# Performance Barriers in highly scaling earth-system models

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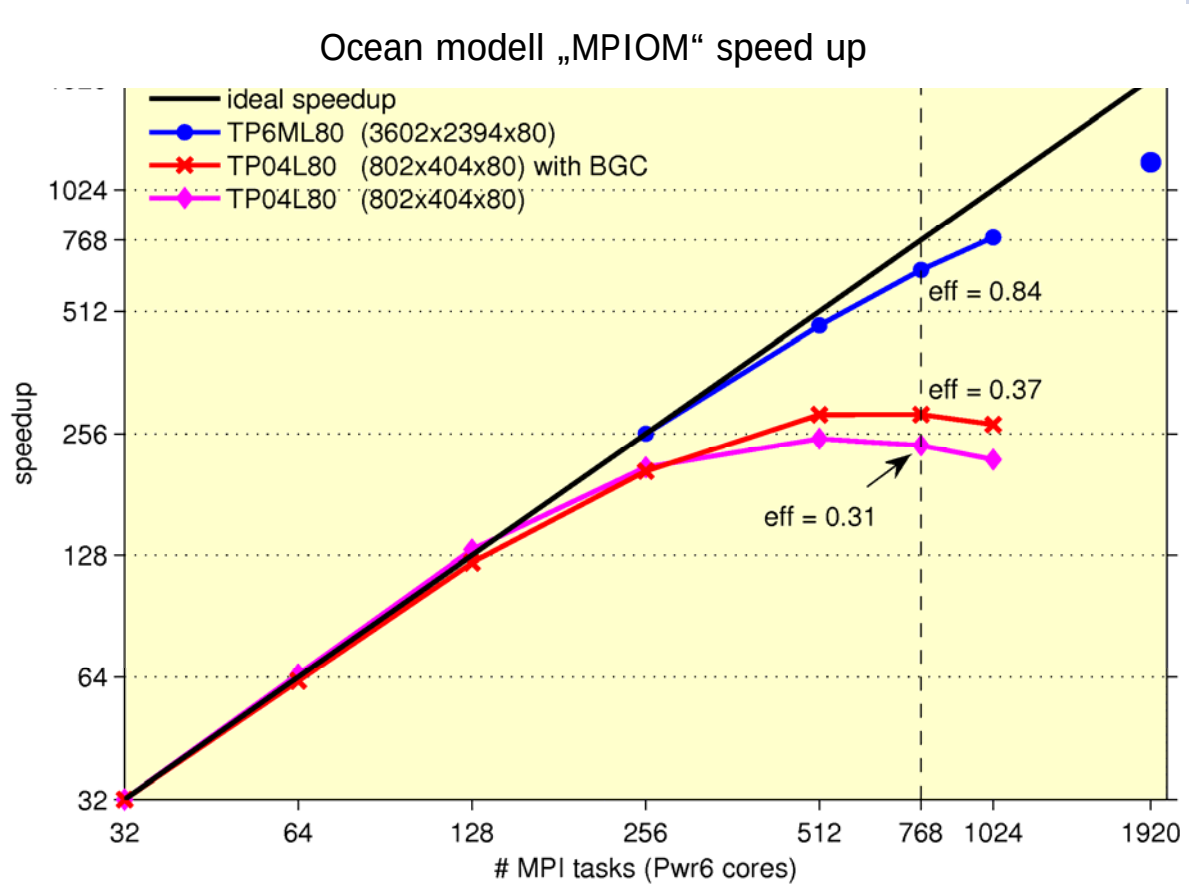
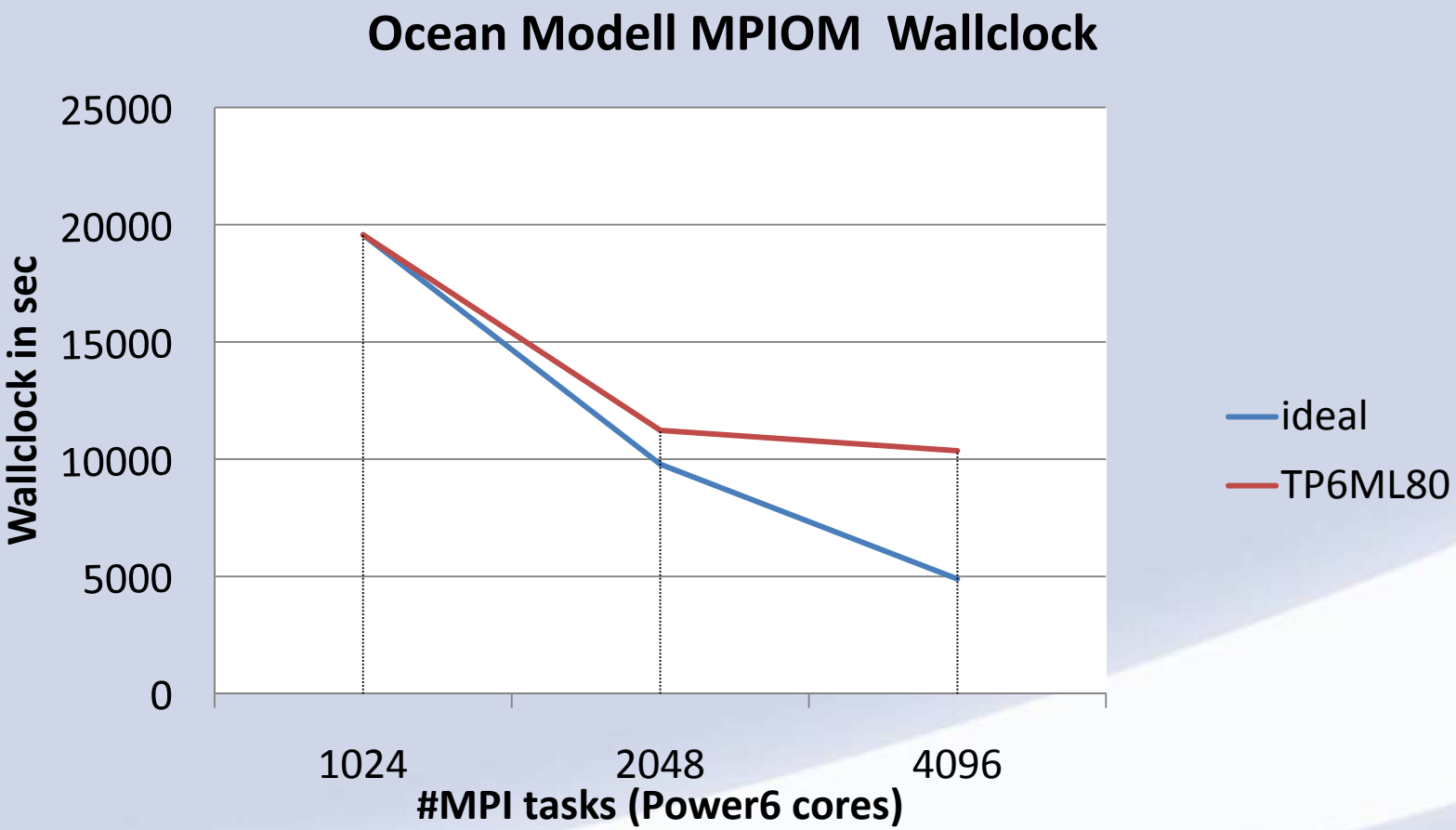
# Bottlenecks

- Bottlenecks of Massively Parallel Computing Systems
  - Communication Network
  - Memory Bandwidth
  - Idle Processors

