

Towards OpenMP Support in LLVM

Alexey Bataev, Andrey Bokhanko, James Cownie
Intel

Agenda

- **What is the OpenMP* language?**
- **Who Can Benefit from the OpenMP language?**
- **OpenMP Language Support**
 - Early / Late Outlining
 - History
 - OpenMP Runtime
- **OpenMP support in Clang***

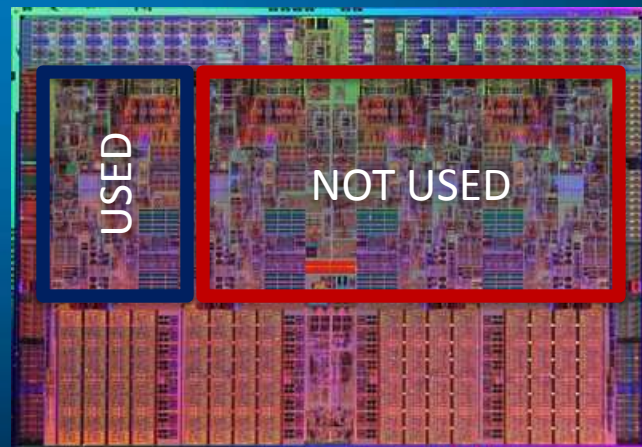
What is the OpenMP Language?

- **Industry-wide standard** for shared memory multiprocessing programming
- Vendor-neutral, platform-neutral, portable, managed by an independent consortium
- Supports C, C++ and Fortran
 - Implemented in GCC*, ICC, Open64*, Visual C++*, ...
 - But not in Clang / LLVM*
- Current version is 3.1
 - 4.0 under development
- **www.openmp.org**

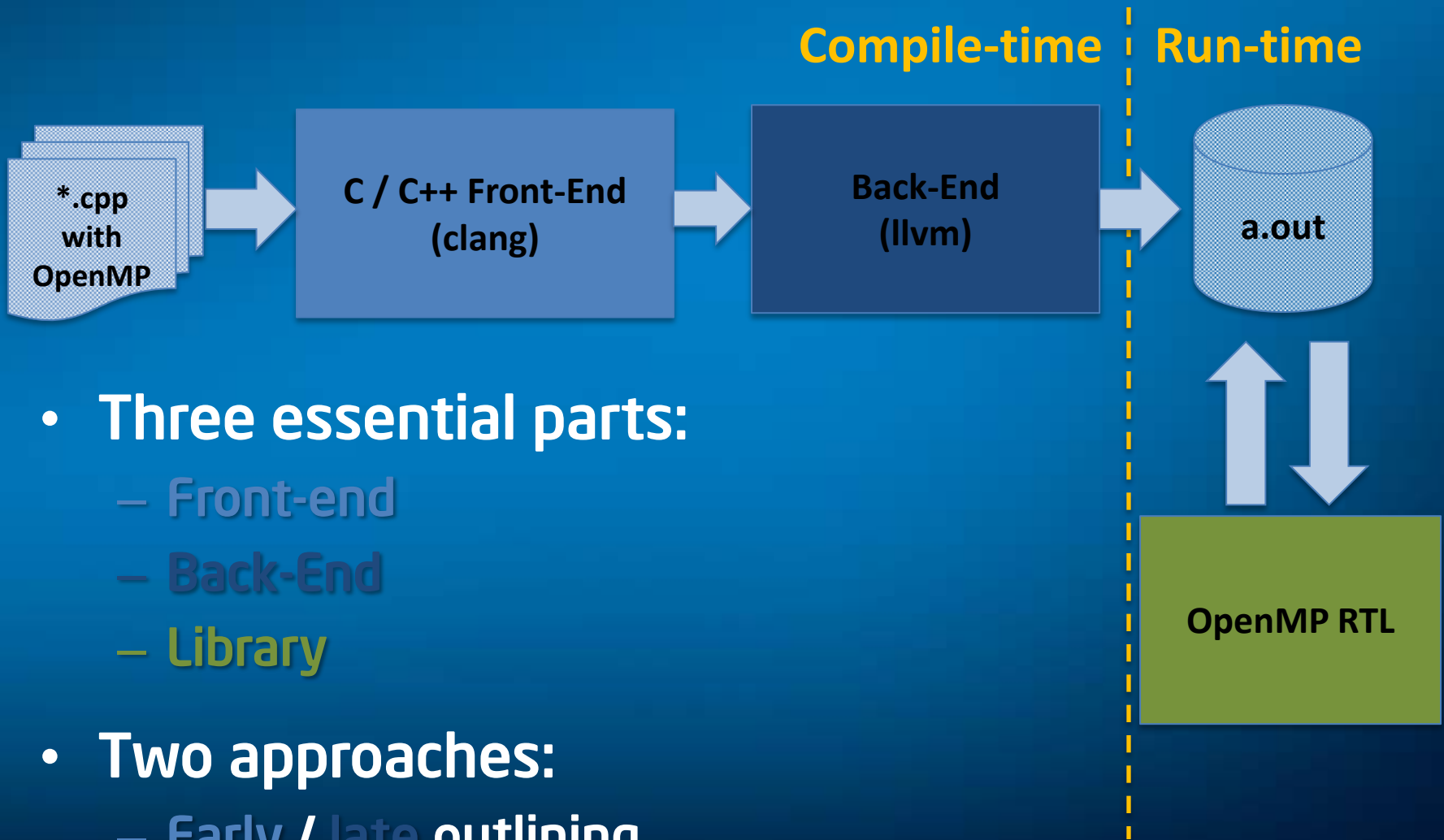
```
#pragma omp parallel for
for (i = 0; i < N; i++)
{
    ...
}
```

