From DSL to HPC Component-Based Runtime: A Multi-Stencil DSL Case Study

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WOLFHPC 2015 - 16^{th} November 2015

Motivation

+ Domain Specific Languages

- Separation of concerns (domain/implementation)
- Easy language for the user
- Implicit optimizations
- Implicit parallelization

- Domain Specific Languages

- Difficulties deported to the DSL designer
  - Low level high performance programming
  - Maintainability and portability
- As many DSLs as domains
  - DSL composition ?

Motivation

Component models

- Divide an application into several independent black boxes
- Each component defines its interactions with outer world
- Application = Assembly of components

+ Component models

- Maintainability through separation of concerns
- Code-reuse and productivity
- Dynamic assembly of components

Motivation

Motivation

What if a DSL produces a component-based runtime ?

- Is it feasible ?
- Is it efficient ?
- Does it improve issues of DSLs ? (maintainability etc.)

Contributions

- The Multi-Stencil Language (MSL)
- A first component-based back end
- No overheads introduced

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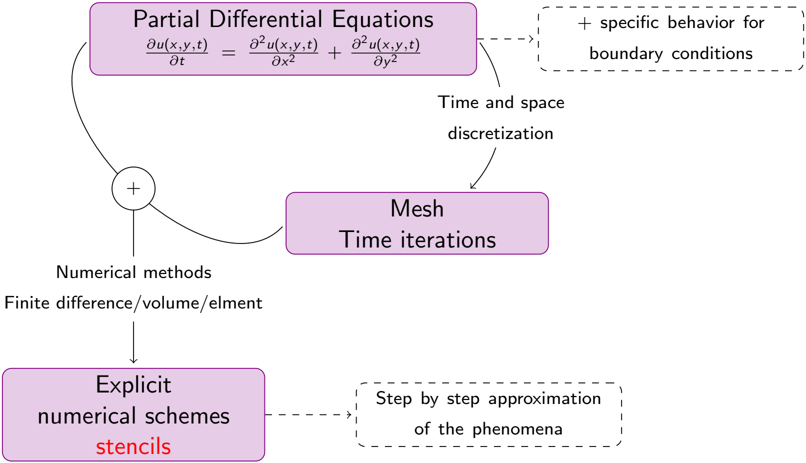
Numerical simulation = Multi-Stencil application



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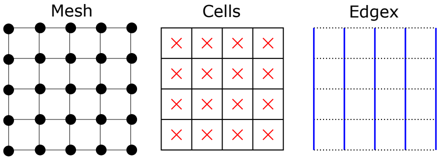
Time and Mesh

Time

At each time iteration of the simulation are applied the *computation kernels* of the application.

Mesh

- A Mesh is a connected undirected graph $\mathcal{M} = (V, E)$ without bridges
- Mesh entities are a subset of $V \cup E$



Data and Computation Kernels

Data

Data is a set of numerical values, each one attached to a given mesh entity

Computation kernel

- Set of data read for the computation
  - Each one associated to a stencil shape
- Data written by the computation
- A numerical expression
- A computation domain
  - Subset of mesh entities

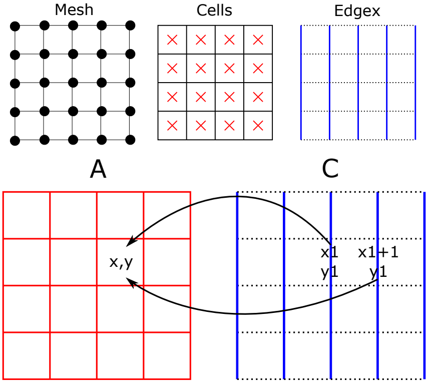
Multi-Stencil application

$$\mathcal{MSP}(T, \mathcal{M}, \mathcal{E}, \mathcal{D}, \Delta, \Gamma)$$

- T the set of time iterations to tun the simulation
- $\mathcal{M}$ the mesh of the simulation
- $\mathcal{E}$ the set of mesh entities
- $\mathcal{D}$ the set of computation domains
- Δ the set of data
- Γ the set of computations

$=$ *the six sections of a Multi-Stencil Language program !*

Example



$\mathcal{MSP}(\mathcal{T}, \mathcal{M}, \mathcal{E}, \mathcal{D}, \Delta, \Gamma)$

blue = MSL and black = user identifiers

```
mesh: cart
mesh entities: cell,edgex
computation domains:
  allcell in cell
  alledgex in edgex
data:
  A,cell
  C,edgex
time:500
computations:
  A[allcell]=comp(C[n1])
```

Where is the code ?

Keywords + identifiers ? That's it ? Where is the code ? ? ?

Where is the code ?

