Enabling mixed-precision with VerifiCarlo: Sharing CEEC experience

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CEEC Centre of Excellence in Exascale CFD

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Outline

Energy efficiency: from hardware to NLA

- Supercomputing is constrained by **power consumption**

→ Power-efficient hardware
  - RIKEN's Fugaku w A64FX (FP64:FP32:FP16 = 1:2:4)
  - EPI (ARM, FPGA, RISC-V)
  - **Jülich to host the first EPI-based supercomputer**

- Numerical linear algebra is known to be dominant by **double precision**

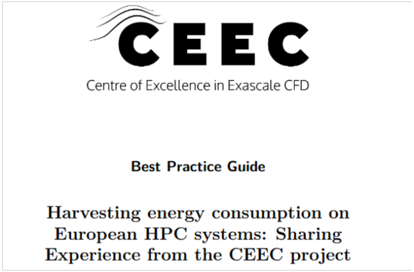
→ **Energy-efficient algorithms**

math Mixed and adaptive precision computing

code Communication hiding or avoiding

tools Numerical abnormalities and precision cropping

Measuring energy consumption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Best Practice Guide

Harvesting energy consumption on European HPC systems: Sharing Experience from the CEEC project

Iakymchuk et al. Zenodo, 2024
doi:10.5281/zenodo.13306639

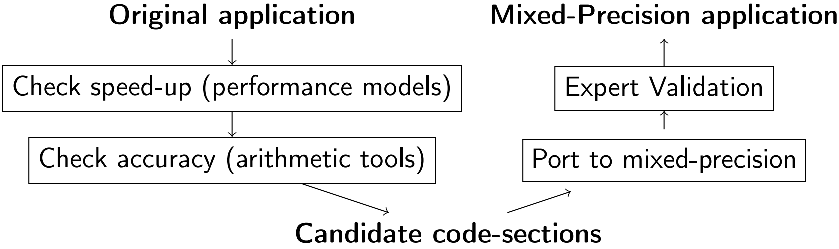
- **More complex than measuring time-to-solution**
- Measurements require elevated privileges

Objectives

- Facilitate energy measurements on the European HPC systems
- Teach the community how to conduct such measurements
- Provide examples with easy-to-use guide

Methodology

Methodology to enable mixed-precision algorithmic solutions in applications with accuracy guarantees.



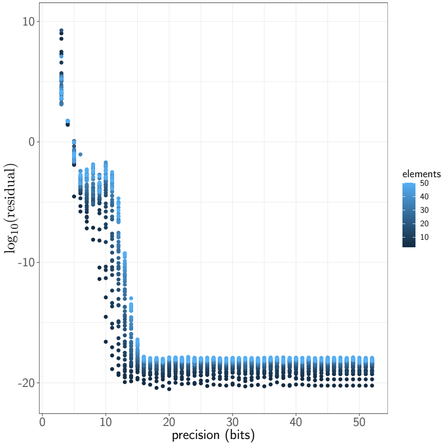
Nekbone w Vprec

$$\boxed{Ax = b}$$

while $(\tau > \tau_{\max})$

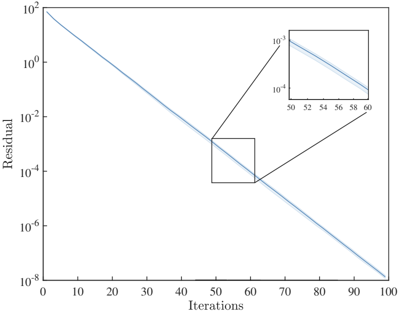
Step	Operation
$S1:$	$w := Ad$
$S2:$	$\rho := \beta / < d, w >$
$S3:$	$x := x + \rho d$
$S4:$	$r := r - \rho w$
$S5:$	$z := M^{-1} r$
$S6:$	$\beta := < z, r >$
$S7:$	$d := (\beta / \beta_{old}) d + z$
$S8:$	$\tau := < r, r >$

