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DFL

A Data Flow Language to Develop High Performance Computing DSLs

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Motivation

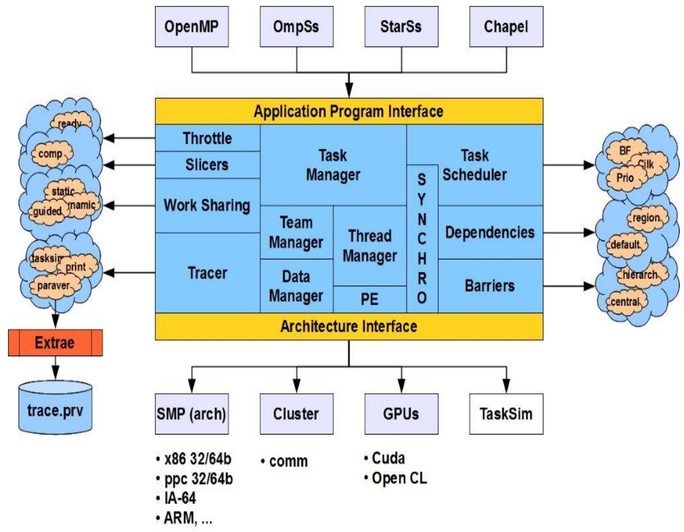
- Domain-Specific Languages (DSLs)
  - Hide the complexity of HPC systems
  - Boost programmer's productivity

- DSL drawbacks
  - High development cost due to implementation complexity
  - Efficiency and high scalability are a must

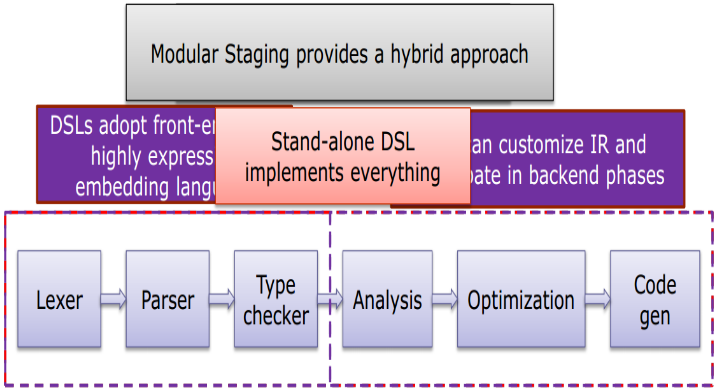
- Our proposal
  - Provide a common DSL development infrastructure
  - Amortize its cost by implementing many HPC DSLs with it

Underlying Technologies

- HPC Execution Framework
  - OmpSs programming model
    - High-level, task-based, parallel programming model supporting SMPs, heterogeneous systems and clusters
    - Coupled with its Nanos++ runtime system, is ideal as target language for the DSL framework



- Compilation Framework
  - Scala
    - Statically typed, multi–paradigm language with type inference
    - Supports both functional and object-oriented styles
  - Lightweight Modular Staging (LMS)
    - A technique for embedding DSLs as Scala libraries
    - Enables domain-specific optimizations and code generation



DFL

- Data-Flow Language (DFL)
  - A DSL meant to be used as target language for HPC DSLs implemented with Scala and LMS
  - Wraps up OmpSs features

- Main Features
  - Tasks and Kernels
  - Buffers & Distributed buffers
  - High-level parallel, distributed operations
    - Map
    - Reduce
    - Divide & Conquer

DFL – Data flow design features

- Buffers
  - Generic data containers

```
// Allocate space for 4096 floating point values
val buf1 = Buffer.fill[Float](4096)
// Buffer of 4 integer values
val buf2 = Buffer(5, 8, 21, -3)
```

- Distributed Buffers
  - Generic data containers for **distributed** environments
  - Provide high level operations

```
// 4096 Floats distributed among all nodes
val  world = MPI_COMM()
val dbuf = DistBuffer.fill[Float](world, 4096)
dbuf map { f => sqrt(f) }
dbuf.rotateLeft
val result = dbuf allReduce +
```

DFL – Data flow design features

- Buffers
  - Generic data containers

```
// Allocate space for 4096 floating point values
val buf1 = Buffer.fill[Float](4096)
// Buffer of 4 integer values
val buf2 = Buffer(5, 8, 21, -3)
```

