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OpenMP in Flang using MLIR

LLVM Compiler and Tools for HPC
ISC-HPC 2020

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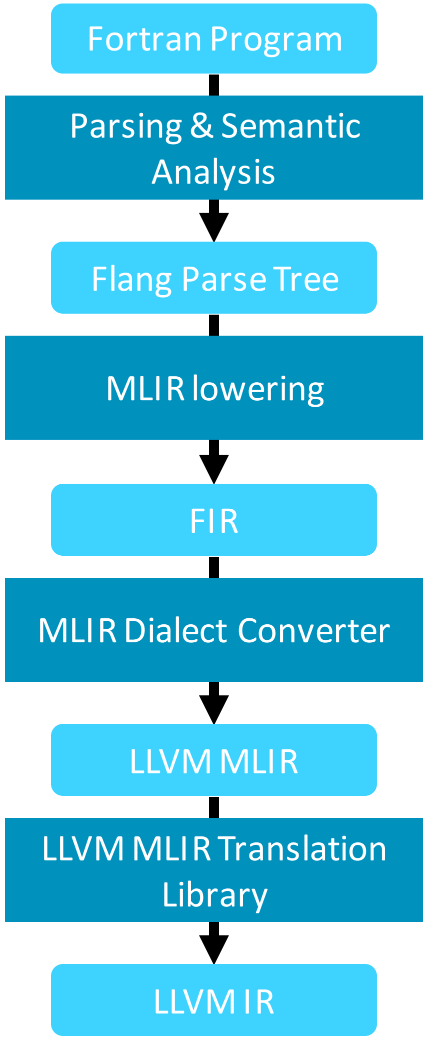
Introduction

- The Flang Fortran frontend was merged into LLVM on April 9
  - Flang started off as the F18 project at Nvidia in collaboration with US DoE
  - Arm, AMD and US DoE labs and a few individuals are contributing
  - Intends to replace the old Flang project (github.com/flang-compiler/flang)
- Built using modern technologies
  - Written in C++17
  - Uses MLIR
- Flang is a work in progress
  - Currently Flang performs parsing and semantic checks when invoked
  - It then unparses to Fortran
  - Searches for an external compiler to complete the compilation
    - Note: This is for testing

Flang compiler flow

- Parses Fortran 2018
- Performs semantic checks
- Lowers to a high level IR, FIR
  - Uses the MLIR framework
  - Come to this later
- Converts to a lower level IR, LLVM MLIR
- Lowers to LLVM IR



OpenMP support in Flang

- Support for latest OpenMP standards is important in HPC
  - Latest published standard is OpenMP 5.0
  - OpenMP 5.1 to be announced later this year
- Support for latest OpenMP standards is important for Flang to enter production
  - Old Flang (flang-project/flang) has partial support for OpenMP 4.5
- What is supported in Flang now?
  - OpenMP 4.5 parsing
  - Semantic Checks (in progress)
  - Use –`fopenmp` flag to enable OpenMP
- Uses two components for OpenMP codegen
  - MLIR
  - OpenMP IRBuilder

MLIR

- Multi Level Intermediate Representation
- A new approach for building compiler infrastructure
  - Can use to build SSA-based Intermediate Representations (IRs)
  - Provides a declarative system for defining IRs
  - Provides common infrastructure (printing, parsing, location tracking, pass management etc)
- Flang compiler uses the MLIR based FIR dialect as its IR
- FIR models the Fortran language portion
  - Does not have a representation for OpenMP constructs
- Add a dialect in MLIR for OpenMP
  - MLIR provides common framework for representing OpenMP and Fortran constructs
  - Makes OpenMP codegen re-usable

MLIR

- Operations in the IR can contain regions
- LLVM IR instructions cannot
- Representation in LLVM IR involves outlining

