TECHNISCHE UNIVERSITÄT DRESDEN

- Exercises: April 11

TECHNISCHE UNIVERSITÄT DRESDEN

PARTITIONING IN MPI
COMMUNICATION AND NOISE AS HPC BOTTLENECK
LOAD BALANCING

DISTRIBUTED OPERATING SYSTEMS, SCALABILITY, SS 2017

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THIS LECTURE

- Partitioning:
  bulk synchronous execution
  MPI collectives
- Communication and Noise
- Load Balancing (MosiX):
  migration mechanisms
  information dissemination
  decision making

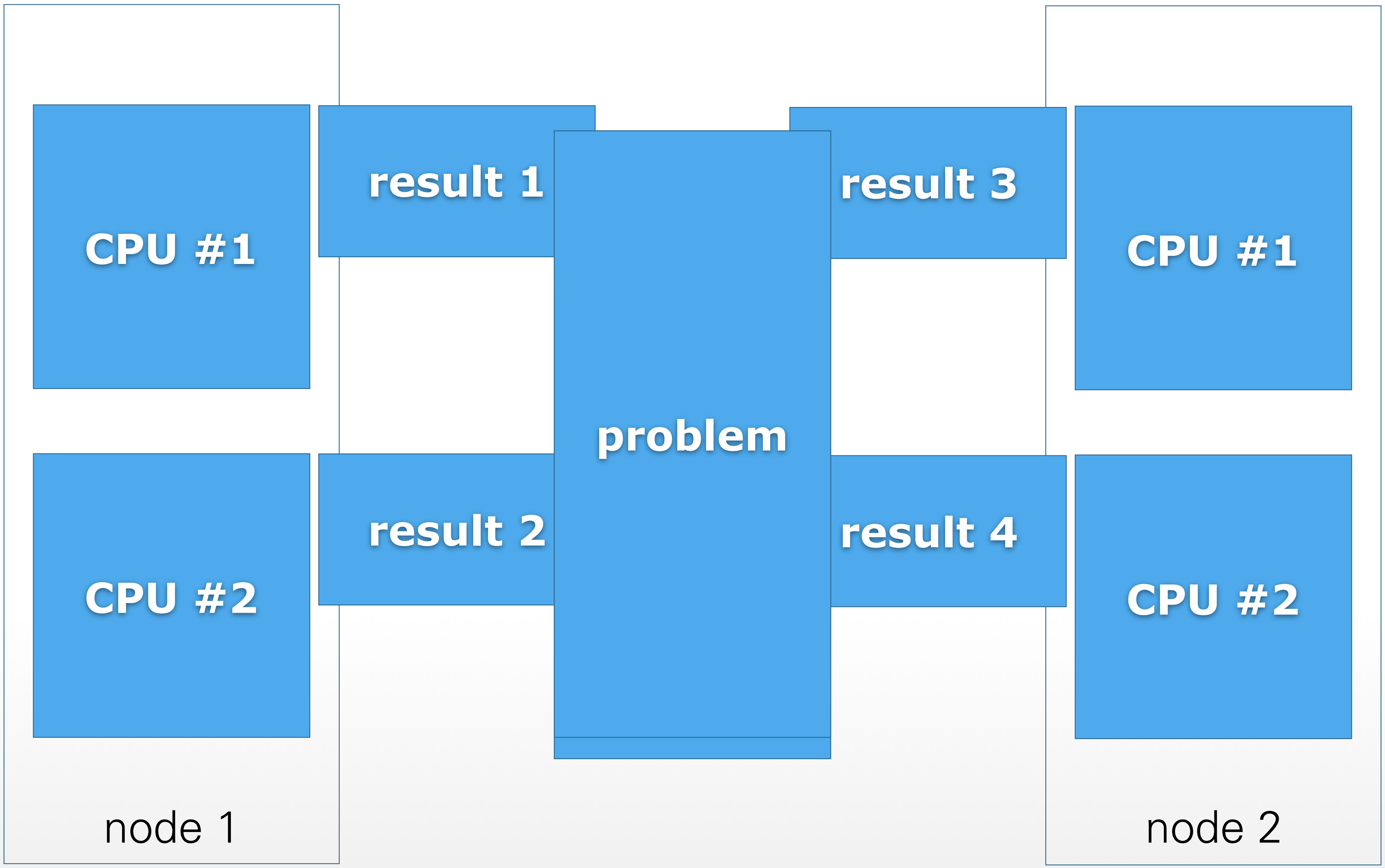
EXTREME STARTING POINTS

- independent OS processes
- bulk synchronous execution (HPC)
  - sequence: compute - communicate
  - all processes wait for all other processes
  - often: message passing
    for example Message Passing Library (MPI)

BULK SYNCHRONOUS

- all processes execute same program
- while (true)
  { work; exchange data (barrier)}
- common in
  High Performance Computing:
  Message Passing Interface (MPI)
  library

DIVIDE AND CONQUER



BRIEF INTRO INTO "MPI"

MPI: Message Passing Interface

- Library for message-oriented parallel programming
- Common but not mandatory
Programming model:
  - Multiple instances of same program
  - Independent calculation
  - Communication, synchronization

MPI STARTUP & TEARDOWN

- MPI program is started on all processors
- `MPI_Init()`, `MPI_Finalize()`
- Communicators (e.g., MPI_COMM_WORLD)
  - `MPI_Comm_size()`
  - `MPI_Comm_rank()`:
    “Rank” of process within this set
  - Typed messages
- (Dynamically create and spread processes using `MPI_Spawn()` (since MPI-2))

MPI EXECUTION

- Communication
  - Point-to-point
  - Collectives
- Synchronization
  - Test
  - Wait
  - Barrier

```
MPI_Send(
  void *buf,
  int count,
  MPI_Datatype datatype,
  int dest,
  int tag,
  MPI_Comm comm
)
```

BLOCK AND SYNC

	blocking call	non-blocking call
synchronous communication	returns when message has been delivered	returns immediately, following test/wait checks for delivery
asynchronous communication	returns when send buffer can be reused	returns immediately, following test/wait checks for send buffer

EXAMPLE

```
int rank, total;
MPI_Init();
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
MPI_Comm_size(MPI_COMM_WORLD, &total);

MPI_Bcast(...);
/* work on own part, determined by rank */

if (id == 0) {
  for (int rr = 1; rr < total; ++rr)
    MPI_Recv(...);
  /* Generate final result */
} else {
    MPI_Send(...);
}
MPI_Finalize();
```

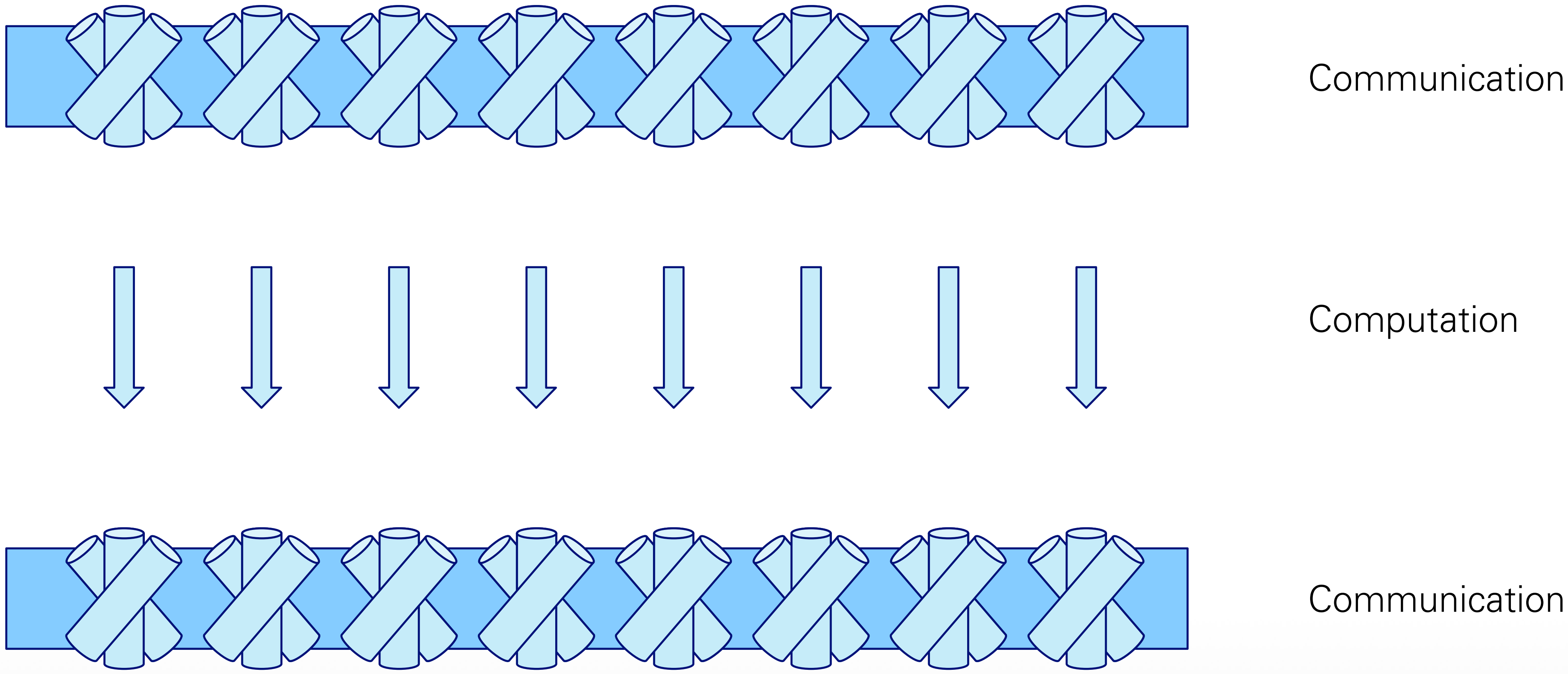
AMDAHLS' LAW

interpretation for parallel systems:

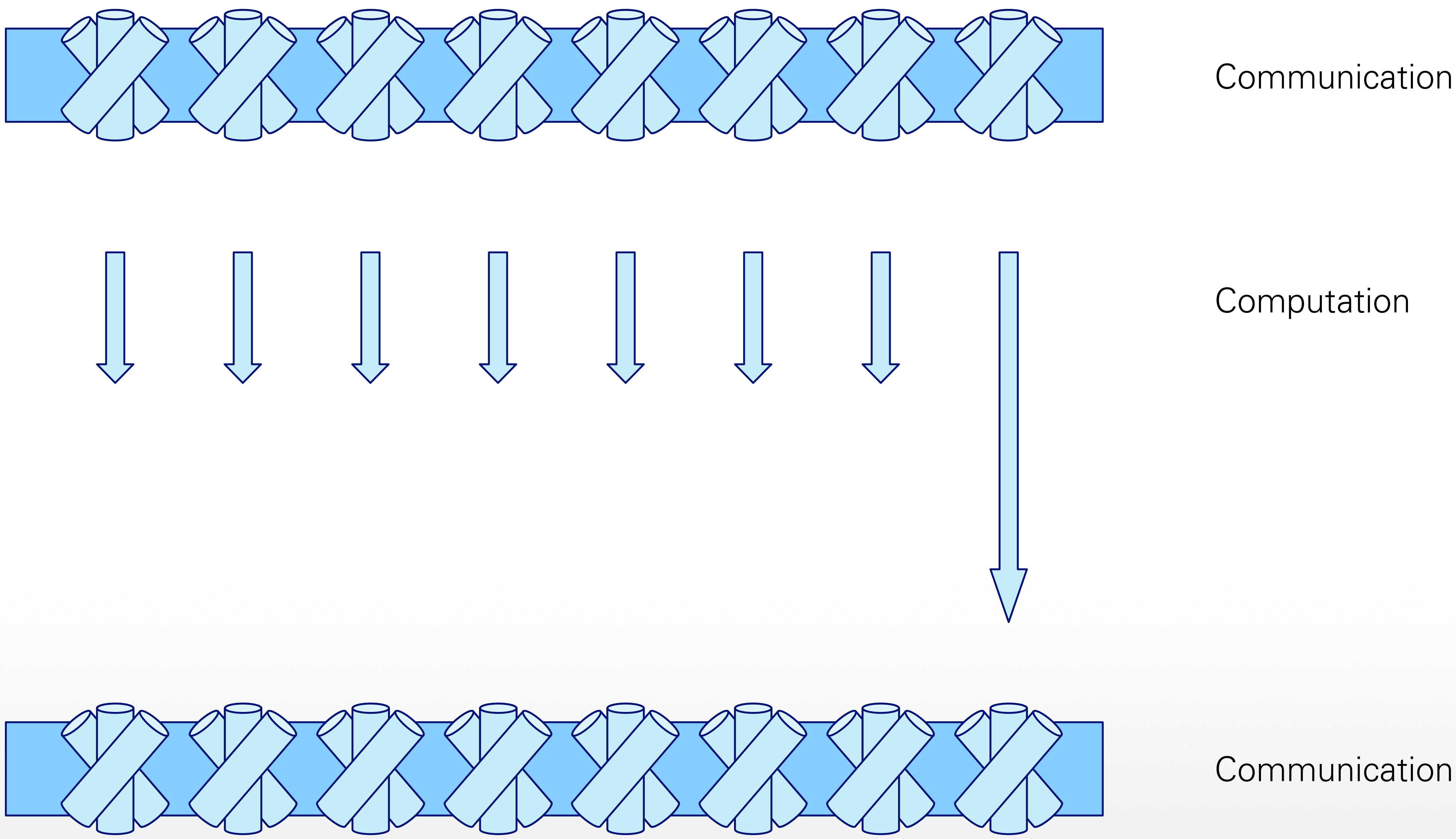
- P: section that can be parallelized
- 1-P: serial section
- N: number of CPUs

$$\text{Speedup}(P,N) = \frac{1}{\left(1 - P + \frac{P}{N}\right)}$$

BLOCK SYNCHRONOUS EXECUTION



BLOCK SYNCHRONOUS EXECUTION



AMDAHL'S LAW

Serial section:
communicate, longest sequential section

Parallel,	"Serial",	possible speedup:	
1ms,	100 µs:	1/0.1	→ 10
1ms,	1 µs:	1/0.001	→ 1000
10 µs,	1 µs:	0.01/0.001	→ 10
...			

WEAK VS. STRONG SCALING

Strong:

- accelerate same problem size

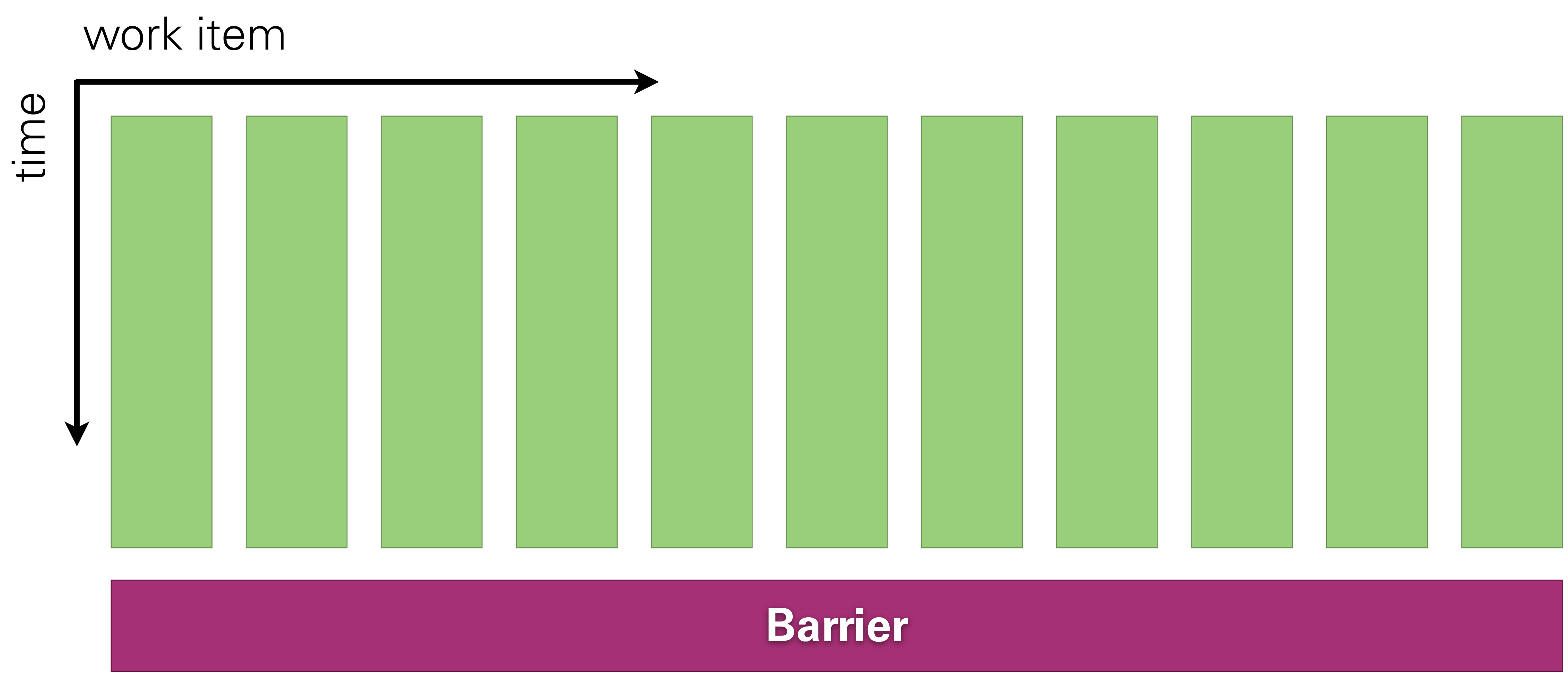
Weak:

- extend to larger problem size

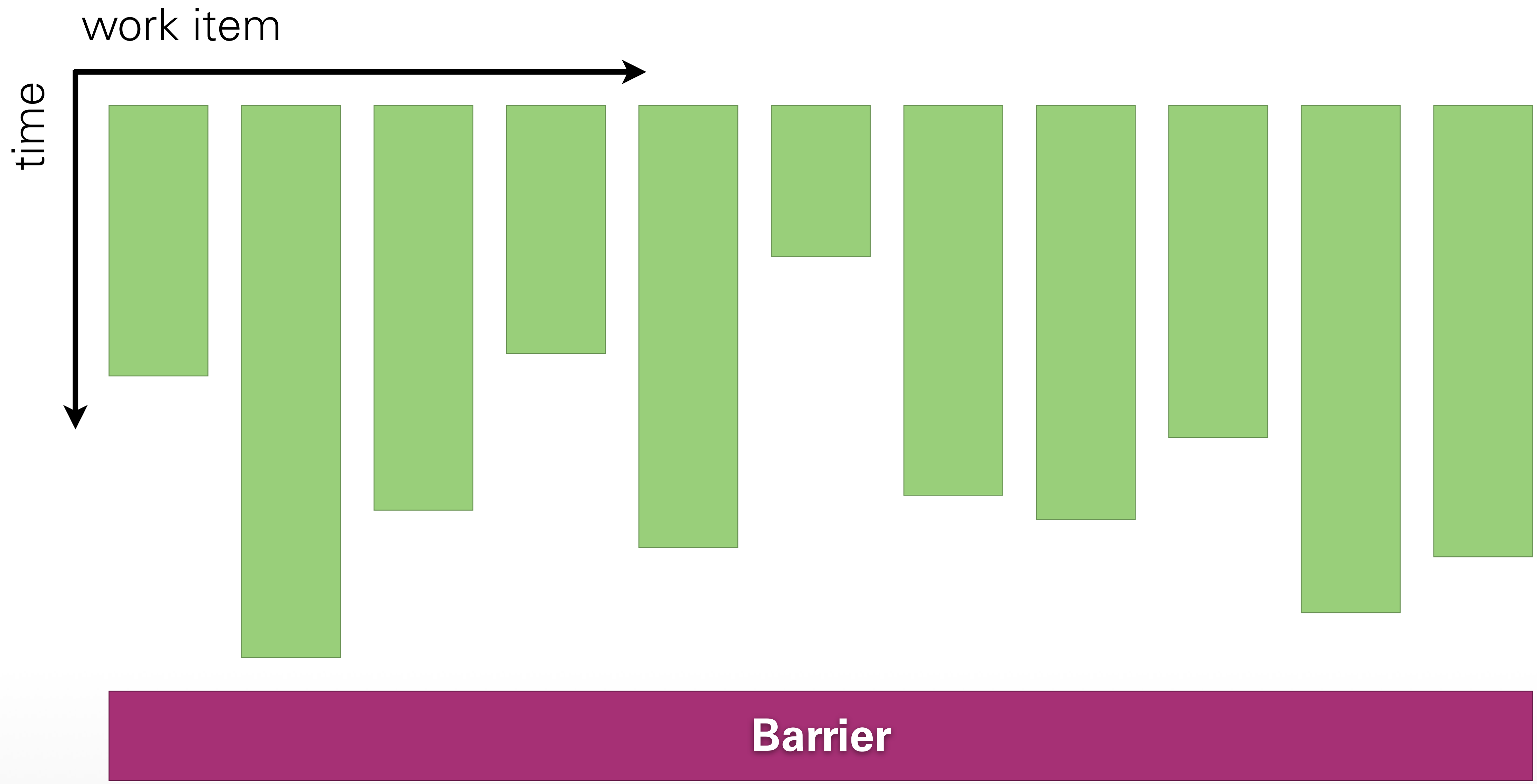
PROBLEMS

- noise
  - execution time jitter
  - interrupt latency
- balance load in case of unbalanced applications

