A Framework for Automatic OpenMP Code Generation

Raghesh A (CS09M032)

Outline

- Introduction
- The Polyhedral Model
- LLVM
- Polly
- OpenMP Code Generation in Polly
- Testing with PolyBench
- Conclusion and Future Work
- Setting up the environment
- Various Tools Used in Polyhedral Community

Introduction

- Parallelism in programs
  - Parallelism and locality
  - Realizing parallelism
- Auto parallelization
- The polyhedral model
- LLVM
- Polly and OpenMP code generation

The Polyhedral Model I

- Program transformations with polyhedral model
  - Transformation for improving data locality

```
for(i = 1; i <= 10; i++)
  A[i] = 10;
for(j = 6; j <= 15; j++)
  A[j] = 15;
```

```
for(i = 1; i <= 5; i++)
  A[i] = 10;
for(j = 6; j <= 15; j++)
  A[j] = 15;
```

  - Scalar expansion

```
for (i = 0; i < 8; i++)
  sum += A[i];
```

```
<create and initialize an array 'tmp'>
for (i = 0; i < 8; i++)
   tmp[i % 4] += A[i];
sum = tmp[0] + tmp[1] + tmp[2] + tmp[3];
```

```
parfor (ii = 0; ii < 4; ii++)
  tmp[ii] = 0;
  for (i = ii * 2; i < (ii+1) * 2; i++)
    tmp[ii] += A[i];
sum = tmp[0] + tmp[1] + tmp[2] + tmp[3];
```

The Polyhedral Model II

- Polyhedral representation of programs
  - Iteration domain
  - Schedule
  - Access function

Iteration domain

```
for (int i = 2; i <= N; i++)
  for (int j = 2; j <= N; j++)
    A[i] = 10; // S1
```

```
for (int i = 2; i <= 6; i++)
  for (int j = 2; j <= 6; j++)
    if(i <= j)
      A[i] = 10; // S2
```

Iteration domain

```
for (int i = 2; i <= N; i++)
  for (int j = 2; j <= N; j++)
    A[i] = 10; // S1
```

```
for (int i = 2; i <= 6; i++)
  for (int j = 2; j <= 6; j++)
    if(i <= j)
      A[i] = 10; // S2
```

Iteration domain for **S**1 is

$$D_{S1} = \{(i,j)\ \epsilon\ Z^2 \mid 2 \leq i \leq N \wedge 2 \leq j \leq N\}$$

Iteration domain for **S**2 is

$$D_{S2} = \{(i,j)\ \epsilon\ Z^2 \mid 2 \leq i \leq 6 \wedge 2 \leq j \leq 6 \wedge i \leq j\}$$

Iteration domain

```
for (int i = 2; i <= N; i++)
  for (int j = 2; j <= N; j++)
    A[i] = 10; // S1
```

```
for (int i = 2; i <= 6; i++)
  for (int j = 2; j <= 6; j++)
    if(i <= j)
      A[i] = 10; // S2
```

Iteration domain for **S**1 is

$$D_{S1} = \{(i,j)\ \epsilon\ Z^2 \mid 2 \leq i \leq N \wedge 2 \leq j \leq N\}$$

Iteration domain for **S**2 is

$$D_{S2} = \{(i,j)\ \epsilon\ Z^2 \mid 2 \leq i \leq 6 \wedge 2 \leq j \leq 6 \wedge i \leq j\}$$

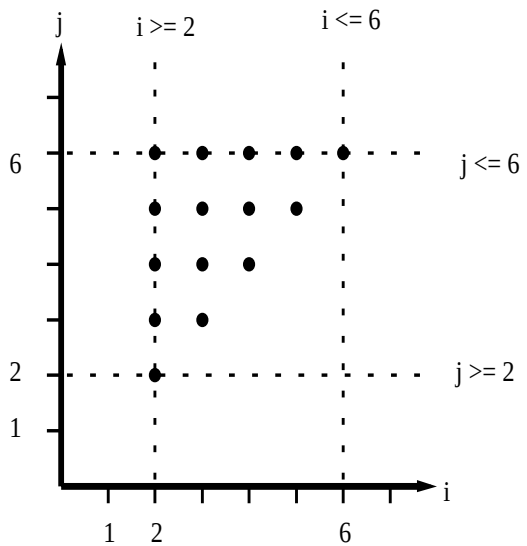

Figure: Graphical representation of iteration domain(S2)