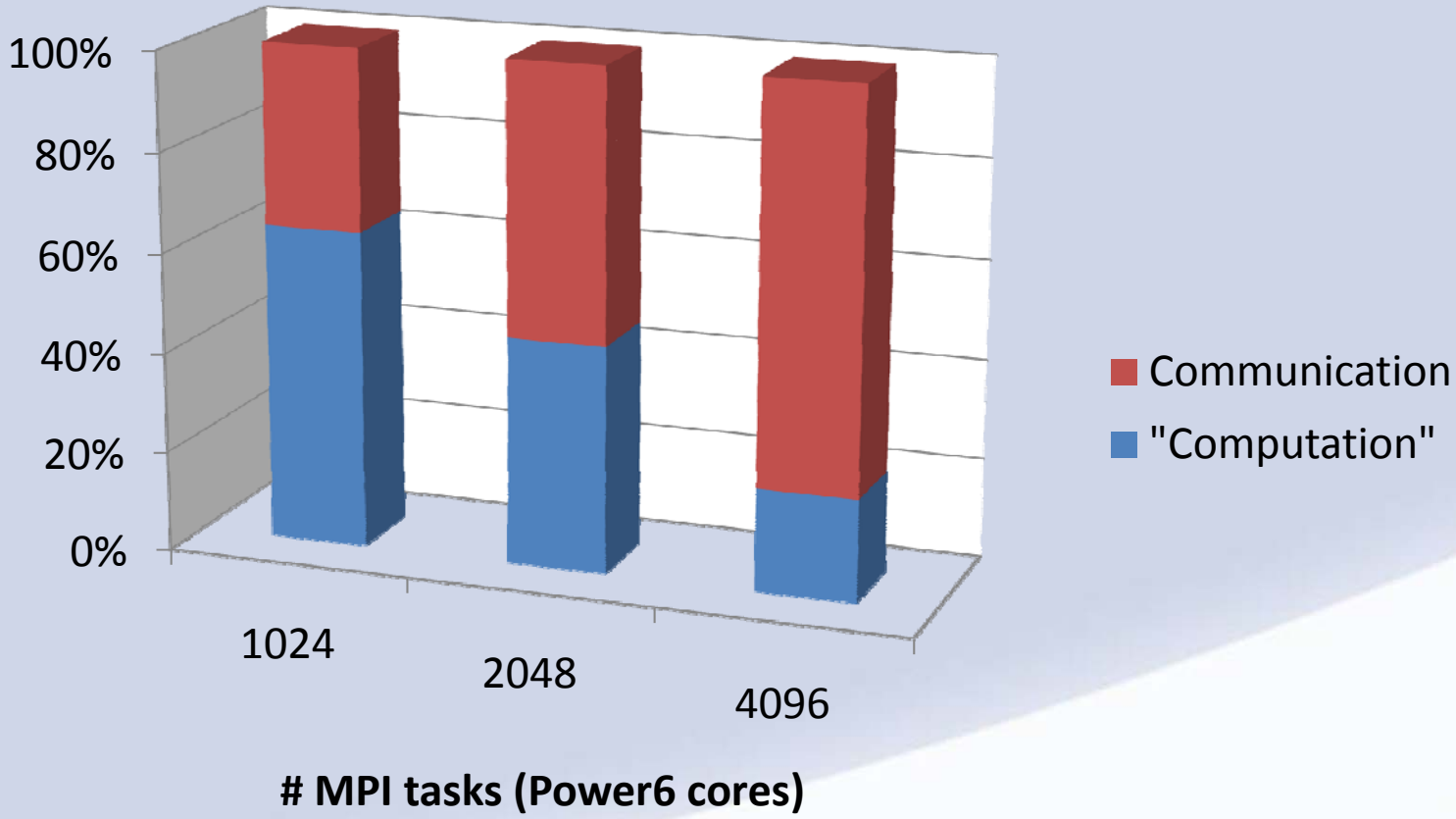
# Scaling today



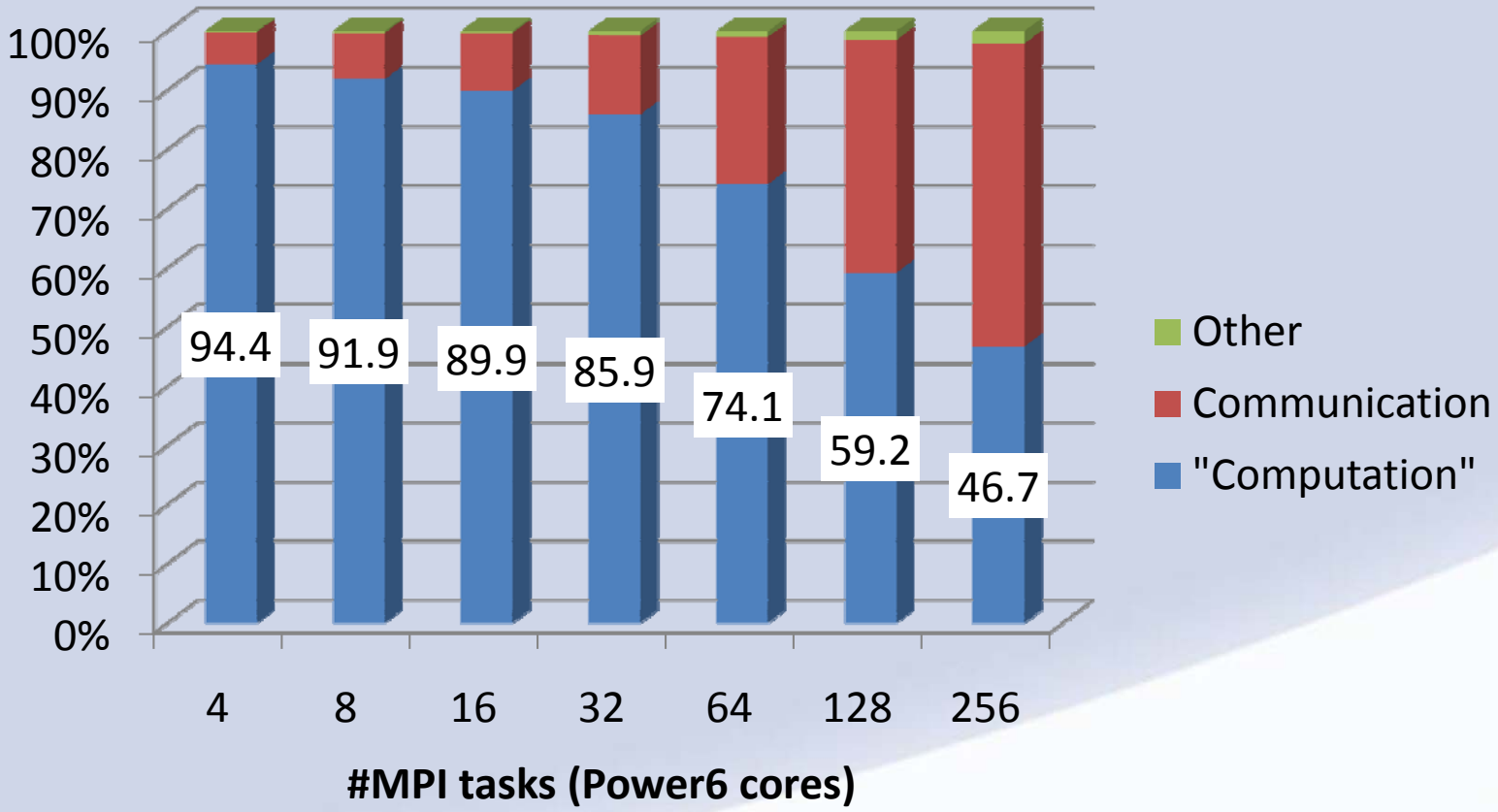
# Simulating 1 month with dt=600



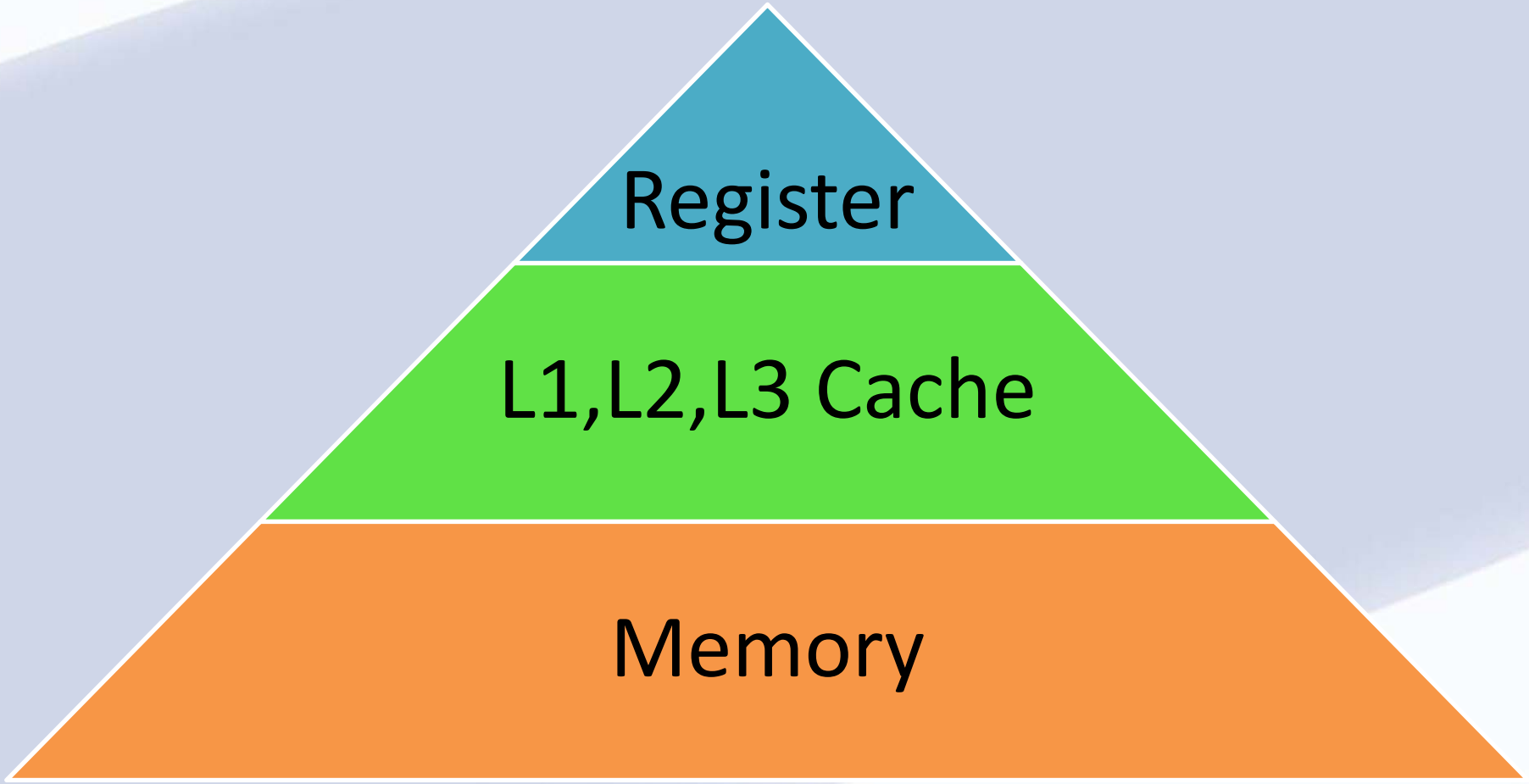
# Computation vs Communication TP6ML80



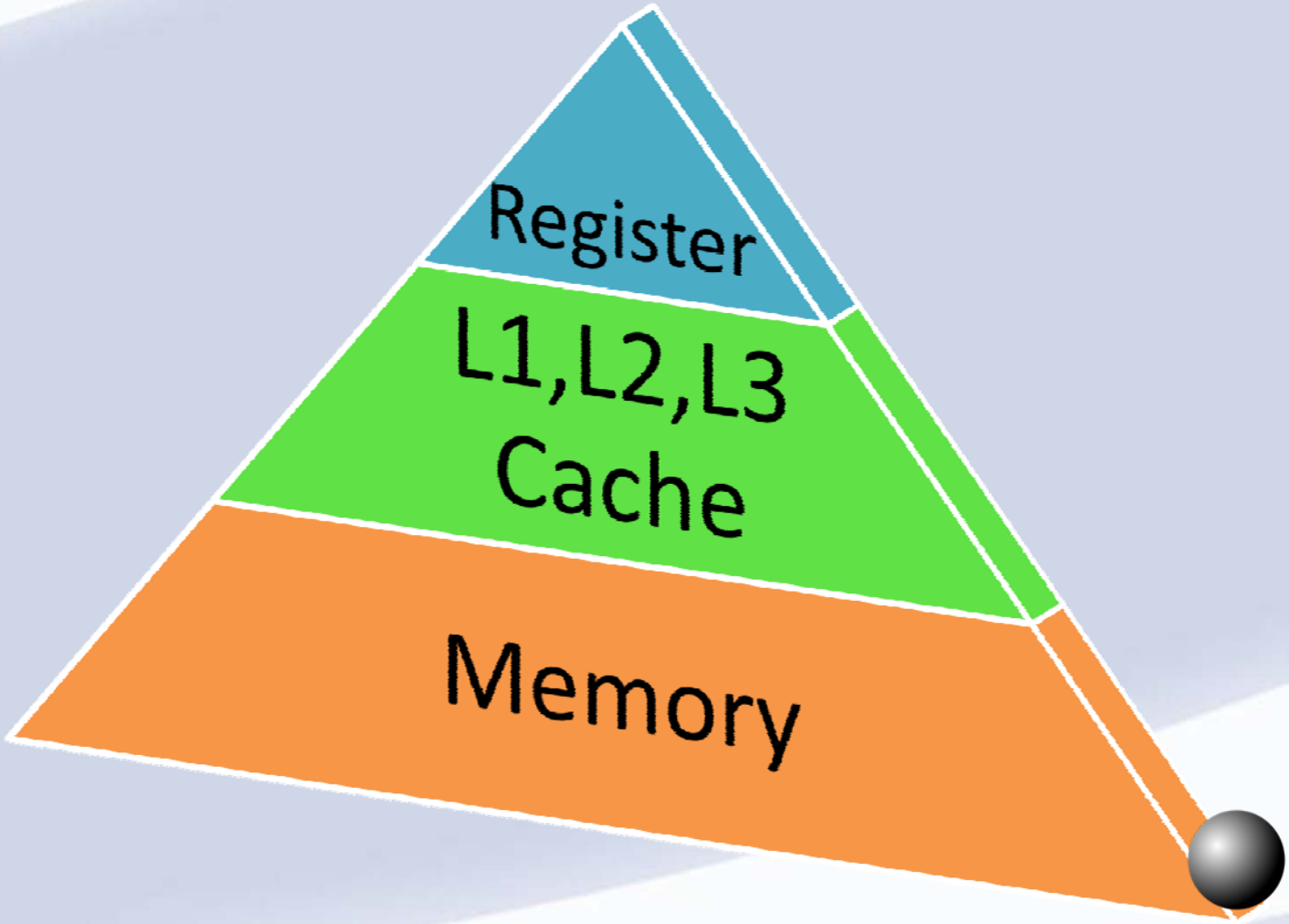
# Computation vs Communication TP04L80



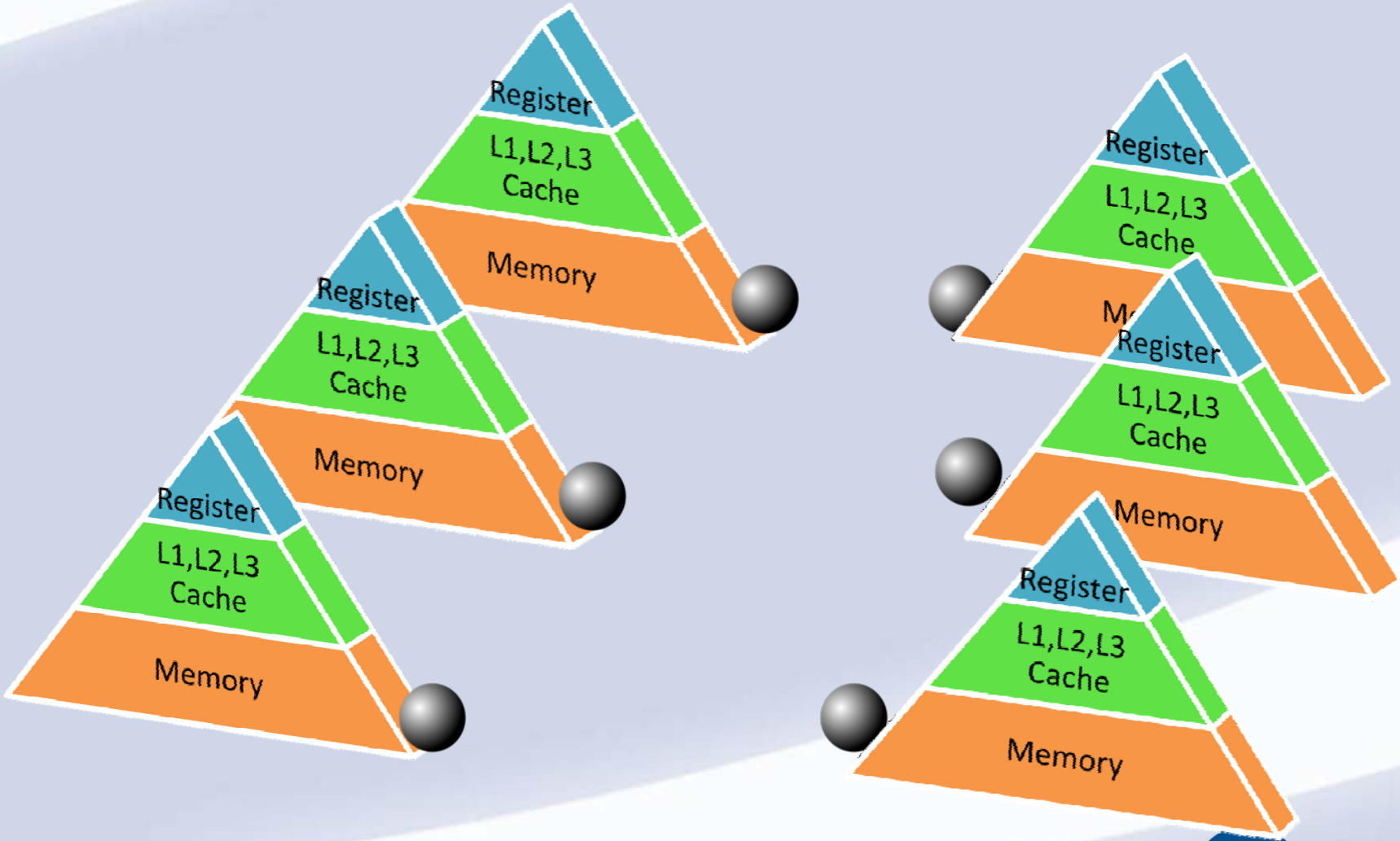
# Memory Hierarchy



# Data Movement



# Data Movement in Parallel Systems



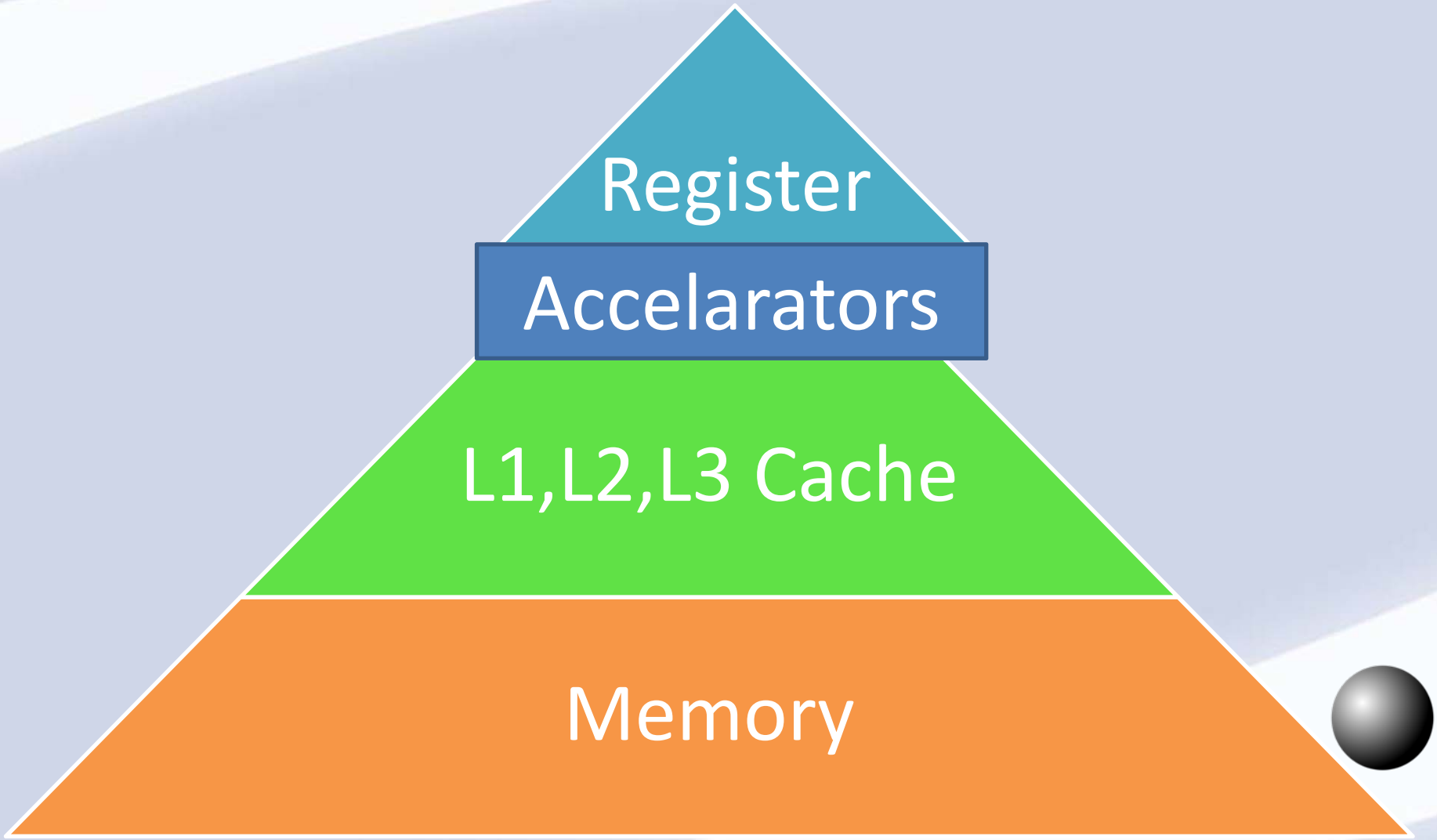