THE NEED FOR BALANCING



THE NEED FOR BALANCING



OPERATING SYSTEM "NOISE"

Use common sense to avoid:

- OS usually not directly on the critical path,
  BUT OS controls: interference via interrupts, caches, network, memory bus, (RTS techniques)
- avoid or encapsulate side activities
- small critical sections (if any)
- partition networks to isolate traffic of different applications (HW: Blue Gene)
- do not run Python scripts or printer daemons in parallel

RESEARCH TOPIC

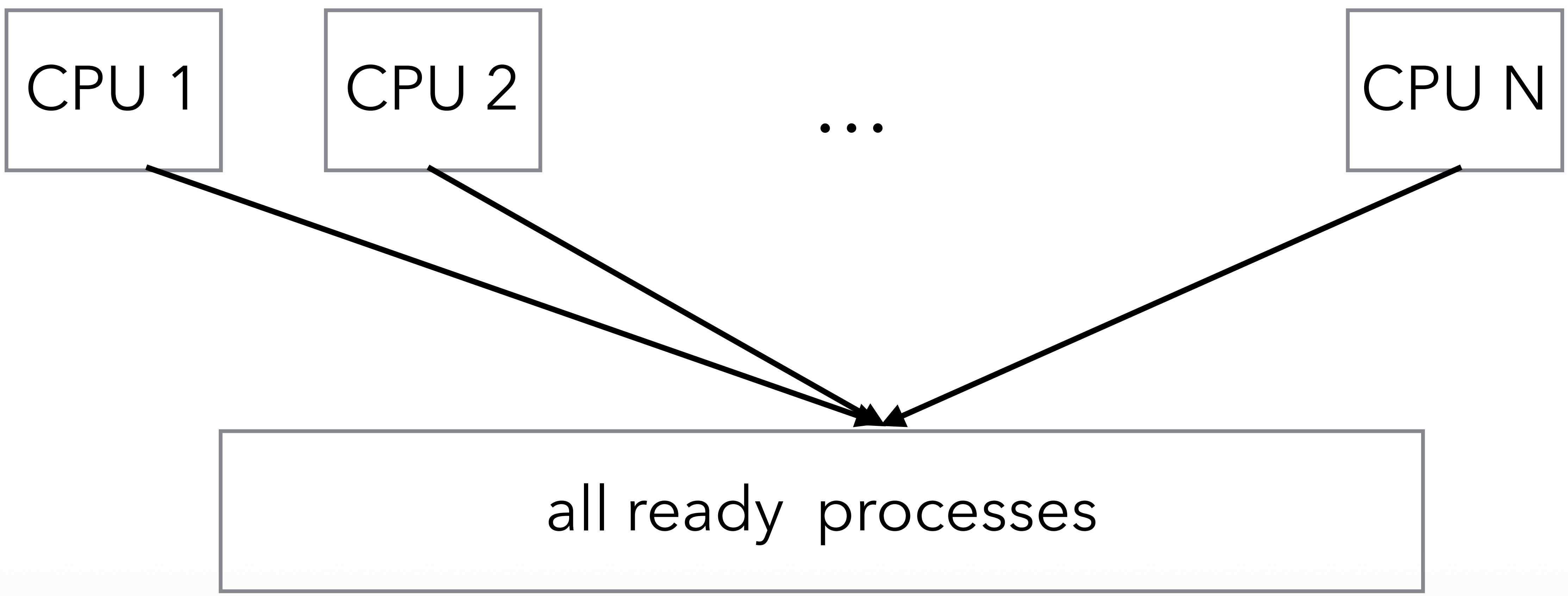
- use small kernel to isolate

BALANCING

balancing in systems architecture

- application
- run-time library
- operating system

SCHEDULER: GLOBAL RUN QUEUE



immediate approach: global run queue

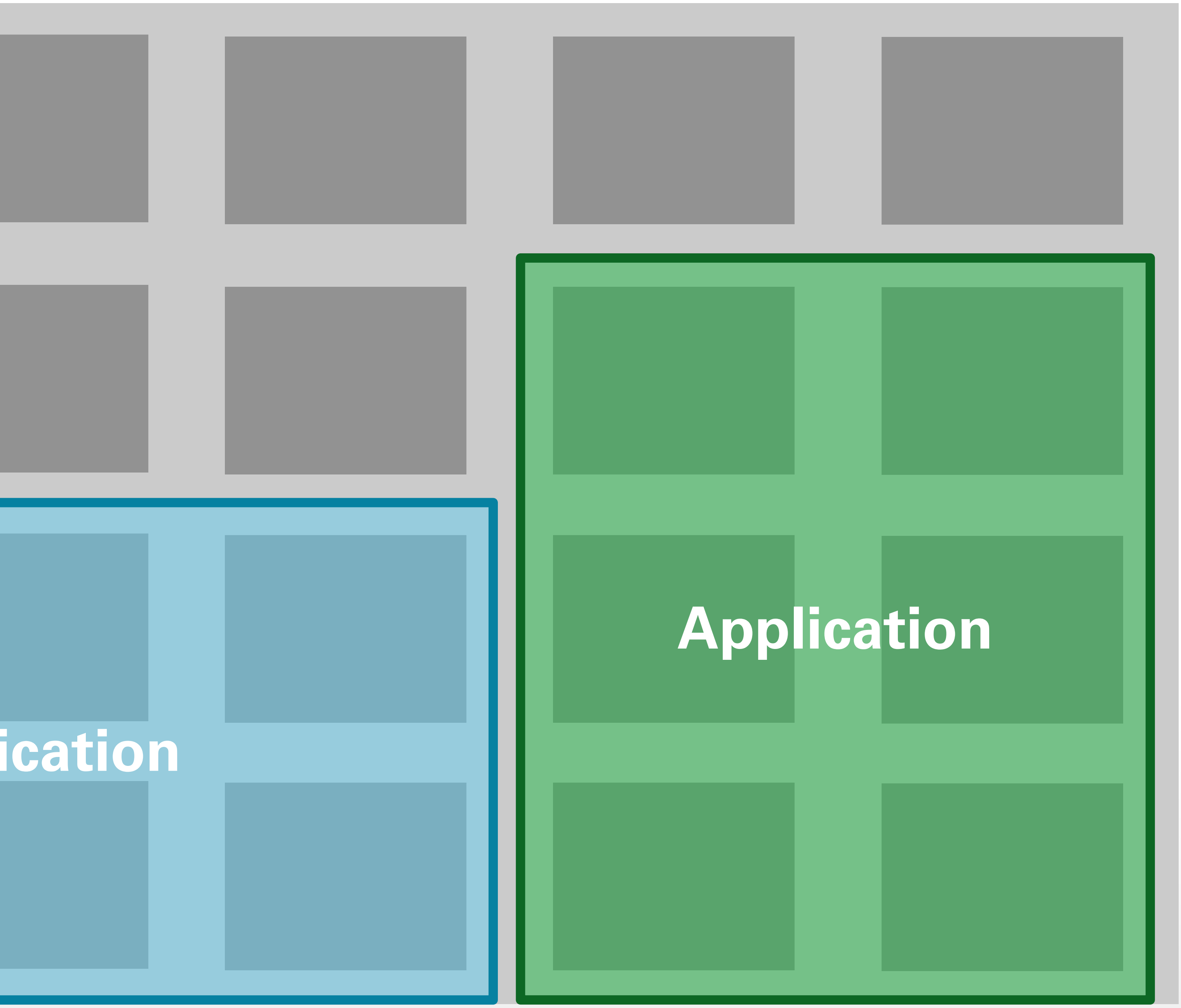
SCHEDULER: GLOBAL RUN QUEUE

- … does not scale
  - shared memory only
  - contended critical section
  - cache affinity
  - …
- ⇒ separate run queues with explicit movement of processes

High Performance Computing

- Operating System / Hardware:
  "All" participating CPUs: active / inactive
  - Partitioning (HW)
  - Gang Scheduling (OS)
- Within Gang/Partition:
  Applications balance !!!

