Distributed Algorithms

CS 308 Compiler Techniques

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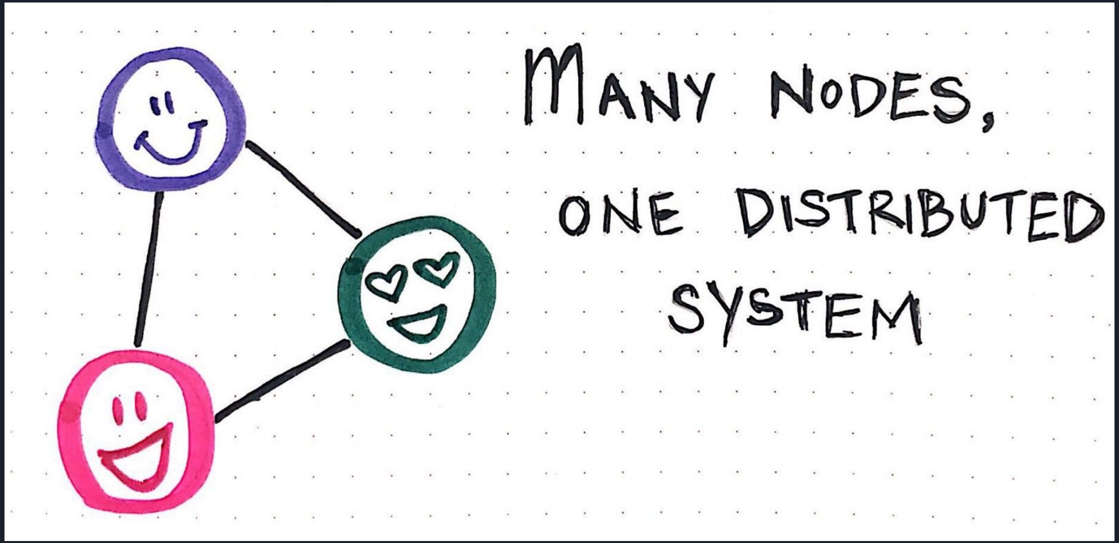
Distributed Systems : Overview

- A model in which components located on networked computers communicate and coordinate their actions by passing messages.

