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PROGRAMME DE RECHERCHE
NUMÉRIQUE POUR L'EXASCALE

Apollo - Automatic speculative POLyhedral Loop Optimizer

Exa-Soft Annual Meeting

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Outline

1. Apollo
2. Polyhedral model
3. Runtime polyhedral optimization
4. The path ahead
5. Try it for yourself

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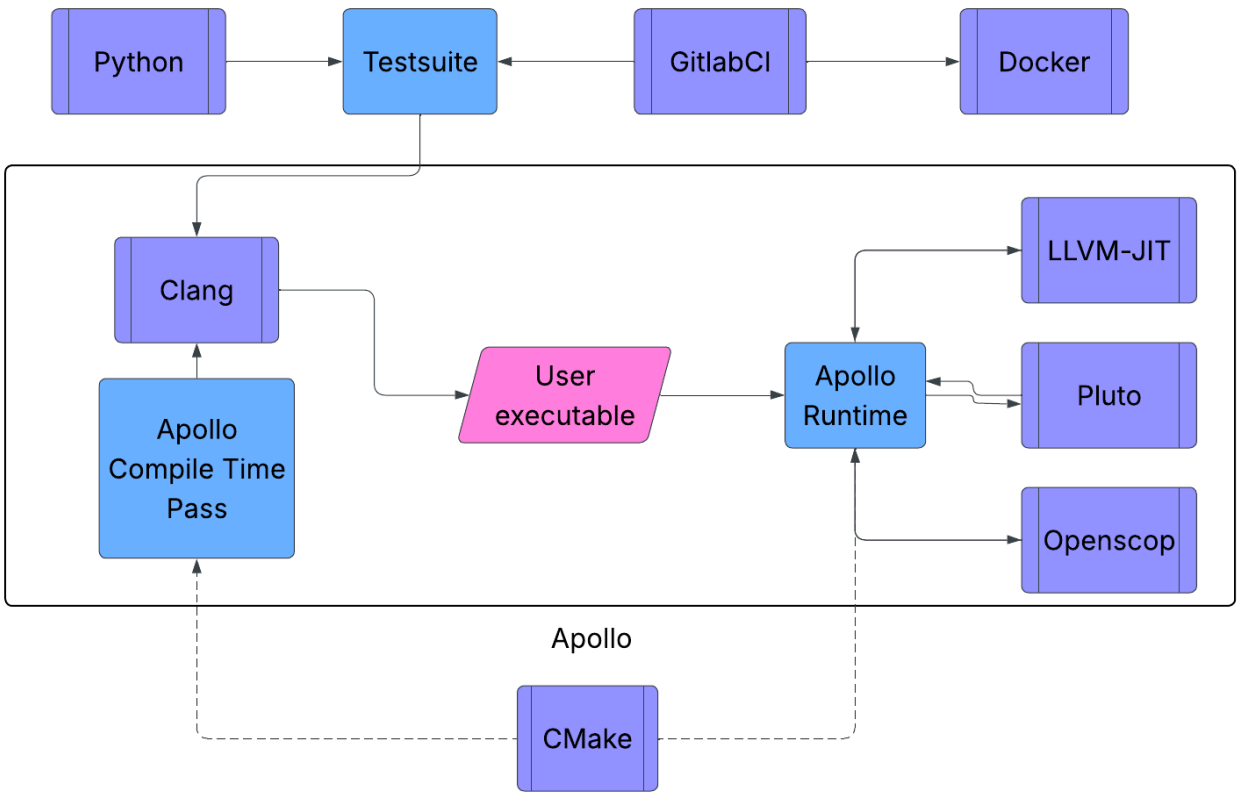
Apollo

- Compiler built on Clang and LLVM
- Seek to apply the polyhedral model at runtime
- Aimed at scientific code

