Using X3

Using Spirit X3 to Write Parsers

ciere consulting

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Part I

Introduction

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Outline

1. Introduction
   - Spirit X3
   - Concepts
2. Elements
   - Parsers
   - Rules
   - Grammars
   - Attributes

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Spirit X3

- Next generation of Spirit
- Modern C++14 language features
- Hackable, simpler internal design.
- Minimal code base and dependencies
- Compiles faster and runs faster
- Better error handling
- Optimized attribute processing

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Spirit X3

Domain Specific Embedded Language

Spirit X3

Domain Specific Embedded Language

Parsing

Spirit X3

Domain Specific **Embedded** Language

C++ via *Expression Templates*

Spirit X3

Domain Specific Embedded **Language**

PEG - Parsing Expression Grammar

Ad-hoc Parsing

```cpp
std::string::const_iterator iter = argument.begin();
std::string::const_iterator iter_end = argument.end();
while( iter != iter_end )
{
   if( *iter == '+' )
   {
      if( building_key ){ key += ' ';     }
      else              { value += ' ';   }
   }
   else if( *iter == '=' )
   {
      building_key = false;
   }
   else if( *iter == '&' )
   {
      argument_map[ key ] = value;
      key = "";
      value = "";
      building_key = true;
   }
   else if( *iter == '?' )
   {}
   else
```

Ad-hoc Parsing and Generating

```
boost::regex expression( "(request_firmware_version)|(calibrat
boost::smatch match;

if( boost::regex_search( product_data, match, expression ) )
{
   if( match[ 1 ].matched )
   {
      message_to_send += char( STX );
      message_to_send += char( 0x11 );
      message_to_send += char( ETX );
   }
   else if( match[ 2 ].matched )
   {
      message_to_send += char( STX );
      message_to_send += char( 0x12 );
      message_to_send += char( ETX );
   }
   else if( match[ 3 ].matched )
   {
      boost::regex expression( "calibrate_sensor (\\d+) (\\d+)
      if( boost::regex_search( product_data, match, expression
      {
         try
```

Concepts

PEG grammar Email (*not really*)

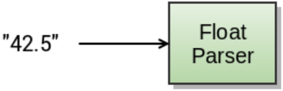
```
name     <-  [a-z]+ ("." [a-z]+)*
host     <-  [a-z]+ "." ("com" / "org" / "net")
email    <-  name "@" host
```

```
auto name  = +char_("a-z") >> *('.' >> +char_("a-z"));
auto host  = +char_("a-z") >> '.' >> (lit("com") | "org" | "net");
auto email = name >> '@' >> host;
```

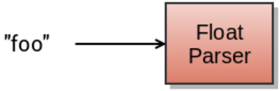
Concepts

- Parsers
- Rules
- Attribute Parsing

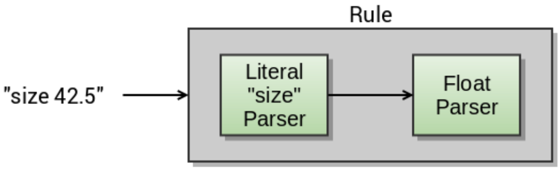
Parsers



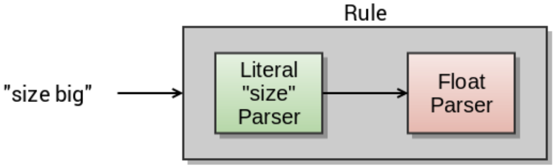
Parsers



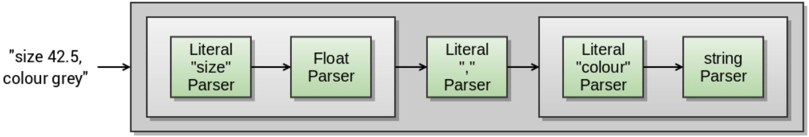
Rules



Rules



Rules



"size 42.5, colour grey"

Literal "size" Parser

Float Parser

Literal "," Parser

Literal "colour" Parser

string Parser

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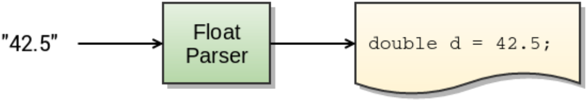
Attributes

Synthesized Attribute



Attributes

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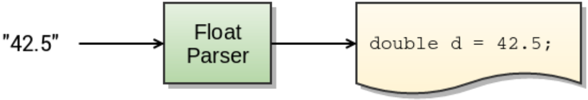
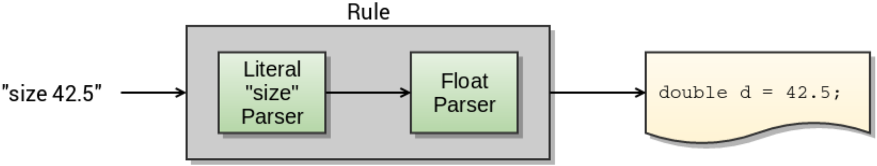


```
double d = 42.5;
```

Attributes



Grammars??

shhhhhh ....

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Parser

Data Stream → X3 → Abstract Syntax Tree (AST)

A First, Simple Example

A parser for integers is simply:

Example (Integer Parser)

```
int_
```

A parser for doubles:

Example (Double Parser)

```
double_
```

A literal string parser:

Example (Parse literal string "foo")

```
lit("foo")
```

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Example (Double Parser)

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```

A literal string parser:

Example (Parse literal string "foo")

```
lit("foo")
```

A First, Simple Example

We can use the parser with the `x3::parse` API.

```
std::string input( "1234" );

auto iter = input.begin();
auto end_iter = input.end();

x3::parse( iter, end_iter,
           int_ );
```

A First, Simple Example

We can use the parser with the `x3::parse` API.

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A First, Simple Example

We can use the parser with the `x3::parse` API.

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std::string input( "1234" );

auto iter = input.begin();
auto end_iter = input.end();

x3::parse( iter, end_iter,
           int_ );
```

A First, Simple Example

Parsing the double in just as simple.

