Detection of Silent Data Corruptions in Smoothed Particle Hydrodynamics Simulations

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PASC
Platform for Advanced Scientific Computing

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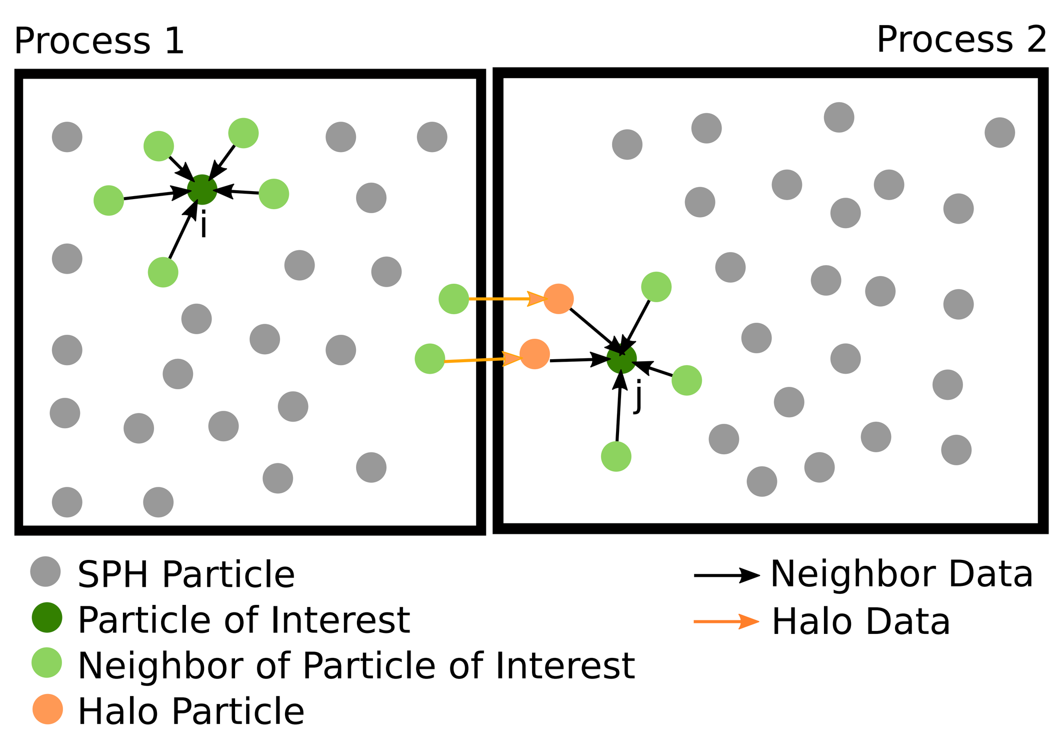
SPH

- **Smoothed particle hydrodynamics (SPH)** is a fully Lagrangian meshless method to perform hydrodynamical simulations.
- SPH discretizes the fluid in a series of interpolation points (SPH particles), and their evolution relies then on a **weighted interpolation over close neighboring particles**.



In the above example, particle j has two neighbors on process 1, and needs a copy of each (halo particles).

SPH Computational Workflow

while Target simulated time is not reached **do**
1. Build Tree
   - 1.1 Detection
   - 1.2 Exchange halo particle data
2. Find neighbors and smoothing length
   - 2.1 Detection
   - 2.2 Select ghost particles
   - 2.3 Exchange halo particle data
3. Execute SPH interpolation kernels
   - 3.1 Detection
   - 3.2 Exchange halo particle data
4. Find new time-step
   - 4.1 Detection
   - 4.2 Exchange halo particle data
5. Update velocity and position
   - 5.1 Detection
   - 5.2 Exchange halo particle data
6. (Optional) Compute self-gravity
   - 6.1 Detection
   - 6.2 Exchange halo particle data

end while

Detection must occur before halo particle data exchange, which might propagate an error to both the ghost and the original particle.

Acknowledgments

This work is supported by the Swiss Platform for Advanced Scientific Computing (PASC) project SPH-EXA and by a grant from the Swiss National Supercomputing Centre (CSCS) under project ID c16.

