ASSIST: Using performance analysis tools for driving Feedback Directed Optimizations

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Hardware trends and consequences

- The performance model shifted from high frequency single core processors to multitasking high-core-count parallel architectures
- Larger vector lengths (AVX512)
- Specialized units (FMA, …)
- New memory technology (HBM, Optane)

CONSEQUENCES

- Increasing number of different architectures
- Additional optimization challenges related to parallelism (task and data).
- Performance issues are heavily tied to increased vector lengths and advanced memory hierarchy
- The optimization process remains key to maintain a reasonable perfomance level on modern micro-processor architectures

- Optimizing code has become an art
- Codes are harder and harder to optimize and maintain manually
- Optimization is Time consuming and error-prone

Optimizing compilers

- ✚ Transparent for the user (no effort required) and code unmodified
- ✚ Can be improved through user inserted directives
- ▬ Remains conservative (static performance cost models & heuristics)
- ▬ Limited search space for optimizations (compilation time)
- ▬ Black Box : can ignore user directives ☺

An interesting alternative: Profile Guided Optimizations/Feedback Directed Optimizations

THREE STEPS PROCESS:

- Producing an instrumented binary
- Executing the binary in order to obtain a profile (feedback data)
- Using the obtained feedback data to produce a new version that is expected to be more efficient

FDO/PGO

- ✚ Gets dynamic info on code behavior (stop shooting in the dark)
- ✚ Can implement well targeted optimizations
- ▬ Needs a first pass run or use continuous compilation (AutoFDO Google)
- ▬ Depends upon (often limited) info gathered during the profiling phase
- ▬ Data dependent

An interesting example: Intel PGO

- ➢ Value profiling of indirect and virtual function calls
- ➢ Intermediate language (IR) is annotated with edge frequencies and block counts to guide optimization decisions
- ➢ Grouping hot/cold functions

ASSIST GOALS

Key idea: Performance analysis tools (e.g. Scalasca, MAQAO, Tau, Vtune, HPCToolkit, …) are pretty good at identifying some specific problems, but users do not want issues but solutions. We need to go further and fix automatically performance issues.

- Automatic Source-to-Source assISTant: ASSIST
  - Source code transformation framework
  - Transformation driven framework: ideally detect whether a transformation is beneficial or not
  - Exploiting performance analysis tools metrics
  - Open to user advice (interacts with the user)
  - Keep a maintainable code

MAQAO components provide two types of analysis

- Static: simple performance model and quantitative code quality assesment
- Dynamic: precise estimate of CPU versus memory bound information, accurate analysis of memory hierarchy (DL1 variant in which all of the data access are forced to be L1)

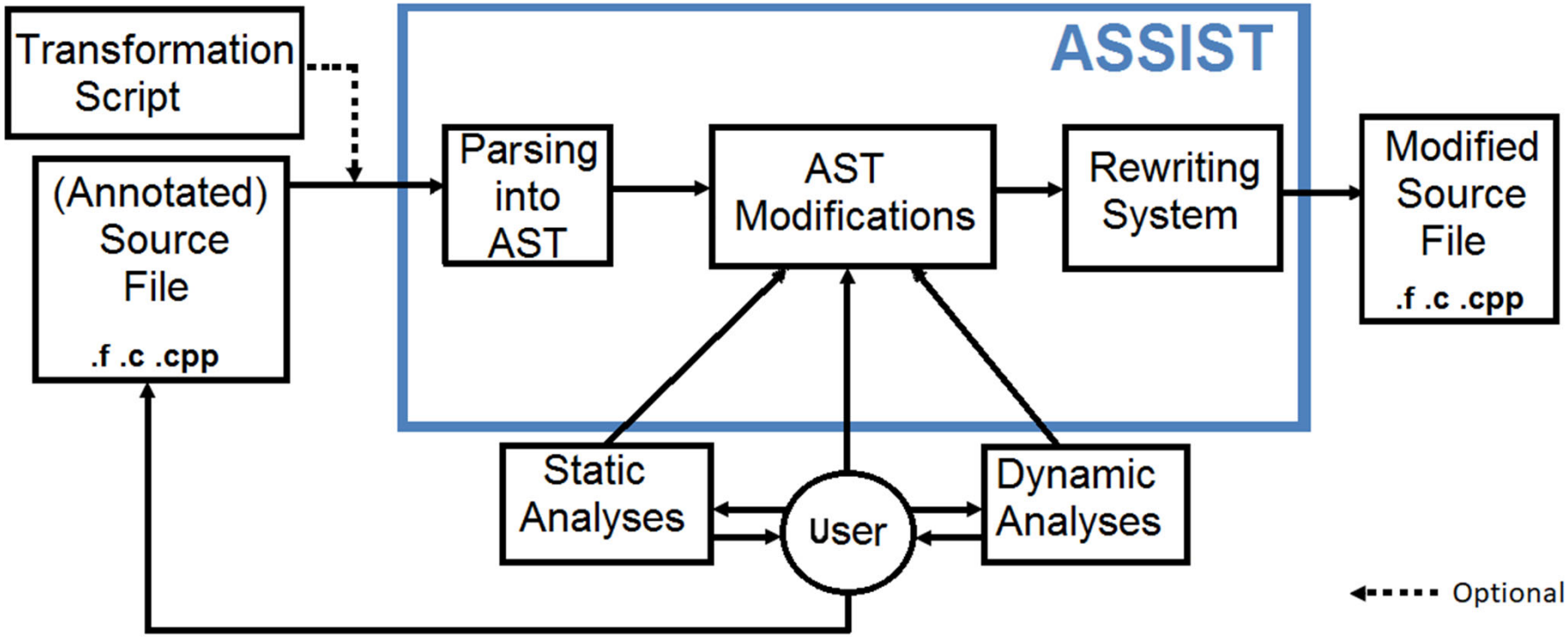
ONE VIEW (performance aggregator) provides analysis of code optimization opportunities

- Vectorization: Full and Partial
- Code quality
- CPU bound versus memory bound
- Blocking and array restructuring

Overview of Tool Usage

Automatic Source-to-source assISTant (ASSIST).

Staic and dynamic analysis are provided by MAQAO/ONE VIEW



- Technical Design
  - Based on the Rose Compiler Project
  - Support of Fortran 77, 90, 95, 2003 / C / C++03
  - Same language at input and output
  - Aiming at be easy to use with a simple user interface
  - Targeting different kind of users
  - Integrated as a MAQAO module

Supported Transformations

Directive(s) Insertion

- Loop Count (LCT)
- Forcing Vectorization

AST Modifier (very classic transformations)

- Unroll
- Full Unroll
- Interchange
- Tile
- Strip Mine
- Loop/function Specialization

Combination of both

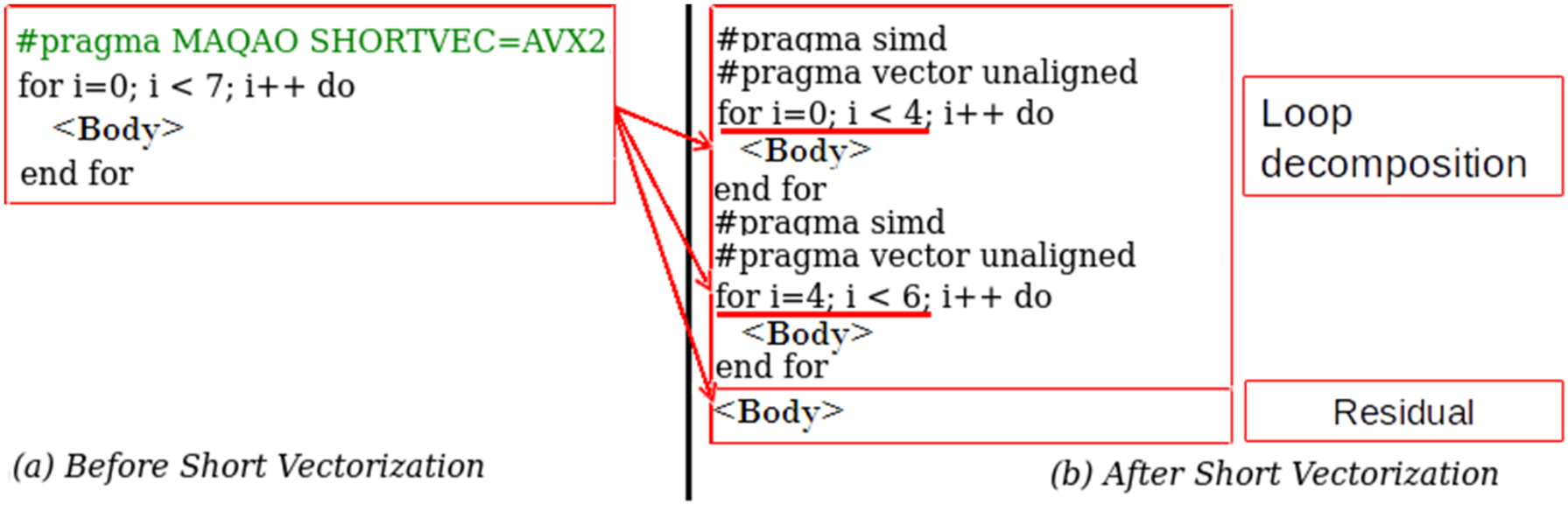
- Short Vectorization (SVT)

