libclang: Thinking Beyond the Compiler

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- Clang is also a library for processing source code
  - Translates text into **A**bstract **S**yntax **T**rees
  - Resolves identifiers and symbols
  - Expands macros
  - Makes implicit information explicit

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  - Resolves identifiers and symbols
  - Expands macros
  - Makes implicit information explicit
- Clang obsessively tracks source-level location information

Introducing `libclang`

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- Parsing

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- Indexing and cross-referencing

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- Syntax highlighting

Introducing `libclang`

- Parsing
- Indexing and cross-referencing
- Syntax highlighting
- Code completion

Parsing Source Code

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```
int main(int argc, char *argv[]) {



    return 0;
}
```

Parsing Source Code

```
int main(int argc, char *argv[]) {
  CXIndex Index = clang_createIndex(0, 0);

  clang_disposeIndex(Index);
  return 0;
}
```

Parsing Source Code

```
int main(int argc, char *argv[]) {
  CXIndex Index = clang_createIndex(0, 0);
  CXTranslationUnit TU = clang_parseTranslationUnit(Index, 0,
                                    argv, argc, 0, 0, CXTranslationUnit_None);
  clang_disposeTranslationUnit(TU);
  clang_disposeIndex(Index);
  return 0;
}
```

Parsing Source Code

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int main(int argc, char *argv[]) {
  CXIndex Index = clang_createIndex(0, 0);
  CXTranslationUnit TU = clang_parseTranslationUnit(Index, 0,
                                    argv, argc, 0, 0, CXTranslationUnit_None);
  clang_disposeTranslationUnit(TU);
  clang_disposeIndex(Index);
  return 0;
}
```

Parsing Source Code

```
int main(int argc, char *argv[]) {
  CXIndex Index = clang_createIndex(0, 0);
  CXTranslationUnit TU = clang_parseTranslationUnit(Index, 0,
                                    argv, argc, 0, 0, CXTranslationUnit_None);
  for (unsigned I = 0, N = clang_getNumDiagnostics(TU); I != N; ++I) {
    CXDiagnostic Diag = clang_getDiagnostic(TU, I);
    CXString String = clang_formatDiagnostic(Diag,
                                  clang_defaultDiagnosticDisplayOptions());
    fprintf(stderr, "%s\n", clang_getCString(String));
    clang_disposeString(String);
  }
  clang_disposeTranslationUnit(TU);
  clang_disposeIndex(Index);
  return 0;
}
```

Parsing Source Code—Results

- Given list.c:

```
struct List { ... };
int sum(union List *L) { /* ... */ }
```

- Run our syntax-checker:

```
$ syntax-check -I../../ list.c

list.c:2:9: error: use of 'List' with tag type that
does not match previous declaration
list.c:1:8: note: previous use is here
```

Parsing Source Code—Results

- Given list.c:

```
struct List { ... };
int sum(union List *L) { /* ... */ }
```

- Run our syntax-checker:

```
list.c:2:9: error: use of 'List' with tag type that does not match
      previous declaration
int sum(union List *Node) {
        ^~~~~
        struct
list.c:1:8: note: previous use is here
struct List {
       ^
```

Dissecting Diagnostics

Dissecting Diagnostics

- Core diagnostic information:
  - enum CXDiagnosticSeverity clang_getDiagnosticSeverity(CXDiagnostic Diag);
  - CXSourceLocation clang_getDiagnosticLocation(CXDiagnostic Diag);
  - CXString clang_getDiagnosticSpelling(CXDiagnostic Diag);

Dissecting Diagnostics

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- Highlighted source ranges

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  - enum CXDiagnosticSeverity clang_getDiagnosticSeverity(CXDiagnostic Diag);
  - CXSourceLocation clang_getDiagnosticLocation(CXDiagnostic Diag);
  - CXString clang_getDiagnosticSpelling(CXDiagnostic Diag);
- Highlighted source ranges
- Fix-its:
  - unsigned clang_getDiagnosticNumFixIts(CXDiagnostic Diag);
  - CXString clang_getDiagnosticFixIt(CXDiagnostic Diag,
    unsigned FixIt,
    CXSourceRange *ReplacementRange);

Indexing & Cross-Referencing

Indexing and Cross-Referencing

```
struct List {
  int Data;
  struct List *Next;
};

int sum(struct List *Node) {
  int result = 0;
  for (; Node; Node = Node->Next)
    result = result + Node->Data;
  return result;
}
```