Who Can Benefit from the OpenMP Language?

- **Anyone** who uses a multi-core processor
 - Your phone almost certainly has more than 1 core!
- “Must have” for HPC
 - Without OpenMP support, LLVM is at a disadvantage in this area
- Becomes a “must have” for “power clients”
 - You can hardly find a desktop / notebook with a single core



OpenMP Support



- **Three essential parts:**

- Front-end
- Back-End
- **Library**

- **Two approaches:**

- Early / late outlining

Early / Late Outlining

- Parallel regions are put into separate routines
 - To be executed in separate threads
 - This can be done either in **front-end** or **back-end**

```
float a,x,y,z;
#pragma omp parallel for
for (i = 0; i < N; i++) {
    a[i] = x * y * z;
    ... // rest of loop
}
```

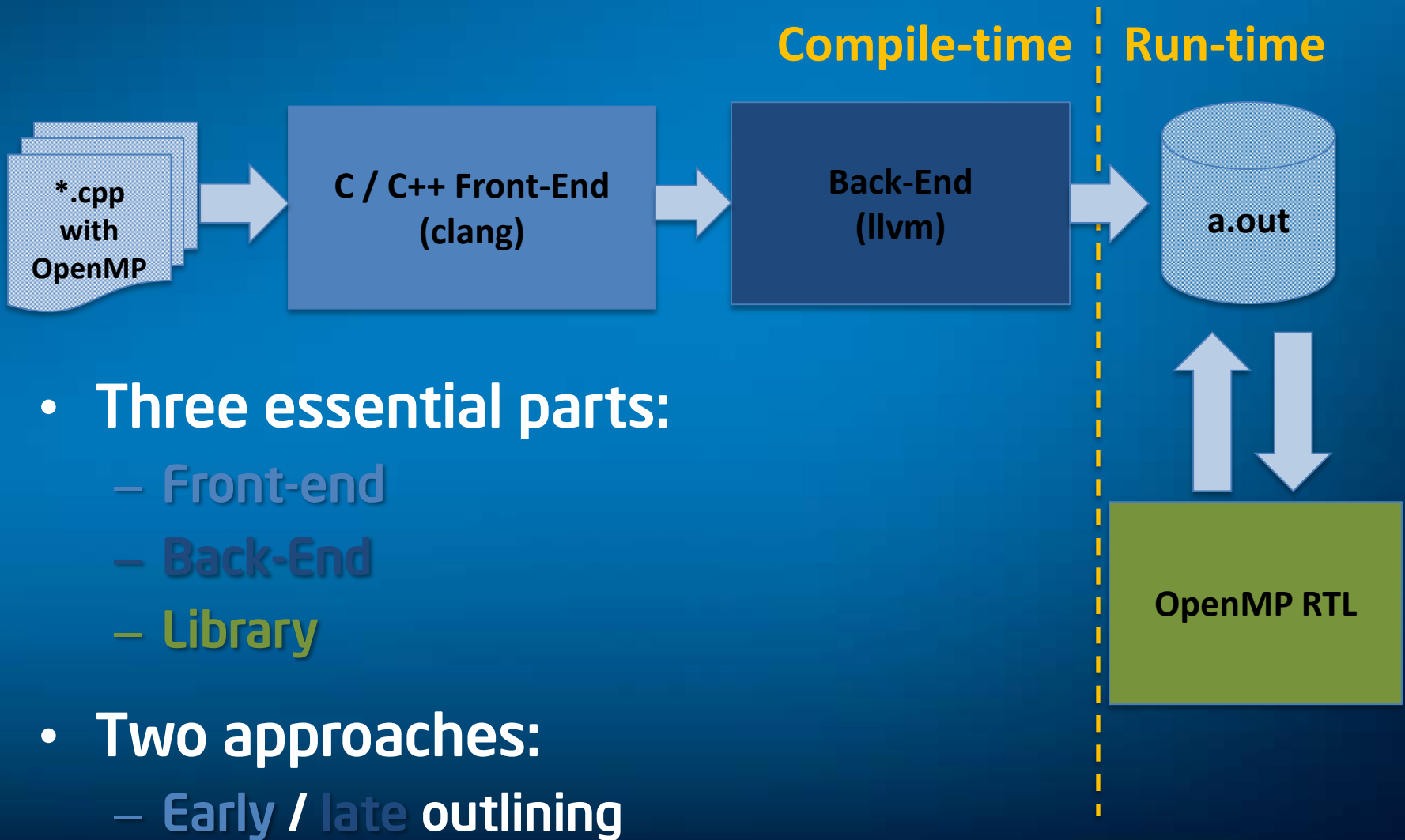


```
omp_parallel_for(0, N,
N/omp_get_num_threads(), forb)
...
void forb(int L, int U, R *r) {
    for (i = L; i < U; i++) {
        r->a[i] = r->x * r->y * r->z;
        ... // rest of loop
    }
}
```

