An experimental framework for Pragma handling in Clang

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Background

This work has been done as part of the *Insieme Compiler* (`www.insieme-compiler.org`)

- A Source-to-Source compiler infrastructure
- Uses LLVM/Clang as a frontend, but relies on its own IR (*INSPIRE*)
- Targets HPC and research issues of parallel paradigms, i.e. OpenMP/MPI/OpenCL
- Developed by the University of Innsbruck[1]

[1] Funded by FWF Austrian Science Fund and by the Austrian Research Promotion Agency.

Motivation & Goal

Pragma Directives

"The `#pragma` *directive is the method specified by the C standard for providing additional information to the compiler, beyond what is conveyed in the language itself."*

```
#pragma omp parallel for num_threads(x-2) (i)
for(unsigned i=0; i<1000; ++i) {
   do_embarrassingly_parallel_work();
   #pragma omp barrier                   (ii)
}
```

Their actions are either associated with the following statement/declaration *(i)* or the position *(ii)*.

Motivation

- Researchers love defining new `#pragmas` to augment compiler's knowledge

  Compiler Extensions: *Intel Compiler, Microsoft Visual Studio, PGI, GCC, etc...*

  Programming paradigms: *OpenMP, OpenACC, StarSS, etc...*

- Clang makes it very difficult!

Pragma Handling in Clang

Clang provides an interface to *react* to new `#pragmas`

```
class PragmaHandler {
   virtual void HandlePragma(
      Preprocessor &PP,
      PragmaIntroducerKind Introducer,
      Token &FirstToken)=0;
};

// Hierarchical pragmas can be defined with
class PragmaNamespace : PragmaHandler {
   void AddPragma (PragmaHandler *Handler);
};
```

#pragma unused(id(,id)*)

```
Token Tok;
PP.Lex(Tok);
if (Tok.isNot(tok::l_paren))
    throw ...; // error, expected '('

bool LexID = true; // expected 'identifier' next
while(true) {
    PP.Lex(Tok); // consumes next token

    if(LexID) {
        if (Tok.is(tok::identifier)) {
            // save the id for sema checks
            Lex = false;
            continue;
        }
        throw ...; // error, expected 'identifier'
    }
```

#pragma unused(id(,id)*)

```
   if (Tok.is(tok::comma)) {
      LexID = true; // expected 'identifier' next
      continue;
   }

   if (Tok.is(tok::r_paren))
      break; // success

   throw ...; // error, illegal token
}
```

Next. . . semantic checks.

`clang::Sema`

- Once gathered the information
  => `Sema.ActOnPragmaUnused(...)`
  - Check semantics (access to the `clang::Parser` and context)
  - Bind pragmas to stmts/decls
  - Store/Apply pragma semantics

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  - Store/Apply pragma semantics
- Very little is automated!

Not `#pragma` friendly!

Defining new pragmas in Clang is cumbersome:

- User has to directly interface with the *lexer* and *preprocessor*
- New pragmas cannot be defined without modifying core data structures (e.g. `clang::Sema`)
  - Use of patches (updated every new LLVM release)
  - Difficult to implement pragmas as Clang *extensions* (e.g. *LibTooling* interface)
- Most of the code can be factorized!

Features of a pragma framework

1. Adding a new pragma possible without touching core classes
2. Pragma syntax defined in a declarative form
   - Automatic syntactic *checks* and *generation* of error messages with completion hints
   - Easy access to *useful* information
3. Mapping of pragmas to associated statements/declarations

Pragma Definition

Pragma definition (1/2)

Declarative form[2], similar to EBNF

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Pragma definition (1/2)

Declarative form[2], similar to EBNF

```
#pragma unused( identifier (, identifier)* )
#pragma kwd('unused')
    .followedBy( tok::l_paren )
    .followedBy( tok::identifier )
    .followedBy(
```

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Pragma definition (1/2)

Declarative form[2], similar to EBNF

```
#pragma unused( identifier (, identifier)* )
#pragma kwd('unused')
    .followedBy( tok::l_paren )
    .followedBy( tok::identifier )
    .followedBy(
      .repeat<0,inf>(
        ( tok::comma )
          .followedBy( tok::identifier )
      )
```

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    .followedBy( tok::identifier )
    .followedBy(
      .repeat<0,inf>(
        ( tok::comma )
          .followedBy( tok::identifier )
      )
    ).followedBy( tok::r_paren )
    .followedBy( tok::eod )
```

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Pragma definition (2/2)

Use convenience operators (because C++ is awesome):

`a.followedBy(b)`	=>	`a » b`	*(binary)*
`repeat<0,inf>(a)`	=>	`*a`	*(unary)*

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Use convenience operators (because C++ is awesome):

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a.followedBy(b)  =>   a » b   (binary)
repeat<0,inf>(a) =>    *a     (unary)
```

```
#pragma kwd('unused')
    >> tok::l_paren
        >> tok::identifier
            >> *( tok::comma >> tok::identifier )
    >> tok::r_paren >> tok::eod
```

