CODE OPTIMISATION

ON INTEL XEON (CO)PROCESSORS

André Pereira ampereira@di.uminho.pt

Agenda

- The Case Study
- Identifying Inefficiencies
  - Common code pitfalls
  - Using compiler flags
- Vectorisation
- Shared Memory Parallelisation
- Intel Xeon Phi Coprocessor

The Case Study

```
void matMult (float **a, float **b, float **c, int size) {
    for (int i = 0; i < size; i++)
        for (int j = 0; j < size; j++) {
            c[i][j] = 0;
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                c[i][j] += a[i][k] * b[k][j];
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- Row/Column major - *work assignment…*

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Avoidable Memory Accesses

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  - The same element in a data structure (matrix c) is being accessed twice from memory per cycle iteration
- Solution:
  - Use a temporary variable to store intermediate results

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- Solution:
  - General C++ case prefer references over pointers!
  - Give hints to the compiler (pragmas or restrict)

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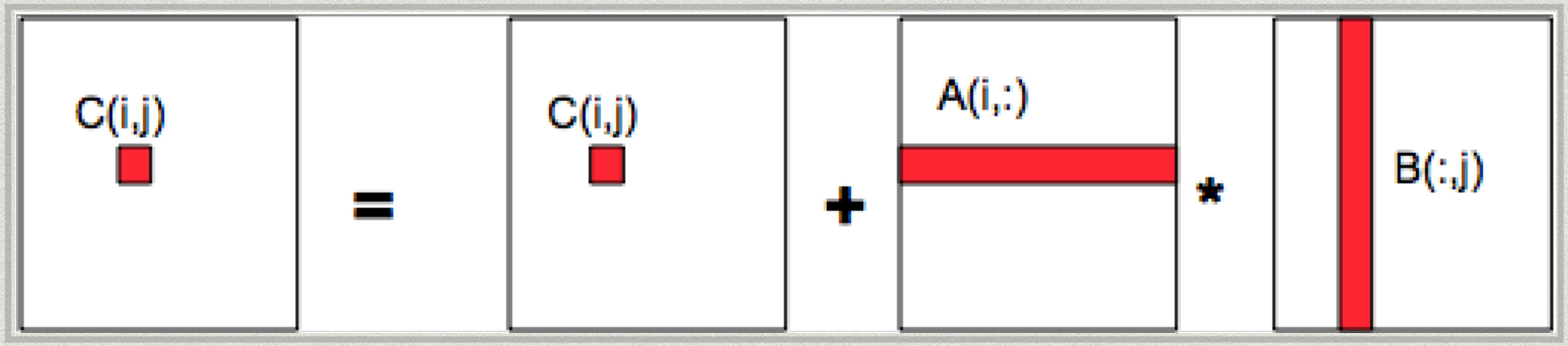
- Solution:
  - Guarantee the proper alignment of data structures manually

Blocking/Tiling



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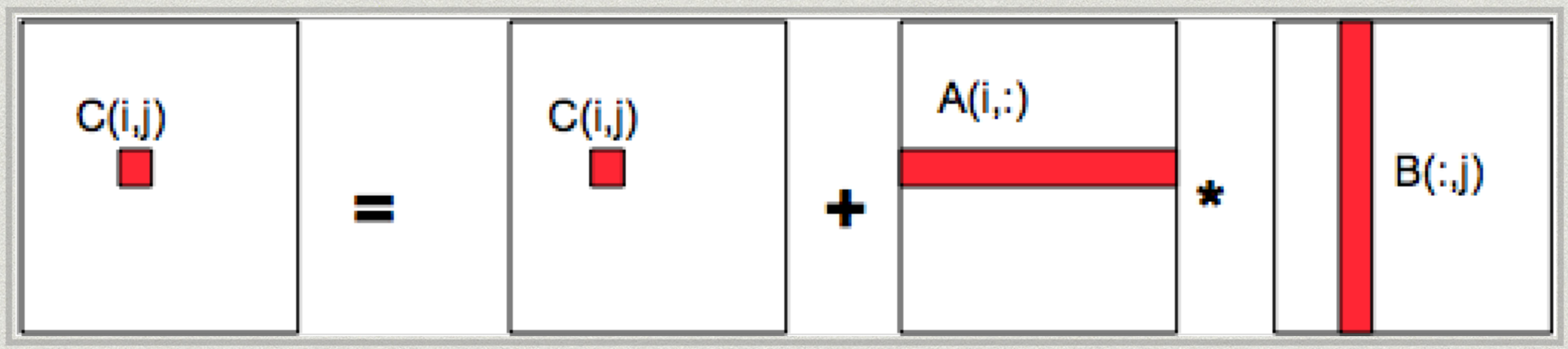
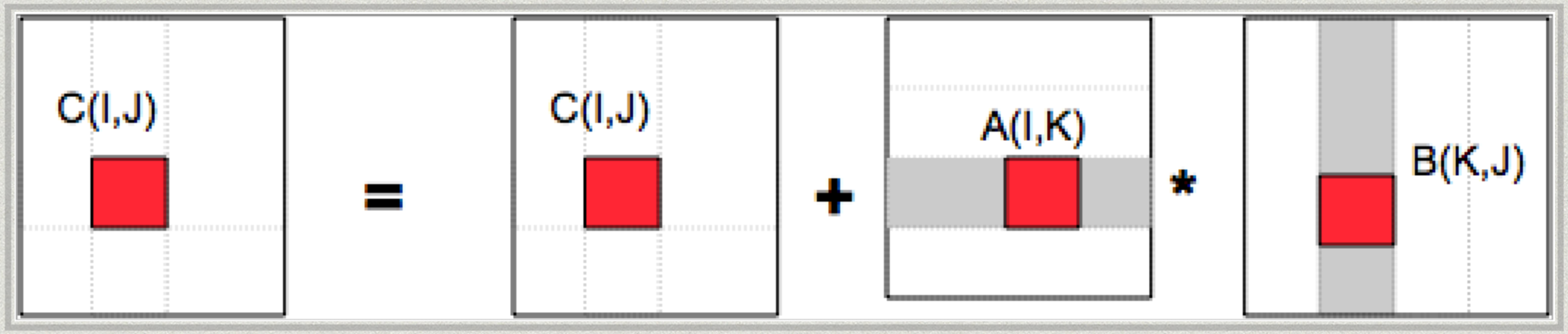
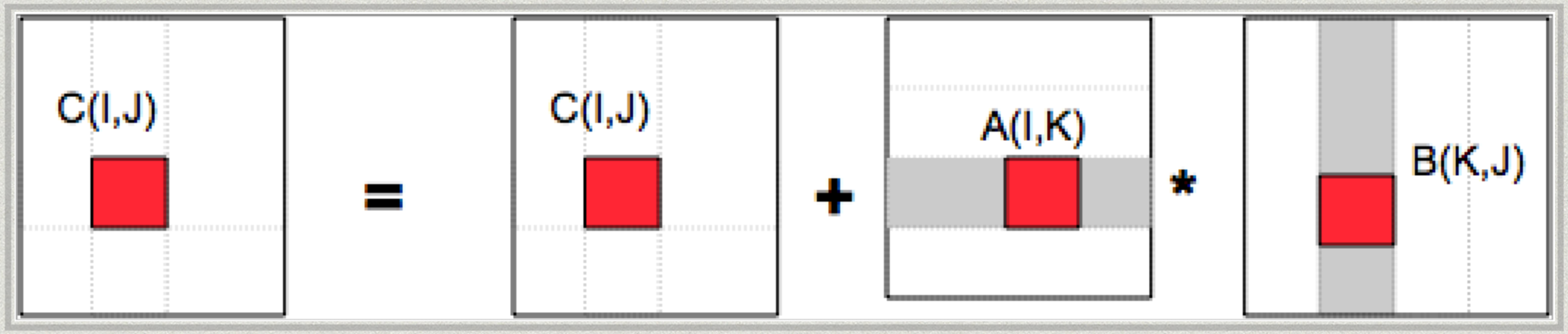




Blocking/Tiling

```
for I = 1 to N
	for J = 1 to N
	 {read block C(I,J) into fast memory}
	 for K = 1 to N
		{read block A(I,K) into fast memory}
		{read block B(K,J) into fast memory}
		 do a matrix multiply on blocks to compute block C(I,J)
	 {write block C(I,J) back to slow memory}
```



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- “Free lunch” speedups!

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- -O1
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  - Reduces both code size and execution time
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* -O2
  * Performs almost all supported optimisations
  * Generates faster code without compromising the space
* -O3
  * Almost all available optimisations without considering any trade-off

Vectorisation

- How is it achieved? By hand?

