Abstract Syntax Trees

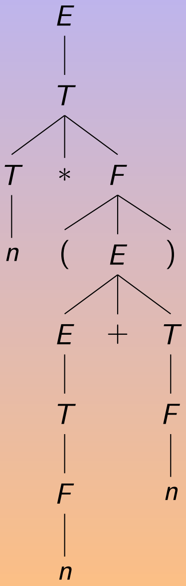
Akim Demaille   Étienne Renault   Roland Levillain
first.last@lrde.epita.fr

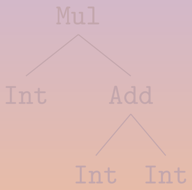
EPITA — École Pour l'Informatique et les Techniques Avancées

January 22, 2016

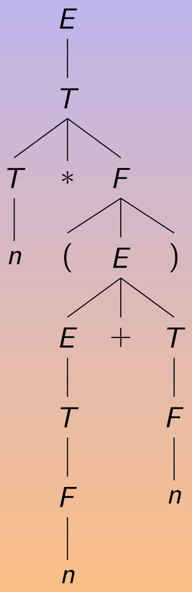
Abstract Syntax Trees

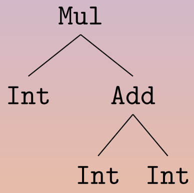
$1 * (2 + 3)$, twice





$1 * (2 + 3)$, twice





Abstract Syntax Tree

- Parse Tree, Concrete Syntax
- Abstract Syntax Tree, Abstract Syntax
- Syntactic Sugar
- Traversals

Abstract Syntax Tree

- Parse Tree, Concrete Syntax
- Abstract Syntax Tree, Abstract Syntax
- Syntactic Sugar
- Traversals

Abstract Syntax Tree

- Parse Tree, Concrete Syntax
- Abstract Syntax Tree, Abstract Syntax
- Syntactic Sugar
- Traversals

Abstract Syntax Tree

- Parse Tree, Concrete Syntax
- Abstract Syntax Tree, Abstract Syntax
- Syntactic Sugar
- Traversals

AST Generators

1. Structured Data for Input/Output: Trees
   - AST Generators
   - Exchanging Trees
   - Simple Implementation of ast in C++
2. Algorithms on trees: Traversals
3. Applications
4. The Case of the Tiger Compiler

Syntax Definition Formalism [Visser, 1995]

```
module Tiger-Expressions
imports Tiger-Lexicals Tiger-Literals
exports
  sorts Exp Var
  context-free syntax
    Id                              → Var        {cons("Var")}
    Var                             → LValue
    LValue "." Id                   → LValue     {cons("FieldVar")}
    LValue "[" Exp "]"              → LValue     {cons("Subscript")}
    IntConst                        → Exp        {cons("Int")}
    StrConst                        → Exp        {cons("String")}
    "nil"                           → Exp        {cons("NilExp")}
    LValue                          → Exp
    Var "(" {Exp ","}* ")"          → Exp        {cons("Call")}
    Id "=" Exp                      → InitField  {cons("InitField")}
    TypeId "{" {InitField ","}* "}"      → Exp   {cons("Record")}
    TypeId "[" {Exp ","}+ "]" "of" Exp → Exp    {cons("Array")}
```

Exchanging Trees

1. Structured Data for Input/Output: Trees
   - AST Generators
   - Exchanging Trees
   - Simple Implementation of ast in C++
2. Algorithms on trees: Traversals
3. Applications
4. The Case of the Tiger Compiler

Abstract Syntax Notation number One

ASN.1 [ASN.1 Consortium, 2003, Dubuisson, 2003]

- an international standard
- specify data used in communication protocols
- powerful and complex language
- describe accurately and efficiently communications between homogeneous or heterogeneous systems

Abstract Syntax Notation number One

ASN.1 [ASN.1 Consortium, 2003, Dubuisson, 2003]

- an international standard
- specify data used in communication protocols
- powerful and complex language
- describe accurately and efficiently communications between homogeneous or heterogeneous systems

Abstract Syntax Notation number One

ASN.1 [ASN.1 Consortium, 2003, Dubuisson, 2003]

- an international standard
- specify data used in communication protocols
- powerful and complex language
- describe accurately and efficiently communications between homogeneous or heterogeneous systems

Abstract Syntax Notation number One

ASN.1 [ASN.1 Consortium, 2003, Dubuisson, 2003]

- an international standard
- specify data used in communication protocols
- powerful and complex language
- describe accurately and efficiently communications between homogeneous or heterogeneous systems

ASN.1

```
Example DEFINITIONS ::=
BEGIN
    AddressType ::= SEQUENCE {
        name            OCTET STRING,
        number          INTEGER,
        street          OCTET STRING,
        apartNumber     INTEGER OPTIONAL,
        postOffice      OCTET STRING,
        state           OCTET STRING,
        zipCode         INTEGER
    }
END
```

ASN.1

Tags to avoid problems similar to matching a*a*.

```
Example DEFINITIONS ::=
BEGIN
    Letter ::= SEQUENCE {
        opening         OCTET STRING,
        body            OCTET STRING,
        closing         OCTET STRING,
        receiverAddr    [0] AddressType OPTIONAL,
        senderAddr      [1] AddressType OPTIONAL
    }
END
```

ATerms

Grammar of ATerms

```
t  ::= bt               -- basic term
     | bt { t }         -- annotated term
bt ::= C                -- constant
     | C(t1,...,tn)     -- n-ary constructor
     | (t1,...,tn)      -- n-ary tuple
     | [t1,...,tn]      -- list
     | "ccc"            -- quoted string
     | int              -- integer
     | real             -- floating point number
     | blob             -- binary large object
```

C is a *constructor* name — an identifier or a quoted string [Centrum voor Wiskunde en Informatica, 2004].

Examples of ATerms

constants `abc`

numerals `42`

literals `"asdf"`

lists `[], [1, "abc" 2], [1, 2, [3, 4]]`

functions `f("a"), g(1,[])`

annotations `f("a") {"remark"}`

Other Frameworks

- SGML/XML
    - YAXX: YAcc eXtension to XML [Yu and D'Hollander, 2003]
- CORBA
- JSON
- YAML
- SDL
- S-expressions (sexps)
    - SXML

Simple Implementation of ast in C++

Simple Grammar

$$\langle \texttt{exp} \rangle ::= \langle \texttt{exp} \rangle \; (\texttt{'+'} \mid \texttt{'-'} \mid \texttt{'*'} \mid \texttt{'/'}) \; \langle \texttt{exp} \rangle$$
$$\mid \; \texttt{'('} \; \langle \texttt{exp} \rangle \; \texttt{')'}$$
$$\mid \; \langle \texttt{num} \rangle \texttt{.}$$

Simple Grammar

$$\langle \texttt{exp} \rangle ::= \langle \texttt{exp} \rangle \; (\texttt{'+'} \mid \texttt{'-'} \mid \texttt{'*'} \mid \texttt{'/'}) \; \langle \texttt{exp} \rangle$$
$$\mid \; \texttt{'('} \; \langle \texttt{exp} \rangle \; \texttt{')'}$$
$$\mid \; \langle \texttt{num} \rangle .$$

$$\langle \texttt{exp} \rangle ::= \texttt{Add} \; \langle \texttt{exp} \rangle \; \langle \texttt{exp} \rangle$$
$$\mid \; \texttt{Sub} \; \langle \texttt{exp} \rangle \; \langle \texttt{exp} \rangle$$
$$\mid \; \texttt{Mul} \; \langle \texttt{exp} \rangle \; \langle \texttt{exp} \rangle$$
$$\mid \; \texttt{Div} \; \langle \texttt{exp} \rangle \; \langle \texttt{exp} \rangle$$
$$\mid \; \texttt{Num} \; \langle \texttt{num} \rangle .$$

Expressions: Exp

```
class Exp
{
protected:
  Exp() {};
  Exp(const Exp& rhs) {};
  Exp& operator=(const Exp& rhs) {};

public:
  virtual ~Exp();
};
```

Binary Expressions: Bin

```
class Bin : public Exp
{
public:
  Bin(char oper, Exp* lhs, Exp* rhs)
    : Exp(), oper_(oper), lhs_(lhs), rhs_(rhs)
  {}

  virtual ~Bin()
  { delete lhs_; delete rhs_; }

private:
  char oper_; Exp* lhs_; Exp* rhs_;
};
```

Numbers: Num

```
class Num : public Exp
{
public:
  Num(int val)
    : Exp(), val_(val)
  {}

private:
  int val_;
};
```

Constructing an ast

```
int
main()
{
  Exp* tree = new Bin('+', new Num(42), new Num(51));
  delete tree;
}
```

How to process the AST?

