Using Component Model to implement a DSL: The Multi-Stencil Language Case Study

Hélène Coullon, Julien Bigot, Christian Perez

Avalon project team
Maison de la simulation

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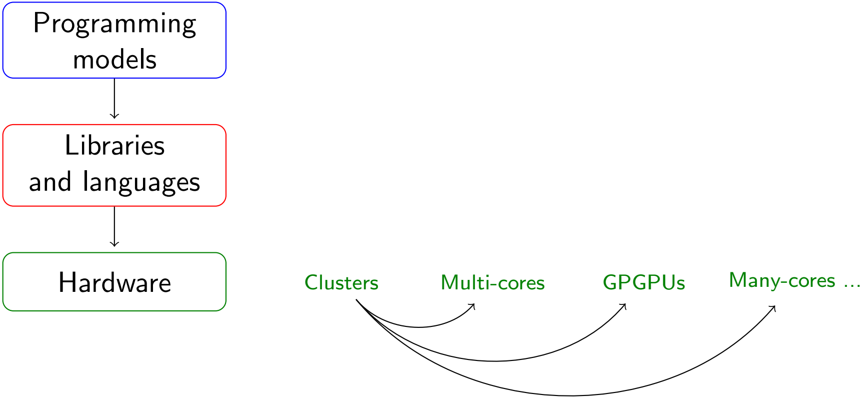
High performance computing and parallelism in 2016



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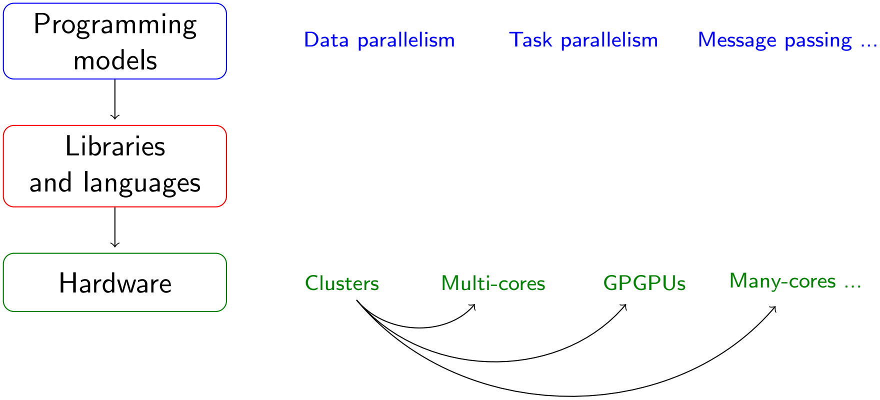

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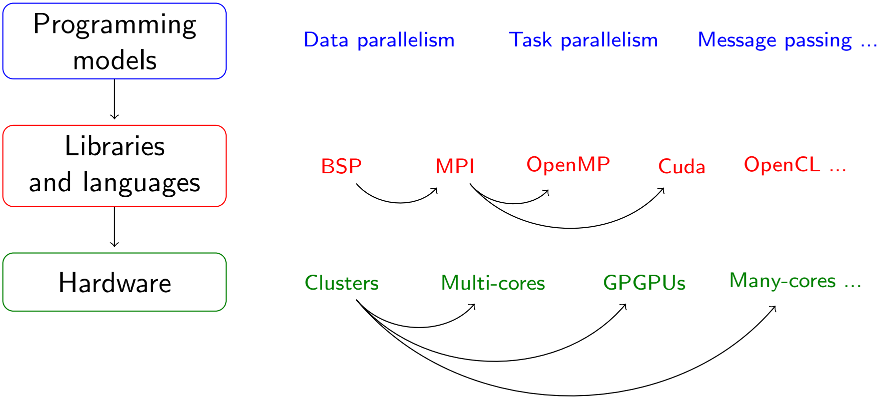

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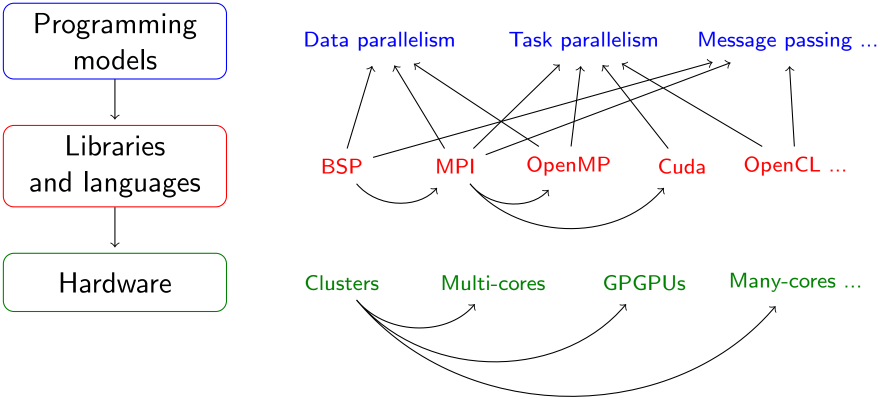