- Loop count transformation – Type: Directives insertion
  - Loop count knowledge enables to guide compiler optimizations choices
  - Compilers cannot always guess the loop trip count at compile time
  - Simplify
    - Control flow (less loop versions)
    - Choice of vectorization/unrolling
  - Requires dynamic feedback (VPROF)
  - Limitations
    - Loop bounds are dataset dependent
    - Only for Intel Compiler, unfortunately, other compilers do not offer such capability

Short Vectorization Transformation – Type: Mixed AST modifier and directive insertion

- Compilers may refuse to vectorize a loop with too few iterations
- Performing a loop decomposition
- Increasing the vectorization ratio by:
  - Forcing the vectorization (SIMD directive)
  - Avoiding dynamic or static loop peeling transformation (UNALIGNED directive)

Zoom on SVT


#pragma MAQAO SHORTVEC=AVX2
for i=0; i < 7; i++ do
<Body>
end for
#pragma simd
#pragma vector unaligned
for i=0; i < 4; i++ do
<Body>
end for
#pragma simd
#pragma vector unaligned
for i=4; i < 6; i++ do
<Body>
end for
<Body>
Loop decomposition
Residual
(a) Before Short Vectorization
(b) After Short Vectorization

Zoom on SPECIALIZATION

Spezialization is performed either at the function level or the loop level. Specialization proceeds in 3 steps

- ASSIST/ROSE identifies in the source code key integer variables: loop bounds, stride, involved in conditions, array index
- MAQAO/VPROF, at execution, profiles values of these variables and identifies the interesting ones with biased distributions: constant across all execution, very few values, a single very frequent value.
- ASSIST will then generate a specialised version of the function/loop

How to Enable Transformations

Two main approaches

- Under user full responsibility: insert directly directives in source code
- Use MAQAO report + User guidance(examples below)
  - CQA Vectorization Gain => Vectorization Directives
  - CQA (vectorization ratio) + VProf (iteration count) => SVT
  - DECAN (DL1) => Tiling
  - VProf (iteration count) => LCT

Additional approach: provide a transformation script, specifying transformations to be applied on a per source line number.

Assessing Transformation Verification

FIRST VERSION: STATIC ANALYSIS based on MAQAO/CQA

- Step 1: Perform static analysis using CQA on the target loop **BEFORE** transformation
- Step 2: Perform static analysis using CQA on the target loop **AFTER** transformation
- Step 3: Compare and decide.

Experiments

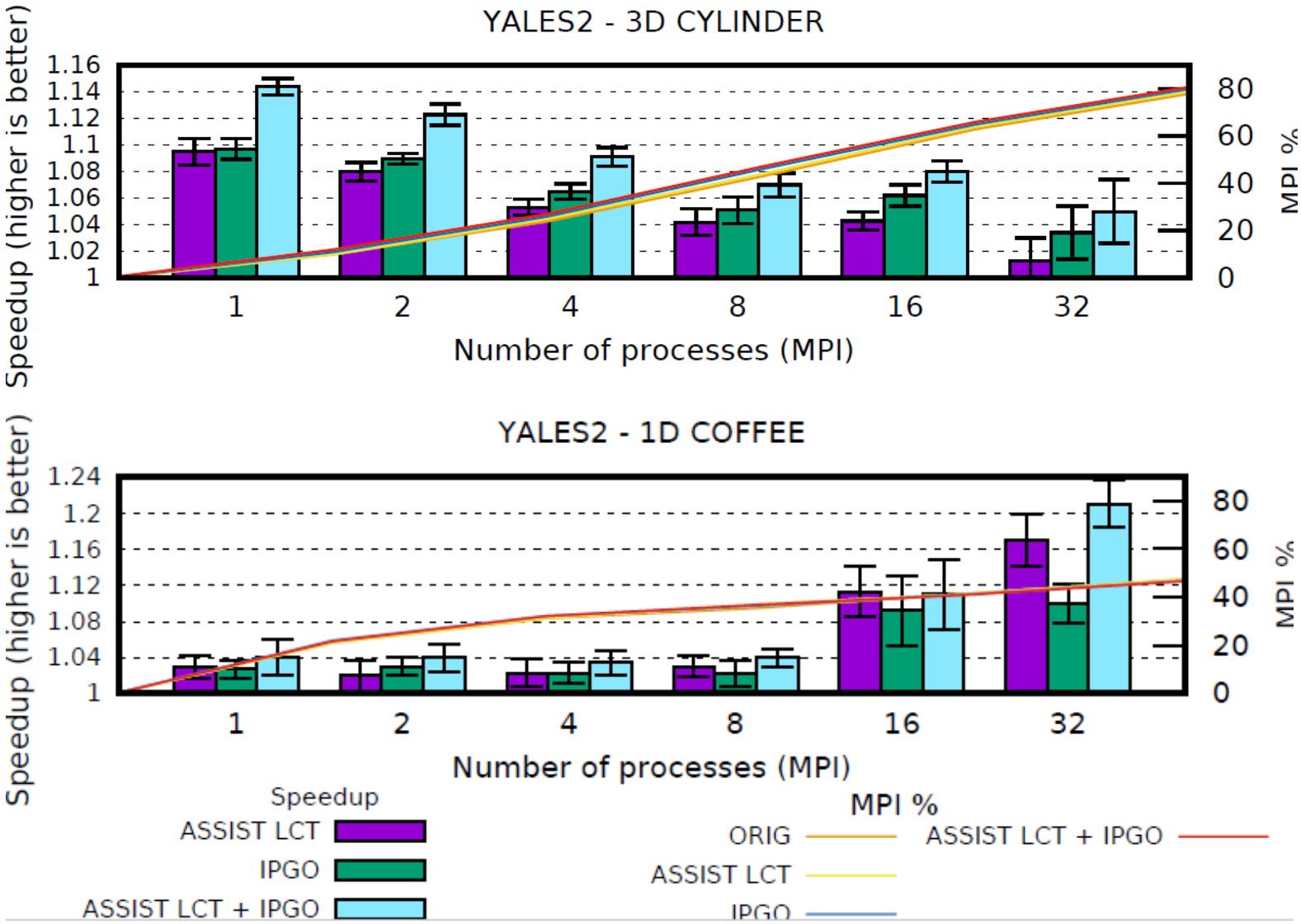
Results have been obtained on a Skylake Server and are compiled with Intel 17.0.4 and compared with Intel PGO version 17.0.4 (IPGO)

Application Pool

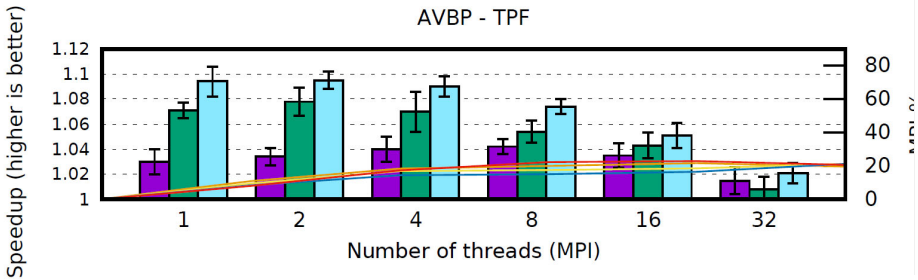
- **Yales2 (F03):** numerical simulation of turbulent reactive flows
- **AVBP (F95):** parallel computational fluid dynamics code
- **ABINIT (F90):** find the total energy charge density and the electronic structure of systems made of electrons and nuclei
- **POLARIS MD (F90):** microscopic simulator for molecular systems
- **Convolution Neural Networks (C):** object recognition
- **QmcPack (C++):** computation of the real space quantum Monte-Carlo algorithms

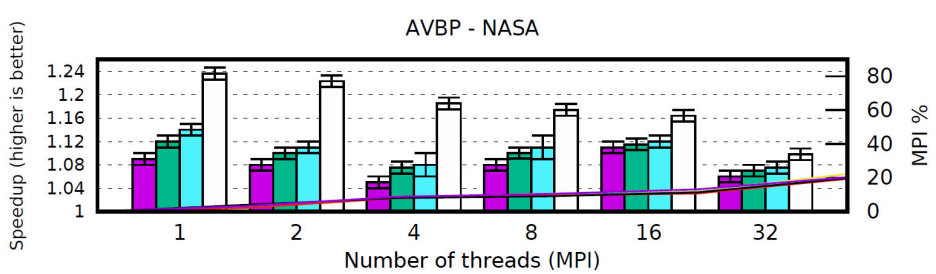
Impact of the Loop Count

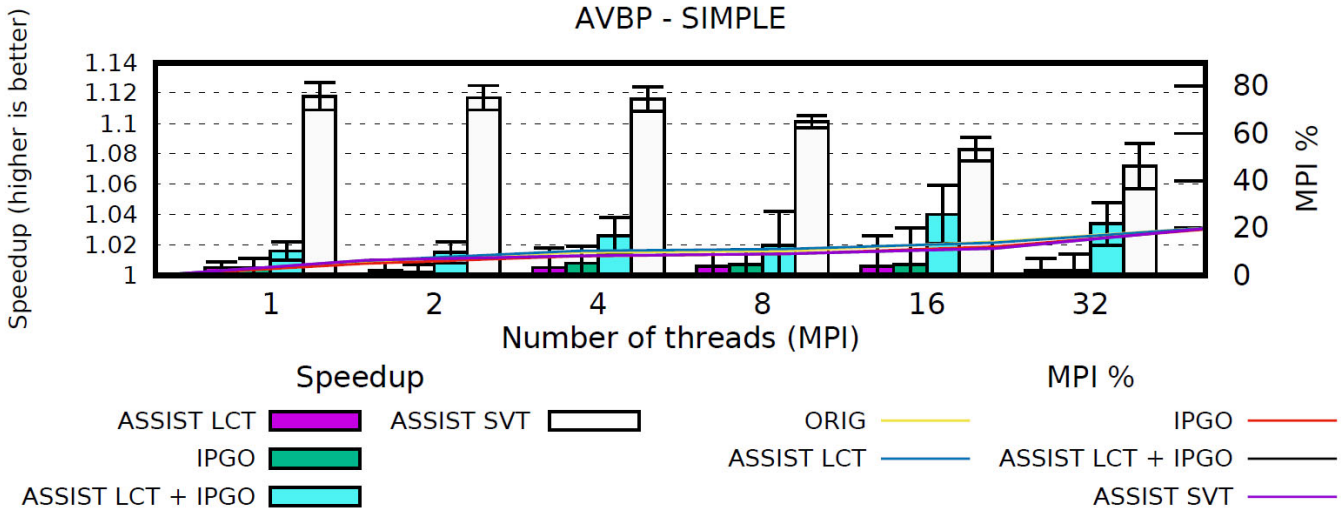
Comparison with IPGO and ASSIST LCT+IPGO



Impact of Specialization Combined with SVT

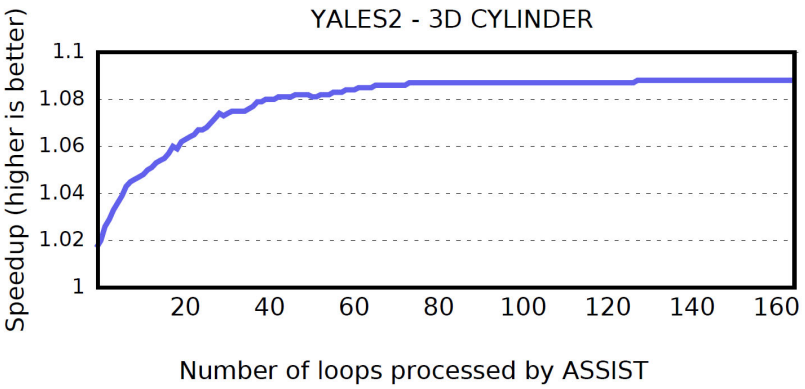


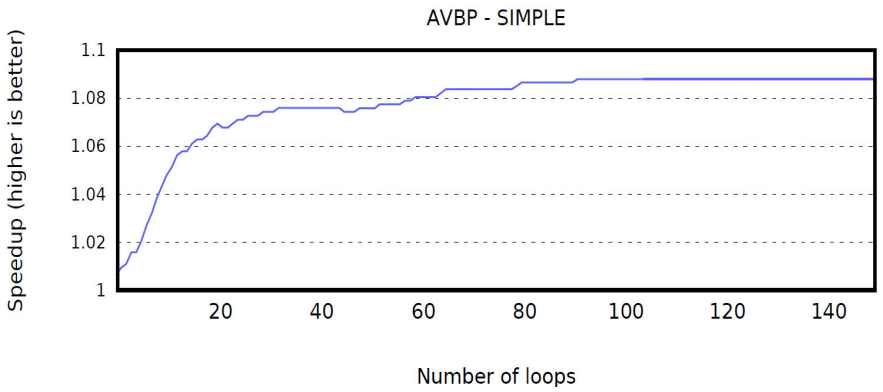




Number of loops processed

	AVBP NASA	AVBP TPF	AVBP SIMPLE	Yales2 3D Cylinder	Yales2 1D COFFEE
Number of loops	149	173	158	162	122



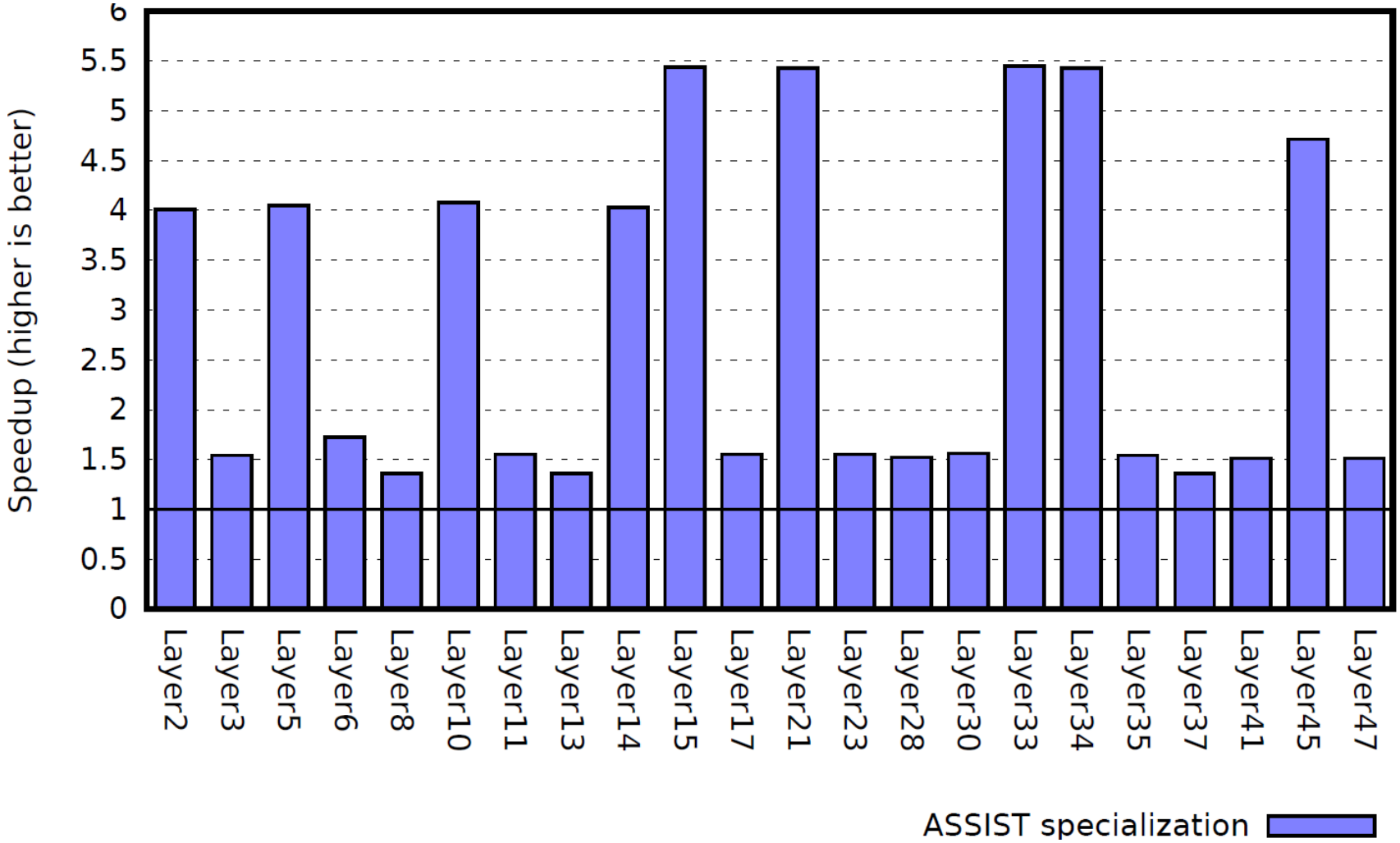


CNN: Impact of Specialization

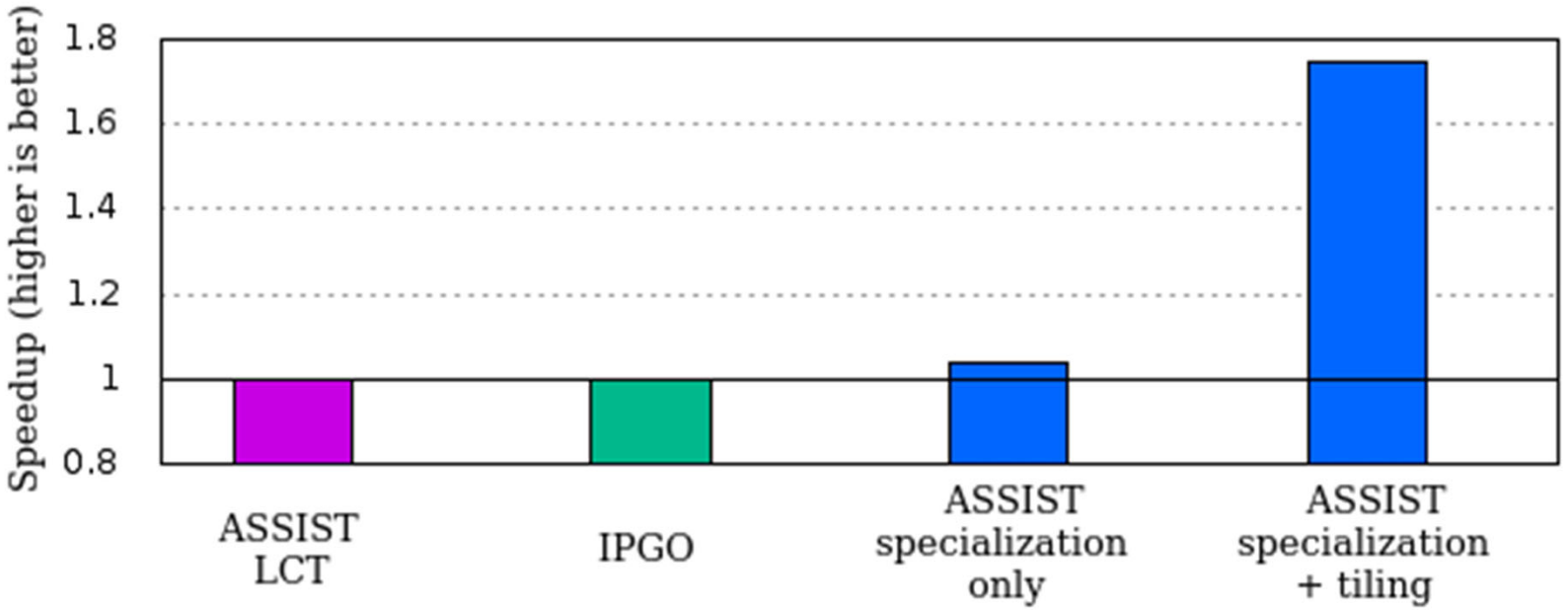
```
for (img = 0; img < nImg; ++img) {
  for (ifm = 0; ifm < nIfm; ++ifm) {
    for (ofm = 0; ofm < nOfm; ++ofm) {
      for (oj = 0; oj < ofh; ++oj) {
        ij = oj * stride_h - pad_h;
        for (oi = 0; oi < ofw; ++oi) {
          ii = oi * stride_w - pad_w;
          for (kj = 0; kj < kh; ++kj) {
            if (ij+kj < 0 || ij+kj >= ifh) continue;
            for (ki = 0; ki < kw; ++ki) {
              if (ii+ki < 0 || ii+ki >= ifw) continue;
              input_t[(img * input_img_stride) +
                      (ifm * input_ifm_stride) +
                     ((ij + kj) * ifwp) + (ii + ki)] +=
              output[(img * output_img_stride) +
                     (ofm * output_ofm_stride) +
                     (oj * ofw) + oi] *
              filter[(ofm * weight_ofm_stride) +
                     (ifm * weight_ifm_stride) +
                     (kj * kw) + ki];
            }
          }
        }
      }
    }
  }
}
```

```
if (kw == 1 && ifw == 28 && stride_w == 1 && pad_w == 0
    && ofw == 28 && kh == 1 && ifh == 28 && ofh == 28
    && stride_h == 1 && pad_h == 0 ) {
  for (img = 0; img < nImg; ++img) {
    for (ifm = 0; ifm < nIfm; ++ifm) {
      for (ofm = 0; ofm < nOfm; ++ofm) {
        for (oj = 0; oj < 28; ++oj) {
          ij = oj * 1 - 0;
          for (oi = 0; oi < 28; ++oi) {
            ii = oi * 1 - 0;
            for (kj = 0; kj < 1; ++kj)  {
              for (ki = 0; ki < 1; ++ki) {
                input_t[(img * input_img_stride) +
                        (ifm * input_ifm_stride) +
                       ((ij + kj) * ifwp) + (ii + ki)] +=
                output[(img * output_img_stride) +
                       (ofm * output_ofm_stride) +
                       (oj * 28) + oi] *
                filter[(ofm * weight_ofm_stride) +
                       (ifm * weight_ifm_stride) +
                       (kj * 1) + ki];
              }
            }
          }
        }
      }
    }
  }
} else {
  <Original Body>
}
```

CNN: Impact of Specialization



Abinit: Impact of Specialization Combined with Tiling



	# lines of code	Execution time (sec)	Speedup
Original version	716	2.55	1
ASSIST version	1338	1.47	1.75

Results Summary

- By application and dataset
  - Yales2
    - 3D Cylinder – 10% (LCT), 14% (LCT+IPGO)
    - 1D COFFEEE – 4% (LCT), 6% (LCT+IPGO)
  - AVBP
    - SIMPLE – 1% (LCT), 12% (SVT)
    - NASA – 8% (LCT), 24% (SVT)
    - TPF – 3% (LCT), 9% (SVT)
  - POLARIS
    - Test.1.0.5.18 – 4% (SVT)
  - CNN
    - All layers – 50% -550%

Issues & Limitations

- **Analysis**
  - Debug information accuracy
  - What information to collect while limiting the overhead
- **Transformation**
  - Rose frontend/backend on Fortran/C++
  - How to match the right transformation with collected metrics
  - Compiler can ignore a transformation
  - Directives are often compiler dependent
- **Verification**
  - Compare two different binaries (Loop split/duplicated, disappeared, etc)

Conclusion

Contributions

- Good gains on real-world applications
- New study of how and when well-known transformations work (such as LCT)
- New semi-automatic & user controllable method
- An FDO tool which can use both static and dynamic analysis information to guide code optimization
- A flexible alternative to current compilers PGO/FDO modes

Available on github

https://youelebr.github.io **: maqao binary, assist sources, test suite and documentation)**

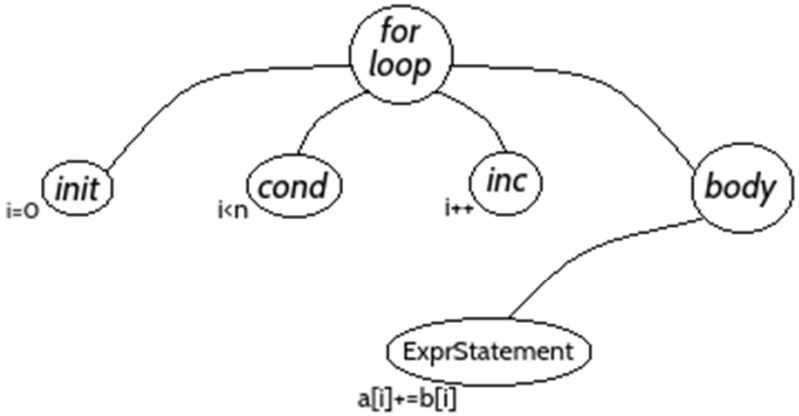
Perspectives

- Complement MAQAO binary analysis with source code analysis
- Add new transformations and/or extend existing ones (e.g. specialization)
- Find more metrics and how to associate them to know when to trigger/enable a transformation
- Multiple datasets
- Auto-tuning with iterative compilation using our verification system
- Drive transformation for energy consumption and/or memory

Transformation Example

```
#pragma MAQAO UNROLL=4
for i=0; i < n; i++ do
   a[i] += b[i];
end for
```

(a) Source code



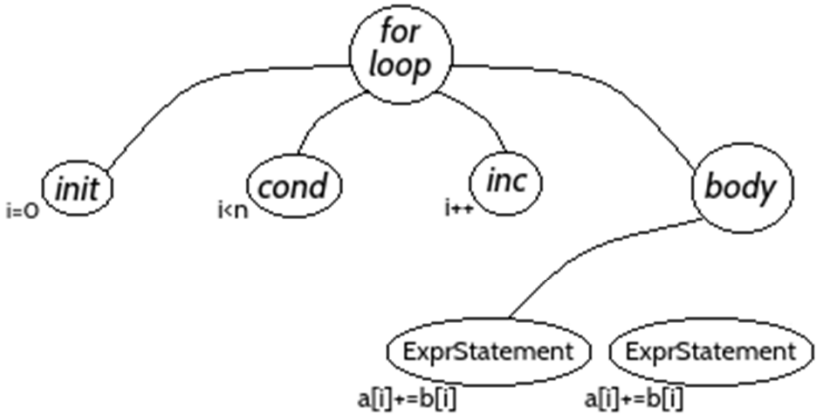
(b) Corresponding AST

Transformation Example

```
for i=0; i < n; i++ do
    a[i] += b[i];

end for
```

(a) Source code



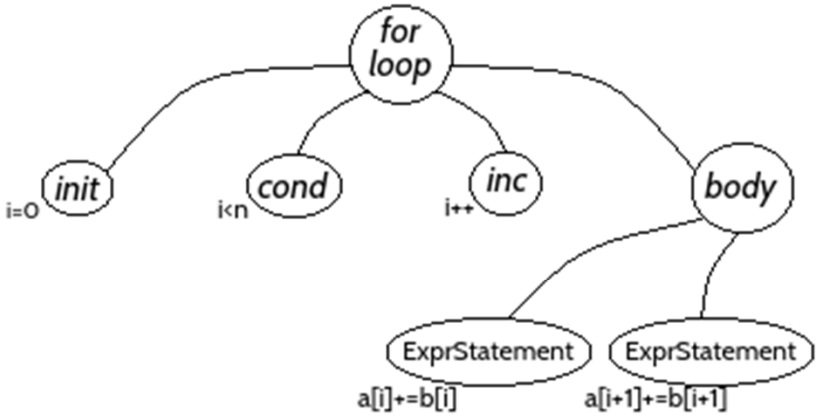
(b) Corresponding AST

Transformation Example

```
for i=0; i < n; i++ do
   a[i] += b[i];
   a[i+1] +=b [i+1];

end for
```

(a) Source code



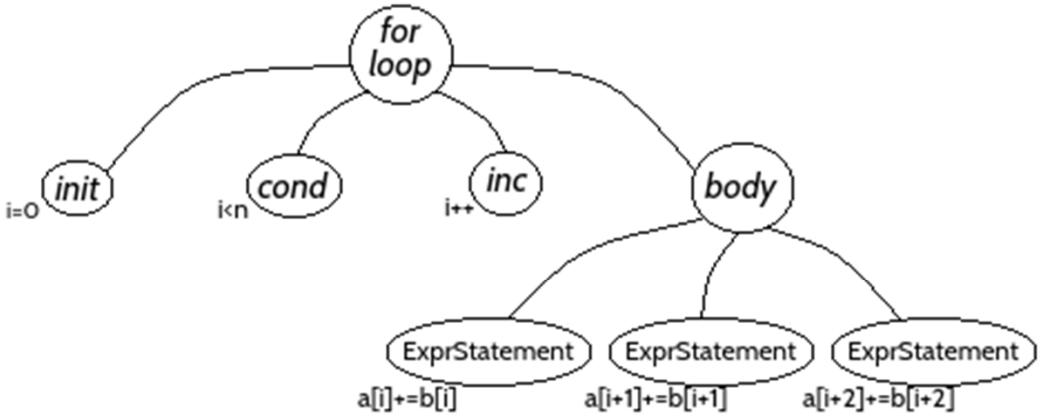
(b) Corresponding AST

Transformation Example

```
for i=0; i < n; i++ do
    a[i] += b[i];
    a[i+1] +=b [i+1];
    a[i+2] += b[i+2];

end for
```

(a) Source code

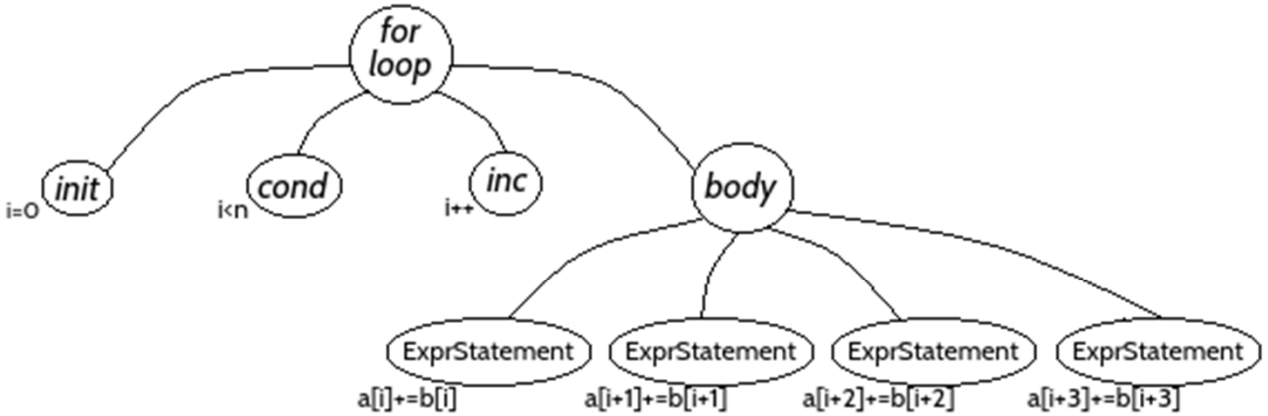


(b) Corresponding AST

Transformation Example

```
for i=0; i < n; i++ do
    a[i] += b[i];
    a[i+1] +=b [i+1];
    a[i+2] += b[i+2];
    a[i+3] += b[i+3];
end for
```

(a) Source code

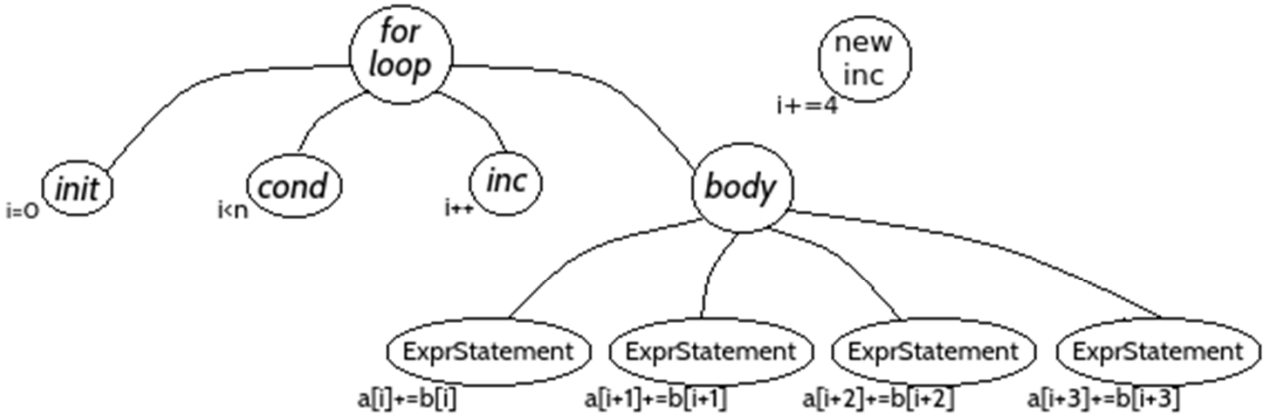


(b) Corresponding AST

Transformation Example

```
for i=0; i < n; i++ do
    a[i] += b[i];
    a[i+1] +=b [i+1];
    a[i+2] += b[i+2];
    a[i+3] += b[i+3];
end for
```

(a) Source code

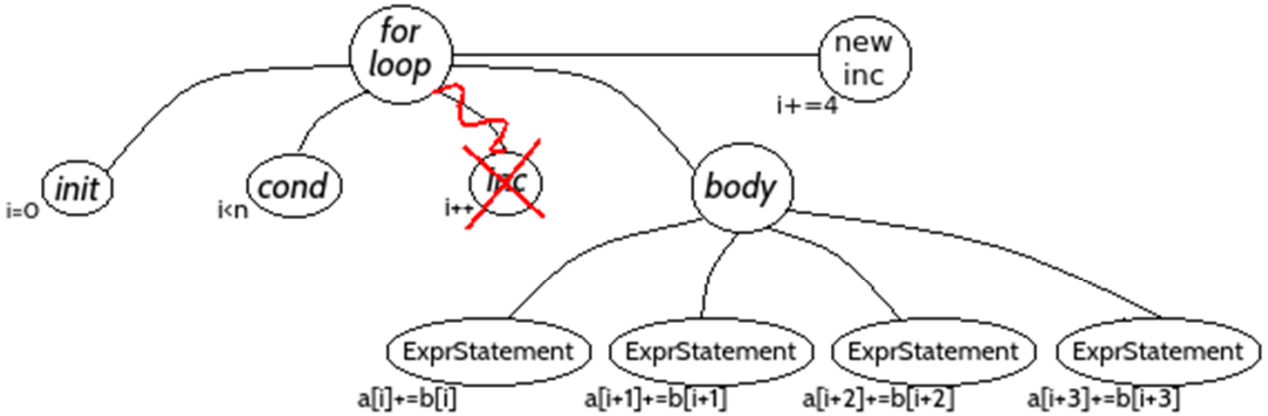


(b) Corresponding AST

Transformation Example

```
for i=0; i < n; i+=4 do
  a[i] += b[i];
  a[i+1] +=b [i+1];
  a[i+2] += b[i+2];
  a[i+3] += b[i+3];
end for
```

(a) Source code

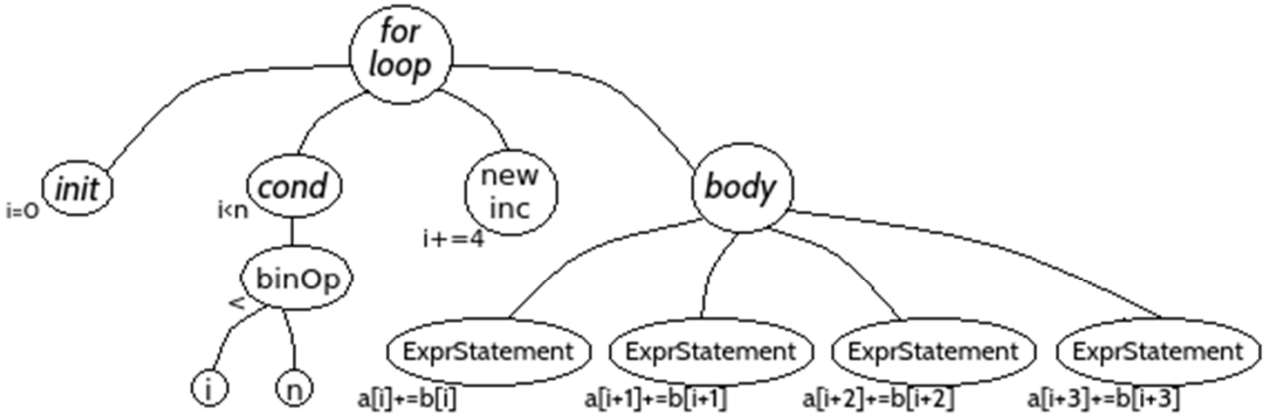


(b) Corresponding AST

Transformation Example

```
for i=0; i < n; i+=4 do
   a[i] += b[i];
   a[i+1] +=b [i+1];
   a[i+2] += b[i+2];
   a[i+3] += b[i+3];
end for
```

(a) Source code

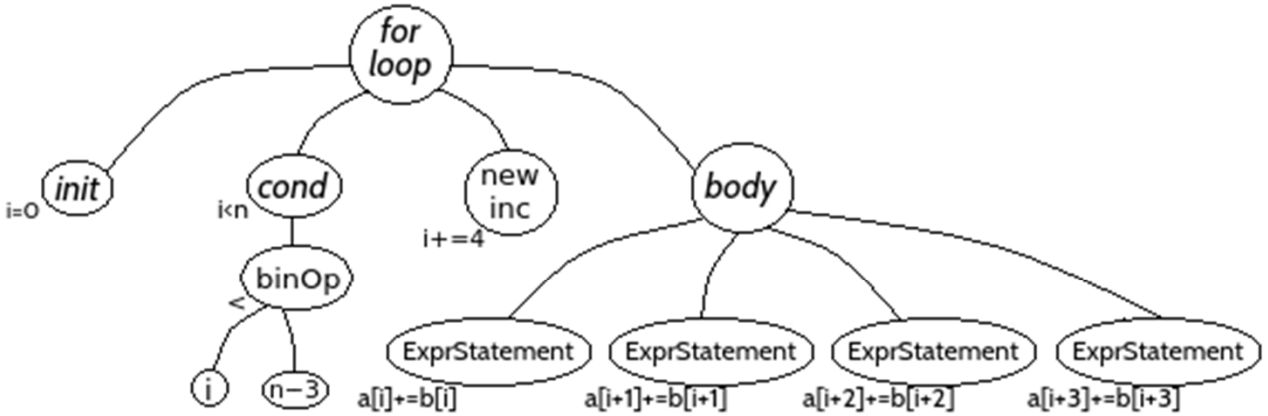


(b) Corresponding AST

Transformation Example

```
for i=0;i<n-3; i+=4 do
  a[i] += b[i];
  a[i+1] +=b [i+1];
  a[i+2] += b[i+2];
  a[i+3] += b[i+3];
end for
```

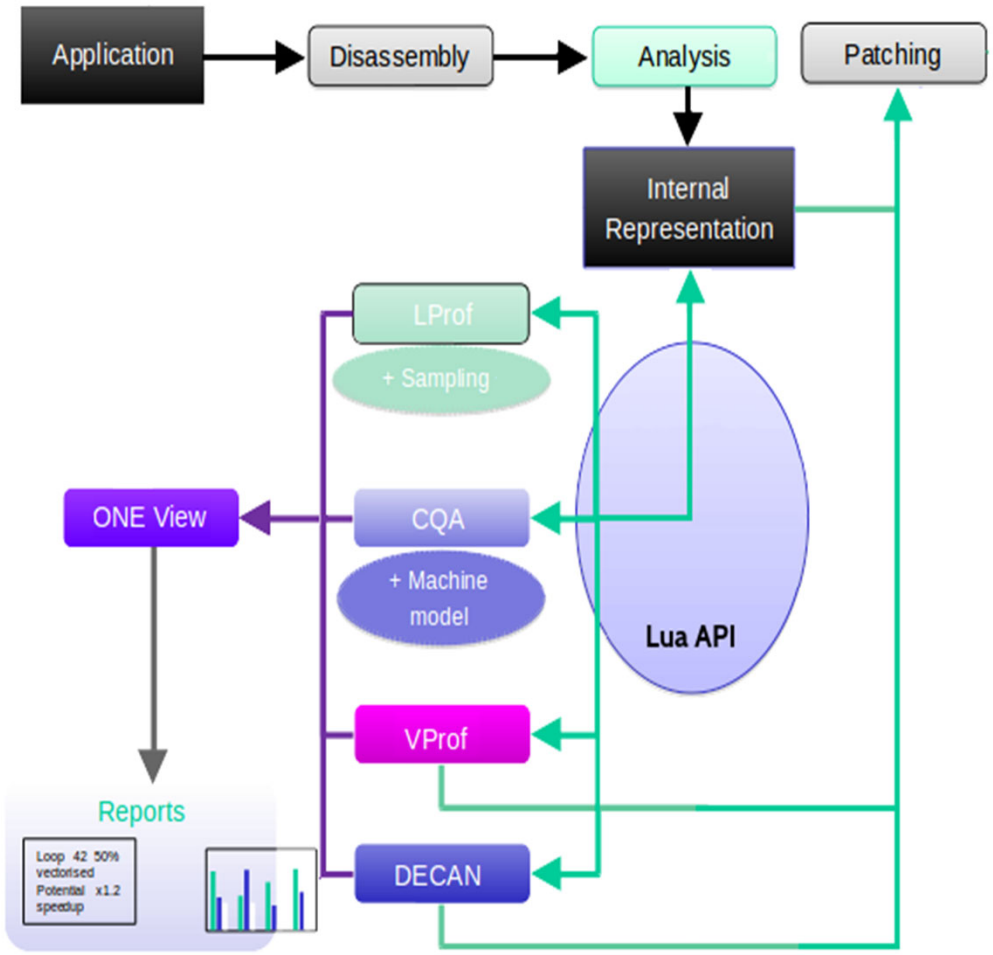
(a) Source code



(b) Corresponding AST

II – ASSIST

- MAQAO
- Design & Implementation
- Supported Transformations
- How to trigger Transformations
- Assessing Transformation Verification