```
void matrixAdd (void) {
    __m256 ymm1, ymm2;

    for (unsigned i = 0; i < SIZE; ++i) {
        for (unsigned j = 0; j < VEC_SIZE; ++j) {
            ymm1 = _mm256_load_ps(&m1[i][j * 8]);
            ymm2 = _mm256_load_ps(&m2[i][j * 8]);

            ymm1 = _mm256_add_ps(ymm1, ymm2);
            _mm256_store_ps(&result[i][j * 8], ymm1);
        }
    }
}
```

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```
src/matrix.cpp(244): (col. 2) remark: loop was not vectorized: existence of vector dependence.
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        }
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Vectorisation

- Vectorisation report ICC: -qopt-report=X, where X
  - 1 - Loops successfully vectorised
  - 2 - Loops not vectorised (and the justification)
  - 3 - Adds dependency information
  - 4 - Non-vectorised loops report
  - 5 - Non-vectorised loops report with dependency information

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- Avoid nested loops
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- Data alignment and layout

Exercise 1

- Perform basic code optimisations
- Parallelise code execution for shared memory systems
- https://bitbucket.org/ampereira/matrix-optimization/downloads

Shared Memory Parallelism

- Several libraries to produce parallel code for shared memory environments
  - **OpenMP**
  - TBB
  - CILK
  - ...

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- Add the <omp.h> header to the code and use the pragmas

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- Options:
  - num_threads
  - schedule(X)
  - private(X)

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* Nested parallelism

PARALLELIZATION STRATEGIES

PCAM Methodology

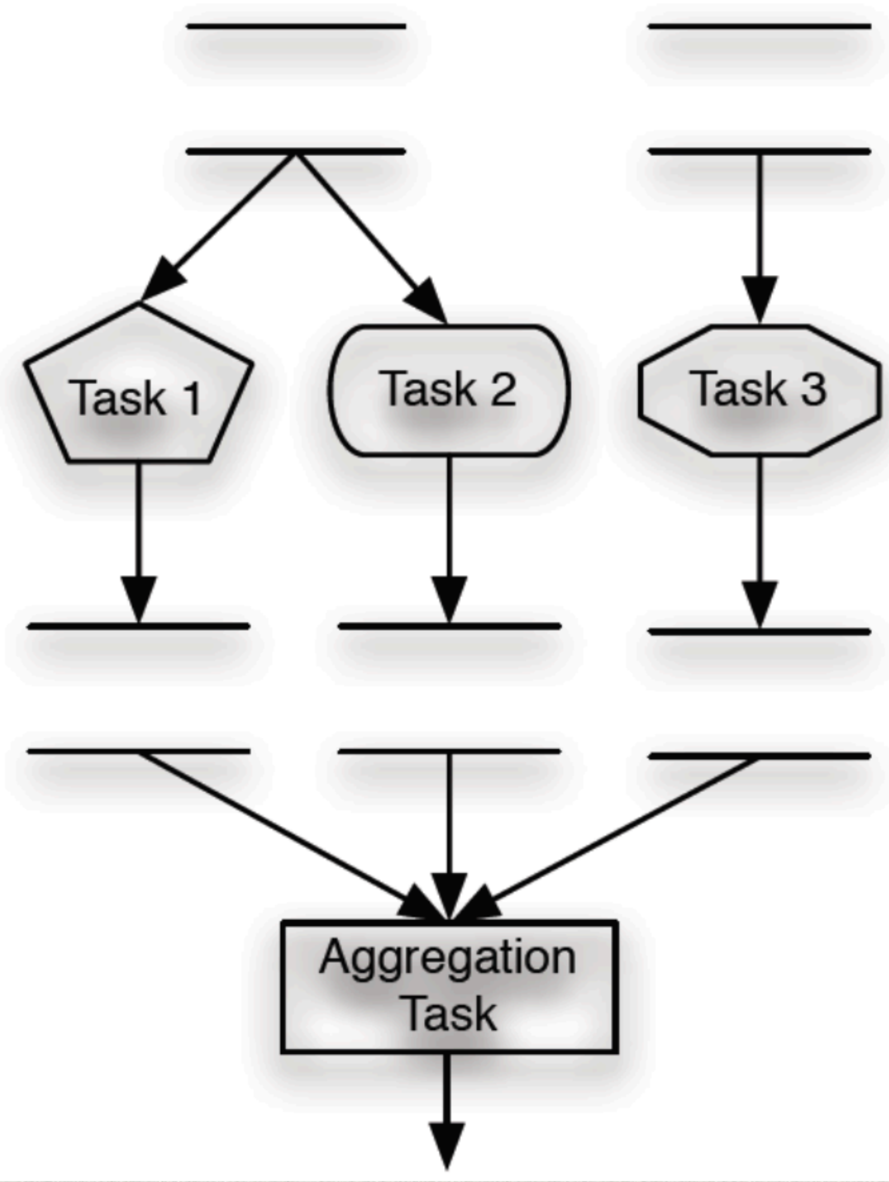
- **P**artitioning
  - Break computation into small pieces
- **C**ommunication
  - Identify communication among pieces
- **A**gglomeration
  - Group pieces to avoid communication
- **M**apping
  - Map the pieces to the computational devices

Decomposition Patterns

- Task parallelism
- Divide-and-conquer decomposition
- Geometric decomposition
- Recursive data decomposition
- Pipeline decomposition

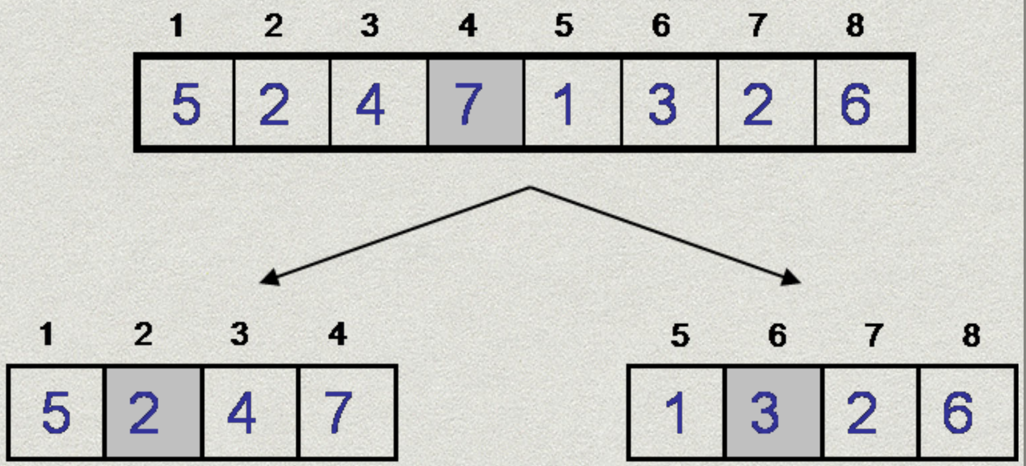
Task Parallelism

* Divide the workload into tasks
* Process independent tasks in parallel