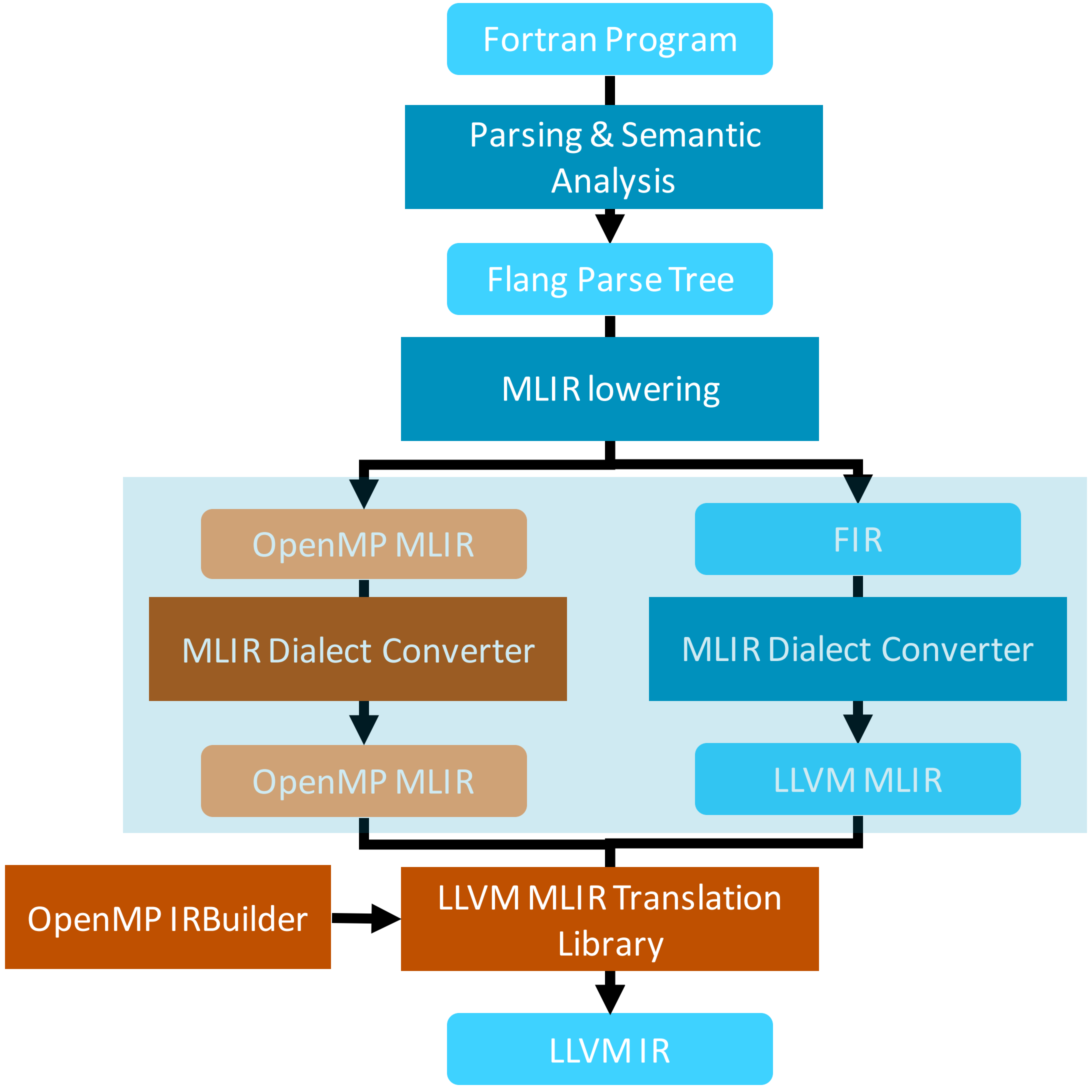
```
//MLIR

omp.parallel {
  %3 = llvm.add %1, %2 : !llvm.float
  omp.terminator
}
```

```
//LLVM IR

define @outlined_parallel(...)
{
  …
  %1 = fadd float %2, %3
  …
}

call kmpc_fork_call(...,outlined_parallel,...)
```