Schedule

- Scattering function

Schedule

- Scattering function

```
for (int i = 2; i <= 4; i++)
  for (int j = 2; j <= 4; j++)
    P[i][j] = A[i] * B[j] ; // S3
```

Examples:

$\phi_{S3}(i,j) = (i,j)$

$\phi_{S3}(i,j) = (j,i)$

Schedule

- Scattering function

```
for (int i = 2; i <= 4; i++)
  for (int j = 2; j <= 4; j++)
    P[i][j] = A[i] * B[j] ; // S3
```

Examples:

$\phi_{S3}(i,j) = (i,j)$

$\phi_{S3}(i,j) = (j,i)$

Code generated by Cloog for $\phi_{S3}(i,j) = (j,i)$

```
for (t1 = 2; t1 <= 4; t1++) {
  for (t2 = 2; t2 <= 4; t2++) {
    i = t2; j = t1;
    P[i+j] += A[i] + B[j];
  }
}
```

Loops are interchanged here by applying this transformation.

Access function

A[i+j][i+N]

Array access function: $F_A(i, j) = (i + j, i + N)$

Change array access function for better locality

LLVM

- LLVM (Low Level Virtual Machine)
  - Framework for implementing compilers
  - Common low level code repersentation
  - Lifelong analysis and transformation of programs

Polly I

- Polly (Polyhedral Optimization in LLVM)
  - Implementing Polyhedral Optimization in LLVM
  - Effort towards Auto Parallelism in programs.
- Implementation
  - LLVM-IR to polyhedral model
    - Region-based SCoP detection
    - Semantic SCoPs
  - Polyhedral model
    - The integer set library
    - Composable polyhedral transformations
    - Export/Import
  - Polyhedral model to LLVM-IR
- Related work
  - gcc Graphite