```
std::string input( "1234.56" );

auto iter = input.begin();
auto end_iter = input.end();

x3::parse( iter, end_iter,
           double_ );
```

Some of the Available Parsers

Type	Parser	Example
signed	`short_, int_, long_, long_long, int_(-42)`	578, -1865, 99301
unsigned	`bin, oct, hex, ushort_, ulong_, uint_, ulong_long, uint_(82)`	01101, 24, 7af2, 243
real	`float_, double_, long_double, double_(123.5)`	-1.9023, 9328.11928
boolean	`bool_, true_, false_`	true, false
binary	`byte_, word, dword, qword, word(0xface)`	
big endian	`big_word, big_dword, big_qword, big_dword(0xdeadbeef)`	
litte endian	`litte_word, litte_dword, litte_qword, little_dword(0xefbeadde)`	

Some of the Available Parsers

Type	Parser	Example
signed	`short_`, **`int_`**, `long_`, `long_long`, `int_(-42)`	578, -1865, 99301
unsigned	`bin`, `oct`, `hex`, `ushort_`, `ulong_`, **`uint_`**, `ulong_long`, `uint_(82)`	01101, 24, 7af2, 243
real	`float_`, **`double_`**, `long_double`, `double_(123.5)`	-1.9023, 9328.11928
boolean	**`bool_`**, `true_`, `false_`	true, false
binary	`byte_`, **`word`**, `dword`, `qword`, `word(0xface)`	
big endian	`big_word`, **`big_dword`**, `big_qword`, `big_dword(0xdeadbeef)`	
litte endian	`litte_word`, **`litte_dword`**, `litte_qword`, `little_dword(0xefbeadde)`	

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real	`float_, double_, long_double,` **`double_(123.5)`**	-1.9023, 9328.11928
boolean	`bool_,` **`true_`**`, false_`	true, false
binary	`byte_, word, dword, qword,` **`word(0xface)`**	
big endian	`big_word, big_dword, big_qword,` **`big_dword(0xdeadbeef)`**	
litte endian	`litte_word, litte_dword, litte_qword,` **`little_dword(0xefbeadde)`**	

Some of the Available Parsers

Type	Parser	Example
character	char_, char_(’x’), char_(x), char_(’a’,’z’), char_("a-z8A-Z"), ~char_(’a’)	a b e $ 1 }
	lit(’a’), ’a’	a
string	string("foo"), string(s), lit("bar"), "bar", lit(s)	
classification	alnum, alpha, blank, cntrl, digit, graph, lower, print, punct, space, upper, xdigit	

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string	string("foo"), string(s), lit("bar"), "bar", lit(s)	
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	`char_('a','z')``, char_("a-z8A-Z"),`
	`~char_('a')`
		a b e $ 1 }

	`lit('a'), 'a'`	a

string	`string("foo"), string(s), lit("bar"),`
	`"bar", lit(s)`	

classification	`alnum, alpha, blank, cntrl, digit,`
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Type	Parser	Example

character	`char_, char_(’x’), char_(x),`
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	`~char_(’a’)`
		a b e $ 1 }

	`lit(’a’), ’a’`	a

string	`string("foo"), string(s), lit("bar"),`
	`"bar", lit(s)`	

classification	`alnum, alpha, blank, cntrl, digit,`
	`graph, lower, print, punct, space,`
	`upper, xdigit`	

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Sequence of Parsers

Combining parsers allows us to build more complex parsers.

```
std::string input( "876 1234.56" );

auto iter = input.begin();
auto end_iter = input.end();

x3::parse( iter, end_iter,
           int_ >> ’ ’ >> double_ );
```

Sequence of Parsers

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auto end_iter = input.end();

x3::parse( iter, end_iter,
           int_ >> ' ' >> double_ );
```

Operators

Description	PEG	Spirit X3
Sequence	a b	a >> b
Alternative	a | b	a | b
Zero of more (Kleene)	a*	*a
One or more (Plus)	a+	+a
Optional	a?	-a
And-predicate	&a	&a
Not-predicate	!a	!a
Difference		a - b
Expectation		a > b
List		a % b

Operators

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Sequence	a b	**a >> b**
Alternative	a | b	a | b
Zero of more (Kleene)	a*	*a
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Optional	a?	-a
And-predicate	&a	&a
Not-predicate	!a	!a
Difference		a - b
Expectation		a > b
List		a % b

Read as *a* is followed by *b*

```
int_ >> ' ' >> double_
"42 -89.3"
```

```
char_ >> ':' >> int_
"a:19"
```

Operators

Description	PEG	Spirit X3
Sequence	a b	a >> b
Alternative	a | b	**a | b**
Zero of more (Kleene)	a*	*a
One or more (Plus)	a+	+a
Optional	a?	-a
And-predicate	&a	&a
Not-predicate	!a	!a
Difference		a - b
Expectation		a > b
List		a % b

Either *a* **or** *b* are allowed.
Evaluated in listed order.

```
alpha | digit | punct
"a"
"9"
";"
"+" fails to parse
```

Operators

Description	PEG	Spirit X3
Sequence	a b	a >> b
Alternative	a | b	a | b
Zero of more (Kleene)	a*	***a**
One or more (Plus)	a+	**+a**
Optional	a?	**-a**
And-predicate	&a	&a
Not-predicate	!a	!a
Difference		a - b
Expectation		a > b
List		a % b

```
*alpha >> int_
"z86"
"abcde99"
"99"
```

```
+alpha >> int_
"z86"
"abcde99"
"99" parse fails
```

```
-alpha >> int_
"z86"
"abcde99" parse fails
"99"
```

Operators

Description	PEG	Spirit X3
Sequence	a b	a >> b
Alternative	a | b	a | b
Zero of more (Kleene)	a*	*a
One or more (Plus)	a+	+a
Optional	a?	-a
And-predicate	&a	**&a**
Not-predicate	!a	!a
Difference		a - b
Expectation		a > b
List		a % b

And-predicate can provide basic look-ahead. It matches *a* without consuming *a*.

```
int_ >> &char_(';')
"86;"
"-99" fails to parse
```