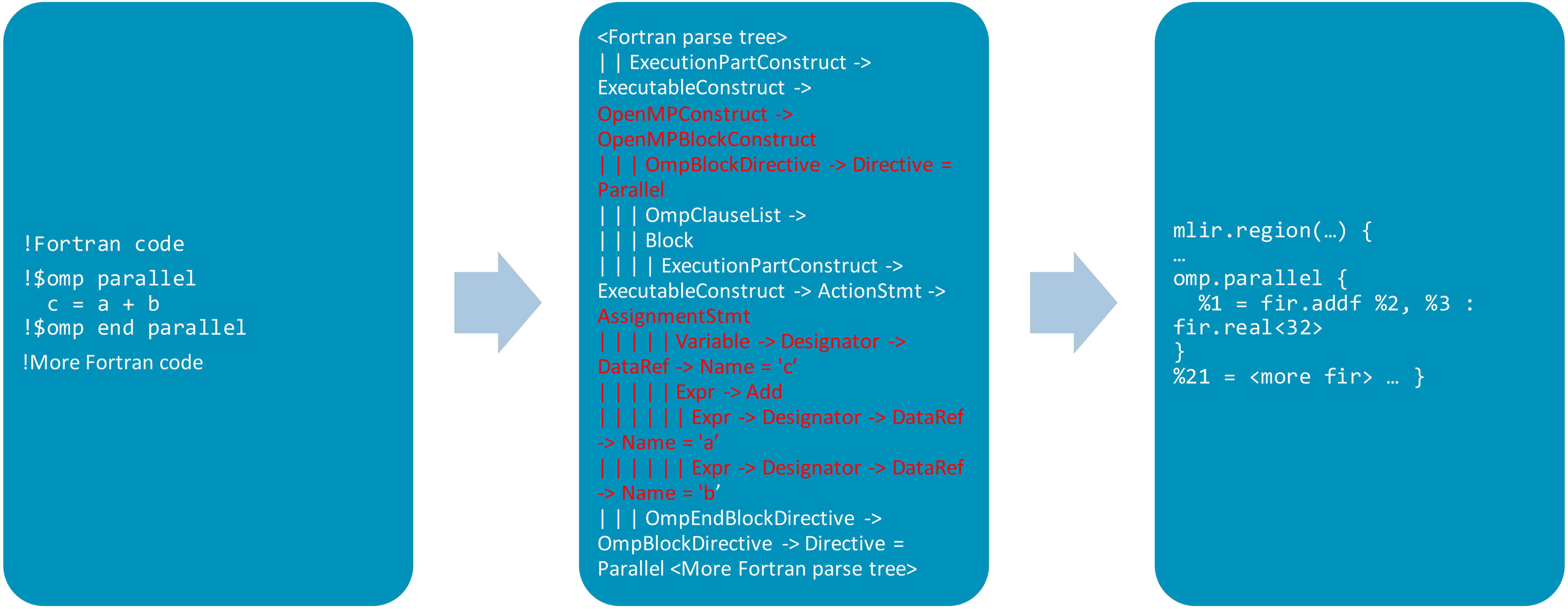
OpenMP IRBuilder

- Generating LLVM IR involves two important tasks
  - Inserting calls to OpenMP runtime
  - Outlining OpenMP regions
- Code exists in Clang for these tasks.
  - Reuse codegen from Clang
- Refactor codegen for OpenMP constructs in Clang and move to the LLVM directory
  - llvm/lib/Frontend/OpenMP

OpenMP plan for Flang



Example : OpenMP Parallel



Fortran source with OpenMP

```
!Fortran code
!$omp parallel
  c = a + b
!$omp end parallel
!More Fortran code
```

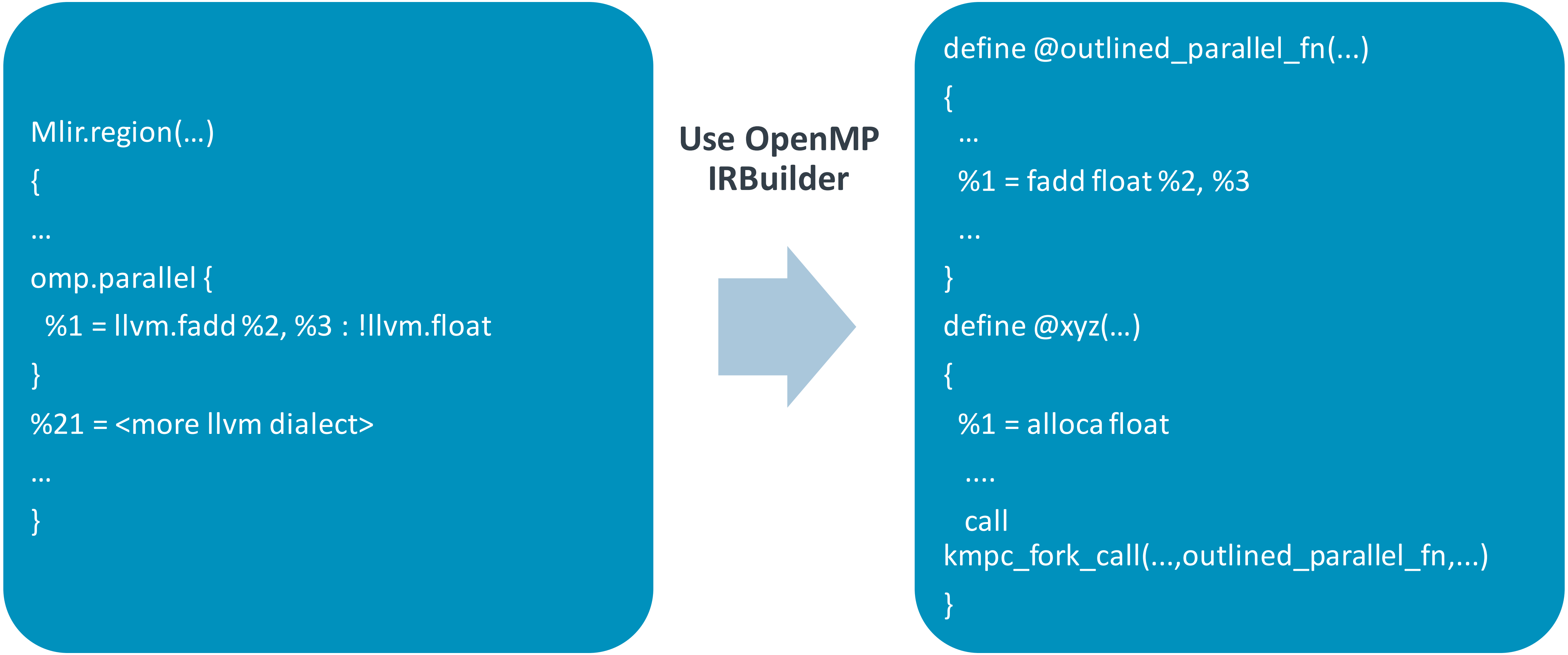
Flang parse tree

```
<Fortran parse tree>
| | ExecutionPartConstruct ->
ExecutableConstruct ->
OpenMPConstruct ->
OpenMPBlockConstruct
| | | OmpBlockDirective -> Directive =
Parallel
| | | OmpClauseList ->
| | | Block
| | | | ExecutionPartConstruct ->
ExecutableConstruct -> ActionStmt ->
AssignmentStmt
| | | | | Variable -> Designator ->
DataRef -> Name = 'c’
| | | | | Expr -> Add
| | | | | | Expr -> Designator -> DataRef
-> Name = 'a’
| | | | | | Expr -> Designator -> DataRef
-> Name = 'b’
| | | OmpEndBlockDirective ->
OmpBlockDirective -> Directive =
Parallel <More Fortran parse tree>
```

MLIR: FIR + OpenMP

```
mlir.region(…) {
…
omp.parallel {
  %1 = fir.addf %2, %3 :
fir.real<32>
}
%21 = <more fir> … }
```

