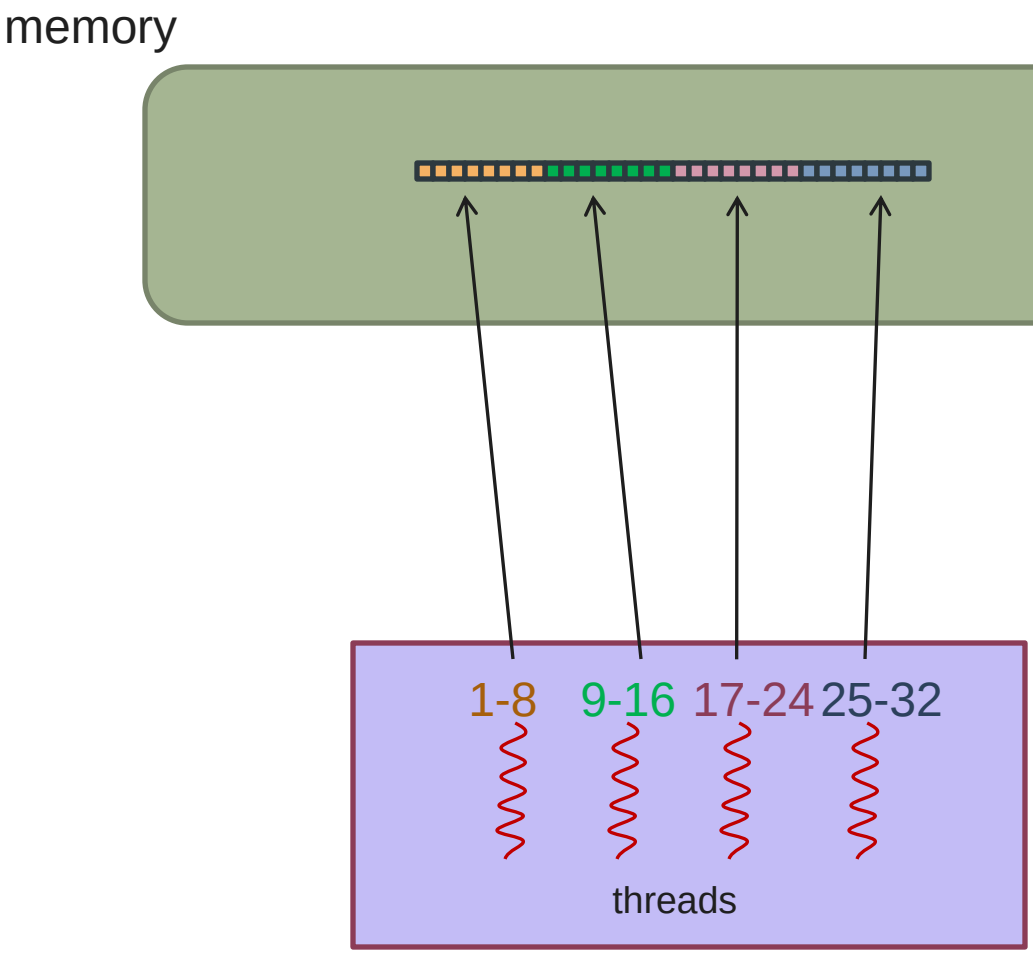
Shared-memory directives and OpenMP

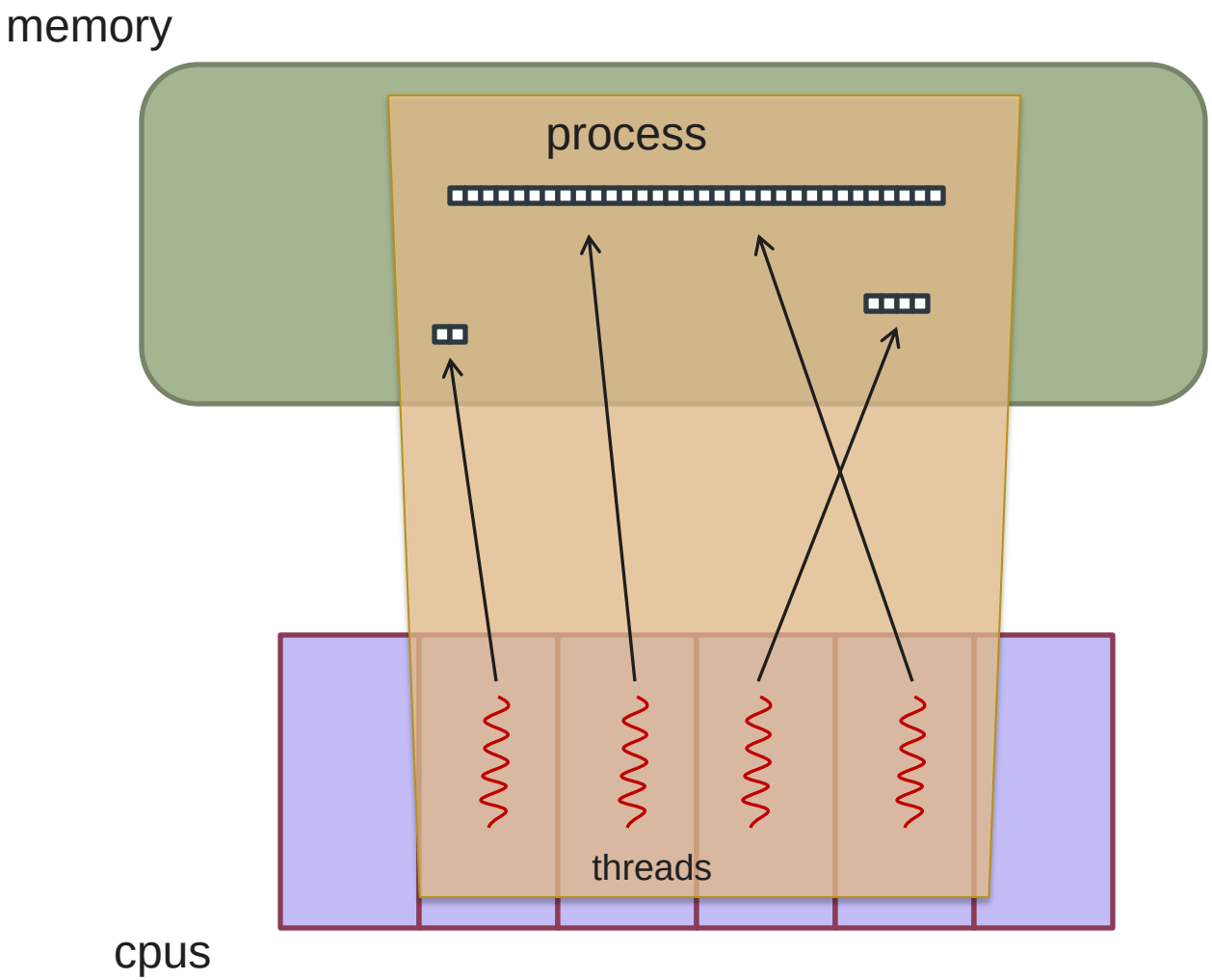


OpenMP: work distribution




```
!$OMP PARALLEL DO
do i=1,32
  a(i)=a(i)*2
end do
```

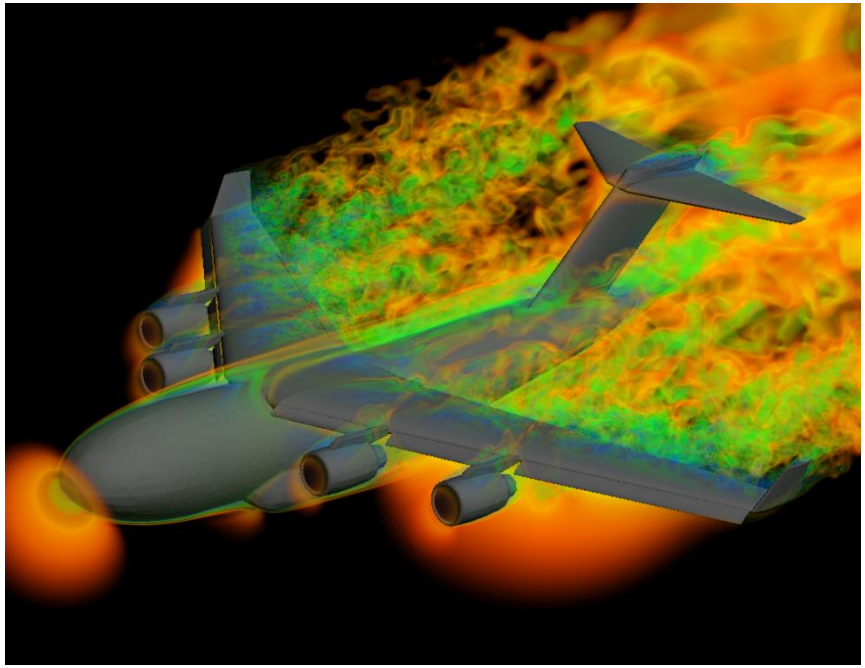
OpenMP implementation



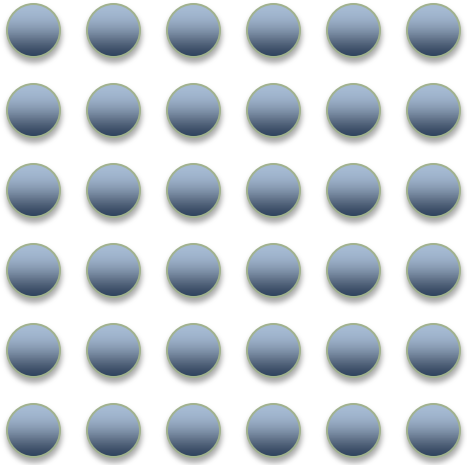
Shared Memory Directives

- Multiple threads share global memory
- Most common variant: OpenMP
- Program loop iterations distributed to threads, more recent task features
  - Each thread has a means to refer to private objects within a parallel context
- Terminology
  - Thread, thread team
- Implementation
  - Threads map to user threads running on one SMP node
  - Extensions to distributed memory not so successful
- OpenMP is a good model to use within a node