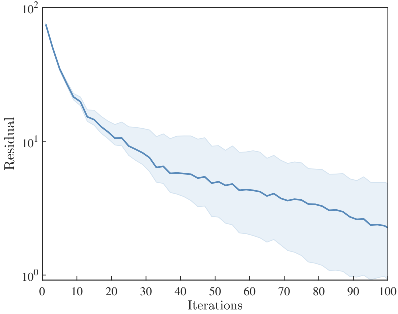
end while



Nekbone w MCA for FP32

Entire program, no preconditioner

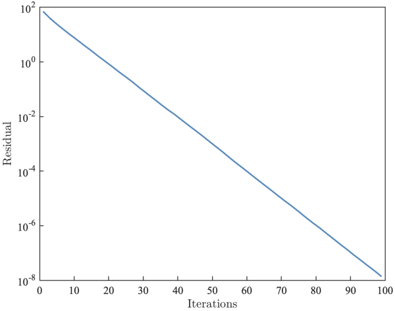


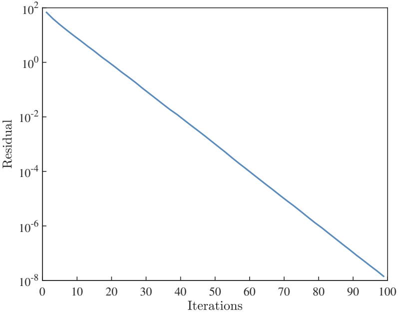


- Random Rounding (rr) mode (left)
- MCA (mca) mode (right)
- Issue in initialization $10^9 \cos(x) \rightarrow$ focus on the solver only

Nekbone w MCA for FP32

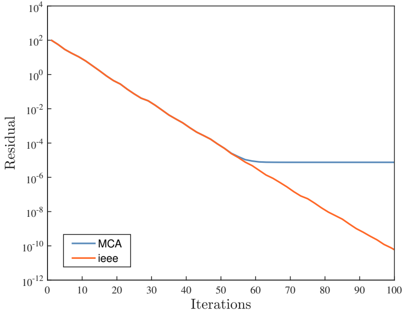
Only the CG loop, no preconditioner

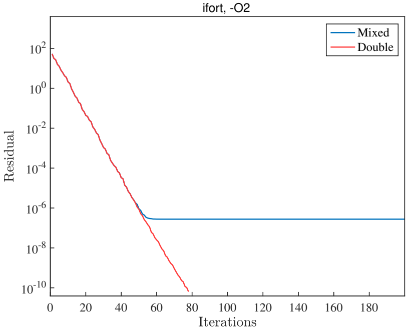




- Random Rounding (rr) mode (left)
- MCA (mca) mode (right)

Nekbone: CG with preconditioner

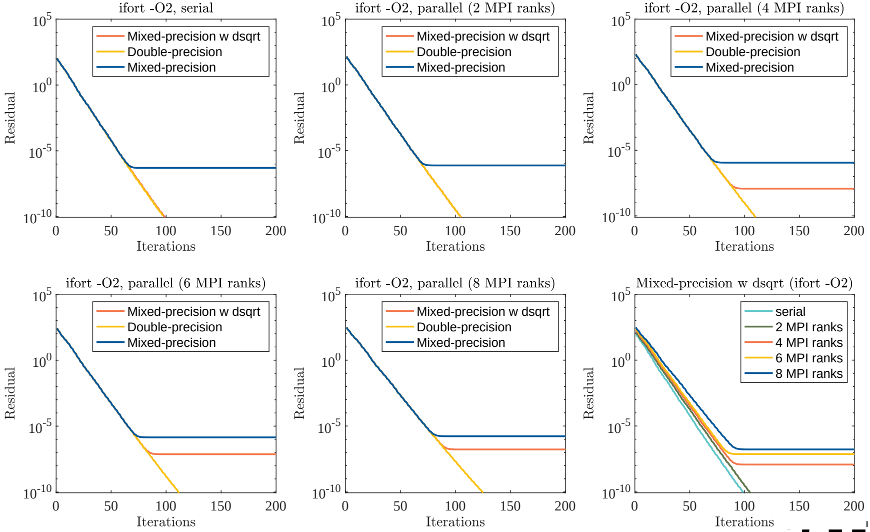




- Verificarlo predicts stagnation (left plot)
- Stagnation in the mixed-precision Nekbone (right plot)
- Stagnation occurs after 61st iteration w residual $r = 7.94 \times 10^{-6}$

Nekbone: CG with preconditioner

Square root



Nekbone: CG with preconditioner

Mixed-precision strategies

Mixed-precision strategy evaluation

GSO mode	MPI	Precond. Ops	Precond. GSO	PCG Ops	PCG GSO	Conv.
pairwise	< 4	fp32	fp32	fp32	fp32	stagnates
		fp64	fp64			converges
		fp32+fp64sqrt	fp32			converges
		fp32	fp64			converges
	≥ 4	fp64	fp64		fp32	stagnates
		fp32+fp64sqrt	fp32			stagnates
		fp32	fp64			stagnates
		fp32+fp64sqrt	fp64		fp64	converges
		fp64	fp64		fp64	converges

- Gather-Scatter Operations have strong impact on convergence
- dot product impacts convergence too

Nekbone: CG with preconditioner

128 elements per MPI rank on MareNostrum 5: Intel Sapphire Rapids 8460Y+ w 40 cores

MPI ranks/ secs	8	20	40	80
Double	5.79	8.98	13.33	24.02
Mixed-1[a]	4.79	5.99	9.42	14.85
Gain-1	17.27%	33.30%	29.33%	38.18%
Mixed-2[b]	4.88	6.02	8.37	10.11
Gain-2	15.72%	32.96%	**37.21%**	**2.38x**

