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1 About

This document is intended to be used as a reference book for the AspectC++ language elements. It describes in-depth the use and meaning of each element providing examples. For experienced users the contents of this document are summarized in the AspectC++ Quick Reference. Detailed information about the AspectC++ compiler ac++ can be looked up in the AspectC++ Compiler Manual.

AspectC++ is an aspect-oriented extension to the C++ language\(^1\). It is similar to AspectJ\(^2\) but, due to the nature of C++, in some points completely different. The first part of this document introduces the basic concepts of the AspectC++ language. The in-depth description of each language element is subject of the second part.

2 Basic Concepts

2.1 Pointcuts

Aspects in AspectC++ implement crosscutting concerns in a modular way. With this in mind the most important element of the AspectC++ language is the pointcut. Pointcuts describe a set of join points by determining on which condition an aspect shall take effect. Thereby each join point can either refer to a function, a type/class, a variable, or a point from which a join point is accessed so that this condition can be for instance the event of reaching a designated code position or the allocation of a variable with a certain value. Depending on the kind of pointcuts, they are evaluated at compile time or at runtime.

2.1.1 Match Expressions

There are two types of pointcuts in AspectC++: code pointcuts and name pointcuts. Name pointcuts describe a set of (statically) known program entities like types/classes, variables, functions, or namespaces. All name pointcuts are based on match expressions. A match expression can be understood as a search pattern. In such a search pattern the special character “%” is interpreted as a wildcard for names or parts of a signature. The special character sequence “…” matches any

\(^{1}\text{defined in the ISO/IEC 14882:1998(E) standard}\)
\(^{2}\text{http://www.eclipse.org/aspectj/}\)
2 BASIC CONCEPTS

number of parameters in a function signature or any number of scopes in a qualified name. A match expression is a quoted string.

Example: match expressions (name pointcuts)

"int C::%(...)"
matches all member functions of the class C that return an int

"%List"
matches any namespace, class, struct, union, or enum whose name ends with List. In case of a matched namespace or class the match expression also matches entities inside the namespace resp. class. For more information see section 3.2.

"% printf(const char *, ...)"
matches the function printf (defined in the global scope) having at least one parameter of type const char * and returning any type

"const %& ....::%(...)"
matches all functions that return a reference to a constant object

Match expressions select program entities with respect to their definition scope, their type, and their name. A detailed description of the match expression semantics follows in section 3 on page 19. The grammar which defines syntactically valid match expressions is shown in appendix B on page 56.

2.1.2 Pointcut Expressions

The other type of pointcuts, the code pointcuts, describe an intersection through the set of the points in the control flow of a program. A code pointcut can refer to a call or execution point of a function, to a call of a built-in operator or and to write and read points of member variables and global variables. They can only be created with the help of name pointcuts because all join points supported by AspectC++ require at least one name to be defined. This is done by calling predefined pointcut functions in a pointcut expression that expect a pointcut as argument. Such a pointcut function is for instance within(pointcut), which filters all join points that are within the functions or classes in the given pointcut.
2.1 Pointcuts

Name and code pointcuts can be combined in pointcut expressions by using the algebraic operators “&&”, “||”, and “!”.

Example: pointcut expressions

"%List" && !derived("Queue")

describes the set of classes with names that end with “List” and that are not derived from the class Queue

call("void draw()") && within("Shape")

describes the set of calls to the function draw that are within methods of the class Shape

2.1.3 Types of Join Points

According to the two types of pointcuts supported by AspectC++ there are also two coarse types of join points: name join points and code join points. As diagramed in figure 1 both of these have sub join point types. The types Any, Name, Code and Access are abstract types and exist just for categorizing the other join point types.

![Figure 1: join point type hierarchy](image)

Figure 1 is extracted from the AspectC++ project repository hierarchy, that can be found in appendix C.

Based on a short code fragment the differences and relations between the types of join points shall be clarified.

```java
1 class Shape { /*...*/ };
2 void draw(Shape& shape) { /*...*/ }
```
namespace Circle {
    typedef int PRECISION;

    class S_Circle : public Shape {
        PRECISION m_radius;
        public:
            void radius(PRECISION r) {
                m_radius = r;
            }
            ~S_Circle() { /*...*/ } }
    }

    void draw(PRECISION r) {
        S_Circle circle;
        circle.radius(r);
        draw(circle);
    }
}

int main() {
    Circle::draw(10);
    return 0;
}

Code join points are used to form code pointcuts and name join points (i.e. names) are used to form name pointcuts. Figure 2 on the next page shows join points of the code fragment above and how they correlate. Built-in constructors, destructors and uncalled operators are not shown. Additionally appendix D shows the contents of the project repository\(^3\) for the code fragment.

\(^3\)The AspectC++ project repository is a file, that contains the internal AspectC++ model as xml-tree. The actual style and format of the content may change at any time. For more information see the AspectC++ Compiler Manual.
2.1 Pointcuts

Every execution join point is associated with the name of an executable function. Pure virtual functions are not executable. Thus, advice code for execution join points would never be triggered for this kind of function. However, the call of such a function, i.e. a call join point with this function as target, is absolutely possible. Furthermore there are no execution join points for built-in operator functions.

Every call or builtin join point is associated with two names: the name of the source and the target function (in case of builtin this is the global built-in operator function) of a function call. As there can be multiple function calls within the same function, each function name can be associated with a list of call join points and builtin join points. The same holds for set and get join points, which represent write resp. read operations on data members or global variables. Each of these join points is associated with the name of the function that contains the join point and the name of the accessed member variable or global variable. A construction join point means the class specific instruction sequence executed when an instance is created. In analogy, a destruction join point means the object destruction.

2.1.4 Pointcut declarations

AspectC++ provides the possibility to name pointcut expressions with the help of pointcut declarations. This makes it possible to reuse pointcut expressions in dif-

Figure 2: join points and their relations
Different parts of a program. They are allowed where C++ declarations are allowed.
Thereby the usual C++ name lookup and inheritance rules are also applicable for
pointcut declarations.

A pointcut declaration is introduced by the keyword `pointcut`.

**Example: pointcut declaration**

```cpp
pointcut lists() = derived("List");
    lists can now be used everywhere in a program where a pointcut expression
    can be used to refer to derived("List")
```

Furthermore pointcut declarations can be used to define pure virtual pointcuts. This
enables the possibility of having re-usable abstract aspects that are discussed in
section 2.5. The syntax of pure virtual pointcut declarations is the same as for usual
pointcut declarations except the keyword `virtual` following `pointcut` and that the
pointcut expression is “0”.

**Example: pure virtual pointcut declaration**

```cpp
pointcut virtual methods() = 0;
    methods is a pure virtual pointcut that has to be redefined in a derived aspect
to refer to the actual pointcut expression
```

### 2.2 Attributes

Based on the C++11 attribute syntax AspectC++ provides an annotation mechanism
for join points. All join points annotated with the same attribute “a”, e.g. `class
[[a]] C { ...}`, can be referred to in a pointcut expression as `a()`. Further information
can be found in section 5.

### 2.3 Slices

A slice is a fragment of a C++ language element that defines a scope. It can be used
by advice to extend the static structure of the program. For example, the elements of
a class slice can be merged into one or more target classes by introduction advice.
The following example shows a simple class slice declaration.

---

4 In other languages this mechanism is known as “annotations”.
2.4 Advice Code

Example: class slice declaration

```cpp
slice class Chain {
    Chain *next;
public:
    Chain *next() const { return _next; }
};
```

2.4 Advice Code

To a code join point so-called advice code can be bound. Advice code can be understood as an action activated by an aspect when a corresponding code join point in a program is reached. The activation of the advice code can happen before, after, or before and after the code join point is reached. The AspectC++ language element to specify advice code is the advice declaration. It is introduced by the keyword `advice` followed by a pointcut expression defining where and under which conditions the advice code shall be activated.

Example: advice declaration

```cpp
advice execution("void login(...)") : before() {
    cout << "Logging in." << endl;
}
```

The code fragment `:before()` following the pointcut expression determines that the advice code shall be activated directly **before** the code join point is reached. It is also possible here to use `:after()` which means **after** reaching the code join point respectively `:around()` which means that the advice code shall be executed instead of the code described by the code join point. In an **around** advice the advice code can explicitly trigger the execution of the program code at the join point so that advice code can be executed **before** and **after** the join point. There are no special access rights of advice code regarding to program code at a join point.

Beside the pure description of join points pointcuts can also bind variables to context information of a join point. Thus for instance the actual argument values of a function call can be made accessible to the advice code.
Example: advice declaration with access to context information

```cpp
pointcut new_user(const char *name) = 
  execution("void login(...)") && args(name);
advice new_user(name) : before(const char *name) {
  cout << "User " << name << " is logging in." << endl;
}
```

In the example above at first the pointcut `new_user` is defined including a context variable `name` that is bound to it. This means that a value of type `const char*` is supplied every time the join point described by the pointcut `new_user` is reached. The pointcut function `args` used in the pointcut expression delivers all join points in the program where an argument of type `const char*` is used. Therefore `args(name)` in touch with the `execution` join point binds `name` to the first and only parameter of the function `login`.

