Generic Visitors in C++

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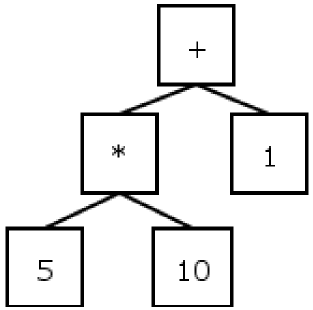
Introduction

- We have an abstract Syntax Trees (AST)



- We want to
  - ▷ Walk the tree
  - ▷ Perform actions on nodes (evaluation, printing ...)

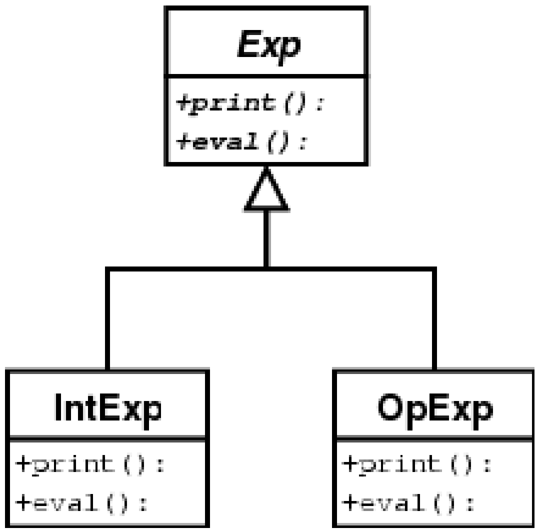
→ We need an appropriate design

Visitor designs

- First attempt
- Multi methods
- Visitor design pattern
- Visitor combinators

First attempt

Naive design for a simple arithmetic expressions abstract syntax tree:



Adding a polymorphic operation requires modifying all the classes **:(**

Multi methods

- Generalized virtual methods (`virtual` on an arbitrary number of chosen parameters)
- Work like external methods added to classes

Imaginary example:

```
void print (virtual IntExp*) { /* ... */ }
void print (virtual OpExp*)  { /* ... */ }

Exp* e = new IntExp(51));
print (e); // dispatches to the first print method,
           // according to the dynamic type of e
```

Multi methods

- They are available in some languages (CLOS, Nice, Perl6) ...
- ... but **not** in C++ **:(**
  C++ dispatches only the first (hidden) argument (`this`) of a method
- They can be emulated using various tricks (Alexandrescu, 2001)

