Marco: Safe, Expressive Macros for Any Language

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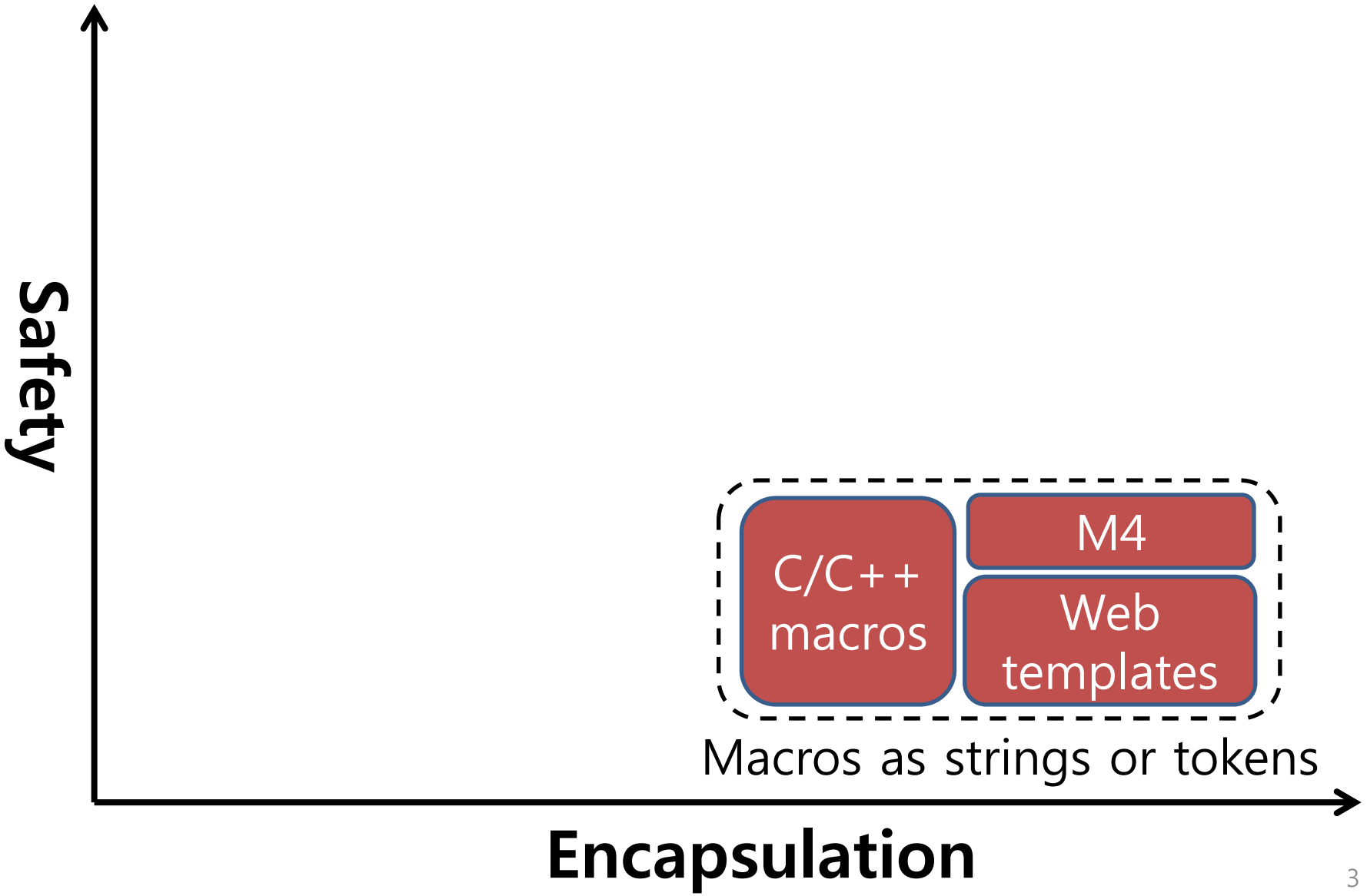
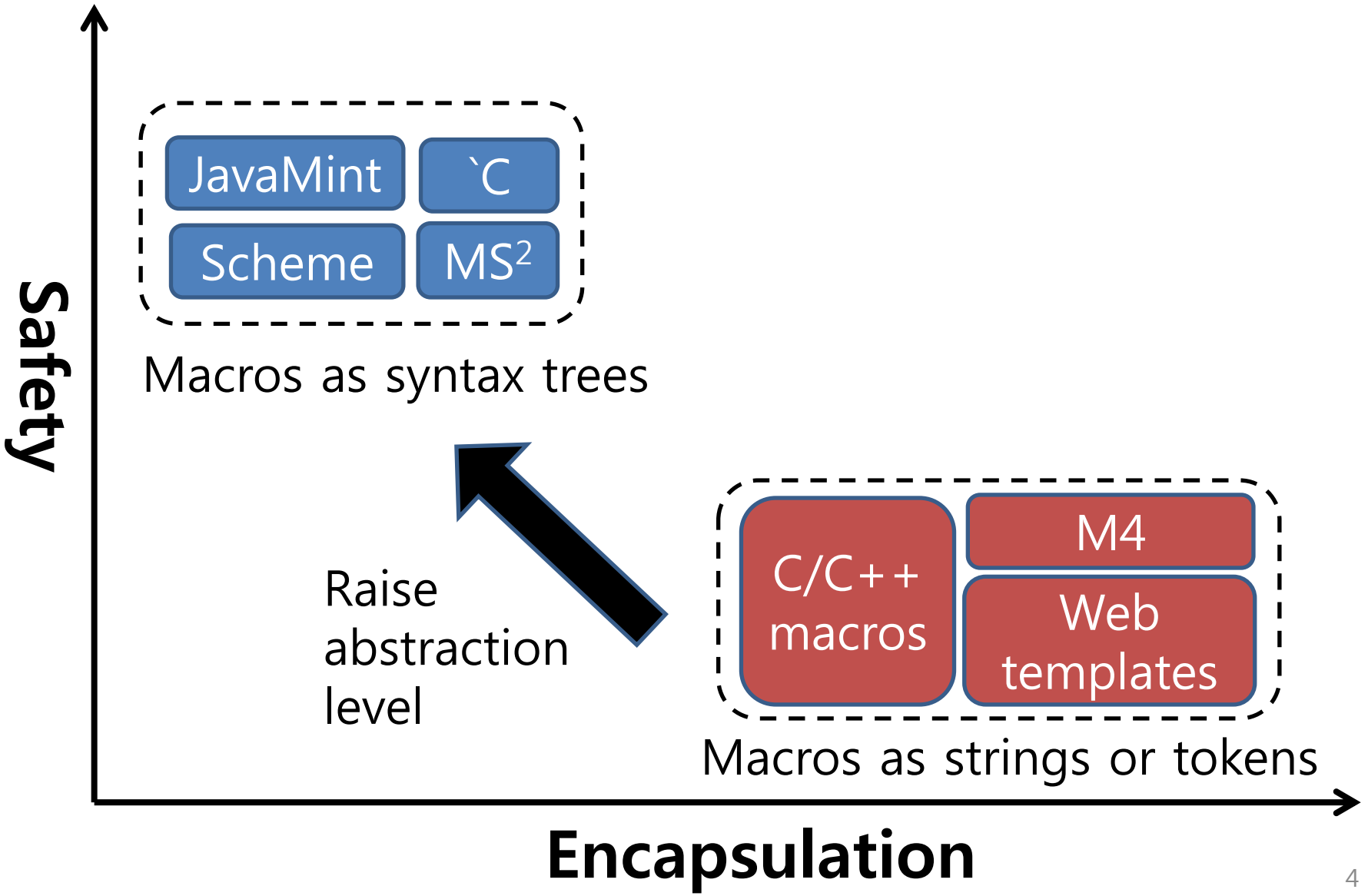
Macros in programming languages

- Abstraction
  - Simple, elegant core languages
  - Macros in C and Scheme
- Language interoperability
  - Target-language code as host-language data
  - Web templates for HTML and SQL code