# Sisyphean Challenge

- According to greek mythology, “Sisyphus” was a greek King, famous for his cleverness.
- He played his tricks not only on humans but also on the Gods, thus being the craftiest of men
- He even managed to outwit “Thanatos” (death) himself

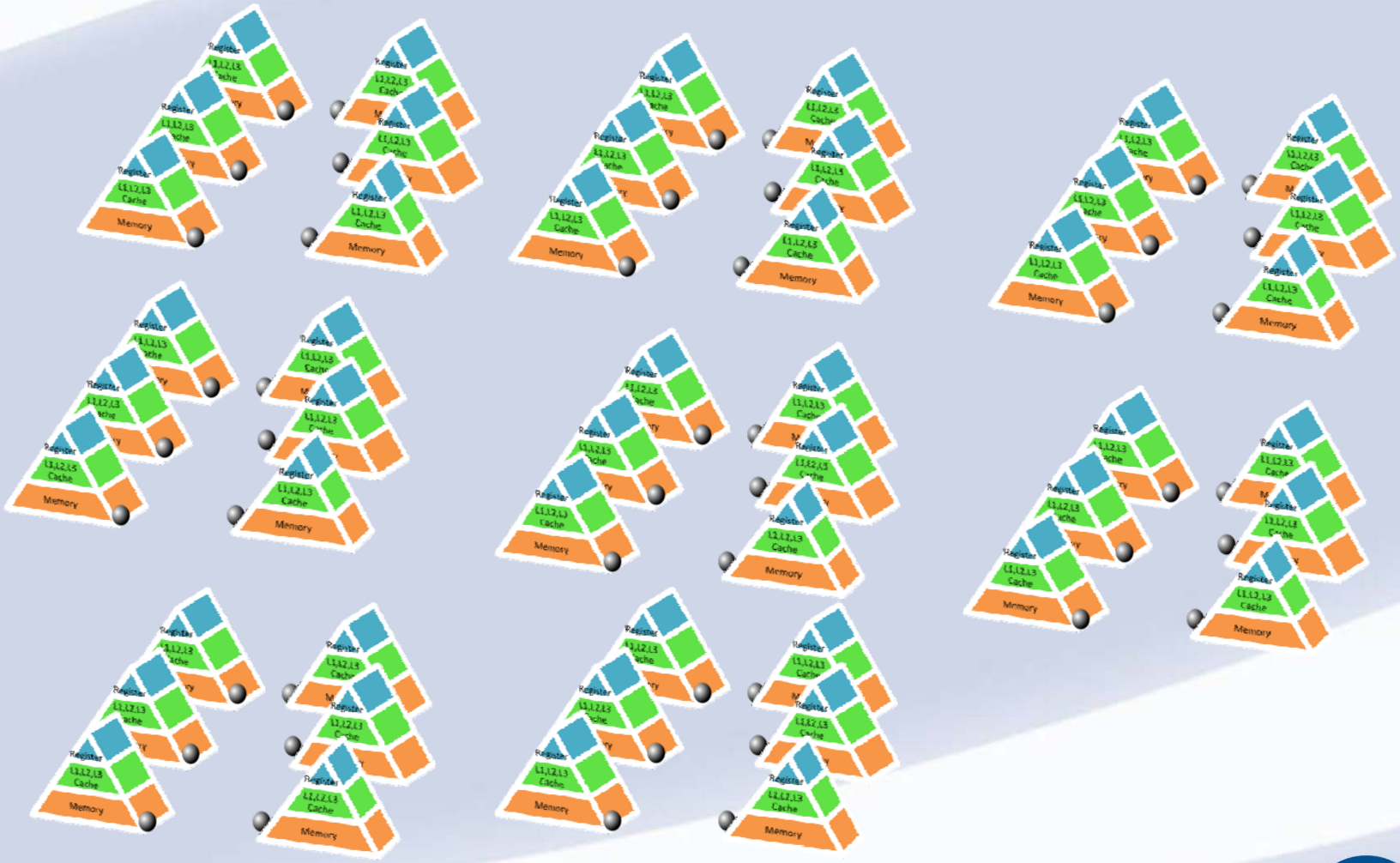
# Sisyphean Challenge

- As a punishment for his trickery, Sisyphus was compelled to roll a huge rock up a steep hill, only to watch it roll back down, and to repeat this throughout eternity