The advice declaration in the example above following the pointcut declaration binds the execution of advice code to the event when a join point described in `new_user` is reached. The context variable that holds the actual value of the parameter of the reached join point has to be declared as a formal parameter of `before`, `after`, or `around`. This parameter can be used in the advice code like an ordinary function parameter.

Beside the pointcut function `args` the binding of context variables is performed by `that`, `target`, and `result`. At the same time these pointcut functions act as filters corresponding to the type of the context variable. For instance `args` in the example above filters all join points having an argument of type `const char*`.

2.4.1 Introductions

The second type of advice supported by AspectC++ are the introductions. Introductions are used to extend program code and data structures in particular. The following example extends two classes each by a member variable and a member function.

Example: introductions

```cpp
pointcut shapes() = "Circle" || "Polygon";
advice shapes() : slice class {
```
bool m_shaded;
void shaded(bool state) {
    m_shaded = state;
}
};

Like an ordinary advice declaration an introduction is introduced by the keyword `advice`. If the following pointcut is a name pointcut the slice declaration following the token `:` is introduced in the classes and aspects described by the pointcut. Introduced code can then be used in normal program code like any other member function, member variable, etc. Advice code in introductions has full access rights regarding to program code at a join point, i.e. a method introduced in a class has access even to private members of that class.

Slices can also be used to introduce new base classes. In the first line of the following example it is made sure that every class with a name that ends with “Object” is derived from a class `MemoryPool`. This class may implement an own memory management by overloading the `new` and `delete` operators. Classes that inherit from `MemoryPool` must redefine the pure virtual method `release` that is part of the implemented memory management. This is done in the second line for all classes in the pointcut.

**Example: base class introduction**

```cpp
advice "%Object" : slice class : public MemoryPool {
    virtual void release() = 0;
}
```

### 2.4.2 Advice Ordering

If more than one advice affects the same join point it might be necessary to define an order of advice execution if there is a dependency between the advice codes (“aspect interaction”). The following example shows how the precedence of advice code can be defined in AspectC++.

**Example: advice ordering**

```cpp
advice call("% send(...)") : order("Encrypt", "Log");
```
If advice of both aspects (see 2.5) Encrypt and Log should be run when the function send(...) is called this order declaration defines that the advice of Encrypt has a higher precedence. More details on advice ordering and precedence can be found in section 9 on page 52.

2.5 Aspects

The aspect is the language element of AspectC++ to collect introductions and advice code implementing a common crosscutting concern in a modular way. This put aspects in a position to manage common state information. They are formulated by means of aspect declarations as a extension to the class concept of C++. The basic structure of an aspect declaration is exactly the same as an usual C++ class definition, except for the keyword aspect instead of class, struct or union. According to that, aspects can have member variables and member functions and can inherit from classes and even other aspects.

Example: aspect declaration

```cpp
aspect Counter {
    static int m_count;

    pointcut counted() = "Circle" || "Polygon";
    advice counted() : slice struct {
        class Helper {
            Helper() { Counter::m_count++; }
        } m_counter;
    };
    advice execution("% main(...)") : after() {
        cout << "Final count: " << m_count << " objects"
        << endl;
    }
};
... and at an appropriate place
#include "Counter.ah"
int Counter::m_count = 0;
```
In this example the count of object instantiations for a set of classes is determined. Therefore, a member variable \texttt{m\_counter} is introduced into the classes described by the pointcut incrementing a global counter on construction time. By applying advice code for the function \texttt{main} the final count of object instantiations is displayed when the program terminates.

This example can also be rewritten as an abstract aspect that can for instance be archived in an aspect library for the purpose of reuse. It only require to reimplement the pointcut declaration to be pure virtual.

\textbf{Example: abstract aspect}

\begin{verbatim}
aspect Counter {
    static int m_count;
    Counter() : m_count(0) {}
    pointcut virtual counted() = 0;
    ...
};
\end{verbatim}

It is now possible to inherit from \texttt{Counter} to reuse its functionality by reimplementing \texttt{counted} to refer to the actual pointcut expression.

\textbf{Example: reused abstract aspect}

\begin{verbatim}
aspect MyCounter : public Counter {
    pointcut counted() = derived("Shape");
};
\end{verbatim}

2.5.1 Aspect Instantiation

By default aspects in AspectC++ are automatically instantiated as global objects. The idea behind it is that aspects can also provide global program properties and therefore have to be always accessible. However in some special cases it may be desired to change this behavior, e.g. in the context of operating systems when an aspect shall be instantiated per process or per thread.

The default instantiation scheme can be changed by defining the static method \texttt{aspectof resp. aspectOf} that is otherwise generated for an aspect. This method is intended to be always able to return an instance of the appropriate aspect.
Example: aspect instantiation using `aspectof`

```c++
aspect ThreadCounter : public Counter {
    pointcut counted() = "Thread";
    advice counted() : ThreadCounter m_instance;
    static ThreadCounter *aspectof() {
        return tjp->target()->m_instance;
    }
};
```

The introduction of `m_instance` into `Thread` guarantees that every thread object has an instance of the aspect. By calling `aspectof` it is possible to get this instance at any join point which is essential for accessing advice code and members of the aspect. For this purpose code in `aspectof` has full access to the actual join point in a way described in the next section.

## 2.6 Runtime Support

### 2.6.1 Support for Advice Code

For many aspects access to context variables may not be sufficient to get enough information about the join point where advice code was activated. For instance a control flow aspect for a complete logging of function calls in a program would need information about function arguments and its types on runtime to be able to produce a type-compatible output.

In AspectC++ this information is provided by the members of the class `JoinPoint` (see table below).

<table>
<thead>
<tr>
<th>types:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Result</td>
<td>result type</td>
</tr>
<tr>
<td>That</td>
<td>object type</td>
</tr>
<tr>
<td>Target</td>
<td>target type</td>
</tr>
<tr>
<td>AC::Type</td>
<td>encoded type of an object</td>
</tr>
<tr>
<td>AC::JPType</td>
<td>join point types</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>static methods:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>int args()</td>
<td>number of arguments</td>
</tr>
<tr>
<td>AC::Type type()</td>
<td>typ of the function or attribute</td>
</tr>
</tbody>
</table>
### Table 1: API of class JoinPoint available in advice code

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC::Type argtype(int)</td>
<td>types of the arguments</td>
</tr>
<tr>
<td>const char *signature()</td>
<td>signature of the function or variable</td>
</tr>
<tr>
<td>unsigned id()</td>
<td>identification of the join point</td>
</tr>
<tr>
<td>AC::Type resulttype()</td>
<td>result type</td>
</tr>
<tr>
<td>AC::JPType jptype()</td>
<td>type of join point</td>
</tr>
<tr>
<td>non-static methods:</td>
<td></td>
</tr>
<tr>
<td>void *arg(int)</td>
<td>actual argument</td>
</tr>
<tr>
<td>Result *result()</td>
<td>result value</td>
</tr>
<tr>
<td>That *that()</td>
<td>object referred to by this</td>
</tr>
<tr>
<td>Target *target()</td>
<td>target object of a call</td>
</tr>
<tr>
<td>void proceed()</td>
<td>execute join point code</td>
</tr>
<tr>
<td>AC::Action &amp;action()</td>
<td>Action structure</td>
</tr>
</tbody>
</table>

Types and static methods of the JoinPoint API deliver information that is the same for every advice code activation. The non-static methods deliver information that differ from one activation to another. These methods are accessed by the object `tjp` resp. `thisJoinPoint` which is of type `JoinPoint` and is always available in advice code, too.

The following example illustrates how to implement a re-usable control flow aspect using the JoinPoint API.

### Example: re-usable trace aspect

```cpp
aspect Trace {
    pointcut virtual methods() = 0;
    advice execution(methods()) : around() {
        cout << "before " << JoinPoint::signature() << "(";
        for (unsigned i = 0; i < JoinPoint::args(); i++)
            printvalue(tjp->arg(i), JoinPoint::argtype(i));
        cout << ")" << endl;
        tjp->proceed();
        cout << "after" << endl;
    }
}
```

This aspect weaves tracing code into every function specified by the virtual pointcut redefined in a derived aspect. The helper function \texttt{printvalue} is responsible for the formatted output of the arguments given at the function call. After calling \texttt{printvalue} for every argument the program code of the actual join point is executed by calling \texttt{proceed} on the \texttt{JoinPoint} object. The functionality of \texttt{proceed} is achieved by making use of the so-called actions.

2.6.2 Actions

In AspectC++ an action is the statement sequence that would follow a reached join point in a running program if advice code would not have been activated. Thus \texttt{tjp->proceed()} triggers the execution of the program code of a join point. This can be the call or execution of a function as well as the writing or reading of member variables or global variables. The actions concept is realized in the \texttt{AC::Action} structure. In fact, \texttt{proceed} is equivalent to \texttt{action().trigger()} so that \texttt{tjp->proceed()} may also be replaced by \texttt{tjp->action().trigger()}. Thereby the method \texttt{action()} of the \texttt{JoinPoint} API returns the actual action object for a join point.

3 Match Expressions

Match expressions are used to describe a set of statically known program entities in a C++ source code. These program entities correspond to name join points. Therefore a match expression always returns a name pointcut. There can be match expressions for namespaces, classes, functions or variables.