Operators

Description	PEG	Spirit X3
Sequence	a b	a >> b
Alternative	a | b	a | b
Zero of more (Kleene)	a*	*a
One or more (Plus)	a+	+a
Optional	a?	-a
And-predicate	&a	&a
Not-predicate	!a	**!a**
Difference		a - b
Expectation		a > b
List		a % b

Not-predicate can provide basic look-ahead. If *a* does match the parse is successful without consuming *a*.

```
"for" >> !(alnum|'_')
"for()"
"forty" fails to parse
```

Operators

Description	PEG	Spirit X3
Sequence	a b	a >> b
Alternative	a | b	a | b
Zero of more (Kleene)	a*	*a
One or more (Plus)	a+	+a
Optional	a?	-a
And-predicate	&a	&a
Not-predicate	!a	!a
Difference		**a - b**
Expectation		a > b
List		a % b

Match *a* but not *b*.

```
   "/*"
>> *(char_ - "*/")
>> "*/"
```

```
"/* comment */"
```

Always fails.

```
lit("obiwatanabe") -
"obiwa"
```

Operators

Description	PEG	Spirit X3
Sequence	a b	a >> b
Alternative	a | b	a | b
Zero of more (Kleene)	a*	*a
One or more (Plus)	a+	+a
Optional	a?	-a
And-predicate	&a	&a
Not-predicate	!a	!a
Difference		a - b
Expectation		**a > b**
List		a % b

a must be followed by *b*. No backtracking allowed. A Sequence returns no-match, an Expectation throws `expectation_failure<iter>`

```
   char_('o')
 > char_('k')
```

```
"ok"
"ox" throws exception
```

Operators

Description	PEG	Spirit X3
Sequence	a b	a >> b
Alternative	a | b	a | b
Zero of more (Kleene)	a*	*a
One or more (Plus)	a+	+a
Optional	a?	-a
And-predicate	&a	&a
Not-predicate	!a	!a
Difference		a - b
Expectation		a > b
List		**a % b**

Shortcut for:

```
 a >> *( b >> a )
```

```
int_ % ','
```

```
"9,2,42,-187,76"
```

Combining Parsers - Parse key/value pairs

```
std::string input{ "foo    : bar , "
                   "gorp   : smart , "
                   "falcou : \"crazy frenchman\" , "
                   "name   : sam " };

auto iter = input.begin();
auto iter_end = input.end();

phrase_parse( iter, iter_end,
              // ------ start parser -------


              ( name >> ':' >> ( quote | name ) ) % ','




              // ------- end parser --------
              , space );
```

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Combining Parsers - Rules

Rules allow us to organize parsers into named units. They provide a few facilities:

- Allows us to name parsers
- Specify the attribute type
- Allows for recursion (the rule may recursively call itself directly or indirectly)
- Provide error handling (on_error)
- Attach custom handlers when a match is found (on_sucess)

Combining Parsers - Rules

Using C++11 auto.

```
auto name  = alpha >> *alnum;

auto quote = '"' >> *( ~char_('"') ) >> '"';
```

Combining Parsers - Rules

Using C++11 auto.

```
auto name  = alpha >> *alnum;

auto quote = '"' >> *( ~char_('"') ) >> '"';
```

Caution

Only use **`auto`** for non-recursive rules.

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Combining Parsers - Rules

Using X3 Rules.

```
auto name = x3::rule<class name>{}
          = alpha >> *alnum;


auto quote = x3::rule<class quote>{}
           = '"' >> *( ~char_('"') ) >> '"';
```

Combining Parsers - Rules

Using X3 Rules.

```
auto name = x3::rule<class name>{}
          = alpha >> *alnum;


auto quote = x3::rule<class quote>{}
           = '"' >> *( ~char_('"') ) >> '"';
```

Combining Parsers - Rules

The ID tag to be used by the rule.

```
auto name = x3::rule<class name>{}
          = alpha >> *alnum;

auto quote = x3::rule<class quote>{}
           = '"' >> *( ~char_('"') ) >> '"';
```

Combining Parsers - Parse key/value pairs refined

```
std::string input{ "foo         : bar , "
                   "gorp        : smart , "
                   "falcou      : \"crazy frenchman\" , "
                   "name        : sam " };

auto iter = input.begin();
auto iter_end = input.end();

auto name  = alpha >> *alnum;
auto quote =    '"'
             >> lexeme[ *(~char_('"')) ]
             >> '"'
           ;


phrase_parse(iter, iter_end,

             ( name >> ':' >> (quote | name) ) % ','

             , space);
```

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No Grammar in X3

Grammars are not required in X3

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Getting Parse Results

How do we get at the parsed results?

```
std::string input{ "foo    : bar , "
                   "gorp   : smart , "
                   "falcou : \"crazy frenchman\" , "
                   "name   : sam " };

std::map<std::string, std::string> key_value_map;

// Do something clever here ??????????
```

Parsers Expose Attributes - Synthesized Attributes

	X3 Parser Type	Attribute Type
Literals	’a’, "abc", int_(42), …	No attribute
Primitives	int_, char_, double_, …	int, char, double, …
	bin, oct, hex	unsigned
	string("abc")	"abc"
Non-terminal	rule<Tag, A>	A
Operators	a >> b	tuple<A, B>
	a | b	boost::variant<A,B>
	⋆a	std::vector<A>
	+a	std::vector<A>
	−a	boost::optional<A>
	&a, !a	No attribute
	a % b	std::vector<A>

Parsers Expose Attributes - Synthesized Attributes

	X3 Parser Type	Attribute Type
Literals	`'a'`, **`"abc"`**, `int_(42)`, …	**No attribute**
Primitives	`int_`, `char_`, `double_`, …	`int`, `char`, `double`, …
	`bin`, `oct`, `hex`	`unsigned`
	`string("abc")`	`"abc"`
Non-terminal	`rule<Tag, A>`	`A`
Operators	`a >> b`	`tuple<A, B>`
	`a | b`	`boost::variant<A,B>`
	`*a`	`std::vector<A>`
	`+a`	`std::vector<A>`
	`-a`	`boost::optional<A>`
	`&a, !a`	No attribute
	`a % b`	`std::vector<A>`