# Future Processors ?



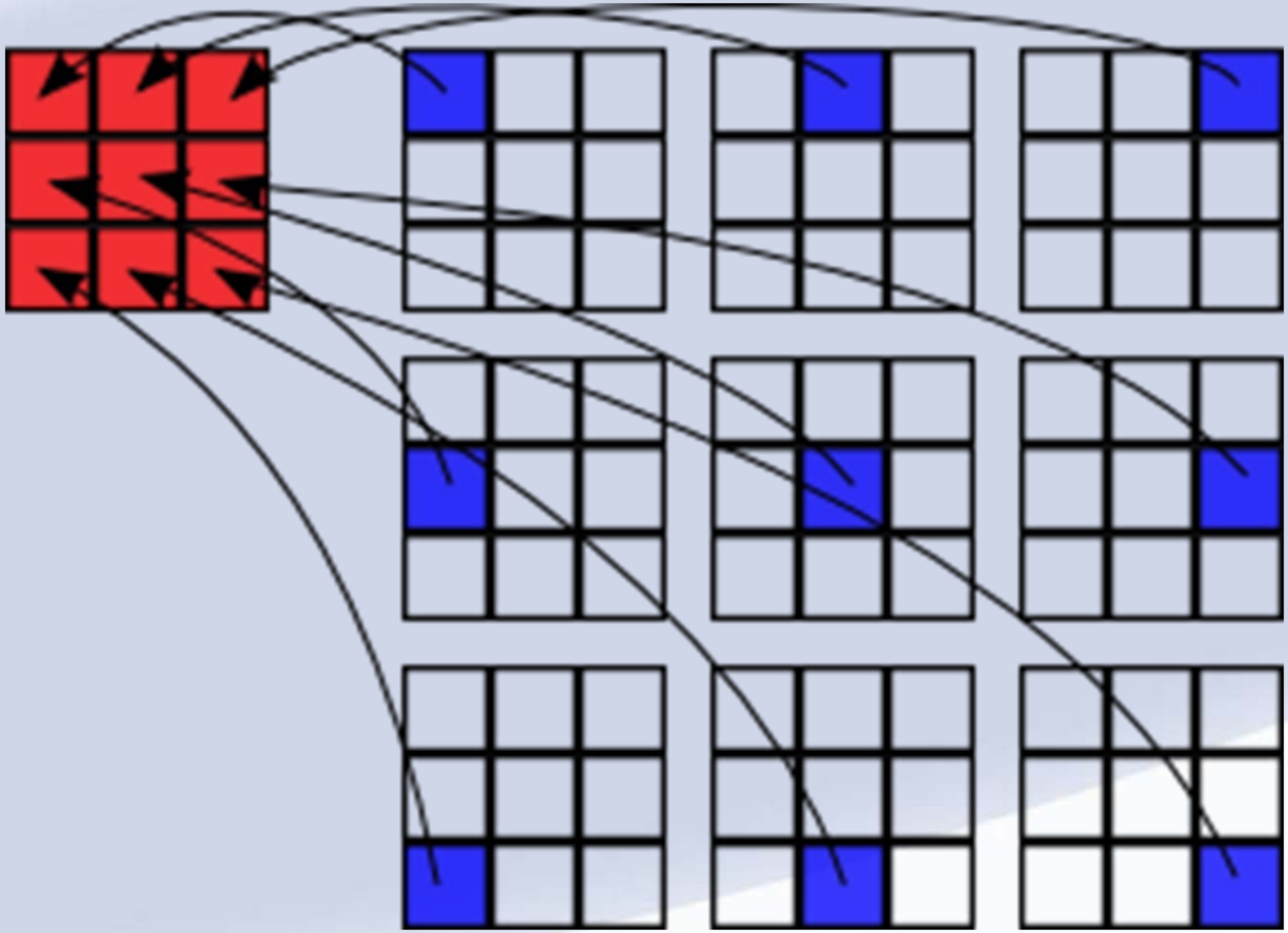
# Future Parallel Systems

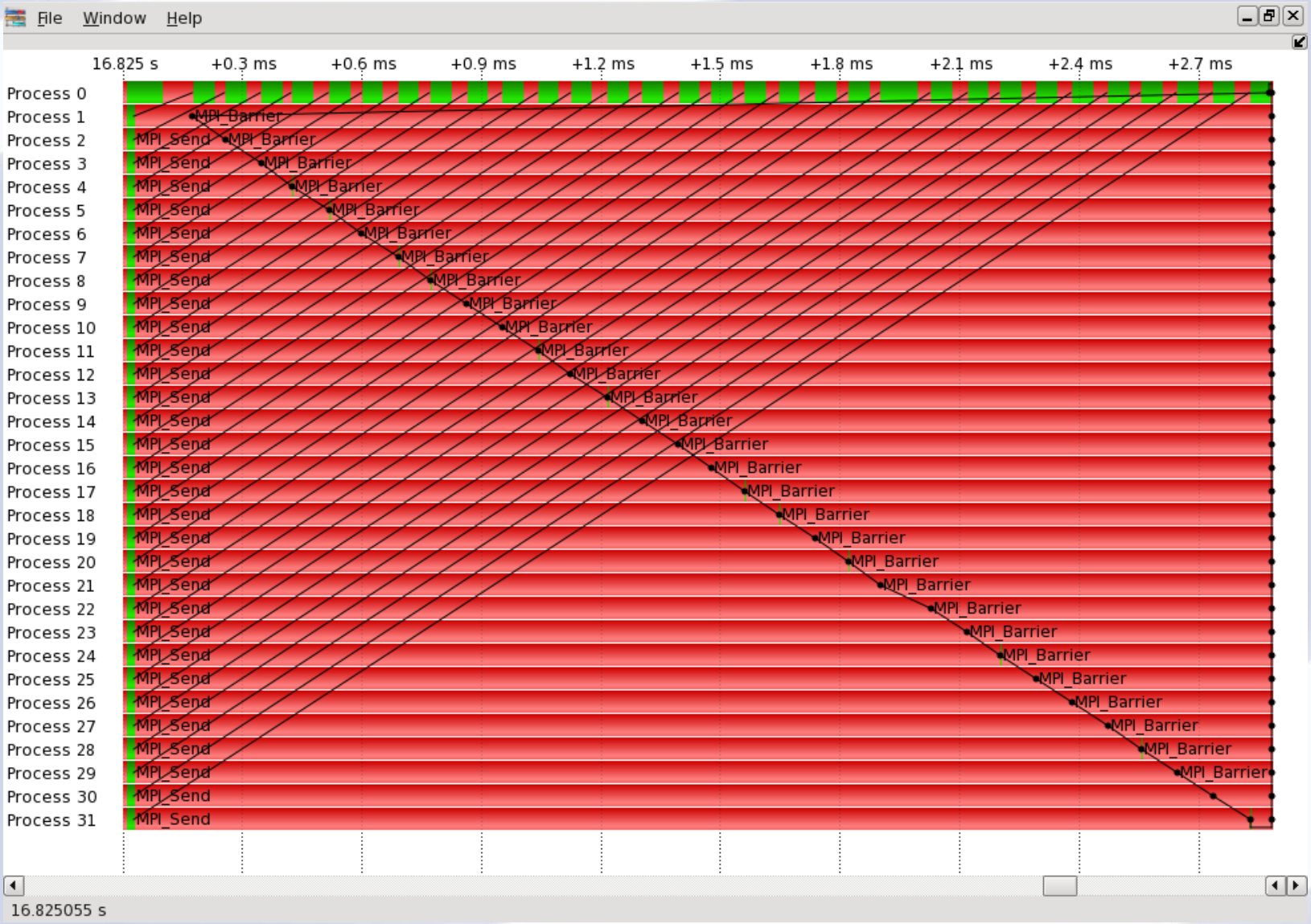


# Approach

- Solutions
  - Optimizing Communication
  - Load Balancing
  - Algorithms which are better suited for the specific architecture

# Optimizing Communication




File Window Help
16.825 s
+0.3 ms
+0.6 ms
+0.9 ms
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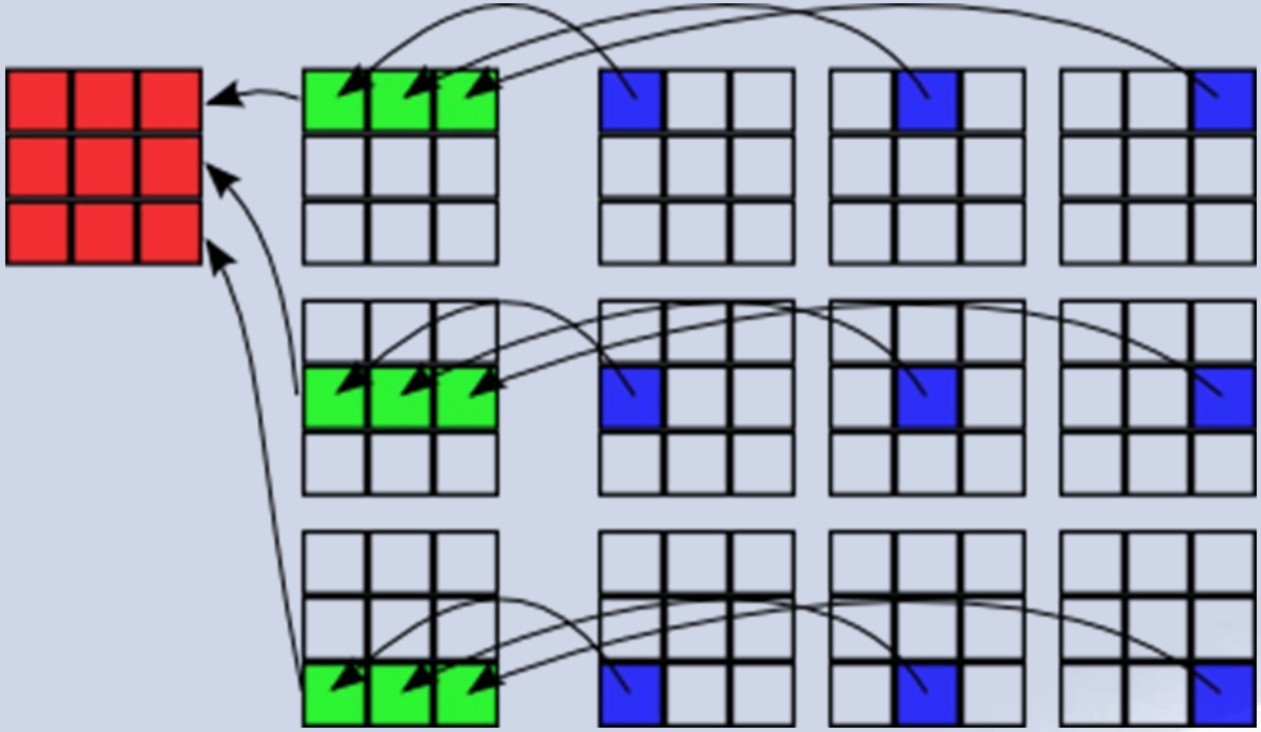
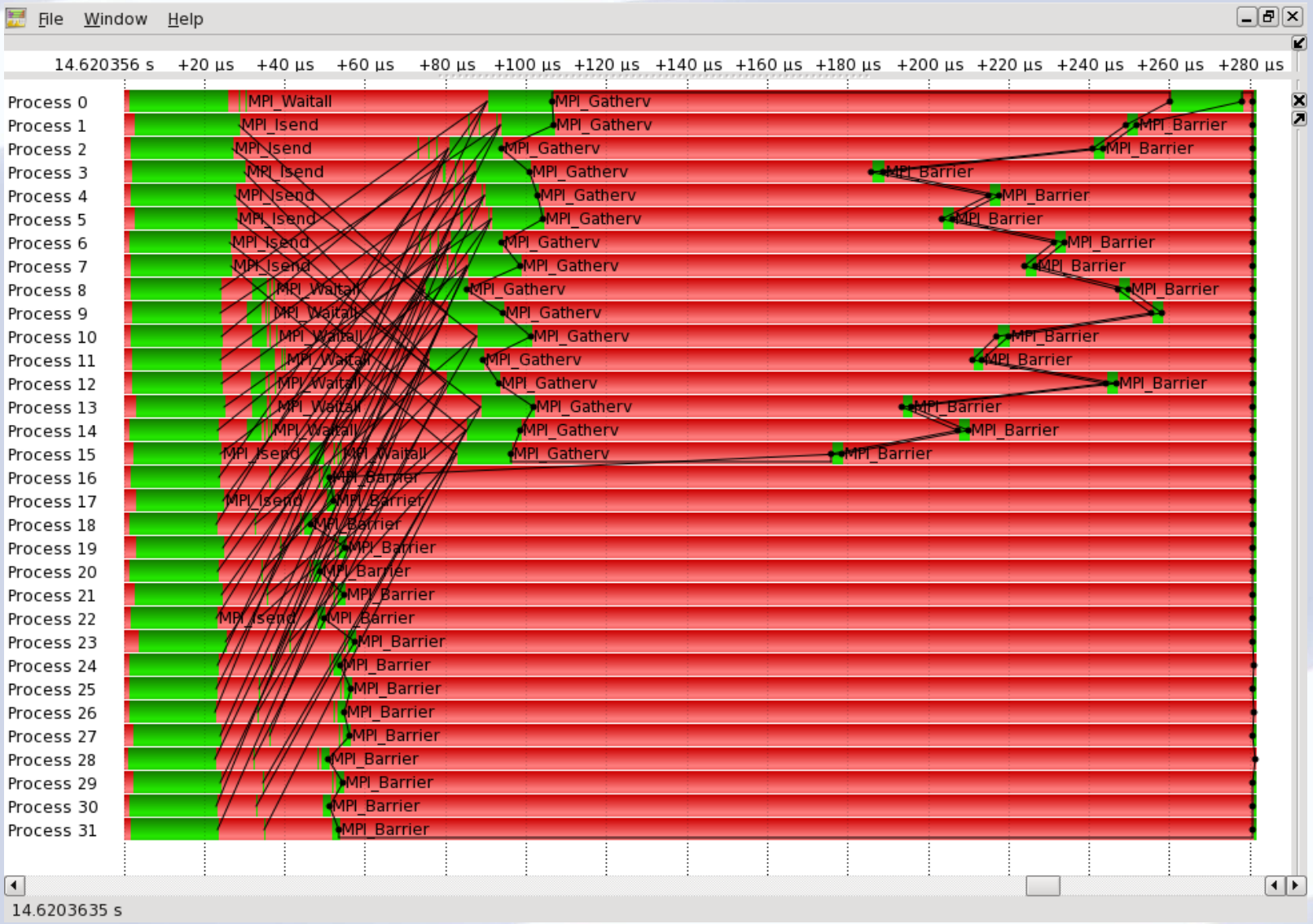
Process 31
MPI_Send
MPI_Barrier
16.825055 s

# Optimizing Communication




File Window Help
14.620356 s +20 µs +40 µs +60 µs +80 µs +100 µs +120 µs +140 µs +160 µs +180 µs +200 µs +220 µs +240 µs +260 µs +280 µs
Process 0 MPI_Waitall MPI_Gatherv MPI_Barrier
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Process 2 MPI_Isend MPI_Gatherv MPI_Barrier
Process 3 MPI_Isend MPI_Gatherv MPI_Barrier
Process 4 MPI_Isend MPI_Gatherv MPI_Barrier
Process 5 MPI_Isend MPI_Gatherv MPI_Barrier
Process 6 MPI_Isend MPI_Gatherv MPI_Barrier
Process 7 MPI_Isend MPI_Gatherv MPI_Barrier
Process 8 MPI_Waitall MPI_Gatherv MPI_Barrier
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Process 13 MPI_Waitall MPI_Gatherv MPI_Barrier
Process 14 MPI_Waitall MPI_Gatherv MPI_Barrier
Process 15 MPI_Isend MPI_Waitall MPI_Gatherv MPI_Barrier
Process 16 MPI_Barrier
Process 17 MPI_Isend MPI_Barrier
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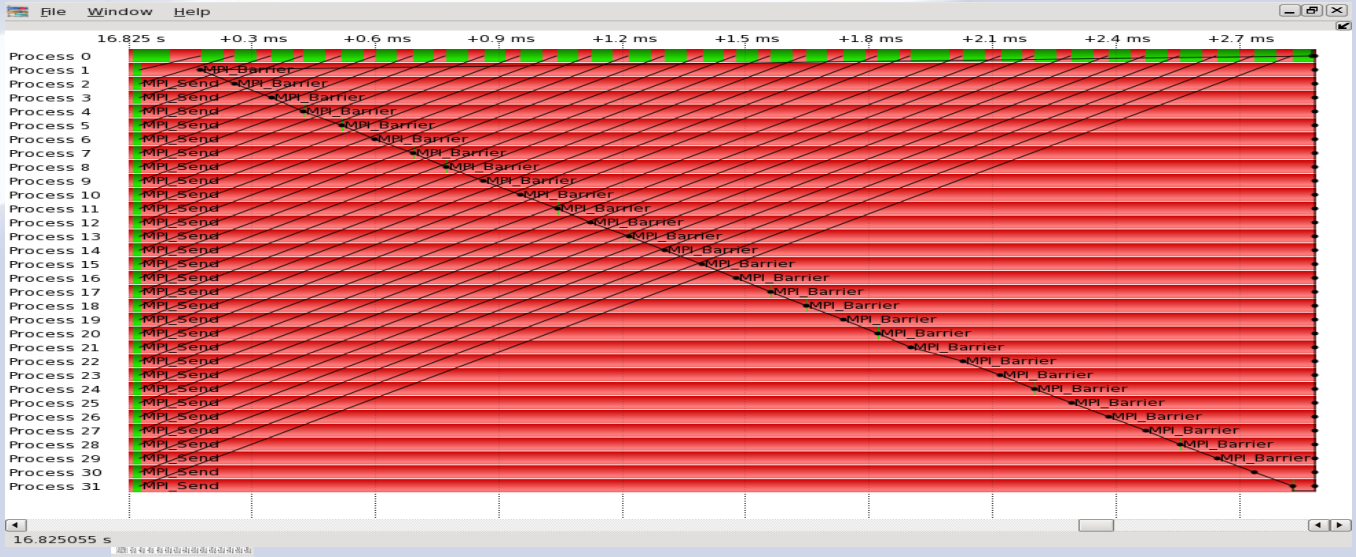
Process 30 MPI_Barrier
Process 31 MPI_Barrier
14.6203635 s