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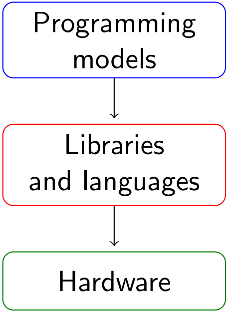
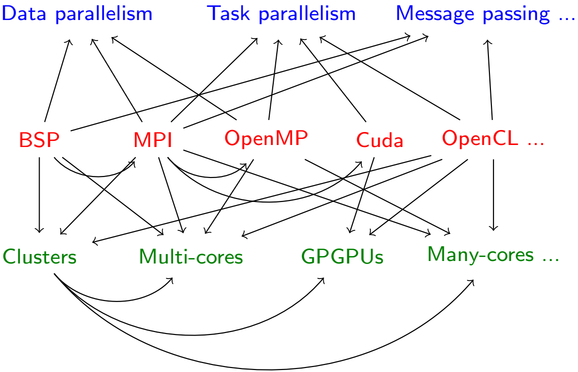




ETP4HPC: programming models for non experts to reach exascale!

Domain Specific Languages

Advantages

- Easy language for end users (can be application specific)
- Separation of concerns (domain/implementation)
- Implicit parallelization and optimizations

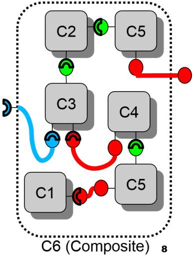
Limitations

- Difficulties deported to the DSL designer and implementer
  - Low level high performance programming
  - Maintainability and portability
- Difficult to combine DSLs (interoperability)
  - exascale applications = many specific domains and interactions

Component Models

Overview

- Technology advocating composition rather than development
  - Old idea (late 60') but major development in the 90'
  - After Object and before Model Driven Engineering (MDE)
- Component = black box with well defined interactions
  - Provides / Requires
- Application = Assembly of components



Benefits

- Application structure well defined
- Code-reuse and productivity
- Maintainability through separation of concerns

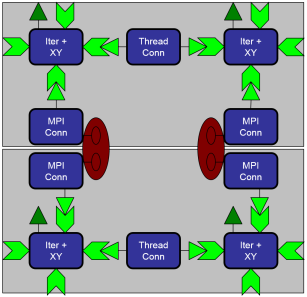
L2C: A HPC Component Model

A minimalist component model for HPC

- Component creation/deletion, configuration, and connection
- No L2C code between components runtime
  - No language interoperability provided
- Support of native interactions
  - Use/Provide: C++, CORBA, [FORTRAN (2008)]
  - MPI communicator
- `hlcm.gforge.inria.fr`

Ongoing extensions

- Concurrent reconfiguration
  - DirectL2C
- Task support
  - Cf next talk on Comet!



This talk

From a DSL: Multi Stencil Language

- Descriptive language,
- for Multi-Stencil simulations,
- without numerical code.

To a generated component assembly

- with automatic synchronizations for data and task parallelism,
- with empty functions to fill (components),
- with good performance.

Separation of concerns between domain/implementation/parallelization

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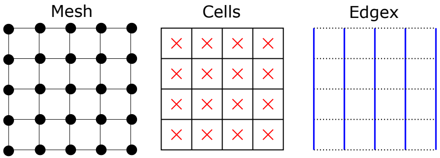
The MSL language: the mesh




```
mesh : cart
mesh entities : cell , edgex
computation domains :
  d1 in cell
  d2 in edgex
stencil shapes :
  ncc from cell to cell
  nce from cell to edgex
  nec from edgex to cell
```

- A Cartesian mesh is used
- Two kinds of mesh entities are declared onto it
- Two computations domains, one for each entity type
- Three stencil shapes (neighborhood from mesh entity to mesh entity)

The MSL language: quantity

```
quantity :
  A, cell
  B, cell
  C, edgex
  D, cell
  E, cell
  F, cell
  G, cell
  H, edgex
  I, cell
  J, cell
scalar : mu, tau
```

- A is a quantity applied onto cell
- C is a quantity applied onto edgex
- mu and tau are scalar values

The MSL language: time and computations

```
time : 500
computations :
   B[d1] = k0({tau},{A})
   C[d2] = k1({},{B[nce]})
   D[d1] = k2({},{C})
   E[d1] = k3({},{C})
   F[d1] = k4({},{D,C[nec]})
   G[d1] = k0({mu,tau},{E})
   H[d2] = k6({},{F})
   I[d1] = k7({},{G,H})
   J[d1] = k8({mu},{I[ncc]})
```

- The time loop is composed of 500 iterations.
- J is written
- onto the computation domain d1,
- by the computation k8,
- which read the scalar mu
- and the quantity I,
- which is accessed with the neighborhood ncc.

