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JSSPP

Evaluation of Heuristic Task-to-Thread Mapping Using Static and Dynamic Approaches

Presenter:

Mohammad Samadi

Co-authors:

Tiago Carvalho, Luis Miguel Pinho, Sara Royuela

Polytechnic Institute of Porto & INESC TEC, Porto, Portugal

Barcelona Supercomputing Center, Barcelona, Spain

Universitat Politècnica de Catalunya, Barcelona, Spain

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isep Instituto Superior de Engenharia do Porto

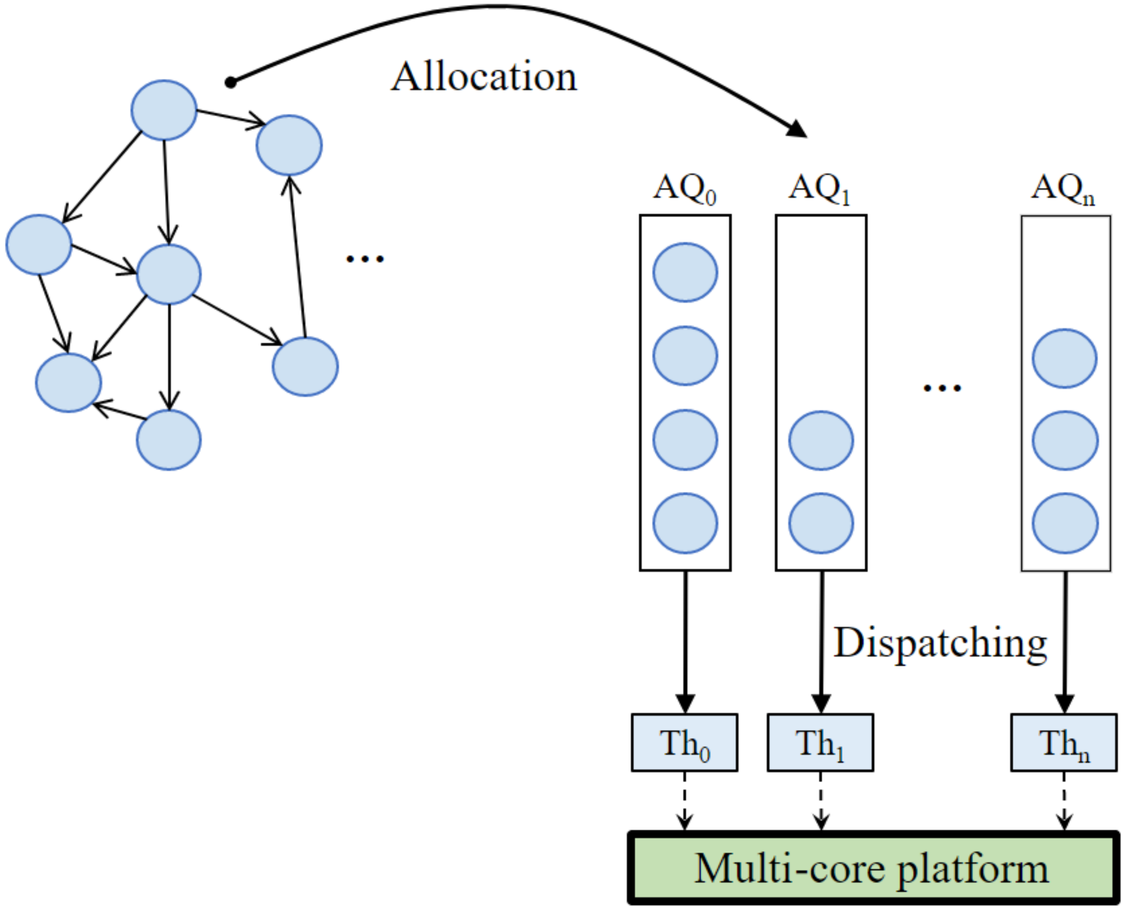
BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación

UPC UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Introduction

- Increase the need for high-performance computing (HPC) capabilities in complex cyber-physical systems
- Use OpenMP in real-time HPC applications running on shared-memory platforms
- Apply dynamic process in OpenMP runtime implementations
- Lack of time predictability in dynamic mapping algorithm
- Need time-predictable task-to-thread mapping in OpenMP

