Incremental, zero-config Code Navigation using stack graphs

Douglas Creager
@dcreager

Strange Loop
October 1, 2021 – St. Louis

Builds on the Scope Graphs framework
from Eelco Visser's group at TU Delft.

`https://pl.ewi.tudelft.nl/research/projects/scope-graphs/`

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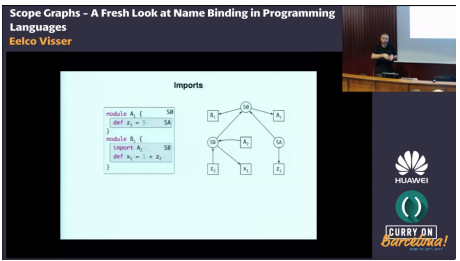
Curry On Barcelona 2017



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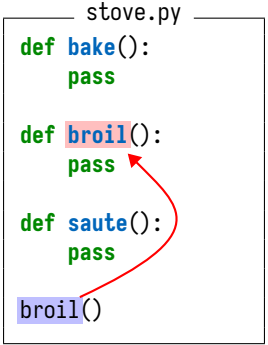


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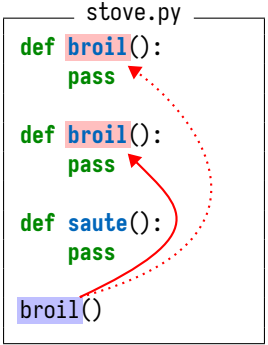

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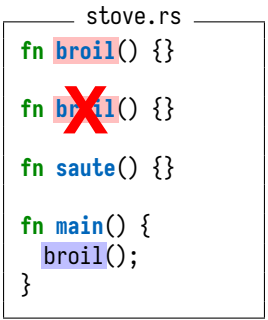

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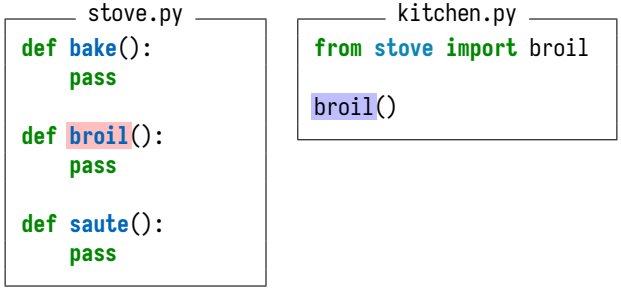

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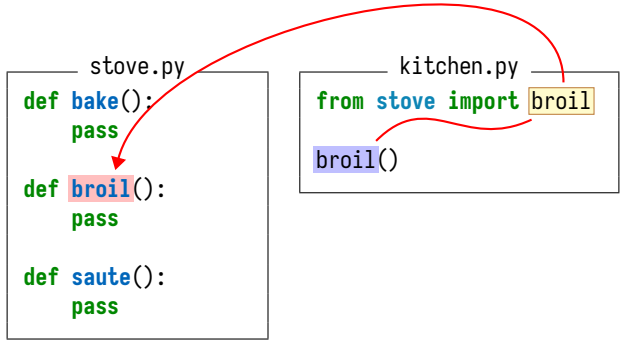

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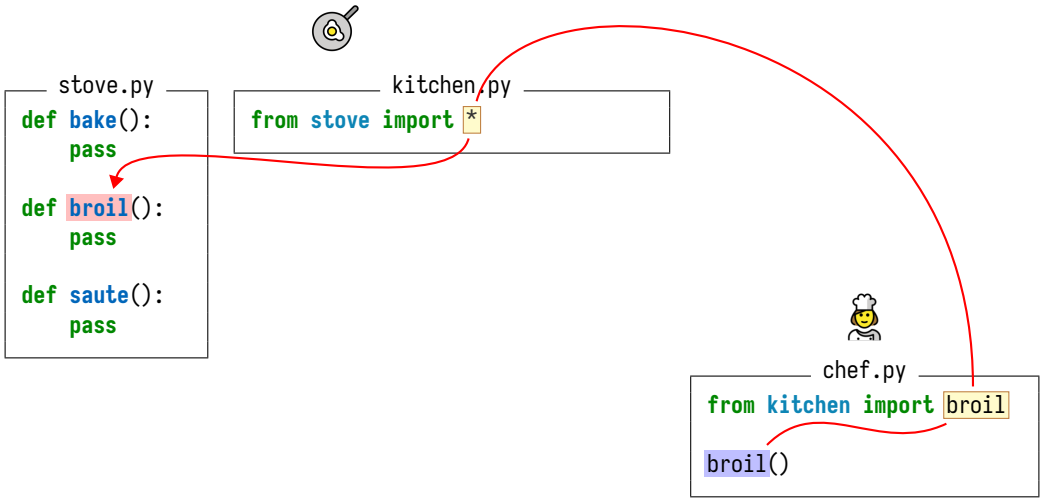

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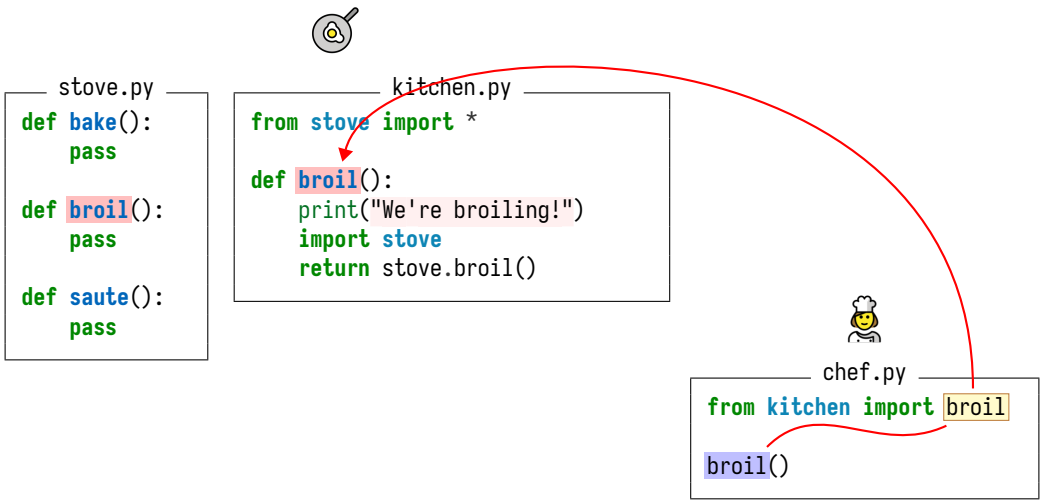

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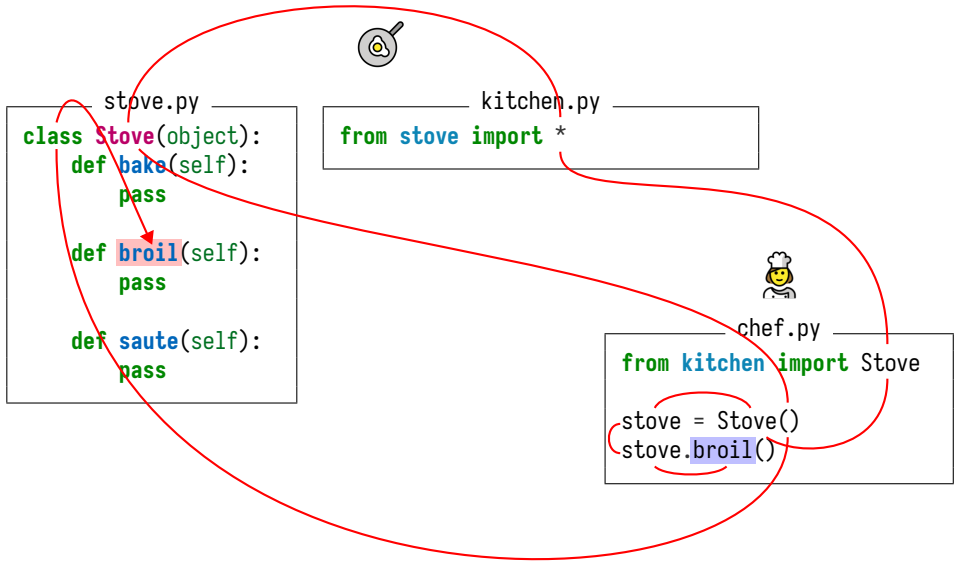

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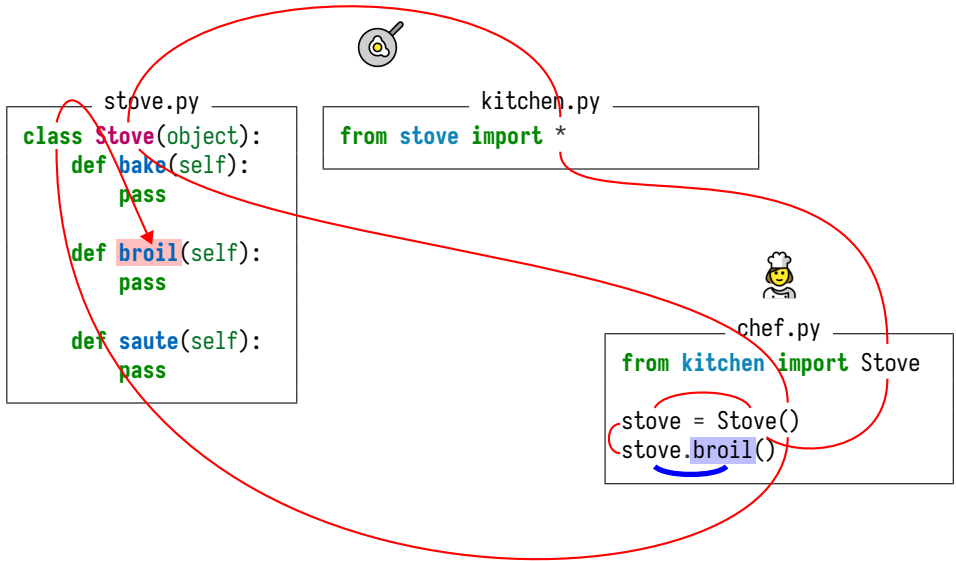

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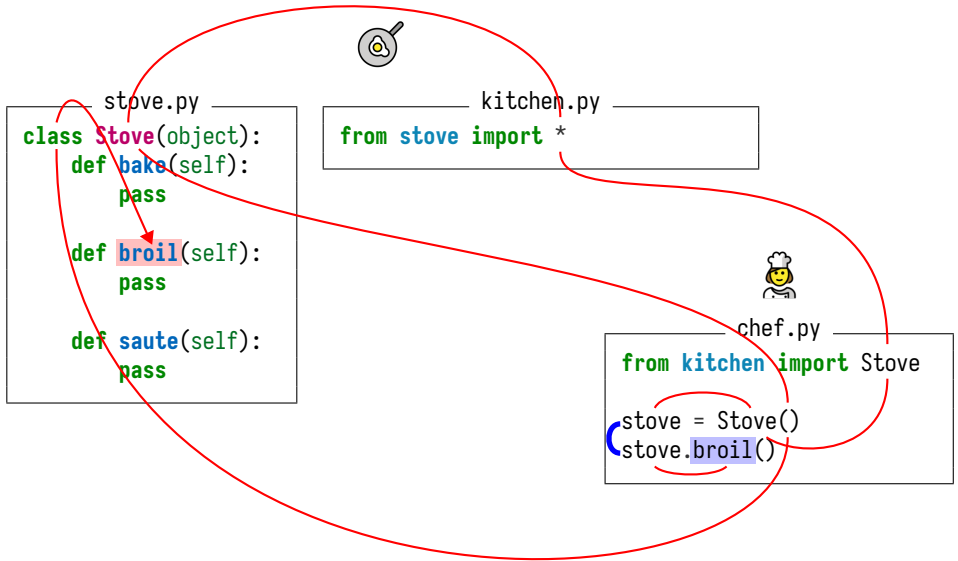

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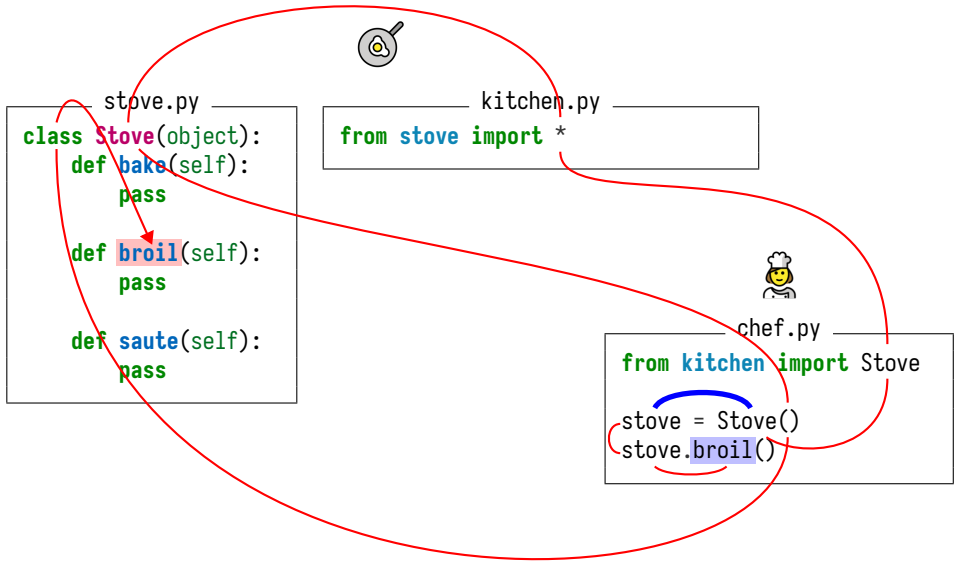

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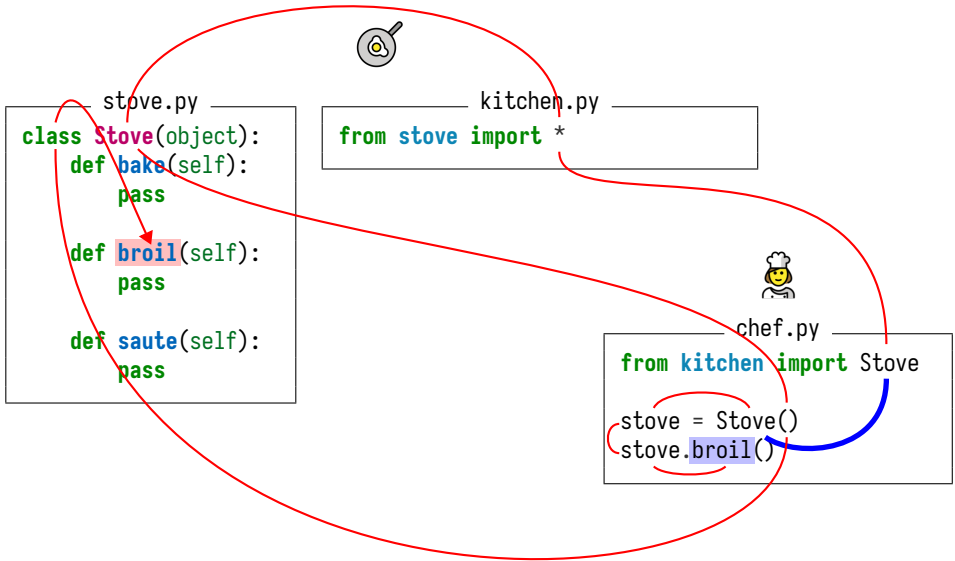

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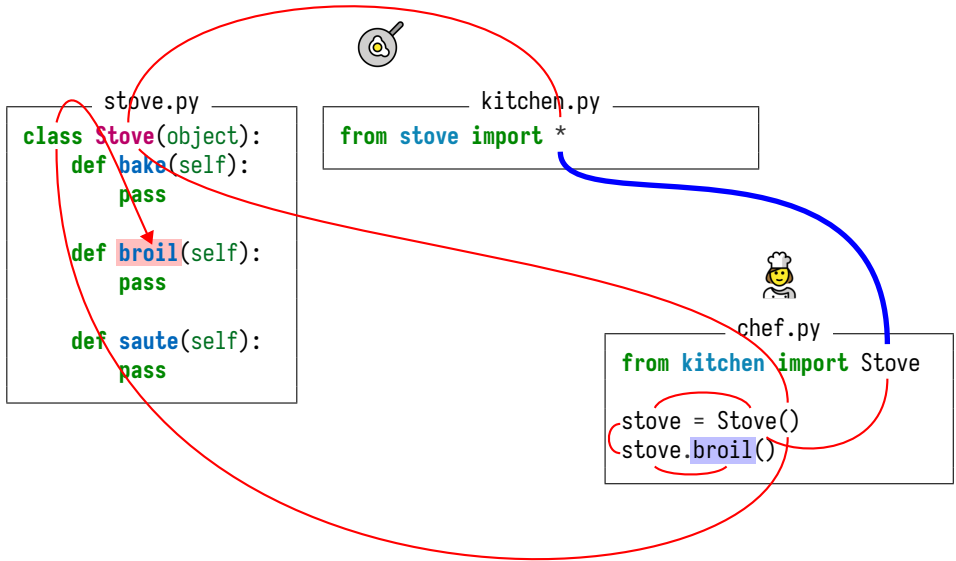