Example : OpenMP Parallel



MLIR: LLVM + OpenMP dialect

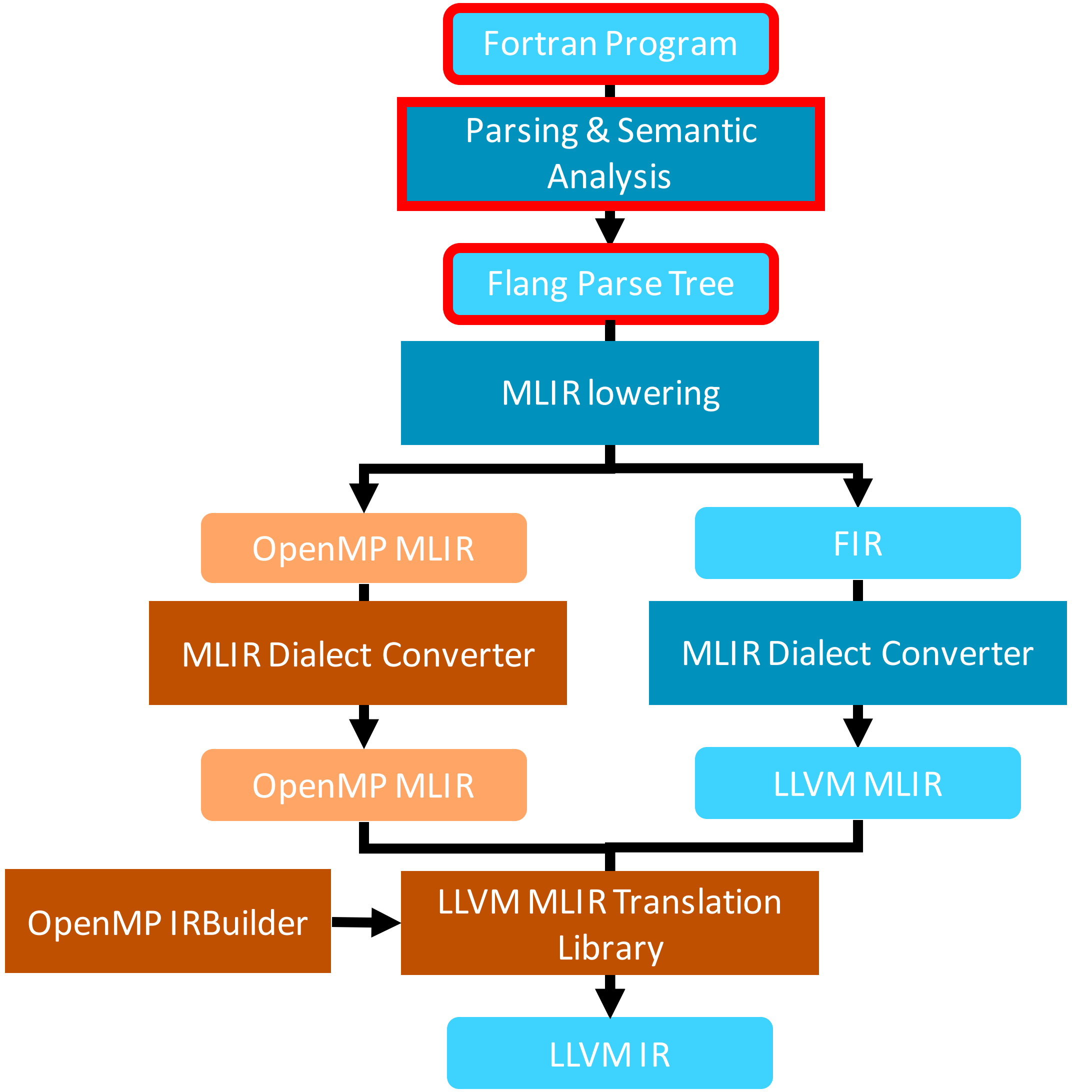
```
Mlir.region(…)
{
…
omp.parallel {
  %1 = llvm.fadd %2, %3 : !llvm.float
}
%21 = <more llvm dialect>
…
}
```

Use OpenMP IRBuilder

LLVM IR

```
define @outlined_parallel_fn(…)
{
  …
  %1 = fadd float %2, %3
  …
}
define @xyz(…)
{
  %1 = alloca float
   ….
   call kmpc_fork_call(…,outlined_parallel_fn,…)
}
```

OpenMP plan for Flang



OpenMP Parse Tree representation

- OpenMP constructs are represented in the parse tree as
  - Executable Constructs: OpenMPConstruct
  - Declarative Constructs: OpenMPDeclarativeConstruct
- Flang uses variants in the parse tree representation

```
struct OpenMPConstruct {
  UNION_CLASS_BOILERPLATE(OpenMPConstruct);
  std::variant<OpenMPStandaloneConstruct, OpenMPSectionsConstruct,
      OpenMPLoopConstruct, OpenMPBlockConstruct, OpenMPAtomicConstruct,
      OpenMPCriticalConstruct>
      u;
};
```