Indexing and Cross-Referencing

- Walk the Abstract Syntax Tree

```
struct List {
  int Data;
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};

int sum(struct List *Node) {
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```

Indexing and Cross-Referencing

- Walk the Abstract Syntax Tree
  - Declarations

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struct List {
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```

Indexing and Cross-Referencing

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```

Indexing and Cross-Referencing

- Walk the Abstract Syntax Tree
  - Declarations
  - References
  - Statements & expressions

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  int Data;
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};

int sum(struct List *Node) {
  int result = 0;
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    result = result + Node->Data;
  return result;
}
```

Indexing and Cross-Referencing

- Walk the Abstract Syntax Tree
  - Declarations
  - References
  - Statements & expressions
  - Macro definitions & instantiations

```
struct List {
  int Data;
  struct List *Next;
};

int sum(struct List *Node) {
  int result = 0;
  for (; Node; Node = Node->Next)
    result = result + Node->Data;
  return result;
}
```

CXCursor: AST Node, Simplified

- `typedef struct { ... } CXCursor;`
- Unifies AST nodes (declaration, reference, expression, statement, etc.)
  - Source location and extent
  - Name and symbol resolution
  - Type
  - Child nodes

Example CXCursor: struct List

```
struct List {
  int Data;
  struct List *Next;
};
```

Example CXCursor: struct List

- Top-level cursor C for List:
  - clang_getCursorKind(C) == CXCursor_StructDecl
  - clang_getCursorSpelling(C) == “List”

```
struct List {
  int Data;
  struct List *Next;
};
```

Example CXCursor: struct List

- Top-level cursor C for List:
  - clang_getCursorKind(C) == CXCursor_StructDecl
  - clang_getCursorSpelling(C) == “List”
  - clang_getCursorLocation(C)

```
struct List {
  int Data;
  struct List *Next;
};
```

Example CXCursor: struct List

- Top-level cursor C for List:
  - clang_getCursorKind(C) == CXCursor_StructDecl
  - clang_getCursorSpelling(C) == “List”
  - clang_getCursorLocation(C)
  - clang_getCursorExtent(C)

```
struct List {
  int Data;
  struct List *Next;
};
```

Example CXCursor: struct List

- Top-level cursor C for List:
  - clang_getCursorKind(C) == CXCursor_StructDecl
  - clang_getCursorSpelling(C) == “List”
  - clang_getCursorLocation(C)
  - clang_getCursorExtent(C)
  - clang_visitChildren(C, …);

```
struct List {
  int Data;
  struct List *Next;
};
```

Reference Cursors

```
struct List {
  int Data;
  struct List *Next;
};
```

Reference Cursors

- Reference cursor R for List:
  - clang_getCursorKind(R) == CXCursor_TypeRef
  - clang_getCursorSpelling(R) == “List”
  - clang_getCursorLocation(R)

```
struct List {
  int Data;
  struct List *Next;
};
```

Reference Cursors

- Reference cursor R for List:
  - clang_getCursorKind(R) == CXCursor_TypeRef
  - clang_getCursorSpelling(R) == “List”
  - clang_getCursorLocation(R)
  - clang_getCursorExtent(R)

```
struct List {
  int Data;
  struct List *Next;
};
```

Reference Cursors

- Reference cursor R for List:
  - clang_getCursorKind(R) == CXCursor_TypeRef
  - clang_getCursorSpelling(R) == “List”
  - clang_getCursorLocation(R)
  - clang_getCursorExtent(R)
  - clang_getCursorReferenced(R) == C

```
struct List {
  int Data;
  struct List *Next;
};
```

Local Renaming of Declarations

```
struct List {
  int Data;
  struct List *Next;
};
```

Local Renaming of Declarations

- Walk all cursors in the AST, recursively:

```
struct List {
  int Data;
  struct List *Next;
};
```

Local Renaming of Declarations

- Walk all cursors in the AST, recursively:
  - Identify the cursor C corresponding to the declaration we want to rename

```
struct List {
  int Data;
  struct List *Next;
};
```

Local Renaming of Declarations

- Walk all cursors in the AST, recursively:
  - Identify the cursor C corresponding to the declaration we want to rename
  - Find each cursor R: clang_getCursorReferenced(R) = C

```
struct List {
  int Data;
  struct List *Next;
};
```

Local Renaming of Declarations

- Walk all cursors in the AST, recursively:
  - Identify the cursor C corresponding to the declaration we want to rename
  - Find each cursor R: clang_getCursorReferenced(R) = C
- Perform textual replacement of the name at the locations of C and each R

```
struct MyList {
  int Data;
  struct MyList *Next;
};
```

Spanning Translation Units

- **U**nified **S**ymbol **R**esolutions provide a stable name for declarations
  - Every entity with external linkage has a USR
  - USRs are stable across translation units, time

```
CXString clang_getCursorUSR(CXCursor C);
```

Syntax Coloring

What's Under My Cursor?

```
struct List {
  int Data;
  struct List *Next;
};

int sum(struct List *Node) {
  int result = 0;
  for (; Node; Node = Node->Next)
    result = result + Node->Data;
  return result;
}
```

What's Under My Cursor?

```
struct List {
  int Data;
  struct List *Next;
};

int sum(struct List *Node) {
  int result = 0;
  for (; Node; Node = Node->Next)
    result = result + Node->Data;
  return result;
}
```

What's Under My Cursor?