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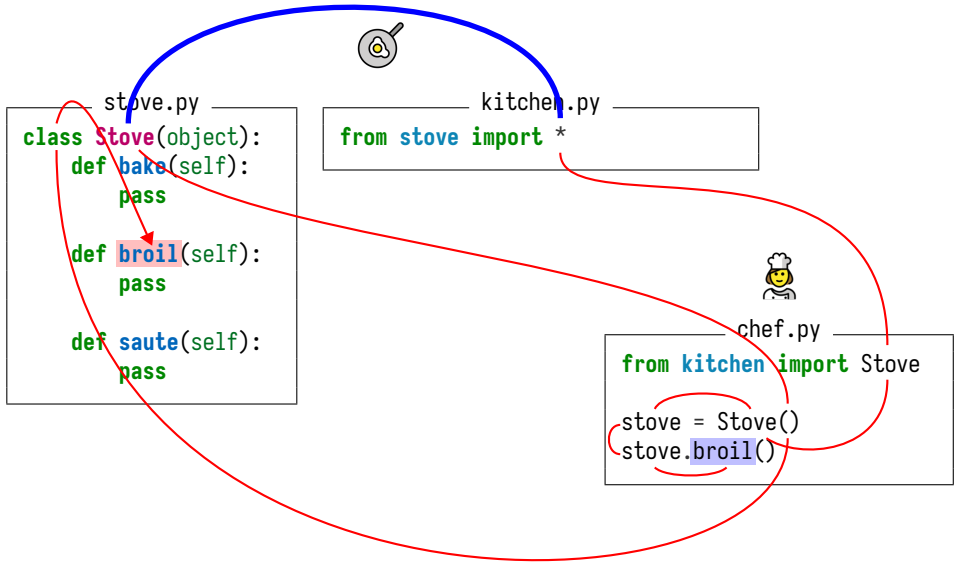

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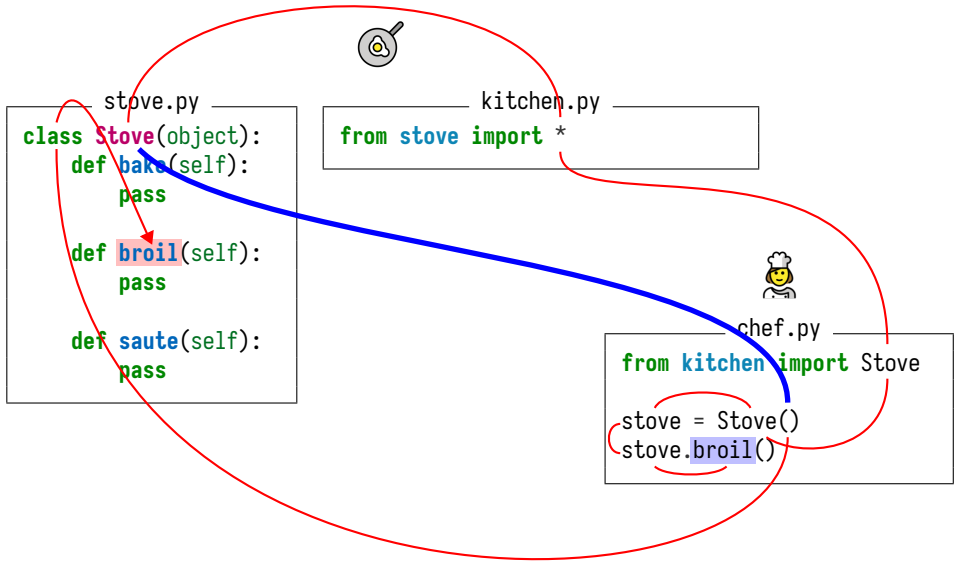

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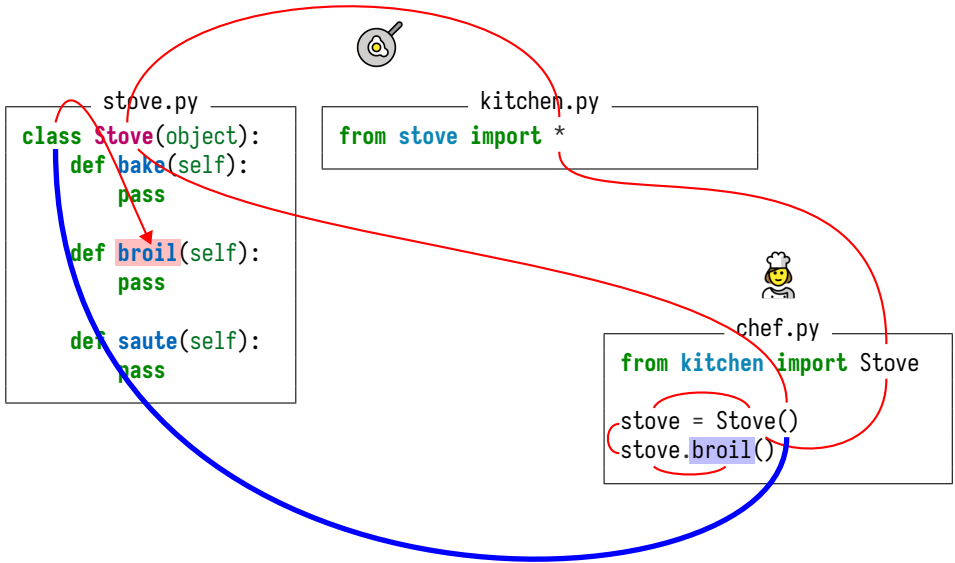

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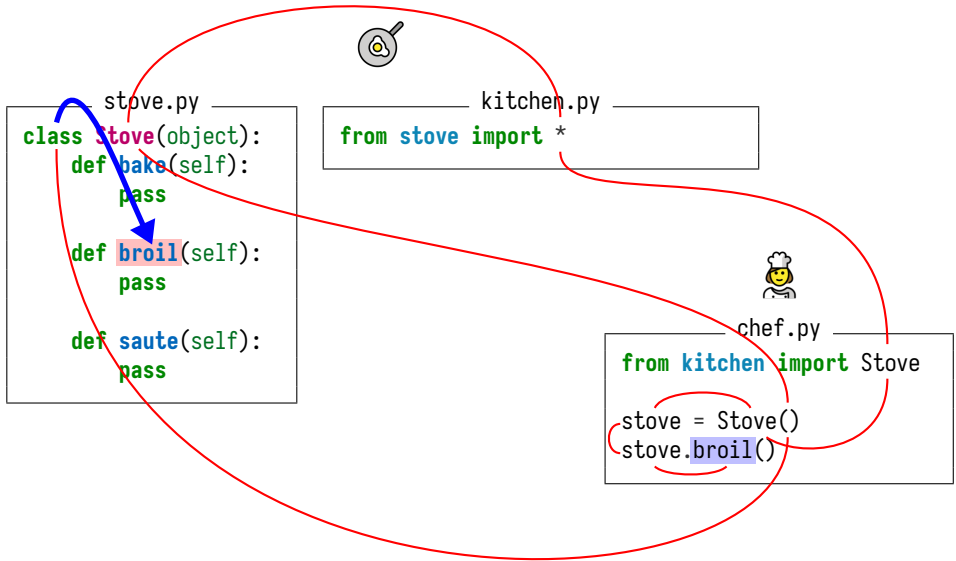

Oh is that all?

Zero configuration

We don't want to have to ask the package owner how to collect the data we need.

Or ask them to configure a job to produce that data.

It should **Just Work**.

SCALE

200 million repositories and counting

2 billion contributions
in the last 12 months

500 programming languages

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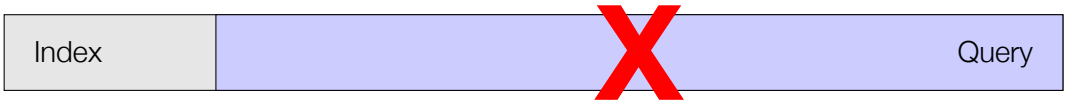
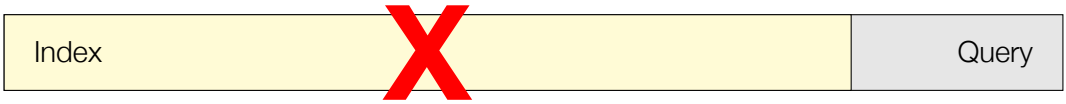


This is an interactive feature, so we can't do too much work at query time.

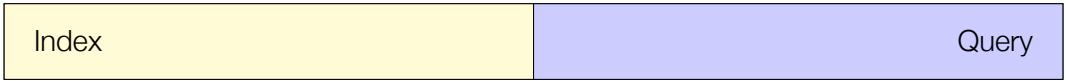
Goal: < 100ms

When do we do the work?



Because of our scale, we can't doo too much work at index time, either!
(Compute and storage costs are too high, work is wasted, etc.)

When do we do the work?



We want to strike a balance.

Precalculate as much as we can.
Minimize the amount of **duplicated** work.
Defer **some** work until query time to make that happen.

Incremental processing

In a typical commit, a small fraction of files in the repo change.

We want to reuse results that we've
already calculated for unchanged files.

Structural sharing (like git itself) helps save storage.

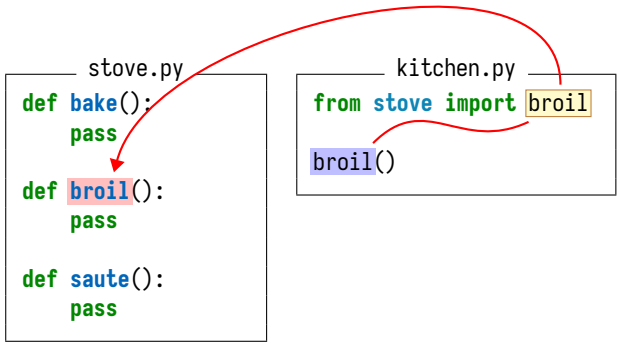
Incremental processing also helps save compute.

Why is this hard?

- Different languages have different name binding rules.
- Some of those rules can be quite complex.
- The result might depend on intermediate files.
- We don’t want to require manual per-repo configuration.
- We need incremental processing to handle our scale.

Incremental results

What would incremental results look like?



What would incremental results look like?

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def bake():
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`stove.broil` is defined at *stove.py:4:5*

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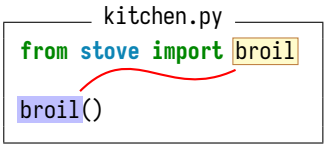

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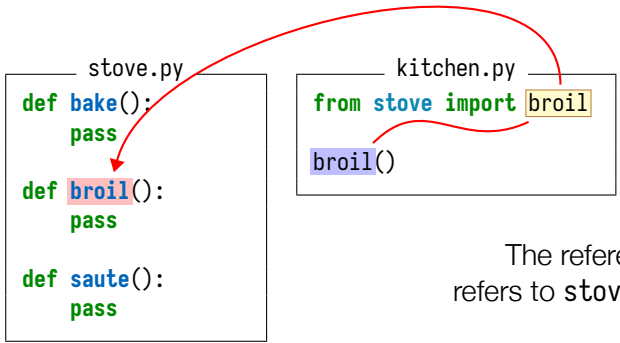

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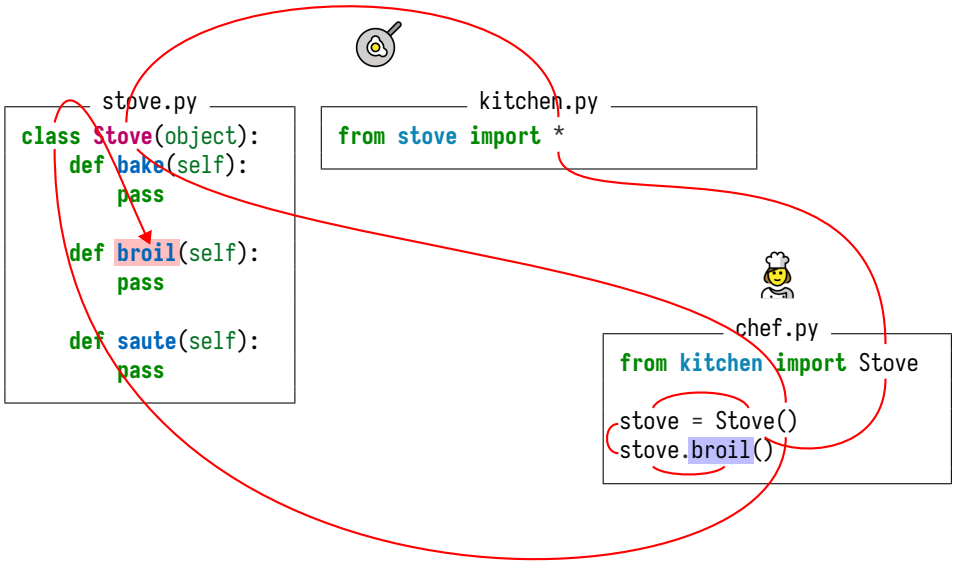
The more complex example



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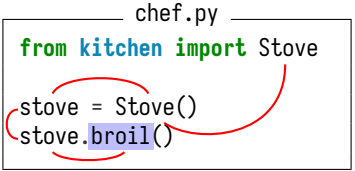

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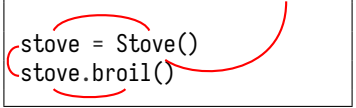

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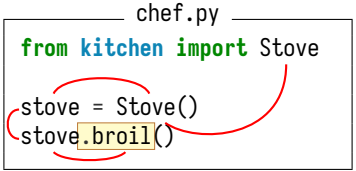

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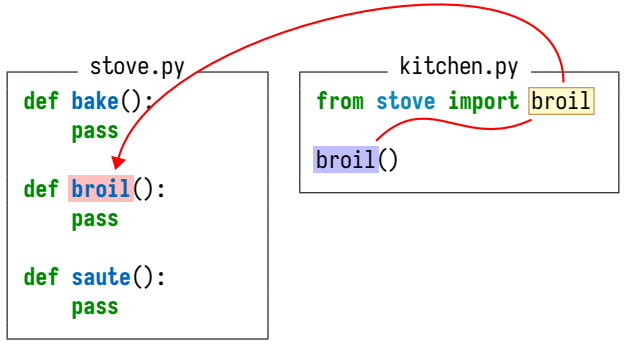

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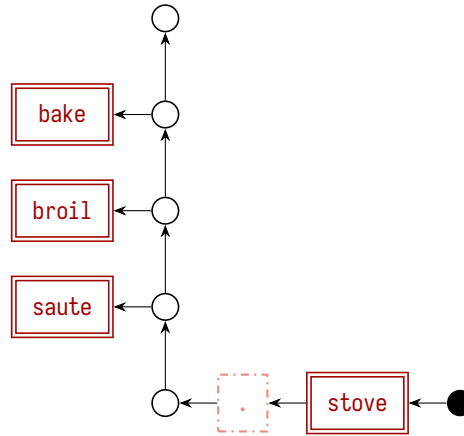

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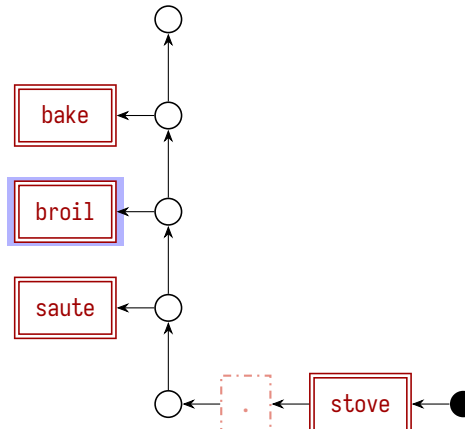

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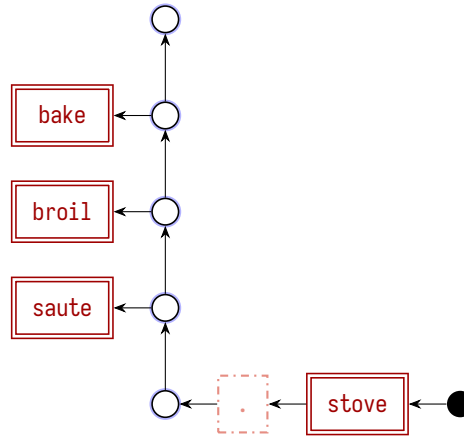

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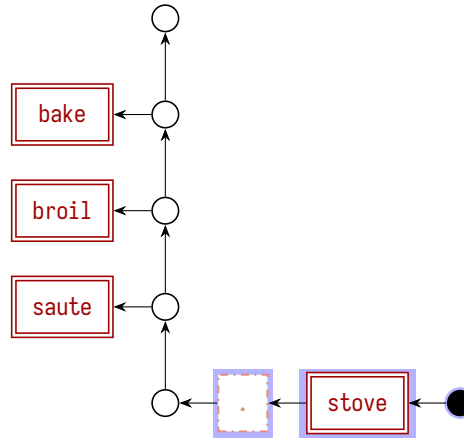

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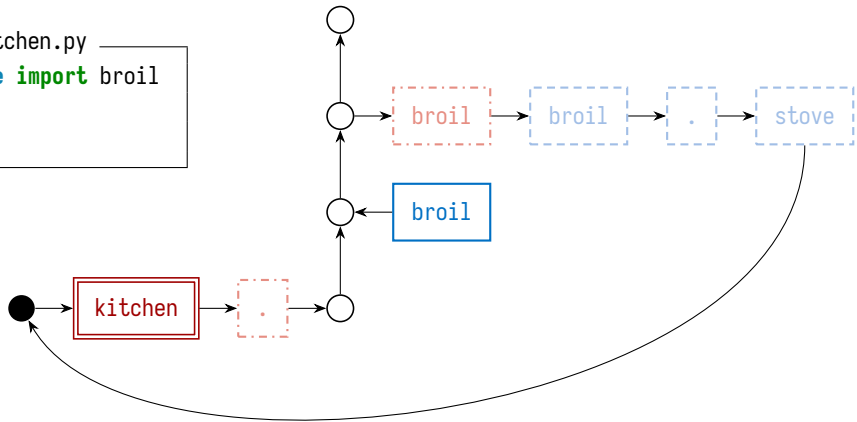

