Index-While-Building and Refactoring in Clang

Alex Lorenz and Nathan Hawes, Apple.

Index-While-Building

Indexing, historically.

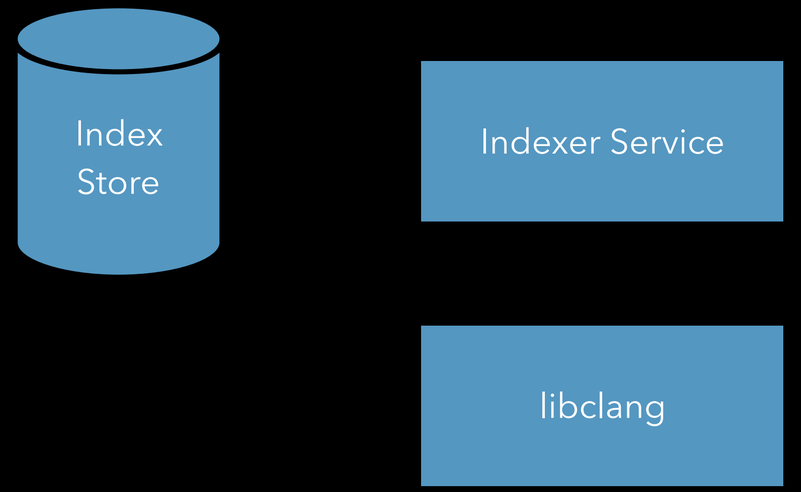
Indexing while building.

Its implementation in Clang.

What the produced index data looks like.

How we use it in the indexer service.

Indexing
in the background



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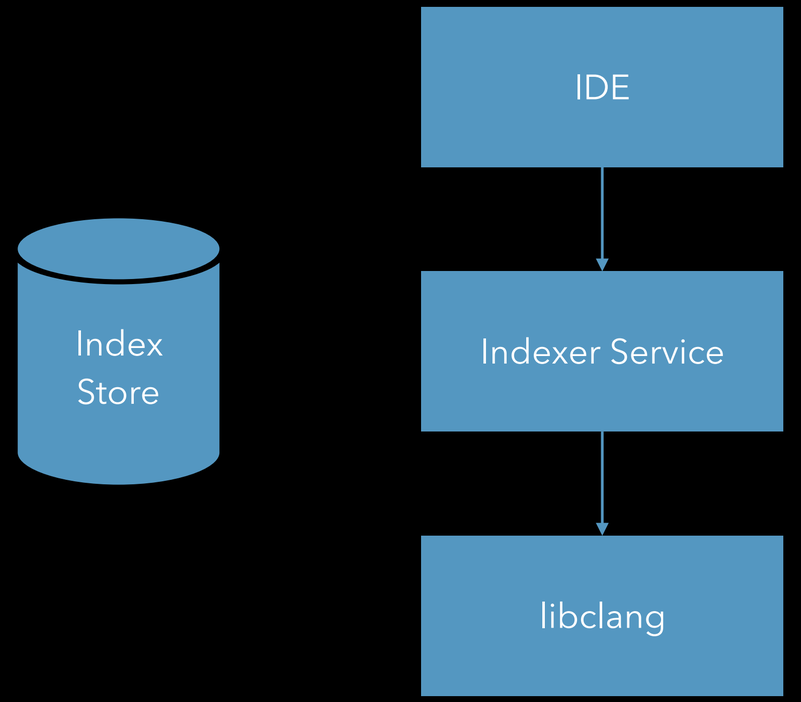

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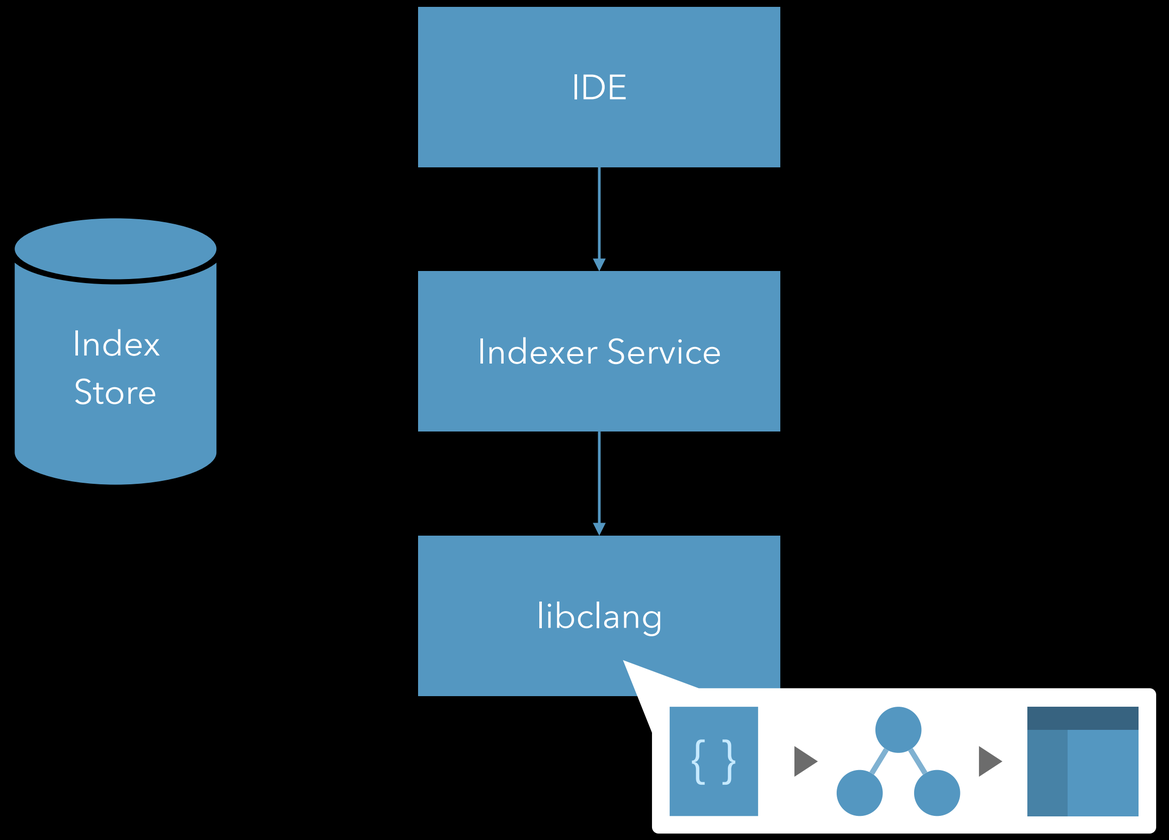

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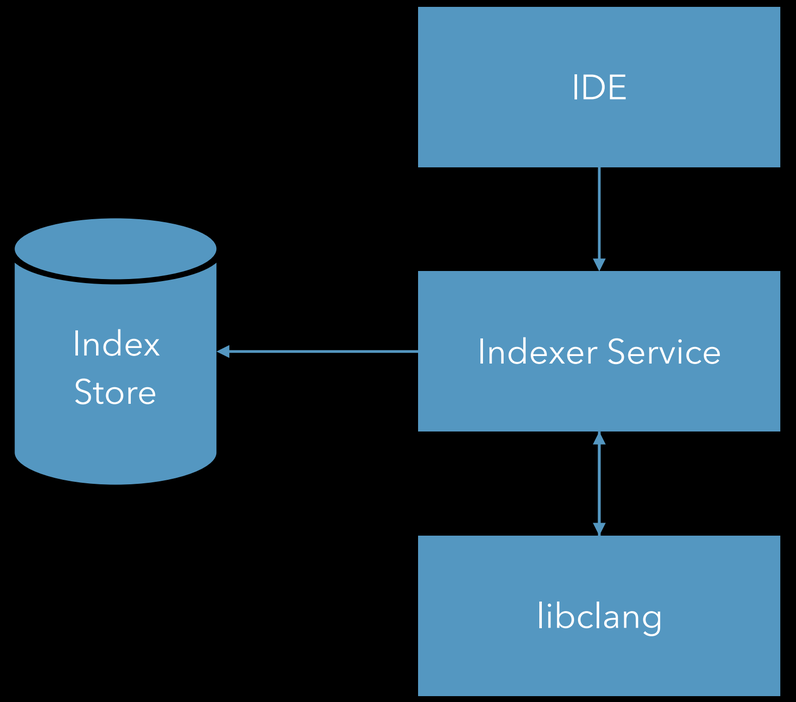

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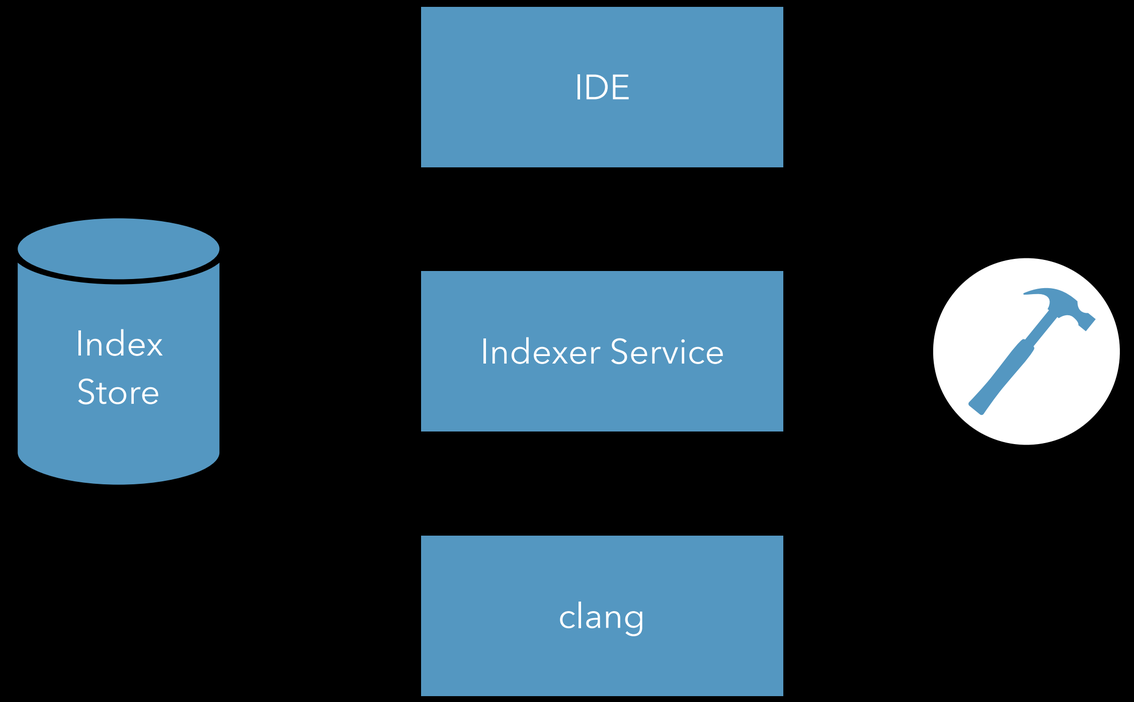

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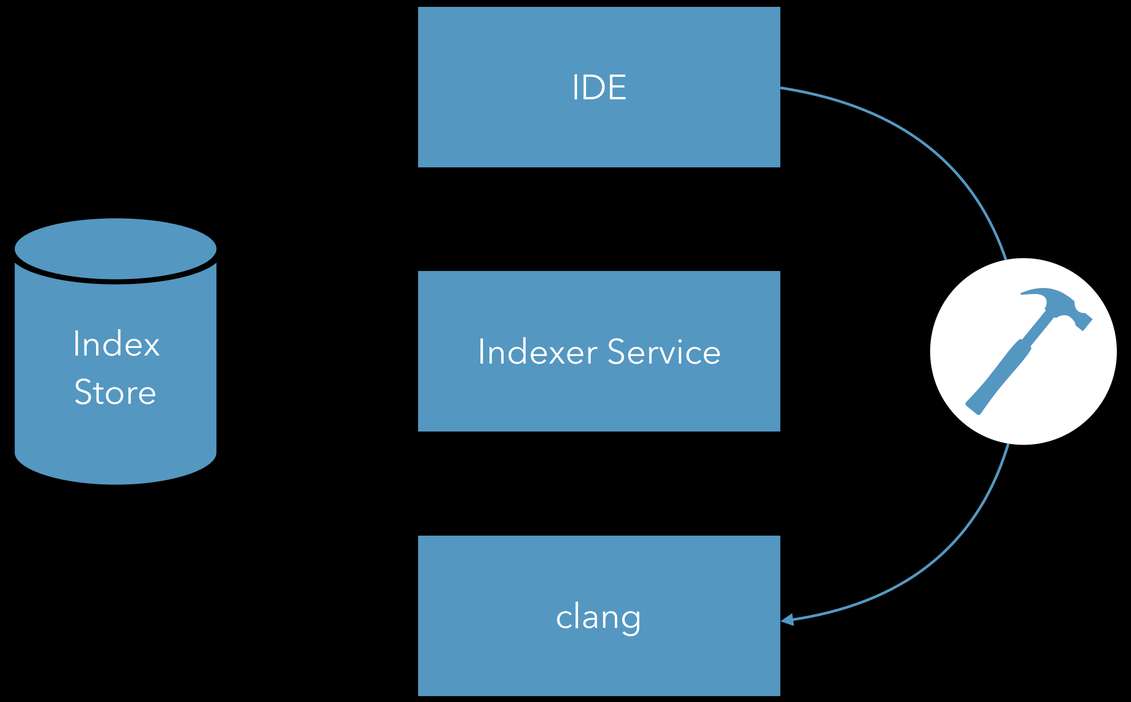

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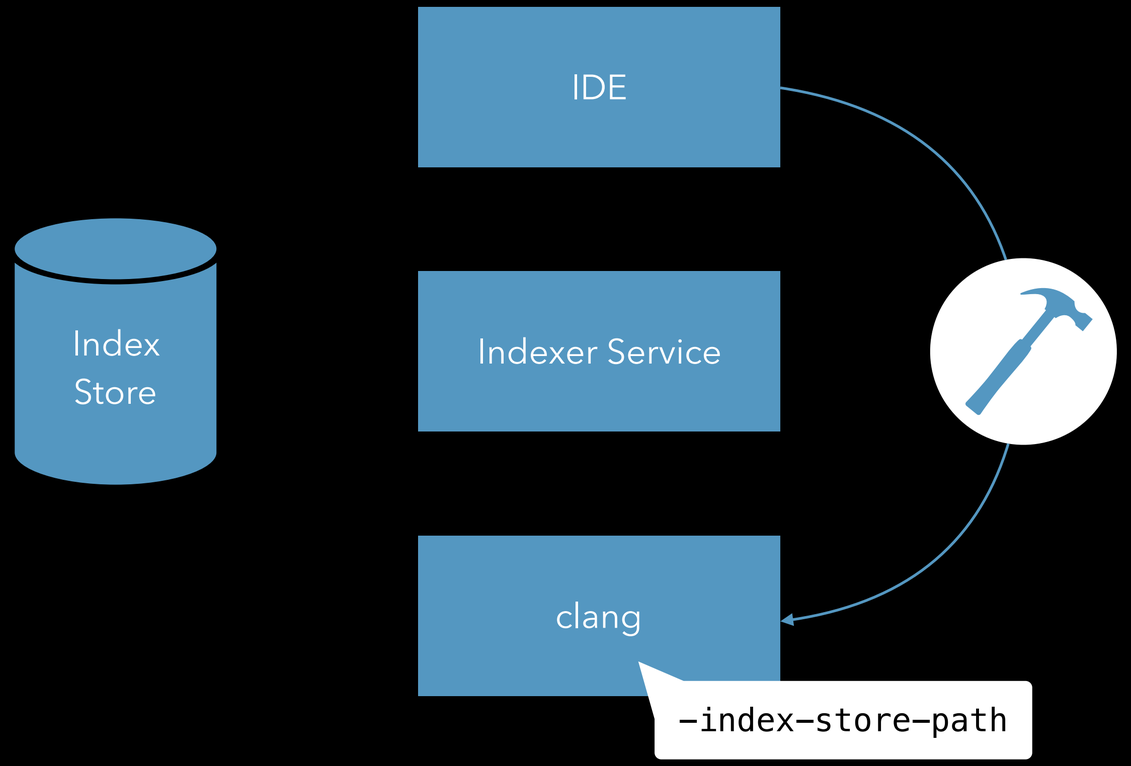

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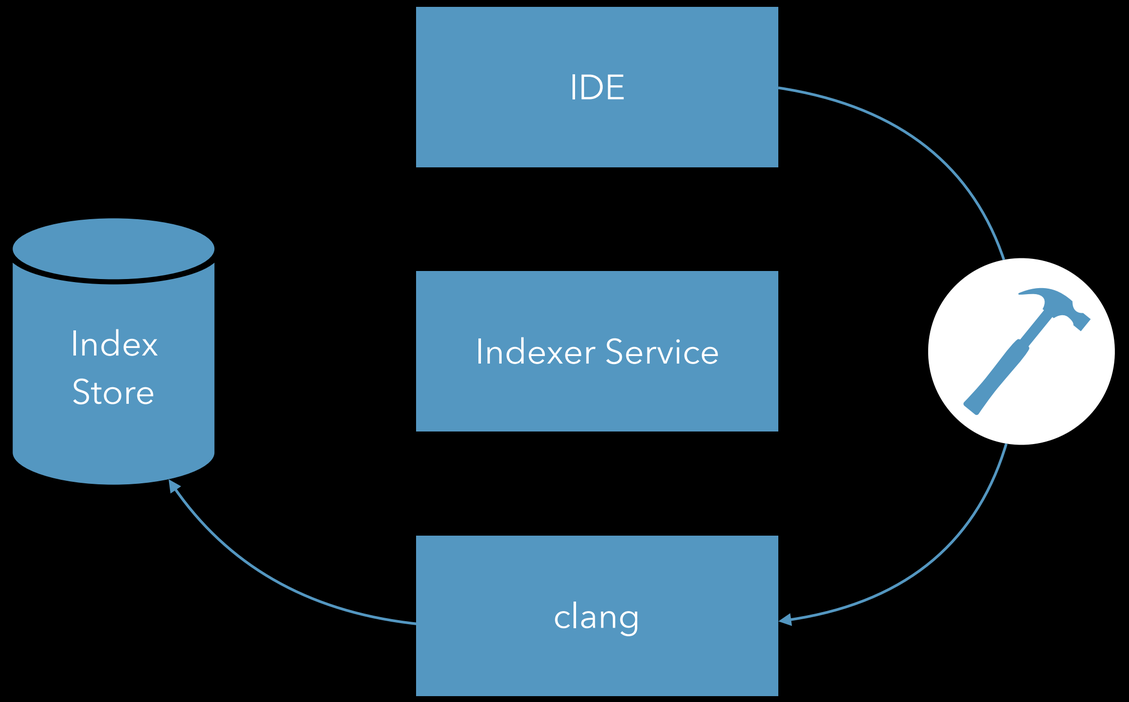

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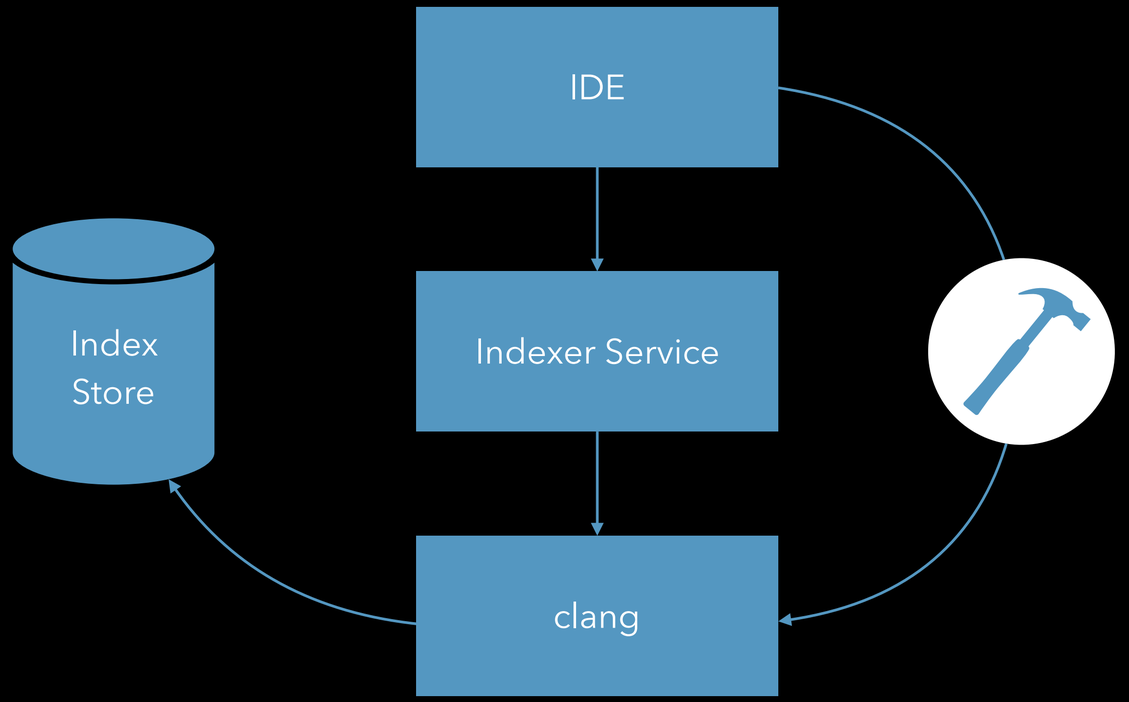

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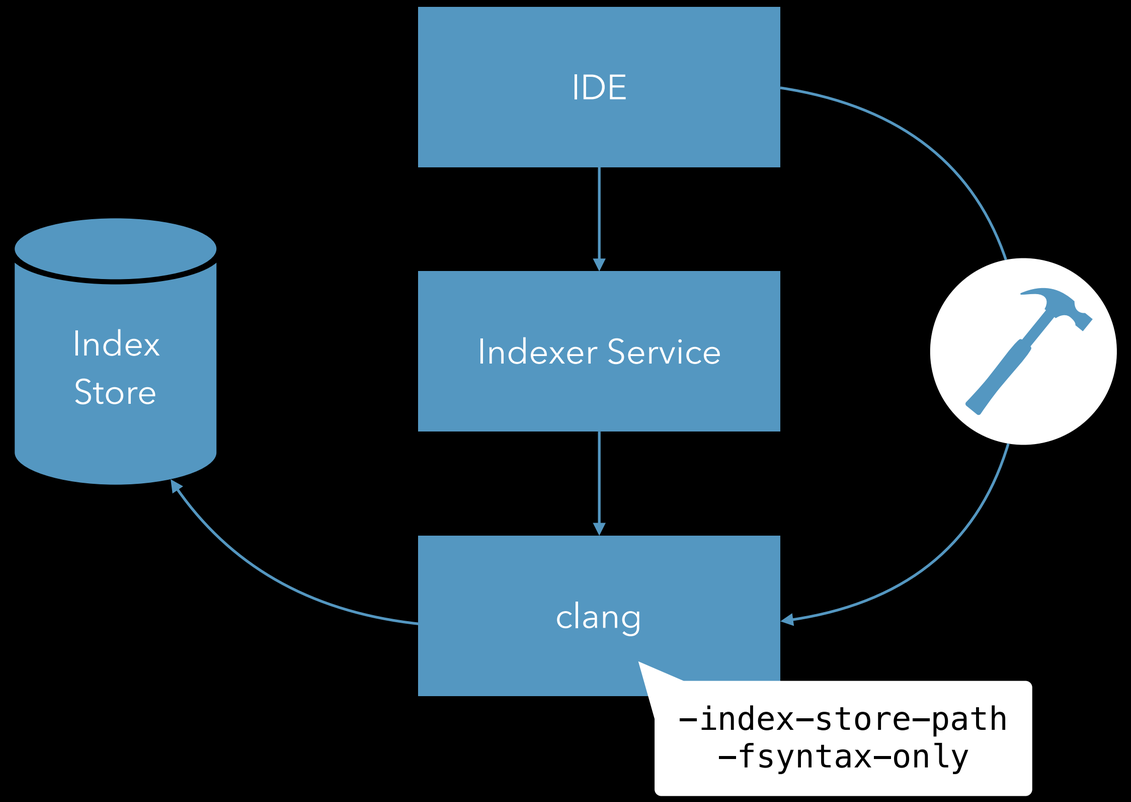

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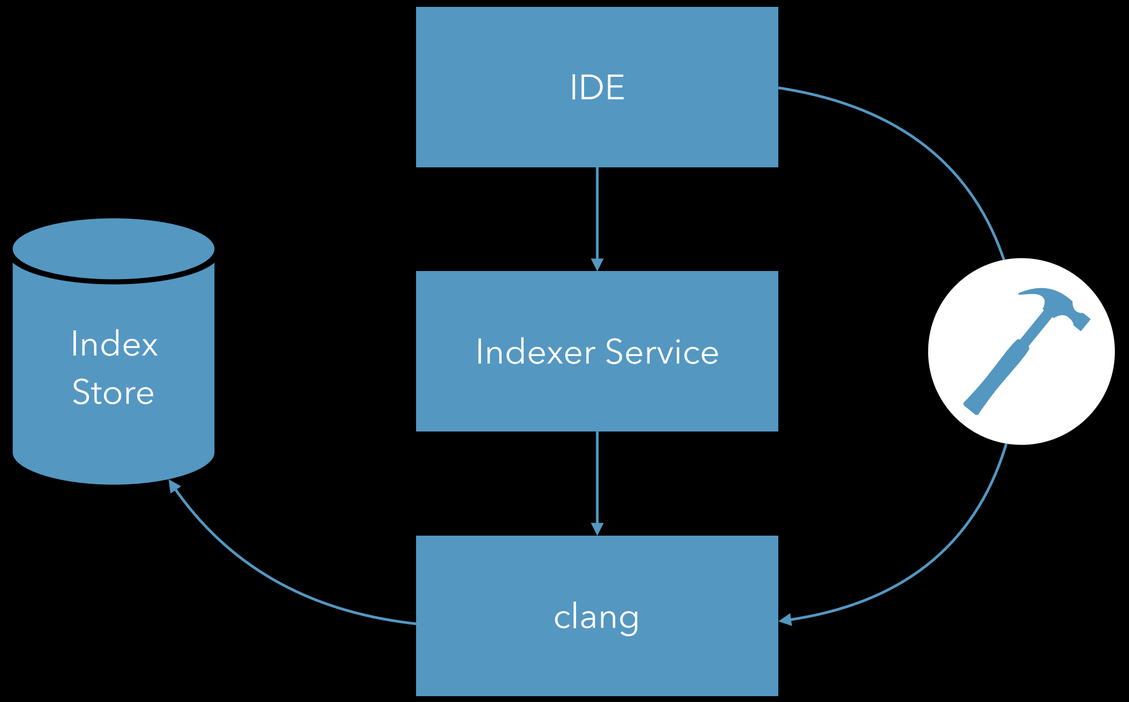

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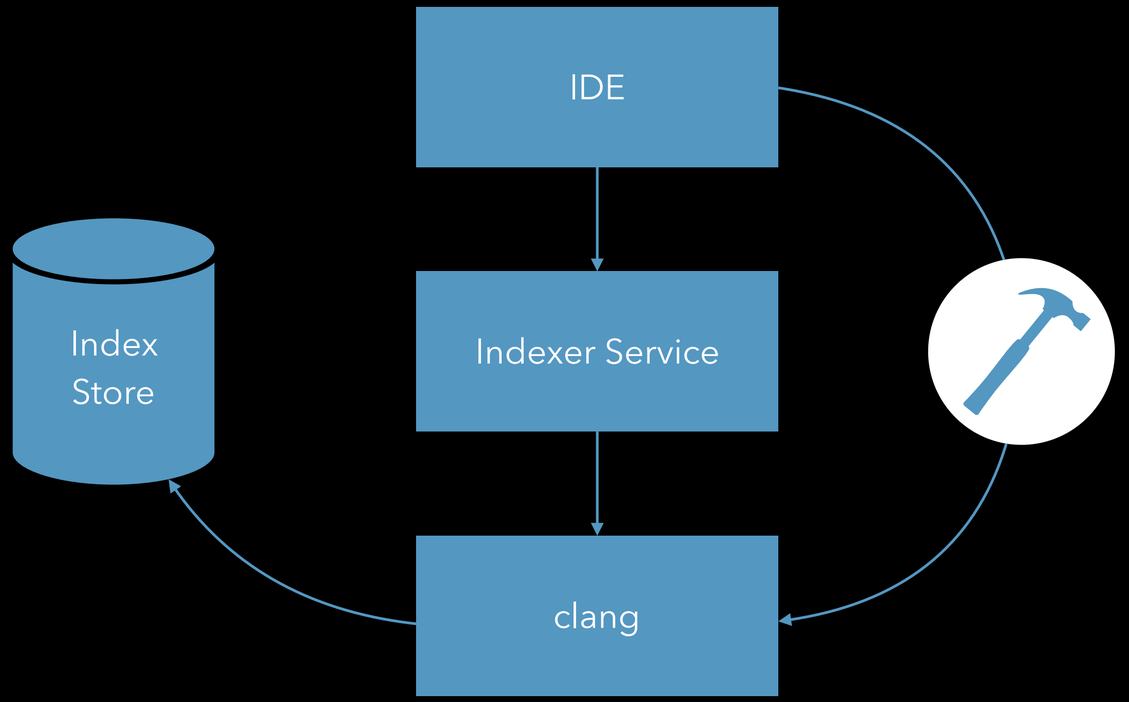