Constructing an ast

```
int
main()
{
  Exp* tree = new Bin('+', new Num(42), new Num(51));
  delete tree;
}
```

How to process the AST?

Algorithms on trees: Traversals

Traversals in Compilers

- pretty printer
- name analysis
- unique identifiers
- desugaring
- type checking
- non local (escaping) variables
- inlining
- high level optimizations
- translation to other intermediate representations
- etc.

Traversals in Compilers

- pretty printer
- name analysis
- unique identifiers
- desugaring
- type checking
- non local (escaping) variables
- inlining
- high level optimizations
- translation to other intermediate representations
- etc.

Traversals in Compilers

- pretty printer
- name analysis
- unique identifiers
- desugaring
- type checking
- non local (escaping) variables
- inlining
- high level optimizations
- translation to other intermediate representations
- etc.

Traversals in Compilers

- pretty printer
- name analysis
- unique identifiers
- desugaring
- type checking
- non local (escaping) variables
- inlining
- high level optimizations
- translation to other intermediate representations
- etc.

Traversals in Compilers

- pretty printer
- name analysis
- unique identifiers
- desugaring
- type checking
- non local (escaping) variables
- inlining
- high level optimizations
- translation to other intermediate representations
- etc.

Traversals in Compilers

- pretty printer
- name analysis
- unique identifiers
- desugaring
- type checking
- non local (escaping) variables
- inlining
- high level optimizations
- translation to other intermediate representations
- etc.

Traversals in Compilers

- pretty printer
- name analysis
- unique identifiers
- desugaring
- type checking
- non local (escaping) variables
- inlining
- high level optimizations
- translation to other intermediate representations
- etc.

Traversals in Compilers

- pretty printer
- name analysis
- unique identifiers
- desugaring
- type checking
- non local (escaping) variables
- inlining
- high level optimizations
- translation to other intermediate representations
- etc.

Traversals in Compilers

- pretty printer
- name analysis
- unique identifiers
- desugaring
- type checking
- non local (escaping) variables
- inlining
- high level optimizations
- translation to other intermediate representations
- etc.

Traversals in Compilers

- pretty printer
- name analysis
- unique identifiers
- desugaring
- type checking
- non local (escaping) variables
- inlining
- high level optimizations
- translation to other intermediate representations
- etc.

Tagging the Abstract Syntax Tree

Some traversals discover information that change the translation:

- an escaping variable must not be stored in a register
- the code for `a < b` depends on the types of `a` and `b`
- `a := print_int(51)` must not produce a real assignment

Annotate some ast nodes.

Tagging the Abstract Syntax Tree

Some traversals discover information that change the translation:

- an escaping variable must not be stored in a register
- the code for `a < b` depends on the types of `a` and `b`
- `a := print_int(51)` must not produce a real assignment

Annotate some ast nodes.

Tagging the Abstract Syntax Tree

Some traversals discover information that change the translation:

- an escaping variable must not be stored in a register
- the code for `a < b` depends on the types of `a` and `b`
- `a := print_int(51)` must not produce a real assignment

Annotate some ast nodes.

Tagging the Abstract Syntax Tree

Some traversals discover information that change the translation:

- an escaping variable must not be stored in a register
- the code for `a < b` depends on the types of `a` and `b`
- `a := print_int(51)` must not produce a real assignment

Annotate some ast nodes.

Supporting the operator<<

Expressions: Exp

```
#include <iostream>

class Exp
{
protected:
  Exp() {};
  Exp(const Exp& rhs) {};
  Exp& operator=(const Exp& rhs) {};

public:
  virtual ~Exp() {};
};

std::ostream&
operator<<(std::ostream& o, const Exp& tree)
{
  return o << "Uh oh...";
}
```

Binary Expressions: Bin

```
class Bin : public Exp {
public:
  Bin(char oper, Exp* lhs, Exp* rhs)
    : Exp(), oper_(oper), lhs_(lhs), rhs_(rhs)
  {}
  virtual ~Bin() { delete lhs_; delete rhs_; }

  friend std::ostream&
  operator<<(std::ostream& o, const Bin& tree);

private:
  char oper_; Exp* lhs_; Exp* rhs_;
};

std::ostream& operator<<(std::ostream& o, const Bin& tree) {
  return o << '(' << *tree.lhs_
           << tree.oper_ << *tree.rhs_ << ')';
}
```

Numbers: Num

```
class Num : public Exp
{
public:
  Num(int val)
    : Exp(), val_(val)
  {}

  friend std::ostream&
  operator<<(std::ostream& o, const Num& tree);

private:
  int val_;
};

std::ostream&
operator<<(std::ostream& o, const Num& tree)
{
  return o << tree.val_;
}
```

Invoking and Printing

```cpp
int
main()
{
  Bin* bin = new Bin('+', new Num(42), new Num(51));
  Exp* exp = bin;
  std::cout << "Exp: " << *exp << std::endl;
  std::cout << "Bin: " << *bin << std::endl;
  delete bin;
}
```

Using operator<<

```
% ./bin2
Exp: Uh oh...
Bin: (Uh oh...+Uh oh...)
```

- compile time selection (*static binding*) based on the containing/variable type.
- We need it at run time (*dynamic binding*) based on the contained/object type.
  - also called *inclusion polymorphism*
  - provided by `virtual` in C++

Using operator<<

```
% ./bin2
Exp: Uh oh...
Bin: (Uh oh...+Uh oh...)
```

- compile time selection (*static binding*) based on the containing/variable type.
- We need it at run time (*dynamic binding*) based on the contained/object type.
  - also called *inclusion polymorphism*
  - provided by `virtual` in C++

Using operator<<

```
% ./bin2
Exp: Uh oh...
Bin: (Uh oh...+Uh oh...)
```

- compile time selection (*static binding*) based on the containing/variable type.
- We need it at run time (*dynamic binding*) based on the contained/object type.
  - also called *inclusion polymorphism*
  - provided by `virtual` in C++

Using operator<<

```
% ./bin2
Exp: Uh oh...
Bin: (Uh oh...+Uh oh...)
```

- compile time selection (*static binding*) based on the containing/variable type.
- We need it at run time (*dynamic binding*) based on the contained/object type.
  - also called *inclusion polymorphism*
  - provided by `virtual` in C++

Using operator<<

```
% ./bin2
Exp: Uh oh...
Bin: (Uh oh...+Uh oh...)
```

- compile time selection (*static binding*) based on the containing/variable type.
- We need it at run time (*dynamic binding*) based on the contained/object type.
  - also called *inclusion polymorphism*
  - provided by `virtual` in C++

Expressions: Exp

```
#include <iostream>

class Exp
{
public:
  virtual std::ostream& print(std::ostream& o) const = 0;
};
```

Binary Expressions: Bin

```
class Bin : public Exp
{
public:
  Bin(char op, Exp* l, Exp* r)
    : Exp(), oper_(op), lhs_(l), rhs_(r)
  {}

  virtual ~Bin() {
    delete lhs_; delete rhs_;
  }

  virtual std::ostream& print(std::ostream& o) const {
    o << '('; lhs_->print(o); o << oper_;
    rhs_->print(o); return o << ')';
  }

private:
  char oper_; Exp* lhs_; Exp* rhs_;
};
```

Numbers: Num

```
class Num : public Exp
{
public:
  Num(int val) : Exp(), val_(val)
  {}

  virtual std::ostream&
  print(std::ostream& o) const
  {
    return o << val_;
  }

private:
  int val_;
};
```

Using this ast

```
std::ostream&
operator<<(std::ostream& o, const Exp& e)
{
  return e.print(o);
}

int
main()
{
  Bin* bin = new Bin('+', new Num(42), new Num(51));
  Exp* exp = bin;
  std::cout << "Exp: " << *exp << std::endl;
  std::cout << "Bin: " << *bin << std::endl;
  delete bin;
}
```

