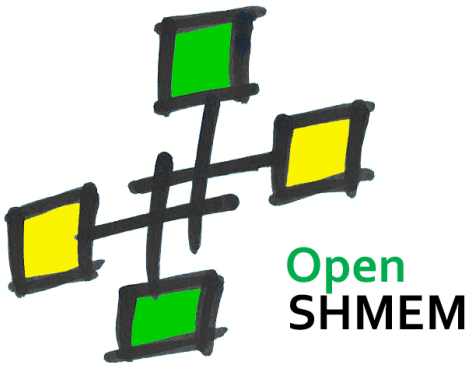

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Extending the OpenSHMEM Analyzer to perform synchronization and multi-valued analysis

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Outline

- Motivation
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  - OpenUH compiler
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Motivation

- The OpenSHMEM Analyzer (OSA) is a compiler-based tool to help the user correctly use the OpenSHMEM library API.
  - Paper: Oscar, H., Siddhartha, J., Pophale, S., Stephen, P., Kuehn, J., Barbara, C.: The OpenSHMEM Analyzer. In: Proceedings of the Sixth Conference on Partitioned Global Address Space Programming Model. PGAS '12 (2012)

- Extending the OpenSHMEM to perform concurrent analysis
  - In OpenSHMEM you can write syntactically correct parallel programs but that are semantically wrong are possible.
  - Optimizations are often limited to portions of code between barriers.
  - Synchronization errors can lead to race conditions and deadlock.

Discovering Synchronization Phases

- Extending OSA to discover the synchronization phases of an OpenSHMEM program
  - Important for memory consistency and control points in an application
  - Two forms of collective synchronization exists in OpenSHMEM
    - shmem_barrier_all is defined over all PEs.
    - shmem_barrier is defined over an ***active set***.
      - An active set is a logical grouping of PEs based on three parameters (passed as arguments) namely, PE start, logPE_stride and PE size triplet .
  - OpenSHMEM specification allows unaligned barriers.

- Optimizations are possible only between global synchronization calls.
- Same concepts are applicable to other PGAS languages/libraries.

Textually Unaligned Barriers

- Textually Non-aligned vs. Aligned code

```
if (me%2==0){
  …
  shmem_barrier_all();
}
else{
  …
  shmem_barrier_all();
}
```

```
if (me%2==0){
  …
  …
}
else{
  …
  …
}
shmem_barrier_all();
```

- BOTH ARE VALID IN OPENSHMEM

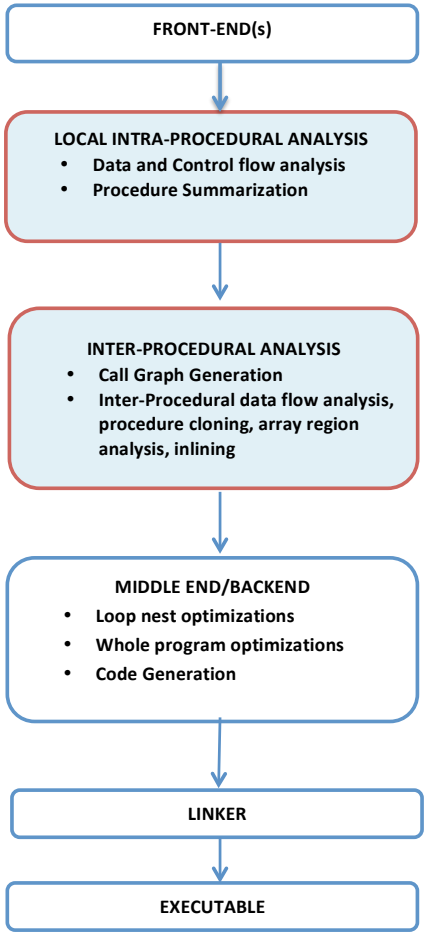
Introduction: OpenUH Compiler

- Open source research compiler based on Open64
- Complete support for OpenMP 2.5 (in C/C++ & Fortran) and CAF
- Stable, portable, modularized with complete optimization framework
- Available on most Linux platforms

Introduction: OSA

- OpenSHMEM Analyzer (OSA) extends the existing compiler technology to report errors accurately in context of C and OpenSHMEM.
- Provided basic syntactic and semantic checks.
- Verifies at compile time that all OpenSHMEM library calls are using the appropriate classes of data as required by Specification 1.0.
- Mainly focuses on IPA phase of the OpenUH compiler.