- Distributed Buffers
  - Generic data containers for **distributed** environments

```
// 4096 Floats distributed among all nodes
val  world = MPI_COMM()
val dbuf = DistBuffer.fill[Float](world, 4096)
```

DFL – Tasks and Kernels

- Tasks
  - Computational function with annotated parameters
  - Parameters can be of any type

```
Task(A, B)(In, InOut) {
    B += A;
}
```

- Kernels
  - Tasks (written in OpenCL C) for accelerators (GPUs, Intel's Xeon Phi, etc)
  - Parameters can be primitive types or Buffers

```
val kc = KernelContainer("/path/to/kernels.cl")
// This retrieves the 3-parameter "add" kernel
// from kc, namely myAdd
val myAddKernel = Kernel(kc, "add")(In, In, Out)
myAddKernel(A, B, C)
```

DFL – High Level Operations

- Map
  - Applied locally or at a distributed level, depending on buffer type

```
val b = Buffer.fill(4096*4096)
B map { _ => rand }

val db = DistBuffer.fill(world, 4096*4096) // Collective operation
db map { x => sqrt(x) }                    // Collective operation
```

- Reduce
  - Fold a buffer with a binary operator and accumulate the result

```
val result = db.allReduce{ (x,y) => max(x/2, y+5) }
```

- Divide & Conquer pattern
  - Split a problem into smaller subproblems, solve them and combine the solutions in a potentially distributed environment (see next slides)

DFL – Divide and Conquer

- Divide
  - A function that partitions the problem if its size is bigger than a certain threshold (base case size)

```
val divFun = { p =>
        if (p.size > BASE_CASE_SIZE) {
                val chunkSize = p.size / 2
                // setRange is a shallow copy with just range override
                val pleft = p.setRange(p.begin, p.begin+chunkSize)
                val pright = p.setRange(p.begin+chunkSize, p.end)
                List(pleft, pright)
        }
        else List(p)
}
```

DFL – Divide and Conquer

- Solve
  - A function that solves a problem given its size

```
val solveFun = { p =>
        sort(p.data, p.begin, p.end)
}
```

DFL – Divide and Conquer

- Combine
  - A function that combines a list of solved problems into a whole solution

```
val combineFun= { xl =>
        xl reduceLeft { (sorted, ls) => merge(sorted, ls) }
}
```

DFL – Divide and Conquer

- Execution
  - Initialize a distributed problem, solve it with divide a conquer on each node, combine the distributed solution

```
val world = MPI_COMM()
val data = new DistBuffer[Int](world, 4096)
val tmp = new DistBuffer[Int](world, 4096)
data map { _ => rand }
data divConquer(divFun, solveFun, combineFun)
(0 until world.size) foreach { _ =>
        // Pairwise exchange and function application
        data exchangeAndApply(tmp, merge)
}
show(data)
```

Conclusions & Future Work

- DFL is a DSL designed to exploit distributed and heterogeneous HPC systems
  - Serves as the target language for other DSLs, enabling simple code generators without sacrificing HPC performance
  - Leverages the LMS framework for the DSL compiler infrastructure and the hybrid MPI/OmpSs programming model the DSL runtime systems

- Interoperability
  - DFL can enable DSL interoperation via a convenient infrastructure, which will also enable reuse of different DSL implementations, not just the DFL infrastructure

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Thank you!

For further information please contact
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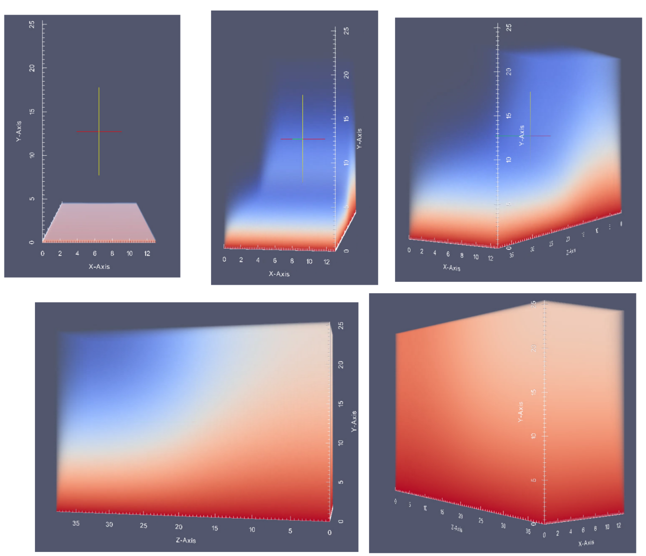
CS / CASE collaboration

