Tasks approach, StarPU

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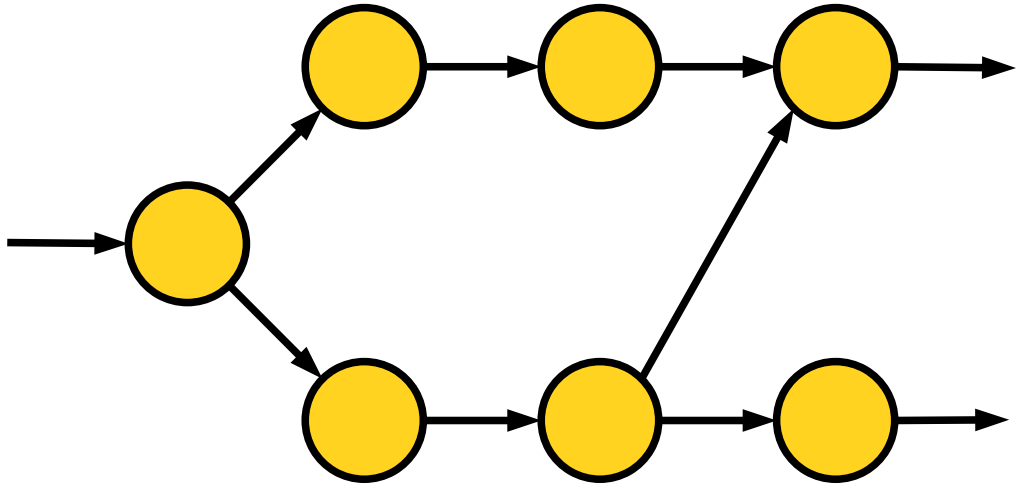
Task graphs

- Well-studied for scheduling parallelism (since 60's!)
- But only recent trend in HPC
- Departs from usual sequential programming

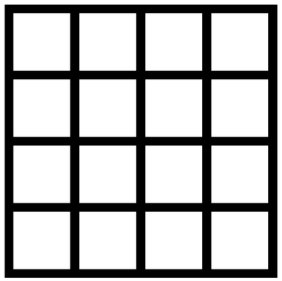
Really ?



Expressing a task graph

Implicit task dependencies

- Right-Looking Cholesky decomposition (from PLASMA)



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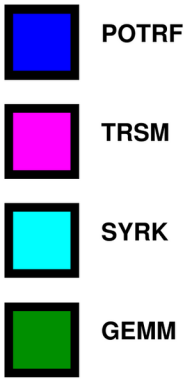

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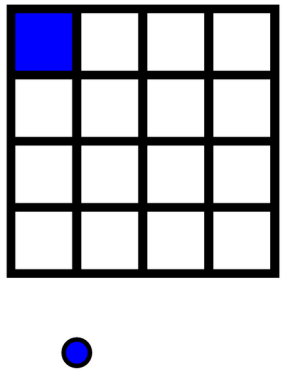

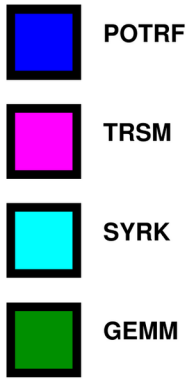

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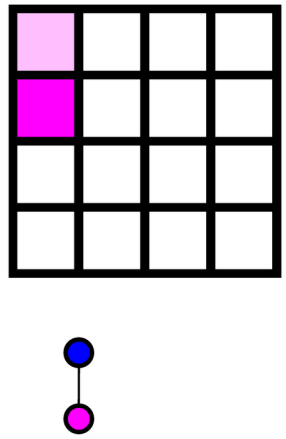

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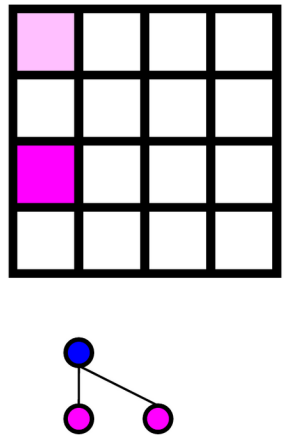

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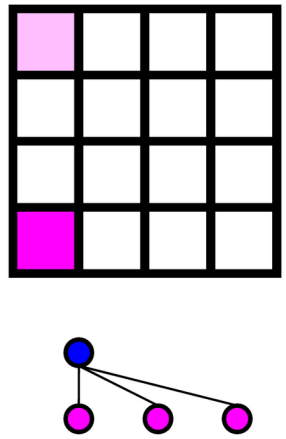

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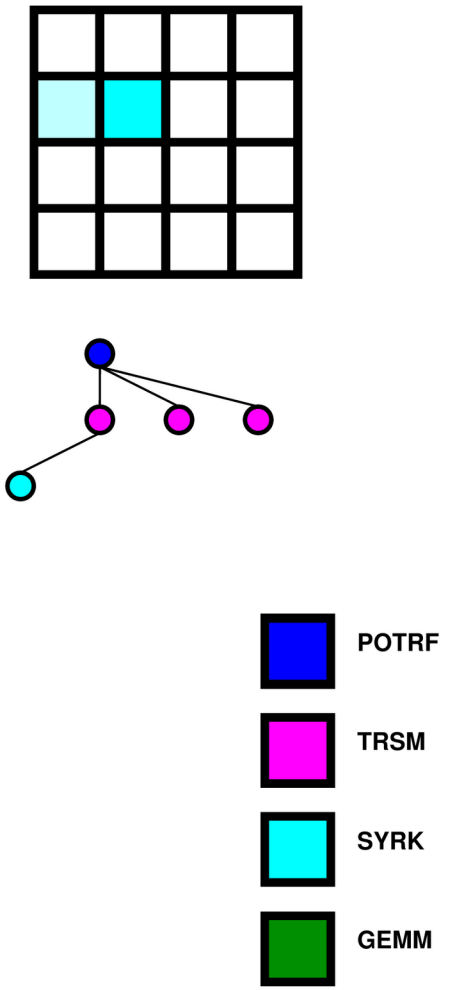

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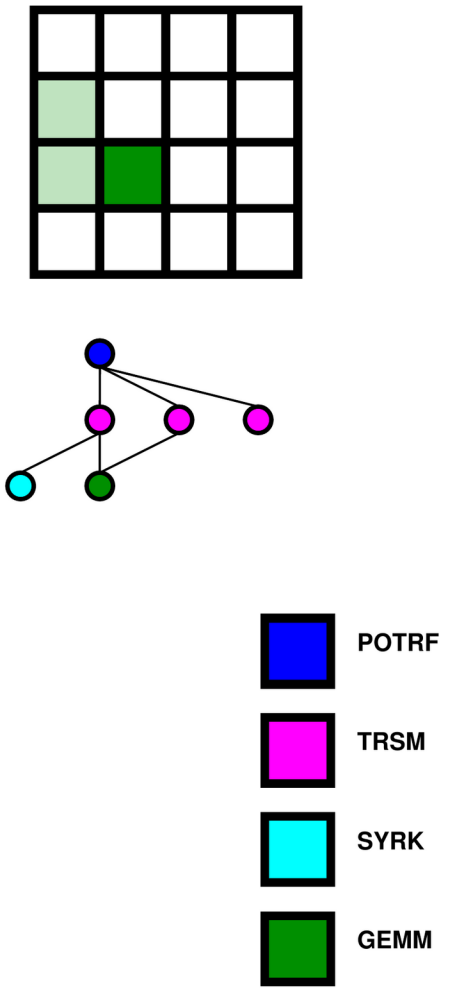

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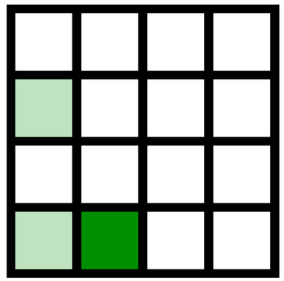

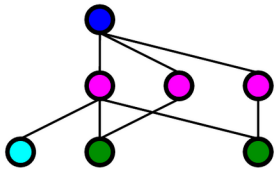

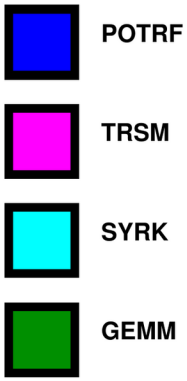

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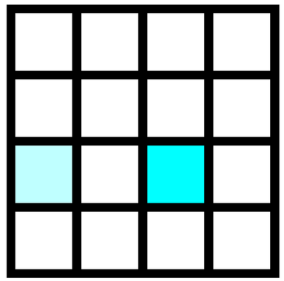