References

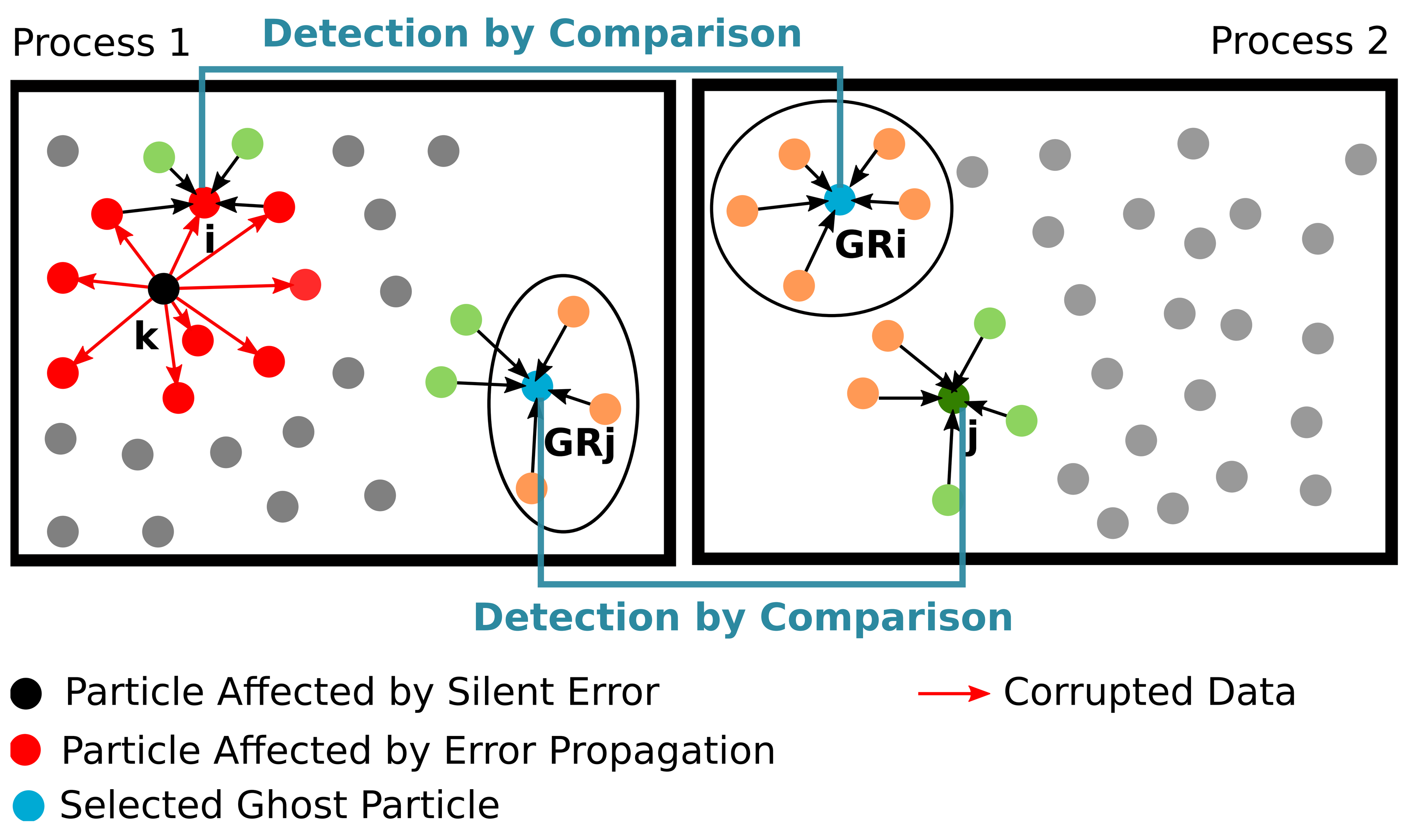
[1] R. Cabezón, D. García-Senz, J. Figueira. SPHYNX: an accurate density-based SPH method for astrophysical applications. In *Astronomy & Astrophysics*, vol. 606, A78, 2017

[2] PIZ DAINT. *https://www.cscs.ch/computers/piz-daint/*

[3] A. Evrard. Beyond N-body: 3D cosmological gas dynamics. In *Monthly Notices of the Royal Astronomical Society*, vol. 235, Dec. 15, p. 911-934, 1988