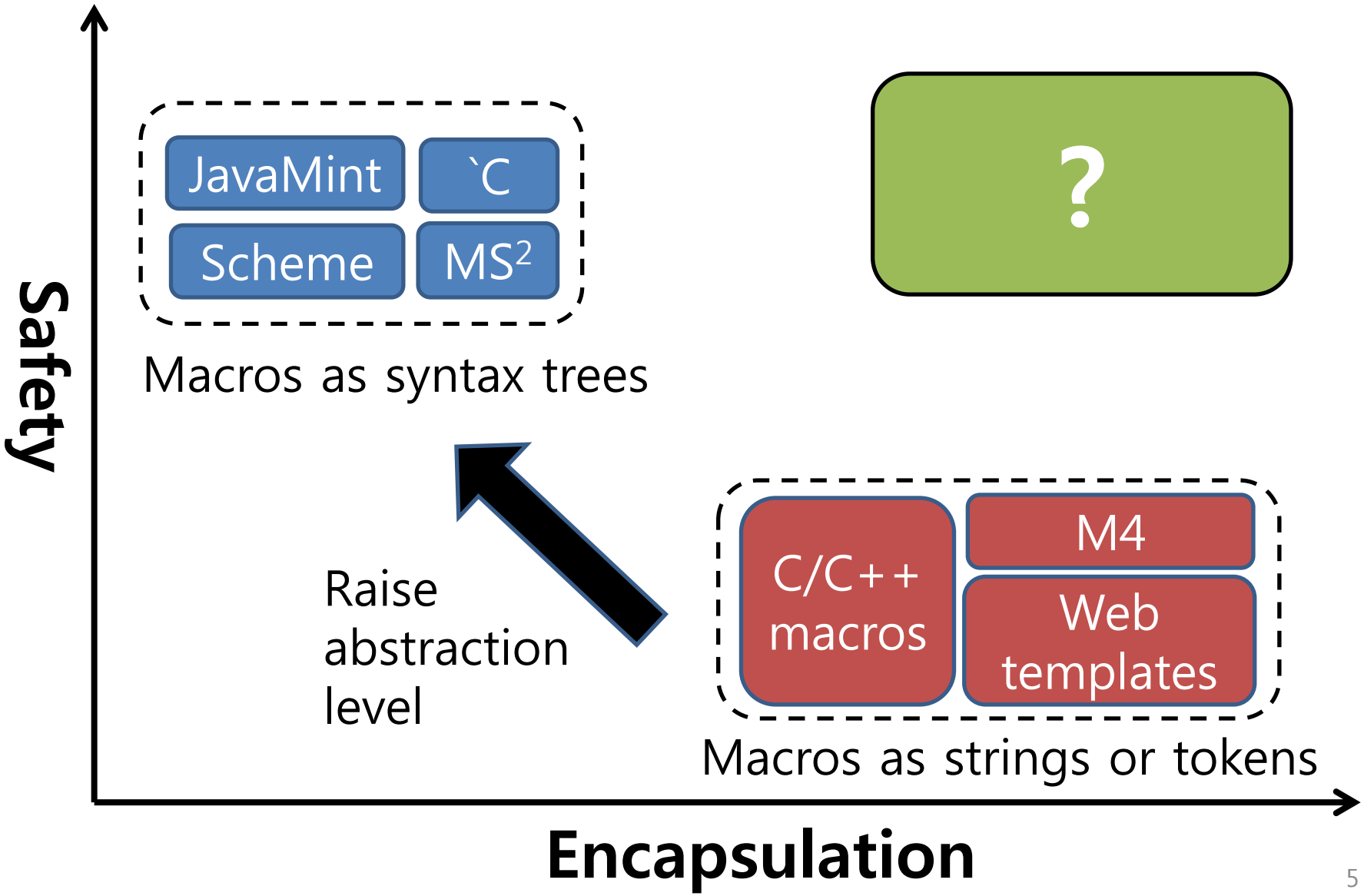
Unsafe macros for any Language



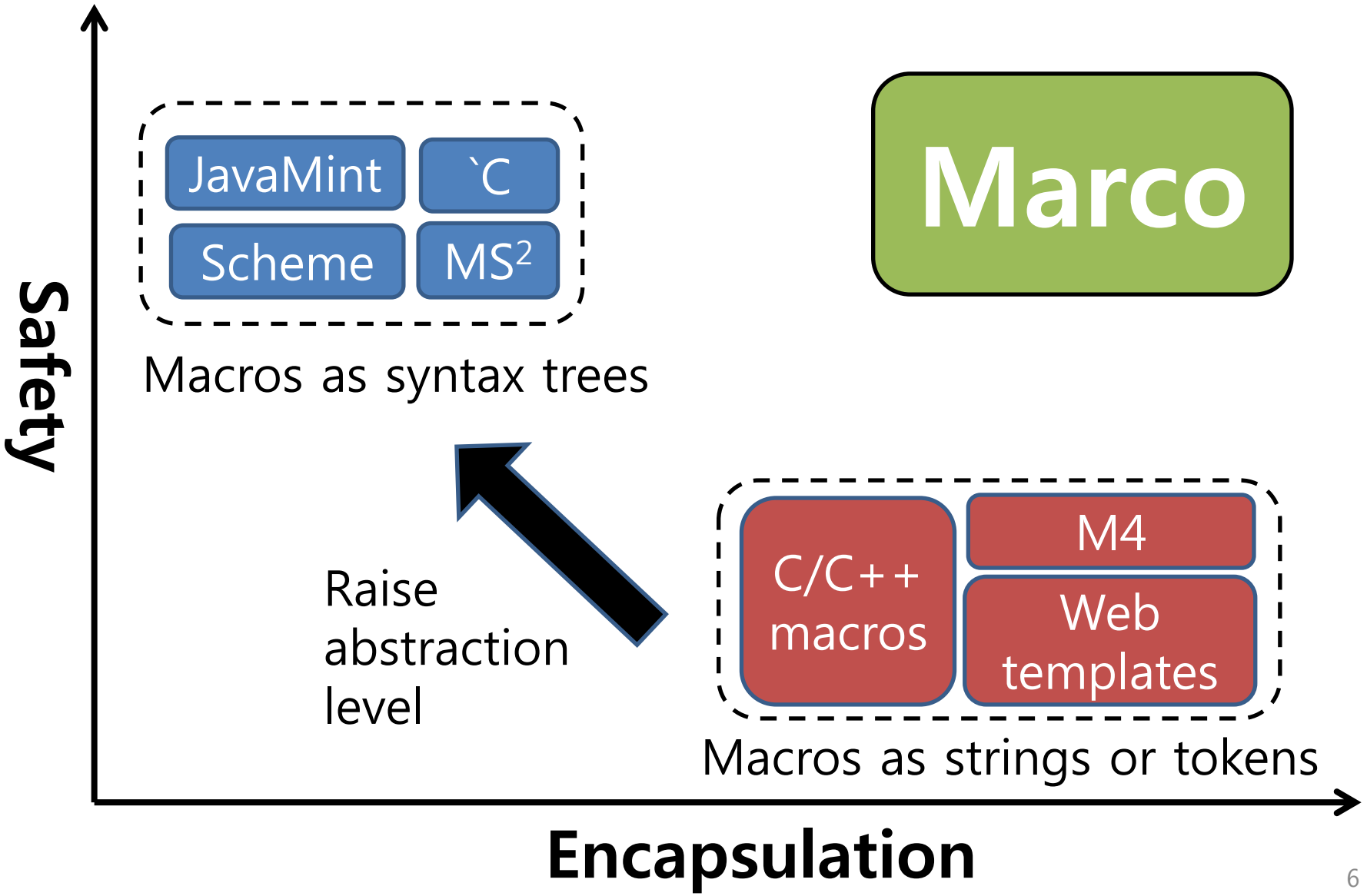
Safe macros for one language



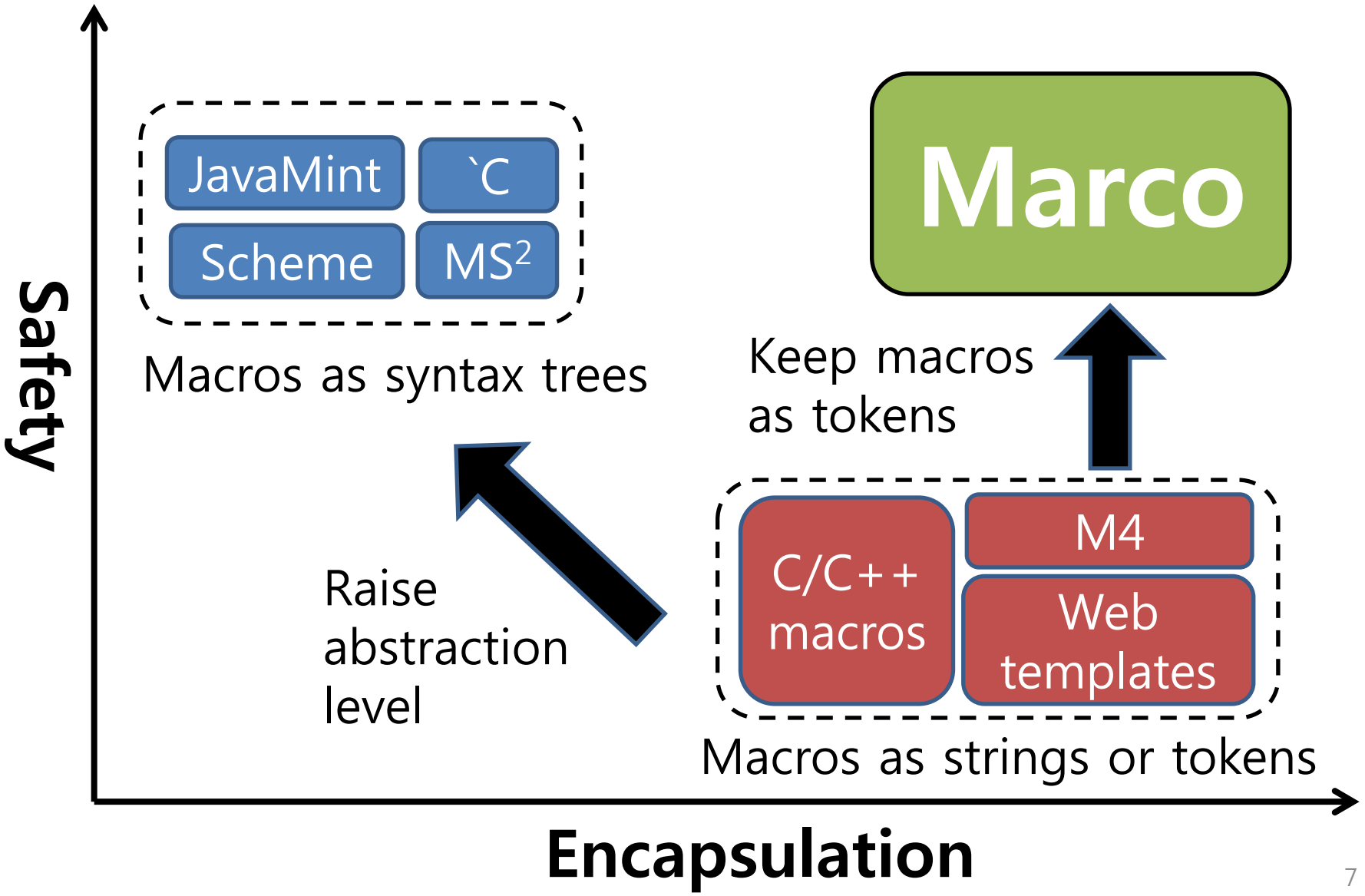
Safe macros for any Language



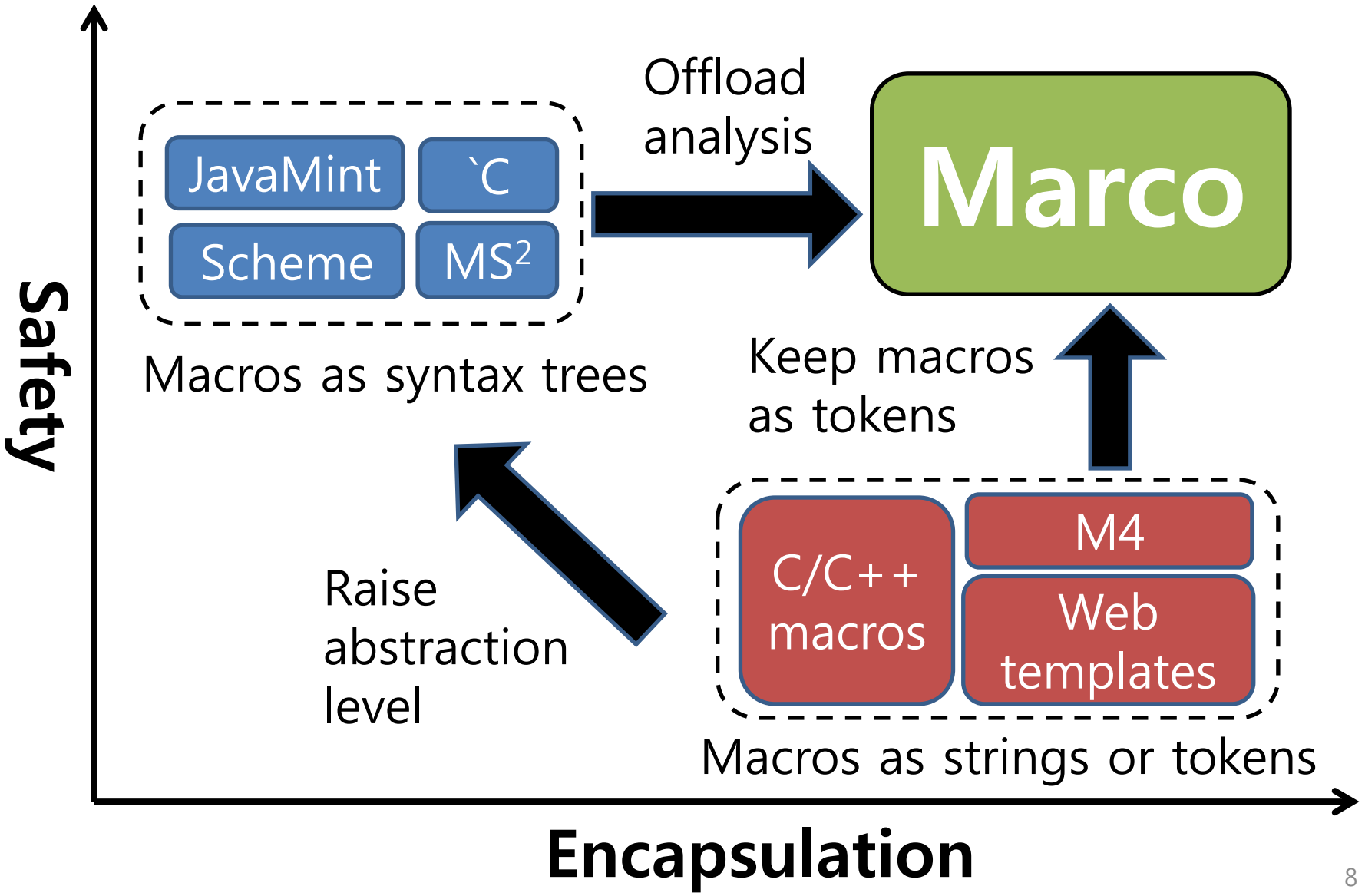
Marco: safe macros for any Language



Marco: safe macros for any Language



Marco: safe macros for any Language



Outline

- Introduction
- Marco language and architecture
  - Expressing macros as Tokens
  - Offloading analysis using oracle queries
- Oracle analysis in practice
  - Handling context sensitivity in C++
  - Classifying error messages
- Enforcing hygienic macro expansion
  - Discovering captured names
  - Propagating free names
- Summary

Expressing macros as tokens

```
#define swap(x, y) {
    int temp = x;
    x = y;
    y = temp;
}
```

C/C++ macro

```
code<cpp,stmt> swap(
  code<cpp,id> x,
  code<cpp,id> y) {
  return `cpp(stmt) [ {
    int temp = $x;
    $x = $y;
    $y = temp;
  }]; }
```

Marco macro

- **Static typing**
  - **code types parametized by language and category**
  - **code<cpp,stmt> and `cpp(stmt) for C++ statement**
- **Explicit blanks**

Multilingual macros in Marco

```
code<cpp,stmt> swap(
  code<cpp,id> x,
  code<cpp,id> y) {
  return `cpp(stmt) [ {
    int temp = $x;
    $x = $y;
    $y = temp;
  }]; }
```

C++

```
code<sql,stmt> select(
  code<sql,expr> cond)
{
  return `sql(stmt) [
   select names
     from employees
     where $cond
  ]; }
```