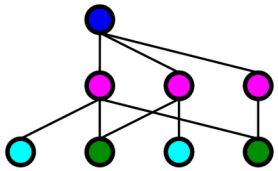

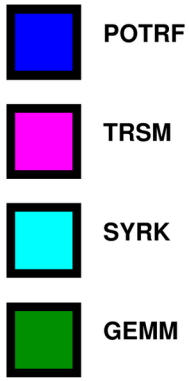

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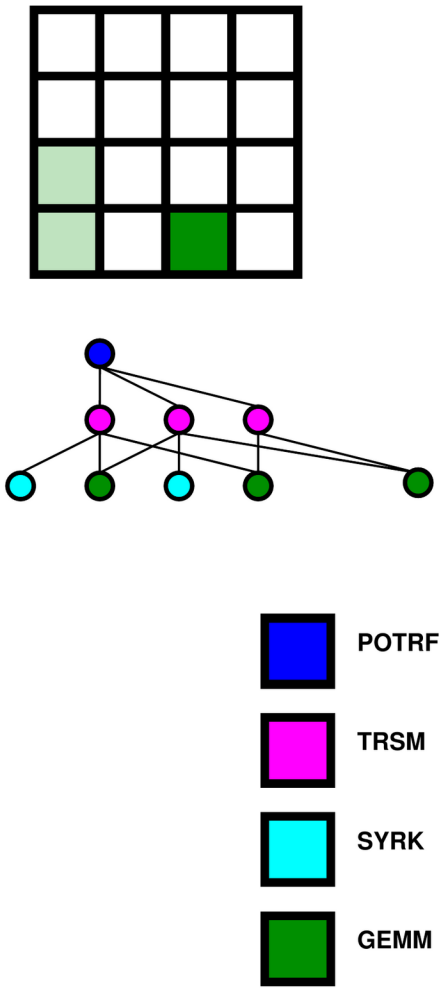

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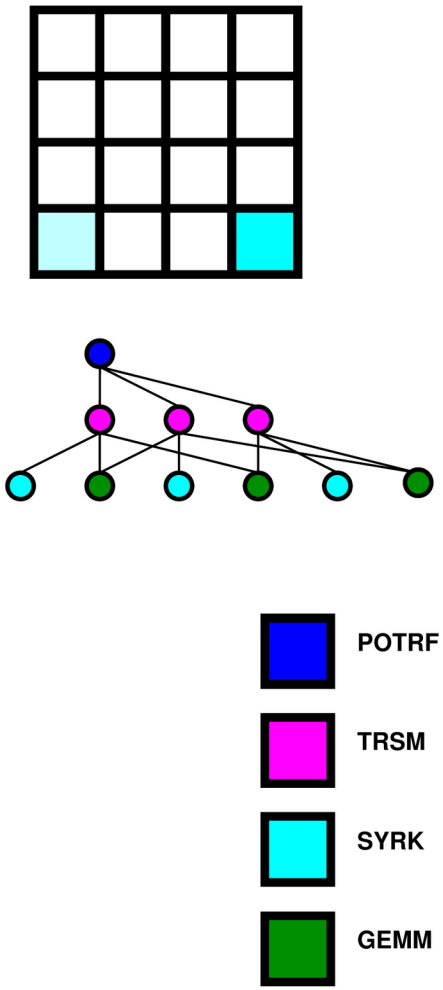

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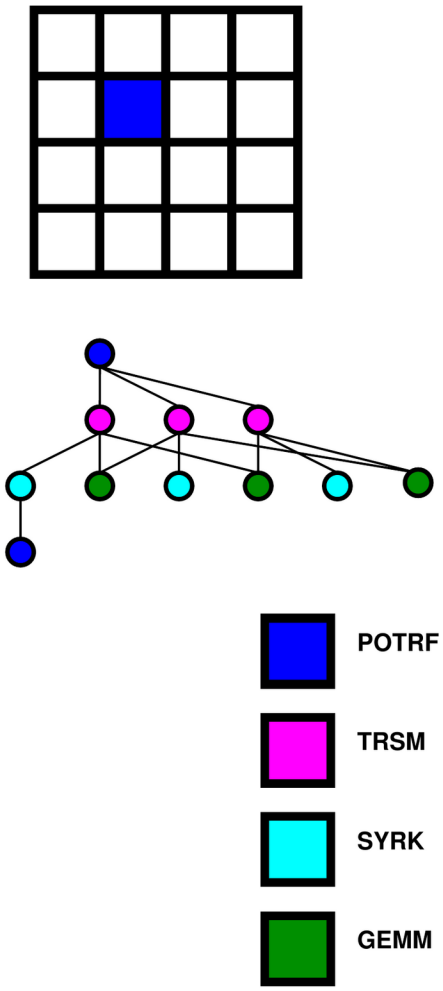

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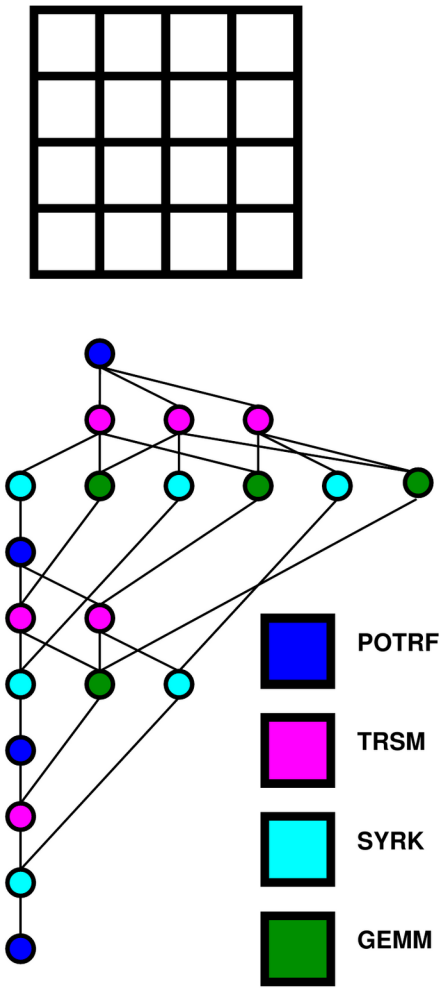


Write your application as a task graph

Even if using a sequential-looking source code

➔ Portable performance

Sequential Task Flow (STF)

- Algorithm remains the same on the long term
- Can debug the sequential version.
- Only kernels need to be rewritten
  - BLAS libraries, multi-target compilers
- Runtime will handle parallel execution

Task-based programming

- Needs code restructuring
  - Split computation into tasks
    - BLAS, typically
    - Supposed to have “stable” performance
- Constraining
  - No global variables
    - Mandatory for GPUs
- Actually… functional programming

So a good move, in the end ☺

- Have to accept constraints and losing control

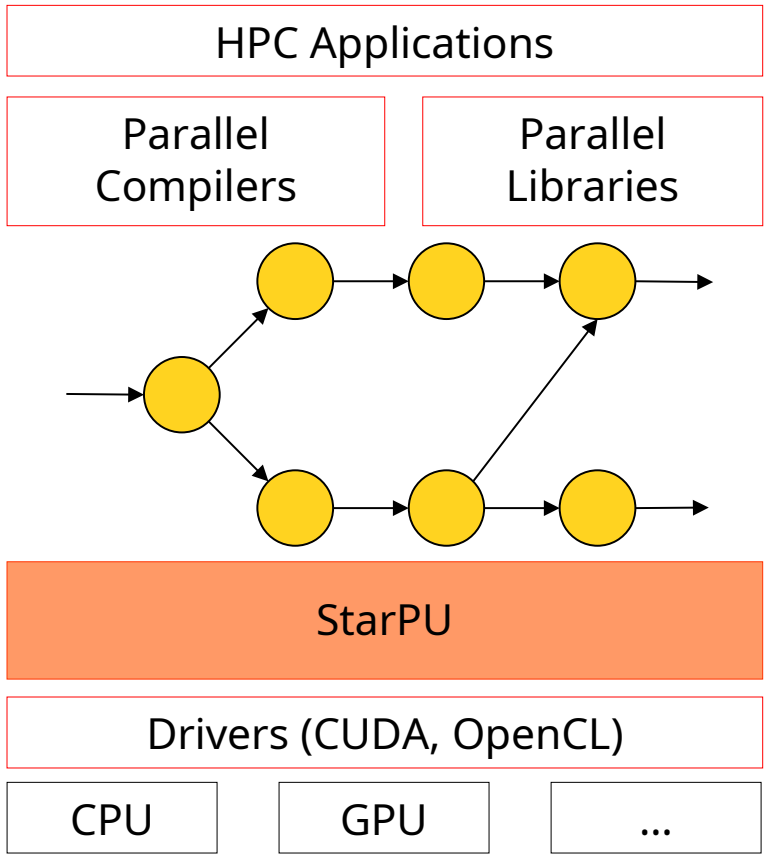
Just like we did when moving from assembly to high-level languages