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Data and Task parallelism

Synchronizations

When a computation read a data, using a stencil shape, that has been written by a previous computation.

$\Gamma = [c_0, c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8]$
$\hookrightarrow [c_0, sync_1, c_1, c_2, c_3, sync_4, c_4, c_5, c_6, c_7, sync_8, c_8]$

Dependency graph

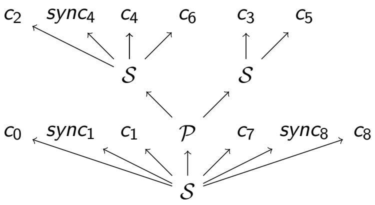
Node: a computation or a synchronization
Edge: a direct data dependency (Read / Write)

$$
\begin{tikzcd}
 & & & c_2 \arrow[r, dashed] & sync_4 \arrow[r, dashed] & c_4 \arrow[r] & c_6 \arrow[dr] & & & \\
c_0 \arrow[r, dashed] & sync_1 \arrow[r, dashed] & c_1 \arrow[ur] \arrow[dr] & & & & & c_7 \arrow[r, dashed] & sync_8 \arrow[r, dashed] & c_8 \\
 & & & c_3 \arrow[r] & c_5 \arrow[urrr] & & & & &
\end{tikzcd}
$$

Static or dynamic scheduling ?

Series-Parallel Tree

Valdes & Al, The Recognition of Series Parallel Digraphs, STOC '79



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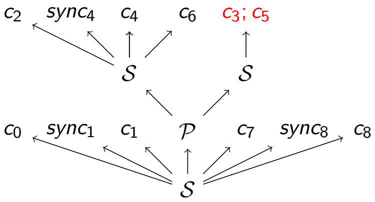

Loop fusion optimization possible

Series-Parallel Tree

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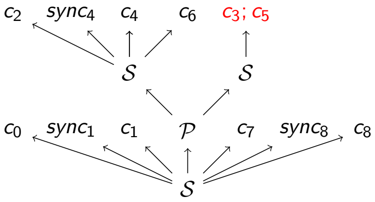


Loop fusion optimization possible

Specific components

- *SEQ* to directly replace $\mathcal{S}$ nodes
- *PAR* to directly replace $\mathcal{P}$ nodes
- *SYNC* for synchronizations
- *K* for computation kernels

MSL to Component-based runtime

Ready-to-fill parallel pattern

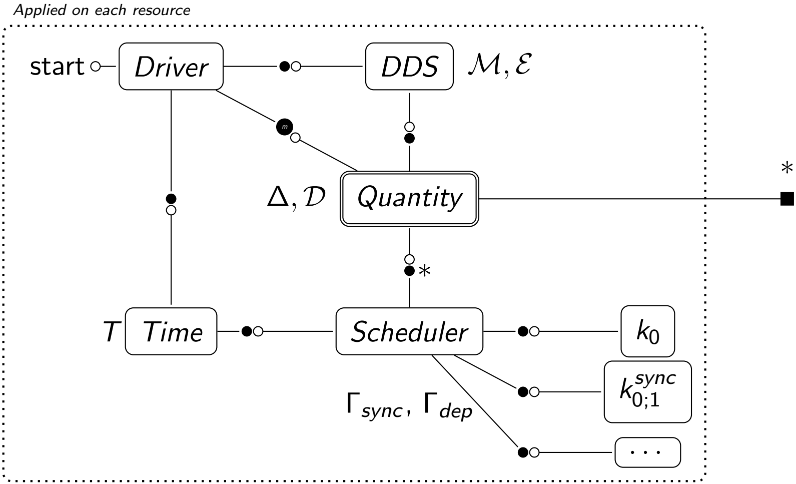
- Data parallelism
  - External distributed data structure
  - Automatic detection of synchronizations
- Task parallelism (mid-grain)
  - Static scheduling at the assembly level
  - Dynamic scheduling within a driver component
    - OpenMP task

The fine grain task parallelism is left to other languages:

- OpenMP in the kernels
- Kernels generated by stencil compilers
  - Pochoir, PATUS, Liszt etc.