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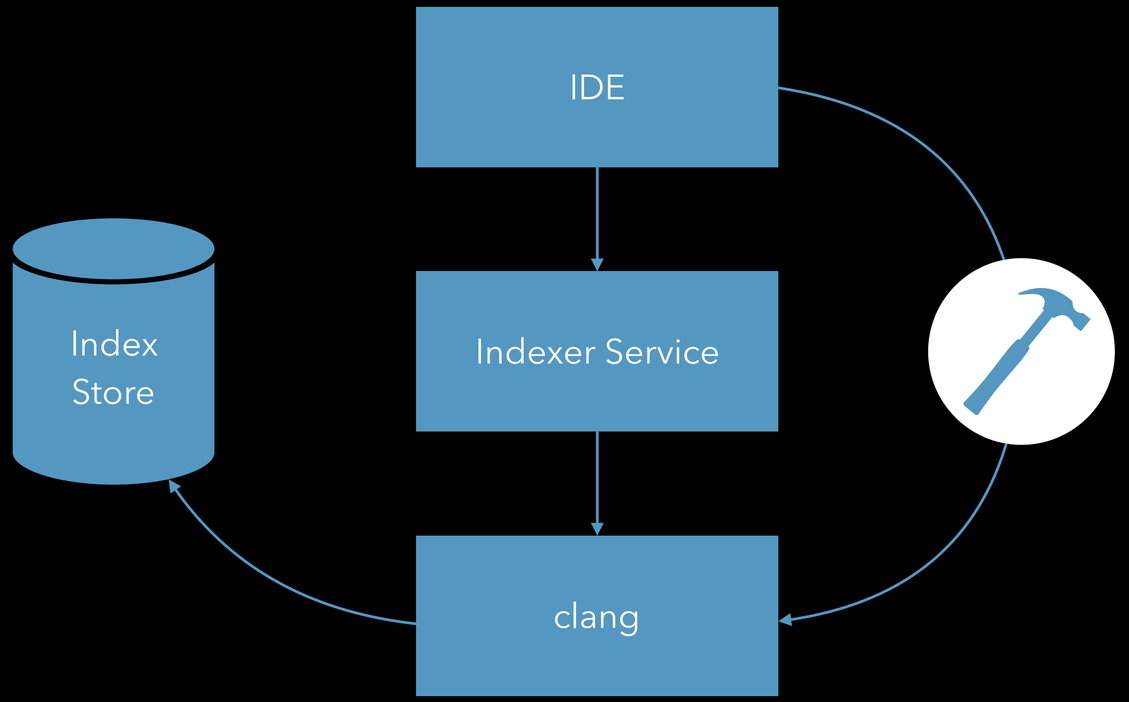

Indexing
while building

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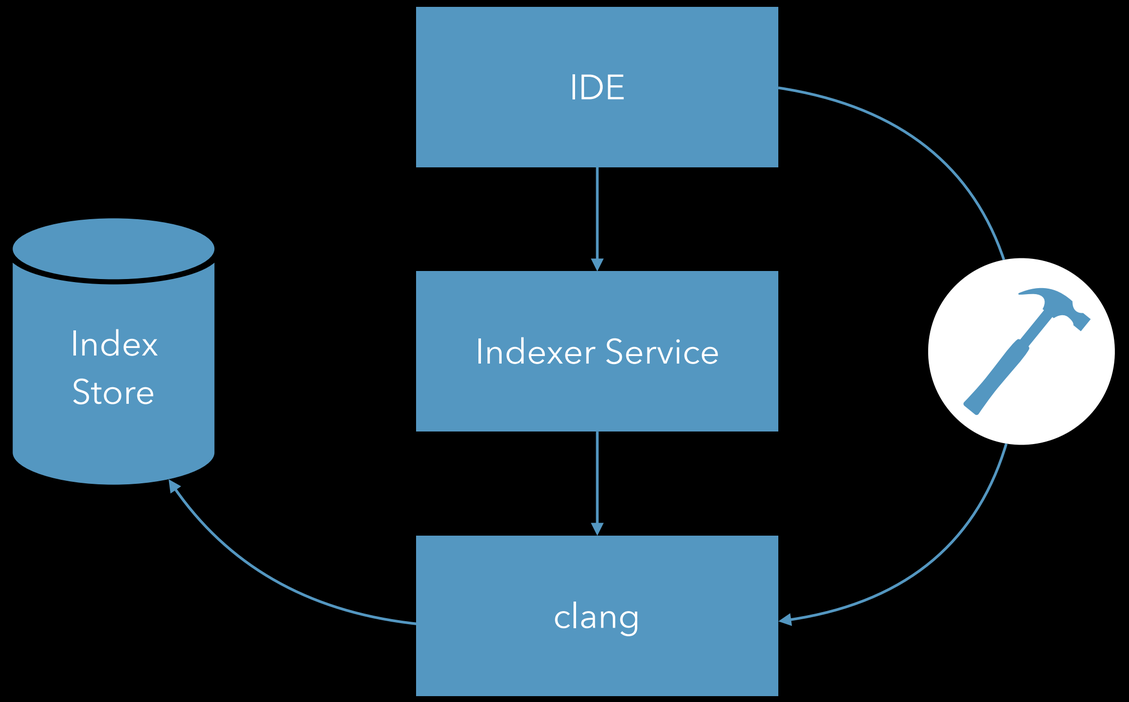
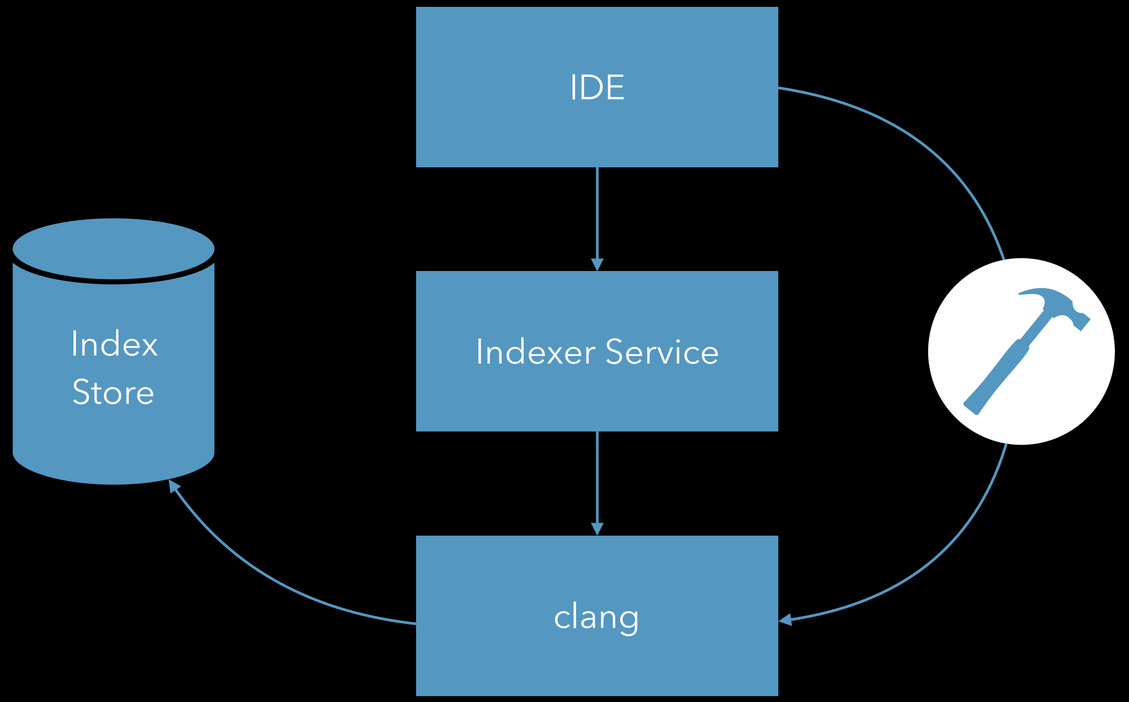


Indexing
while building

- User-initiated so unthrottled.
- Reuses ASTs from build.



Build overhead: 3–5%

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LLVM+CLANG

3.2%

Generating the index data

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- Uses `IndexDependencyProvider` to track source and module dependencies.

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- Implemented via a new `FrontendAction`: `WrappingIndexRecordAction`.
- Uses `IndexASTConsumer` to collect symbol information from the AST.
- Uses `IndexDependencyProvider` to track source and module dependencies.
- Writes this out to the provided store path once complete.

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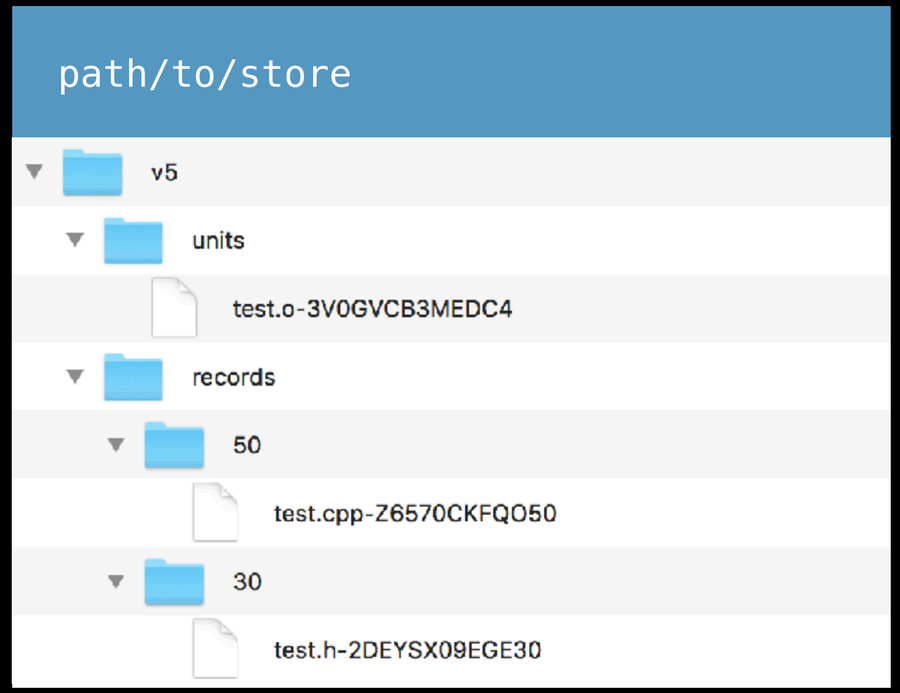

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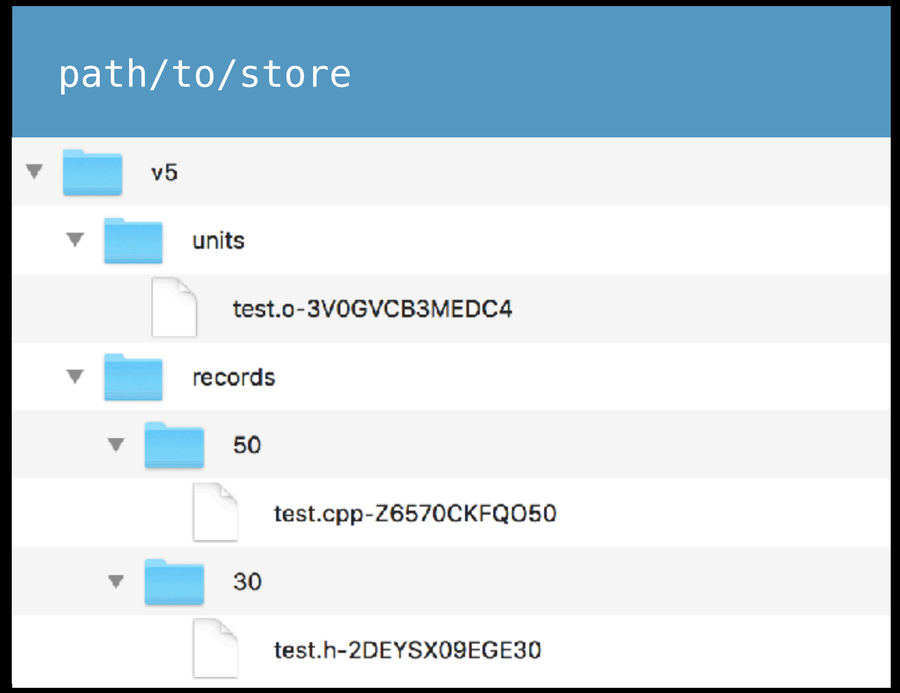

Unit

Provider
IsSystem
IsModule
HasMain
MainPath
WorkingDir
OutputFile
Target

Dependencies

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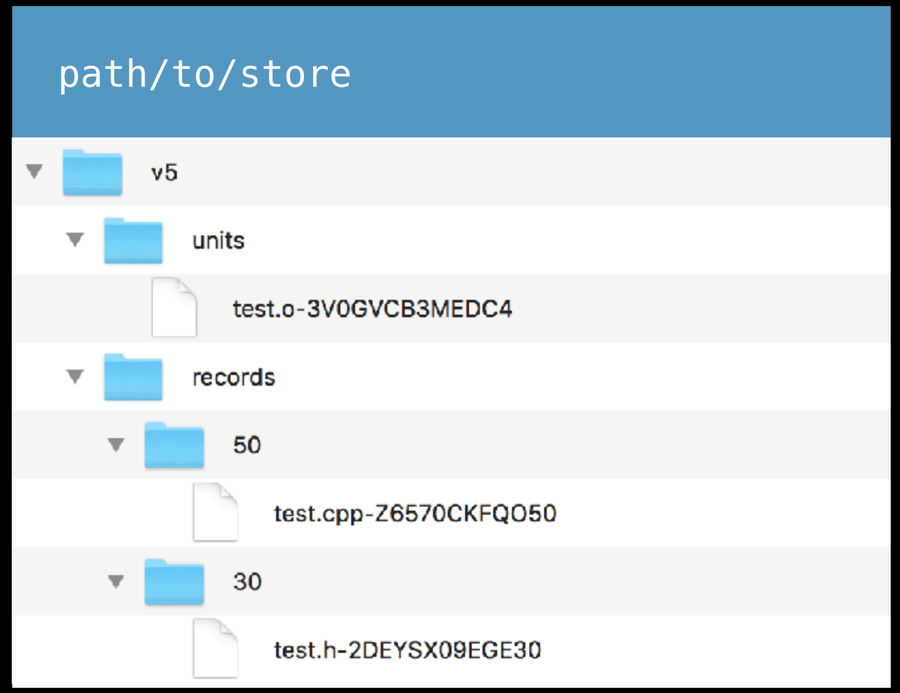

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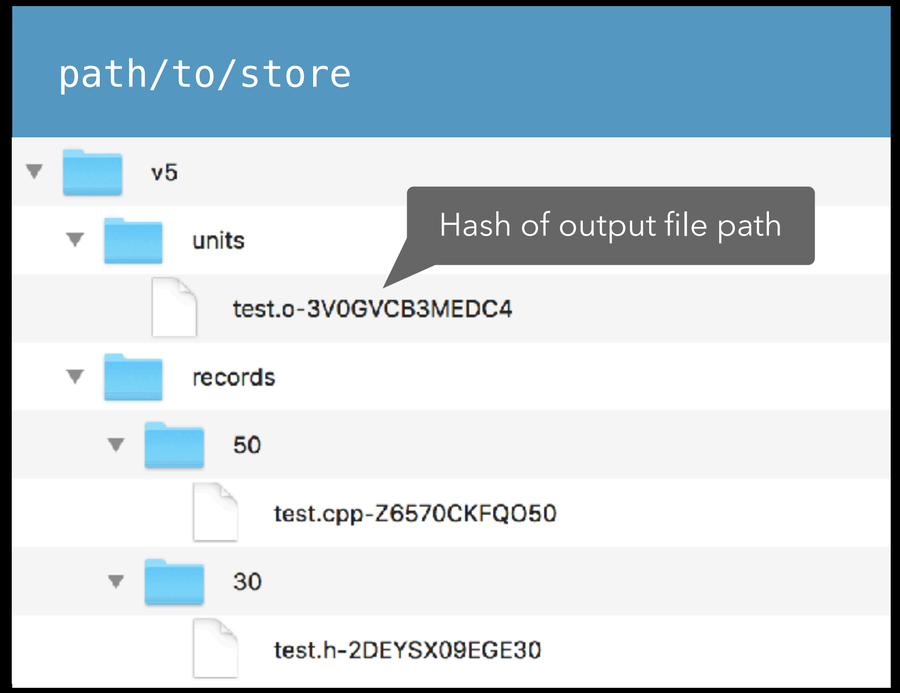

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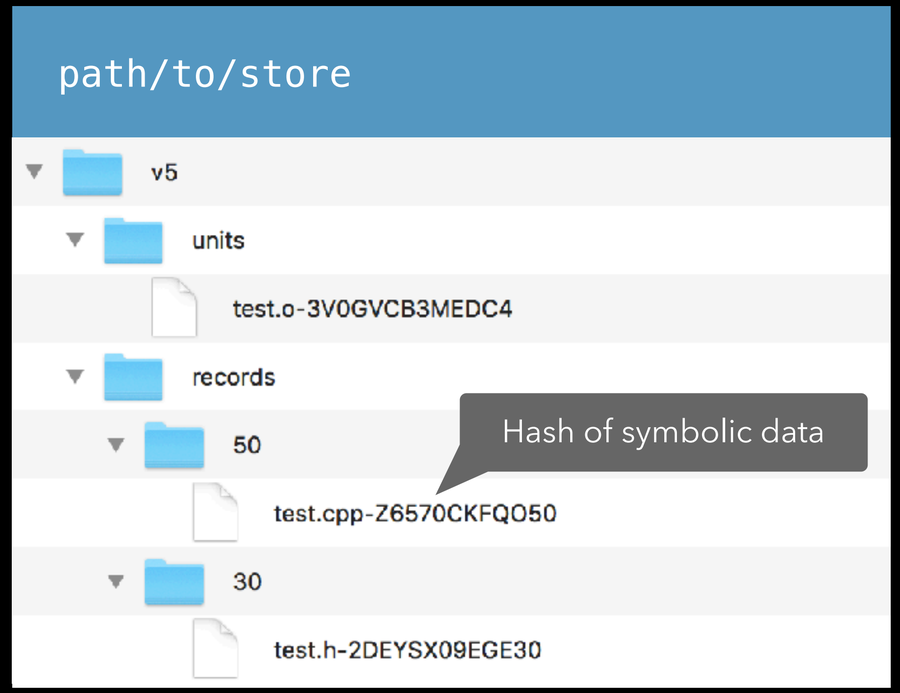

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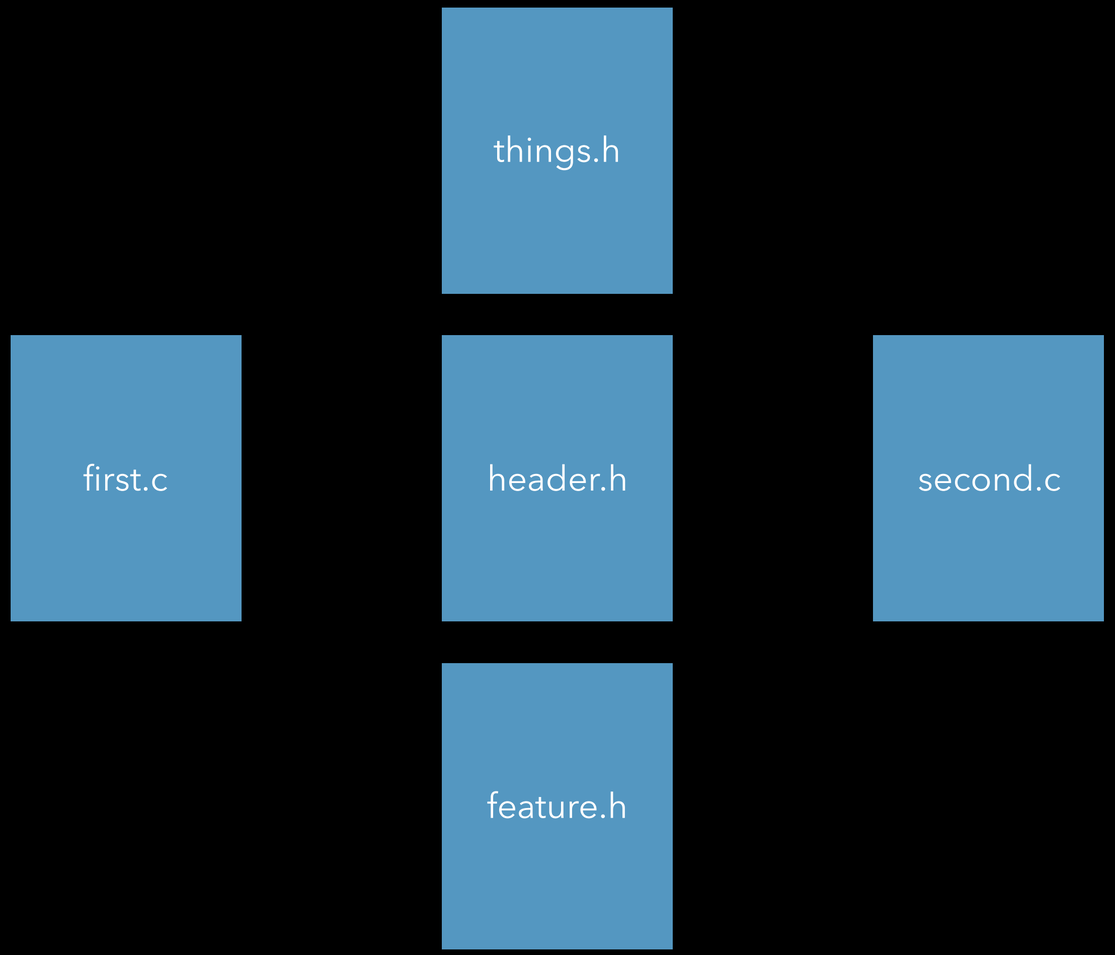
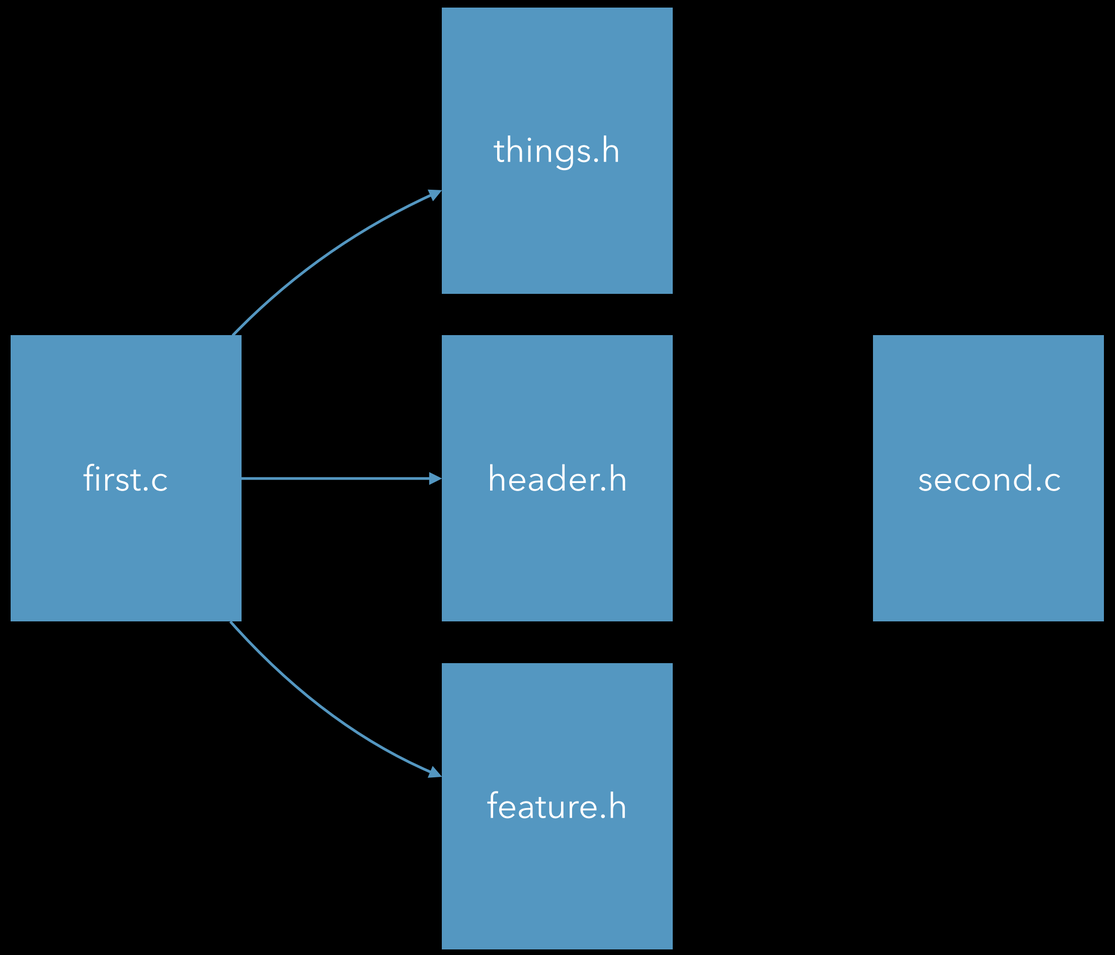