Heuristic Task-to-Thread Mapping



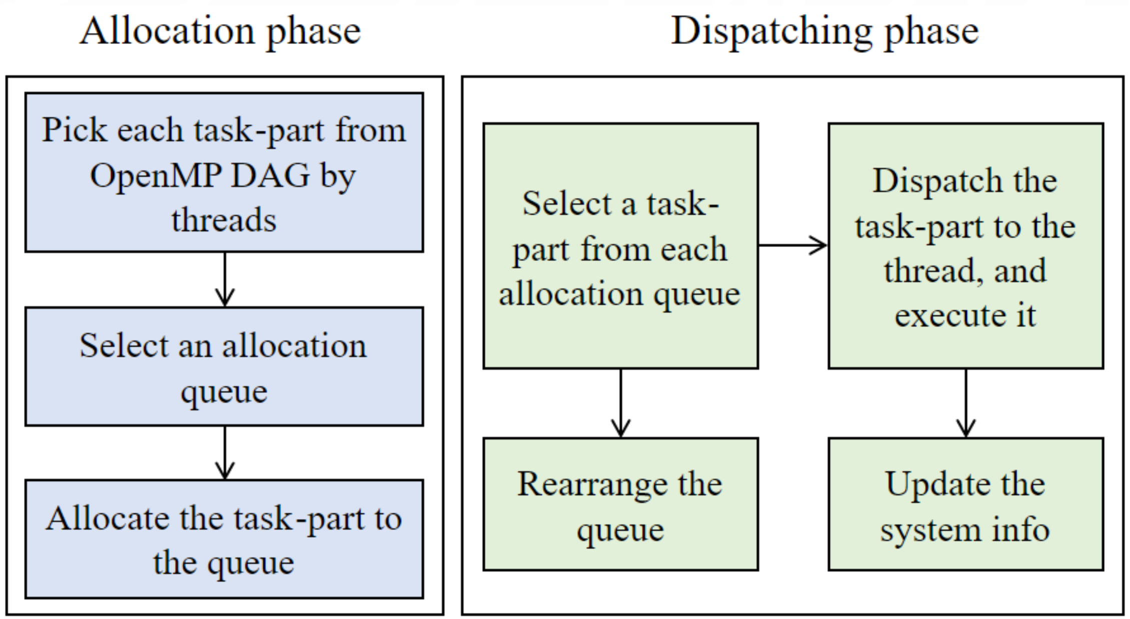
Allocation

AQ_0 AQ_1 … AQ_n

Dispatching

Th_0 Th_1 Th_n

Multi-core platform



Allocation phase

Pick each task-part from OpenMP DAG by threads

Select an allocation queue

Allocate the task-part to the queue

Dispatching phase

Select a task-part from each allocation queue

Dispatch the task-part to the thread, and execute it

Rearrange the queue

Update the system info

Heuristic Task-to-Thread Mapping

The allocation heuristics to select threads:

- MNTP: Minimum number of task-parts
- NT: Next thread
- MRIT: Most recent idle time
- MTET: Minimum total execution time
- MTRT: Maximum total response time
- TMCD: Total multi-criteria decision based on MNTP, MRIT and MTET

The dispatching heuristics to select task-parts:

- MET: Minimum execution time
- MRT: Maximum response time
- MCD: Multi-criteria decision based on MET and MRT