OSA within OpenUH



Concurrency Analysis

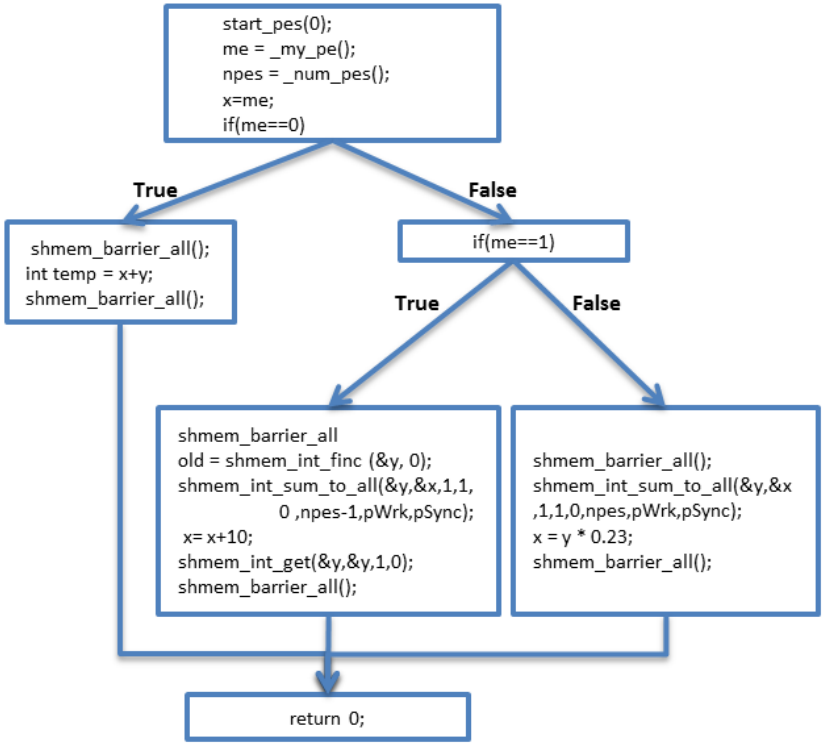
- All PEs execute the application in SPMD style
- Different PEs may take different execution paths based on the implicit or explicit conditions set by the programmer.
- Variables that have different values on different PEs.
  - **Multivalued seed**
- Multi-Valued Expressions
  - "An expression is multi-valued if it evaluates differently in different threads."

Implementation

- Step 1: Identification of multivalued seeds and multivalued expression
  - Analyze Control and Data flow
  - Construct System dependence graph
  - Analyze effect of OpenSHMEM calls on multivalued seeds
- Step 2: Detection of OpenSHMEM barriers and their ordering
- Step 3: Barrier tree generation and barrier matching