Other operators

Given a position (•) within a stream: $t_{-1}, t_0 \bullet t_1, t_2, t_3, \ldots$

- `a » b`: *'concatenation'*, matches iff $t_1 = a$ *and* $t_2 = b$
- `a | b`: *'choice'*, matches if either $t_1 = a$ *or* $t_2 = b$
- `!a`: *'option'*, matches if $t_1 = a$ or ϵ (empty rule)
- `*a`: *'repetition'*, matches if $t_1 = \cdots = t_N = a$ or ϵ

- Expressions can be *combined*
- Brackets `( )` can be used to control *associativity* and *priority*

Tokens (1/2)

Leaf elements used within pragma specifications:

```
template<clang::tok::TokenKind T>
struct Tok : public node { ... };
```

Import Tokens defined within the Clang lexter:

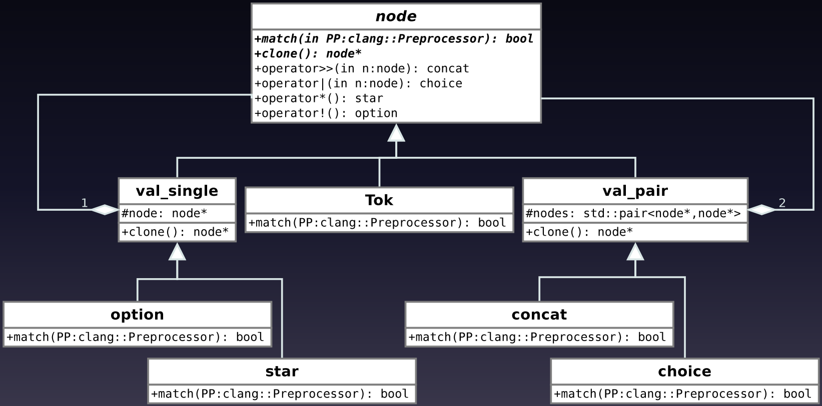
```
#define PUNCTUATOR(N, _) \
   static Tok<clang::tok::N> N = Tok<clang::tok::N>();
#define TOK(N) \
   static Tok<clang::tok::N> N = Tok<clang::tok::N>();
#include <clang/Basic/TokenKinds.def>
#undef PUNCTUATOR
#undef TOK
```

Tokens (2/2)

Special *"semantic tokens"* (syntax + sema)

- `kwd`: 1 token defining *new keywords* for the DSL supporting the pragma (e.g. `num_threads`)
- `var`: 1 token which is a valid *identifier* (i.e. `tok::identifier`) and declared as a *variable*
- `expr`: placeholder for a sequence of tokens forming a *syntactically* and *semantically* valid C/C++ *expression*

Classes organization



Parsing

From spec. to matching

Every concrete `node` implements the *bool match(clang::Preprocessor& p)* method.

```
bool concat::match(clang::Preprocessor& PP) {
    PP.EnableBacktrackAtThisPos();
    if (lhs.match(PP) && rhs.match(PP)) {
        PP.CommitBacktrackedTokens();
        return true;
    }
    PP.Backtrack();
    return false;
}
```

```
bool choice::match(clang::Preprocessor& PP) {
    PP.EnableBacktrackAtThisPos();
    if (lhs.match(PP)) {
        PP.CommitBacktrackedTokens();
        return true;
    }
    PP.Backtrack();
    PP.EnableBacktrackAtThisPos();
    if (rhs.match(PP)) {
        PP.CommitBacktrackedTokens();
        return true;
    }
    PP.Backtrack();
    return false;
}
```

From spec. to matching

Implements a top-down recursive descent parser with backtracking

- Not particularly efficient, but practical for small DSLs

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```
auto var_list =
   l_paren >> var >> *(comma >> var) >> r_paren;
auto for_clause = (
      ( kwd("first_private") >> var_list )
   | ( kwd("last_private") >> var_list )
   | ( kwd("collapse") >> l_paren >> expr >> r_paren )
   |   kwd("nowait")
   | ...
);
auto omp_for = Tok<tok::kw_for>() >> *for_clause >> eod;
```

Hack for expr parsing

We don't want to write the grammar for C expressions, the `clang::Parser` already does it for free!

Why not expose the `clang::Parser` instance?

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We don't want to write the grammar for C expressions, the `clang::Parser` already does it for free!

Why not expose the `clang::Parser` instance?