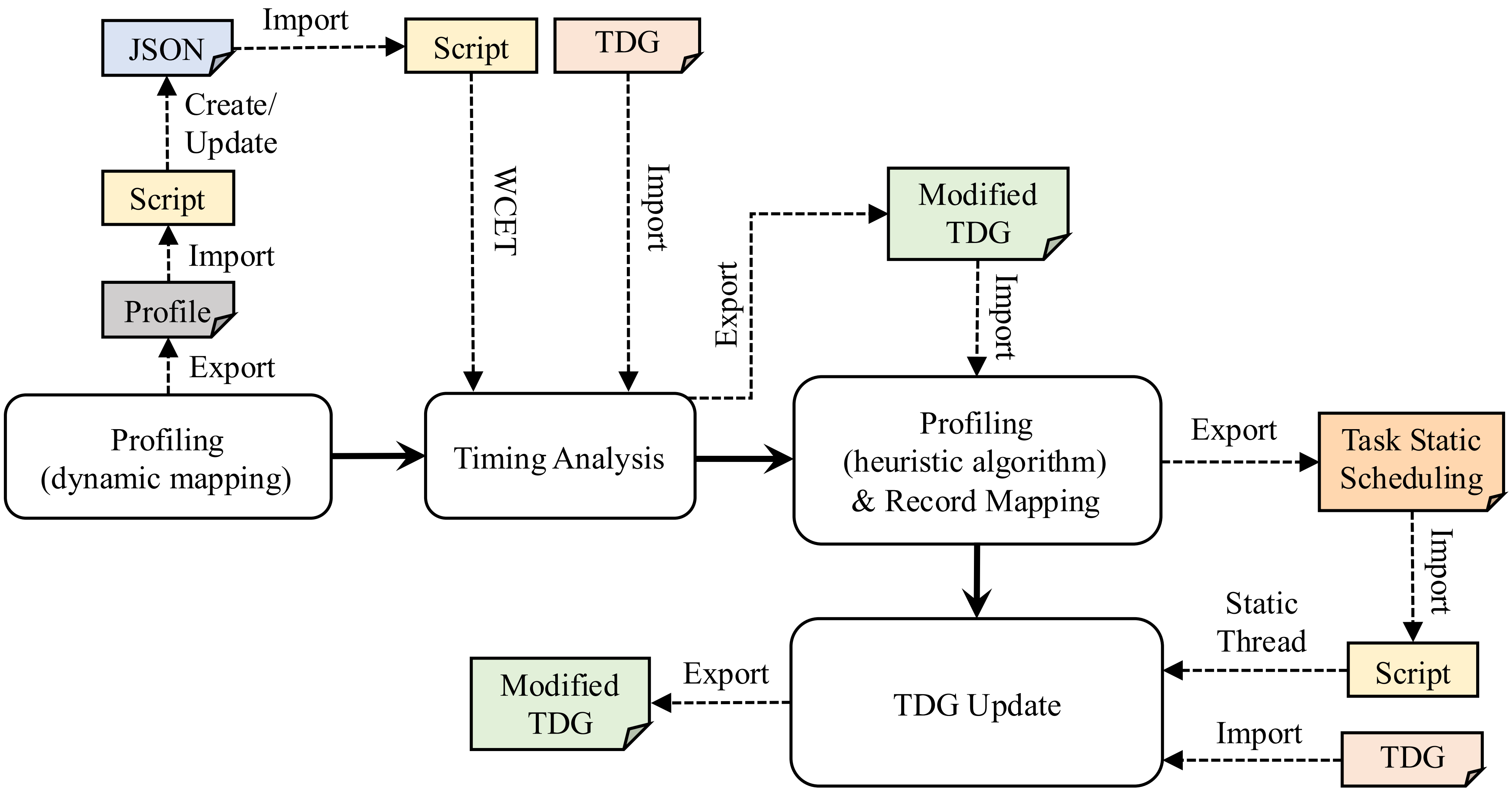
Problems With Heuristic Mapping

- Implementation of the MTET heuristic in LLVM is not efficient.
- MRT heuristic needs more information of the system.
- Current evaluations did not consider embarrassingly parallel applications.
- Experiments were carried out based on the WCET, without considering the variability of results.

Contributions

- Compare execution of the heuristics considering decisions made during execution, against static enforcement of the mapping.
- Determine static mapping by recording the execution in real platform instead by simulation.
- Reduce overhead by changing the implementation of one of the heuristics.
- Implement a new heuristic in the dispatching phase.

Methodology for Static Mapping



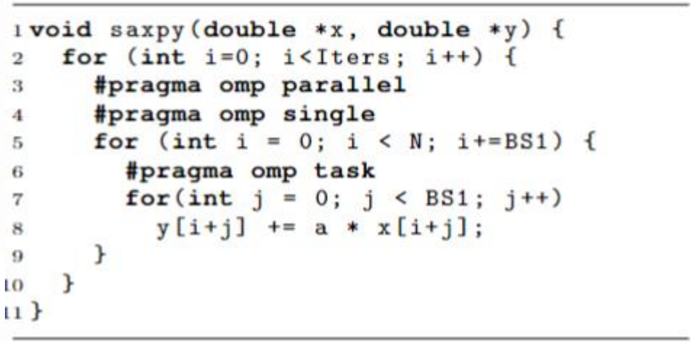
LLVM Extensions

- Improve the MTET heuristic by materializing the time expend in execution for each thread to reduce mapping overhead.
- Propose the highest execution time (HET) heuristic algorithm to reduce the workload of each queue and increase its chance of getting new tasks.