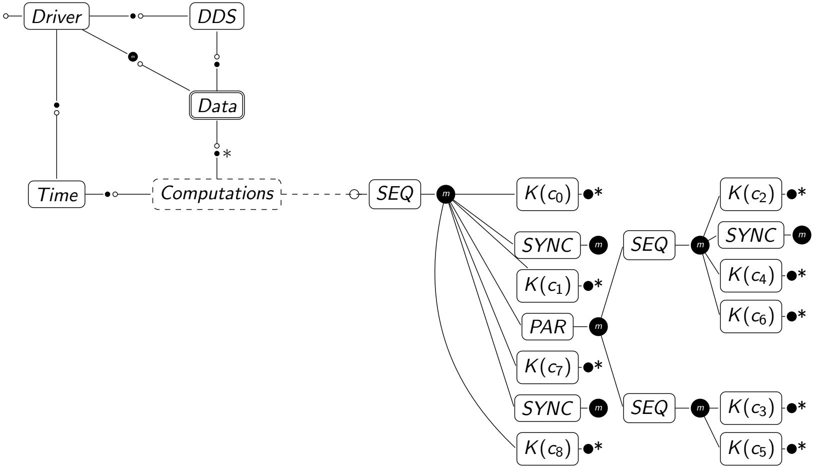
Component Assembly Runtime Template

A data parallel/task parallel component assembly.



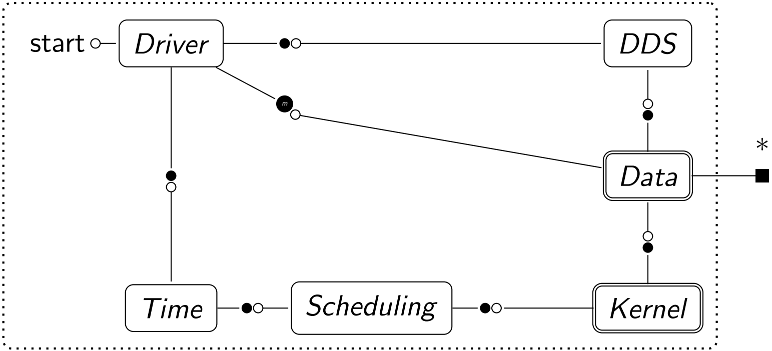
DDS: Distributed Data Structure (using SkelGIS)

Component-based runtime: Static Scheduling



Component-based runtime: Dynamic Scheduling

- *mpiOmpDyn*
  - *DDS* and *Quantity*: data parallelization.
  - *Scheduler*: DAG encoded into OpenMP tasks



Duplicated on each processor/core

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Evaluation Setup

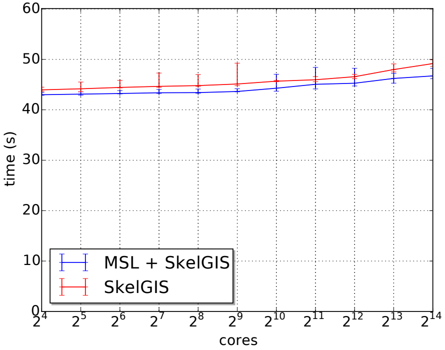
Application

- FullSWOF2D: developed at the MAPMO, University of Orléans
- Solve the shallow-water equations using a finite volume method
- Cartesian mesh
- 3 mesh entities, 7 computation domains, 48 quantities
- 98 computations (32 stencils, 66 local kernels)

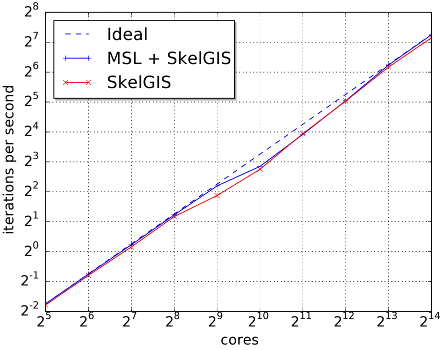
Machines

- Thin nodes TGCC Curie
- 2 CPU, 8 cores, Sandy Bridge EP (E5-2680) 2.7 GHz, 64 GB
- OpenMPI and gcc 4.9