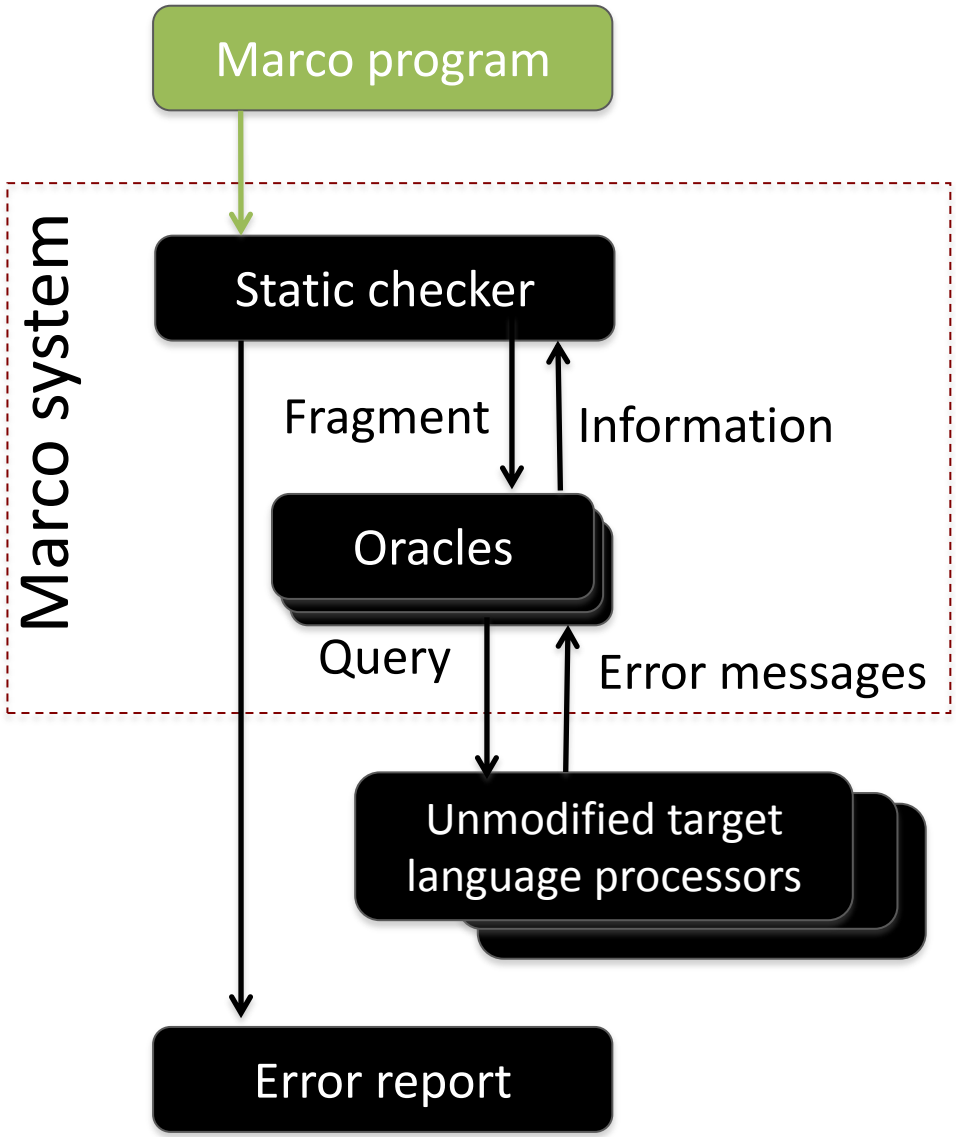
SQL

- Scannerless, extensible parser in ***Rats!***
- **`cpp** selects a C++ lexical analyzer
- **`sql** selects an SQL lexical analyzer

Offloading analysis

```
code<cpp,stmt>
swap(
  code<cpp,id> x,
  code<cpp,id> y) {
  return `cpp(stmt)
[ {
    int temp = $x;
    $x = $y;
    $y = temp;
  }];
}
```

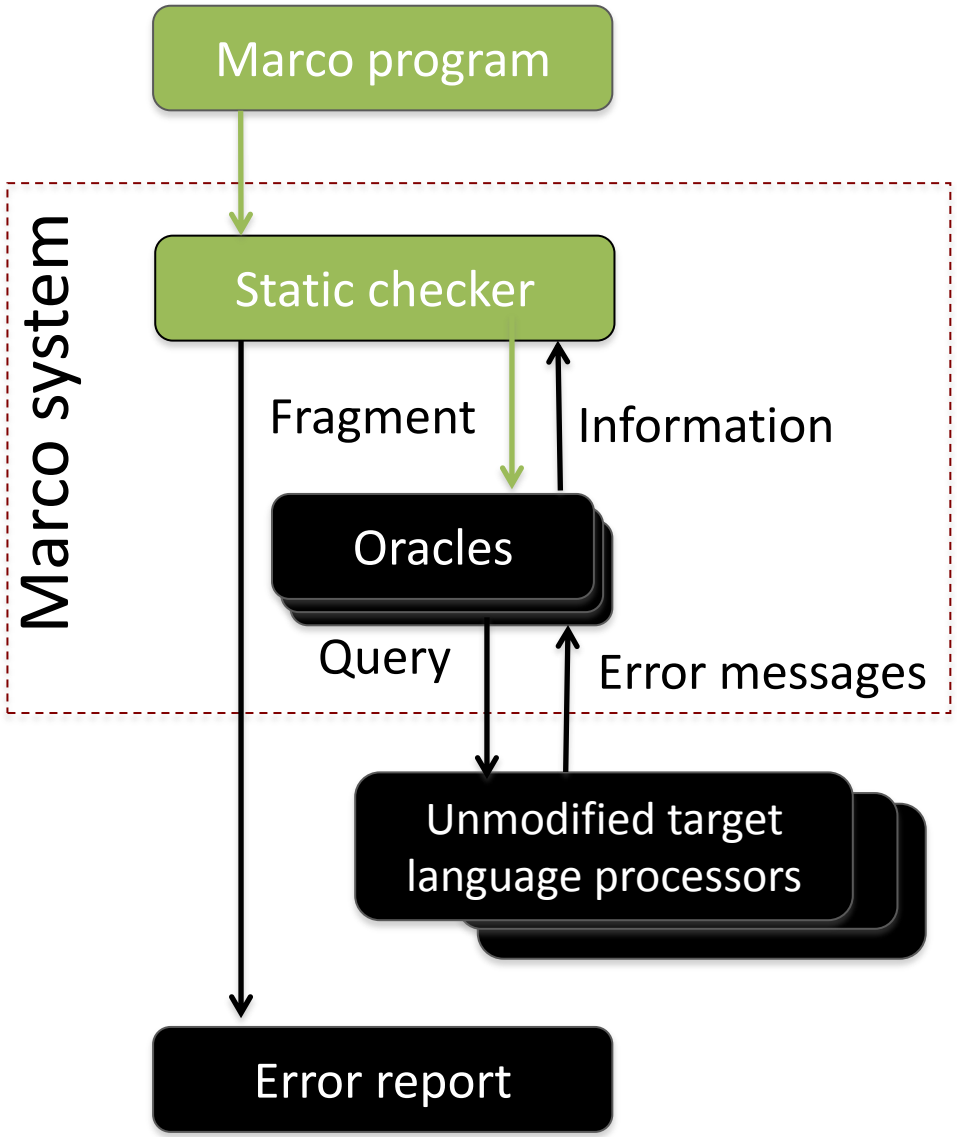
Marco program



Offloading analysis

```
`cpp(stmt) [ {
    int temp = $x;
    $x = $y;
    $y = temp;
 }]
```