- MAQAO Modules
  - Static analyser
    - CQA: Code Quality Analyzer
  - Dynamic analyser (using sampling & tracing)
    - LProf: Lightweight Profiler
    - VProf: Value Profiler
    - DECAN: DECremental Analysis
  - Global view
    - OneView

Assessing Transformation Verification

GLOBAL METRICS	BEFORE TRANSFO	AFTER TRANSFO	IS BETTER ?
Total Time (s) :	2.34	1	
Flow Complexity :	1	1	lower is better
Array Access Efficiency (%) :	71.95	54.66	higher is better
Speedup if clean :	1	1.04	lower is better
Nb loops to get 80% if clean :	1	1	lower is better
Speedup if FP Vectorised :	1	1.47	lower is better
Nb loops to get 80% if FP vectorized :	1	1	lower is better
Speedup if Fully Vectorised :	1.66	1.87	lower is better
Nb loops to get 80% if Fully vectorized :	3	2	lower is better
Speedup if data in L1 Cache :	1	1.18	lower is better
Nb loops to get 80% if data in L1 Cache :	0	2	lower is better
Compilation Options :	OK	OK	
Loop lines :	314 - 314	881-884	
Loop_id :	74	246	
Speedup if clean :	1.00	1.06	lower is better
Speedup if fully vectorized :	1.62	2.06	lower is better
Bottlenecks :	p5	P0,01	
Unroll confidence level :	max	max	
Cycles L1 if clean :	13	8.00	higher is better
Cycles L1 if fully vec :	8	2.06	higher is better
Vector-efficiency ratio all :	85.71	42.00	higher is better
Vectorization ratio all :	67.86	68.00	higher is better
FP op per cycle L1 :	2.46,	3.76	higher is better

IV – Experiments

Impact of Specialization Combined with SVT

```
218   ...
219   DO n=1, nel
220     DO no = 1, nvert
221       !DIR$ SIMD
222       DO k= -nproduct+1, 0
223         zobj(no * nproduct + k , n) = z(ielob(no,n) * nproduct + k)
224       END DO
225     END DO
226   END DO
227   ...
```

Name	Coverage (%)	Time (s)
▼ gather_o_cpy	13.67	21.18
▼ Loop 16183 - gather_o_cpy.f90:197-201 - AVBP_V7.0.1_orig	0.27	0.42
○ Loop 16182 - gather_o_cpy.f90:198-201 - AVBP_V7.0.1_orig	3.83	5.93
▼ Loop 16181 - gather_o_cpy.f90:197-201 - AVBP_V7.0.1_orig	0.23	0.36
○ Loop 16180 - gather_o_cpy.f90:198-201 - AVBP_V7.0.1_orig	2.32	3.59
▼ Loop 16178 - gather_o_cpy.f90:197-201 - AVBP_V7.0.1_orig	0.09	0.14
○ Loop 16177 - gather_o_cpy.f90:198-201 - AVBP_V7.0.1_orig	0.58	0.9
▼ Loop 16194 - gather_o_cpy.f90:197-201 - AVBP_V7.0.1_orig	0.08	0.12
○ Loop 16193 - gather_o_cpy.f90:198-201 - AVBP_V7.0.1_orig	2.07	3.21
▼ Loop 16192 - gather_o_cpy.f90:197-201 - AVBP_V7.0.1_orig	0.07	0.11
○ Loop 16191 - gather_o_cpy.f90:198-201 - AVBP_V7.0.1_orig	1.82	2.82
▼ Loop 16214 - gather_o_cpy.f90:197-201 - AVBP_V7.0.1_orig	0	0
▼ Loop 16213 - gather_o_cpy.f90:198-201 - AVBP_V7.0.1_orig	0	0
○ Loop 16216 - gather_o_cpy.f90:200-201 - AVBP_V7.0.1_orig	0	0
○ Loop 16215 - gather_o_cpy.f90:200-201 - AVBP_V7.0.1_orig	0	0
○ Loop 16201 - gather_o_cpy.f90:197-201 - AVBP_V7.0.1_orig	0	0
○ Loop 16202 - gather_o_cpy.f90:197-201 - AVBP_V7.0.1_orig	0	0
▼ Loop 16218 - gather_o_cpy.f90:197-201 - AVBP_V7.0.1_orig	0	0

Impact of Specialization Combined with SVT

Function specialization

	Name	Coverage (%)	Time (s)
	▼ gather_o_cpy_flat_2d_assist_nverte4_nproductmod42	7.55	12.21
1	▼ Loop 9633 - gather_o_cpy.f90:314-318 - AVBP_V7.0.1_speF	0.36	0.58
1	▼ Loop 9632 - gather_o_cpy.f90:315-318 - AVBP_V7.0.1_speF	2	3.23
1	○ Loop 9635 - gather_o_cpy.f90:317-318 - AVBP_V7.0.1_speF	3.79	6.13
1	○ Loop 9634 - gather_o_cpy.f90:317-318 - AVBP_V7.0.1_speF	1.37	2.21
	▼ gather_o_cpy_flat_2d_assist_nverte4_nproductmod41	3.92	6.34
2	▼ Loop 9637 - gather_o_cpy.f90:288-292 - AVBP_V7.0.1_speF	0.27	0.44
2	▼ Loop 9636 - gather_o_cpy.f90:289-292 - AVBP_V7.0.1_speF	1.51	2.44
2	○ Loop 9639 - gather_o_cpy.f90:291-292 - AVBP_V7.0.1_speF	1.7	2.75
2	○ Loop 9638 - gather_o_cpy.f90:291-292 - AVBP_V7.0.1_speF	0.43	0.7
	▼ gather_o_cpy	2.88	4.66
4	○ Loop 9567 - gather_o_cpy.f90:155-158 - AVBP_V7.0.1	2.17	3.51
5	▼ Loop 9569 - gather_o_cpy.f90:339-343 - AVBP_V7.0.1_speF	0.04	0.06
5	○ Loop 9568 - gather_o_cpy.f90:340-343 - AVBP_V7.0.1_speF	0.58	0.94
	▼ gather_o_cpy_flat_2d_assist_nverte4	2.14	3.46
3	▼ Loop 9645 - gather_o_cpy.f90:235-239 - AVBP_V7.0.1_speF	0.07	0.11
3	▼ Loop 9644 - gather_o_cpy.f90:236-239 - AVBP_V7.0.1_speF	0.39	0.63
3	○ Loop 9647 - gather_o_cpy.f90:238-239 - AVBP_V7.0.1_speF	1.28	2.07
3	○ Loop 9646 - gather_o_cpy.f90:238-239 - AVBP_V7.0.1_speF	0.4	0.65