Parsers Expose Attributes - Synthesized Attributes

	X3 Parser Type	Attribute Type
Literals	`'a', "abc", int_(42),` ...	No attribute
Primitives	`int_, char_,` **`double_`**, ...	`int, char,` **`double`**, ...
	`bin, oct, hex`	`unsigned`
	`string("abc")`	`"abc"`
Non-terminal	`rule<Tag, A>`	`A`
Operators	`a >> b`	`tuple<A, B>`
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	bin, oct, hex	unsigned
	string("abc")	"abc"
Non-terminal	rule<Tag, A>	A
Operators	**a >> b**	**tuple<A, B>**
	a | b	boost::variant<A,B>
	⋆a	std::vector<A>
	+a	std::vector<A>
	−a	boost::optional<A>
	&a, !a	No attribute
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	`a % b`	**`std::vector<A>`**

A First Attribute Example

We can simply provide a reference to the parse API and get the ***Synthesized Attribute***.

```
std::string input "1234" ;
auto iter = input.begin();
auto end_iter = input.end();

int result;
parse( iter, end_iter,
       int_,
       result );
```

A First Attribute Example

We can simply provide a reference to the parse API and get the ***Synthesized Attribute***.

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int result;
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       int_,
       result );
```

Parse a string into a std::string

Attribute parsing can produce *compatible attributes*

```
std::string input{ "pizza" };
auto iter = input.begin();
auto end_iter = input.end();

std::string result;
parse( iter, end_iter,
       *char_,
       result );
```

`std::string` is compatible with `std::vector<char>` attribute of the `*char_` parser.

Parse a string into a std::string

Attribute parsing can produce *compatible attributes*

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std::string result;
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std::string result;
parse( iter, end_iter,
       *char_,
       result );
```

`std::string` is compatible with `std::vector<char>` attribute of the `*char_` parser.

Attribute Parsing - Sequence Parse API

```
std::string input{ "cosmic pizza" };
auto iter = input.begin();
auto end_iter = input.end();

std::string result1;
std::string result2;

parse( iter, end_iter,
       *(~char_(’ ’)) >> ’ ’ >> *char_,
       result1,
       result2 );
```

Attribute Parsing - Sequence Parse API

```
std::string input{ "cosmic pizza" };
auto iter = input.begin();
auto end_iter = input.end();

std::string result1;
std::string result2;

parse( iter, end_iter,
       *(~char_(' ')) >> ' ' >> *char_,
       result1,
       result2 );
```

Attribute Parsing - Sequence Parse API

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std::string input{ "cosmic pizza" };
auto iter = input.begin();
auto end_iter = input.end();

std::string result1;
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parse( iter, end_iter,
       *(~char_(' ')) >> ' ' >> *char_,
       result1,
       result2 );
```

Attribute Parsing - Sequence Parse API

Compatible attributes to the rescue!

```
std::string input( "cosmic pizza" );
auto iter = input.begin();
auto end_iter = input.end();

std::pair<std::string, std::string> result;

parse( iter, end_iter,
       *(~char_(’ ’)) >> ’ ’ >> *char_,
       result );
```

Attribute Parsing - Sequence Parse API

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Attribute Parsing - Sequence Parse API

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```
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auto end_iter = input.end();

std::pair<std::string, std::string> result;

parse( iter, end_iter,
       *(~char_(' ')) >> ' ' >> *char_,
       result );
```

Attribute Parsing - Compatibility

Attribute parsing is where the Spirit *Magic* lives.

```
std::string input( "foo    : bar ,"
                   "gorp   : smart ,"
                   "falcou : \"crazy frenchman\" " );

auto iter = input.begin();
auto iter_end = input.end();

auto name = rule<class name, std::string>()
    = alpha >> *alnum;
auto quote = rule<class quote, std::string>()
    = ’"’
    >> lexeme[ *(~char_(’"’)) ]
    >> ’"’;

auto item = rule<class item, std::pair<std::string, std::string>>()
    name >> ’:’ >> ( quote | name );

std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ’,’,
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

The rule’s (synthesized) attribute must be compatible with its (RHS) definition.

```
std::string input( "foo    : bar ,"
                   "gorp   : smart ,"
                   "falcou : \"crazy frenchman\" " );

auto iter = input.begin();
auto iter_end = input.end();

auto name = rule<class name, std::string>()
    = alpha >> *alnum;
auto quote = rule<class quote, std::string>()
    = ’"’
    >> lexeme[ *(~char_(’"’)) ]
    >> ’"’;

auto item = rule<class item, std::pair<std::string, std::string>>()
    name >> ’:’ >> ( quote | name );

std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ’,’,
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

a: char, b: std::vector<char> → (a >> b): std::vector<char>

```
std::string input( "foo      : bar ,"
                   "gorp     : smart ,"
                   "falcou : \"crazy frenchman\" " );

auto iter = input.begin();
auto iter_end = input.end();

auto name = rule<class name, std::string>()
    = alpha >> *alnum;
auto quote = rule<class quote, std::string>()
    = '"'
    >> lexeme[ *(~char_('"')) ]
    >> '"';

auto item = rule<class item, std::pair<std::string, std::string>>()
    name >> ':' >> ( quote | name );

std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ',',
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

a: char, **b: std::vector<char>** → (a >> b): std::vector<char>

```
std::string input( "foo    : bar ,"
                   "gorp   : smart ,"
                   "falcou : \"crazy frenchman\" " );

auto iter = input.begin();
auto iter_end = input.end();

auto name = rule<class name, std::string>()
    = alpha >> *alnum;
auto quote = rule<class quote, std::string>()
    = ’"’
    >> lexeme[ *(~char_(’"’)) ]
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auto item = rule<class item, std::pair<std::string, std::string>>()
    name >> ’:’ >> ( quote | name );

std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ’,’,
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

a: char, b: std::vector<char> → (a >> b): **std::vector<char>**

```
std::string input( "foo    : bar ,"
                   "gorp   : smart ,"
                   "falcou : \"crazy frenchman\" " );

auto iter = input.begin();
auto iter_end = input.end();

auto name = rule<class name, std::string>()
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    >> lexeme[ *(~char_(’"’)) ]
    >> ’"’;

auto item = rule<class item, std::pair<std::string, std::string>>()
    name >> ’:’ >> ( quote | name );

std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ’,’,
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

a: unused, b: vector<char>, **c: unused** → (a >> b >> c): std::vector<char>