3.1 Commonly Used Matching Mechanisms

This section describes matching mechanisms that are used in match expressions listed in sections 3.2 to 3.4.

The grammar used for match expression parsing is shown in appendix B on page 56. The following subsections separately describe the name, scope, and type matching mechanisms. All of them are used in match expressions of functions and variables, while match expressions of namespaces and classes only uses name and scope matching.
3.1 Commonly Used Matching Mechanisms

3.1.1 Name Matching

Name matching is trivial as long as the compared name is a normal C++ identifier. If the name pattern does not contain the special wildcard character %, it matches a name only if it is exactly the same. Otherwise each wildcard character matches an arbitrary sequence of characters in the compared name. The wildcard character also matches an empty sequence.

Example: simple name patterns

<table>
<thead>
<tr>
<th>Token</th>
<th>only matches Token</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>any name</td>
</tr>
</tbody>
</table>
| parse_%     | any name beginning with parse_ like parse_declarator or parse_
| parse_%id%  | names like parse_type_id, parse_private_identifier, etc. |
| _token      | all names that end with _token like start_token, end_token, and _token |

3.1.2 Scope Matching

Restrictions on definition scopes can be described by scope patterns. This is a sequence of name patterns (or the special any scope sequence pattern . . .), which are separated by ::, like in Puma:::. A scope pattern always ends with :: and should never start with ::, because scope patterns are interpreted relative to the global scope anyway\(^5\). The definition scope can either be a namespace or a class.

A scope pattern matches the definition scope of a compared function or type if every part can successfully be matched with a corresponding part in the qualified name of the definition scope. The compared qualified name has to be relative to the global scope and should not start with ::, which is optional in a C++ nested-name-specifier. The special . . . pattern matches any (even empty) sequence of scope names. If no scope pattern is given, a compared namespace, class, function or variable has to be defined in the global scope to be matched.

---

\(^5\)This restriction is also needed to avoid ambiguities in the match expression grammar: Does “A :: B :: C(int)” mean “A ::B::C(int)” or “A::B ::C(int)”?
Example: scope patterns

...::
    matches any definition scope, even the global scope

Puma::CCParser::
    matches the scope Puma::CCParser exactly

...:%Compiler%::
    matches any class or namespace, which matches the
    name pattern %Compiler%, in any scope

Puma::....::
    matches any scope defined within the class or names-
    space Puma and Puma itself

3.1.3 Type Matching

C++ types can be represented as a tree. For example, the function type
int(double)
is a function type node with two children, one is an int node, the
other a double node. Both children are leaves of the tree.

The types used in match expressions can also be interpreted as trees. As an
addition to normal C++ types they can also contain the % wildcard character, name
patterns, and scope patterns. A single wildcard character in a type pattern becomes
a special any type node in the tree representation.

For comparing a type pattern with a specific type the tree representation is used
and the any type node matches an arbitrary type (sub-)tree.

Example: type patterns with the wildcard character

%        matches any type

void (*)(%)
    matches any pointer type that points to functions with a sin-
    gle argument and a void result type

%*
    matches any pointer type

Matching of Named Types

Type patterns may also contain name and scope patterns. They become a named
type node in the tree representation and match any union, struct, class, or enumera-
tion type if its name and scope match the given pattern (see section 3.1.1 and 3.1.2).

Matching of “Pointer to Member” Types

Patterns for pointers to members also contain a scope pattern, e.g.
% (Puma::CSyntax::*)(
In this context the scope pattern is mandatory. The pattern is used for matching the class associated with a pointer to member type.
3.1 Commonly Used Matching Mechanisms

Matching of Qualified Types (const/volatile)

Many C++ types can be qualified as `const` or `volatile`. In a type pattern these qualifier can also be used, but they are interpreted restrictions. If no `const` or `volatile` qualifier is given in a type pattern, the pattern also matches qualified types\(^6\).

**Example: type patterns with const and volatile**

- `%` matches any type, even types qualified with `const` or `volatile`
- `const %` matches only types qualified by `const`
- `% (*)(*) const volatile` matches the type of all pointers to functions that are qualified by `const` and `volatile`

Handling of Conversion Function Types

The result type of conversion functions is interpreted as a special `undefined` type in type patterns as well as in compared types. The `undefined` type is only matched by the `any type` node and the `undefined type` node.

Ellipses in Function Type Patterns

In the list of function argument types the type pattern `...` can be used to match an arbitrary (even empty) list of types. The `...` pattern should not be followed by other argument type patterns in the list of argument types.

Matching Virtual Functions

The `decl-specifier-seq` of a function type match expression may include the keyword `virtual`. In this case the function type match expression only matches virtual or pure virtual member functions. As `const` and `volatile`, the `virtual` keyword is regarded as a restriction. This means that a function type match expression without `virtual` matches virtual and non-virtual functions.

---

\(^6\)Matching only non-constant or non-volatile types can be achieved by using the operators explained in section 4.9 on page 42. For example, `!"const %"` describes all types which are not constant.
3  MATCH EXPRESSIONS  3.2  Namespace and Class Match Expressions

Example: type patterns with virtual
virtual % ...::%(...) matches all virtual or pure virtual functions in any scope
% C::%(...) matches all member functions of C, even if they are virtual

Matching Static Functions
Matching static functions works similar as matching virtual functions. The decl-specifier-seq of a function type match expression may include the keyword static. In this case the function type match expression only matches static functions in global or namespace scope and static member functions of classes. As const and volatile, the static keyword is regarded as a restriction. This means that a function type match expression without static matches static and non-static functions.

Example: type patterns with static
static % ...::%(...) matches all static member and non-member functions in any scope
% C::%(...) matches all member functions of C, even if they are static

Argument Type Adjustment
Argument types in type patterns are adjusted according to the usual C++ rules, i.e. array and function types are converted to pointers to the given type and const/volatile qualifiers are removed. Furthermore, argument type lists containing a single void type are converted into an empty argument type list.

3.2  Namespace and Class Match Expressions

For namespaces and classes the matching process is special because it consists of two steps.

First, each namespace and class is compared with a given match expression. A match expression that matches a namespace or class begins with the optional scope
part and ends with the required name part. In course of this step the matching name join points are collected in a temporary pointcut.

**Example: scope and name parts of a namespace or class match expression**

"Puma::...::Parser%"

This match expression describes the following requirements on a compared namespace or class:

**scope:** the scope in which the namespace or class is defined has to match

Puma::...::

**name:** the name of the namespace or class has to match the name pattern

Parser%

For more information about these parts see sections Scope Matching (3.1.2) and Name Matching (3.1.1).

In the second step the temporary pointcut will be extended by contained name join points yielding the result pointcut. The extension rules are as follows:

- If a namespace $N$ is matched, the resulting pointcut additionally contains the following name join points:
  all functions, variables, (nested) classes, member functions, data members, constructors and destructors that are anywhere and arbitrary nested inside $N$.

- If a class $C$ is matched, the resulting pointcut additionally contains the following name join points:
  all member functions, data members and constructors of $C$ as well as the destructor of $C$ that are directly located inside $C$. So name join points that are nested inside a member function, a data member or a nested class are not added to the pointcut.

The following list contains example match expressions and the results after the first as well as after the second step.
### 3.2 Namespace and Class Match Expressions

<table>
<thead>
<tr>
<th>Token</th>
<th>after step one</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Token</td>
<td>only matches namespaces or classes with the name <strong>Token</strong> that are directly inside the global namespace</td>
<td><strong>step one extended as described in step two</strong></td>
</tr>
<tr>
<td>...::Token</td>
<td>matches <strong>Token</strong> at arbitrary location</td>
<td><strong>step one extended as described in step two</strong></td>
</tr>
<tr>
<td>%</td>
<td>matches any namespace or class that is directly located in the global namespace but not the global namespace itself</td>
<td>matches any namespace except the global namespace, any class that is arbitrary nested in a non-global namespace, any class directly located in the global namespace and all functions, member functions, variables, data members, constructors and destructors that are contained in one of the just mentioned entities</td>
</tr>
<tr>
<td>::</td>
<td>matches the global namespace</td>
<td>matches any function, variable, (nested) class, member function, data member, constructor or destructor</td>
</tr>
</tbody>
</table>
after step one

OOSTuBS::CGA
matches any namespace or class inside OOSTuBS beginning with CGA like OOSTuBS::CGA,
OOSTuBS::CGA_Screen or OOSTuBS::CGA_Stream. Note that this matches OOSTuBS only inside the global namespace.

%::Smtp%Bldr%
matches namespaces and classes like SmtpBldr, SmtpClientBldr or SmtpServerBldrCreator, that are nested in exact one namespace or class.

%Node
matches any namespace or class ending with Node like ModelNode, GraphNode and Node

Please note that local classes inside functions or member functions are never matched.

3.3 Function Match Expressions

For function (or member function) matching a match expression is internally decomposed into the function type pattern, the scope pattern, and the name pattern.

Example: type, scope, and name parts of a function match expression

"const % Puma::...::parse_% (Token *)"

This match expression describes the following requirements on a compared function name:

name: the function name has to match the name pattern parse_%

scope: the scope in which the function is defined has to match Puma::...::
**type:** the function type has to match `const % (Token *)`

If an entity matches all parts of the match expression, it becomes an element of the pointcut, which is defined and returned by the match expression.