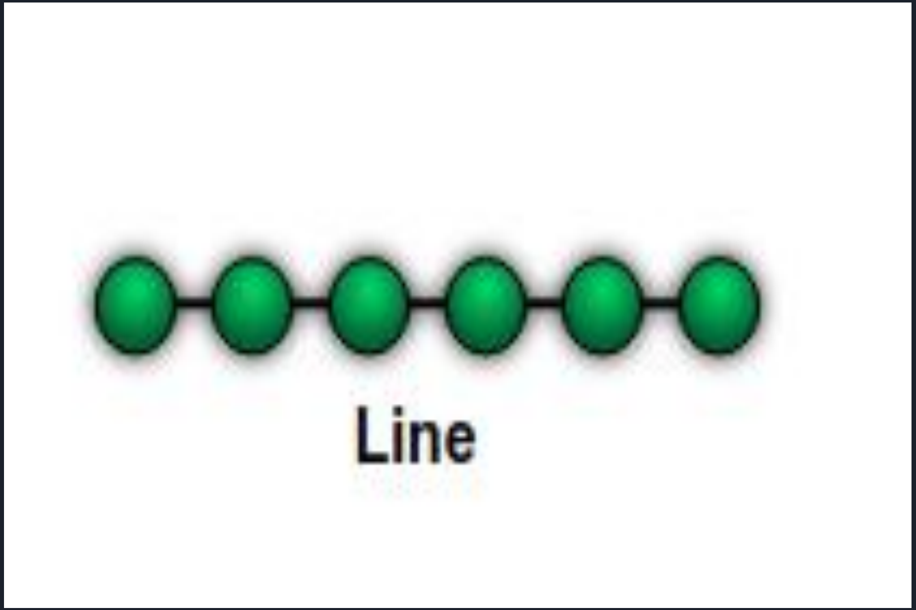
Distributed Systems : Overview



Source : medium.com

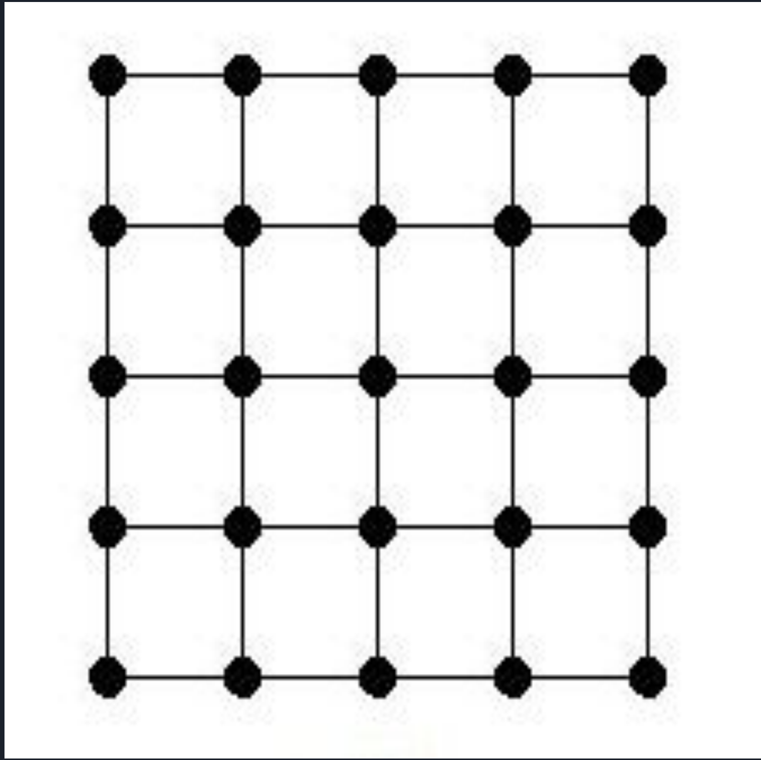
Network Topologies

Linear



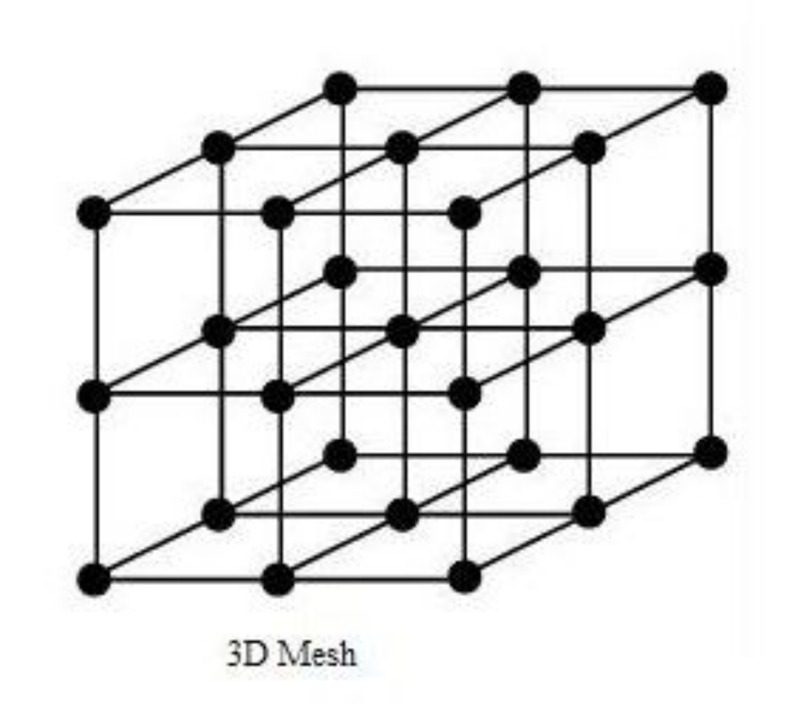
Source: Wikipedia

Grid



Source: http://wiki.expertiza.ncsu.edu

Mesh 3D



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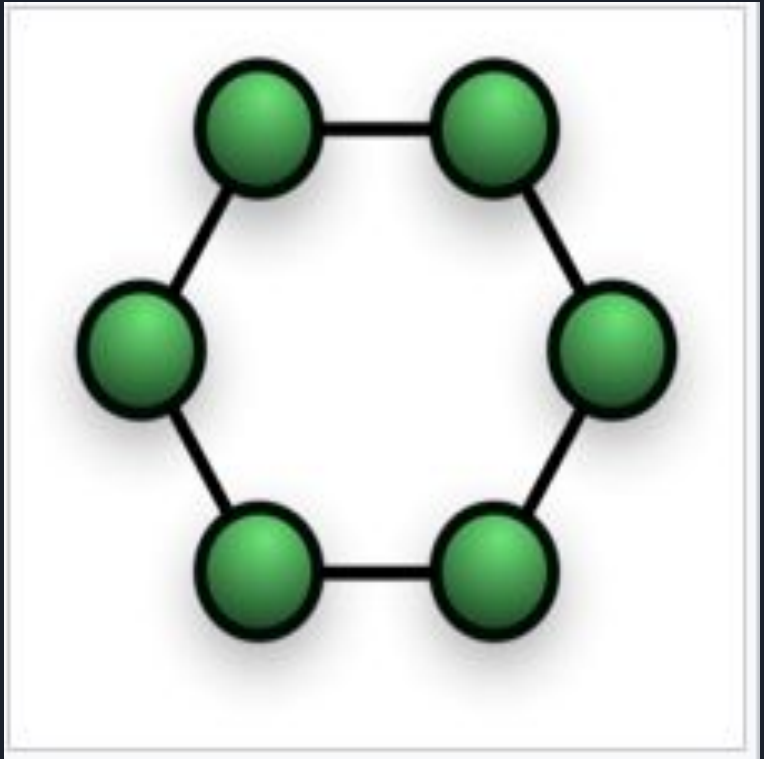
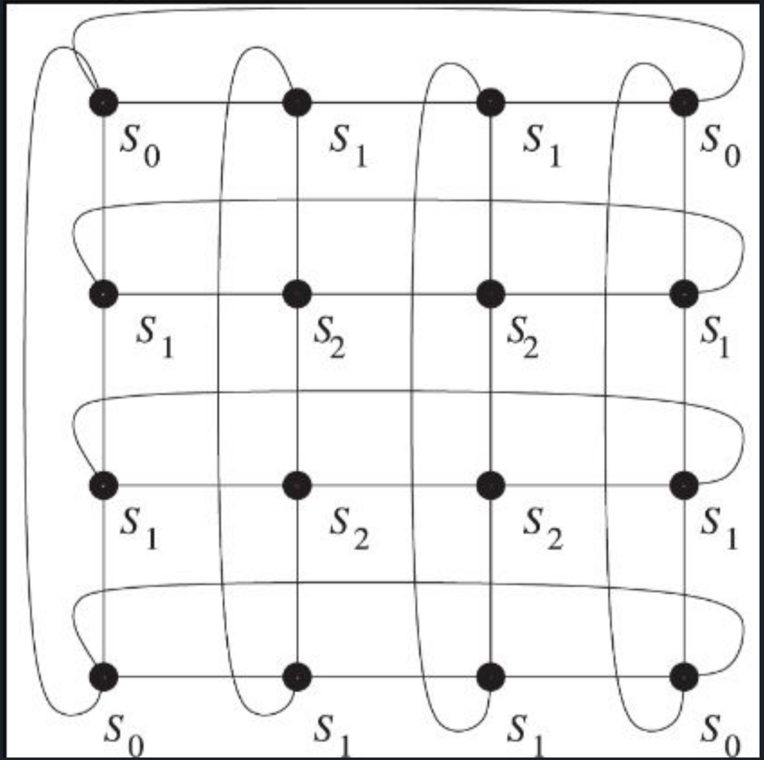
Ring