```
std::string input( "foo    : bar ,"
                   "gorp   : smart ,"
                   "falcou : \"crazy frenchman\" " );

auto iter = input.begin();
auto iter_end = input.end();

auto name = rule<class name, std::string>()
    = alpha >> *alnum;
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    = '"'
    >> lexeme[ *(~char_('"')) ]
    >> '"';

auto item = rule<class item, std::pair<std::string, std::string>>()
    name >> ':' >> ( quote | name );

std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ',',
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

a: unused, **b: vector<char>**, c: unused → (a >> b >> c): std::vector<char>

```
std::string input( "foo     : bar ,"
                   "gorp    : smart ,"
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auto iter = input.begin();
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phrase_parse( iter, iter_end,
              item % ',',
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

a: unused, b: vector<char>, c: unused → (a >> b >> c): **std::vector<char>**

```
std::string input( "foo    : bar ,"
                   "gorp   : smart ,"
                   "falcou : \"crazy frenchman\" " );

auto iter = input.begin();
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auto item = rule<class item, std::pair<std::string, std::string>>()
    name >> ':' >> ( quote | name );

std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ',',
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

a: string, b: string → (a | b): variant<string, string> → string

```
std::string input( "foo     : bar ,"
                   "gorp    : smart ,"
                   "falcou : \"crazy frenchman\" " );

auto iter = input.begin();
auto iter_end = input.end();

auto name = rule<class name, std::string>()
    = alpha >> ⋆alnum;
auto quote = rule<class quote, std::string>()
    = ’"’
    >> lexeme[ ⋆(~char_(’"’)) ]
    >> ’"’;

auto item = rule<class item, std::pair<std::string, std::string>>()
    name >> ’:’ >> ( quote | name );

std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ’,’,
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

a: string, **b: string** → (a | b): variant<string, string> → string

```
std::string input( "foo    : bar ,"
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std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ',',
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

a: string, b: string → (a | b): variant<string, string> → **string**

```
std::string input( "foo     : bar ,"
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auto iter = input.begin();
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std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ’,’,
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

a: string, b: unused, **c: string** → (a >> b >> c): tuple<string, string>

```
std::string input( "foo    : bar ,"
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auto iter = input.begin();
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auto name = rule<class name, std::string>()
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phrase_parse( iter, iter_end,
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```

Attribute Parsing - Compatibility

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    name >> ':' >> ( quote | name );

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phrase_parse( iter, iter_end,
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```

Attribute Parsing - Compatibility

a: string, b: unused, c: string → (a >> b >> c): **tuple<string, string>**

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std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ',',
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

a: std::pair<string, string> → (a % b): vector< std::pair<string, string> >

```
std::string input( "foo    : bar ,"
                   "gorp   : smart ,"
                   "falcou : \"crazy frenchman\" " );

auto iter = input.begin();
auto iter_end = input.end();

auto name = rule<class name, std::string>()
    = alpha >> *alnum;
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    = '"'
    >> lexeme[ *(~char_('"')) ]
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auto item = rule<class item, std::pair<std::string, std::string>>()
    name >> ':' >> ( quote | name );

std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ',',
              space,
              key_value_map );
```

Attribute Parsing - Compatibility

a: std::pair<string, string> → (a % b): **vector< std::pair<string, string> >**

```
std::string input( "foo    : bar ,"
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                   "falcou : \"crazy frenchman\" " );

auto iter = input.begin();
auto iter_end = input.end();

auto name = rule<class name, std::string>()
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std::map< std::string, std::string > key_value_map;

phrase_parse( iter, iter_end,
              item % ’,’,
              space,
              key_value_map );
```

Rule Declarations

The rule's attribute type (optional).

```
auto name = x3::rule<class name, name_attr>{}
          = alpha >> *alnum;

auto quote = x3::rule<class quote, quote_attr>{}
           = '"' >> *( ~char_('"') ) >> '"';
```

Rule Declarations

The rule’s attribute type (optional).

```
auto name = x3::rule<class name, name_attr>{}
          = alpha >> ⋆alnum;

auto quote = x3::rule<class quote, quote_attr>{}
           = ’"’ >> ⋆( ~char_(’"’) ) >> ’"’;
```

Part II

Example

Outline

3 Grammars from Scratch
- Grammars from Scratch

4 JSON Parser
- What is JSON
- AST
- Grammars

5 Fun with X3
- X3 Fun
- ASTs
- Grammars
- Error Handling

6 Attributes
- AST Traversal

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Build on Success

- Start small
  - Alternatives are a natural place to build
  - Leaves up
- Compose and test
- Test early and often
- Parsing first, Attributes second
- Allow the natural AST to fall out
- Refine grammar/AST

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JSON Example

```
{
  "firstName": "John",
  "lastName": "Smith",
  "isAlive": true,
  "age": 25,
  "address": {
    "streetAddress": "21 2nd Street",
    "city": "New York",
    "state": "NY",
    "postalCode": "10021-3100"
  },
  "phoneNumbers": [
    {
      "type": "home",
      "number": "212 555-1234"
    },
    {
      "type": "office",
      "number": "646 555-4567"
    }
  ],
  "children": [],
  "spouse": null
}
```

Outline

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AST

```
using  string_t         =  std::string;
using  double_t         =  double;
using  float_t          =  double;
using  int_t            =  int64_t;
using  bool_t           =  bool;
struct null_t              {};

class  value;

using  object_t         =  std::map<std::string, value>;
using  object_member_t  =  object_t::value_type;
using  array_t          =  container::stable_vector<value>;
```

AST

```
class value
   : public x3::variant<
                null_t
              , bool_t
              , string_t
              , int_t
              , double_t
              , object_t
              , array_t      >
{

public:
   using value_type = value;

   using base_type::base_type;
   using base_type::operator=;

   value(null_t val = null_t{})     : base_type(val) {}
   value(char const * val)          : base_type((string_t(val))) {}

};
```