Discussion

It works. . .

```
% ./exp3
Exp: (42+51)
Bin: (42+51)
```

but Bin::print is obfuscated.

```
std::ostream&
Bin::print(std::ostream& o) const
{
  o << '(';
  lhs_->print(o);
  o << oper_;
  rhs_->print(o);
  o << ')';
  return o;
}
```

Discussion

It works. . .

```
% ./exp3
Exp: (42+51)
Bin: (42+51)
```

but Bin::print is obfuscated.

```
std::ostream&
Bin::print(std::ostream& o) const
{
  o << '(';
  lhs_->print(o);
  o << oper_;
  rhs_->print(o);
  o << ')';
  return o;
}
```

Discussion

It works. . .

```
% ./exp3
Exp: (42+51)
Bin: (42+51)
```

but `Bin::print` is obfuscated.

```
std::ostream&
Bin::print(std::ostream& o) const
{
  o << '(';
  lhs_->print(o);
  o << oper_;
  rhs_->print(o);
  o << ')';
  return o;
}
```

Making operator<< Polymorphic

Just use the operator<< in print!

```
class Exp {
public:
  virtual std::ostream& print(std::ostream& o) const = 0;
};

std::ostream& operator<<(std::ostream& o, const Exp& e) {
  return e.print(o);
}

std::ostream& Bin::print(std::ostream& o) const {
  return o << '(' << *lhs_ << oper_ << *rhs_ << ')';
}
```

Cuter, but you cannot pass additional arguments to print.

Making operator<< Polymorphic

Just use the operator<< in print!

```
class Exp {
public:
  virtual std::ostream& print(std::ostream& o) const = 0;
};

std::ostream& operator<<(std::ostream& o, const Exp& e) {
  return e.print(o);
}

std::ostream& Bin::print(std::ostream& o) const {
  return o << '(' << *lhs_ << oper_ << *rhs_ << ')';
}
```

Cuter, but you cannot pass additional arguments to print.

Separate processing and dispatching

- In the previous code, `operator<<` processes and dispatches
- Additional operations will require processing and dispatching

Processing

- Keep it external
- Add new easily

Dispatching

- Keep it internal
- Once for all: Factor it!

Separate processing and dispatching

- In the previous code, `operator<<` processes and dispatches
- Additional operations will require processing and dispatching

Processing

- Keep it external
- Add new easily

Dispatching

- Keep it internal
- Once for all: Factor it!

Separate processing and dispatching

- In the previous code, `operator<<` processes and dispatches
- Additional operations will require processing and dispatching

Processing

- Keep it external
- Add new easily

Dispatching

- Keep it internal
- Once for all: Factor it!

Separate processing and dispatching

- In the previous code, `operator<<` processes and dispatches
- Additional operations will require processing and dispatching

Processing

- Keep it external
- Add new easily

Dispatching

- Keep it internal
- Once for all: Factor it!

operator<< to process

```
std::ostream& operator<<(std::ostream& o, const Bin& e)
{
  return o << '(' << *e.lhs_ << oper_ << *e.rhs_ << ')';
}

std::ostream& operator<<(std::ostream& o, const Num& e)
{
  return o << e.val;
}

std::ostream& operator<<(std::ostream& o, const Exp& e)
{
  return e.print(o);
}
```

operator<< to process

```
std::ostream& operator<<(std::ostream& o, const Bin& e)
{
  return o << '(' << *e.lhs_ << oper_ << *e.rhs_ << ')';
}

std::ostream& operator<<(std::ostream& o, const Num& e)
{
  return o << e.val;
}

std::ostream& operator<<(std::ostream& o, const Exp& e)
{
  return e.print(o);
}
```

print to dispatch

```
class Exp {
public:
  virtual std::ostream& print(std::ostream& o) const = 0;
};

class Bin {
public:
  virtual std::ostream& print(std::ostream& o) const {
    return o << *this;
  }
  ...
};

class Num {
public:
  virtual std::ostream& print(std::ostream& o) const {
    return o << *this;
  }
  ...
```

Separate processing and dispatching

- Now `operator<<` processes
- `print` dispatches
- Each processing requires its dispatching
- Pass pointers to functions to factor the dispatching?

Separate processing and dispatching

- Now `operator<<` processes
- `print` dispatches
- Each processing requires its dispatching
- Pass pointers to functions to factor the dispatching?

Separate processing and dispatching

- Now `operator<<` processes
- `print` dispatches
- Each processing requires its dispatching
- Pass pointers to functions to factor the dispatching?

Multimethods

Multimethods

- Polymorphism over any argument, not only just on the object:

```
using std::ostream;
ostream& operator<<(ostream& o, virtual const Exp& e);
ostream& operator<<(ostream& o, virtual const Bin& e);
ostream& operator<<(ostream& o, virtual const Num& e);
```

- This is called multimethods
- CLOS, Common Lisp Object System

Multimethods

- Polymorphism over any argument, not only just on the object:

```
using std::ostream;
ostream& operator<<(ostream& o, virtual const Exp& e);
ostream& operator<<(ostream& o, virtual const Bin& e);
ostream& operator<<(ostream& o, virtual const Num& e);
```

- This is called multimethods
- CLOS, Common Lisp Object System

Multimethods

- Polymorphism over any argument, not only just on the object:

```
using std::ostream;
ostream& operator<<(ostream& o, virtual const Exp& e);
ostream& operator<<(ostream& o, virtual const Bin& e);
ostream& operator<<(ostream& o, virtual const Num& e);
```

- This is called multimethods
- CLOS, Common Lisp Object System

Multimethods in C++

- No multimethods in C++03/11 (nor 1y)
- Simulate via a *trampoline*

```
std::ostream&
operator<<(std::ostream& o, const Exp& e)
{
  return e.print(o);
}
virtual std::ostream& Exp::print(std::ostream& o) = 0;
virtual std::ostream& Bin::print(std::ostream& o) { ... };
virtual std::ostream& Num::print(std::ostream& o) { ... };
```

- Ask the hierarchy to perform the dispatch
- Additional work on the hierarchy
- The concept is spread in several files
- Requires the ability to edit the hierarchy

Multimethods in C++

- No multimethods in C++03/11 (nor 1y)
- Simulate via a *trampoline*

```
std::ostream&
operator<<(std::ostream& o, const Exp& e)
{
  return e.print(o);
}
virtual std::ostream& Exp::print(std::ostream& o) = 0;
virtual std::ostream& Bin::print(std::ostream& o) { ... };
virtual std::ostream& Num::print(std::ostream& o) { ... };
```

- Ask the hierarchy to perform the dispatch
- Additional work on the hierarchy
- The concept is spread in several files
- Requires the ability to edit the hierarchy

Multimethods in C++

- No multimethods in C++03/11 (nor 1y)
- Simulate via a *trampoline*

```
std::ostream&
operator<<(std::ostream& o, const Exp& e)
{
  return e.print(o);
}
virtual std::ostream& Exp::print(std::ostream& o) = 0;
virtual std::ostream& Bin::print(std::ostream& o) { ... };
virtual std::ostream& Num::print(std::ostream& o) { ... };
```

- Ask the hierarchy to perform the dispatch
- Additional work on the hierarchy
- The concept is spread in several files
- Requires the ability to edit the hierarchy

Multimethods in C++

- No multimethods in C++03/11 (nor 1y)
- Simulate via a *trampoline*

```
std::ostream&
operator<<(std::ostream& o, const Exp& e)
{
  return e.print(o);
}
virtual std::ostream& Exp::print(std::ostream& o) = 0;
virtual std::ostream& Bin::print(std::ostream& o) { ... };
virtual std::ostream& Num::print(std::ostream& o) { ... };
```

- Ask the hierarchy to perform the dispatch
- Additional work on the hierarchy
- The concept is spread in several files
- Requires the ability to edit the hierarchy

Multimethods in C++

- No multimethods in C++03/11 (nor 1y)
- Simulate via a *trampoline*

```
std::ostream&
operator<<(std::ostream& o, const Exp& e)
{
  return e.print(o);
}
virtual std::ostream& Exp::print(std::ostream& o) = 0;
virtual std::ostream& Bin::print(std::ostream& o) { ... };
virtual std::ostream& Num::print(std::ostream& o) { ... };
```

