Towards OpenMP Support in LLVM

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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*

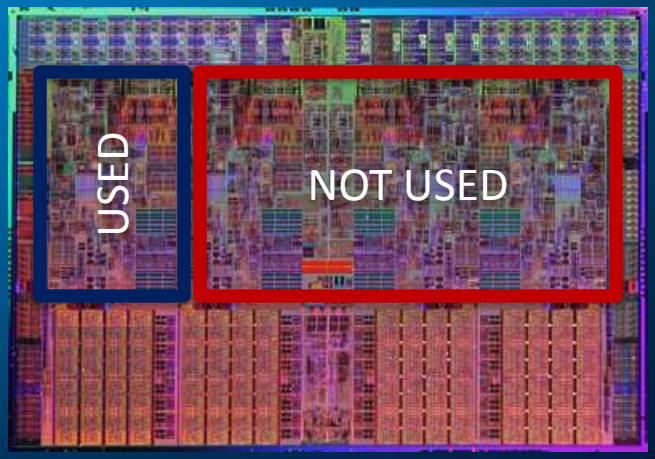
What is the OpenMP Language?

- **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**

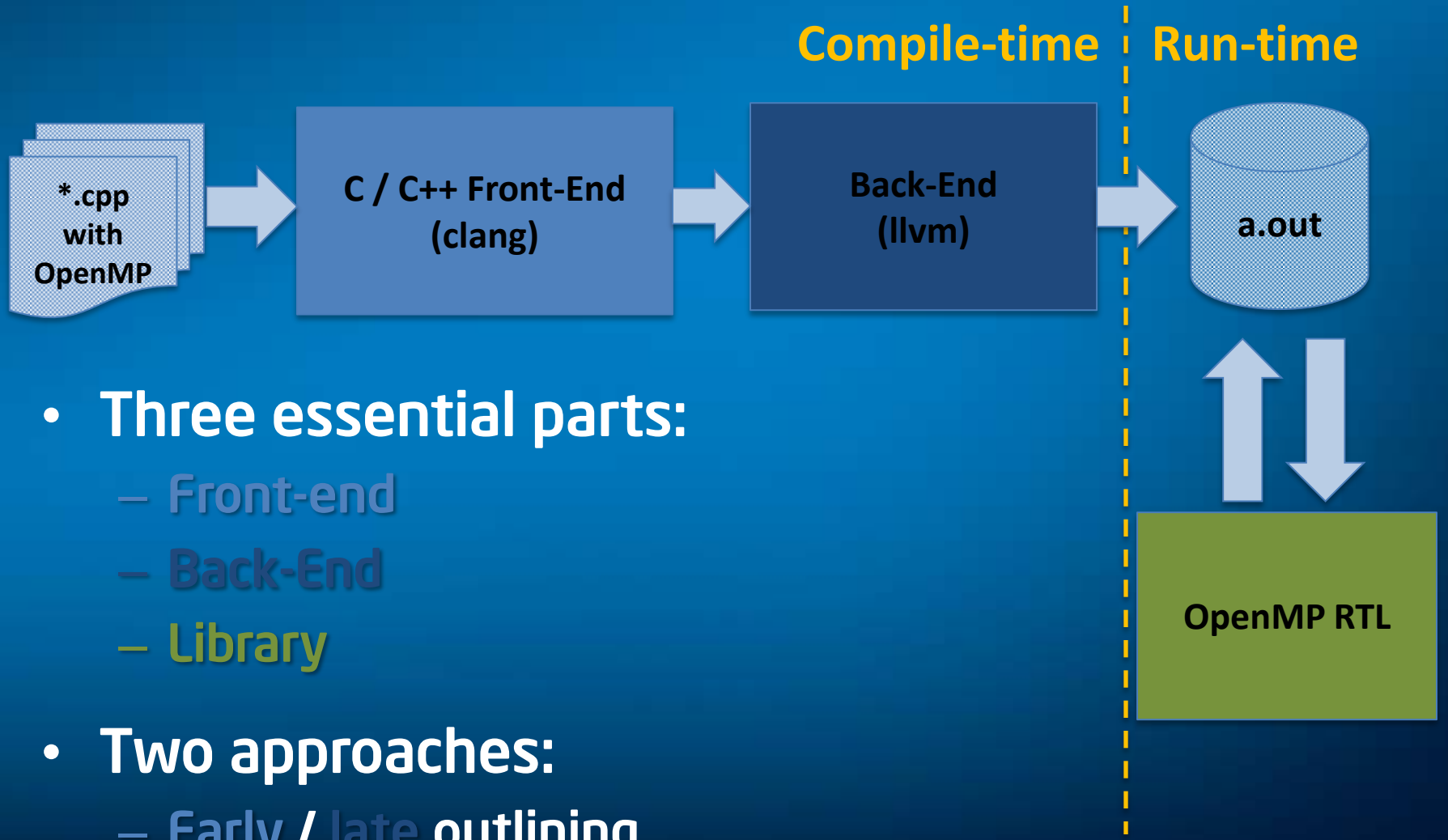
```
#pragma omp parallel for
for (i = 0; i < N; i++)
{
    ...