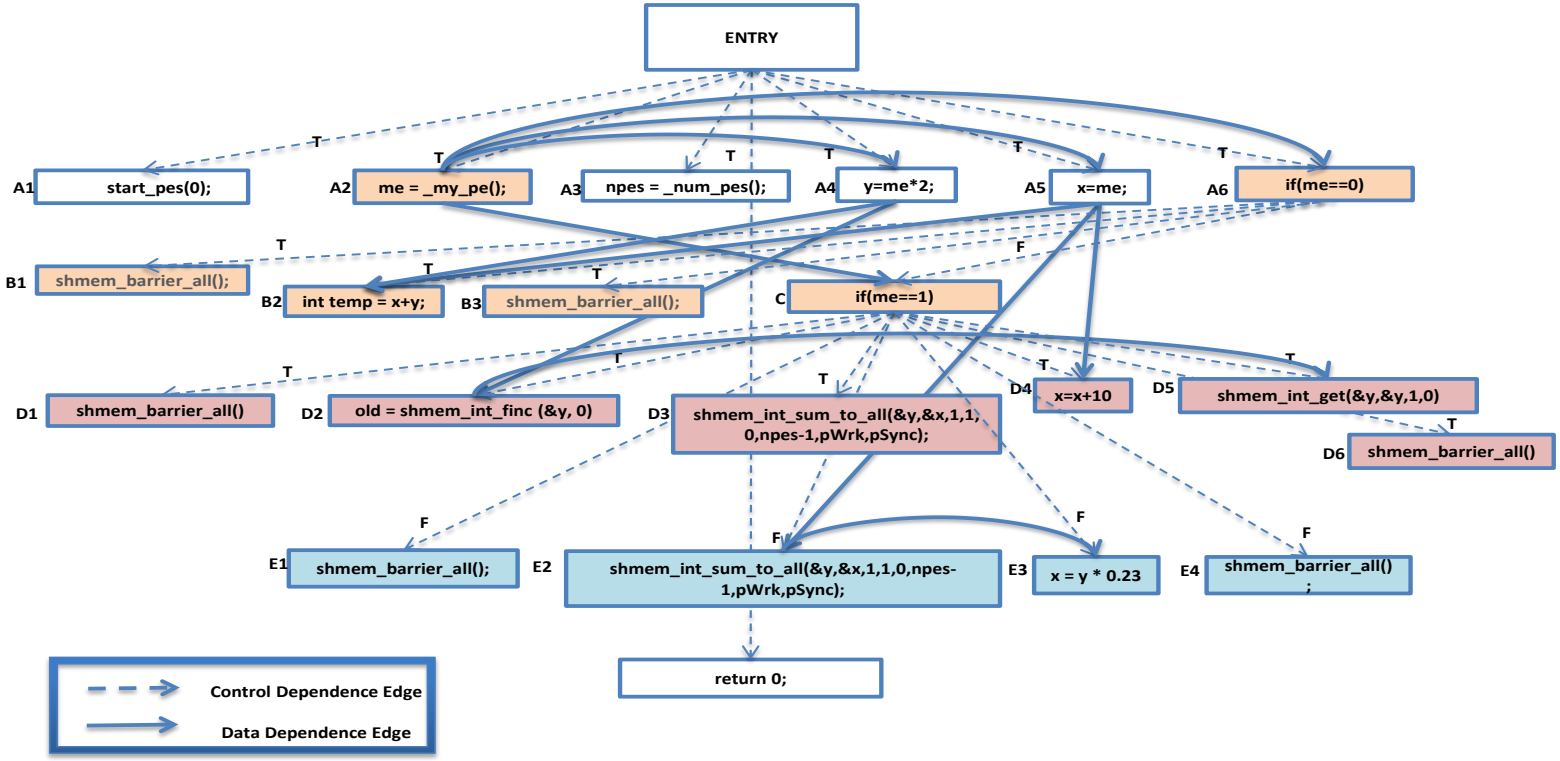
Step 1: Control Flow and Data Flow

```
int main(int argc, char *argv[]){
 …
   if(me==0){
      shmem_barrier_all();
      int temp = x+y;
      shmem_barrier_all();
   }
   else {
     if(me==1){
         shmem_barrier_all();
         old = shmem_int_finc (&y, 0);
         shmem_int_sum_to_all(&y,&x,
                1,1,0,npes-1,pWrk,pSync);
          x= x+10;
         shmem_int_get(&y,&y,1,0);
         shmem_barrier_all();
        }
     else{
         shmem_barrier_all();
         shmem_int_sum_to_all(&y,&x,
                1,1,0,npes-1,pWrk,pSync);
         x=y*0.23
         shmem_barrier_all();
        }
   }
  return 0;
}
```



Control Flow Graph

Step 1: System Dependence Graph



Step 1: Multi-valued and OpenSHMEM

- *Multi-valued-ness* depends on the semantics of OpenSHMEM and its treatment of different program variables.

OpenSHMEM Library Operations	Variable Affected	Effect
_num_pes	*npes*	Single-valued
_my_pe	*me*	Multi-valued
PUT (elemental, block, strided)	*target*	Multi-valued
GET (elemental, block, strided)	*target*	Multi-valued
ATOMICS (fetch and operate)	*target*	Multi-valued
BROADCAST	*target*	Multi-valued
COLLECTS (fixed and variable length)	*target* array	Single-valued if *active set* = npes else Multi-valued

TABLE I
EFFECT OF OPENSHMEM LIBRARY CALLS ON PROGRAM VARIABLES

Step 2: Barrier Detection

- We analyze the CFG of the program to determine the presence and relative ordering of the barriers.
- Based on the multivalued analysis we mark points at which the execution paths diverge.
- Mark conditionals with appropriate operator:

Placement of barriers	Operator used	Result
b1 followed by b2	·	b1 · b2
if((*single-valued*) *conditional*) b1 else b2;	|	b1 | b2
if((*multivalued-valued*) *conditional*) b1 else b2;	$\|^c$	b1 $\|^c$ b2

TABLE II
RULES FOR BUILDING A BARRIER EXPRESSION

Step 3: Barrier Tree Generation and Barrier Matching

- Generating a barrier tree
  - Iterate over the AST
  - Analyze conditionals
  - Determine relationship
  - Output using graphviz

- Use barrier tree to match unaligned barriers
  - Traverse barrier tree to match barriers
  - Gives line number information where potential unmatched barrier is found.

Results

- Application: Matrix Multiplication

- The application consists of three 2-D arrays A, B, and C, where C is used to store the product of two matrices A and B.

Output (1)

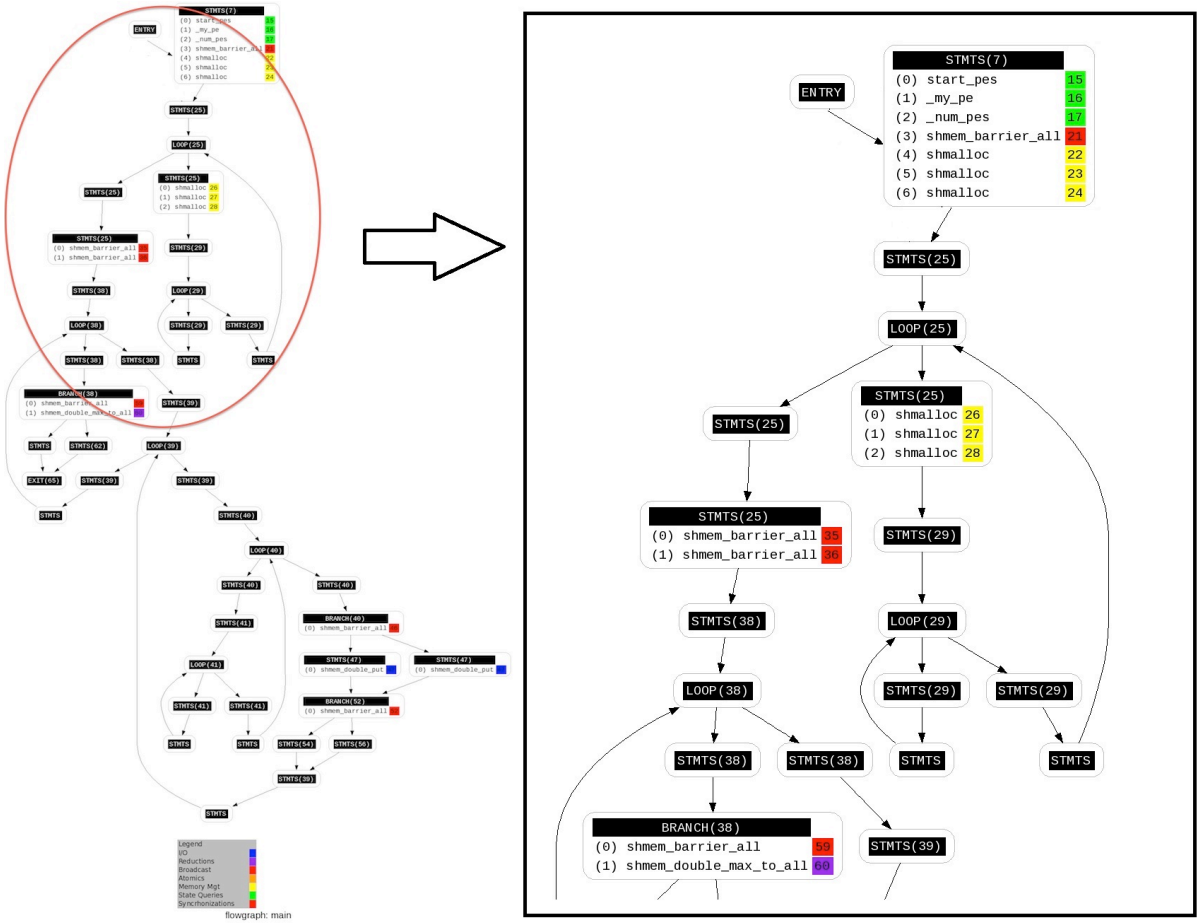


Figure: CFG with OpenSHMEM calls

Output (2)