File Window Help
16.825 s
+0.3 ms
+0.6 ms
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Process 26
Process 27
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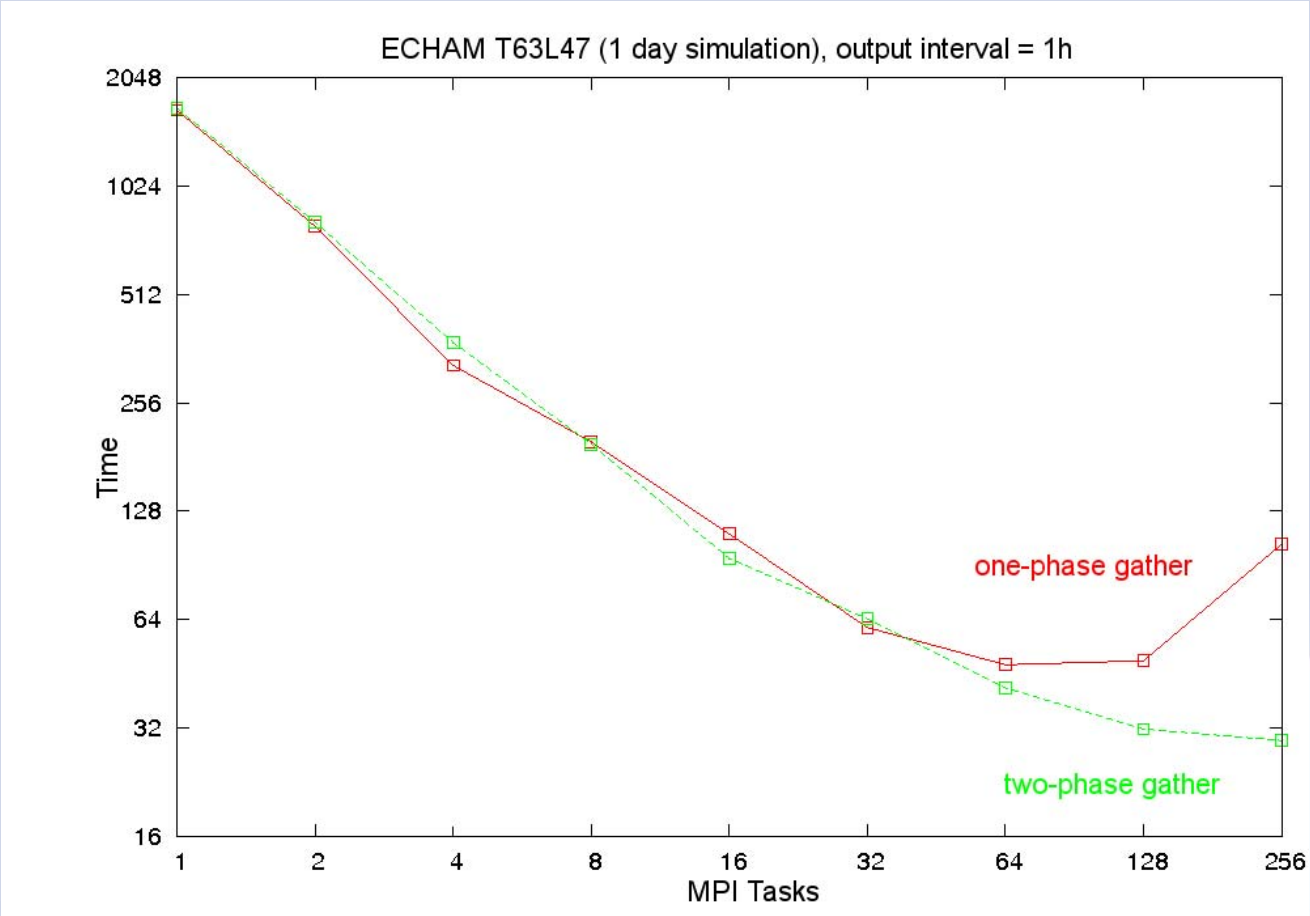
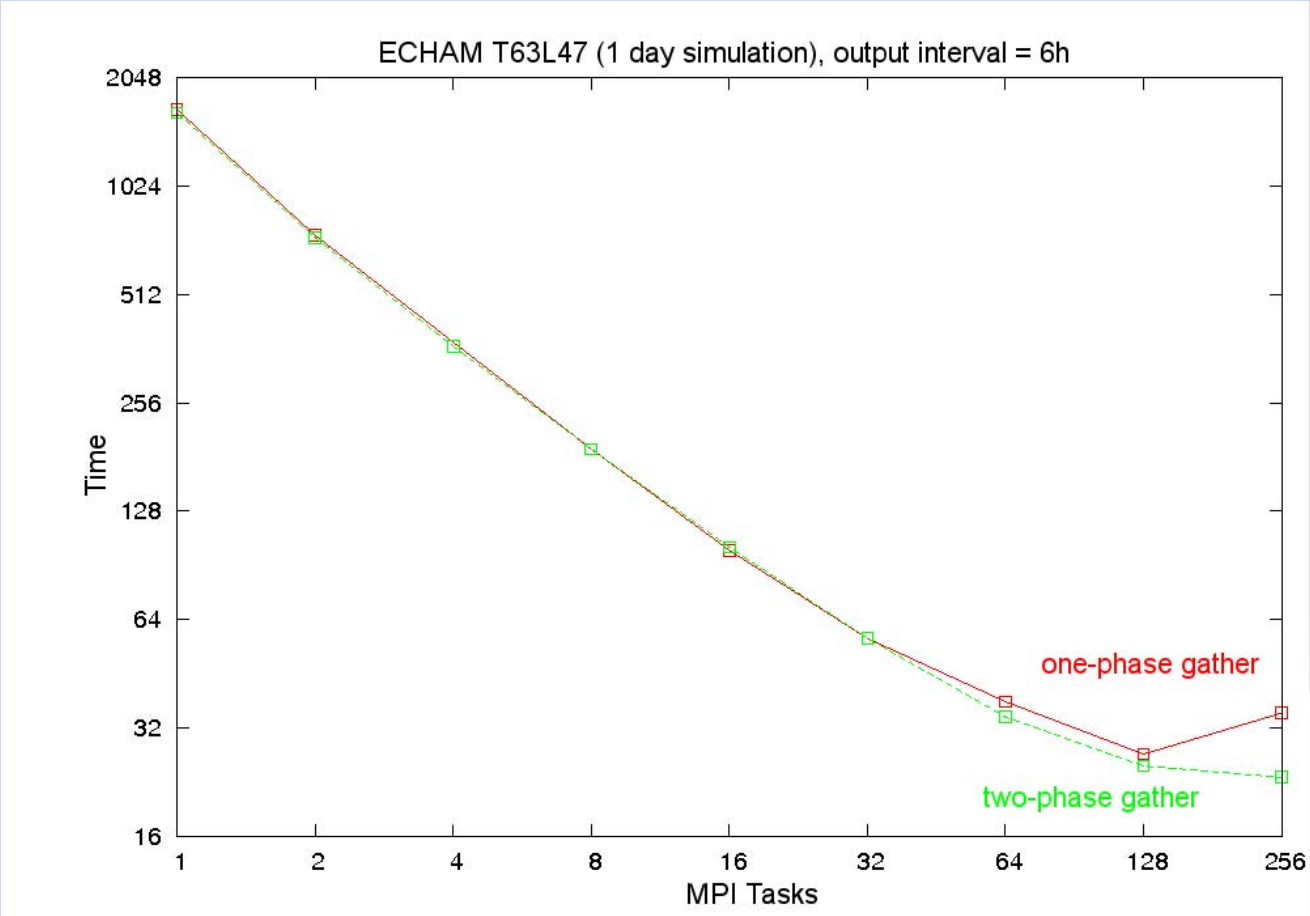
Process 30
Process 31
MPI_Send
MPI_Barrier
16.825055 s