}
```

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

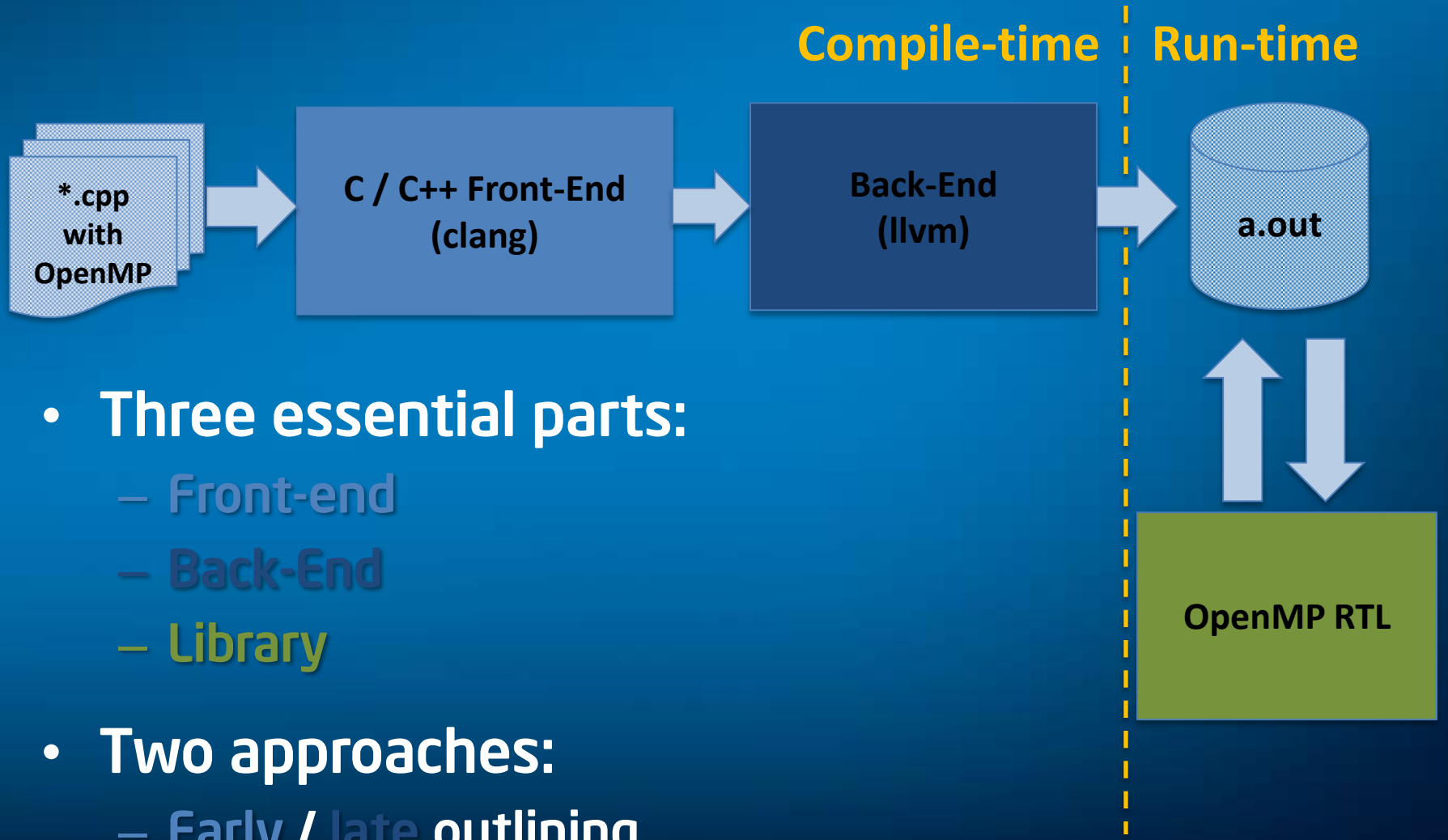
```
float a,x,y,z;
#pragma omp parallel for
for (i = 0; i < N; i++) {
  a[i] = x * y * z;
  ... // rest of loop
