Syntax Macros: a Case-Study in Extending Clang

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LLVM Cauldron

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(since 2014)

Prof. Jeronimo Castrillon

- code generation for multicore systems-on-chip
- dataflow programming models
- heterogeneous platforms

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- domain-specific languages (DSLs) and tools
- languages for numerical applications
- software composition

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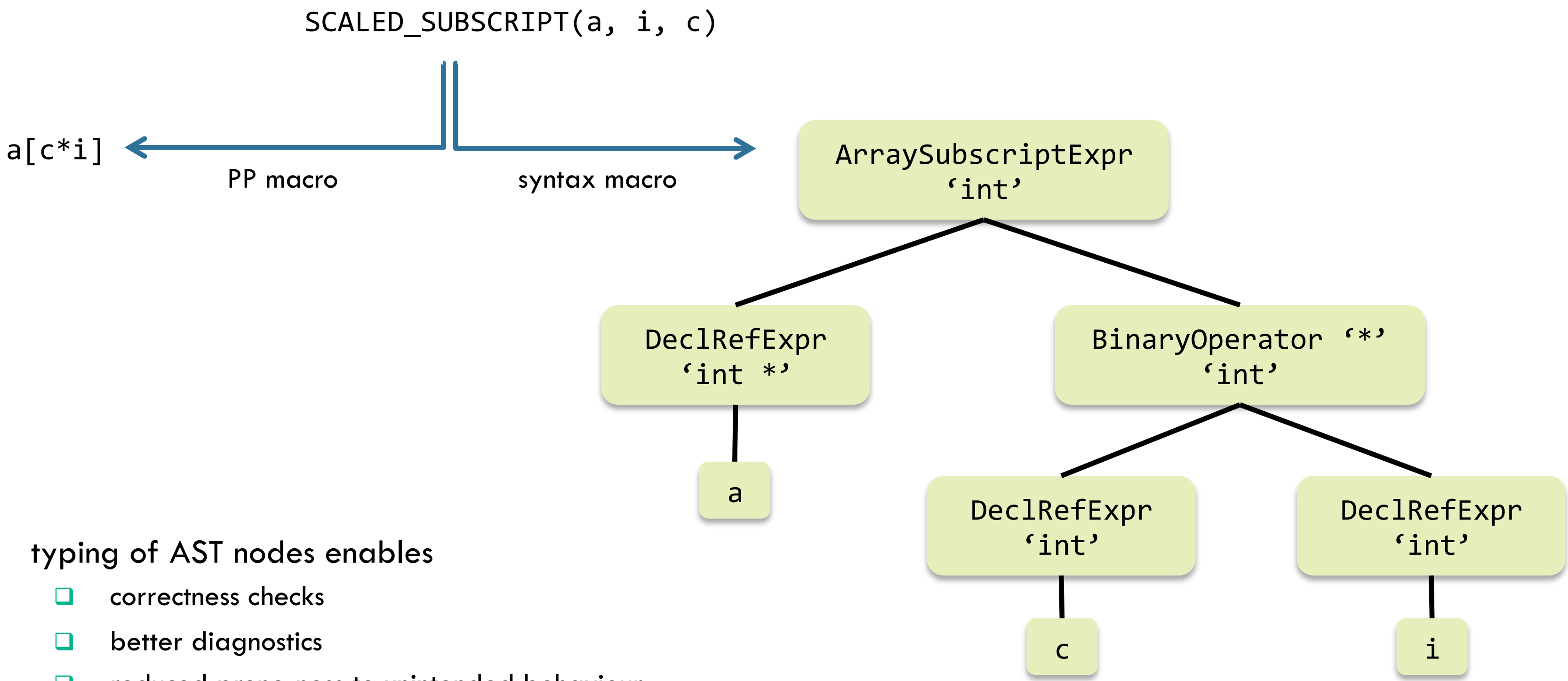
Introduction

*Macros are the world's second oldest programming language.**

- macros are a meta-programming tool
  - can be used to abstract programming tasks
  - reduce repetition of code patterns, esp. boilerplate code
  - "old" example: macro assembler
- preprocessor (PP) macros
  - very widely used
  - textual replacement → no type safety, poor diagnostics (but improving)
- syntax macros
  - expand to sub-trees of the AST (abstract syntax tree)
  - compose programs in the sense that ASTs are composed
  - compiler can check that the composed AST is valid

*) D. Weise, R. Crew

Introduction – cont’d



SCALED_SUBSCRIPT(a, i, c)

a[c*i]

PP macro

syntax macro

ArraySubscriptExpr ‘int’

DeclRefExpr ‘int *’

a

BinaryOperator ‘*’ ‘int’