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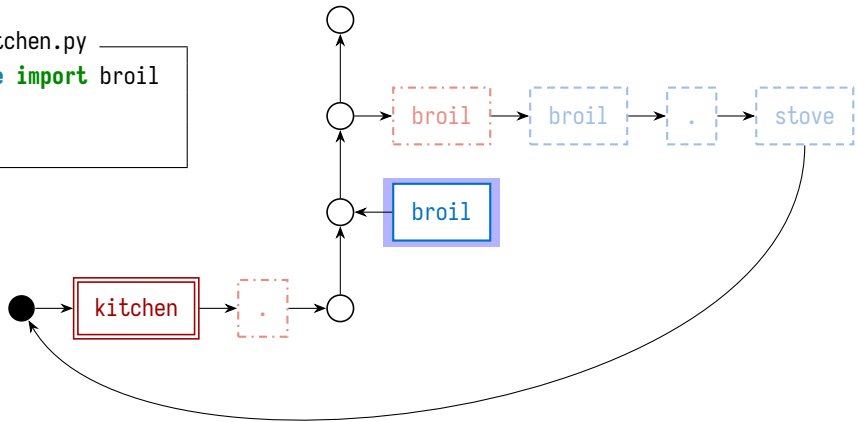
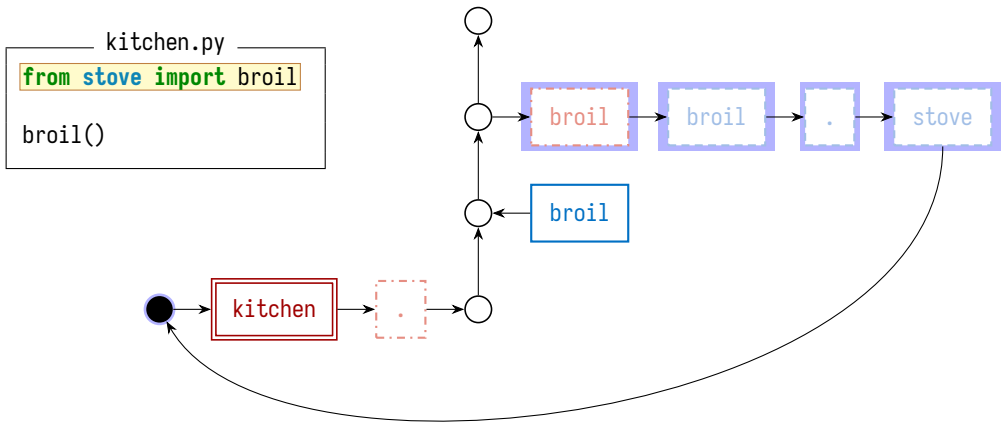


Stack graphs



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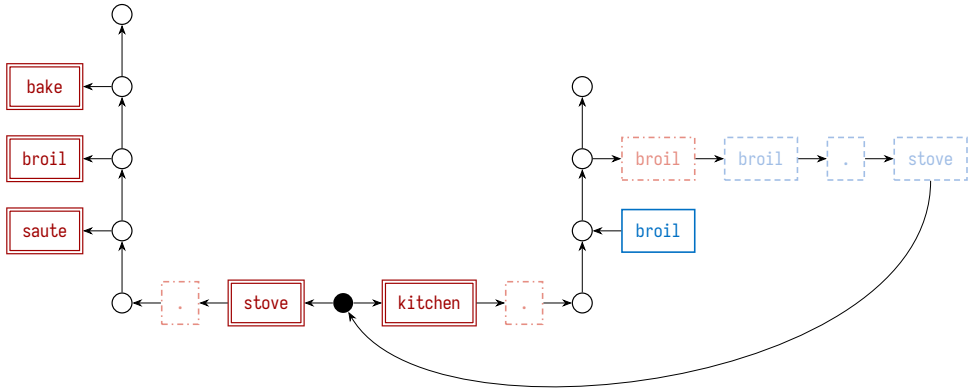

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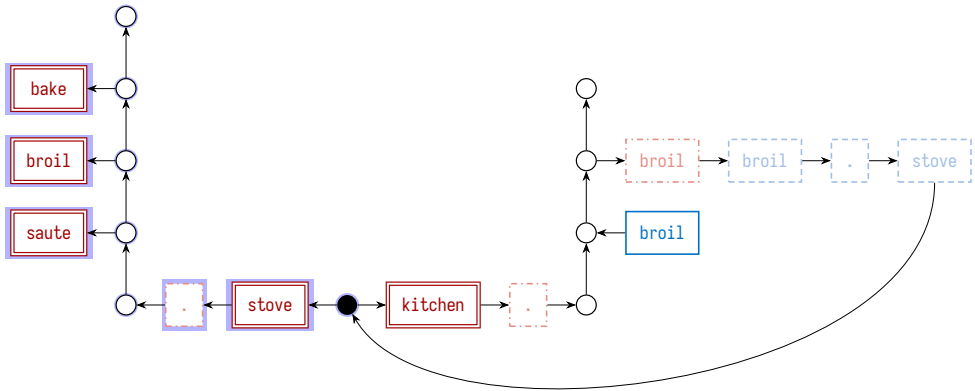

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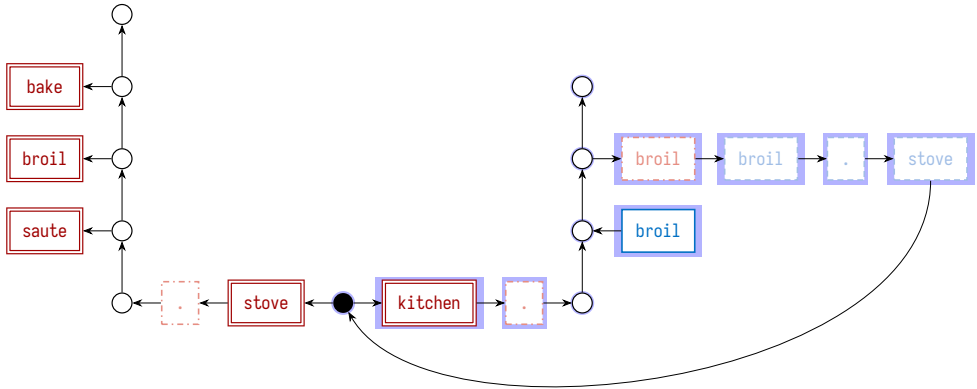

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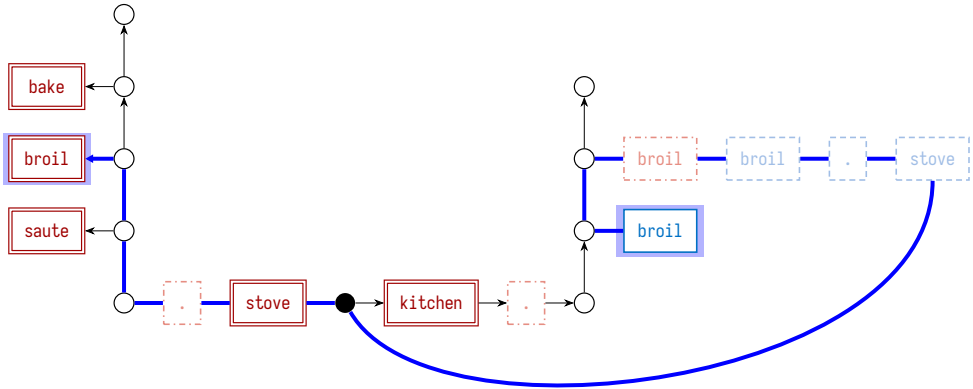

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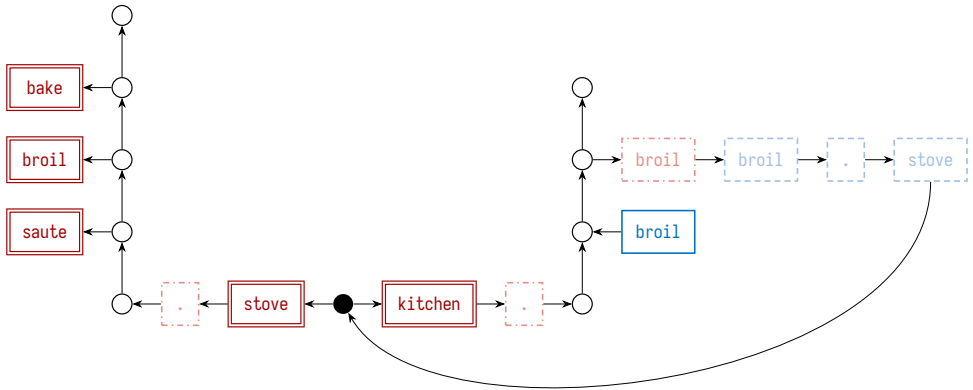

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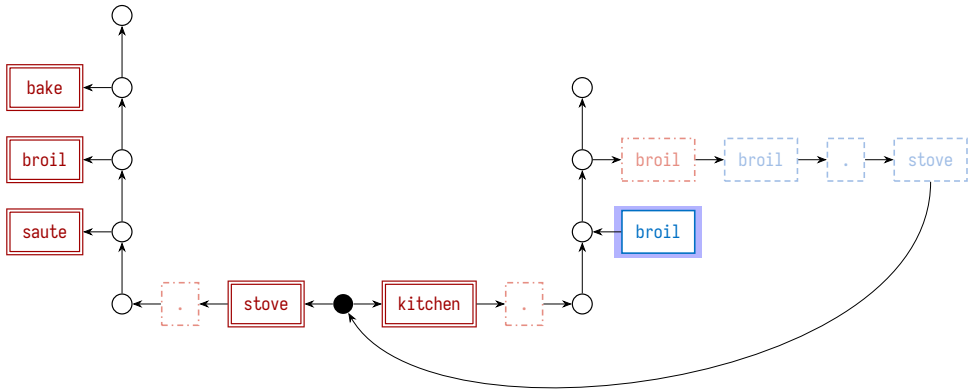
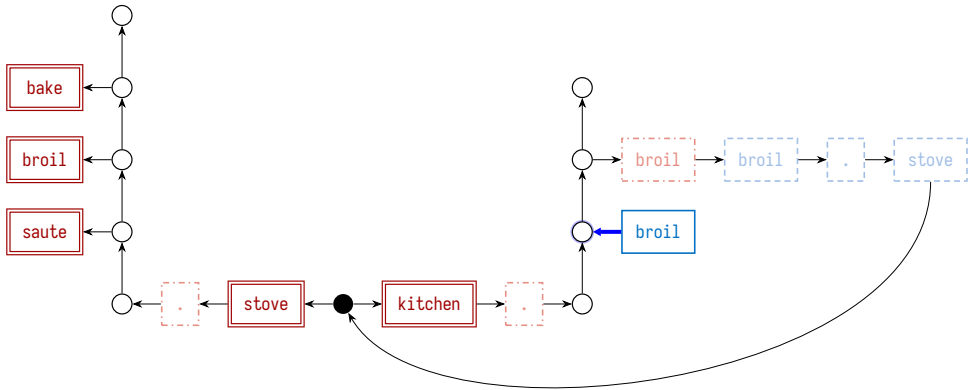


Symbol stack: ⟨broil⟩

Stack graphs



Symbol stack: ⟨broil⟩

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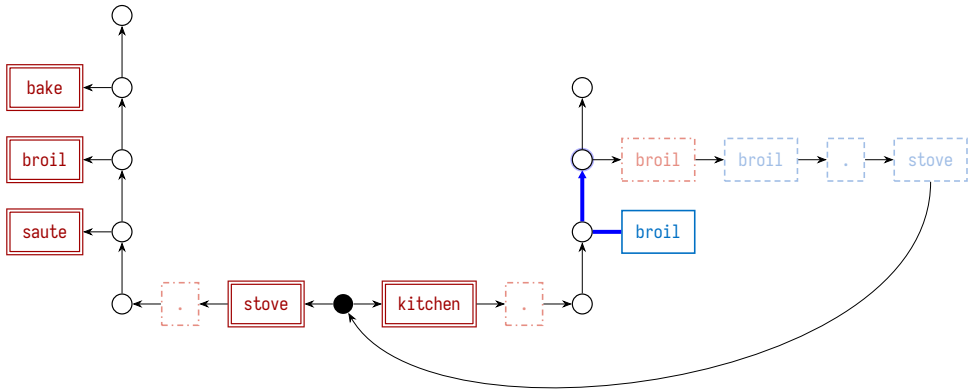
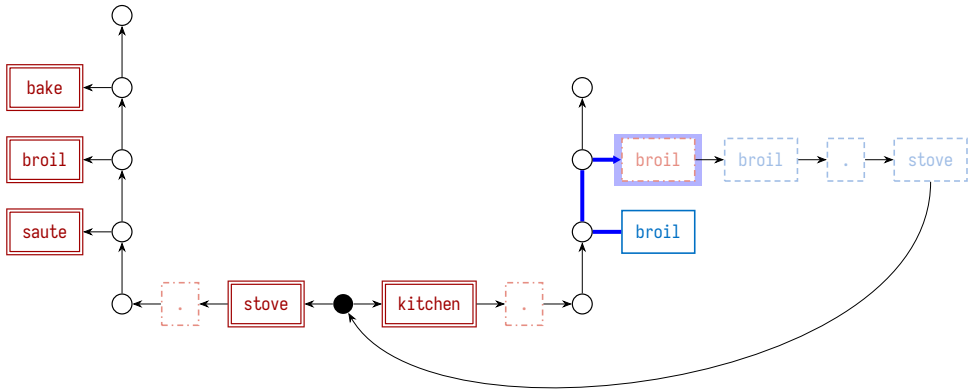


Symbol stack: ⟨broil⟩

Stack graphs



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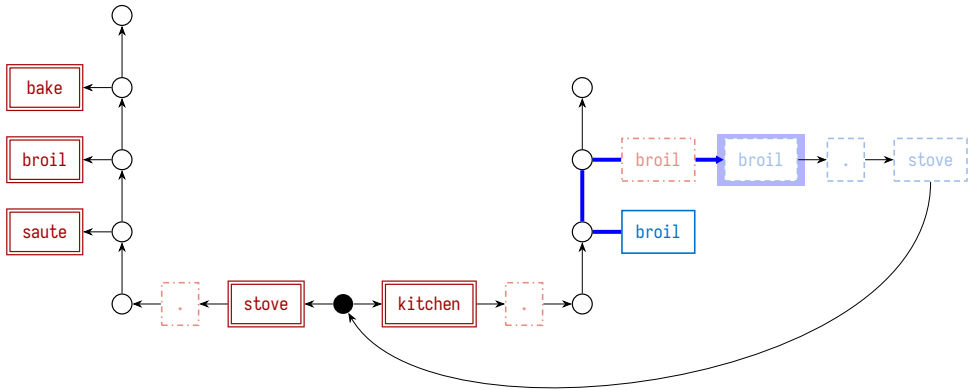
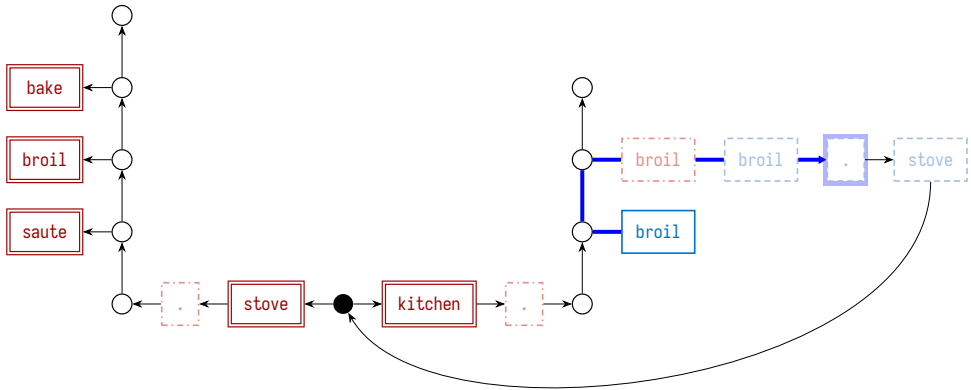