- Ask the hierarchy to perform the dispatch
- Additional work on the hierarchy
- The concept is spread in several files
- Requires the ability to edit the hierarchy

Multimethods in C++

- No multimethods in C++03/11 (nor 1y)
- Simulate via a *trampoline*

```
std::ostream&
operator<<(std::ostream& o, const Exp& e)
{
  return e.print(o);
}
virtual std::ostream& Exp::print(std::ostream& o) = 0;
virtual std::ostream& Bin::print(std::ostream& o) { ... };
virtual std::ostream& Num::print(std::ostream& o) { ... };
```

- Ask the hierarchy to perform the dispatch
- Additional work on the hierarchy
- The concept is spread in several files
- Requires the ability to edit the hierarchy

Multimethods

- Support for indentation: a new argument is needed.
- Similarly if we want to return a value.
- Introduce structures carried in the traversals.

```
struct stick_t
{
  std::ostream& ostr;
  int res;
  unsigned tab;
};
void traverse(stick_t& s, const Exp& e);
void traverse(stick_t& s, const Bin& e);
void traverse(stick_t& s, const Num& e);
```

- Better yet: make them objects.

Multimethods

- Support for indentation: a new argument is needed.
- Similarly if we want to return a value.
- Introduce structures carried in the traversals.

```
struct stick_t
{
  std::ostream& ostr;
  int res;
  unsigned tab;
};
void traverse(stick_t& s, const Exp& e);
void traverse(stick_t& s, const Bin& e);
void traverse(stick_t& s, const Num& e);
```

- Better yet: make them objects.

Multimethods

- Support for indentation: a new argument is needed.
- Similarly if we want to return a value.
- Introduce structures carried in the traversals.

```
struct stick_t
{
  std::ostream& ostr;
  int res;
  unsigned tab;
};
void traverse(stick_t& s, const Exp& e);
void traverse(stick_t& s, const Bin& e);
void traverse(stick_t& s, const Num& e);
```

- Better yet: make them objects.

Multimethods

- Support for indentation: a new argument is needed.
- Similarly if we want to return a value.
- Introduce structures carried in the traversals.

```
struct stick_t
{
  std::ostream& ostr;
  int res;
  unsigned tab;
};
void traverse(stick_t& s, const Exp& e);
void traverse(stick_t& s, const Bin& e);
void traverse(stick_t& s, const Num& e);
```

- Better yet: make them objects.

Visitors

Visitors

Visitors

Visitors encapsulate the traversal data and algorithm.

```
class PrettyPrinter
{
public:
  void visitBin(const Bin& e) {
    ostr_ << '('; ...
  }
  void visitNum(const Num& e); {
    ostr_ << e.val_;
  }

private:
  std::ostream& ostr_;
  unsigned tab_;
};
```

Class Visitor

```
#include <iostream>

// Fwd.
class Exp;
class Bin;
class Num;

class Visitor
{
public:
  virtual void visitBin(const Bin& exp) = 0;
  virtual void visitNum(const Num& exp) = 0;
};
```

Classes Exp and Num

```
class Exp {
public:
  virtual void accept(Visitor& v) const = 0;
};


class Num : public Exp {
public:
  Num(int val)
    : Exp(), val_(val)
  {}

  virtual void accept(Visitor& v) const {
    v.visitNum(*this);
  }

private:
  int val_;
};
```

Class Bin

```
class Bin : public Exp
{
public:
  Bin(char op, Exp* l, Exp* r)
    : Exp(), oper_(op), lhs_(l), rhs_(r)
  {}

  virtual ~Bin() {
    delete lhs_; delete rhs_;
  }

  virtual void accept(Visitor& v) const {
    v.visitBin(*this);
  }

private:
  char oper_; Exp* lhs_; Exp* rhs_;
};
```

Class PrettyPrinter

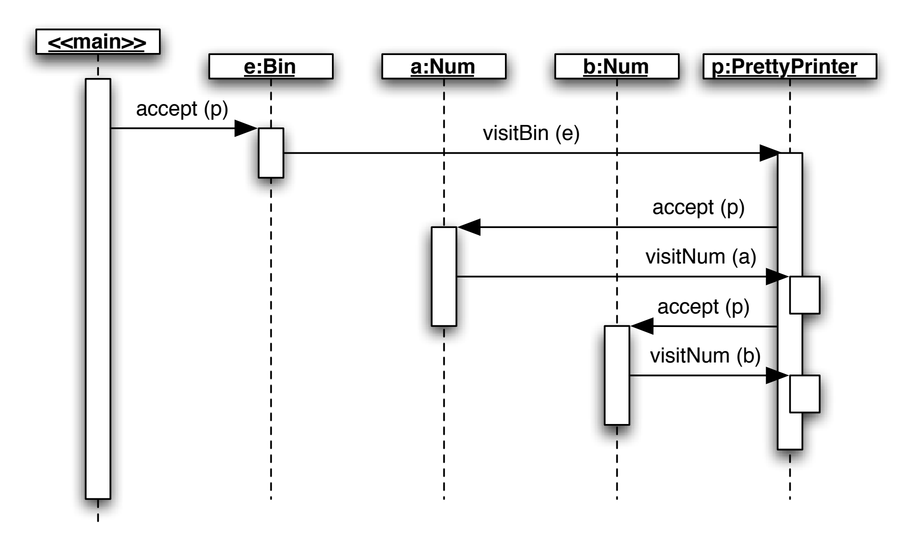
```
class PrettyPrinter : public Visitor
{
public:
  PrettyPrinter(std::ostream& ostr)
    : ostr_(ostr) {}

  virtual void visitBin(const Bin& e) {
    ostr_ << '('; e.lhs_->accept(*this);
    ostr_ << e.oper_; e.rhs_->accept(*this); ostr_ << ')';
  }

  virtual void visitNum(const Num& e) {
    ostr_ << e.val_;
  }

private:
  std::ostream& ostr_;
};
```

operator<< and main

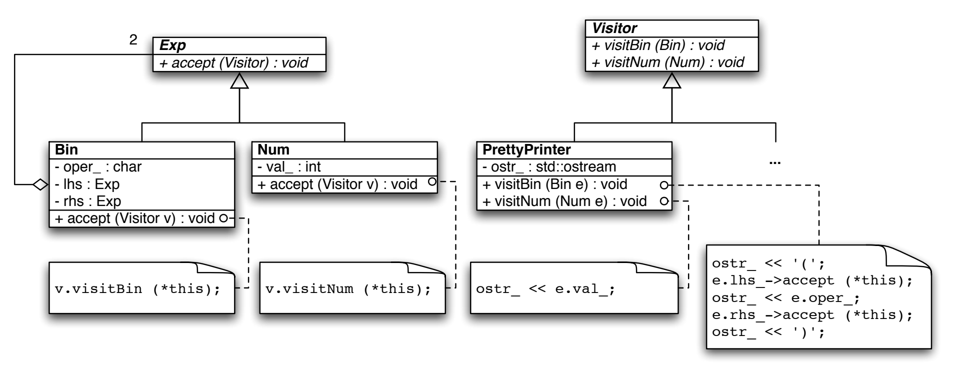
```
std::ostream&
operator<<(std::ostream& o, const Exp& e)
{
  PrettyPrinter printer(o);
  e.accept(printer);
  return o;
}

int
main()
{
  Bin* bin = new Bin('+', new Num(42), new Num(51));
  Exp* exp = bin;
  std::cout << "Bin: " << *bin << std::endl;
  std::cout << "Exp: " << *exp << std::endl;
  delete bin;
}
```

A pretty-printing sequence diagram

```
Exp* a = new Num(42); Exp* b = new Num(51);
Exp* e = new Bin('+', a, b); std::cout << *e << std::endl;
```



A class diagram: Visitor and Composite design patterns



Further with Visitors

Visitors in C++

- `Visitor` and `ConstVisitor`
  similar to `iterator` and `const_iterator`
- Use C++ templates to factor
  (e.g., `Visitor` and `ConstVisitor`, see the lecture on generic programming)
- Use C++ overloading
  only `visit` instead of `visitBin` and `visitNum`