Applications

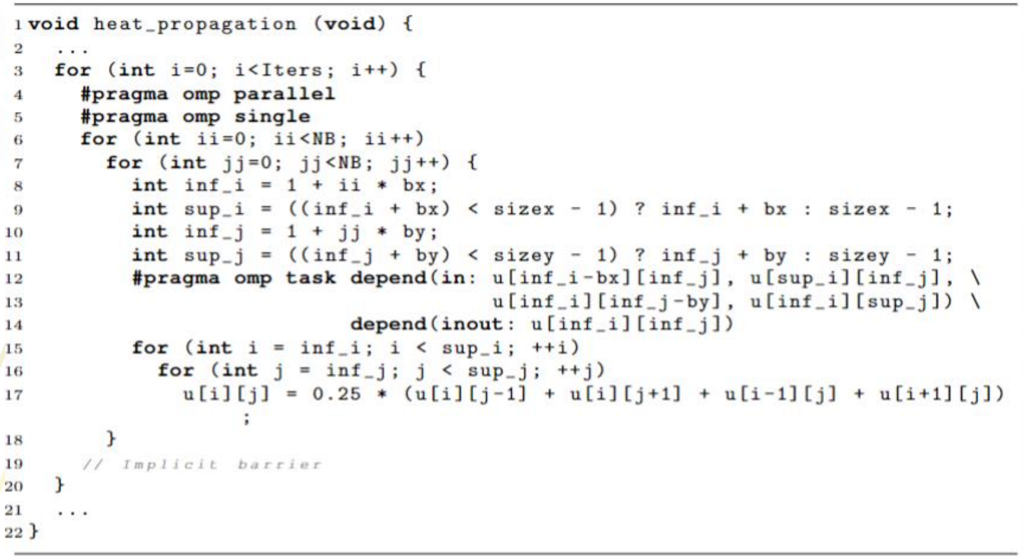
- Axpy: A Level 1 operation in the Basic Linear Algebra Subprograms (BLAS) package that combines scalar multiplication and vector addition.
- Heat: A simulator of heat diffusion based on the Gauss-Seidel method implementing a stencil computation.
- SparseLU: A matrix decomposition implementing a diamond-like form of irregular parallelism.

Applications



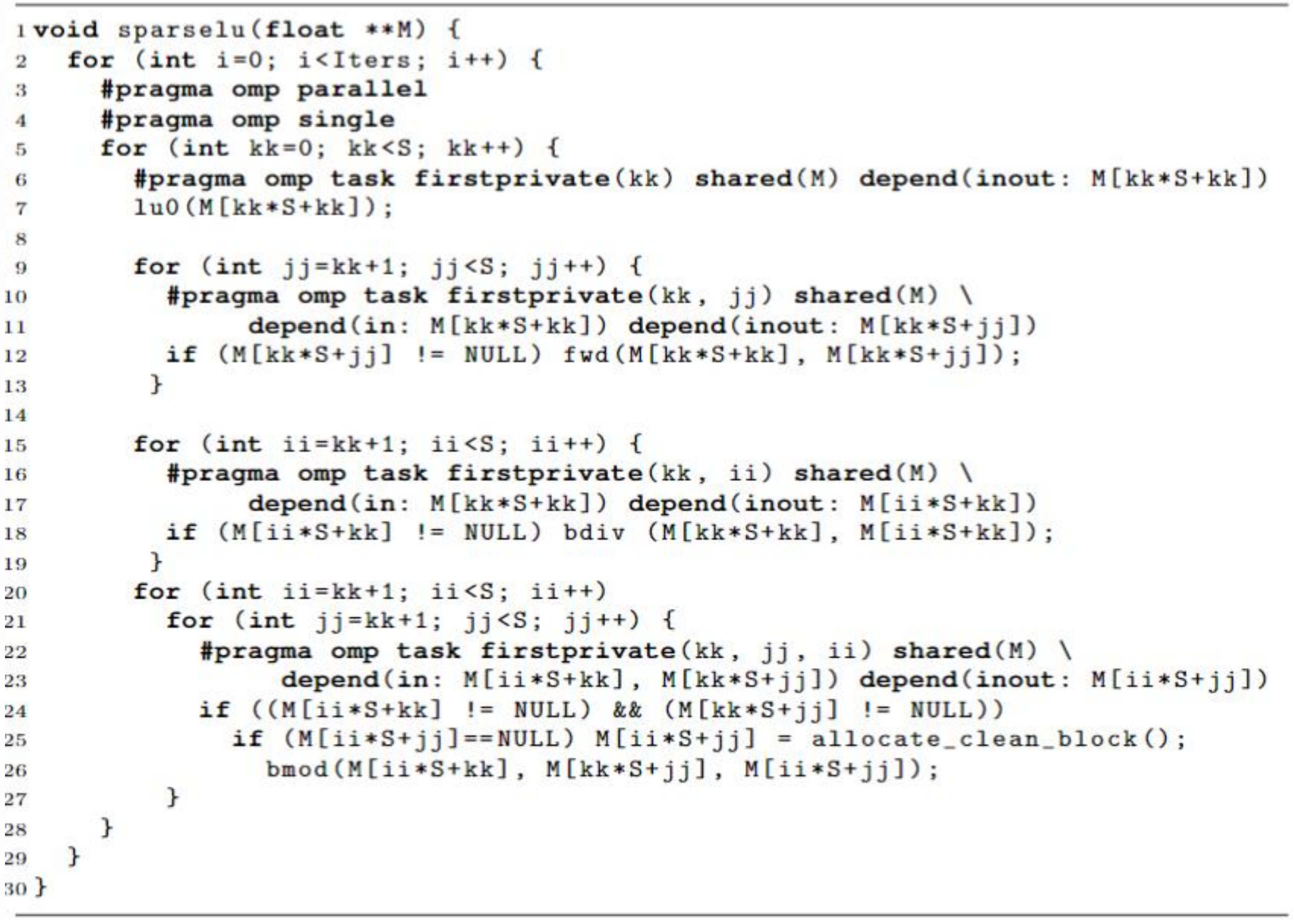
```
void saxpy(double *x, double *y) {
  for (int i=0; i<Iters; i++) {
    #pragma omp parallel
    #pragma omp single
    for (int i = 0; i < N; i+=BS1) {
      #pragma omp task
      for(int j = 0; j < BS1; j++)
        y[i+j] += a * x[i+j];
    }
  }
}
```