* Map tasks to processes/threads
* Aggregate the results



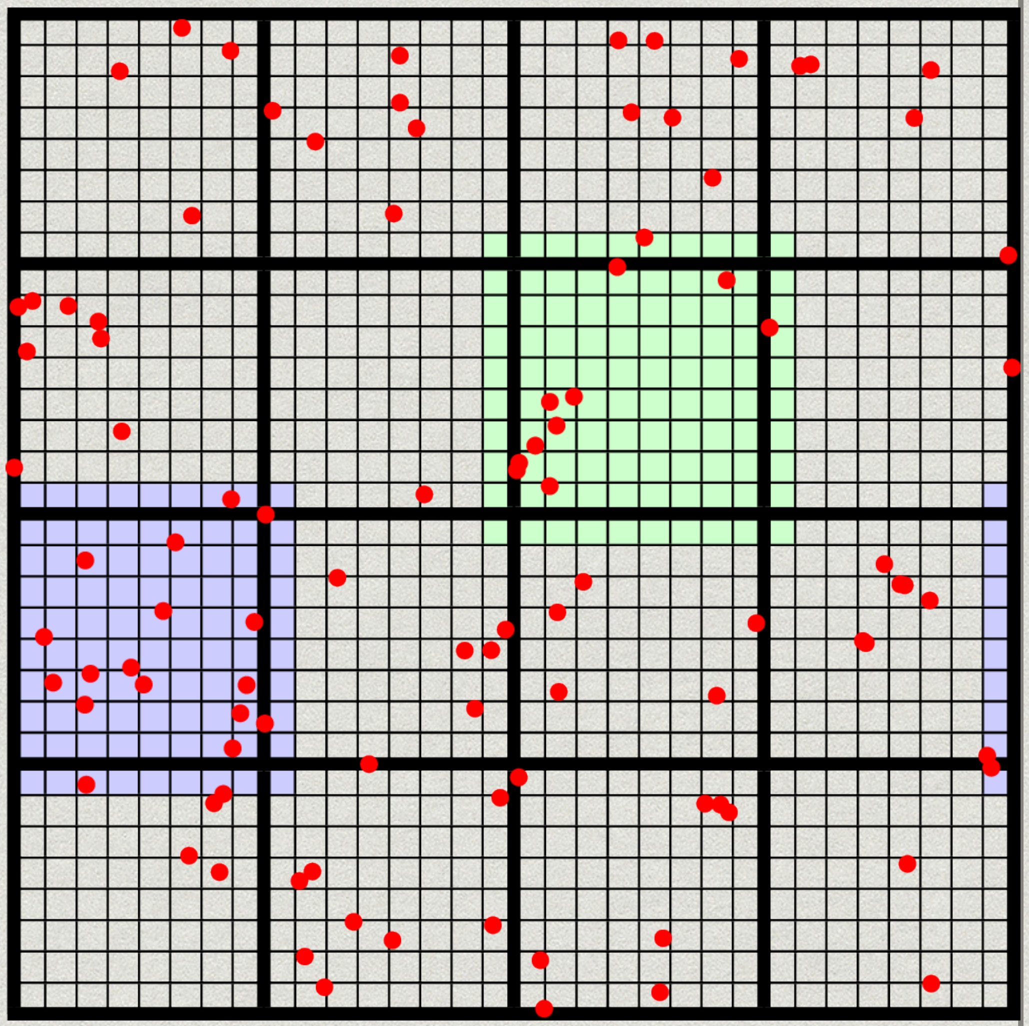
Divide-and-Conquer

- Divide the algorithm into tasks
- Tasks can be subdivided
- Map groups of tasks to processes/threads



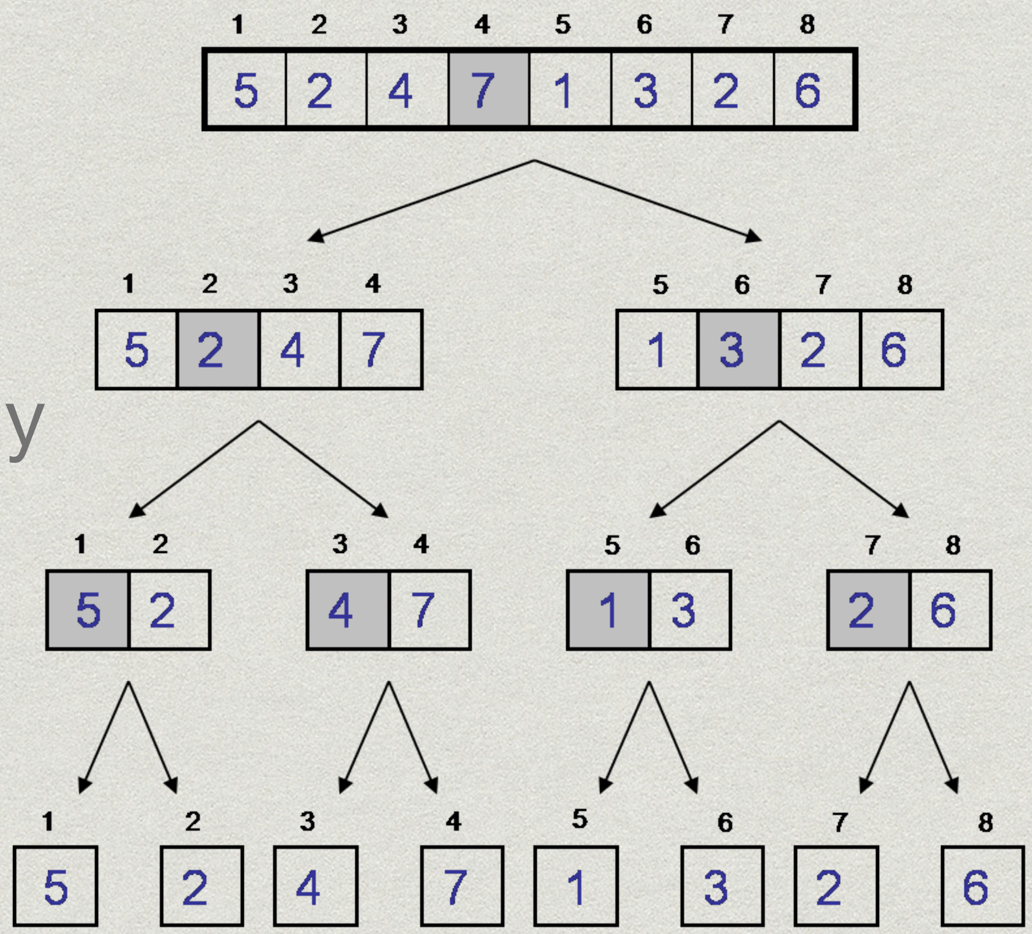
Geometric Decomposition

- Divide the geometric space
- Each sub-space is assigned to a process/thread
- Communication may be required in the boundary regions



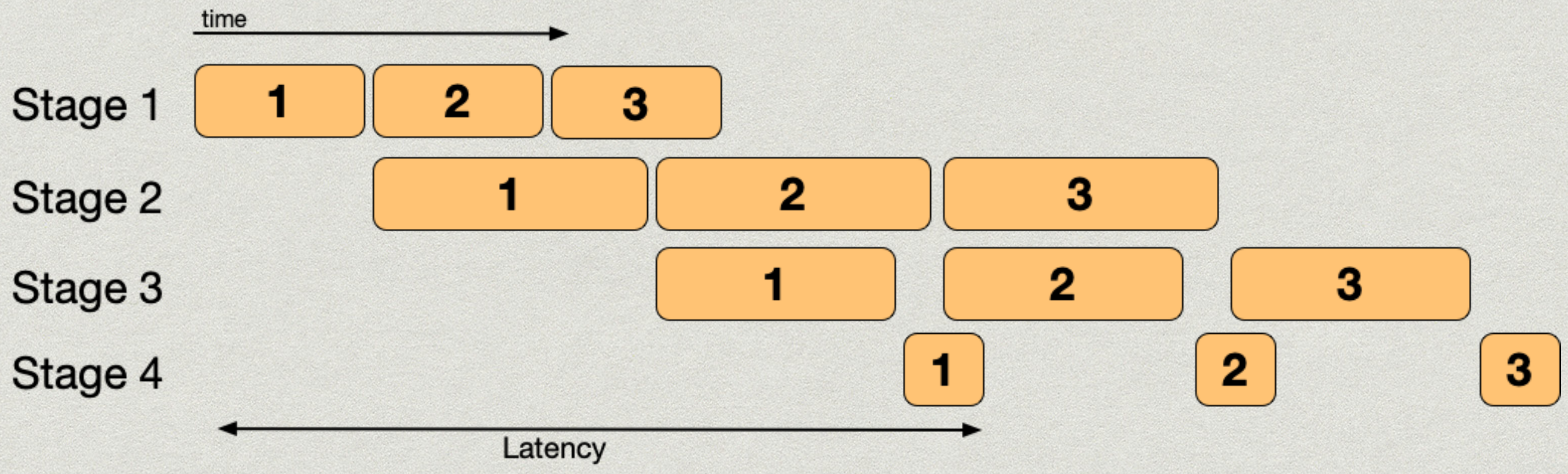
Recursive Decomposition

- Data structures that cannot be easily partitioned
  - Trees, lists, graphs, …
- Tasks **must** be subdivided recursively
- Process the tree of tasks from the bottom
- Map groups of tasks to processes/threads



Pipeline Decomposition

- Sets of subsequent tasks (pipeline stages) applied to independent data
- Data can be processed simultaneously by different pipeline stages
- Assumes that the same stage cannot process multiple items simultaneously

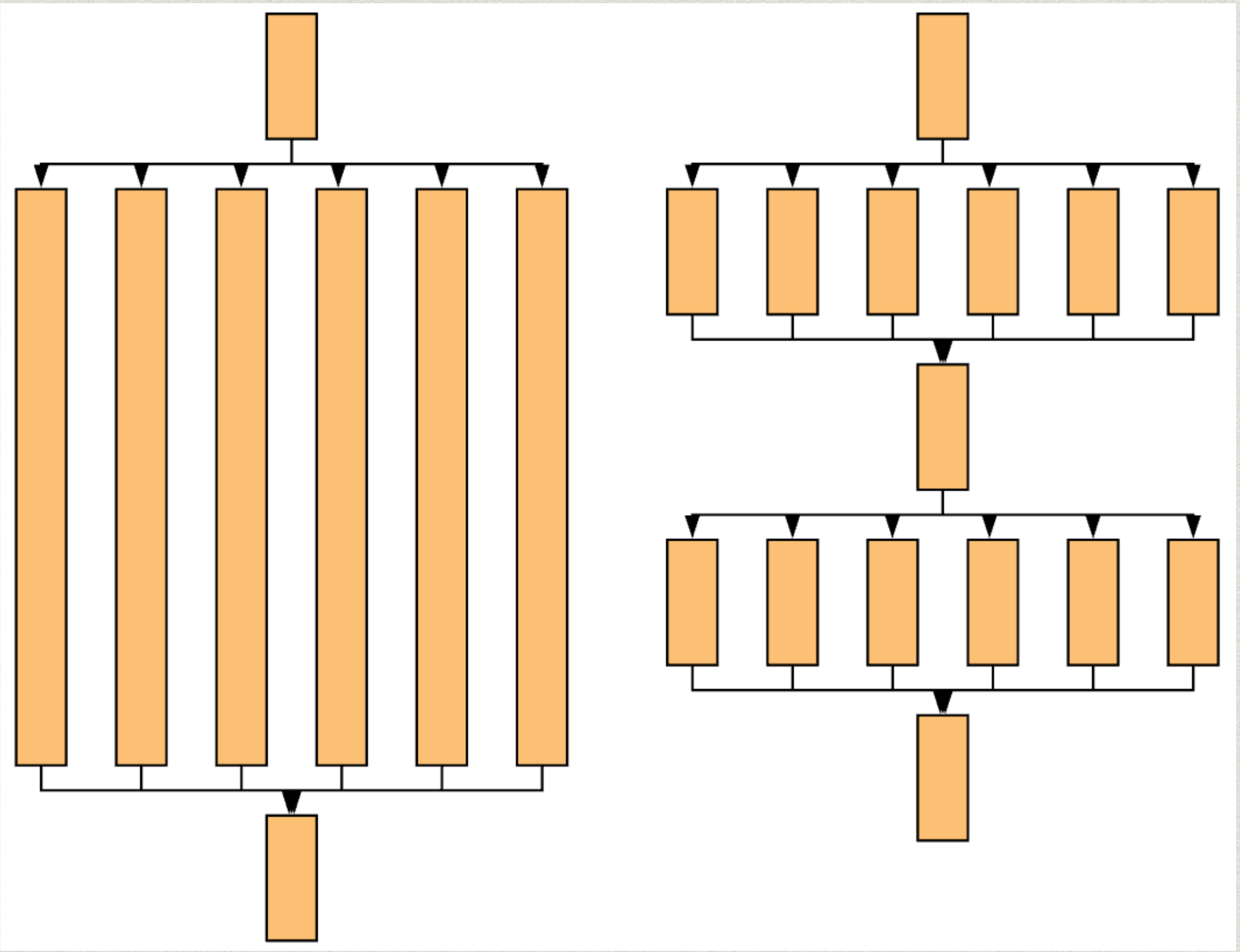


PARALLELIZATION IMPLEMENTATION

Program Structure

- **Globally parallel, locally sequential** - multiple tasks performed simultaneously, each task sequential