Common descriptions of name, scope and type matching can be found in section 3.1. The following sections additionally describe the name matching of special functions.

### 3.3.1 Operator Function and Conversion Function Name Matching

The name matching mechanism is more complicated if the pattern is compared with the name of a conversion function or an operator function. Both are matched by the name pattern `%`. However, with a different name pattern than `%` they are only matched if the pattern begins with "operator ". The pattern "operator %" matches any operator function or conversion function name.

C++ defines a fixed set of operators which are allowed to be overloaded. In a name pattern the same operators may be used after the "operator " prefix to match a specific operator function name. Operator names in name patterns are not allowed to contain the wildcard character. For ambiguity resolution the operators `%` and `%=` are matched by `%%` and `%%=` in a name pattern.

**Example: operator name patterns**

- `operator %` matches any operator function name (as well as any conversion function name)
- `operator +=` matches only the name of a `+=` operator
- `operator %%` matches the name of an operator `%`

Conversion functions don’t have a real name. For example, the conversion function `operator int*()` defined in a class `C` defines a conversion from a `C` instance into an object of type `int*`. To match conversion functions the name pattern may contain a type pattern after the prefix "operator ". The type matching mechanism is explained in section 3.1.3.

**Example: conversion function name patterns**
3.4 Variable Match Expressions

For variable (or member) matching a match expression is internally decomposed into the variable type pattern, the scope pattern, and the name pattern.

Example: type, scope, and name parts of a variable match expression

"const % Puma::...::parsed_%"

This match expression describes the following requirements on a compared variable name:

name: the variable name has to match the name pattern parsed_%

scope: the scope in which the variable is defined has to match Puma::...::

type: the variable type has to match const %

If an entity matches all parts of the match expression, it becomes an element of the pointcut, which is defined and returned by the match expression.

Descriptions of name, scope and type matching can be found in section 3.1.

4 Predefined Pointcut Functions

On the following pages a complete list of the pointcut functions supported by AspectC++ is presented. For every pointcut function it is indicated which type of pointcut is expected as argument(s) and of which type the result pointcut is. Thereby “N”
stands for name pointcut and “C” for code pointcut. The optionally given index is an assurance about the type of join point(s) described by the result pointcut\(^7\). If a pointcut is used as argument of a pointcut function and the type of some join points in argument pointcut does not match one of the expected argument types of the pointcut function, these non-matching join points are silently ignored.

### 4.1 Types

**base(pointcut)**

\[ N_{C,F,V} \rightarrow N_{C,F,V} \]

returns a pointcut \( p_b \) of name join points created as follows

\[ p_b \leftarrow \{ \text{all base classes of classes in pointcut but not the classes in pointcut} \}, \]

\[ p_b \leftarrow p_b \upharpoonright \{ \text{all member functions and data members of classes in } p_b \}, \]

\[ p_b \leftarrow p_b \upharpoonright \{ \text{all previous definitions of member functions in pointcut but not the member functions in pointcut} \}, \]

\[ p_b \leftarrow p_b \upharpoonright \{ \text{all previous definitions of data members in pointcut but not the data members in pointcut} \} \]

**derived(pointcut)**

\[ N_{C,F,V} \rightarrow N_{C,F,V} \]

returns a pointcut \( p_d \) of name join points created as follows

\[ p_d \leftarrow \{ \text{all classes in pointcut and all classes derived from them} \}, \]

\[ p_d \leftarrow p_d \upharpoonright \{ \text{all member functions and data members of classes in } p_d \}, \]

\[ p_d \leftarrow p_d \upharpoonright \{ \text{all member functions in pointcut and all redefinitions of these member functions in derived classes} \}, \]

\[ p_d \leftarrow p_d \upharpoonright \{ \text{all data members in pointcut and all redefinitions of these data members in derived classes} \} \]

**Example: derived function matching**

```cpp
struct A {};  
struct B : public A { void f(); };  
struct C : public B { void f(); };  
aspect Z {

\[ ^7 \text{C, C, C, C, } C_b, C_s, C_g: \text{ Code (any, only Call (without Builtin), only Execution, only Builtin, only Set, only Get); } \text{ N, N, N, N, N, N: Names (any, only Namespace, only Class, only Function, only Type, only Variable) } \]
```
4.2 Control Flow

```
advice execution(derived("A")) : before() {
  // before execution of B::f() or C::f()
}
```

**Example: type matching**

A software may contain the following class hierarchy.

```cpp
class Shape { ... };  
class Scalable { ... };  
class Point : public Shape { ... };  
...  
class Rectangle : public Line, public Rotatable { ... };  
```

With the following aspect a special feature is added to a designated set of classes of this class hierarchy.

```cpp
aspect Scale {
  pointcut scalable() = "Rectangle" ||
    (base("Rectangle") && derived("Point"));
  advice "Point" : slice class : public Scalable;
  advice scalable() : slice class {
    void scale(int value) { ... }
  };
}
```

The pointcut describes the classes *Point* and *Rectangle* and all classes derived from *Point* that are direct or indirect base classes of *Rectangle*. With the first advice *Point* gets a new base class. The second advice adds a corresponding method to all classes in the pointcut.

**4.2 Control Flow**

\texttt{cflow(pointcut)} \hspace{1cm} \texttt{C \rightarrow C}

captures join points occurring in the dynamic execution context of join points in \texttt{pointcut}. Currently the language features being used in the argument pointcut
are restricted. The argument is not allowed to contain any context variable bindings (see 4.8) or other pointcut functions which have to be evaluated at runtime like \texttt{cflow(pointcut)} itself.

**Example: control flow dependant advice activation**

The following example demonstrates the use of the \texttt{cflow} pointcut function.

```cpp
class Bus {
    void out (unsigned char);
    unsigned char in ();
};
```

Consider the class \texttt{Bus} shown above. It might be part of an operating system kernel and is used there to access peripheral devices via a special I/O bus. The execution of the member functions \texttt{in()} and \texttt{out()} should not be interrupted, because this would break the timing of the bus communication. Therefore, we decide to implement an interrupt synchronization aspect that disables interrupts during the execution of \texttt{in()} and \texttt{out()}:

```cpp
aspect BusIntSync {
    pointcut critical() = execution("% Bus::%(...)");
    advice critical() && !cflow(execution("% os::int_handler() ")) : around() {
        os::disable_ints();
        tjp->proceed();
        os::enable_ints();
    }
}
```

As the bus driver code might also be called from an interrupt handler, the interrupts should not be disabled in any case. Therefore, the pointcut expression exploits the \texttt{cflow()} pointcut function to add a runtime condition for the advice activation. The advice body should only be executed if the control flow did not come from the interrupt handler \texttt{os::int_handler()}, because it is not interruptable by definition and \texttt{os::enable_ints()} in the advice body would turn on the interrupts too early.
4.3 Scope

within(pointcut) \( N \rightarrow C \)

returns all code join points that are located directly inside or at a name join point in pointcut

member(pointcut) \( N \rightarrow N \)

maps the scopes given in pointcut to any contained named entities. Thus a class name for example is mapped to all contained member functions, variables and nested types.

Example: matching in scopes

aspect Logger {
  pointcut calls() =
    call("void transmit()") && within("Transmitter");
  advice calls() : around() {
    cout << "transmitting ... " << flush;
    tjp->proceed();
    cout << "finished." << endl;
  }
}

This aspect inserts code logging all calls to transmit that are within the methods of class Transmitter.

4.4 Functions

call(pointcut) \( N_F \rightarrow C_C \)

returns all code join points where a user provided function or member function in pointcut is called. The resulting join points are located in the scope of the resp. caller meaning where the function or member functions is called. The pointcut does not include join points at calls to built-in operators.

execution(pointcut) \( N_F \rightarrow C_E \)

returns all code join points where a function or member function in pointcut is executed. The resulting join points are located in the scope of the callee meaning where the function or member function is defined/implemented.
Example: function matching

The following aspect weaves debugging code into a program that checks whether a method is called on a null pointer and whether the argument of the call is null.

```java
aspect Debug {
    pointcut fct() = "% MemPool::dealloc(void*)";
    pointcut exec() = execution(fct());
    pointcut calls() = call(fct());

    advice exec() && args(ptr) : before(void *ptr) {
        assert(ptr && "argument is NULL");
    }
    advice calls() : before() {
        assert(tjp->target() && "'this' is NULL");
    }
};
```

The first advice provides code to check the argument of the function `dealloc` before the function is executed. A check whether `dealloc` is called on a null object is provided by the second advice. This is realized by checking the target of the call.

### 4.5 Built-in Operators

```latex\text{n}_F \rightarrow C_B```

returns all code join points where a built-in operator in `pointcut` is called. This pointcut function does not return join points at constructor or destructor calls. See section Object Construction and Destruction (4.6) to find out how to describe these join points.

The builtin pointcut function is a new feature that was introduced in version 2.0 and is therefore not enabled by default to avoid compatibility issues (e.g., if someone named a pointcut “builtin”). The `--builtin_operators` command-line argument enables the described functionality.

The intersection of the results of `call` and `builtin` always yields the empty pointcut:

\[
\text{call}(\text{pointcut}) \&\& \text{builtin}(\text{pointcut}) = \emptyset \quad \forall \text{pointcut}
\]
### Example: operator matching

The following aspect weaves code into a program that checks whether a null-pointer will be dereferenced. If this occurs, the advice will provide the code position on the error stream.