Axpy



```
void heat_propagation (void) {
  ...
  for (int i=0; i<Iters; i++) {
    #pragma omp parallel
    #pragma omp single
    for (int ii=0; ii<NB; ii++)
      for (int jj=0; jj<NB; jj++) {
        int inf_i = 1 + ii * bx;
        int sup_i = ((inf_i + bx) < sizex - 1) ? inf_i + bx : sizex - 1;
        int inf_j = 1 + jj * by;
        int sup_j = ((inf_j + by) < sizey - 1) ? inf_j + by : sizey - 1;
        #pragma omp task depend(in: u[inf_i-bx][inf_j], u[sup_i][inf_j], \
                                    u[inf_i][inf_j-by], u[inf_i][sup_j]) \
                        depend(inout: u[inf_i][inf_j])
        for (int i = inf_i; i < sup_i; ++i)
          for (int j = inf_j; j < sup_j; ++j)
            u[i][j] = 0.25 * (u[i][j-1] + u[i][j+1] + u[i-1][j] + u[i+1][j])
                ;
      }
    // Implicit barrier
  }
  ...
}
```

Heat



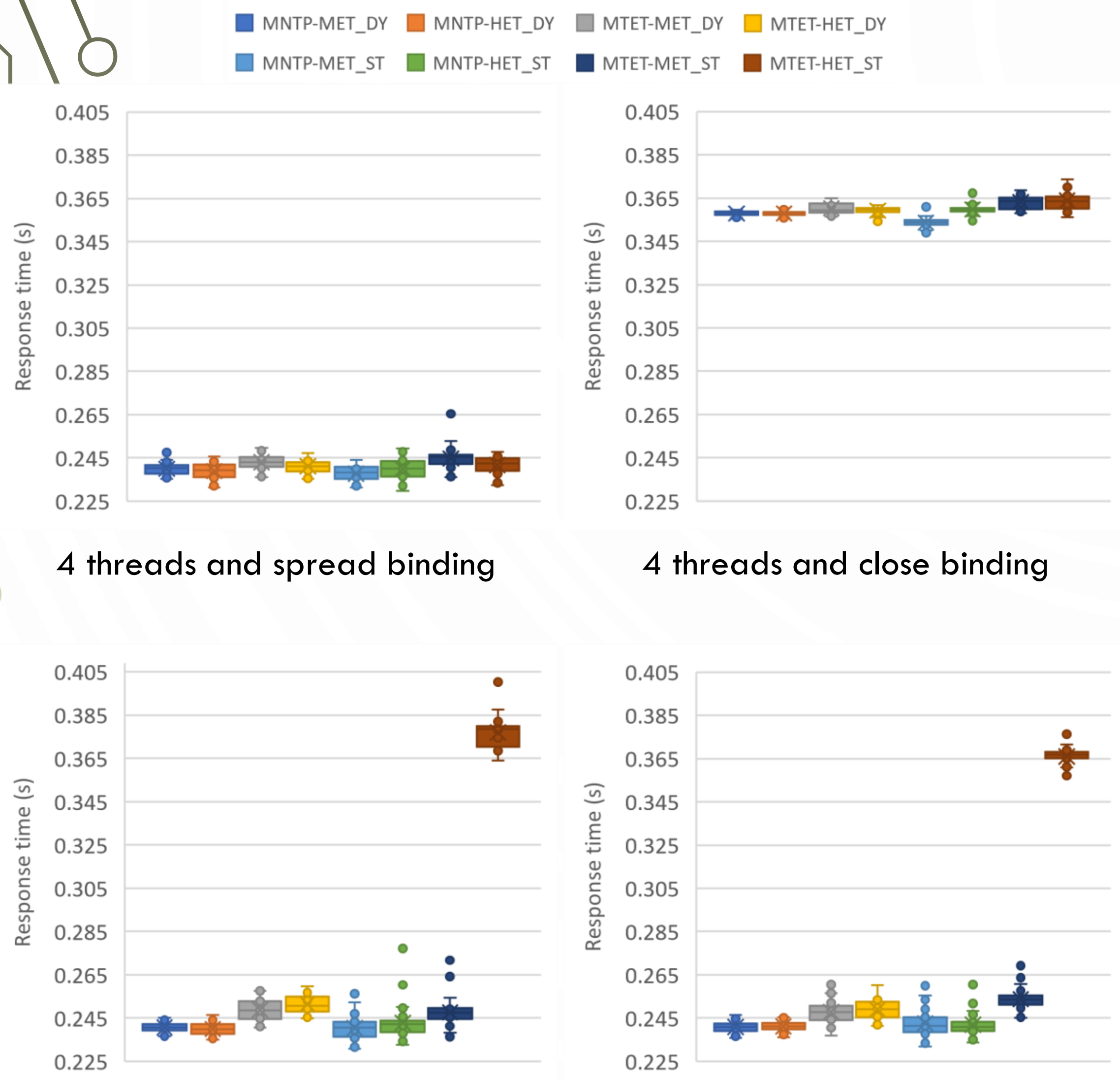
```
void sparselu(float **M) {
  for (int i=0; i<Iters; i++) {
    #pragma omp parallel
    #pragma omp single
    for (int kk=0; kk<S; kk++) {
      #pragma omp task firstprivate(kk) shared(M) depend(inout: M[kk*S+kk])
      lu0(M[kk*S+kk]);

      for (int jj=kk+1; jj<S; jj++) {
        #pragma omp task firstprivate(kk, jj) shared(M) \