Overview of StarPU

The StarPU runtime system

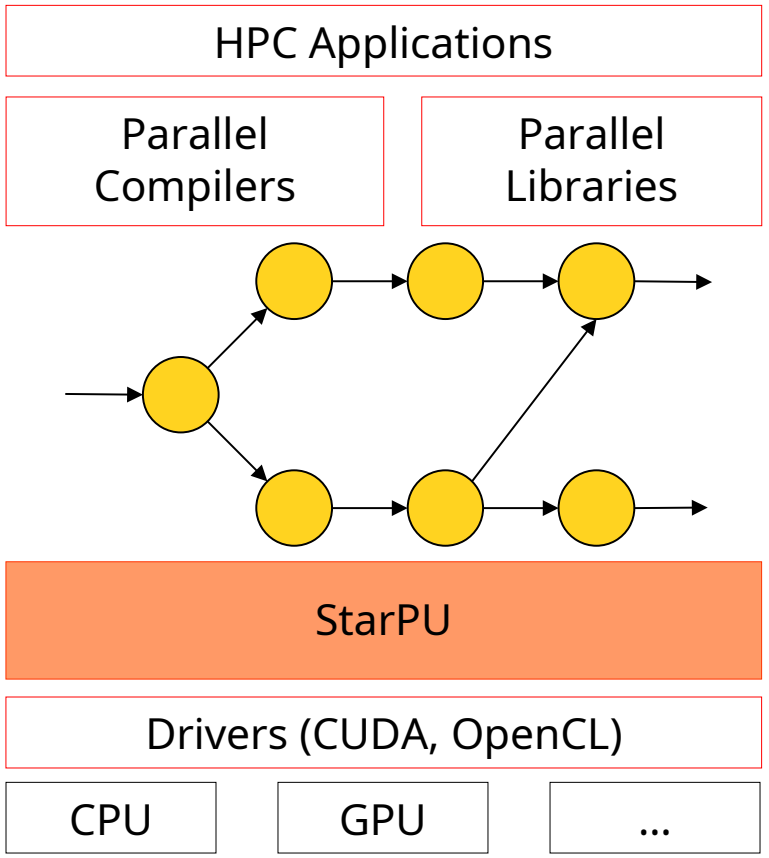
The need for runtime systems

- "do dynamically what can't be done statically anymore"
- Compilers and libraries generate (graphs of) tasks
  - Additional information is welcome!
- StarPU provides
  - Task scheduling
  - Memory management



Data management

- StarPU provides a Virtual Shared Memory (VSM) subsystem (aka DSM)
  - Replication
  - Consistency
  - Single writer
    - Or reduction, ...
- Input & ouput of tasks = reference to VSM data

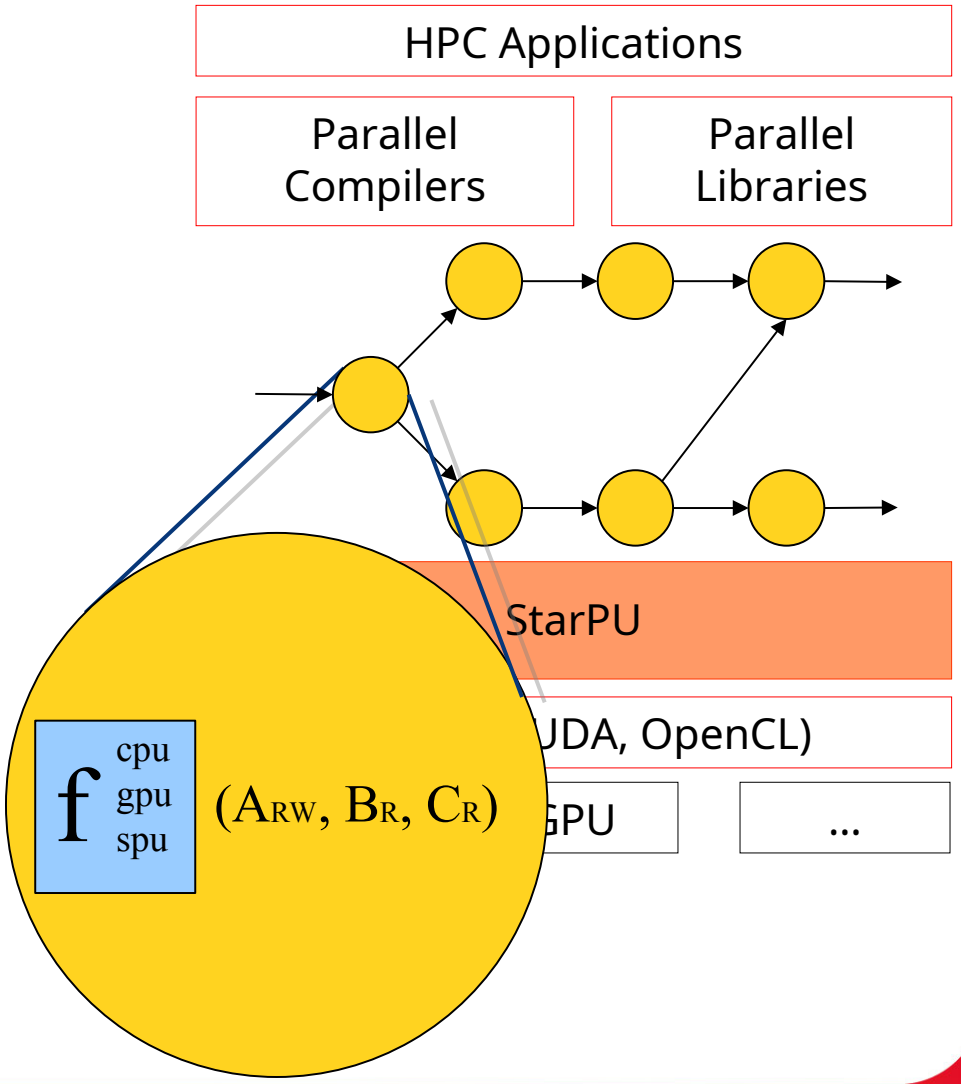


The StarPU runtime system

Task scheduling

- Tasks =
  - Data input & output
    - Reference to VSM data
  - Multiple implementations
    - E.g. CUDA + CPU implementation
  - Non-preemptible
  - Dependencies with other tasks

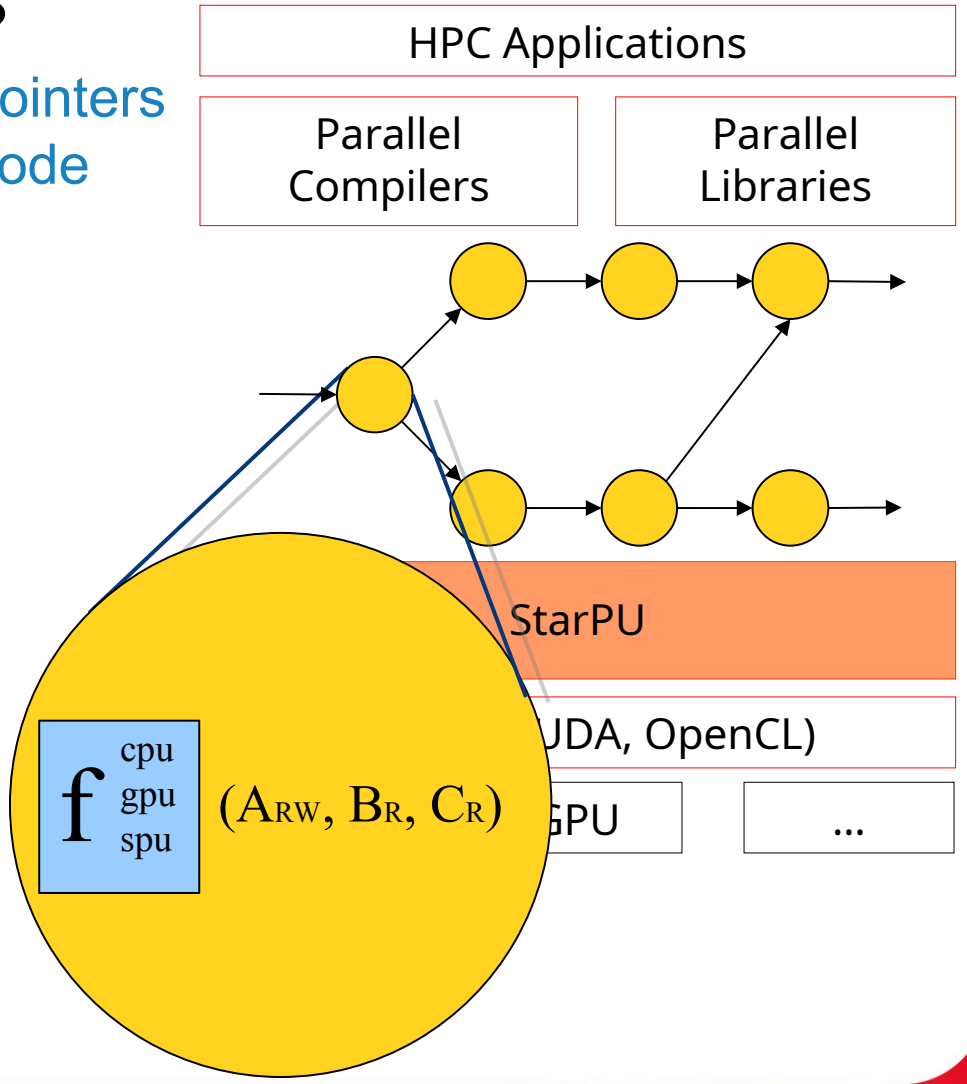
- StarPU provides an Open Scheduling platform
  - Scheduling algorithm = plug-ins