Cooperating Processes Models

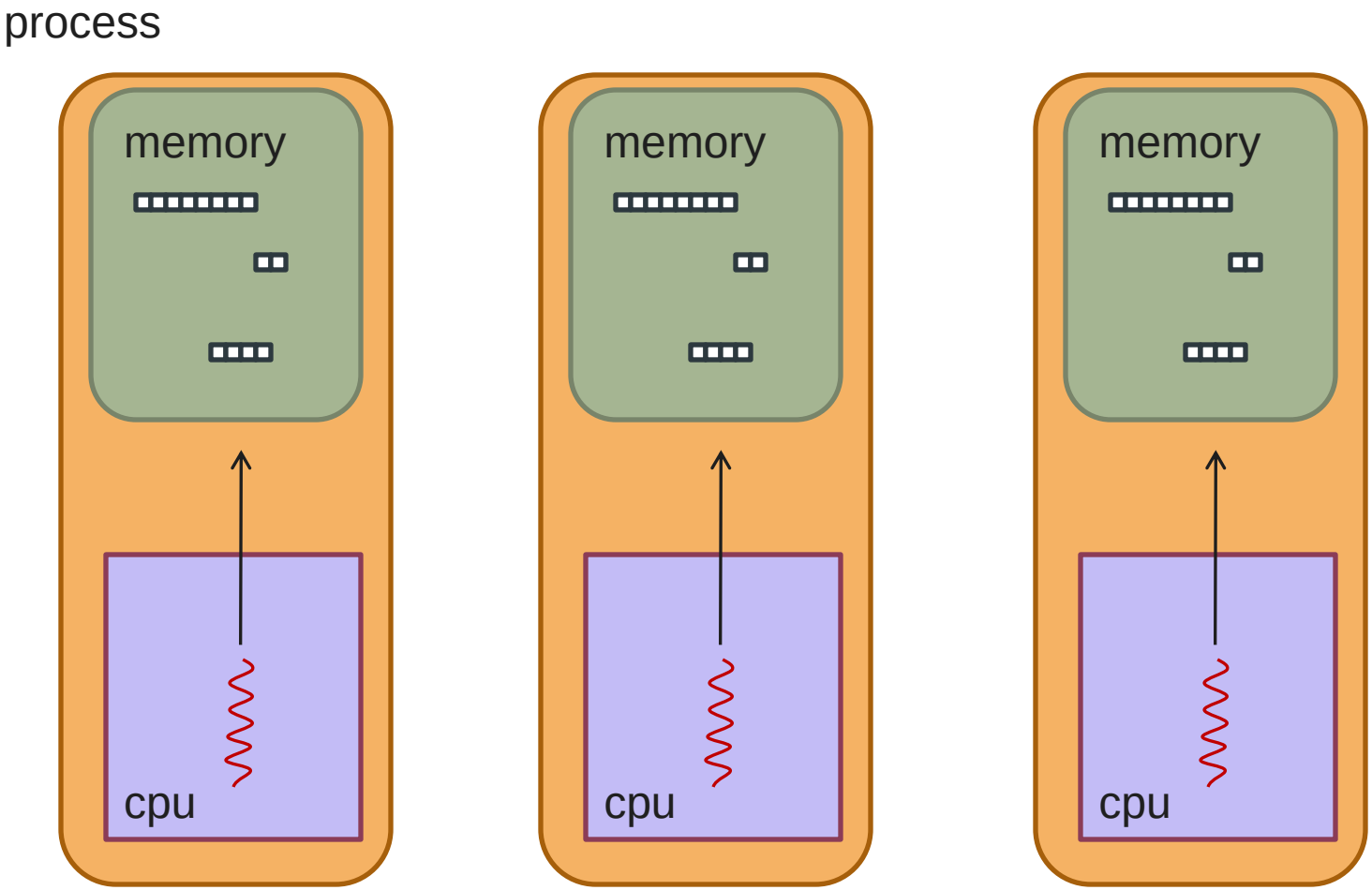


PROBLEM

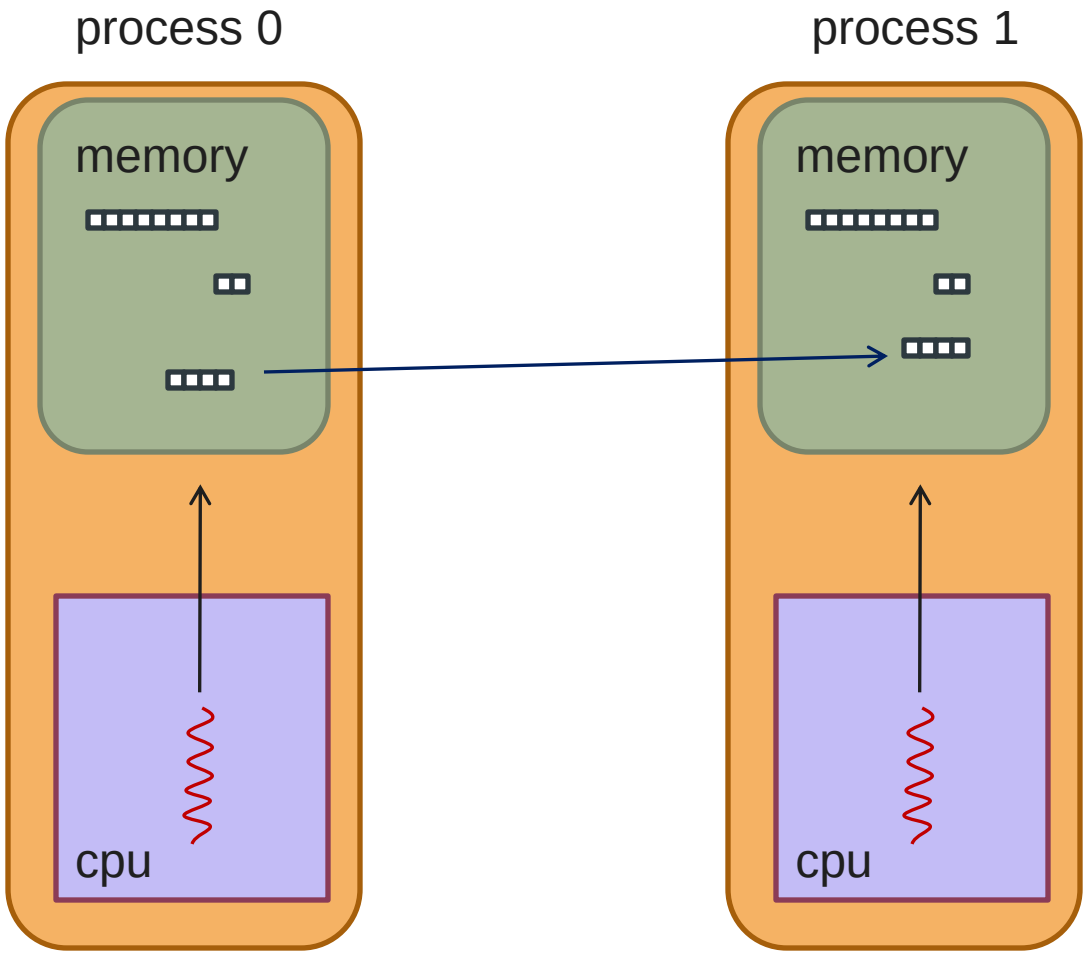


processes

Message Passing, MPI



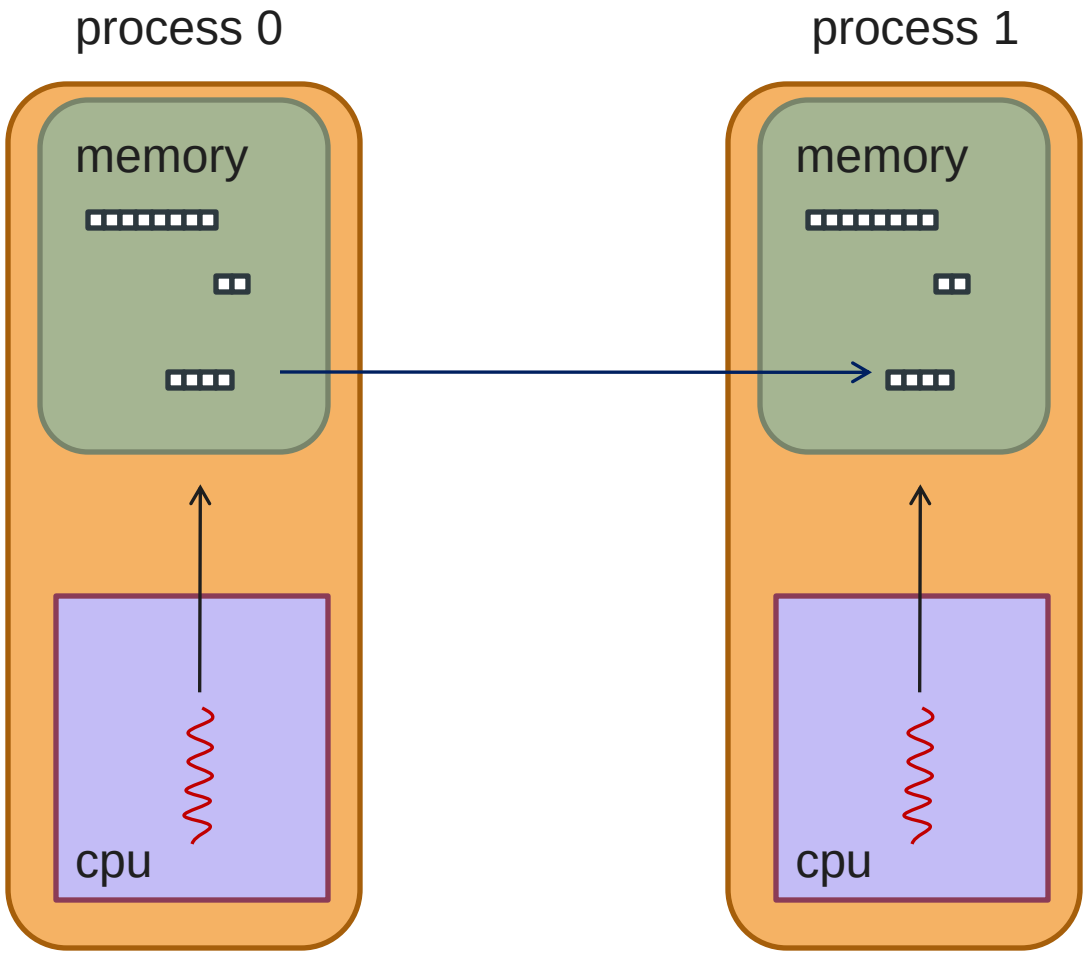
MPI


process 0
process 1
memory
memory
cpu
cpu
MPI_Send(a,...,1,…)
MPI_Recv(b,...,0,…)

Message Passing

- Participating processes communicate using a message-passing API
- Remote data can only be communicated (sent or received) via the API
- MPI (the Message Passing Interface) is the standard
- Implementation:
  MPI processes map to processes within one SMP node or across multiple networked nodes
- API provides process numbering, point-to-point and collective messaging operations
- Mostly used in two-sided way, each endpoint coordinates in sending and receiving