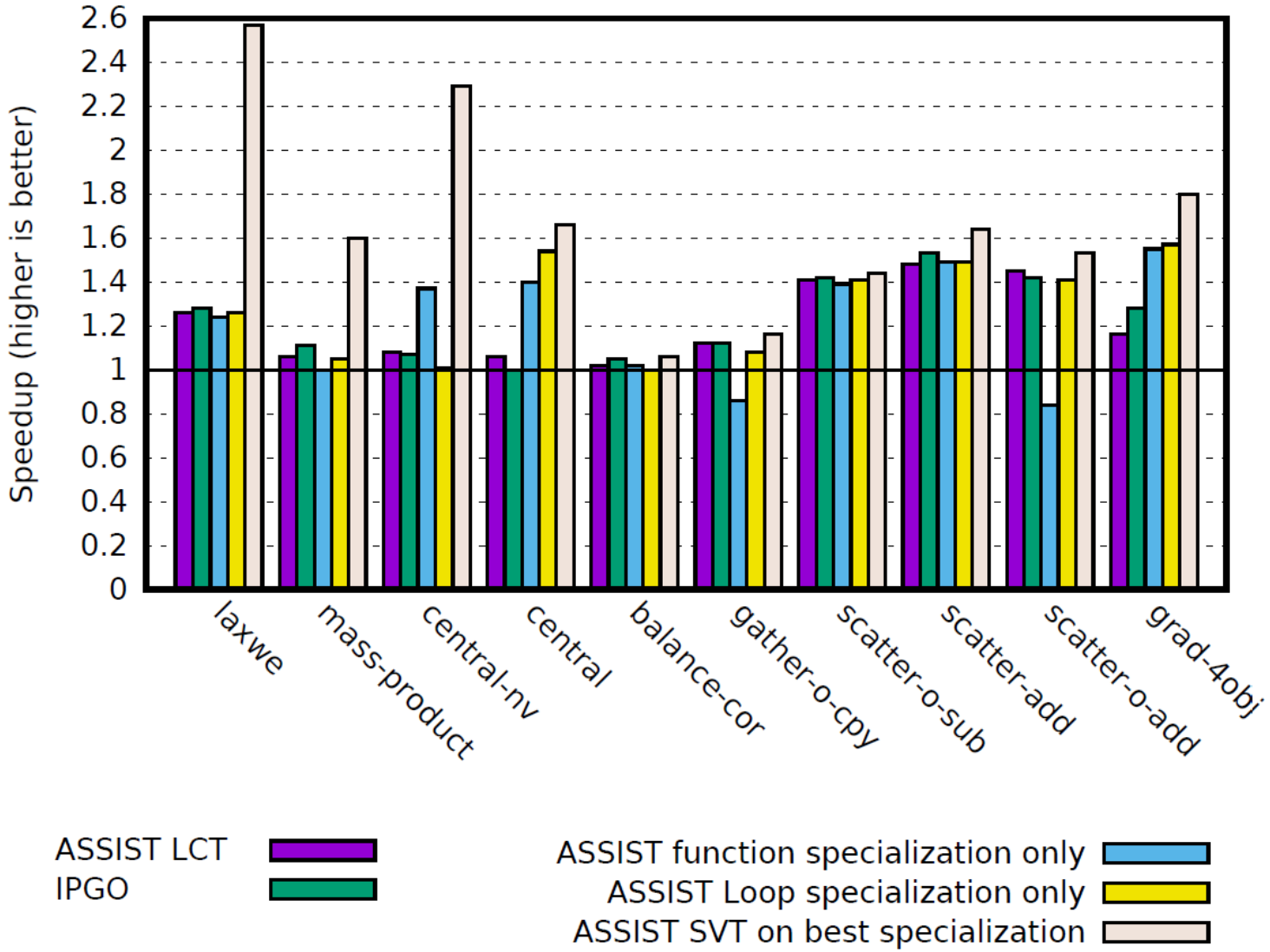
Loop specialization

	Name	Coverage (%)	Time (s)
	▼ gather_o_cpy	13.91	21.31
4	○ Loop 9465 - gather_o_cpy.f90:165-168 - AVBP_V7.0.1_speL	2.21	3.39
1	▼ Loop 9473 - gather_o_cpy.f90:223-227 - AVBP_V7.0.1_speL	0.29	0.44
1	○ Loop 9472 - gather_o_cpy.f90:224-227 - AVBP_V7.0.1_speL	3.87	5.93
2	▼ Loop 9471 - gather_o_cpy.f90:214-218 - AVBP_V7.0.1_speL	0.21	0.32
2	○ Loop 9470 - gather_o_cpy.f90:215-218 - AVBP_V7.0.1_speL	2.55	3.91
1	▼ Loop 9486 - gather_o_cpy.f90:223-227 - AVBP_V7.0.1_speL	0.09	0.14
1	○ Loop 9485 - gather_o_cpy.f90:224-227 - AVBP_V7.0.1_speL	2.05	3.14
3	▼ Loop 9484 - gather_o_cpy.f90:241-245 - AVBP_V7.0.1_speL	0.08	0.12
3	○ Loop 9483 - gather_o_cpy.f90:242-245 - AVBP_V7.0.1_speL	1.78	2.73
5	▼ Loop 9468 - gather_o_cpy.f90:232-236 - AVBP_V7.0.1_speL	0.07	0.11
5	○ Loop 9467 - gather_o_cpy.f90:233-236 - AVBP_V7.0.1_speL	0.59	0.9

Best specialization + SVT

	Name	Coverage (%)	Time (s)
	▼ gather_o_cpy	14.81	20.51
1	○ Loop 16014 - gather_o_cpy.f90:226-236 - AVBP_V7.0.1_SVT	3.52	4.87
2	○ Loop 16013 - gather_o_cpy.f90:215-222 - AVBP_V7.0.1_SVT	3.09	4.28
4	○ Loop 16009 - gather_o_cpy.f90:165-168 - AVBP_V7.0.1_SVT	2.51	3.48
1	○ Loop 16021 - gather_o_cpy.f90:226-236 - AVBP_V7.0.1_SVT	2.46	3.41
3	○ Loop 16020 - gather_o_cpy.f90:252-265 - AVBP_V7.0.1_SVT	2.45	3.39
5	○ Loop 16011 - gather_o_cpy.f90:241-248 - AVBP_V7.0.1_SVT	0.66	0.91

Impact of Specialization Combined with SVT



Impact of Specialization Combined with SVT

	Execution Time before trans (sec)	Execution Time after trans (sec)	Speedup	Coverage (orig version)
Polaris	73.32	70.26	1.04	
Loop 6909	4.27	3.14	1.36	5.72%
Loop 6911	3.64	2.36	1.54	4.98%

Table: Execution time and speedups of ASSIST SVT compared with the original version on Polaris using the “test.1.0.5.1.8” test case.

Impact of Specialization Combined with Tiling

```
!DIR$ MAQAO SPECIALIZE(choice=1,paw_opt=3,cplex=2)
!DIR$ MAQAO SPECIALIZE(choice=1,paw_opt<3,cplex=2)
!DIR$ MAQAO SPECIALIZE(choice=1,paw_opt>3,cplex=2)
subroutine opernlb_ylm(choice,cplex,paw_opt,...)
 ...
 if(choice==1) then
  !DIR$ MAQAO IF_SPE_choicee1_TILE_INNER=8
  do ilmn=1, nlmn
   do k=1, npw
    z(k)=z(k)+ffnl(K,1,ilmn)*cplx(gxf(1,ilmn) &
         ,gxf(2,ilmn),kind=dp)
   end do
  end do
 end if
 ...
end subroutine
```

(a) Before specialization + tiling

```
SUBROUTINE opernlb_ylm(...)
 IF ((choice.EQ.1).AND.(paw_opt.EQ.3)/aND(cplex.EQ.2)) then
  CALL opernlb_ylm_ASSIST_choicee1_paw_opte3_cplexe2(...)
  RETURN
 END IF
 IF ((choice.EQ.1).AND.(paw_opt.LT.3)/aND(cplex.EQ.2)) then
  CALL opernlb_ylm_ASSIST_choicee1_paw_opte3_cplexe2(...)
  RETURN
 END IF
 IF ((choice.EQ.1).AND.(paw_opt.GT.3)/aND(cplex.EQ.2)) then
  CALL opernlb_ylm_ASSIST_choicee1_paw_opte3_cplexe2(...)
  RETURN
 END IF
 ...
END SUBROUTINE
...
SUBROUTINE opernlb_ylm_ASSIST_choicee1_paw_opte3_cplexe2(...)
 ...
 lt_bound_npw = (npw / 8) * 8
 DO lv_var_k = 1, lt_bound_npw, 8
   DO ilmn = 1, ilmn
     DO k = lt_var_k, lt_var_k + (8-1)
      z(k)=z(k)+ffnl(K,1,ilmn)*cplx(gxf(1,ilmn) &
          ,gxf(2,ilmn),kind=dp)
     END DO
   END DO
 END DO
 ...
END SUBROUTINE
SUBROUTINE opernlb_ylm_ASSIST_choicee1_paw_opti3_cplexe2(...)
 ...
END SUBROUTINE
SUBROUTINE opernlb_ylm_ASSIST_choicee1_paw_opts3_cplexe2(...)
 ...
END SUBROUTINE
```

(b) After specialization + tiling

Other results: QMCPACK other transformations

	Orig	Fu	Split	Fume
Total	58.11	55.4	53.81	51.21
Loop 18800	16.75	16.59	16.2	13.6
Loop 26027	16.07	12.42	12.27	11.9
Loop 26026	3.22	2.19	2.27	2.1
Loop 26028	3.24	2.21	2.09	2.05
Loop 18501	1.49	1.51	1.23	1.16
Loop 26800	1.3	1.01	1.03	1.00

Execution time (sec) of multiple versions of QMCPACK (k64s64).

Orig: Original version;

fu: Full unroll version;

split: fu + split a loop to increase its vectorization ratio;

fume: split + full unroll the inbetween loop of a nest and merge unrolled body in the innermost;

Contributions

- A study of how and when well-known transformations allow to gain on real-world HPC applications using a novel FDO source-to-source approach
- A novel semi-automatic and user controllable method with a system open to user advices
- An FDO tool combining both dynamic and static analysis information to guide code optimization
- A more flexible alternative to compilers PGO/FDO modes
- A verification system to check if our transformations do not have a negative impact on performances

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Short Vectorization Transformation – Type: Mixed AST modifier and directive insertion

- Compilers may refuse to vectorize a loop with too few iterations
- Performing a loop decomposition
- Increasing the vectorization ratio by:
  - Forcing the vectorization (SIMD directive)
  - Avoiding dynamic or static loop peeling transformation (UNALIGNED directive)