Visitors in C++

- `Visitor` and `ConstVisitor`
  similar to `iterator` and `const_iterator`
- Use C++ templates to factor
  (e.g., `Visitor` and `ConstVisitor`, see the lecture on generic programming)
- Use C++ overloading
  only `visit` instead of `visitBin` and `visitNum`

Visitors in C++

- `Visitor` and `ConstVisitor`
  similar to `iterator` and `const_iterator`
- Use C++ templates to factor
  (e.g., `Visitor` and `ConstVisitor`, see the lecture on generic programming)
- Use C++ overloading
  only `visit` instead of `visitBin` and `visitNum`

Object Functions

- How about `operator()` instead of `visit`?
- Does not help the user, pure for implementation convenience
- But then, we can improve this

```
int eval(const Exp& e) {
  Evaluator eval;

  return eval.value;
}
```

```
int eval(const Exp& e) {
  Evaluator eval;

  return eval.value;
}
```

provided

Object Functions

- How about `operator()` instead of `visit`?
- Does not help the user, pure for implementation convenience
- But then, we can improve this

```
int eval(const Exp& e) {
  Evaluator eval;

  return eval.value;
}
```

```
int eval(const Exp& e) {
  Evaluator eval;

  return eval.value;
}
```

provided

Object Functions

- How about `operator()` instead of `visit`?
- Does not help the user, pure for implementation convenience
- But then, we can improve this

```
int eval(const Exp& e) {
  Evaluator eval;
  e.accept(eval);
  return eval.value;
}
```

```
int eval(const Exp& e) {
  Evaluator eval;
  eval(e);
  return eval.value;
}
```

provided

Object Functions

- How about `operator()` instead of `visit`?
- Does not help the user, pure for implementation convenience
- But then, we can improve this

```
int eval(const Exp& e) {
  Evaluator eval;
  e.accept(eval);
  return eval.value;
}
```

```
int eval(const Exp& e) {
  Evaluator eval;
  eval(e);
  return eval.value;
}
```

provided

Object Functions

- How about `operator()` instead of `visit`?
- Does not help the user, pure for implementation convenience
- But then, we can improve this

```
int eval(const Exp& e) {
  Evaluator eval;
  e.accept(eval);
  return eval.value;
}
```

```
int eval(const Exp& e) {
  Evaluator eval;
  eval(e);
  return eval.value;
}
```

provided

```
void Evaluator::operator()(const Exp& e) {
  e.accept(*this);
}
```

Sugaring Visitors 1

```
struct Evaluator : public ConstVisitor {
  virtual void operator()(const Exp& e) { e.accept(*this); }
  virtual void operator()(const Bin& e) {
    e.lhs_->accept(*this); int lhs = value;
    e.rhs_->accept(*this); int rhs = value;
    ... value = lhs + rhs; ...
  }
  virtual void operator()(const Num& e) { value = e.val; }
  int value;
};

int eval(const Exp& e) {
  Evaluator eval;
  eval(e);
  return eval.value;
}
```

Sugaring Visitors 2

```
struct Evaluator : public ConstVisitor
{
  ...
  virtual void
  operator()(const Bin& e) {
    ...
    value = eval(e.lhs_)
          + eval(e.rhs_);
    ...
  }

  virtual void
  operator()(const Num& e) {
    value = e.val;
  }

  int value;
};
```

One visitor per eval invocation

- A useless cost
- Easy automatic variables
- Harder for shared data (no `static` please!)

Sugaring Visitors 2

```
struct Evaluator : public ConstVisitor
{
  ...
  virtual void
  operator()(const Bin& e) {
    ...
    value = eval(e.lhs_)
          + eval(e.rhs_);
    ...
  }

  virtual void
  operator()(const Num& e) {
    value = e.val;
  }

  int value;
};
```

One visitor per eval invocation

- A useless cost
- Easy automatic variables
- Harder for shared data (no static please!)

Sugaring Visitors 2

```
struct Evaluator : public ConstVisitor
{
  ...
  virtual void
  operator()(const Bin& e) {
    ...
    value = eval(e.lhs_)
          + eval(e.rhs_);
    ...
  }

  virtual void
  operator()(const Num& e) {
    value = e.val;
  }

  int value;
};
```

One visitor per eval invocation

- A useless cost
- Easy automatic variables
- Harder for shared data (no static please!)

Sugaring Visitors 2

```
struct Evaluator : public ConstVisitor
{
  ...
  virtual void
  operator()(const Bin& e) {
    ...
    value = eval(e.lhs_)
          + eval(e.rhs_);
    ...
  }

  virtual void
  operator()(const Num& e) {
    value = e.val;
  }

  int value;
};
```

One visitor per eval invocation

- A useless cost
- Easy automatic variables
- Harder for shared data (no static please!)

Sugaring Visitors 2

```
struct Evaluator : public ConstVisitor
{
  ...
  virtual void
  operator()(const Bin& e) {
    ...
    value = eval(e.lhs_)
          + eval(e.rhs_);
    ...
  }

  virtual void
  operator()(const Num& e) {
    value = e.val;
  }

  int value;
};
```

One visitor per eval invocation

- A useless cost
- Easy automatic variables
- Harder for shared data (no `static` please!)

Sugaring Visitors 3

```
struct Evaluator : public ConstVisitor
{
  virtual int eval(const Exp& e) {
    e.accept(*this); return value;
  }

  virtual void operator()(const Exp& e) { e.accept(*this); }
  virtual void operator()(const Bin& e) {
    ...
    value = eval(e.lhs_) + eval(e.rhs_);
    ...
  }
  virtual void operator()(const Num& e) {
    value = e.val;
  }

  int value;
};
```

Sugaring the PrettyPrinter

```
virtual void
PrettyPrinter::operator()(const Bin& e)
{
  ostr_ << '(';
  e.lhs_->accept(*this);
  ostr_ << e.oper_;
  e.rhs_->accept(*this);
  ostr_ << ')';
}
```

- We could insert a print method
- But that's not nice
- We can use the operator<<
- But we no longer can pass additional arguments
- Unless...

Sugaring the PrettyPrinter

```
virtual void
PrettyPrinter::operator()(const Bin& e)
{
  ostr_ << '(';
  e.lhs_->accept(*this);
  ostr_ << e.oper_;
  e.rhs_->accept(*this);
  ostr_ << ')';
}
```

- We could insert a print method
- But that's not nice
- We can use the operator<<
- But we no longer can pass additional arguments
- Unless...

Sugaring the PrettyPrinter

```
virtual void
PrettyPrinter::operator()(const Bin& e)
{
  ostr_ << '(';
  e.lhs_->accept(*this);
  ostr_ << e.oper_;
  e.rhs_->accept(*this);
  ostr_ << ')';
}
```

- We could insert a print method
- But that's not nice
- We can use the operator<<
- But we no longer can pass additional arguments
- Unless...

Sugaring the PrettyPrinter

```
virtual void
PrettyPrinter::operator()(const Bin& e)
{
  ostr_ << '(';
  e.lhs_->accept(*this);
  ostr_ << e.oper_;
  e.rhs_->accept(*this);
  ostr_ << ')';
}
```

- We could insert a `print` method
- But that's not nice
- We can use the `operator<<`
- But we no longer can pass additional arguments
- Unless...

Sugaring the PrettyPrinter

```
virtual void
PrettyPrinter::operator()(const Bin& e)
{
  ostr_ << '(';
  e.lhs_->accept(*this);
  ostr_ << e.oper_;
  e.rhs_->accept(*this);
  ostr_ << ')';
}
```

- We could insert a `print` method
- But that's not nice
- We can use the `operator<<`
- But we no longer can pass additional arguments
- Unless...

Sugaring the PrettyPrinter

```
virtual void
PrettyPrinter::operator()(const Bin& e)
{
  ostr_ << '(';
  e.lhs_->accept(*this);
  ostr_ << e.oper_;
  e.rhs_->accept(*this);
  ostr_ << ')';
}
```

- We could insert a `print` method
- But that's not nice
- We can use the `operator<<`
- But we no longer can pass additional arguments
- Unless...