```java
aspect ProblemReporter {
    advice builtin("% operator *(%)") : before() {
        if(*tjp->arg<0>() == 0) {
            cerr << tjp->filename() << " (Line " << tjp->line() << ")": dereferencing of null-pointer!" << endl;
        }
    }
}
```

### 4.5.1 Limitations

Some built-in operators could not be fully supported. For example, weaving advice code for built-in operators in **constant expressions** would destroy the constancy of the expressions and inhibit evaluation at compile time. Therefore, operators in constant expressions are not matched. The following code listing gives some examples for operators in constant expressions.

```java
class ExampleClass {
    static const int const_member = 5 * 2;
    unsigned int bitfield : 4 / 2;
};
const int const_two = 3 - 1;
static char char_array[const_two + 5];
enum ExampleEnum {
    ENUM_VALUE = const_two + 1
};
switch(const int const_temp = 1) {
    case const_temp + 1: {
        // ...
        break;
    }
}
```
A further limitation results from the fact, that the C++-standard forbids **pointers and references to bit-fields**. Thus all operators that refer to a bit-field (e.g. the assignment- or increment-/decrement-operator needs a reference as first argument) are not supported.

Moreover any operator that has an **anonymous/unnamed or local type or a type with no linkage** as argument or result is not supported (because these types shall not be used as a template argument which makes weaving impossible in most cases).

Additionally **postfix increment/decrement operators** have a second implicit argument of type int to distinguish between pre- and postfix operators. So e.g. “% operator ++(%, int)” matches the postfix increment operator and “% operator ++(%)” matches the prefix increment operator.

Also the **address-of operator &** is not supported, if the argument is a data member or member function, because these types do not exist as type of a variable.

Furthermore the C++-standard states that if the result of .* or ->* is a function, that result can be used only as the operand for the function call operator (). Therefore the **pointer to member operators .* and ->* that get a member function pointer as second argument are not supported**, because a caching of the result is not possible.

At last there are some limitations with the **short-circuiting operators &&, || and ?:**. If the second or third argument is not evaluated, tjp->args() will return a null-pointer for the corresponding argument. Additionally the result of the args pointcut function (see 4.8) is determined at runtime, if an short-circuit argument is bound with the args pointcut function. Thus the advice code in the following example is only executed, if the first argument evaluates to true so that the second argument is available. In case of || the first argument have to be false to make the second argument available and in case of ?: the first argument makes the decision about the availability of the second resp. third argument.

```
advice builtin("% operator &&(bool, bool)") && args("%", b2)
```
A complete list with all limitations and not supported operators can be found in the next section 4.5.2.

### 4.5.2 Supported And Not Supported Operators

This section contains information about the built-in pointcut function in terms of supported operators.

Table 2 shows all operators that are fully or partly supported and indicates the special characteristics of these operators, if available. For more information see section 4.5.1.

Table 3 shows not supported operators.

<table>
<thead>
<tr>
<th>operator and example</th>
<th>special characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>unary ++</td>
<td>a++</td>
</tr>
<tr>
<td>unary --</td>
<td>a--</td>
</tr>
<tr>
<td>unary ++</td>
<td>++a</td>
</tr>
<tr>
<td>unary --</td>
<td>--a</td>
</tr>
<tr>
<td>unary &amp;</td>
<td>&amp;a</td>
</tr>
<tr>
<td>unary *</td>
<td>*a</td>
</tr>
<tr>
<td>unary +</td>
<td>+a</td>
</tr>
<tr>
<td>unary -</td>
<td>-a</td>
</tr>
<tr>
<td>unary ~</td>
<td>~a</td>
</tr>
<tr>
<td>unary !</td>
<td>!a</td>
</tr>
<tr>
<td>binary .*</td>
<td>a.*b</td>
</tr>
<tr>
<td>binary -&gt;*</td>
<td>a-&gt;*b</td>
</tr>
<tr>
<td>binary *</td>
<td>a*b</td>
</tr>
<tr>
<td>binary /</td>
<td>a/b</td>
</tr>
<tr>
<td>binary %</td>
<td>a%b</td>
</tr>
<tr>
<td>binary +</td>
<td>a+b</td>
</tr>
<tr>
<td>binary -</td>
<td>a-b</td>
</tr>
<tr>
<td>binary &lt;&lt;</td>
<td>a&lt;&lt;b</td>
</tr>
</tbody>
</table>

continuation on next page...
<table>
<thead>
<tr>
<th>operator and example</th>
<th>special characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>binary &gt;&gt;</td>
<td>a &gt;&gt; b</td>
</tr>
<tr>
<td>binary &lt;</td>
<td>a &lt; b</td>
</tr>
<tr>
<td>binary &gt;</td>
<td>a &gt; b</td>
</tr>
<tr>
<td>binary &lt;=</td>
<td>a &lt;= b</td>
</tr>
<tr>
<td>binary &gt;=</td>
<td>a &gt;= b</td>
</tr>
<tr>
<td>binary ==</td>
<td>a == b</td>
</tr>
<tr>
<td>binary !=</td>
<td>a != b</td>
</tr>
<tr>
<td>binary &amp;</td>
<td>a &amp; b</td>
</tr>
<tr>
<td>binary ^</td>
<td>a ^ b</td>
</tr>
<tr>
<td>binary</td>
<td></td>
</tr>
<tr>
<td>binary &amp;&amp;</td>
<td>a &amp;&amp; b</td>
</tr>
<tr>
<td>binary</td>
<td></td>
</tr>
<tr>
<td>binary =</td>
<td>a = b</td>
</tr>
<tr>
<td>binary *=</td>
<td>a *= b</td>
</tr>
<tr>
<td>binary /=</td>
<td>a /= b</td>
</tr>
<tr>
<td>binary %=</td>
<td>a %= b</td>
</tr>
<tr>
<td>binary +=</td>
<td>a += b</td>
</tr>
<tr>
<td>binary -=</td>
<td>a -= b</td>
</tr>
<tr>
<td>binary &lt;&lt;=</td>
<td>a &lt;&lt;= b</td>
</tr>
<tr>
<td>binary &gt;&gt;=</td>
<td>a &gt;&gt;= b</td>
</tr>
<tr>
<td>binary &amp;=</td>
<td>a &amp;= b</td>
</tr>
<tr>
<td>binary</td>
<td>=</td>
</tr>
<tr>
<td>binary ^=</td>
<td>a ^= b</td>
</tr>
<tr>
<td>binary []</td>
<td>a [b]</td>
</tr>
<tr>
<td>ternary ?:</td>
<td>a ? b : c</td>
</tr>
</tbody>
</table>

Table 2: operators that are (partly) supported by the built-in pointcut function
4.6 Object Construction and Destruction

Table 3: operators that are not supported by the builtin pointcut function

<table>
<thead>
<tr>
<th>operator and example</th>
</tr>
</thead>
<tbody>
<tr>
<td>binary  ,</td>
</tr>
<tr>
<td>binary  -&gt;</td>
</tr>
<tr>
<td>binary  .</td>
</tr>
<tr>
<td>new</td>
</tr>
<tr>
<td>delete</td>
</tr>
<tr>
<td>new[]</td>
</tr>
<tr>
<td>delete[]</td>
</tr>
</tbody>
</table>

implicit conversions
operators in constant expressions (see 4.5.1)
operators with an anonymous/unnamed or local type (see 4.5.1)
operators that have a type with no linkage (see 4.5.1)

4.6 Object Construction and Destruction

construction(pointcut) \( N_C \rightarrow C_{Cons} \)
returns all code join points where an instance of a class in pointcut is constructed. The construction join point begins after all base class and member construction join points. It can be imagined as the execution of the constructor. However, advice for construction join points work, even if there is no constructor defined explicitly. A construction join point has arguments and argument types, which can be exposed or filtered, e.g. by using the args pointcut function.

destruction(pointcut) \( N_C \rightarrow C_{Des} \)
returns all code join points where an instance of a class in pointcut is destructed. The destruction join point ends before the destruction join point of all members and base classes. It can be imagined as the execution of the destructor, although a destructor does not to be defined explicitly. A destruction join point has an empty argument list.

Example: instance counting

The following aspect counts how many instances of the class ClassOfInterest are created and destroyed.
aspect InstanceCounting {
    // the class for which instances should be counted
    pointcut observed() = "ClassOfInterest";
    // count constructions and destructions
    advice construction (observed ()) : before () {
        _created++;
    }
    advice destruction (observed ()) : after () {
        _destroyed++;
    }
    // counters
    int _created, _destroyed;

    public:
    // Singleton aspects can have a default constructor
    InstanceCounting () { _created = _destroyed = 0; }
};

The implementation of this aspect is straightforward. Two counters are initialized by
the aspect constructor and incremented by the construction/destruction advice. By
defining \texttt{observed()} as a pure virtual pointcut the aspect can easily be transformed
into a reusable abstract aspect.

### 4.7 Variables

\textbf{get}(pointcut) \quad N_{V} \rightarrow C_{G}

returns all code join points where a global variable or data member in \texttt{pointcut}
is read. The get join points are located at implicit lvalue-to-rvalue conversions
according to the C++ standard. In addition, the get join points are located within
all built-in compound-assignment operators, and within the built-in increment
and decrement operators.

\textbf{set}(pointcut) \quad N_{V} \rightarrow C_{S}

returns all code join points where a global variable or data member in \texttt{pointcut}
is modified. The set join points are located within all built-in assignment
operators, and within the built-in increment and decrement operators. The ini-
tialization of a global variable or data member provides no set join point.

\textbf{ref}(pointcut) \quad N_{V} \rightarrow C_{R}

provides all join points where a reference (reference type or pointer) to a global
variable or data member in the pointcut is created. The ref join points are located within the built-in address-of operator &., if the operand is a global variable or data member. In addition, the ref join points are located before the initialization of a variable of reference type, including return values. Moreover, the binding of a reference parameter of a function, including default values, provides ref join points. The ref join points are also located within implicit array-to-pointer conversions according to the C++ standard.

Example: variable matching

The following aspect observes the modification of all variables (in any scope) of the type int. When such an integer variable is modified, the aspect reports the name of the variable and its new value, obtained by *tjp->entity().