Time
0.28msec
2.8msec

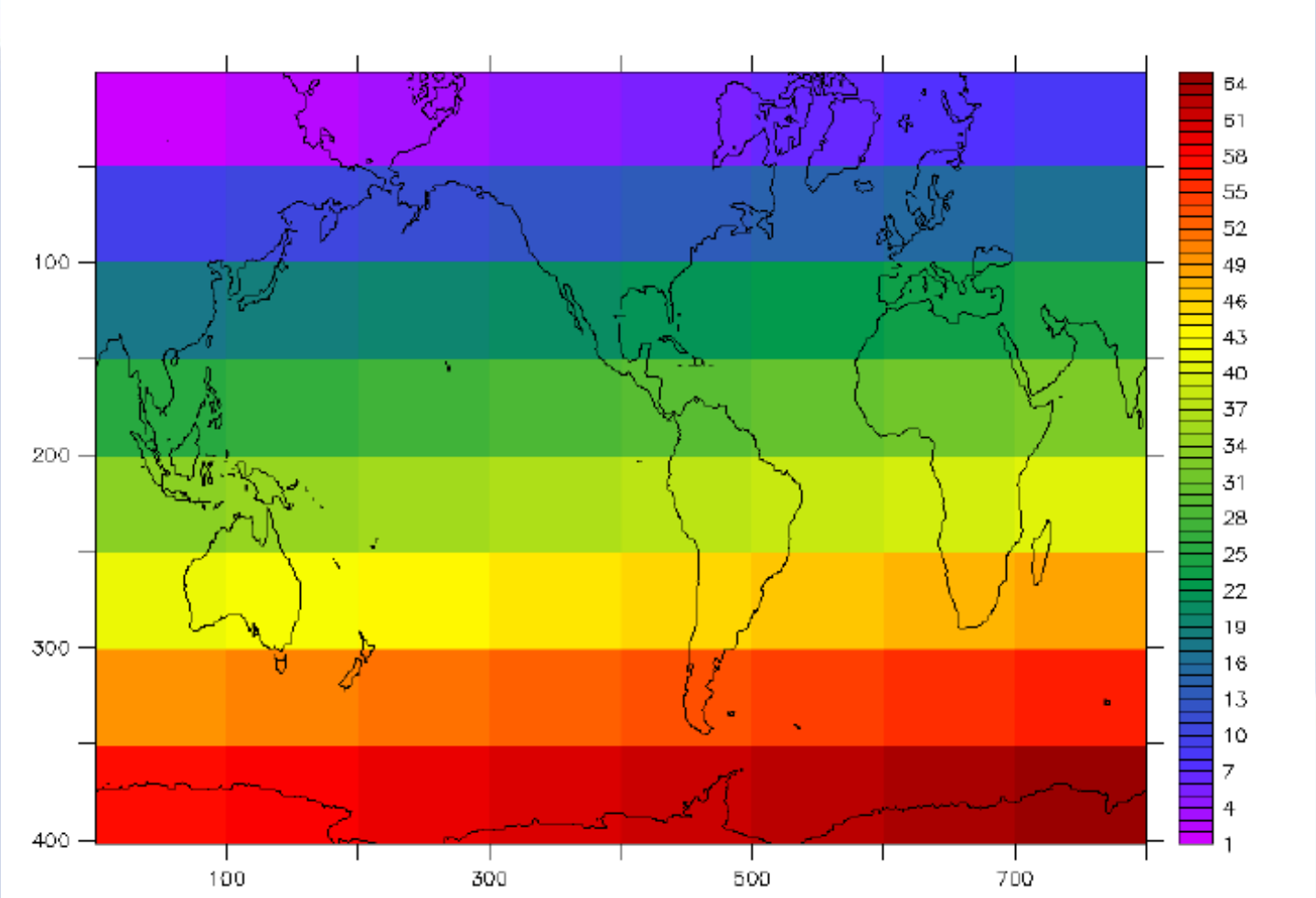
# Optimizing Communication



# Optimizing Communication

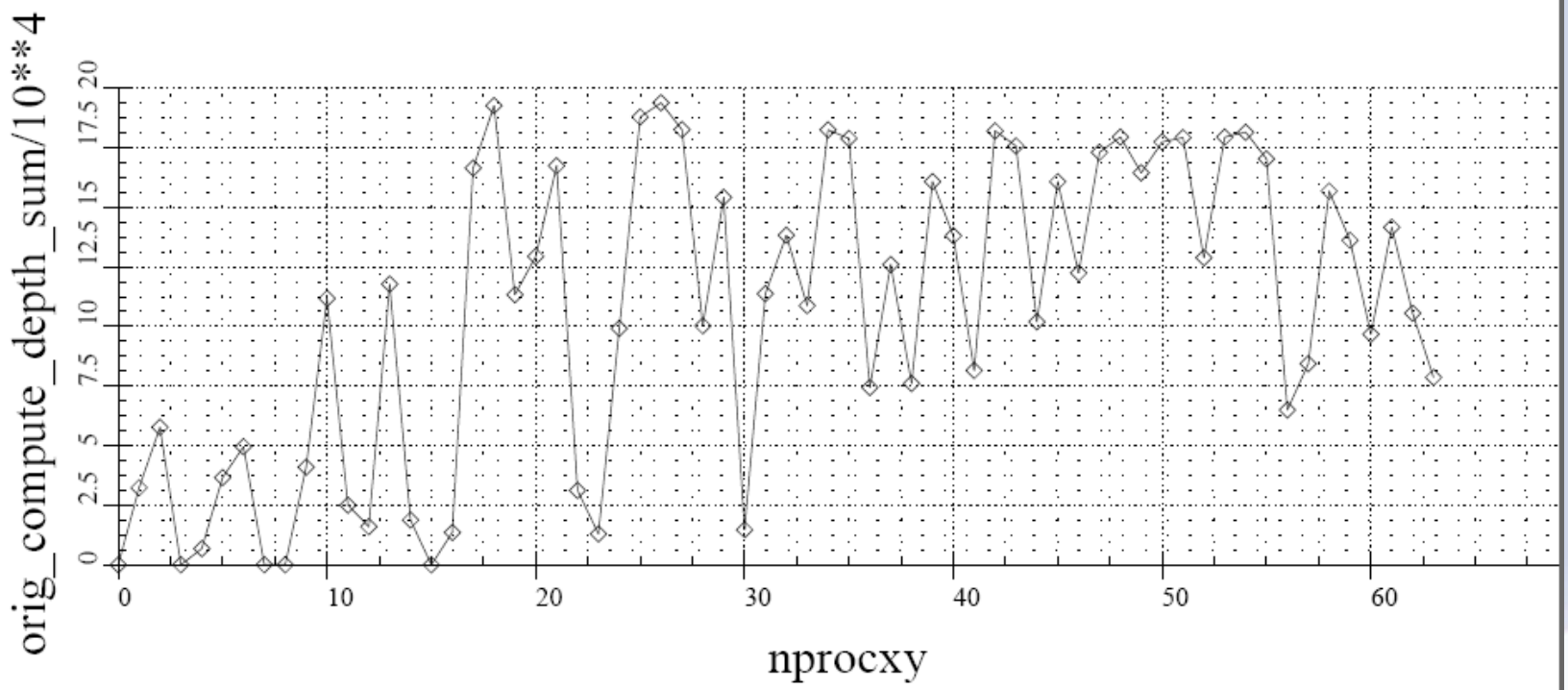


# Load Balancing




ECMWF, 2010

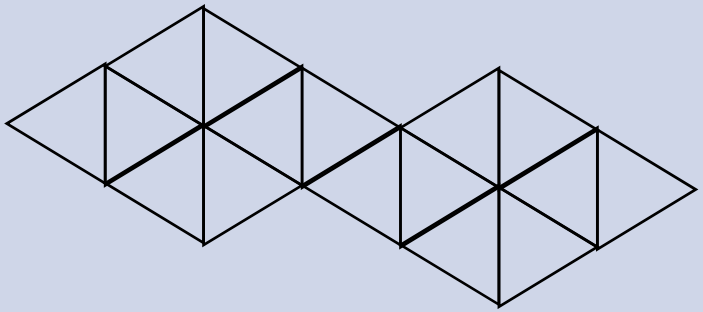
# Load Imbalance



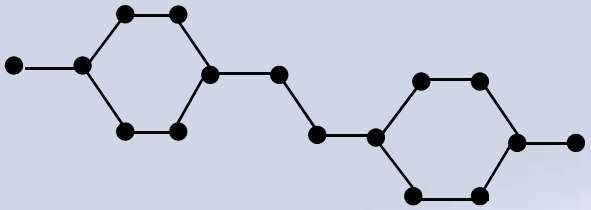

orig_compute_depth_sum

# Mapping Mesh ⇨ Graph

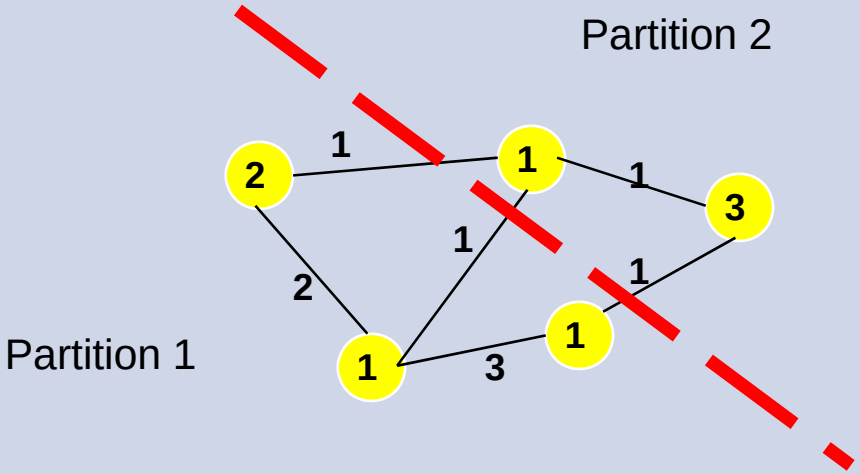
Mesh



Graph

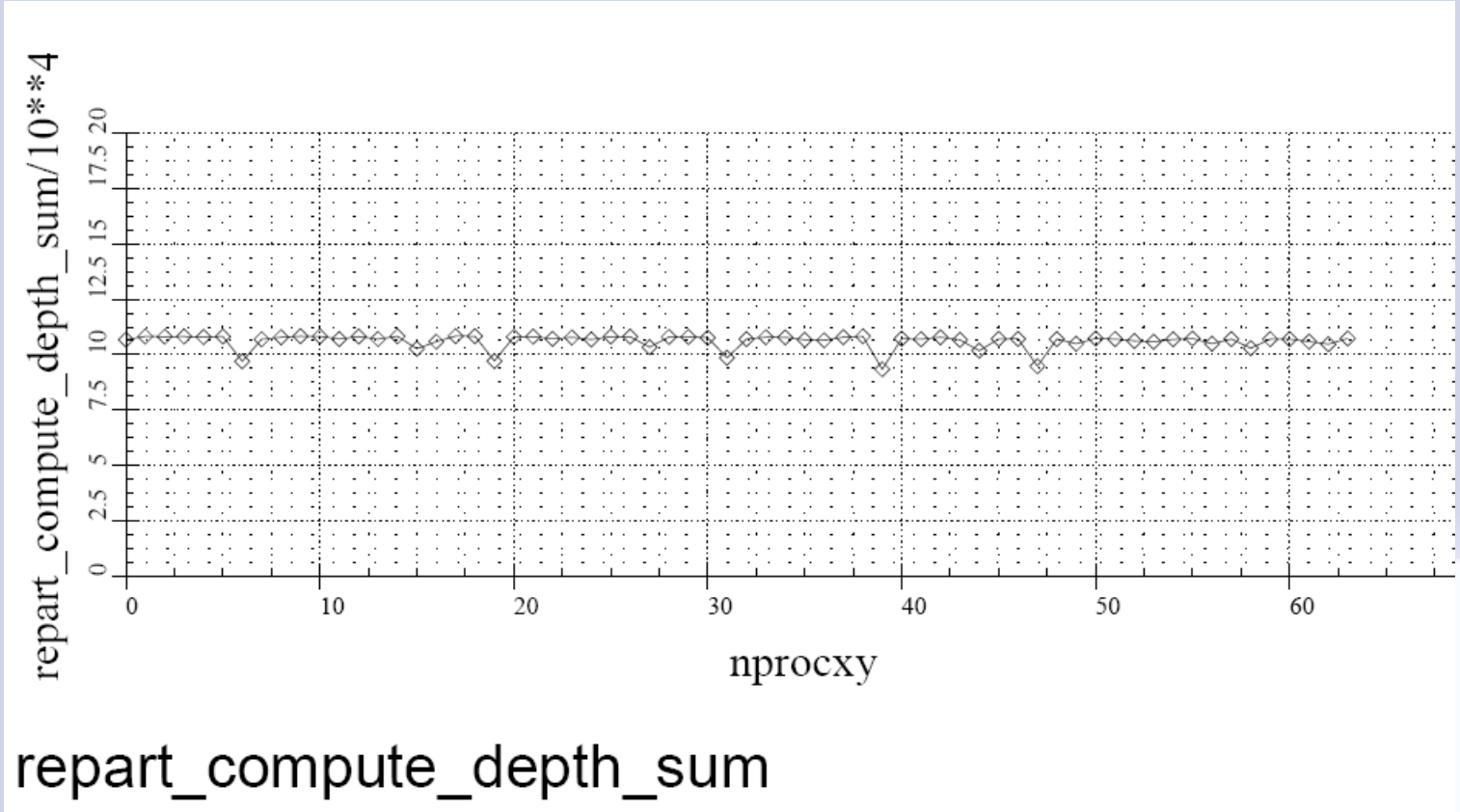


# Graph Partitioning



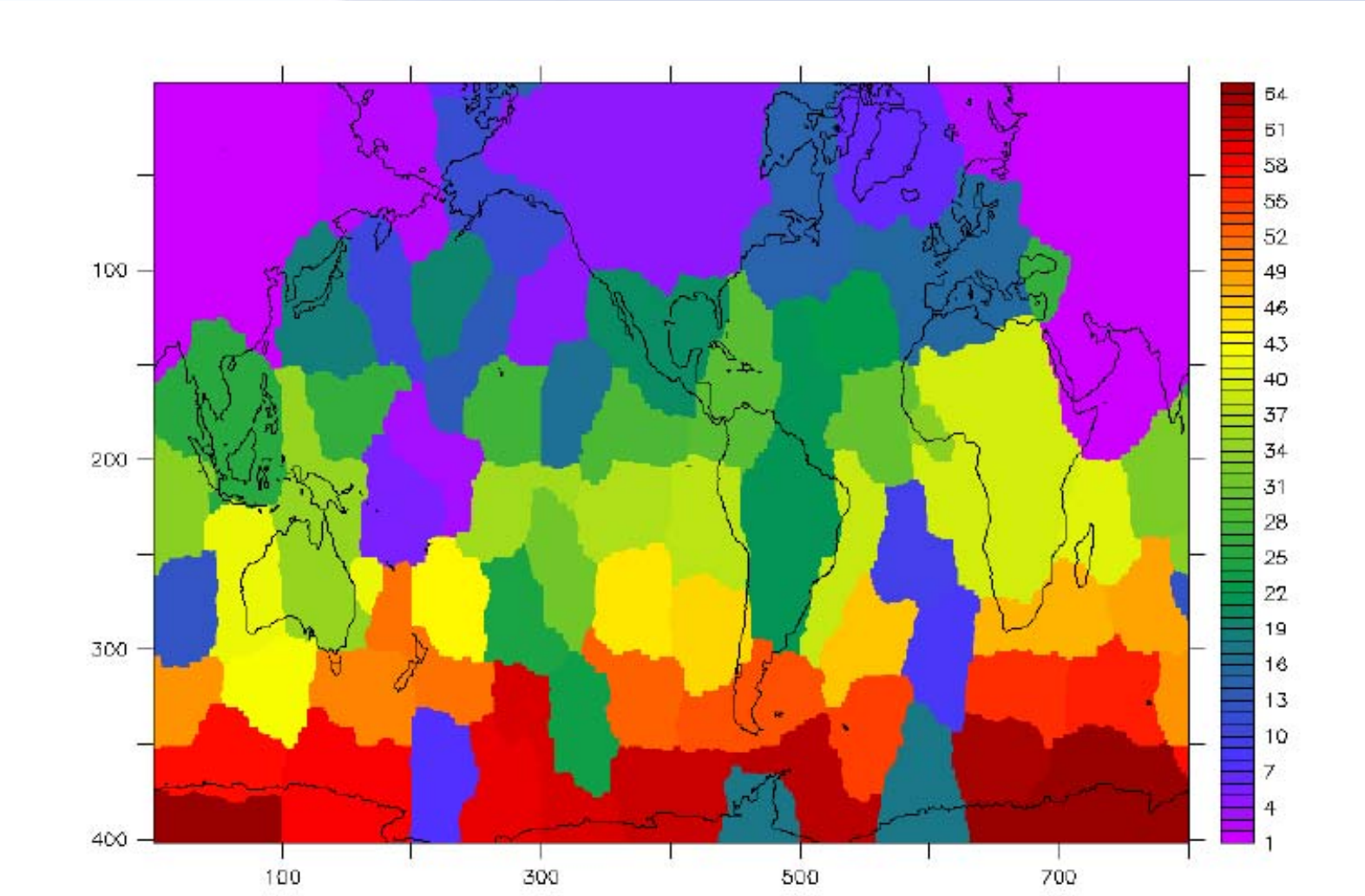