DeclRefExpr ‘int’

c

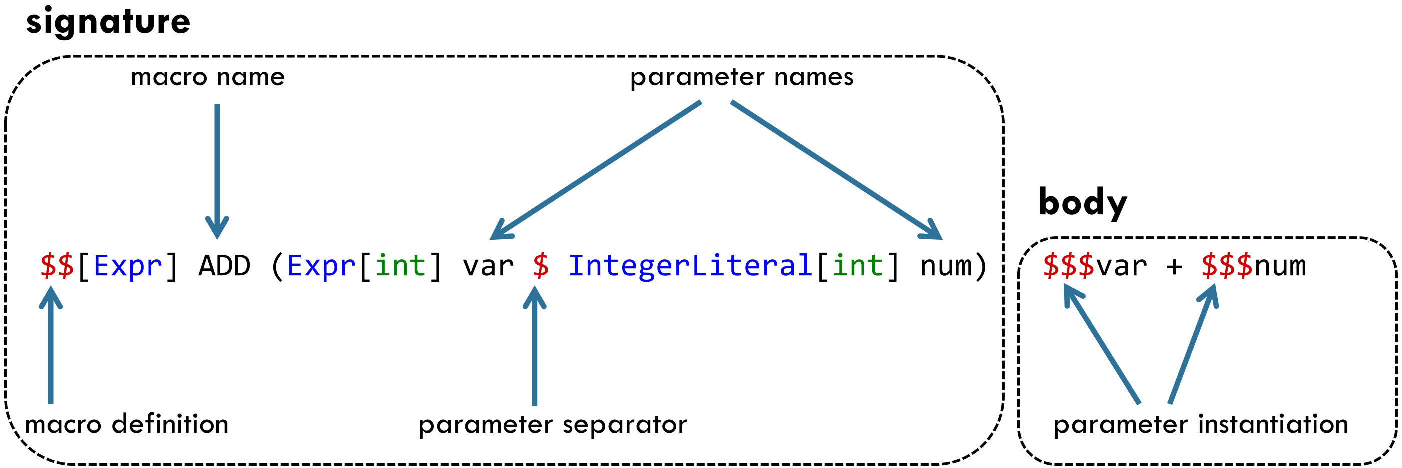
DeclRefExpr ‘int’

i

→ typing of AST nodes enables

- ❑ correctness checks
- ❑ better diagnostics
- ❑ reduced prone-ness to unintended behaviour

Defining syntax macros



signature

macro name

parameter names

```
$$[Expr] ADD (Expr[int] var $ IntegerLiteral[int] num)
```

macro definition

parameter separator

body

```
$$$var + $$$num
```

parameter instantiation

Using syntax macros

```
int simple() {
      int x = 1;
      x = $ADD(x $ 41);

      return x;
}
```

macro instantiation

parameter separator

```
-FunctionDecl simple 'int ()'
 `-CompoundStmt
   |-DeclStmt
   | `-VarDecl x 'int'
   |   `-IntegerLiteral 'int' 1
   |-BinaryOperator 'int' '='
   | |-DeclRefExpr 'int' lvalue Var 'x' 'int'
   | `-BinaryOperator 'int' '+’
   |     | `-ImplicitCastExpr 'int' <LValueToRValue>
   |     |   `-DeclRefExpr 'int' lvalue Var 'x' 'int'
   |     `-IntegerLiteral 'int' 41
   `-ReturnStmt
     `-ImplicitCastExpr 'int' <LValueToRValue>
       `-DeclRefExpr 'int' lvalue Var 'x' 'int'
```

macro sub-AST

Summary of syntax macros

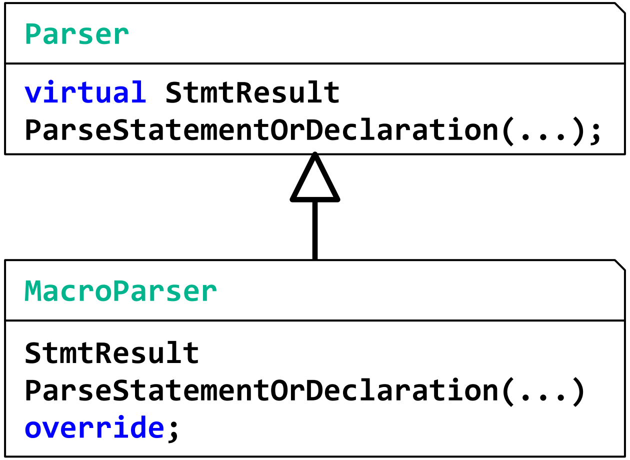
- Goal: use syntax macros instead of PP macros everywhere.
  - For safety and better diagnostics.
  - Are there any theoretical limitations to replacing PP macros?

- Use cases:
  - Find (potential) errors in code that relies on PP macros.
  - Aid language designers in prototyping syntactic sugar.
  - Here: toy model used to study the extensibility of Clang.
  - Further suggestions welcome!

- Reference: “Programmable Syntax Macros” (PLDI 1993)
  - by D. Weise, R. Crew
  - Describes a more comprehensive system than the prototype discussed here.