Flang parse tree with OpenMP

Fortran source

```
program mn
...
!$omp flush(arr)
...
end
```

Flang Parse tree

```
Program -> ProgramUnit -> MainProgram
| ProgramStmt -> Name = 'mn'
| SpecificationPart
| | ...
| ExecutionPart -> Block
| | ExecutionPartConstruct -> ExecutableConstruct ->
OpenMPConstruct -> OpenMPStandaloneConstruct ->
OpenMPFlushConstruct
| | | Verbatim
| | | OmpObjectList -> OmpObject -> Designator ->
DataRef -> Name = 'arr'
| | ...
| EndProgramStmt ->
```

Flang parse tree with OpenMP: Tooling

- Visitor Class

```
class OpenMPCounter
{
  template<typename A> bool Pre(const A &) { return true; }
  template<typename A> void Post(const A &) {}
  void Post(const Fortran::parser::OpenMPConstruct &) {counter++;}
  int counter{0};
}
```

- Usage

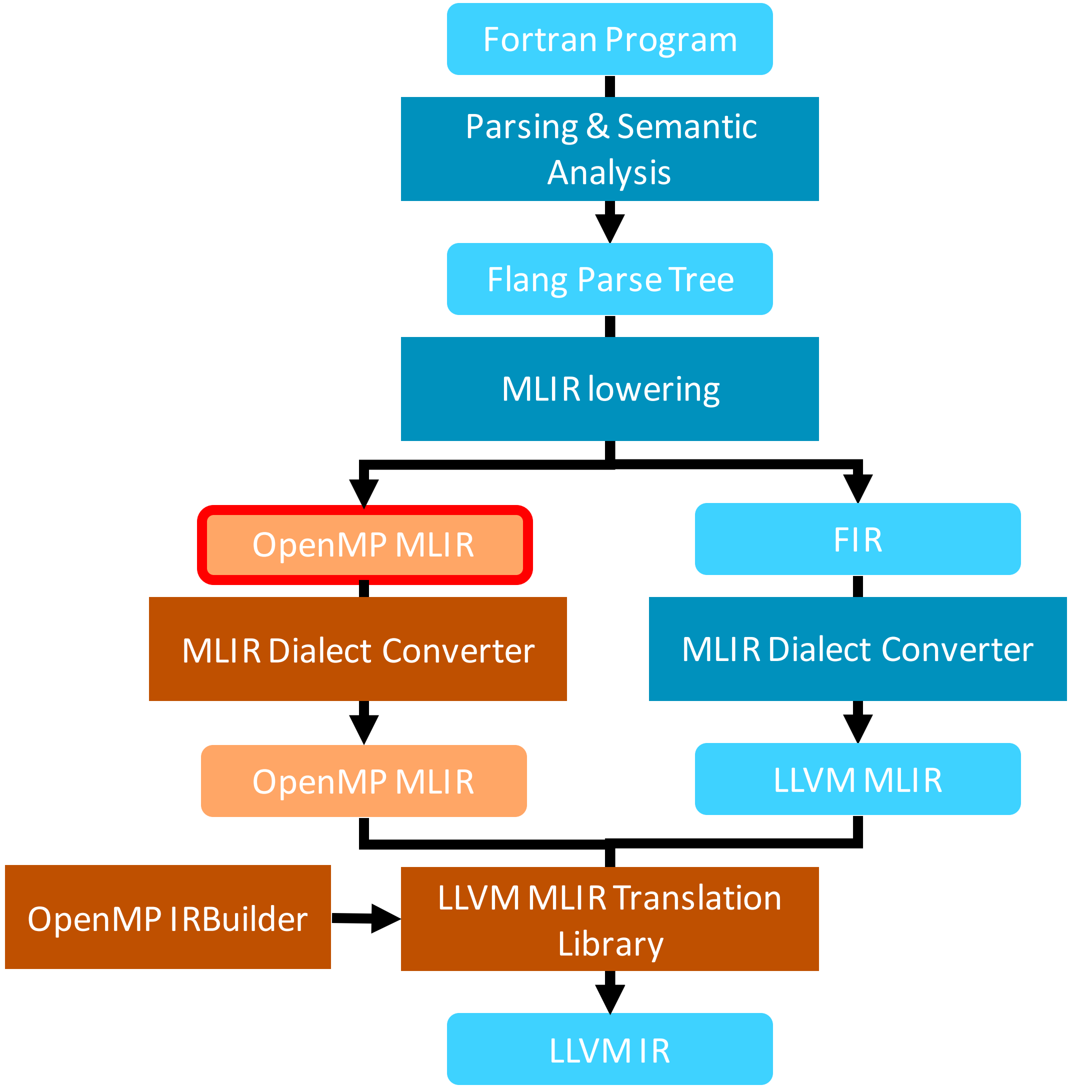
```
OpenMPCounter visitor;
void OpenMPStatisticsParseTree(const Fortran::parser::Program &program) {
  Fortran::parser::Walk(program, visitor);
}
```

OpenMP Semantic Checks

- Checks to ensure that Constructs and Clauses conform to the standard.
  - Permitted clauses in a construct
  - Clauses not occurring together
  - Specifying that expressions evaluate to a positive integer
  - Nesting checks

```
void OmpStructureChecker::Enter(const parser::OpenMPDeclareSimdConstruct &x) {
  const auto &dir{std::get<parser::Verbatim>(x.t)};
  PushContext(dir.source, OmpDirective::DECLARE_SIMD);
  OmpClauseSet allowed{
      OmpClause::LINEAR, OmpClause::ALIGNED, OmpClause::UNIFORM};
  SetContextAllowed(allowed);
  SetContextAllowedOnce({OmpClause::SIMDLEN});
  SetContextAllowedExclusive({OmpClause::INBRANCH, OmpClause::NOTINBRANCH});
}
```

