



中国科学技术大学  
University of Science and Technology of China



# Accelerating AP3M-Based Computational Astrophysics Simulations with Reconfigurable Clusters

*Tianqi Wang*<sup>\*^</sup>, Tong Geng<sup>^</sup>, Xi Jin<sup>\*</sup>, Martin Herbordt<sup>^</sup>

<sup>\*</sup>Department of Physics; University of Science and Technology of China, Hefei, China

<sup>^</sup>Department of Electrical and Computer Engineering; Boston University, Boston, MA, USA

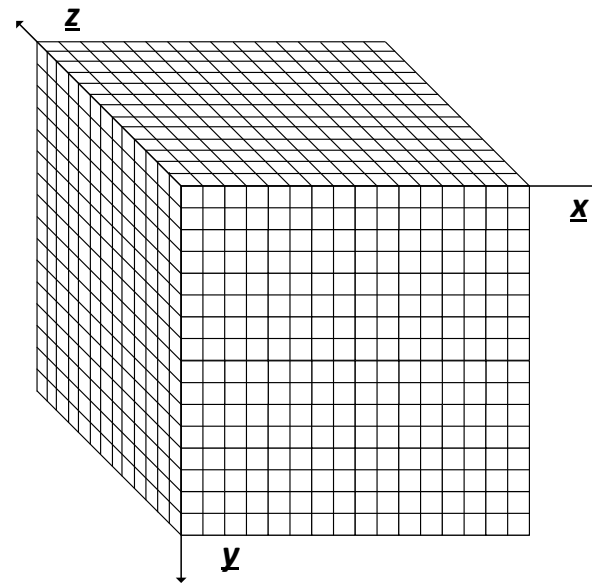
- **Particle-Particle (PP) Method**

- Direct summation
- Pro: High resolution
- Con: High complexity  $\sim O(N^2)$
- $N \sim$  number of particles

$$F(x) = \sum_{i=1}^N Gmm_i \frac{x - x_i}{|x - x_i|^3}$$

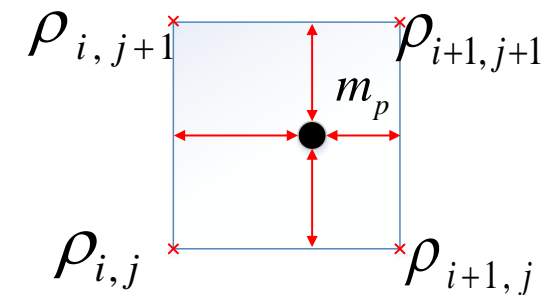
- **Particle-Mesh (PM) Method**

- Assign particles to mesh
- Solve problem in Fourier space
- Pro: Low resolution
- Con: Low complexity  $\sim O(N_g \log N_g)$
- $N_g \sim$  number of mesh points

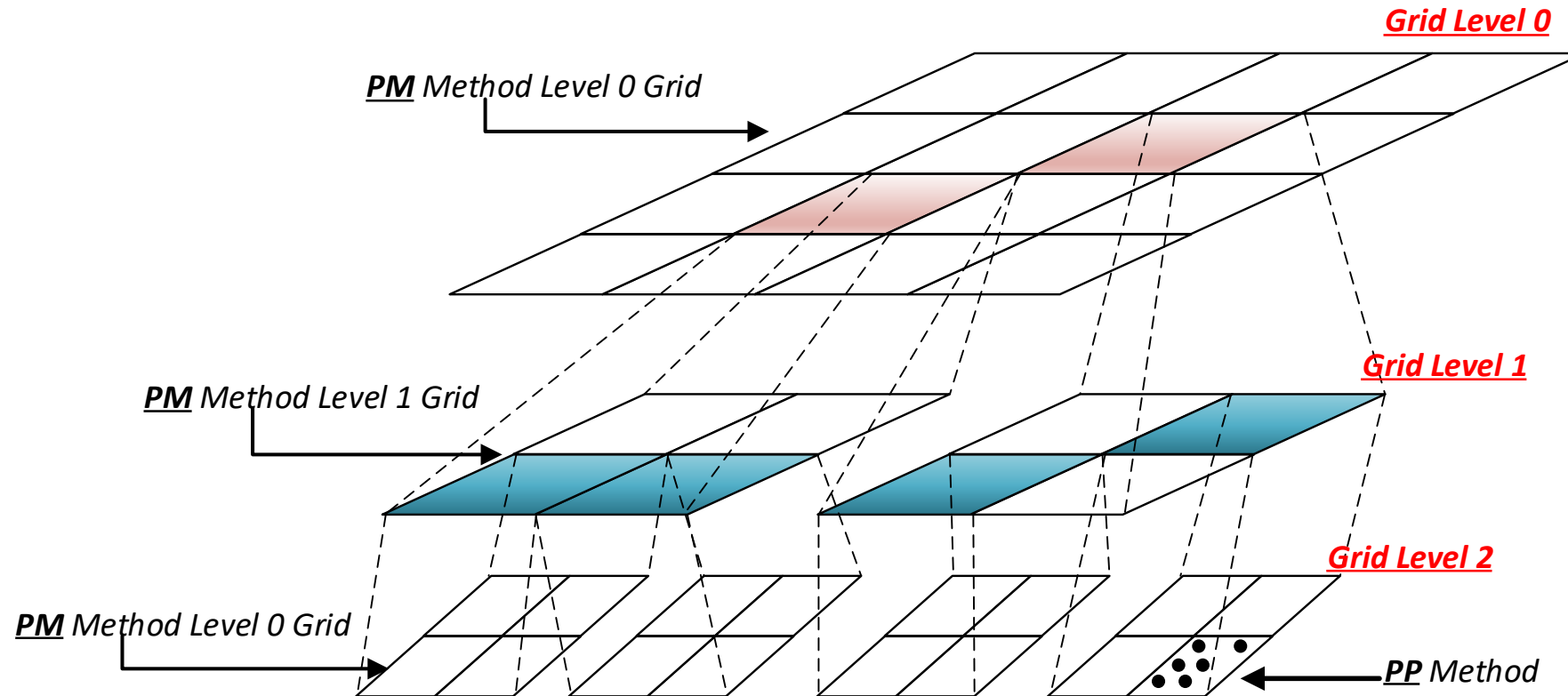


$$\Phi(x) = \int g(x - x') \rho(x')$$

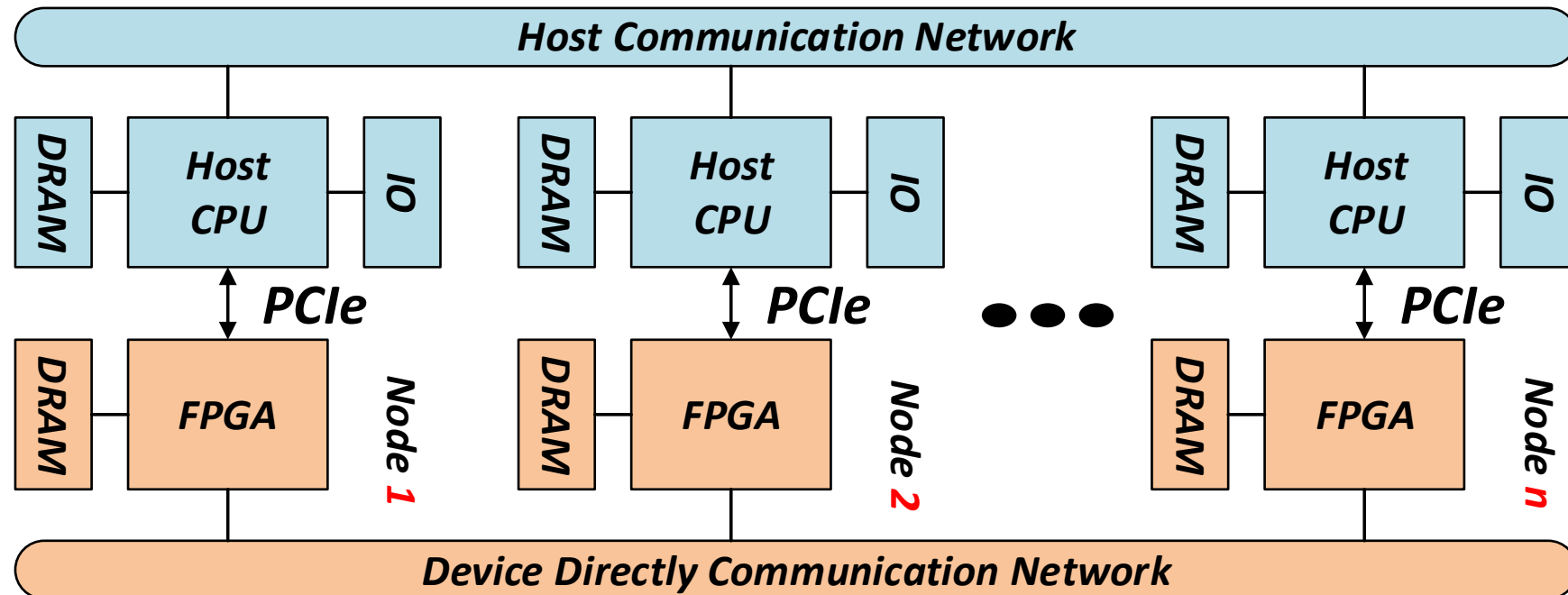
$$\hat{\Phi}(x) = \hat{g}(k) \hat{\rho}(k)$$



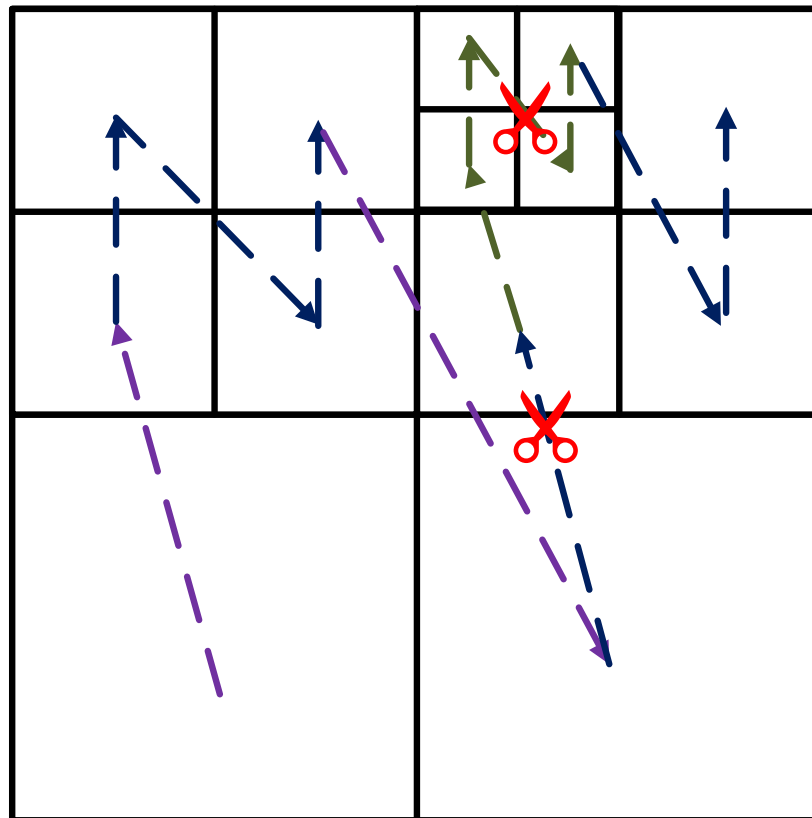
- Trade-off:
  - ***Adaptive Particle-Particle, Particle-Mesh Method*** (Adaptive PP-PM = ***AP3M***)
  - Low-density region: Adaptive Particle Mesh for **lower complexity**
  - High-density region: Particle-Particle for **high resolution**



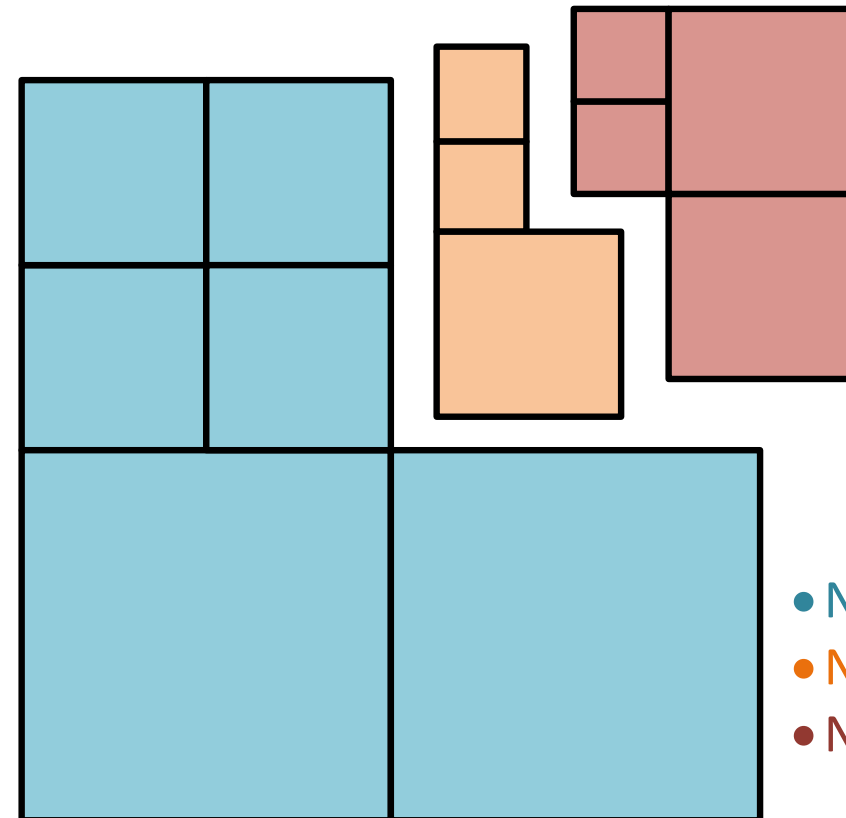
- FPGA-Centric Cluster
  - Device directly communication network
  - Each time-step's synchronization via Dev-to-Dev network



- Workload partition among nodes
  - Z-order traverse
  - Keep locality ~ Reduce inter-node particle information exchange



(A) Workload Balanced Partition



- Node 1
- Node 2
- Node 3

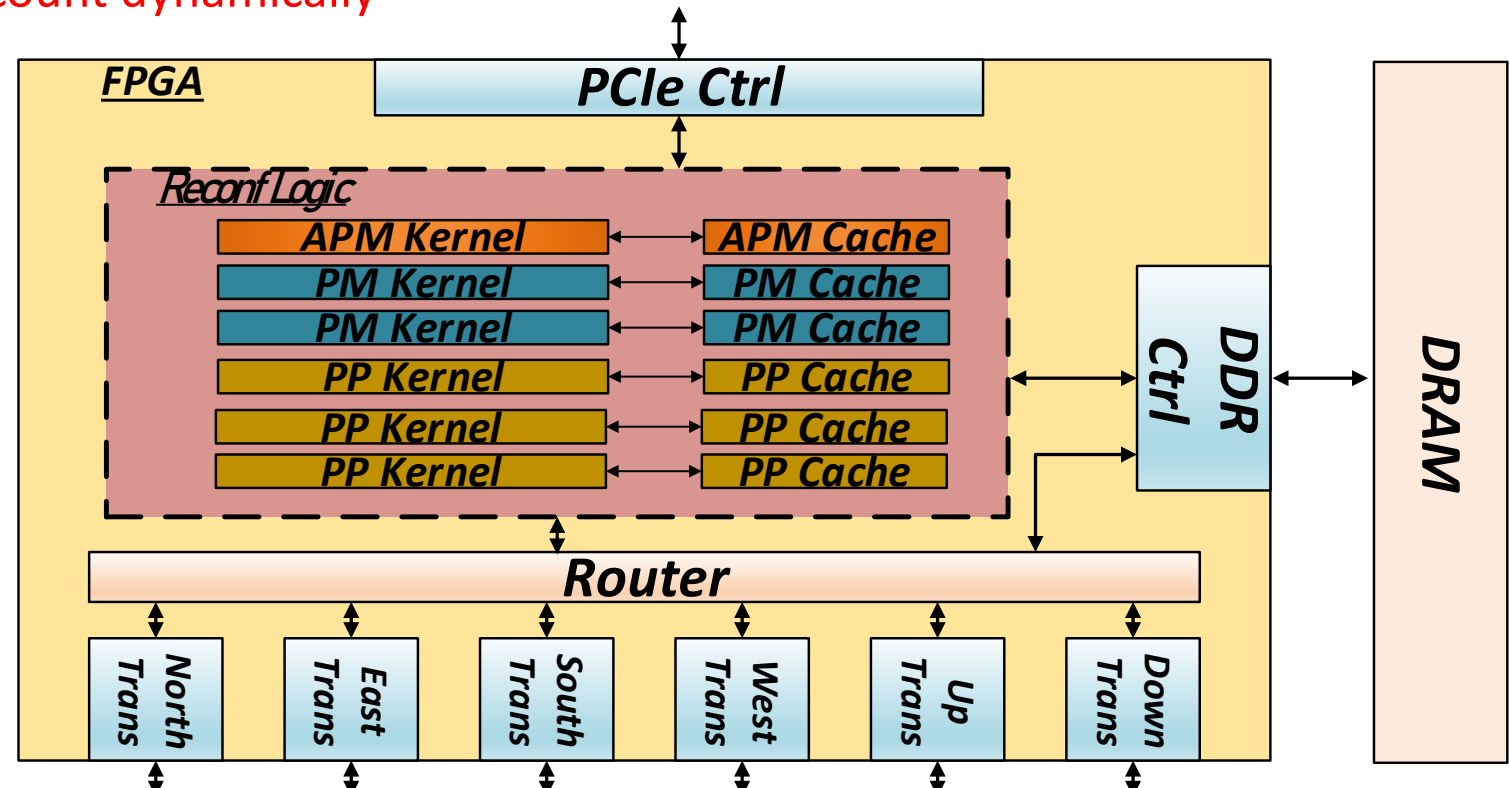
(B) Allocate Workload

- Workload partition in single node

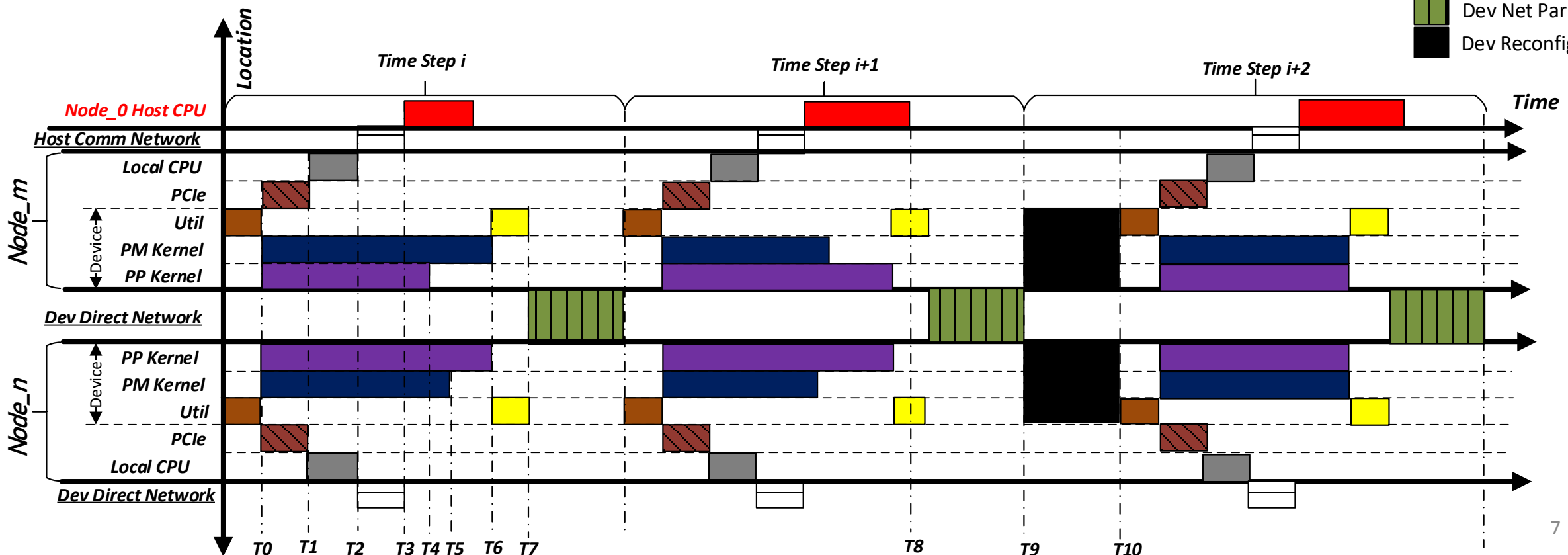
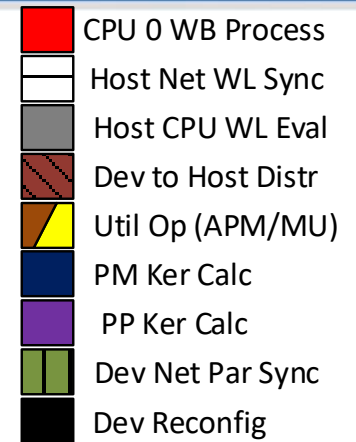
- Dedicate hardware kernel

- Adaptive Particle Mesh (APM)
- Particle Mesh (PM)
- Particle-Particle (PP)

- Partial Reconfig ~ Adjust kernel account dynamically

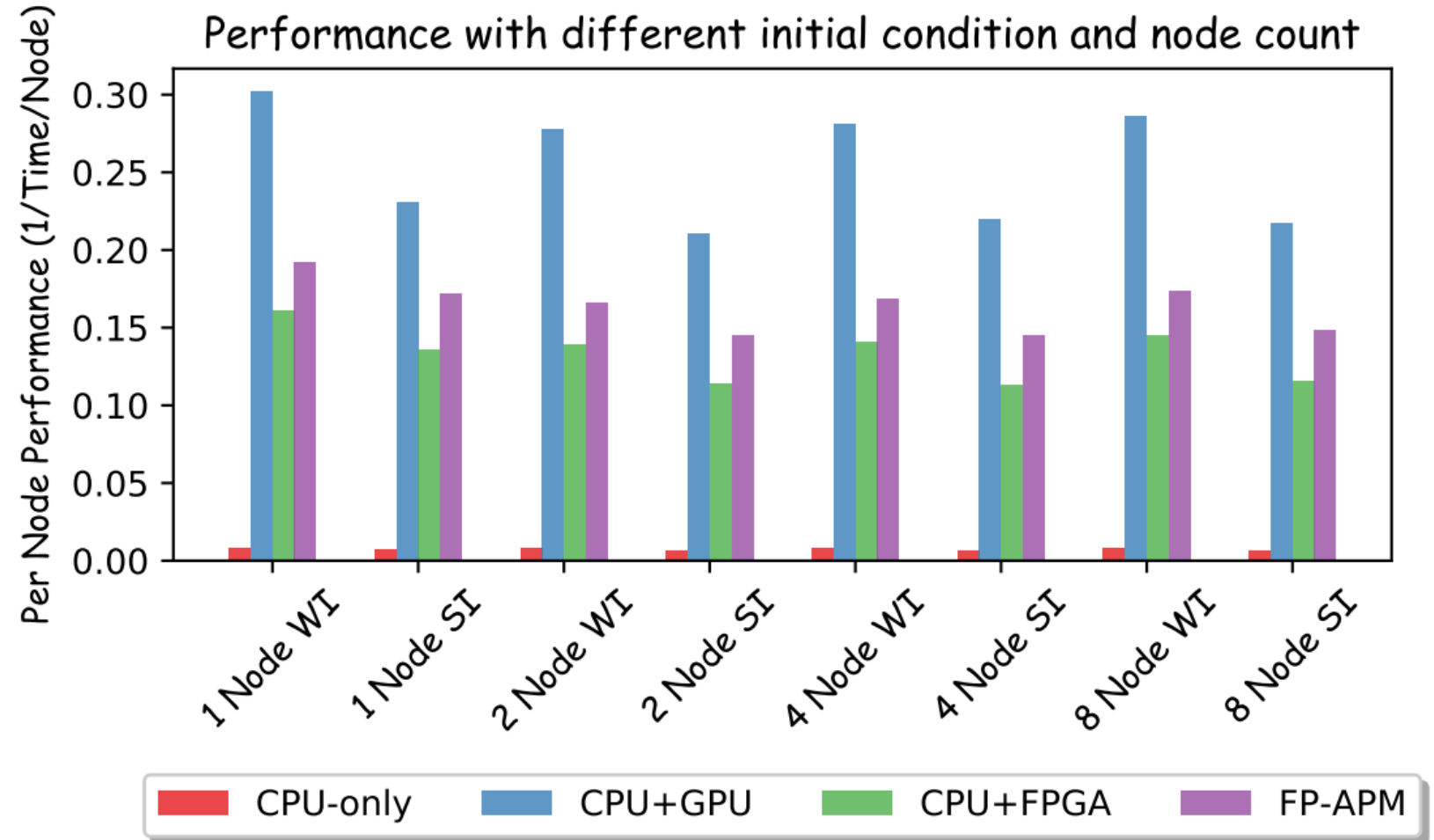


- Workload Scheduling
  - APM ~ PP/PM sequential
  - Overlap host operation/communication





- Experiment result
  - Performance





- Experiment result
  - Time consumption breakdown
  - Utilization breakdown