MPI ranks/ joules	8	20	40	80
Double	1875	3035	7191	16261
Mixed-1[a]	939	2088	3133	7428
Gain-1	1.97x	31.20%	2.30x	2.19x
Mixed-2[b]	934	1566	2570	3482
Gain-2	2.01x	1.94x	**2.80x**	**4.67x**

[a] fp64+fp32+fp64sqrt (fp32 GS, allreduce)
[b] fp64+fp32+fp64sqrt (fp64 GS, pairwise)

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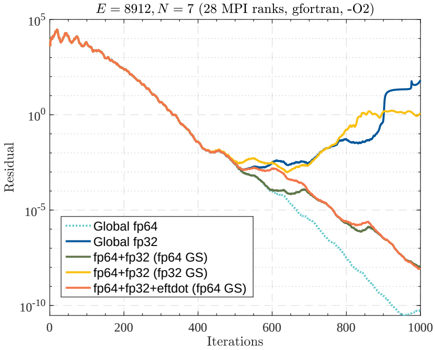
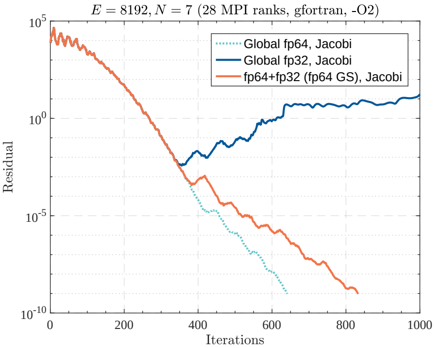
Neko: convergence



CG with the identity preconditioner



CG with the Jacobi preconditioner

- Solving the Poisson's equation with Neko
- The winning strategy is fp64+fp32 (fp64 GS)

Neko: CG with the identity preconditioner

16,384 elements with pol. degree 7 on MareNostrum 5

MPI ranks/ secs	8	20	40	80
Double	14.10	6.61	4.80	1.87
Mixed	12.50	5.77	3.41	1.55
Gain	11.35%	12.71%	**28.96%**	**17.11%**

MPI ranks/ joules	20	40	80
Double	14437	11686	10612
Mixed	13403	10509	8033
Gain	7.16%	**10.07%**	**24.30%**

- Solving the Poisson's equation with Neko
- Time is for the CG loop
- Energy measurements are for the entire code

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Work in progress: PCG with iterative refinement

```
PCG to solve Ax_m = b until tol = 10^-4          ▷ FP32. PCG breaks at 10^-6
for i ← 1, 2, 3 do                               ▷ Run for few iterations
    r = b − Ax_m                                 ▷ FP64
    r_new = r/‖r‖                                ▷ FP64
    PCG to solve Ad_new = r_new until tol = 10^-6, 10^-8   ▷ FP32
    d = d_new ∗ ‖r‖                              ▷ FP64
    x_m = x_m + d                                ▷ FP64
end for
```

Work in progress: PCG with iterative refinement

```
PCG to solve Ax_m = b until tol = 10^-4            ▷ FP32. PCG breaks at 10^-6
for i ← 1, 2, 3 do                                 ▷ Run for few iterations
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    x_m = x_m + d                                  ▷ FP64
end for
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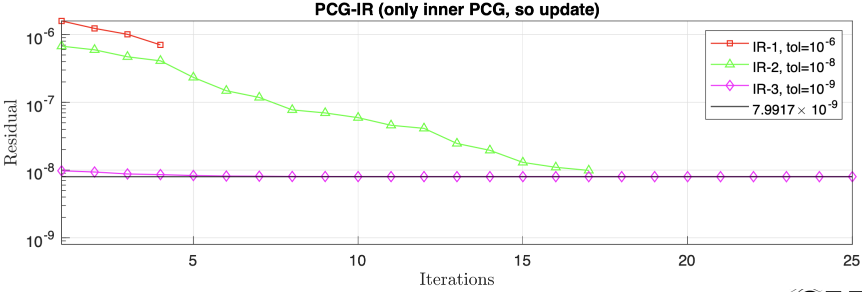

Summary

- Computer arithmetic operates with finite precisions
- Use computer arithmetic tools to
  - detect cancellations
  - get the right FP format
  - verify sensitivity of reduced precision
- Enabling mixed-precision in CFD codes:
  - use tools: Verificarlo, gprof, Intel Advisor
  - target the most time-consuming parts
  - reduced time-to-solution by up to 40 % and **energy-to-solution by up to 2x** on MareNostrum5 & LUMI

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Thank you for your attention !

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References

- Iakymchuk et al. *Best Practice Guide – Harvesting energy consumption on European HPC systems: Sharing Experience from the CEEC project*. Zenodo, Aug 2024
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