Ghost Replication (GR): Detection via Partial Replication

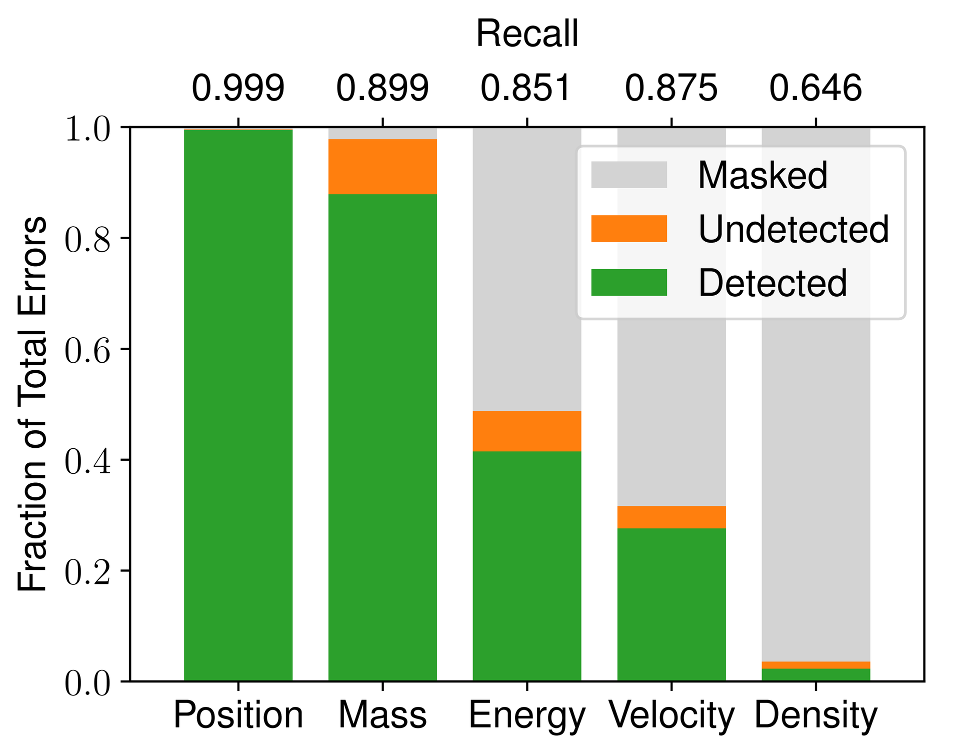
- **Hardware faults (e.g. bit-flips)** can escape hardware detection (e.g. ECC / chipkill) and cause **Silent Data Corruptions (SDCs)**.
- **Ghost Replication**, or GR, consists in selecting SPH particles to replicate (computations and data) on a different process (ghost particles).
- **SDC detection** is then done by **comparing** the data of the original particle against its ghost.



1. An error strikes particle k on process 1, and propagates to neighboring particles.
2. The ghost particle of i, GRi, being on a different process, is not affected by the error.
3. The error is detected by comparing the data of particle i against the data of its ghost, GRi.

- **Selecting ghost particles** is achieved with a greedy maximal independent set algorithm that runs in $\mathcal{O}(n_{particles} \times n_{neighbors})$ time: **any given particle must be adjacent to a ghost**.

Injection and Detection of SDCs with GR

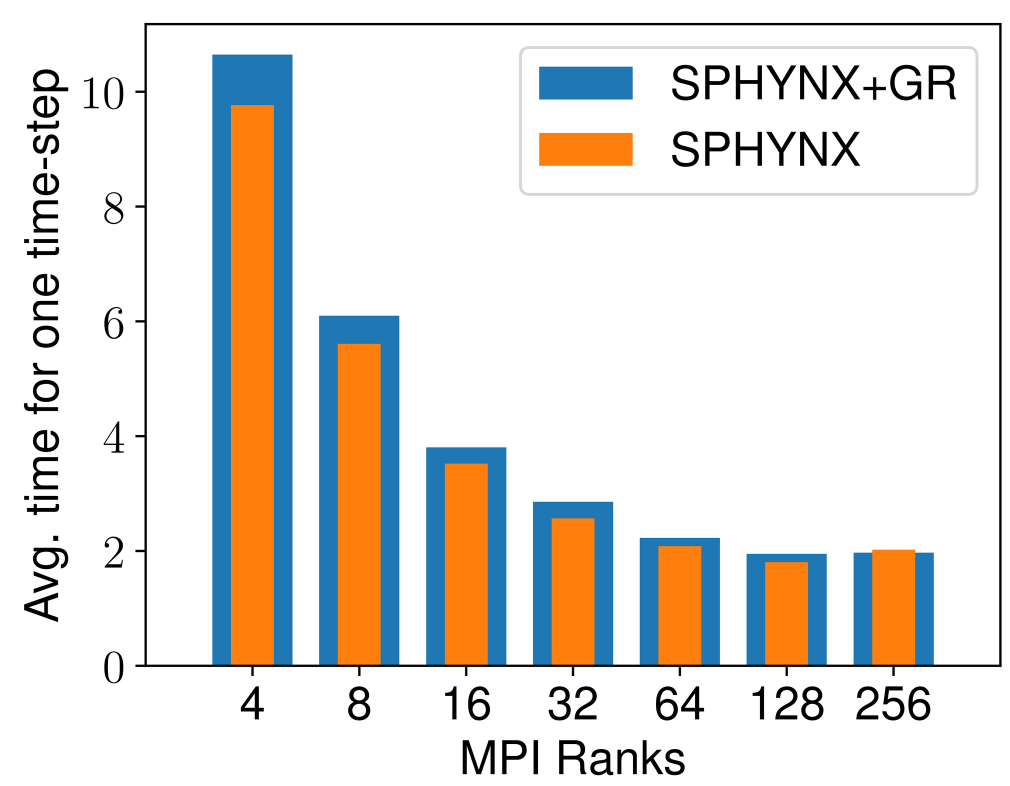


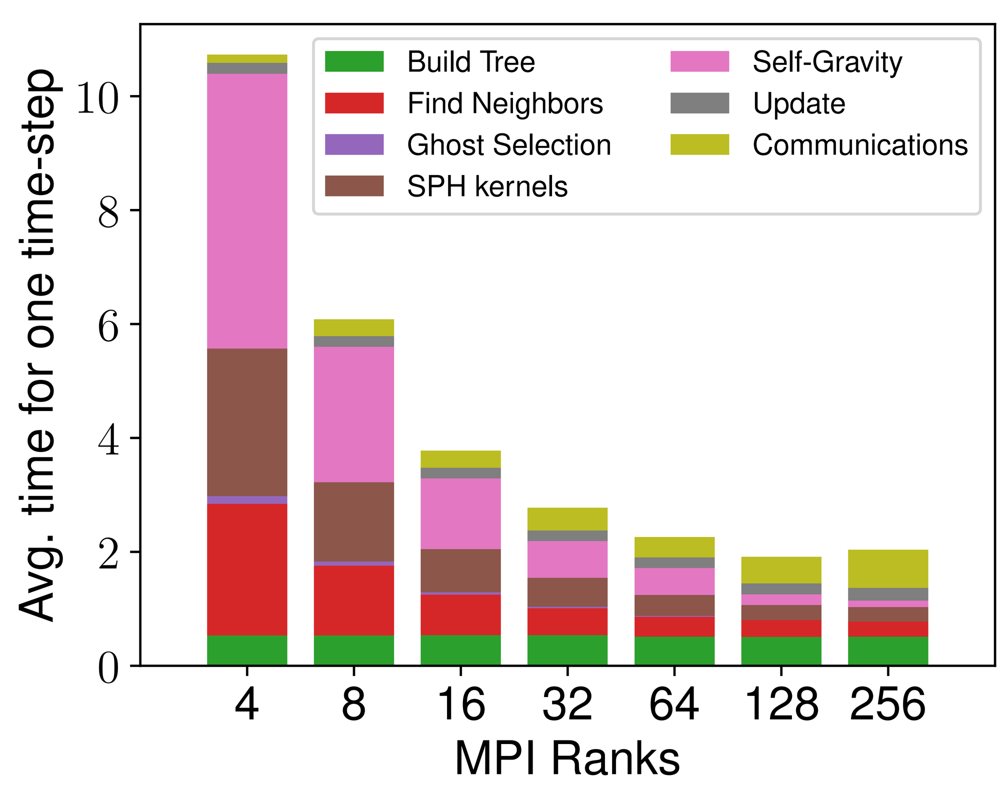
$$Recall = \frac{\text{errors detected}}{\text{errors detected} + \text{errors undetected}}$$

- $25,000$ bit-flips injected in $50,000$ time-steps
- **High recall:** $90 - 99.9\%$ of all bit-flips detected
- **Perfect precision:** no false-positives
- **As few as 2% of all particles need to be replicated to detect SDCs in any particle.**

Ghost Replication Overhead

GR has been incorporated in SPHYNX [1] and experiments were performed on Piz Daint [2] running the Evrard Collapse [3] test simulation with 10^6 particles and 100 neighbors per particles.





- GR is **scalable**, **non-intrusive** (minor changes in the application) and **precise** (no false-positives).
- GR can be applied to other particle-based simulations (i.e. N-body, stencil codes, computational fluid dynamics). This deserves further investigation in the future.