Polly II

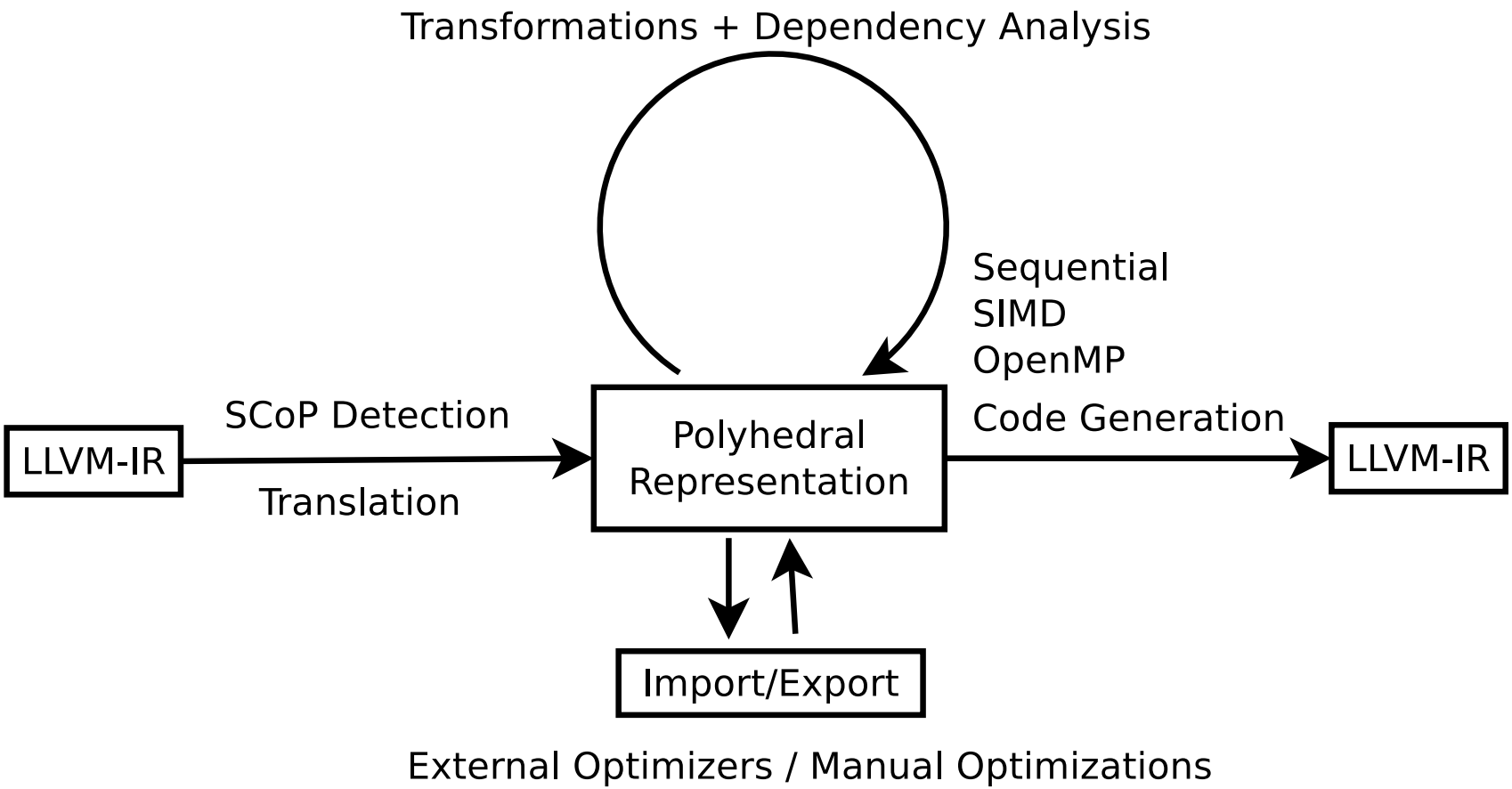

Figure: Architecture of Polly

OpenMP Code Generation in Polly I

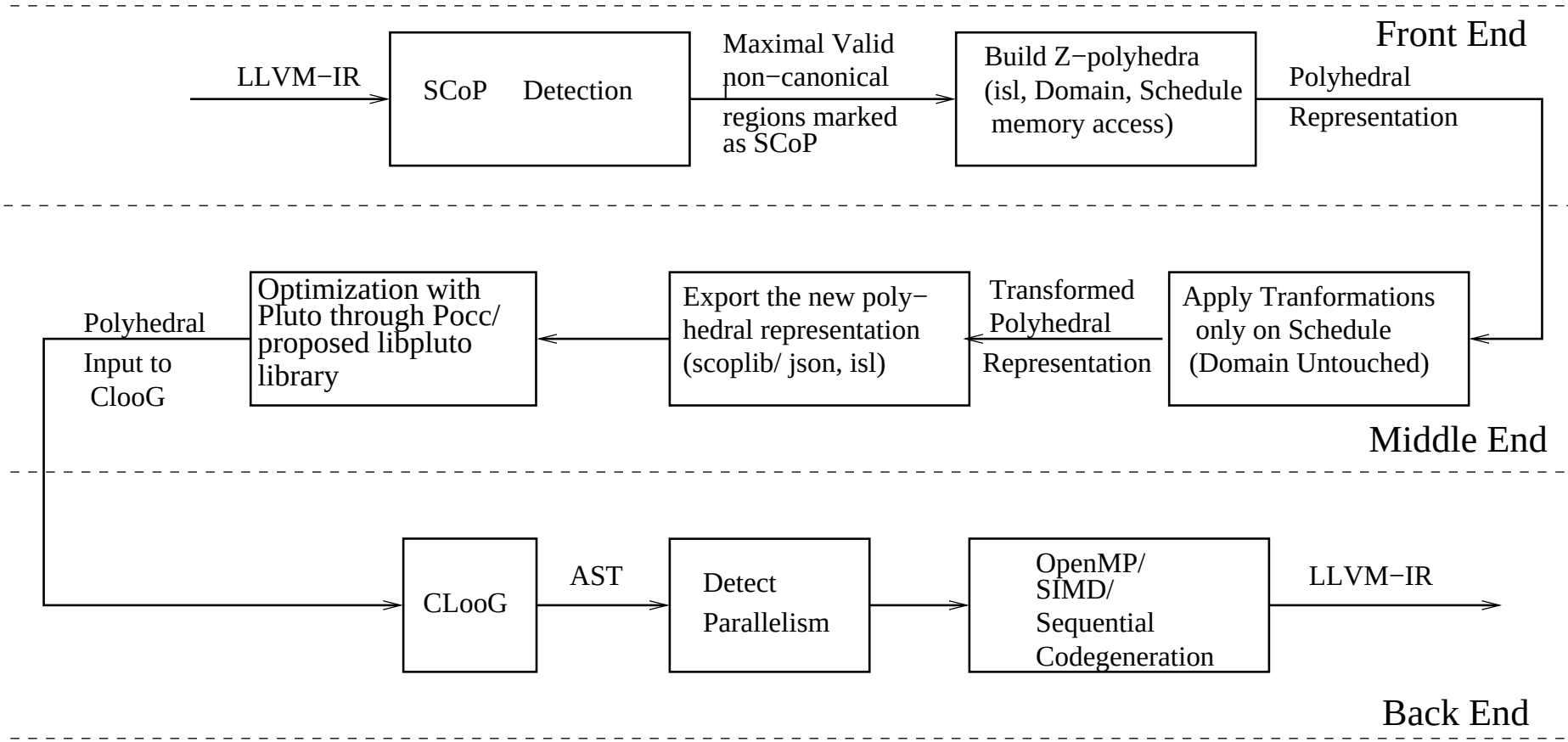

Figure: Detailed control flow in Polly

OpenMP Code Generation in Polly I

- Code generation pass in Polly
- Detecting parallelism in Polly
- Generating OpenMP library calls

```
for (int i = 0; i <= N; i++)
  A[i] = 1 ;
```