OpenMP Operation Definition



MLIR: Operation Definition

- Declaratively define OpenMP operations
  - Uses tablegen
- Can define the input and output operands
- Whether operations have regions inside them
- Provides generic printers and parsers for operations
- Simple example of barrier operation in the next slide

OpenMP barrier construct : Definition

```
def OpenMP_Dialect : Dialect {
  let name = "omp";
}

class OpenMP_Op<string mnemonic, list<OpTrait> traits = []> :
      Op<OpenMP_Dialect, mnemonic, traits>;

def BarrierOp : OpenMP_Op<"barrier"> {
  let summary = "barrier construct";
  let description = [{
    The barrier construct specifies an explicit barrier at the point at which
    the construct appears.
  }];

  let assemblyFormat = “attr-dict”;
}
```

MLIR: Customized Op Definition

- Sometimes custom printers and parsers are required
- This helps to define operations in a domain specific way
- OpenMP clauses are best defined as in a directive
- Clauses can have a variable number of arguments
- Definition of parallel operation in the next slide
  - Clauses are modeled as arguments
  - Arguments are operands or attributes (constants)
  - Most OpenMP clauses are optional
  - OpenMP clauses can have a variable number of elements (like variables)

OpenMP Parallel Construct : Definition

```
def ParallelOp : OpenMP_Op<"parallel", [AttrSizedOperandSegments]> {
  let summary = "parallel construct";
  let description = [{ The parallel construct includes a region of code which is to be executed by a team of
threads.}];
  let arguments = (ins Optional<AnyType>:$if_expr_var,
             Optional<AnyType>:$num_threads_var,
             OptionalAttr<ClauseDefault>:$default_val,
             Variadic<AnyType>:$private_vars,
             Variadic<AnyType>:$firstprivate_vars,
             Variadic<AnyType>:$shared_vars,
             Variadic<AnyType>:$copyin_vars,
             OptionalAttr<ClauseProcBind>:$proc_bind_val);

  let regions = (region AnyRegion:$region);

  let parser = [{ return parseParallelOp(parser, result); }];
  let printer = [{ return printParallelOp(p, *this); }];
}
```

OpenMP Parallel : Example

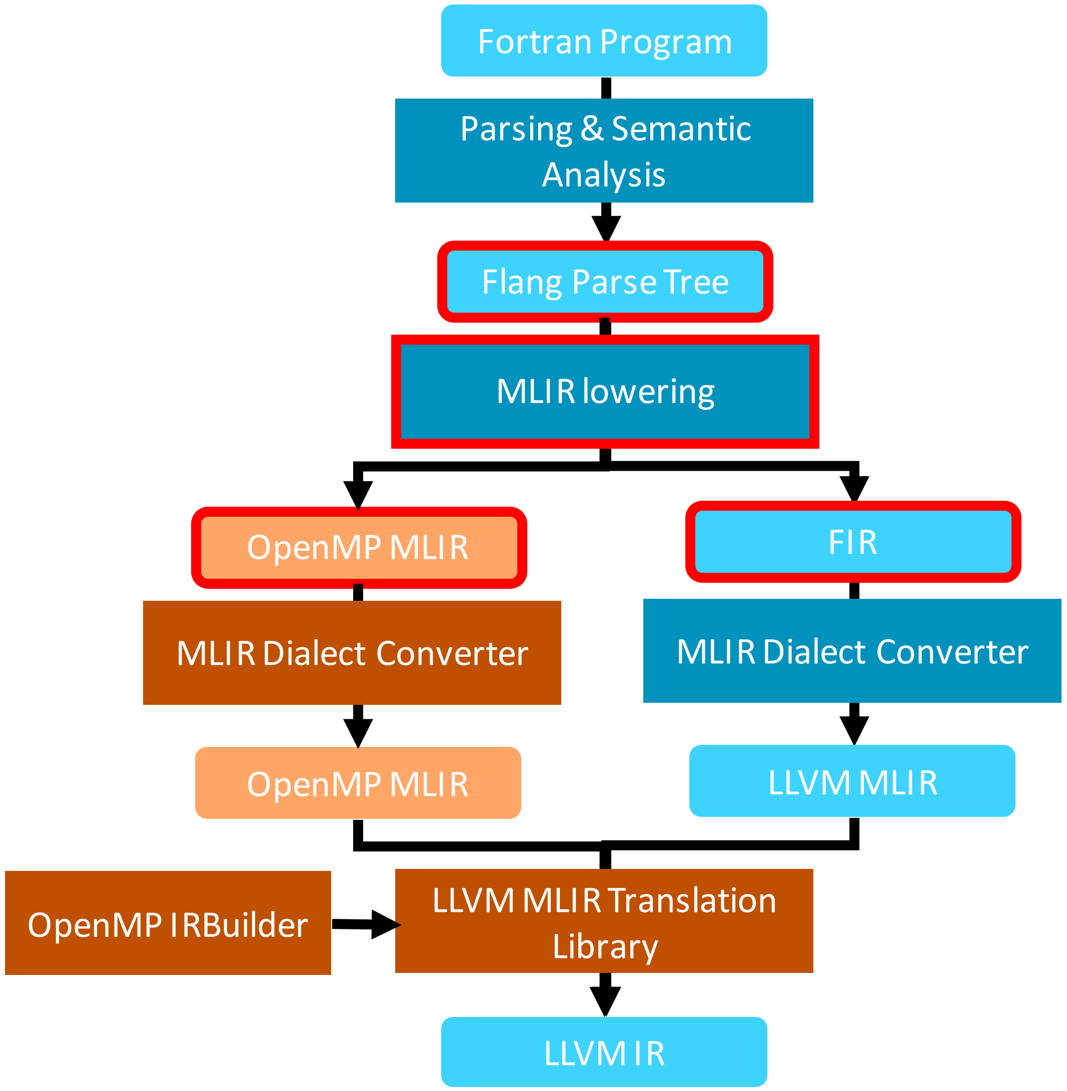
Standard types

```
omp.parallel shared(%data_var : memref<i32>)
             copyin(%data_var : memref<i32>,
                    %data_var : memref<i32>) {
    omp.parallel if(%if_cond : i32) {
      omp.terminator
    }
    omp.terminator
}
```