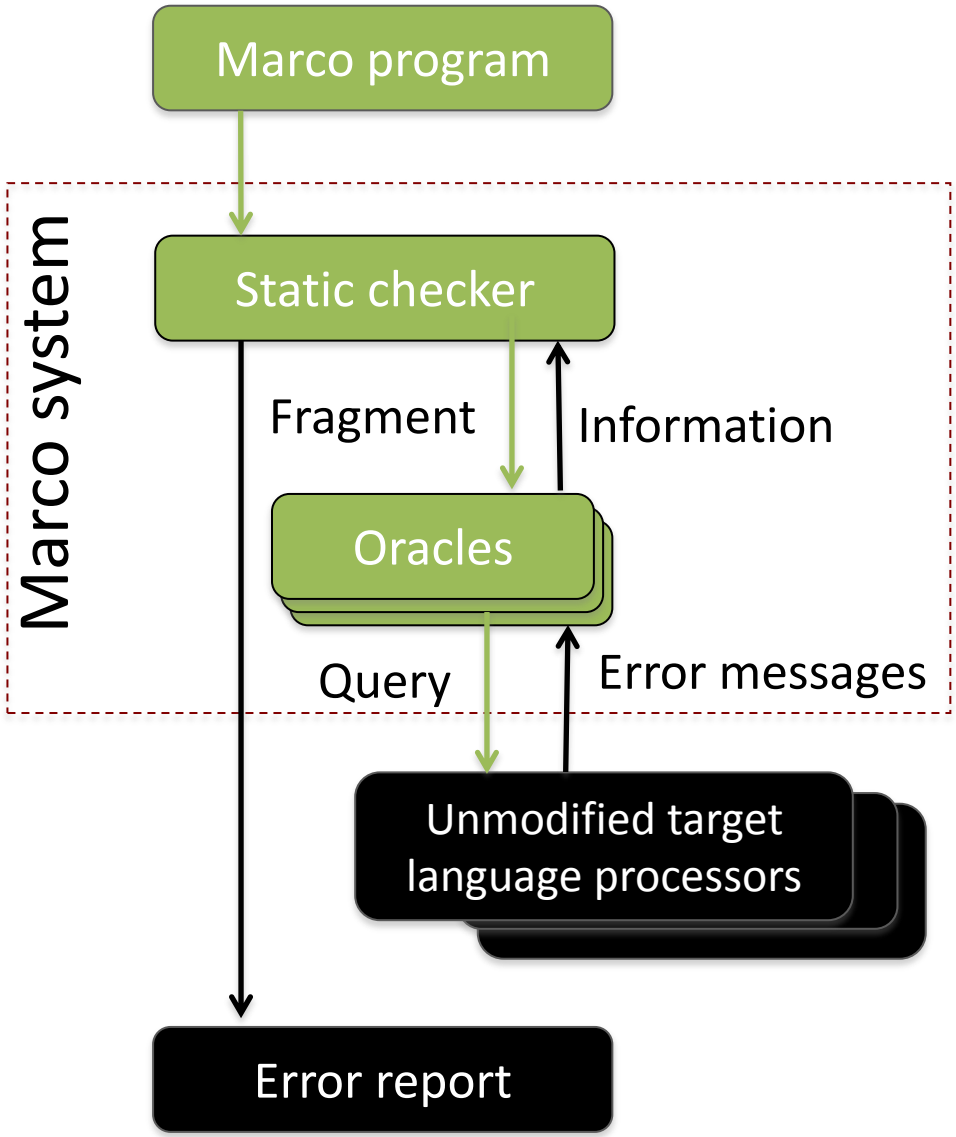
Fragment



Offloading analysis

```
`cpp(stmt) [ {
  int temp = _id0_;
  _id1_ = _id2_;
  _id3_ = temp;
 }]
```

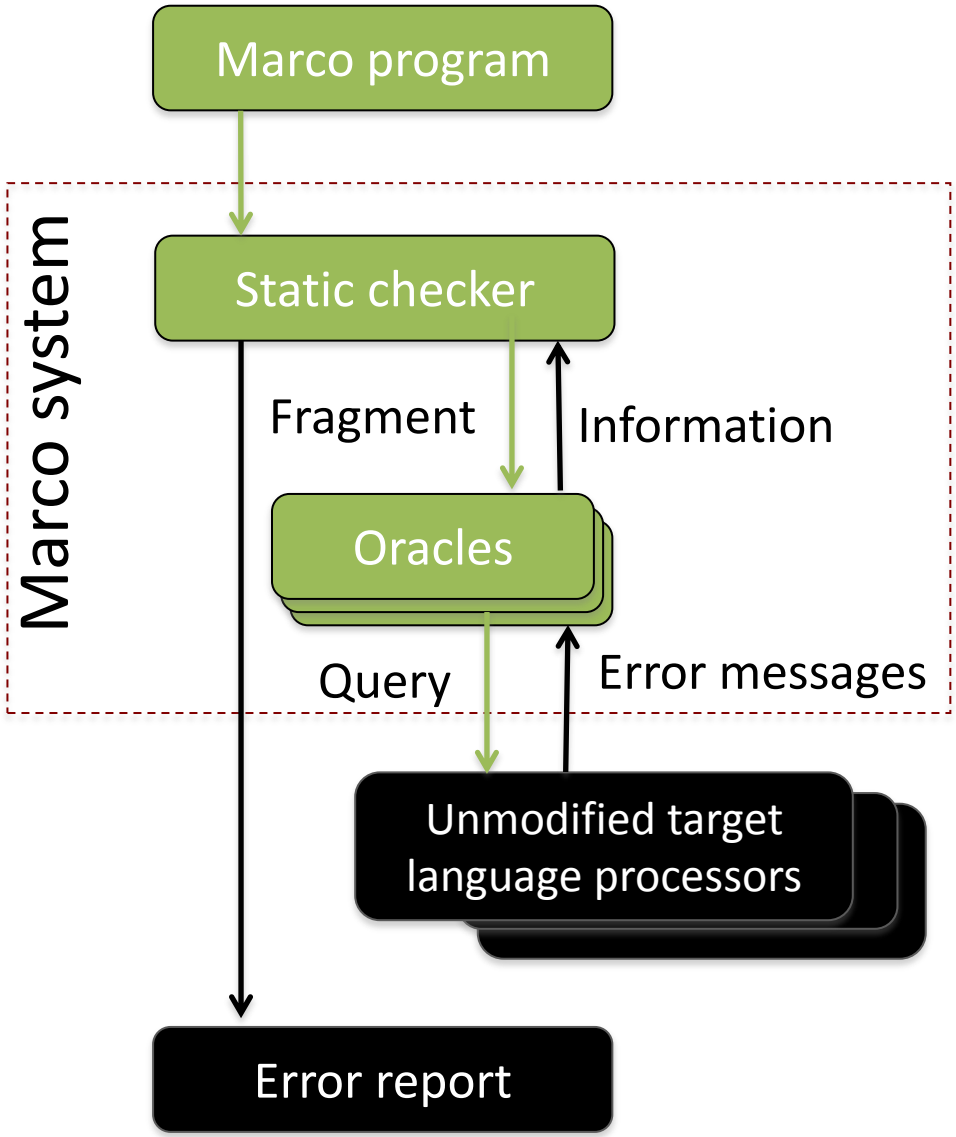
Fragment with concretized blanks



Offloading analysis

```
void _id4_() {
  if (1) {
    int temp == _id0_;
    _id1_ = _id2_;
    _id3_ = temp;
  }
  else ;
}
```