The StarPU runtime system

Task scheduling

- Who generates the code ?
  - StarPU Task ~= function pointers
  - StarPU doesn't generate code
- Libraries era
  - PLASMA + MAGMA
  - FFTW + CUFFT…
  - Variants management
- Rely on compilers



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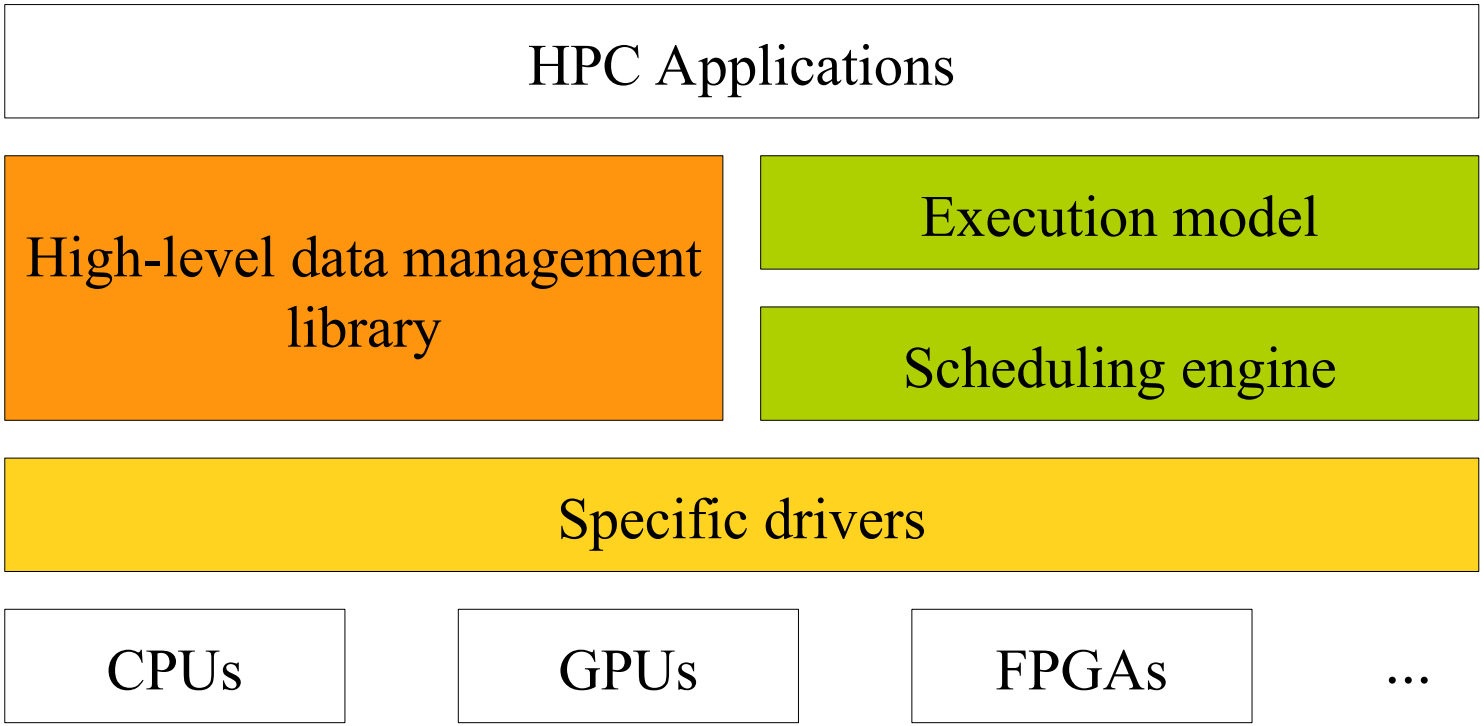
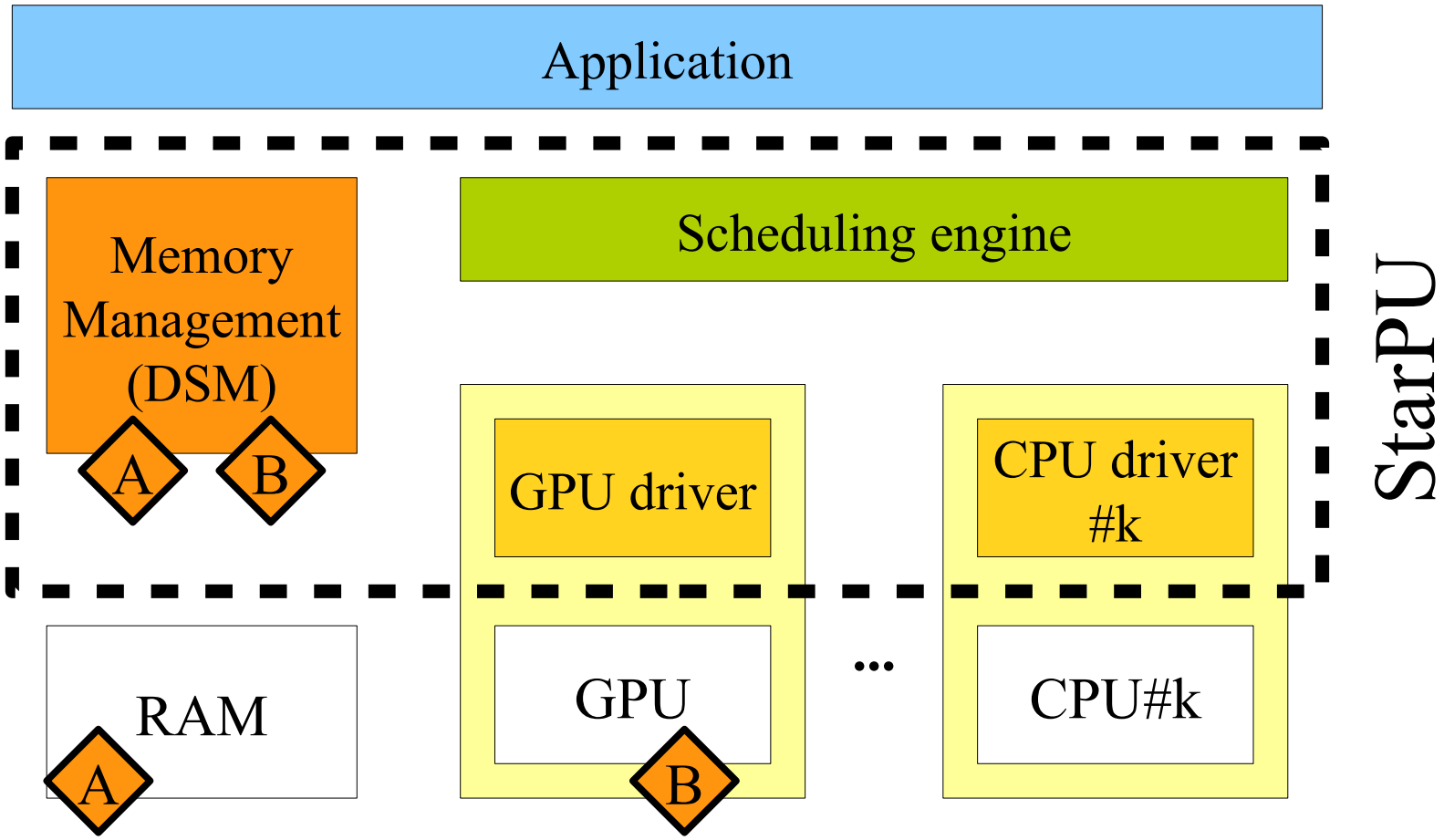