             depend(in: M[kk*S+kk]) depend(inout: M[kk*S+jj])
        if (M[kk*S+jj] != NULL) fwd(M[kk*S+kk], M[kk*S+jj]);
      }

      for (int ii=kk+1; ii<S; ii++) {
        #pragma omp task firstprivate(kk, ii) shared(M) \
             depend(in: M[kk*S+kk]) depend(inout: M[ii*S+kk])
        if (M[ii*S+kk] != NULL) bdiv (M[kk*S+kk], M[ii*S+kk]);
      }
      for (int ii=kk+1; ii<S; ii++)
        for (int jj=kk+1; jj<S; jj++) {
          #pragma omp task firstprivate(kk, jj, ii) shared(M) \
               depend(in: M[ii*S+kk], M[kk*S+jj]) depend(inout: M[ii*S+jj])
          if ((M[ii*S+kk] != NULL) && (M[kk*S+jj] != NULL))
            if (M[ii*S+jj]==NULL) M[ii*S+jj] = allocate_clean_block();
             bmod(M[ii*S+kk], M[kk*S+jj], M[ii*S+jj]);
        }
    }
  }
}
```

SparseLU

Experimental Setup

- Hardware: NVIDIA Jetson AGX Xavier with 8-core CPU
- Operating system: Linux OS with the highest real-time priority
- Compiler and runtime system: An extended version of LLVM/Clang 17.0.0, supporting OpenMP 5.0 and Taskgraph
- Configurations: Different number of threads and binding options
- Execution process: Running the applications in 50 iterations and removing the first 10% of results as a warm-up phase

Experiments (Axpy)