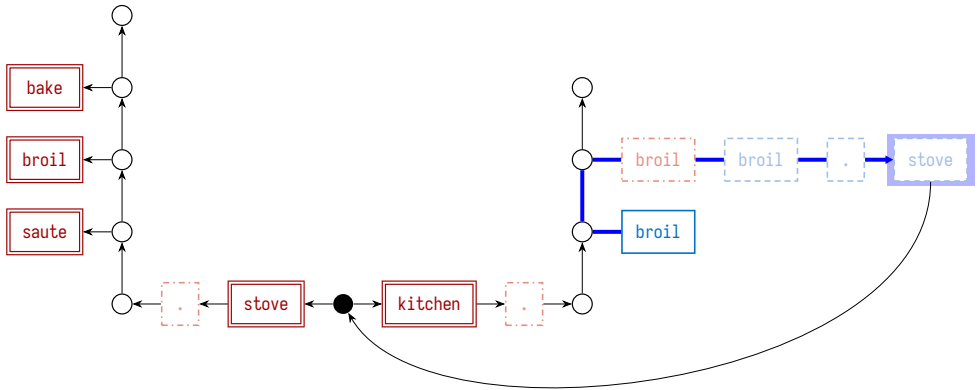
Symbol stack: ⟨broil⟩

Stack graphs



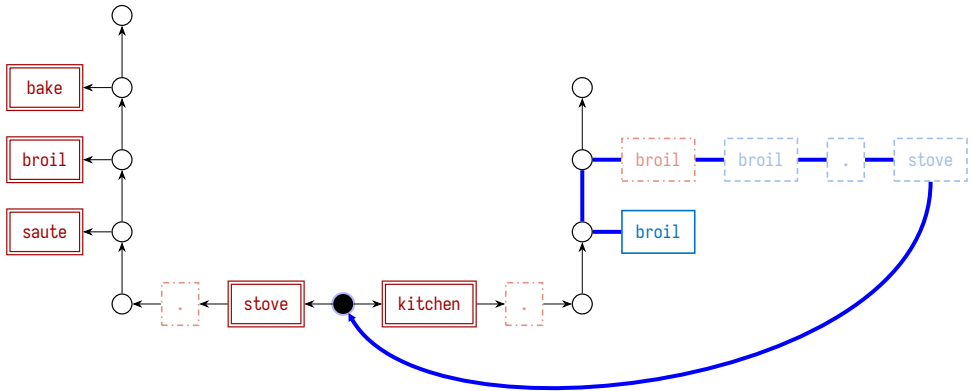
Symbol stack: ⟨.broil⟩

Stack graphs



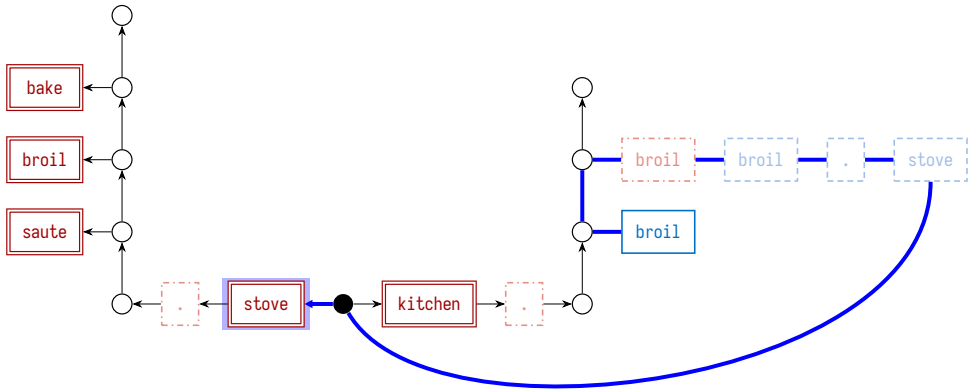
Symbol stack: ⟨stove.broil⟩

Stack graphs



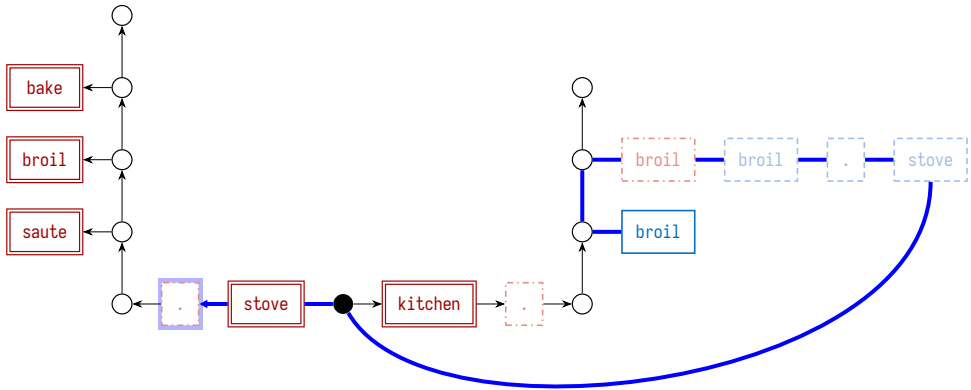
Symbol stack: ⟨stove.broil⟩

Stack graphs



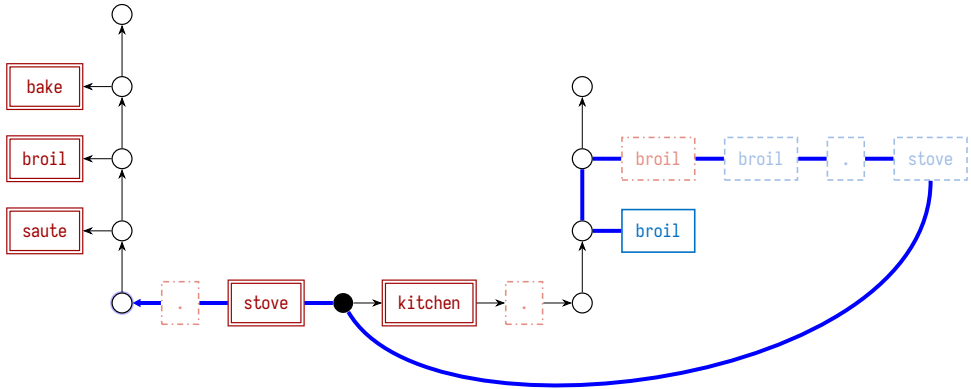
Symbol stack: ⟨.broil⟩

Stack graphs



Symbol stack: ⟨broil⟩

Stack graphs



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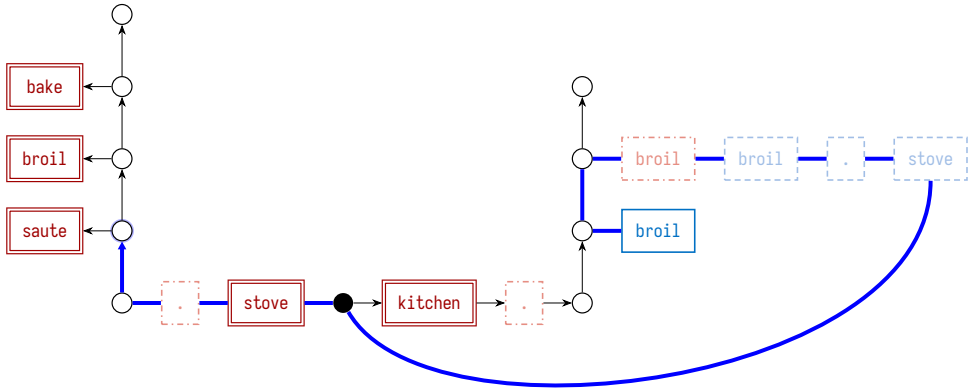
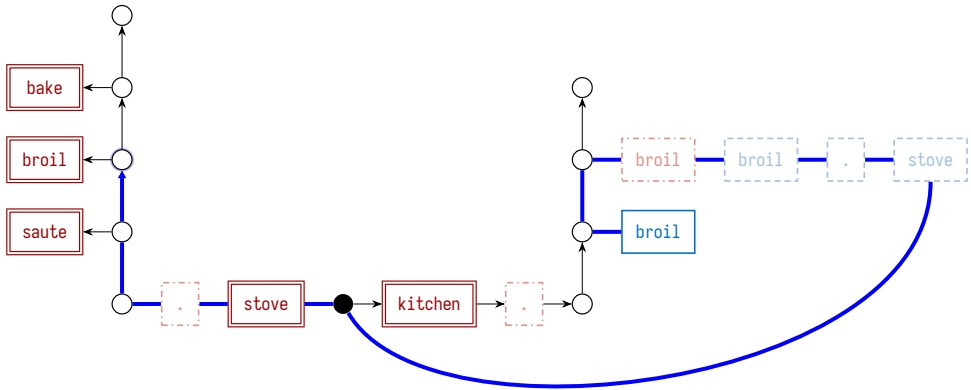
Stack graphs



Symbol stack: ⟨broil⟩

Stack graphs



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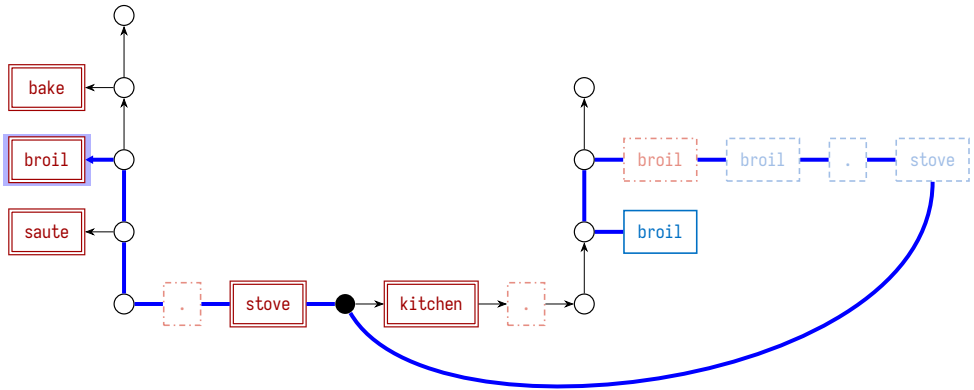
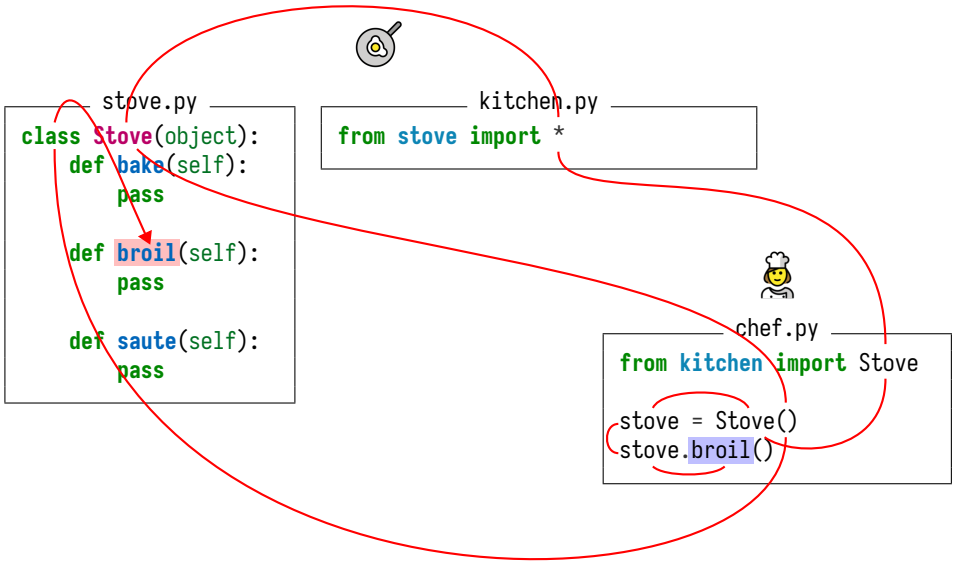
Stack graphs



Symbol stack: ⟨⟩

The more complex example



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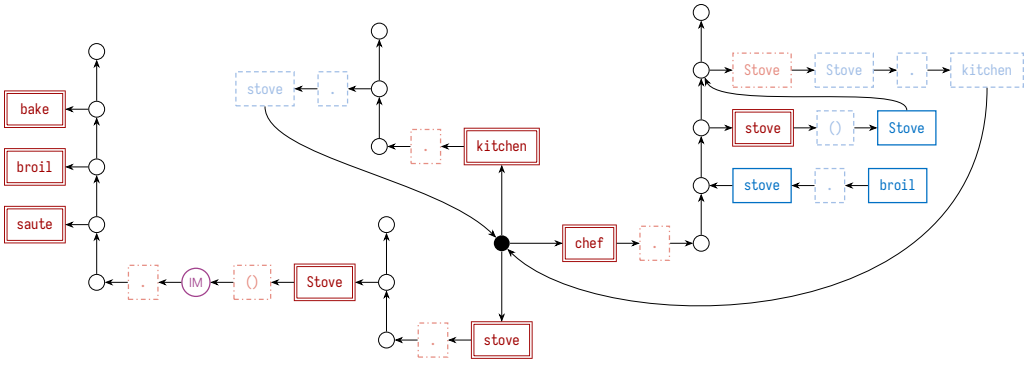

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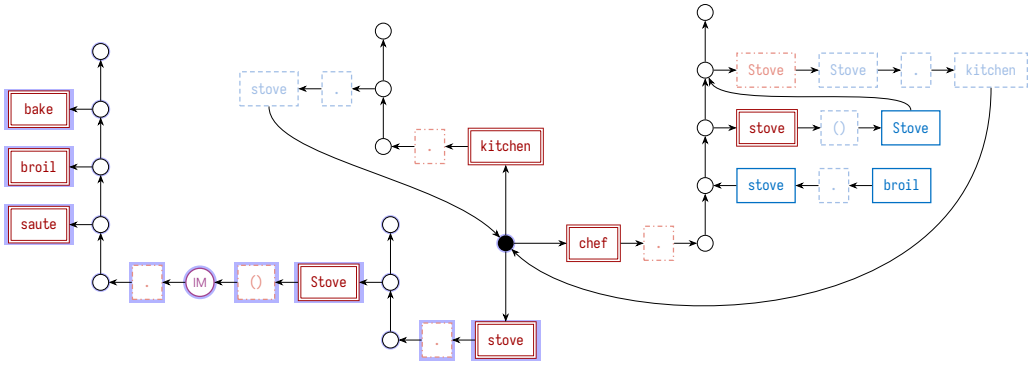

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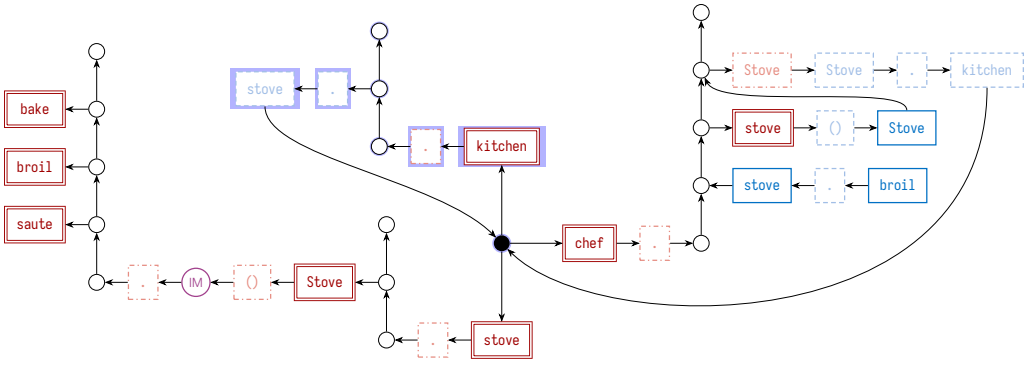

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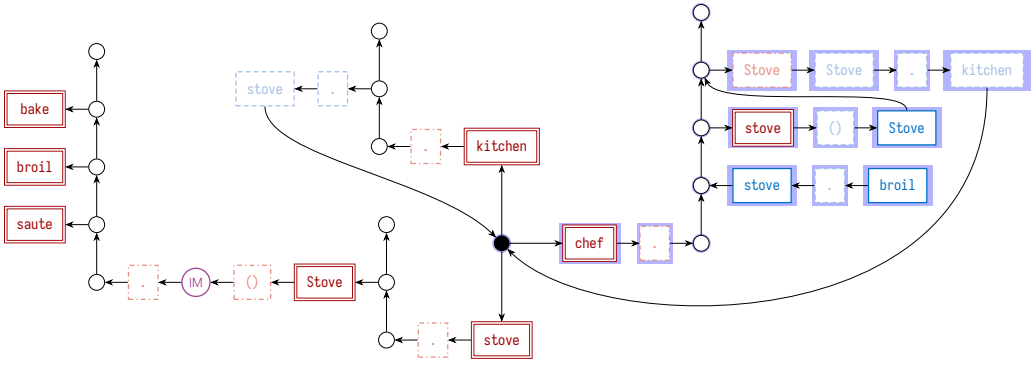

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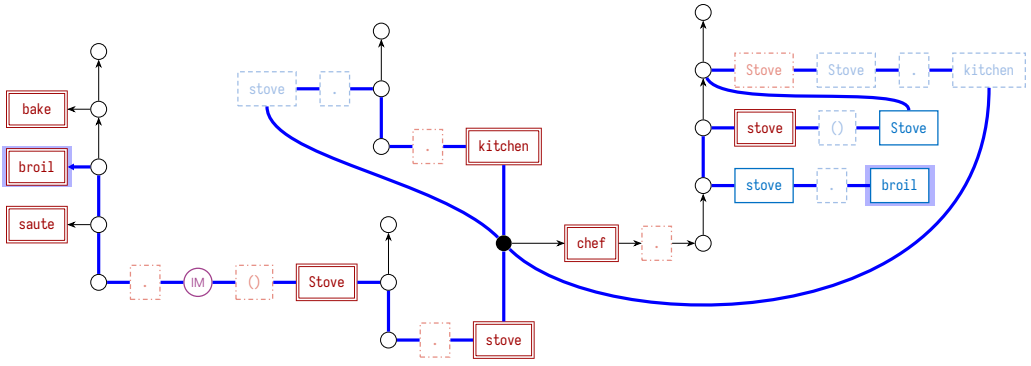

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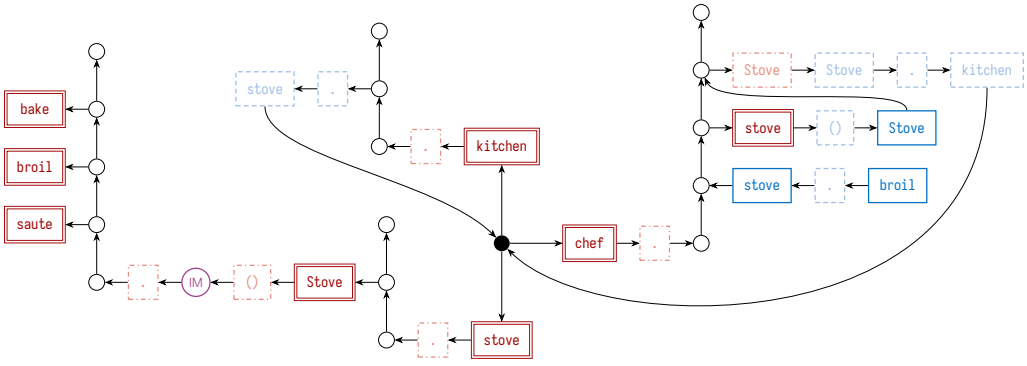
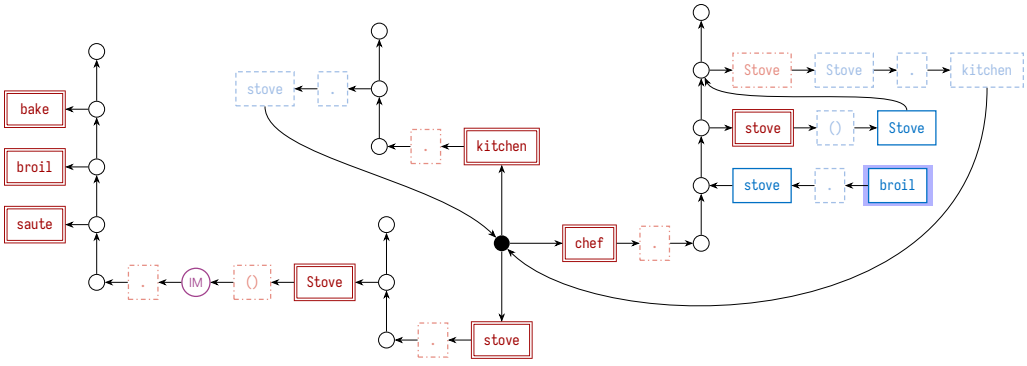