OpenMP Code Generation in Polly I

OpenMP Code Generation in Polly II

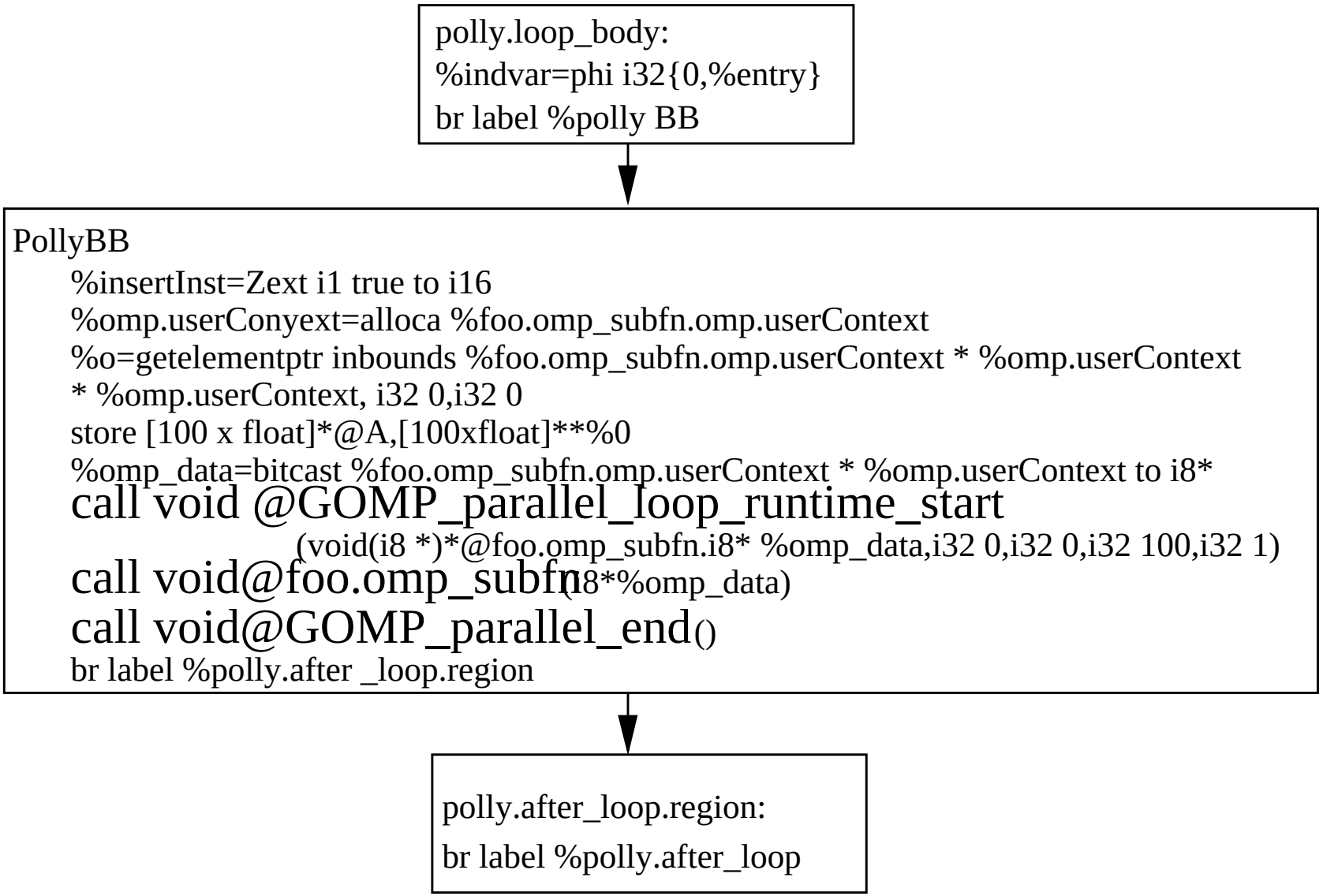

Figure: CFG showing sequence of OpenMP library calls

OpenMP Code Generation in Polly I

- Support for inner loops

```
for (int i = 0; i < M; i++)
  for (int j = 0; j < N; j++)
    A[j] += M;
```

  Surrounding induction variables and parameters need to be passed to the subfunction

- Dealing with memory references

```
#define N 10
void foo() {
  float A[N];
  for (int i=0; i < N; i++)
    A[i] = 10;
  return;
}
```

  - Adding and extracting memory references

OpenMP Code Generation in Polly II

- Enabling OpenMP code generation in Polly

```
export LIBPOLLY=<path to cmake>/lib/LLVMPolly.so
pollycc -fpolly -fparallel a.c

OR

# Generate the LLVM-IR files from source code.
clang -S -emit-llvm a.c
alias opt="opt -load $LIBPOLLY
# Apply optimizations to prepare code for polly
opt -S -mem2reg -loop-simplify -indvars a.c -o a.preopt.ll
# Generate OpenMP code with Polly
opt -S -polly-codegen -enable-polly-openmp a.preopt.ll -o a.ll
# Link with libgomp
llc a.ll -o a.s
llvm-gcc a.s -lgomp
```

- OpenMP testcases
  - Polly follows LLVM testing infrastrcutre

Testing with PolyBench I

- PolyBench
  Benchmarks from
  - linear algebra
  - datamining
  - stencil computation
  - solver and manipulation algorithms operating on matrices