- CASE expertise on Partial Differential Equations and HPC
  - Alya Red

- Domain: Convection-Diffusion-Reaction equations
  - Well know domain (by the CASE people)
  - Several implementations already available in C and Fortran
  - First design decisions of the DSL
    - Level of abstraction
    - Types
    - Operators



The result: A DSL for solving CDR equations

- **Saiph: A domain specific language for solving PDEs**
  - Simple and high level syntax
    - High level constructs that directly associate with domain knowledge
    - Efficient development/maintenance cycle
  - High performance computing for free (for the end user)
    - Ability to solve large complex problems with 20 lines of clean, simple code

- This is a program that runs on a **GPU**: **10.000 time steps in 7 seconds**

```
val c = Cartesian(12.5, 25.0, 37.5)
val temp = Unknown(c)
val cond = Dirichlet(lowXZ of c, temp, 400)
val hv = Vector(0.5, 0.5, 0.5)
val pre = PreProcess(nsteps = 10000, deltaT = 0.25, h = hv)(cond)
solve(pre) equation (0.15 * lapla(temp) - dt(temp)) to "diffusion"
```

CDR: Example 1 – Pure diffusion phenomena

```
def KFun(xp: Float, yp: Float, zp: Float) = {
    if (zp > 18.75) 0.02
    else 0.15
}

val c = Cartesian(12.5, 25.0, 37.5)
val temp = Unknown(c)
val plane = Dirichlet(lowXZ of c, temp, 400)

val hv = Vector(0.5, 0.5, 0.5)
val pre = PreProcess(nsteps = 100000, deltaT = 0.125, h = hv)(plane)

val K = KFun _
val diffusion = K * lapla(temp) - dt(temp)

val post = snapshoot each 100 steps

solve(pre)(post) equation diffusion to "diffusion"
```

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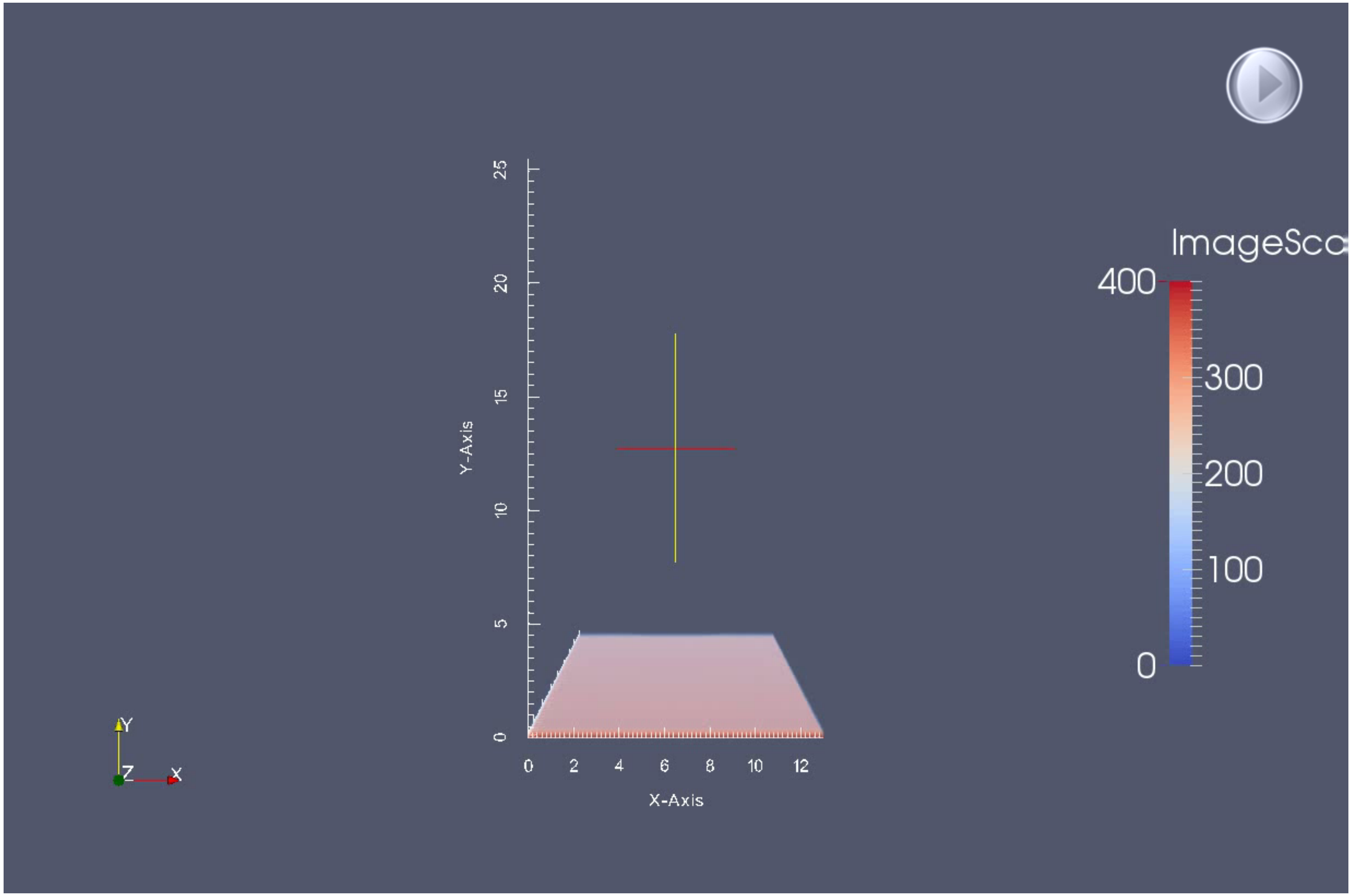
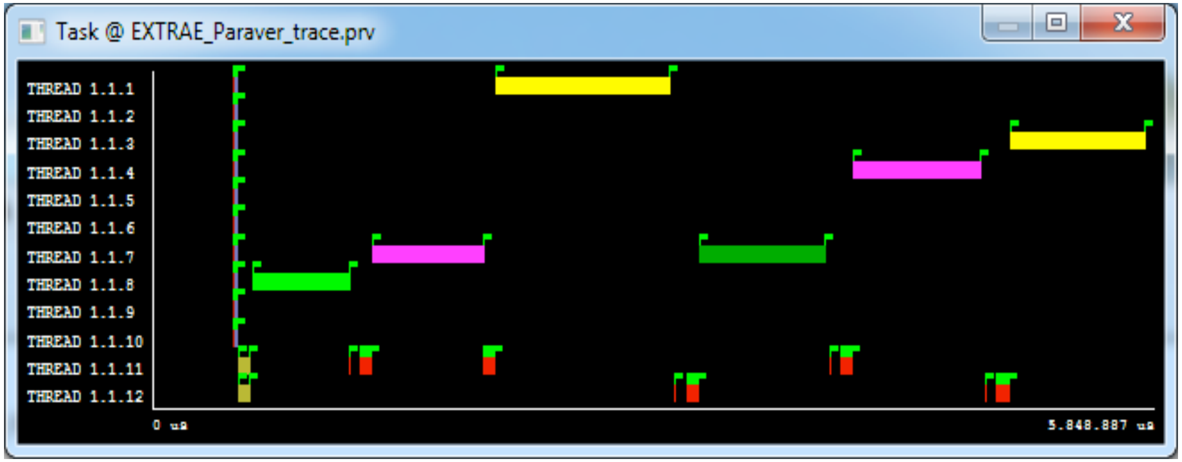
CDR: Example 1 – Pure diffusion phenomena



CDR: Example 1 – Pure diffusion phenomena

- Saiph generates
  - Two OpenCL kernels (tasks)
  - One I/O task
  - The initialization code + body of the application + OmpSs pragmas
- OmpSs runtime orchestrates the execution
  - Schedules task based on data dependencies
  - Manages data transfers between host and GPU



CDR: Example 2 – Pure convection phenomena

```
def hotCube(cx: Float, cy: Float, cz: Float, edgeSize: Float)
                    (xp: Float, yp: Float, zp: Float) = {
       if (xp >= cx - edgeSize && xp <= cx + edgeSize &&
          yp >= cy - edgeSize && yp <= cy + edgeSize &&
          zp >= cz - edgeSize && zp <= cz + edgeSize)     Some(10)
       else Some(5)
}
val c = Cartesian(25, 50, 75)
val temp = Unknown(c)
val cube = Source(hotCube(12.5, 25, 37.5, 6) _, temp)

val hv = Vector(1, 1, 1)
val pre = PreProcess(nsteps = 500, deltaT = 1, h = hv)(cube)(PeriodicHighZ)

val v = Vector(0, 0, 1)
val convection = dt(temp) + grad(temp) * v

solve(pre)(flush) equation convection to "convection"
```

Stabilization scheme done internally by CDR

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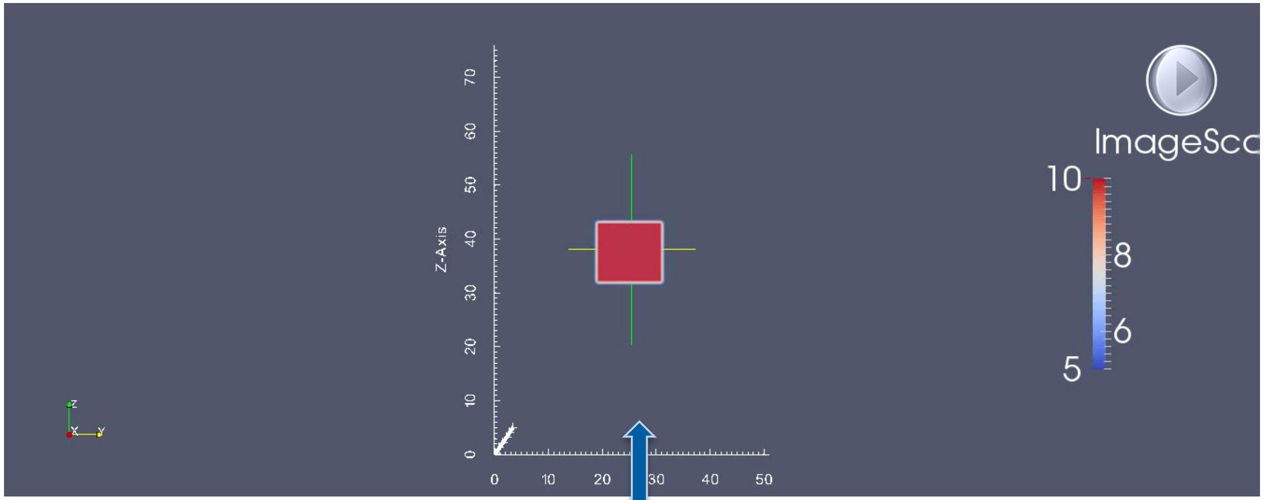
CDR: Example 2 – Pure convection phenomena

```
val v = Vector(0, 0, 1)
val convection = dt(temp) + grad(temp) * v

solve(pre)(flush) equation convection to "convection"
```

Stabilization scheme done internally by Saiph (upwind)



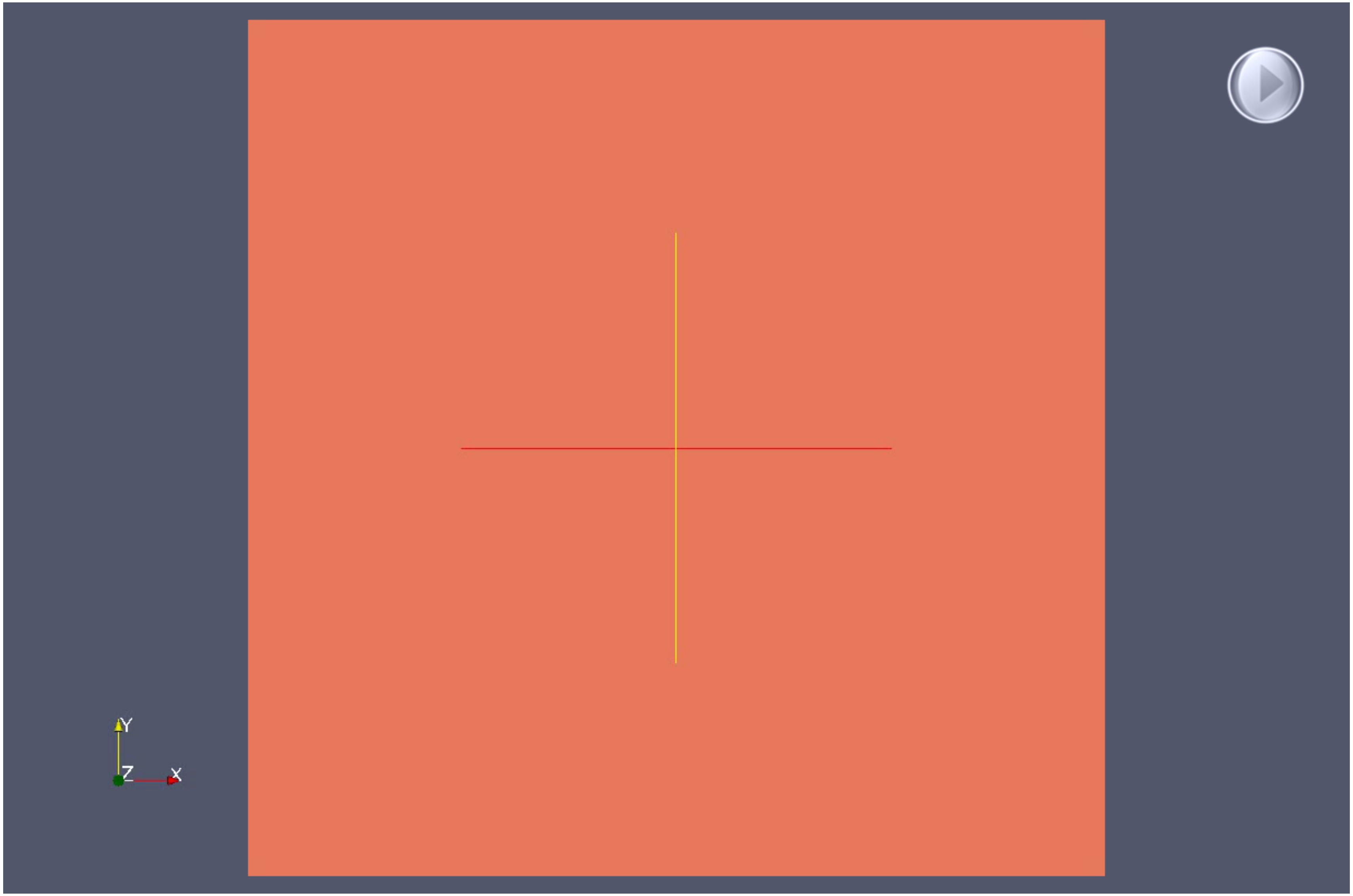
The numerical scheme do not introduce artificial diffusion due to the stabilization. The cubic form is preserved

CDR: Example 4 – Acoustic wave equation

- Complete code in backup slides

```
def CDef(x: Rep[Float], y: Rep[Float], z: Rep[Float]) = {
        if (x >= 300 && x <= 400 && y >= 300 && y <= 400) (1700*1700)
        else (2000*2000)
}
val c = Cartesian(500, 500, 9)
val pressure = Unknown(c)
val waveSource = PointSourceSource(250,250,5)(rickerWalet(20)_,pressure)

val hv = Vector(1, 1, 1)
val pre = PreProcess(nsteps = 50000, deltaT = 0.003333, h = hv)(waveSource)
val C = CDef _

val wavePropagation = C * lapla(pressure) – dt2(pressure)

val post = snapshoot each 10 steps
solve(pre)(post) equation wavePropagation to ”wave”
```

CDR:
Example 4 – Acoustic wave equation

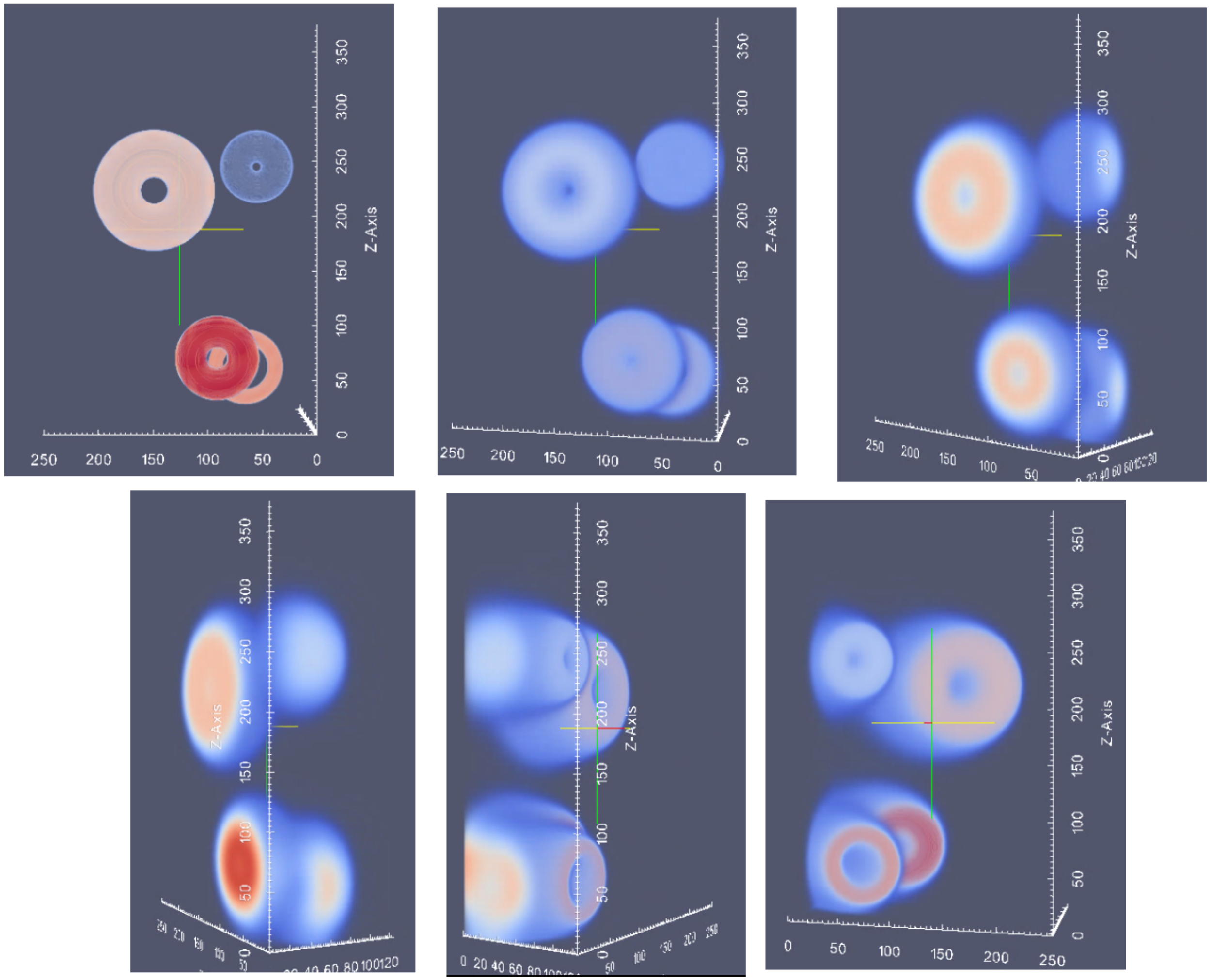


Example 3 – Heat convection and diffusion using toroidal sources

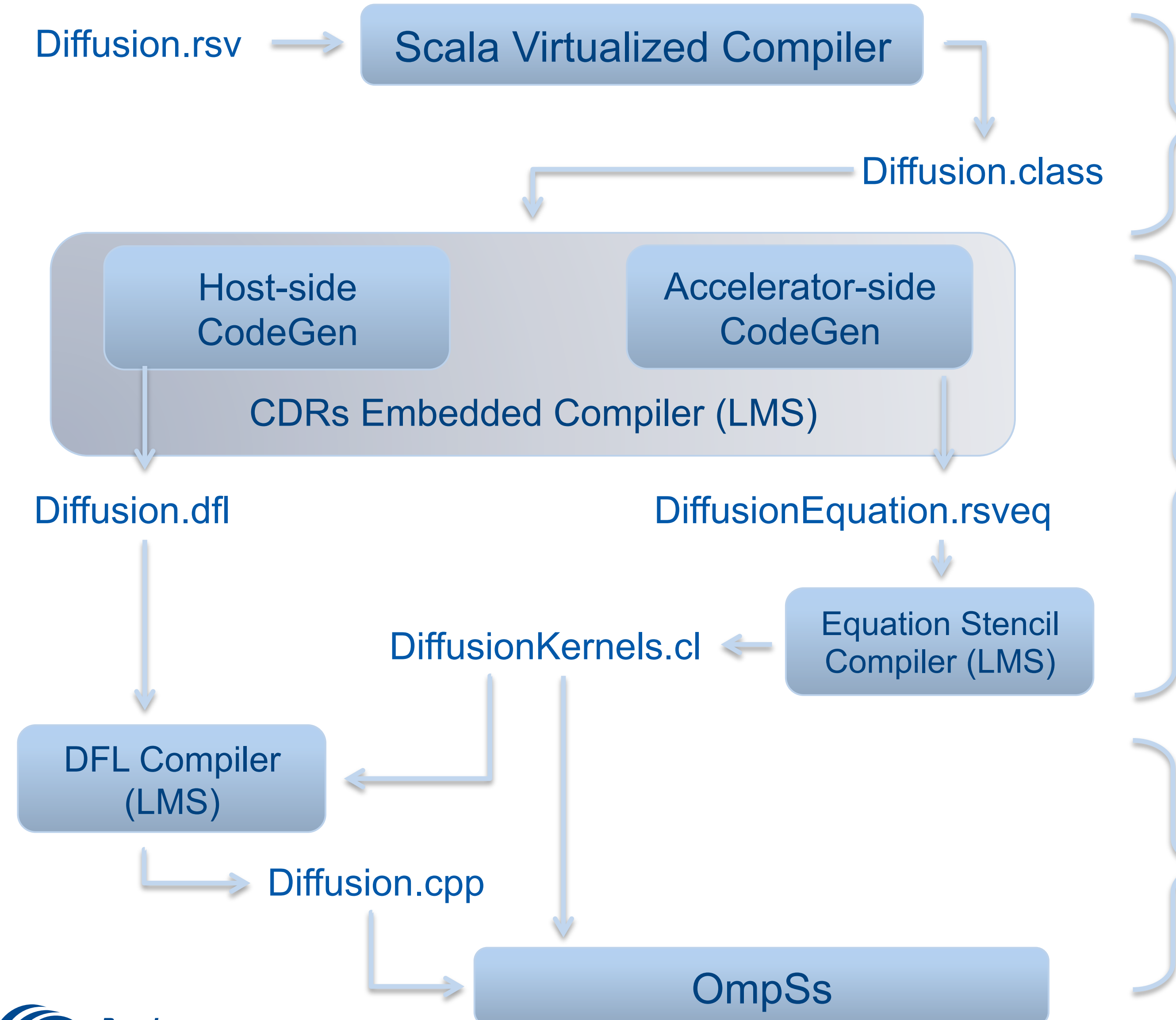
- Complete code in backup slides

```
val c = Cartesian(125, 250, 375)
val temp = Unknown(c)
val tori = Source(MyTori _, temp)

val hv = Vector(0.95, 0.95, 0.95)
val pre = PreProcess(nsteps = 10000, deltaT = 0.5, h = hv)()(tori)

val K = KVarFun _
val v = Vector(0.05, 0.05, 0)

val heat = K * lapla(temp) + grad(temp) * v - dt(temp)

val post = snapshoot each 200 steps

solve(pre)(post) equation heat to "toriHeat"
```

CDR:
Example 3 – Heat convection and diffusion using toroidal sources



Underlying Technologies



Front end
- Compile the program with the LMS Library and the compiler implementation together

Middle end
- 1^{st} stage
- Domain Specific Opt.
- LMS IR generation

Back end
- 2^{nd} stage
- DFL code + OpenCL kernels