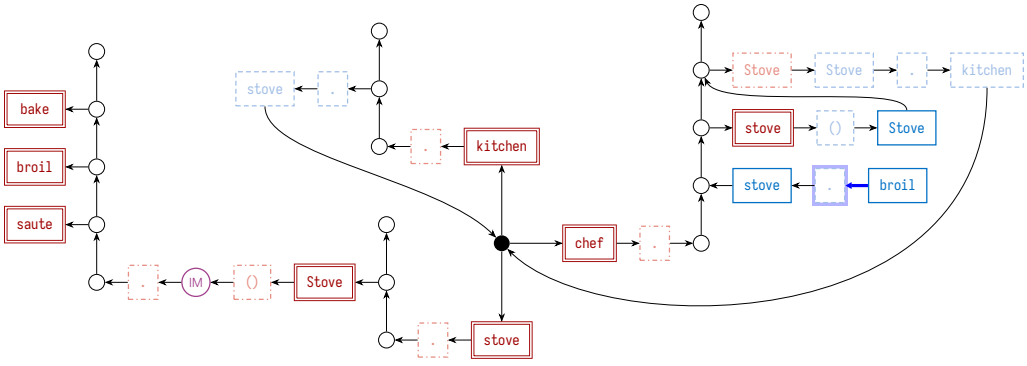
Symbol stack: ⟨⟩

The more complex example



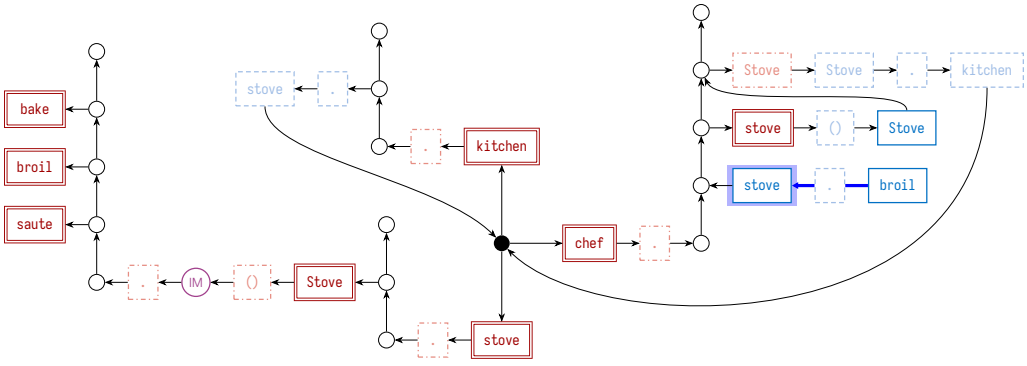
Symbol stack: ⟨`broil`⟩

The more complex example



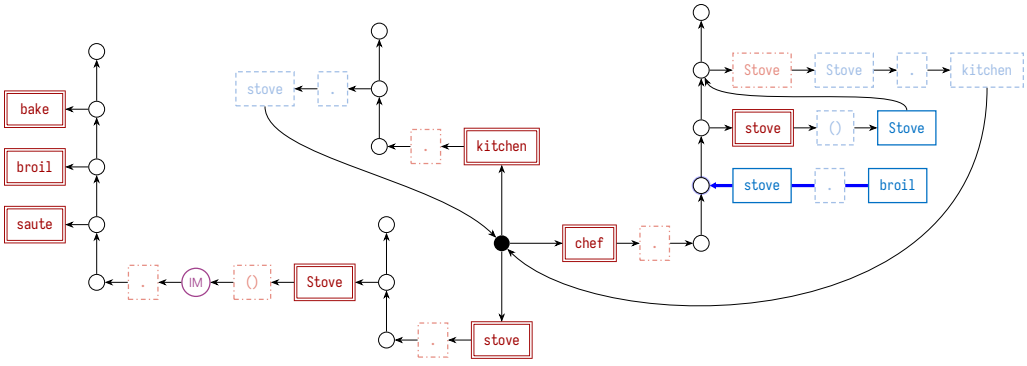
Symbol stack: ⟨`.broil`⟩

The more complex example



Symbol stack: ⟨`stove.broil`⟩

The more complex example



Symbol stack: ⟨`stove.broil`⟩

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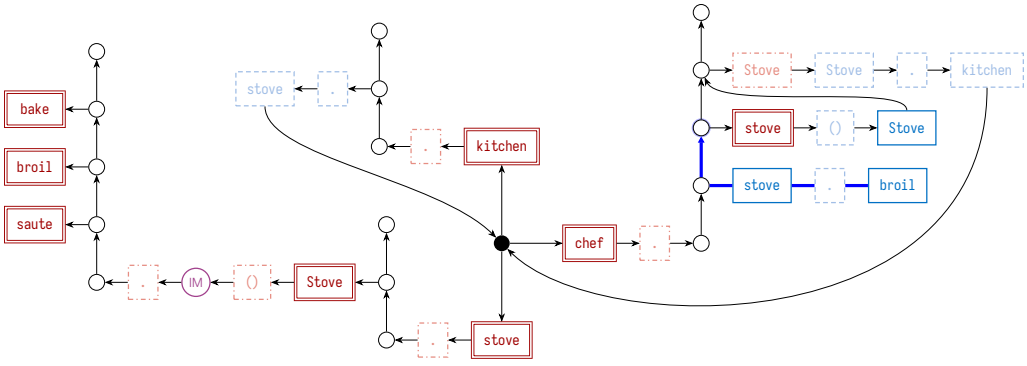

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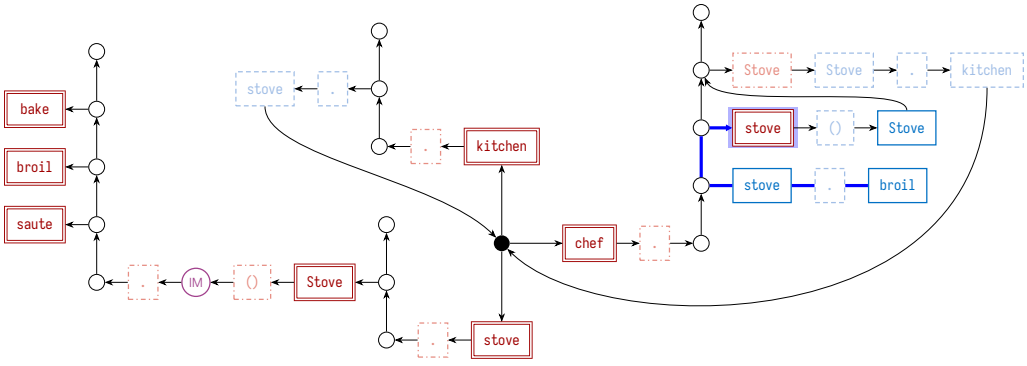

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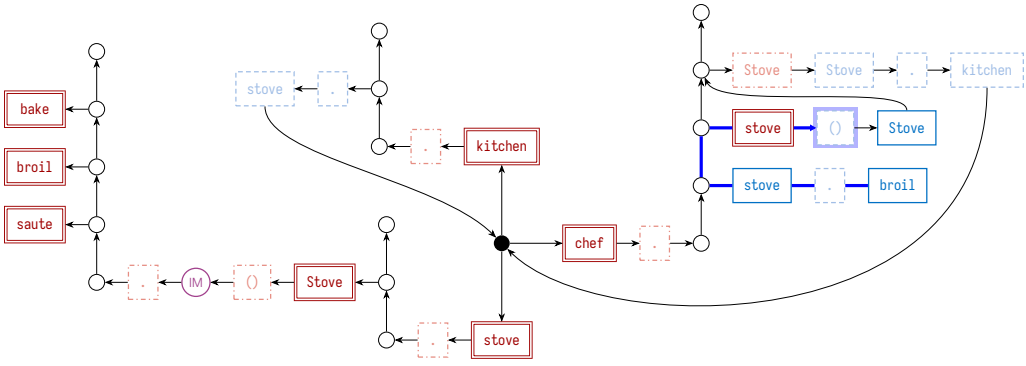
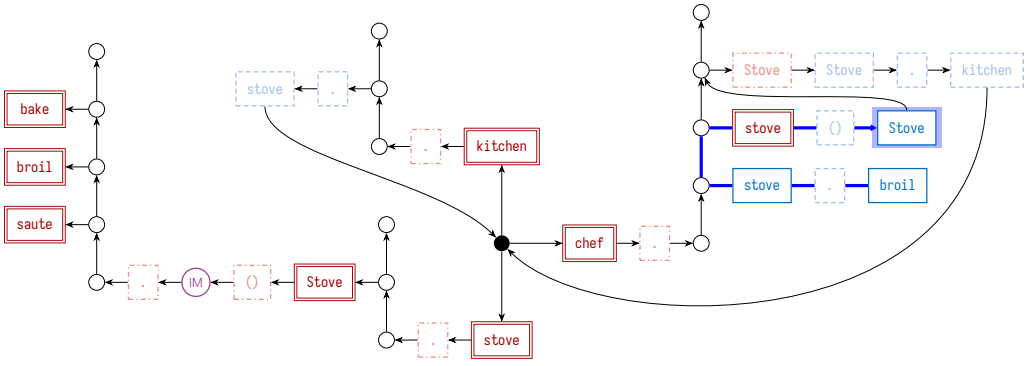
The more complex example



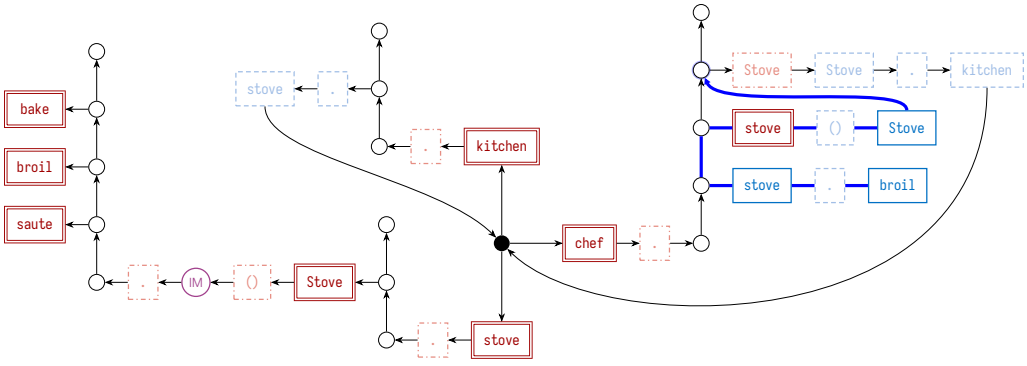
Symbol stack: ⟨`().broil`⟩

The more complex example



Symbol stack: ⟨`Stove().broil`⟩

The more complex example



Symbol stack: ⟨`Stove().broil`⟩

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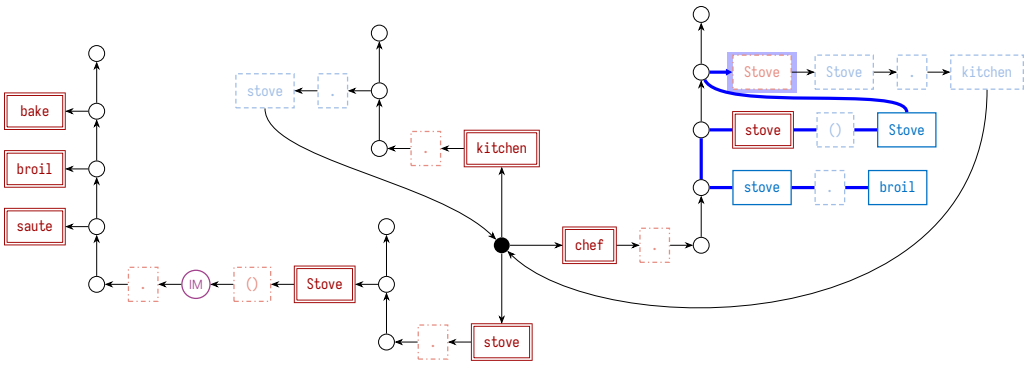
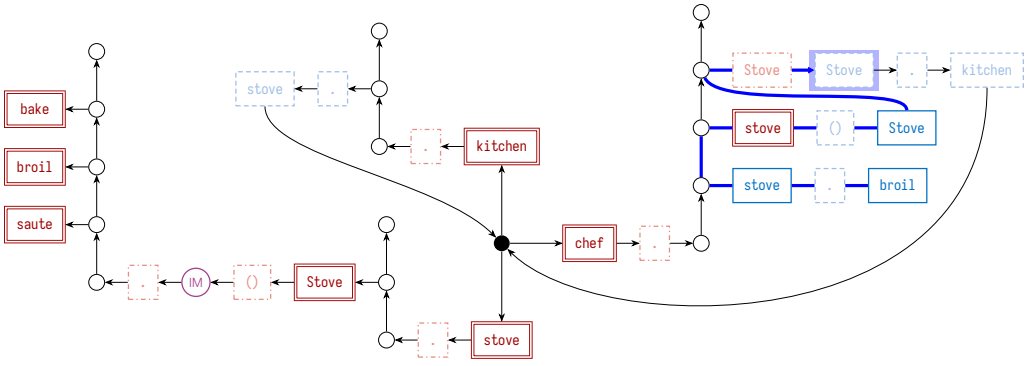