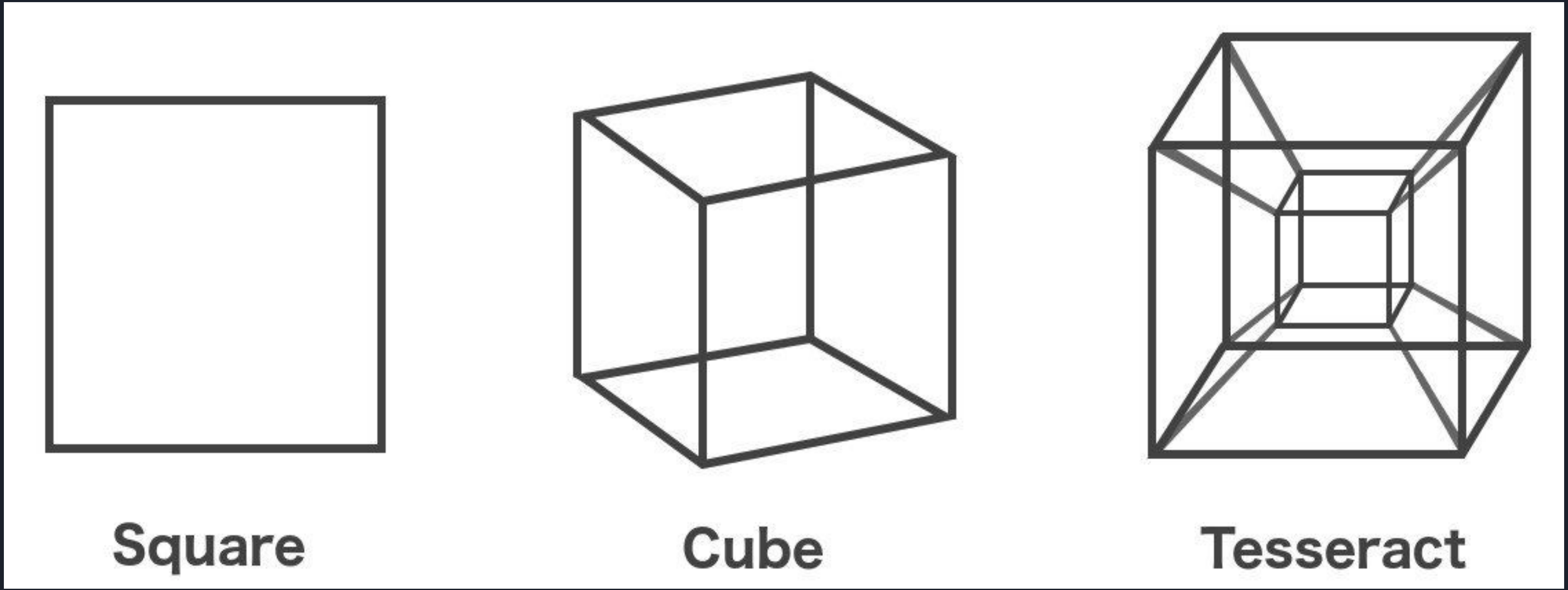
Source: Wikipedia

Torus 2D

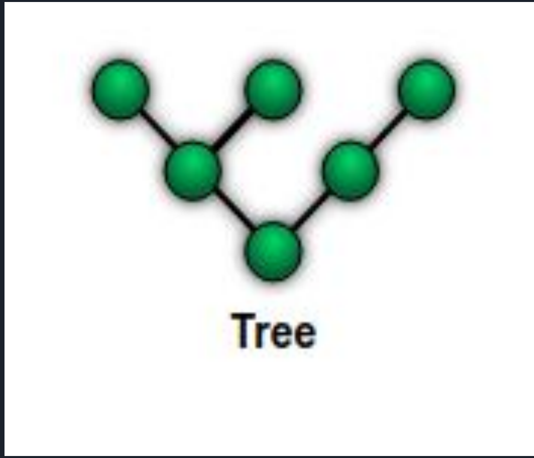


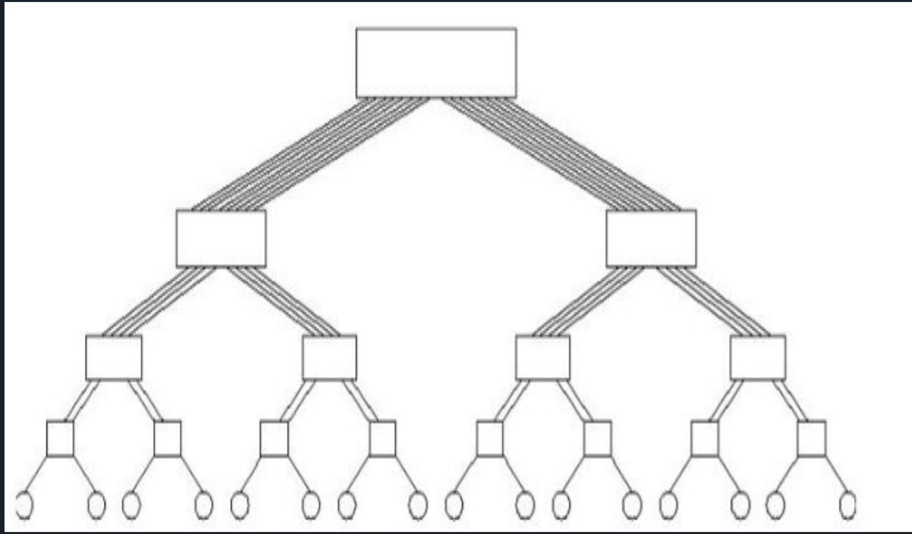
Source: www.computer.org

Hypercubes



Tree And Fat Tree

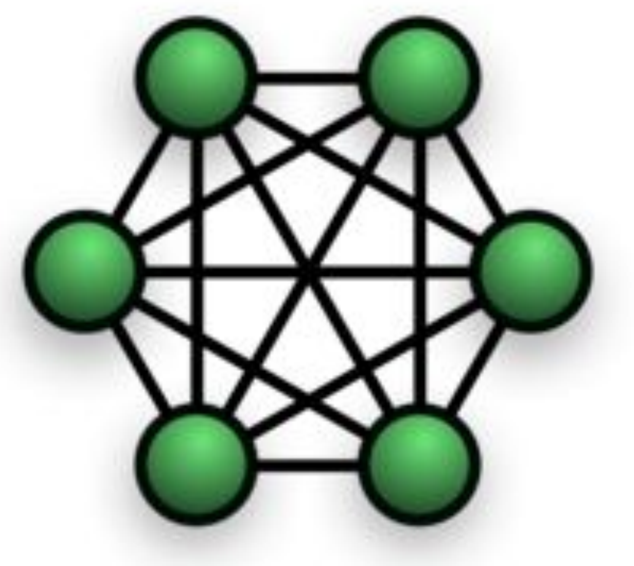




Fat Tree

Source: Ashley Dickerson

Fully Connected Graph



Fully connected mesh topology

Source: Wikipedia

Topology Parameters

- Number of Links
- Diameter
- Bisection Width
- Bisection Bandwidth
- Congestion

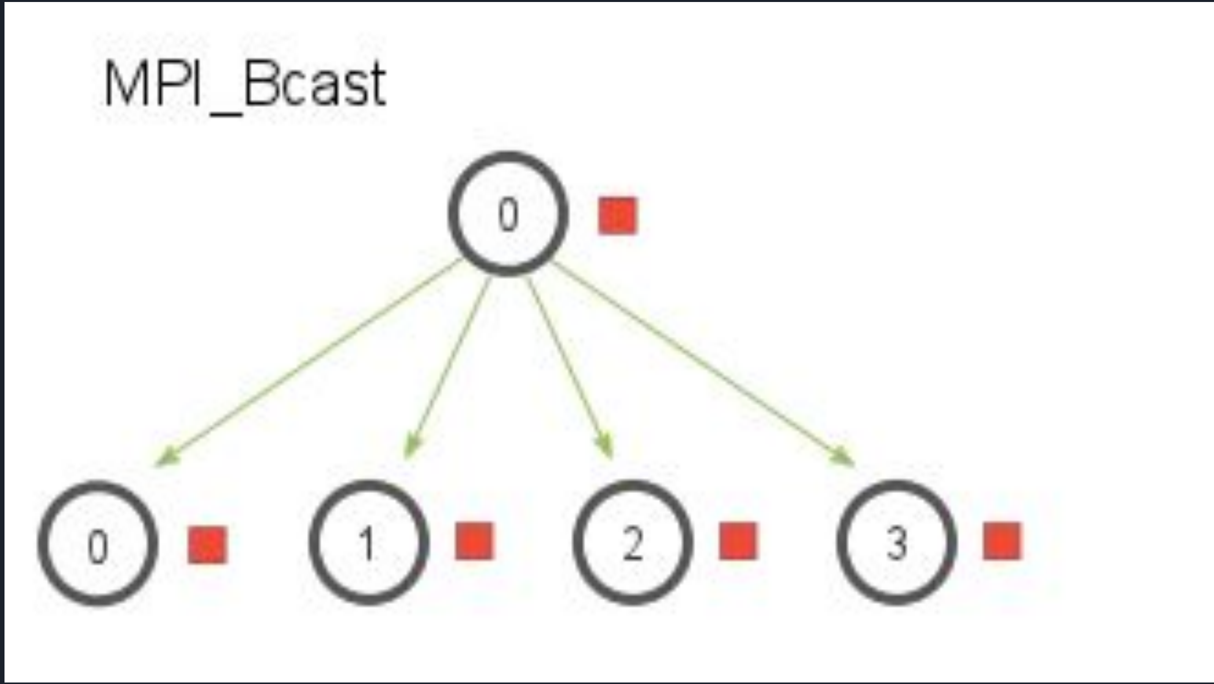
$$C = \Omega(B_L/B_p)$$

Topology Related Complexities

Topology	Metric		
	# Links	Diameter	Bisection Width
Linear	$p-1$	$p-1$	1
2D Mesh	$2p-2\sqrt{p}$	$2(\sqrt{p}-1)$	$\sqrt{p}$
kD Mesh	$kp-kp^{\left(\frac{k-1}{k}\right)}$	$kp^{\frac{1}{k}}$	$p^{\left(\frac{k-1}{k}\right)}$
Ring	p	$p/2$	2
2D Torus (Doughnut)	$2p$	$\sqrt{p}-1$	$2\sqrt{p}$
kD Torus	kp	$\frac{k}{2}(p^{\frac{1}{k}}-1)$	$2p^{\left(\frac{k-1}{k}\right)}$
$log(p)$ D Hypercube	$\frac{p\,log(p)}{2}$	$log(p)$	$p/2$
Binary Tree	$p-1$	$2log(p)$	1
Fully Connected	$\frac{p\,(p-1)}{2}$	1	$\frac{p^2}{4}$