OpenMP in LLVM: A Brief History

- **2H 2012: Several proposals with late outlining**
 - From Intel, Hal Finkel, others
 - All of them involve changes to LLVM IR and thus, require modifications of LLVM phases
 - None of them got enough support in the community
- **October 2012: OpenMP in Clang project**
 - Started by AMD*, continued by Intel
 - Early outlining
 - OpenMP RTL calls generated in Clang
 - No changes to LLVM IR

OpenMP Support



OpenMP Runtime

- Fortunately, there is libgomp
 - Unfortunately, it is under **GPLv3***
 - “Copyleft” license
- Clang / LLVM uses UoI / NCSA OSL*
 - Permissive (aka BSD-style) free software license
- **Permissively licensed** free runtime library is needed

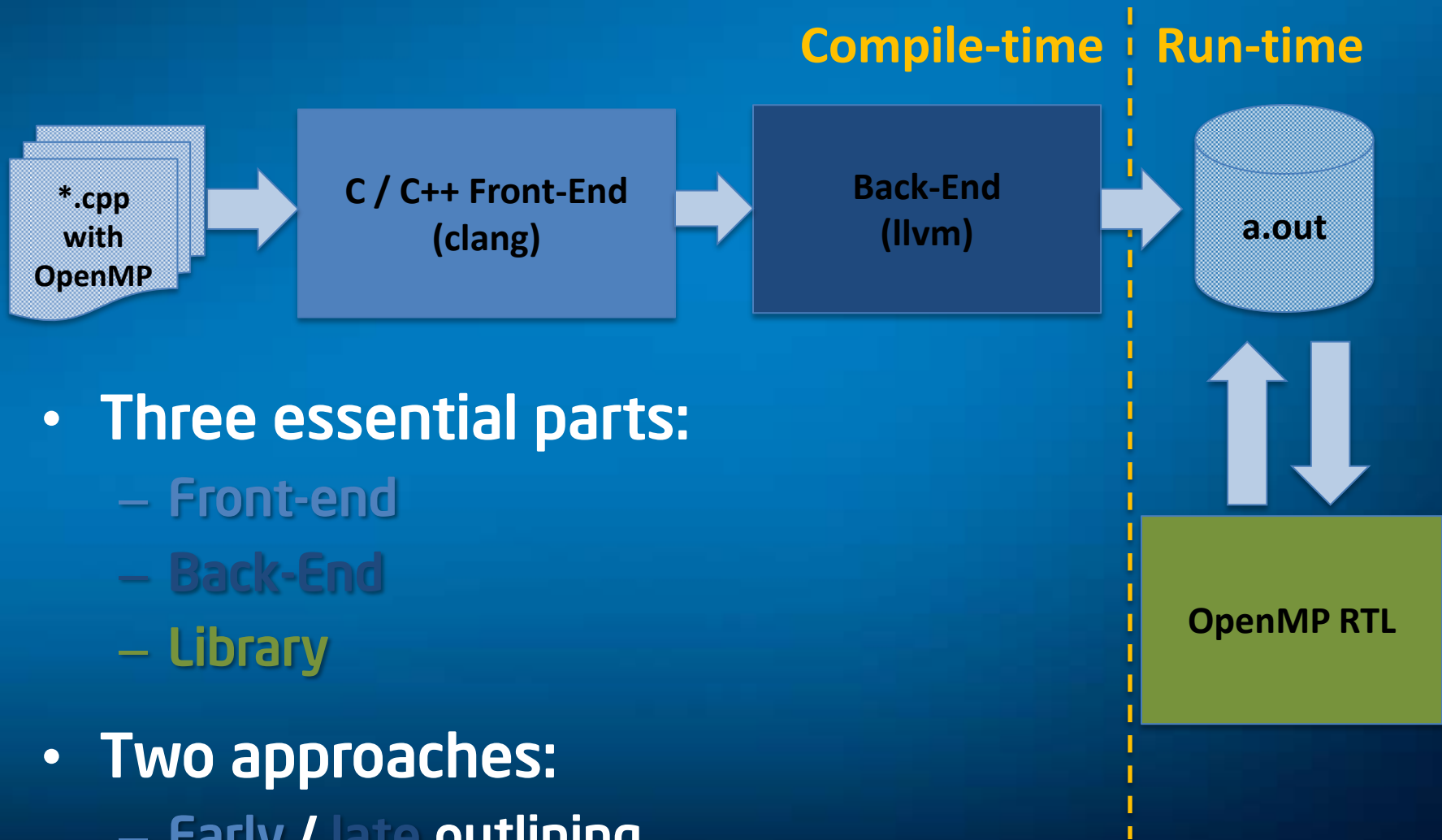
Intel® OpenMP Runtime

- Intel® OpenMP runtime was released in April with LLVM compatible 3-clause **BSD license**
- This is Intel's production runtime used by `icc` and `ifort`
- Continual development/tuning since before the OpenMP language existed (>15 years)
- Highly scalable (used on Intel® Xeon Phi™ coprocessor with 244 threads, large SGI* and Bull* ccNUMA SMP machines)

Intel® OpenMP Runtime

- Supports OpenMP 3.1 (and parts of OpenMP 4.0 [work in progress])
- ABI compatible with
 - Intel Compilers (icc, icpc, ifort)
 - GCC
 - so gcc compiled code can be linked in without libgomp to avoid issues if there are multiple OpenMP runtimes in the same process
- Doxygen* documentation in the source
- Available from www.openmpRTL.org