- Kind: CXCursor_DeclRefExpr
- Type: int
- References: variable declaration "result"

```
struct List {
  int Data;
  struct List *Next;
};

int sum(struct List *Node) {
  int result = 0;
  for (; Node; Node = Node->Next)
    result = result + Node->Data;
  return result;
}
```

What's Under My Cursor?

```
CXSourceLocation
  clang_getLocation(CXTranslationUnit TU,
                    CXFile File,
                    unsigned Line,
                    unsigned Column);

CXCursor clang_getCursor(CXTranslationUnit TU,
                         CXSourceLocation Where);
```

```
  int result = 0;
  for (; Node; Node = Node->Next)
    result = result + Node->Data;
  return result;
}
```

What's Under My Cursor?

- Kind: CXCursor_UnexposedExpr
- Type: int

```
struct List {
  int Data;
  struct List *Next;
};

int sum(struct List *Node) {
  int result = 0;
  for (; Node; Node = Node->Next)
    result = result + Node->Data;
  return result;
}
```

What's Under My Cursor?

- Kind: CXCursor_MemberRefExpr
- Type: struct List *
- References: field declaration "Next"

```
struct List {
  int Data;
  struct List *Next;
};

int sum(struct List *Node) {
  int result = 0;
  for (; Node; Node = Node->Next)
    result = result + Node->Data;
  return result;
}
```

Syntax Coloring

```
struct MyList {
  int Data;
  struct MyList *Next;
};
```

Syntax Coloring

```
struct MyList {
  int Data;
  struct MyList *Next;
};
```

Syntax Coloring

- `void clang_tokenize(CXTranslationUnit, CXSourceRange, CXToken **Tokens, unsigned *NumTokens);`

```
struct MyList {
  int Data;
  struct MyList *Next;
};
```

Syntax Coloring

```
• void clang_tokenize(CXTranslationUnit, CXSourceRange,
                      CXToken **Tokens, unsigned *NumTokens);
```

- Keyword [1:1-1:7]:“struct”
- Identifier [1:8-1:14]:“MyList”
- Punctuation [1:15-1:16]:“{“
- Keyword [2:3-2:6]:“int”
- Identifier [2:7-2:11]:“Data”
- Punctuation [2:11-2:12]:“;”
- Keyword [3:3-3:9]:“struct”
- Identifier [3:10-3:16]:“MyList”

```
struct MyList {
  int Data;
  struct MyList *Next;
};
```

Syntax Coloring

```
• void clang_annotateTokens(CXTranslationUnit,
                            CXToken *Tokens, unsigned NumTokens,
                            CXCursor *Cursors);
```

- Keyword [1:1-1:7]:“struct”
- Identifier [1:8-1:14]:“MyList”
- Punctuation [1:15-1:16]:“{“
- Keyword [2:3-2:6]:“int”
- Identifier [2:7-2:11]:“Data”
- Punctuation [2:11-2:12]:“;”
- Keyword [3:3-3:9]:“struct”
- Identifier [3:10-3:16]:“MyList”

```
struct MyList {
  int Data;
  struct MyList *Next;
};
```

Syntax Coloring

```
• void clang_annotateTokens(CXTranslationUnit,
                            CXToken *Tokens, unsigned NumTokens,
                            CXCursor *Cursors);
```

- Keyword [1:1-1:7]:“struct”
- Identifier [1:8-1:14]:“MyList” (MyList struct declaration)
- Punctuation [1:15-1:16]:“{“
- Keyword [2:3-2:6]:“int”
- Identifier [2:7-2:11]:“Data” (Data member declaration)
- Punctuation [2:11-2:12]:“;”
- Keyword [3:3-3:9]:“struct”
- Identifier [3:10-3:16]:“MyList” (MyList type reference)

```
struct MyList {
  int Data;
  struct MyList
*Next;
};
```

Code Completion

What Can I Do <here>?

What Can I Do <here>?

- Code completion suggests what we can type, e.g.
  - “Data”
  - “Next”

```
int sum(struct List *Node) {
  int result = 0;
  for (; Node; Node = Node->Next)
    result = result + Node->□
```

What Can I Do <here>?