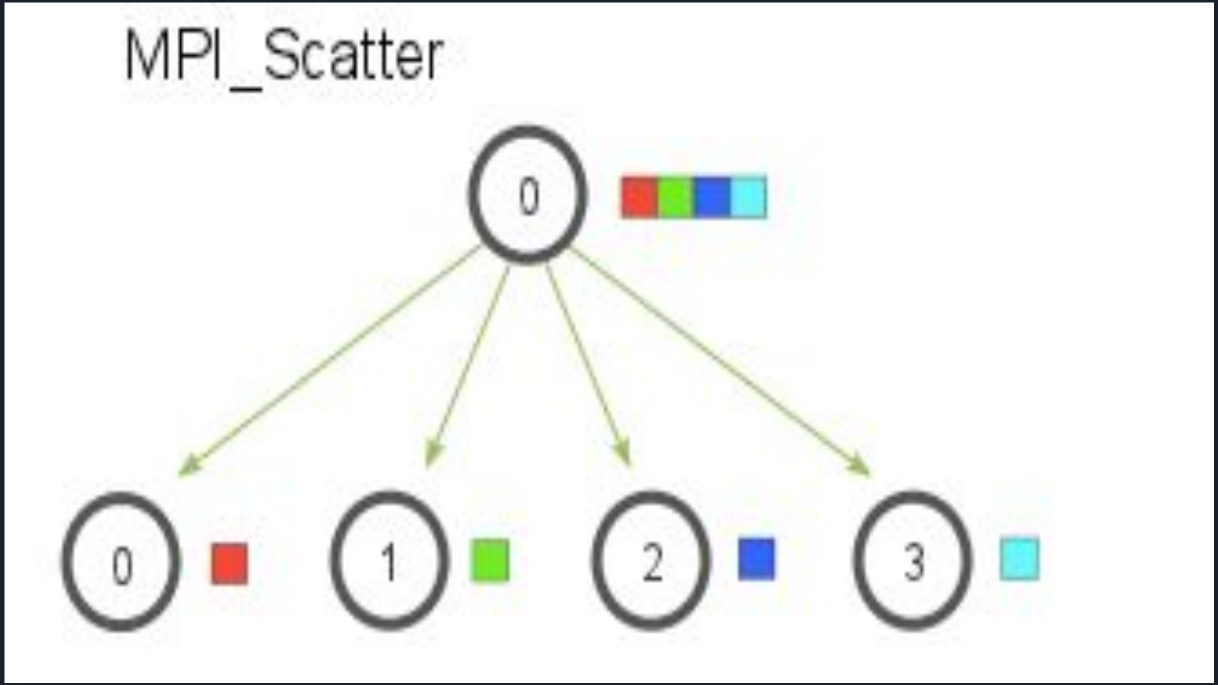
Distributed Algorithms

Broadcast Algorithm



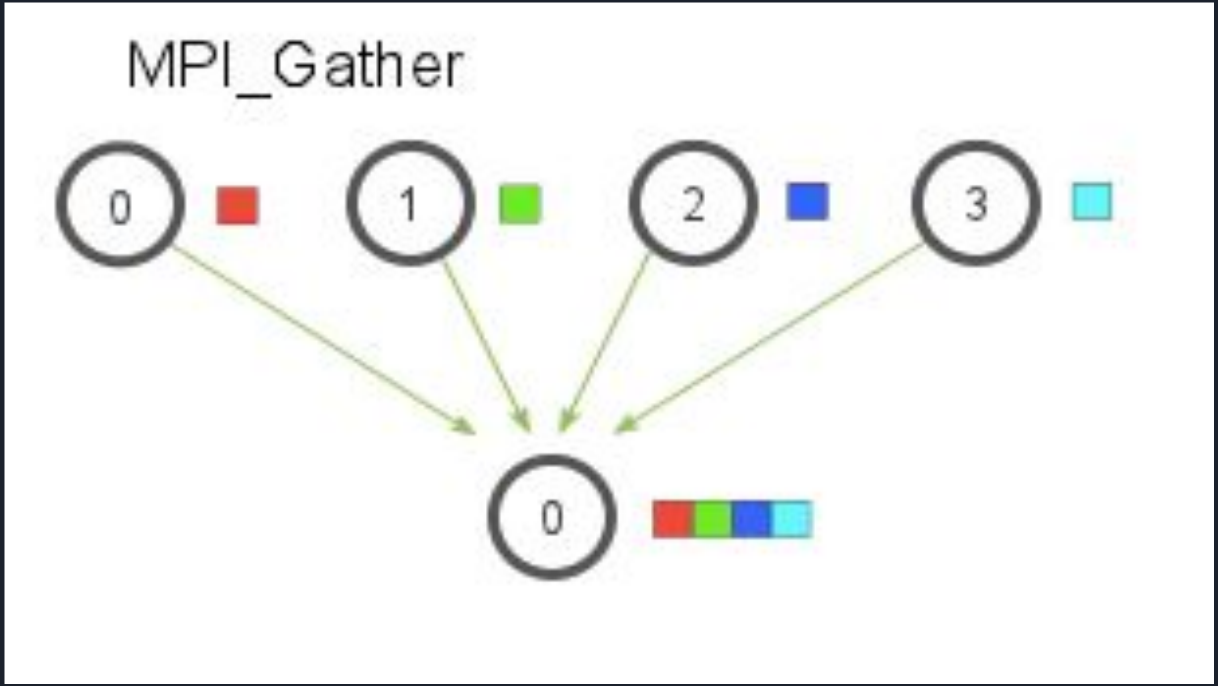
Source: mpitutorial.com

Scatter Algorithm



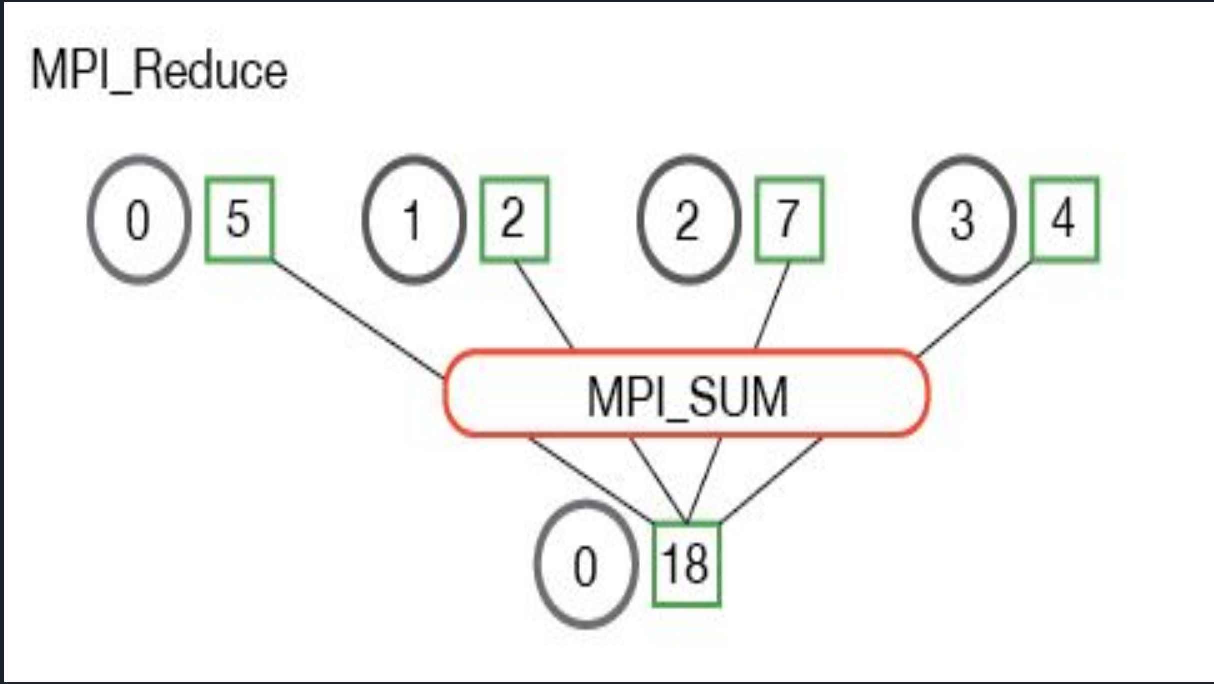
Source: mpitutorial.com

Gather Algorithm



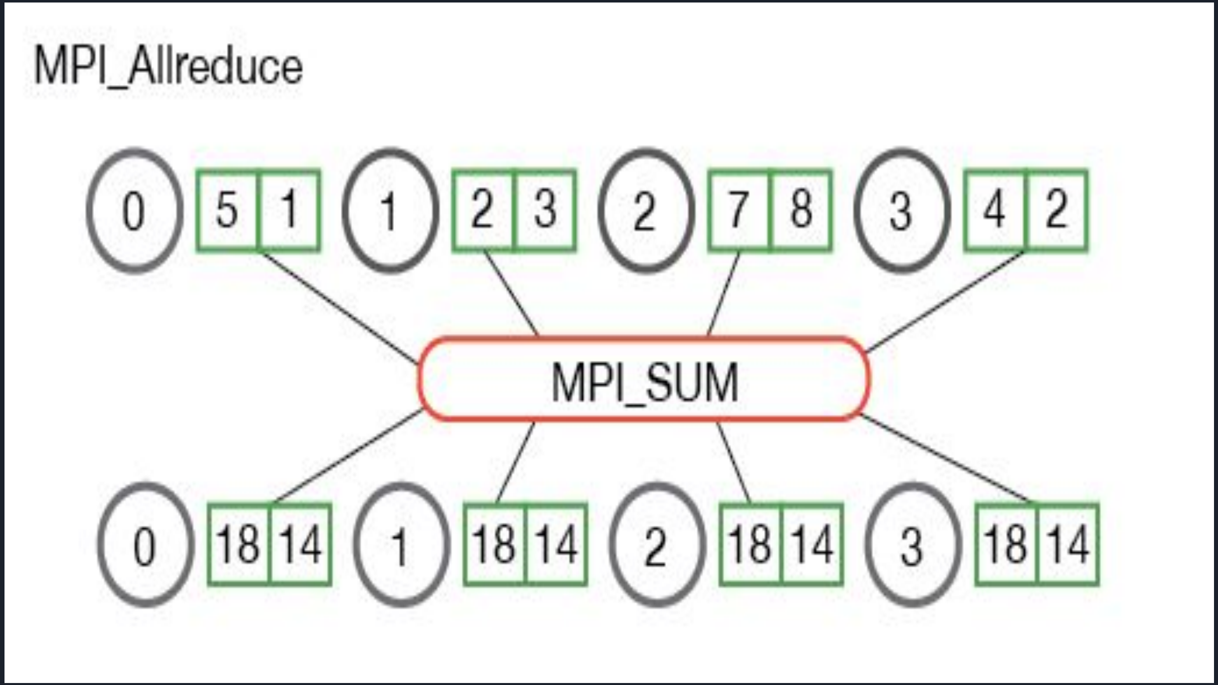
Source: mpitutorial.com

Reduce Algorithm



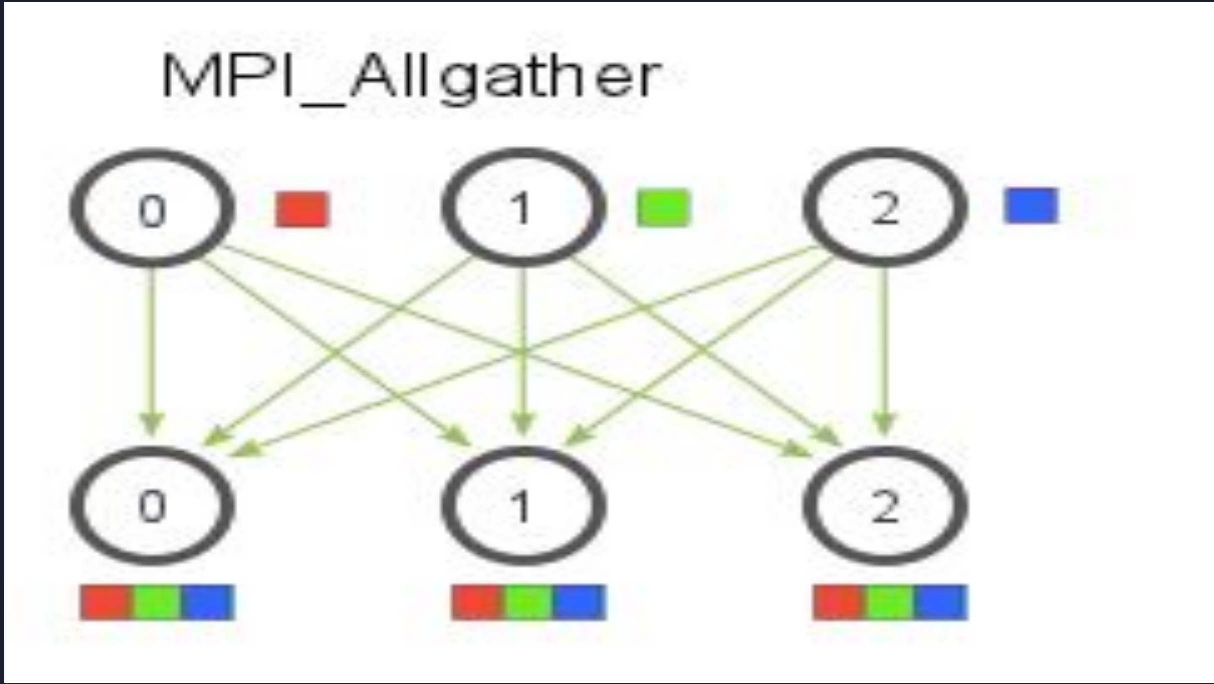
Source: mpitutorial.com

All Reduce Algorithm



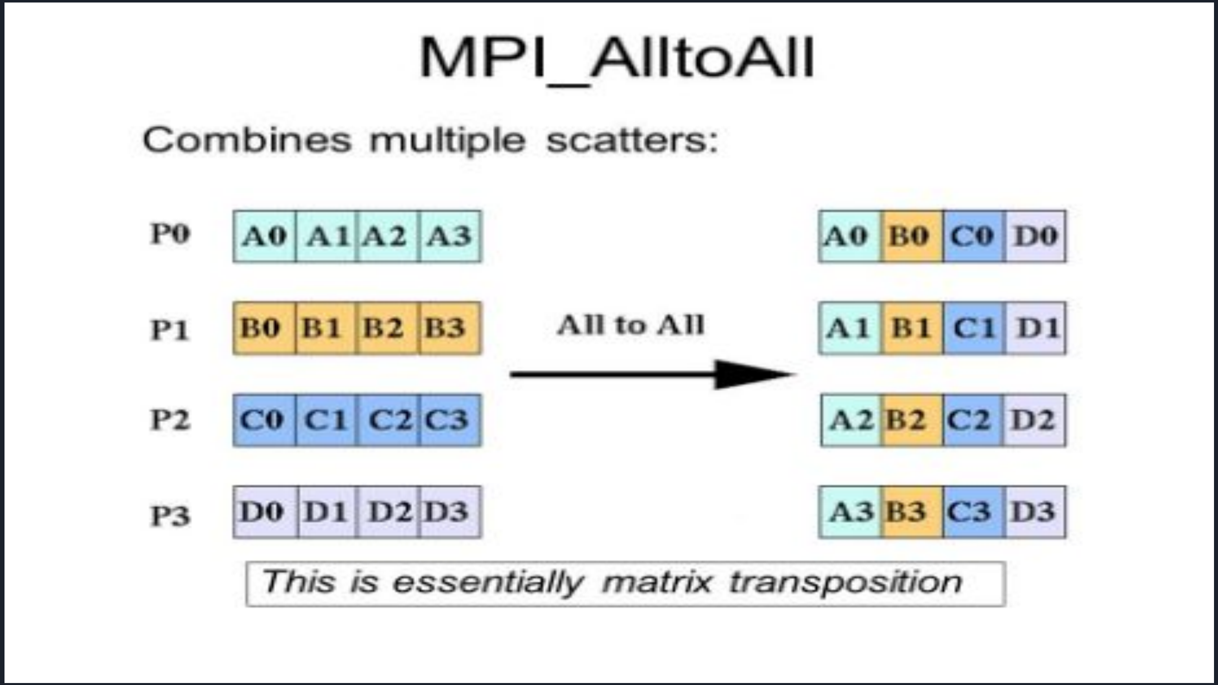
Source: mpitutorial.com

All Gather Algorithm



Source: mpitutorial.com

All-to-All Algorithm



Source: UNC-Charlotte

Algorithm Complexity Parameters

- α = latency (units of time)
- β = inverse bandwidth (units of time/word)
- Time to send a message of n-words between two nodes :

$$T(n) = \alpha + \beta n$$

Algorithm Complexity Parameters

- Time during K-way congestion :

$$T(n) = \alpha + \beta n k$$

Time Complexities

Algorithm	Topology	Time Complexity
One-to-all Broadcast All-to-one Reduction	*Linear*	$(\alpha + \beta m)(p)$
	Ring	$(\alpha + \beta m) \, log(p)$
	Mesh	$(\alpha + \beta m) \, log(p)$
	Torus (2-D)	$(\alpha + \beta m) \, log(p)$
	Hypercube	$(\alpha + \beta m) \, log(p)$
	Tree	$(\alpha + \beta m) \, p$
	FCG	$(\alpha + \beta m) \, log(p)$

Time Complexities

All-to-all Broadcast All-to-all Reduction	*Linear*	$(\alpha + \beta m)(p - 1)$
	Ring	$(\alpha + \beta m)(p - 1)$