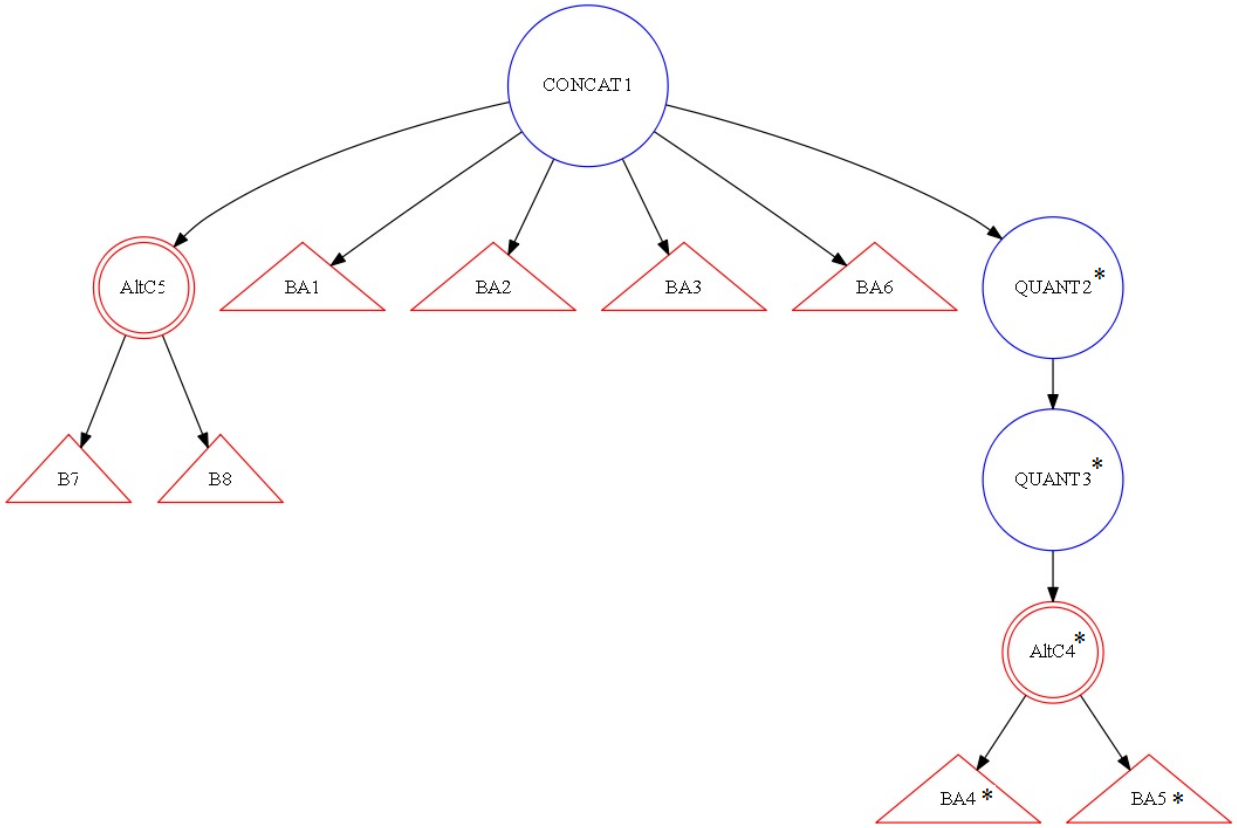


Figure: Barrier Tree generated for Matrix Multiplication benchmark

Limitations

- Static analysis tool
- shmem_barrier statements are tricky
  - active set parameters
  - Solution: explicit active sets

Summary

- OSA combines data and control flow information to determine concurrent paths in OpenSHMEM application.
- Barriers are points in OpenSHMEM applications that guarantee memory consistency.
- Unaligned barriers are a challenge for application programmers.
- OSA provides visual feedback of analysis to application programmer to better understand the program structure and synchronization structure of the program.

Acknowledgement

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