LLVM dialect types

```
omp.parallel
   num_threads(%num_threads : !llvm.i32)
   proc_bind(master) {
   omp.terminator
 }
```

Lowering to OpenMP dialect



Fortran Program

Parsing & Semantic Analysis

Flang Parse Tree

MLIR lowering

OpenMP MLIR

FIR

MLIR Dialect Converter

MLIR Dialect Converter

OpenMP MLIR

LLVM MLIR

OpenMP IRBuilder

LLVM MLIR Translation Library

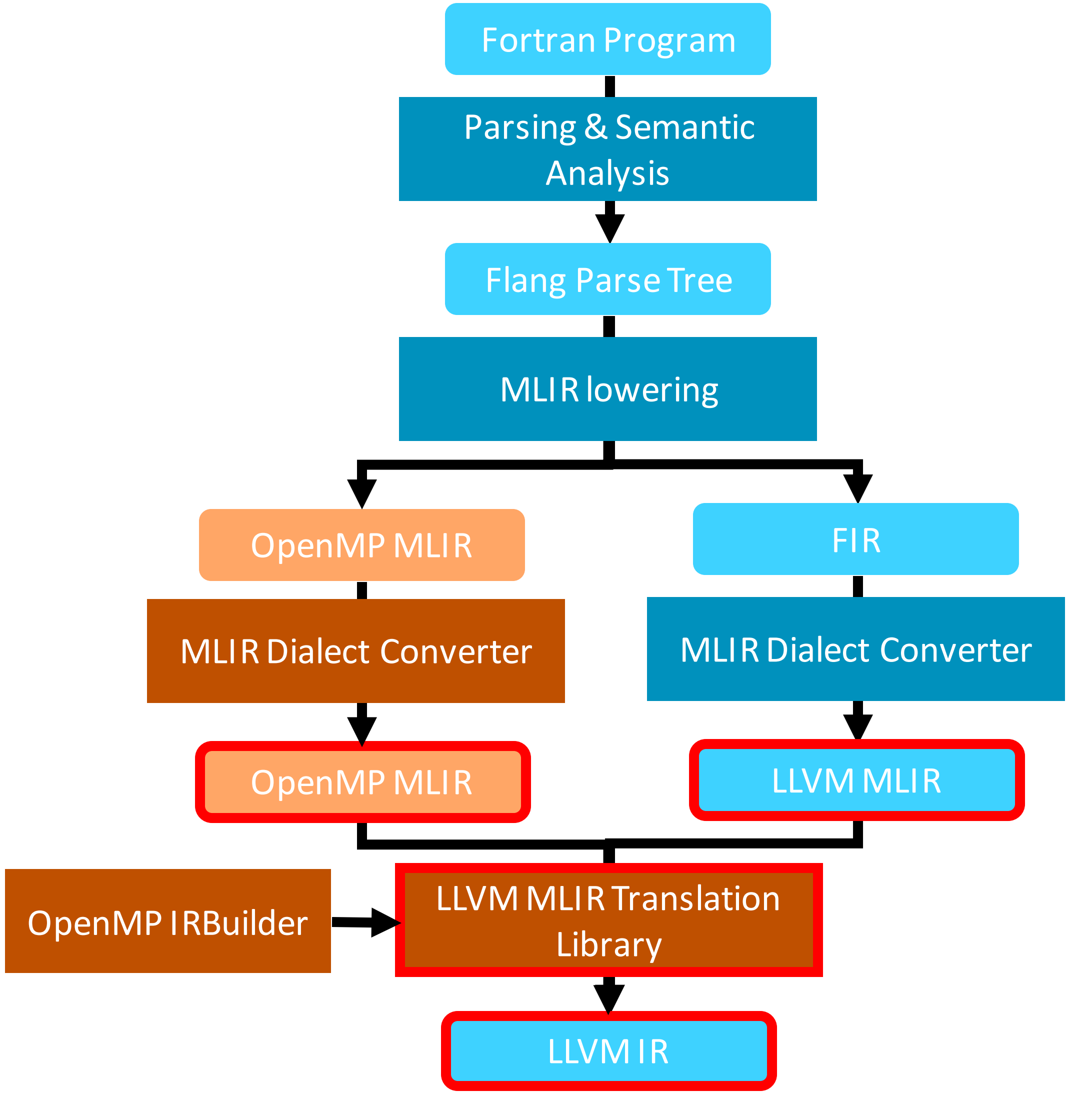
LLVM IR

Lowering to OpenMP dialect

- Happens along with FIR lowering
- Lowering code in flang/lib/Lower/Bridge.cpp
  - Calls code in flang/lib/Lower/OpenMP.cpp

