DE LA RECHERCHE À L'INDUSTRIE

Enhancing MPI + OpenMP Task based Applications for Heterogenous Architectures with GPU support

18th International Workshop on OpenMP, IWOMP 2022 Chattanooga, TN, USA, September 27–30, 2022

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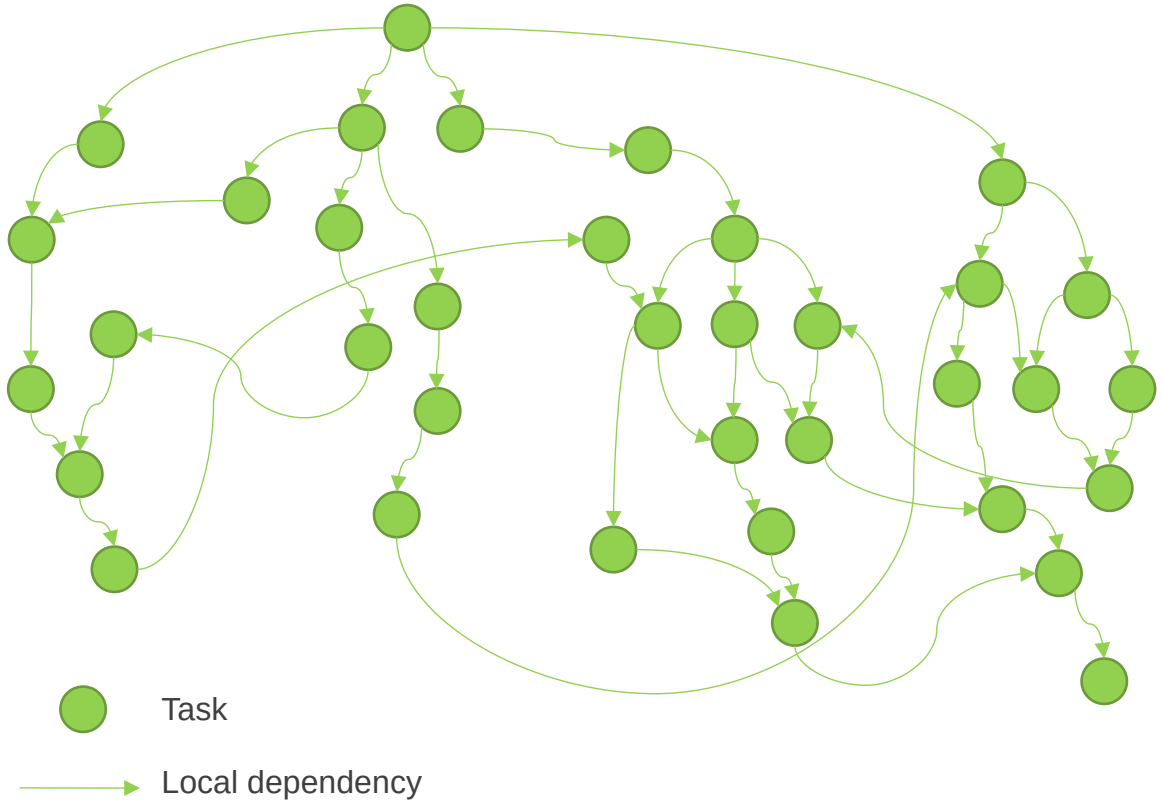
Context

- **Dependent Task-based programming model**
  - Application' parallelism represented as directed acyclic graph (DAG)
    - Node : tasks, code to execute with its associated data
    - Arcs : precedence constraints



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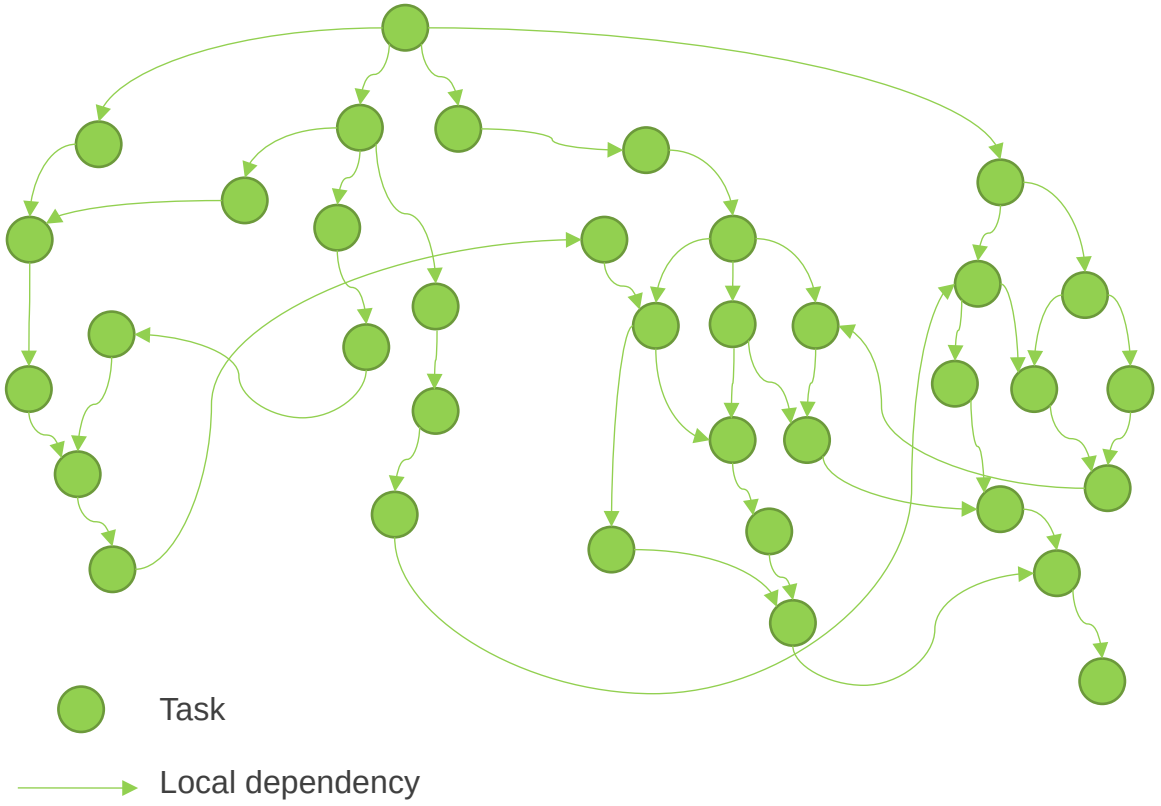