	Mesh	$2\alpha(\sqrt{p} - 1) + \beta m(p - 1)$
	Torus (2-D)	$2\alpha(\sqrt{p} - 1) + \beta m(p - 1)$
	Hypercube	$\alpha log(p) + \beta m(p - 1)$
	Tree	$(\alpha + \beta m)(p - 1)$
	FCG	$(\alpha + \beta m)(p - 1)$

Time Complexities

All Reduce	*Linear*	$(\alpha + \beta m)\ log(p)$
	Ring	$(\alpha + \beta m)\ log(p)$
	Mesh	$(\alpha + \beta m)\ log(p)$
	Torus (2-D)	$(\alpha + \beta m)\ log(p)$
	Hypercube	$(\alpha + \beta m)\ log(p)$
	Tree	$(\alpha + \beta m)\ p$
	FCG	$(\alpha + \beta m)\ log(p)$

Time Complexities

Scatter Gather	*Linear*	$\alpha log(p) + \beta m(p-1)$
	Ring	$\alpha log(p) + \beta m(p-1)$
	Mesh	$\alpha log(p) + \beta m(p-1)$
	Torus (2-D)	$\alpha log(p) + \beta m(p-1)$
	Hypercube	$\alpha log(p) + \beta m(p-1)$
	Tree	$\alpha log(p) + \beta m(p-1)$
	FCG	$\alpha log(p) + \beta m(p-1)$

Time Complexities

Scatter-all Gather-all	*Linear*	$(\alpha + \beta m\frac{p}{2})(p-1)$
	Ring	$(\alpha + \beta m\frac{p}{2})(p-1)$
	Mesh	$(2\alpha + \beta mp)(\sqrt{p}-1)$
	Torus (2-D)	$(2\alpha + \beta mp)(\sqrt{p}-1)$
	Hypercube	$(\alpha + \beta m)(p-1)$
	Tree	$(\alpha + \beta m\frac{p}{2})(p-1)$
	FCG	$(\alpha + \beta m\frac{p}{2})(p-1)$

Simulations & Plots

MPI

- **Message Passing Interface (MPI)** is a standardized and portable message-passing standard designed by a group of researchers from academia and industry to function on a wide variety of parallel computing architectures.