HW PARTITIONS & ENTRY QUEUE



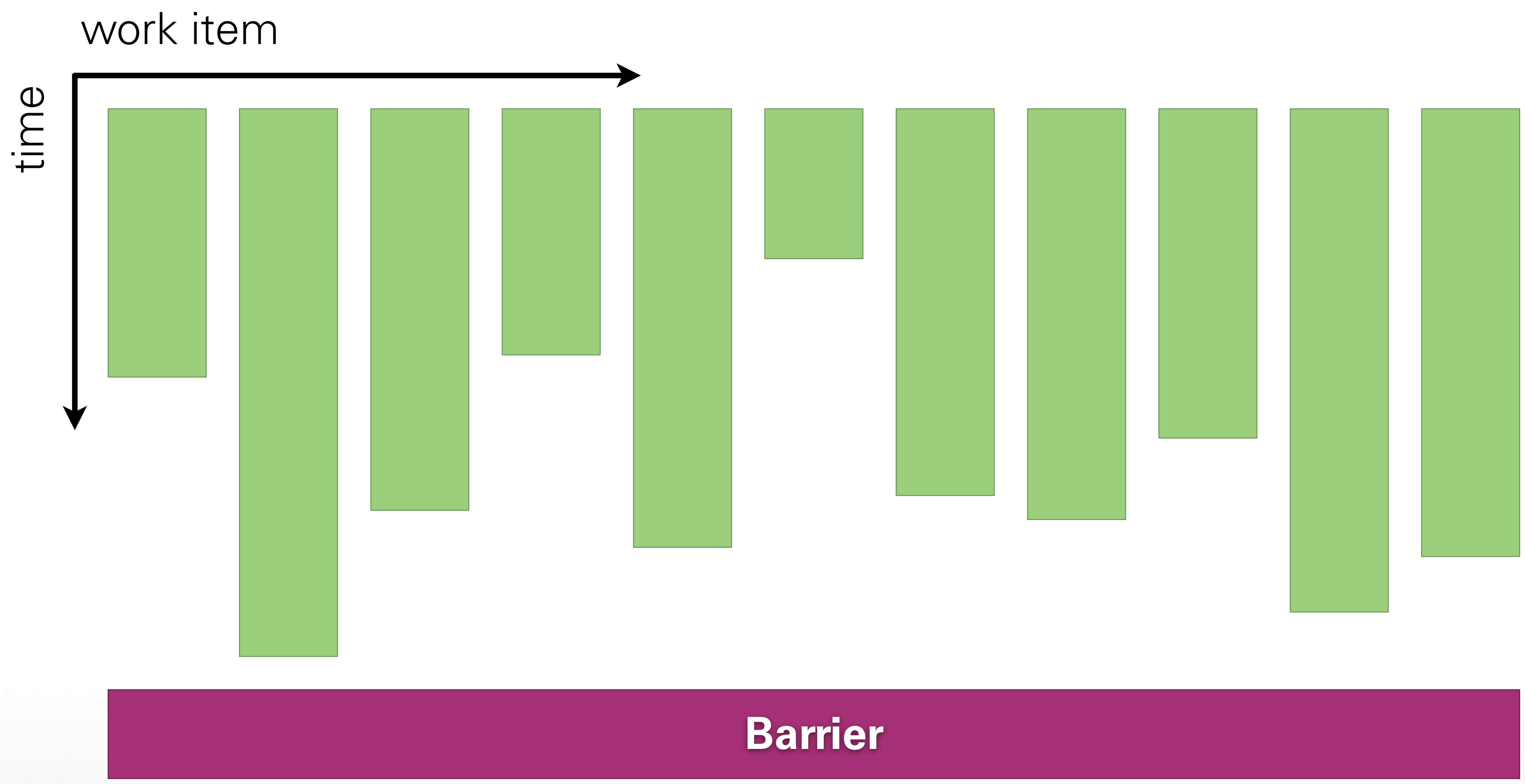
request queue

BATCH SCHEDULER

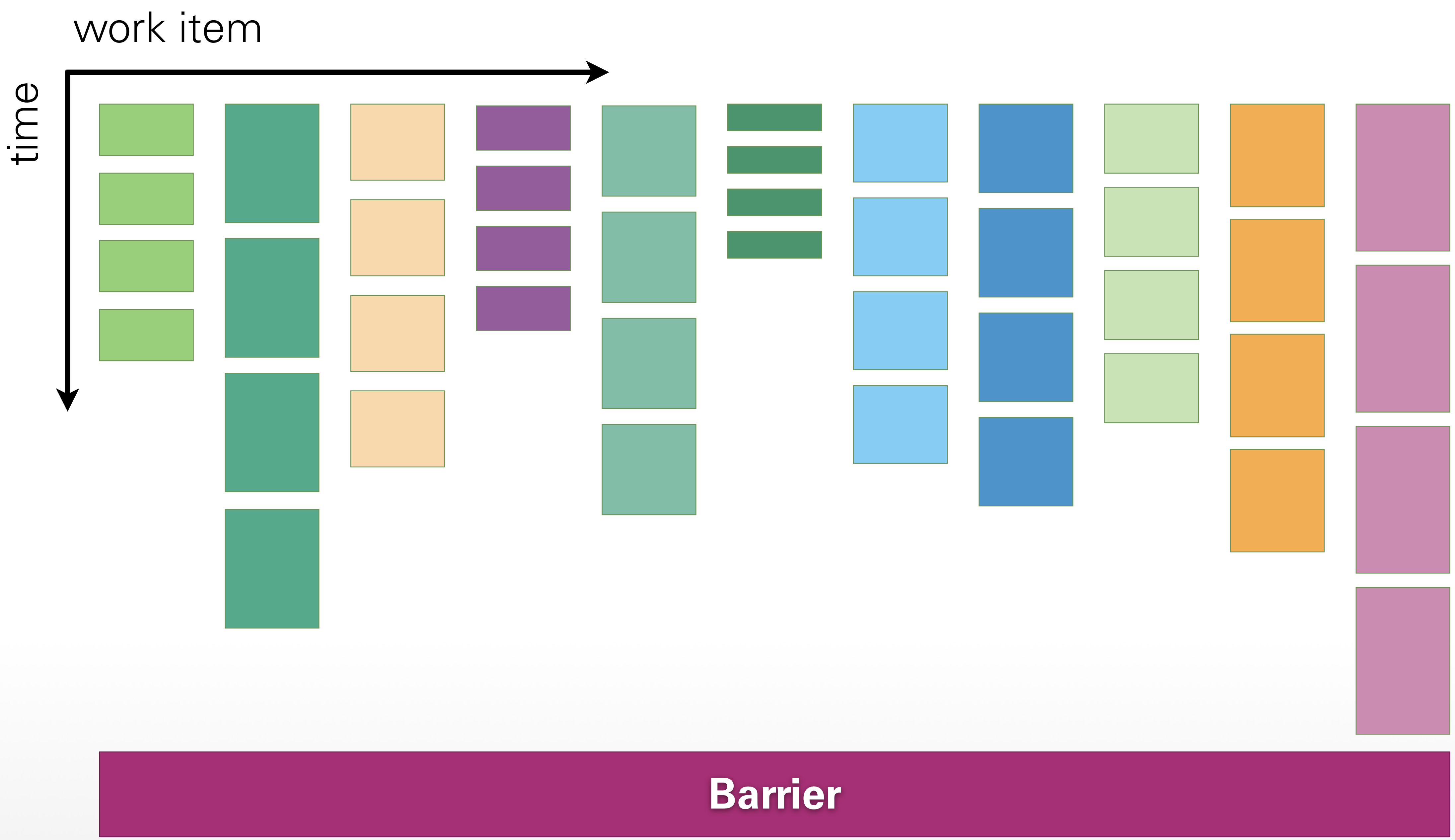
PROPERTIES HW PARTITIONS

- optimizes usage of network
- takes OS off critical path (busy waiting)
- best for strong scaling
- burdens application/library with balancing
- potentially wastes resources
- current state of the art in High Performance Computing (HPC)

TOWARDS SYSTEM-LEVEL BALANCING

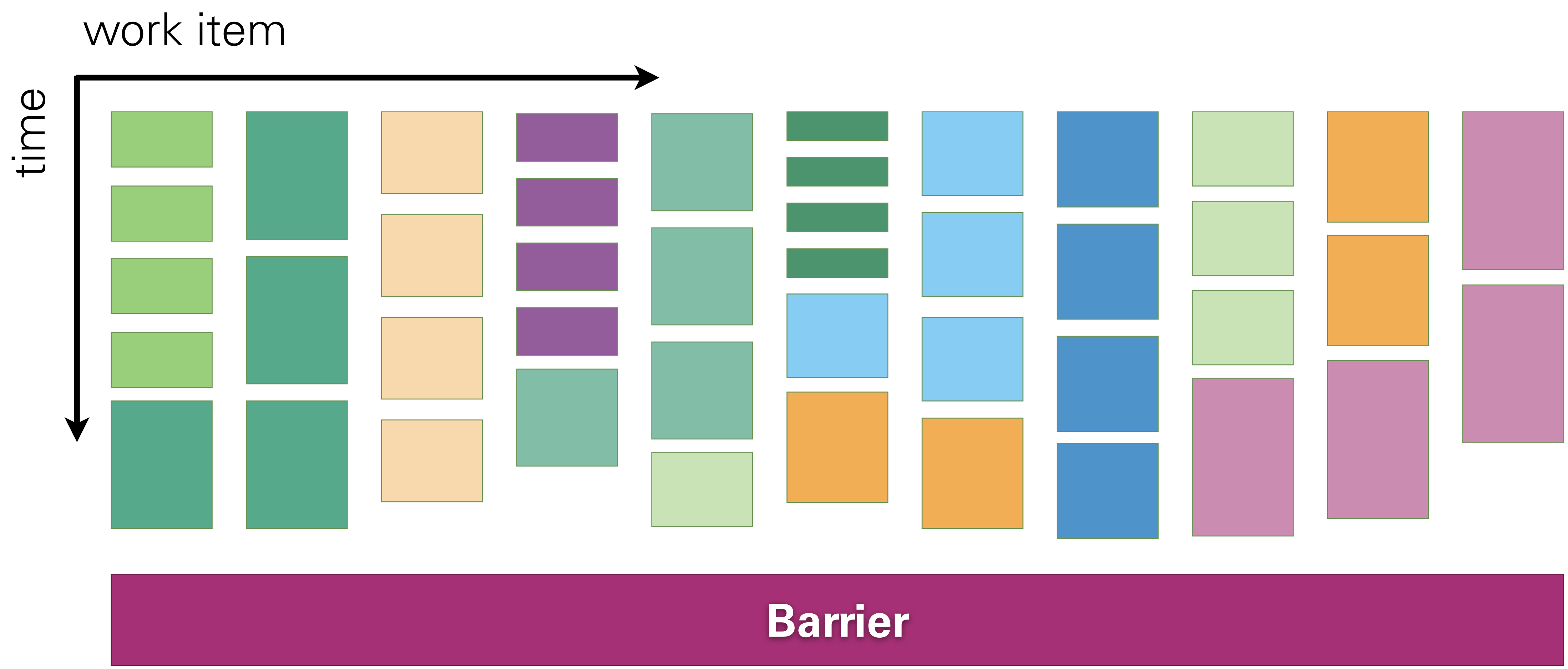


SPLITTING BIG JOBS



overdecomposition & “oversubscription”

SMALL JOBS (NO DEPS)



Execute small jobs in parallel (if possible)

BALANCING AT LIBRARY LEVEL

Programming Model

- many (small) decoupled work items
- overdecompose
  create more work items than active units
- run some balancing algorithm

Example: CHARM ++

BALANCING AT SYSTEM LEVEL

- create many more processes
- use OS information on run-time and system state to balance load
- examples:
  - run multiple applications
  - create more MPI processes than nodes (!)