Experimental results I

Experimental results II

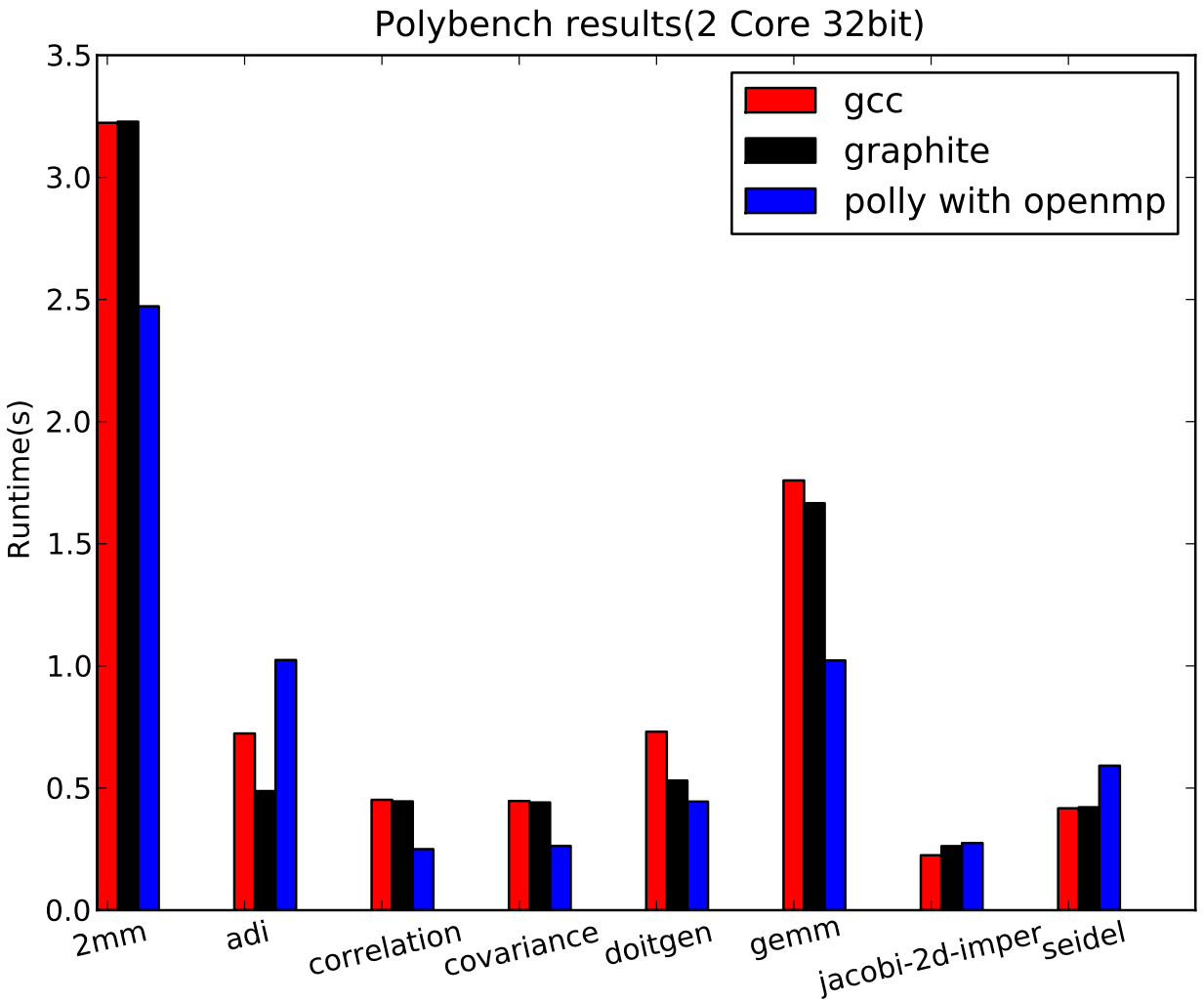

Figure: Performance comparison(2 core 32 bit)