4 threads and spread binding

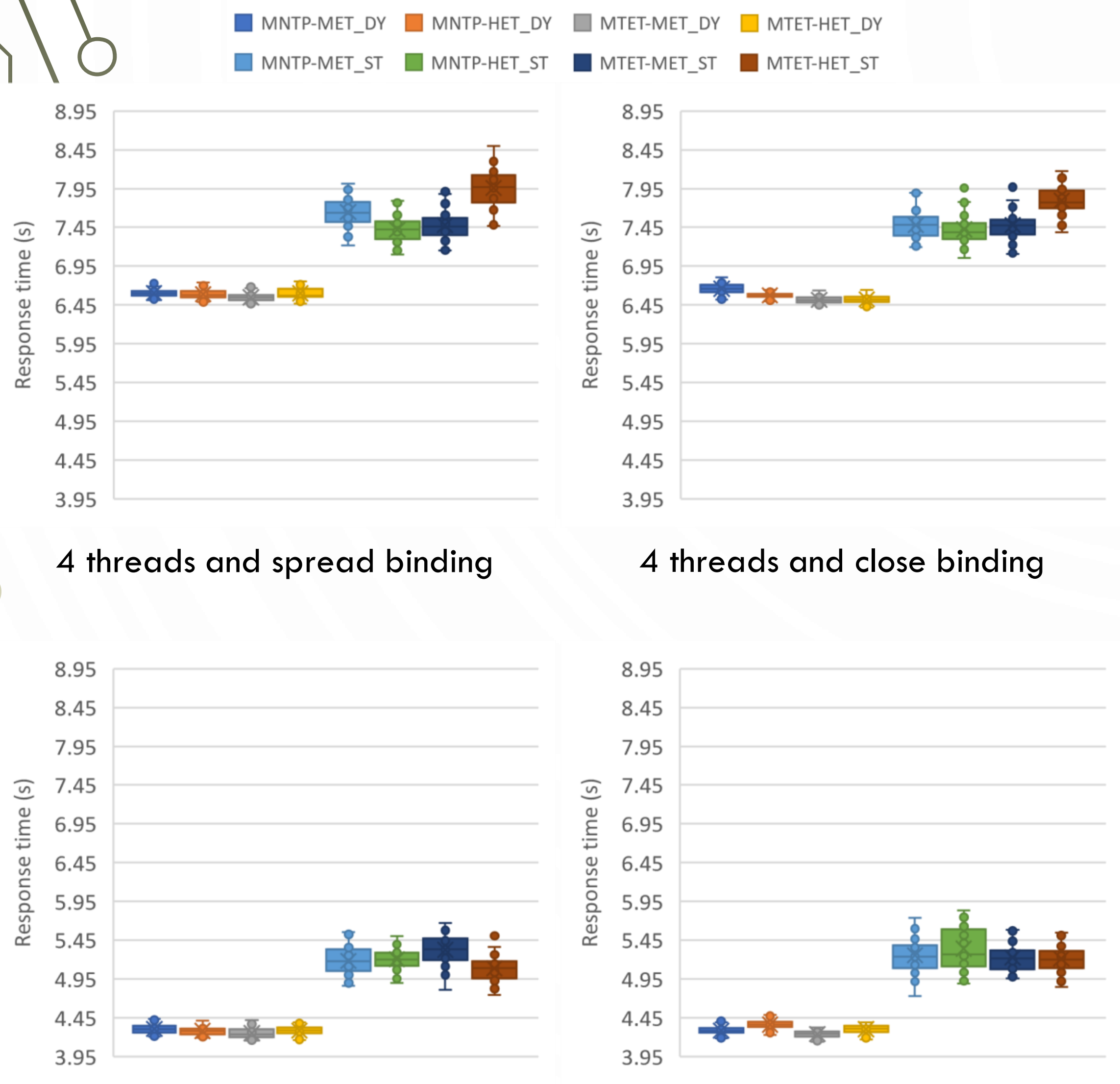
4 threads and close binding

8 threads and spread binding

8 threads and close binding

- Variability of MNTP-X in dynamic mapping is smaller than that of the other heuristic pairs.
- Response time with MNTP-X is slightly lower than others.
- Response time with MTET-HET and 8 threads in static mapping is higher than others.
- Response time with 4 threads and spread binding has not been decreased by increasing the number of threads to 8.
- There is not a considerable difference between the results obtained in dynamic and static mapping.

Experiments (Heat)