How to parse macro definitions

```
$$[Expr] ADD (Expr[int] var $ IntegerLiteral[int] num)   $$$var + $$$num
```



```
Parser
virtual StmtResult
ParseStatementOrDeclaration(...);
```

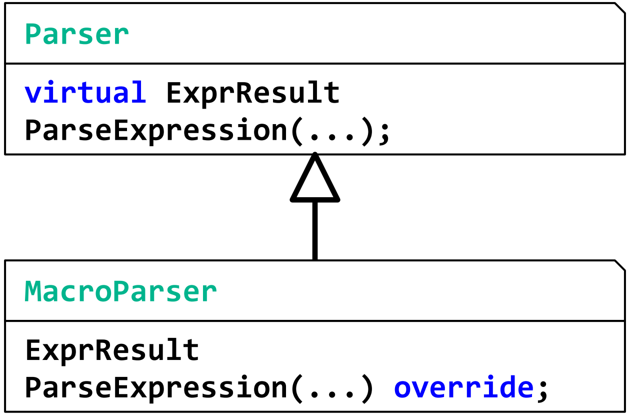
```
MacroParser
StmtResult
ParseStatementOrDeclaration(...)
override;
```

- Replace `Parser` by `MacroParser` in `ParseAST`.
- Macro signature:
  - Look out for $$ at the beginning of a statement.
  - If $$ is present, parse the macro signature.
  - Otherwise, defer to statement parsing in base class `Parser`.
- Macro body:
  - Look out for $$$ to indicate macro parameter expression.
  - Otherwise, defer to statement/expression parsing in `Parser`.

Very natural to use polymorphism to adjust the parser’s behaviour.

How to instantiate macros

```
$ADD(x $ 41)
```



```
Parser
virtual ExprResult
ParseExpression(...);
```

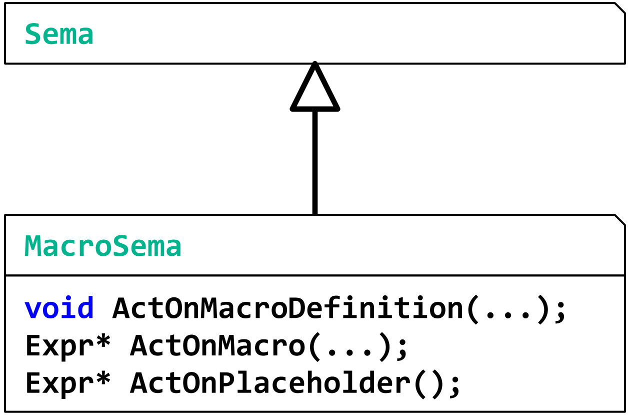
```
MacroParser
ExprResult
ParseExpression(...) override;
```

- If $ at the beginning of an expression,
  - parse the macro parameters.
  - instantiate the macro body’s AST with the parameters pasted in.
- Otherwise defer to expression parsing in the base class `Parser`.

Again, very natural to use polymorphism to adjust the parser’s behaviour.

How to instantiate macros – cont’ed

```
$ADD(x $ 41)
```



```
void ActOnMacroDefinition(...);
Expr* ActOnMacro(...);
Expr* ActOnPlaceholder();
```

- ❑ No virtual methods needed since `MacroParser` knows that it calls into `MacroSema` for constructing the AST.
- ❑ Subtlety: `Placeholder` node in the AST.
  - ❑ Required to represent (formal) macro parameters in the body AST.
  - ❑ Must type-check that parameters are in scope in the macro body.

Introduction of new AST nodes is tedious.

Problems with semantics and scope

```
$$[Stmt] RET (Expr[int] var)   return $$$var;
```

- Problem: return statements are only valid inside function scope.
  - If the macro is defined at global scope, Sema will silently produce an empty AST for the macro body.

```
$$[Expr] ADD_TO_X (Expr[int] var)   x += $$$var
```

- Problem: x may not be bound correctly.
  - If x is in scope at the macro definition, it will be bound. → Binding may be incorrect at macro instantiation.
  - If x is not in scope, it is a free variable. → Sema will raise an error.

This is the “open scope problem”:
What is a suitable scope for macro definitions?

Summary of extensibility issues

problem/need	solution	benefit	difficulty
polymorphism of Parser	make Parser virtual	enables language extensions, DSLs	easy, but may impact performance
polymorphism of CodeGen	make CodeGen virtual	eases implementation of new compiler flags	easy, but may impact performance
new AST node types	add generic sub-classes of Stmt, Expr etc.	makes the AST readily extensible, reduces boilerplate code required for prototyping	moderate, must integrate with existing infrastructure
adjust the behaviour of Sema to the parser's context		enable extensions/DSLs with fully independent semantics	easy if doable by Scope class, moderate to hard otherwise
"open context problem"	separate Parser from Sema?	full extensibility of C/C++, including semantics	hard

- Deliberate blank: How to support embedded semantics without fully separating Parser and Sema?
- Medium-term goal: Have a clean interface for adding language extensions to Clang.

Source code for syntax macros

Sources can be found on GitHub:

Norman Rink https://github.com/normanrink

- ❑ extended Clang: https://github.com/normanrink/clang-syntax-macros
- ❑ compatible (vanilla) version of LLVM: https://github.com/normanrink/llvm-syntax-macros

→ Please contribute:
questions, bugs, patches, improvements all welcome!

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Thank you.