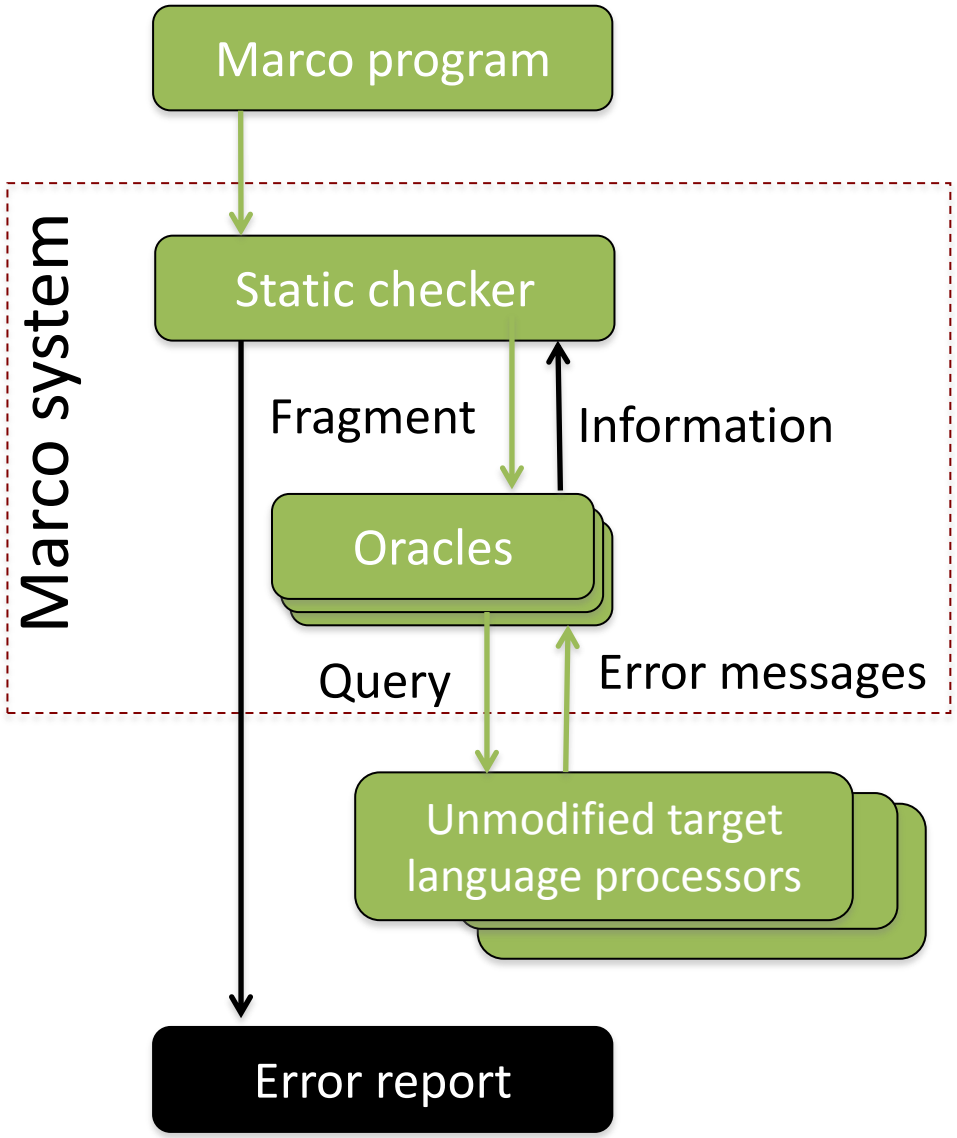
Query



Offloading analysis

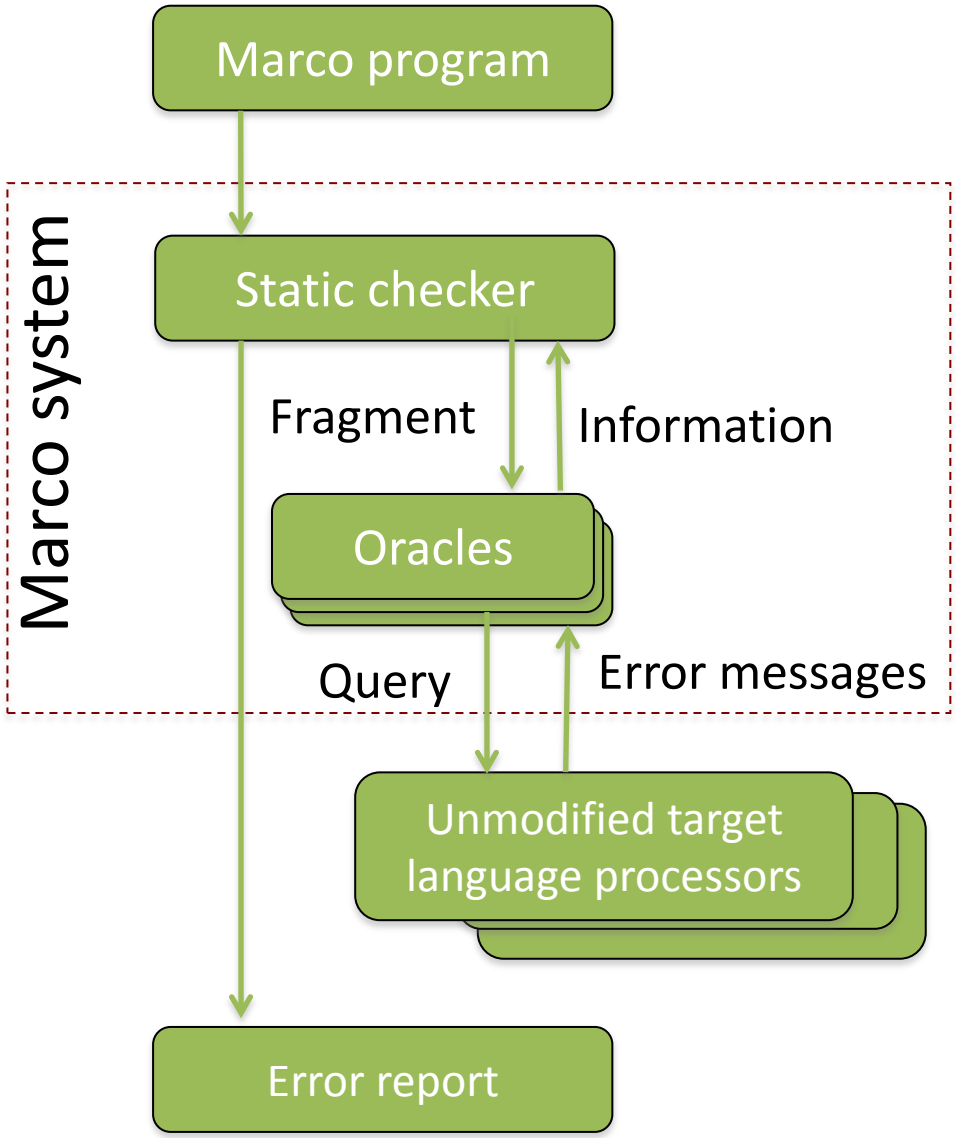
- '_id4_' was not declared
- '_id0_' was not declared
- '_id1_' was not declared
- '_id2_' was not declared
- '_id3_' was not declared

GCC Error messages



Offloading analysis

No syntax error



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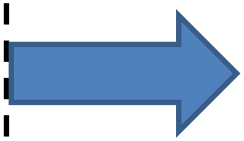
Naïve oracle analysis in theory

```
void* foo(typeless c)
{
   return 0;
}
```

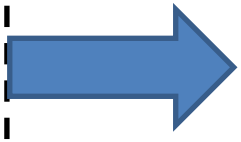
well-formed fragment



No syntax error

```
void foo(typeless c)
{
  shadowed  syntax
  errors
}
```

ill-formed fragment



Expected ‘;’ before ‘syntax’

Syntax error

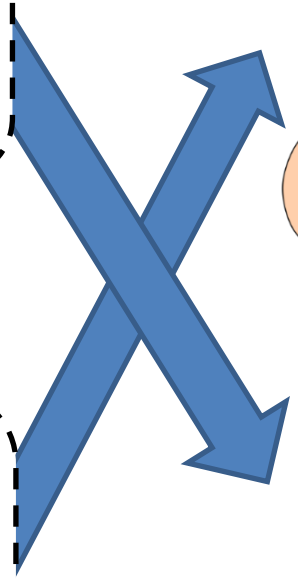
Naïve oracle analysis in practice

```
void* foo(typeless c)
{
   return 0;
}
```

well-formed fragment

```
void foo(typeless c)
{
  shadowed  syntax
  errors
}
```

ill-formed fragment



'foo' declared void

'typeless' was not declared

GCC

No syntax error

Expected ';' before 'syntax'

GCC

Syntax error

Syntax errors for well-formed fragments

```
void* foo(typeless c)
{
   return 0;
}
```

well-formed fragment

'typeless' was not declared

expected ',' or ';' before '{'

Syntax errors

Syntax errors for correct fragments

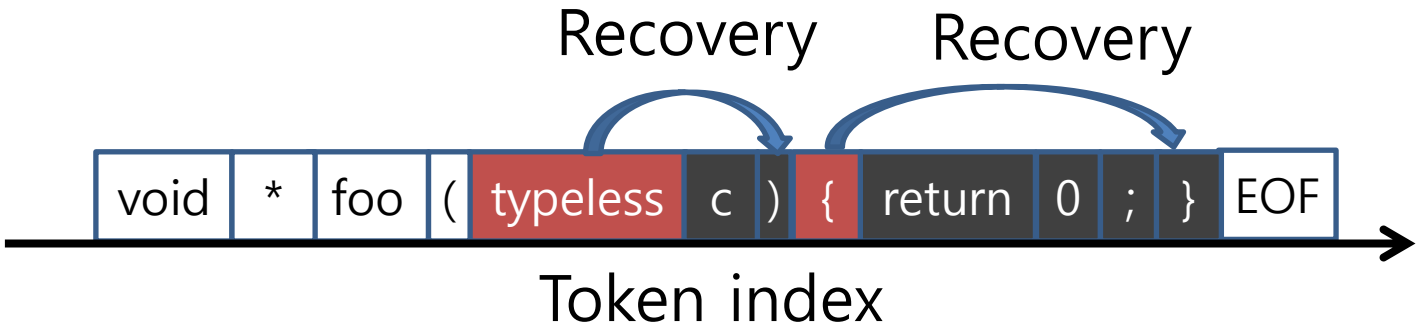
```
void* foo(typeless c)
{
   return 0;
}
```

well-formed fragment

'typeless' was not declared

expected ',' or ';' before '{'