Experimental results I

Experimental results II

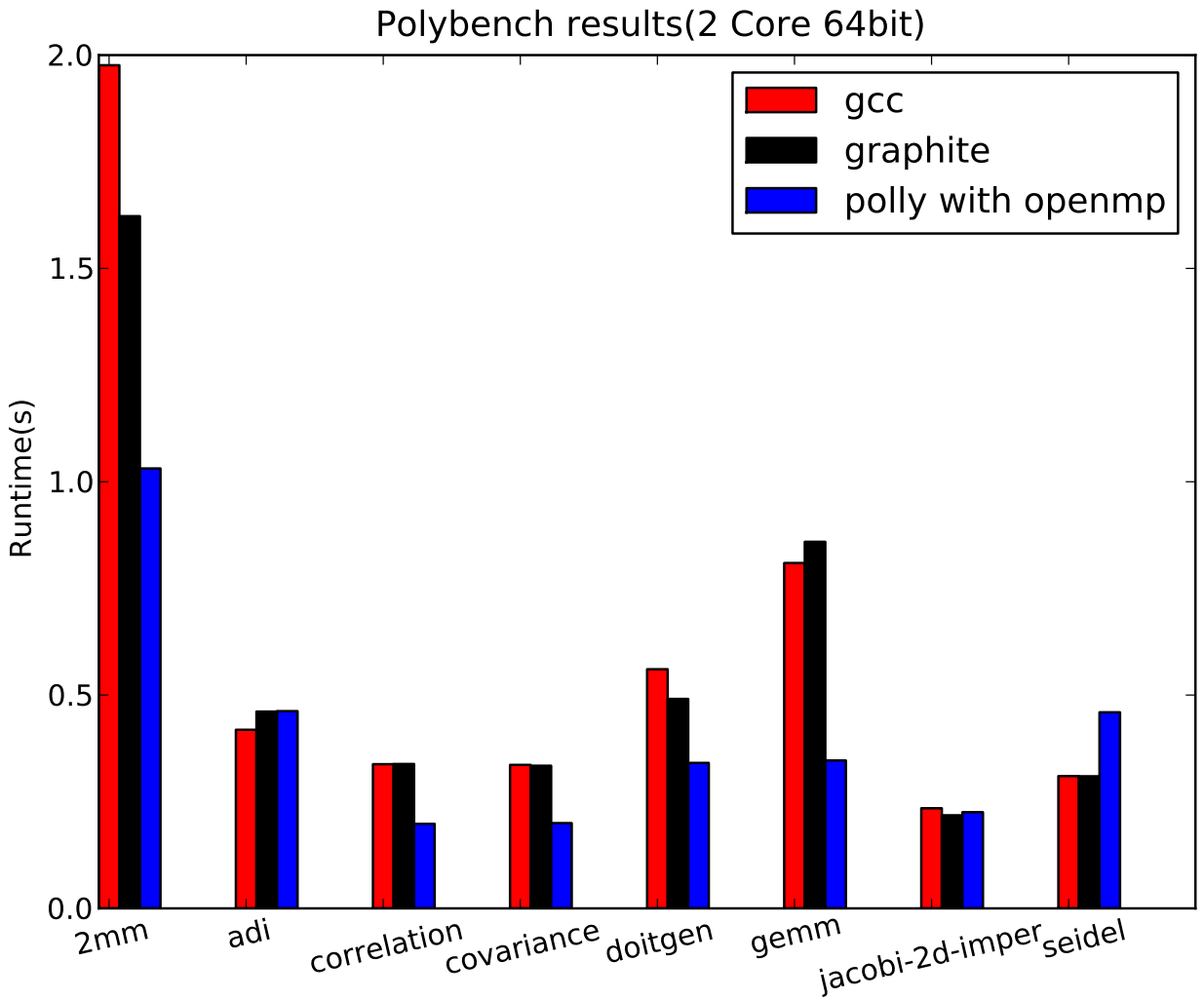

Figure: Performance comparison(2 core 64bit)

