Towards OpenMP Support in LLVM

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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](http://www.openmp.org)

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

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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

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OpenMP Support

• Three essential parts:
  – Front-end
  – Back-End
  – Library

• Two approaches:
  – Early / late outlining

 Compile-time | Run-time

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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
  }
}
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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

- Three essential parts:
  - Front-end
  - Back-End
  - Library

- Two approaches:
  - Early / late outlining

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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

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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)

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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.openmp rtl.org

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OpenMP Support

C / C++ Front-End (clang)

Back-End (llvm)

Compile-time

Run-time

a.out

• Three essential parts:
  – Front-end
  – Back-End
  – Library

• Two approaches:
  – Early / late outlining

*.cpp with OpenMP

Software and Services Group

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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

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Representation in AST
Declarative Directives

OMPTThreadPrivateDecl

Variable

... 

Variable

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Representation in AST
Executable Directives

OMPExecutableDirective
  OMPClause
  ...
  OMPClause
  CapturedStmt

OMPExecutableDirective
  OMPParallelDirective
  OMPForDirective
  ...

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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

```c
#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'`
  - `OMPPPrivateClause <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)'`

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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

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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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