Data parallelism

Whatever the mesh is and the exact computations are :

- mesh and data are splitted among resources
- synchronizations detected from **computation dependencies**

Mid-grain task parallelism

Task = complete computation

Whatever the mesh is and the exact computations are :

- task dependencies detected from **computation dependencies**

Fine grain optimizations and parallelizations

Stencil compilers already exist !

Where is the code ?

Data parallelism

Whatever the mesh is and the exact computations are :

- m
- sy … cies

Mid-g

Task =
Whate

- task dependencies detected from computation dependencies

MSL = computation dependencies

- produces a component based parallel scheduling of the simulation
- it is agnostic from the mesh
- it is agnostic from the actual numerical code

Fine grain optimizations and parallelizations

Stencil compilers already exist !

Related Work

Complementary work

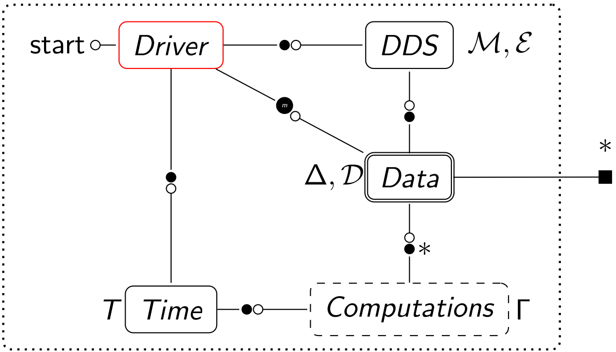
- Distributed data structures : SkelGIS, Global Arrays
- Stencil DSLs (on grids) : Pochoir, PATUS
- Stencil DSLs (on unstructured meshes) : OP2, Liszt

Similar work

- Pipeline of stencil computations for image processing : Halide
  - On grids (image), different abstraction level
- DSL to component-based runtime ?

MSL to Component-based runtime

$$\mathcal{MSP}(T, \mathcal{M}, \mathcal{E}, \mathcal{D}, \Delta, \Gamma)$$



Duplicated on each processor/core

MSL to Component-based runtime

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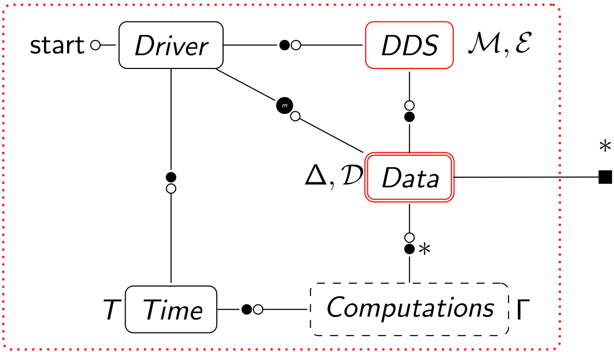

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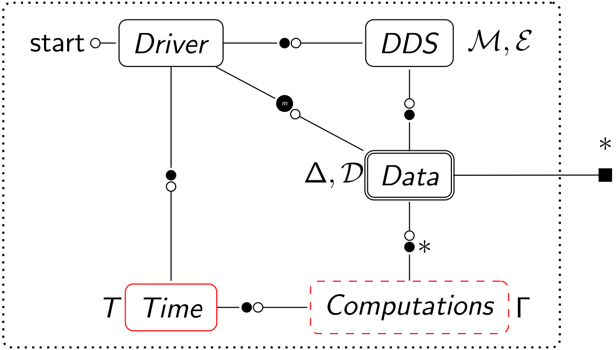


Duplicated on each processor/core

Example

```
mesh: cart
mesh entities: cell,edgex,edgey
computation domains:
  allcell in cell
  alledgex in edgex
  alledgey in edgey
  part1edgex in edgex
  part2edgex in edgex
data:
  a,cell
  b,cell
  c,edgex
  d,edgex
  e,edgey
  f,cell
  g,edgey
  h,edgex
  i,cell
  j,edgex
time:500
computations:
  b[allcell]=c0(a)
  c[alledgex]=c1(b[n1])
  d[alledgex]=c2(c)
  e[alledgey]=c3(c)
  f[allcell]=c4(d[n1])
  g[alledgey]=c5(e)
  h[alledgex]=c6(f)
  i[allcell]=c7(g,h)
  j[partedgex]=c8(i[n1])
```

Data parallelism

1. Assembly of components duplicated on each resource (SPMD)
2. External Distributed Data Structure to split data among resources
3. Detect when synchronizations are needed

Synchronization

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

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

Data and task parallelism

Dependency graph

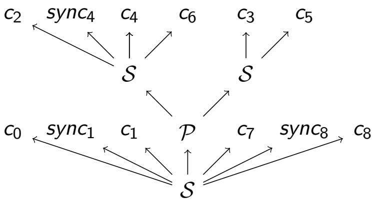
1. Each node is a computation or a synchronization
2. Each edge is a dependency : a computation read a data that has been written before.