Sugaring the PrettyPrinter

```
virtual void
PrettyPrinter::operator()(const Bin& e)
{
  ostr_ << '(';
  e.lhs_->accept(*this);
  ostr_ << e.oper_;
  e.rhs_->accept(*this);
  ostr_ << ')';
}
```

- We could insert a `print` method
- But that's not nice
- We can use the `operator<<`
- But we no longer can pass additional arguments
- Unless... we can put data in the stream

Visitors Hierarchies

- Implement default behaviors (`DefaultVisitor`, `DefaultConstVisitor`)
- Overloaded virtual member functions must be imported.

```
class Renamer : public DefaultVisitor
{
public:
  typedef DefaultVisitor super_type;
  using super_type::operator();
  //...
}
```

Visitors Hierarchies

- Implement default behaviors (`DefaultVisitor`, `DefaultConstVisitor`)
- Overloaded virtual member functions must be imported.

```
class Renamer : public DefaultVisitor
{
public:
  typedef DefaultVisitor super_type;
  using super_type::operator();
  //...
}
```

Visitors Hierarchies

- Specialize behaviors (DesugarVisitor < Cloner, overload::TypeChecker < type::TypeChecker, ...)

```
void TypeChecker::operator()(ast::LetExp& e)
{
  // The type of a LetExp is that of its body.
  super_type::operator()(e);
  type_default(e, type(e.body_get()));
}
```

- Use C++ templates to factor (e.g., DefaultVisitor and DefaultConstVisitor)

Visitors Hierarchies

- Specialize behaviors
  (DesugarVisitor < Cloner, overload::TypeChecker < type::TypeChecker, ...)

```
void TypeChecker::operator()(ast::LetExp& e)
{
  // The type of a LetExp is that of its body.
  super_type::operator()(e);
  type_default(e, type(e.body_get()));
}
```

- Use C++ templates to factor
  (e.g., DefaultVisitor and DefaultConstVisitor)

Visitor Combinators

- Work and traversal are still too heavily interrelated

→ Create visitors from basic traversal bricks: *combinators* [Visser, 2001].

Combinator	Description
Identity	Do nothing.
Sequence(v_1, v_2)	Sequentially run visitor v_1 then v_2.
Fail	Raise an exception.
Choice(v_1, v_2)	Try visitor v_1; if v_1 fails, try v_2.
All(v)	Apply visitor v sequentially to every immediate subtree.
One(v)	Apply visitor v sequentially to the immediate subtrees until it succeeds.

Visitor Combinators (cont.)

- Combine them to create visiting strategies.

$$
\begin{aligned}
\mathrm{Twice}(v) &:= \mathrm{Sequence}(v, v) \\
\mathrm{Try}(v) &:= \mathrm{Choice}(v, \mathit{Identity}) \\
\mathrm{TopDown}(v) &:= \mathrm{Sequence}(v, \mathrm{All}(\mathrm{TopDown}(v))) \\
\mathrm{BottomUp}(v) &:= \mathrm{Sequence}(\mathrm{All}(\mathrm{BottomUp}(v)), v)
\end{aligned}
$$

Applications

Desugaring

Syntactic Sugar in Lambda-Calculus

Curryfication $\lambda xy.e \Rightarrow \lambda x.(\lambda y.e)$

Local variables $\text{let } x = e_1 \text{ in } e_2 \Rightarrow (\lambda x.e_2).e_1$

Core Languages A sound basis.

Syntactic Sugar in Lambda-Calculus

Curryfication $\lambda xy.e \Rightarrow \lambda x.(\lambda y.e)$

Local variables $\text{let } x = e_1 \text{ in } e_2 \Rightarrow (\lambda x.e_2).e_1$

Core Languages A sound basis.

Syntactic Sugar in Lambda-Calculus

Curryfication	$\lambda xy.e \Rightarrow \lambda x.(\lambda y.e)$
Local variables	$\mathrm{let}\ x = e_1\ \mathrm{in}\ e_2 \Rightarrow (\lambda x.e_2).e_1$
Core Languages	A sound basis.

List Comprehension in Haskell

Quicksort in Haskell

```
qsort []     = []
qsort (x:xs) = qsort lt_x ++ [x] ++ qsort ge_x
                 where lt_x = [y | y <- xs, y <  x]
                       ge_x = [y | y <- xs, x <= y]
```

List Comprehension in Haskell

Sugared

```
[(x,y) | x <- [1 .. 6], y <- [1 .. x], x+y < 10]
```

Desugared

```
filter p (concat (map (\ x -> map (\ y -> (x,y))
                              [1..x]) [1..6]))
    where p (x,y) = x+y < 10
```

List Comprehension in Haskell

Sugared

```
[(x,y) | x <- [1 .. 6], y <- [1 .. x], x+y < 10]
```

Desugared

```
filter p (concat (map (\ x -> map (\ y -> (x,y))
                                  [1..x]) [1..6]))
    where p (x,y) = x+y < 10
```

Desugaring

- Interferences with error messages, e.g., during type checking:

```
% echo '"true" | 42' | tc -T -
standard input:1.1-6: type mismatch
  condition type: string
  expected type: int
```

- The code the type-checker actually saw:

```
% echo '"true" | 42' | tc -XA -
/* == Abstract Syntax Tree. == */

function _main() =
  (
    (if "true"
      then 1
      else (42 <> 0));
    ()
  )
```

- Similarly with CPP

Desugaring

- Interferences with error messages, e.g., during type checking:

```
% echo '"true" | 42' | tc -T -
standard input:1.1-6: type mismatch
  condition type: string
  expected type: int
```

- The code the type-checker actually saw:

```
% echo '"true" | 42' | tc -XA -
/* == Abstract Syntax Tree. == */

function _main() =
  (
    (if "true"
      then 1
      else (42 <> 0));
    ()
  )
```

- Similarly with CPP

Desugaring

- Interferences with error messages, e.g., during type checking:

```
% echo '"true" | 42' | tc -T -
standard input:1.1-6: type mismatch
  condition type: string
  expected type: int
```

- The code the type-checker actually saw:

```
% echo '"true" | 42' | tc -XA -
/* == Abstract Syntax Tree. == */

function _main() =
  (
    (if "true"
      then 1
      else (42 <> 0));
    ()
  )
```

- Similarly with CPP

Existing Tools

ast Generators

- built in generation of various hooks, including for visitors
- generation of visitor skeletons

Treecc [Weatherley, 2002]

The approach that we take with "treecc" is similar to that used by "yacc". A simple rule-based language is devised that is used to describe the intended behaviour declaratively. Embedded code is used to provide the specific implementation details. A translator then converts the input into source code that can be compiled in the usual fashion.

The translator is responsible for generating the tree building and walking code, and for checking that all relevant operations have been implemented on the node types. Functions are provided that make it easier to build and walk the tree data structures from within a "yacc" grammar and other parts of the compiler.

Treecc [Weatherley, 2002]

The approach that we take with "treecc" is similar to that used by "yacc". A simple rule-based language is devised that is used to describe the intended behaviour declaratively. Embedded code is used to provide the specific implementation details. A translator then converts the input into source code that can be compiled in the usual fashion.

The translator is responsible for generating the tree building and walking code, and for checking that all relevant operations have been implemented on the node types. Functions are provided that make it easier to build and walk the tree data structures from within a "yacc" grammar and other parts of the compiler.

Treecc: a simple example for expressions [tre,]

Yacc grammar

```
%token INT FLOAT

%%

expr: INT
    | FLOAT
    | '(' expr ')'
    | expr '+' expr
    | expr '-' expr
    | expr '*' expr
    | expr '/' expr
    | '-' expr
    ;
```

Treecc: a simple example for expressions (cont). [tre,]

```
%node expression %abstract %typedef
%node binary expression %abstract = {
  expression* expr1;
  expression* expr2;
}
%node unary expression %abstract = {
  expression* expr;
}
%node intnum expression = {
  int num;
}
%node floatnum expression = {
  float num;
}
%node plus binary
%node minus binary
%node multiply binary
%node divide binary
%node negate unary
```

Treecc: a simple example for expressions [tre,]

Yacc grammar augmented to build the parse tree

```
%union {
    expression* node;   int inum;   float fnum;
}
%token <inum> INT
%token <fnum> FLOAT
%type <node> expr
%%
expr: INT                { $$ = intnum_create($1); }
    | FLOAT              { $$ = floatnum_create($1); }
    | '(' expr ')'       { $$ = $2; }
    | expr '+' expr      { $$ = plus_create($1, $3); }
    | expr '-' expr      { $$ = minus_create($1, $3); }
    | expr '*' expr      { $$ = multiply_create($1, $3); }
    | expr '/' expr      { $$ = divide_create($1, $3); }
    | '-' expr           { $$ = negate_create($2); }
    ;
```

The Introspector

Extract meta-data about programs (from compiler, build & make system, savannah/sourceforge management, packaging system, version control tools and mailing lists) and present it to you for making your job as a programmer easier.