→ We must find something else

Towards an object model

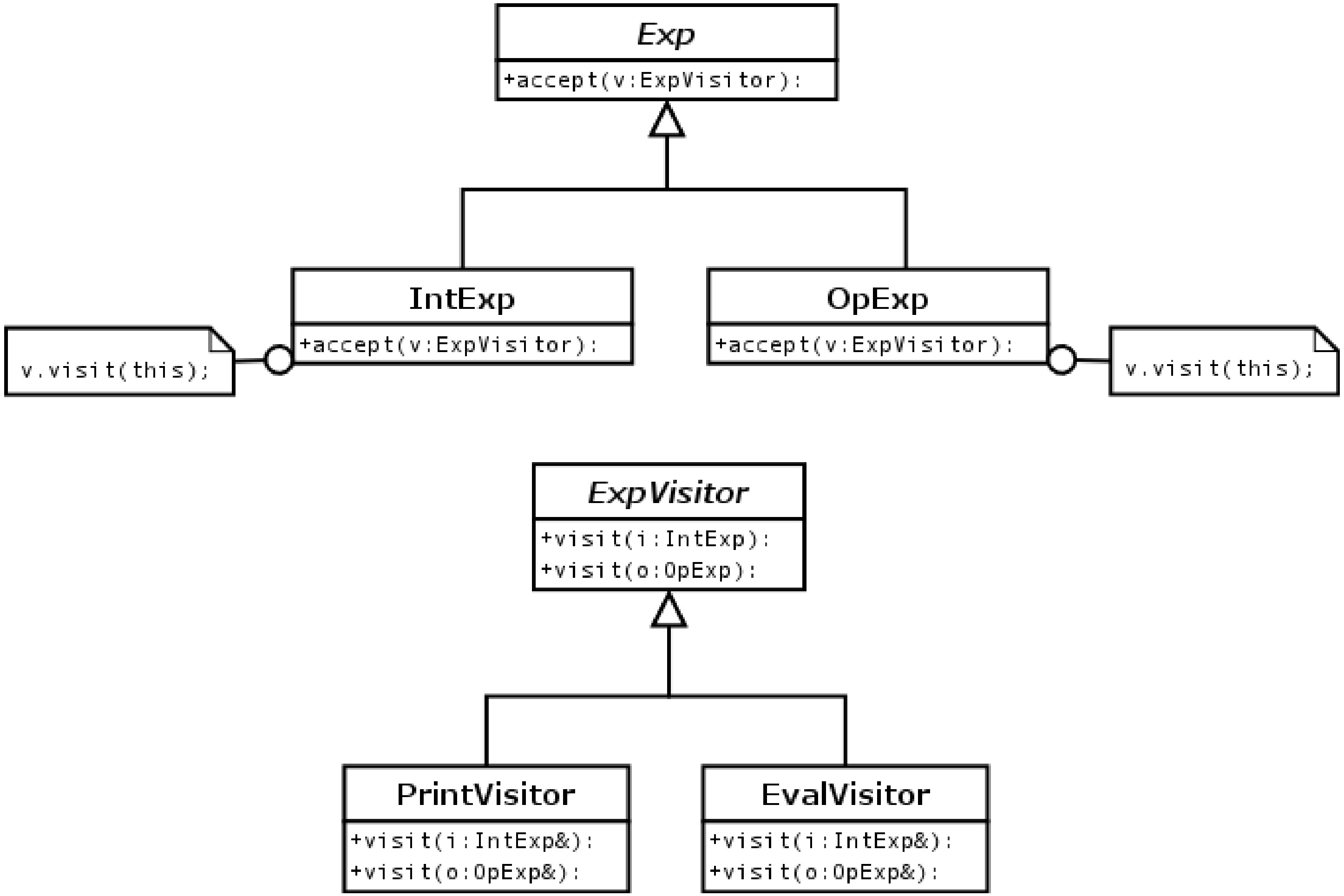
- Encapsulate each processing in one class
- Hierarchy of processings
- Separate AST and Processings
- We need to dispatch over two hierarchies

$\rightarrow$ Someone may already have encountered this problem ...

The visitor design pattern

- Design patterns = Higher order abstractions
- Gamma et al. (Gamma et al., 1994)
- Also called *Vanilla* visitor

Design


Exp
+accept(v:ExpVisitor):
IntExp
+accept(v:ExpVisitor):
OpExp
+accept(v:ExpVisitor):
v.visit(this);
v.visit(this);
ExpVisitor
+visit(i:IntExp):
+visit(o:OpExp):
PrintVisitor
+visit(i:IntExp&):
+visit(o:OpExp&):
EvalVisitor
+visit(i:IntExp&):
+visit(o:OpExp&):

Discussion

- Benefits
  - ▷ Double dispatch
  - ▷ Decoupling of two inter-dependent hierarchies
  - ▷ Factor out default traversal code by inheritance.
- Drawbacks
  - ▷ Mixing of traversal and behavioral code
  - ▷ No genericity
    - ∗ `accept` methods are bound to a specific abstract visitor class
    - ∗ `visit` methods are specific to the target hierarchy

→ We do **not** want to write traversal code each time we write a visitor

Visitor combinators

- Joost Visser, CWI (Visser, 2001) (→ StrategoXT)
- Break a monolithic visitor into small atomic visitors
- Use combinators to compose these visitors between them and get the final visitor
- A visitor combinator acts like a function from visitor to visitor
- Dummy example :

```
Compile = Sequence(Sequence(Escape, TypeCheck), Translate)

(Sequence :  visitor * visitor -> visitor)
```

Sequence

```
struct Sequence : public ExpVisitor
{
  Sequence(ExpVisitor& first, ExpVisitor& second)
    : first_(first), second_(second) {}

  virtual void visit(OpExp& o)
  { o.accept(first_); o.accept(second_); }

  virtual void visit(IntExp& i)
  { i.accept(first_); i.accept(second_); }

  ExpVisitor& first_;
  ExpVisitor& second_;
};
```