Mastering CPUs, GPUs, FPGAs … ***PUs → StarPU**

The StarPU runtime system

Execution model



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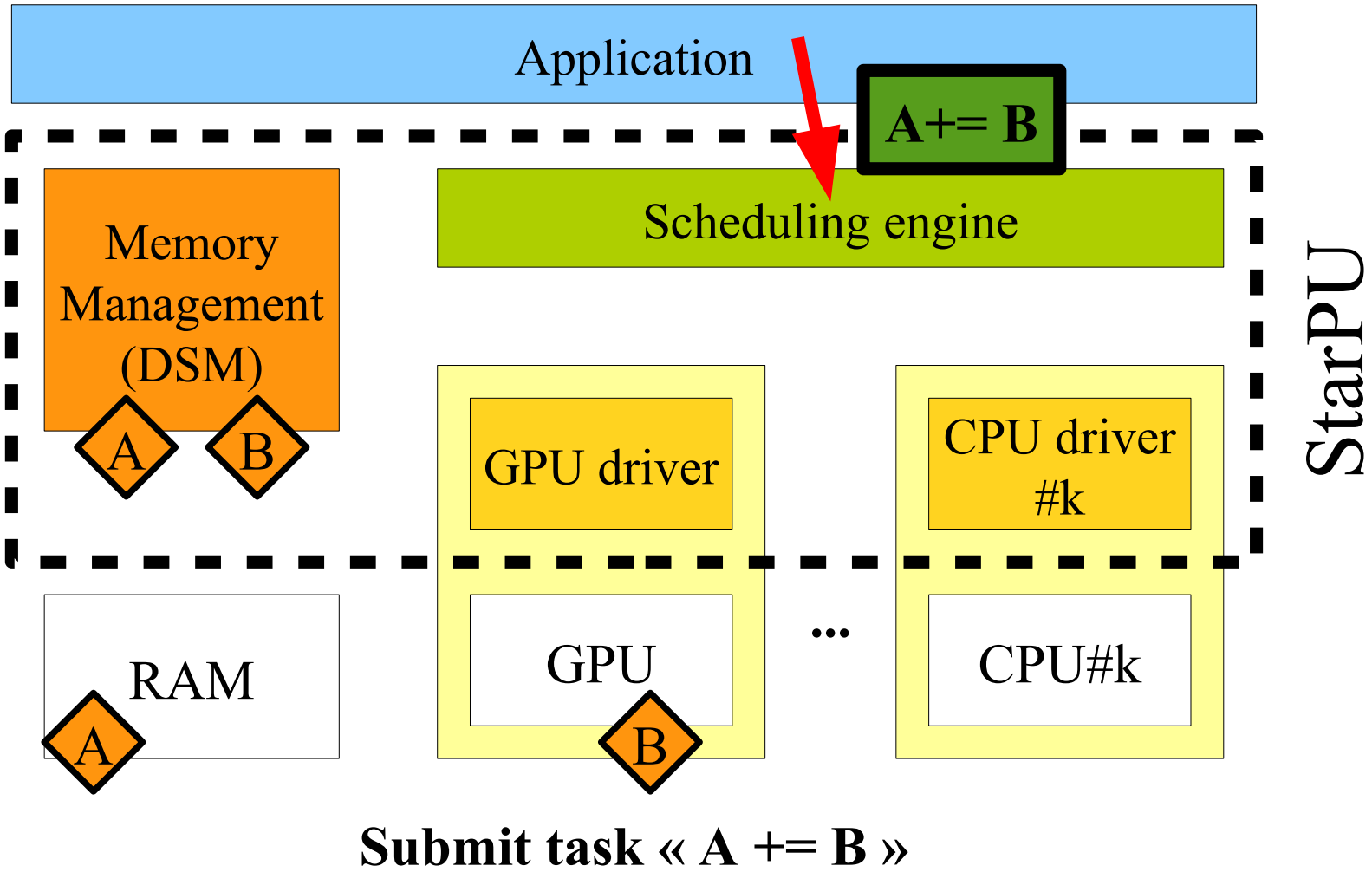

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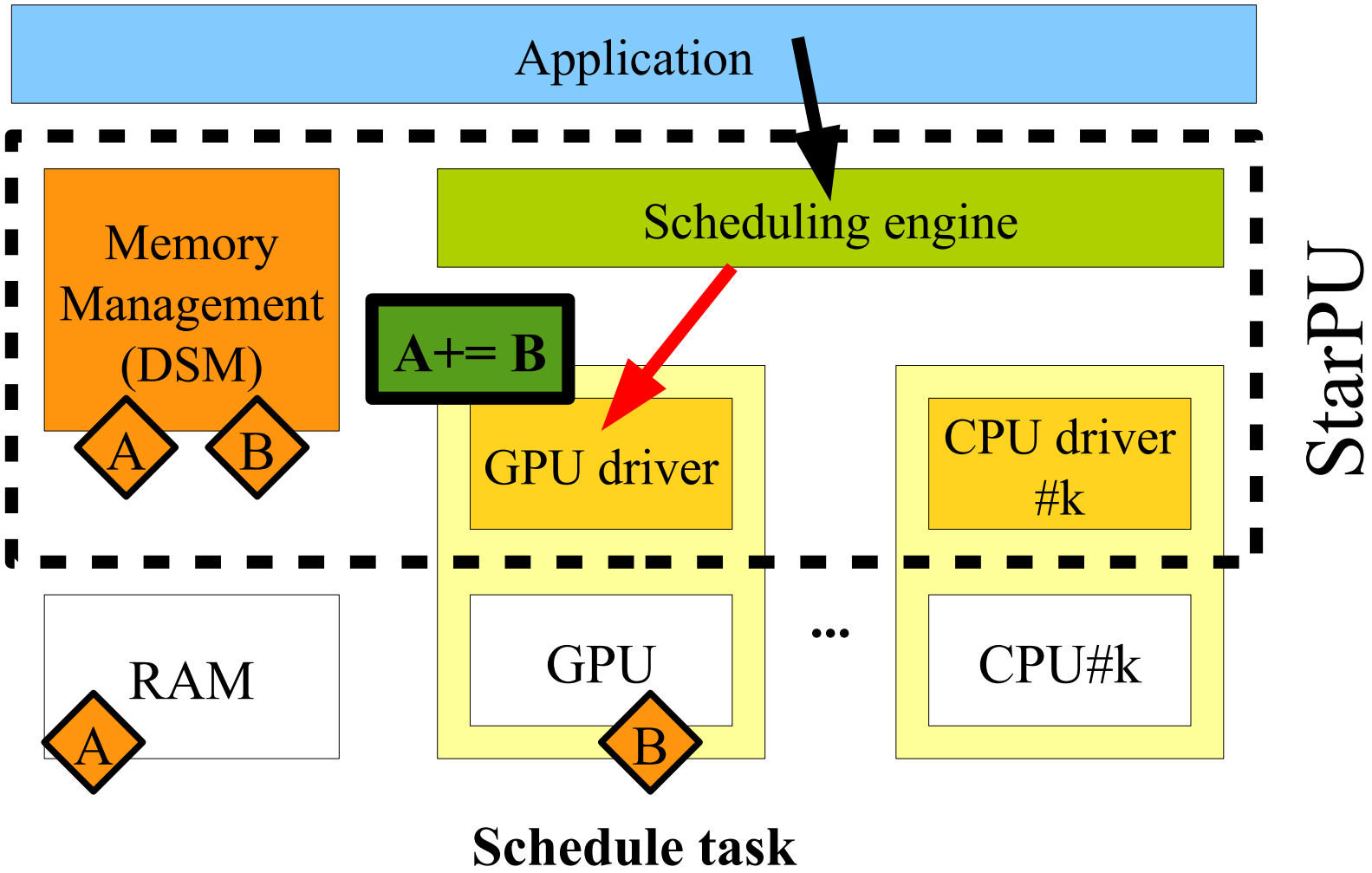

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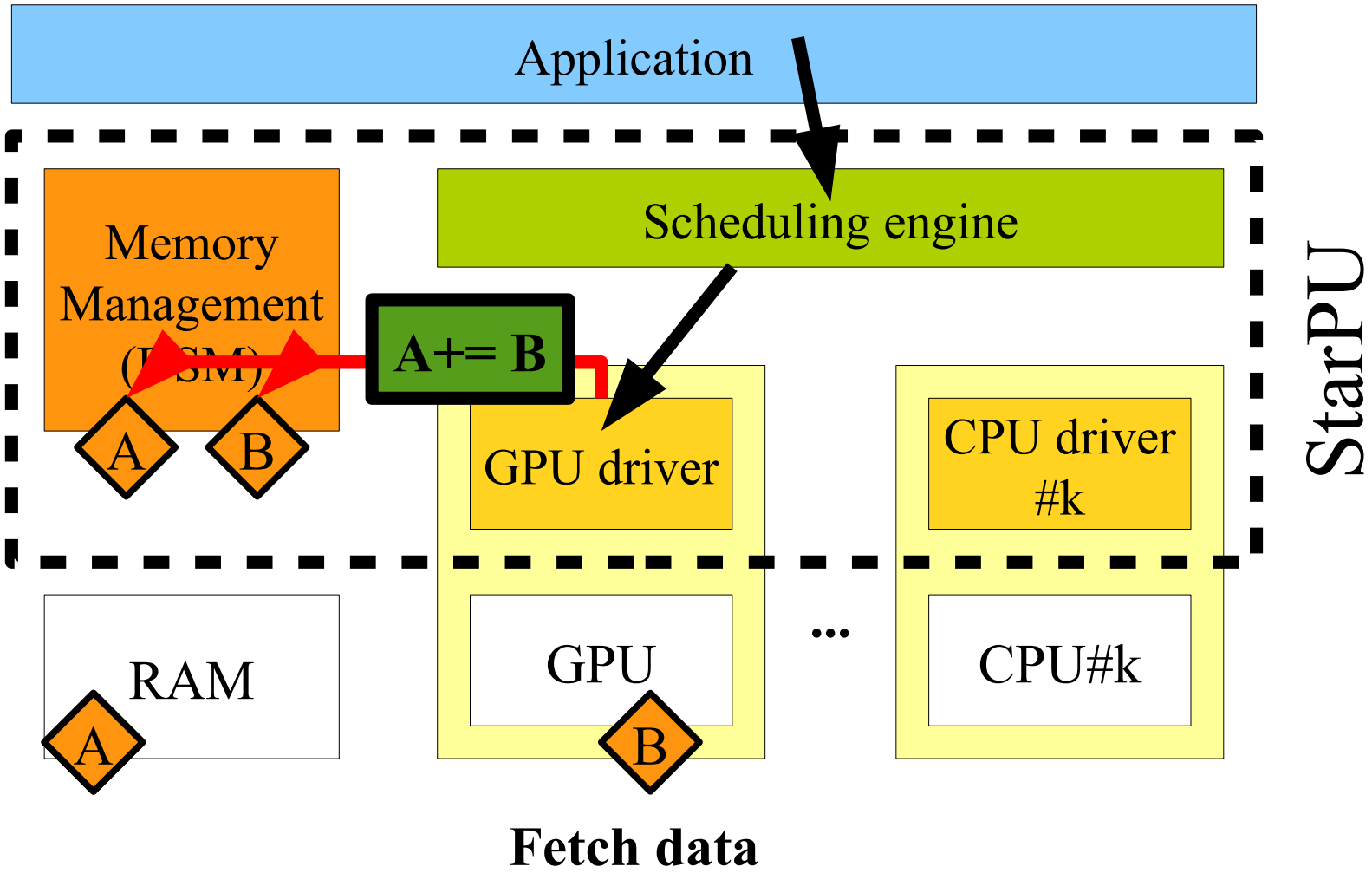