CAVEATS

added overhead

- additional communication between smaller work items (memory & cycles)
- more context switches
- OS on critical path (for example communication)

BALANCING ALGORITHMS

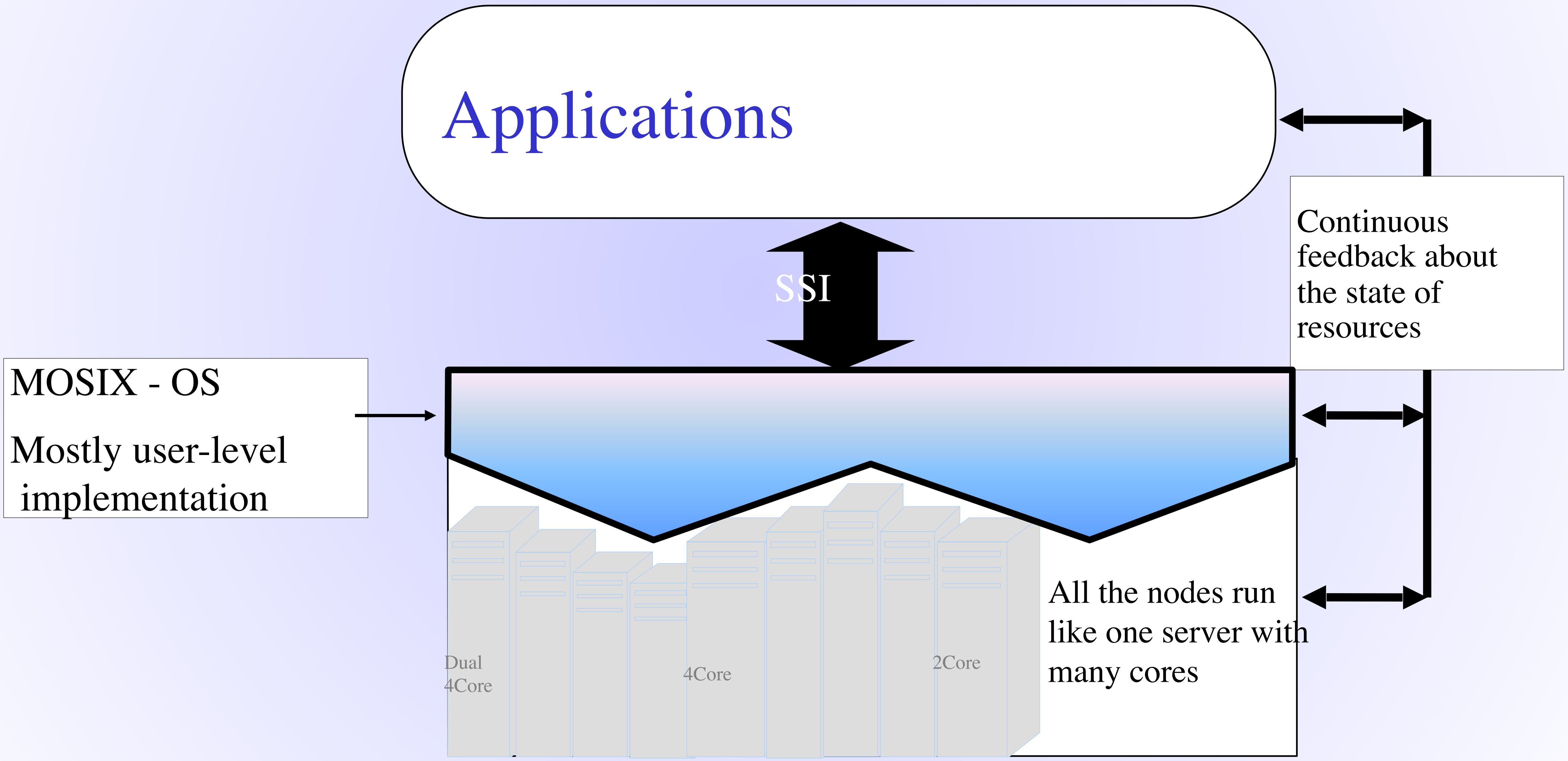
required:

- mechanism for migrating load
- information gathering
- decision algorithms

MosiX system as an example

-> Barak's slides now

MOSIX is a unifying management layer



The main software components

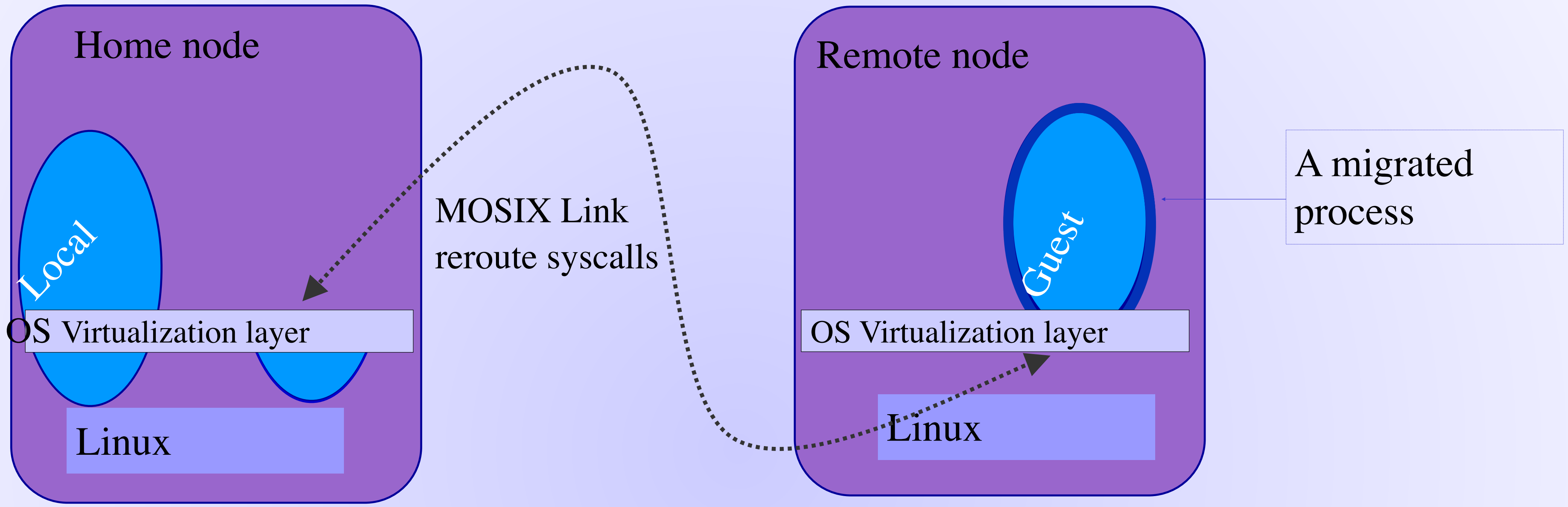
1. Preemptive process migration
   - Can migrate a running processes anytime
   - Like a course-grain context switch
     - Implication on caching, scheduling, resource utilization
2. OS virtualization layer
   - Allows a migrated process to run in remote nodes
3. On-line algorithms
   - Attempt to optimize a given goal function by process migration
     - Match between required and available resources
   - Information dissemination – based on partial knowledge

Note: features that are taken for granted in shared-memory systems, are not easy to support in a cluster

The OS virtualization layer

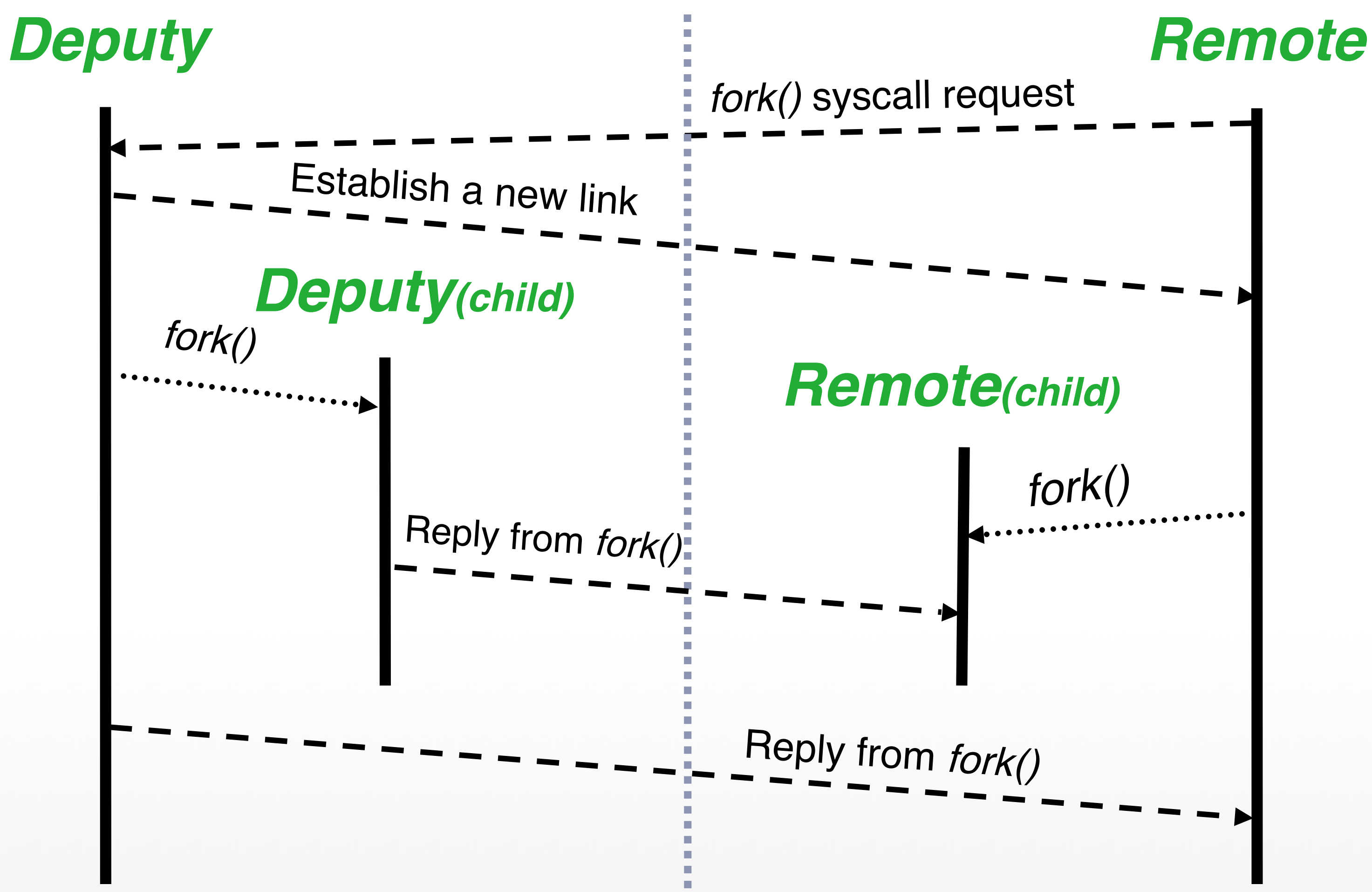
- A software layer that allows a migrated process to run in remote nodes, away from its home node
  - All system-calls are intercepted
    - Site independent sys-calls are performed locally, others are sent home
  - Migrated processes run in a sandbox
- Outcome:
  - A migrated process seems to be running in its home node
  - The cluster seems to the user as one computer
  - Run-time environment of processes are preserved - no need to change or link applications with any library, copy files or login to remote nodes
- Drawback: increased (reasonable) communication overhead