SHMEM




```
shmem_put(a, b, 1, …)
```

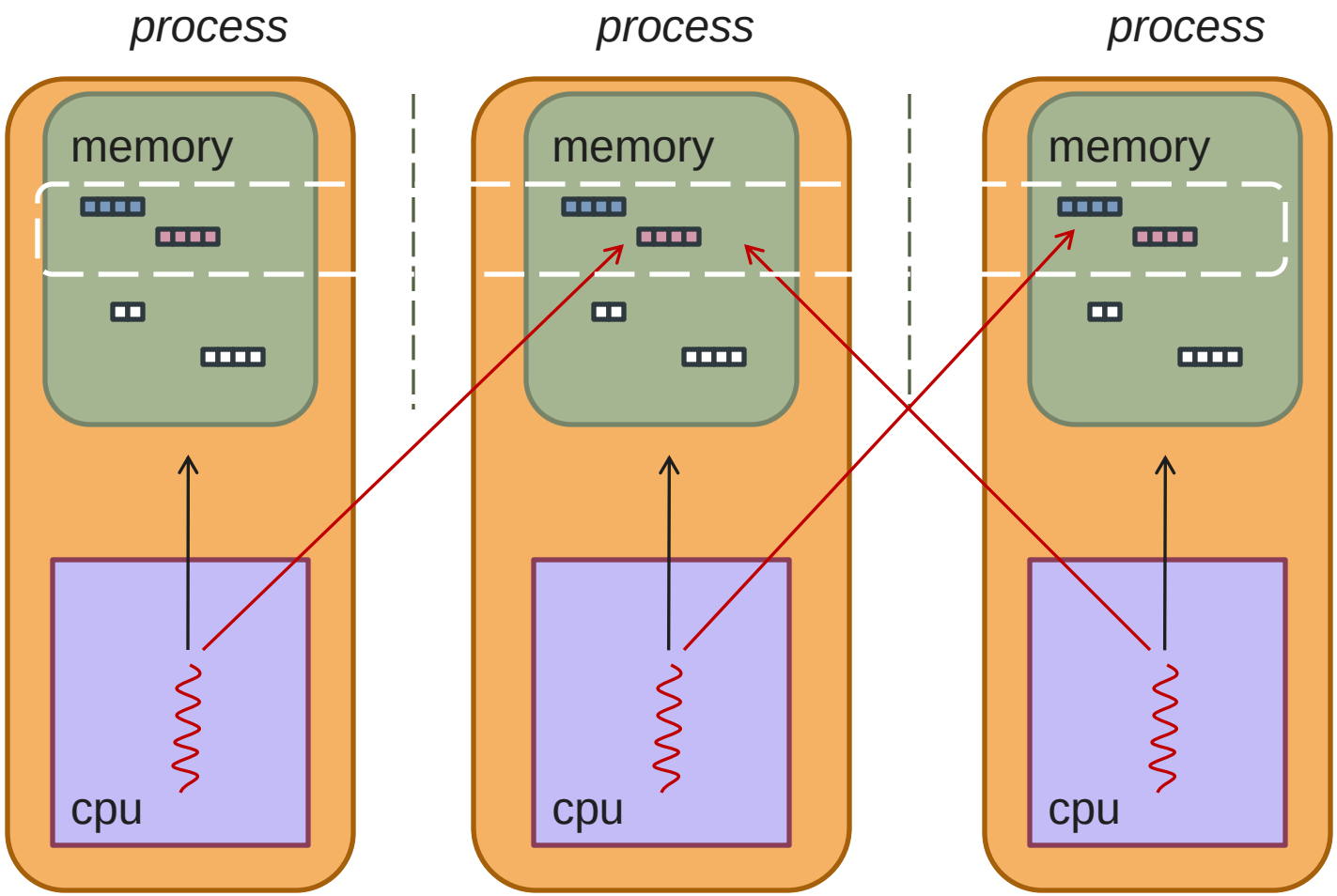
SHMEM

- Participating processes communicate using an API
- Fundamental operations are based on one-sided PUT and GET
- Need to use symmetric memory locations
- Remote side of communication does not participate
- Can test for completion
- Barriers and collectives
- Popular on Cray and SGI hardware, also Blue Gene version
- To make sense needs hardware support for low-latency RDMA-type operations

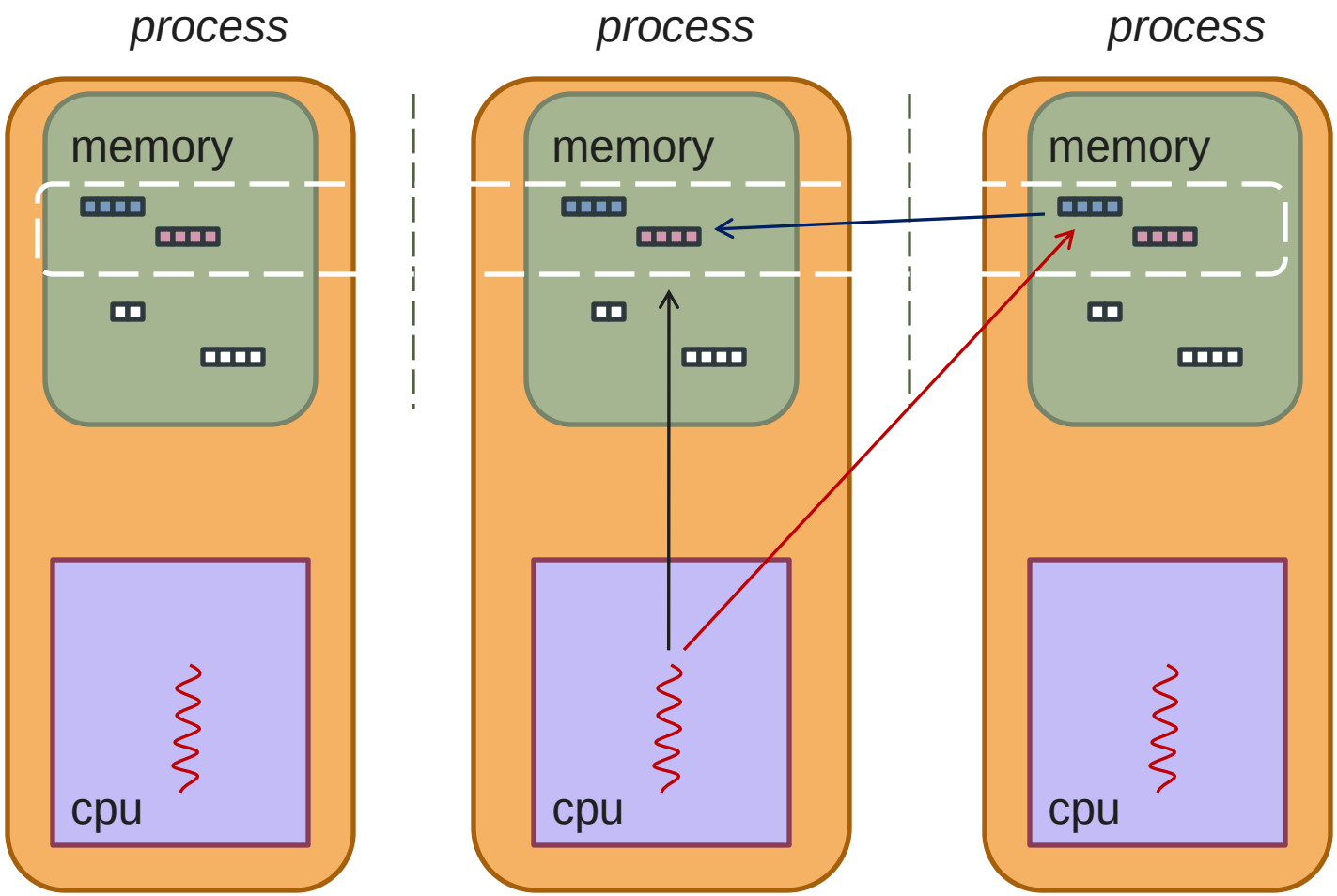
Fortran 2008 coarray model

- Example of a Partitioned Global Address Space (PGAS) model
- Set of participating processes like MPI
- Participating processes have access to **local memory** via standard program mechanisms
- Access to **remote memory** is directly supported by the language