SimGrid

SimGrid is a scientific instrument to study the behavior of large-scale distributed systems such as Grids, Clouds, HPC or P2P systems.

Simgrid and its features

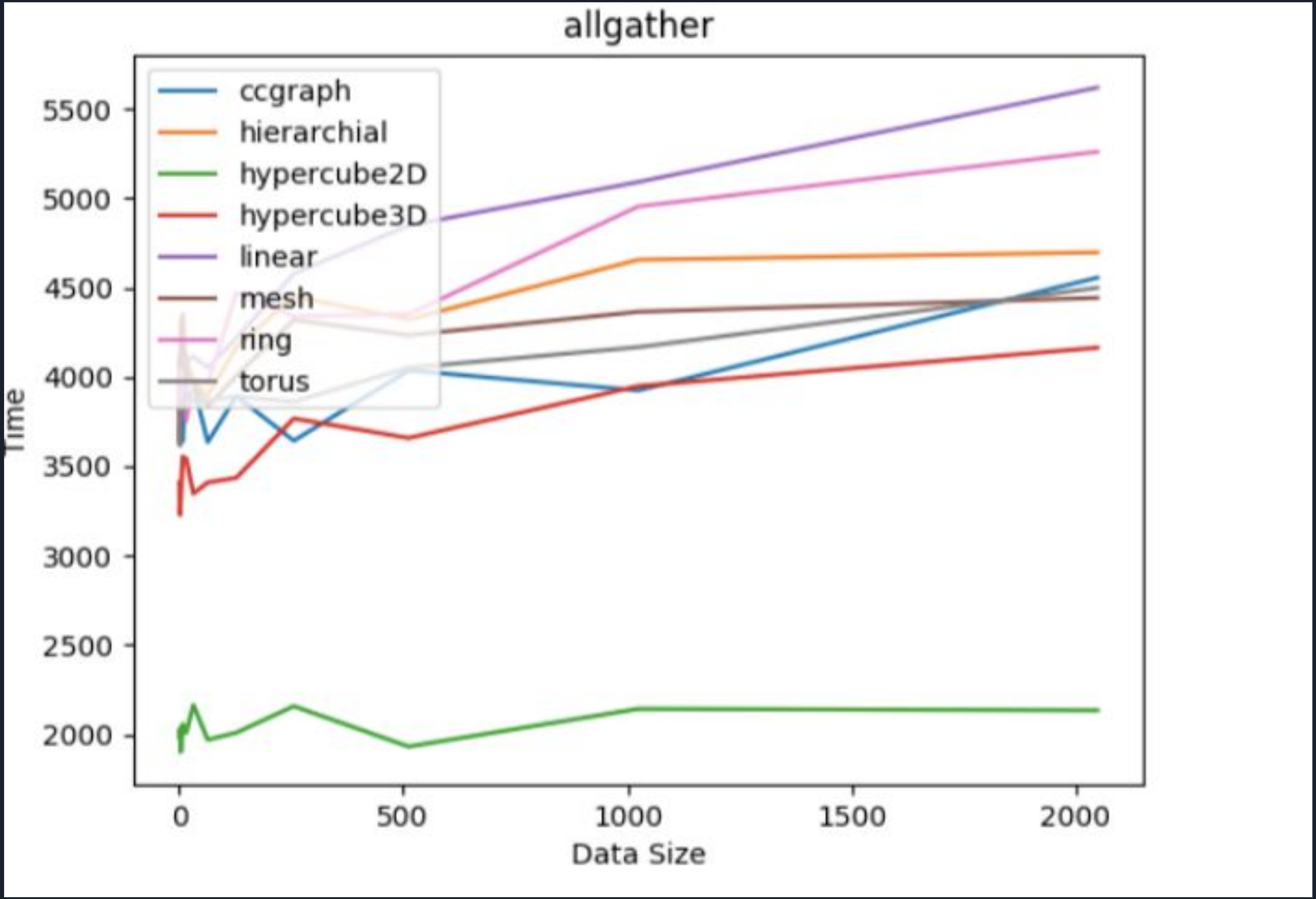
- Allows one to configure :
    - Per host computing power
    - Link latency and bandwidth
    - Simulate MPI programs without modifications
    - Simulate on different architectures

Simgrid and its features

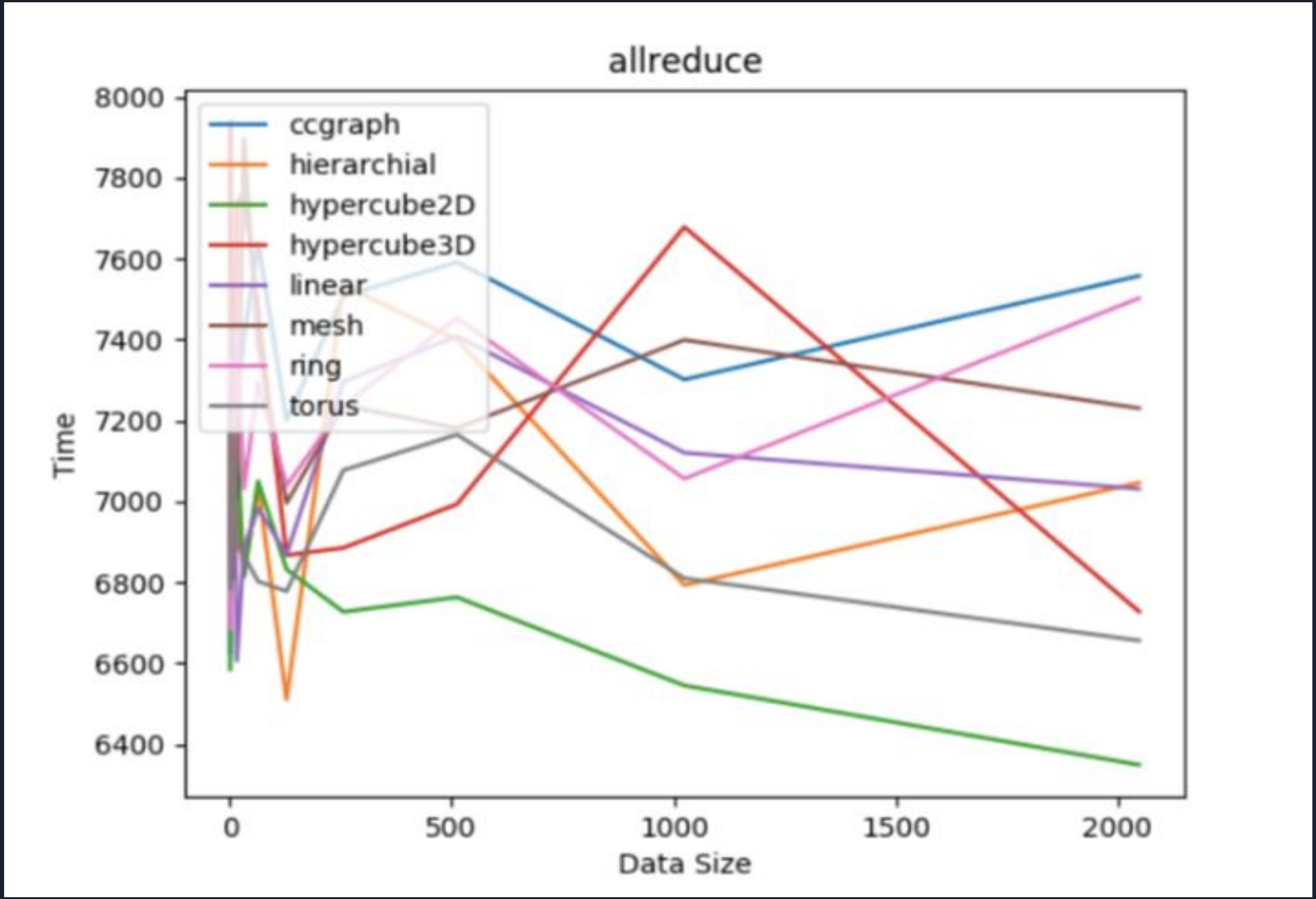
- Provides one with :
  - Link to link message count
  - Power consumption node wise
  - Execution time
- The trace information provided by Simgrid can be visualized using a tool pajeng.