AST

```
class value
   : public x3::variant<
                null_t
              , bool_t
              , string_t
              , int_t
              , double_t
              , object_t
              , array_t      >
{

public:
   using value_type = value;

   using base_type::base_type;
   using base_type::operator=;

   value(null_t val = null_t{})     : base_type(val) {}
   value(char const * val)          : base_type((string_t(val))) {}

};
```

AST

```
class value
   : public x3::variant<
                null_t
              , bool_t
              , string_t
              , int_t
              , double_t
              , object_t
              , array_t      >
{



   template< typename T >
   value( T val
        , typename std::enable_if<
                std::is_floating_point<T>::value
          >::type* = 0)
      : base_type( double_t{val} ) {}



};
```

AST

```
class value
   : public x3::variant<
                null_t
              , bool_t
              , string_t
              , int_t
              , double_t
              , object_t
              , array_t      >
{


   template< typename T >
   value( T val
        , typename std::enable_if<
                std::is_floating_point<T>::value
          >::type* = 0)
      : base_type( double_t{val} ) {}


};
```

AST

```
class value
   : public x3::variant<
                null_t
              , bool_t
              , string_t
              , int_t
              , double_t
              , object_t
              , array_t       >
{


   template< typename T >
   value( T val
        , typename std::enable_if<
             std::integral_constant<
                 bool
               ,   std::is_integral<T>::value
                 | std::is_enum<T>::value
              >
          >::type* = 0)
      : base_type( int_t{val} ) {}


};
```

AST

```
class value
   : public x3::variant<
                null_t
              , bool_t
              , string_t
              , int_t
              , double_t
              , object_t
              , array_t      >
{


   template< typename T >
   value( T val
        , typename std::enable_if<
             std::integral_constant<
                 bool
               ,   std::is_integral<T>::value
                 | std::is_enum<T>::value
              >
          >::type* = 0)
      : base_type( int_t{val} ) {}


};
```

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- Grammars from Scratch

4 JSON Parser
- What is JSON
- AST
- Grammars

5 Fun with X3
- X3 Fun
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- Grammars
- Error Handling

6 Attributes
- AST Traversal

Grammar Declaration

Using BOOST_SPIRIT_DECLARE

```
namespace ciere { namespace json { namespace parser
{
   namespace x3 = boost::spirit::x3;

   struct json_class;
   using  json_type = x3::rule<json_class, json::value>;

   BOOST_SPIRIT_DECLARE(json_type);

}}}
```

Grammar Declaration

Using BOOST_SPIRIT_DECLARE

```
namespace ciere { namespace json { namespace parser
{
   namespace x3 = boost::spirit::x3;

   struct json_class;
   using  json_type = x3::rule<json_class, json::value>;

   BOOST_SPIRIT_DECLARE(json_type);

}}}
```

Rule Naming Convention

Example (The Rule ID)

```
identifier_class
```

Example (The Rule Type)

```
identifier_type
```

Example (The Rule Definition)

```
identifier_def
```

Example (The Rule)

```
identifier
```

Rule Naming Convention

Example (The Rule ID)

```
identifier_class
```

Example (The Rule Type)

```
identifier_type
```

Example (The Rule Definition)

```
identifier_def
```

Example (The Rule)

```
identifier
```

Rule Naming Convention

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```

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```

Example (The Rule)

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identifier
```

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```

Example (The Rule)

```
identifier
```

Rule Naming Convention

Example (The Rule ID)

```
identifier_class
```

Example (The Rule Type)

```
identifier_type
```

Example (The Rule Definition)

```
identifier_def
```

Example (The Rule)

```
identifier
```

Grammar Definition

```
namespace ciere { namespace json { namespace parser
{



   struct value_class;
   struct object_class;
   struct member_pair_class;
   struct array_class;



}}}
```

Grammar Definition

```
namespace ciere { namespace json { namespace parser
{


using value_type = x3::rule<value_class, json::value>;

using object_type = x3::rule<object_class, json::object_t>;

using member_pair_type = x3::rule< member_pair_class
                                 , json::object_member_t>;

using array_type = x3::rule<array_class, json::array_t>;


value_type const value = "value";
object_type const object = "object";
member_pair_type const member_pair = "member_pair";
array_type const array = "array";


}}}
```

Rule Definitions

```
namespace ciere { namespace json { namespace parser
{




auto const value_def =
       null_value
     | bool_value
     | detail::unicode_string
     | lexeme[!('+' | (-lit('-') >> '0' >> digit)) >> int_ >> !char_(".eE")]
     | lexeme[!('+' | (-lit('-') >> '0' >> digit)) >> double_]
     | object
     | array
     ;




}}}
```

Rule Definitions

```
namespace ciere { namespace json { namespace parser
{




   auto const null_value =
         lit("null")
      >> attr(json::null_t{})
      ;





}}}
```

Rule Definitions

```
namespace ciere { namespace json { namespace parser
{



   x3::int_parser<int64_t> const int_ = {};
   ascii::bool_type const bool_value = {};




}}}
```

Rule Definitions

```
namespace ciere { namespace json { namespace parser
{



   auto const object_def =
         lit(’{’)
      >> -(member_pair % ’,’)
      >> lit(’}’)
      ;


   auto const member_pair_def =
         detail::unicode_string
      >> ’:’
      >> value
      ;



}}}
```

Rule Definitions

```
namespace ciere { namespace json { namespace parser
{



   auto const object_def =
         lit('{')
      >> -(member_pair % ',')
      >> lit('}')
      ;


   auto const member_pair_def =
         detail::unicode_string
      >> ':'
      >> value
      ;



}}}
```

Rule Definitions

```
namespace ciere { namespace json { namespace parser
{



   auto const array_def =
         lit('[')
      >> -(value % ',')
      >> lit(']')
      ;



}}}
```

Define

```
namespace ciere { namespace json { namespace parser
{



   BOOST_SPIRIT_DEFINE(
       value
     , object
     , member_pair
     , array
   );