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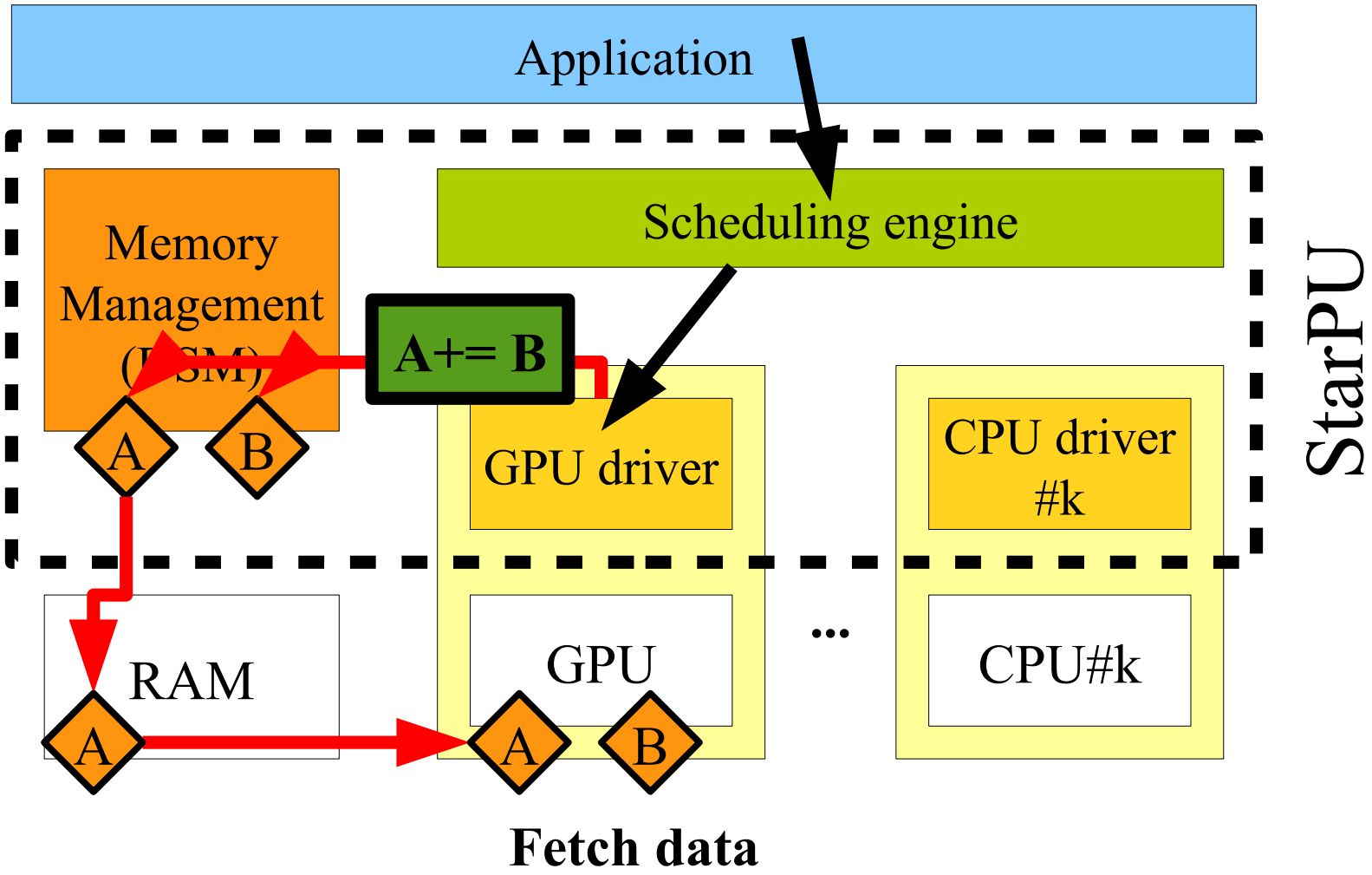

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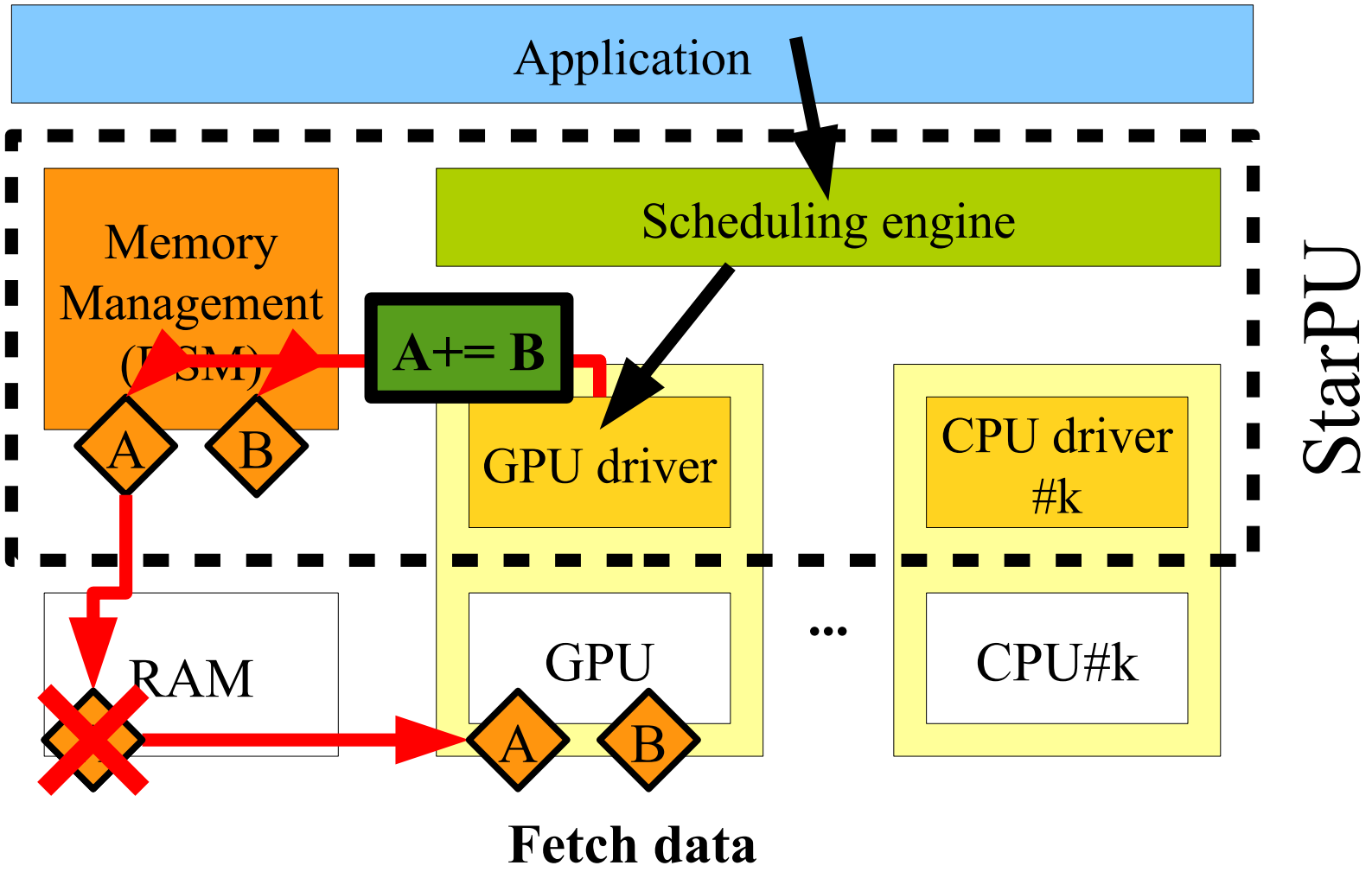