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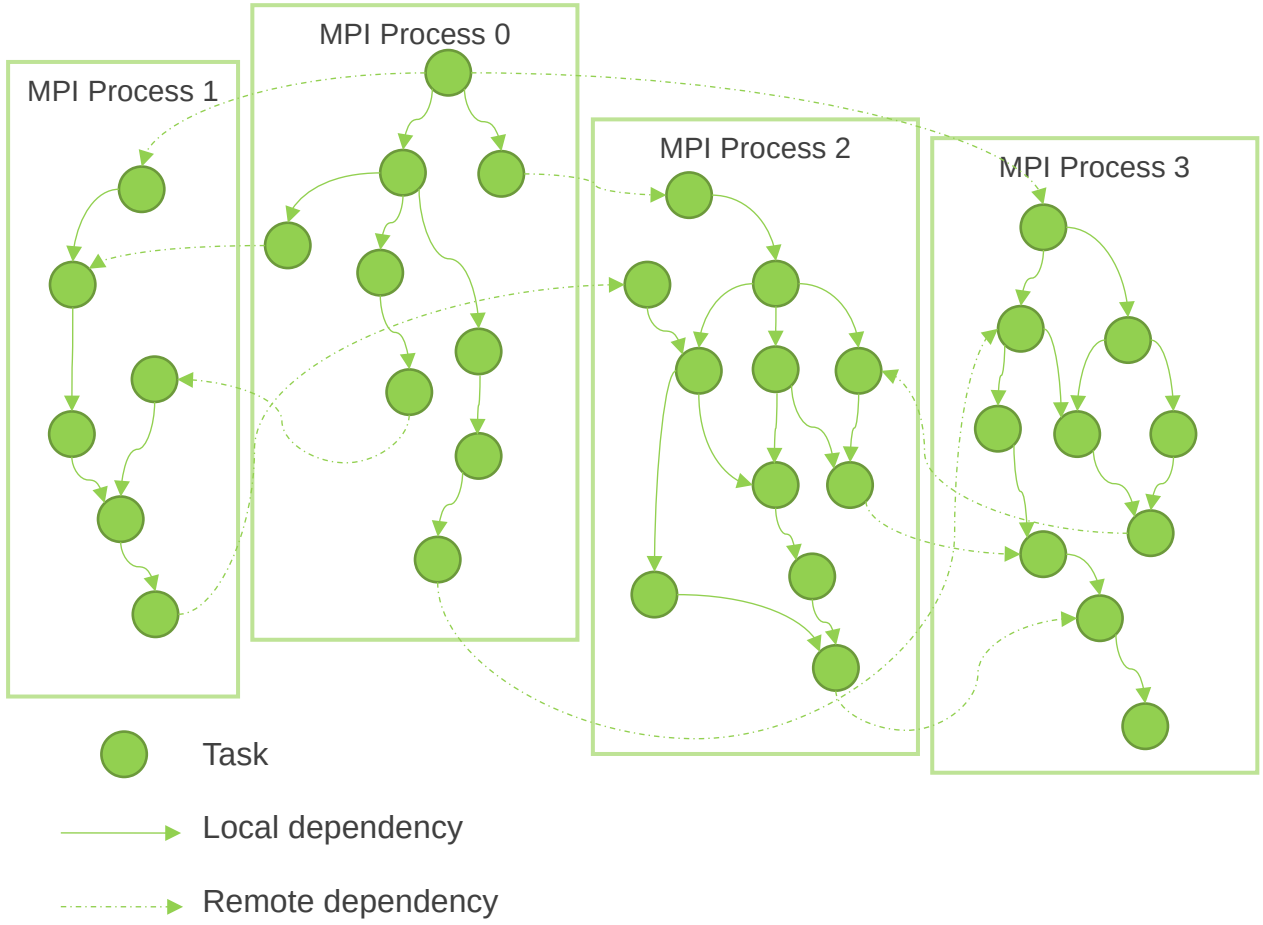