Process migration - the home node model

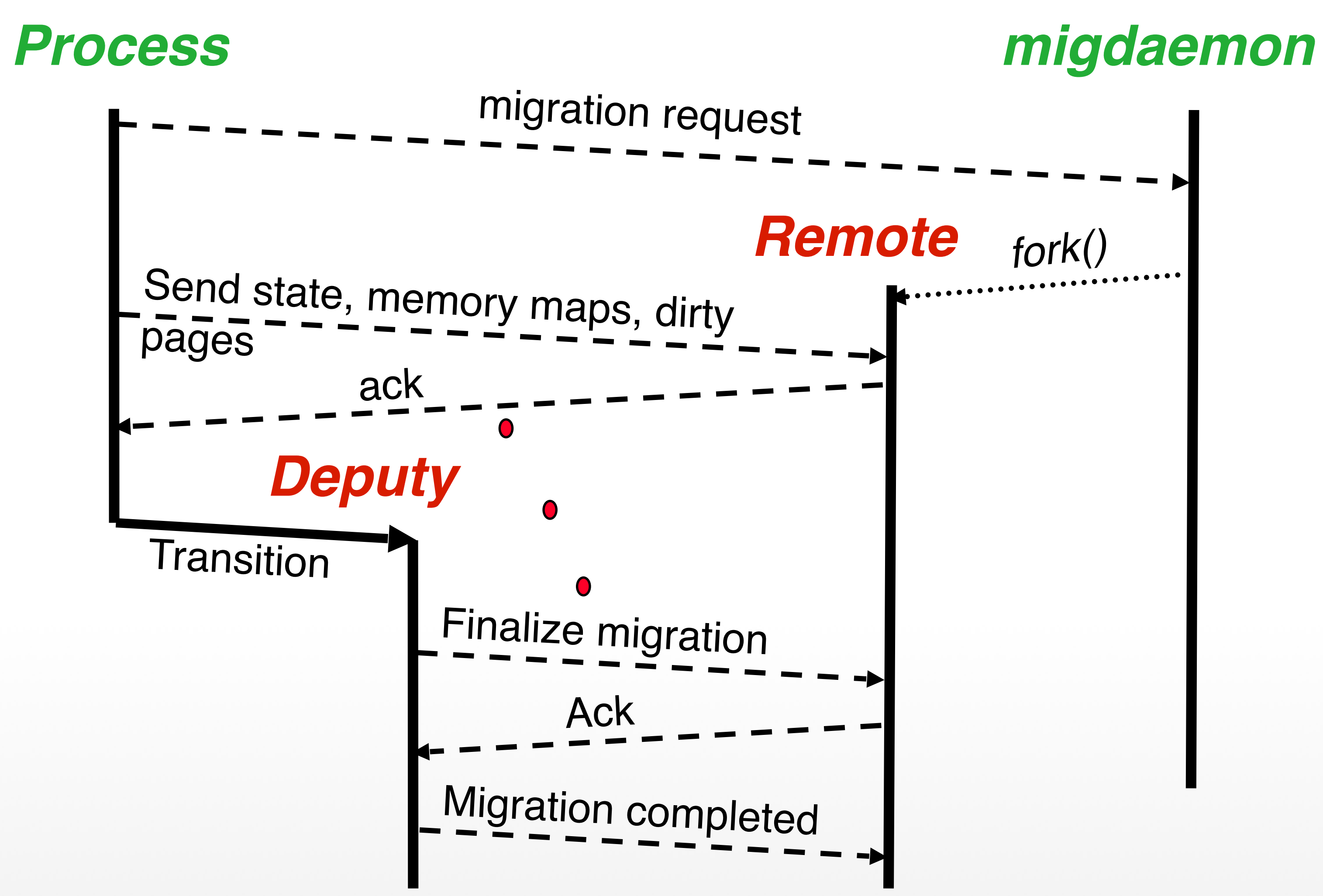


- **Process migration – move the process context to a remote node**
  - **System context stay at “home” thus providing a single point of entry**
- **Process partition preserves the user’s run-time environment**
  - **Users need not care where their process are running**