The software is free software in the spirit of the GNU manifesto and is revolutionary in the freedoms that it intends on granting to its users.

Originally the GCC "C" compiler, but supports Perl, Bison, M4, Bash, C#, Java, C++, Fortran, Objective C, Lisp and Scheme. [DuPont, 2004]

According to some, a threat to Free Software.

The Introspector

Extract meta-data about programs (from compiler, build & make system, savannah/sourceforge management, packaging system, version control tools and mailing lists) and present it to you for making your job as a programmer easier.

The software is free software in the spirit of the GNU manifesto and is revolutionary in the freedoms that it intends on granting to its users.

Originally the GCC "C" compiler, but supports Perl, Bison, M4, Bash, C#, Java, C++, Fortran, Objective C, Lisp and Scheme. [DuPont, 2004]

According to some, a threat to Free Software.

The Introspector

Extract meta-data about programs (from compiler, build & make system, savannah/sourceforge management, packaging system, version control tools and mailing lists) and present it to you for making your job as a programmer easier.

The software is free software in the spirit of the GNU manifesto and is revolutionary in the freedoms that it intends on granting to its users.

Originally the GCC "C" compiler, but supports Perl, Bison, M4, Bash, C#, Java, C++, Fortran, Objective C, Lisp and Scheme. [DuPont, 2004]

According to some, a threat to Free Software.

The Introspector

> *Extract meta-data about programs (from compiler, build & make system, savannah/sourceforge management, packaging system, version control tools and mailing lists) and present it to you for making your job as a programmer easier.*
>
> *The software is free software in the spirit of the GNU manifesto and is revolutionary in the freedoms that it intends on granting to its users.*
>
> *Originally the GCC "C" compiler, but supports Perl, Bison, M4, Bash, C#, Java, C++, Fortran, Objective C, Lisp and Scheme. [DuPont, 2004]*

According to some, a threat to Free Software.

GCC-XML

C++ has become a popular and powerful language, but parsing it is a very challenging problem. This has discouraged the development of tools meant to work directly with the language.

There is one open-source C++ parser, the C++ front-end to GCC, which is currently able to deal with the language in its entirety. The purpose of the GCC-XML extension is to generate an XML description of a C++ program from GCC's internal representation.

Since XML is easy to parse, other development tools will be able to work with C++ programs without the burden of a complicated C++ parser. [King, 2004]

GCC-XML

C++ has become a popular and powerful language, but parsing it is a very challenging problem. This has discouraged the development of tools meant to work directly with the language.

There is one open-source C++ parser, the C++ front-end to GCC, which is currently able to deal with the language in its entirety. The purpose of the GCC-XML extension is to generate an XML description of a C++ program from GCC's internal representation.

Since XML is easy to parse, other development tools will be able to work with C++ programs without the burden of a complicated C++ parser. [King, 2004]

GCC-XML

C++ has become a popular and powerful language, but parsing it is a very challenging problem. This has discouraged the development of tools meant to work directly with the language.

There is one open-source C++ parser, the C++ front-end to GCC, which is currently able to deal with the language in its entirety. The purpose of the GCC-XML extension is to generate an XML description of a C++ program from GCC's internal representation.

Since XML is easy to parse, other development tools will be able to work with C++ programs without the burden of a complicated C++ parser. [King, 2004]

The ast

Tiger Abstract Syntax

```
/Ast/                   (Location location)
  /Exp/                 ()
*   ArrayExp
*   AssignExp
*   BreakExp
*   CallExp
*     MethodCallExp
    CastExp             (Exp exp, Ty ty)
    ForExp              (VarDec vardec, Exp hi, Exp body)
*   IfExp
    IntExp              (int value)
*   LetExp
    NilExp              ()
*   ObjectExp
    OpExp               (Exp left, Oper oper, Exp right)
*   RecordExp
*   SeqExp
*   StringExp
    WhileExp            (Exp test, Exp body)
```

Tiger Abstract Syntax

```
/Ast/               (Location location)
  /Exp/             ()
*   /Var/
      CastVar       (Var var, Ty ty)
*     FieldVar
      SimpleVar     (symbol name)
      SubscriptVar  (Var var, Exp index)

  /Dec/             (symbol name)
    FunctionDec     (VarDecs formals, NameTy result, Exp body)
      MethodDec     ()
    TypeDec         (Ty ty)
    VarDec          (NameTy type_name, Exp init)

  /Ty/              ()
    ArrayTy         (NameTy base_type)
    ClassTy         (NameTy super, DecsList decs)
    NameTy          (symbol name)
*   RecordTy
```

Tiger Abstract Syntax

`DecsList`	`(decs_type decs)`
`Field`	`(symbol name, NameTy type_name)`
`FieldInit`	`(symbol name, Exp init)`

Tiger Abstract Syntax

Some of these classes also derive from other classes.

```
/Escapable/
  VarDec              (NameTy type_name, Exp init)

/Typable/
  /Dec/               (symbol name)
  /Exp/               ()
  /Ty/                ()

/TypeConstructor/
  /Ty/                ()
  FunctionDec         (VarDecs formals, NameTy result, Exp body)
  TypeDec             (Ty ty)
```

Syntactic Sugar

Tiger Sugar

Light
- `if then`

Regular
- Unary -
- & and |
- Beware of `( exp )` vs. `( exps )`
- Declarations (Types and Functions)

Extra
- `for`
- `?:` as in GNU C (`a ?: b`)
- `where`
- Function overload

Tiger Sugar

Light	• `if then`
Regular	• Unary `-`
	• `&` and `|`
	• Beware of `( exp )` vs. `( exps )`
	• Declarations (Types and Functions)
Extra	• `for`
	• `?:` as in GNU C (`a ?: b`)
	• `where`
	• Function overload

Tiger Sugar

Light
- `if then`

Regular
- Unary `-`
- `&` and `|`
- Beware of `( exp )` vs. `( exps )`
- Declarations (Types and Functions)

Extra
- `for`
- `?:` as in GNU C (`a ?: b`)
- `where`
- Function overload

Desugaring

Desugaring in Abstract Syntax

```
exp: exp "&" exp
{
  $$ = new IfExp(@$, $1,
                 new OpExp(@$,$3, OpExp::ne, new IntExp(@2, 0)),
                 new IntExp(@2, 0));
}
```

Desugaring in Concrete Syntax

```
exp: exp "&" exp
{
  $$ = parse::parse(parse::Tweast() <<
    "if " << $1 << " then " << $3 << "<> 0 else 0");
}
```

Tweast: Text With Embedded Abstract Syntax Trees

Desugaring

Desugaring in Abstract Syntax

```
exp: exp "&" exp
{
  $$ = new IfExp(@$, $1,
                 new OpExp(@$,$3, OpExp::ne, new IntExp(@2, 0)),
                 new IntExp(@2, 0));
}
```

Desugaring in Concrete Syntax

```
exp: exp "&" exp
{
  $$ = parse::parse(parse::Tweast() <<
     "if " << $1 << " then " << $3 << "<> 0 else 0");
}
```

Tweast: Text With Embedded Abstract Syntax Trees

Desugaring

Desugaring in Abstract Syntax

```
exp: exp "&" exp
{
  $$ = new IfExp(@$, $1,
                 new OpExp(@$,$3, OpExp::ne, new IntExp(@2, 0)),
                 new IntExp(@2, 0));
}
```

Desugaring in Concrete Syntax

```
exp: exp "&" exp
{
  $$ = parse::parse(parse::Tweast() <<
     "if " << $1 << " then " << $3 << "<> 0 else 0");
}
```

Tweast: Text With Embedded Abstract Syntax Trees

Visitors

Stubs in ast nodes

Every single AST node needs `accept`.

ast/let-exp.cc

```
void LetExp::accept(ConstVisitor& v) const
{
  v(*this);
}

void LetExp::accept(Visitor& v)
{
  v(*this);
}
```

This can be factored by inheritance [Alexandrescu, 2001].