}}}
```

Unicode

```
struct unicode_string_class;
using unicide_string_type =
   x3::rule<unicode_string_class, std::string>;
unicode_string_type const unicode_string = "unicode_string";

auto const unicode_string_def = double_quoted;

BOOST_SPIRIT_DEFINE(unicode_string);
```

Unicode

```
auto const char_esc =
   '\\' > escape
   ;

auto const append = [](auto& ctx) { _val(ctx) += _attr(ctx); }

auto const double_quoted =
     lexeme[ '"'
   > *(  char_esc
       | (char_("\x20\x21\x23-\x5b\x5d-\x7e")  )    [append]
      )
   > '"' ]
   ;
```

Unicode

```
auto const char_esc =
   '\\' > escape
   ;
```

```
auto const append = [](auto& ctx) { _val(ctx) += _attr(ctx); }
```

```
auto const double_quoted =
     lexeme[ '"'
   > *(  char_esc
       | (char_("\x20\x21\x23-\x5b\x5d-\x7e")  )    [append]
      )
   > '"' ]
   ;
```

Unicode

```
auto const char_esc =
   '\\' > escape
   ;

auto const append = [](auto& ctx) { _val(ctx) += _attr(ctx); }

auto const double_quoted =
     lexeme[ '"'
   > *(  char_esc
       | (char_("\x20\x21\x23-\x5b\x5d-\x7e")  )    [append]
      )
   > '"' ]
   ;
```

Unicode

```
uint_parser<uchar, 16, 4, 4> const hex4 = {};

auto const escape =
       (’u’ > hex4)           [push_utf8]
   |   char_("\"\\/bfnrt")   [push_esc]
   ;
```

Unicode

```
auto push_esc = [](auto& ctx)
{
   auto& utf8 = _val(ctx);
   switch (_attr(ctx))
   {
      case '"': utf8 += '"';          break;
      case '\\': utf8 += '\\';        break;
      case '/': utf8 += '/';          break;
      case 'b': utf8 += '\b';         break;
      case 'f': utf8 += '\f';         break;
      case 'n': utf8 += '\n';         break;
      case 'r': utf8 += '\r';         break;
      case 't': utf8 += '\t';         break;
   }
};
```

Unicode

```
auto push_utf8 = [](auto& ctx)
{
   typedef std::back_insert_iterator<std::string> insert_iter;
   insert_iter out_iter(_val(ctx));
   boost::utf8_output_iterator<insert_iter> utf8_iter(out_iter);
   *utf8_iter++ = _attr(ctx);
};
```

Invoke the Parse

```
auto const grammar = ciere::json::parser::value;
try
{
   parse_success = spirit::x3::phrase_parse( iter, iter_end
                                           , grammar
                                           , x3::ascii::space_type{}
                                           , v );
}
catch(spirit::x3::expectation_failure<Iterator> const &){}
```

Thank you

Boost.Spirit X3

Find it in current Boost releases

You can find us on freenode : **`##spirit`**

The CiereLabs JSON library is in github:

`https://github.com/cierelabs/json_spirit`

See C++Now 2015 X3 Workshop Slides/Video for more X3 tutorials.

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   - Grammars from Scratch
4. JSON Parser
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   - AST
   - Grammars
5. Fun with X3
   - X3 Fun
   - ASTs
   - Grammars
   - Error Handling
6. Attributes
   - AST Traversal

x3_fun

A calculator example supporting functions.

x3_fun

Input:

```
(123 + 456) * 789
```

Output:

```
456831
```

x3_fun

Input:

```
sin(45 * (pi / 180))
```

Output:

```
0.707
```

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AST

```
struct nil {};
struct signed_;
struct expression;
struct function_call;

struct operand :
    x3::variant<
        nil
      , double
      , x3::forward_ast<signed_>
      , x3::forward_ast<expression>
      , x3::forward_ast<function_call>
    >
{
    using base_type::base_type;
    using base_type::operator=;
};
```

AST

```
struct signed_
{
    char sign;
    operand operand_;
};

struct operation : x3::position_tagged
{
    char operator_;
    operand operand_;
};

struct expression : x3::position_tagged
{
    operand first;
    std::list<operation> rest;
};

struct function_call : x3::position_tagged
{
    std::string name;
    std::list<expression> arguments;
};
```

Fusion Adaptation (ast_adapted.hpp)

```
BOOST_FUSION_ADAPT_STRUCT(
    fun::ast::signed_,
    (char, sign)
    (fun::ast::operand, operand_)
)

BOOST_FUSION_ADAPT_STRUCT(
    fun::ast::operation,
    (char, operator_)
    (fun::ast::operand, operand_)
)

BOOST_FUSION_ADAPT_STRUCT(
    fun::ast::expression,
    (fun::ast::operand, first)
    (std::list<fun::ast::operation>, rest)
)

BOOST_FUSION_ADAPT_STRUCT(
    fun::ast::function_call,
    (std::string, name)
    (std::list<fun::ast::expression>, arguments)
)
```

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Simple Grammars

Using BOOST_SPIRIT_DEFINE

```
using x3::raw;
using x3::lexeme;
using x3::alpha;
using x3::alnum;

struct identifier_class;
typedef
    x3::rule<identifier_class, std::string>
identifier_type;
identifier_type const identifier = "identifier";

auto const identifier_def
    = raw[lexeme[(alpha | ’_’) >> *(alnum | ’_’)]];

BOOST_SPIRIT_DEFINE(identifier);
```

Simple Grammars

Using BOOST_SPIRIT_DEFINE

```
struct identifier_class;

typedef
    x3::rule<identifier_class, std::string>
identifier_type;
identifier_type const identifier = "identifier";

auto const identifier_def
    = raw[lexeme[(alpha | ’_’) >> ⋆(alnum | ’_’)]];

BOOST_SPIRIT_DEFINE(identifier);
```

Simple Grammars

Using BOOST_SPIRIT_DEFINE

```
struct identifier_class;

typedef
    x3::rule<identifier_class, std::string>
identifier_type;
identifier_type const identifier = "identifier";

auto const identifier_def
    = raw[lexeme[(alpha | ’_’) >> *(alnum | ’_’)]];