FORK IN MOSIX



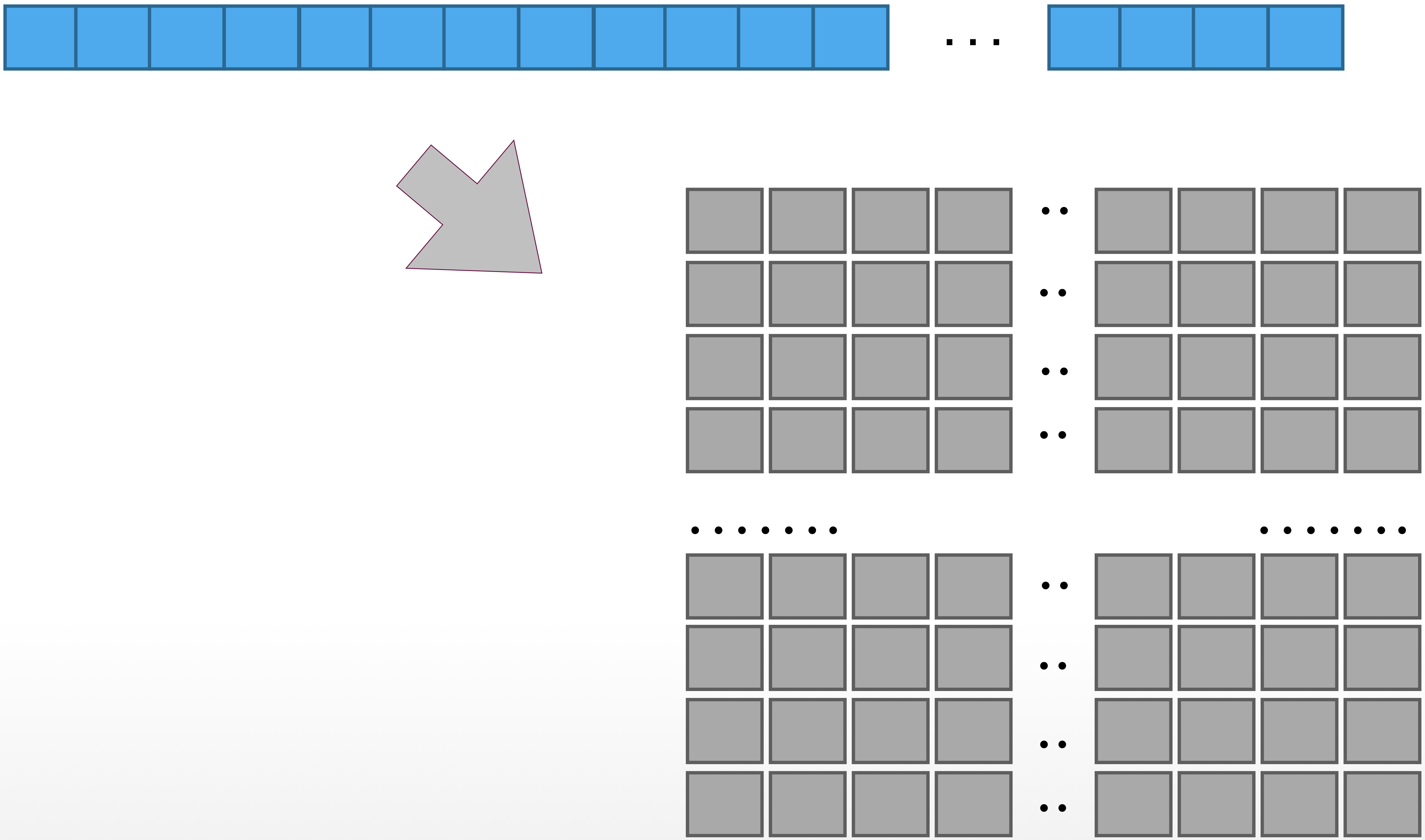
PROCESS MIGRATION IN MOSIX



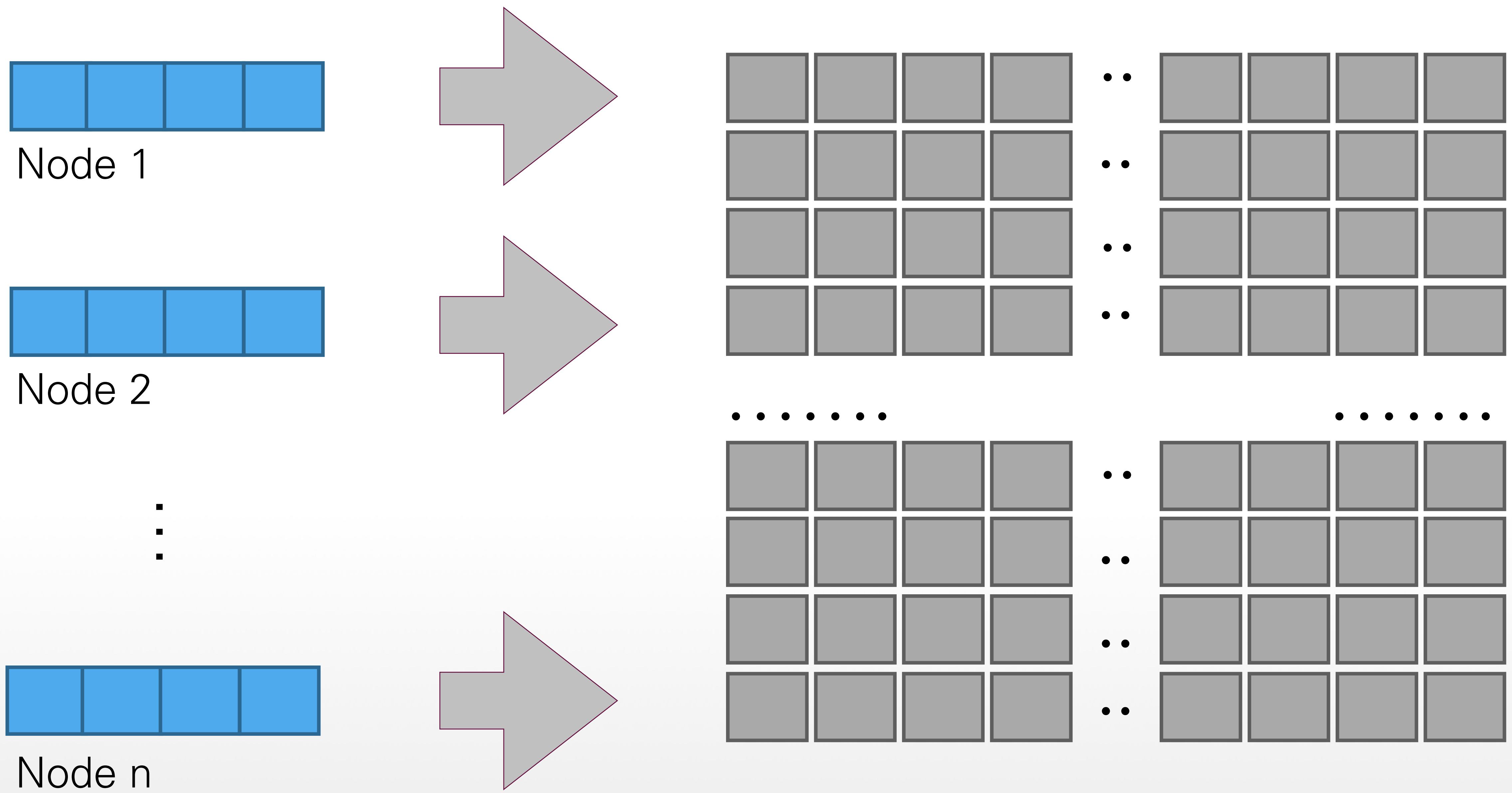
Distributed bulletin board

- An n node cluster/Cloud system
  - Decentralized control
  - Nodes can fail at any time
- *Each node maintains a data structure (vector) with an entry about selected (or all) the nodes*
- Each entry contains:
  - State of the resources of the corresponding node, e.g. load
  - Age of the information (tune to the local clock)
- The vector is used by each node as a distributed bulletin board
  - Provides information about allocation of new processes