Fortran coarray model



Fortran coarray model




```
a = b[3]
```

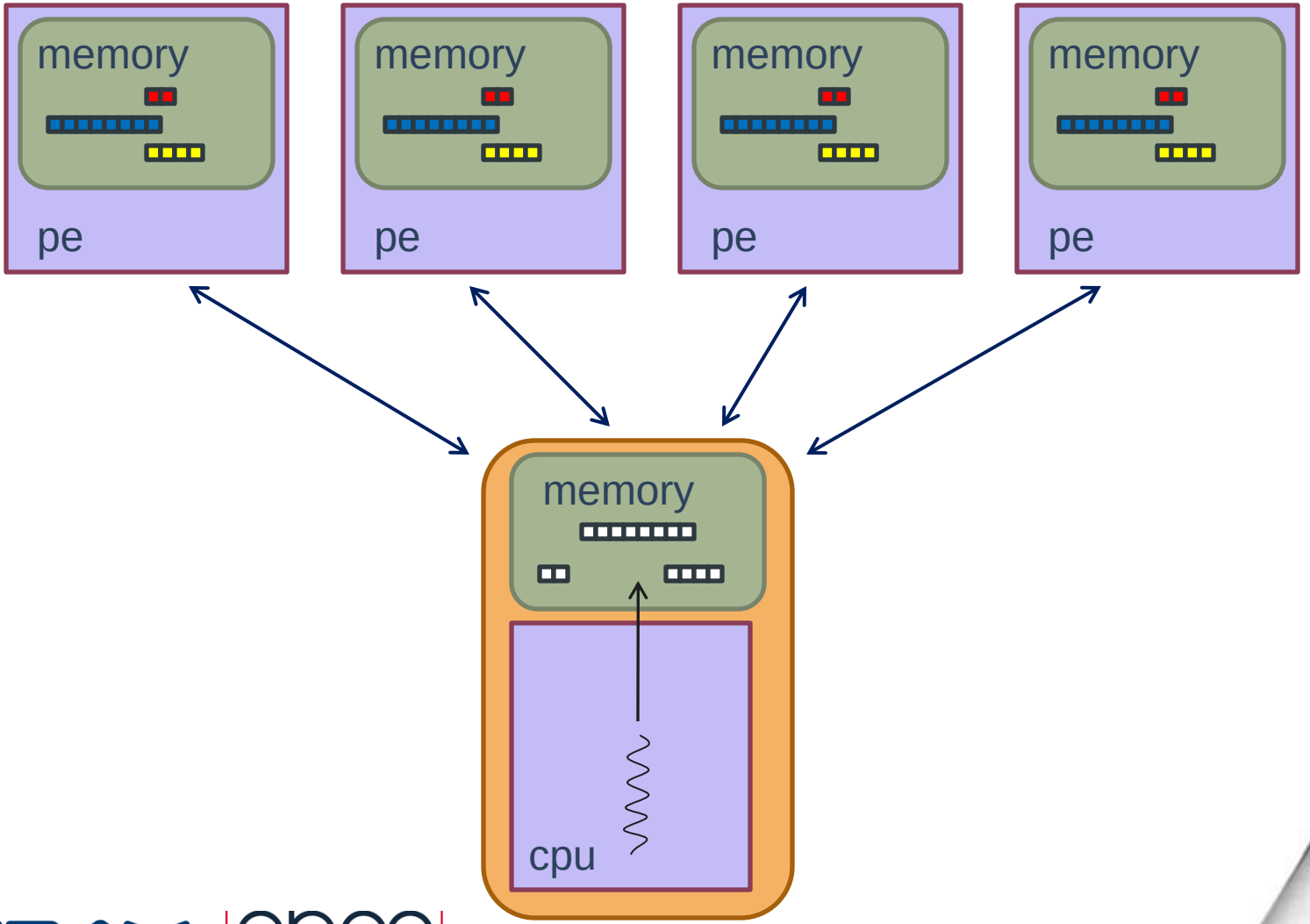
Fortran coarrays

- Remote access is a full feature of the language:
  - Type checking
  - Opportunity to optimize communication
- No penalty for local memory access
- Single-sided programming model more natural for some algorithms
  - and a good match for modern networks with RDMA

High Performance Fortran (HPF)

- Data Parallel programming model
- Single thread of control
- Arrays can be distributed and operated on in parallel
- Loosely synchronous
- Parallelism mainly from Fortran 90 array syntax, FORALL and intrinsics.
- This model popular on SIMD hardware (AMT DAP, Connection Machines) but extended to clusters where control thread is replicated