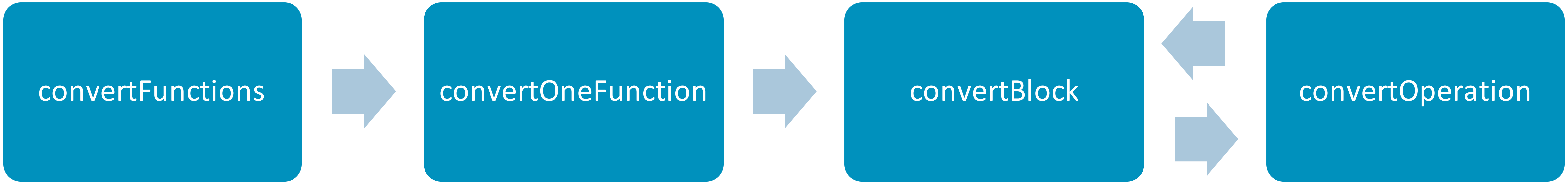
```
void Fortran::lower::genOpenMPConstruct(
                     Fortran::lower::AbstractConverter &,
                     Fortran::lower::pft::Evaluation &,
                     const Fortran::parser::OpenMPConstruct &)
```

Lowering to LLVM IR



Lowering to LLVM IR

- LLVM dialect in MLIR contains a list of functions
- Each function has a list of blocks
- Blocks have a list of operations
- OpenMP operations can have blocks inside



convertFunctions

convertOneFunction

convertBlock

convertOperation

Lowering to LLVM IR

```
LogicalResult
ModuleTranslation::convertOmpOperation(Operation &opInst,
                                       llvm::IRBuilder<> &builder) {
  if (!ompBuilder) {
    ompBuilder = std::make_unique<llvm::OpenMPIRBuilder>(*llvmModule);
    ompBuilder->initialize();
  }
  return llvm::TypeSwitch<Operation *, LogicalResult>(&opInst)
      .Case([&](omp::BarrierOp) {
        ompBuilder->CreateBarrier(builder.saveIP(), llvm::omp::OMPD_barrier);
        return success();
      })
      .Case([&](omp::TaskwaitOp) {
        ompBuilder->CreateTaskwait(builder.saveIP());
        return success();
      })
      …
```

OpenMP barrier : Lowering

mlir-translate -mlir-to-llvmir test/Target/openmp-llvm.mlir

```
llvm.func @empty()
{
  omp.barrier
  llvm.return
}
```

```
define void @empty() !dbg !3
{
  %omp_global_thread_num = call i32 @__kmpc_global_thread_num(%struct.ident_t* @2)
  call void @__kmpc_barrier(%struct.ident_t* @1, i32 %omp_global_thread_num)
  ret void, !dbg !7
}

; Function Attrs: nounwind
declare i32 @__kmpc_global_thread_num(%struct.ident_t*) #0

; Function Attrs: inaccessiblemem_or_argmemonly
declare void @__kmpc_barrier(%struct.ident_t*, i32) #1

attributes #0 = { nounwind }
attributes #1 = { inaccessiblemem_or_argmemonly }

!llvm.dbg.cu = !{!0}
!llvm.module.flags = !{!2}
```

Status

- Implementing vertically construct by construct
- Joint work with Nvidia, AMD, ANL, ORNL, LANL, BSC, Arm

Parsing	OpenMP 4.5 complete OpenMP 5.0 in progress (Flush, Taskwait, Depends)
Semantic Checks	Allowed clauses, Exclusive clauses, Integer properties Allowed nesting checks
Lowering to OpenMP Dialect	Waiting on Bridge code to arrive
OpenMP Dialect and LLVM IR lowering	Barrier, Flush, Taskwait, Taskyield complete Parallel, Master in progress
OpenMP IRBuilder	Parallel and several constructs complete Sections, Target, Privatisation in progress

How to get involved

- Project Management via google docs spreadsheet
- Separate sheets for parsing, semantics, OpenMP MLIR, lowerings, OpenMP IRBuilder
  - Currently has entries as per OpenMP 5.0
  - https://docs.google.com/spreadsheets/d/1FvHPuSkGbl4mQZRAwCIndvQx9dQboffiD-xD0oqxgU0/edit#gid=0
- Weekly meeting on Thursday (4pm UK time)
  - https://docs.google.com/document/d/1yA-MeJf6RYY-ZXpdol0t7YoDoqtwAyBhFLr5thu5pFI/edit

Thank You

Danke

Merci

谢谢

ありがとう

Gracias

Kiitos

감사합니다

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