Toolchain



Apollo Toolchain

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Polyhedral model

Theory

- In an ideal loop, all statements should run in parallel
- In an ideal loop, memory accesses should have a good locality
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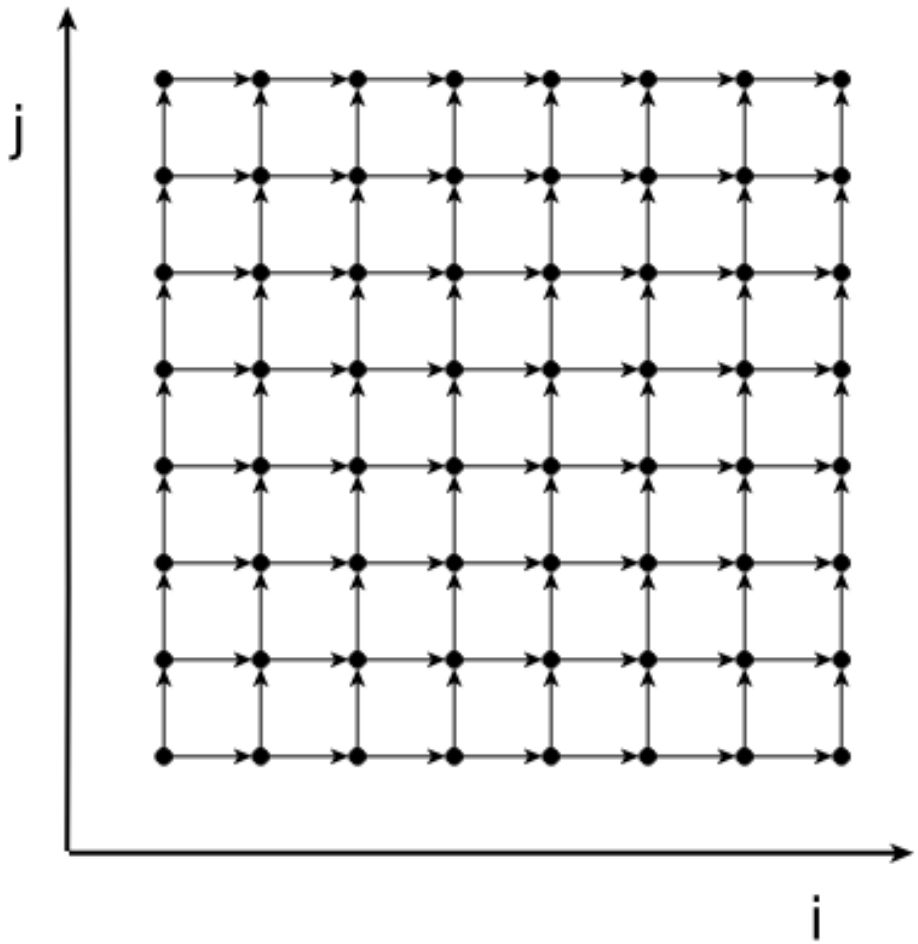
Theory

- In an ideal loop, all statements should run in parallel
- In an ideal loop, memory accesses should have a good locality
- Loop nest can be represented as an iteration domain
- This iteration domain is a discrete polyhedron, which can be transformed
- The underlying loop nest can thus be transformed and optimized

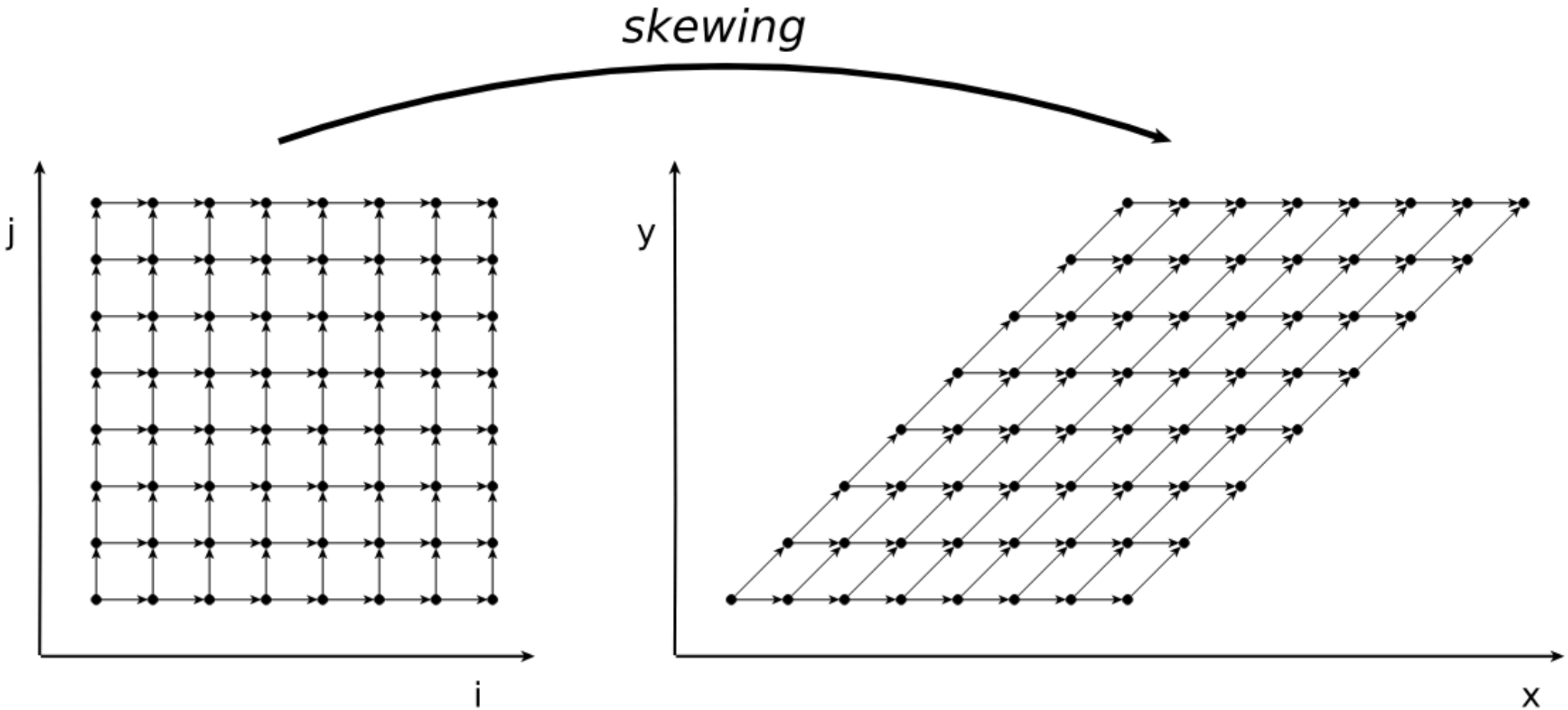
Parallelize statements

```c
1  for (i = 1; i < N; i++) // i axis
2    for (j = 1; j < M; j++) // j axis
3      a[i][j] += a[i-1][j] * a[i][j-1]; // (i,j) point
```

Problem



Applying the model



Parallelized statements

```
1  for (x = 2; x <= N+M-2; x++)                                    c
2    #pragma omp parallel for
3    for (y = max(1, x-N+1); y <= min(x-1, M-1); y++)
4      a[x-y][y] += a[x-y-1][y] * a[x-y][y-1];
```

Solution

Other polyhedral optimizations

- Loop tiling
- Loop unrolling
- Loop fusion
- ...

Applying the model

```c
#pragma scop
  for (i = 0; i < M; i++)
    for (j = 0; j < N; j++)
      for (k = 0; k < K; k++)
        C[i][j] = beta * C[i][j] + alpha * A[i][k] * B[k][j];
#pragma endscop
```

c

pluto/examples/matmul/matmul.c

Applying the model

```
1   #def S1(...) C[i][j] = beta*C[i][j]+alpha*A[i][k]*B[k][j];
2   [...]
3   #pragma omp parallel for private(lbv,ubv,t2,t3,t4,t5,t6)
4     for (t1=lbp;t1<=ubp;t1++) {
5       [...]
6       for (t5=32*t3;t5<=(min(K-1,32*t3+31))-7;t5+=8) {
7         [...]
8           S1(t1,t2,t3,(t4+7),t6,(t5+7));
9   [...]
10  for (;t4<=min(M-1,32*t1+31);t4++) {
11      [...]
12        S1(t1,t2,t3,t4,t6,t5);
13  [...]
```

c

Limitations

- Limits on the iteration domain
- Indexes must be known and affine from one another
- Memory accesses must be affine from indexes
- Memory mapping must be known at compile time
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- Limits on the iteration domain
- Indexes must be known and affine from one another
- Memory accesses must be affine from indexes
- Memory mapping must be known at compile time
- A[x] = B[y - 1] + C[x] => OK
- A[X] += B[C[y - 1]] => KO, indirect access
- (A + x) += (B + y) => KO, A alias B ?
- while(x) => KO, unknown bounds

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Runtime polyhedral optimization

Reasoning

- Indexes or accesses can hide their affineness
- Pointer can be unraveled at runtime
- Memory analysis at runtime allows for speculation

Implementation

Compile time

- Preanalyse the code
- Instrument the loop for runtime analysis
- Split the loop into rearrangeable code pieces
- Create an entry point for the JIT

Implementation

Compile time

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Run time

- Profile samples at runtime to create speculation pattern
- Analyse the reorganized loop using working polyhedral tool
- Run optimized loop while ensuring speculation error correction

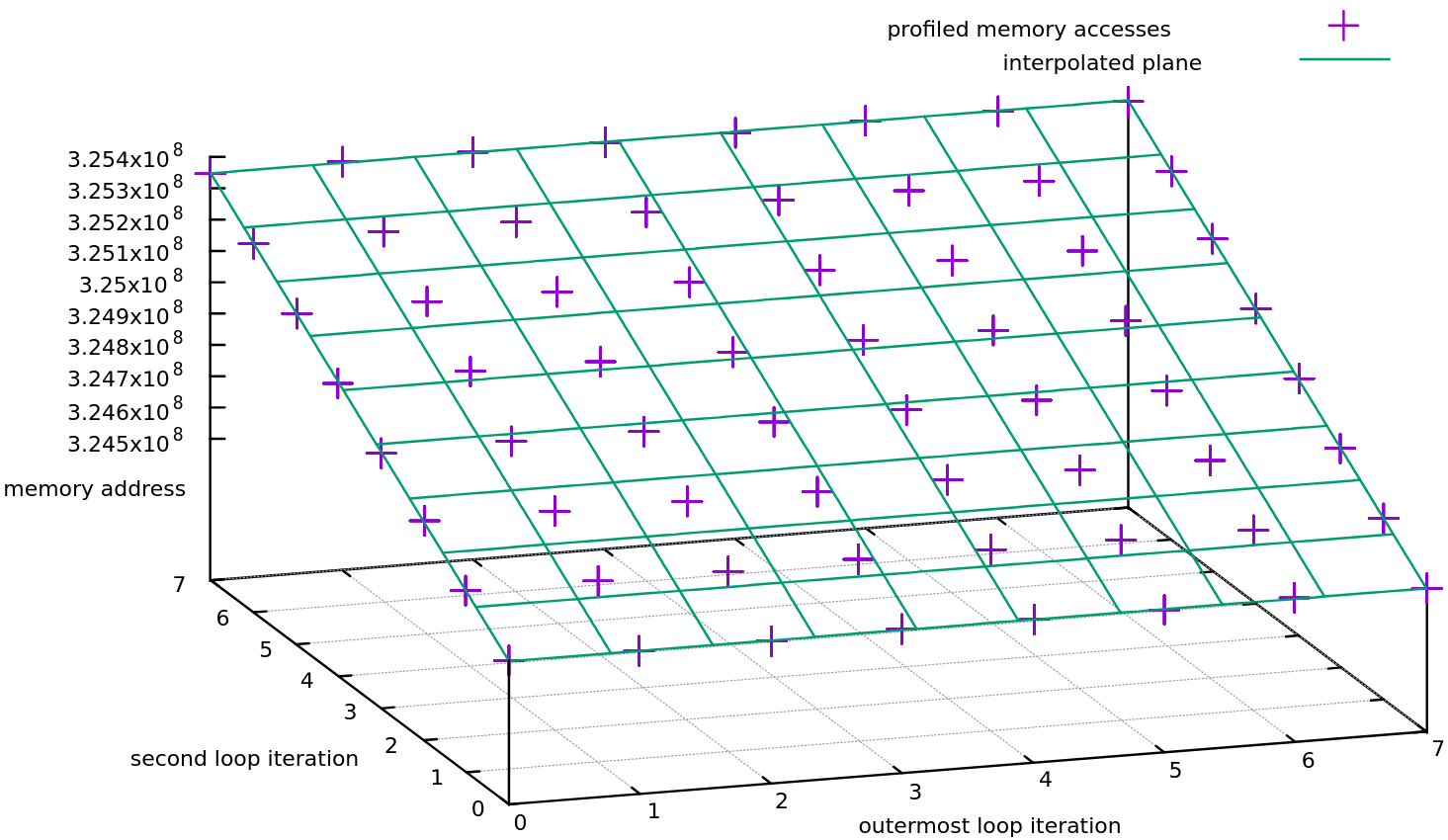
Sparse matrix multiplication

```c
for(row = 1; row <= left->Size; row++) {
  pElem = left->FirstInRow[row];
  while(pElem) {
    for(col = 1; col <= cols; col++) {
      result[row][col] += pElem->Real * right[pElem->Col][col];
    }
    pElem = pElem->NextInRow;
  }
}
```