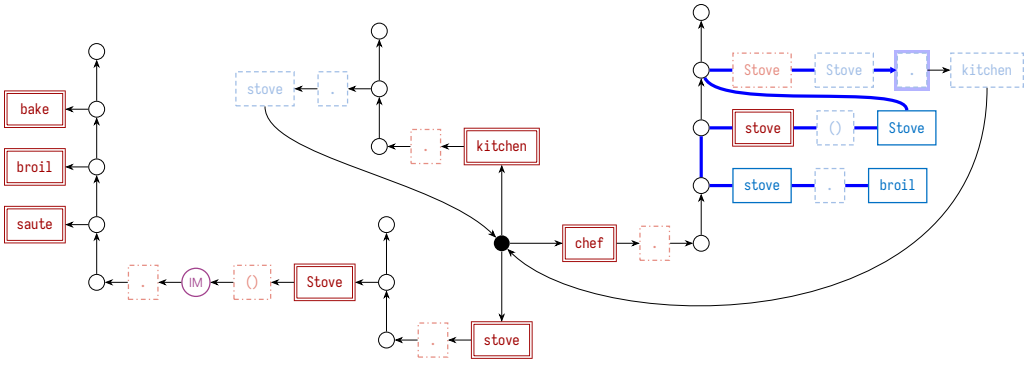
Symbol stack: ⟨`().broil`⟩

The more complex example



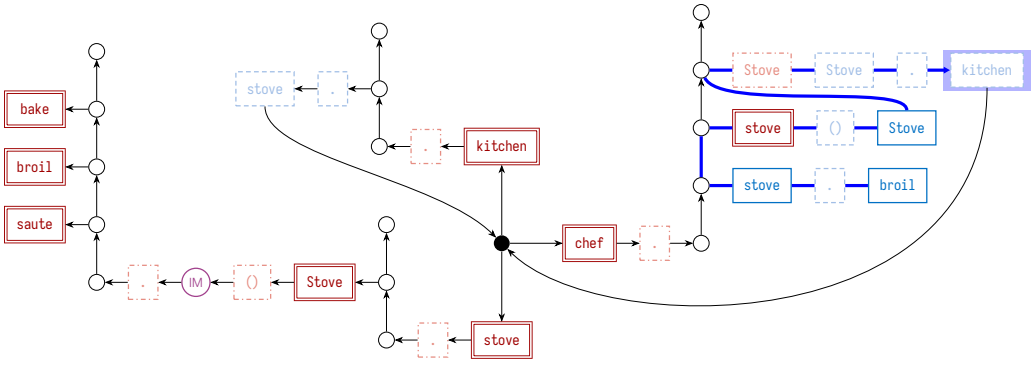
Symbol stack: ⟨`Stove().broil`⟩

The more complex example



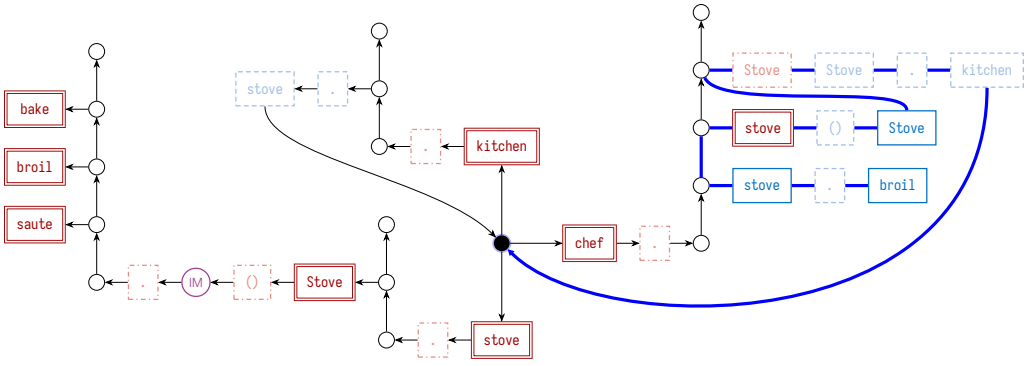
Symbol stack: ⟨.Stove().broil⟩

The more complex example



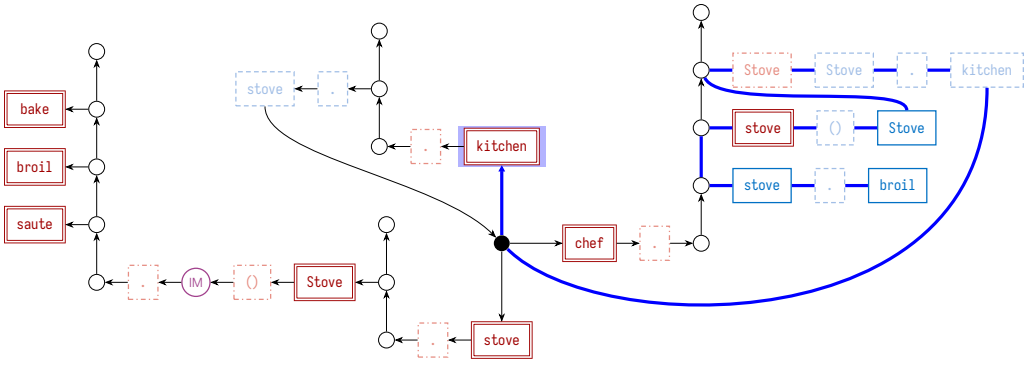
Symbol stack: ⟨`kitchen.Stove().broil`⟩

The more complex example



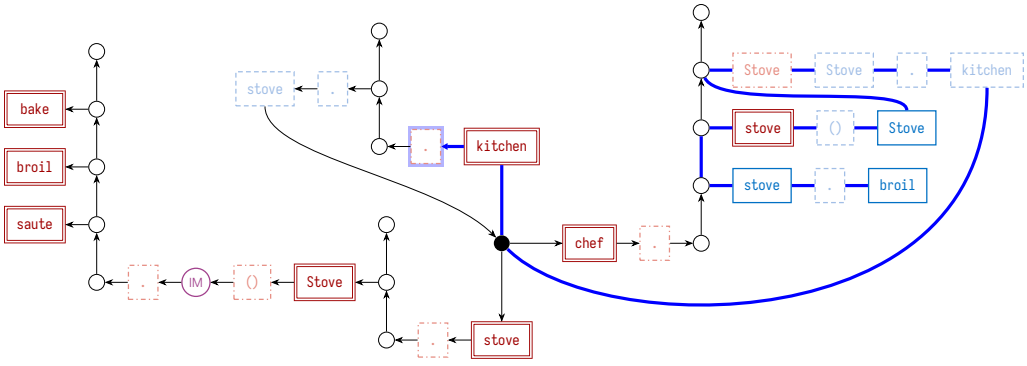
Symbol stack: ⟨`kitchen.Stove().broil`⟩

The more complex example



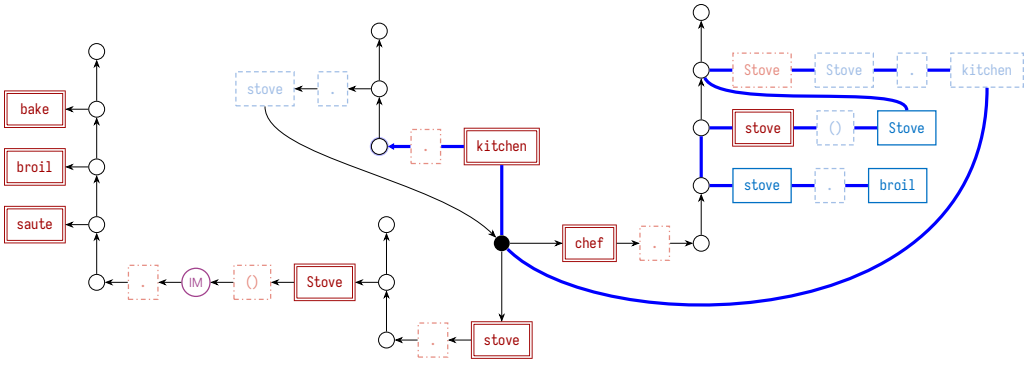
Symbol stack: ⟨.Stove().broil⟩

The more complex example



Symbol stack: ⟨`Stove().broil`⟩

The more complex example



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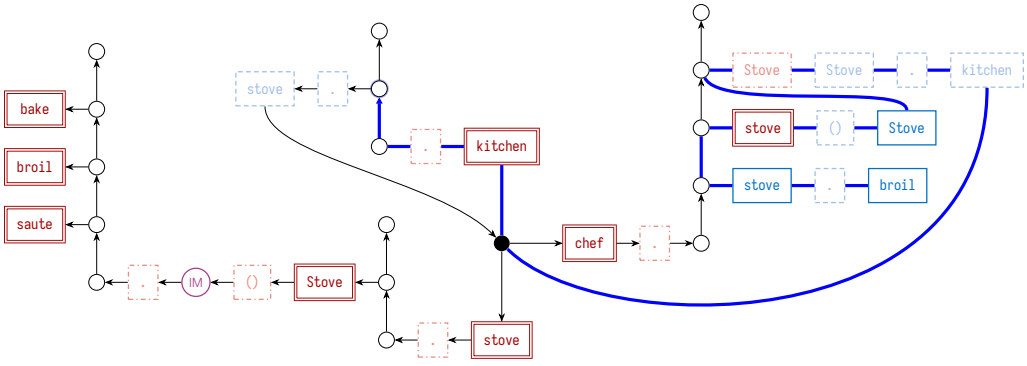
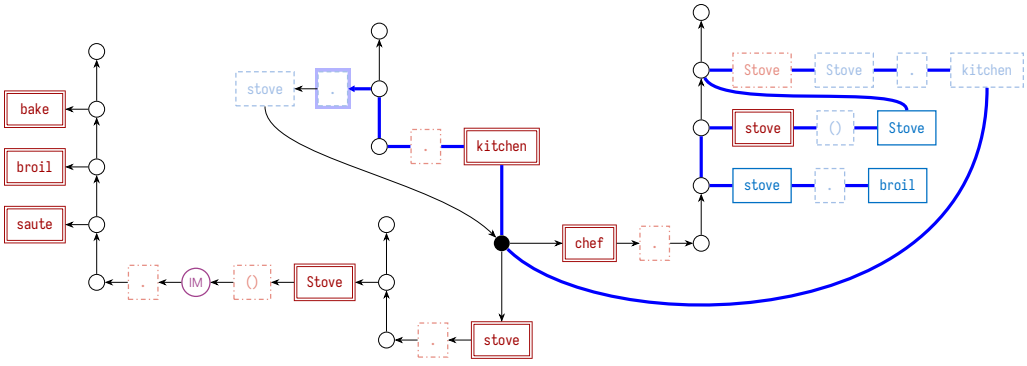


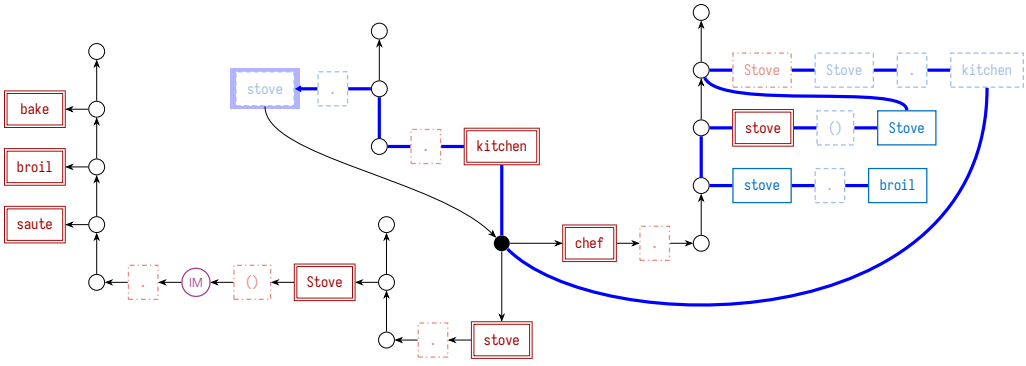
Symbol stack: ⟨`Stove().broil`⟩

The more complex example



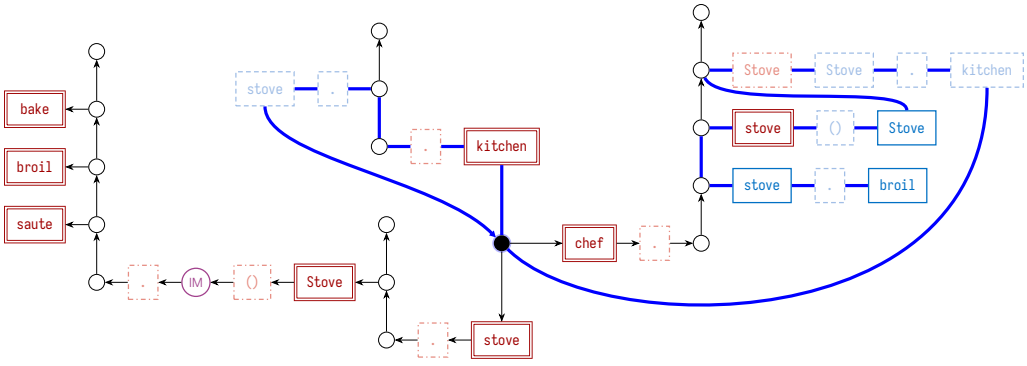
Symbol stack: ⟨.Stove().broil⟩

The more complex example



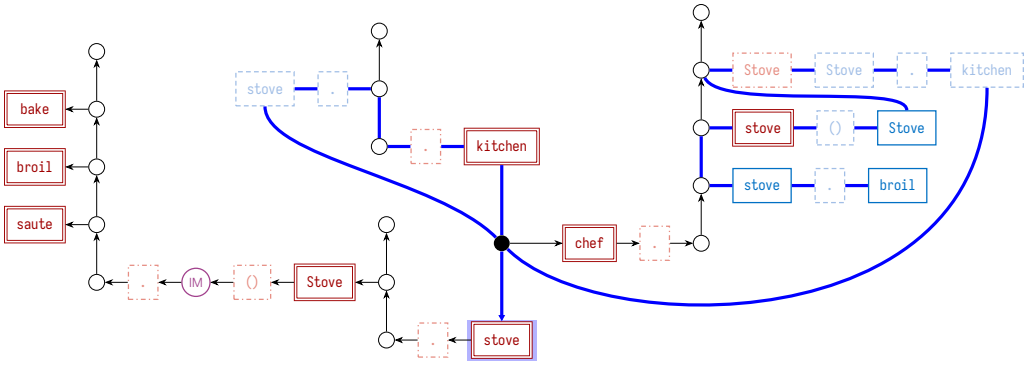
Symbol stack: ⟨`stove.Stove().broil`⟩

The more complex example



Symbol stack: ⟨`stove.Stove().broil`⟩

The more complex example



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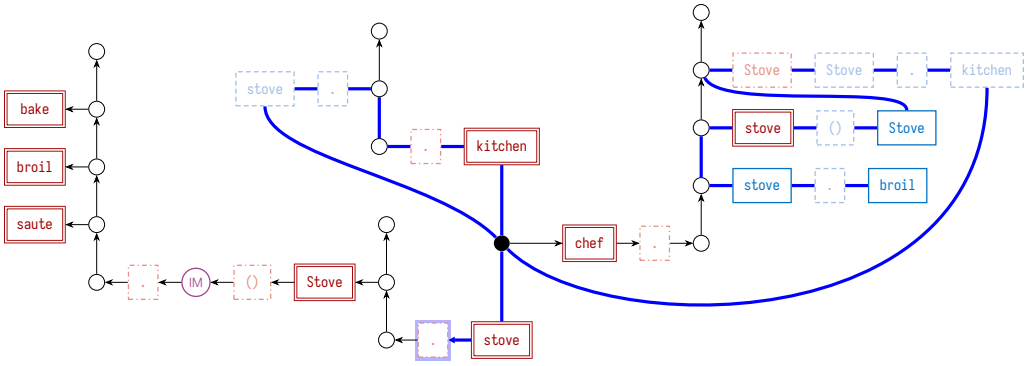
The more complex example



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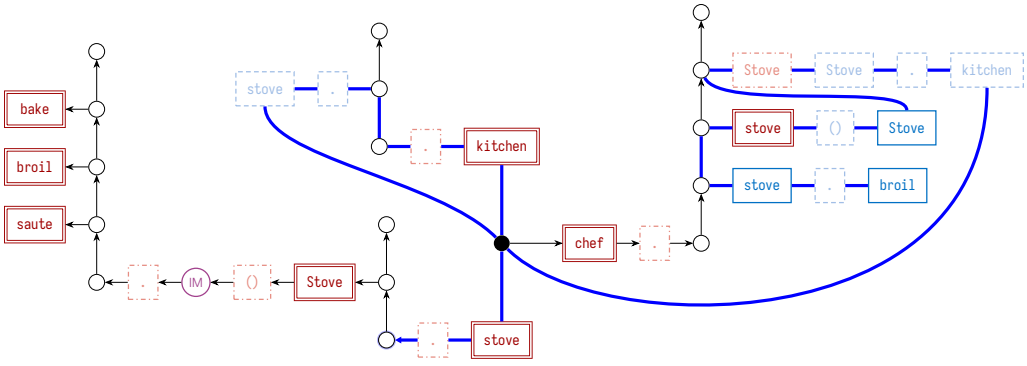

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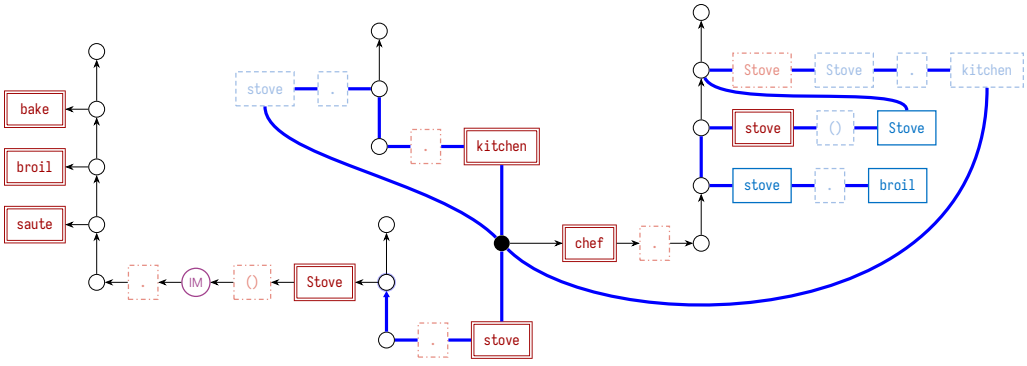
The more complex example



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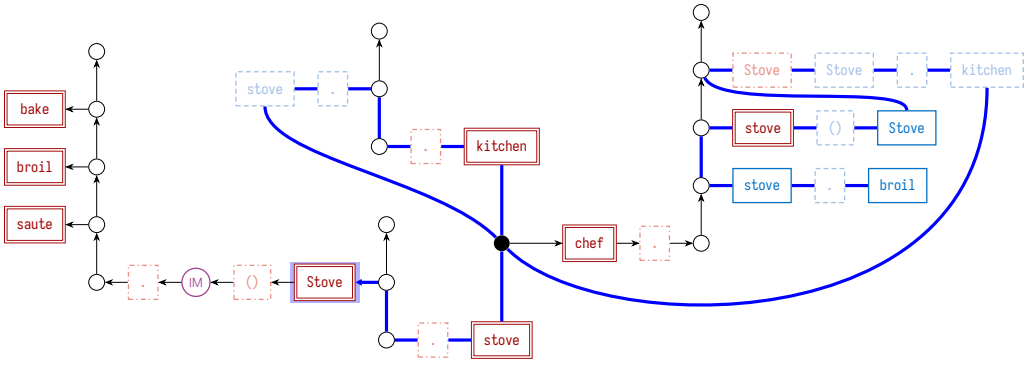
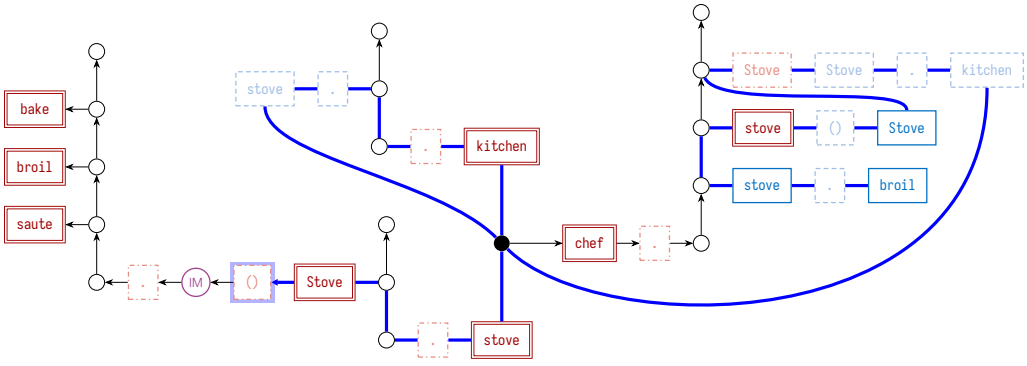
The more complex example