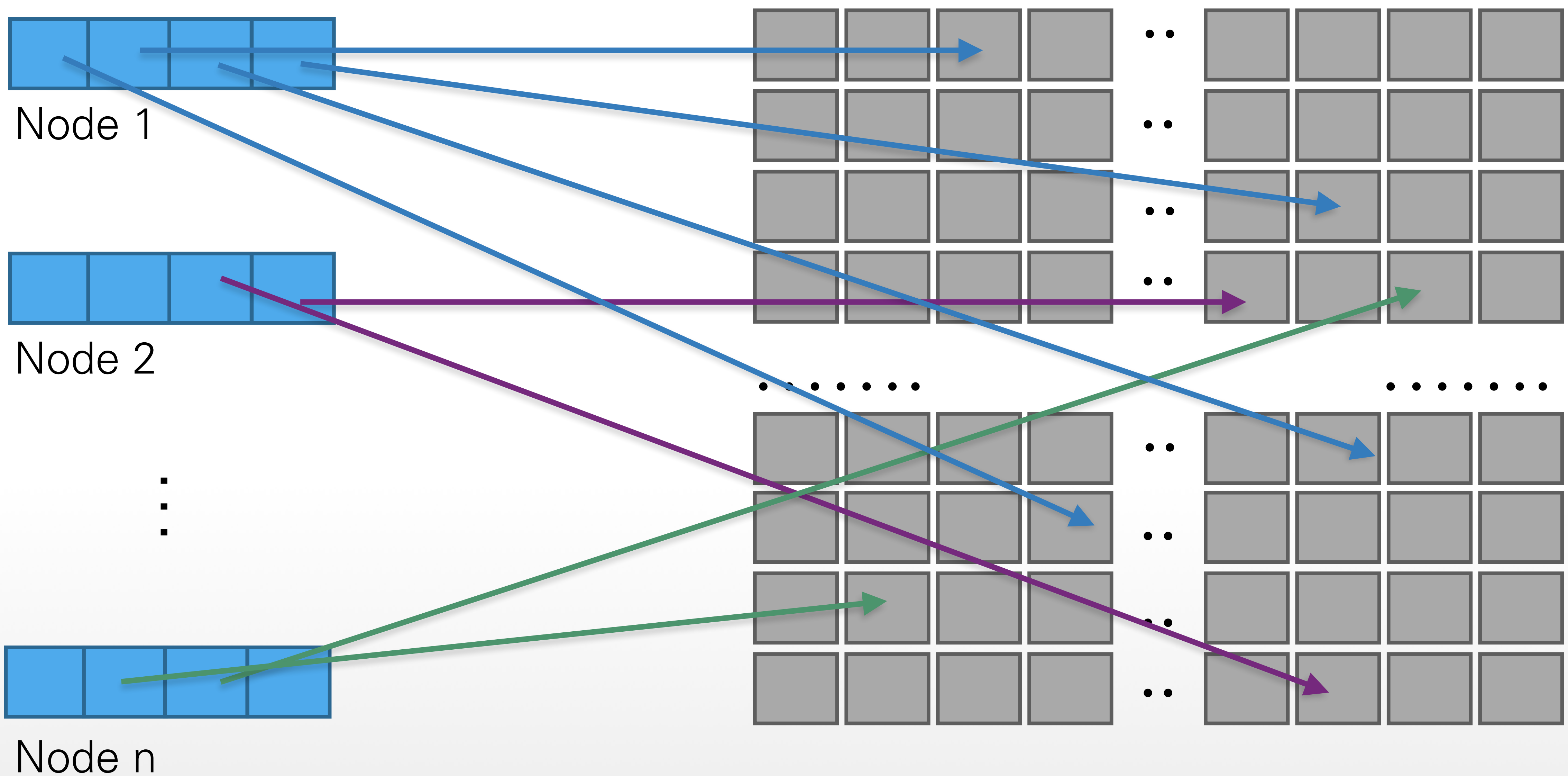
CENTRALIZED GLOBAL STATE



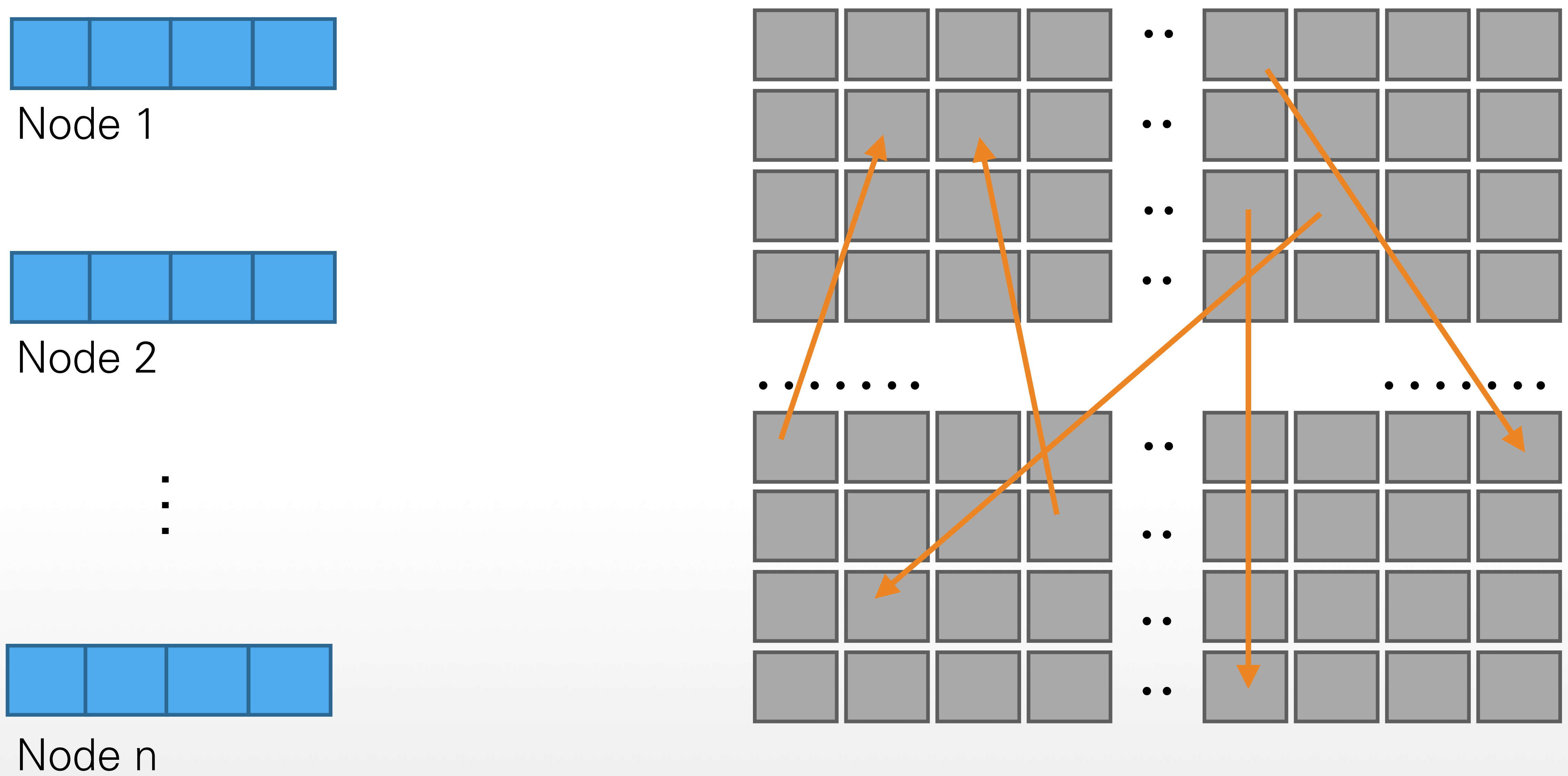
DECENTRALIZED GLOBAL STATE



DECENTRALIZED GLOBAL STATE



GOSSIP



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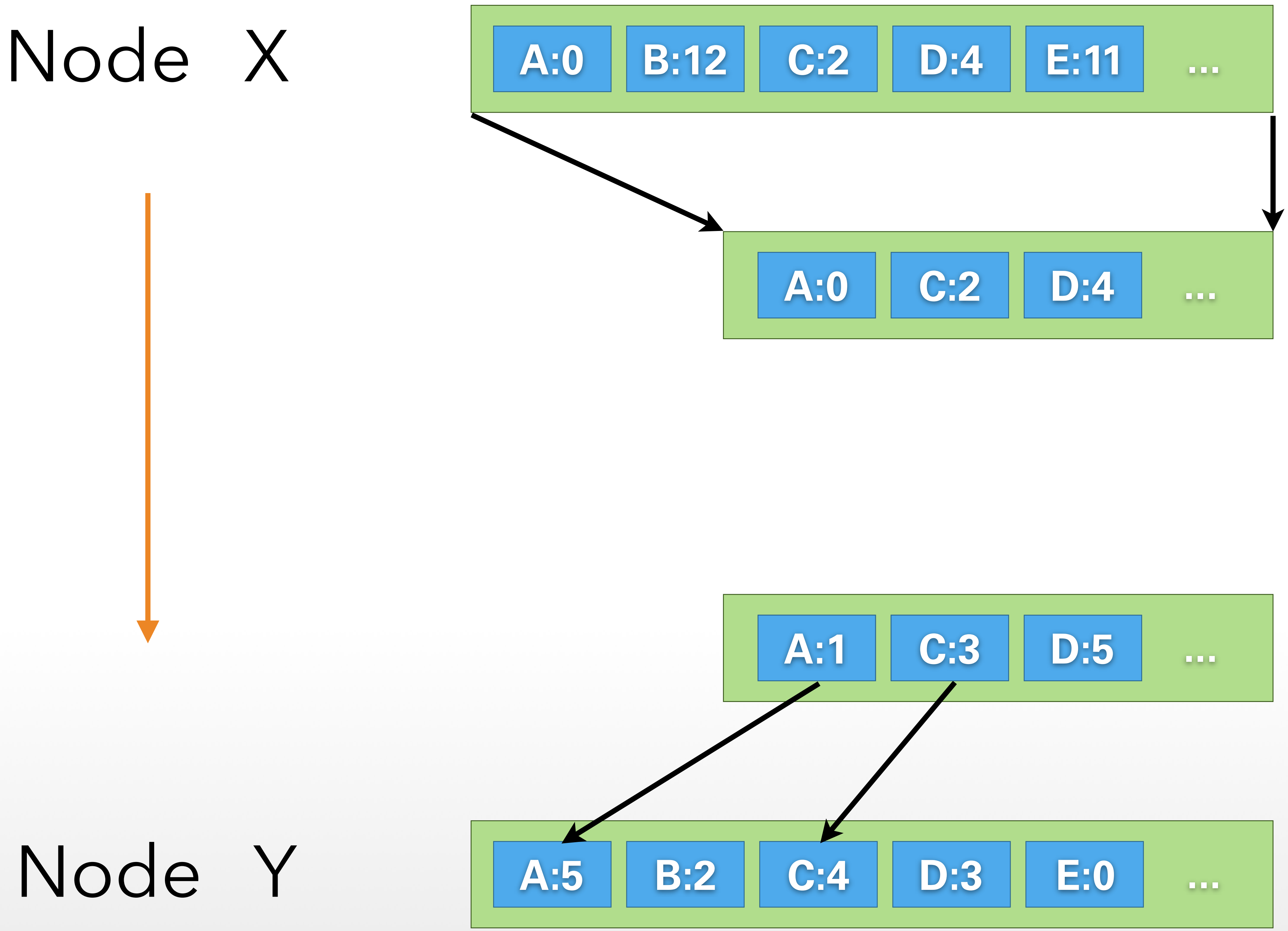
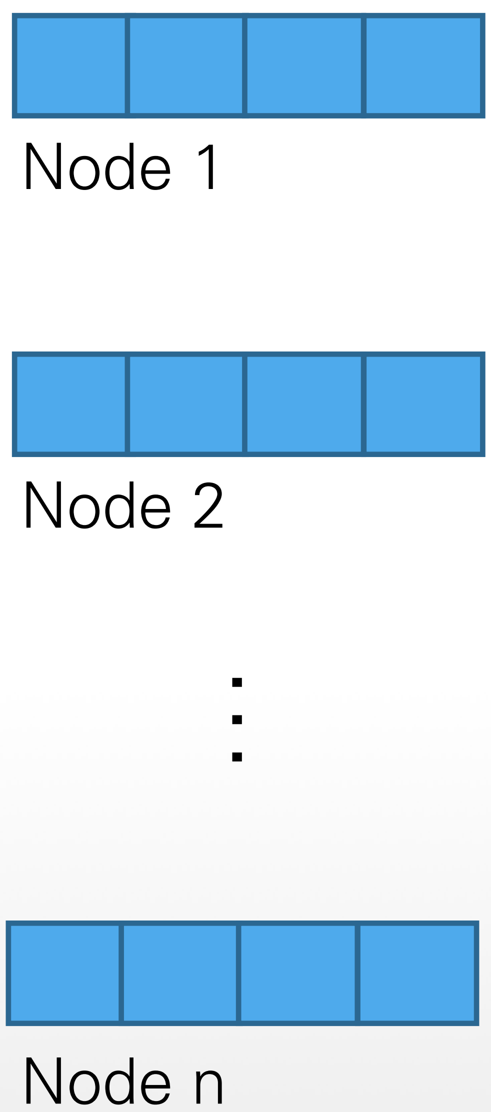


WWW



When

- **M:** load difference discovered
- anomaly discovered
- anticipated

Where

- **M:** memory, cycles, comm
- consider topology
- application knowledge

Which

- **M:** past predicts future
- application knowledge

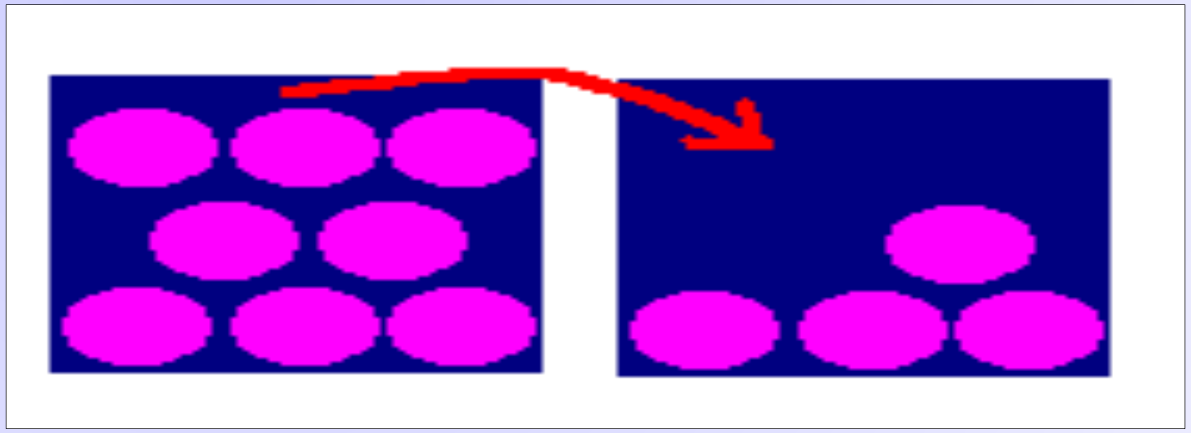
Load balancing algorithms

- When - Load difference between a pair of nodes is above a threshold value
- Which - Oldest process (assumes past-repeat)
- Where - To the known node with the lowest load
- Many other heuristics

- Performance: our online algorithm is only ~2% slower than the optimal algorithm (which has complete information about all the processes)

Memory ushering

- **Heuristics: initiate process migration from a node with no free memory to a node with available free memory**
- **Useful: when non-uniform memory usage (many users) or nodes with different memory sizes**
- **Overrides load-balancing**



- Recall: **placement problem is NP-hard**

Memory ushering algorithm

- **When** - free memory drops below a threshold
- **Where** - the node with the lowest load, to avoid unnecessary follow-up migrations
- **Which** - smallest process that brings node under threshold
  - To reduce the communication overhead

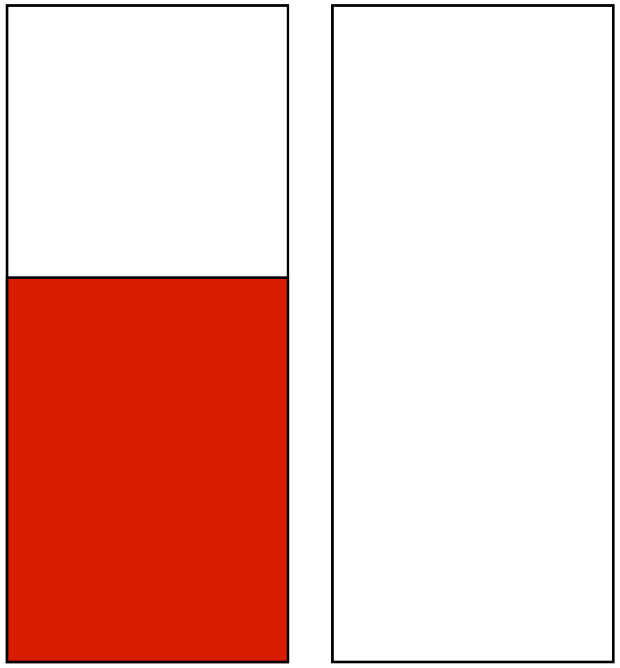
PRECEDENCE

- memory
- cpu load
- IPC

SOME PRACTICAL PROBLEMS

- flooding
  all processes jump to one new empty node
  => decide immediately before migration commitment
  extra communication, piggy packed
- ping pong
  if thresholds are very close, processes moved back and forth
  => tell a little higher load than real

PING PONG



One process two nodes

Scenario:
compare load on nodes 1 and 2
node 1 moves process to node 2

Solutions:
add one + little bit to load
average over time

Solves short peaks problem as well
(short cron processes)

LESSONS

- execution/communication time jitter matters (Amdahl)
- HPC approaches: partition ./. balance
- dynamic balance components:
  migration mechanism,
  information bulletin,
  decision: which, when, where