Sample Trace Data after filtering

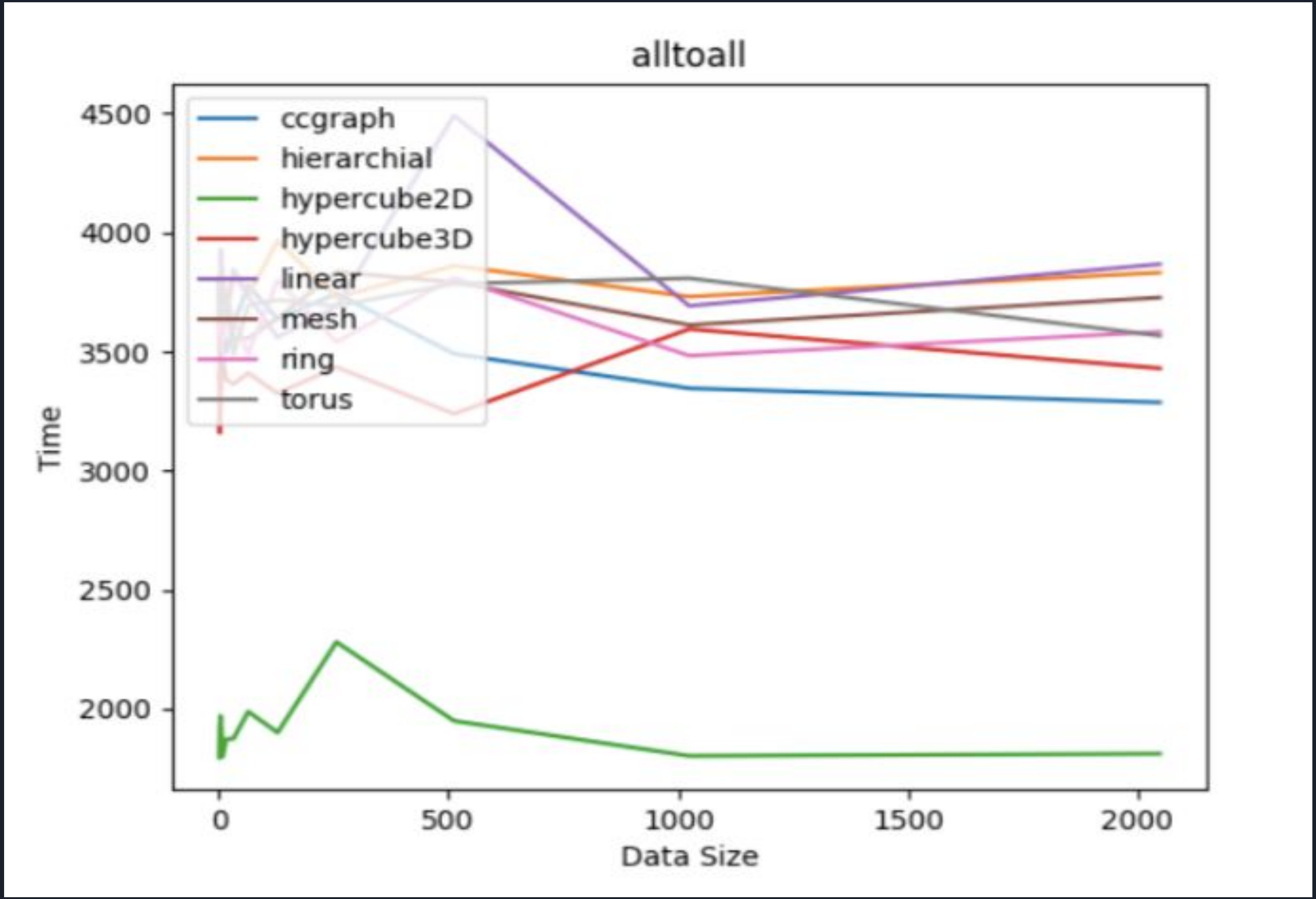
Source	Dest	Hop Count
1	2	4
1	9	1
1	3	3
3	4	5
1	5	2
5	6	7
5	7	6
7	8	8



allgather
ccgraph
hierarchial
hypercube2D
hypercube3D
linear
mesh
ring
torus
Time
Data Size
5500
5000
4500
4000
3500
3000
2500
2000
0
500
1000
1500
2000



allreduce
8000
7800
7600
7400
7200
7000
6800
6600
6400
Time
0
500
1000
1500
2000
Data Size
ccgraph
hierarchial
hypercube2D
hypercube3D
linear
mesh
ring
torus