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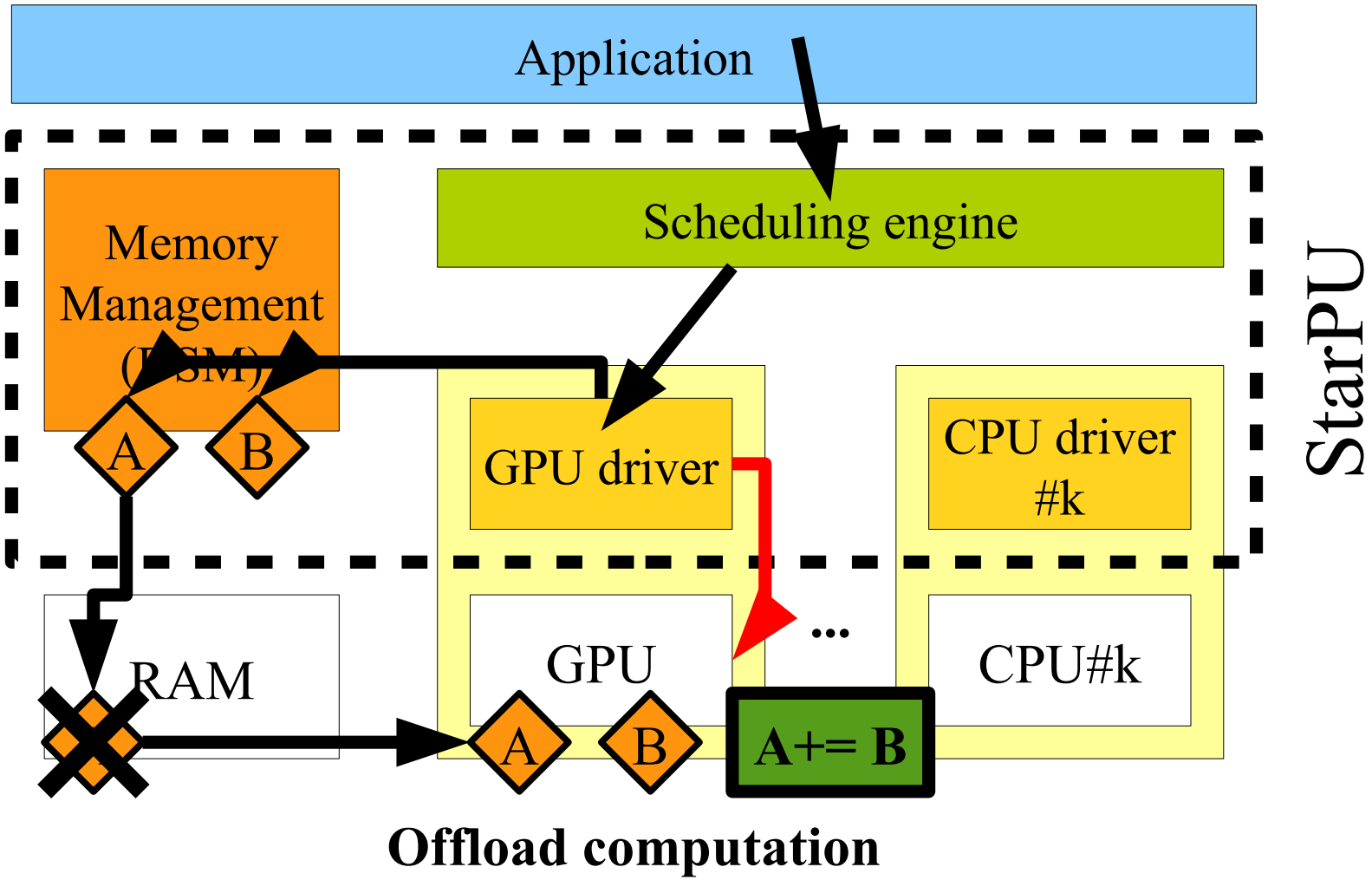

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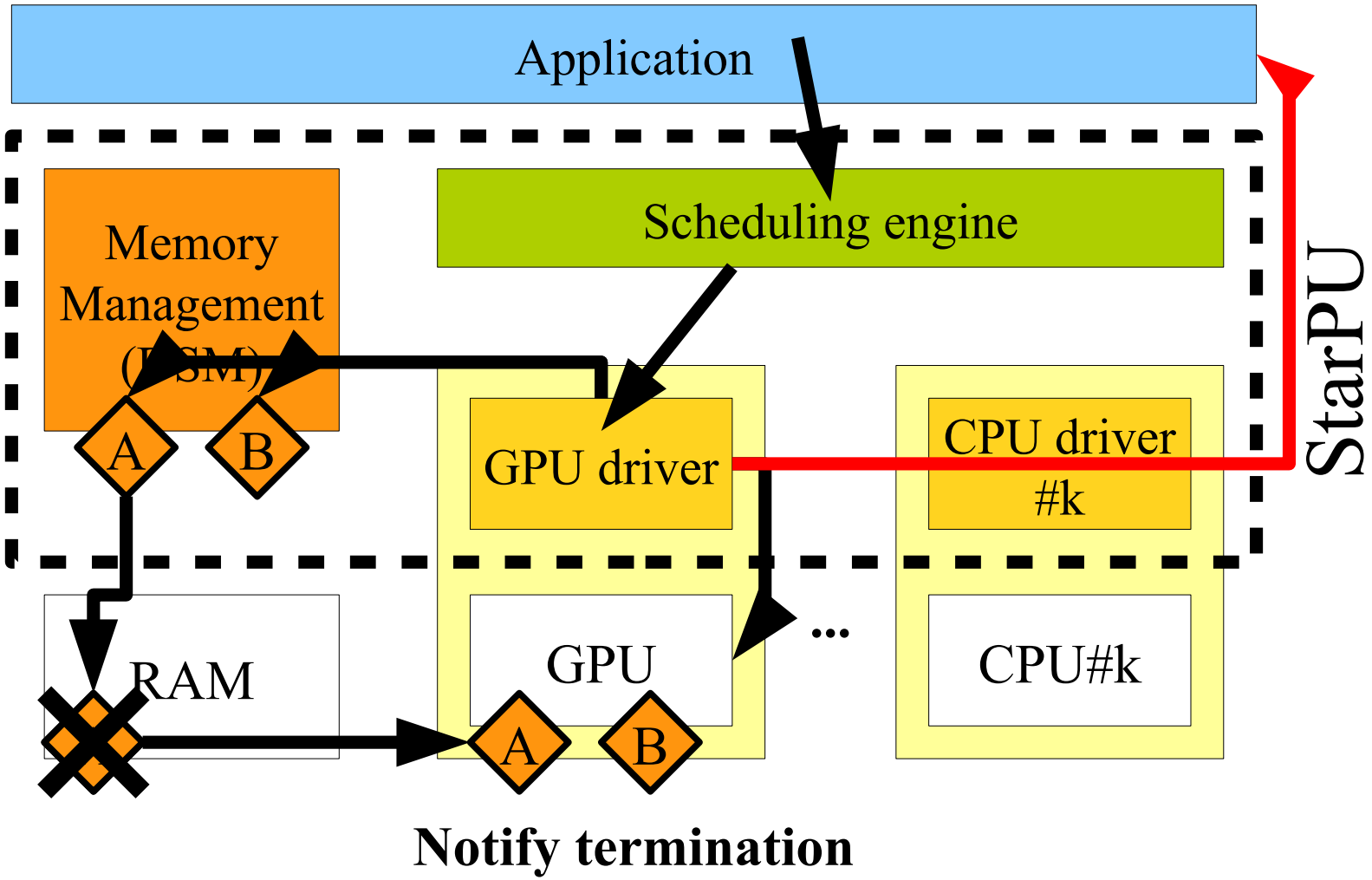


The StarPU runtime system

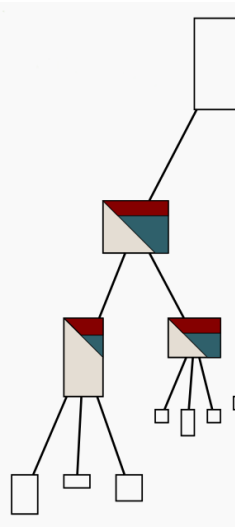
Development context

- History
  - Started in 2008
    - PhD Thesis of Cédric Augonnet
  - StarPU main core ≈ 70k lines of code
  - Written in C
- Open Source
  - Released under LGPL
  - Sources freely available
    - git repository and nightly tarballs
    - See https://starpu.gitlabpages.inria.fr/
  - Open to external contributors
- [HPPC'08]
- [Europar'09] – [CCPE'11],... >1900 citations

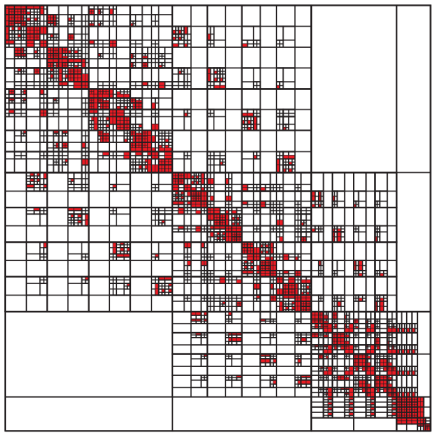
The StarPU runtime system

Success stories

Task-based programming actually makes things easier!