Data Parallelization: Weak and Strong Scaling



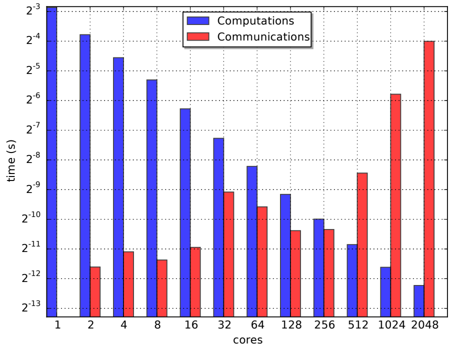
Weak Scaling
400x400 domain/core



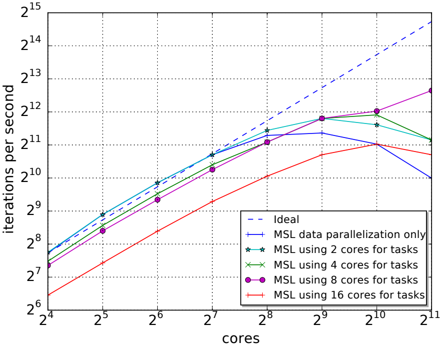
Strong Scaling
10k x 10k domain

No overhead introduced by components

Data Parallelization to Hybrid Parallelization: Strong Scaling



Data Parallelization



Data and Hybrid Parallelizations

Parallelism Level	1	2	3	4	6	10	12	16
Frequency	2	1	3	5	3	1	1	2

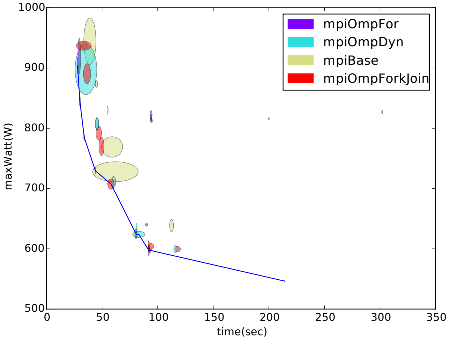
Task graph analysis

Dynamic Scheduling and Energy Evaluations

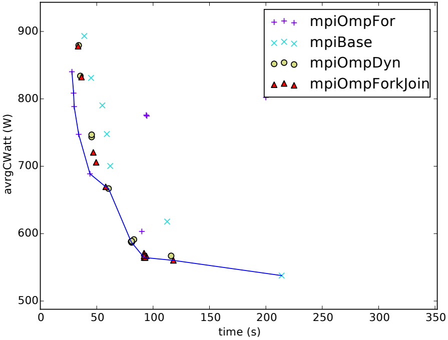
Application versions:

Variant Name	DDS / Quantity	Kernels	Scheduler
mpiBase	MPI	Sequential	Sequential
mpiOmpFor	MPI	Parallel loops	Sequential
mpiOmpForkJoin	MPI	Sequential	SPT
mpiOmpDyn	MPI	Sequential	OpenMP Tasks

Energy Usage on Grid'5000



Time vs Max Watt on 4 nodes

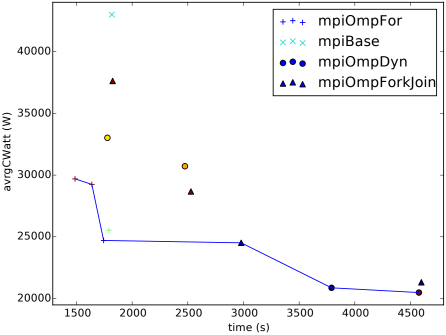


Time vs Average Watt on 4 nodes

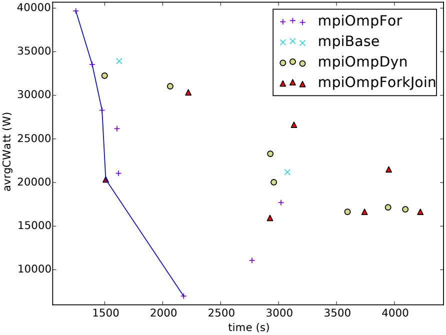
Parameters:

- Domain: 4000 x 4000
- #Iteration: 100

Energy Usage on Curie



Time vs Max Watt on 2048 cores



Time vs Average Watt on 2048 cores

Parameters:

- Domain: 20,000 x 20,000
- #Iteration: 10,000
- One measure every 5 min!

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Conclusion and Future Work

Conclusion

- A DSL for Multi-Stencil applications (MSL)
- The generation of a component based runtime, including scheduling
  - Data and task parallelism
- Evaluation on Grid'5000 and Curie: no overhead introduced
- Basis for ongoing energy studies

Perspectives

- Language improvement (convergence criteria, reduction etc.)
- OpenMP inside kernels/components
- CPU+GPGPUs using stencil compilers (Pochoir, PATUS etc.)
- Composition of various DSLs by agreeing on component runtimes?