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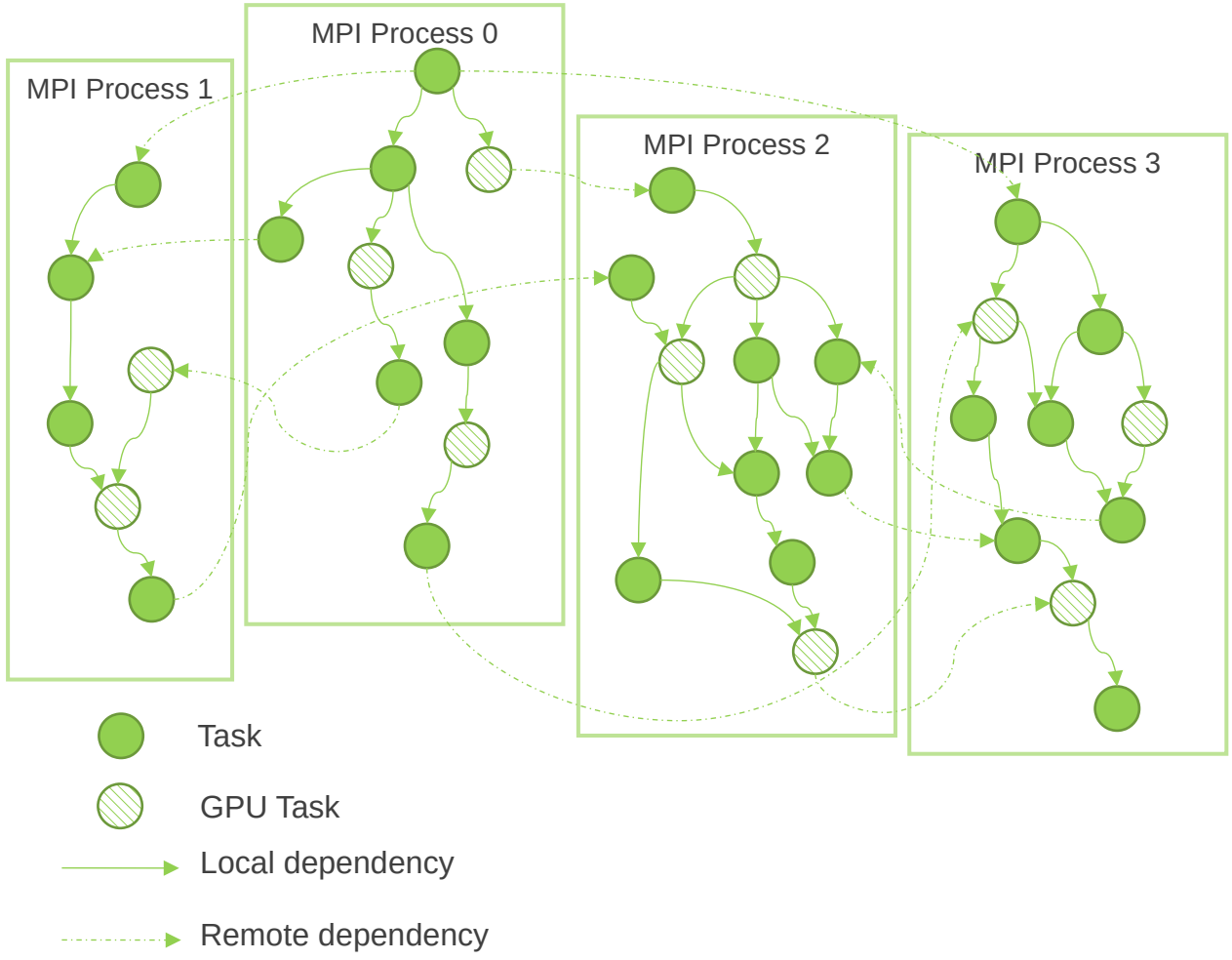

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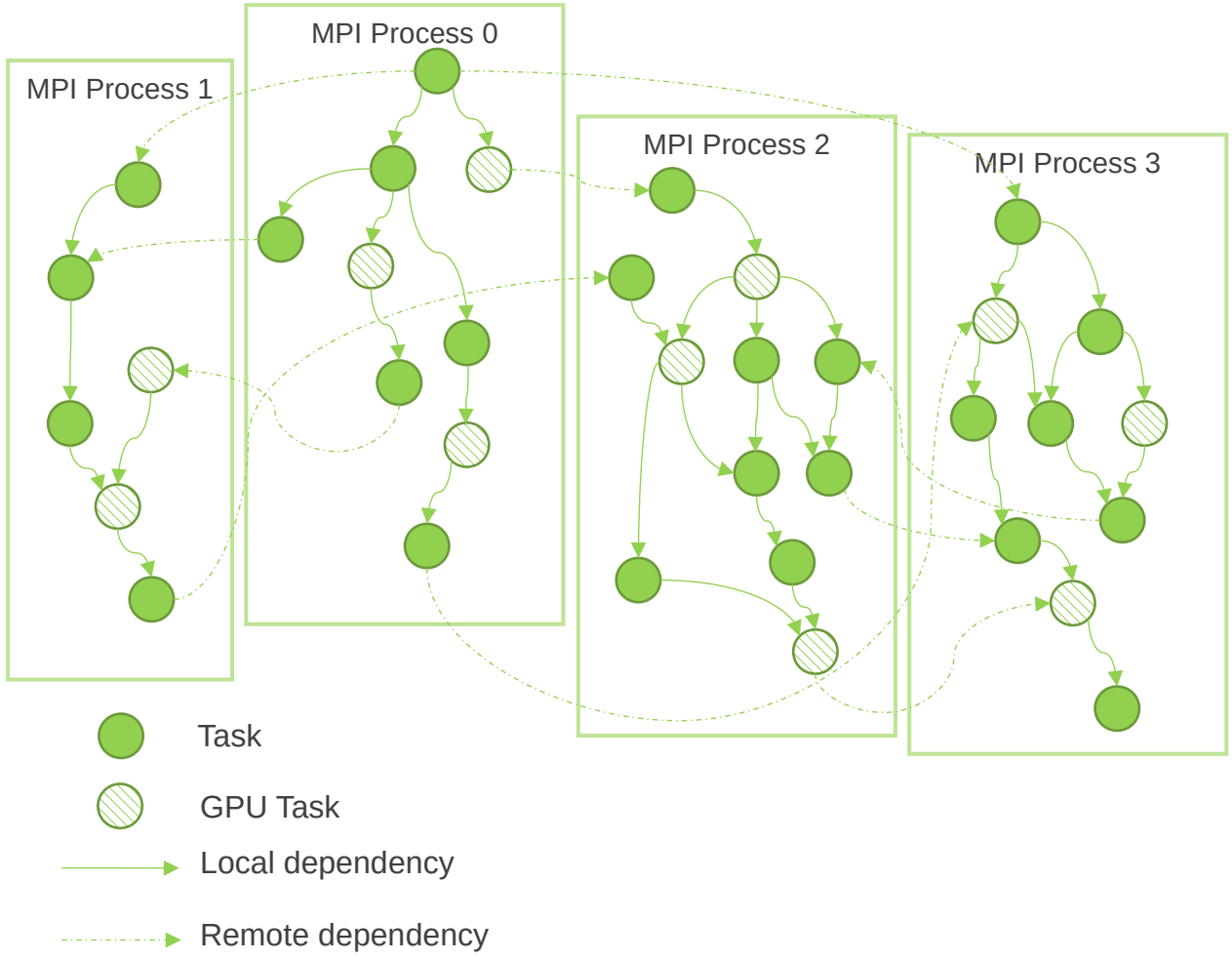