Syntax errors

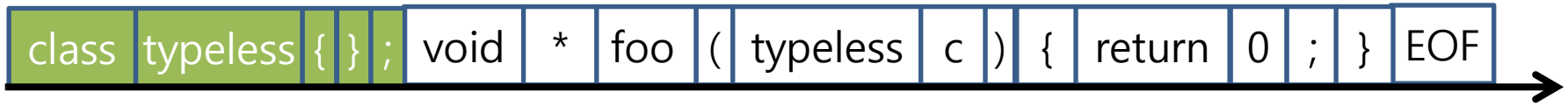


Our solution of speculating a context

```
class typeless {};
void* foo(typeless c)
{
   return 0;
}
```

well-formed fragment

No syntax errors



Token index

No syntax errors for wrong fragments

```
void foo(typeless c)
{
  shadowed  syntax
  errors
}
```

ill-formed fragment

'foo' declared void

'typeless' was not declared

No syntax error

No syntax errors for wrong fragments

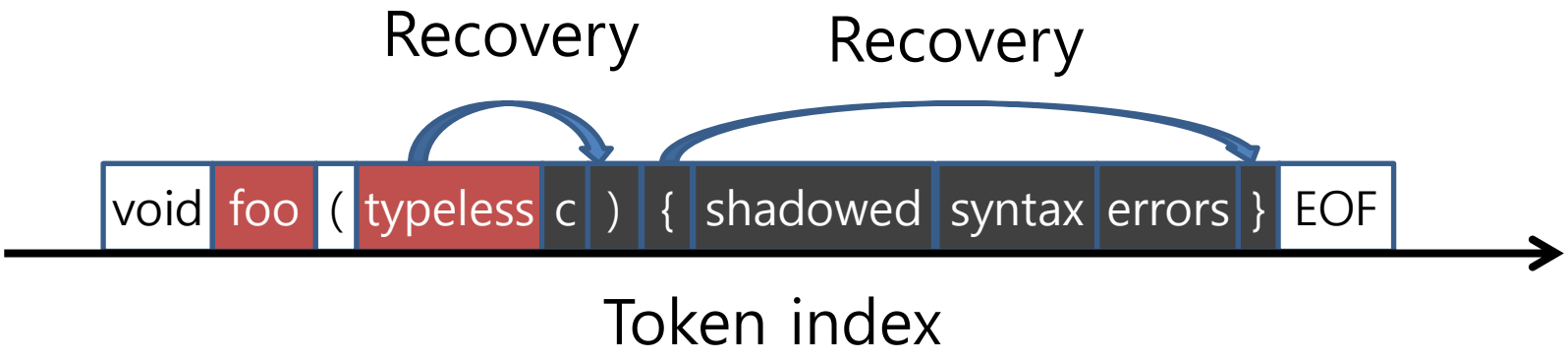
```
void foo(typeless c)
{
  shadowed  syntax
  errors
}
```

ill-formed fragment

'foo' declared void

'typeless' was not declared

No syntax error



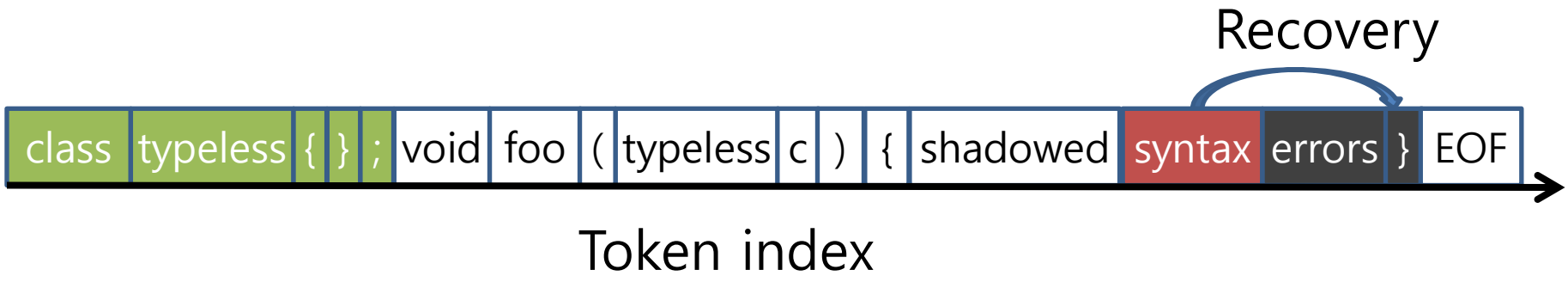
Our solution of speculating a context

```
class typeless {};
void foo(typeless c)
{
  shadowed  syntax
  errors
}
```

Ill-formed fragment

Expected ';'
before 'syntax'

Syntax error



Speculations and backtracking

- Speculation
  - Guess entities for C++ identifiers
  - Type, variable, method, field, namespace
- Backtracking
  - Invalidate some speculations
  - Modest number of backtrackings in practice
- Empirical evaluation
  - 8 microbenchmarks and one realistic one
  - 10-20% backtrackings over 136 fragments

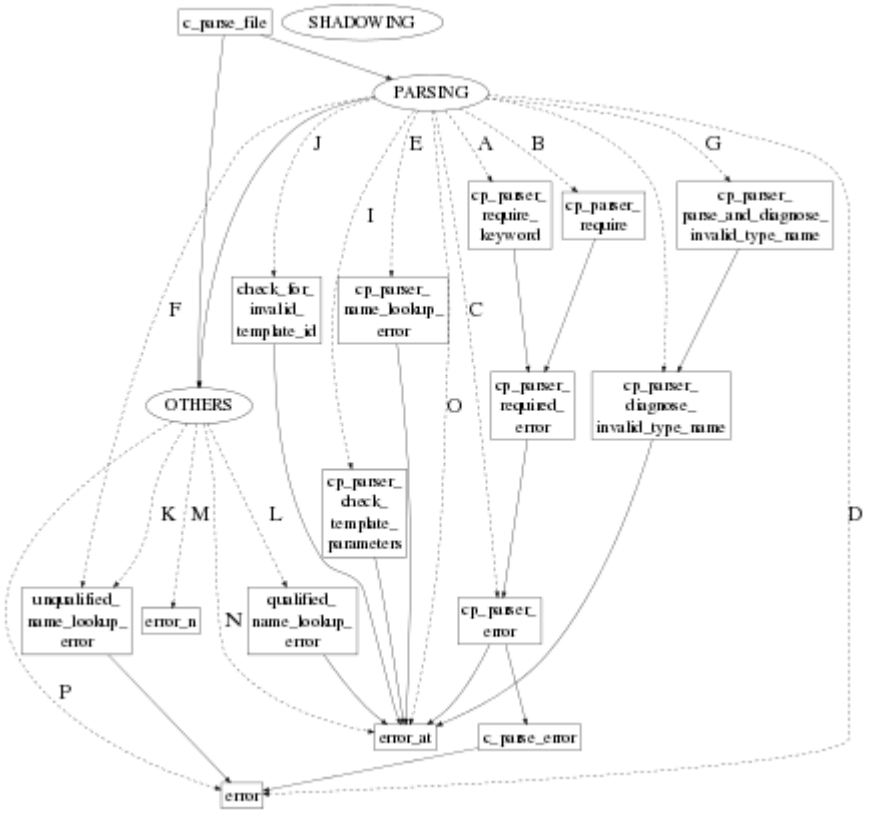
Backtracking in practice

- 8 micro benchmarks
  - 21 fragments
  - 20% queries backtrack
- "Aggregate" operator in IBM InfoSphere Streams
  - 115 fragments
  - 13% backtracking rate
- Modest rate of backtrackings

Classifying and handling error messages

Classes	Example	Handling
Syntax	expected ';' before '{'	Forward to programmers
Lookup	'typeless' was not declared	**Eliminate them by speculating a proper context.**
Shadowing	function 'typeless' was duplicated	
Non-shadowing	'foo' declared void	Ignore