}
```

```
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



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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

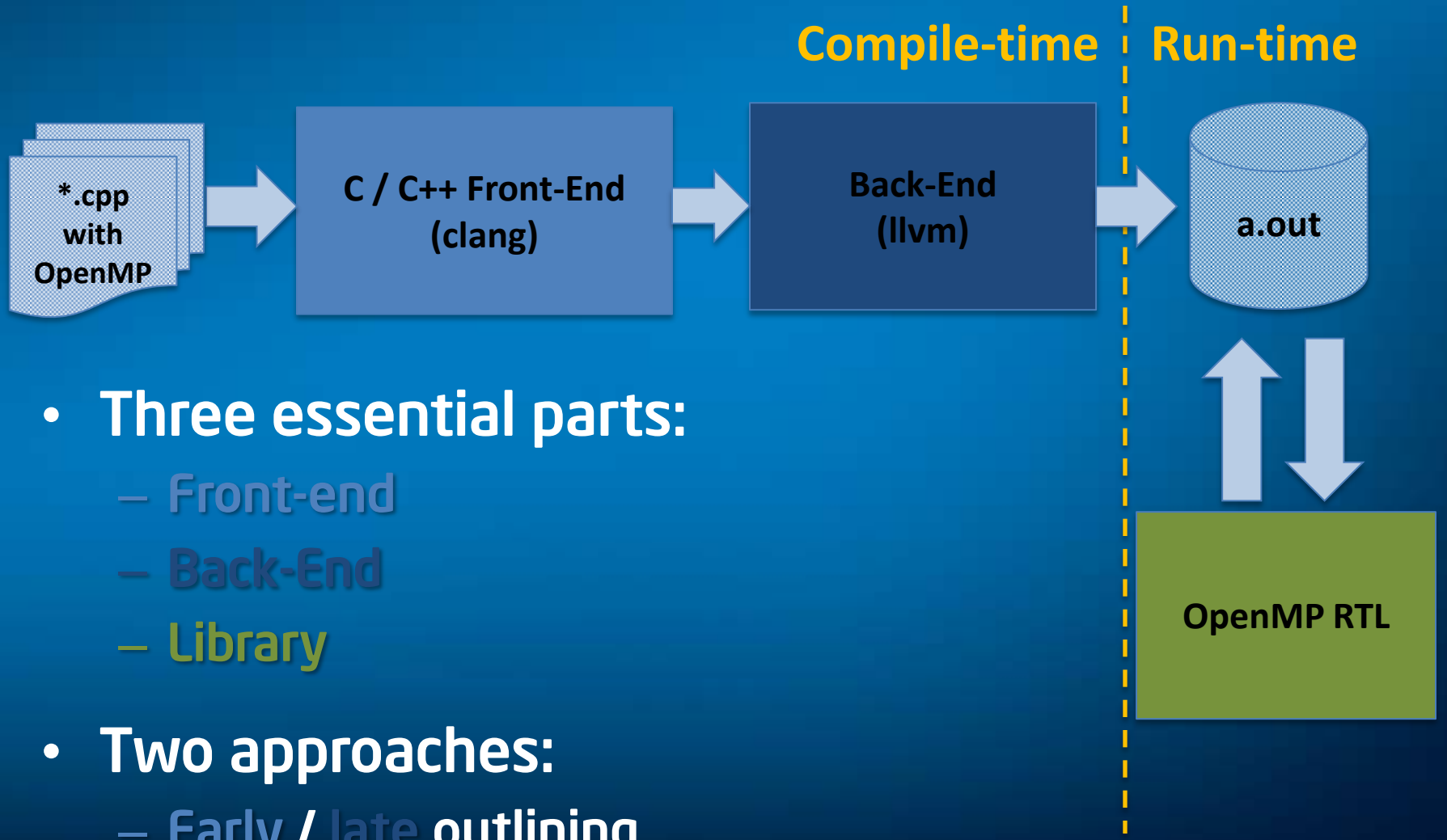