OpenMP Support



- **Three essential parts:**

- Front-end
- Back-End
- **Library**

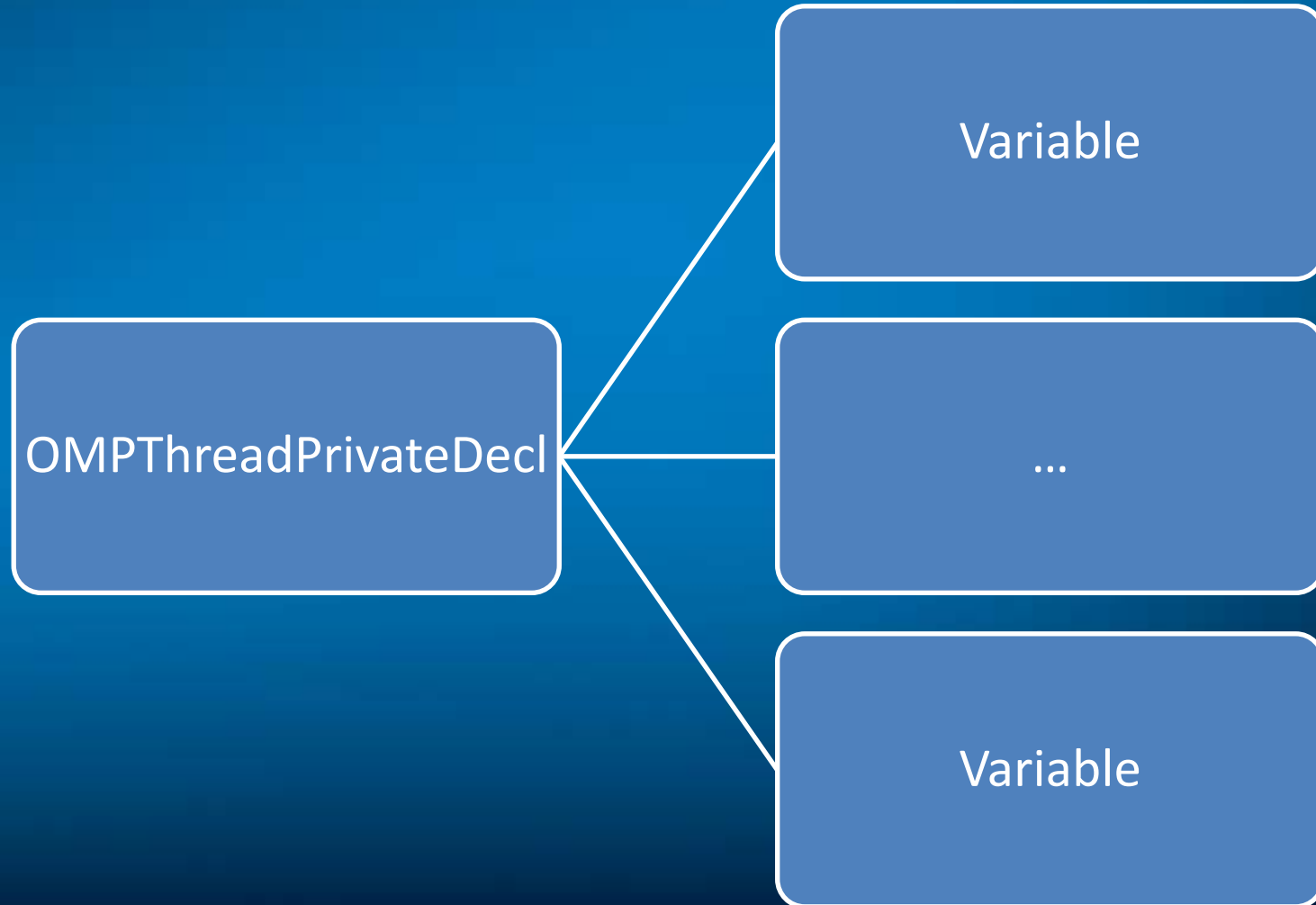
- **Two approaches:**

- Early / late outlining

OpenMP Support in Clang

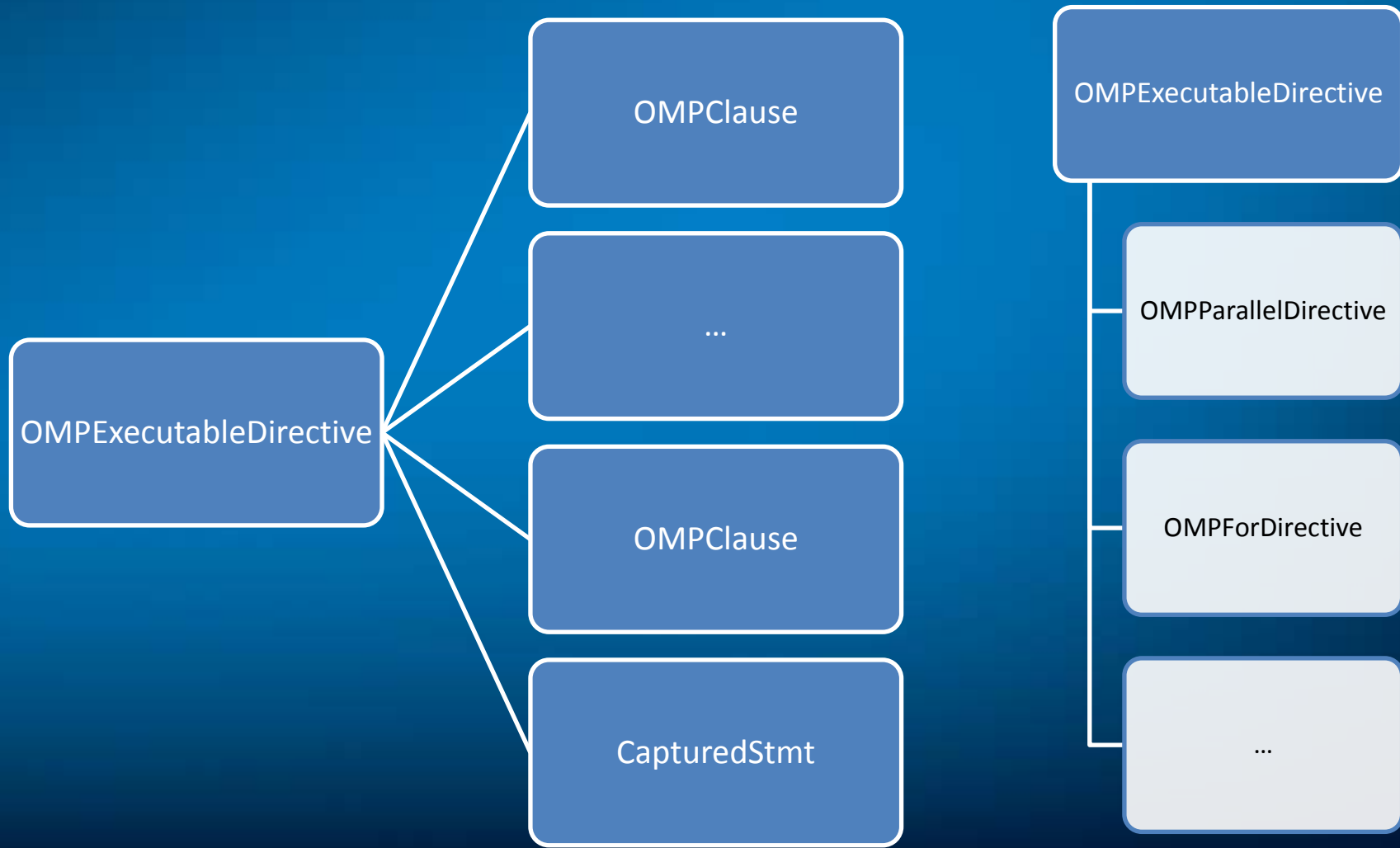
- First approach is to represent OpenMP directives as **C++11 attributes** (Olaf Krzikalla, Nov. 2012)
 - Currently may require two parsing passes
 - May need to change code generation for standard statements
- Second approach is to use **standard pragma parsing harness**
 - Declarative directive is represented as a special kind of declaration
 - Executable directives and clauses are represented as a special kind of statements