load balance: 100 %
weight of cut edges: 3

# Static Loadbalacing with METIS



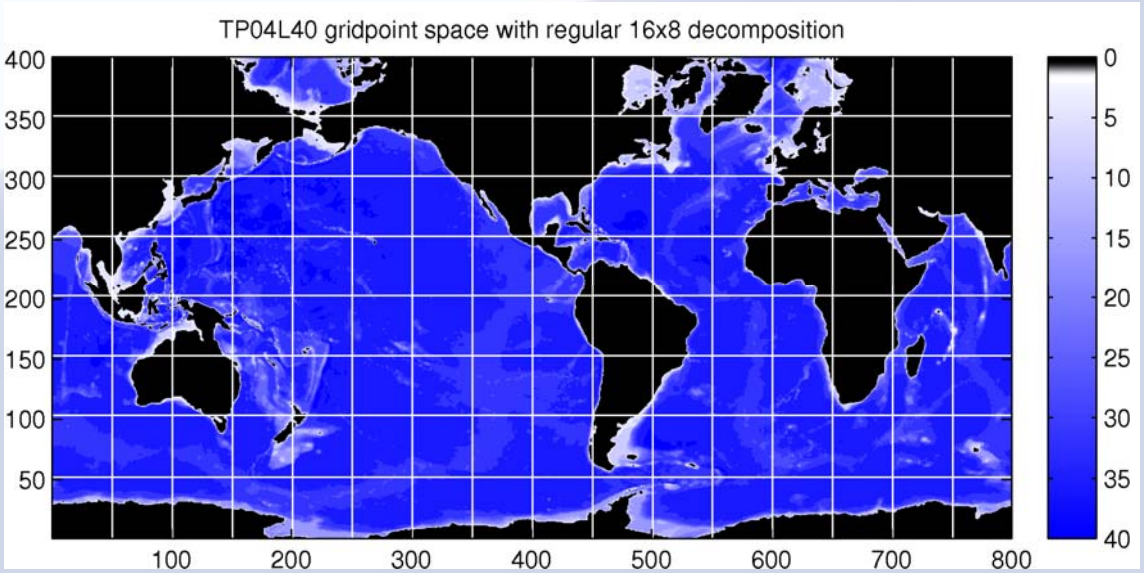

repart_compute_depth_sum

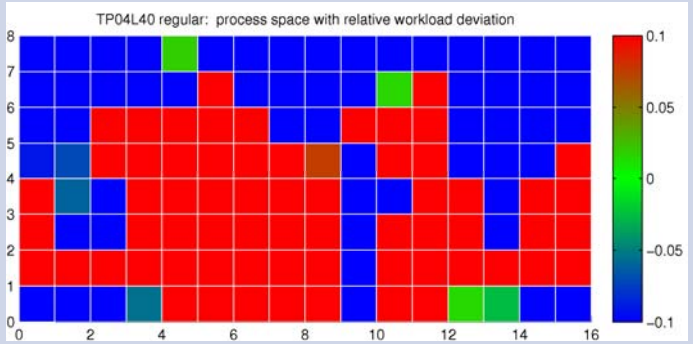
# Problem of Graph Partitioning

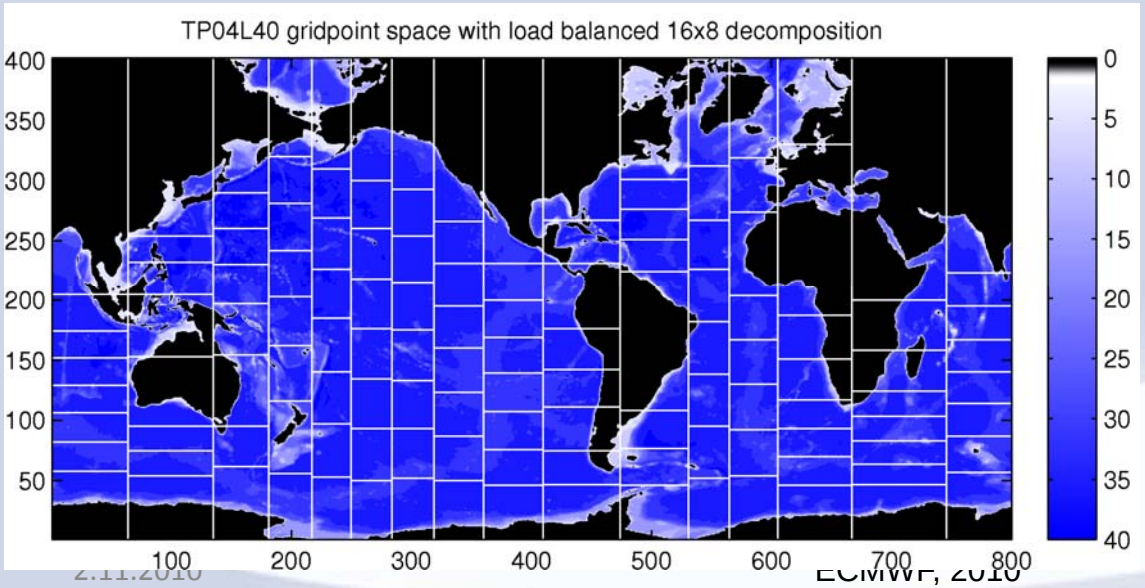


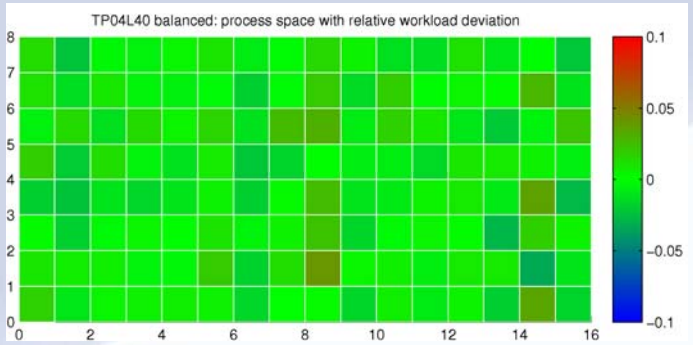

ECMWF, 2010

# Loadbalancing



ScalES

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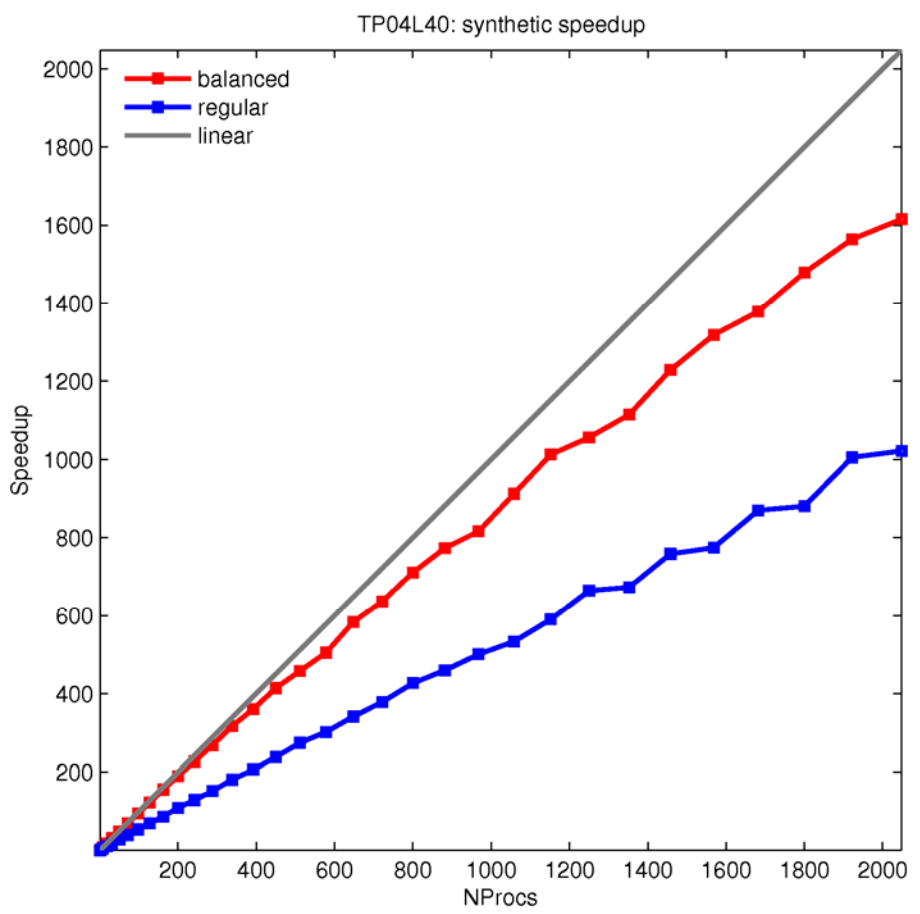
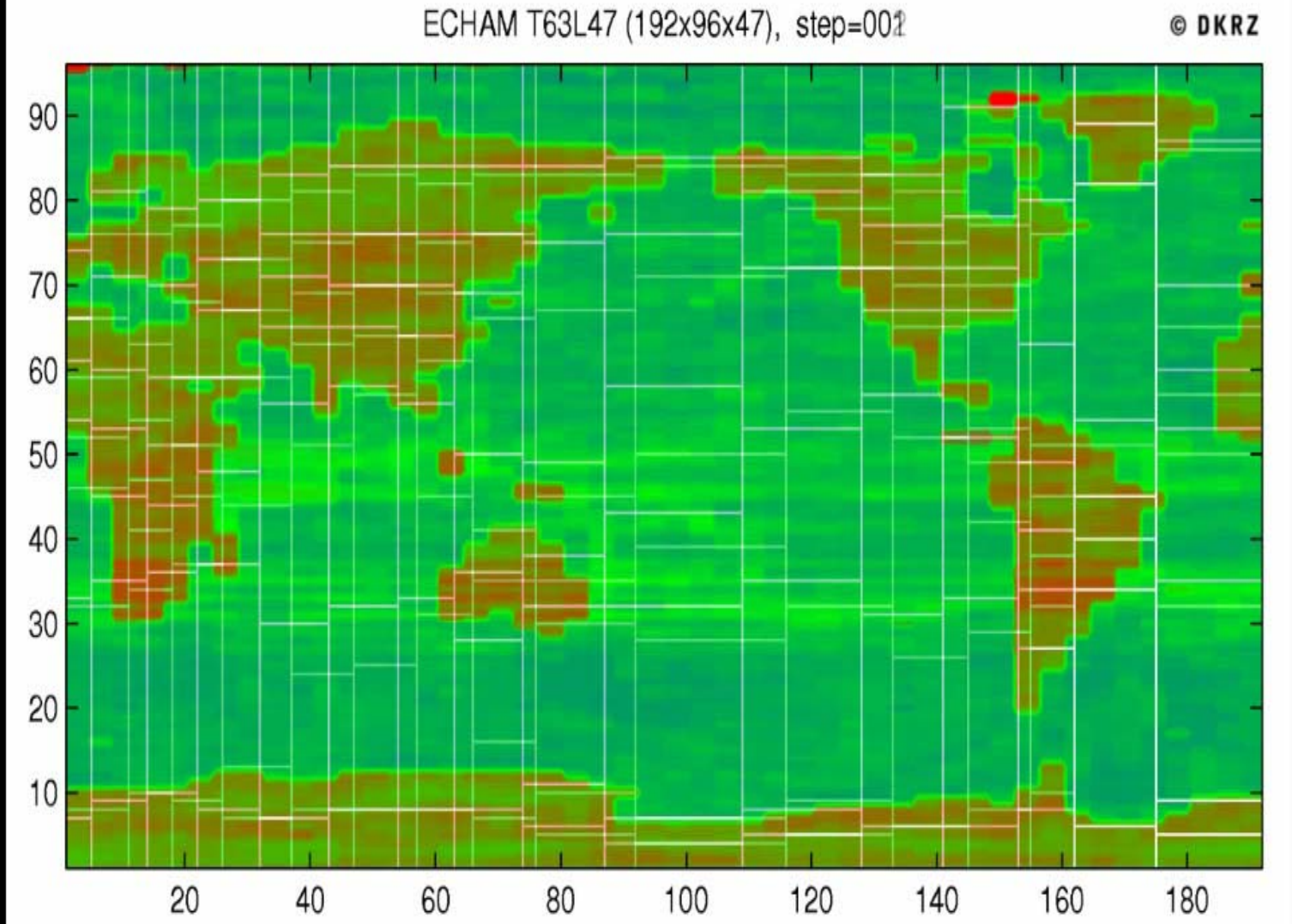
für Bildung
und Forschung