Intel® OpenMP Runtime

- 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



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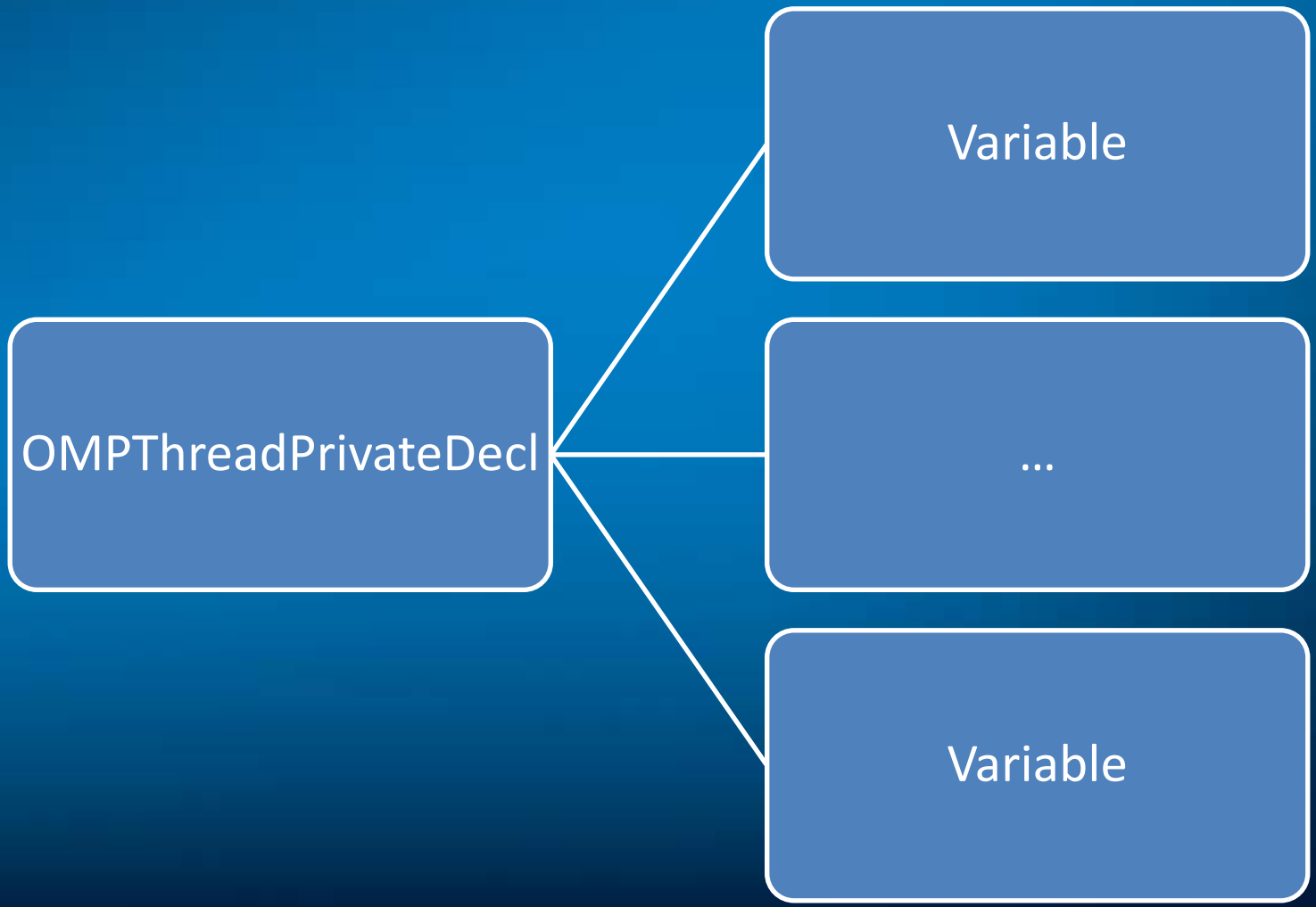