Symbol stack: ⟨`().broil`⟩

The more complex example



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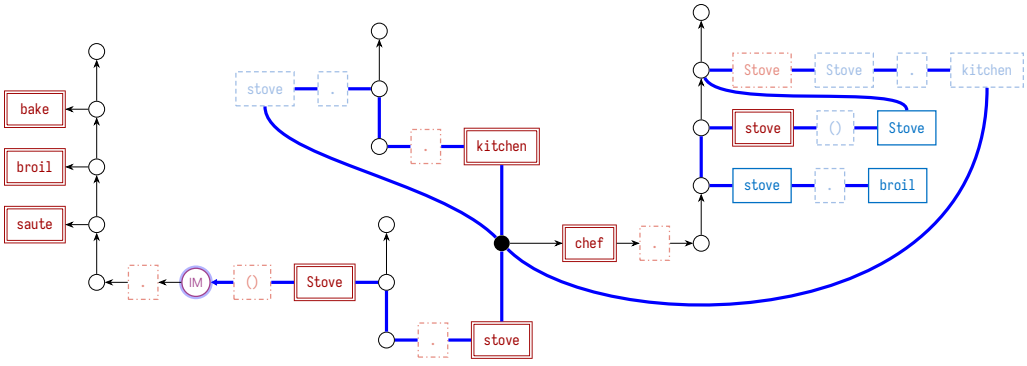
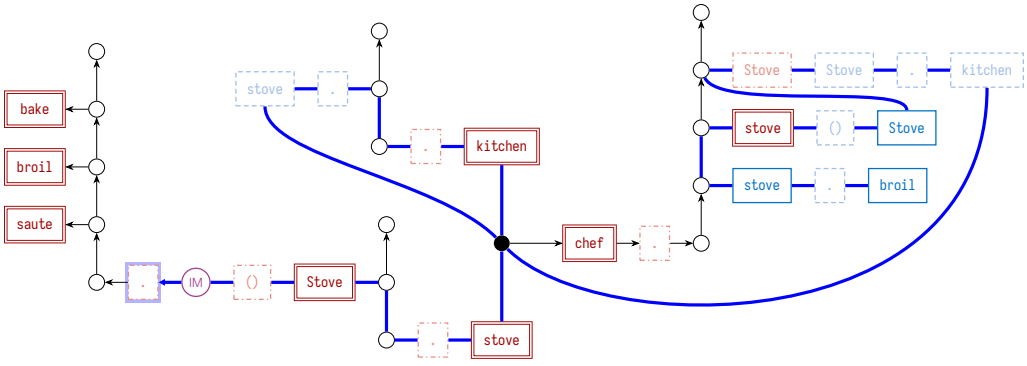
The more complex example



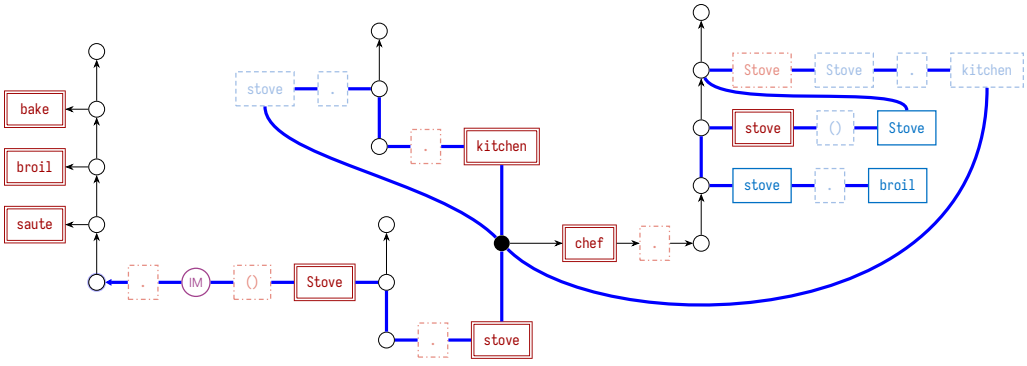
Symbol stack: ⟨`.broil`⟩

The more complex example



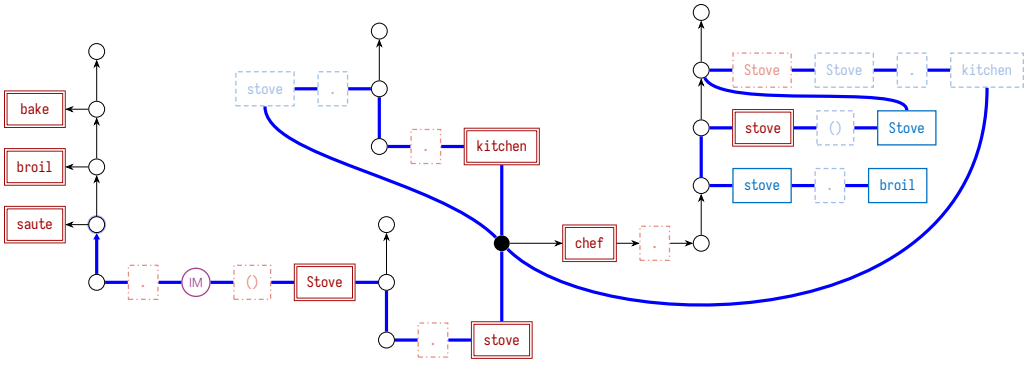
Symbol stack: ⟨`broil`⟩

The more complex example



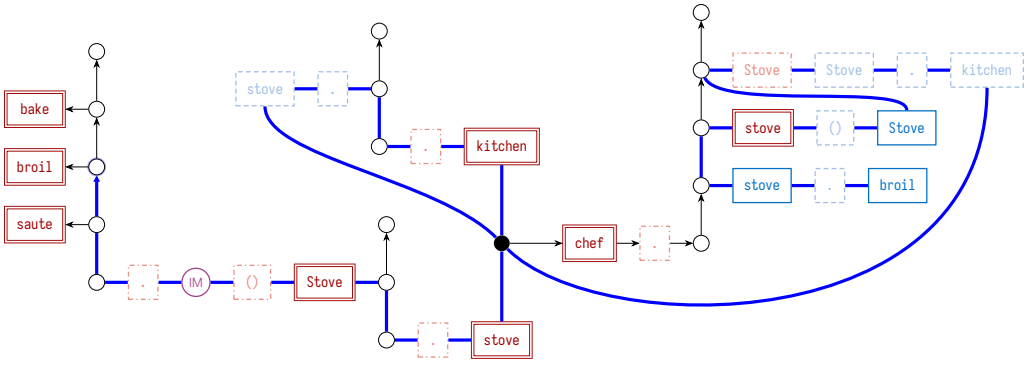
Symbol stack: ⟨`broil`⟩

The more complex example



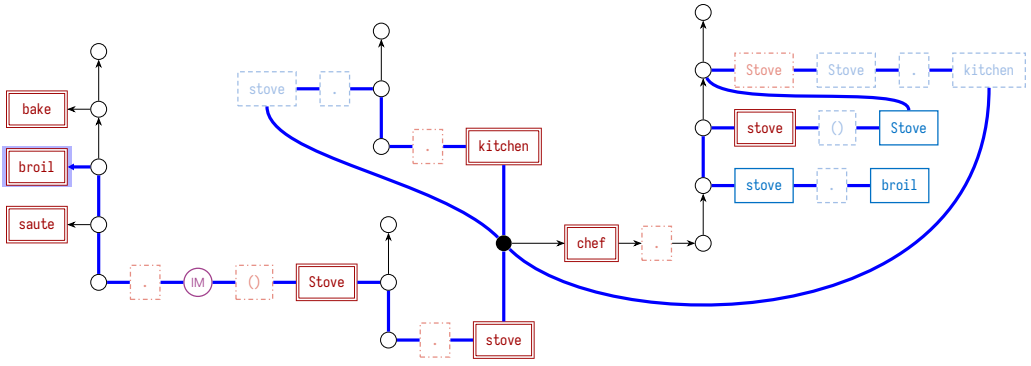
Symbol stack: ⟨`broil`⟩

The more complex example



Symbol stack: ⟨`broil`⟩

The more complex example



Symbol stack: ⟨⟩

Are we done?

We're still doing too much work at query time!

Can we shift more of the work to index time,
while still remaining incremental?

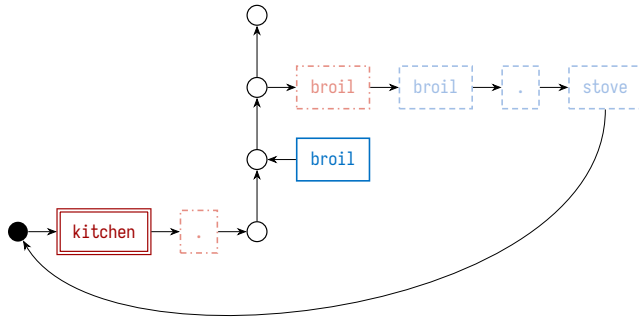

Partial paths

Partial paths

kitchen.py

```
from stove import broil

broil()
```



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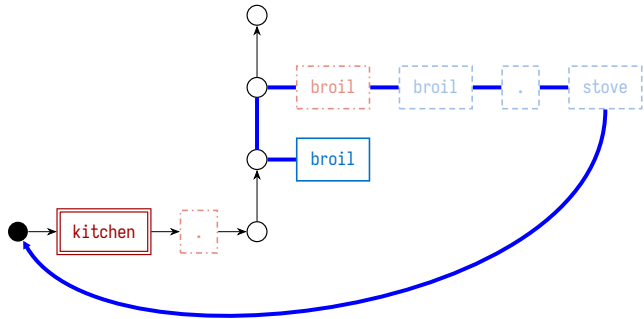

Partial paths

kitchen.py

```
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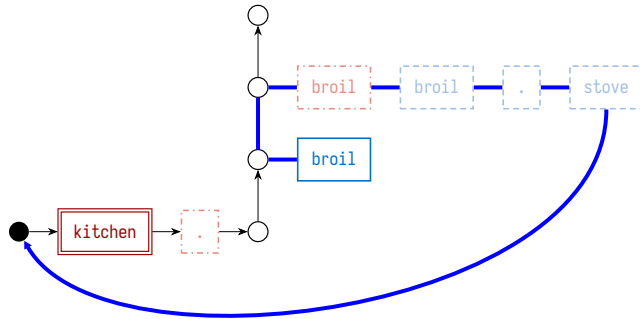
broil()
```



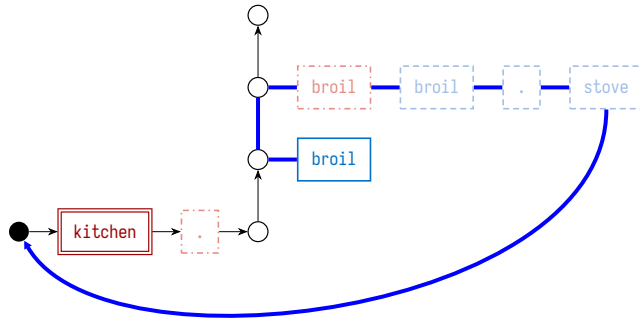
⟨⟩ broil ⇝ ● ⟨stove.broil⟩

Partial paths

kitchen.py

```
from stove import broil

broil()
```



⟨⟩ broil ⇝ ● ⟨stove.broil⟩

The reference at *kitchen.py:3:1* refers to **`stove.broil`** in some other file

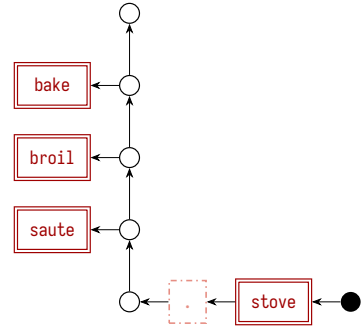
Partial paths

stove.py

```
def bake():
    pass

def broil():
    pass

def saute():
    pass
```



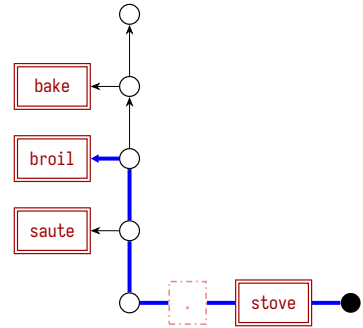
Partial paths

stove.py

```
def bake():
    pass

def broil():
    pass

def saute():
    pass
```



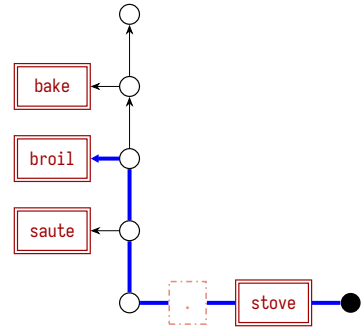
Partial paths

stove.py

```
def bake():
    pass

def broil():
    pass

def saute():
    pass
```



⟨stove.broil⟩ ● ⇝ broil ⟨⟩

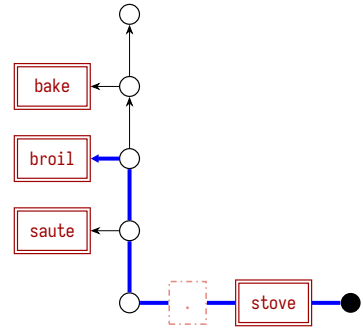
Partial paths

stove.py

```
def bake():
    pass

def broil():
    pass

def saute():
    pⁱass
```



⟨stove.broil⟩ ● ⇝ broil ⟨⟩

`stove.broil` is defined at *stove.py:4:5*.

Concatenating partial paths

The reference at *kitchen.py:3:1* refers to `stove.broil` in some other file + `stove.broil` is defined at *stove.py:4:5*

Concatenating partial paths

The reference at *kitchen.py:3:1*
is defined at *stove.py:4:5*.

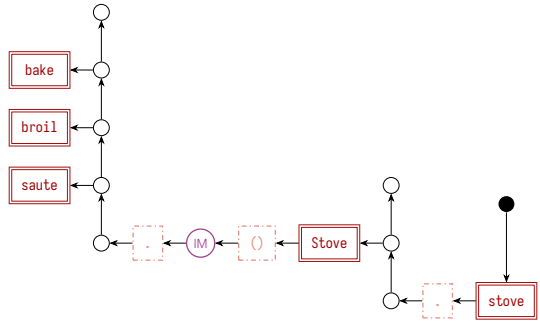
The more complex example

stove.py

```
class Stove(object):
    def bake(self):
        pass

    def broil(self):
        pass

    def saute(self):
        pass
```



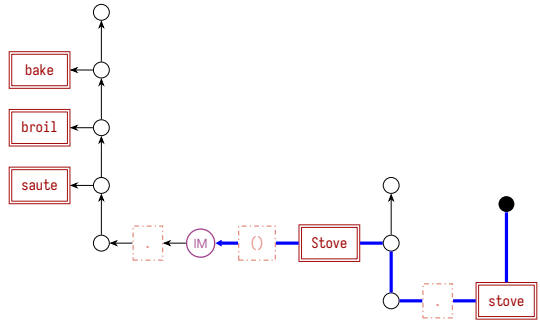
The more complex example

stove.py

```
class Stove(object):
    def bake(self):
        pass

    def broil(self):
        pass

    def saute(self):
        pass
```



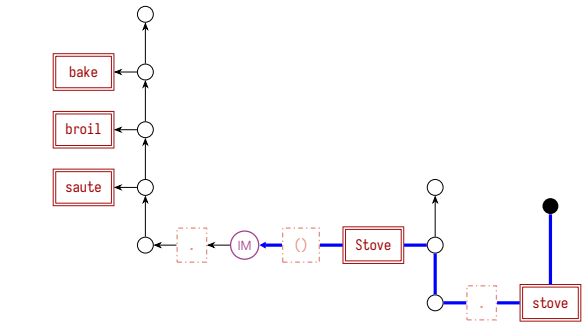
The more complex example

stove.py

```
class Stove(object):
    def bake(self):
        pass

    def broil(self):
        pass

    def saute(self):
        pass
```



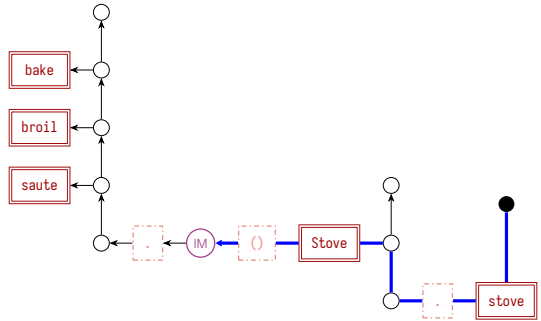
The more complex example

stove.py

```
class Stove(object):
    def bake(self):
        pass

    def broil(self):
        pass

    def saute(self):
        pass
```



Invoking `stove.Stove`
gives you an instance of the `Stove` class.