# Loadbalancing



ScalES


ECHAM T63L47 (192x96x47), step=001
© DKRZ
90
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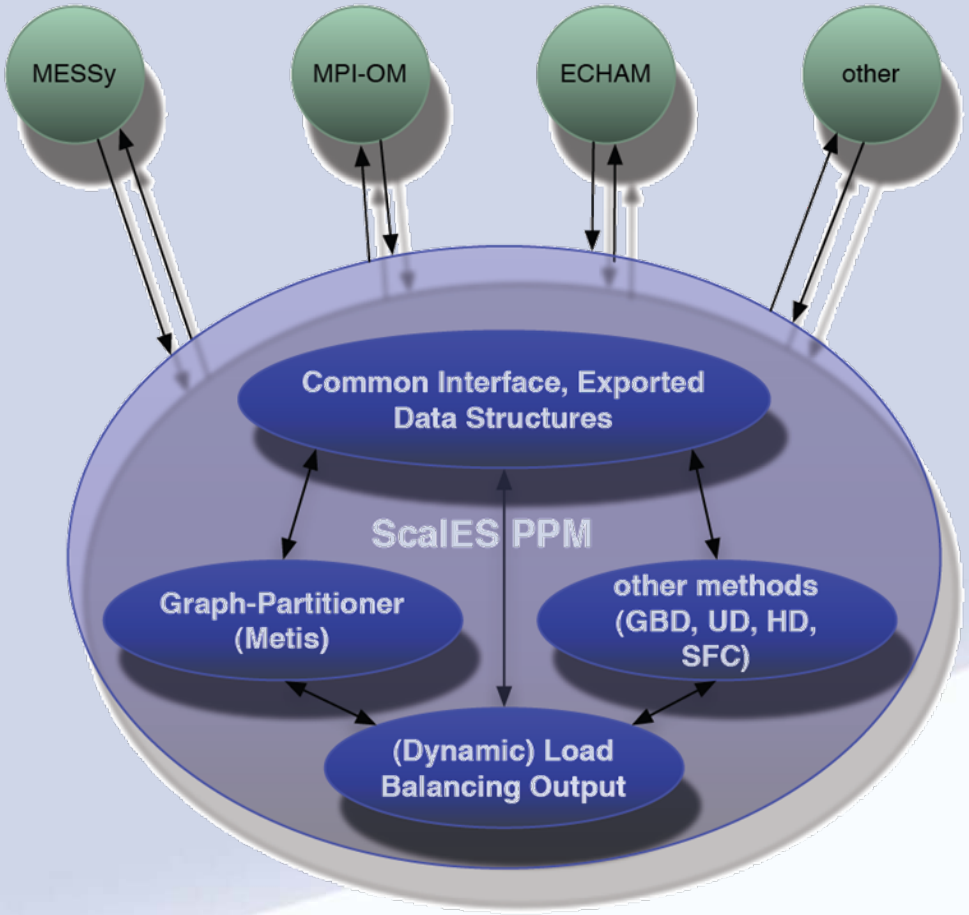
160
180

# ScalES PPM (Parallel Partioning Modul)

**Features:**

- Describe partitioning in model-independent data structures.
- Provide convenient API to multiple partitioning algorithms.
- Support data relocation for repartitioning
- Provide solid foundation for other partitioning dependent functionality.




**ScalES PPM schematic library design**

# Optimization

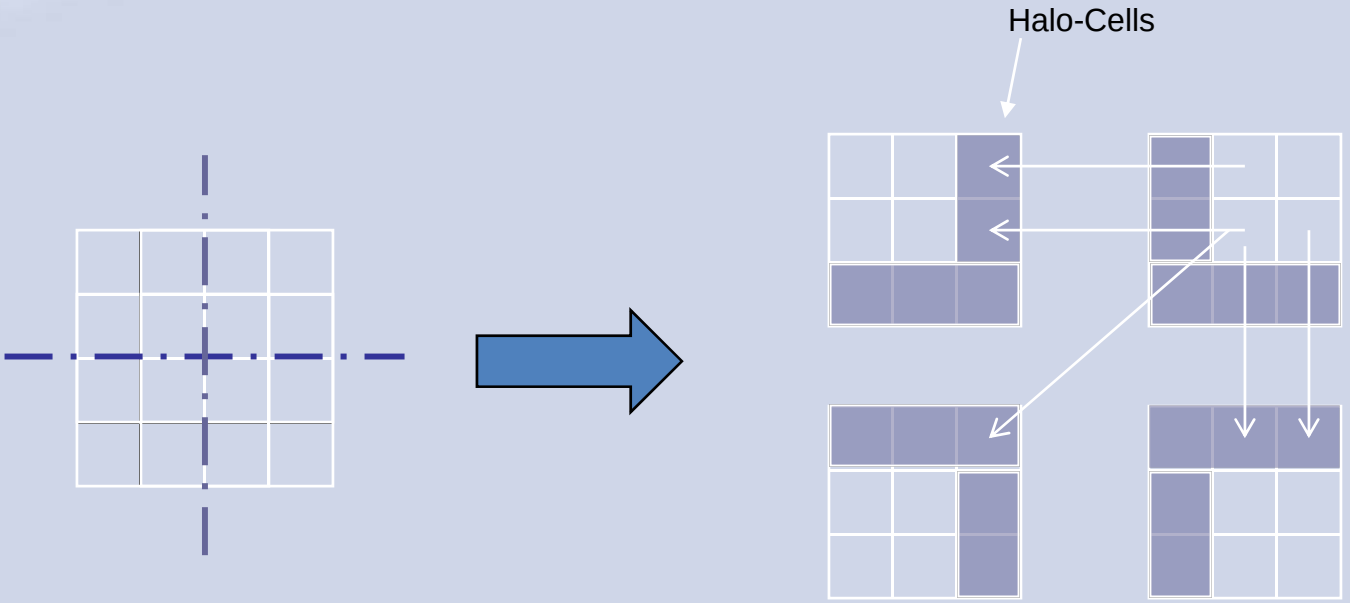
Computation vs Communication

- Expanding Halos
  - More Local Operations
  - Less Communication

CG Method with appropriate Preconditioner

- Faster Convergence =>
  - Less Iterations
- Less Communication

# Structure of a partitioned mesh

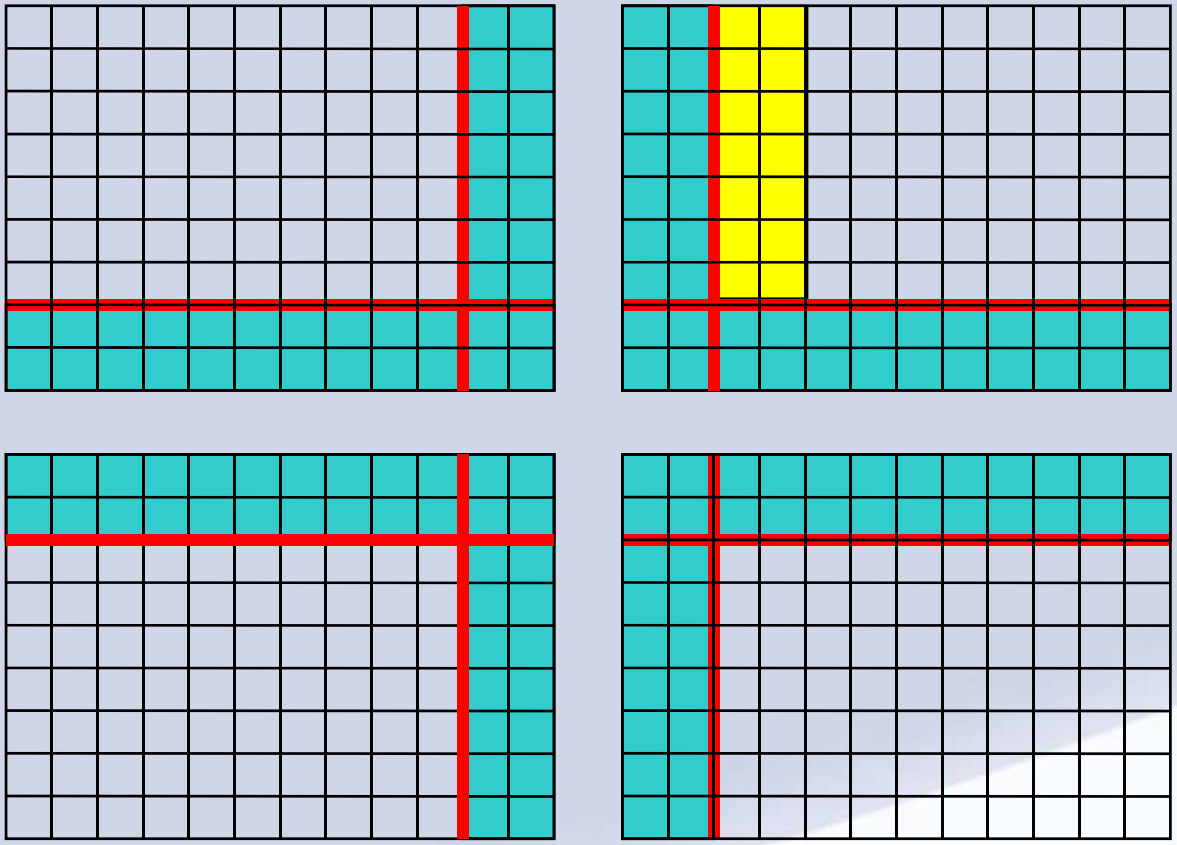



Global mesh

Partitioned mesh

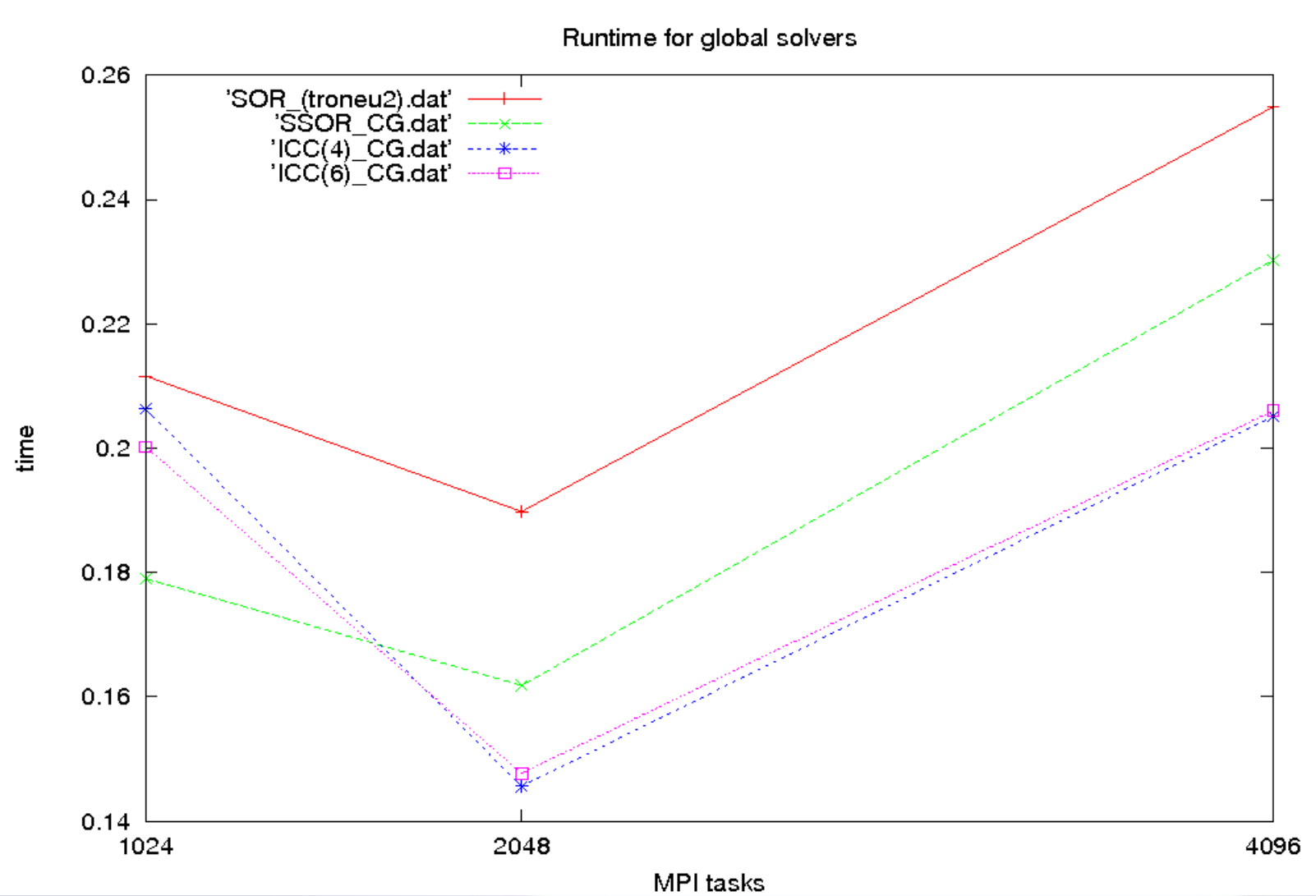
Exchange of halos at each iteration

# Expanding Halos



Exchange of expanded halos every 2nd iteration

# Library of Solvers (KIT)



# Optimization

- Compilers cannot optimize automatically everything
- Optimization is not just finding the right compiler flag
- Major algorithmic changes are necessary
- Solutions must be generic otherwise the whole process is a “Sisyphean Task”

ScalES

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# Scalable Earth-System Models

- **Project:**
  - Facilitate High Productivity Climate Simulations
  - Three year program
  - Funded by Federal Ministry for Science and Research (01IH08004E)
  - Started in January 2009

- **Partners:**
  - DKRZ (German Climate Computing Centre)
  - MPIM (Max-Planck-Institute for Meteorology)
  - MPIC (Max-Planck-Institute for Chemisty)
  - AWI (Alfred-Wegner-Institute for Polar Research)
  - KIT (Karlsruhe Institute for Technology)
  - IBM (International Business Machines)

# ScalES:

## Use case: COSMOS

- ECHAM5 (global atmosphere)
- MESSY/MECCA (atmospheric chemistry)
- MPI-OM (global ocean)
- OASIS4 (coupler)

## Work Packages

- Parallel I/O
- Load Balancing
- Architectural issues
- Coupling (e.g. of atmosphere and ocean models)

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