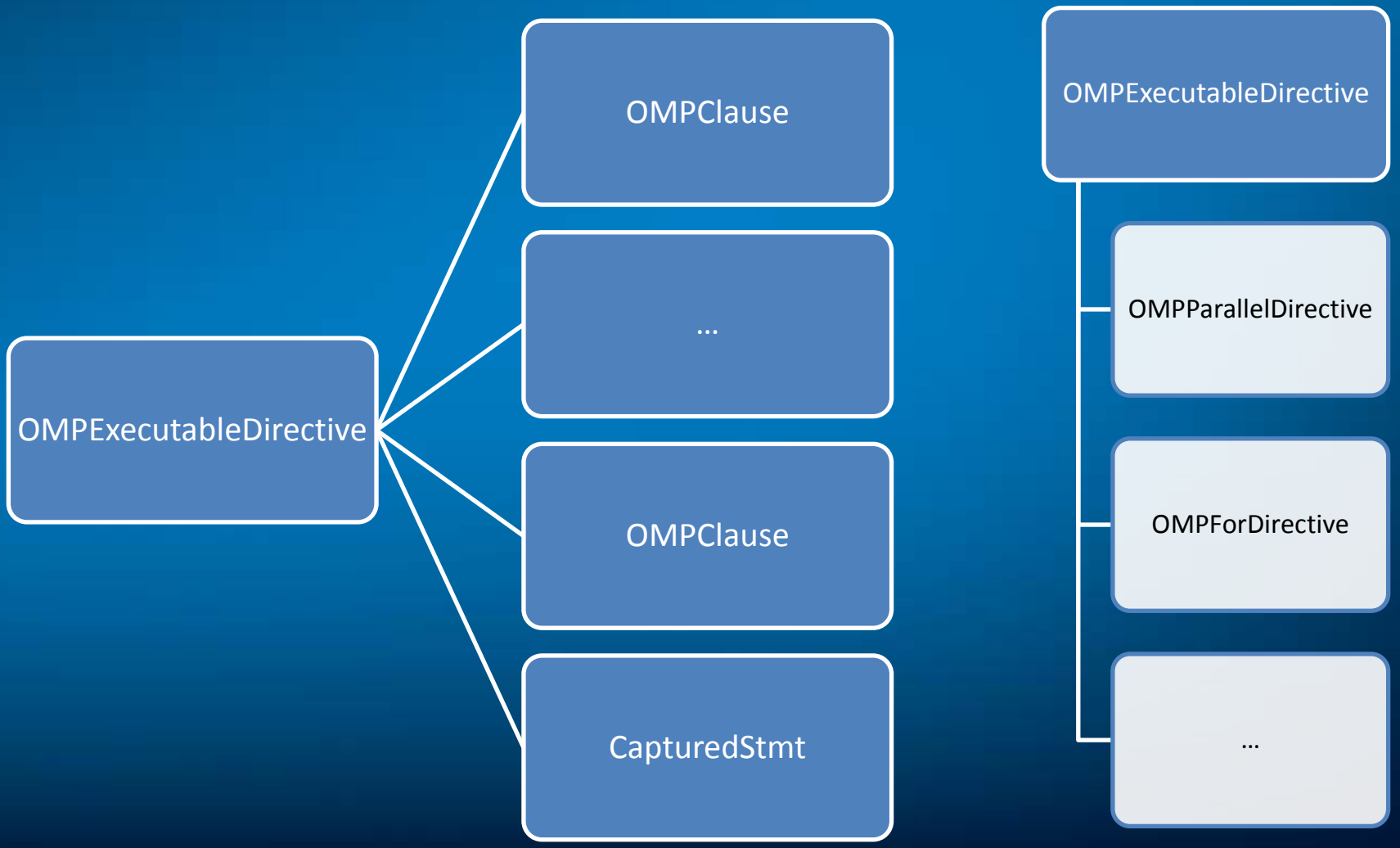
OpenMP Support in Clang

- 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

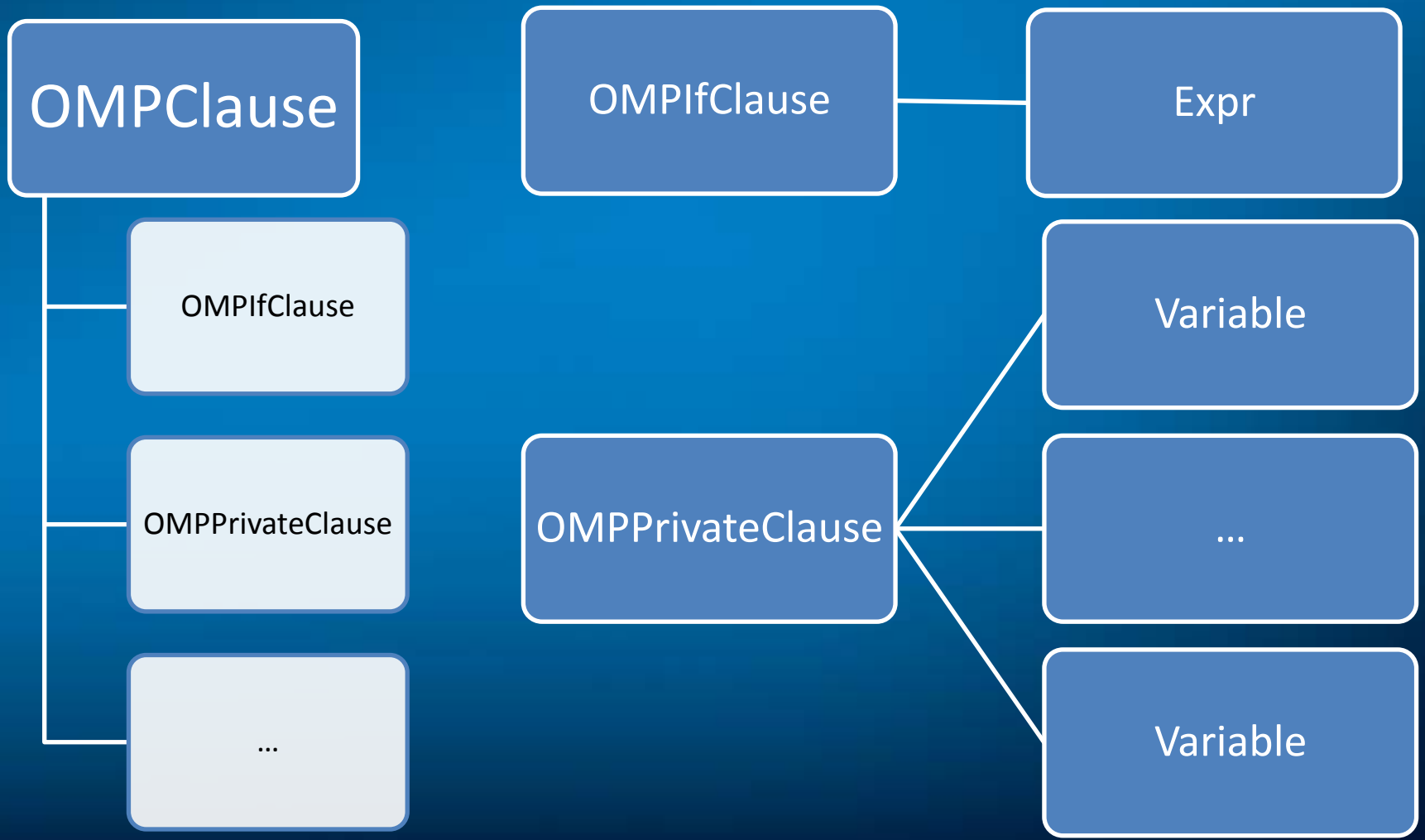
Representation in AST Declarative Directives



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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  - Especially to Dmitri Gribenko, Hal Finkel and Doug Gregor

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