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

Dynamic or static scheduling ?

Series-Parallel Tree

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



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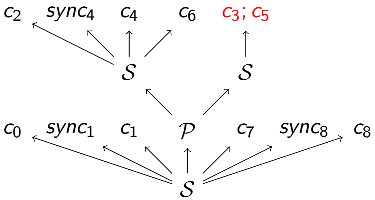

Loop fusion optimization possible

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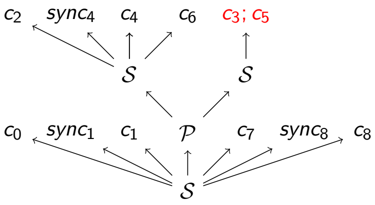
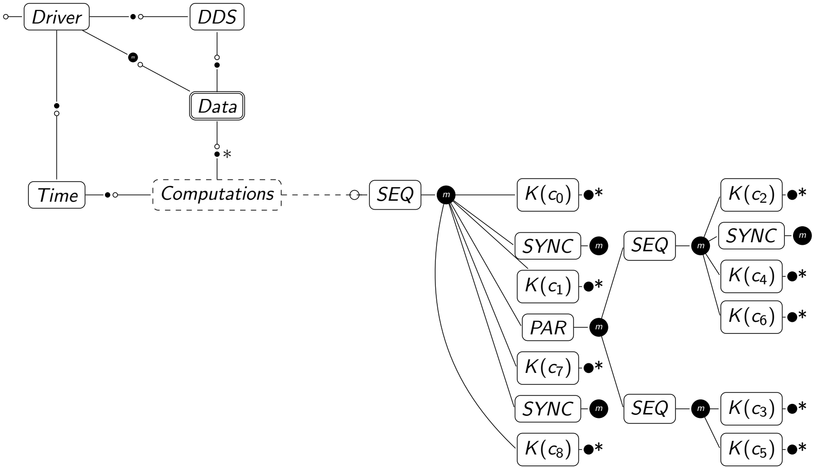


Loop fusion optimization possible

Specific components

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

Component-based runtime



Separation of concerns

- Non-computer scientist who uses the DSL
- The numerician who writes numerical codes
- The computer-scientists who writes
  - parallel components
  - DDS + Data

Implementation and evaluation

Implementation of MSL : Python, SkelGIS and L^2C

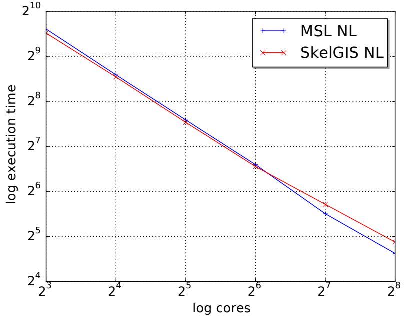
Shallow-water equations : 1 mesh, 3 mesh entities, 7 computation domains, 48 data, 98 computations (32 stencils, 66 local kernels)

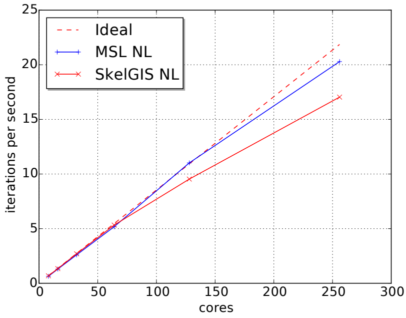
Evaluation of the data parallelism

- SkelGIS DDS + manual synchronizations and fusions
- SkelGIS DDS + MSL
- Thin Nodes TGCC Curie : two 8-cores Intel Sandy Bridge 2.7GHz, 64GB RAM, Infiniband

Evaluations

Mesh size : $10k \times 10k$ Number of iterations : 500





Conclusion

Conclusion

- A DSL for Multi-Stencil applications (MSL)
- The compilation of MSL to get a parallel scheduling pattern of the simulation
  - Data parallelism
  - Task parallelism
- The dump to a component-based runtime
- Data parallelism evaluation : no overhead introduced

Perspectives

Perspectives

- Improvment of the language (convergence criteria, reduction etc.)
- Scalability up to $32k$ cores on TGCC Curie (CEA)
- Evaluations on Data+Task parallelism
  - OpenMP 3 inside kernels
- Dynamic scheduling
  - OpenMP 4 with a scheduling component
  - Kstar for StarPU and XKaapi runtimes
- CPU+GPGPUs using stencil compilers (Pochoir, PATUS etc.)

$\hookrightarrow$ Show portability, maintainability introduced by components

Photos !