Non-Intrusively Avoiding Scaling Problems in and out of MPI Collectives

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Outline

- Scaling Problem
- Avoidance Framework
- Evaluation
- Conclusion

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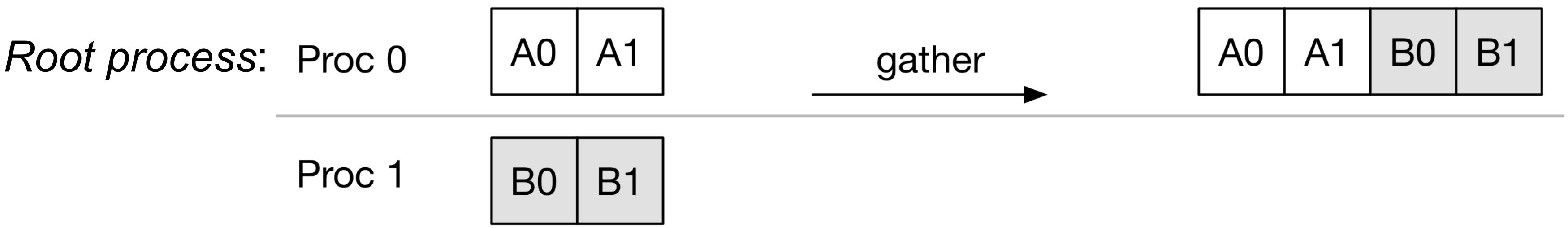
Scaling Problem

- Scaling problem is a type of bug that occurs when the program runs at a large scale in terms of
  - the number of processes (P)
  - OR the input size
  - OR both

- They frequently arise with the use of MPI collectives as collective communication involves
  - a group of processes
  - and message size (input size)

An Example of MPI Collective



MPI_Gather using two processes ($P = 2$) with each transferring two elements $n = 2$.

Symbol	Meaning
n	Element count in one message
s	Size of the data type in bytes
P	Total number of processes

Scaling Problem

- The root cause of a scaling problem with the use of MPI collectives can be
  - inside MPI collectives
  - or outside MPI collectives

Inside MPI

- Many scaling problems are challenging to deal with
  - They escape the testing in the development phase
- It takes days and months to wait for an official fix
  - Difficulty exists in bug reproduction, root-cause diagnosis, and fixing

Scaling problems reported online.

Prob.	Collective	MPI library	Type	Effect	Scale (P, M)	Root cause (inside MPI)
1	MPI_Gather	OpenMPI 1.4.3	3	H	(64, 4KB)	Environment setting dependency
2	MPI_Alltoall	OpenMPI 1.4.3	3	H	(44, 4MB)	Environment setting dependency
3	MPI_Allgather	OpenMPI 1.4.3	3	H	(64, 4MB)	–
4	MPI_Alltoallv	OpenMPI 1.7	3	H	(96, 512KB)	Network connection failure
5	MPI_Allgather	MPICH 2	3	D	$P \cdot M >$ INT_MAX	Integer overflow in MPI
6	MPI_Send + Recv	Intel MPI 5.1.2	2	H	(2, 64KB)	OS (ubuntu) dependency
7	MPI_Bcast	Intel MPI 5.1.2	2 or 3	H	(2, 64KB)	Unknown to developers
8	MPI_Bcast	Intel MPI 2017	2 or 3	H	(–, 16KB)	Platform (KNL & BDW) dependency

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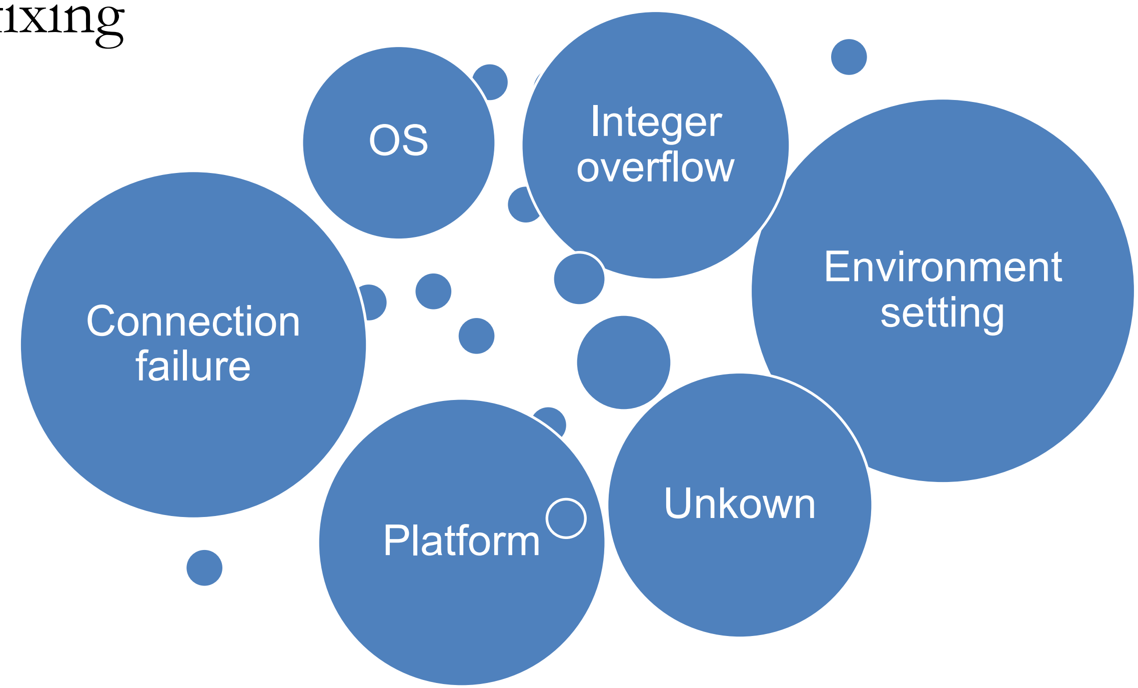

Outside MPI

- In the user code, displacement array ***displs*** (C int, commonly 32 bits) of **irregular collectives** can be easily corrupted by integer overflow

Calculate address: $recvbuf + displs[0] * s$

Each process' *sendbuf*

0

Root's *recvbuf*

In MPI_Gatherv, the root process calculate addresses for the incoming messages when *displs* is not corrupted.

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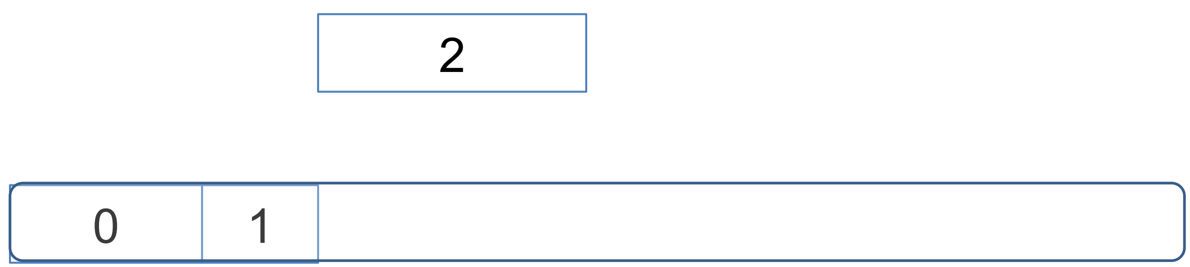

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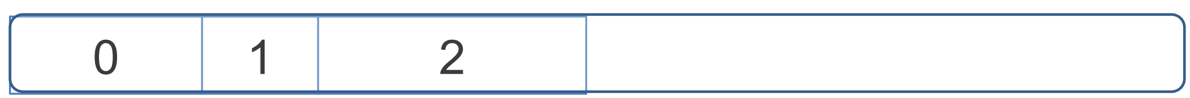

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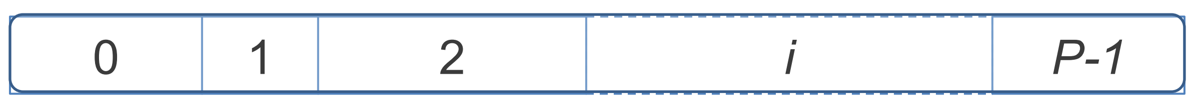

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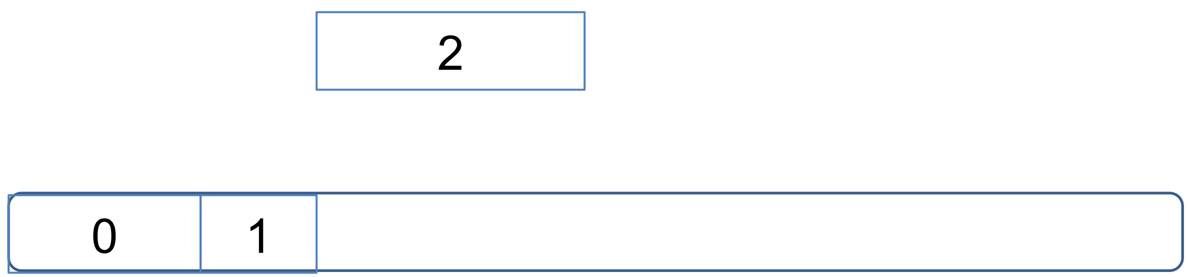

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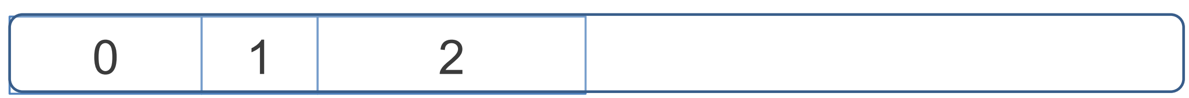

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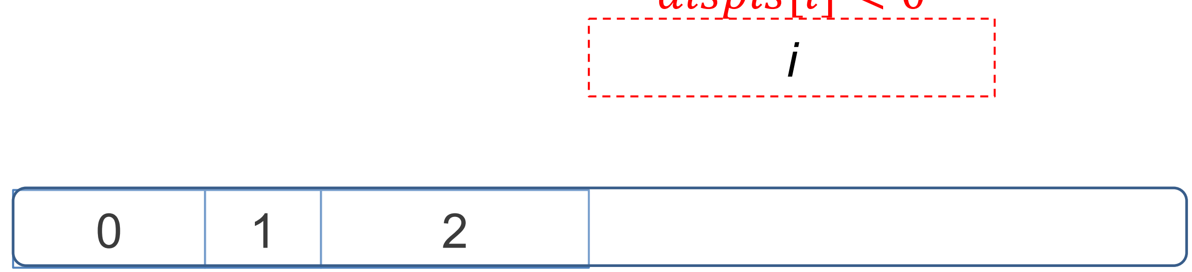
Calculate address: $recvbuf + displs[i] * s$

$displs[i] < 0$



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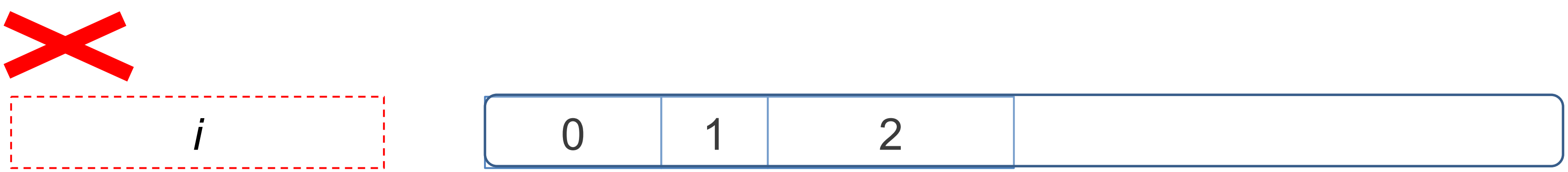

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- For MPI_Gatherv, the number of elements (N) received by the root process satisfies

$$N < displs[P-1] + INT\_MAX$$

$$\rightarrow \boldsymbol{N < 2\ INT\_MAX}$$

- For MPI_Gather (a regular collective),

$$\boldsymbol{N \leq P\ INT\_MAX}$$

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Huge gap: $\boldsymbol{\frac{2}{P}}$

- For MPI_Gather (a regular collective),

$$\boldsymbol{N \le P\ INT\_MAX}$$

Outside MPI

- Irregular collectives' limitation due to displacement array *displs* of data type *C int*

- Replace *int* with *long long int* ?
  - Discussed yet never done --- backward compatibility

An immediate remedy is in need!

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Avoidance

```
int MPI_Collective (…) {
        if (true == check_problem_trigger)
                MPI_Collective_Fix (…)        // invoke our fix
        else
                PMPI_Collective (…)           // invoke the default
}
```

Scaling problem's trigger

Workaround strategy

Trigger (1) [Outside MPI]

- Irregular collectives' limitation's trigger is

$$displs[i] < 0$$

Trigger (2) [Inside MPI]

- **Users perform testing**
  - It tells users if there is a scaling problem
  - It also tells at what scale the problem occurs

- Do users really need a fancy supercomputer to perform testing?

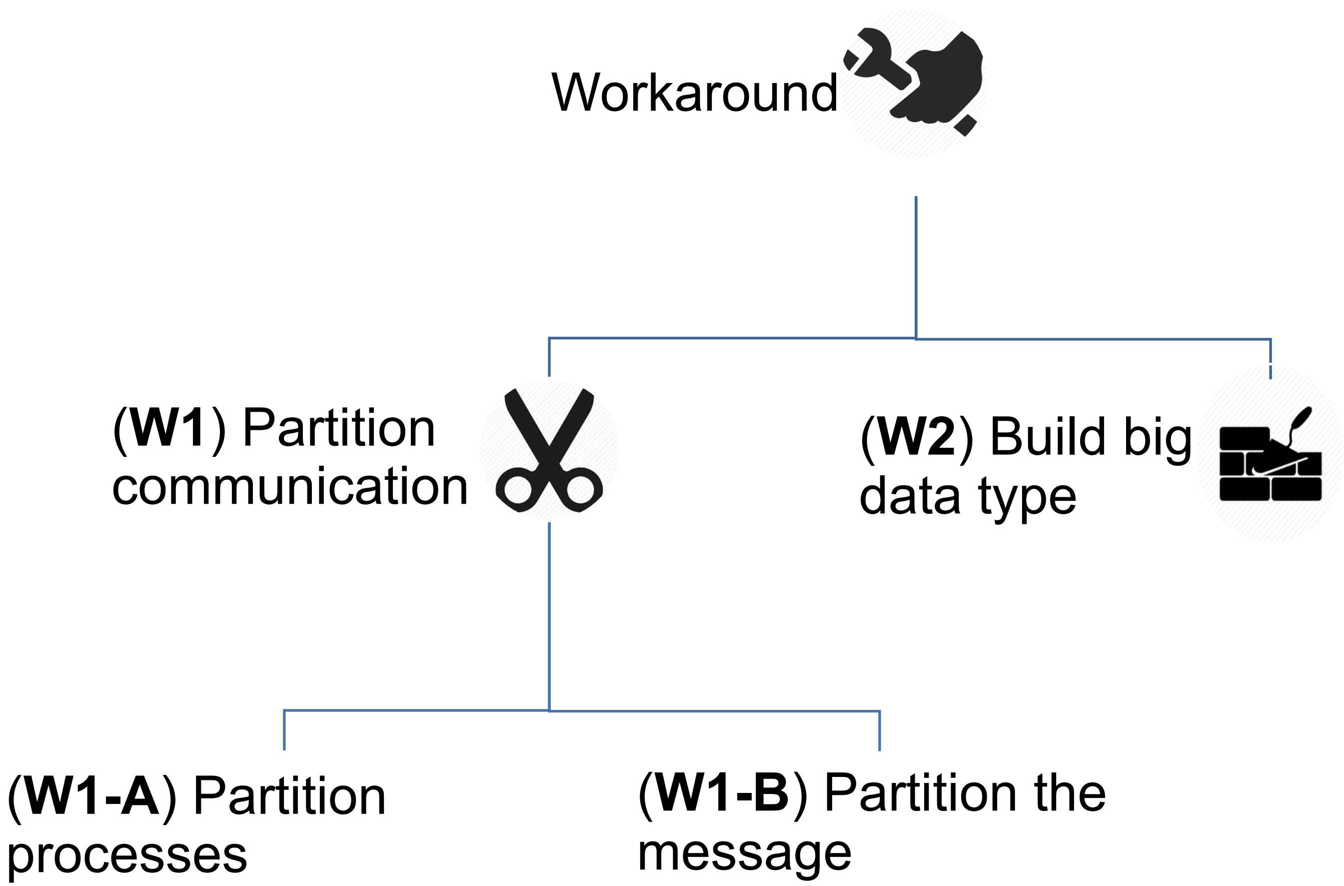
Not Necessary!

Trigger (2) [Inside MPI]

- **User side testing:** users manifest potential scaling problems of MPI routines of their interest
  - It tells users if there is a scaling problem
  - It also tells at what scale the problem occurs

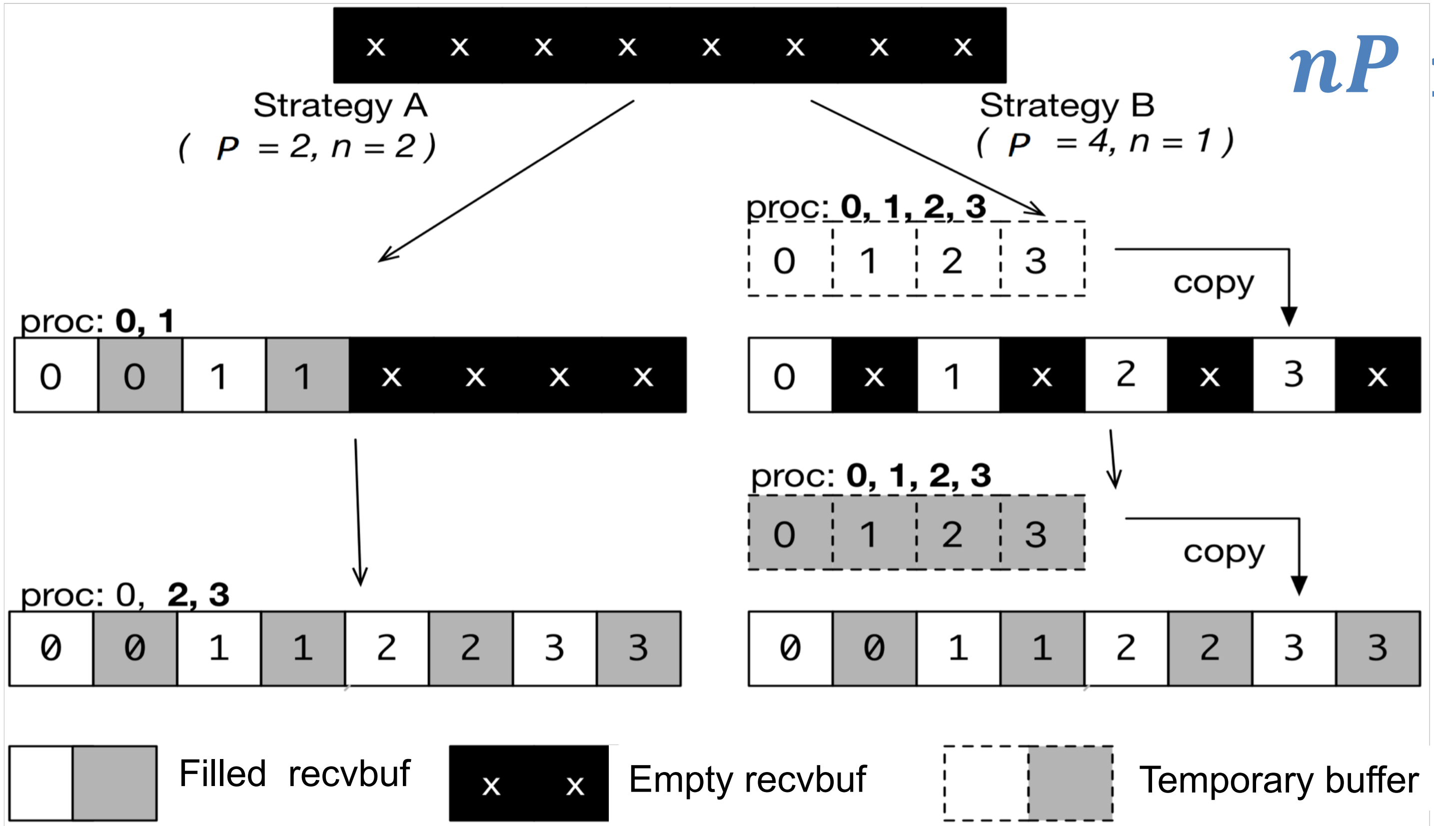
- Most scaling problems with the use of MPI collectives relate to both parallelism scale and message size
  - With ONLY 2 nodes with each having 24 cores and 64 GB memory, we easily find 4 scaling problems inside released MPI libraries.
  - Scaling problems related only to the number of processes are not found yet

Workarounds



Workaround (1) ✂

$nP \leq 4$



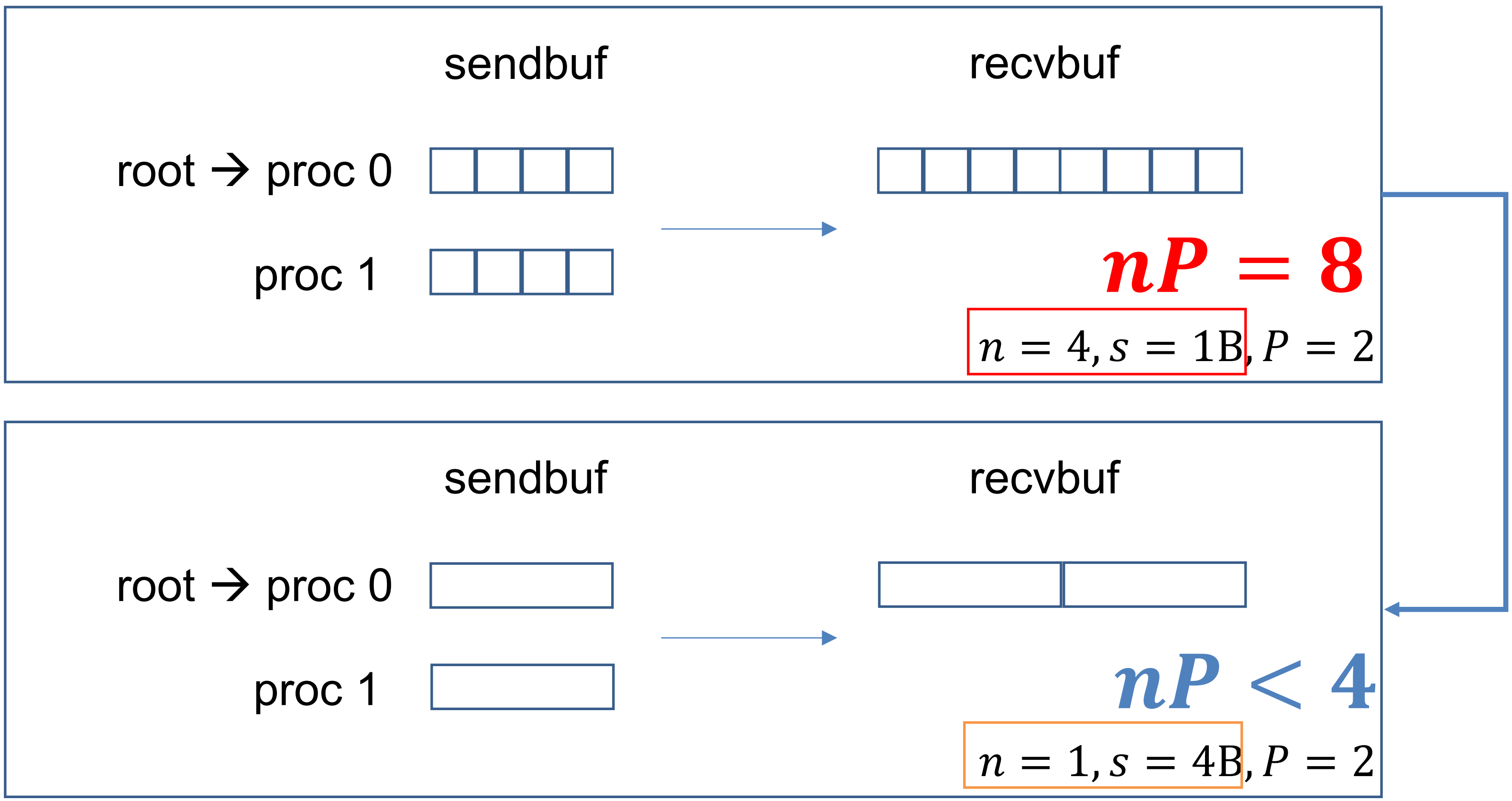
Partitioning one MPI_Gatherv communication using two strategies supposing the bug is triggered when $nP > 4$. Four processes ($P = 4$) are involved with each sending two elements ($n = 2$) and process 0 is the root process.

Workaround (2)

- Build big data type
  - Message size = s*n
  - Bigger data type (bigger s) → smaller n

- Only effective when the scaling problem is unrelated to s
  - Effective case: $nP > 4$
  - Ineffective case: $snP > 4$

Workaround (2)



Build big data type for MPI_Gather to avoid a bug triggered when $nP > 4$.

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Evaluation – Setting

- Tianhe-2:
  - Each node has 24 cores and 64GB DRAM
  - One process per core
- MPI_Gatherv
  - Effectiveness of avoiding scaling problem
  - Performance

Evaluation – Effectiveness

- Our workarounds are effective till the memory limit is hit

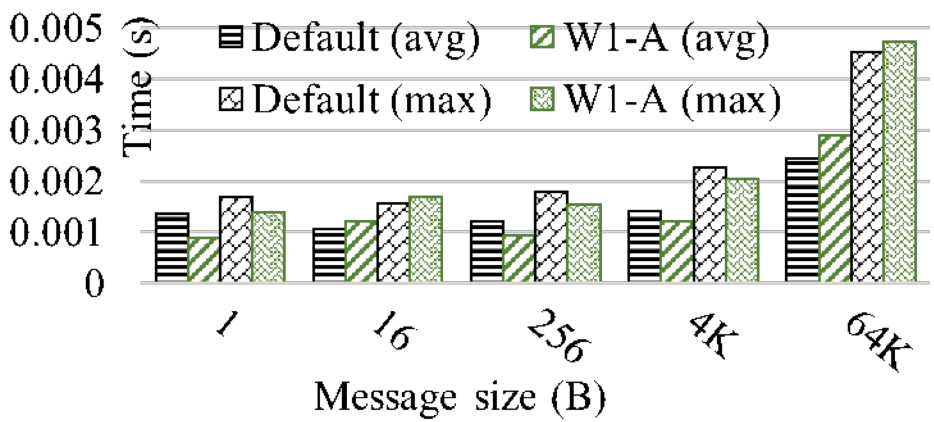
Workarounds for MPI_Gatherv that avoids the irregular collective limitation problem.

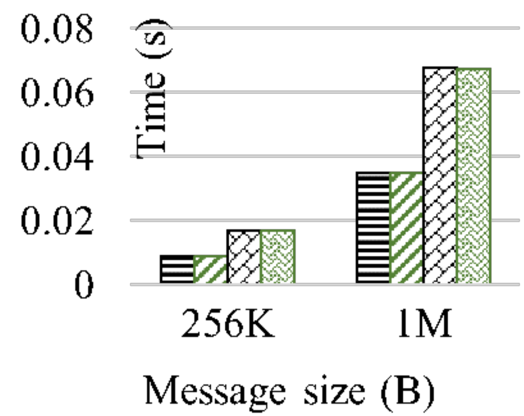
Scale ↓		Original		W1-A		W1-B		W2	
		n_s	R_M	n_s	R_M	n_s	R_M	n_s	R_M
P	192	10.5	2.21	256	54.00	256	54.0	272	57.38
	768	2.625	2.03	68	52.60	72	55.69	72	55.69

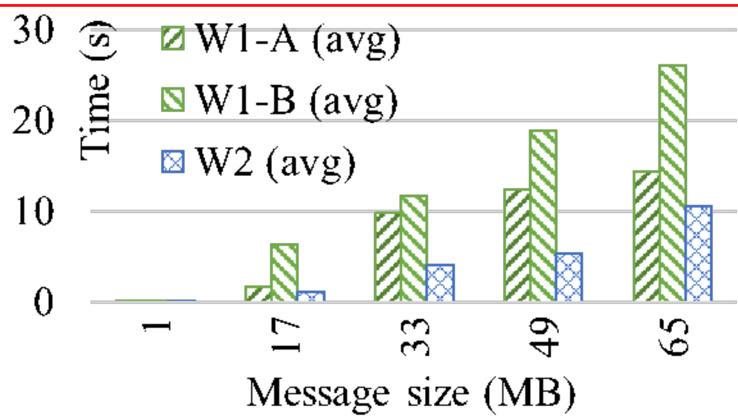
- n_s: the maximal workable n (unit: 1 M, i.e., 2^20)
- R_M : the maximal memory consumption on one node calculated according to MPI standard

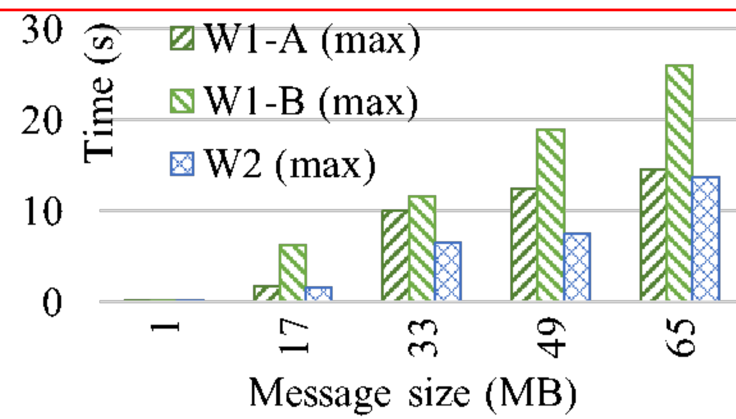
23X increase!

Evaluation – Performance









MPI_Gatherv [*P=768*, *s=1* B bug occurs when *n>2.625* M].

Evaluation -- Summary

- Effectiveness:
  - W1-B is the best
- Performance:
  - W2 is the best
  - The time cost of a collective based on either W1-A or W1-B increases linearly as n increases

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Conclusion

- Scaling problems are hard to be fixed and thus uses often need to spend days and months to wait for an official fix

- We provide a non-intrusive framework for application users as an immediate remedy
  - Easier than debugging
  - Faster than official fix

Thank you!