⟹ How the task-based programming model is implemented by OpenMP

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Vectors addiction OpenMP Target example

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Problem

- **How to efficiently schedule CPU and GPU tasks over processing units?**
  - Automatic overlap of communication and computation with the GPU

Related works

- **LLVM – Hidden Helper Thread** [1]
  - Uses a team of kernel thread for scheduling target tasks
  - Limits : lack of flexibility on scheduling policy
    - Fixed team size (number of “target nowait” parallel limited)
    - Implicit kernel preemption scheduling decision made by the kernel

1 - Tian, S., Doerfert, J., Chapman, B.: Concurrent Execution of Deferred OpenMP Target Tasks with Hidden Helper Threads. In: Chapman, B., Moreira, J. (eds.) Languages and Compilers for Parallel Computing. pp. 41–56. Springer International Publishing, Cham (2022)

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    - Characterizes the problem: in GOMP/Clang, blocking MPI call in a task retain CPU resources
    - No automatic overlap communication/calculation need for interoperability

2 - Schuchart, J., Tsugane, K., Gracia, J., Sato, M.: The Impact of Taskyield on the Design of Tasks Communicating Through MPI. In: de Supinski, B.R., Valero-Lara, P., Martorell, X., Mateo Bellido, S., Labarta, J. (eds.) Evolving OpenMP for Evolving Architectures. pp. 3–17. Springer International Publishing, Cham (2018)

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3 - Sala, K., Teruel, X., Pérez, J., Peña, A., Beltran, V., Labarta, J.: Integrating Blocking and Non-Blocking MPI Primitives with Task-Based Programming Models. Parallel Computing 85, 153–166 (07 2019). https://doi.org/10.1016/j.parco.2018.12.008

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    - In particular we are interested in MPC
      - Standard implementation of OpenMP 3.0 [4]
      - Full support for all tasks except targets
      - The MPC-OpenMP runtime adds "light context (fiber)" to tasks [5]
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4 - Clet-Ortega, J., Carribault, P., Pérache, M.: Evaluation of OpenMP task scheduling algorithms for large NUMA architectures, Proc. Eur. Conf. Parallel Process., pp. 596-607, 2014

5 - Pereira, R., Roussel, A., Carribault, P., Gautier, T.: Communication-Aware Task Scheduling Strategy in Hybrid MPI+OpenMP Applications. In: McIntosh-Smith,S., de Supinski, B.R., Klinkenberg, J. (eds.) OpenMP: Enabling Massive Node-Level Parallelism. pp. 197–210. Springer International Publishing, Cham (2021)

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Contribution

- **Addition of GPU task support with the target-nowait directives in MPC-OpenMP**
- **Enhance asynchronous executions through user-space task scheduling**

Contents

- Introduction
  - Context
  - Problem
  - Related works
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- Contribution
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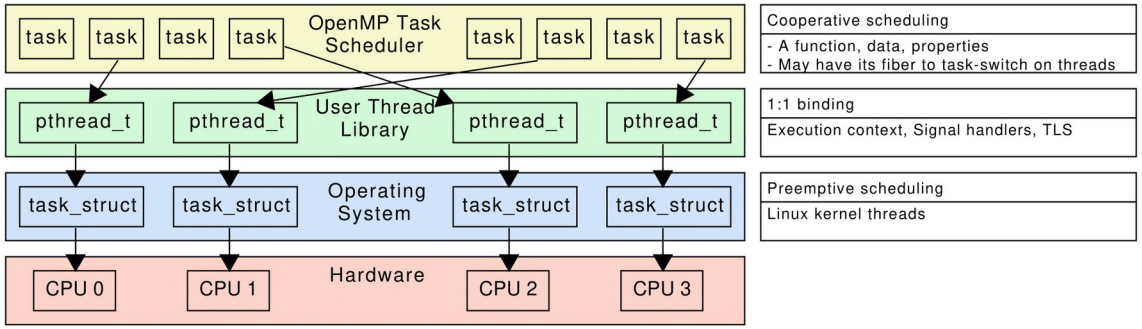
  - Heterogeneity support in MPC
- Evaluation
  - State of art comparison
  - LULESH MPI+OpenMP(tasks+target)
- Conclusion

Target with asynchronous tasks

- **Cooperative target task design**
  - After asynchronous calls tasks are explicitly preempt before synchronization points without the operating system scheduler
  - Polling functions ensure asynchronous events progression