  - Single program, multiple data (SPMD)
  - Multiple program, multiple data (MPMD)
  - Master-worker
  - Map-reduce
- **Globally sequential, locally parallel** - sequential application with individual parallel sections
  - Fork-join
  - Loop parallelism

GPLS vs GSLP



GPLS

- SPMD
  - Single executable
  - All devices compute the same code on different data
- MPMD
  - Different executables for each device
  - Useful for heterogeneous nodes (x86 + ARM, PU + GPU)
- Master-worker
  - Separates management and processing roles
  - Single master handles work to multiple workers using a strategy
- Map-reduce
  - Maps independent data to different workers
  - Reduces (merges) the results of each worker

SPMD

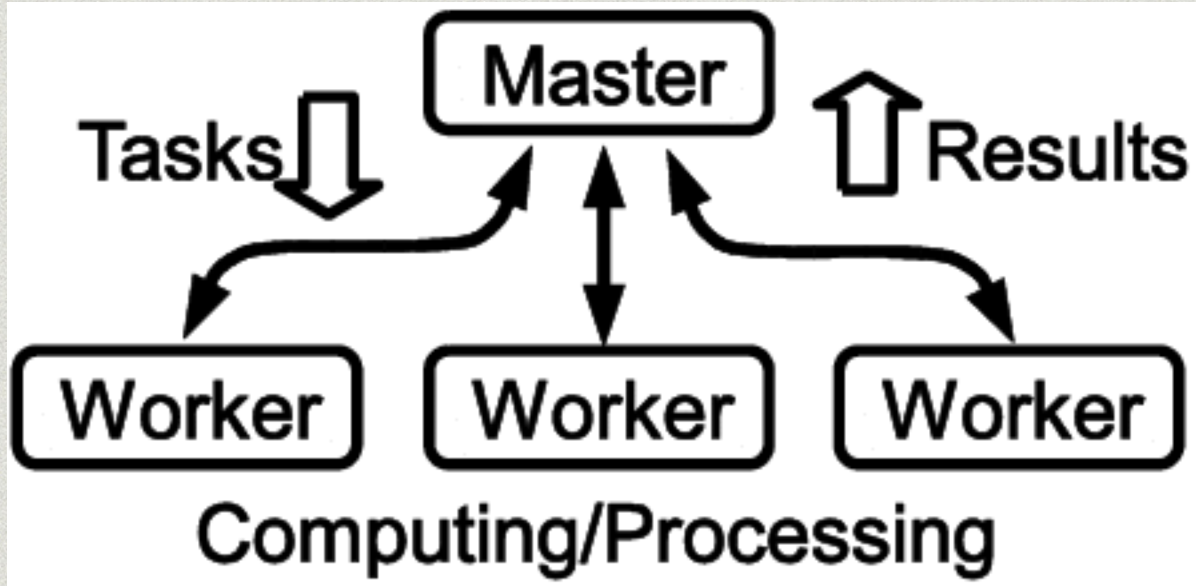
- Single code base is easier to maintain
- Typical structure
  - Initialisation - thread pool and management
  - Obtain unique thread identifier - scalar or vector id
  - Run the code according to each id - workload distribution
  - Shutdown - thread shutdown and result merge
- Prone to algorithm logic errors due to data races

MPMD

- Multiple code bases - harder to maintain
- May require multiple different programming paradigms