things.h
first.c
header.h
second.c
feature.h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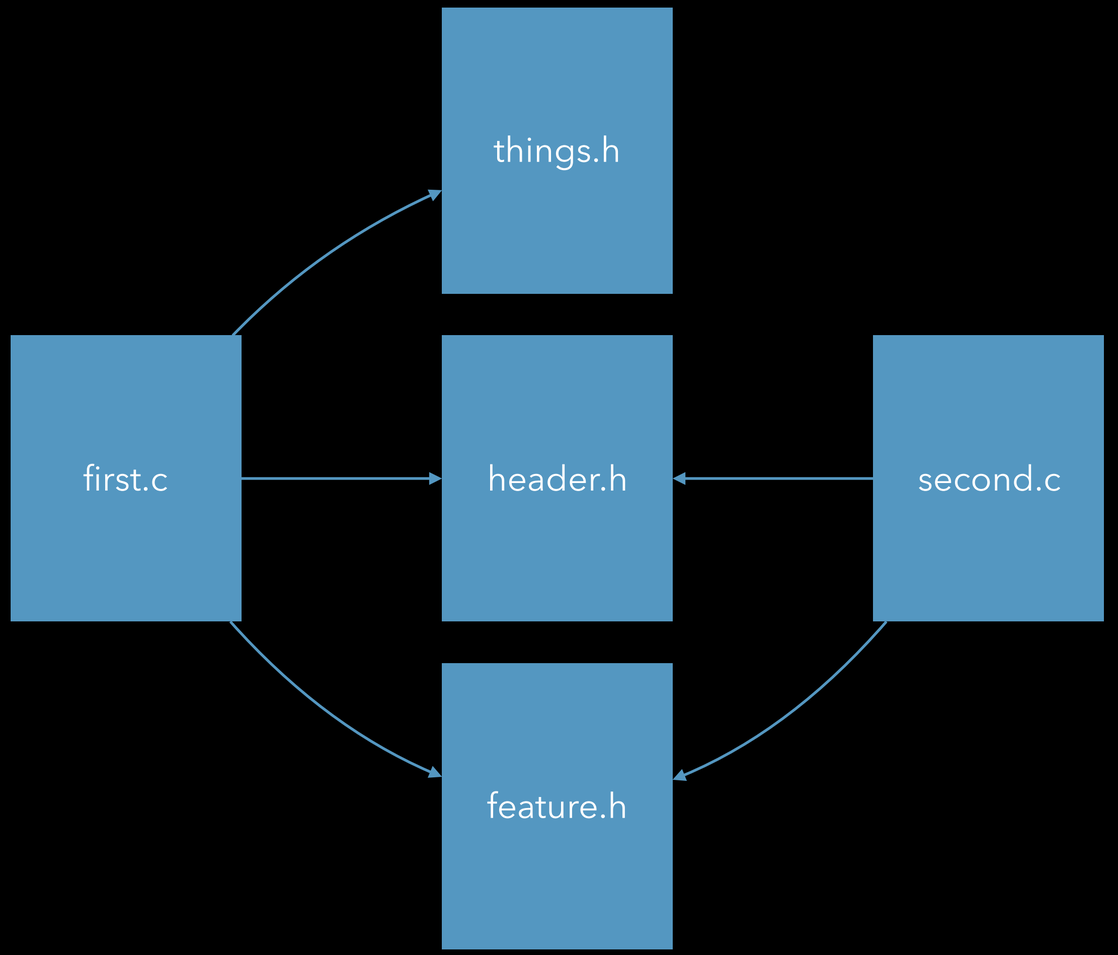
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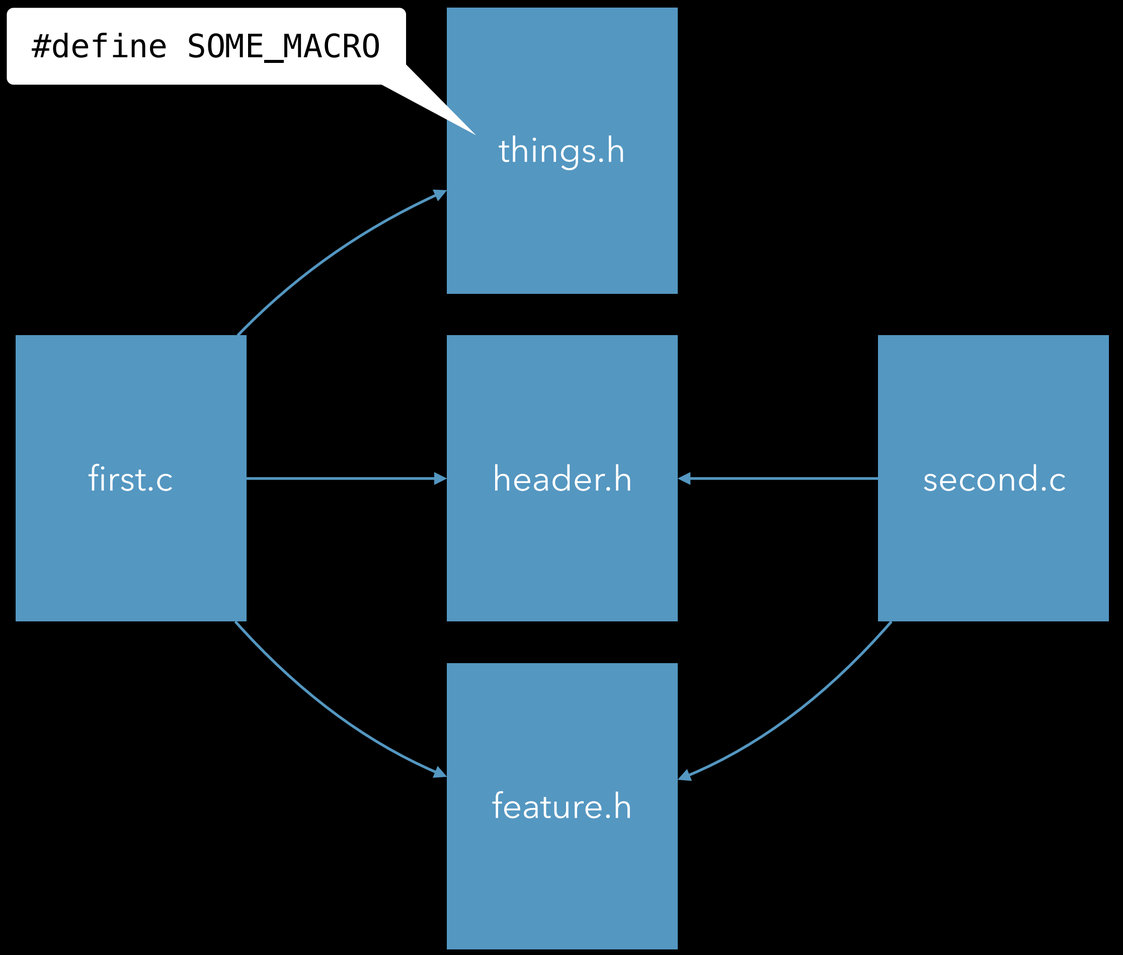
#define SOME_MACRO
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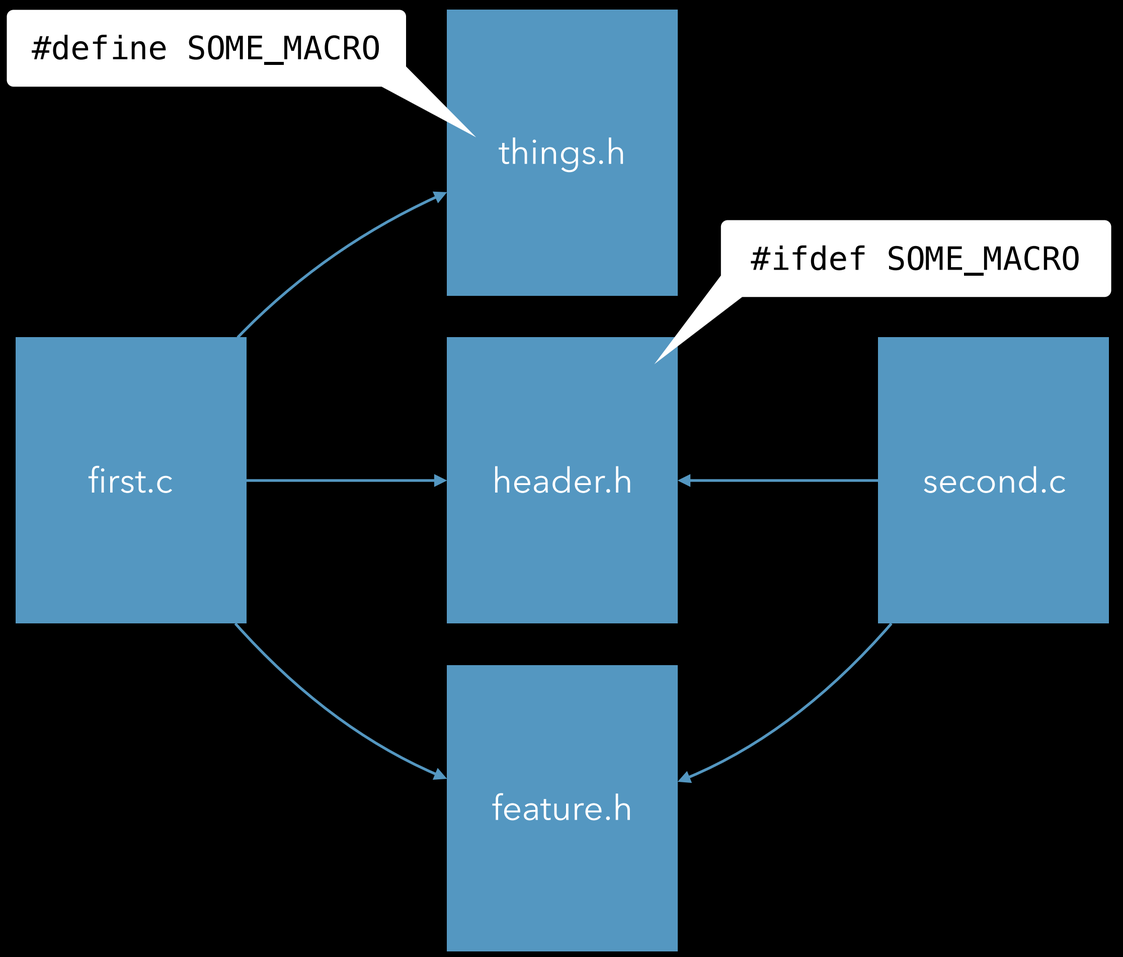
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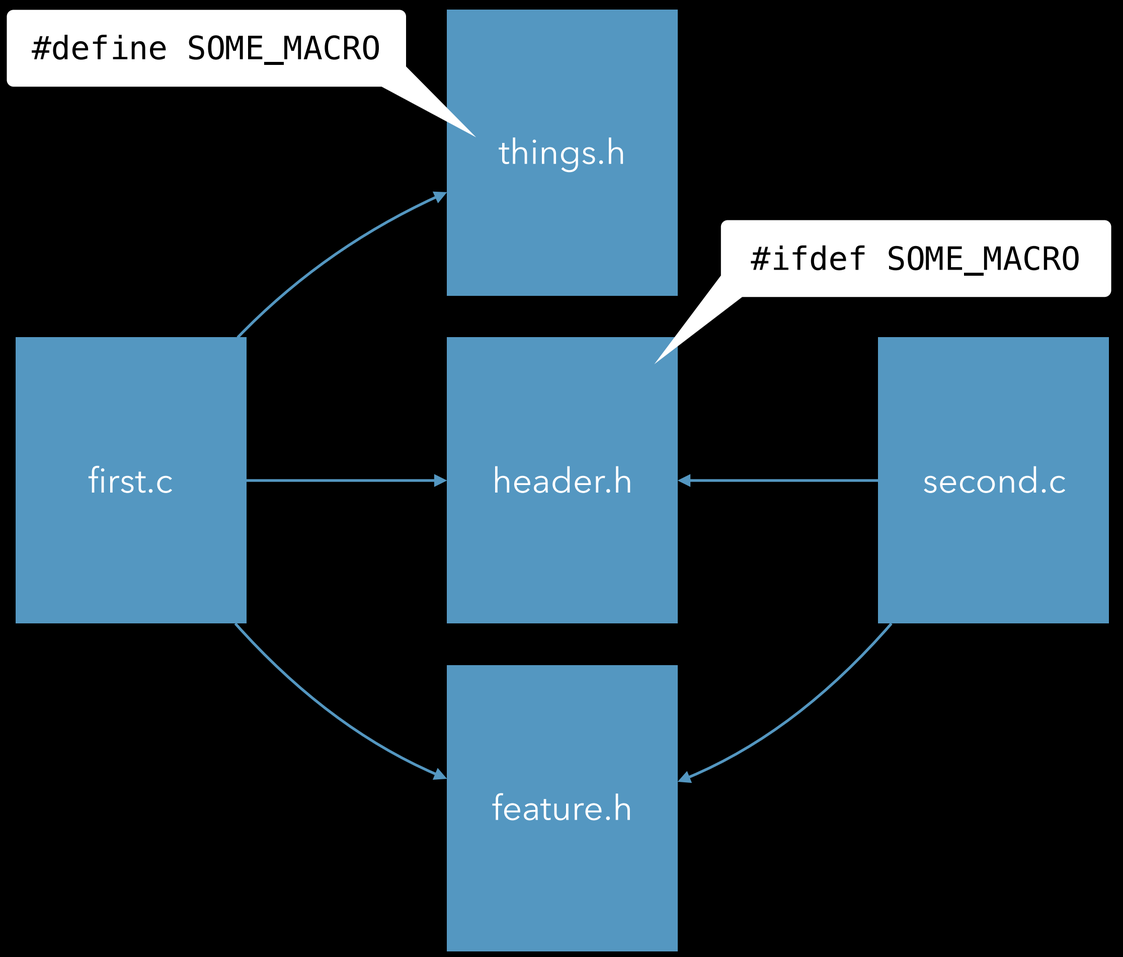
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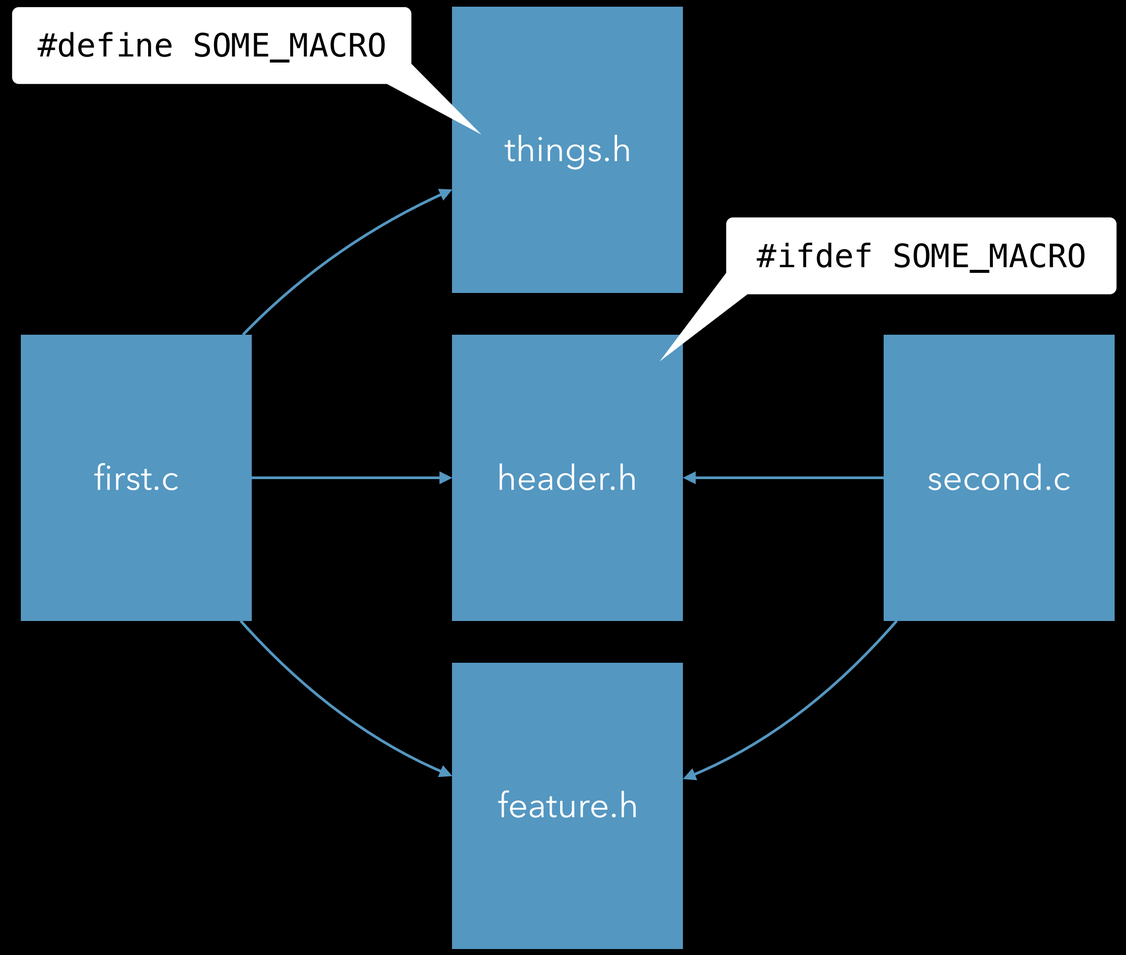

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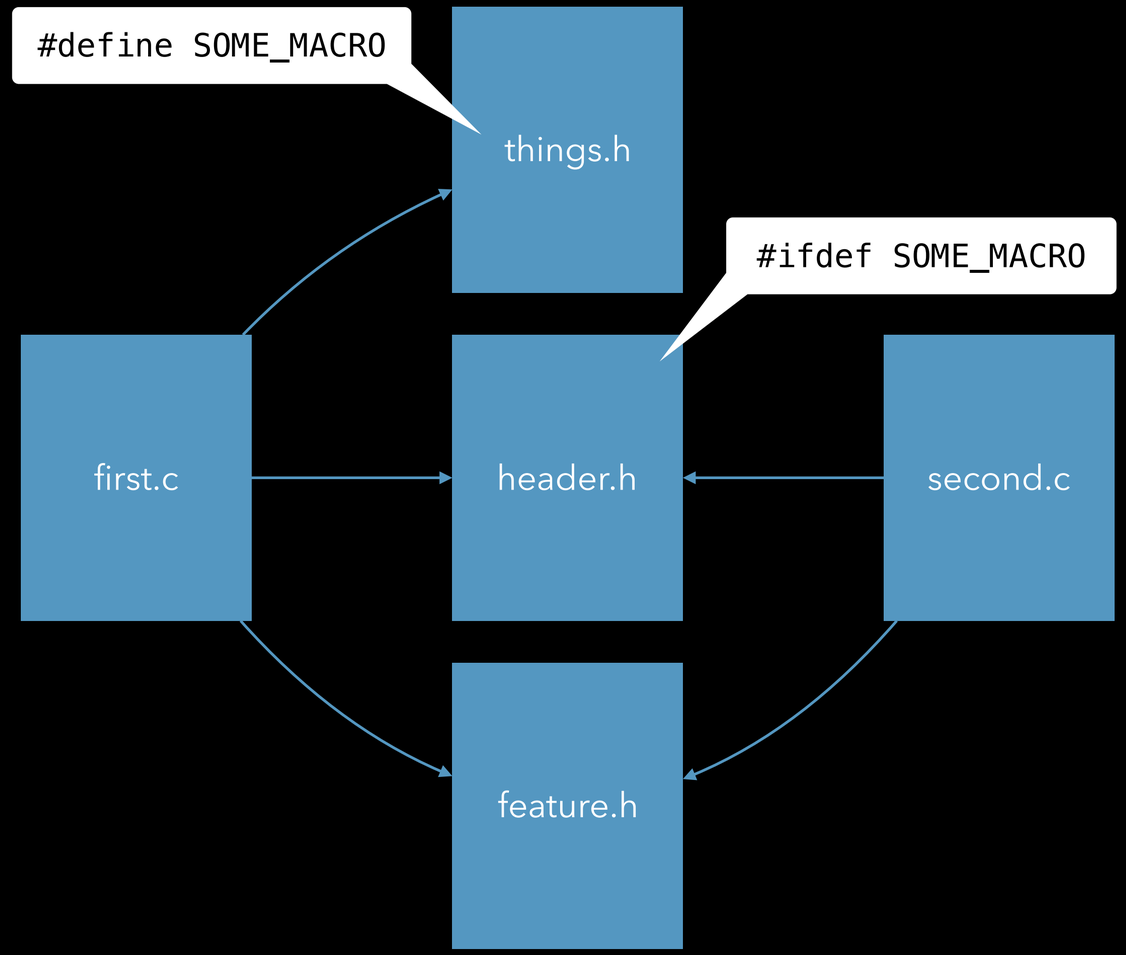

Unit
first.o-2J808UIU…

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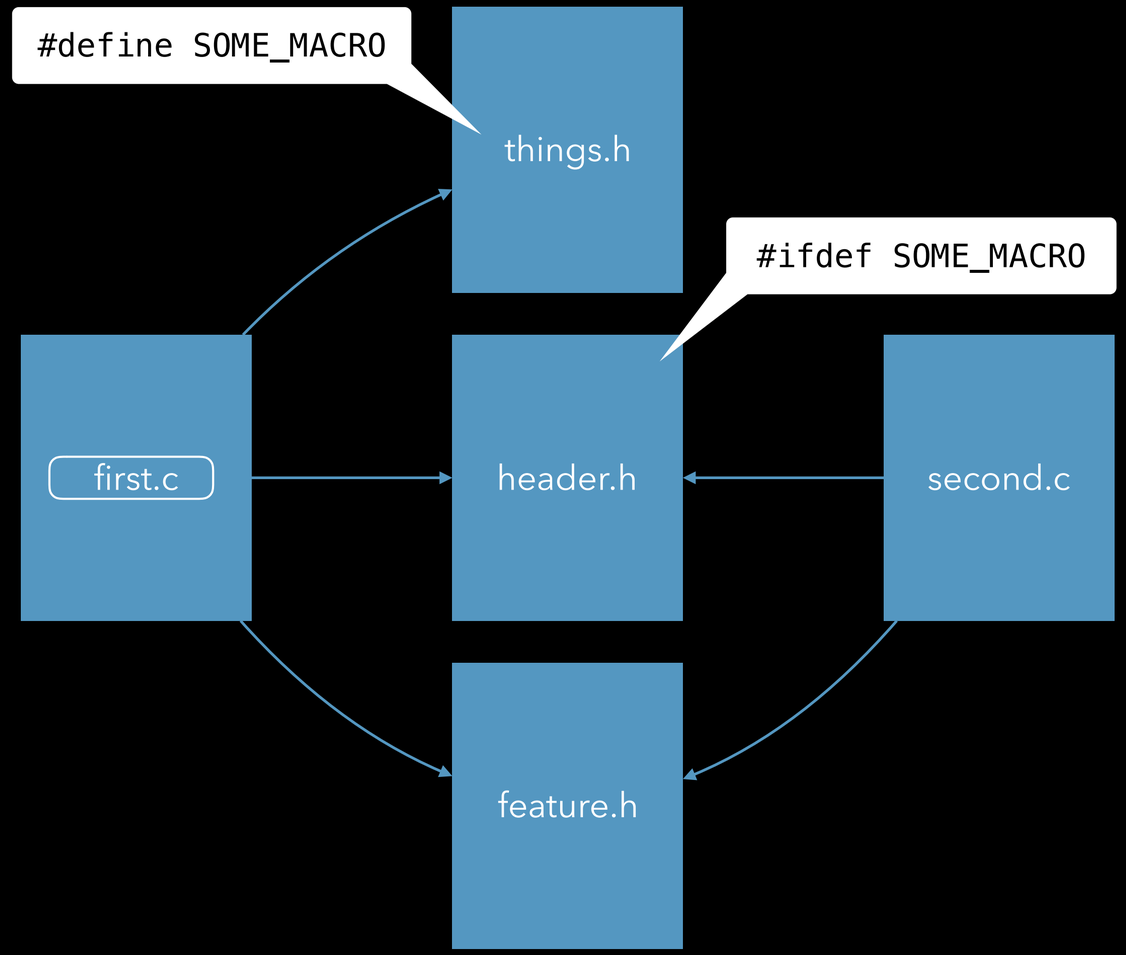

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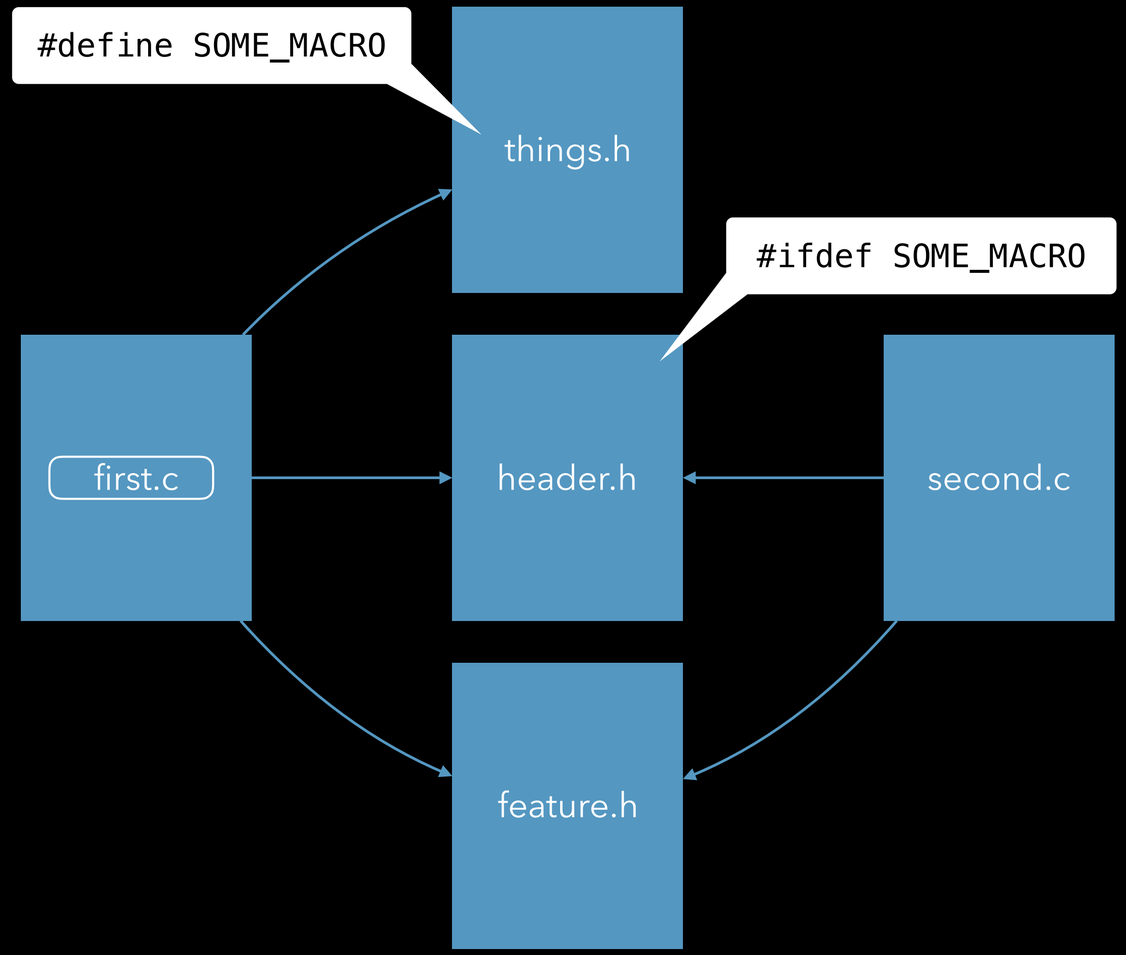

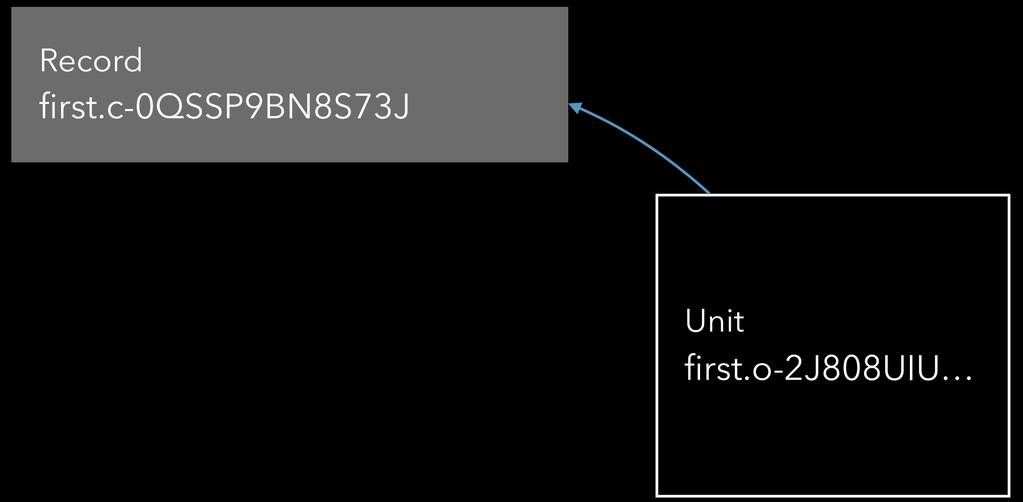

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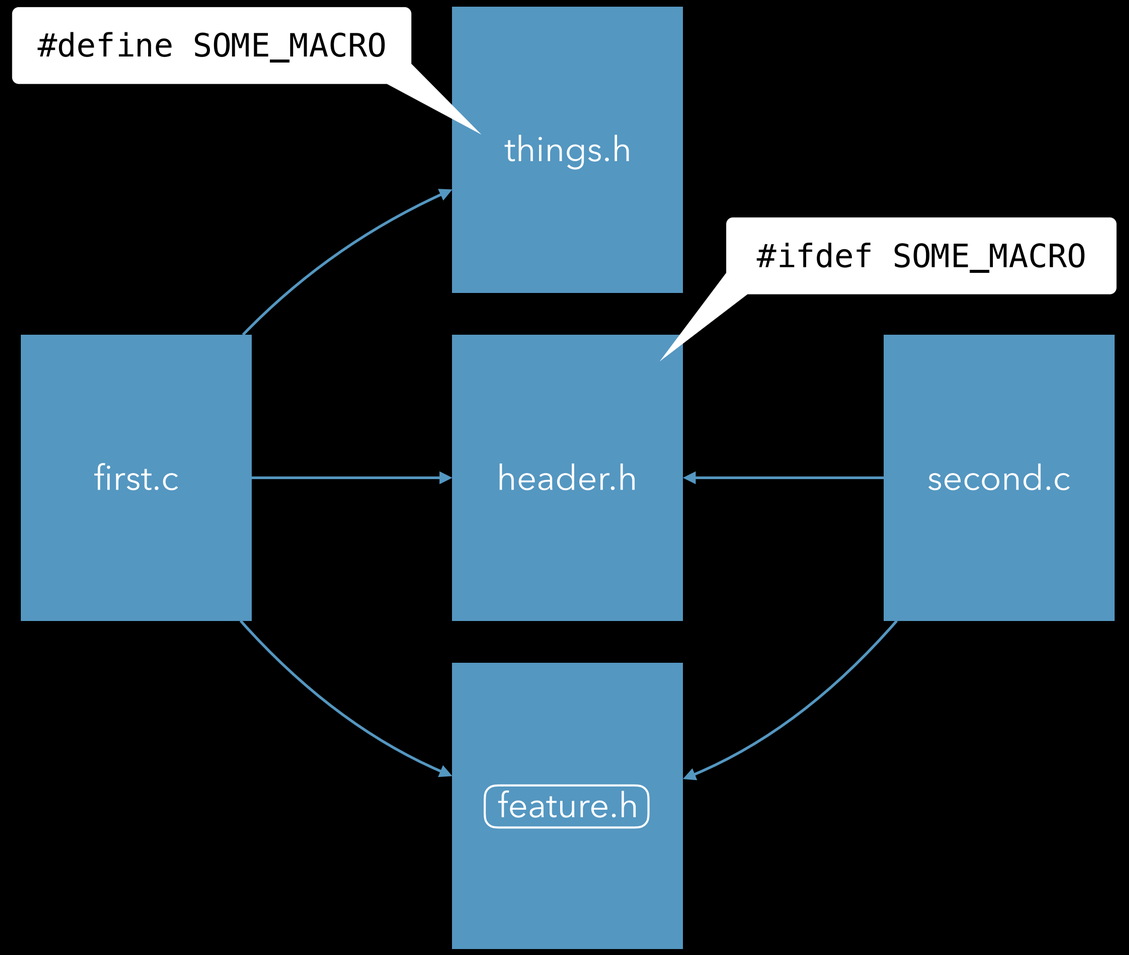