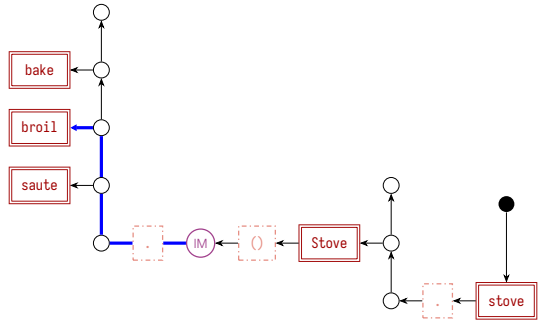
The more complex example

stove.py

```
class Stove(object):
    def bake(self):
        pass

    def broil(self):
        pass

    def saute(self):
        pass
```



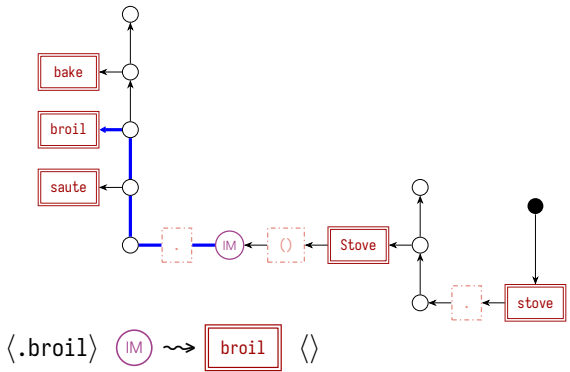
The more complex example

stove.py

```
class Stove(object):
    def bake(self):
        pass

    def broil(self):
        pass

    def saute(self):
        pass
```



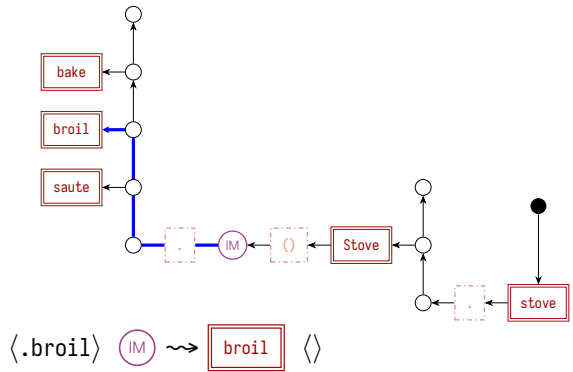
The more complex example

stove.py

```
class Stove(object):
    def bake(self):
        pass

    def broil(self):
        pass

    def saute(self):
        pass
```

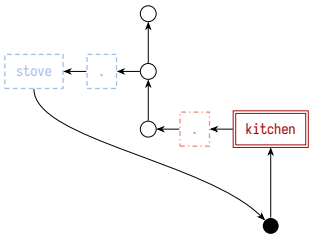


The `Stove` class
has an instance member named `broil`
defined at *stove.py:5:9*.

The more complex example

kitchen.py

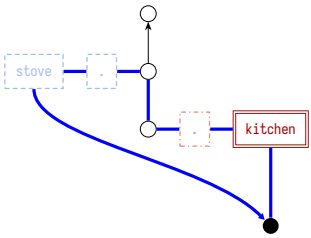
```
from stove import *
```



The more complex example

kitchen.py

```
from stove import *
```



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kitchen.py

```
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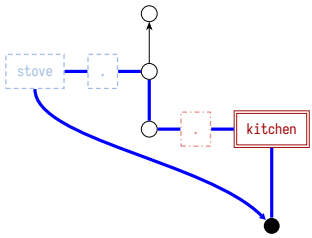
```



⟨kitchen.⟩ ● ⇝ ● ⟨stove.⟩

The more complex example

kitchen.py

```
from stove import *
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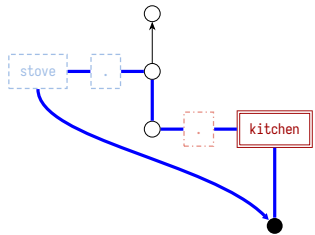


⟨kitchen.⟩ ● ⇝ ● ⟨stove.⟩

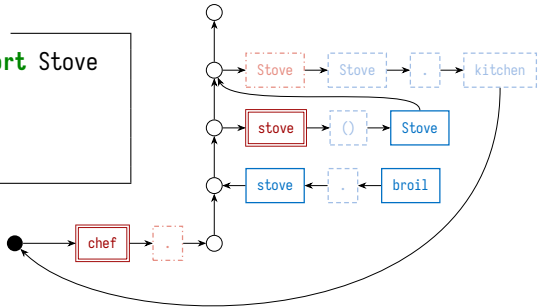
If you are looking for `kitchen.[anything]`
then you might find it at `stove.[anything]`.

The more complex example

chef.py

```
from kitchen import Stove

stove = Stove()
stove.broil()
```

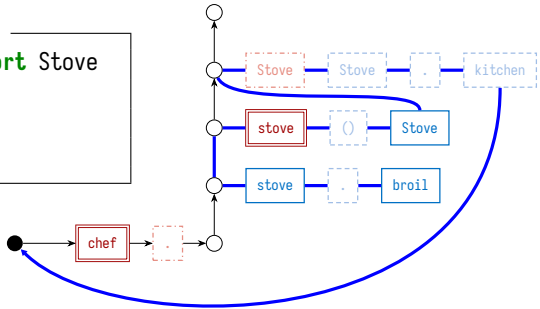


The more complex example

chef.py

```
from kitchen import Stove

stove = Stove()
stove.broil()
```



The more complex example

chef.py

```
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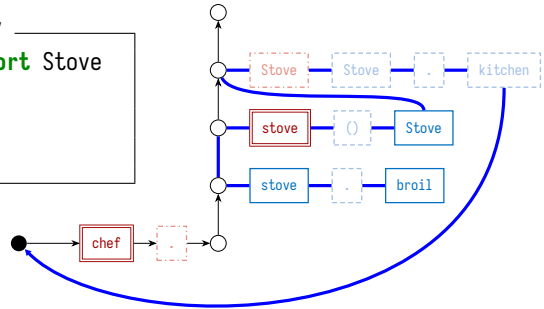
stove = Stove()
stove.broil()
```



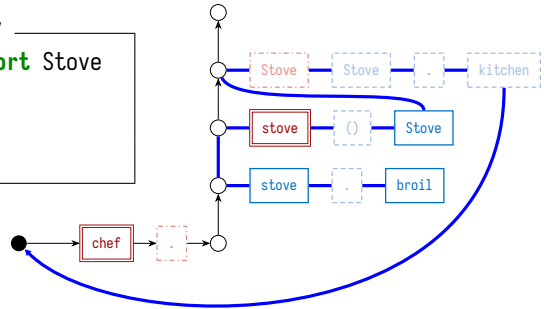
⟨⟩ broil ⇝ ● ⟨kitchen.Stove().broil⟩

The more complex example

chef.py

```
from kitchen import Stove

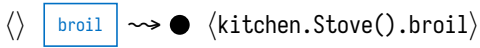
stove = Stove()
stove.broil()
```



⟨⟩ broil ⇝ ● ⟨kitchen.Stove().broil⟩

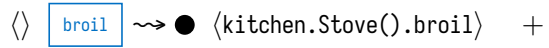
If you can find what **`kitchen.Stove`** resolves to and can call it
then the result should have a member named **`broil`**
which the reference at *chef.py:4:7* resolves to.

The more complex example



If you can find what `kitchen.Stove` resolves to and can call it, then the result should have a member named `broil` which the reference at *chef.py:4:7* resolves to.

The more complex example



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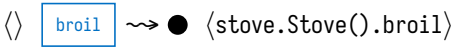
+

If you are looking for `kitchen.[anything]` then you might find it at `stove.[anything]`.

The more complex example



If you can find what `stove.Stove` resolves to and can call it, then the result should have a member named `broil` which the reference at *chef.py:4:7* resolves to.

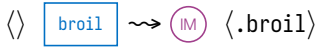
The more complex example

If you can find what `stove.Stove` resolves to and can call it, then the result should have a member named `broil` which the reference at *chef.py:4:7* resolves to.

+

Invoking `stove.Stove` gives you an instance of the `Stove` class.

The more complex example



The `Stove` class
should have a member
named `broil` which the reference at
chef.py:4:7 resolves to.

The more complex example

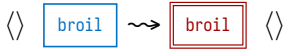
+

The `Stove` class should have a member named `broil` which the reference at *chef.py:4:7* resolves to.

+

The `Stove` class has an instance member named `broil` defined at *stove.py:5:9*.

The more complex example



The definition at *stove.py:5:9* is what the reference at *chef.py:4:7* resolves to.

Are we done?

- Different languages have different name binding rules.
- Some of those rules can be quite complex.
- The result might depend on intermediate files.
- We don’t want to require manual per-repo configuration.
- We need incremental processing to handle our scale.

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Making stack graphs


tree-sitter

tree-sitter

stove.py

```
def bake():
    pass

def broil():
    pass

def saute():
    pass

broil()
```

tree-sitter

```
(module [0, 0] - [10, 0]
  (function_definition [0, 0] - [1, 8]
    name: (identifier [0, 4] - [0, 8])
    parameters: (parameters [0, 8] - [0, 10])
    body: (block [1, 4] - [1, 8]
      (pass_statement [1, 4] - [1, 8])))
  (function_definition [3, 0] - [4, 8]
    name: (identifier [3, 4] - [3, 9])
    parameters: (parameters [3, 9] - [3, 11])
    body: (block [4, 4] - [4, 8]
      (pass_statement [4, 4] - [4, 8])))
  (function_definition [6, 0] - [7, 8]
    name: (identifier [6, 4] - [6, 9])
    parameters: (parameters [6, 9] - [6, 11])
    body: (block [7, 4] - [7, 8]
      (pass_statement [7, 4] - [7, 8])))
  (expression_statement [9, 0] - [9, 7]
    (call [9, 0] - [9, 7]
      function: (identifier [9, 0] - [9, 5])
      arguments: (argument_list [9, 5] - [9, 7]))))
```

tree-sitter

```
(module [0, 0] - [10, 0]
  (function_definition [0, 0] - [1, 8]
    name: (identifier [0, 4] - [0, 8])
    parameters: (parameters [0, 8] - [0, 10])
    body: (block [1, 4] - [1, 8]
      (pass_statement [1, 4] - [1, 8])))
  (function_definition [3, 0] - [4, 8]
    name: (identifier [3, 4] - [3, 9])
    parameters: (parameters [3, 9] - [3, 11])
    body: (block [4, 4] - [4, 8]
      (pass_statement [4, 4] - [4, 8])))
  (function_definition [6, 0] - [7, 8]
    name: (identifier [6, 4] - [6, 9])
    parameters: (parameters [6, 9] - [6, 11])
    body: (block [7, 4] - [7, 8]
      (pass_statement [7, 4] - [7, 8])))
  (expression_statement [9, 0] - [9, 7]
    (call [9, 0] - [9, 7]
      function: (identifier [9, 0] - [9, 5])
      arguments: (argument_list [9, 5] - [9, 7]))))
```

```
(function_definition
  name: (identifier) @name) @function
```

tree-sitter

```
(module [0, 0] - [10, 0]
  (function_definition [0, 0] - [1, 8]
    name: (identifier [0, 4] - [0, 8])
    parameters: (parameters [0, 8] - [0, 10])
    body: (block [1, 4] - [1, 8]
      (pass_statement [1, 4] - [1, 8])))
  (function_definition [3, 0] - [4, 8]
    name: (identifier [3, 4] - [3, 9])
    parameters: (parameters [3, 9] - [3, 11])
    body: (block [4, 4] - [4, 8]
      (pass_statement [4, 4] - [4, 8])))
  (function_definition [6, 0] - [7, 8]
    name: (identifier [6, 4] - [6, 9])
    parameters: (parameters [6, 9] - [6, 11])
    body: (block [7, 4] - [7, 8]
      (pass_statement [7, 4] - [7, 8])))
  (expression_statement [9, 0] - [9, 7]
    (call [9, 0] - [9, 7]
      function: (identifier [9, 0] - [9, 5])
      arguments: (argument_list [9, 5] - [9, 7]))))
```

```
(function_definition
  name: (identifier) @name) @function
```

tree-sitter

```
(module [0, 0] - [10, 0]
  (function_definition [0, 0] - [1, 8]
    name: (identifier [0, 4] - [0, 8])
    parameters: (parameters [0, 8] - [0, 10])
    body: (block [1, 4] - [1, 8]
      (pass_statement [1, 4] - [1, 8])))
  (function_definition [3, 0] - [4, 8]
    name: (identifier [3, 4] - [3, 9])
    parameters: (parameters [3, 9] - [3, 11])
    body: (block [4, 4] - [4, 8]
      (pass_statement [4, 4] - [4, 8])))
  (function_definition [6, 0] - [7, 8]
    name: (identifier [6, 4] - [6, 9])
    parameters: (parameters [6, 9] - [6, 11])
    body: (block [7, 4] - [7, 8]
      (pass_statement [7, 4] - [7, 8])))
  (expression_statement [9, 0] - [9, 7]
    (call [9, 0] - [9, 7]
      function: (identifier [9, 0] - [9, 5])
      arguments: (argument_list [9, 5] - [9, 7]))))
```

```
(function_definition
  name: (identifier) @name) @function
```

tree-sitter

```
(module [0, 0] - [10, 0]
  (function_definition [0, 0] - [1, 8]
    name: (identifier [0, 4] - [0, 8])
    parameters: (parameters [0, 8] - [0, 10])
    body: (block [1, 4] - [1, 8]
      (pass_statement [1, 4] - [1, 8])))
  (function_definition [3, 0] - [4, 8]
    name: (identifier [3, 4] - [3, 9])
    parameters: (parameters [3, 9] - [3, 11])
    body: (block [4, 4] - [4, 8]
      (pass_statement [4, 4] - [4, 8])))
  (function_definition [6, 0] - [7, 8]
    name: (identifier [6, 4] - [6, 9])
    parameters: (parameters [6, 9] - [6, 11])
    body: (block [7, 4] - [7, 8]
      (pass_statement [7, 4] - [7, 8])))
  (expression_statement [9, 0] - [9, 7]
    (call [9, 0] - [9, 7]
      function: (identifier [9, 0] - [9, 5])
      arguments: (argument_list [9, 5] - [9, 7]))))
```

```
(function_definition
  name: (identifier) @name) @function
{
    node @function.def
    attr (@function.def) kind = "definition"
    attr (@function.def) symbol = @name

    edge @function.containing_scope -> @function.def
}
```

tree-sitter

```
(module [0, 0] - [10, 0]
  (function_definition [0, 0] - [1, 8]
    name: (identifier [0, 4] - [0, 8])
    parameters: (parameters [0, 8] - [0, 10])
    body: (block [1, 4] - [1, 8]
      (pass_statement [1, 4] - [1, 8])))
  (function_definition [3, 0] - [4, 8]
    name: (identifier [3, 4] - [3, 9])
    parameters: (parameters [3, 9] - [3, 11])
    body: (block [4, 4] - [4, 8]
      (pass_statement [4, 4] - [4, 8])))
  (function_definition [6, 0] - [7, 8]
    name: (identifier [6, 4] - [6, 9])
    parameters: (parameters [6, 9] - [6, 11])
    body: (block [7, 4] - [7, 8]
      (pass_statement [7, 4] - [7, 8])))
  (expression_statement [9, 0] - [9, 7]
    (call [9, 0] - [9, 7]
      function: (identifier [9, 0] - [9, 5])
      arguments: (argument_list [9, 5] - [9, 7]))))
```

```
(function_definition
  name: (identifier) @name) @function
{
    node @function.def
    attr (@function.def) kind = "definition"
    attr (@function.def) symbol = @name

    edge @function.containing_scope -> @function.def
}
```

github/stack-graphs
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tree-sitter/tree-sitter-graph

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tree-sitter/tree-sitter-javascript

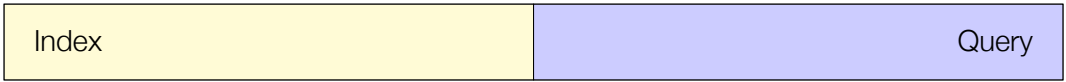
tree-sitter/tree-sitter-rust

tree-sitter/tree-sitter-ruby

elixir-lang/tree-sitter-elixir

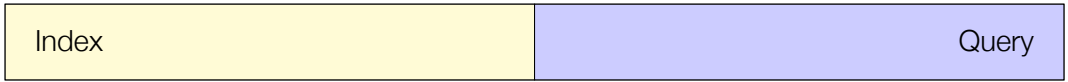
r-lib/tree-sitter-r

⋮



Clone changed files
Parse using tree-sitter
Construct stack graph
Find partial paths

Load partial paths lazily
Stitch them together



Clone changed files
Parse using tree-sitter
Construct stack graph
Find partial paths

p50: 5 sec
p99: 1-2 min

Load partial paths lazily
Stitch them together

p50: 50ms
p99: 100ms

The *really* hard ones...

dataflow.py

```
def passthrough(x):
    return x

class A:
    one = 1

passthrough(A).one
```

MyMap.java

```
import java.util.HashMap;

class MyMap extends HashMap<String, String> {
    int firstLength() {
        return this.entrySet().iterator()
            .next().getKey().length();
    }
}
```

Picture credits

Slide 3 Ivan Radic, “Close-up of a compass graffiti on the ground”
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github/stack-graphs
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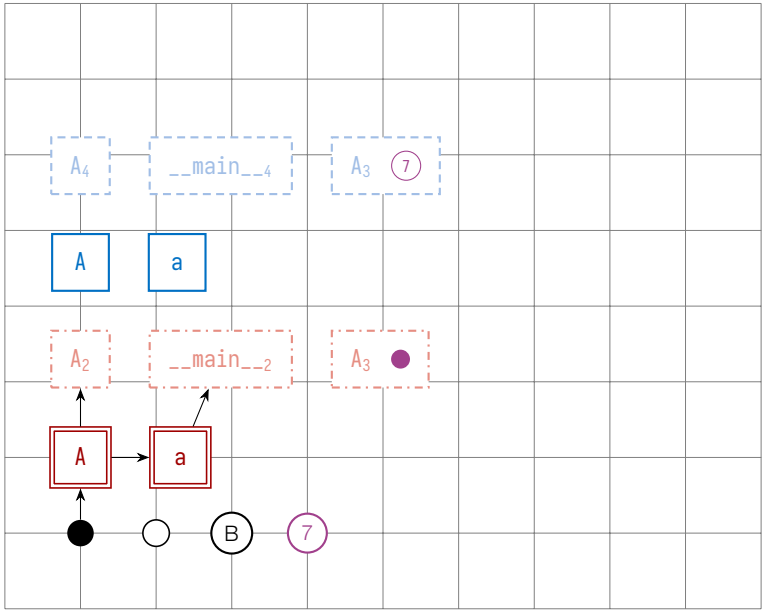
A4
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A3
7
A
a
A2
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A3
A
a
B
7