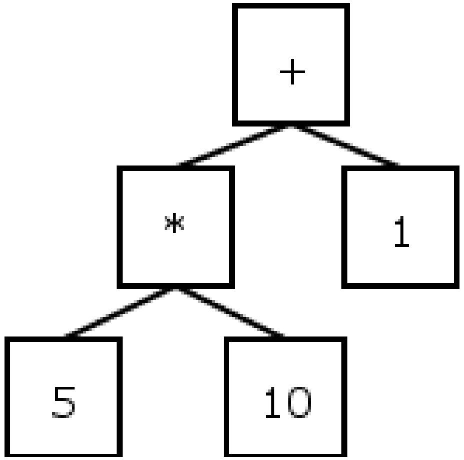
Traversal combinators

- We now need to traverse nodes
- `all(v)` applies v to all the children of the accepting node
- `traversal = all(traversal)`
- `topdown(v) = sequence(v, all(topdown(v)))`
  applies v to all the subtrees of the accepting node, in a top-down fashion
- `bottomup(v) = sequence(all(bottomup(v), v))` applies v to all the subtrees of the accepting node, in a bottom-up fashion

Topdown example

```
prefix_print = topdown(print)
             = sequence(print, all(prefix_print))
```

... once accepted by our example Exp AST



... outputs:

```
+ * 5 10 1
```

Conditional combinators

- `fail` throws a VisitFailure exception
- `sequence` works like “`and`”
- `choice(v1, v2)` let a node accept v1 firstly and, in case of failure, v2 secondly
- `choice` works like “`or`”
- Many other combinators exist: `one`, `try` ...

Discussion

- Benefits
  - ▷ Traversal and behavioral code cleanly separated
  - ▷ Re-usability improved
- Drawbacks
  - ▷ Too dynamic
  - ▷ Hierarchy specific

→ We do not want to rewrite a visitor combinator framework for each target AST.

What we want

- Generic visitor combinators C++ library
- Instrument external visitable AST hierarchies
- **No** intrusion in target code
- Performance
- Ease of use

→ Use visitors combinators on any vanilla visitable hierarchy
(like the LRDE Tiger compiler AST)

Implementation techniques

- Use genericity
- Adapt a foreign AST hierarchy
- Avoid dynamic binding
- Allow generic traversal

Generic combinators

- Some combinators (like identity or sequence) behave equally on any AST
- Wouldn't it be possible to write them only once ?

$\rightarrow$ Let's try to benefit from C++ static genericity

Writing generic combinators

A generic `Identity` could be rewritten as follows:

```
template < class AbstractVisitor >
struct Identity : public AbstractVisitor
{
  template < typename T >
  void visit (T& t) {}
};
```

However:

- This new combinator is still an abstract class
- `template virtual` methods are illegal

Writing generic combinators

- Generic combinators cannot be accepted directly by a target AST node
- Static and dynamic dispatch are not compatible
- We must implement an adapter between the two dispatches

→ We need a generic way to build concrete classes implementing any target visitor interface.

Acting as a Vanilla visitor

- Visitors of the target hierarchy can be described by:
  - ▷ the abstract visitor type
  - ▷ the list of visited types
- Meta C++ features
  - ▷ parameterized inheritance
  - ▷ static lists

→ Let's use some meta-programming

Hierarchy Unrolling

We want a Visitor class parameterized by:

- static list of types `List< Type1, List< Type2, ... List< TypeN > ... > >`
- the abstract visitor type `AbstractVisitor`

... which generates, once instantiated:

```
struct Visitor : public AbstractVisitor {
  virtual void visit (Type1&) { /* ... */ }
  virtual void visit (Type2&) { /* ... */ }
  // ...
  virtual void visit (TypeN&) { /* ... */ }
};
```

A solution

```
template < typename L, typename V >
struct Visitor;

// Base specialization.
template < typename T, typename Tail, typename V >
struct Visitor < List < T, Tail >, V >
: public Visitor < Tail, V > {
  virtual void visit (T& t) { /* ... */ }
};

// Last element specialization.
template < typename T, typename V, typename H >
struct Visitor < List < T, Empty >, V > : public V {
  virtual void visit (T& t) { /* ... */  }
};
```

- The instantiated visitor inherits from N classes
- The virtual table is built once for the instantiated visitor
- No additional indirection
- Replace the "`...`" in the visit methods of the previous code by a delegation to an aggregated static visitor to make a static/dynamic adapter.