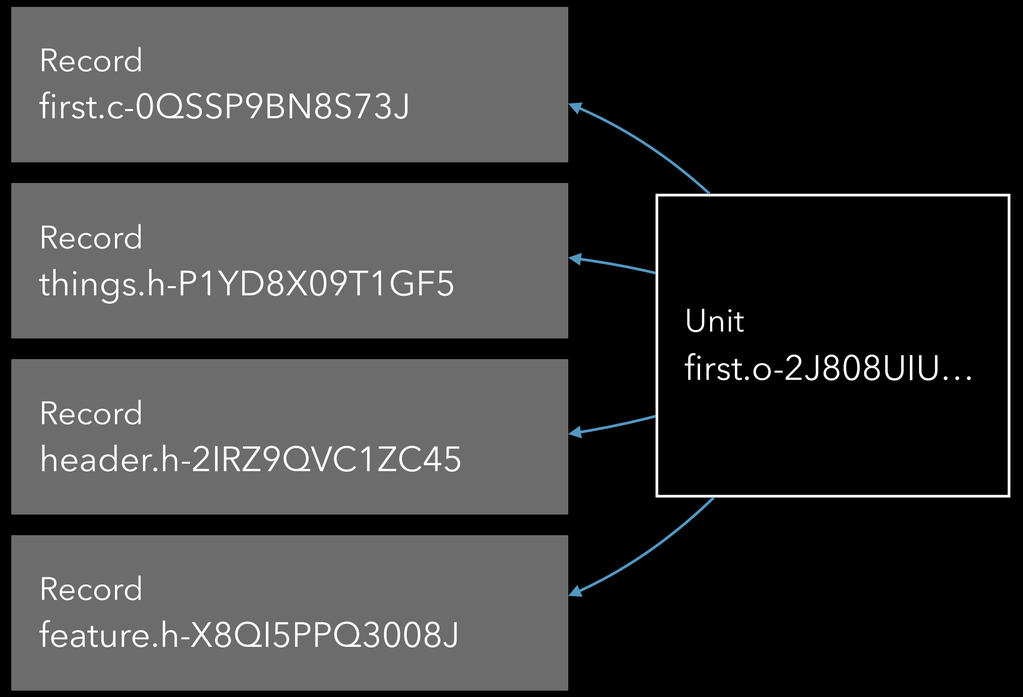

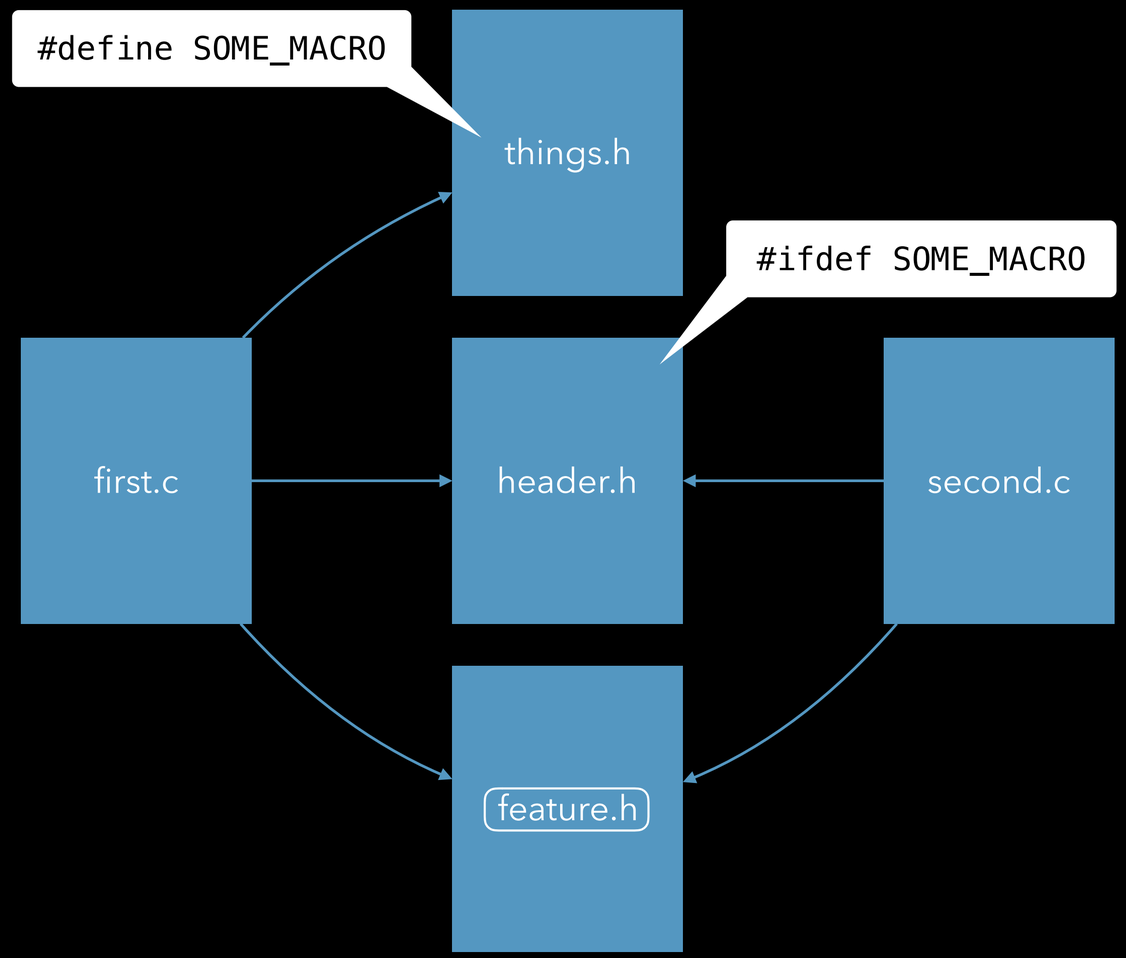
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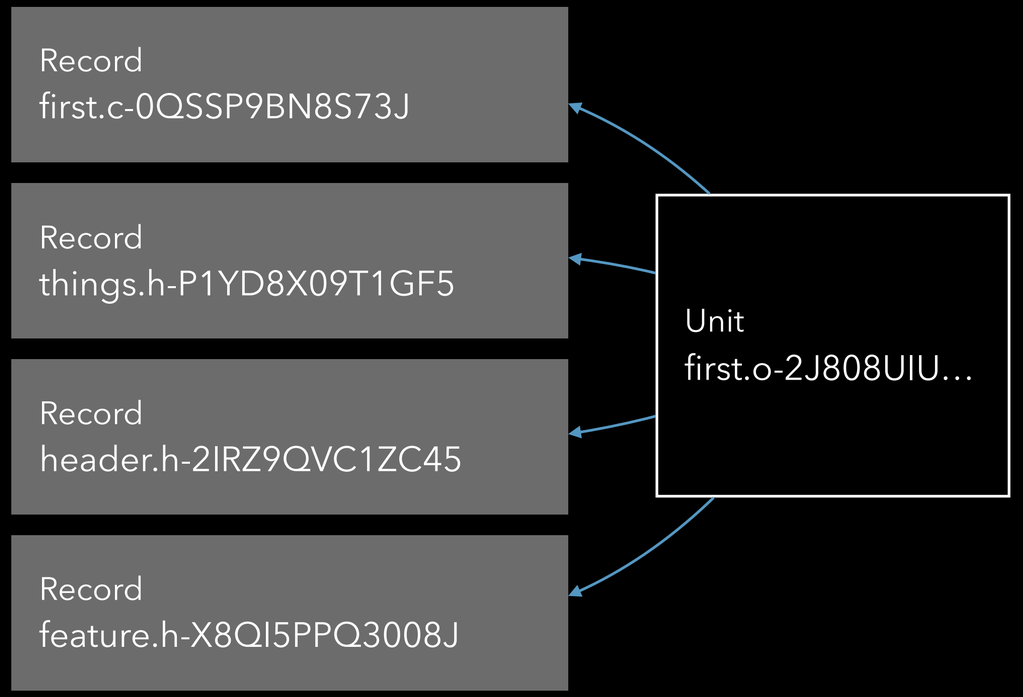
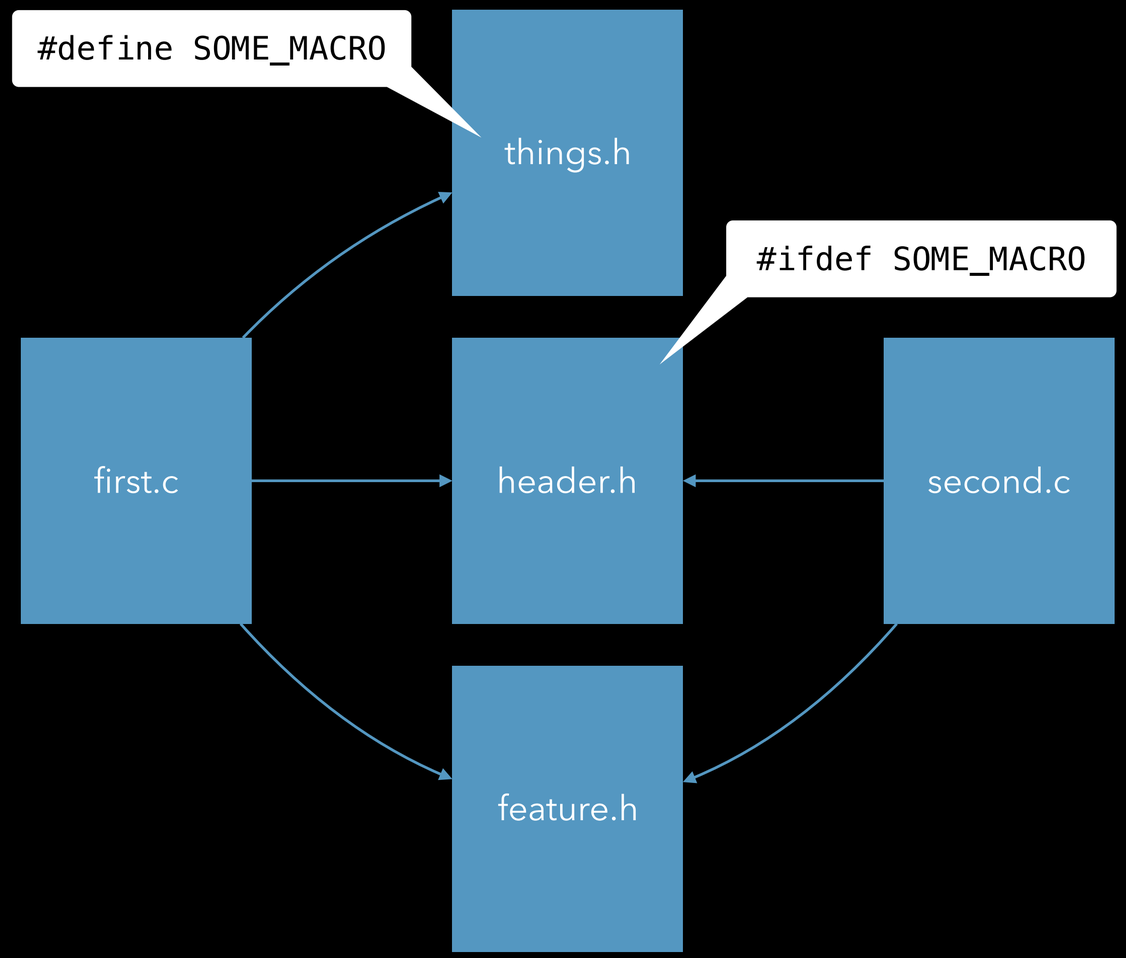

Record
first.c-0QSSP9BN8S73J
Record
things.h-P1YD8X09T1GF5
Record
header.h-2IRZ9QVC1ZC45
Record
feature.h-X8QI5PPQ3008J
Unit
first.o-2J808UIU…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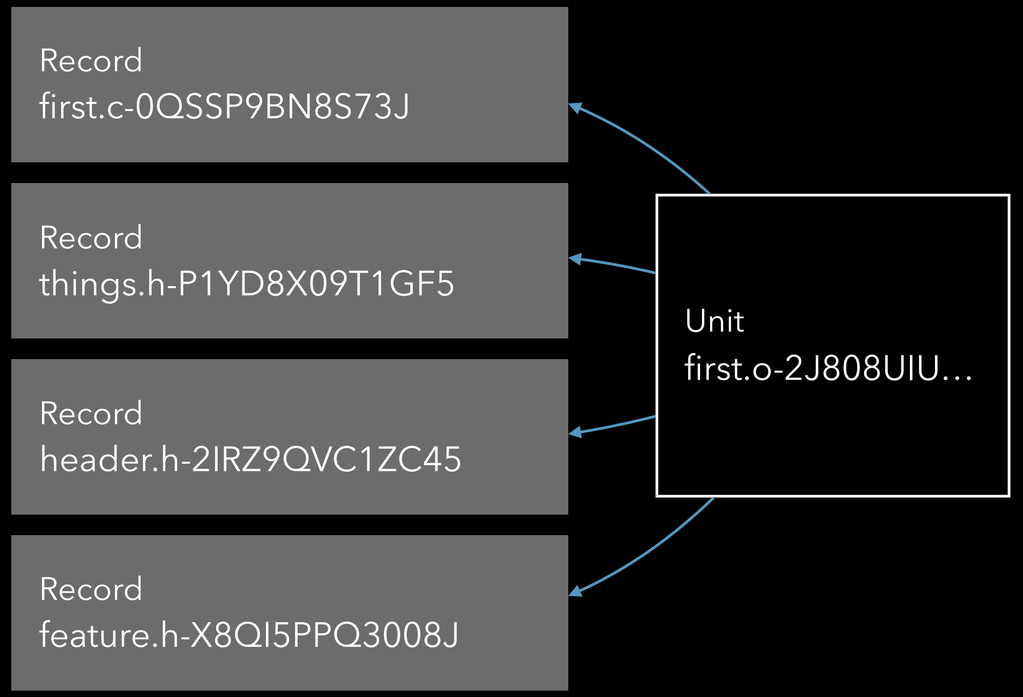
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first.c-0QSSP9BN8S73J
Record
things.h-P1YD8X09T1GF5
Record
header.h-2IRZ9QVC1ZC45
Record
feature.h-X8QI5PPQ3008J
Unit
first.o-2J808UIU…

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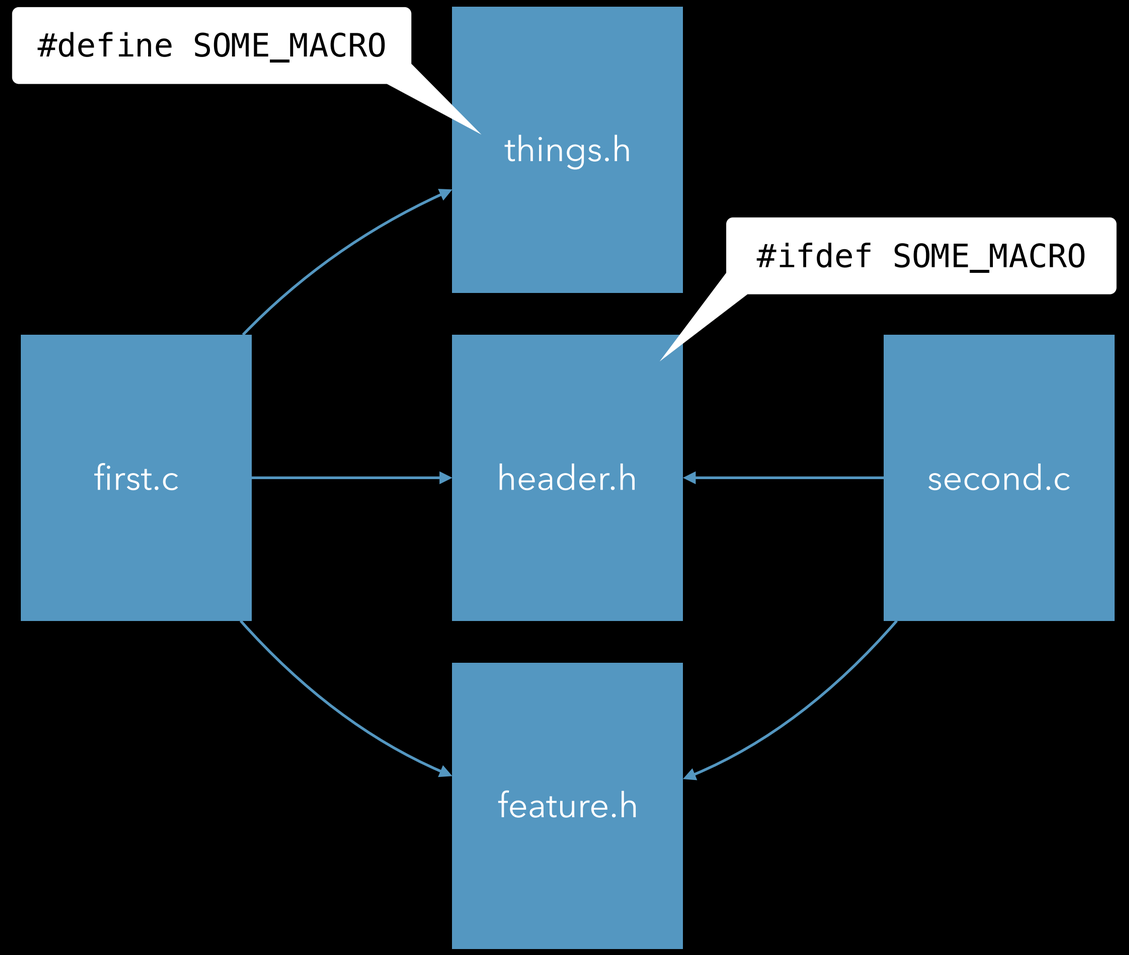

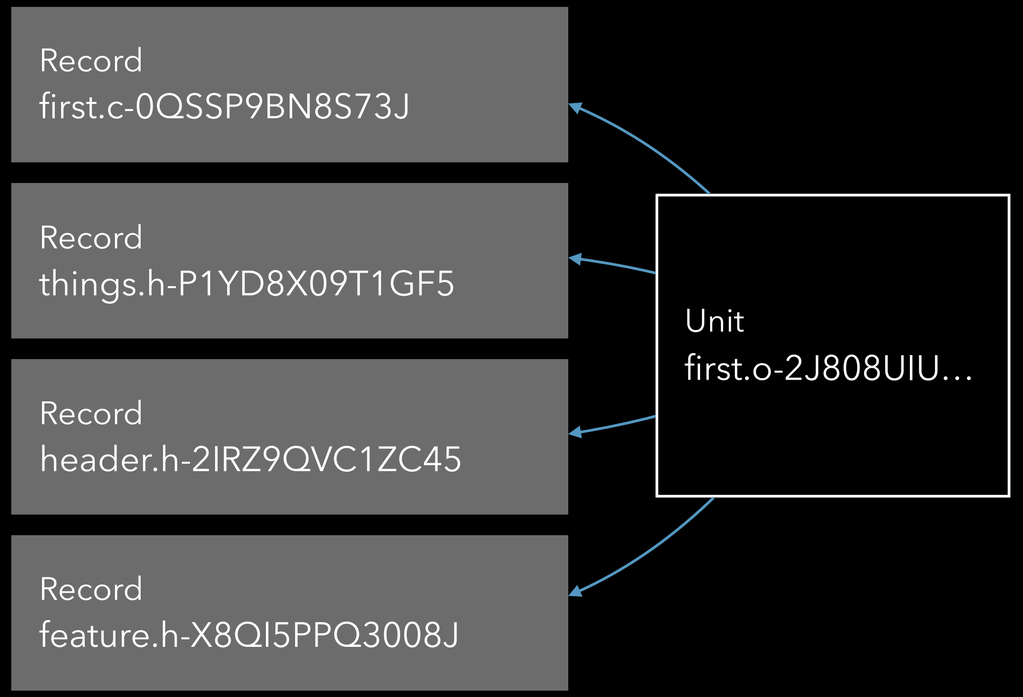

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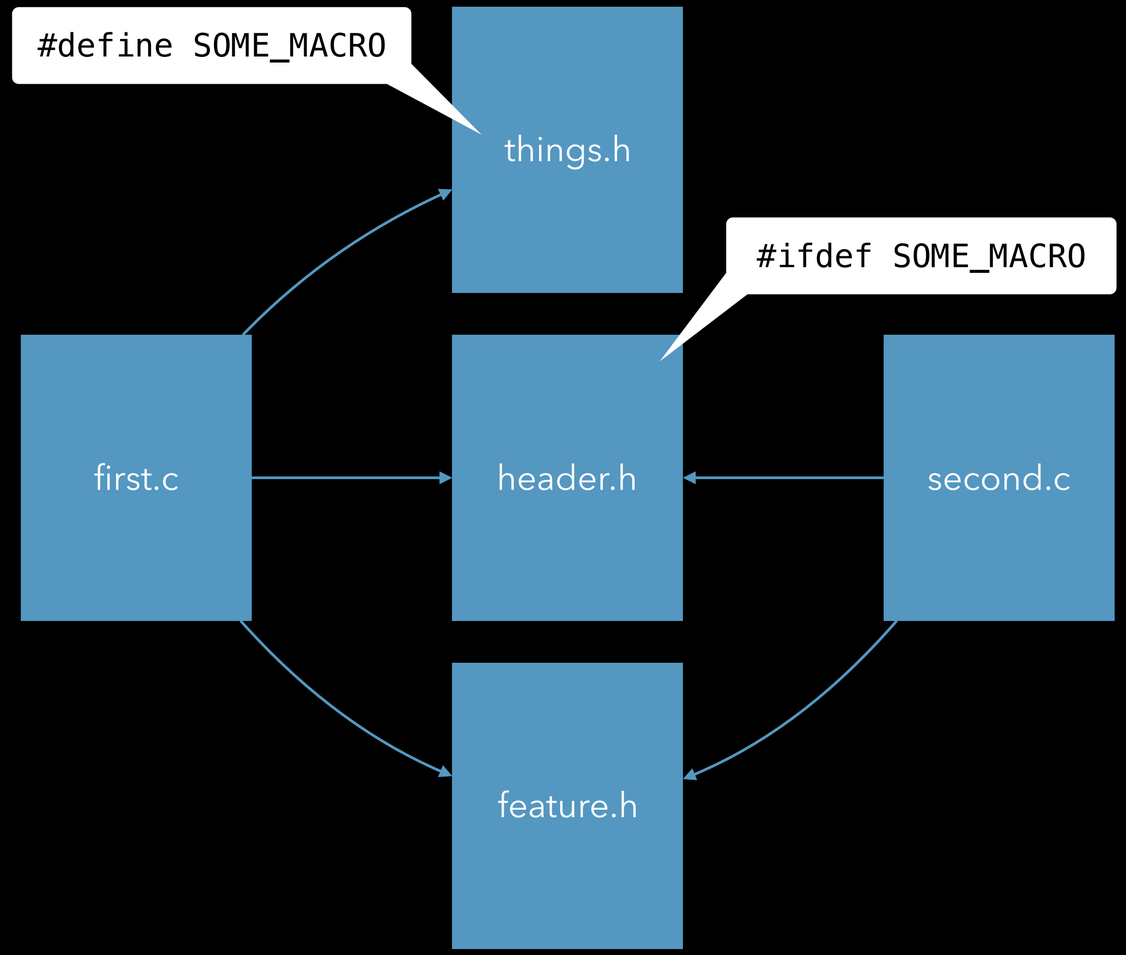
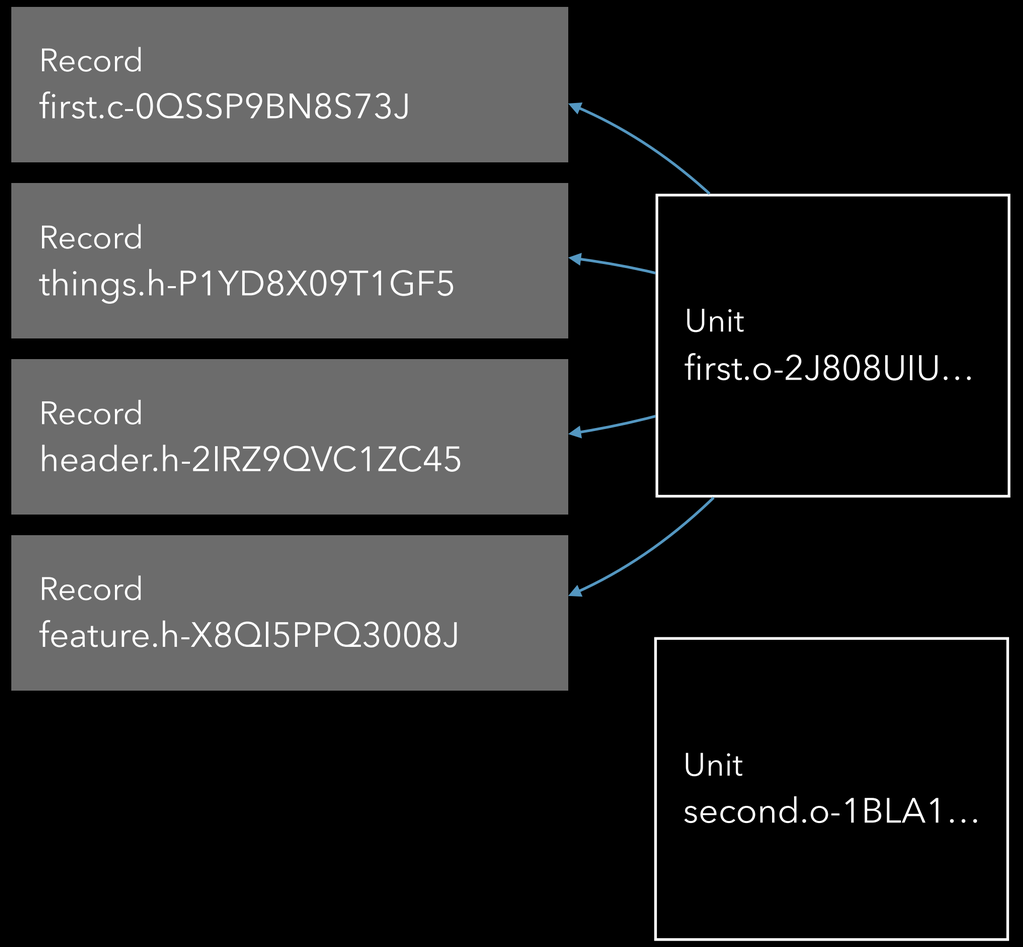
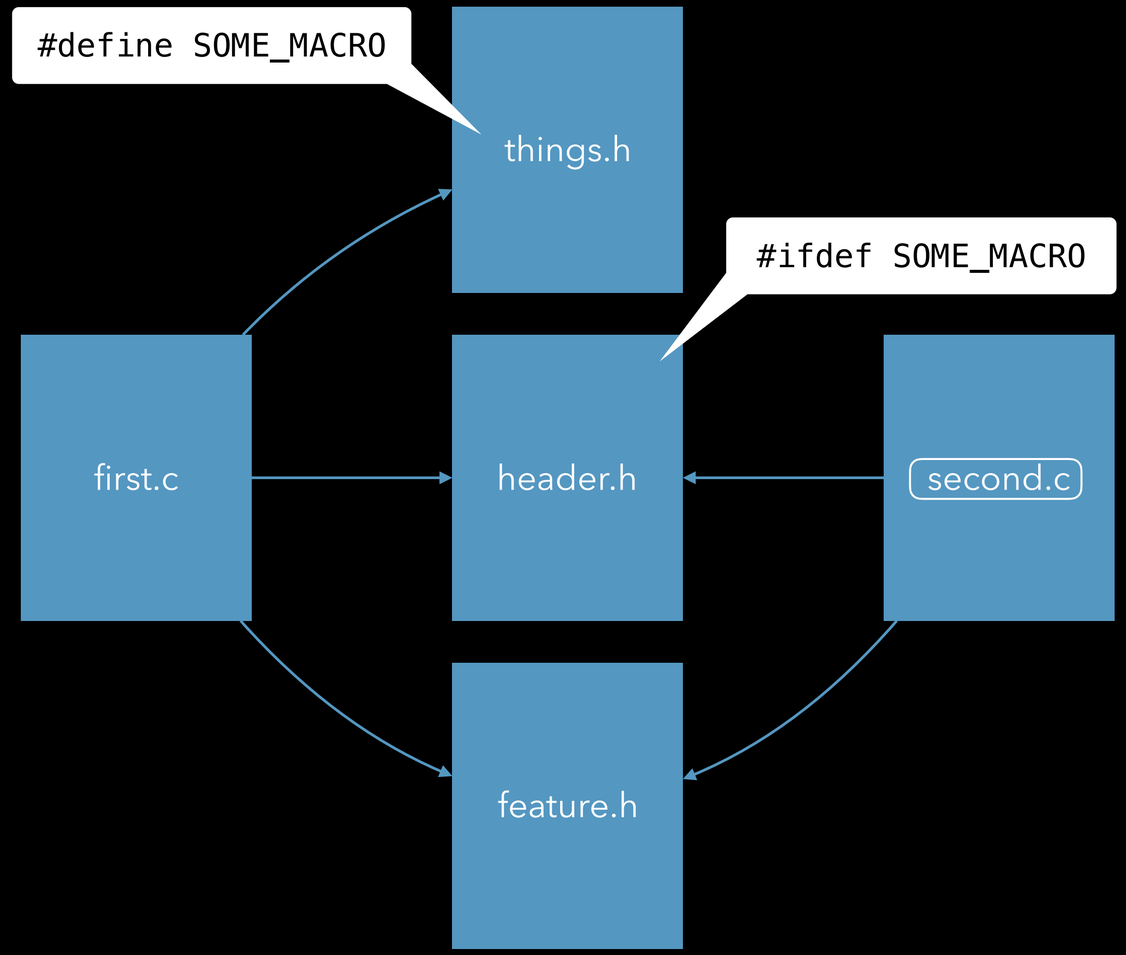




```
$ clang -o second.o -c second.c -index-store-path path/to/store
```