4 threads and spread binding

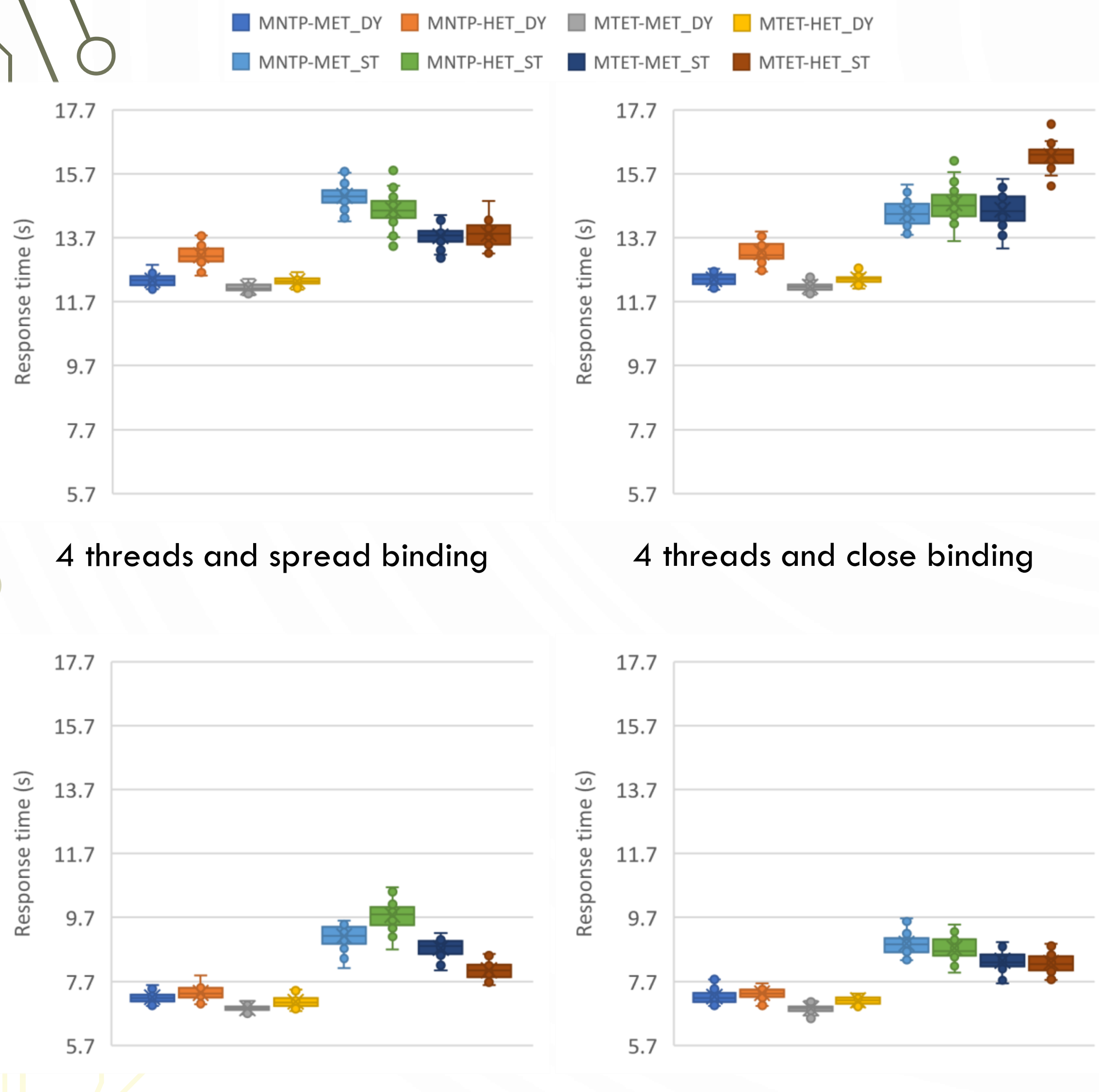
4 threads and close binding

8 threads and spread binding

8 threads and close binding

- Response time and variability of results achieved in dynamic mapping are lower than that in static mapping.
- Both the static and the dynamic versions show the same scalability when changing the number of threads.
- MTET-MET consistently shows slightly better performance and variability than the other pairs.

Experiments (SparseLU)



4 threads and spread binding

4 threads and close binding

8 threads and spread binding

8 threads and close binding

- Response time and variability given in dynamic mapping are better than those given in static mapping.
- Response time and variability of the results achieved with MTET-X are lower than those achieved with MNTP-X in most of the results.
- In this application with a complex TDG, there is a noticeable difference among the results given with the heuristics.

Discussion

- In the application without data dependencies, the performance of the heuristics in dynamic and static mapping is similar to each other.
- In the applications with data dependencies, their performance in dynamic mapping is better than that in static mapping.
- Variability in the dynamic mapping approach is lower than static mapping, important for real-time systems.

Future Works

The evaluation of the mappings under a wider set of conditions, supporting:

- Various artificial intelligence and data analytics applications
- Different hardware platforms with higher parallel capabilities

THANKS FOR YOUR ATTENTION!

For more information:
mmasa@isep.ipp.pt

isep Instituto Superior de Engenharia do Porto

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BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación