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Optimizing Scientific Computations with the Sparse Polyhedral Framework

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Abstract

Scientific applications are computationally intensive and require expensive HPC resources. Optimizing scientific applications requires that we balance three competing goals: Performance, Productivity, and Portability. *Performance* is important because it reduces time to solution and power consumption. However, optimization has the potential to negatively impact scientific *productivity* due to obfuscating the code. *Portable* code, code that can be moved to different computers, tends to be slow and difficult to maintain. We propose to automate optimization by using the Sparse Polyhedral Framework as a compiler intermediate representation. In this work, we present SPF-IE, a tool for translating scientific applications from legacy C/C++ code to our internal representation, and present a high-level overview of our internal representation.

Optimizing Scientific Computations with the Sparse Polyhedral Framework

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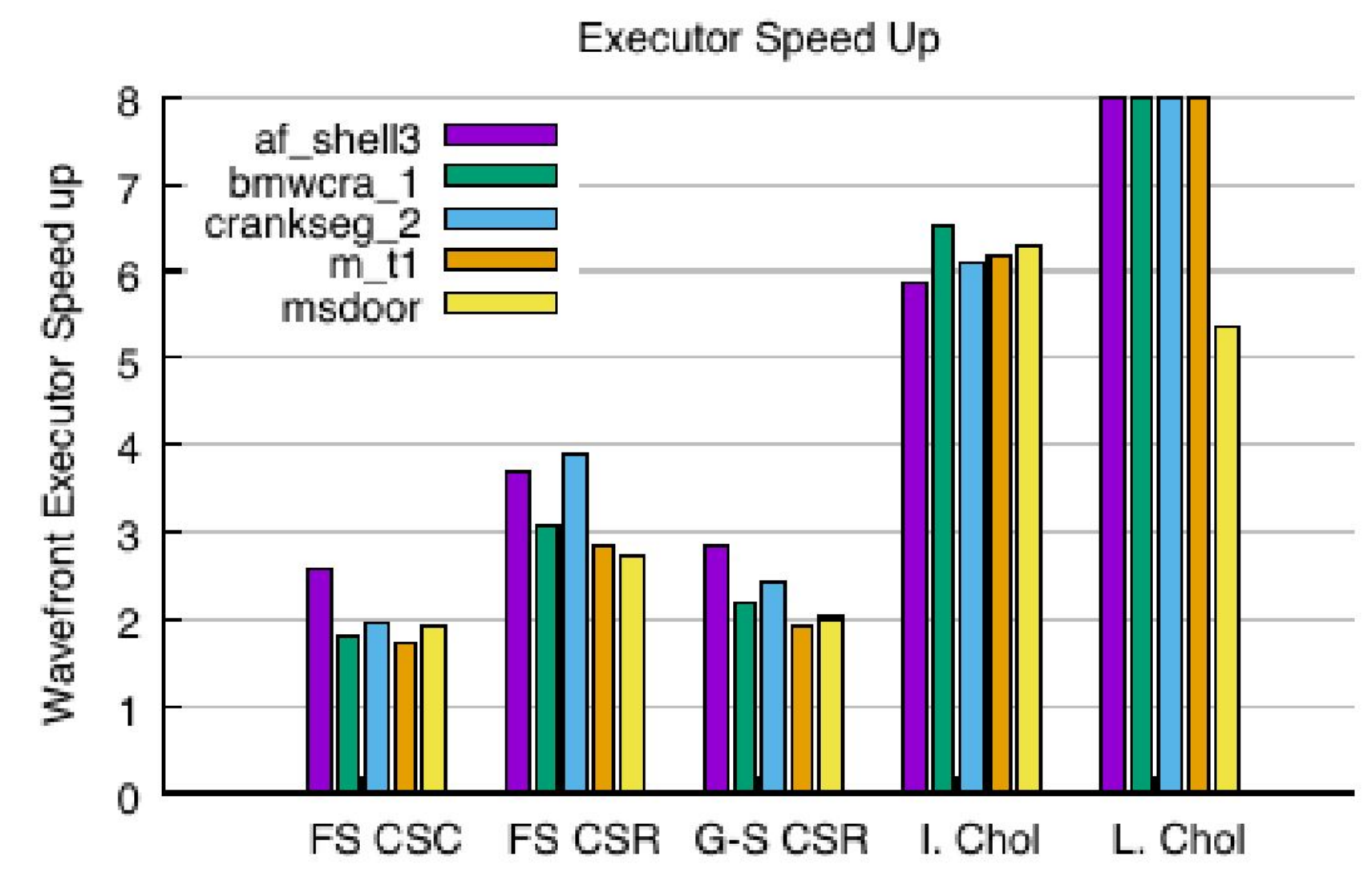
1. Problem Statement

- ❑ Scientific applications are computationally intensive, requiring expensive HPC resources
- ❑ optimizing scientific applications requires a balance of Performance, Productivity, and Portability

2. Motivation

Speedup of executor transformed for wavefront parallelism vs. library serial code.



FS CSC - Forward Solve, Compressed Sparse Column format
FS CSR - Forward Solve, Compressed Sparse Row format
G-S CSR - Gauss Seidel, Compressed Sparse Row format
I. Chol - Incomplete Cholesky
L. Chol - Left Cholesky

Source: Mahdi et. al.

3. The Polyhedral Model

- ❑ Represents the iteration of each statement of a computation in a loop nest as lattice points in a polyhedron
- ❑ Only supports affine data accesses -- **does not work for sparse computations**

```
for (i = 1; i <= 3; ++i)
  for (j = 1; j <= 3; ++j)
    S1(i, j)
```

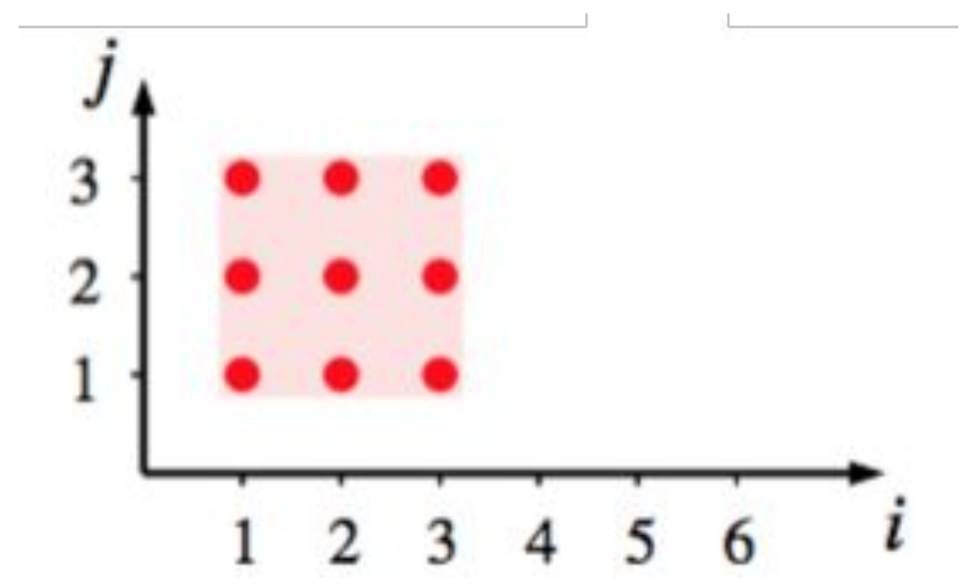
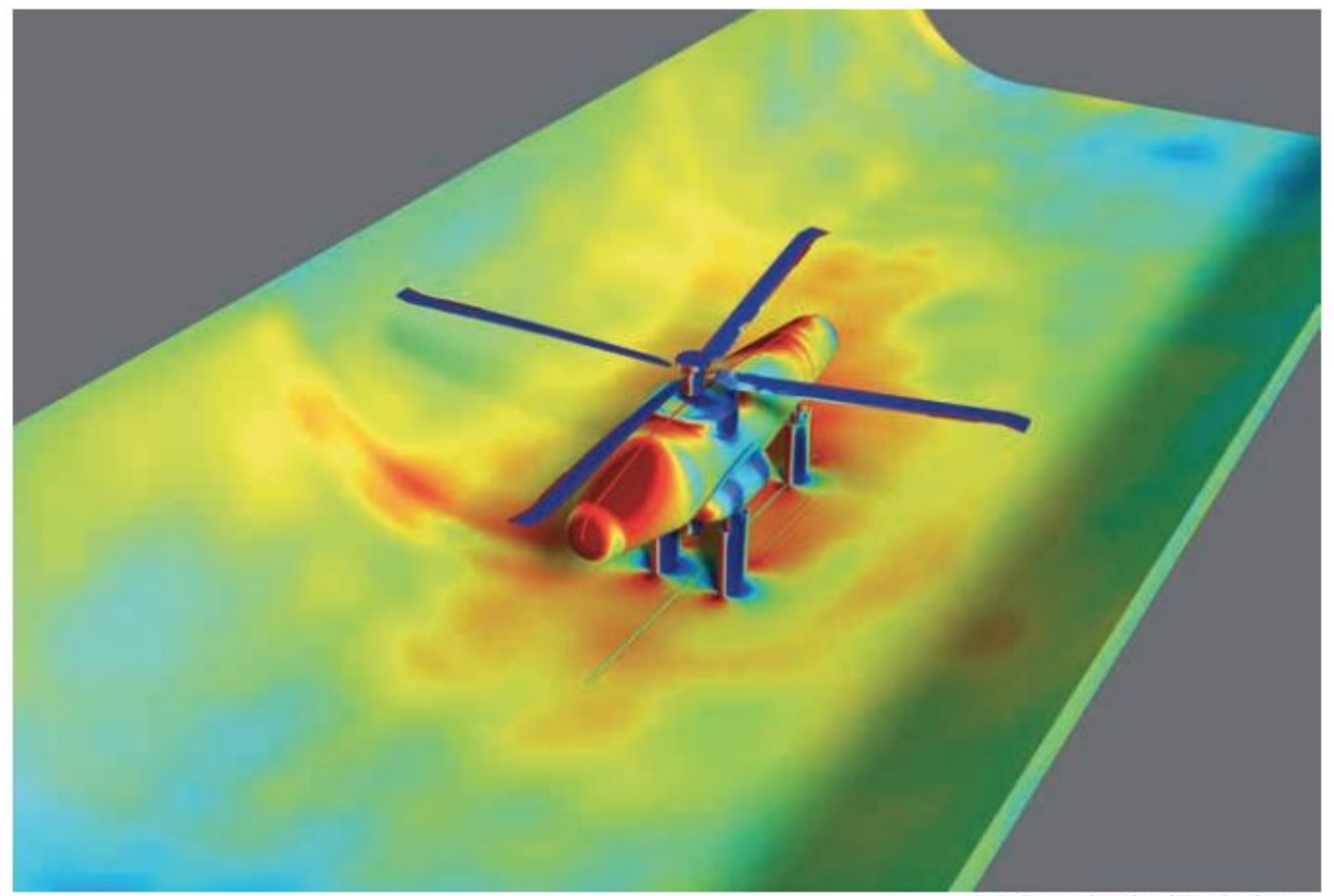


Image source: http://web.cse.ohio-state.edu/~pouchet.2/doc/cc-slides.10.pdf

4. Sparse Data



NASA/Jasim Ahmad and Tim Sandstorm

This colorful image is a Computational Fluid Dynamics simulation of a full-scale UH-60A rotor from a Black Hawk helicopter in the giant 40-by 80-Foot Wind Tunnel at NASA Ames Research Center in Moffett Field, California. Colors represent pressure – red is high pressure and blue is low pressure.

5. Sparse Polyhedral Framework (SPF)

- ❑ Extends the polyhedral model
- ❑ Provides a mathematical framework for representing and transforming irregular computations (uninterpreted functions)
- ❑ Suitable for **non-affine** loop bounds present in irregular applications

```
for (i = 0; i < N; i++)
  for (k = index[i]; k < index[i + 1]; k++)
    product[i] += A[k] * x[col[k]];
```

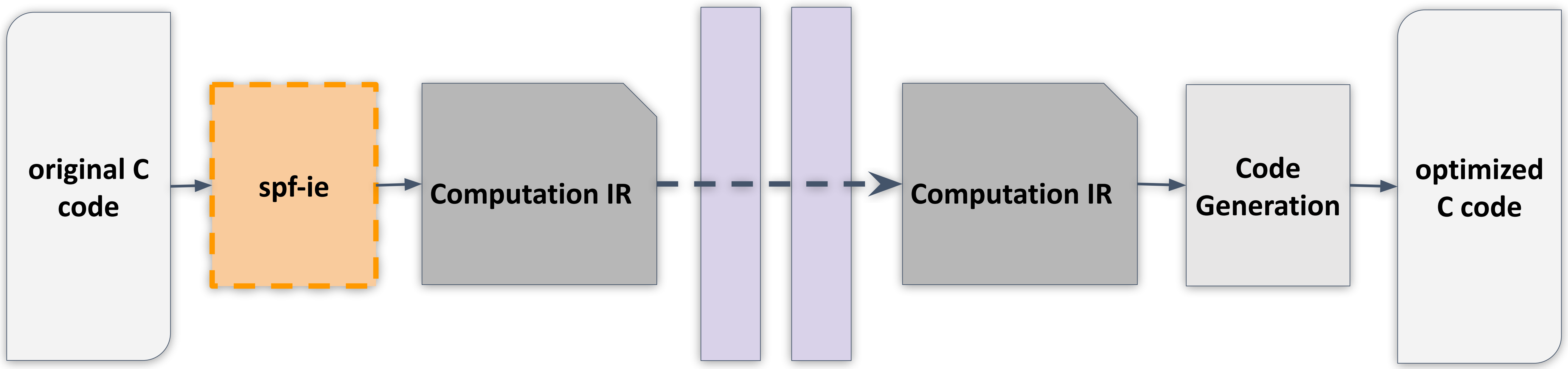
⇩

$$\{[i,k] : i \geq 0 \;\&\&\; i < N \;\&\&\; k \geq index(i) \;\&\&\; k < index(i+1)\}$$