→ We can build arbitrary vanilla visitors without performance penalty

Static composition

- The type of parameters of many combinators (like sequence or choice) could be known at compile time
- We want to use this fact to avoid dynamic binding on visit methods calls

→ Let's try to write a static choice combinator

Static composition

```
template < typename First, typename Second >
struct Choice {
  Choice (First& first, Second& second)
    : first_(first), second_(second) {}

  template < typename T >
  inline bool visit_ (T& t)
  { return first_.visit_ (t) || second_.visit_ (t); }

  First& first_;
  Second& second_;
};
```

Those combinators are then combined using expression templates

Self recursive combinators ?

Static composition is nice, but ...

- self recursive types are **impossible** in C++

- we would like to write self recursive combinators

Think about : `traversal = all ( traversal )`

$\rightarrow$ We need a way to "break" static composition

Self recursive combinator

- Concept coming from the *Spirit* parser framework (Spirit, 2001)
- Proxy for a static combinator

```
struct Combinator
{
  template < typename V >
  Combinator& operator = (V& v) {
       v_ = new ConcreteCombinator < V > (v);
       return *this;
  }
  AbstractCombinator* v_;  // visit methods delegated to v_
};
```

Self recursive combinators

- We can now use self-recursion:

```
Combinator top_down_v = v && all(top_down_v);
```

  - ▷ rhs type is `Sequence < V, All < Combinator > >`
  - ▷ a reference on `topdown_v` can safely be taken before the end of its initialization

- An extra dynamic binding is used

Handy assignation

When trying to assign combinators, we can now write:

```
Combinator v = all(v1 && v2);
```

... instead of explicitly specifying the expression template return type:

```
All < Sequence < V1, V2 > > v = all(v1 && v2);
```

Similar results could be possible with the **non-standard** `typeof` extension:

```
typeof(all(v1 && v2)) v = all(v1 && v2);
```

Traversal

- We want generic traversal combinators like all or one
- They need to know about node structures

→ We must find a way to describe the AST nodes

Adaptation

- Nodes can fall in three categories:
  - ▷ n-ary nodes (number of children known at compile time)
  - ▷ list nodes (dynamic number of children, iterator access)
  - ▷ leaf nodes (no children)
- We describe them through traits specialization
- We use adapter classes, templated by static method pointers to ease traits specialization