- QR-Mumps (sparse linear algebra)
  - Non-task version: only 1D decomposition
  - Task version: 2D decomposition, flurry of parallelism
    - With seamless memory control
- H-Matrices (compressed linear algebra, AirBus)
  - Out-of-core support
    - Could run cases unachievable before
    - e.g. 1600 GB matrix with 256 GB memory
  - Shipped to AirBus customers
- Implemented CFD, FMM, CG, stencils, …



The StarPU runtime system

Supported platforms

- Supported architectures
  - Multicore CPUs (x86, PPC, ...)
  - NVIDIA GPUs
  - OpenCL devices (eg. AMD cards)
  - HIP
  - FPGA (ongoing)
  - Old Intel Xeon Phi (MIC), SCC, Kalray MPPA, Cell (decommissioned)
- Supported Operating Systems
  - Linux
  - Mac OS
  - Windows

Scaling a vector

Data registration

- Register a piece of data to StarPU (vector, matrix, ...)

```
float array[NX];
for (unsigned i = 0; i < NX; i++)
    array[i] = 1.0f;

starpu_data_handle vector_handle;
starpu_vector_data_register(&vector_handle, 0,
        array, NX, sizeof(vector[0]));
```

- Submit tasks….
- Unregister data
  - starpu_data_unregister(**vector_handle**);

Scaling a vector

Defining a codelet

- Codelet = multi-versionned kernel
  - Function pointers to the different kernels
  - Number of data parameters managed by StarPU
  - Access modes

```
starpu_codelet scal_cl = {
    .cpu_funcs = { scal_cpu_func, scal_cpu_func_sse },
    .cuda_funcs = { scal_cuda_func },
    .opencl_funcs = { scal_opencl_func },
    .nbuffers = 1,
    .modes = { STARPU_RW },
};
```

Scaling a vector

Defining a codelet (2)

- CPU kernel

```
void scal_cpu_func(void *buffers[], void *cl_arg)
{
    struct starpu_vector_interface_s *vector = buffers[0];

    unsigned n = STARPU_VECTOR_GET_NX(vector);
    float *val   = STARPU_VECTOR_GET_PTR(vector);

    float *factor = cl_arg;

    for (int i = 0; i < n; i++)
        val[i] *= *factor;
}
```

Scaling a vector

Defining a task, starpu_insert_task helper

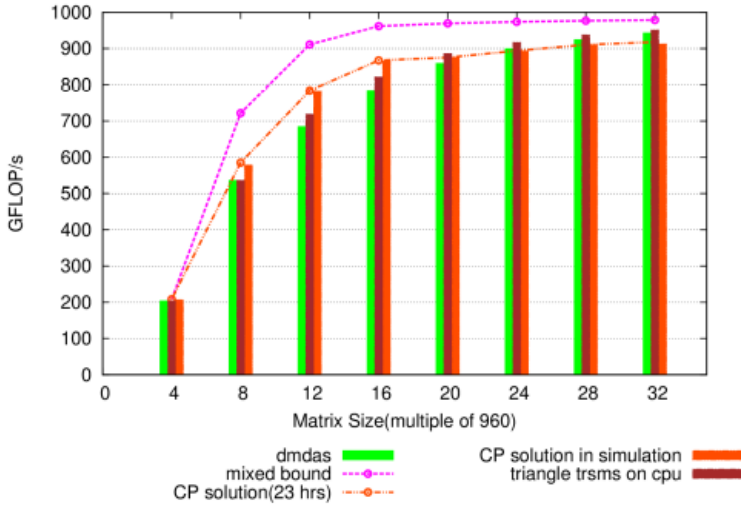
- Define a task that scales the vector by a constant

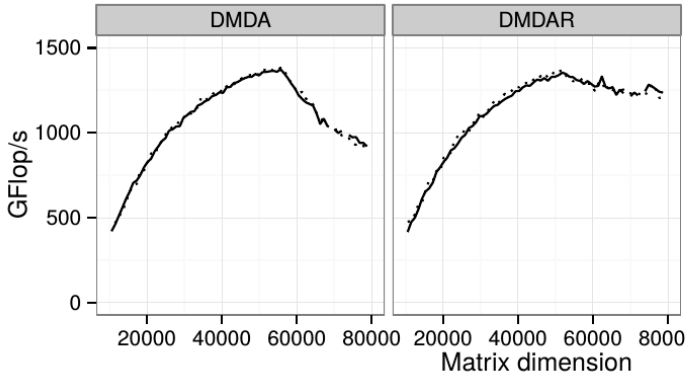
```
float factor = 3.14;

starpu_insert_task(
        &scal_cl,
        STARPU_RW, vector_handle,
        STARPU_VALUE,&factor,sizeof(factor),
        0);
```

Task-based support

Then all of this comes “for free” :

- Task/data scheduling
  - Pipelining
  - Load balancing
  - GPU memory limitation management
  - Data prefetching
- Performance bounds
- Distributed execution through MPI
- High-level performance analysis
- Out-of-core : optimized swapping to disk
- Debugging sequential execution
- Reproducible performance simulation





Applications on top of StarPU

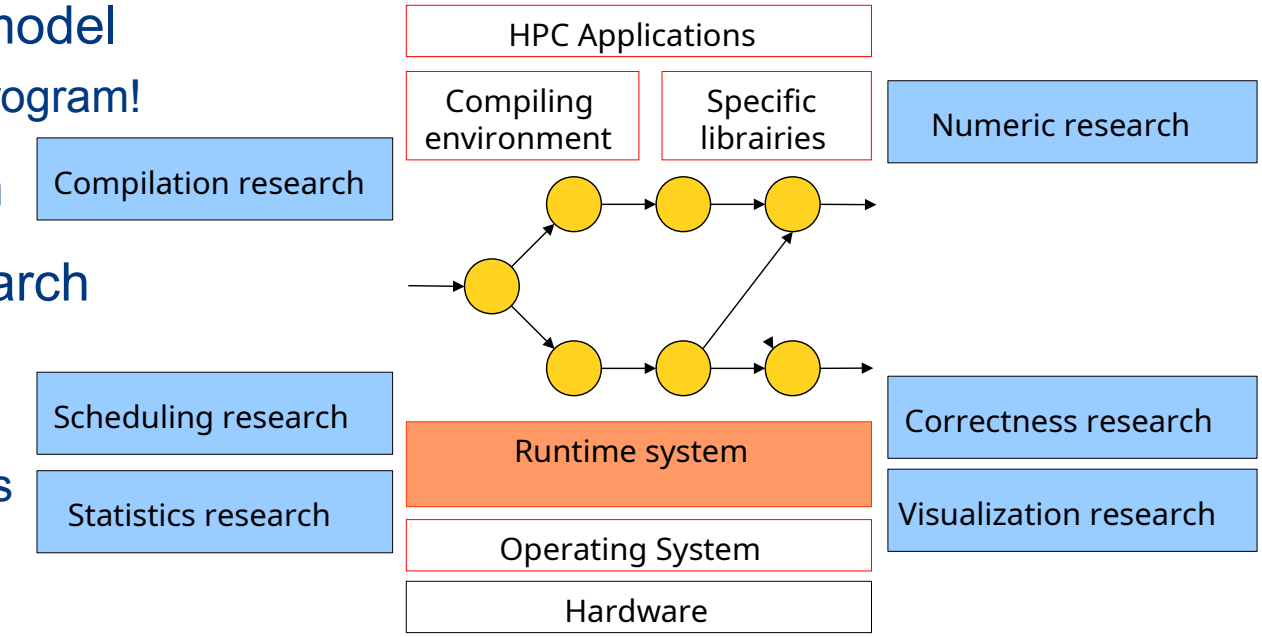
Using CPUs, GPUs, distributed, out of core, ...

- Dense linear algebra
  - Cholesky, QR, LU, ... : Chameleon (based on Plasma/Magma)
- Sparse linear algebra
  - QR_MUMPS
  - PaStiX
- Compressed linear algebra
  - BLR, h-matrices
- Fast Multipole Method
  - ScalFMM
- Conjugate Gradient
- Other programming models : Data flow, skeletons
  - SignalPU, SkePU
- ...

Conclusion

Task graphs

- Nice programming model
  - Keep sequential program!
- Optimized execution
- Playground for research
  - Runtime
  - Scheduling
  - Numeric algorithms
  - Statistics
  - Correctness
- Used for various real-world computations
  - Cholesky/QR/LU (dense/sparse/compressed), stencil, CG, CFD, FMM…



http://starpu.gitlabpages.inria.fr/tutorials/