Towards Capturing Nondeterminism Motifs in HPC Applications

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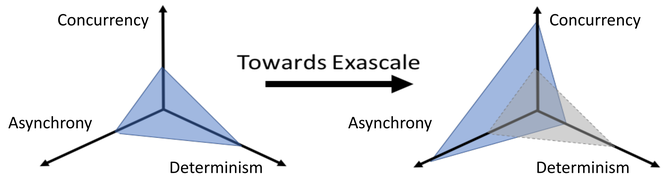
Nondeterminism in HPC Applications

- Nondeterminism (ND) is increasingly embraced for scalability



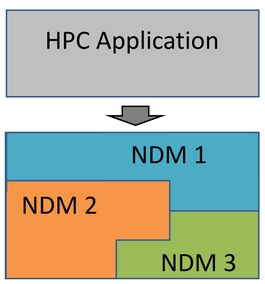
- Nondeterminism can lead to numerical and debugging side-effects for applications moving towards exascale

	Nondeterminism Sources	Side Effects
Recv side	• MPI_ANY_SOURCE • Nonblocking receives	• Numerical irreproducibility • Intermittent, scale-based bugs [1]
Send side	• Nondeterministic receive-dependent sends • Timing-dependent sends	• Incompatibility with tools and protocols that assume sender-determinism [2][3]

- Tools like PRUNERS[4] try to control some of the side-effects **BUT** an automatic identification of ND sources is missing
- Developers are forced to characterize ND by doing many runs with different *printf* debugging operations

Our Proposed Approach

- Identify and analyze representative nondeterminism snippets (small regions of source code)
- Build a classification system of ND patterns or *motifs* associated to these snippets to enable systematic control of nondeterminism's side-effects



***From* monolithic view of an applications**
- Limited ability to reason about ND
- Hard to debug and tools may not work

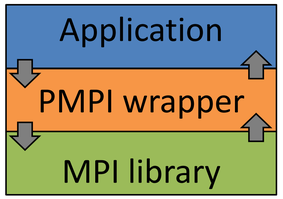
***To* a motif-based view of the application**
- Can reason about and debug effects of each nondeterministic motif (NDM)
- Know in advance which debugging tools will work

Our Target Applications

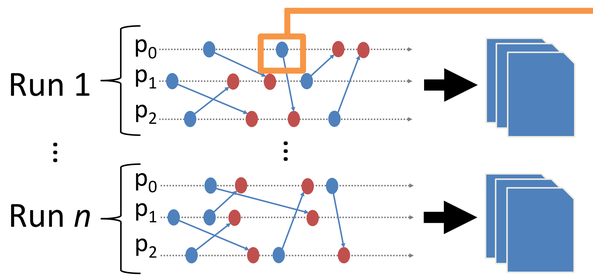
Application	Possible Recv–side Nondeterminism	Possible Send-side Nondeterminism
ParaDiS	Irecv + Waitany/all	Dynamic load-balancing based on wall-time
Monte Carlo Benchmark (MCB)	Irecv + Testsome	Unknown

Our Workflow for Capturing Nondeterminism Motifs

Step 1: Collect Traces from Multiple Runs



- Use MPI profiling API (PMPI)
  - Intercepts all send-initiation and receive-completion function calls
  - Logs each function call signature and its associated call stack

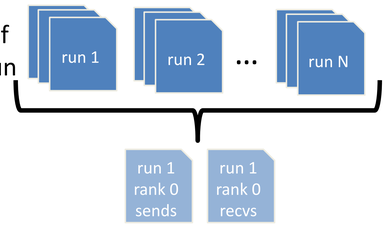


Example event record: isend signature and call stack

```
isend, idx=2, dst=2, cnt=59, tag=2010
0x2aaaab150ea2: (MPI_Isend+0xbf)
0x42cc05: (Buffered_MPI_Send::send(…)+0x85)
0x42c0ad: (Nonblocking_Sync::send_finished_internal(…)+0x5d)
0x41028b: (IMC::advancePhotonListDD(…)+0x8eb)
0x4105c1: (IMC::advance(…)+0x81)
0x2aaaad261aff: (GOMP_parallel+0x3f)
0x40574e: (main+0xe9e)
0x2aaaad6a7b35: (__libc_start_main+0xf5)
0x40656f: (_start+0x29)
```

Step 2: Detect Nondeterministic Events

- Collect sequences of events from each run
- Separate sequence into send-initiation events and receive-completion events



- Identify deterministic sequences and nondeterministic sequences
- Example: We identify run-to-run variations in sequences of MPI_Isend calls ([tag, dest, count])

Event	Run 1	Run 2	Run 3
0	[55, 2, 3360]	[55, 2, 3360]	[55, 2, 3360]
1	[55, 1, 3240]	[55, 1, 3240]	[55, 1, 3240]
2	[55, 1, 840]	[55, 1, 840]	[55, 1, 840]
3	[6502, 1, 1]	[6502, 1, 1]	[6502, 1, 1]
4	[6502, 2, 1]	[6502, 2, 1]	[6502, 2, 1]
5	[7294, 1, 1]	[7294, 1, 1]	[7294, 1, 1]
6	[7294, 2, 1]	[7294, 2, 1]	[7294, 2, 1]
7	[55, 2, 7200]	[55, 2, 7200]	[55, 2, 8400]
8	[55, 1, 7920]	[55, 1, 7920]	[55, 1, 7920]
9	[55, 2, 1320]	[55, 1, 1560]	[55, 1, 1680]
10	[55, 1, 1560]	[55, 2, 1800]	[55, 2, 600]
11	[55, 1, 240]	[55, 1, 240]	[6502, 1, 1]
12	[55, 2, 600]	[6502, 1, 1]	[6502, 2, 1]
13	[6502, 1, 1]	[6502, 2, 1]	[7294, 1, 1]
14	[6502, 2, 1]	[7294, 1, 1]	[7294, 2, 1]

- Only nondeterministic events' call stacks are passed on to next step

```
{ ND_event_1: callstack(ND_event_1),
  ND_event_2: callstack(ND_event_2),
  …
  ND_event_k: callstack(ND_event_k) }
```

Step 3: Associate Nondeterministic Events with Call-stacks

- Reduce ND events into a smaller set of call stacks
- Map each call stack to snippet (small regions of source code)
- Isolate source of ND by inspecting variables and data structures in snippets for local dataflow analysis

Example: MCB rank 0 sender nondeterminism

```
{ ND_event_1: callstack(ND_event_1),
  ND_event_2: callstack(ND_event_2),
  …
  ND_event_k: callstack(ND_event_k) }
```

Identify a single call stack resulting in all nondeterministic sends

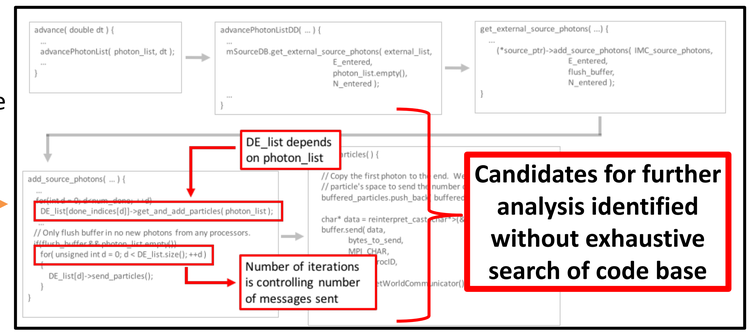
IMC_namespace::
IMC<…>::
advance

IMC_namespace::
IMC<…>::
advancePhotonListDD

IMC_namespace::
Source_data_base<…>::
get_external_source_photons

IMC_namespace::
Buffered_MPI_Send::
send

Map elements in call stack to source code snippets

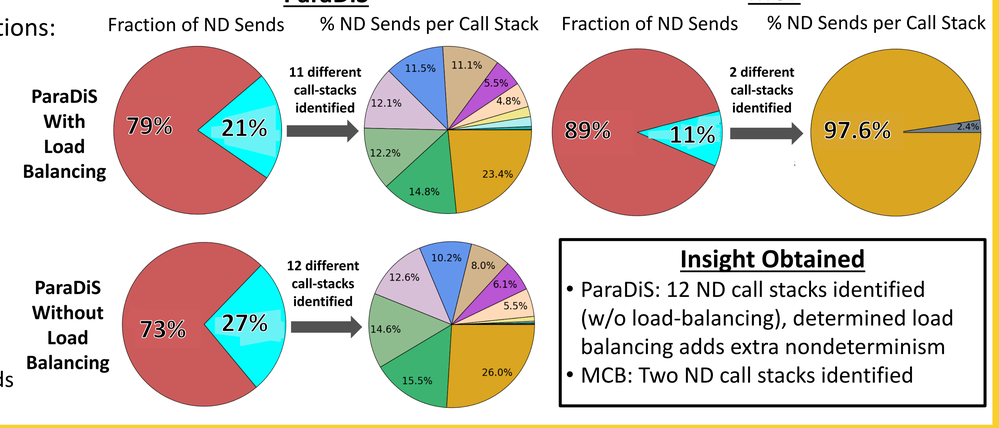


Results

- Workflow applied to two applications:
  - ParaDiS (with and without load-balancing)
  - Monte Carlo Benchmark (MCB)
- Metrics for quantifying nondeterminism:
  - Fraction of sends flagged as:

Deterministic or **Nondeterministic (ND)**

  - Number of call stacks resulting in nondeterministic sends
  - Fraction of nondeterministic sends associated with each call stack



Insight Obtained
- ParaDiS: 12 ND call stacks identified (w/o load-balancing), determined load balancing adds extra nondeterminism
- MCB: Two ND call stacks identified

Future Work

- Expand extraction of snippets for nondeterministic exascale codes
- Annotate exascale workflows with motifs to support reproducibility
- Use knowledge to mitigate runtime nondeterminism side-effects

References

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4. D. H. Ahn, G. Lee, G. Gopalakrishnan, Z. Rakamaric, M. Schulz, I. Laguna, "Overcoming extreme scale reproducibility challenges through a unified, targeted, and multilevel toolset", SE-HPCCSE'13 Proceedings of the 1st International Workshop on Software Engineering for High Performance Computing in Computational Science and Engineering

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