```cpp
aspect IntegerModification {
    advice set("int ...::%") : after() {
        cout << "Setting variable 
            << tjp->signature() << " to "
            << *tjp->entity() << endl;
    }
};
```

4.7.1 Limitations

The get and set pointcut functions cover variables of fundamental type, such as integer and floating-point types, and arrays thereof. Variables of any pointer type and arrays of pointers are also supported. The get and set pointcut functions do not support variables of class type, unions, enumerations, bitfields, and references.

The get, set, and ref pointcut functions match only if the variable is accessed directly by its name. Indirect variable access via pointer or reference does not match.

The get, set, and ref pointcut functions do not match for local variables.
The get, set, and ref joinpoints are not located within constant expressions, such as the built-in operator sizeof.

### 4.7.2 Compatibility

The get, set, and ref pointcut functions are new features that were introduced in version 2.0 and are therefore not enabled by default to avoid compatibility issues (e.g., if someone named a pointcut “get”). The --data_joinpoints command-line argument enables the described functionality.

### 4.8 Context

**that**(type pattern) \[NT \rightarrow C\]
returns all code join points where the current C++ this pointer refers to an object which is an instance of a type that is compatible to the type described by type pattern

**target**(type pattern) \[NT \rightarrow C\]
returns all code join points where the target object of a call/set/get is an instance of a type that is compatible to the type described by type pattern

**result**(type pattern) \[NT \rightarrow C\]
returns all code join points where the type of the return value of a call/builtin/execution/get is matched by type pattern

**args**(type pattern, ...) \[(NT, ... ) \rightarrow C\]
returns all code join points where the types of the arguments of a call/builtin/execution/set are matched by the corresponding type patterns.

Instead of the type pattern it is also possible here to pass the name of a variable to which the context information is bound (a context variable). In this case the type of the variable is used for the type matching. Context variables must be declared in the argument list of before(), after(), or around() and can be used like a function parameter in the advice body.

The that() and target() pointcut functions are special, because they might cause a runtime type check. The args() and result() functions are evaluated at compile time. Exception: If a short-circuit argument is bound with the args pointcut function, then the result of args depends on the runtime availability of the bound argument.
4.9 Algebraic Operators

Example: context matching

4.9 Algebraic Operators

\[ \text{pointcut} \&\& \text{pointcut} \]
\[ \rightarrow (N,N) \rightarrow N, (C,C) \rightarrow C \]
returns the intersection of the join points in the \text{pointcuts}

\[ \text{pointcut} \mid\mid \text{pointcut} \]
\[ \rightarrow (N,N) \rightarrow N, (C,C) \rightarrow C \]
returns the union of the join points in the \text{pointcuts}

\[ ! \text{pointcut} \]
\[ \rightarrow N \rightarrow N, C \rightarrow C \]
returns all name resp. code join points that are not included in \text{pointcut}

Example: combining pointcut expressions

5 Attributes

Attributes are a language element, which AspectC++ developers can use for user-defined annotations. An attribute provides additional information about a join point that aspects can exploit for collecting or filtering pointcuts. The attribute syntax is based on the attribute syntax of C++11 (and following standards). However, AspectC++ provides this mechanism even if the selected language standard is older than C++11. In this case no attributes from the namespaces gnu or clang or the global scope must be used.

5.1 Attribute declarations

Attributes must be declared before being used in a pointcut expression. An attribute that is used for annotating a join point must be declared, but it is not required that the declaration is seen by the parser before the annotation location. The following example shows such a declaration using the keyword \text{attribute}.

Example: attribute declaration

\[ \text{attribute myAttr();} \]

To avoid naming conflicts, attributes can be declared inside of namespaces, classes, or aspects. User-defined attributes shall neither be declared in the global scope nor
in the scope of backend compiler attributes, such as gnu or clang. The current version of AspectC++ supports only empty argument lists. To annotate an element of the program code, the attribute has to be referenced by its fully-qualified name. The following example illustrates this:

**Example: using attributes to annotate program elements**

```cpp
namespace attrib {
    attribute myFuncAttr();
    attribute otherAttr();
}

[[attrib::myFuncAttr, attrib::otherAttr()]] void myFunc();
```

To be compatible with C++11 attributes, it is not necessary to specify parameters if the argument list of an attribute is empty. Furthermore, it is possible to use several attributes in a pair of brackets separated by commas or several pairs of brackets behind each other. For more information about attribute-syntax in C++11 consult the C++11 standard.

Attributes from the namespaces gnu and clang and the global scope are evaluated by AspectC++ and passed through to the backend compiler. All other attributes are only evaluated by AspectC++ and hidden from the backend compiler.

### 5.2 Supported code-elements

Table 5 shows the code elements, for which annotations with attributes are supported, and the possible attribute locations. Positions of attributes are marked by `[[..]]`.

<table>
<thead>
<tr>
<th>Code-Element</th>
<th>Positions</th>
</tr>
</thead>
<tbody>
<tr>
<td>namespaces</td>
<td>namespace [[...]] myNamespace {}</td>
</tr>
<tr>
<td>classes</td>
<td>class [[...]] myClass {}</td>
</tr>
<tr>
<td>functions</td>
<td>[[...]] void myFunc [[...]] ()</td>
</tr>
<tr>
<td>variables</td>
<td>[[...]] int myVar [[...]]</td>
</tr>
<tr>
<td>statements</td>
<td>[[...]] i += 1; [[...]] { i--; }</td>
</tr>
</tbody>
</table>

Table 5: attributes - code-elements and positions
5.3 Attributes and pointcut expressions

If a namespace is opened more than once, all enclosed elements belong semantically to the same namespace. In this case, all attributes of that namespace must be present at its first definition. In subsequent definitions they can be present as well, but don’t have to. It is forbidden to add an attribute in a subsequent definition, which was not present in the first. A similar rule is applied for classes, functions, and variables, which can have multiple forward declarations. In this case, all attributes must be present at the first declaration and can be omitted later on. Attributes on statements (and compound statements) can be used to filter join points that are located within the marked code region.

5.3 Attributes and pointcut expressions

Attributes can be used in pointcut expressions where they are interpreted similar to named pointcuts. They can be combined with logical operators like other pointcut expressions and can be used in pointcut declarations. Thereby, the usual C++ name lookup rules are also applicable for attributes. The following example shows how to use attributes in pointcut expressions.

Example: using attributes in pointcut expressions

```cpp
struct [[output::myAttr]] myStruct {
    [[output::myAttr]] void myFunc() {};
};
aspect output {
    attribute myAttr();
    pointcut all() = myAttr();
}
```

If multiple name joinpoints, such as the namespace N and the class C, are annotated by an attribute A, the meaning of A() in a pointcut expression is equivalent to “N”||”C”. This means that also nested entities within N and C are matched.

6 Slices

This section defines the syntax and semantics of slice declarations. The next section will describe how slices can be used by advice in order to introduce code. Currently,
only class slices are defined in AspectC++.

### 6.1 Class Slice Declarations

Class slices may be declared in any class or namespace scope. They may be defined only once, but there may be an arbitrary number of forward declarations. A qualified name may be used if a class slice that is already declared in a certain scope is redeclared or defined as shown in the following example:

```cpp
slice class ASlice;
namespace N {
    slice class ASlice; // a different slice!
}
slice class ASlice { // definition of the ::ASlice
    int elem;
};
slice class N::ASlice { // definition of the N::ASlice
    long elem;
};
```

If a class slice only defines a base class, an abbreviated syntax may be used:

```cpp
slice class Chained : public Chain;
```

Class slices may be anonymous. However, this only makes sense as part of an advice declaration. A class slice may also be declared with the `aspect` or `struct` keyword instead of `class`. While there is no difference between class and aspect slices, the default access rights to the elements of a struct slice in the target classes are public instead of private. It is forbidden to declare aspects, pointcuts, advice, or slices as members of a class slice.

Class slices may have members that are not defined within the body of a class slice declaration, e.g. static member variable or non-inline functions:

```cpp
slice class SL {
    static int answer;
    void f();
};
```
7 Advice

This section describes the different types of advice offered by AspectC++. Advice are categorized in advice for join points in the dynamic control flow of the running program, e. g. function call or executions, and advice for static join points like introductions into classes.

In either case the compiler makes sure that the code of the aspect header file, which contains the advice definition (if this is the case), is compiled prior to the affected join point location.

7.1 Advice for Dynamic Join Points

before(...)  
the advice code is executed before the join points in the pointcut

after(...)  
the advice code is executed after the join points in the pointcut

around(...)  
the advice code is executed in place of the join points in the pointcut

7.2 Advice for Static Join Points

Static join points in AspectC++ are classes or aspects. Advice for classes or aspects can introduce new members or add a base class. Whether the new member or base class becomes private, protected, or public in the target class depends on the protection in the advice declaration in the aspect.

baseclass(classname)  
a new base class is introduced to the classes in the pointcut

These external member declarations have to appear after the corresponding slice declaration in the source code.
**introduction declaration**

a new member variable, member function, or type is introduced

Introduction declarations are only semantically analyzed in the context of the target. Therefore, the declaration may refer, for instance, to types or constants, which are not known in the aspect definition, but only in the target class or classes. To introduce a constructor or destructor the name of the aspect, to which the introduction belongs, has to be taken as the constructor/destructor name.

*Non-inline introductions* can be used for introductions of static member variables or member function introduction with separate declaration and definition. The name of the introduced member has to be a qualified name in which the nested name specifier is the name of the aspect to which the introduction belongs.

### 8 JoinPoint API

The following sections provide a complete description of the *JoinPoint API*.

#### 8.1 API for Dynamic Join Points

The JoinPoint-API for dynamic join points can be used within the body of advice code.

#### 8.1.1 Types and Constants

**Result**

result type of a function

**Res::Type, Res::ReferredType**

result type of the affected function or entity access

**Arg<i>::Type, Arg<i>::ReferredType**

type of the $i^{th}$ argument of the affected join point (with $0 \leq i < ARGs$)

**ARGS**

number of arguments
8.1 API for Dynamic Join Points

That
object type (object initiating a call)

Target
target object type (target object of a call)

Entity
type of the primary referenced entity (function or variable)

MemberPtr
type of the member pointer for entity or void * for nonmembers

Array
type of the accessed array

Dim<i>::Idx
type of the i\text{th} dimension of the accessed array (with $0 \leq i < DIMS$)

Dim<i>::Size
size of the i\text{th} dimension of the accessed array (with $0 \leq i < DIMS$)

DIMS
number of dimensions of an accessed array or 0 otherwise

Example: type usage

8.1.2 Functions

static AC::Type type()
returns the encoded type for the join point conforming with the C++ ABI V3 specification\textsuperscript{8}

static int args()
returns the number of arguments of a function for call and execution join points

static AC::Type argtype(int number)
returns the encoded type of an argument conforming with the C++ ABI V3 specification

\textsuperscript{8}http://www.codesourcery.com/cxx-abi/abi.html\#mangling
static const char *signature()
  gives a textual description of the join point (function name, class name, ...)

static unsigned int id()
  returns a unique numeric identifier for this join point

static const char *filename()
  returns the name of the file in which the join point (shadow) is located

static int line()
  the number of the line in which the join point (shadow) is located

static AC::Type resulttype()
  returns the encoded type of the result type conforming with the C++ ABI V3 specification

static AC::JPType jptype()
  returns a unique identifier describing the type of the join point

**Example: static function usage**

void *arg(int number)
  returns a pointer to the memory position holding the argument value with index number

Result *result()
  returns a pointer to the memory location designated for the result value or 0 if the function has no result value

That *that()
  returns a pointer to the object initiating a call or 0 if it is a static method or a global function

Target *target()
  returns a pointer to the object that is the target of a call or 0 if it is a static method or a global function

Entity *entity()
  returns a pointer to the accessed entity (function or variable) or 0 for member functions or built-in operators
8.2 API for Static Join Points

MemberPtr *memberptr()

returns a member pointer to entity or 0 for nonmembers

Array *array()

returns a typed pointer to the accessed array

Dim<i>::Idx idx<i>()

returns the value of the \textit{i}th index used for the array access

void proceed()

executes the original join point code in an around advice by calling

action().trigger()

AC::Action &action()

returns the runtime action object containing the execution environment to exe-
cute the original functionality encapsulated by an around advice

Example: non-static function usage

8.2 API for Static Join Points

The JoinPoint-API for static join points can be used within the definition of a slice and
describes the state of target class \textit{before} the introduction took place. It is accessed
through the built-in type JoinPoint (e.g. JoinPoint::signature()) and pro-
vides the following functions, types, and constants:

static const char *signature()

returns the target class name as a string

That

The (incomplete) target type of the introduction

HASHCODE

integer hash value of the target type

BASECLASSES

number of base classes of the target class

BaseClass<i>::Type

type of the \textit{i}th base class
BaseClass\(<I>: prot, BaseClass\(<I>: spec

Montection level (AC::PROT_NONE /PRIVATE /PROTECTED /PUBLIC) and additional specifiers (AC::SPEC_NONE /VIRTUAL) of the $I$th base class

MEMBERS

number of data members of the target class

Member\(<I>: Type, Member\(<I>: ReferredType
type of the $I$th member variable of the target class

Member\(<I>: prot, Member\(<I>: spec
Protection level (see BaseClass\(<I>: prot) and additional member variable specifiers (AC::SPEC_NONE /STATIC /MUTABLE)

\texttt{static ReferredType *Member\(<I>: \text{pointer} (T *obj=0)} 
returns a typed pointer to the $I$th member variable (obj is needed for non-static member variables)

\texttt{static const char *Member\(<I>: \text{name} ()} 
returns the name of the $I$th member variable

FUNCTIONS

number of member functions of the target class

Function\(<I>: prot, Function\(<I>: spec
Protection level (see BaseClass\(<I>: prot) and additional member variable specifiers (AC::SPEC_NONE /STATIC /VIRTUAL)

CONSTRUCTORS

number of user-defined constructors of the target class

Constructor\(<I>: prot, Constructor\(<I>: spec
Protection level (see BaseClass\(<I>: prot) and additional member variable specifiers (AC::SPEC_NONE)

DESTRUCTORS

number (zero or one) of user-defined destructors of the target class

Destructor\(<I>: prot, Destructor\(<I>: spec
Protection level (see BaseClass\(<I>: prot) and additional member variable specifiers (AC::SPEC_NONE /VIRTUAL)
9 Advice Ordering

9.1 Aspect Precedence

AspectC++ provides a very flexible mechanism to define aspect precedence. The precedence is used to determine the execution order of advice code if more than one aspect affects the same join point. The precedence in AspectC++ is a member of a join point. This means that the precedence relationship between two aspects might vary in different parts of the system. The compiler checks the following conditions to determine the precedence of aspects:

order declaration: if the programmer provides an order declaration, which defines the precedence relationship between two aspects for a join point, the compiler will obey this definition or abort with a compile-time error if there is a cycle in the precedence graph. Order declarations have the following syntax:

\[
\text{advice pointcut-expr : order ( high, \ldots \text{low} )}
\]

The argument list of order has to contain at least two elements. Each element is a pointcut expression, which describes a set of aspects. Each aspect in a certain set has a higher precedence than all aspects, which are part of a set following later in the list (on the right hand side). For example ‘("A1" || "A2", "A3" || "A4")’ means that A1 has precedence over A3 and A4 and that A2 has precedence over A3 and A4. This order directive does not define the relation between A1 and A2 or A3 and A4. Of course, the pointcut expressions in the argument list of order may contain named pointcuts and even pure virtual pointcuts.

inheritance relation: if there is no order declaration given and one aspect has a base aspect the derived aspect has a higher precedence than the base aspect.

9.2 Advice Precedence

The precedence of advice is determined with a very simple scheme:

- if two advice declarations belong to different aspects and there is a precedence relation between these aspects (see section 9.1) the same relation will be assumed for the advice.
• if two advice declarations belong to the same aspect the one that is declared first has the higher precedence.

9.3 Effects of Advice Precedence

Only advice precedence has an effect on the generated code. The effect depends on the kind of join point, which is affected by two advice declarations.

Class Join Points

Advice on class join points can extend the member variable list or base class list. If advice has a higher precedence than another it will be handled first. For example, an introduced new base class of advice with a high precedence will appear in the base class list on the left side of a base class, which was inserted by advice with lower precedence. This means that the execution order of the constructors of introduced base classes can be influenced, for instance, by order declarations.

The order of introduced member variables also has an impact on the constructor/destructor execution order as well as the object layout.

Code Join Points

Advice on code join points can be before, after, or around advice. For before and around advice a higher precedence means that the corresponding advice code will be run first. For after advice a higher precedence means that the advice code will be run later.

If around advice code does not call tjp->proceed() or trigger() on the action object no advice code with lower precedence will be run. The execution of advice with higher precedence is not affected by around advice with lower precedence.

For example, consider an aspect that defines advice\(^9\) in the following order: BE1, AF1, AF2, AR1, BE2, AR2, AF3. As described in section 9.2 on the facing page the declaration order also defines the precedence: BE1 has the highest and AF3 the lowest. The result is the following advice code execution sequence:

1. BE1 (highest precedence)

\(^9\)BE is before advice, AF after advice, and AR around advice
2. AR1 (the indented advice will only be executed if `proceed()` is called!)
   
   (a) BE2 (before AR2, buts depends on AR1)
   
   (b) AR2 (the indented code will only be executed if `proceed()` is called!)
       
       i. original code under the join point
       
       ii. AF3

3. AF2 (does not depend on AR1 and AR2, because of higher precedence)

4. AF1 (run after AF2, because it has a higher precedence)

10 List of Examples

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A Grammar

The AspectC++ syntax is an extension to the C++ syntax. It adds five new keywords to the C++ language: aspect, advice, slice, pointcut, and attribute. Additionally it extends the C++ language by advice and pointcut declarations. In contrast to pointcut declarations, advice declarations may only occur in aspect declarations.