Inheritance to Factor (Mixin)

parse/metavar-map.hh

```
template <typename Data>
struct MetavarMap
{
  /// Append a metavariable.
  void append_(int k,
               Data* d);
  /// Extract a metavariable.
  Data* take_(int k);
  /// Metavariables.
  map<int, Data*> map_;
};
```

parse/tweast.cc

```
class Tweast
  : public MetavarMap<Exp>
  , public MetavarMap<Var>
  , public MetavarMap<NameTy>
  , public MetavarMap<DecsList>
{
  // ...
};
```

Inheritance to Factor (Mixin)

parse/metavar-map.hh

```
template <typename Data>
struct MetavarMap
{
  /// Append a metavariable.
  void append_(int k,
               Data* d);
  /// Extract a metavariable.
  Data* take_(int k);
  /// Metavariables.
  map<int, Data*> map_;
};
```

parse/tweast.cc

```
class Tweast
  : public MetavarMap<Exp>
  , public MetavarMap<Var>
  , public MetavarMap<NameTy>
  , public MetavarMap<DecsList>
{
  // ...
};
```

Visitors

PrettyPrinter	Pretty-printer
Binder	Bind uses to declarations
Renamer	Unique names
TypeChecker	Annotate nodes with their type
object::Binder	Bind for Object Tiger
object::TypeChecker	Check types for Object Tiger
overload::Binder	Bind for overloaded Tiger
overload::TypeChecker	Check types for overloaded Tiger

Visitors

PrettyPrinter	Pretty-printer
Binder	Bind uses to declarations
Renamer	Unique names
TypeChecker	Annotate nodes with their type
object::Binder	Bind for Object Tiger
object::TypeChecker	Check types for Object Tiger
overload::Binder	Bind for overloaded Tiger
overload::TypeChecker	Check types for overloaded Tiger

Visitors

PrettyPrinter	Pretty-printer
Binder	Bind uses to declarations
Renamer	Unique names
TypeChecker	Annotate nodes with their type
object::Binder	Bind for Object Tiger
object::TypeChecker	Check types for Object Tiger
overload::Binder	Bind for overloaded Tiger
overload::TypeChecker	Check types for overloaded Tiger

Visitors

PrettyPrinter	Pretty-printer
Binder	Bind uses to declarations
Renamer	Unique names
TypeChecker	Annotate nodes with their type
object::Binder	Bind for Object Tiger
object::TypeChecker	Check types for Object Tiger
overload::Binder	Bind for overloaded Tiger
overload::TypeChecker	Check types for overloaded Tiger

Visitors

PrettyPrinter	Pretty-printer
Binder	Bind uses to declarations
Renamer	Unique names
TypeChecker	Annotate nodes with their type
object::Binder	Bind for Object Tiger
object::TypeChecker	Check types for Object Tiger
overload::Binder	Bind for overloaded Tiger
overload::TypeChecker	Check types for overloaded Tiger

Visitors

PrettyPrinter	Pretty-printer
Binder	Bind uses to declarations
Renamer	Unique names
TypeChecker	Annotate nodes with their type
object::Binder	Bind for Object Tiger
object::TypeChecker	Check types for Object Tiger
overload::Binder	Bind for overloaded Tiger
overload::TypeChecker	Check types for overloaded Tiger

Visitors

PrettyPrinter	Pretty-printer
Binder	Bind uses to declarations
Renamer	Unique names
TypeChecker	Annotate nodes with their type
object::Binder	Bind for Object Tiger
object::TypeChecker	Check types for Object Tiger
overload::Binder	Bind for overloaded Tiger
overload::TypeChecker	Check types for overloaded Tiger

Visitors

PrettyPrinter	Pretty-printer
Binder	Bind uses to declarations
Renamer	Unique names
TypeChecker	Annotate nodes with their type
object::Binder	Bind for Object Tiger
object::TypeChecker	Check types for Object Tiger
overload::Binder	Bind for overloaded Tiger
overload::TypeChecker	Check types for overloaded Tiger

Visitors

object::DesugarVisitor	Desugar Object Tiger code into the non-object core
DesugarVisitor	Handling syntactic sugar
BoundCheckingVisitor	Bounds checking
Inliner	Function inlining
Pruner	Remove useless function definitions
EscapesVisitor	Escaping variables
Translator	Conversion to HIR

Visitors

object::DesugarVisitor	Desugar Object Tiger code into the non-object core
DesugarVisitor	Handling syntactic sugar
BoundCheckingVisitor	Bounds checking
Inliner	Function inlining
Pruner	Remove useless function definitions
EscapesVisitor	Escaping variables
Translator	Conversion to HIR

Visitors

object::DesugarVisitor	Desugar Object Tiger code into the non-object core
DesugarVisitor	Handling syntactic sugar
BoundCheckingVisitor	Bounds checking
Inliner	Function inlining
Pruner	Remove useless function definitions
EscapesVisitor	Escaping variables
Translator	Conversion to HIR

Visitors

object::DesugarVisitor	Desugar Object Tiger code into the non-object core
DesugarVisitor	Handling syntactic sugar
BoundCheckingVisitor	Bounds checking
Inliner	Function inlining
Pruner	Remove useless function definitions
EscapesVisitor	Escaping variables
Translator	Conversion to HIR

Visitors

object::DesugarVisitor	Desugar Object Tiger code into the non-object core
DesugarVisitor	Handling syntactic sugar
BoundCheckingVisitor	Bounds checking
Inliner	Function inlining
Pruner	Remove useless function definitions
EscapesVisitor	Escaping variables
Translator	Conversion to HIR

Visitors

object::DesugarVisitor	Desugar Object Tiger code into the non-object core
DesugarVisitor	Handling syntactic sugar
BoundCheckingVisitor	Bounds checking
Inliner	Function inlining
Pruner	Remove useless function definitions
EscapesVisitor	Escaping variables
Translator	Conversion to HIR

Visitors

object::DesugarVisitor	Desugar Object Tiger code into the non-object core
DesugarVisitor	Handling syntactic sugar
BoundCheckingVisitor	Bounds checking
Inliner	Function inlining
Pruner	Remove useless function definitions
EscapesVisitor	Escaping variables
Translator	Conversion to HIR

Bibliography I

Tree Compiler-Compiler.
The DotGNU Project.
http://dotgnu.org/treecc/treecc.html.

Alexandrescu, A. (2001).
Modern C++ Design: Generic Programming and Design Patterns Applied.
Addison-Wesley.

ASN.1 Consortium (2003).
The ASN.1 Consortium.
http://www.asn1.org/.

Centrum voor Wiskunde en Informatica (2004).
The ATerm Library.
http://www.cwi.nl/htbin/sen1/twiki/bin/view/SEN1/ATermLibrary.

Bibliography II

Dubuisson, O. (2003).
The ASN.1 Information Site.
http://asn1.elibel.tm.fr/en/.

DuPont, J. M. (2004).
The Introspector Project.
http://introspector.sourceforge.net/.

King, B. (2004).
Gcc-xml.
http://gccxml.org.

Bibliography III

Visser, E. (1995).
A family of syntax definition formalisms.
In van den Brand, M. G. J. et al., editors, *ASF+SDF'95. A Workshop on Generating Tools from Algebraic Specifications*, pages 89–126.
Technical Report P9504, Programming Research Group, University of Amsterdam.

Visser, J. (2001).
Visitor combination and traversal control.
ACM SIGPLAN Notices, 36(11):270–282.
OOPSLA 2001 Conference Proceedings: Object-Oriented Programming Systems, Languages, and Applications.

Weatherley, R. (2002).
Treecc: An aspect-oriented approach to writing compilers.
`http://dotgnu.org/treecc_essay.html`.

Bibliography IV

Yu, Y. and D'Hollander, E. (2003).
YAXX: YAcc eXtension to XML, a user manual.
http://yaxx.sourceforge.net/.