c

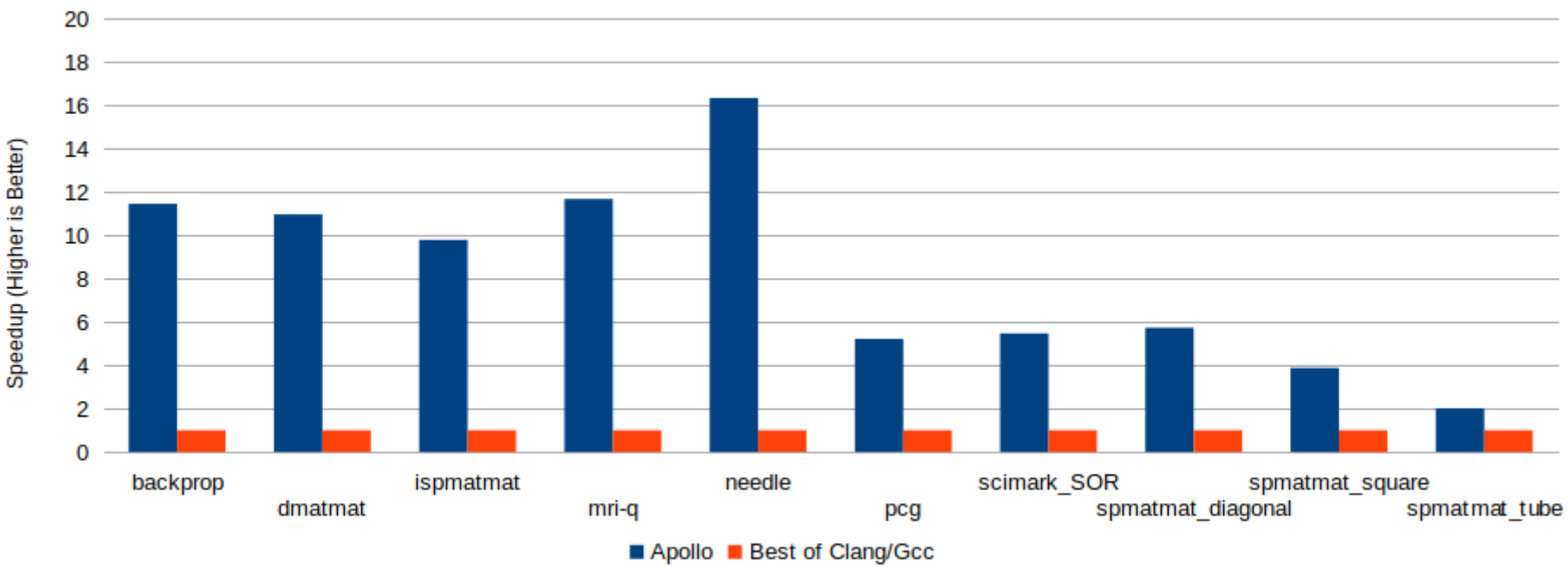
Example

Sparse matrix multiplication



Runtime analysis

Some numbers on polybenchs



AMD Opteron 6172, 2X12-core

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The path ahead

Multiversioning

- Optimization parameters can greatly ehance performance
- Tile size, loop unrolling factor, ...
- Finding the right parameters is a tricky part
- Parameters trials combined with multiversioning could be the key

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Try it for yourself

With Docker

```sh
$ docker run --pull=always -ti registry.gitlab.inria.fr/pclauss/apollo/debian10:latest sh
$ apolloc -O3 -o matmul /root/apollo-build/src/examples/matmul.c
$ ./matmul
```

With Spack

```sh
$ spack config add modules:prefix_inspections:lib64:[LD_LIBRARY_PATH]
$ spack config add modules:prefix_inspections:lib:[LD_LIBRARY_PATH]
$ spack env activate --create myenv
$ spack add apollo
$ spack install apollo@develop
$ apolloc -O3 -o matmul matmul.c
$ ./matmul
```

All links on our website

- https://webpages.gitlabpages.inria.fr/apollo/download

Thank you for your time.

Questions ?