```
struct ParserProxy {
   clang::Parser* mParser;
   ParserProxy(clang::Parser* parser): mParser(parser) { }
public:
   clang::Expr* ParseExpression(clang::Preprocessor& PP);
   clang::Token& ConsumeToken();
   clang::Token& CurrentToken();
   ...
};
```

`ParserProxy` is declared as a **friend** class of `clang::Parser` (via patch)

Extracting Information

Extract useful information

Within pragmas, some information is not semantically relevant (e.g. punctuation)

For example in the pragma:

```
#pragma omp for private(a,b) schedule(static)
...
```

We are interested in the fact that:

1. This is an OpenMP "`for`" pragma
2. Variables `a` and `b` must be "`private`"
3. Scheduling is "`static`"

No interest in: `,` `(` `)`

The MatchMap object

A generic object which stores any relevant information:

```
class MatchMap: std::map<string,
   std::vector<
      llvm::PointerUnion<clang::Expr*, string*>
   >> { ... };
```

MatchMap layout for the previous example:

- *"for"* → { }
- *"private"* → $\{a, b\}$
- *"schedule"* → {*"static"*}

The map is filled while parsing a pragma

Control over mapping

Two operators used within the pragma specification:

- `a["key"]`: All tokens matched by `a` will be referenced by `key` in the `MatchMap`
- `~a`: None of the tokens matched by `a` will be stored in the `MatchMap`

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```
auto var_list =
    ~l_paren >> var >> *(~comma >> var) >> ~r_paren;
auto for_clause = (
      ( kwd("first_private") >> var_list["first_private"] )
    | ( kwd("last_private") >> var_list["last_private"] )
    | ...
);
```

Pragma $\rightarrow$ Stmt

Pragma to stmt association

Hack in `clang::Sema`, works for any new pragma!

- *Correctly* parsed pragmas are stored in a list of *pending* pragmas
- When either a `CompoundStmt`, `IfStmt`, `ForStmt`, `Declarator` or a `FunctionDef` is reduced by `Sema` => an algorithm checks for *association* with pending pragmas based on source locations.
  - Faster than performing *a-posteriori* traversal of the AST
- For positional pragmas (e.g. `omp barrier`) NOPs are inserted in the AST

Framework interface (1/2)

```
struct OmpPragmaCritical: public Pragma {
    OmpPragmaCritical(
        const SourceLocation& startLoc,
        const SourceLocation& endLoc,
        const MatchMap& mmap) { }
    Stmt const* getStatement() const; // derived from Pragma
    Decl const* getDecl() const;      // derived from Pragma
    ...
};
```

Framework interface (1/2)

```
struct OmpPragmaCritical: public Pragma {
   OmpPragmaCritical(
      const SourceLocation& startLoc,
      const SourceLocation& endLoc,
      const MatchMap& mmap) { }
   Stmt const* getStatement() const; // derived from Pragma
   Decl const* getDecl() const;      // derived from Pragma
   ...
};

PragmaNamespace* omp = new clang::PragmaNamespace("omp");
pp.AddPragmaHandler(omp);
// #pragma omp critical [(name)] new-line
omp->AddPragma(
  PragmaFactory::CreateHandler<OmpPragmaCritical>(
    pp.getIdentifierInfo("critical"),
    !(l_paren >> identifier["critical"] >> r_paren) >> eod )
);
```

Framework interface (2/2)

```
MyDriver drv; // instantiates the compiler and registers pragma handlers
TranslationUnit& tu = drv.loadTU( "omp_critical.c" );

const PragmaList& pl = tu.getPragmaList();
const ClangCompiler& comp = tu.getCompiler(); // contains ASTContext

EXPECT_EQ(pl.size(), 4u);
// first pragma is at location [(4:2) - (4:22)]
PragmaPtr p = pl[0];
{
   CHECK_LOCATION(p->getStartLocation(), comp.getSourceManager(), 4, 2);
   CHECK_LOCATION(p->getEndLocation(), comp.getSourceManager(), 4, 22);

   EXPECT_EQ(p->getType(), "omp::critical");
   EXPECT_TRUE(p->isStatement()) << "Pragma is associated with a Stmt";
   const clang::Stmt* stmt = p->getStatement();

   // check the is an omp::critical
   omp::OmpPragmaCritical* omp = dynamic_cast<omp::OmpPragmaCritical*>(p.get());
   EXPECT_TRUE(omp) << "Pragma should be omp::critical";
}
```

Some performance numbers

Used framework to encode the OpenMP 3.0 standard

Total frontend time for some of the OpenMP NAS Parallel Benchmarks:

Bench.	# Pragmas	w/o OpenMP	w OpenMP
BT	58	45 msecs	48 msecs
MG	29	36 msecs	39 msecs
LU	39	47 msecs	54 msecs

Summary

Showed an idea for *easy custom* pragmas in Clang!

The framework code (+Clang 3.2 patches) available at:
`https://github.com/motonacciu/clomp`

Not integrated into Clang. . . yet:

- Little time to invest (to change in the near future)
- Requires some restructuring (use of `attributes`?)
- Level of interest shown by the LLVM/Clang community

La Fin!

Questions?

Want to contribute?

https://github.com/motonacciu/clomp