- Different device architectures adds another layer of irregularity
- Should only be adopted due to apps RAM memory requirements or to use accelerators
- Can be used in conjunction with SPMD strategies

Master-Worker

- Clear definition of tasks for masters and workers
- Masters
  - Hand out work to workers - how to distribute it?
  - Collect results from workers
  - Interacts with files and with the users



Map-Reduce

- A derivative of master-worker
  - Popularised by the initial releases of the Google search engine
- Multiple workers spawned to run the same code
  - Can share intermediate results among them
  - Results are merged by the master at the end
- Master-worker usually implies a set of different tasks and/or different executables
  - Map-reduce uses a single code base in a single executable

GSLP

- Fork-join
  - Creation of dynamic tasks (processes/threads) that must complete for the parent to continue
  - Multiple instances of this behaviour per application
- Loop parallelism
  - Subset of fork-join
  - Creates multiple processes/threads with the same code to process different blocks of independent data

Fork-Join

- Used when the algorithm requires dynamic creation of tasks at runtime
  - Parent task must wait for children tasks to finish to continue
  - Tasks can be processed by pools of pre-generated processes/threads
- Can lead to excessive amounts of idle times if not implemented properly

Loop Parallelism

- The most simple and convenient method for most problems
  - Loop iterations are divided into chunks
  - Chunks are assigned to computing threads
  - Static and dynamic strategies to assign chunks are often available in libraries - which should be used?
- Is not efficient in distributed environments

Match Decomposition to Implementation

	Task Parallelism	Divide-Conquer	Geometric	Recursive	Pipeline
SPMD	✓	✓	✓	✓	✓
MPMD	✓	✓	✓	✓	✓
Master-Worker	✓	✓	✓	✓	
Map-Reduce		✓	✓	✓	
Fork-Join	✓	✓	✓	✓	✓
Parallel Loop		✓	✓		

LOAD BALANCING

References

- An Overview of Programming for Intel® Xeon® processors and Intel® Xeon Phi™ coprocessors, James Reinders, Intel
- Intel® Xeon Phi™ Coprocessor High Performance Programming, Jim Jeffers, James Reinders, Elsevier Waltham (Mass.), 2013
- Intel® 64 and IA-32 Architectures Software Developer's Manual