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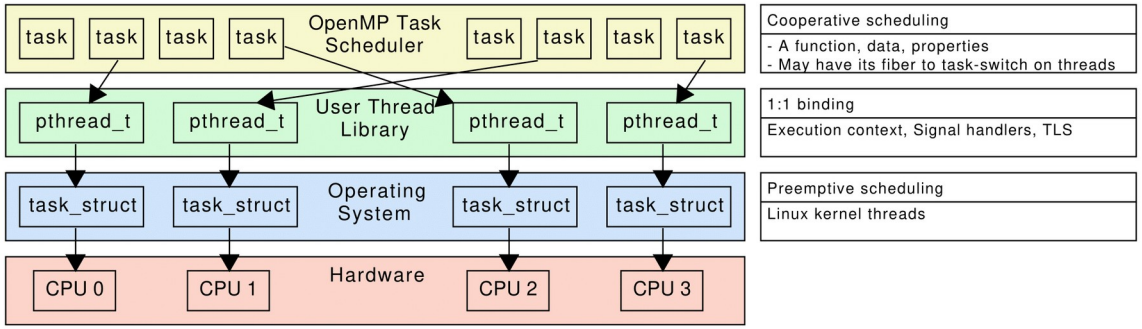

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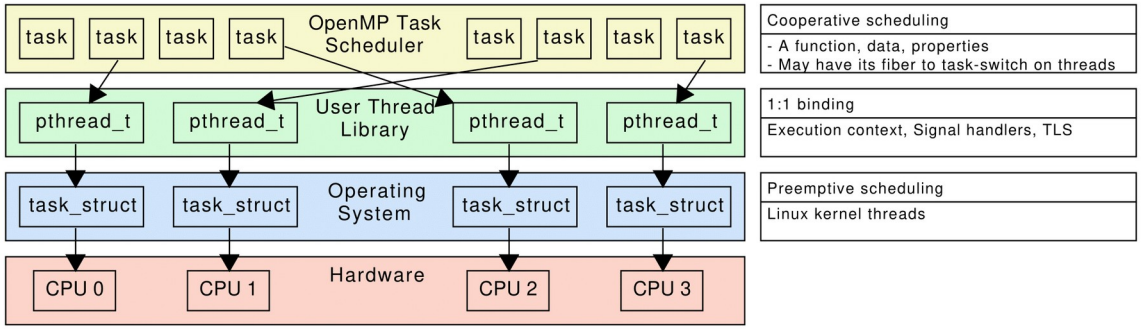
- **Overlapping of GPU operations with CPU computation**
  - Fix loss of core



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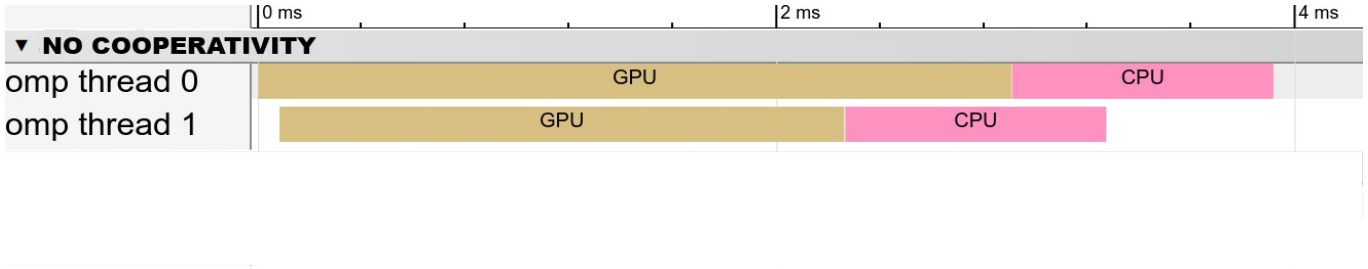

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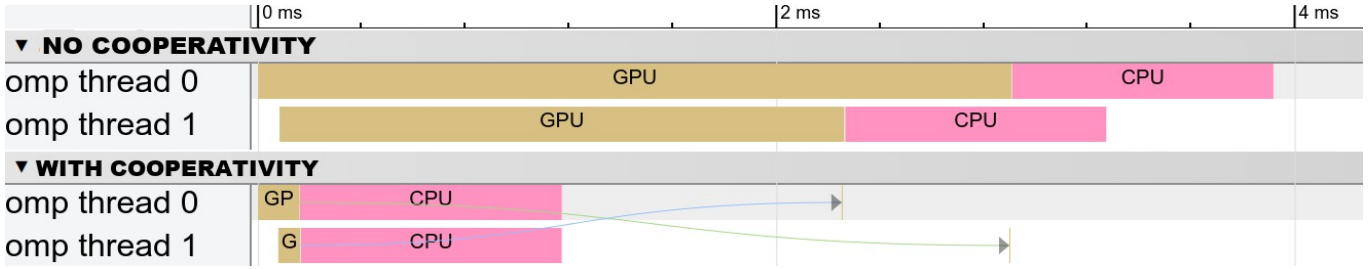
  - Adding fibers to MPC-OpenMP target task
  - Patch LLVM libomptarget CUDA RTL
    - Call a polling into MPC relying on cudaStreamQuery



Execution environment

- **Runtime environment**
  - Inti compute node hosted at CEA
    - 2 x AMD EPYC 7H12 64-core processors (4 NUMA nodes) @2.6GHz
    - 4 x NVIDIA A100 GPUs 40GB
  - The process run on a NUMA domain with 16 cores, 32GB of memory and one GPU

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Software environment

- LLVM 14.x
  - number of threads = number HHT
- NVIDIA/PGI 22.2
- MPC-OpenMP with target support
  - Patched LLVM 14.x libomptarget
  - Open MPI 4.0.5
- Optimization enable

State-of-the-Art comparison

- **Microbenchmark**
  - DAXPY OpenMP (tasks+target)
    - Vector size T*n
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      - data upload, daxpy, data download

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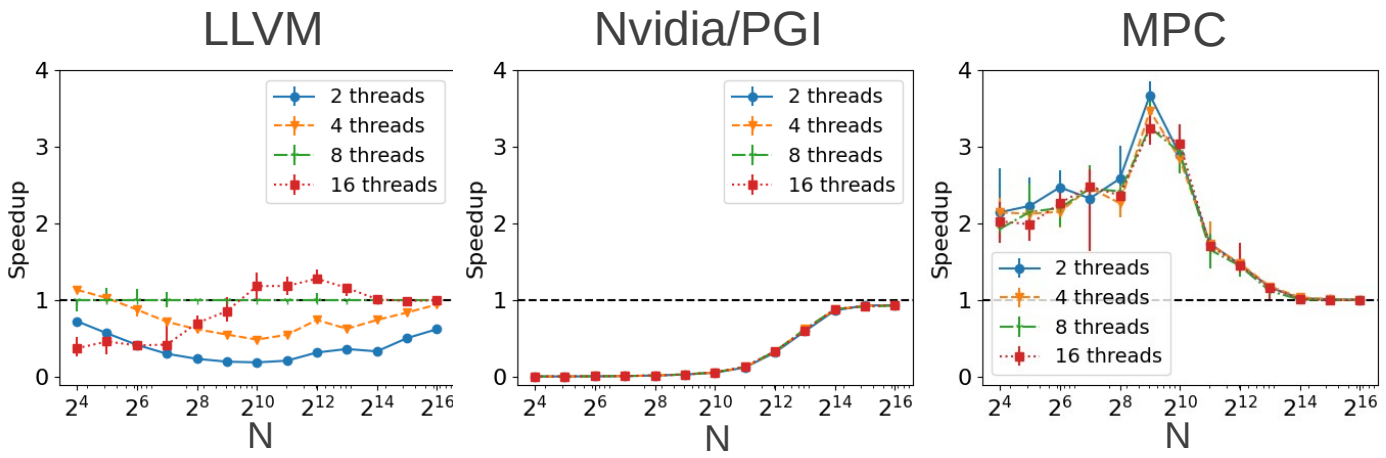

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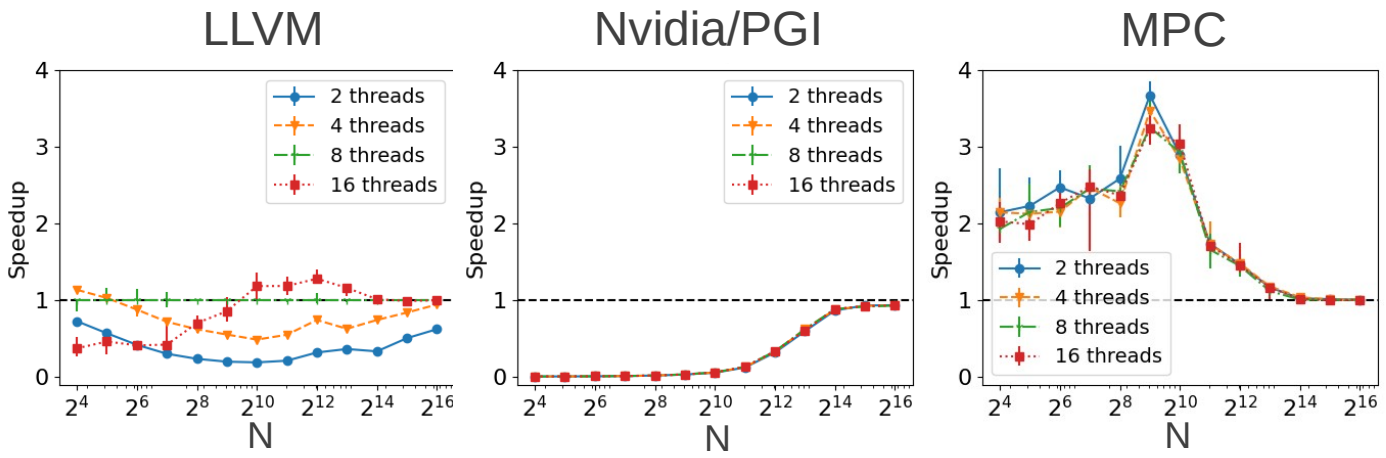

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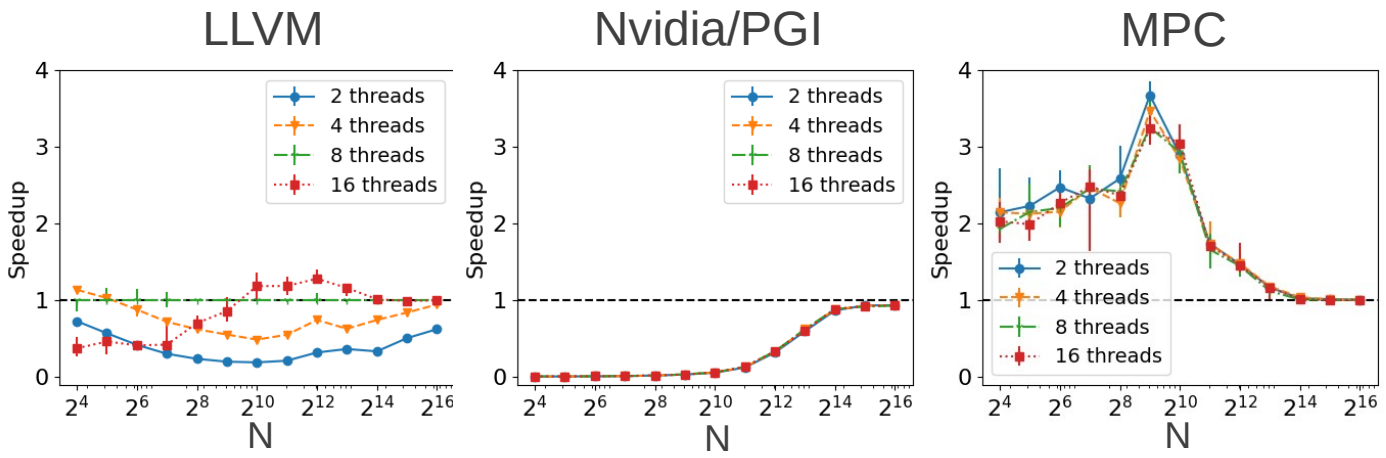

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    - Improve performances on fine-grain offloading
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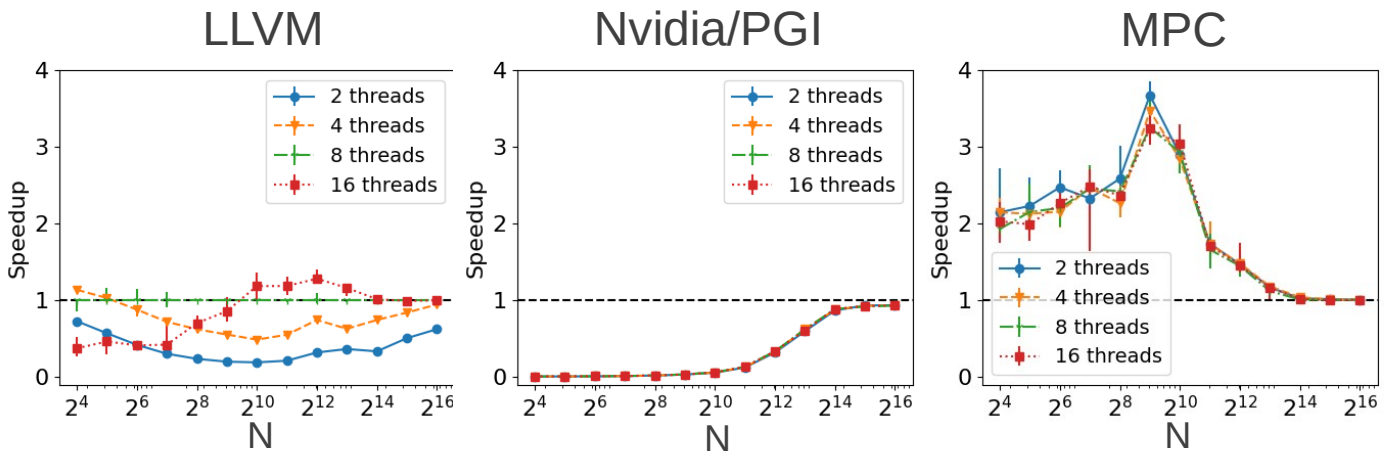

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- Loops were transformed to tasks generating loops with dependencies
- Single-producer/multi-consumer scheme
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Porting MPI + OpenMP Task version to MPI + OpenMP (Task + Target)

- GPU tasks “super tasks” are composed of several CPU tasks
- Offload parts
  - First loop of IntegrateStressForElems and CalcKinematicsForElems
  - Overlap with CalcAccelerationForNodes
- Use of **cudaMallocHost** to allocate memory
  - Pinned memory for asynchronous execution

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Porting MPI + OpenMP Task version to MPI + OpenMP (Task + Target)

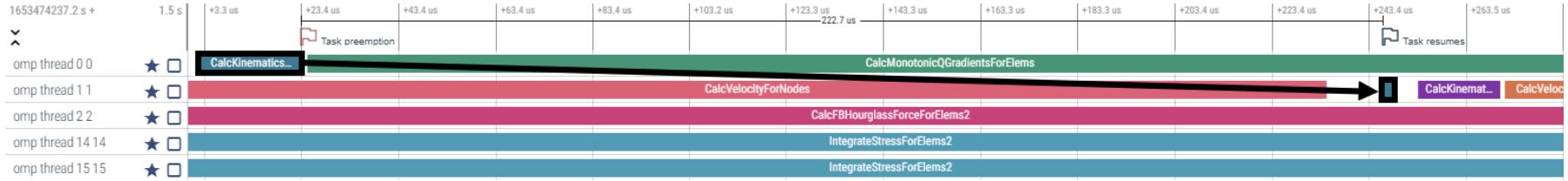
- GPU tasks “super tasks” are composed of several CPU tasks
- Offload parts
  - First loop of IntegrateStressForElems and CalcKinematicsForElems
  - Overlap with CalcAccelerationForNodes
- Use of **cudaMallocHost** to allocate memory
  - Pinned memory for asynchronous execution

Problem size

- 264^3 elements
  - 80% of the NUMA domain memory capacity
  - 20% of the GPU memory capacity
- 128 iterations

LULESH

- **Fully functional Hybrid and Heterogenous task-based version**
  - Automatic overlapping MPI communication and GPU operation



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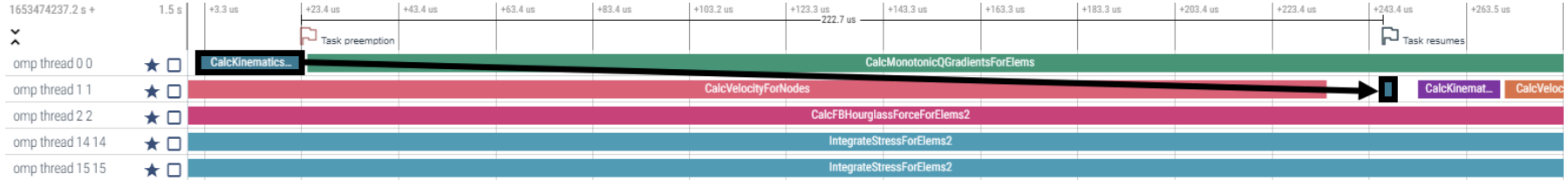

- **Weak scaling**
  - Median runtime of 10 runs
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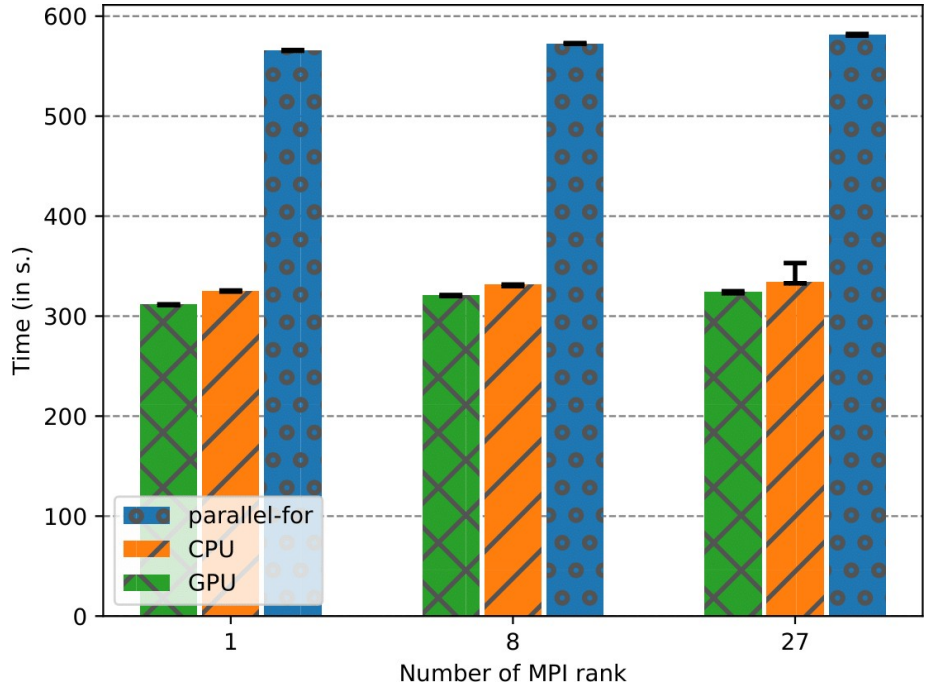

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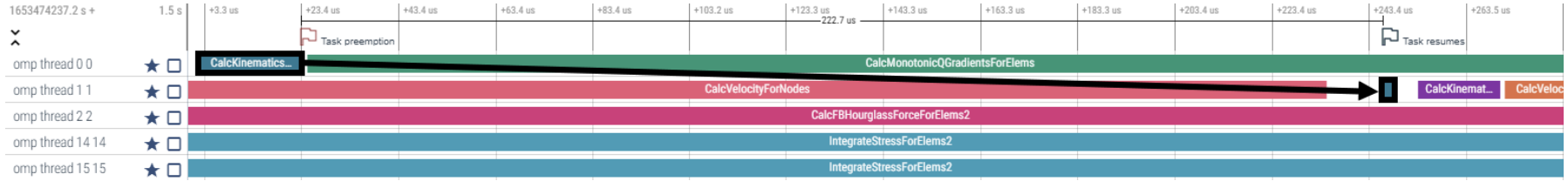
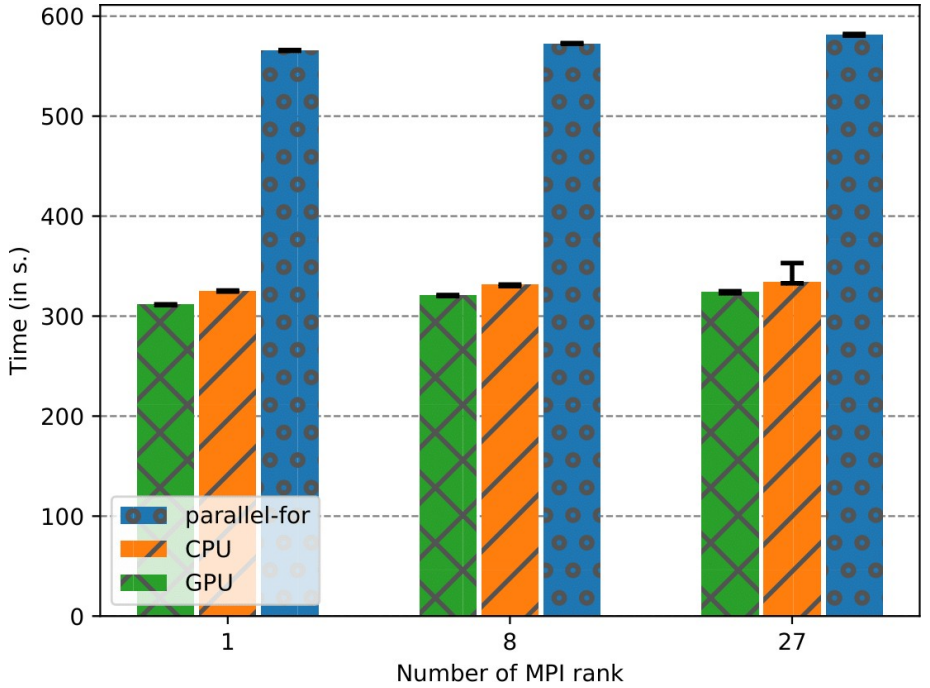


- **Weak scaling**
  - Median runtime of 10 runs
  - Each version scale very well
  - OpenMP tasks version significatively improve performances due to cache reuse
  - Slight performance gain with GPU offloading



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  - Integration of the LLVM libomptarget in MPC
  - Only NVIDIA GPUs are supported

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- **Add heterogeneity support into the MPC framework**
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- **Future works**
  - Increase the computing load on GPU
    - Offload more loops
  - Develop more applications MPI+OpenMP (Task+Target)
  - Support GPUs from other vendors

Thanks for your attention

DE LA RECHERCHE À L'INDUSTRIE

Enhancing MPI + OpenMP Task based Applications for Heterogenous Architectures with GPU support

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