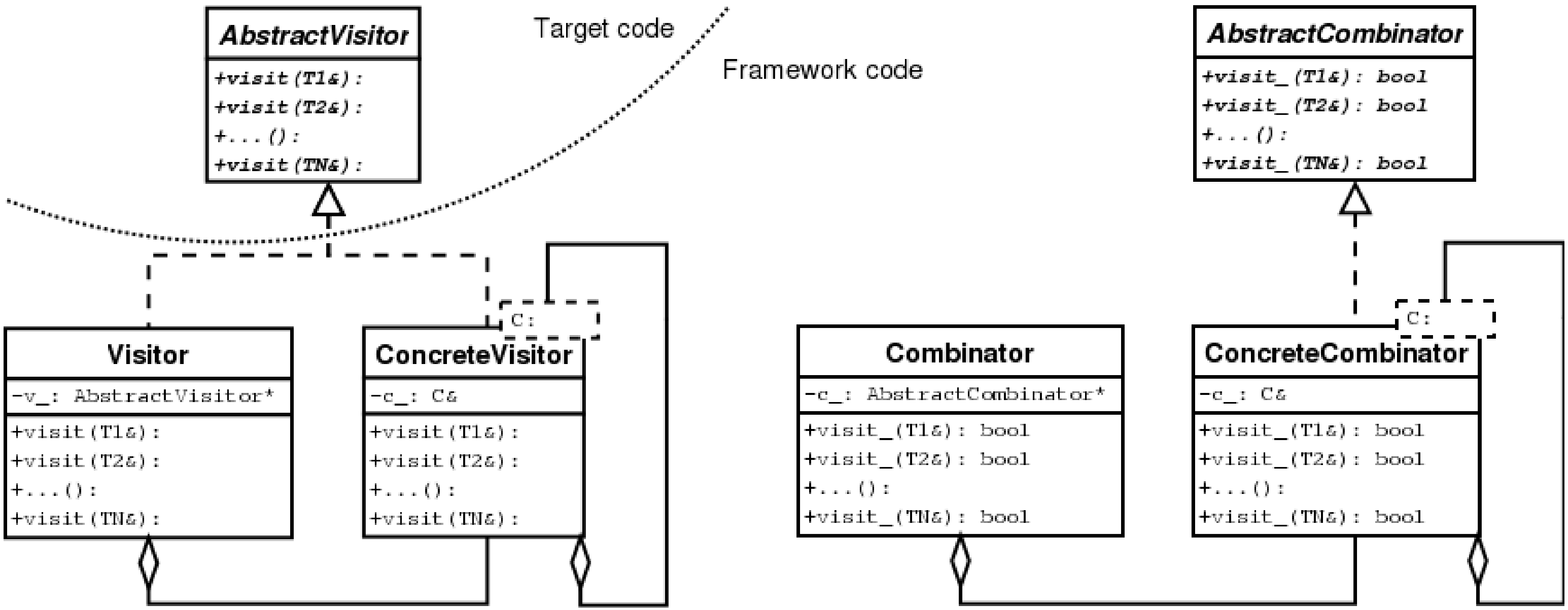
Visitors

- Presentation
- Tiger use case

Presentation

- Target code (the AST to work on)
- Framework code (the *Visitors* library)
- Adapting code
- Client specific code
  - ▷ Custom generic combinators
  - ▷ Custom (AST specific) combinators
  - ▷ Visitor instantiations and use

Visitors Classes



Tiger use case

Description of (a subset of) the Tiger AST:

```
struct TigerHierarchy // Target hierarchy
{
  // Abstract visitor type
  typedef ast :: Visitor visitor_type;

  // Types of the hierarchy
  typedef List < IntExp, List < OpExp > > types;
};
```

Tiger use case

Specialization of the VisitedTypes traits:

```
// OpExp
struct VisitedTypes < OpExp >
  : public NaryNode < OpExp,
                      List < Accessor < OpExp, Exp&,
                                        &OpExp :: left_get >,
                      List < Accessor < OpExp, Exp&,
                                        &OpExp :: right_get
                                           > > > >
{};

// IntExp
DECLARE_LEAF_NODE(ast :: IntExp);
```

print_type visitor

A combinator which prints the type of any node it visits:

```
struct PrintType
{
  template < typename T >
  bool visit_ (T& t)
  {
    const std :: type_info& ti = typeid (t);
    const char* type = ti.name ();
    os_ << type;
    return true;
  }
};

static PrintType print_type;
```

`print_type` visitor

A combinator which prints the types of all the subtrees of the visited node:

```
fifty_one.accept(
visitor(top_down(print_type && print("\n")))
);
```

... and its (demangled) output, when accepted by our sample Exp:

```
ast::OpExp
ast::OpExp
ast::IntExp
ast::IntExp
ast::IntExp
```

`is_const` visitor

A combinator which succeeds if the node is a constant expression and fails otherwise:

```
Match<OpExp>  op_match;
Match<IntExp> int_match;

Combinator<> is_const =
  int_match
  || (op_match && all(is_const));

Visitor<> is_const_visitor =
  (is_const
   && *new Print("const"))
  || *new Print("not const");

exp.accept(is_const_visitor);
```

Problems

- There is a `visit` method for `decs_t` (`std::list < Decs * >`) in the `Visitor` interface, but no `accept` method in `decs_t`
- Hybrid nodes like `FunctionDec` act simultaneously like a list node (the list of parameters) and like a n-ary node (two children: the result and the body)

Conclusion

- Applicability
- Future

Applicability

- Currently restricted to “well-formed” target AST hierarchies
- Writing adapting code for complex AST is harassing and error-prone
- Classical active libraries annoyances:
  - ▷ Slow compilation
  - ▷ Obfuscated code
  - ▷ Cryptic error messages
  - ▷ Compiler support

Future

Some possible improvements ...

- `constness`
- static concept checks
- node substitutions
- placeholders *a la* FC++: (FC++, 2002)

```
Combinator top_down = sequence ( _1 , all (top_down (_1))))
```

References

Alexandrescu, A. (2001). Modern c++ design, design patterns applied.

FC++ (2002). Homepage of fc++: functional programming in c++.

Gamma, Helm, Johnson, and Vlissides (1994). Design patterns, elements of reusable object-oriented software.

Spirit (2001). Homepage of the spirit parser framework.

standard, C. (1998). Iso iec 14882 - programming languages – c++.

Tisserand, N. (2003). Generic visitors in c++ (technical report).

Visser, J. (2001). Visitor combination and traversal control.

Vlissides, J. (1998). Pattern hatching: Design patterns applied.

Vlissides, J. (1999). Pattern hatching - visitor in frameworks.

Questions