HPF



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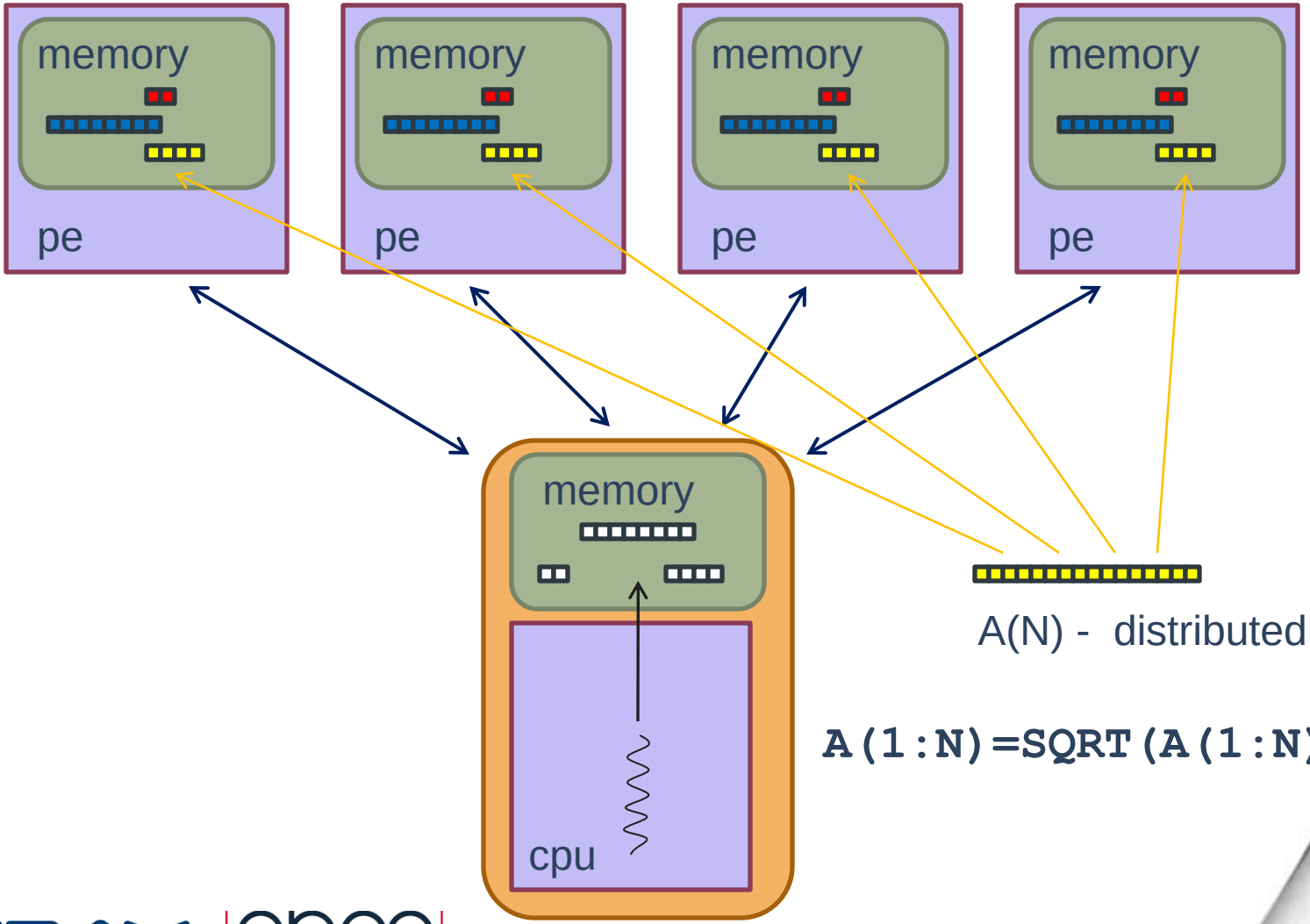
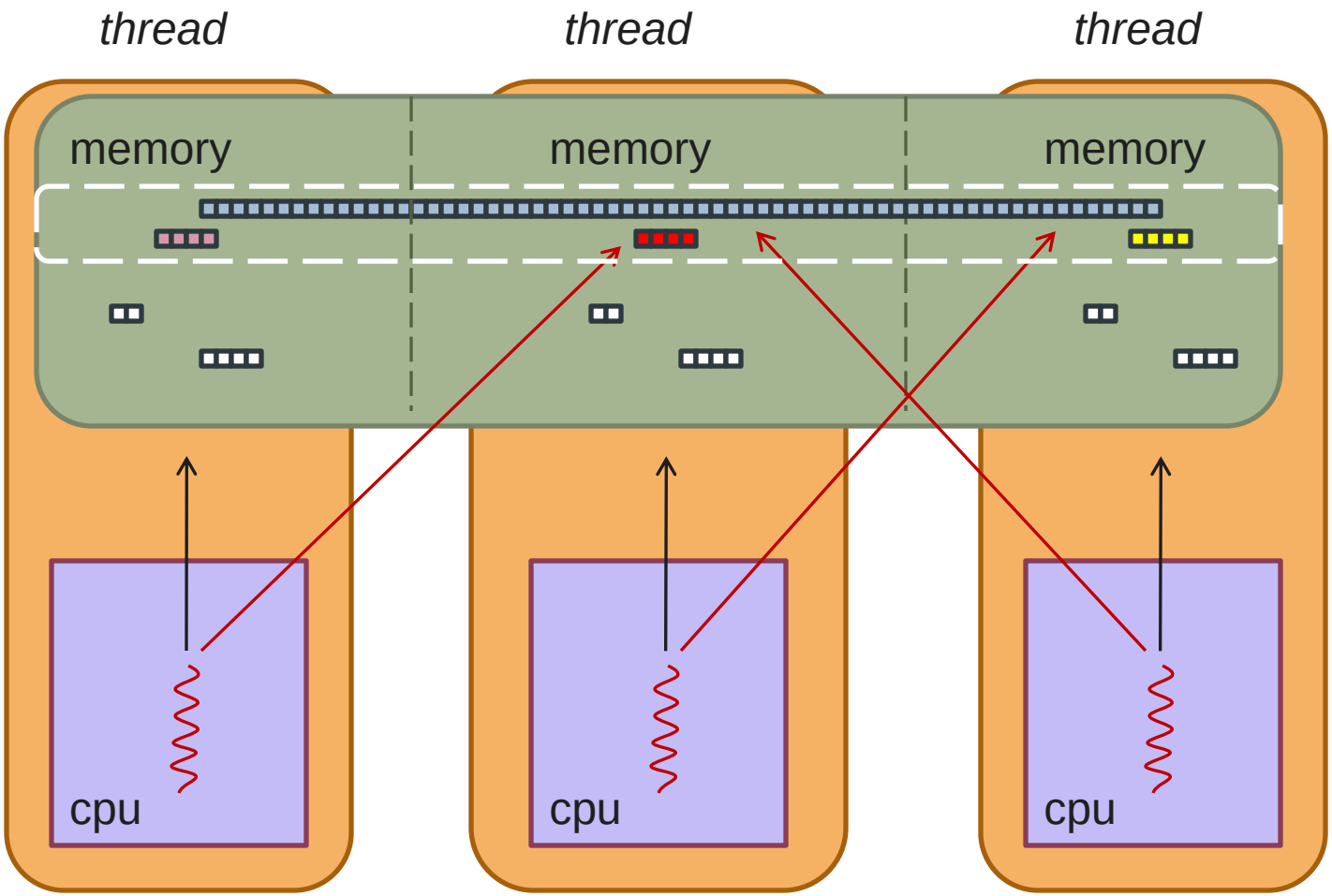
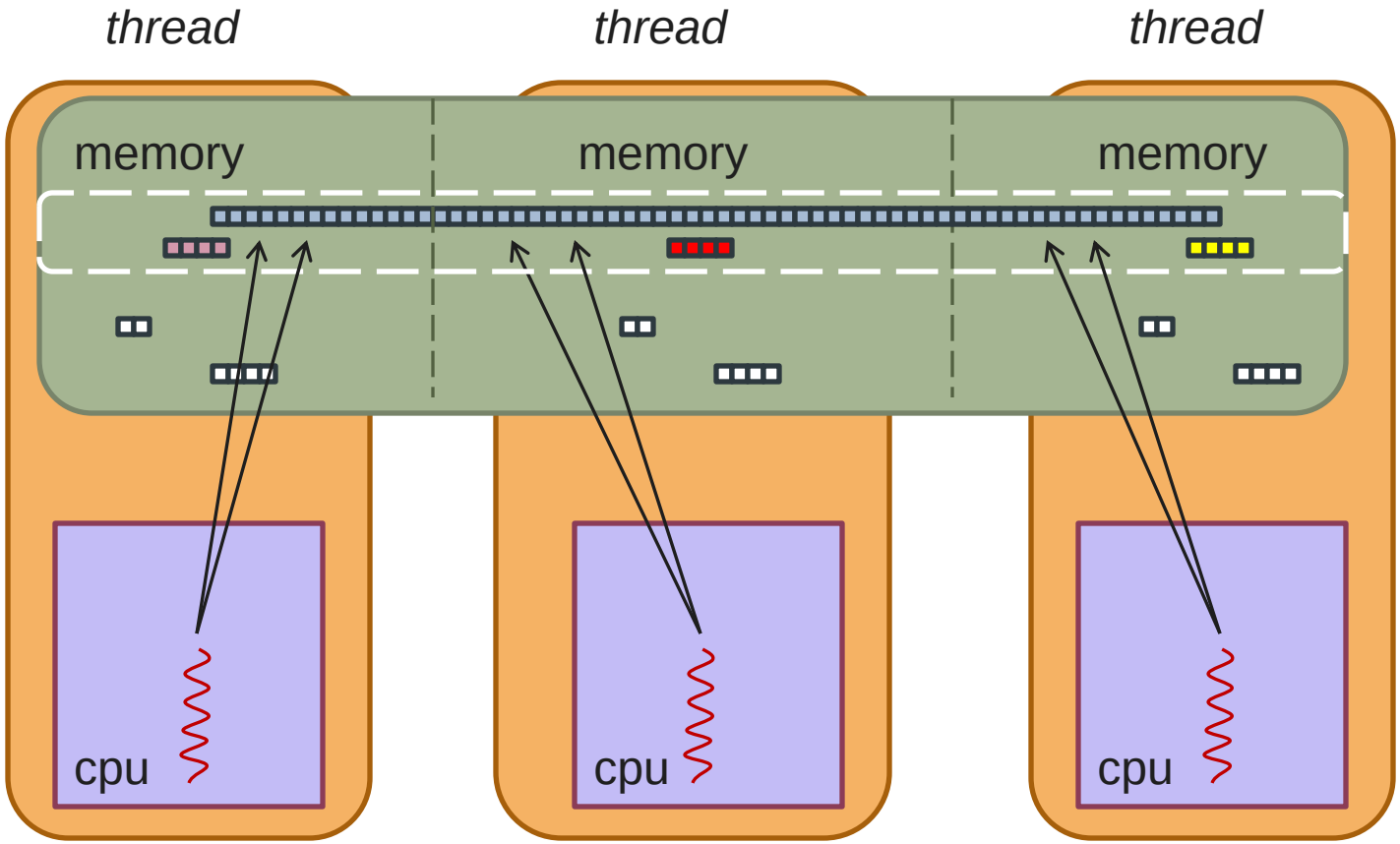
HPF


memory
pe
memory
pe
memory
pe
memory
pe
memory
cpu
A(N) - distributed
A(1:N)=SQRT(A(1:N))

UPC



UPC




```
upc_forall(i=0;i<32;i++;affinity){
  a[i]=a[i]*2;
}
```

UPC

- Extension to ISO C99
- Participating "*threads*"
- New *shared* data structures
  - shared pointers to distributed data (block or cyclic)
  - pointers to shared data local to a thread
  - Synchronization
- Language constructs to divide up work on shared data
  - upc_forall() to distribute iterations of for() loop
- Extensions for collectives
- Both commercial and open source compilers available
  - Cray, HP, IBM
  - Berkeley UPC (from LBL), GCC UPC

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