- Code completion suggests what we can type, e.g.
  - “Data”
  - “Next”
- Implemented in the parser:
  - Insert ◻ token in the lexer
  - Parse ◻ token and call context-sensitive callback function
  - Form completion results

```
int sum(struct List *Node) {
  int result = 0;
  for (; Node; Node = Node->Next)
    result = result + Node->◻
```

What Can I Do <here>? (Cont.)

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```
int sum(struct List *Node) {
  int result = 0;
  for (; Node; Node = Node->Next)
    result = result + □
```

What Can I Do <here>? (Cont.)

- Reference a local variable (`result`,`Node`)
- Call a function (e.g., `sum`)
- Use any C expression (e.g., `sizeof`)
- Use any defined macro (e.g., NULL)
- In C++, name any type (e.g., `List`)
- In C++, refer into a namespace (e.g., `std::`)

```
int sum(struct List *Node) {
  int result = 0;
  for (; Node; Node = Node->Next)
    result = result +
```

Semantic Strings

Semantic Strings

- Code completion results are composed of "chunks":
  - **Typed Text**, which the user types and is inserted into the file
  - **Text**, which is inserted into the buffer
  - **Informative Text**, which is shown but not inserted
  - **Placeholders**, which indicate code the user should modify
  - **Result Type**, which indicates the type of the result
  - **Cursor Kind,** which is the kind of entity in the completion

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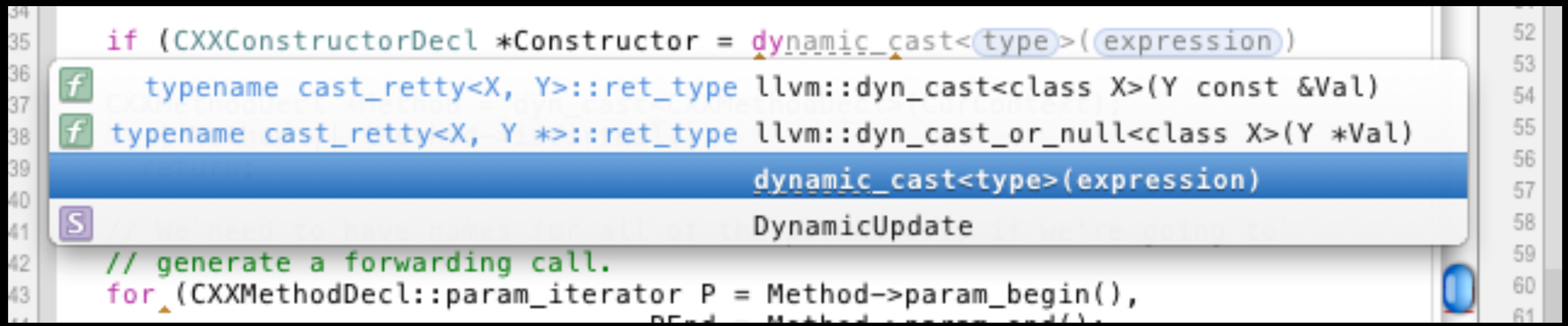
  - **Placeholders**, which indicate code the user should modify
  - **Result Type**, which indicates the type of the result
  - **Cursor Kind,** which is the kind of entity in the completion
- Example completion: `int sum(struct List *Node)`
  - `Cursor kind: CXCursor_FunctionDecl`

Result Type	Typed Text	Text	Placeholder	Text
`int`	`sum`	`(`	`struct List *Node`	`)`


if (CXXConstructorDecl *Constructor = dynamic_cast<type>(expression)
typename cast_retty<X, Y>::ret_type llvm::dyn_cast<class X>(Y const &Val)
typename cast_retty<X, Y *>::ret_type llvm::dyn_cast_or_null<class X>(Y *Val)
dynamic_cast<type>(expression)
DynamicUpdate
// generate a forwarding call.
for (CXXMethodDecl::param_iterator P = Method->param_begin(),

Wrap-Up

Getting Started with libclang

- User-level tools
  - Xcode 4 Developer Preview
  - Emacs code completion "demo" (see `clang/utils/clang-completion-mode.el`)
  - Vim code completion (see `llvm/utils/vim/`)
- Developer-centric resources
  - `c-index-test` provides a command-line interface to the API
  - Doxygen documentation at http://clang.llvm.org

libclang Supports Development Tools

- Simple C API covers a variety of features
  - Parsing
  - Indexing
  - Cross-referencing
  - Mapping between source code and ASTs
  - Syntax coloring
  - Code completion
- Great basis for development tools