Representation in AST Declarative Directives

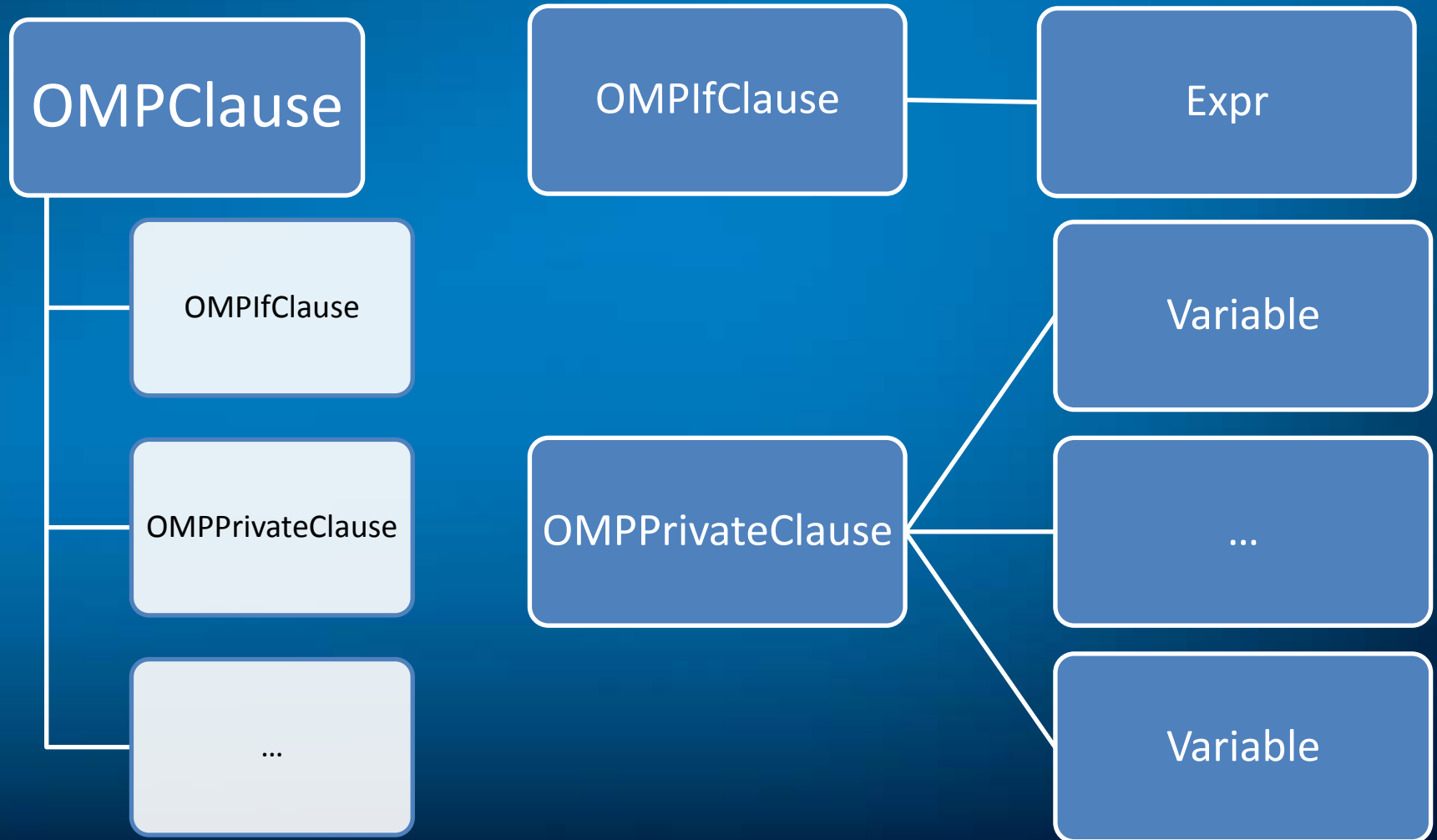


Representation in AST

Executable Directives



Representation in AST Clauses



Representation in AST

Statements And Variables

- **Statements** are **Structured Statements** with protected regions
 - A single statement for #pragma omp parallel
 - One or more for-loops for #pragma omp for
- Statements are represented as **CapturedStmt** to capture local variables
 - Special processing for threadprivate variables
 - **Private** variables are **constructed** by default
 - **Shared** variables are **captured** by reference
 - Special processing for firstprivate, lastprivate, reduction variables

An Example

```
#pragma omp parallel if(a) private(argc,b)
foo();
```



```
-OMPParallelDirective <line:9:2, col:43>
| |-OMPIfClause <col:22, col:27>
| | `ImplicitCastExpr <col:25> '_Bool' <IntegralToBoolean>
| | `ImplicitCastExpr <col:25> 'int' <LValueToRValue>
| | `DeclRefExpr <col:25> 'int' lvalue Var 'a' 'int'
| |-OMPPrivateClause <col:28, col:43>
| | |-DeclRefExpr <col:36> 'int' lvalue ParmVar 'argc' 'int'
| | `DeclRefExpr <col:41> 'int' lvalue Var 'b' 'int'
| `CapturedStmt <line:10:2, col:7>
| `CallExpr <col:2, col:7> 'void'
| `ImplicitCastExpr <col:2> 'void (*)(void)' <FunctionToPointerDecay>
| `DeclRefExpr <col:2> 'void (void)' lvalue Function 'foo' 'void (void)'
```

Code Generation

- All variables are combined into an **auto-generated record** according to their data-sharing attributes (predetermined, explicit or implicit)
- OpenMP regions are outlined as **functions** with a single argument - pointer to the record
- LLVM IR code is generated to use **captured variables** instead of original ones

Current Status and Plans

- **Implemented and committed:**
 - -fopenmp option
 - #pragma omp threadprivate
 - Parsing and semantic analysis , AST representation
- **Implemented, under code review:**
 - All pragmas (parallel, for, sections, task etc.)
 - Parsing and semantic analysis, data-sharing attributes analysis, AST representation
- **Under development**
 - CodeGen for all OpenMP constructs

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- Your contribution is **welcomed!**

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