7. spf-ie

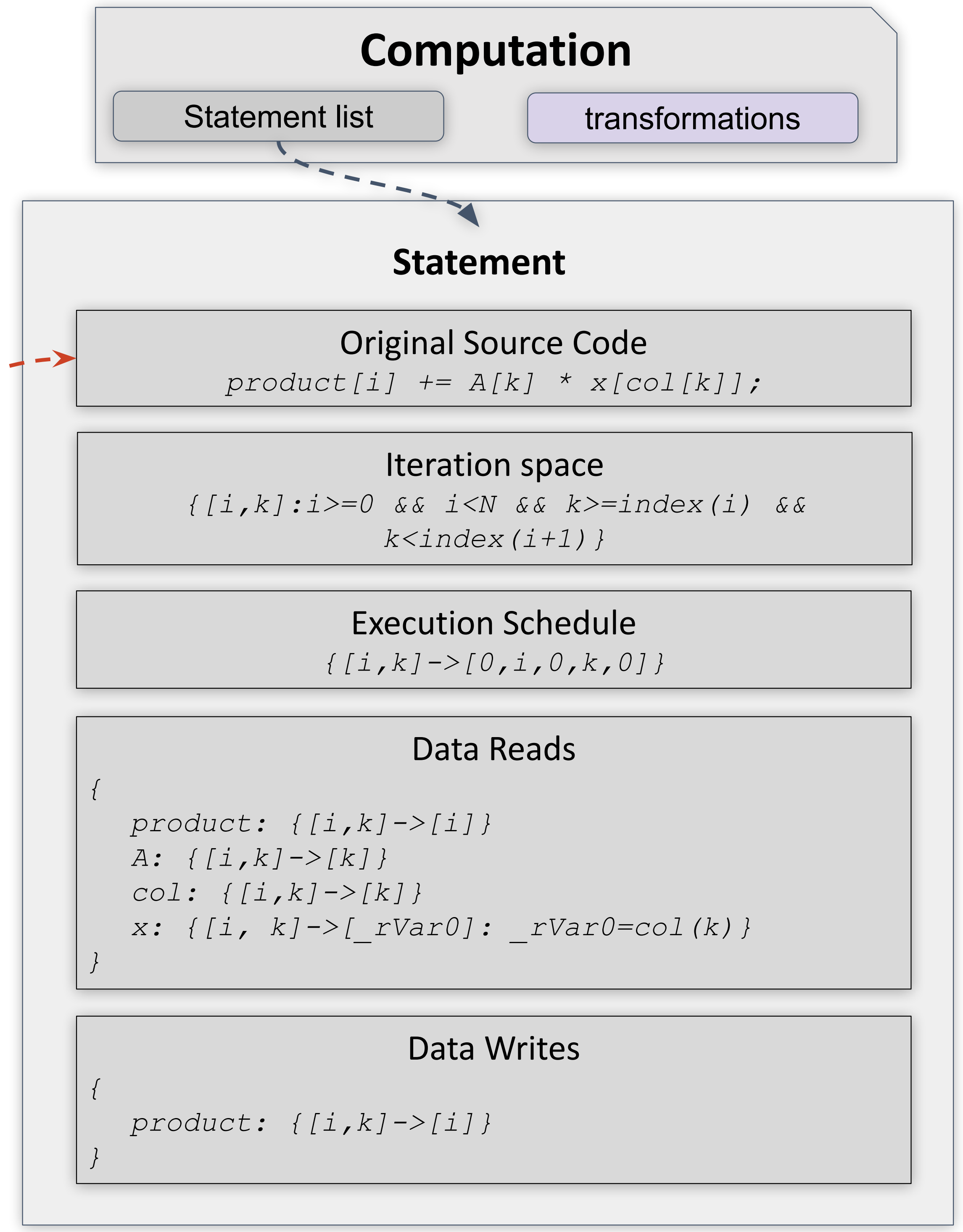
- ❑ Can be thought of as the compiler frontend of the project
- ❑ Extracts SPF representation of original source code, entering it into the Computation IR
- ❑ Implemented as a Clang tool that recursively traverses the abstract syntax tree
- ❑ Enforces polyhedral model restrictions on code (no *goto* statements, etc.)

6. Optimization Overview



Composable Transformations

8. Intermediate Representation



Original Source Code

```
product[i] += A[k] * x[col[k]];
```

Iteration space

```
{[i,k]:i>=0 && i<N && k>=index(i) &&
k<index(i+1)}
```

Execution Schedule

```
{[i,k]->[0,i,0,k,0]}
```

Data Reads

```
{
  product: {[i,k]->[i]}
  A: {[i,k]->[k]}
  col: {[i,k]->[k]}
  x: {[i, k]->[_rVar0]: _rVar0=col(k)}
}
```

Data Writes

```
{
  product: {[i,k]->[i]}
}
```

9. Future Development

- ❑ Currently only have an identity transformation, need to write more
- ❑ Algorithmically manipulating data layout to meet execution requirements
- ❑ Inlining computations that call others
- ❑ Synthesize IR to facilitate conversion from one sparse format to another

10. Acknowledgements

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11. Collaborators

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