Experimental results I

Experimental results II

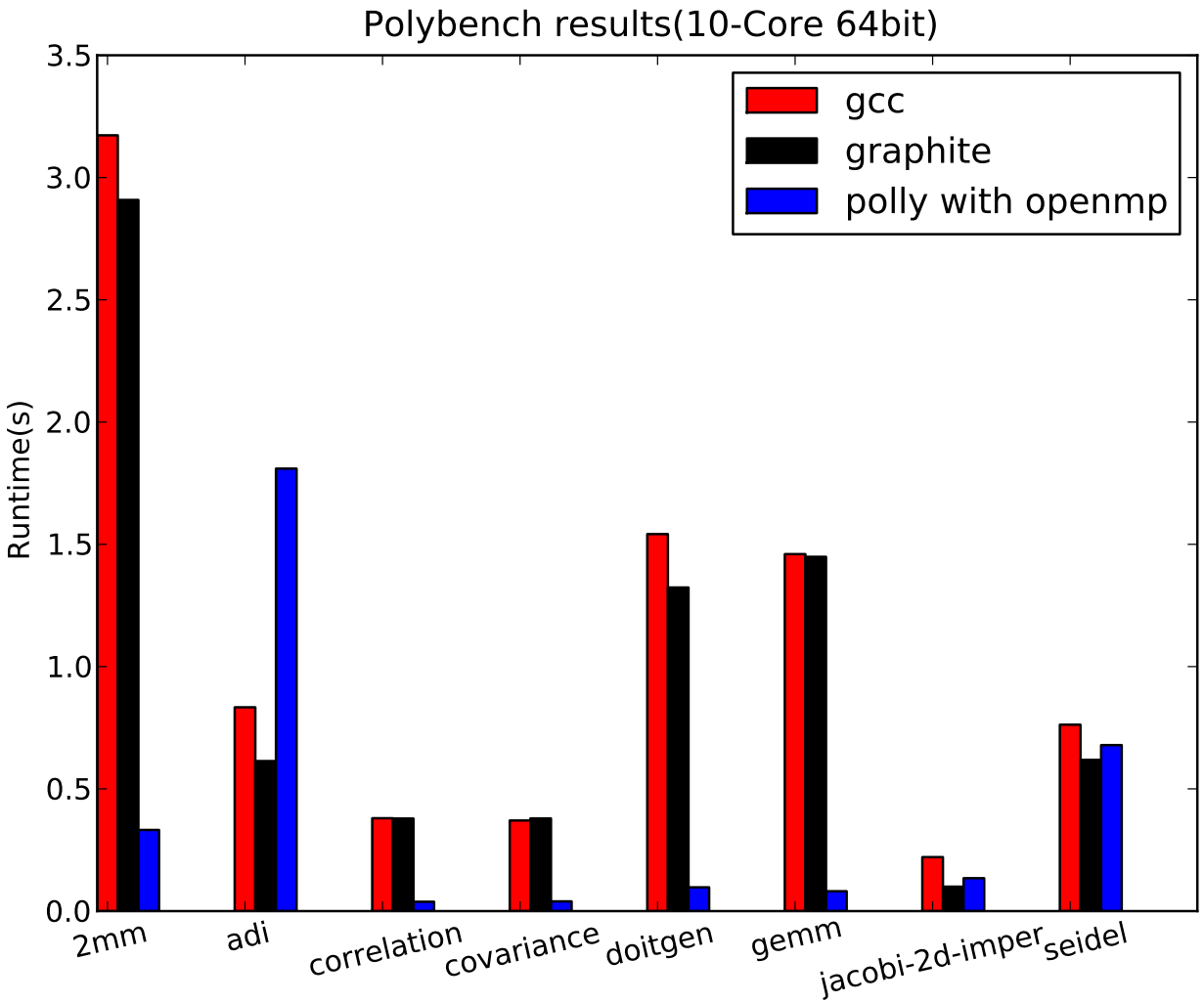

Figure: Performance comparison(10-core 64 bit)

Conclusion and Future Work

- Conclusion
- Support for memory access transformations in Polly
- Increasing coverage of Polly
  - Increasing SCoP coverage
  - Increasing the system coverage
- Integrating profile guided optimization into Polly

Setting up the environment

- CLooG
- PoCC
- Scoplib
- Building LLVM with Polly

Various Tools Used in Polyhedral Community

- ClooG
- PLUTO
- VisualPolylib