alltoall
ccgraph
hierarchial
hypercube2D
hypercube3D
linear
mesh
ring
torus
Time
Data Size
4500
4000
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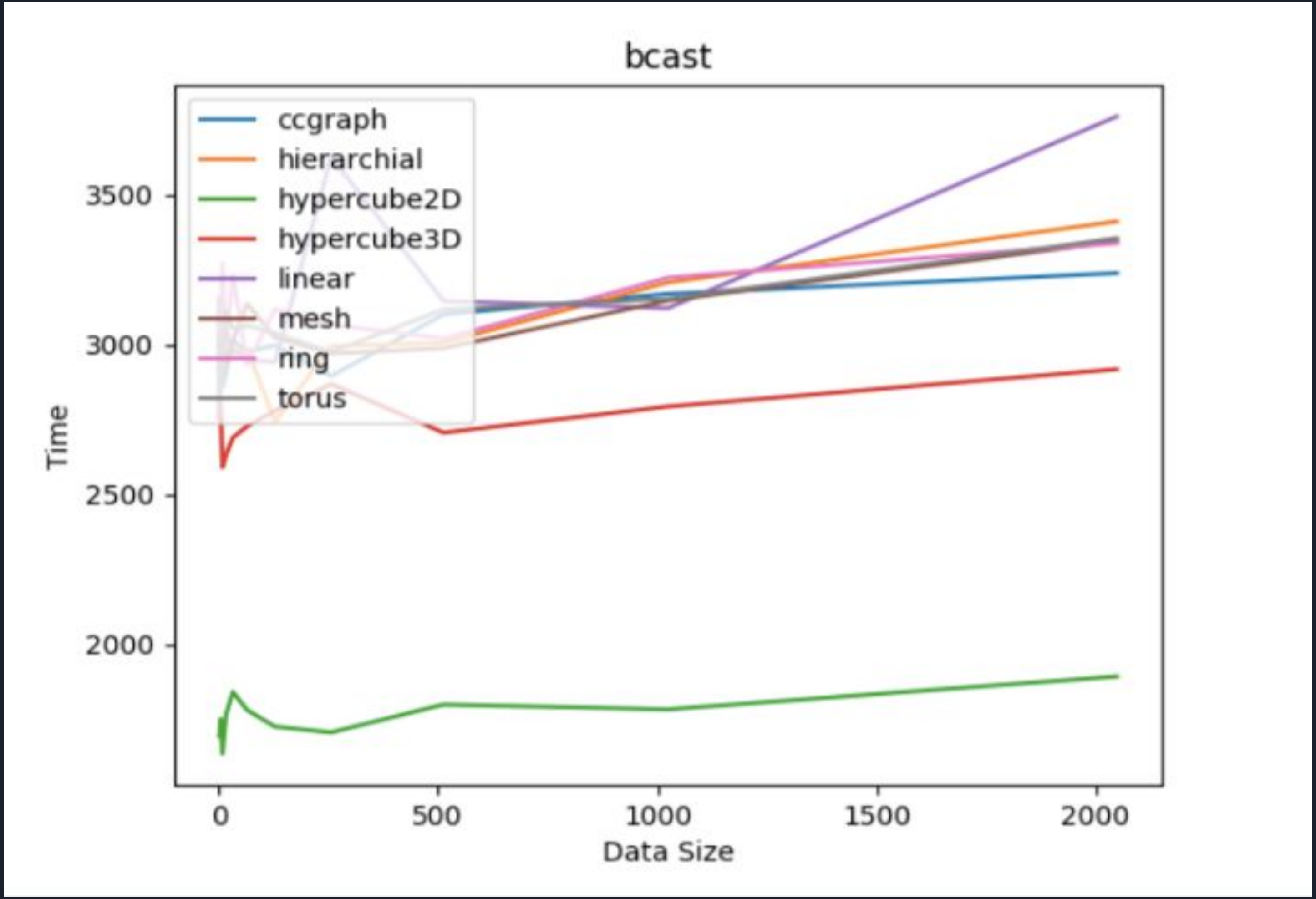
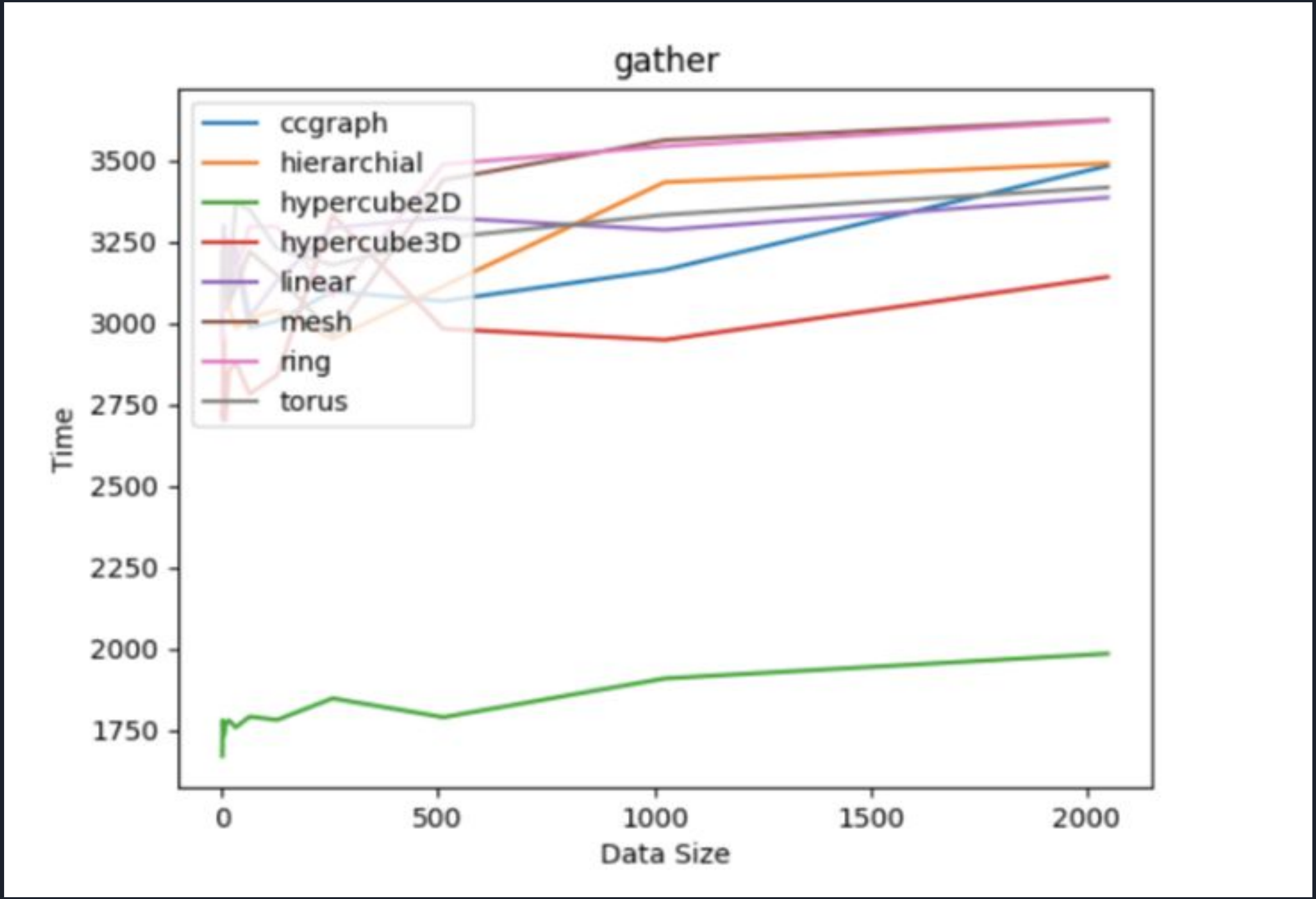
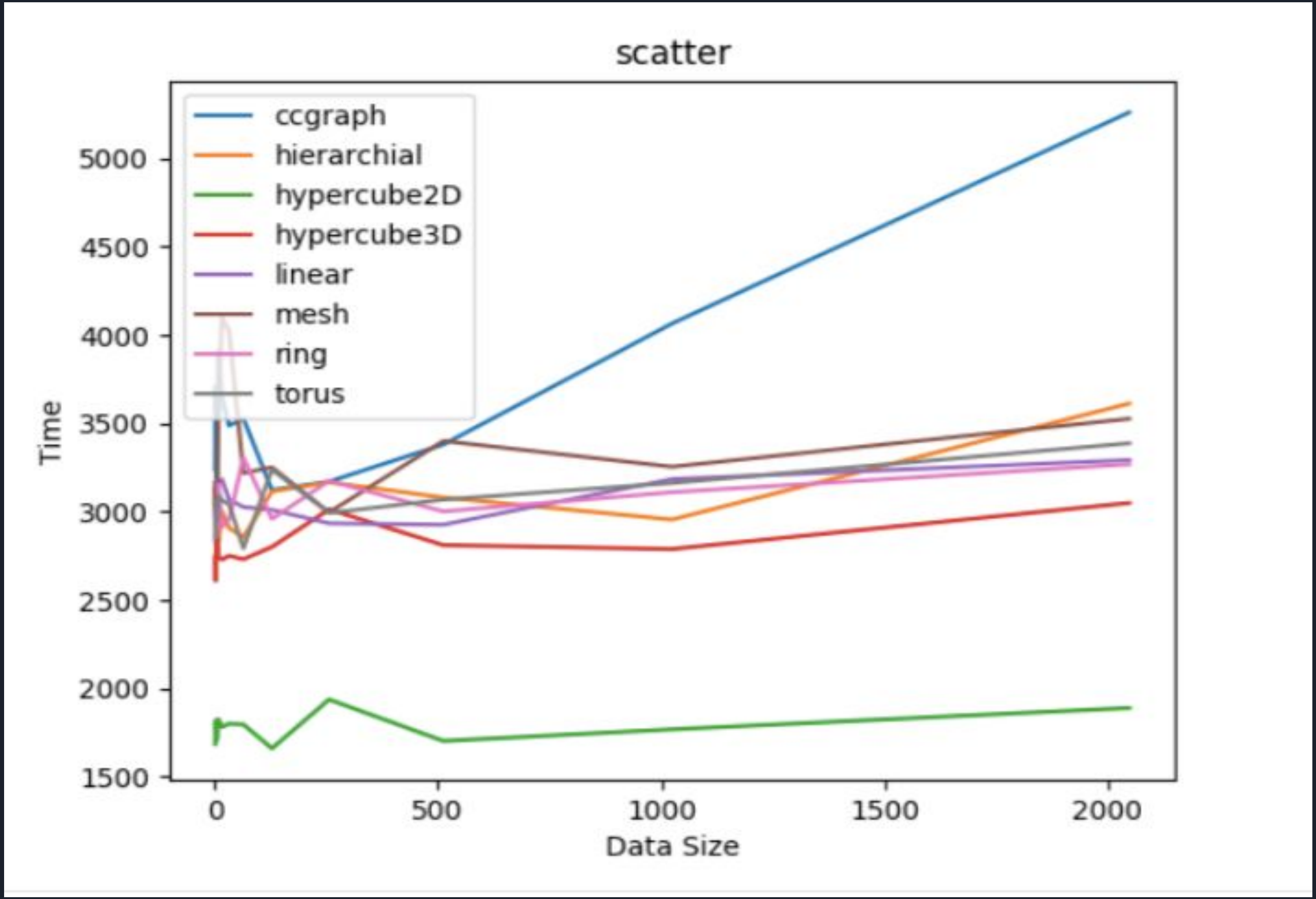
3000
2500
2000
0
500
1000
1500
2000


bcast
ccgraph
hierarchial
hypercube2D
hypercube3D
linear
mesh
ring
torus
Time
Data Size
3500
3000
2500
2000
0
500
1000
1500
2000


gather
ccgraph
hierarchial
hypercube2D
hypercube3D
linear
mesh
ring
torus
Time
3500
3250
3000
2750
2500
2250
2000
1750
0
500
1000
1500
2000
Data Size


scatter
ccgraph
hierarchial
hypercube2D
hypercube3D
linear
mesh
ring
torus
Time
5000
4500
4000
3500
3000
2500
2000
1500
0
500
1000
1500
2000
Data Size

References

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- https://www8.cs.umu.se/kurser/5DV050/VT12/F1b.pdf
- https://s3.amazonaws.com/content.udacity-data.com/courses/gt-cse6220/Course+Notes/Lesson2-1+Basic+Model.pdf
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- https://simgrid.org/tutorials/simgrid-smpi-101.pdf
- http://mpitutorial.com/tutorials/

Thank You