SPolly: Speculative Optimizations in the Polyhedral Model

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The Problem

```
int A[256][256], B[256][256], C[256][256];

void matmul() {
  for (int i=0; i<256; i++)
    for (int j=0; j<256; j++)
      for (int k=0; k<256; k++)
        C[i][j] += A[k][i] * B[j][k];
}
```

The Problem

```
int A[65536], B[65536], C[65536];

void matmul() {
  for (int i=0; i<256; i++)
    for (int j=0; j<256; j++)
      for (int k=0; k<256; k++)
        C[i*256+j] += A[k*256+i] * B[j*256+k];
}
```

The Problem

```
void matmul(int* A, int* B, int* C) {
  for (int i=0; i<256; i++)
    for (int j=0; j<256; j++)
      for (int k=0; k<256; k++)
        C[i*256+j] += A[k*256+i] * B[j*256+k];
}
```

The Problem

```
void matmul(int* A, int* B, int* C, int N) {
  for (int i=0; i<N; i++)
    for (int j=0; j<N; j++)
      for (int k=0; k<N; k++)
        C[i*N+j] += A[k*N+i] * B[j*N+k];
}
```

How urgent is this problem?

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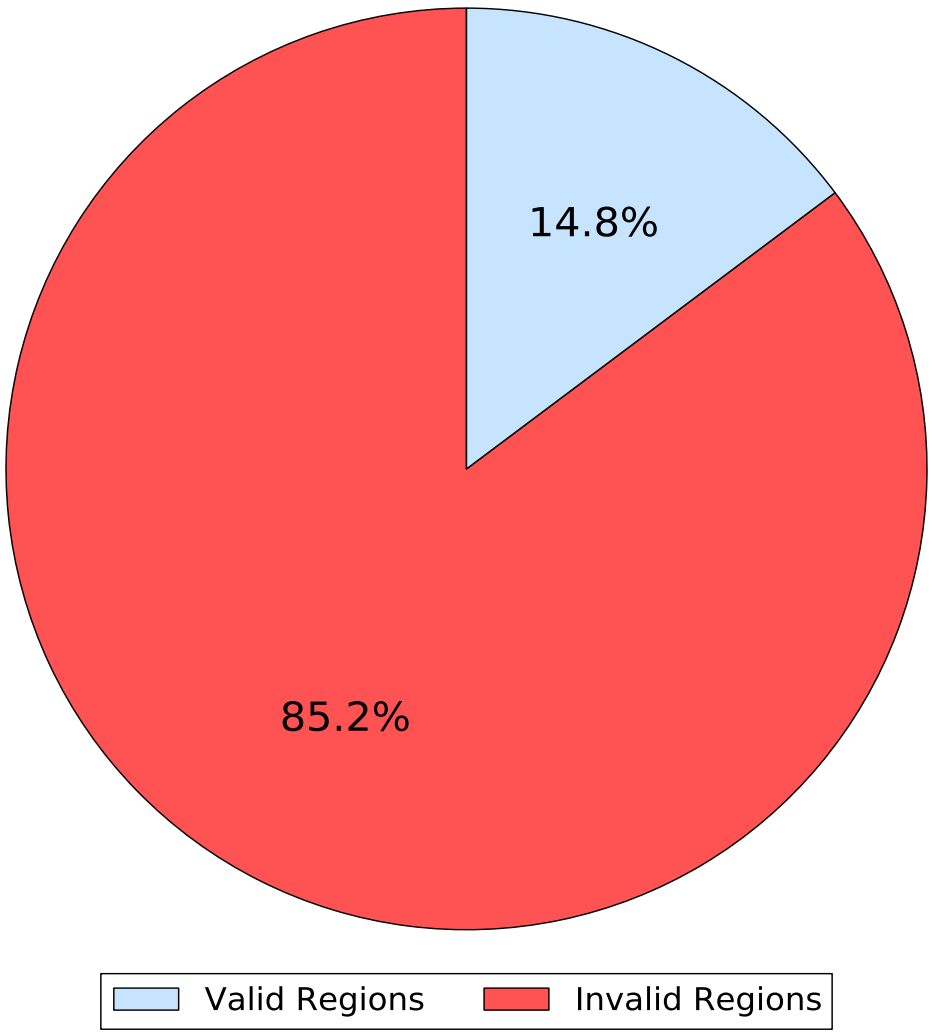

How urgent is this problem?

Setup

- Polly
  - state-of-the-art polyhedral optimizer integrated in LLVM
- SPEC 2000
  - industry standard benchmark suite
  - nine real world programs:
    ammp, art, bzip2, crafty, equake, gzip, mcf, mesa, twolf

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Setup

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  - nine real world programs:
    ammp, art, bzip2, crafty, equake, gzip, mcf, mesa, twolf
- Research questions
  - number of Static Control Parts
    (SCoPs := code regions amenable to polyhedral optimizations)
  - impact of individual rejection causes

How urgent is this problem?

SCoP rejection causes found in 1862 regions

i	Rejection cause	A	B	C
0	Non-affine expressions			
1	Aliasing			
2	Non-affine loop bounds			
3	Function call			
4	Non-canonical indvars			
5	Complex CFG			
6	Unsigned comparison			
7	Others			

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```
for (i = 0; i < N; i++)
  A[i*N] += B[i];
```

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```
void f(int* A, int* B){
  A[0] = B[5];
```

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7	Others			

```
for (i = 0; i < N*M; i++)
  A[i] += B[i];
```

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

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7	Others			

```
for (i=0; i<N; i+=i/2+1)
  A[i] += A[i+1];
```

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How urgent is this problem?

SCoP rejection causes found in 1862 regions

i	Rejection cause	A	B	C
0	Non-affine expressions	1230 (66%)		
1	Aliasing	1093 (59%)		
2	Non-affine loop bounds	840 (45%)		
3	Function call	532 (29%)		
4	Non-canonical indvars	384 (21%)		
5	Complex CFG	253 (14%)		
6	Unsigned comparison	199 (11%)		
7	Others	1 (0%)		

A #regions where condition i is violated.

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SCoP rejection causes found in 1862 regions

i	Rejection cause	A	B	C
0	Non-affine expressions	1230 (66%)	84 (5%)	
1	Aliasing	1093 (59%)	207 (11%)	
2	Non-affine loop bounds	840 (45%)	6 (0%)	
3	Function call	532 (29%)	72 (4%)	
4	Non-canonical indvars	384 (21%)	0 (0%)	
5	Complex CFG	253 (14%)	31 (2%)	
6	Unsigned comparison	199 (11%)	0 (0%)	
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A #regions where condition i is violated.

B #regions where *only* condition i is violated.

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2	Non-affine loop bounds	840 (45%)	6 (0%)	660 (35%)
3	Function call	532 (29%)	72 (4%)	928 (50%)
4	Non-canonical indvars	384 (21%)	0 (0%)	1174 (63%)
5	Complex CFG	253 (14%)	31 (2%)	1387 (74%)
6	Unsigned comparison	199 (11%)	0 (0%)	1586 (85%)
7	Others	1 (0%)	0 (0%)	1587 (85%)

A #regions where condition *i* is violated.

B #regions where *only* condition *i* is violated.

C #regions where *only* conditions 0 to *i* are violated.

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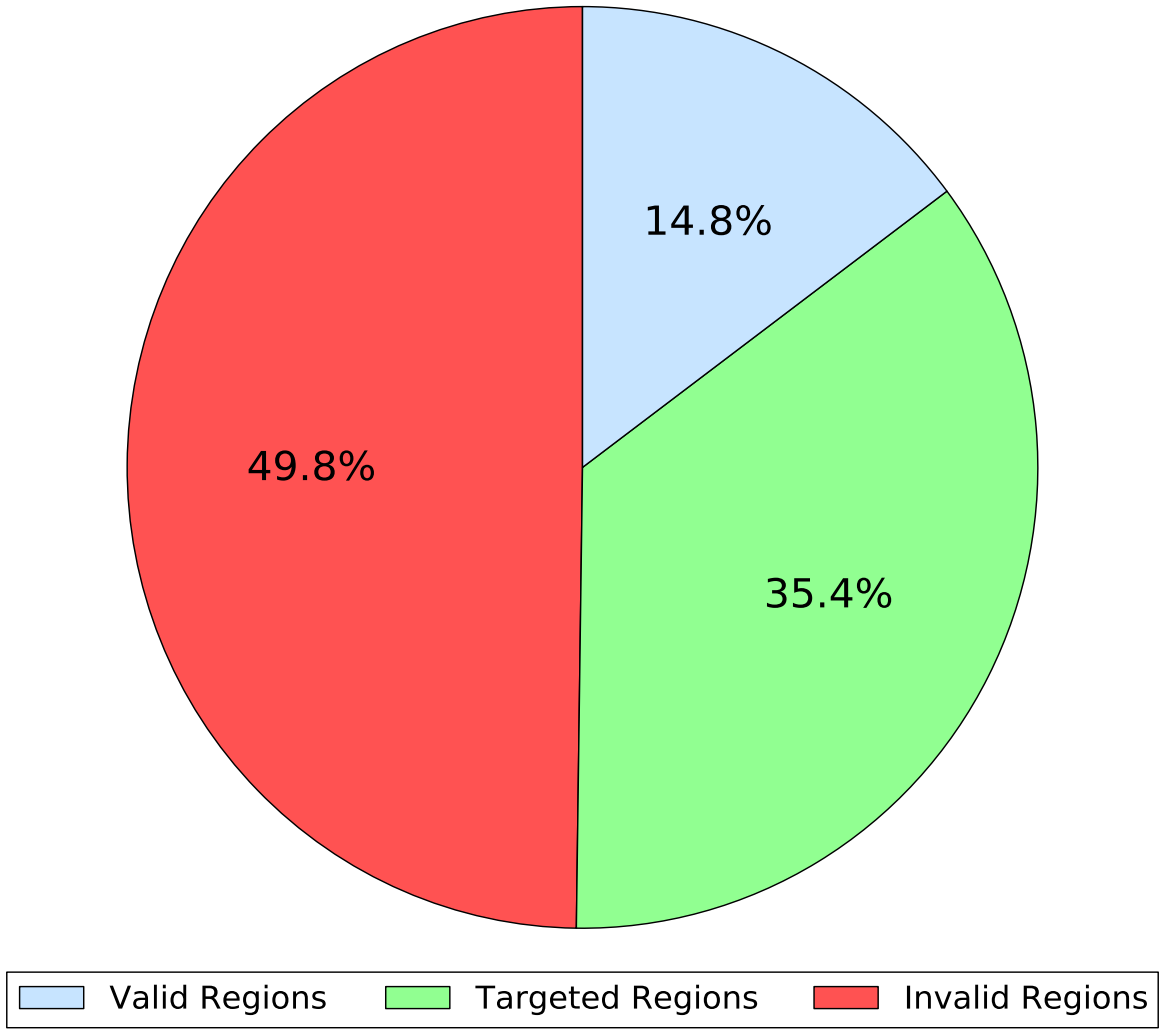
Conclusion



How to allow more polyhedral optimizations?

Example

```
void f(int* A,  int* B) {
  for (int i=0; i < 2048; i++)
    A[i] += B[i];
}
```

How to allow more polyhedral optimizations?

Example

1. **speculatively** assume properties (e.g., constant parameters)

```
void f(int* A,  int* B) {
  for (int i=0; i < 2048; i++)
    A[i] += B[i];
}
```

How to allow more polyhedral optimizations?

Example

1. **speculatively** assume properties (e.g., constant parameters)
2. derive **specialized** versions

```
void f_spec(int* restrict A,  int* restrict B) {
  for (int i=0; i < 2048; i++)
    A[i] += B[i];
}
```

How to allow more polyhedral optimizations?

Example

1. **speculatively** assume properties (e.g., constant parameters)
2. derive **specialized** versions
3. apply **polyhedral optimizations**

```
void f_opt(int* restrict A,  int* restrict B) {
  parfor (int j=0; j < 2048; j+=32)
    for (int i=j; i < 32 + j; i++)
      A[i] += B[i];
}
```

How to allow more polyhedral optimizations?

Example

1. **speculatively** assume properties (e.g., constant parameters)
2. derive **specialized** versions
3. apply **polyhedral optimizations**
4. add **runtime dispatcher**

```
void f_dispatcher(int* A, int* B) {
  if (overlap(A, B, 2048))
    f(A, B);
  else
    f_opt(A, B);
}
```

How to allow more polyhedral optimizations?

Implementation

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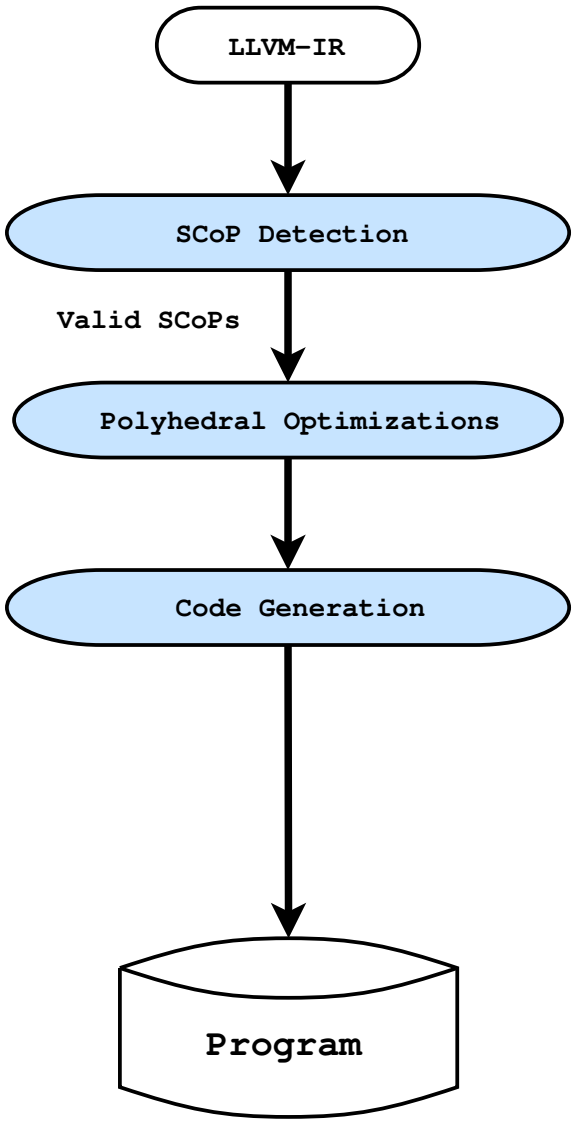
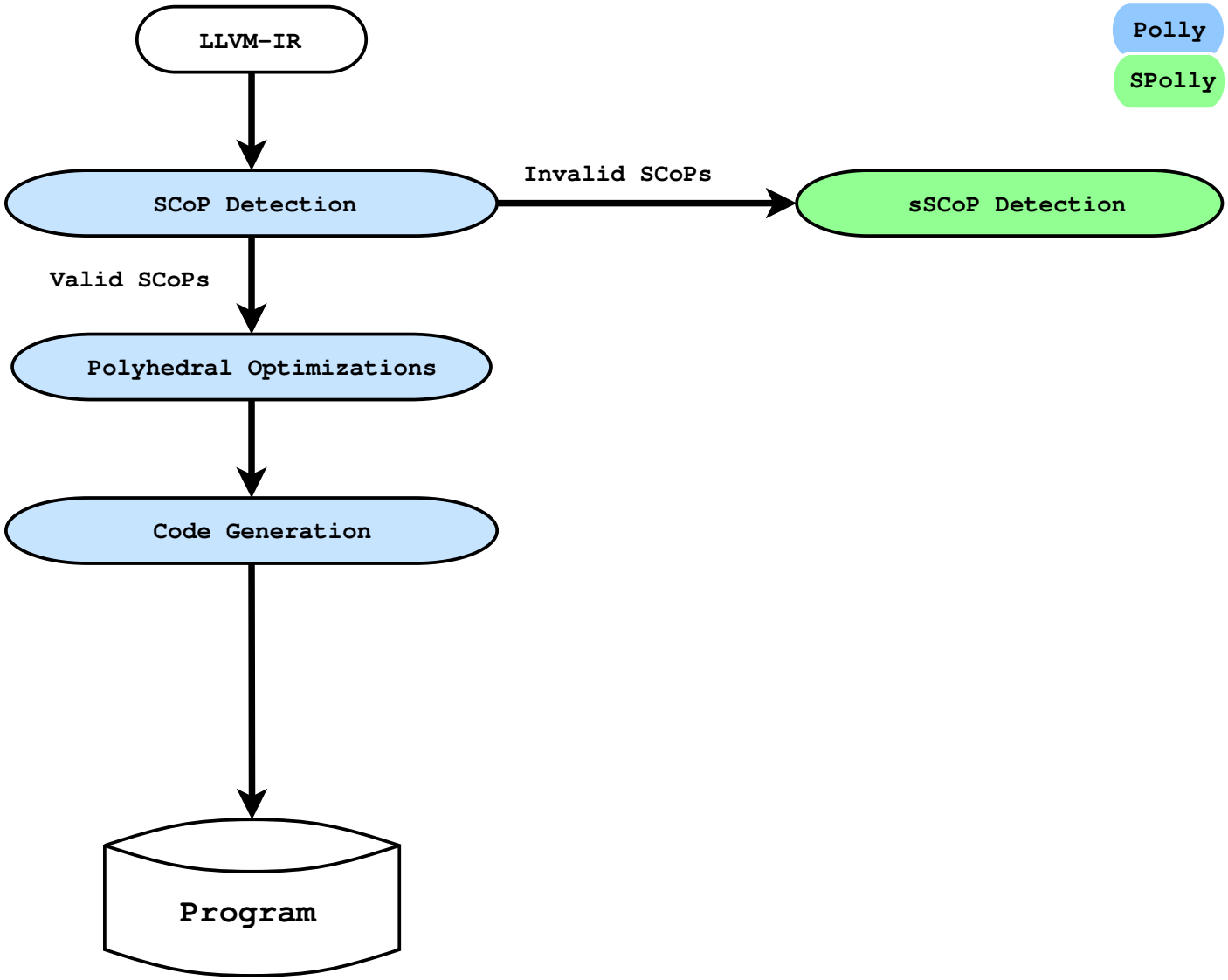
Implementation



Polly

How to allow more polyhedral optimizations?

Implementation



How to allow more polyhedral optimizations?

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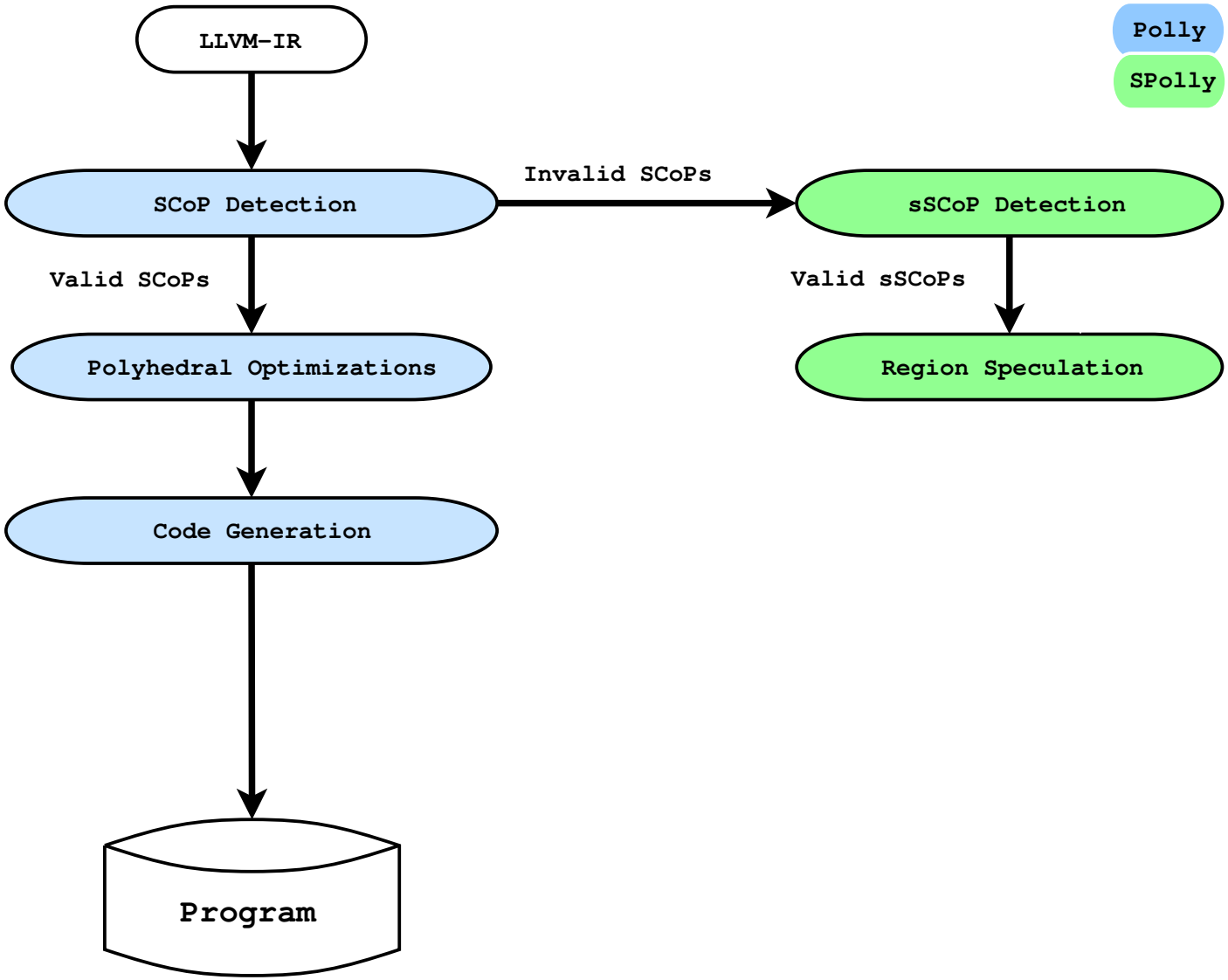

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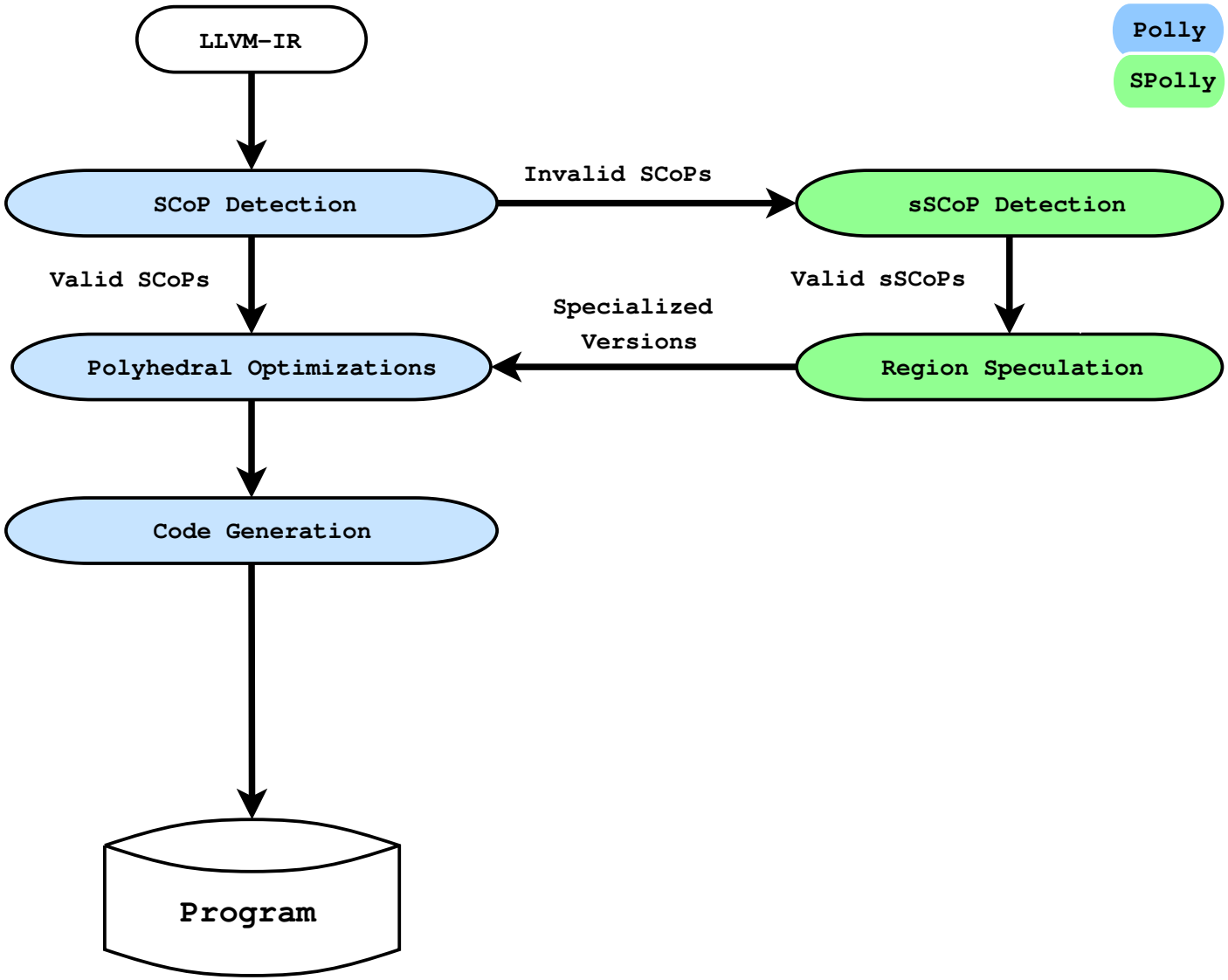

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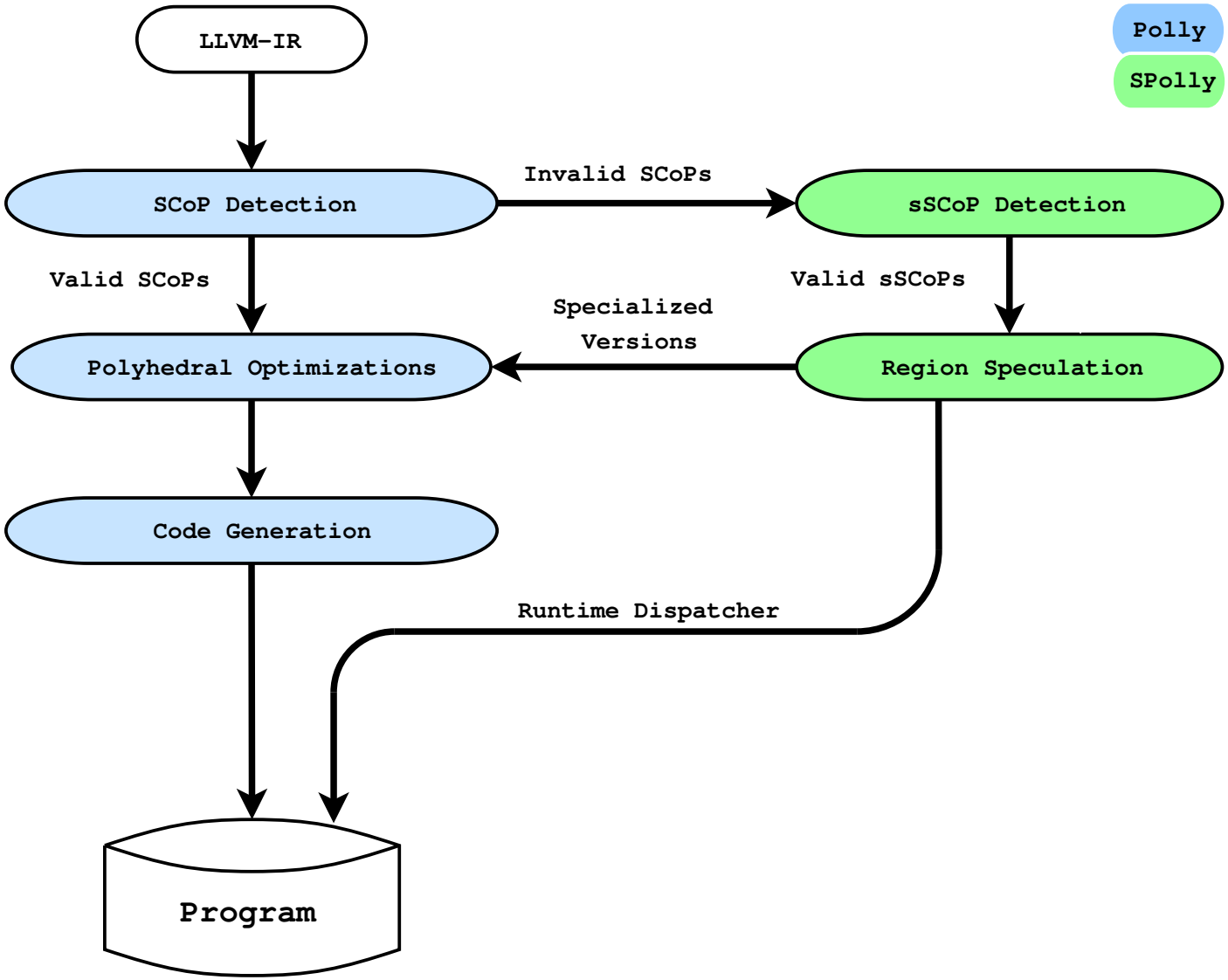

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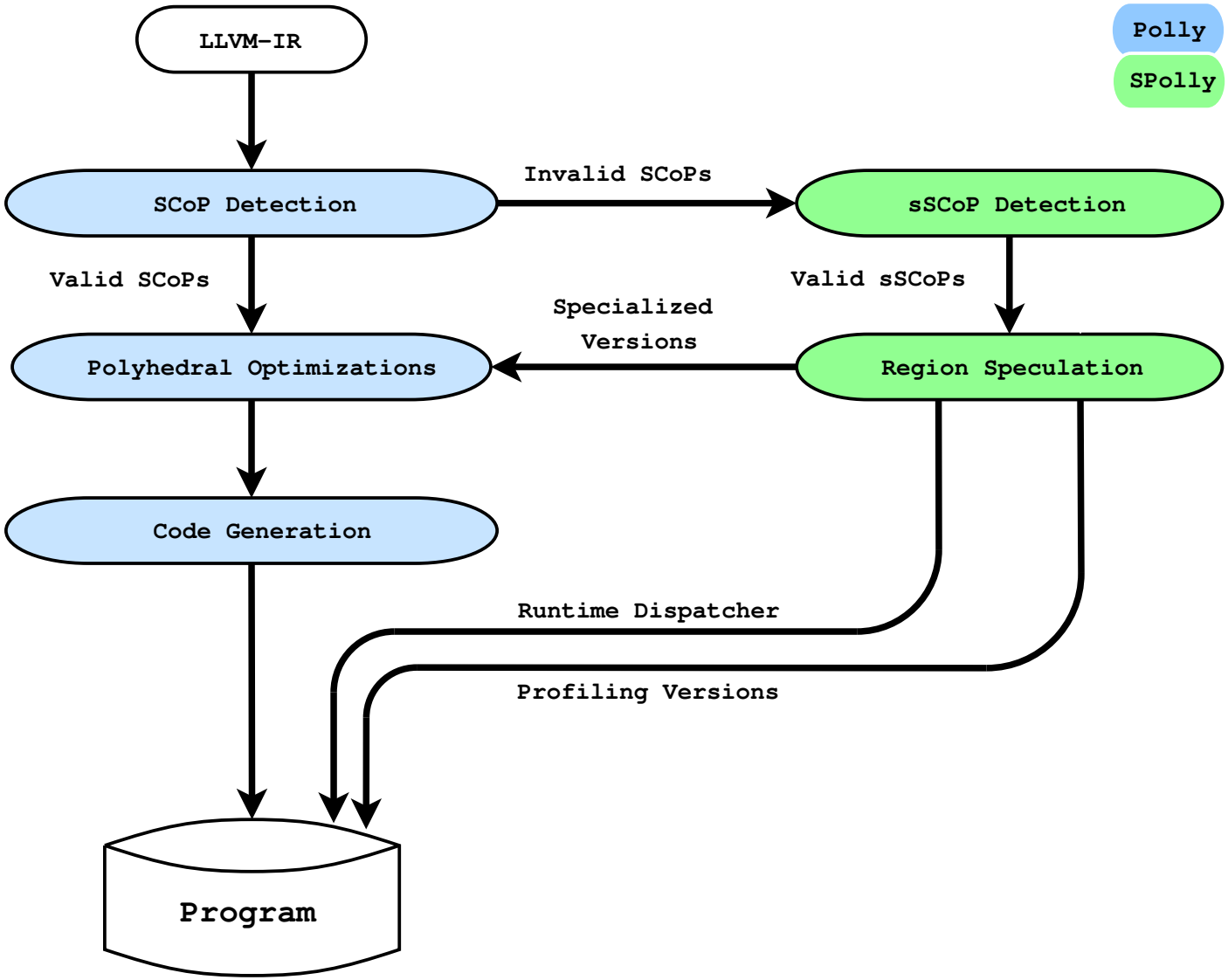

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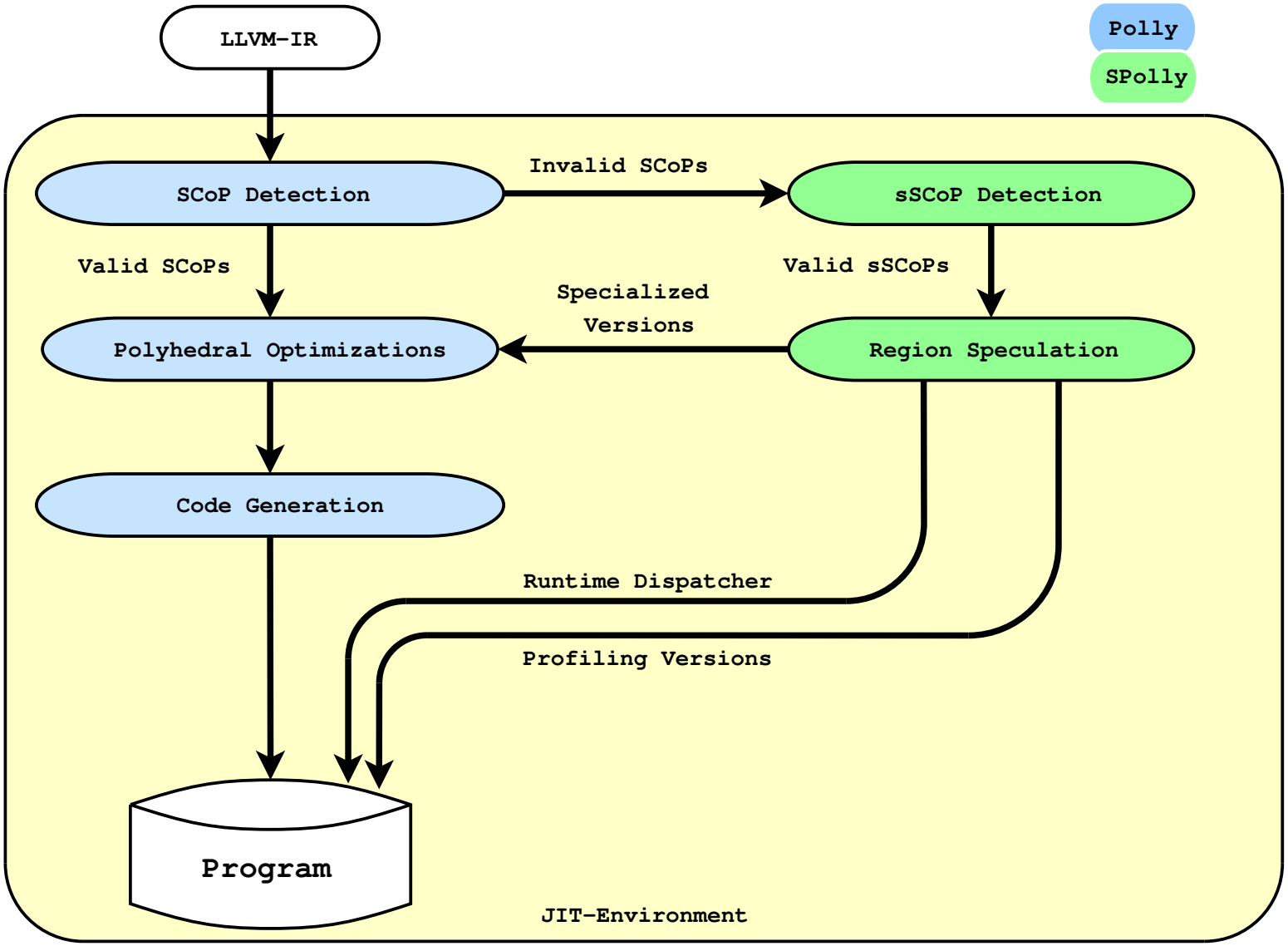

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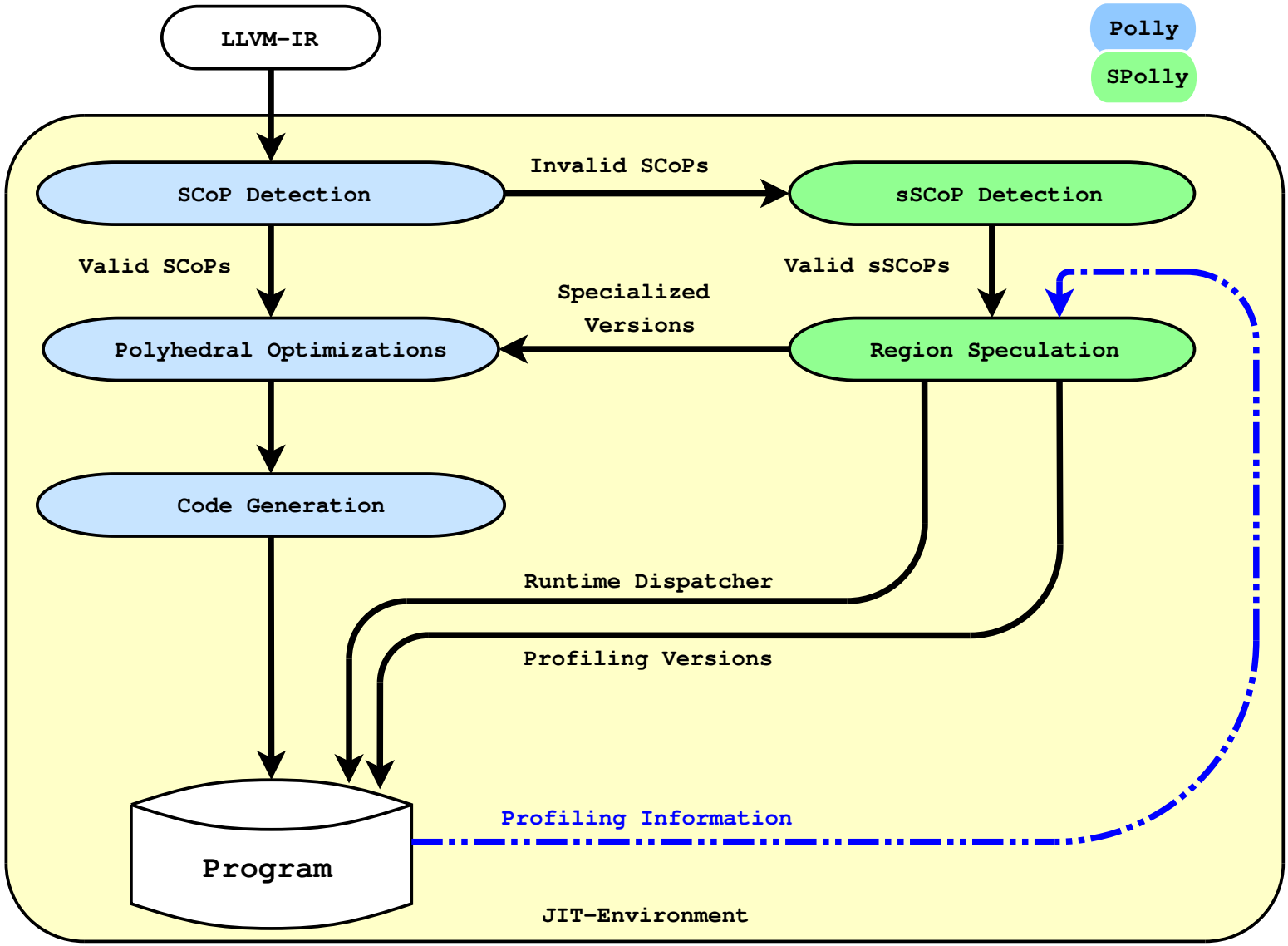

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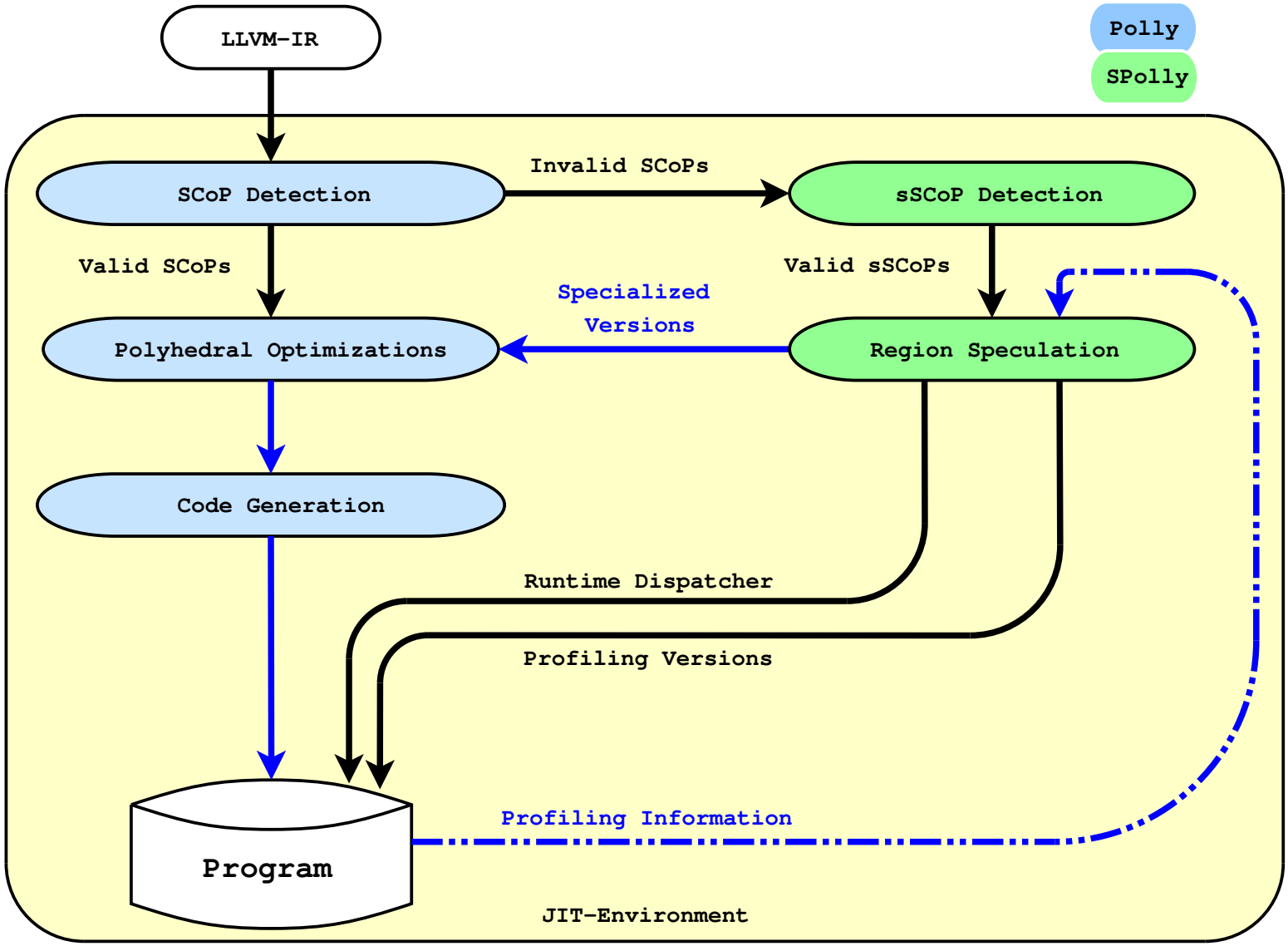

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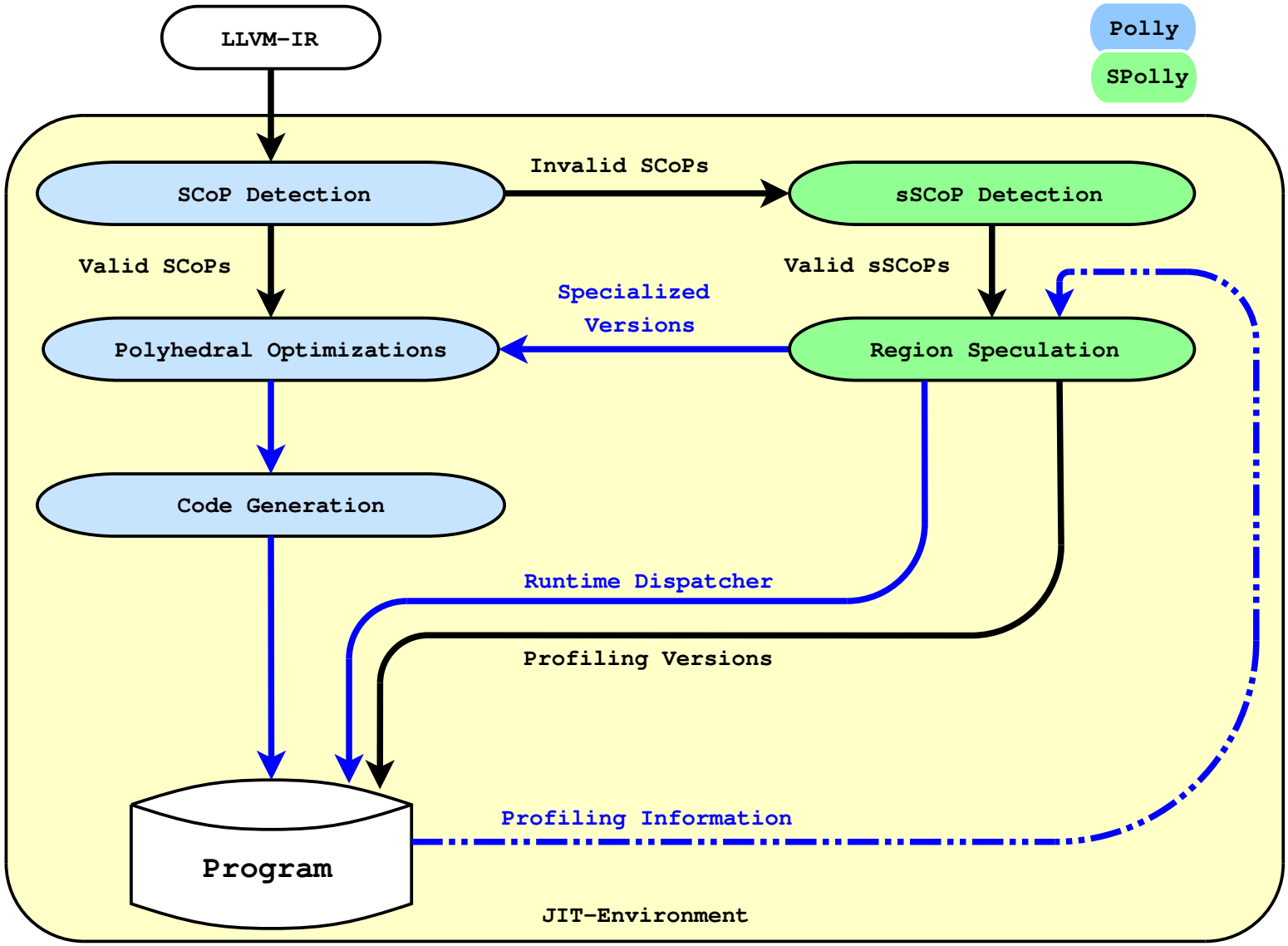


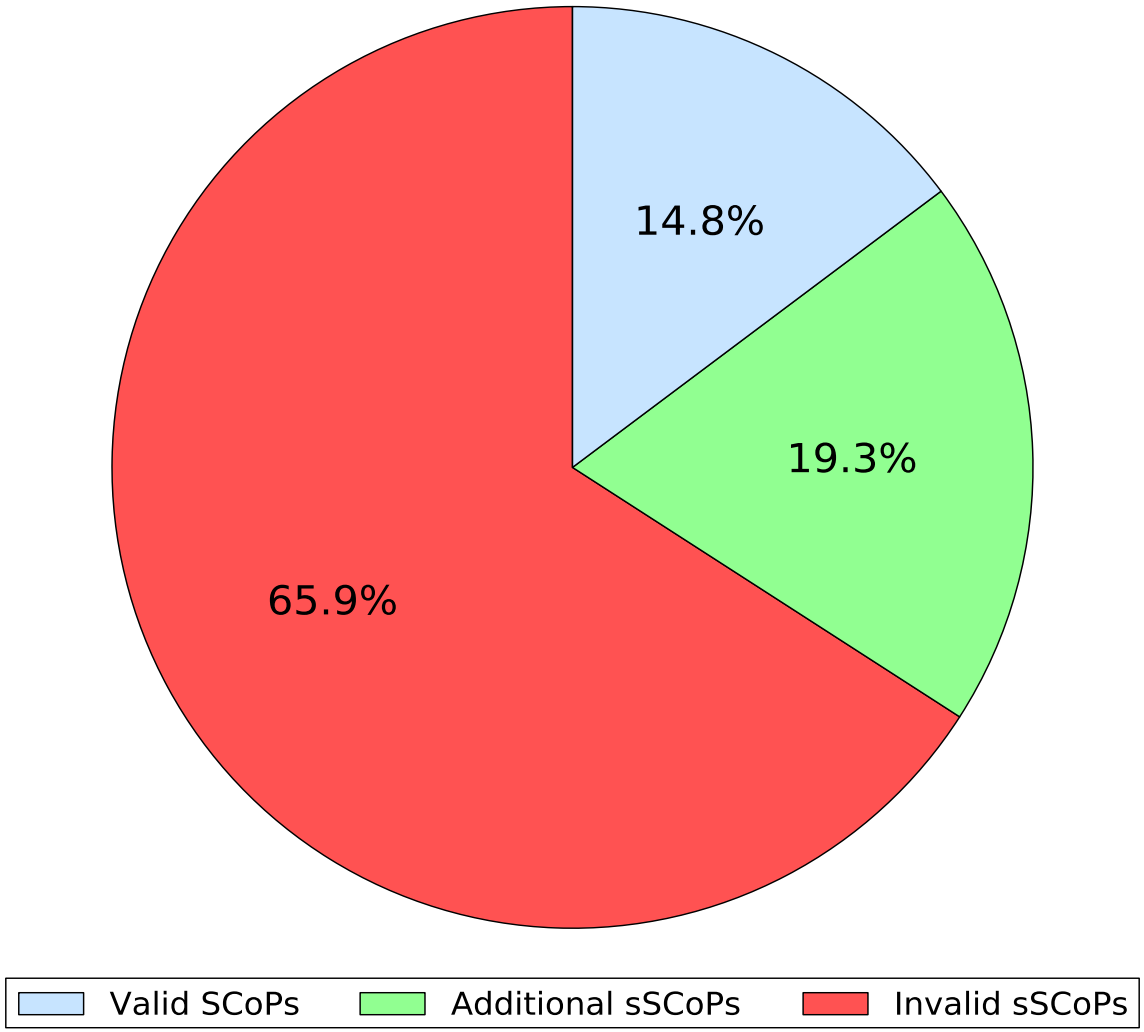
Does it work?

Does it work?

Almost.

Does it work?

Applicability on SPEC 2000



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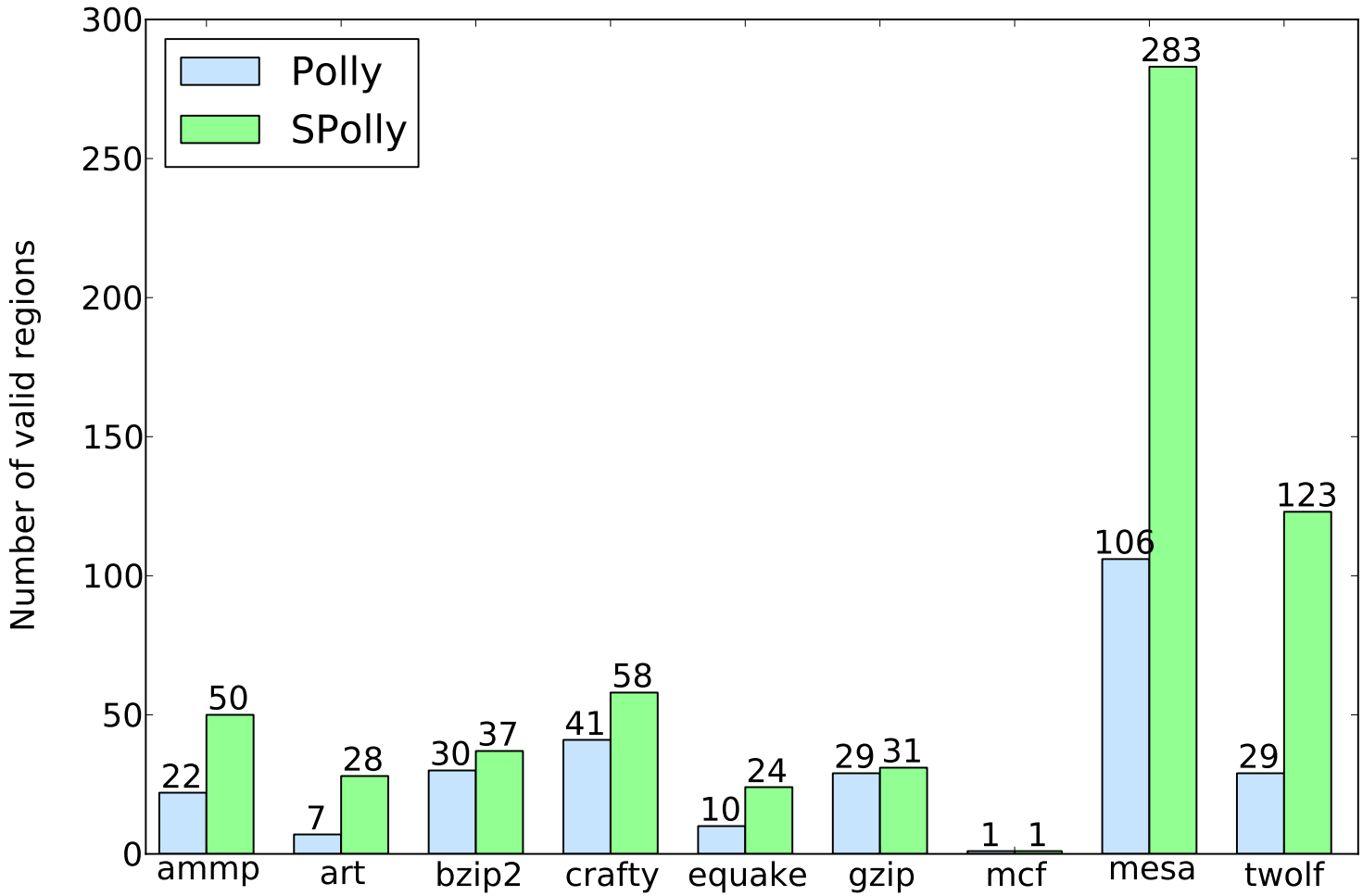
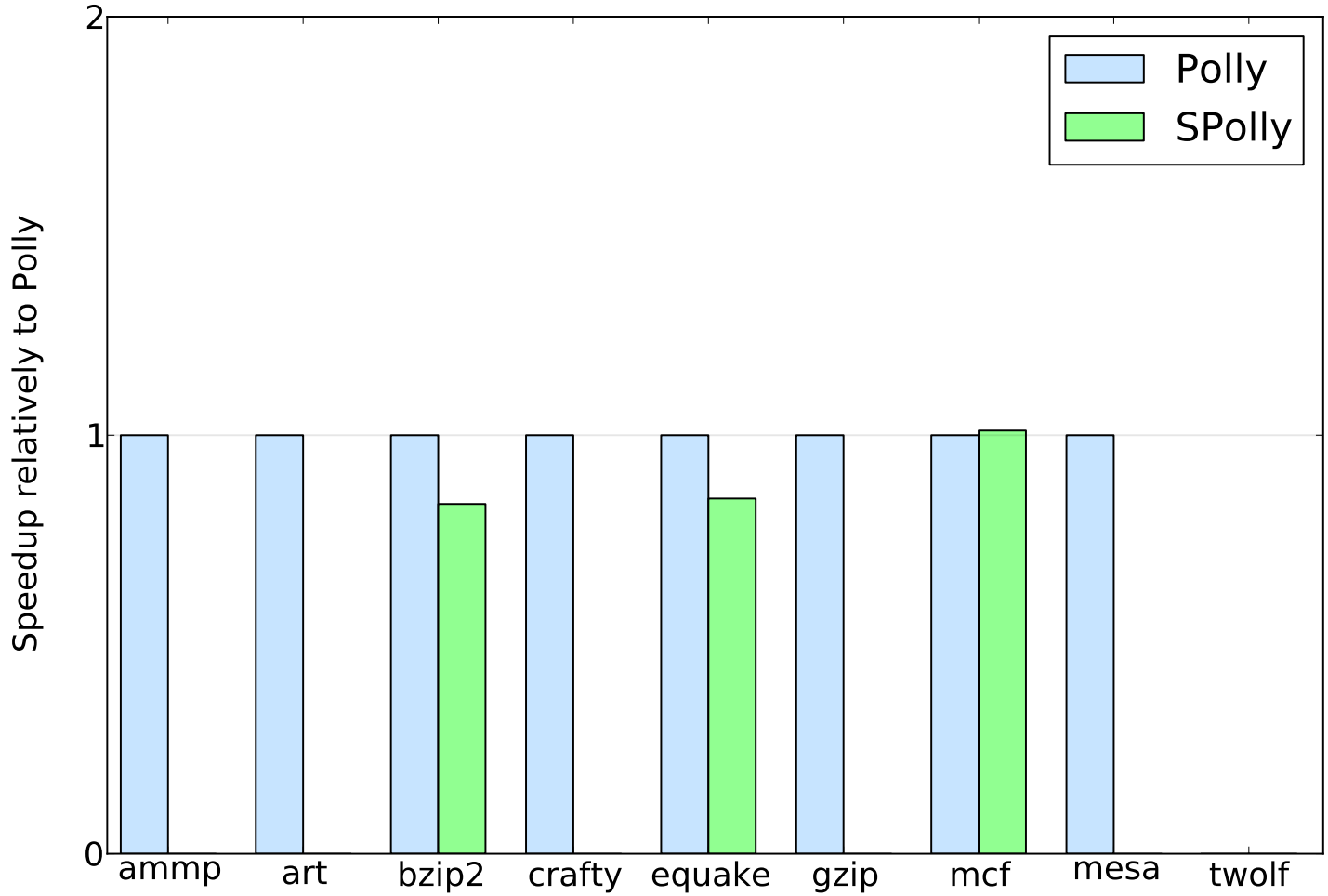


Does it work?

Runtime Results on SPEC 2000



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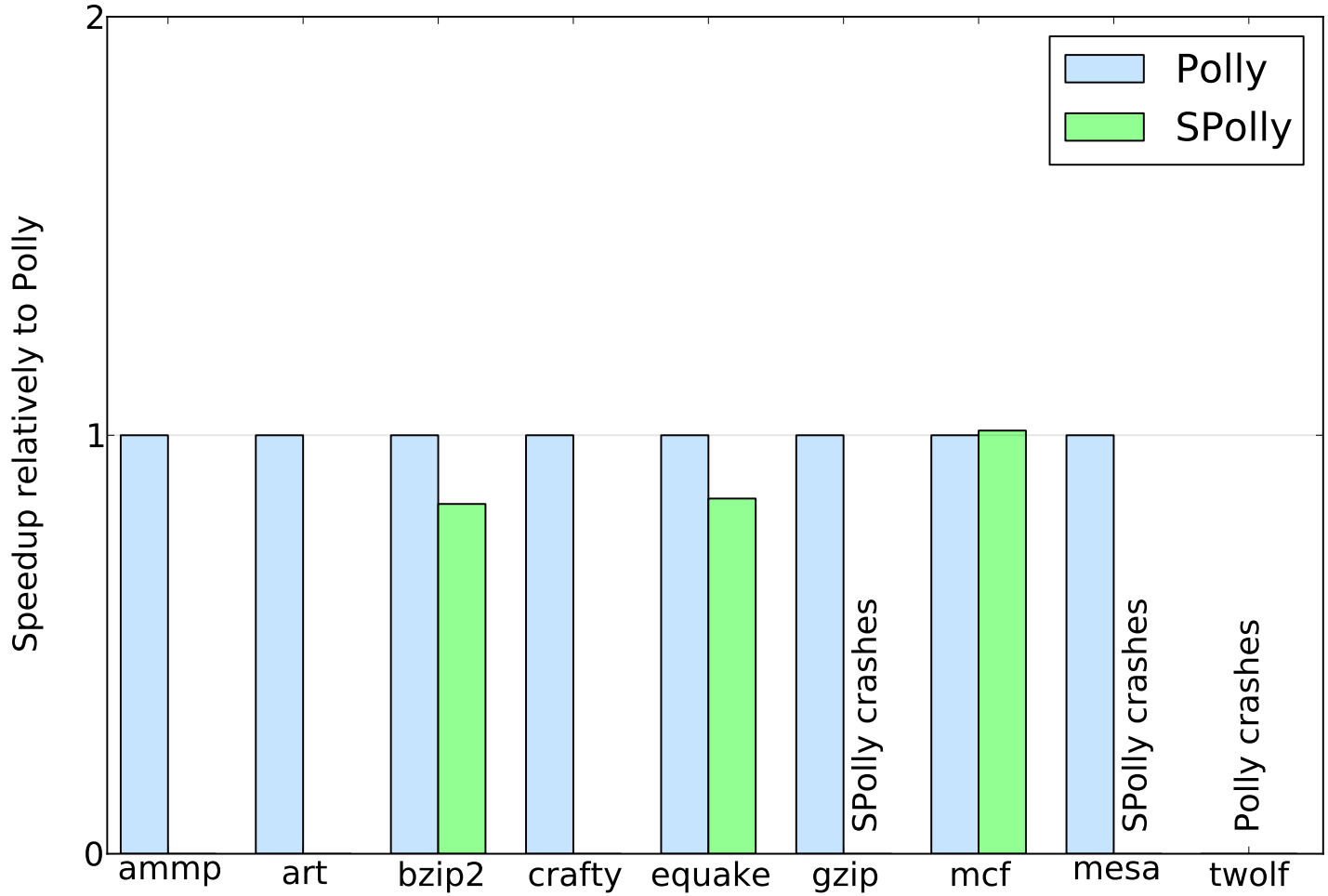

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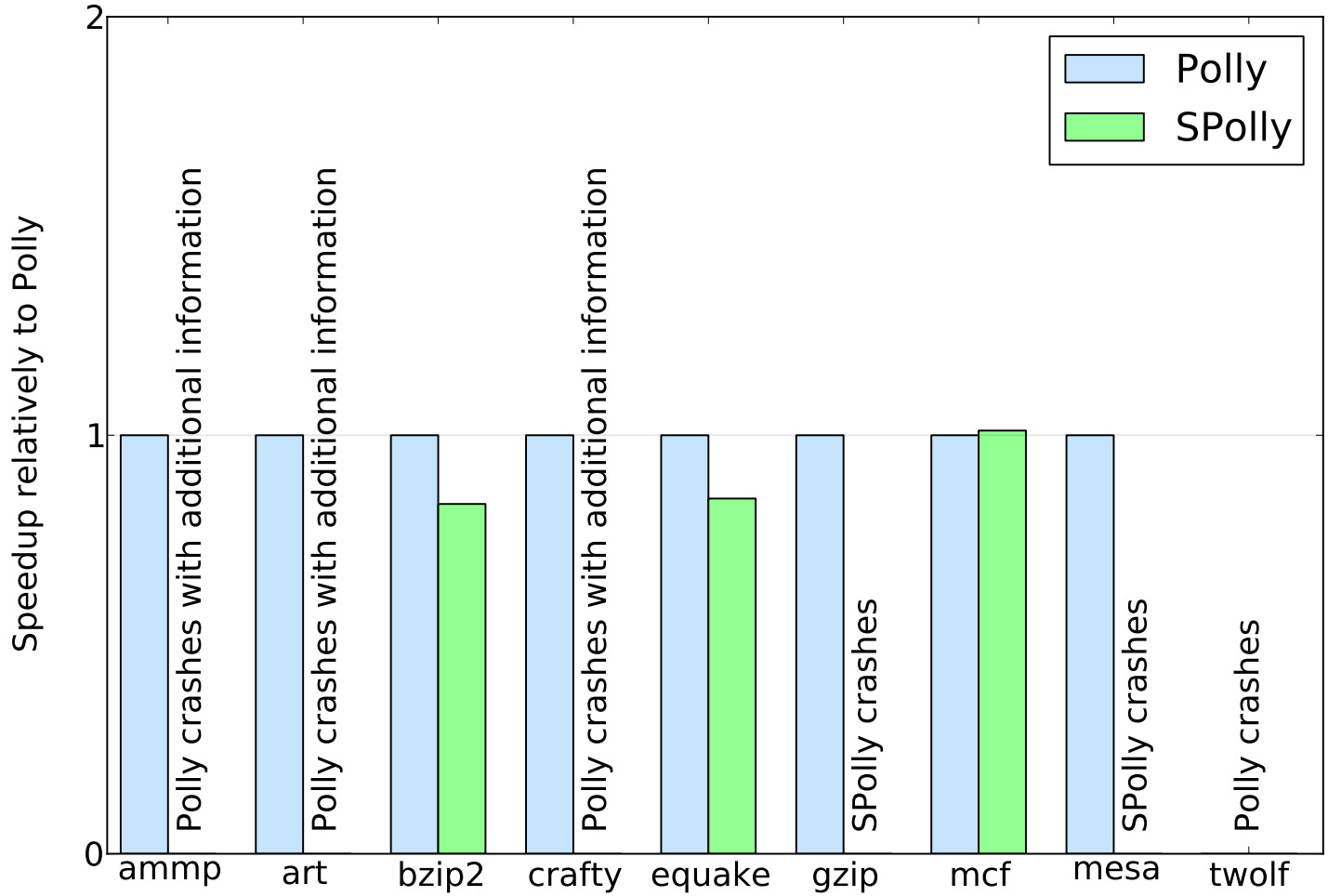


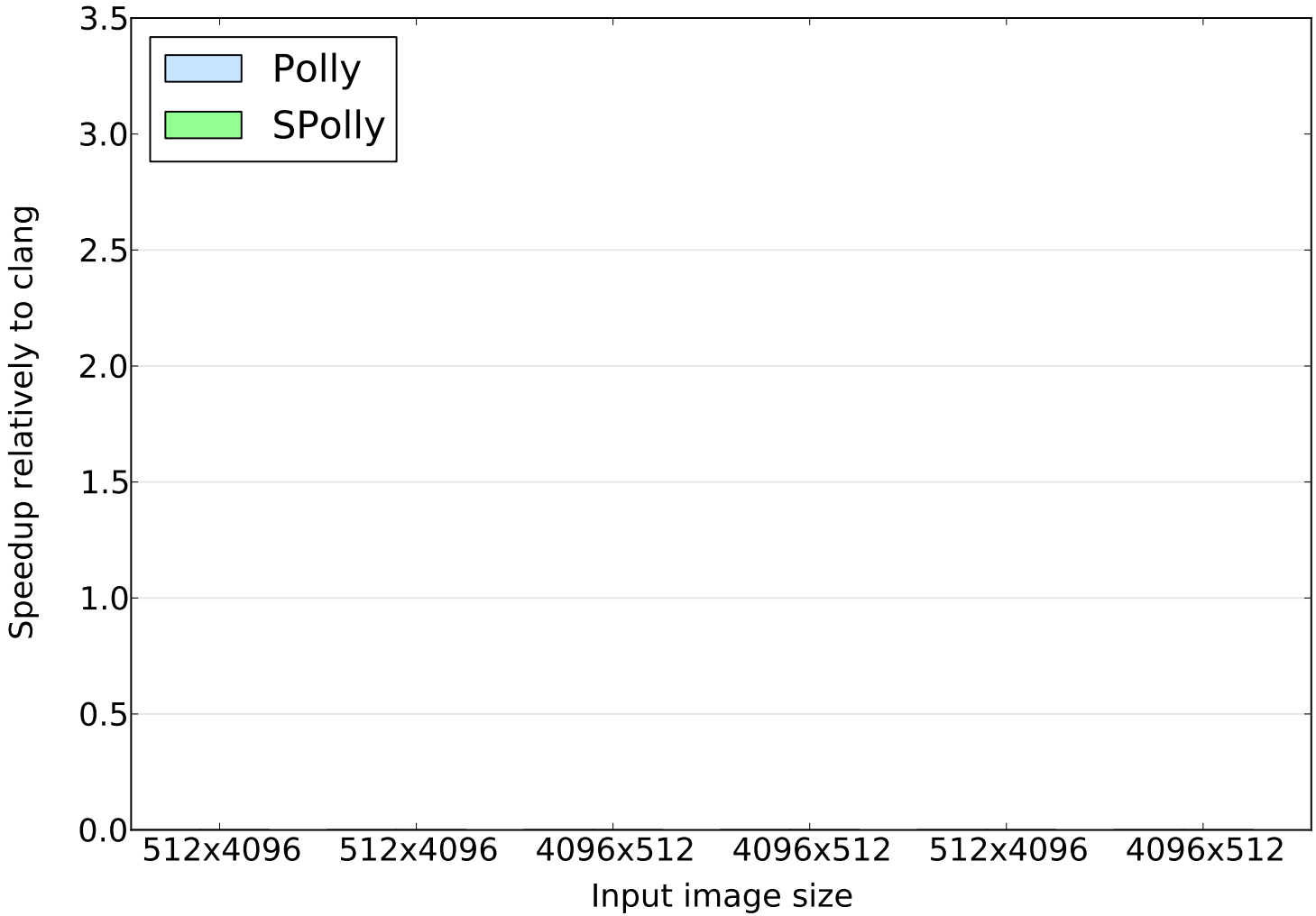
Does it work?

Case Study – Setup

Algorithm	2D derivation computation (basic image processing block)
Inputs	are given in 2 different resolutions
Evaluated	speedup of SPolly normalized against Polly

Does it work?

Case Study – Results



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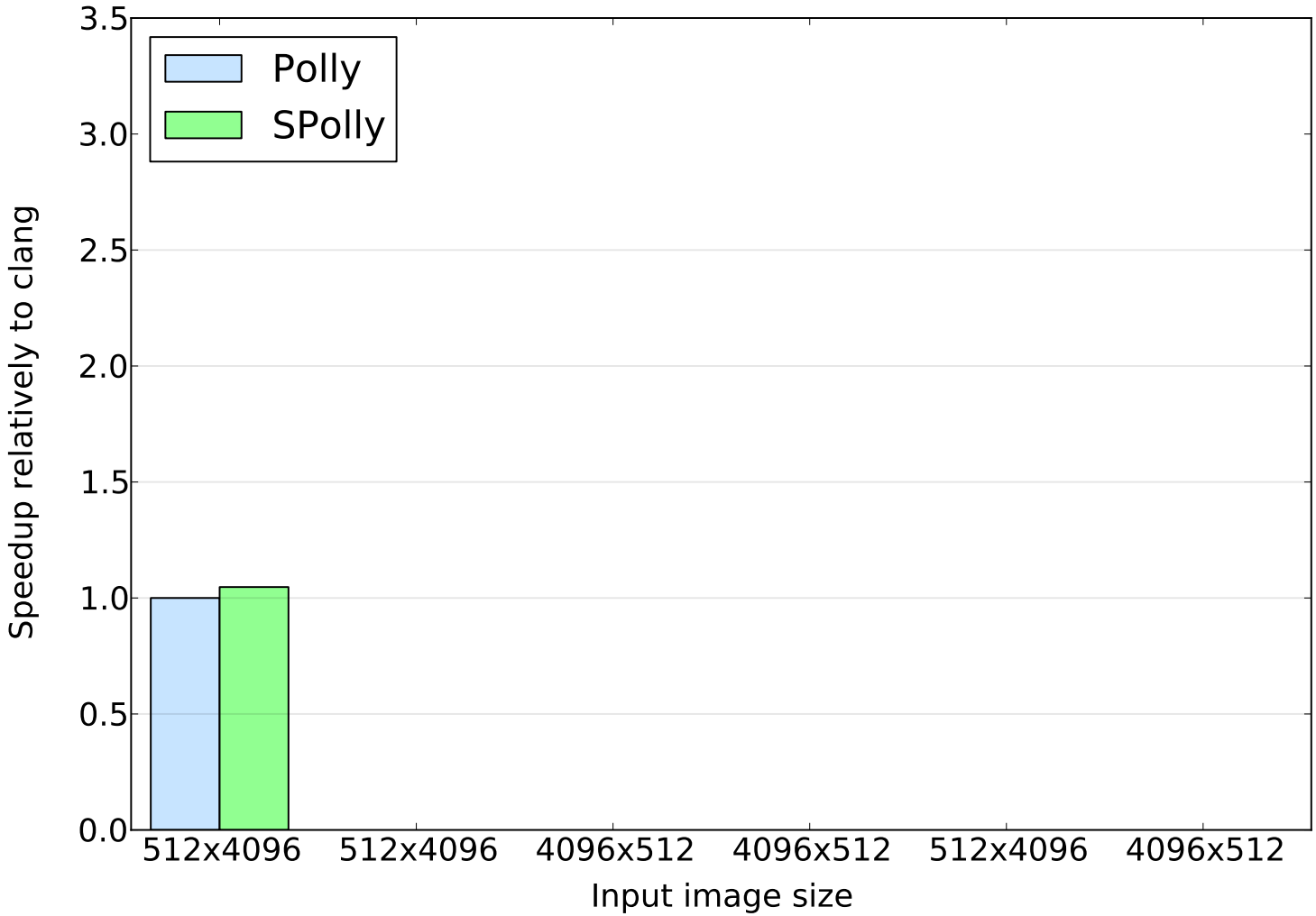

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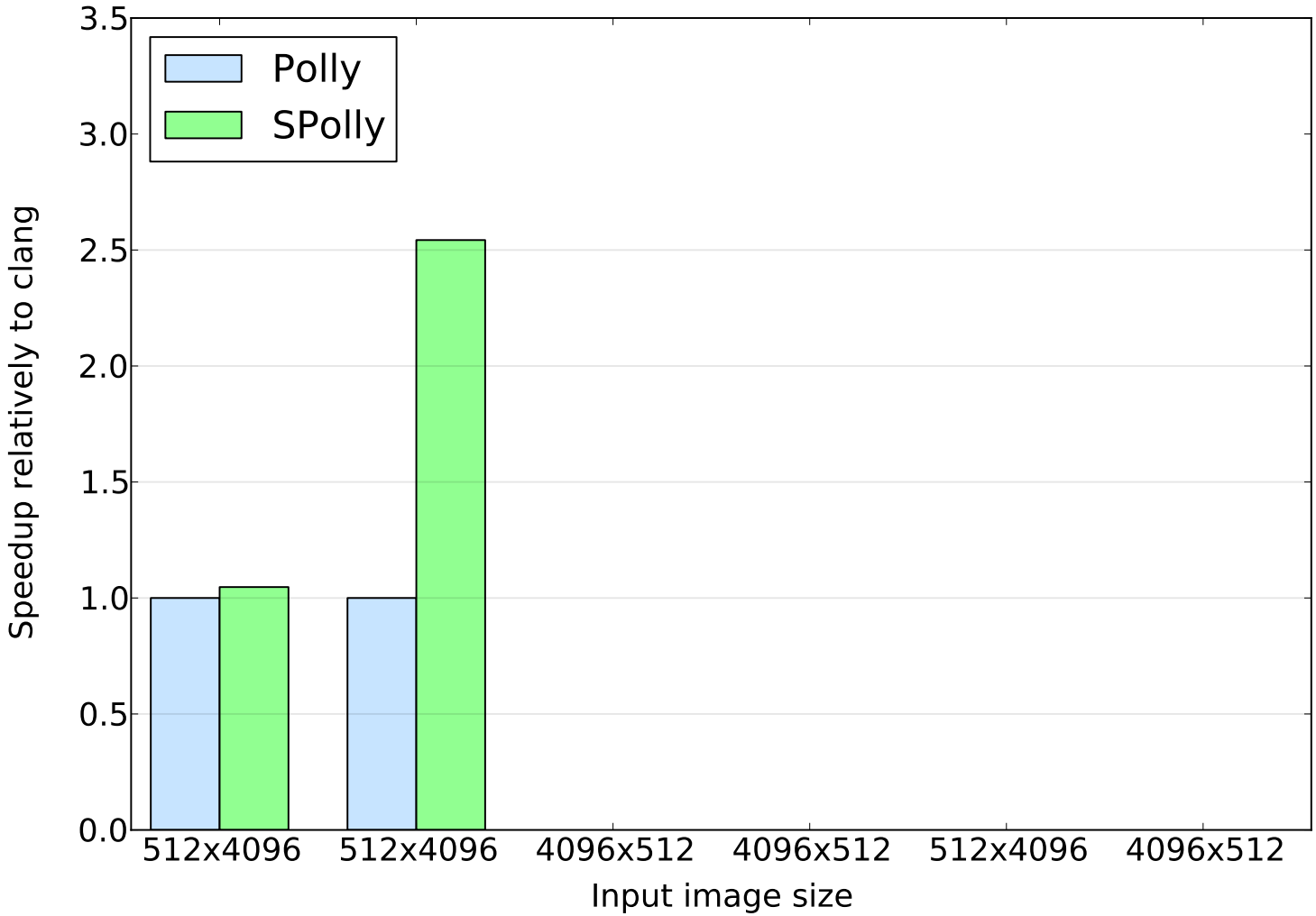
Case Study – Results



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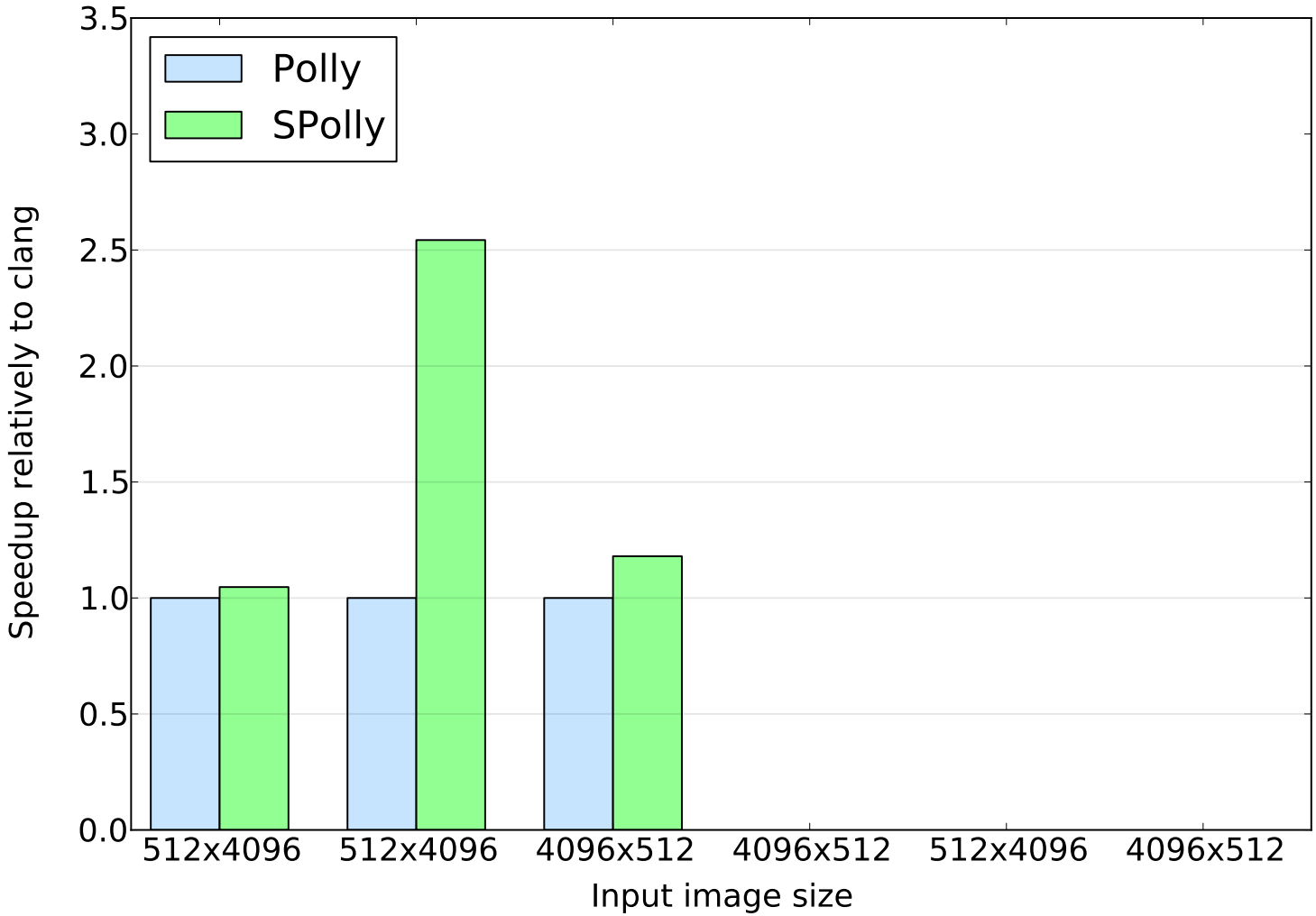

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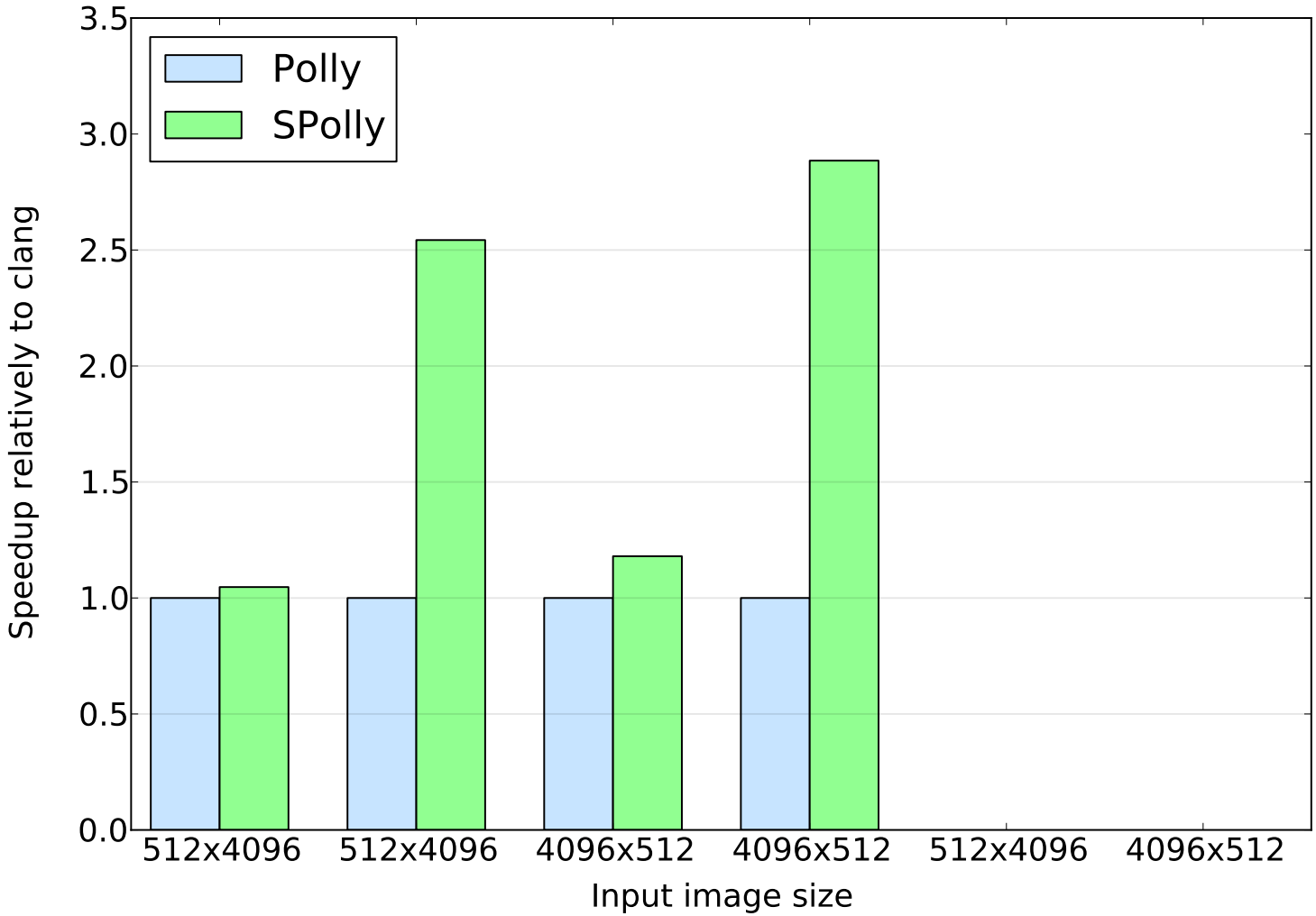

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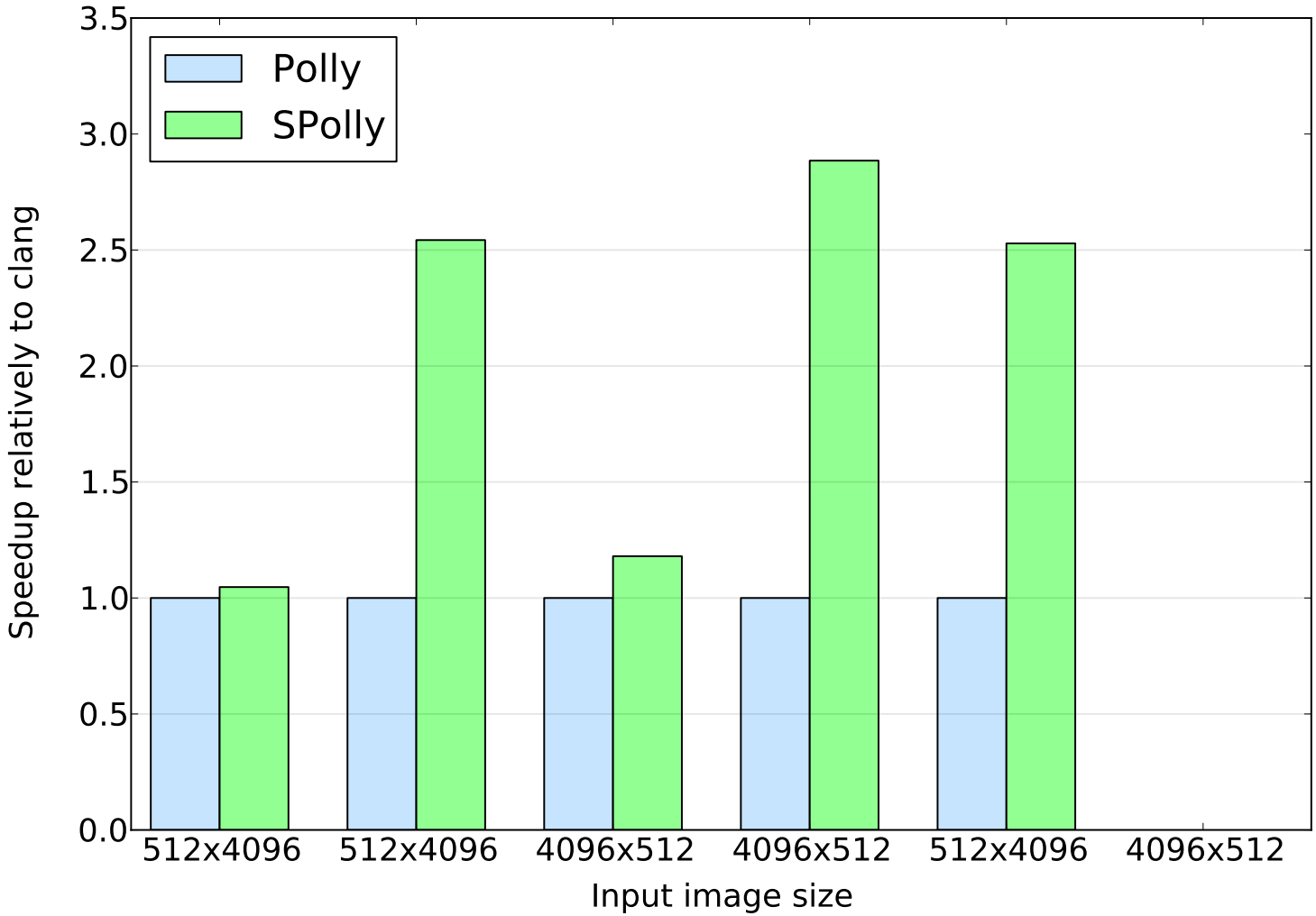

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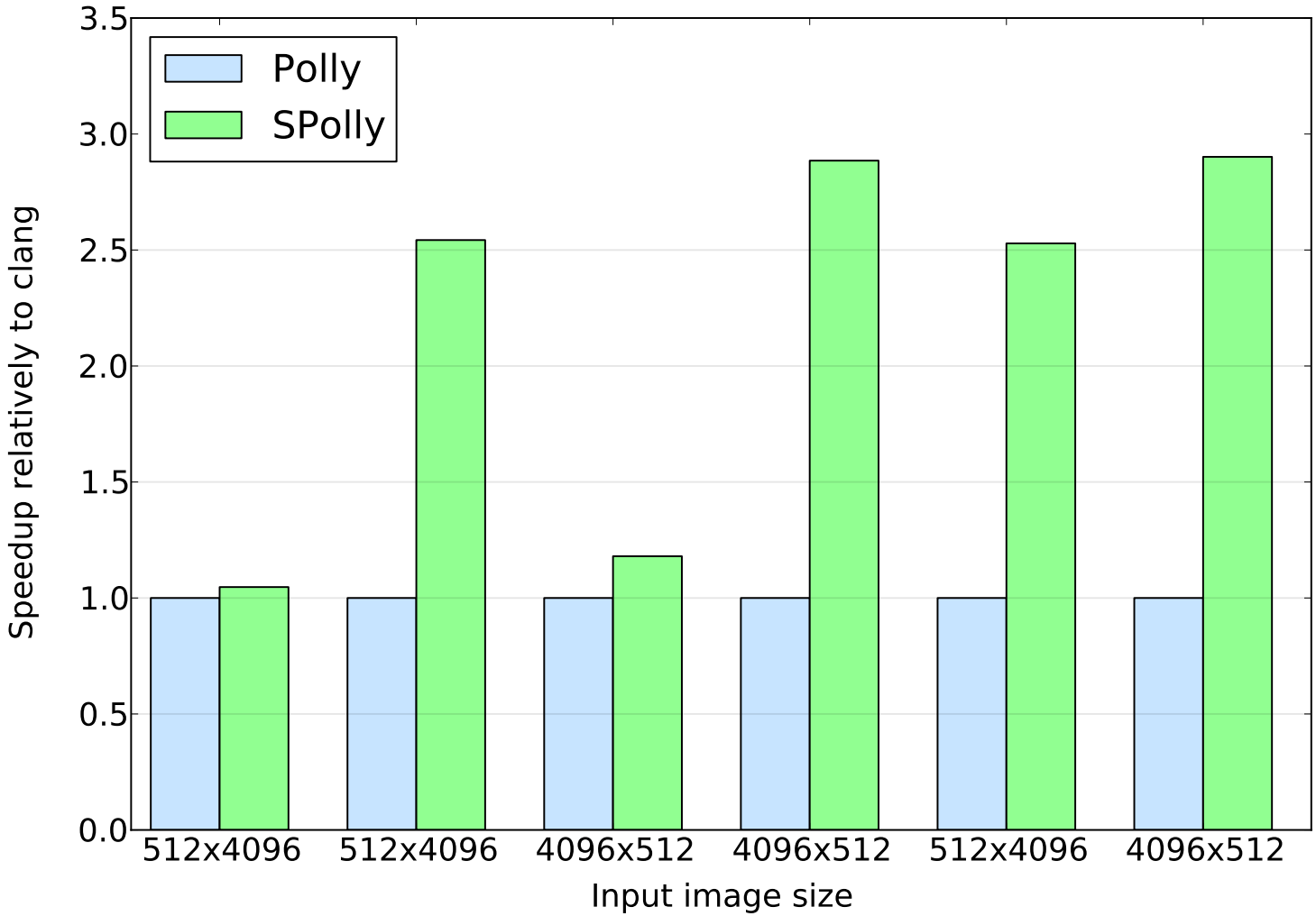
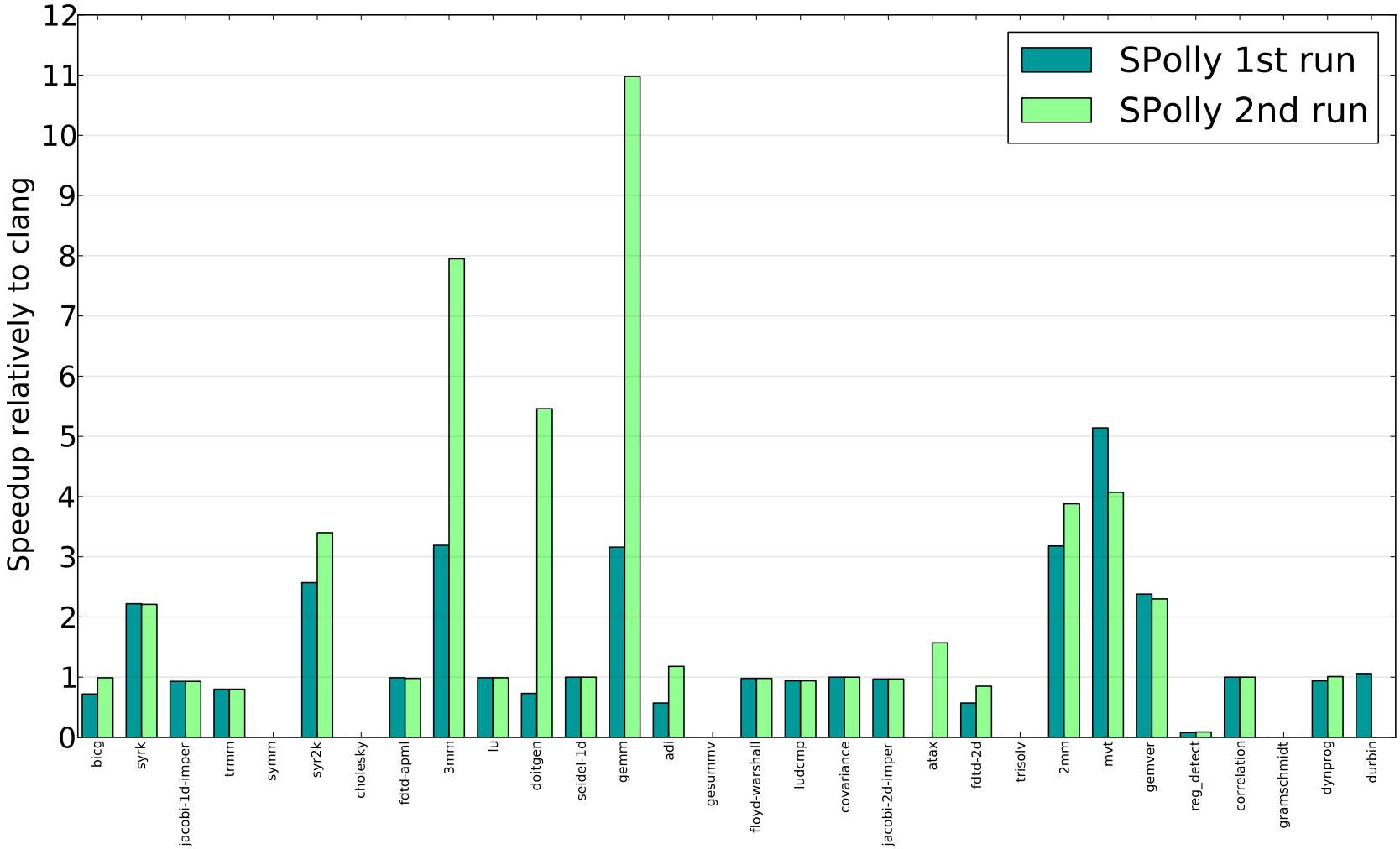


Does it work?

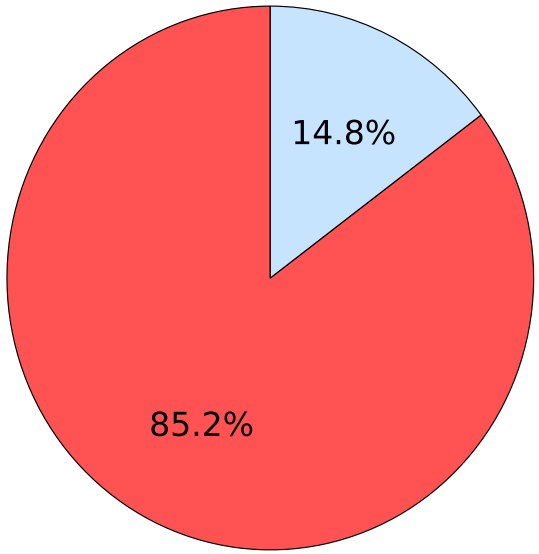
Runtime Results on Polybench



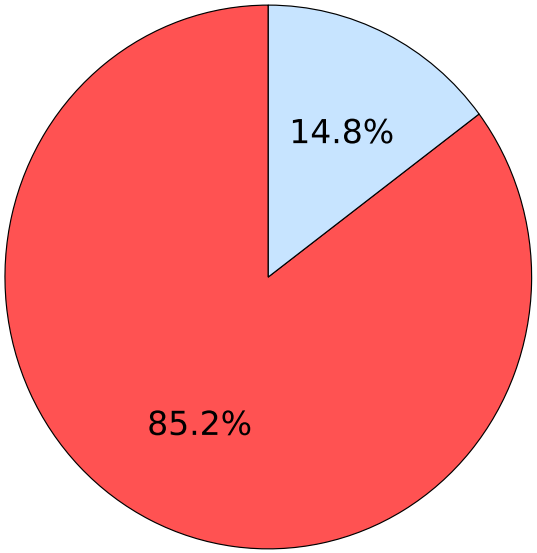
Geomean: [1st run] **1.134** [2nd run] **1.481**

Summary

Summary



Summary


14.8%
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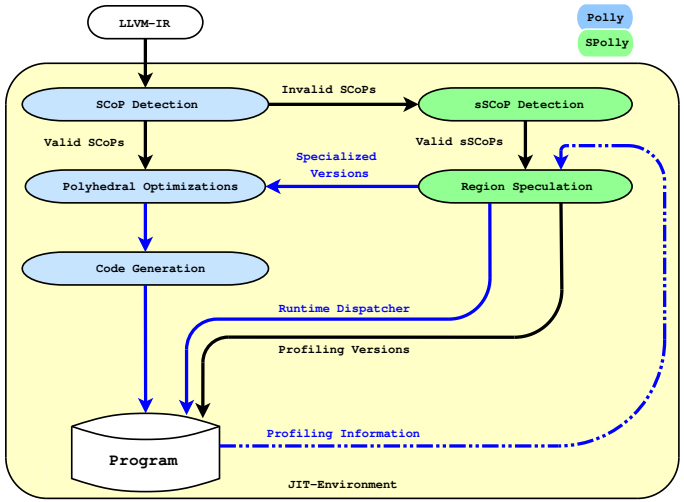
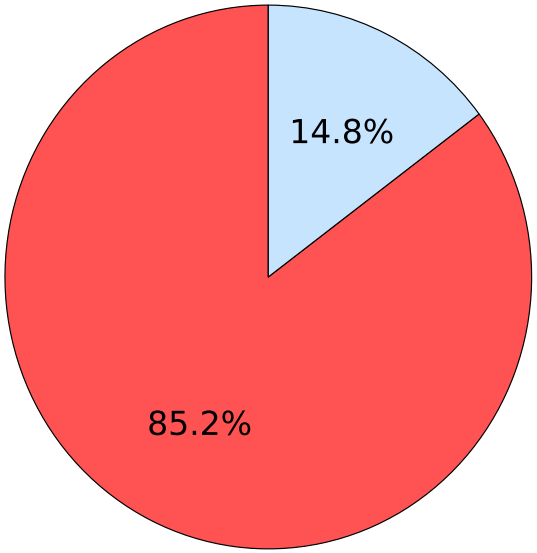

LLVM-IR
Polly
SPolly
SCoP Detection
Invalid SCoPs
sSCoP Detection
Valid SCoPs
Valid sSCoPs
Specialized Versions
Polyhedral Optimizations
Region Speculation
Code Generation
Runtime Dispatcher
Profiling Versions
Profiling Information
Program
JIT-Environment

Summary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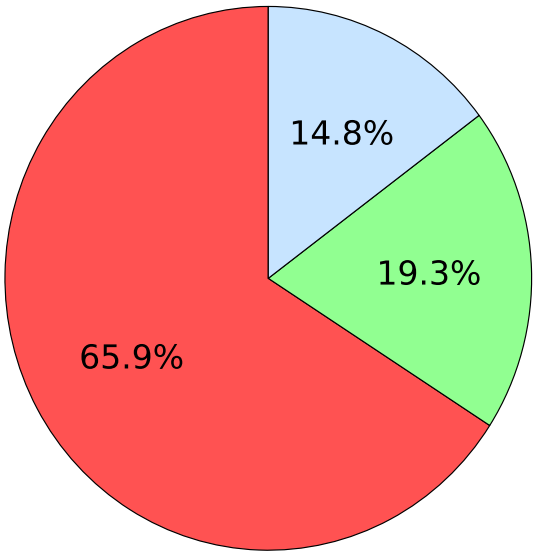
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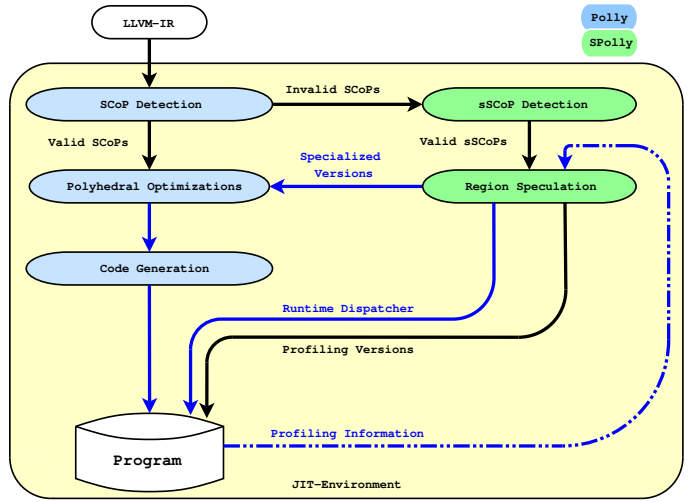
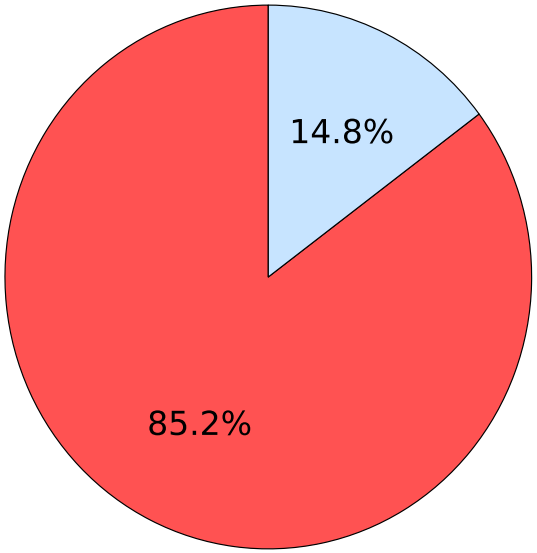
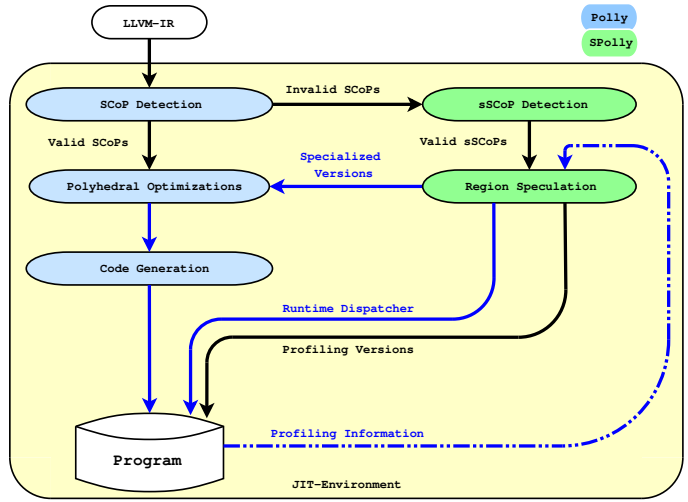
19.3%
65.9%


LLVM-IR
Polly
SPolly
SCoP Detection
Invalid SCoPs
sSCoP Detection
Valid SCoPs
Valid sSCoPs
Specialized Versions
Polyhedral Optimizations
Region Speculation
Code Generation
Runtime Dispatcher
Profiling Versions
Profiling Information
Program
JIT-Environment

Summary


14.8%
85.2%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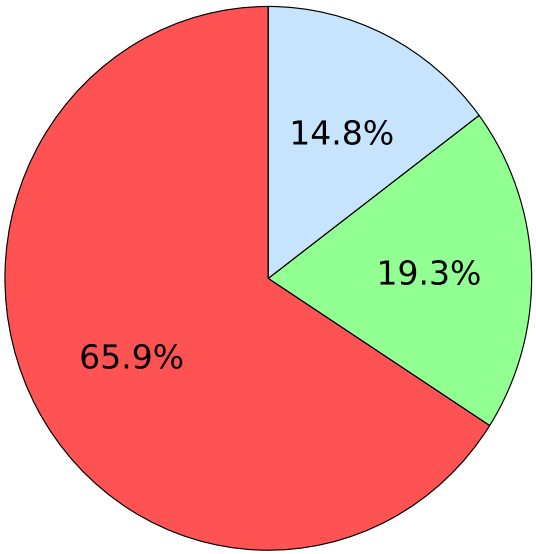
14.8%
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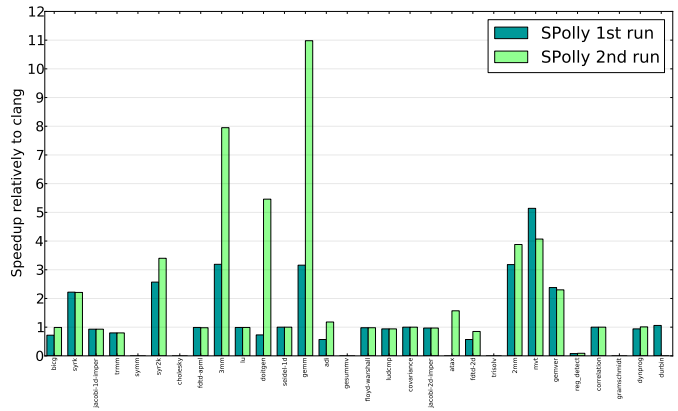

SPolly 1st run
SPolly 2nd run
Speedup relatively to clang
0
1
2
3
4
5
6
7
8
9
10
11
12

Does it work?

Case Study – Setup continued

- Convolution kernel of size 3x3
- Applied to all channels of an RGBA image (e.g., png)
- Measured on a Intel(R) Core(TM) i5 CPU M 560

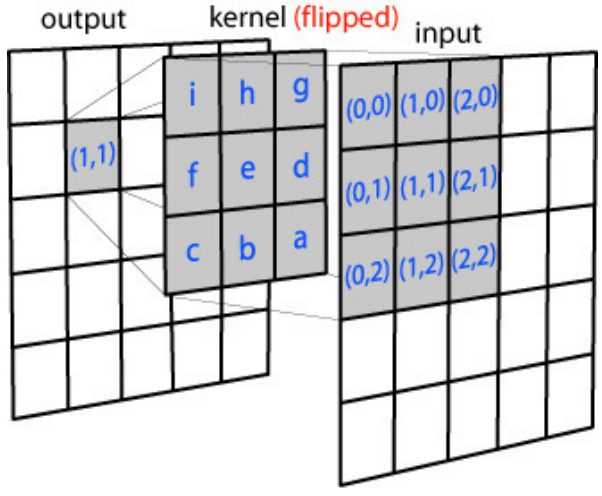
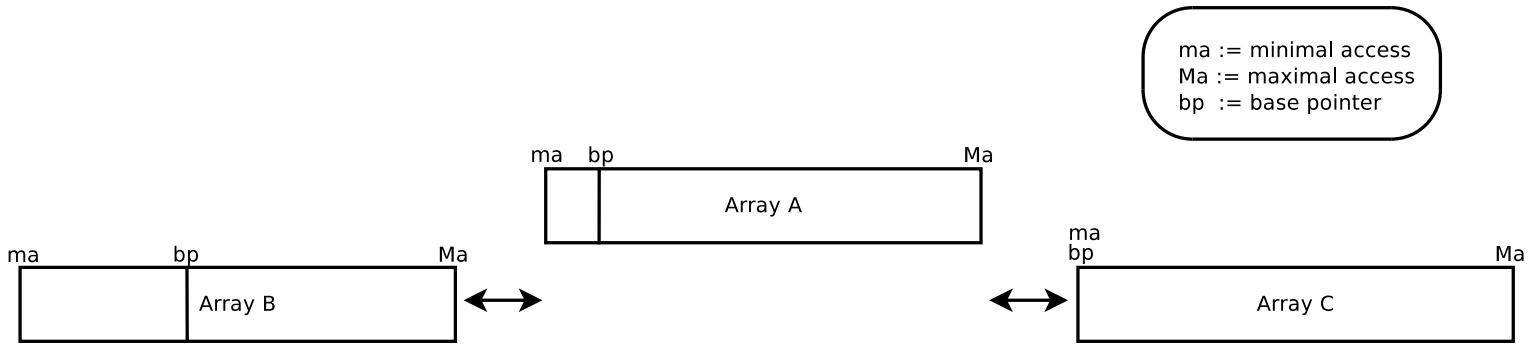


Image source:

https://sonnati.wordpress.com/2010/10/06/flash-h-264-h-264-squared-%E2%80%93-part-iii/

Concept

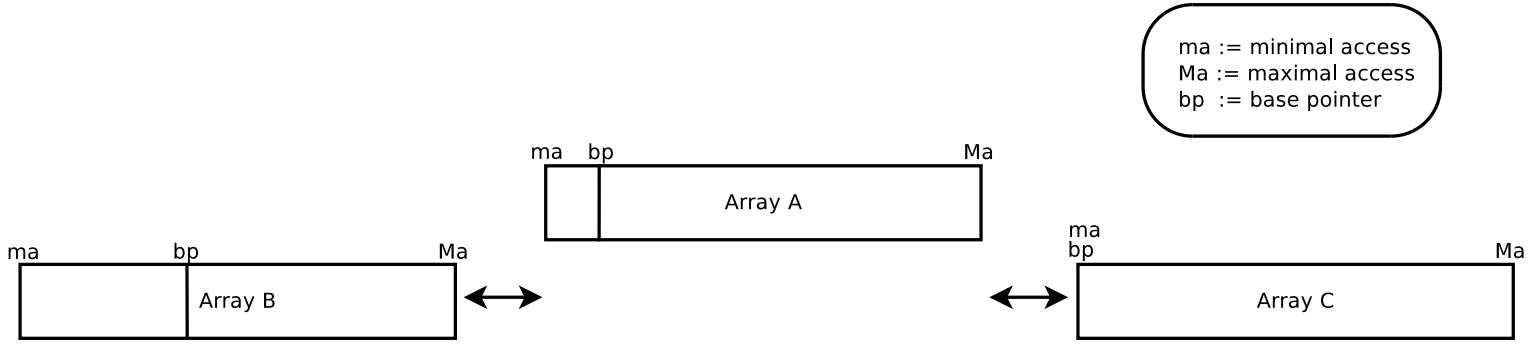
Alias tests



Concept

Alias tests

```
for (i = 0; i < N; i++) {
  for (j = 0; j < N; j++) {
//  I1
    C[i][j] = 0;
    for (k = 0; k < N; k++) {
//    I2          I3          I4
      C[i][j] += A[i][k] * B[k][j];
    }
  }
}
```



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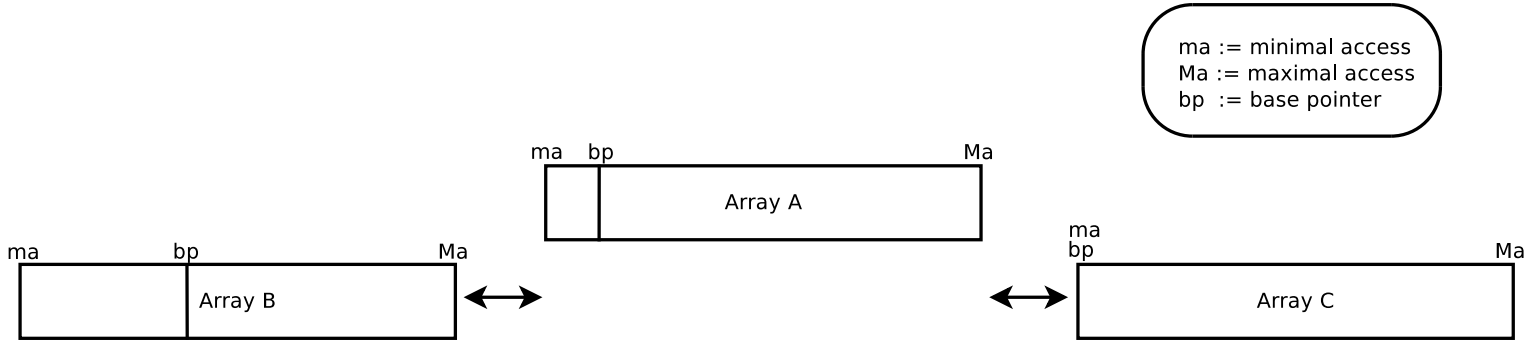
    }
  }
}
```

Acc	bp	ma	Ma
I1 and I2	C	0	N∗N−1
I3	A	0	N∗N−1
I4	B	0	N∗N−1



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}
```

Acc	bp	ma	Ma
I1 and I2	C	0	N∗N−1
I3	A	0	N∗N−1
I4	B	0	N∗N−1

```
bool ab = B[N*N-1] < A[0] || B[0] > A[N*N-1];
bool ac = C[N*N-1] < A[0] || C[0] > A[N*N-1];
bool bc = B[N*N-1] < C[0] || B[0] > C[N*N-1];
bool no_alias_found = ab && ac && bc;
```