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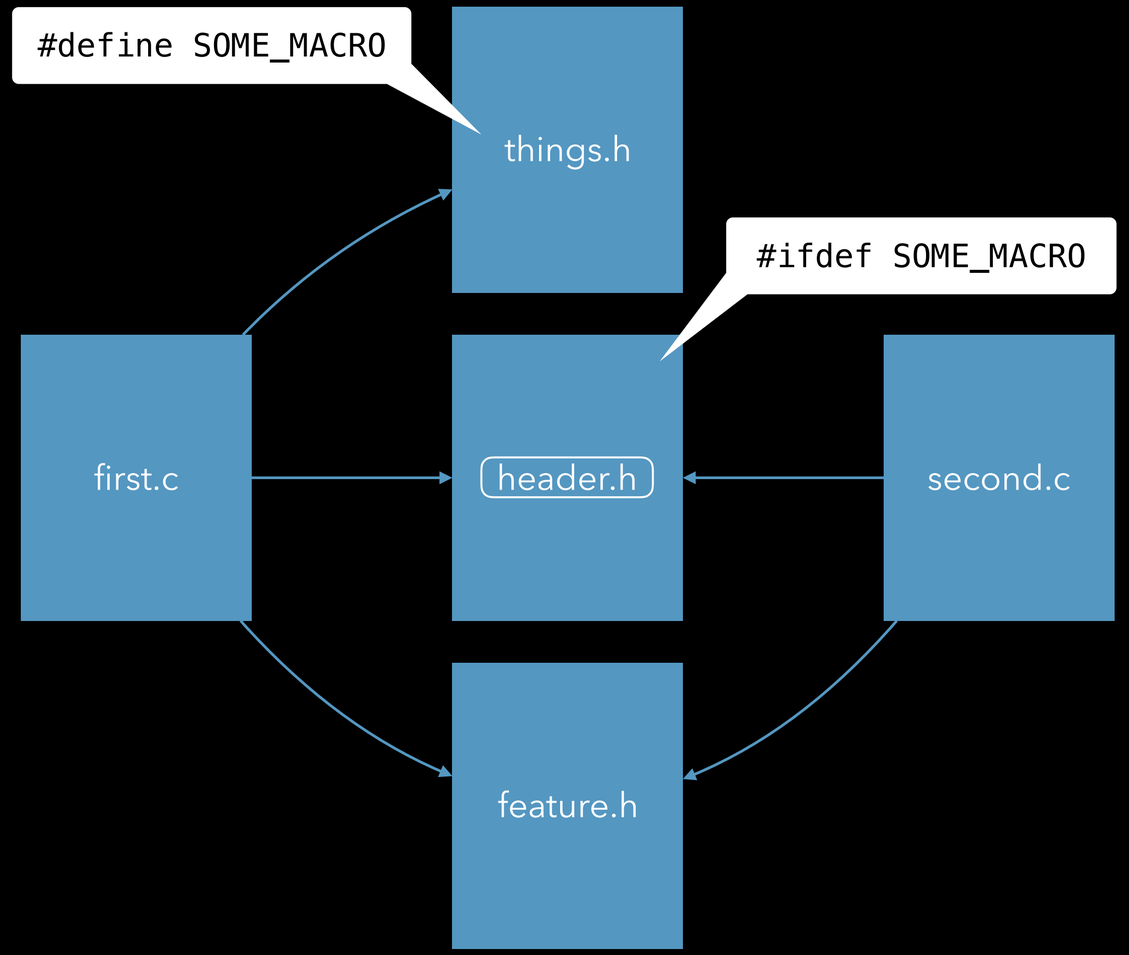

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$ clang -o second.o -c second.c -index-store-path path/to/store
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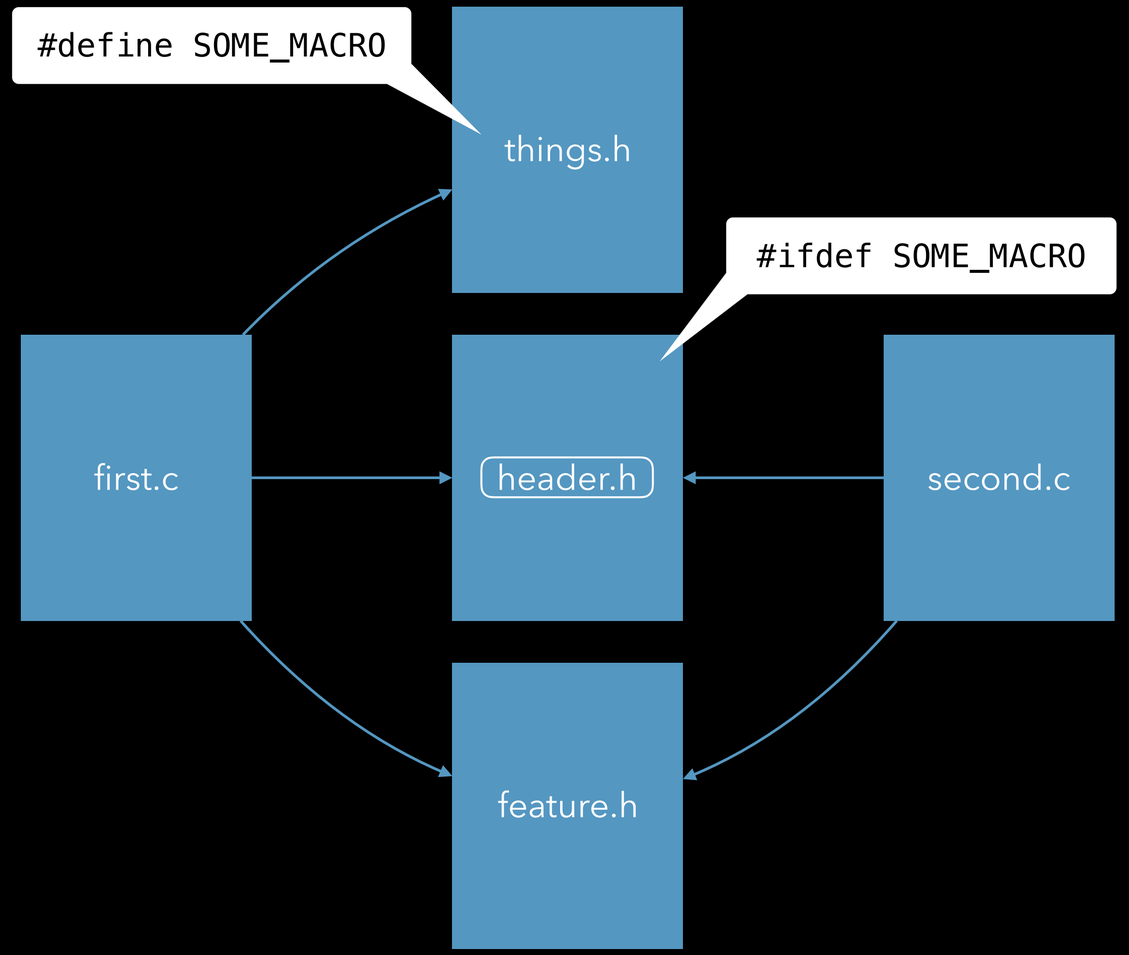

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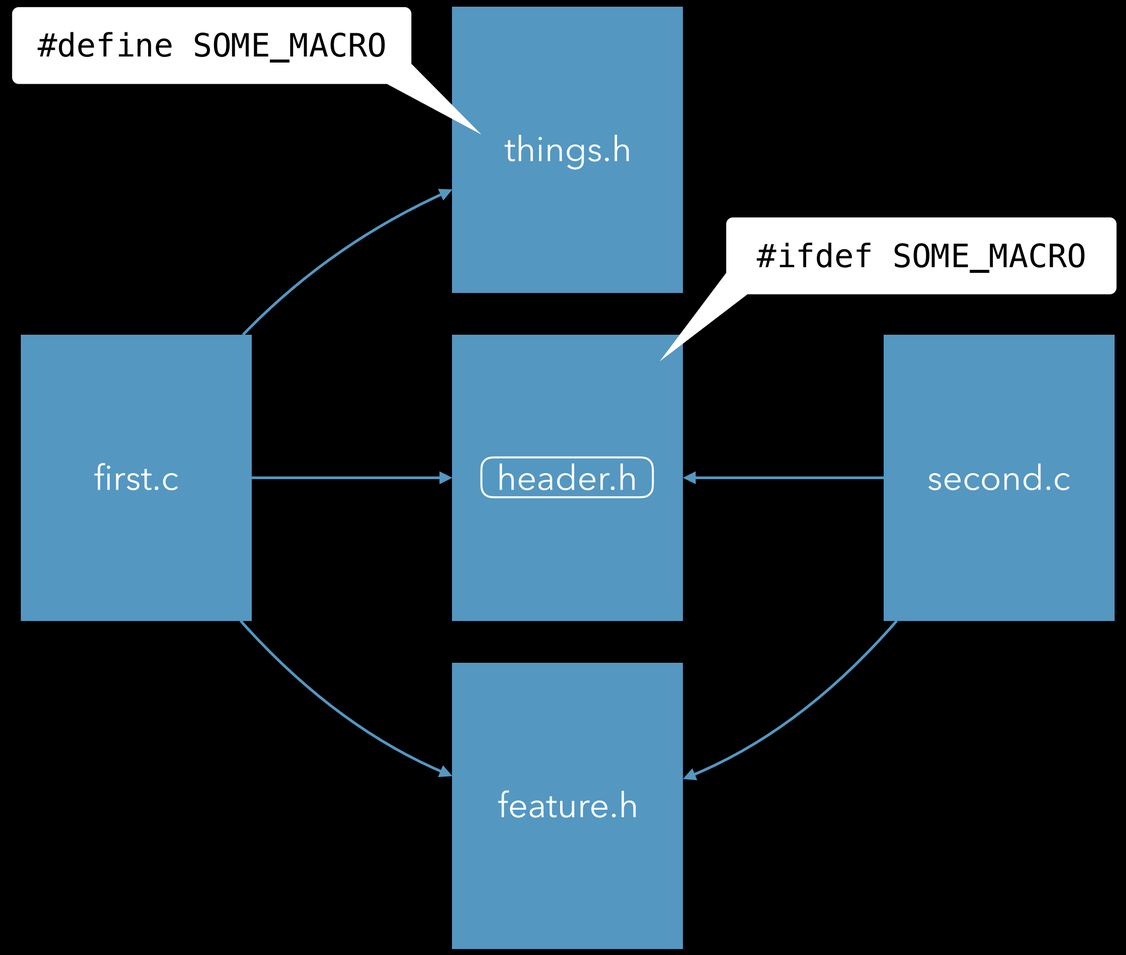

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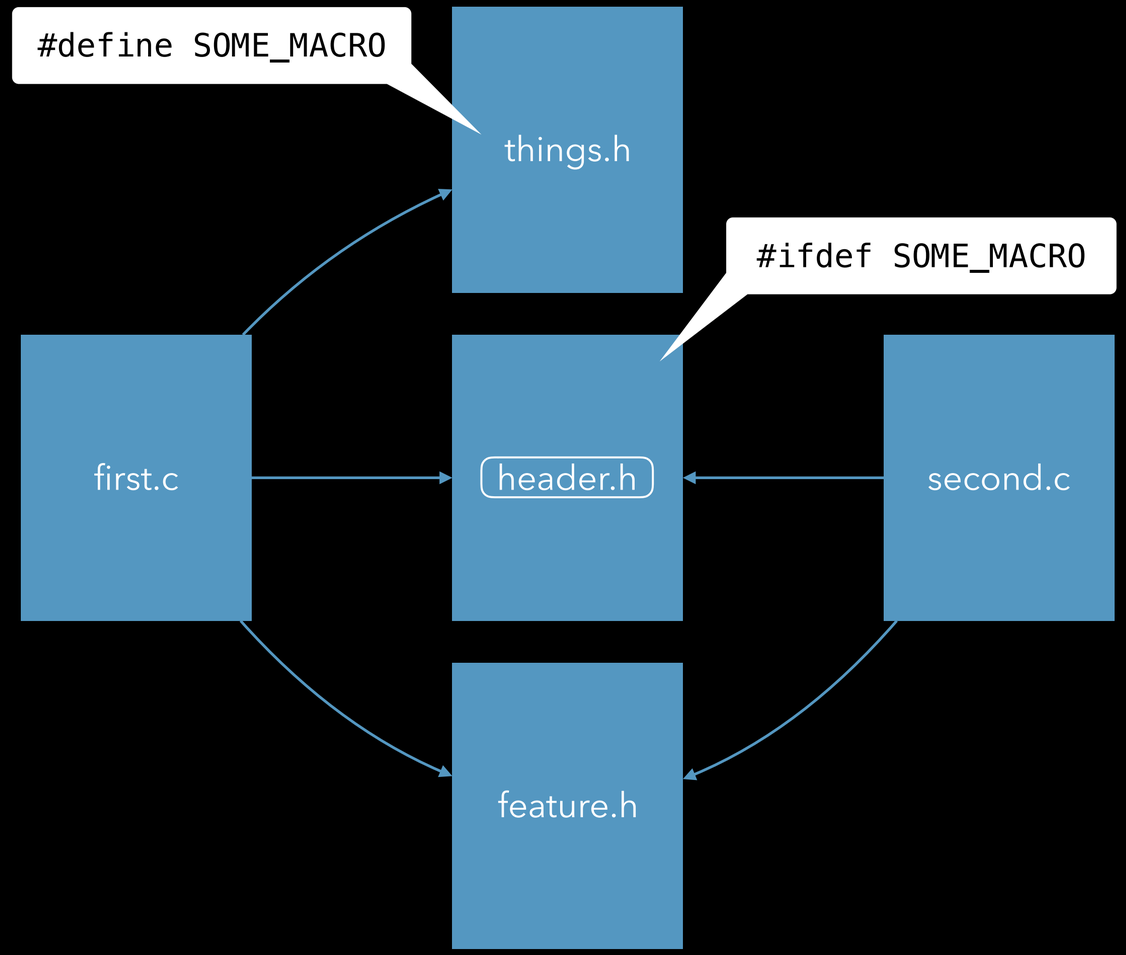

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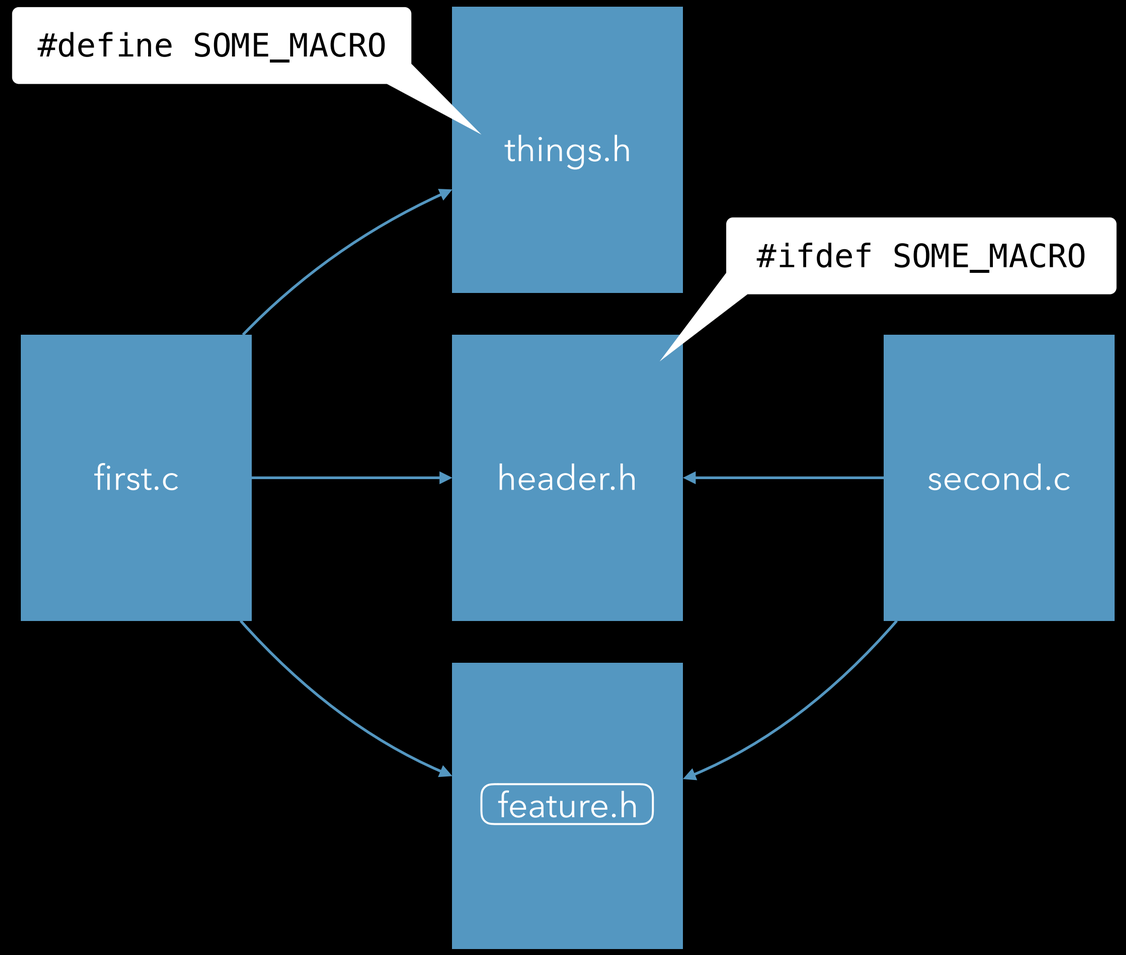

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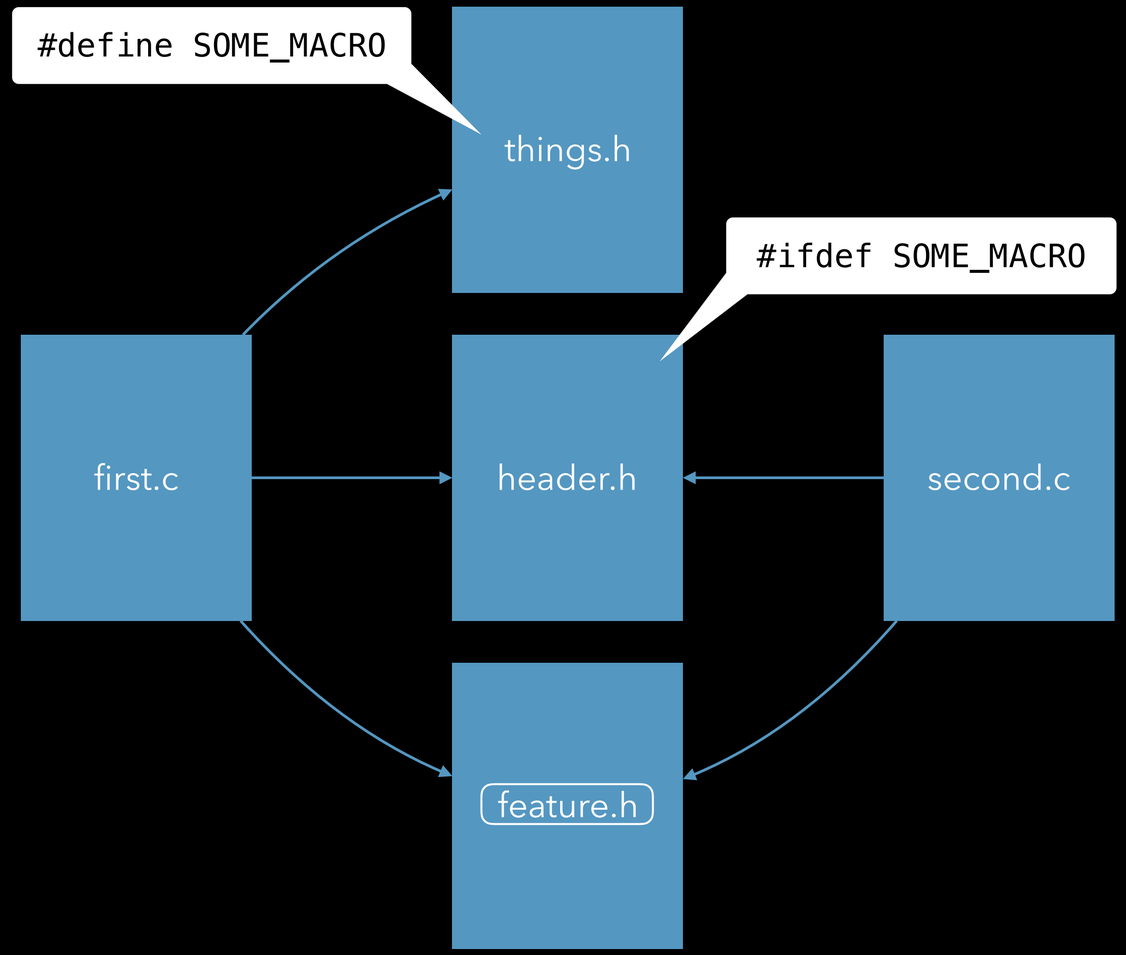

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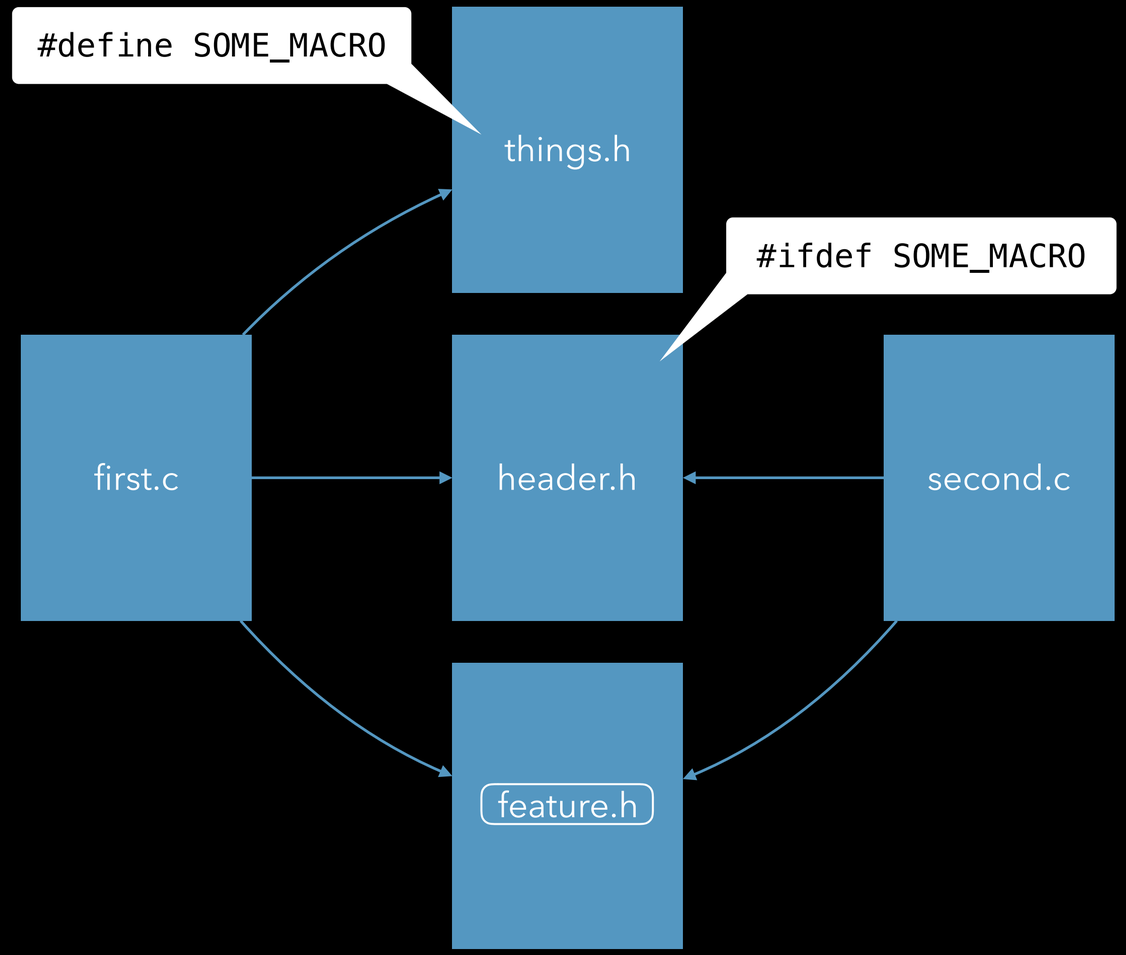
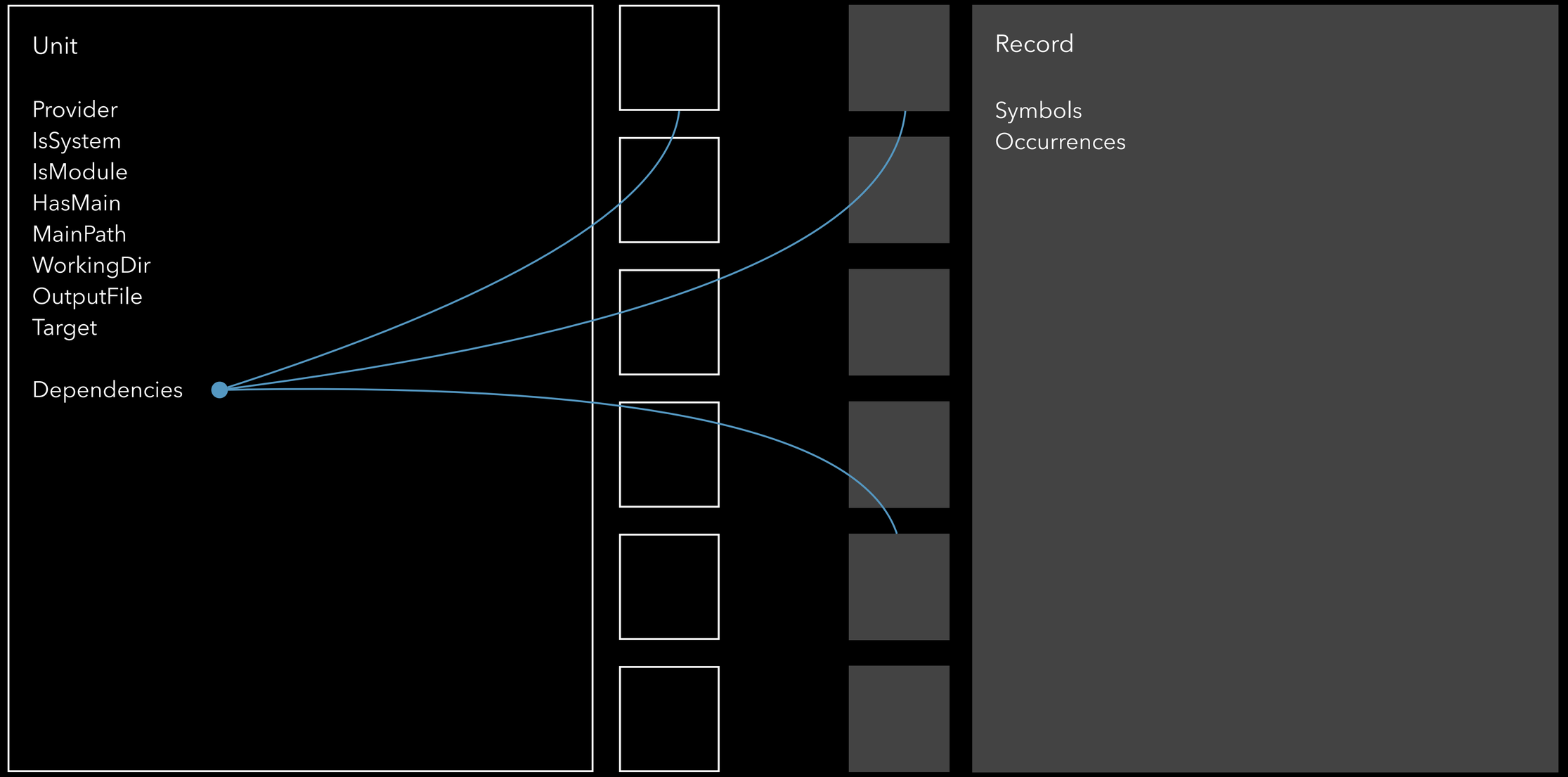


Index data model



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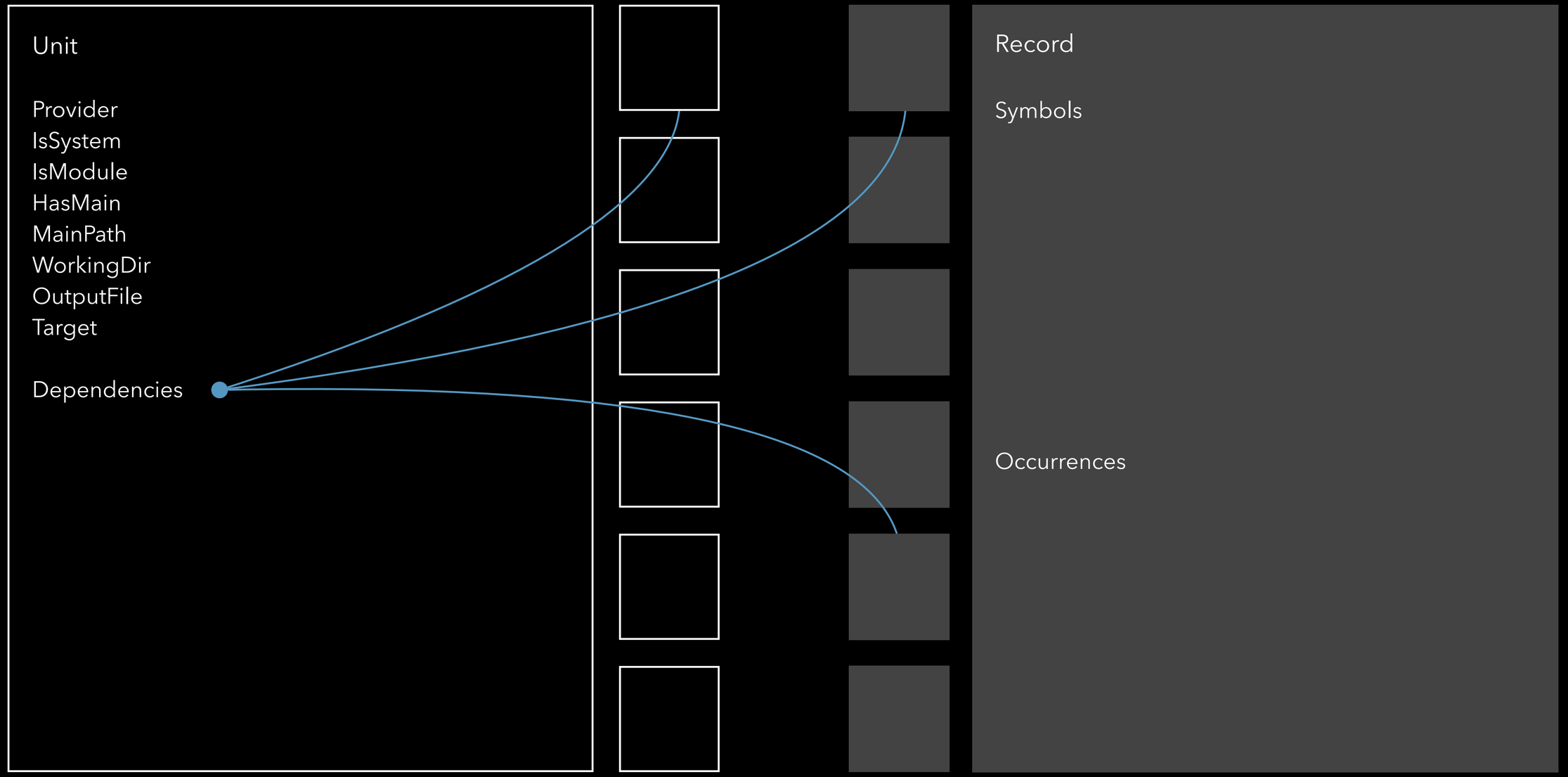

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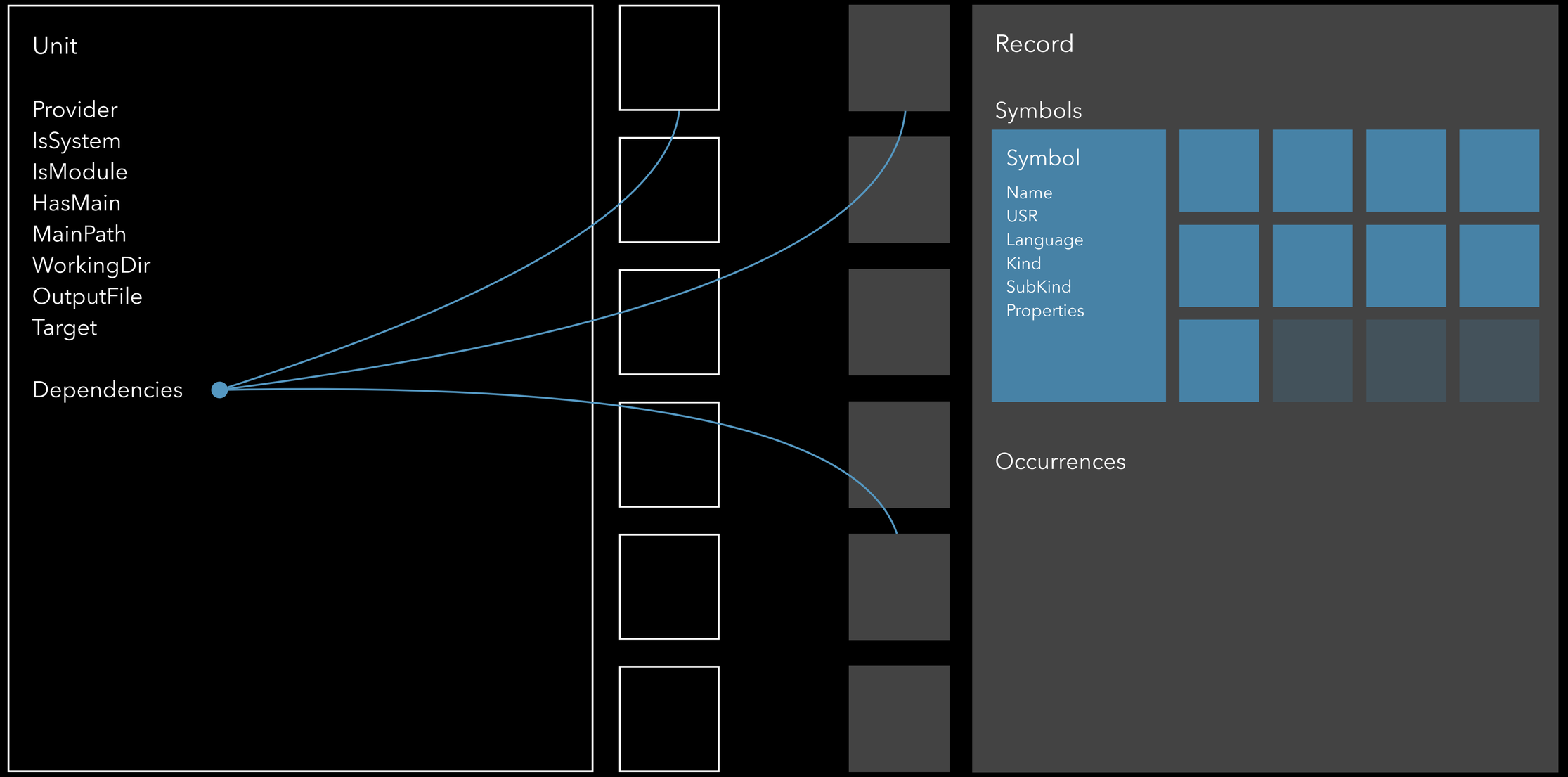

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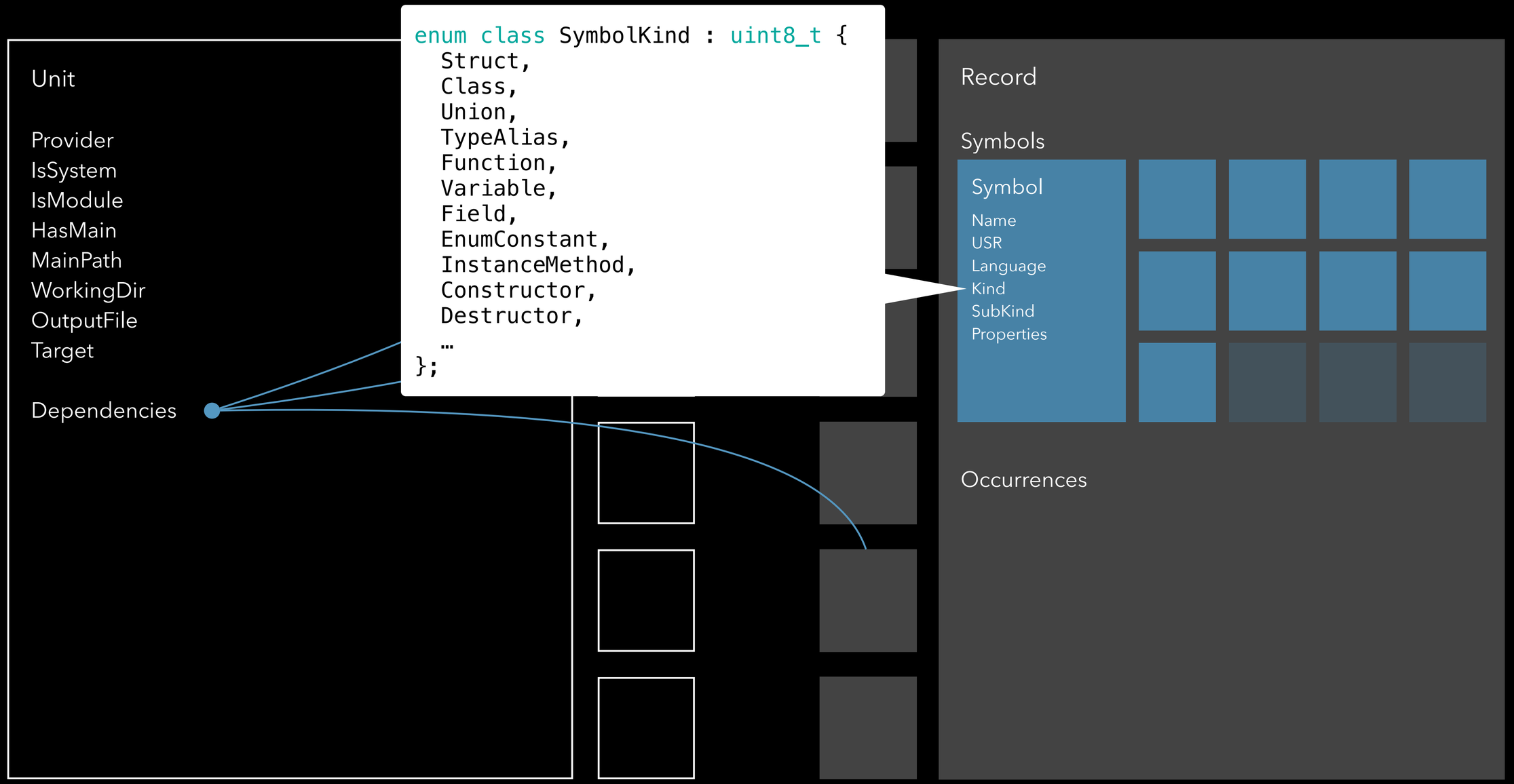

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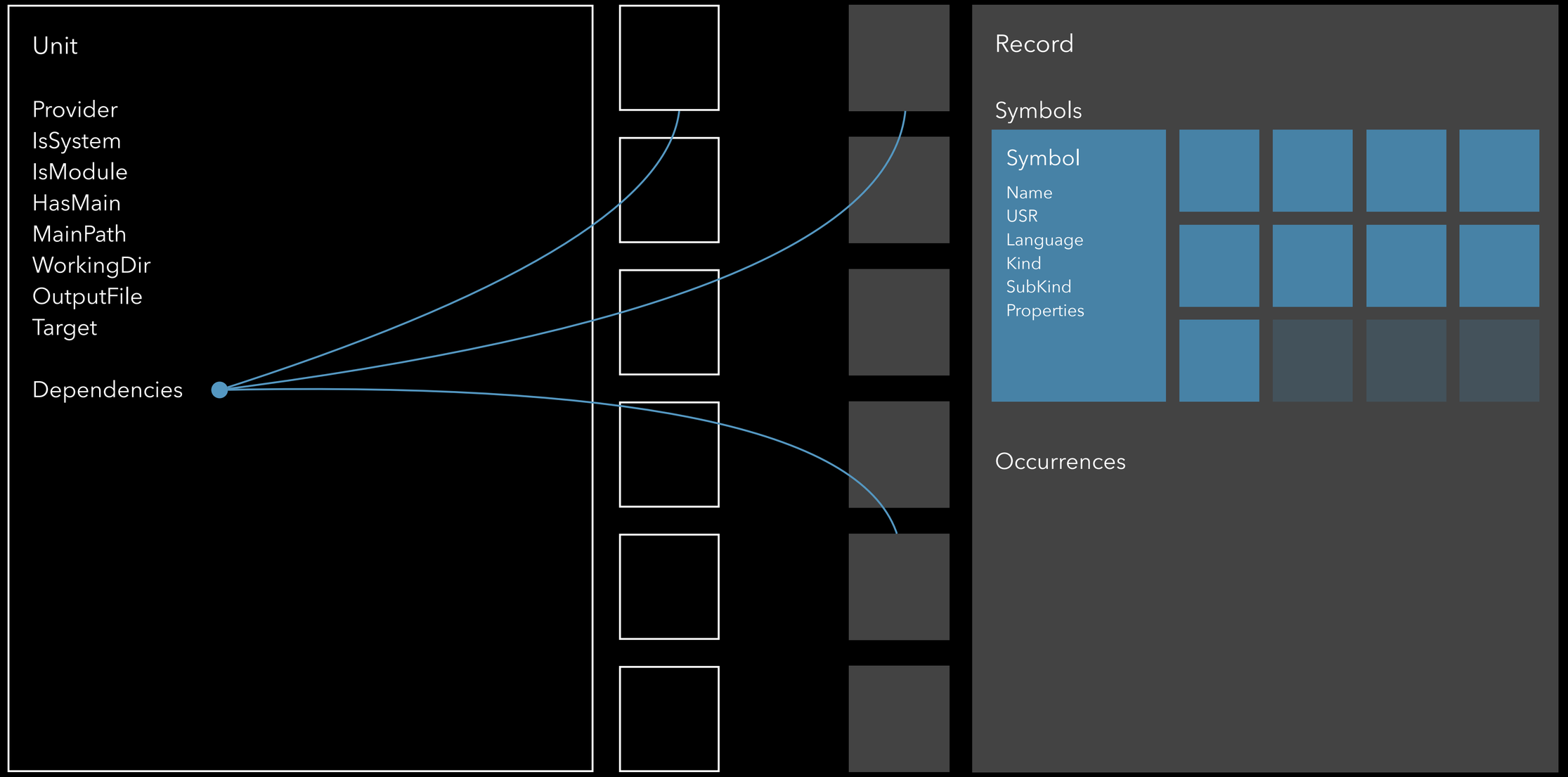
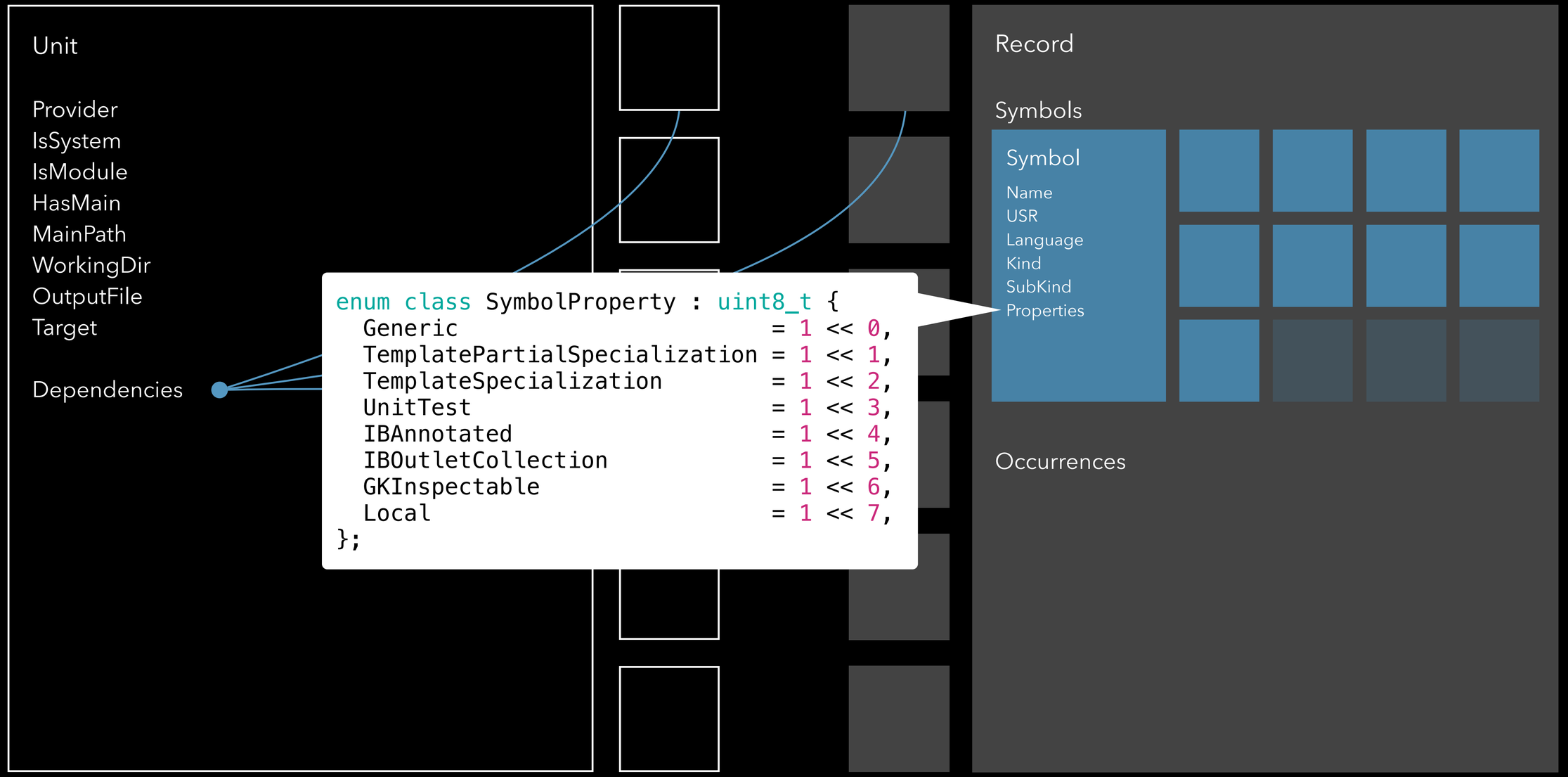
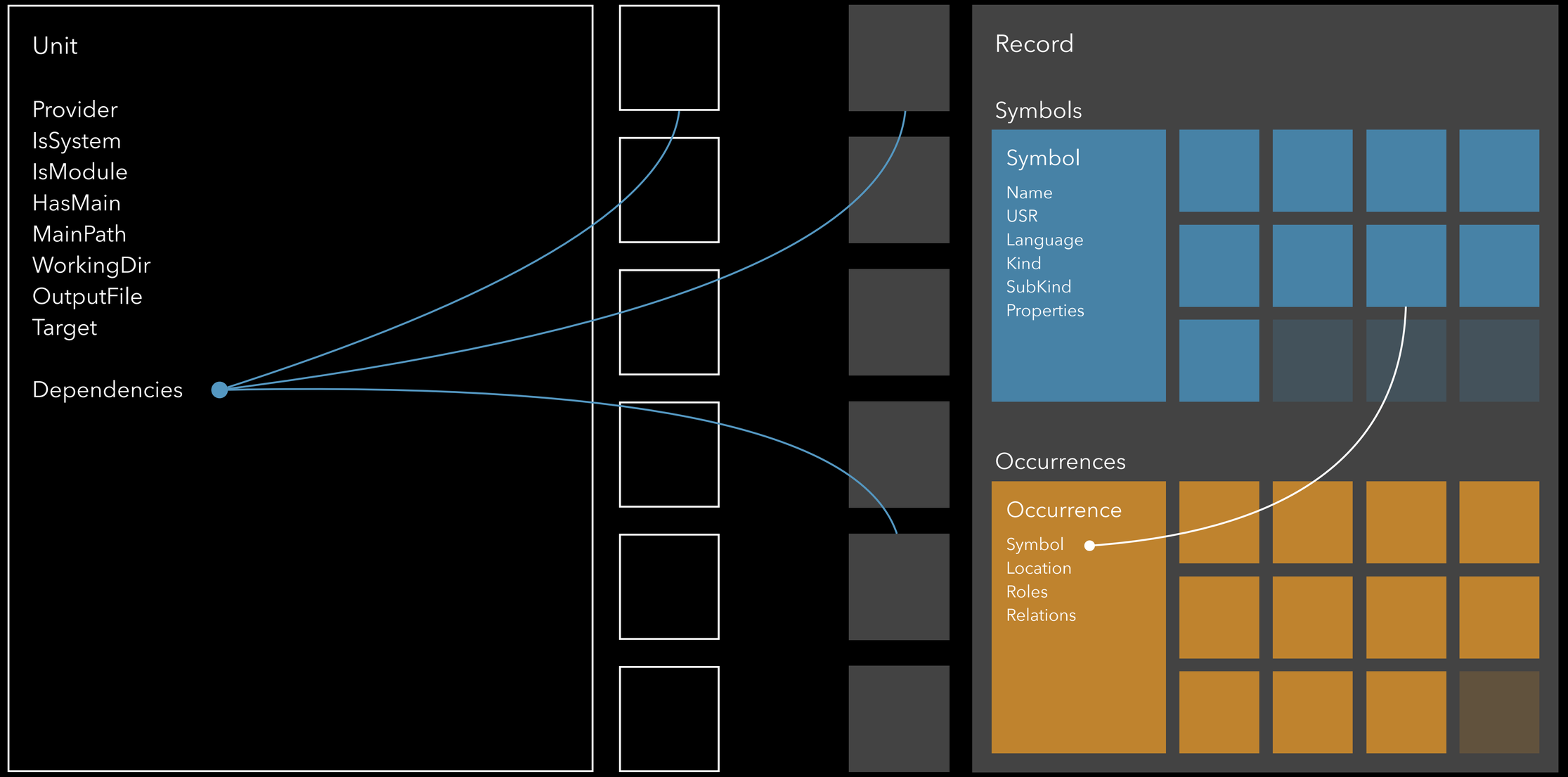


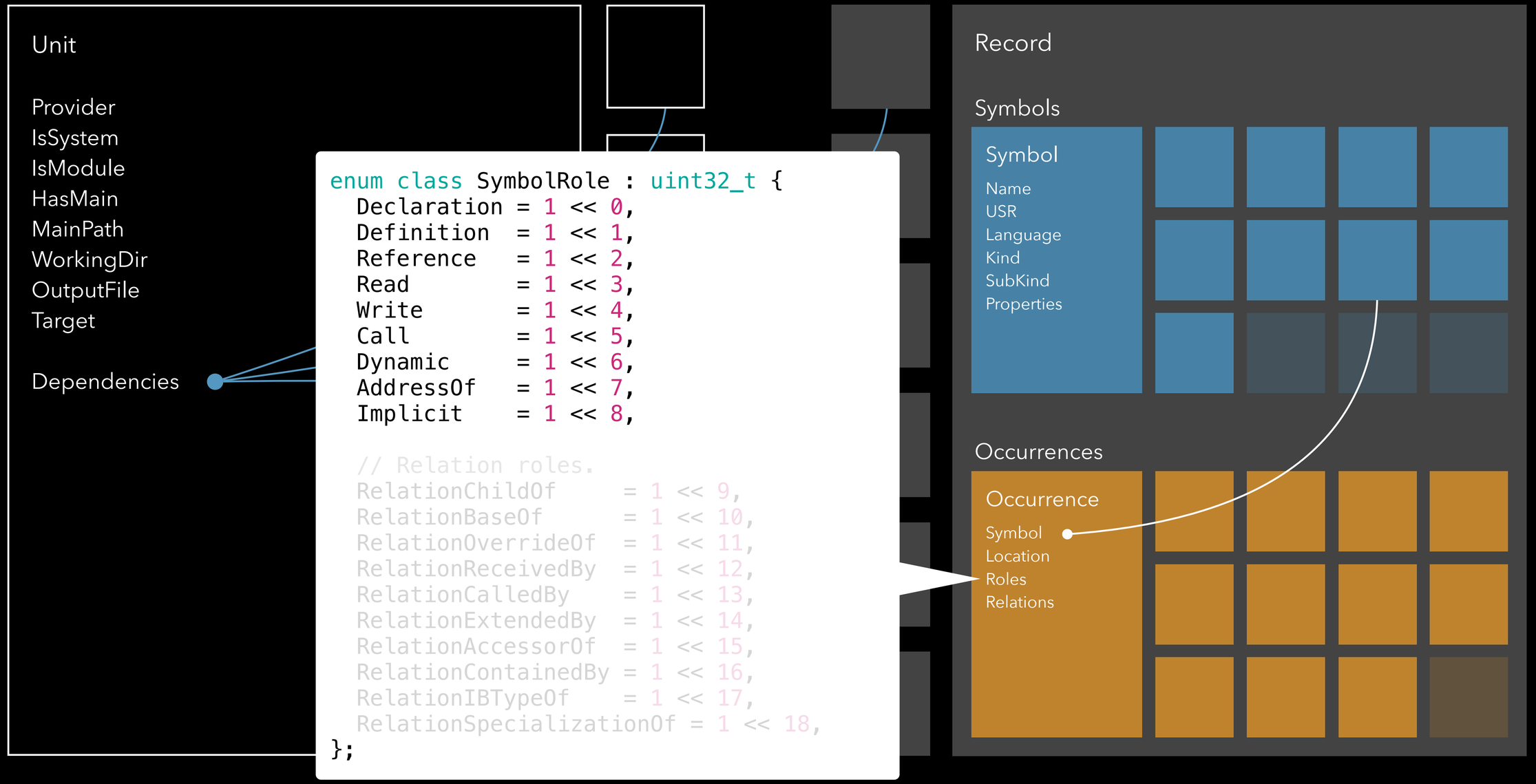
Index data model



Index data model



Index data model



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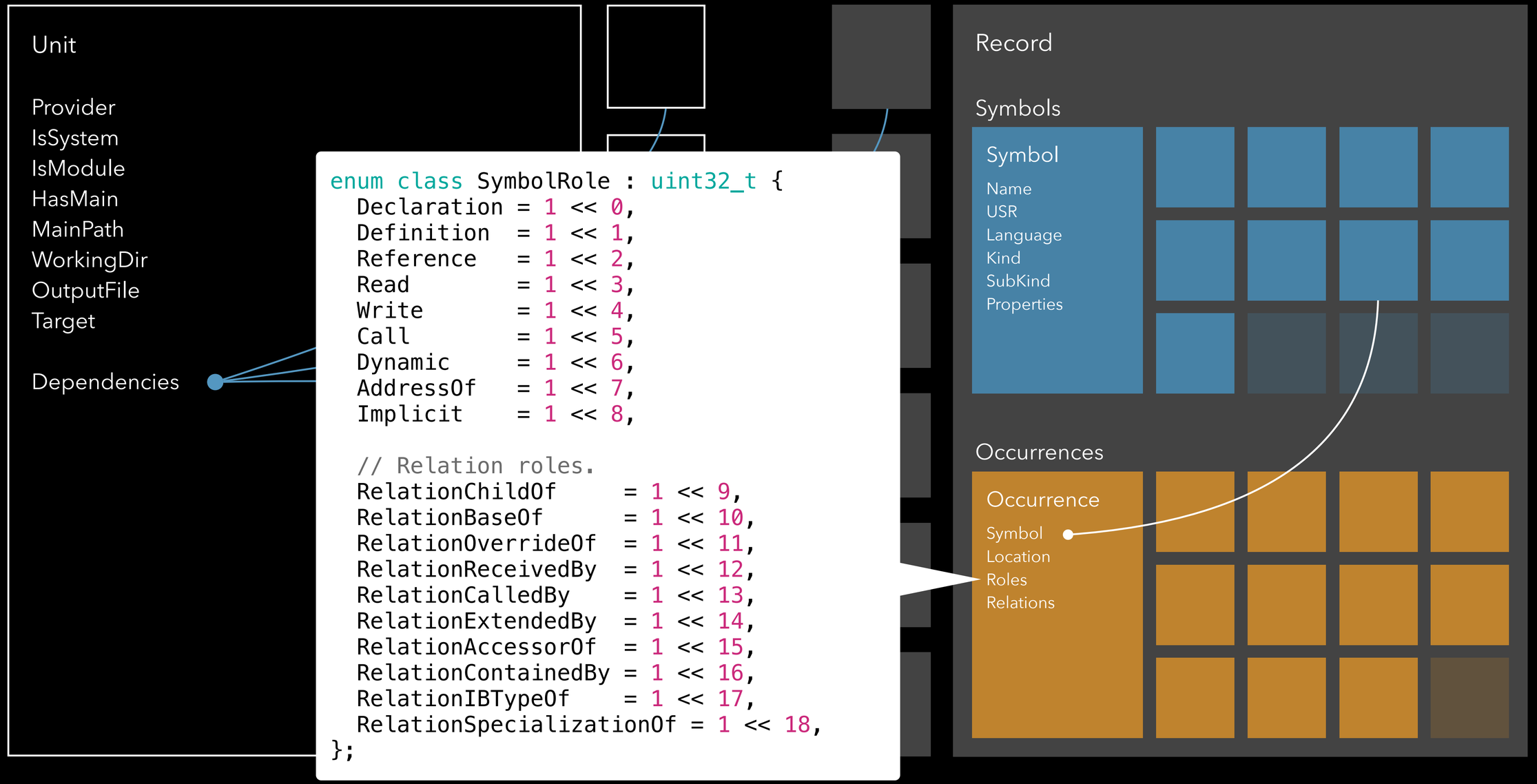

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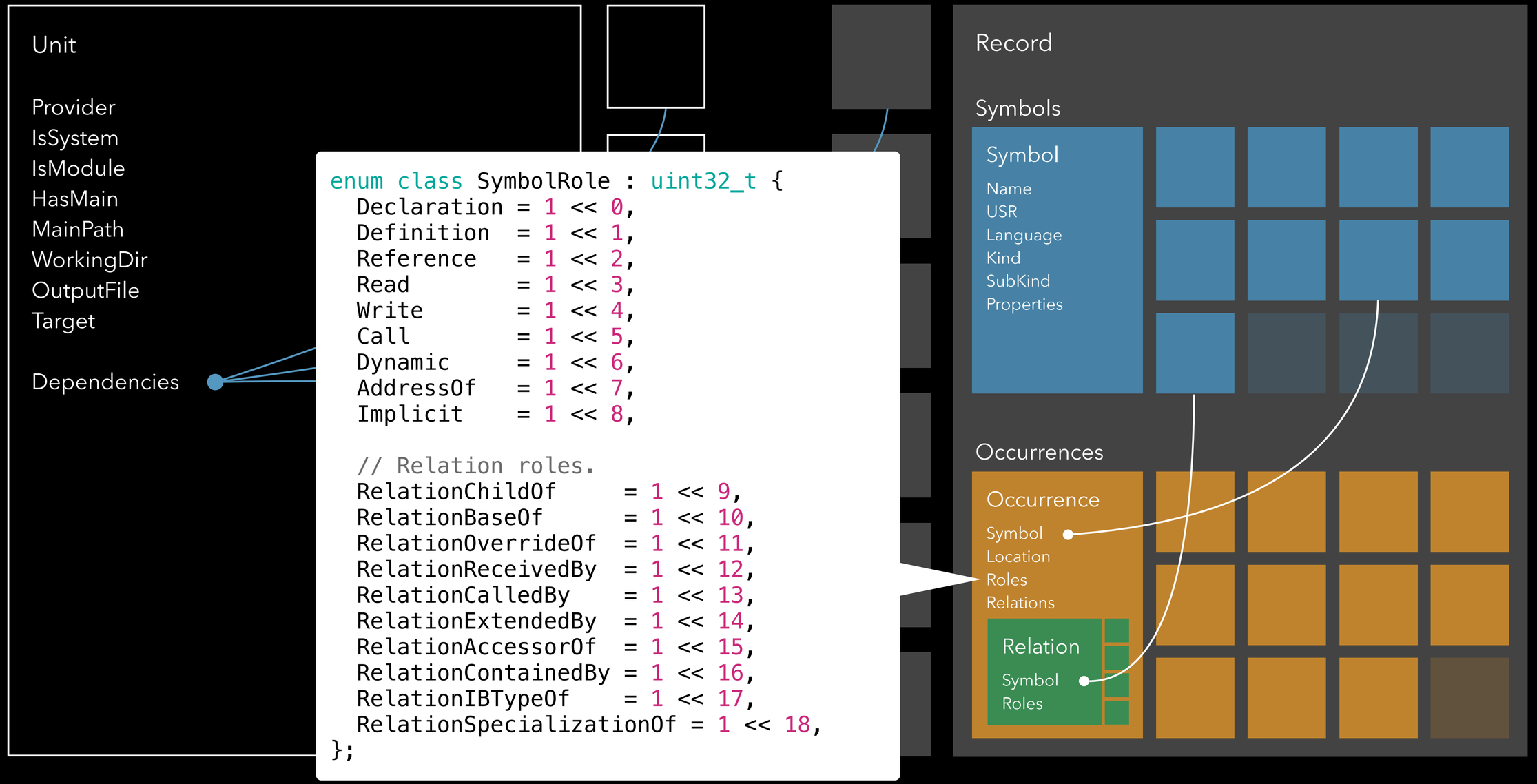

```cpp
class Polygon {
protected:
  int NumberOfSides;

public:
  Polygon(int NumberOfSides)
  : NumberOfSides(NumberOfSides) {}

  int getSideCount() {
    return NumberOfSides;
  }
};

class RegularPolygon : public Polygon {
protected:
  int SideLength;

public:
  RegularPolygon(int NumberOfSides, int SideLength)
  : Polygon(NumberOfSides), SideLength(SideLength) {}

  int getPerimeter() {
    return SideLength * NumberOfSides;
  }
};
```

Symbol 1
Polygon

USR c:@S@Polygon
Language C++
Kind class

Symbol 2
RegularPolygon

USR c:@S@RegularPolygon
Language C++
Kind class

...

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1  class Polygon {
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Occurrence

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Location 1:7
Roles Definition

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Roles Definition

Occurrence

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Location 14:7
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Location 1:7
Roles Definition

Occurrence

Symbol 1
Location 14:31
Roles Reference, RelationBaseOf
Relations

Occurrence

Symbol 2
Location 14:7
Roles Definition

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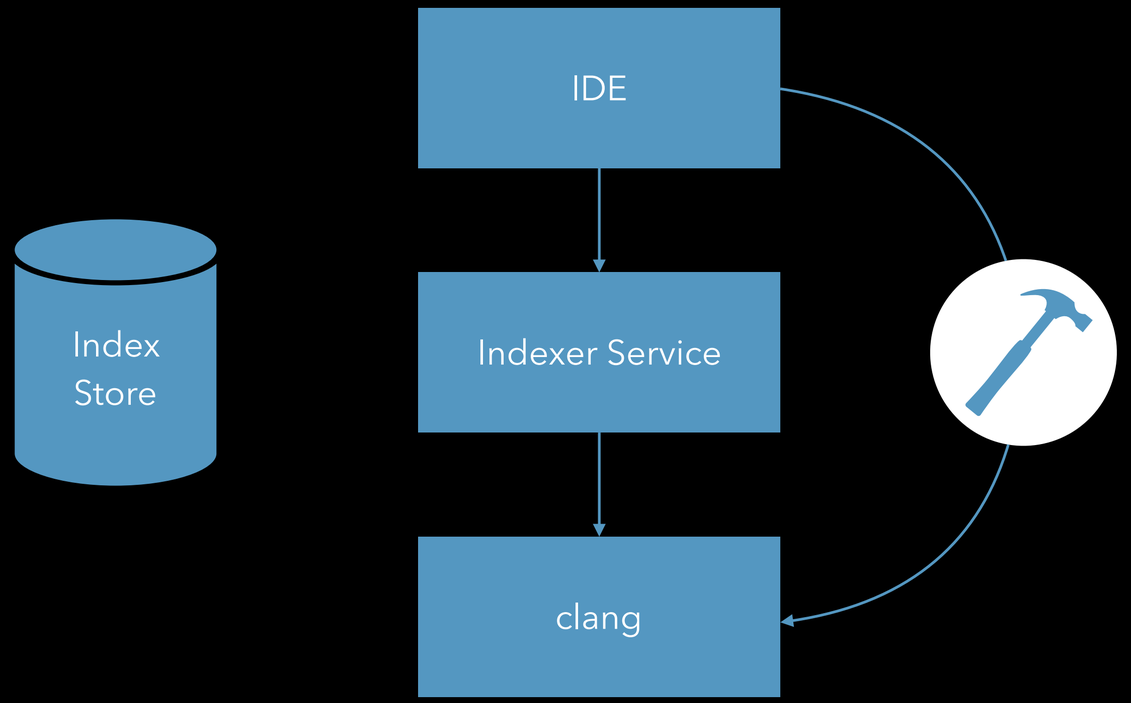
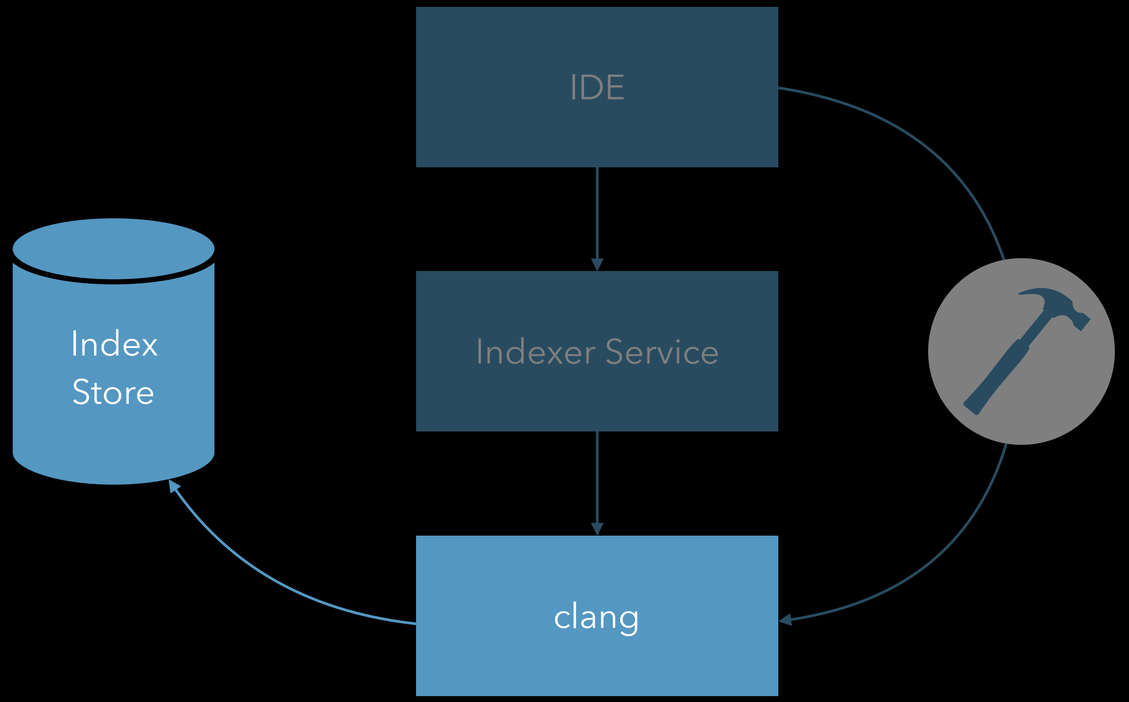
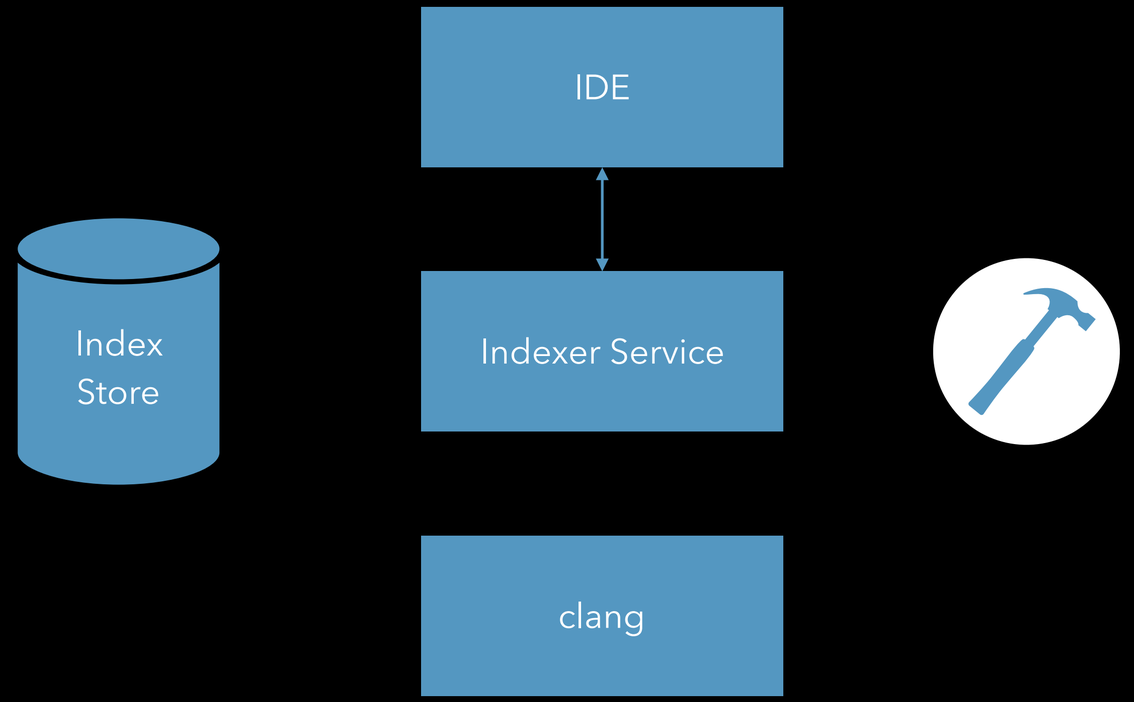
Producing index data



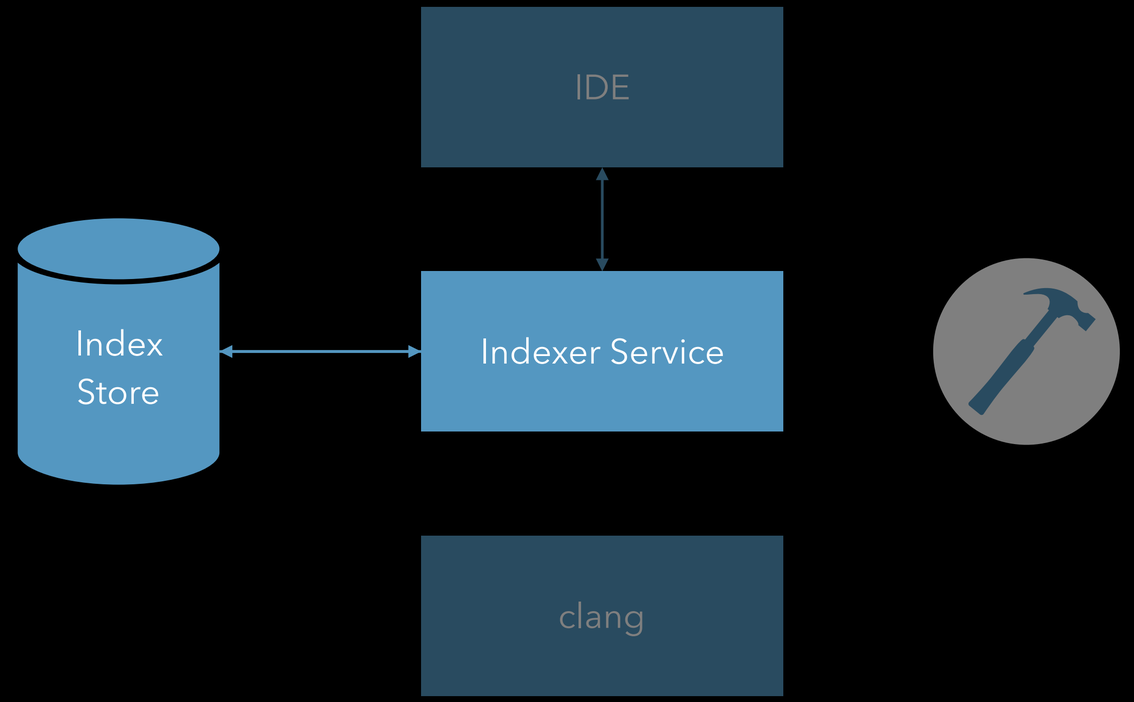
Producing index data



Consuming index data



Consuming index data



Reading the index store

Reading the index store

- New IndexStore library for clients to read and manage the store.

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- Located under tools/IndexStore.

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Not query!

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USR c:@S@RegularPolygon
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Relations

Relation

Roles RelationBaseOf
Symbol 2

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Find subclasses of Polygon

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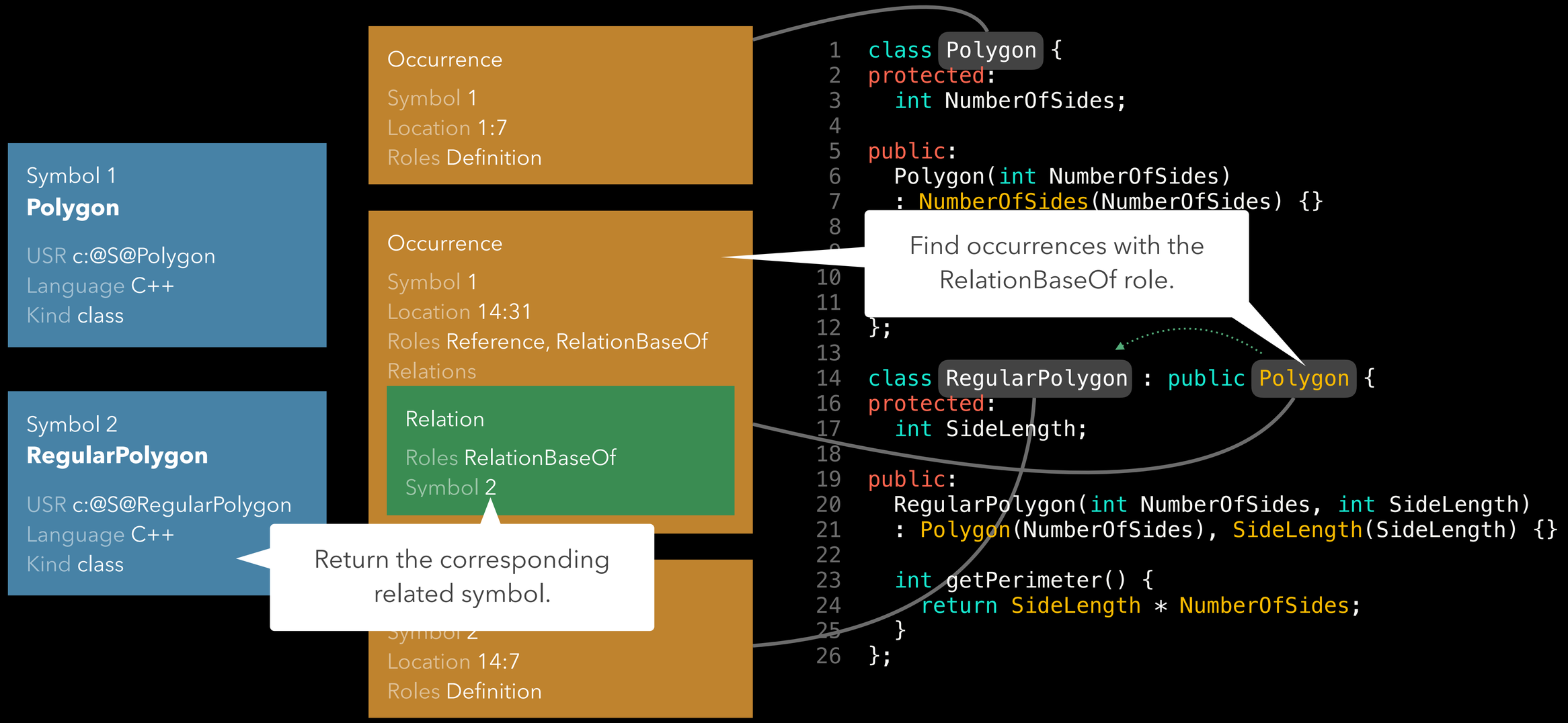
Find occurrences with the RelationBaseOf role.

Find subclasses of Polygon



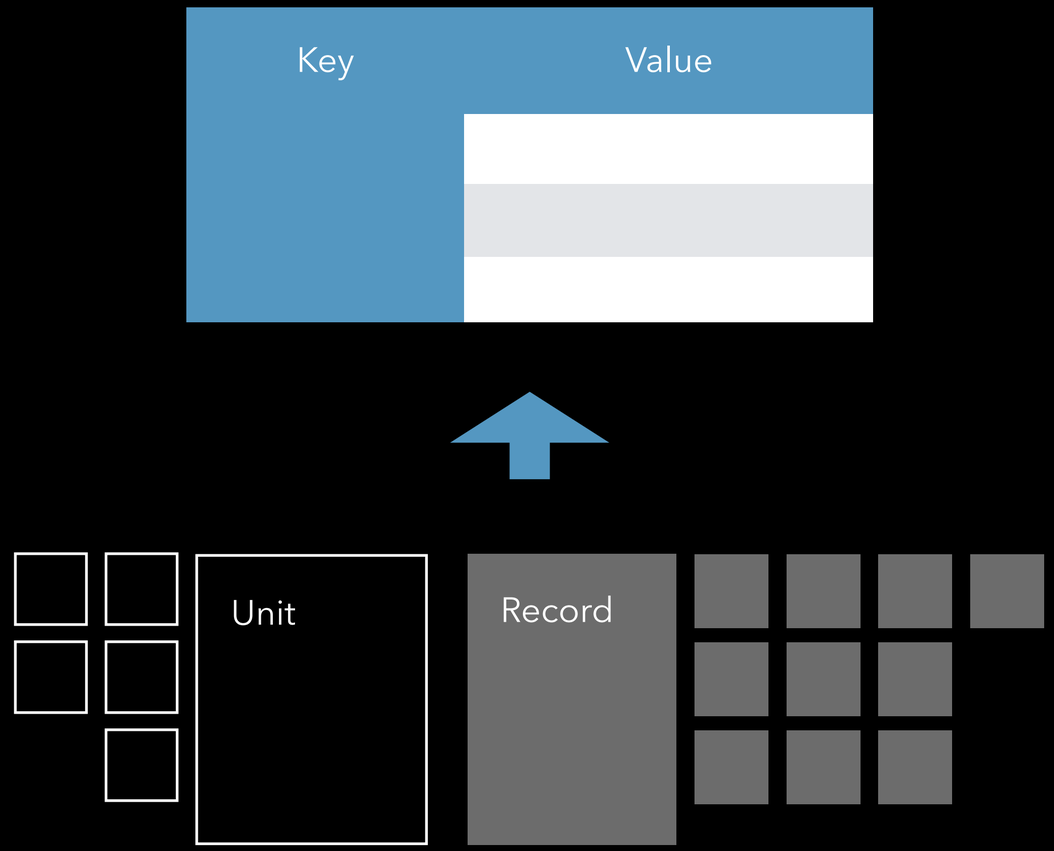
Find subclasses of Polygon

Find subclasses of Polygon

Record	Record	Record	Record	Record	Record	Record	Record	Record	Record	Record	Record	Record
Record	Record	Record	Record	Record	Record	Record	Record	Record	Record	Record	Record	Record
Record	Record	Record	Record	Record	Record	Record	Record	Record	Record	Record	Record	Record
Record	Record	Record	Record	Record	Record	Record	Record	Record	Record	Record	Record	Record

Speeding things up in the indexer service

Speeding things up in the indexer service



Find subclasses of Polygon

Find subclasses of Polygon

USR	Record + Roles
c:@S@**Polygon**	test.cpp-2RLZQAEAVK8SU Definition, Reference, RelationBaseOf other.cpp-X8QI5PPQ303AO Reference, RelationContainedBy
c:@S@**RegularPolygon**	test.cpp-2RLZQAEAVK8SU Definition chess.h-2RLZQAEAVK8SU Reference, RelationBaseOf

Find subclasses of Polygon

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c:@S@**Polygon**	test.cpp-2RLZQAEAVK8SU Definition, Reference, RelationBaseOf other.cpp-X8QI5PPQ303AO Reference, RelationContainedBy
c:@S@**RegularPolygon**	test.cpp-2RLZQAEAVK8SU Definition chess.h-2RLZQAEAVK8SU Reference, RelationBaseOf

1. Lookup USR.

Find subclasses of Polygon

USR	Record + Roles
c:@S@**Polygon**	test.cpp-2RLZQAEAVK8SU Definition, Reference, RelationBaseOf other.cpp-X8QI5PPQ303AO Reference, RelationContainedBy
c:@S@**RegularPolygon**	test.cpp-2RLZQAEAVK8SU Definition chess.h-2RLZQAEAVK8SU Reference, RelationBaseOf

1. Lookup USR.
2. Find records with the RelationBaseOf role.

Find subclasses of Polygon

USR	Record + Roles
c:@S@**Polygon**	test.cpp-2RLZQAEAVK8SU Definition, Reference, RelationBaseOf other.cpp-X8QI5PPQ303AO Reference, RelationContainedBy
c:@S@**RegularPolygon**	test.cpp-2RLZQAEAVK8SU Definition chess.h-2RLZQAEAVK8SU Reference, RelationBaseOf

1. Lookup USR.
2. Find records with the RelationBaseOf role.
3. Retrieve those occurrences and their related symbols.

Find subclasses of Polygon

USR	Record + Roles
c:@S@**Polygon**	test.cpp-2RLZQAEAVK8SU Definition, Reference, RelationBaseOf other.cpp-X8QI5PPQ303AO Reference, RelationContainedBy
c:@S@**RegularPolygon**	test.cpp-2RLZQAEAVK8SU Definition chess.h-2RLZQAEAVK8SU Reference, RelationBaseOf

1. Lookup USR.
2. Find records with the RelationBaseOf role.
3. Retrieve those occurrences and their related symbols.
4. Find the canonical occurrences of those symbols.

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i.e. Find their definitions

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Find definitions of RegularPolygon

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Reference, Declaration, Read, Write, Call, etc.

Other useful mappings

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Symbol Name	USRs
Shape	c:@S@Shape, c:@T@Sh…

Search symbols by name

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Units to re-index when header changes

Other useful mappings

Symbol Name	USRs
Shape	c:@S@Shape, c:@T@Sh…

Search symbols by name

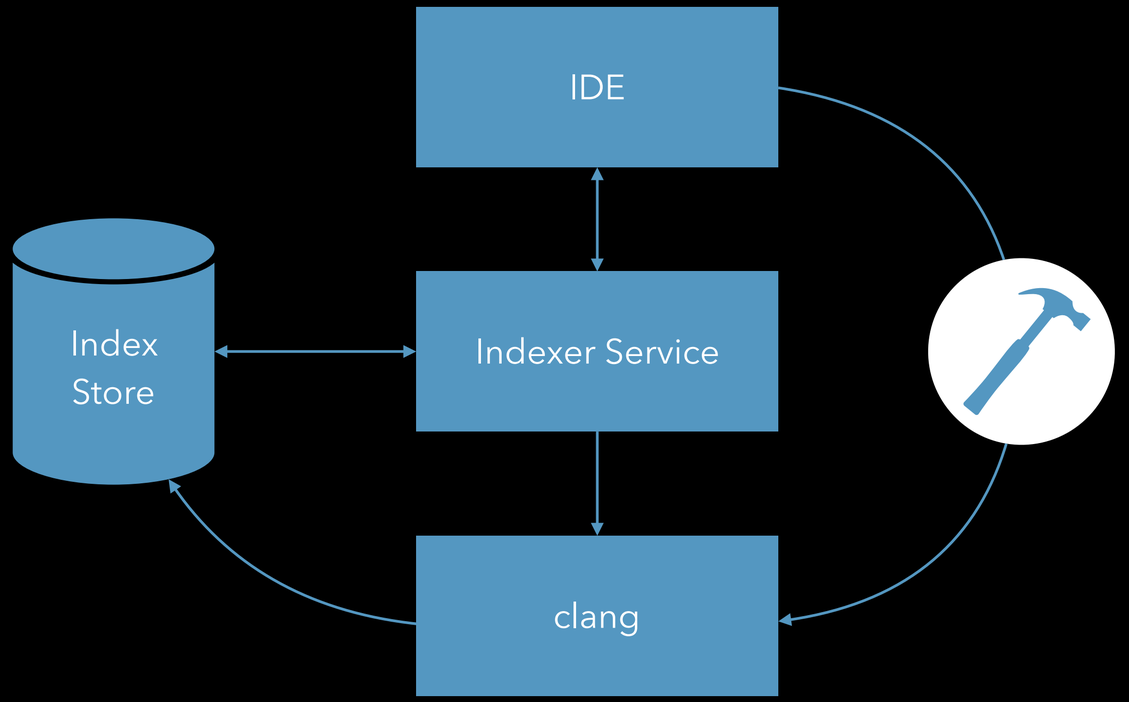
Record	Dependent units
feature.h-XXX	first.o-XXX

Remove data from unreferenced records

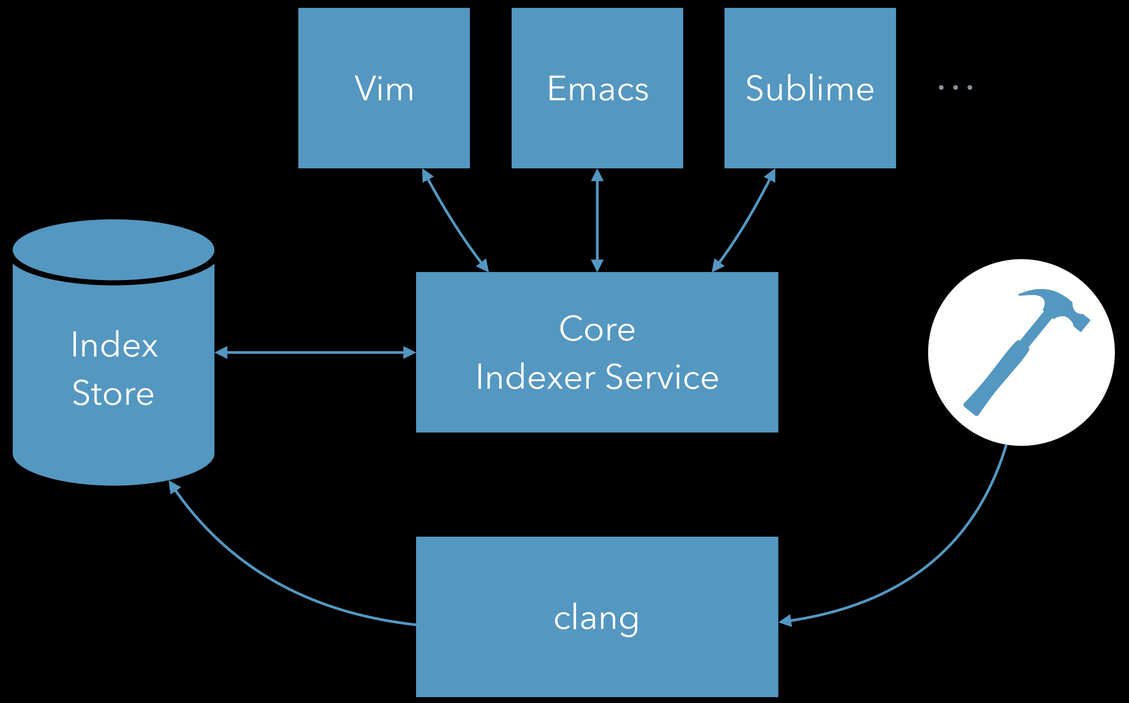
Source file	Dependent units
things.h	first.o-XXX, second.o-XXX

Units to re-index when header changes

Indexing in the IDE



General indexing infrastructure



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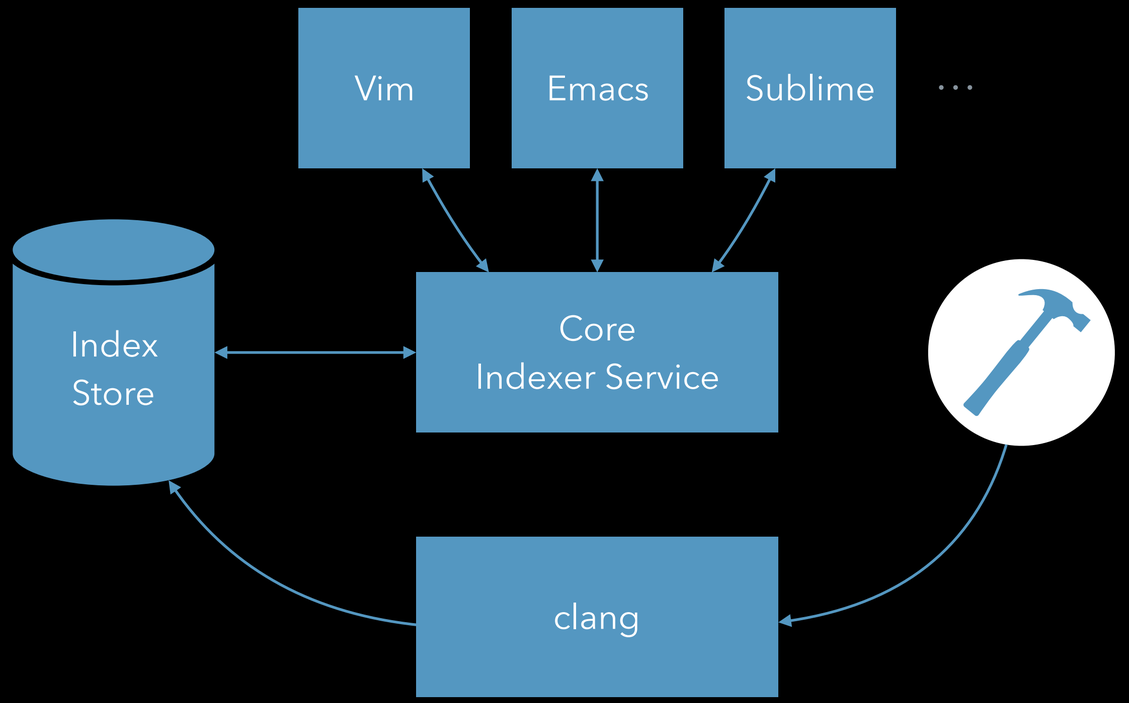
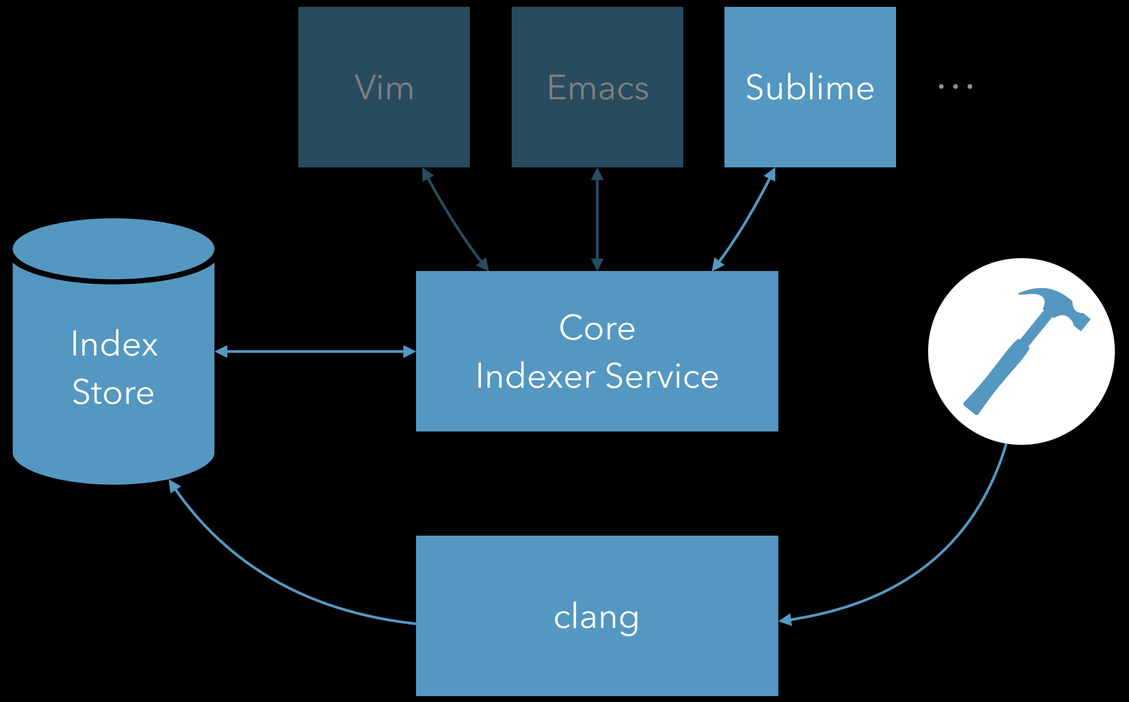


General indexing infrastructure

Demo!



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  https://github.com/apple/swift-clang
- Planning to upstream basic indexer service along with editor plugins for vim, emacs, and sublime.
- To follow along and for more info check out the *RFC: Adding index-while-building support to Clang* thread on the cfe-dev mailing list.

Refactoring

Refactoring agenda

New refactoring engine

Improved IDE support

clang-refactor

Implementing “extract function”

Refactoring library components

Status

Ideas for future contributors

Refactoring

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Let’s start with an example

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struct Rectangle {
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An “extract function” refactoring

Refactoring

User requirements

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- One user lives in an IDE
  - ➡ Clang must provide “extract function” to the IDE

Refactoring

User requirements

- One user lives in an IDE
  - ➡ Clang must provide “extract function” to the IDE
- Another user swears by command-line tools
  - ➡ Clang must provide a refactoring tool that can “extract”

New refactoring engine

New refactoring engine

Overview

New refactoring engine

Overview

- Refactoring library in `libTooling`

New refactoring engine

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- Refactoring library in `libTooling`
- New refactoring actions

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➡ Simple IDE integration for “extract function”

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➡ Automatic support for “extract function”

Using clang-refactor

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Using clang-refactor

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```
clang-refactor extract -selection=test.cpp:6:13-6:31 -name=area test.cpp
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```
clang-refactor extract -selection=test.cpp:6:13-6:31 -name=area test.cpp
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Each action gets its own subcommand

New refactoring engine

Simplified IDE integration process

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- Existing refactorings: `clang-rename`, `clang-reorder-fields`, ...

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  - No `libclang` / `clangd` integration
- New refactorings implemented in `libTooling`
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➡ Easy to integrate with `libclang` / `clangd`

New refactoring engine

clang-refactor *-vs-* existing tools

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clang-refactor *-vs-* existing tools

- `clang-refactor` *vs* `clang-rename`, `clang-reorder-fields`, ...
  - How many tools are needed?
- Single tool enables:
  - Common command-line interface with action-specific options
  - One set of editor plugins
  - No duplication of indexing infrastructure integration efforts

New refactoring engine

Refactoring stages

New refactoring engine

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- Before: monolithic `ASTConsumer` design

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  - Initiation verifies options, handles AST selection, matches AST
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➡ Editor clients use quick initiation to find available actions for selection

➡ `clang-refactor` examines initiation to create command-line interface

Implementing “extract function”

Breakdown of extract

Extract

Extract method

Extract function

```
    float x, y, width, height;
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float area(const Rectangle &r) {
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Breakdown of extract

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`class ExtractRefactoringAction`

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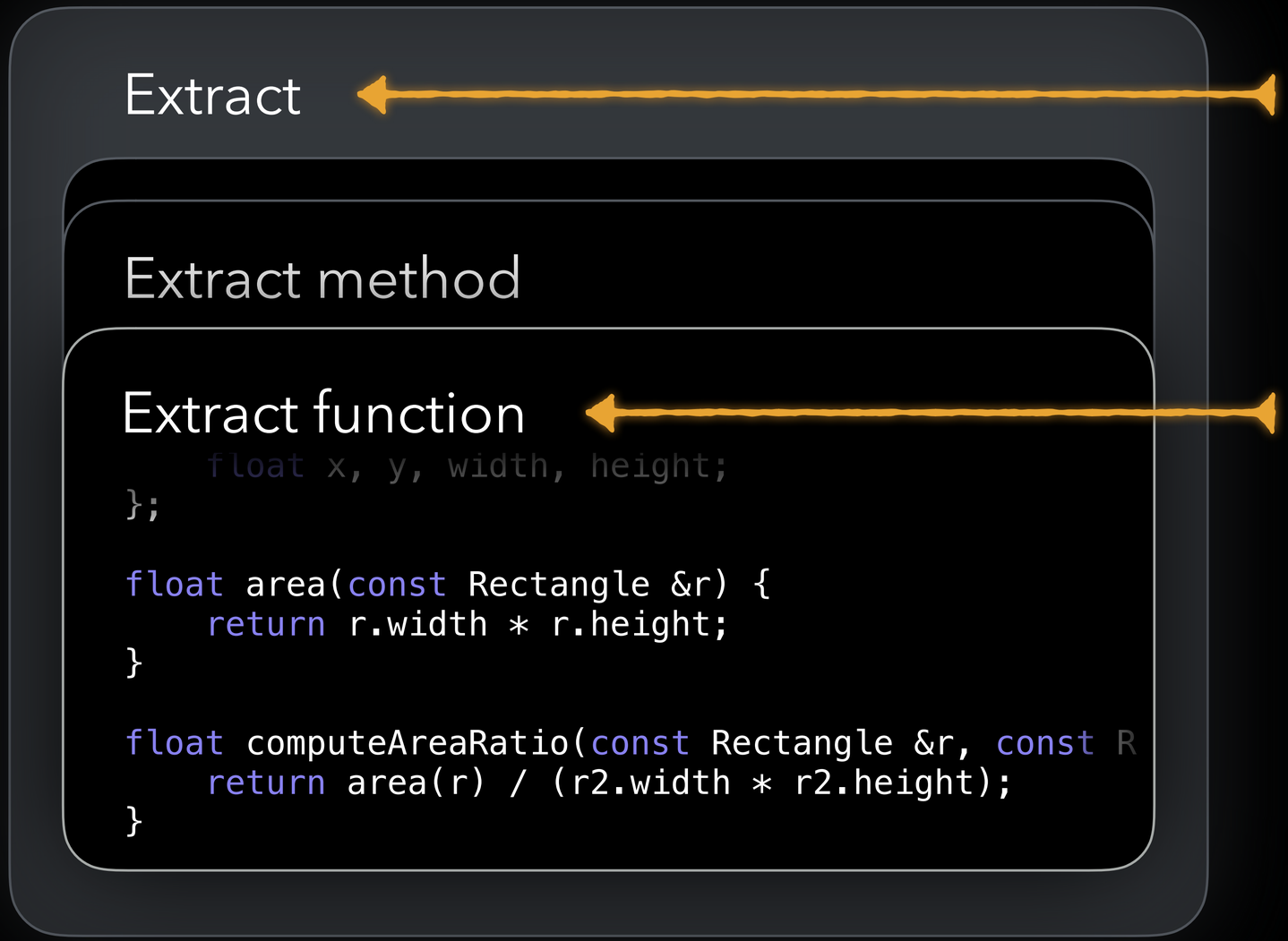


```
class ExtractRefactoringAction
```

```
class ExtractFunction
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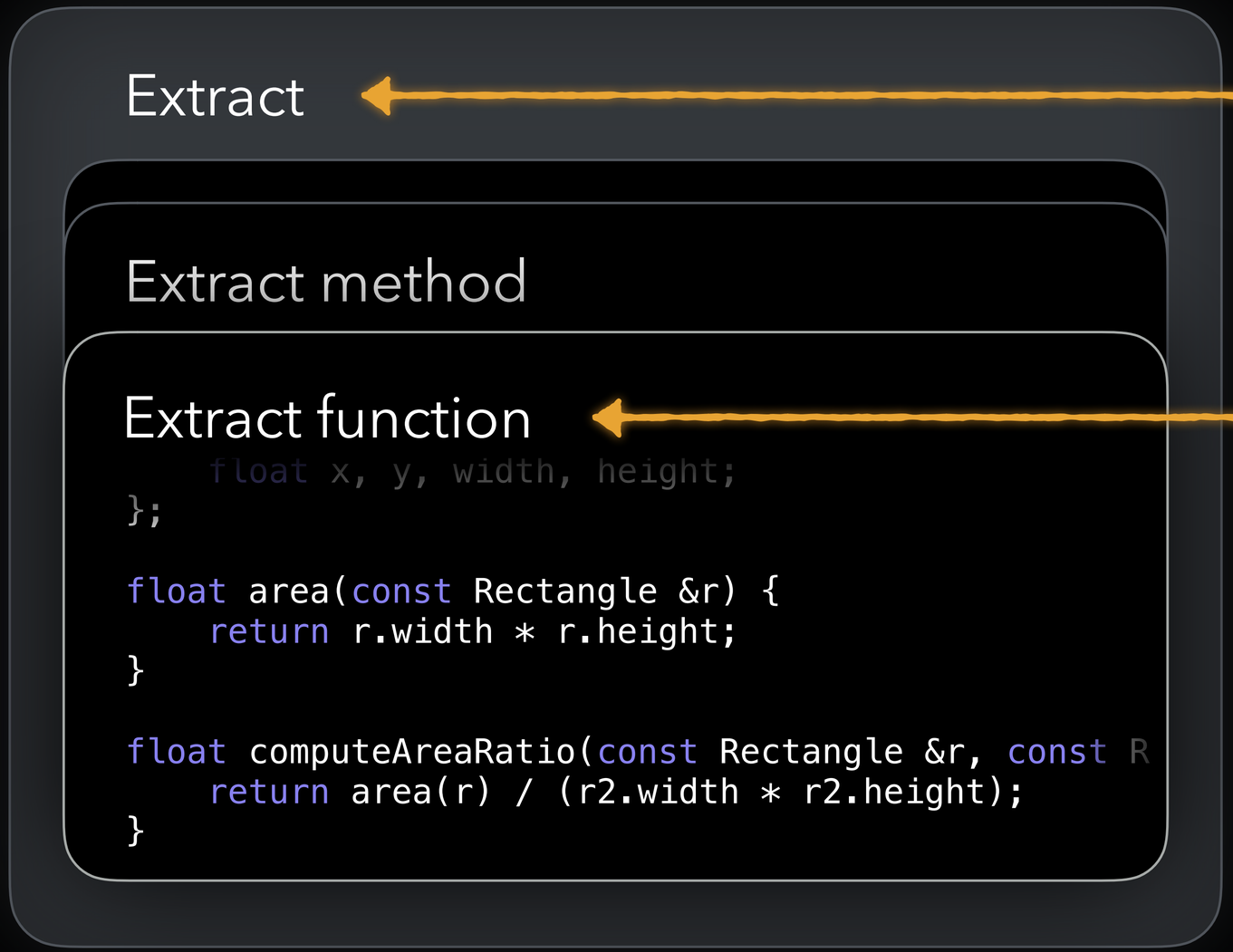
Breakdown of extract




```
class RefactoringAction
class ExtractRefactoringAction
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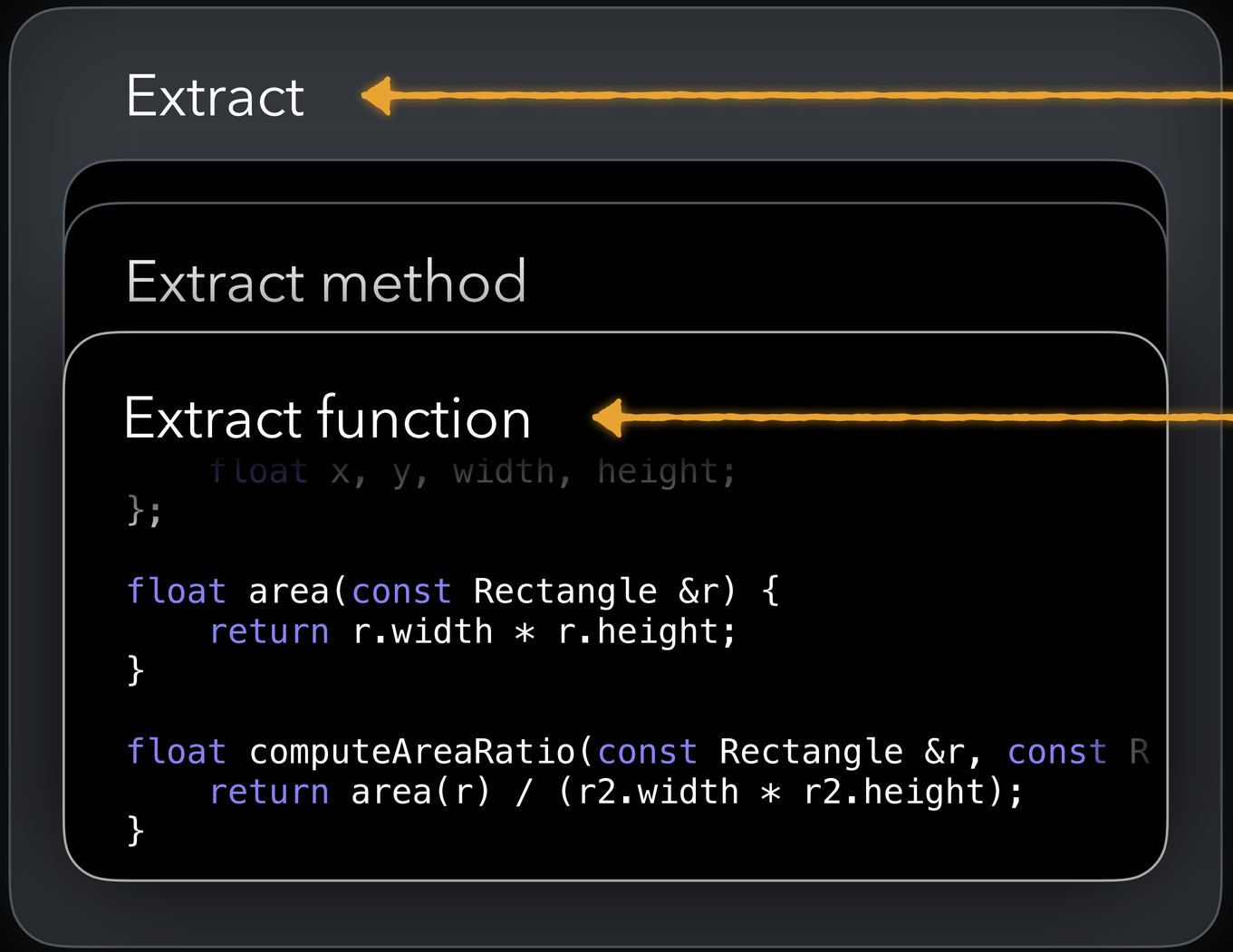
```
class RefactoringActionRule
class ExtractFunction
```

Breakdown of extract

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creates

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class ExtractFunction
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```
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```
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Refactoring action *-vs-* refactoring action rule

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Refactoring action *-vs-* refactoring action rule

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- High-level description of a refactoring

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Refactoring action *-vs-* refactoring action rule

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Refactoring action *-vs-* refactoring action rule

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- Description of a low-level operation

Refactoring action *-vs-* refactoring action rule

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Refactoring action *-vs-* refactoring action rule

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- Description of a low-level operation
- Library manages the initiation stage
- Operations like `ExtractFunction` implement the refactoring stage

Implementing “extract function”

1. Create the operation that performs the refactoring

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class ExtractFunction final : public SourceChangeRefactoringRule {
public:
    ExtractFunction(CodeRangeASTSelection Selection,
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➡ `class SourceChangeRefactoringRule`

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    Expected<AtomicChanges>
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  ➡ `class CodeRangeASTSelection`

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  ➡ `class CodeRangeASTSelection`

- Name of the extracted function will not be provided by the IDE

Implementing “extract function”

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  - ➡ `class CodeRangeASTSelection`
- Name of the extracted function will not be provided by the IDE
  - ➡ `Optional<std::string>`

Initiation stage

```
class ExtractFunction final : public SourceChangeRefactoringRule {
public:
    ExtractFunction(CodeRangeASTSelection Selection,
                    Optional<std::string> Name)
    : Selection(Selection), Name(Name) {}

    Expected<AtomicChanges>
```

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- `ExtractFunction` operation constructed by library after initiation

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- `ExtractFunction` operation constructed by library after initiation
- Inputs provided by operation's initiation requirements

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- Inputs provided by operation's initiation requirements

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```

- `ExtractFunction` operation constructed by library after initiation
- Inputs provided by operation's initiation requirements

➡ Requirement creates one input value for constructor when satisfied

➡ Otherwise refactoring fails or is unavailable

Builtin initiation requirements

```
class ExtractFunction final : public SourceChangeRefactoringRule {
public:
    ExtractFunction(CodeRangeASTSelection Selection,
                    Optional<std::string> Name)
    : Selection(Selection), Name(Name) {}

    Expected<AtomicChanges>
```

Builtin initiation requirements

```
class ExtractFunction final : public SourceChangeRefactoringRule {
public:
    ExtractFunction(CodeRangeASTSelection Selection,
                    Optional<std::string> Name)
    : Selection(Selection), Name(Name) {}

    Expected<AtomicChanges>
```

```
class CodeRangeSelectionRequirement

implements

Expected<CodeRangeASTSelection> evaluate
```

Builtin initiation requirements

```
class ExtractFunction final : public SourceChangeRefactoringRule {
public:
    ExtractFunction(CodeRangeASTSelection Selection,
                    Optional<std::string> Name)
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class ExtractFunction final : public SourceChangeRefactoringRule {
public:
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                    Optional<std::string> Name)
    : Selection(Selection), Name(Name) {}

    Expected<AtomicChanges>
```

```
class OptionRequirement<NameOption>
```

implements

```
Expected<Optional<std::string>> evaluate
```

Builtin initiation requirements

```
class ExtractFunction final : public SourceChangeRefactoringRule {
public:
    ExtractFunction(CodeRangeASTSelection Selection,
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requires definition such as

Builtin initiation requirements

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class ExtractFunction final : public SourceChangeRefactoringRule {
public:
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    Expected<AtomicChanges>
```

```
class OptionRequirement<NameOption>
```

requires definition such as

```
class NameOption : public OptionalRefactoringOption<std::string> {
public:
    StringRef getName() const override { return "name"; }
    StringRef getDescription() const override { return "…"; }
};
```

Implementing “extract function”

1. Create the operation that performs the refactoring

```
class ExtractFunction final : public SourceChangeRefactoringRule {
public:
    ExtractFunction(CodeRangeASTSelection Selection,
                    Optional<std::string> Name)
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Implementing “extract function”

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    : Selection(Selection), Name(Name) {}

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```

1.2. Create constructor that receives the required inputs

Implementing “extract function”

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```
class ExtractFunction final : public SourceChangeRefactoringRule {
public:
    ExtractFunction(CodeRangeASTSelection Selection,
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    : Selection(Selection), Name(Name) {}

    Expected<AtomicChanges>
    createSourceReplacements(RefactoringRuleContext &Context) {
        AtomicChanges Result;
        std::string FnName = Name ? *Name : “extracted”;
        // … Create the new function using selection …
        // … Replace selection with a call to the new function …
        return Result;
    }

private:
```

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1.3. Implement the refactoring function

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private:
    CodeRangeASTSelection Selection;
    Optional<std::string> Name;
};
```

Implementing “extract function”

2. Create the refactoring action

```
class ExtractRefactoringAction final : public RefactoringAction {
public:
    StringRef getCommand() const override { return "extract"; }

    RefactoringActionRules createActionRules() const override {
```

Implementing “extract function”

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class ExtractRefactoringAction final : public RefactoringAction {
public:
    StringRef getCommand() const override { return "extract"; }

    RefactoringActionRules createActionRules() const override {
      RefactoringActionRules Rules;
      Rules.push_back(
        createRefactoringActionRule<ExtractFunction>(
          CodeRangeSelectionRequirement(),
          OptionRequirement<NameOption>()));
      return Rules;
    }
};
```

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2.1. Construct the refactoring action rules

Implementing “extract function”

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        return Rules;
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Implementing “extract function”

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3. Add an entry in the refactoring action registry

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REFACTORING_ACTION(Extract)
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Implementing “extract function”

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4. Define the action factory function

```
std::unique_ptr<RefactoringAction> createExtractAction() {
  return llvm::make_unique<ExtractRefactoringAction>();
}
```

Implementing “extract function”

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➡ `clang-refactor` supports “extract”

Implementing “extract function”

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IDE Integration

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EditorCommand::ExtractFunction().bind(
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```

Implementing “extract function”

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Implementing “extract function”

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Implementing “extract function”

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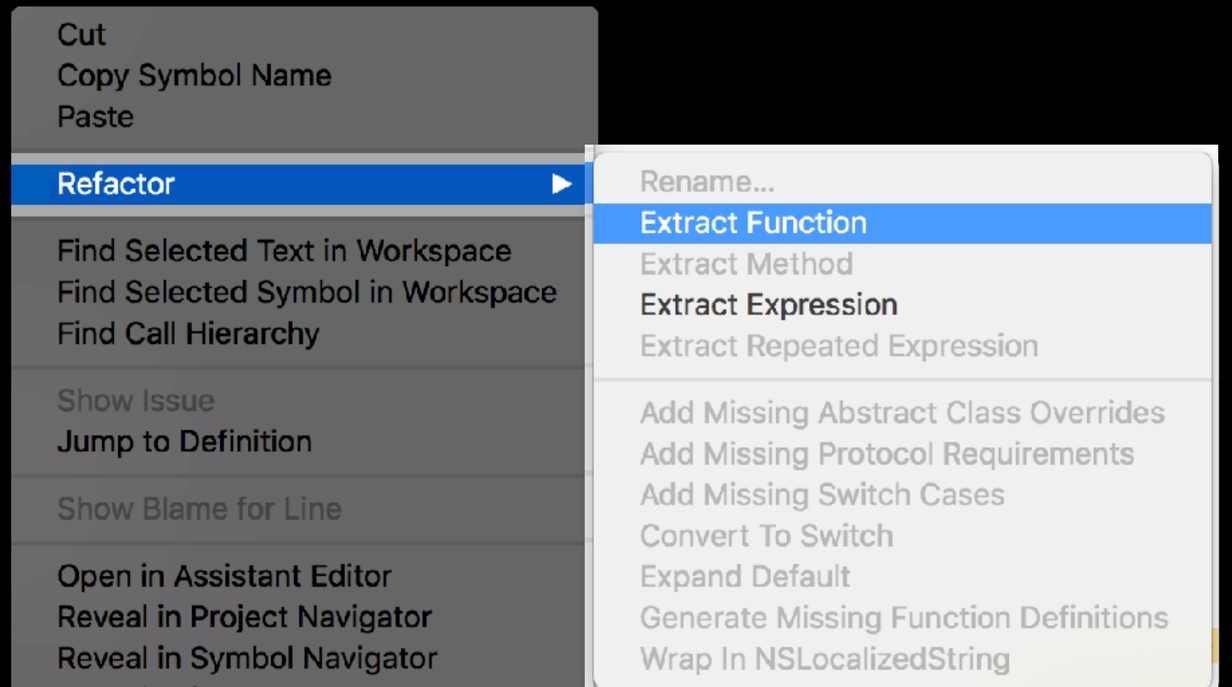

Implementing other refactorings

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  - Future components will help with AST matching and cross-TU operations
- Comprehensive guide available

➡ https://clang.llvm.org/docs/RefactoringEngine.html

Status

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Currently upstreaming…

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- Generate Missing Function Definitions
- Rename
- Extract Function
- Extract Variable
- Add Missing Protocol Requirements
- Convert to Switch
- Add Abstract Class Overrides
- Add Missing Switch Cases

Status

Clients

`clangd`
In review; “rename” later

`clang-refactor`
Mostly works

`libclang`
Coming soon…

Status

Status

- Core components committed or in review

Status

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- Migration of clang-rename ongoing

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- Migration of clang-rename ongoing
- Soon: cross-TU actions using refactoring continuations

Status

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- “extract” undergoing review

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- clangd support

Ideas for improvement

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- Integration with Clang’s indexing infrastructure

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- Verification of semantic correctness

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- Integration with Clang’s indexing infrastructure
- Verification of semantic correctness
- Distributed global refactoring with clang-refactor

Contributing to the new engine

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- Local refactoring tutorial in review: D39027

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- Ideas: bugzilla keyword “beginner” + term “[refactoring]: idea”
- Migration of clang-reorder-fields and other tools?

Q & A