```
class-key:
    aspect

declaration:
    pointcut-declaration
    slice-declaration
    advice-declaration
    attribute-declaration

member-declaration:
    pointcut-declaration
    slice-declaration
    advice-declaration
    attribute-declaration
```
pointcut-declaration:
  pointcut declaration

pointcut-expression:
  constant-expression

advice-declaration:
  advice pointcut-expression : order-declaration
  advice pointcut-expression : slice-reference
  advice pointcut-expression : declaration

order-declaration:
  order ( pointcut-expression-seq )

slice-reference:
  slice ::opt nested-name-specifier opt unqualified-id ;

slice-declaration:
  slice declaration

attribute-declaration:
  attribute unqualified-id ( ) ;

B Match Expression Grammar

Match expression in AspectC++ are used to define a type pattern and an optional object name pattern to select a subset of the known program entities like functions, member variables, or argument/result types. The grammar is very similar to the grammar of C++ declarations. Any rules, which are referenced here but not defined, should be looked up in the ISO C++ standard.

match-expression:
  match-declaration

match-id:
  %
  %
  nondigit
  %
  match-id %
match-id nondigit
match-id digit

match-declaration:
  match-decl-specifier-seq_opt match-declarator

match-decl-specifier-seq:
  match-decl-specifier-seq_opt match-decl-specifier

match-decl-specifier:
  nested-match-name-specifier_opt match-id
  cv-qualifier
  match-function-specifier
  char
  wchar_t
  bool
  short
  int
  long
  signed
  unsigned
  float
  double
  void

match-function-specifier:
  virtual
  static

nested-match-name-specifier:
  match-id :: nested-match-name-specifier_opt
  ... :: nested-match-name-specifier_opt

match-declarator:
  direct-match-declarator
  match-ptr-declarator match-declarator

abstract-match-declarator:
  direct-abstract-match-declarator
match-ptr-declarator abstract-match-declarator

direct-match-declarator:
  match-declarator-id
  direct-match-declarator ( match-parameter-declaration-clause ) cv-qualifier-seq_opt
  direct-match-declarator [ match-array-size ]

direct-abstract-match-declarator:
  direct-abstract-match-declarator ( match-parameter-declaration-clause ) cv-qualifier-seq_opt
  direct-abstract-match-declarator [ match-array-size ]

match-array-size:
  %
  decimal-literal

match-ptr-operator:
  * cv-qualifier-seq_opt
  &
  nested-match-name-specifier * cv-qualifier-seq_opt

match-parameter-declaration-clause:
  \ldots
  match-parameter-declaration-list_opt
  match-parameter-declaration-list , \ldots

match-parameter-declaration-list:
  match-parameter-declaration
  match-parameter-declaration-list , match-parameter-declaration

match-parameter-declaration:
  match-decl-specifier-seq match-abstract-declarator_opt

match-declarator-id:
  nested-match-name-specifier_opt match-id
  nested-match-name-specifier_opt match-operator-function-id
  nested-match-name-specifier_opt match-conversion-function-id

58
match-operator-function-id:
   operator %
   operator match-operator

match-operator: one of
   new delete new[] delete[]
   +  -  *  /  %  %%  ^  &  |  ~  !  =  <  >
   +=  -=  *=  /=  %=%  ^=  &=  |=  <<  >>  >>=  <<=  ==
   !=  <=  >=  &&  ||  ++  --  ,  .*  ->*  ->  ()  []
   ?: 

match-conversion-function-id:
   operator match-conversion-type-id

match-conversion-type-id:
   match-type-specifier-seq match-conversion-declarator\_opt

match-conversion-declarator:
   match-ptr-operator match-conversion-declarator\_opt
C Structure Of The Project Repository

Figure 3 shows the internal structure of the AspectC++ model and the AspectC++ project repository. The distinction between name and code join points and also the inheritance hierarchy is visible.

Figure 3: Structure of the AspectC++ project repository
<?xml version="1.0"?>
<ac-model version="1.2" ids="7">
  <files>
    <TUnit filename="shape.cpp" len="42" time="1442951698" id="0"/>
  </files>
  <root>
    <Namespace name="::">
      <children>
        <Class name="Shape" id="1">
          <children>
            <Function kind="8" cv_qualifiers="0" name="~Shape" builtin="true">
              <children>
                <Destruction/>
              </children>
            </Function>
            <Function kind="7" cv_qualifiers="0" name="Shape" builtin="true">
              <children>
                <Construction/>
              </children>
            </Function>
            <Function kind="7" cv_qualifiers="0" name="Shape" builtin="true">
              <arg_types>
                <Type signature="const Shape &amp;"/>
              </arg_types>
              <children>
                <Construction/>
              </children>
            </Function>
          </children>
          <source>
            <Source kind="1" file="0" line="1" len="1"/>
            <Source kind="2" file="0" line="1" len="1"/>
          </source>
        </Class>
        <Namespace name="Circle">
          <children>
            <Class bases="1" name="S_Circle" id="4">
              <children>
                <Function kind="7" cv_qualifiers="0" name="S_Circle" builtin="true">
                  <children>
                    <Construction/>
                  </children>
                </Function>
                <Function kind="7" cv_qualifiers="0" name="S_Circle" builtin="true">
                  <arg_types>
                    <Type signature="const Circle::S_Circle &amp;"/>
                  </arg_types>
                  <children>
                    <Construction/>
                  </children>
                </Function>
              </children>
            </Class>
          </children>
        </Namespace>
      </children>
    </Namespace>
  </root>
</ac-model>
<Variable kind="3" name="m_radius">
  <type>
    <Type signature="int"/>
  </type>
  <source>
    <Source kind="1" file="0" line="8" len="1"/>
  </source>
</Variable>

<Function kind="3" cv_qualifiers="0" name="radius" id="3">
  <result_type>
    <Type signature="void"/>
  </result_type>
  <arg_types>
    <Type signature="int"/>
  </arg_types>
  <children>
    <Execution/>
    <Builtin target="2" lid="0">
      <source>
        <Source kind="0" file="0" line="11" len="1"/>
      </source>
    </Builtin>
  </children>
  <source>
    <Source kind="1" file="0" line="10" len="3"/>
  </source>
</Function>

<Function kind="8" cv_qualifiers="0" name="~S_Circle">
  <children>
    <Destruction/>
  </children>
  <source>
    <Source kind="1" file="0" line="13" len="1"/>
  </source>
</Function>

<Class>
  <Function kind="1" cv_qualifiers="0" name="draw" id="6">
    <result_type>
      <Type signature="void"/>
    </result_type>
    <arg_types>
      <Type signature="int"/>
    </arg_types>
    <children>
      <Execution/>
      <Call target="3" lid="0" target_class="4">
        <source>
          <Source kind="0" file="0" line="18" len="1"/>
        </source>
      </Call>
    </children>
  </Function>
</Class>
<Call target="5" lid="1">
  <source>
    <Source kind="0" file="0" line="19" len="1"/>
  </source>
</Call>
</children>
</Function>
</children>
<source>
  <Source kind="0" file="0" line="4" len="18"/>
</source>
</Namespace>

<Function kind="1" cv_qualifiers="0" name="draw" id="5">
  <result_type>
    <Type signature="void"/>
  </result_type>
  <arg_types>
    <Type signature="Shape &amp;"/>
  </arg_types>
  <children>
    <Execution/>
  </children>
  <source>
    <Source kind="1" file="0" line="2" len="1"/>
  </source>
</Function>

<Function kind="1" cv_qualifiers="0" name="operator =" builtin="true" tunits="0" id="2">
  <result_type>
    <Type signature="int &amp;"/>
  </result_type>
  <arg_types>
    <Type signature="int &amp;"/>
    <Type signature="int"/>
  </arg_types>
</Function>

<Function kind="1" cv_qualifiers="0" name="main">
  <result_type>
    <Type signature="int"/>
  </result_type>
  <children>
    <Execution/>
    <Call target="6" lid="0">
      <source>
        <Source kind="0" file="0" line="24" len="1"/>
      </source>
    </Call>
  </children>
</Function>
</children>
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