Feasibility of classifying error messages



Abstracted call graph for printing error message in g++

Dozens of regular expressions cover 384 critical error messages

Error Context	Call Sites	Syntax: Parsing	Syntax: Post-Parsing	Semantics: Lookup	Semantics: Other Shadow	Semantics: Non-Shadow
A	27	27				
B	176	176				
C	92	73	17		1	1
D	22	3	2		17	
E	5			5		
F	2			2		
G	4			4		
H	2			2		
I	3			3		
J	4			4		
K	3			3		
L	5			5		
M	2					2
N	71					71
O	125	1			7	117
P	1,012				51	961

Mapping from call sites to error classes

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Unhygienic macro expansion

```
code<cpp,stmt> swap(
  code<cpp,id> x,
  code<cpp,id> y) {
  return `cpp(stmt) [ {
    int temp = $x;
    $x = $y;
    $y = temp;
  }]; }
```

A macro function

```
code<cpp,stmt> fail() {
   return swap(
     `cpp[temp],
     `cpp[i]);
}
```

An unhygienic macro expansion

Unhygienic macro expansion

```
code<cpp,stmt> swap(
  code<cpp,id> x,
  code<cpp,id> y) {
  return `cpp(stmt) [ {
    int temp = $x;
    $x = $y;
    $y = temp;
  }]; }
```

A macro declaring
a local variable (temp)

```
{
   int temp = temp;
   temp = i;
   i = temp;
 }
```

Expanded code
containing accidental
name capture

Constraints for unhygienic expansion

```
code<cpp,stmt> swap(
  code<cpp,id> x,
  code<cpp,id> y) {
  return `cpp(stmt) [ {
    int temp = $x;
    $x = $y;
    $y = temp;
  }]; }
```

A macro generating captured name constraints

captured: x ≠ temp

```
code<cpp,stmt> fail() {
  return swap(
    `cpp[temp],
    `cpp[i]);
}
```

A macro generating free name constraints

free: x = temp

A conflict indicates that the macros are not hygienic

Captured name constraints

```
code<cpp,stmt> swap(
  code<cpp,id> x,
  code<cpp,id> y) {
  return `cpp(stmt) [ {
    int temp = $x;
    $x = $y;
    $y = temp;
  }]; }
```

captured: $x_1 \neq$ temp

How do we discover that **temp** is captured at the first blank?

A macro declaring
a local variable (temp)

Oracle analysis for captured names

```
`cpp(stmt) [ {
    int temp = $x;
    $x = $y;
    $y = temp;
  }]; }
```

Fragment

```
void _id0_() {
  if (1) {
    int temp = temp;
    _id1_ = _id2_;
    _id3_= temp;
  } else ;
}
```

Oracle query

- '_id1_' was not declared
- '__d2_' was not declared
- '_id3_' was not declared

No lookup error for **temp**

captured: x ≠ temp

Finding out free names

```
`cpp(id) [
  temp
]
```

Fragment

```
void _id0_() {
 return temp;
}
```

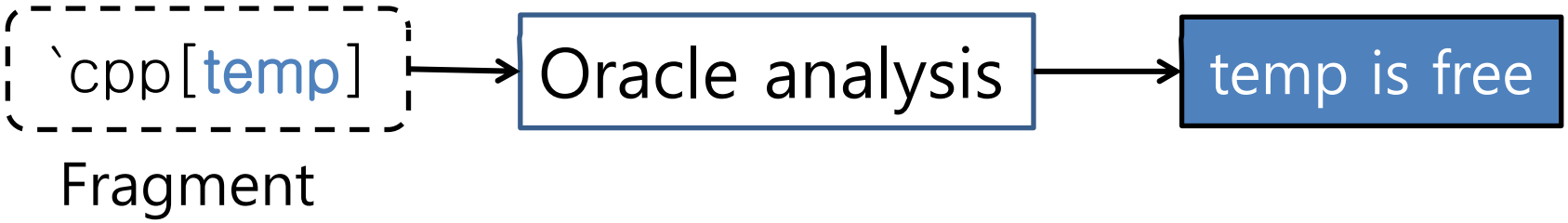
Oracle query

'temp' was not declared

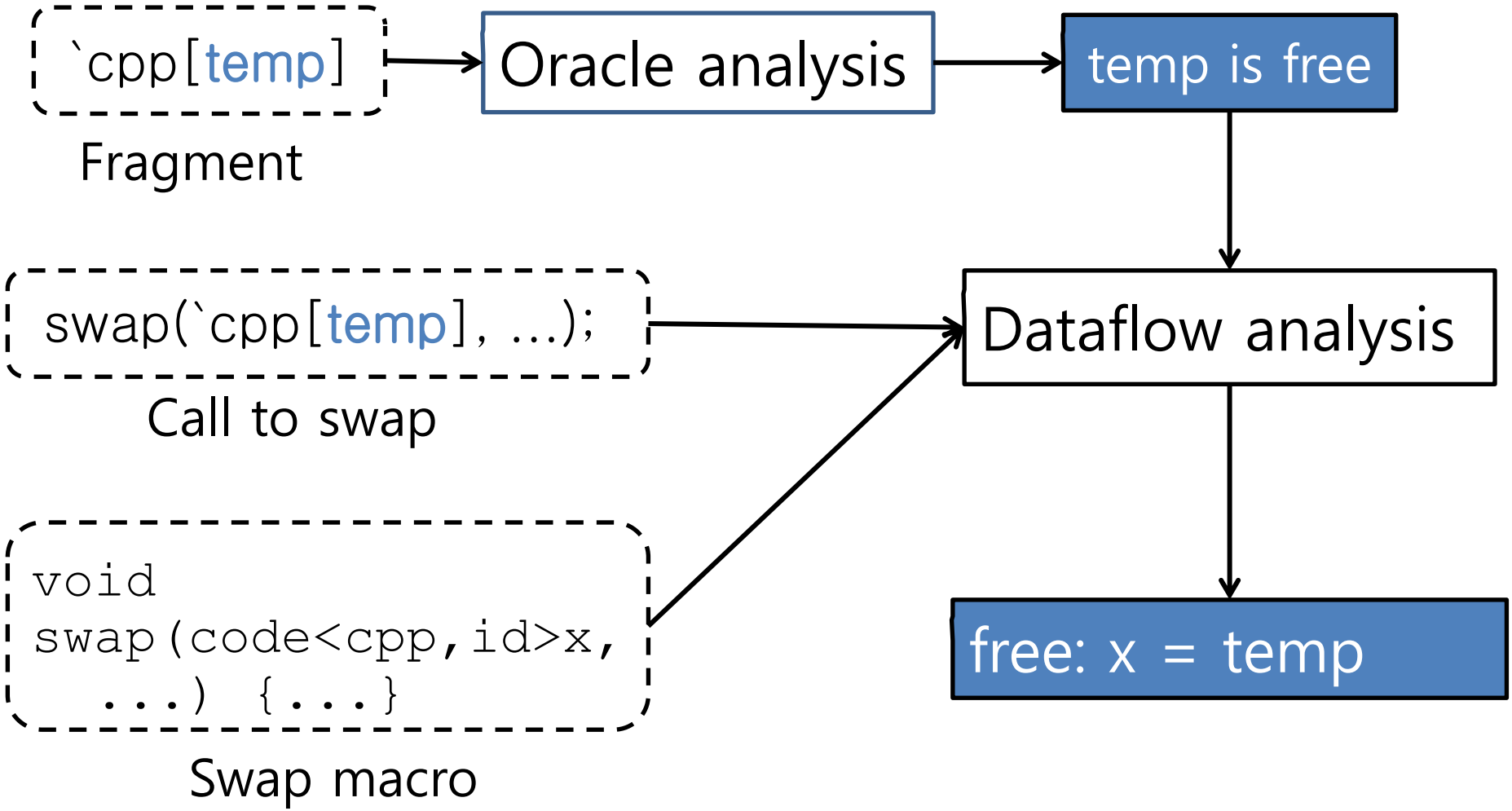
Lookup error for **temp**

temp is free

Propagating free name constraints



Propagating free name constraints



Summary

- Macros in programming languages
  - Simple, elegant core language
  - Abstraction and interoperability
  - Tradeoff between safety and encapsulation
- Our approach in **Marco**
  - Representing marcos as tokens
  - Offloading analyses to target-language processors
- Oracle analysis in practice
  - Context-sensitivity in C/C++
  - Speculations and backtracking
  - Classifying error messages