BOOST_SPIRIT_DEFINE(identifier);
```

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Simple Grammars

Using BOOST_SPIRIT_DEFINE

```
struct identifier_class;

typedef
    x3::rule<identifier_class, std::string>
identifier_type;
identifier_type const identifier = "identifier";

auto const identifier_def
    = raw[lexeme[(alpha | ’_’) >> *(alnum | ’_’)]];

BOOST_SPIRIT_DEFINE(identifier);
```

Simple Grammars

Using BOOST_SPIRIT_DEFINE

```
struct identifier_class;

typedef
    x3::rule<identifier_class, std::string>
identifier_type;
identifier_type const identifier = "identifier";

auto const identifier_def
    = raw[lexeme[(alpha | ’_’) >> *(alnum | ’_’)]];

BOOST_SPIRIT_DEFINE(identifier);
```

Rule Naming Convention

Example (The Rule ID)

```
identifier_class
```

Example (The Rule Type)

```
identifier_type
```

Example (The Rule Definition)

```
identifier_def
```

Example (The Rule)

```
identifier
```

Rule Naming Convention

Example (The Rule ID)

```
identifier_class
```

Example (The Rule Type)

```
identifier_type
```

Example (The Rule Definition)

```
identifier_def
```

Example (The Rule)

```
identifier
```

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Rule Naming Convention

Example (The Rule ID)

```
identifier_class
```

Example (The Rule Type)

```
identifier_type
```

Example (The Rule Definition)

```
identifier_def
```

Example (The Rule)

```
identifier
```

Rule Naming Convention

Example (The Rule ID)

```
identifier_class
```

Example (The Rule Type)

```
identifier_type
```

Example (The Rule Definition)

```
identifier_def
```

Example (The Rule)

```
identifier
```

Rule Naming Convention

Example (The Rule ID)

```
identifier_class
```

Example (The Rule Type)

```
identifier_type
```

Example (The Rule Definition)

```
identifier_def
```

Example (The Rule)

```
identifier
```

Declaring a Grammar

Using BOOST_SPIRIT_DECLARE

```
namespace parser
{
    struct expression_class;
    typedef
        x3::rule<expression_class, ast::expression>
    expression_type;
    BOOST_SPIRIT_DECLARE(expression_type);
}

parser::expression_type const& expression();
```

Defining a Grammar

```
struct additive_expr_class;
struct multiplicative_expr_class;
struct unary_expr_class;
struct primary_expr_class;
struct argument_list_class;
struct function_call_class;
```

Defining a Grammar

```
typedef x3::rule<additive_expr_class, ast::expression>
additive_expr_type;

typedef
    x3::rule<multiplicative_expr_class, ast::expression>
multiplicative_expr_type;

typedef
    x3::rule<unary_expr_class, ast::operand>
unary_expr_type;

typedef
    x3::rule<primary_expr_class, ast::operand>
primary_expr_type;

typedef
    x3::rule<argument_list_class, std::list<ast::expression>>
argument_list_type;

typedef
    x3::rule<function_call_class, ast::function_call>
function_call_type;
```

Defining a Grammar

```
expression_type const
    expression = "expression";

additive_expr_type const
    additive_expr = "additive_expr";

multiplicative_expr_type const
    multiplicative_expr = "multiplicative_expr";

unary_expr_type const
    unary_expr = "unary_expr";

primary_expr_type const
    primary_expr = "primary_expr";

argument_list_type const
    argument_list = "argument_list";

function_call_type const
    function_call = "function_call";
```

Defining a Grammar

```
auto const additive_expr_def =
    multiplicative_expr
    >> *(   (char_('+') > multiplicative_expr)
        |   (char_('-') > multiplicative_expr)
        )
    ;

auto const multiplicative_expr_def =
    unary_expr
    >> *(   (char_('*') > unary_expr)
        |   (char_('/') > unary_expr)
        )
    ;

auto const unary_expr_def =
        primary_expr
    |   (char_('-') > primary_expr)
    |   (char_('+') > primary_expr)
    ;
```

Defining a Grammar

```
auto argument_list_def = expression % ',';

auto function_call_def =
        identifier
    >> -('(' > argument_list > ')')
    ;

auto const primary_expr_def =
        double_
    |   function_call
    |   '(' > expression > ')'
    ;

auto const expression_def = additive_expr;
```

Defining a Grammar

```
BOOST_SPIRIT_DEFINE(
    expression
  , additive_expr
  , multiplicative_expr
  , unary_expr
  , primary_expr
  , argument_list
  , function_call
);
```

Defining a Grammar

Decorators: Annotations and Error Handlers

```
struct unary_expr_class : annotation_base {};
struct primary_expr_class : annotation_base {};
struct function_call_class : annotation_base {};

struct expression_class :
    annotation_base, error_handler_base {};
```

Defining a Grammar

```
namespace fun
{
    parser::expression_type const& expression()
    {
        return parser::expression;
    }
}
```

Instantiating a Grammar

```
// Our Iterator Type
typedef std::string::const_iterator iterator_type;

// The Phrase Parse Context
typedef
    x3::phrase_parse_context<x3::ascii::space_type>::type
phrase_context_type;

// Our Error Handler
typedef error_handler<iterator_type> error_handler_type;

// Combined Error Handler and Phrase Parse Context
typedef x3::with_context<
    error_handler_tag
  , std::reference_wrapper<error_handler_type> const
  , phrase_context_type>::type
context_type;
```

Instantiating a Grammar

```
namespace fun { namespace parser
{
    BOOST_SPIRIT_INSTANTIATE(
        expression_type, iterator_type, context_type);
}}
```

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Error Handling

Expectation Operator

```
auto const additive_expr_def =
    multiplicative_expr
    >> *(    (char_('+') > multiplicative_expr)
        |    (char_('-') > multiplicative_expr)
        )
    ;
```

Error Handling

Expectation Operator

```
auto const additive_expr_def =
    multiplicative_expr
    >> *(    (char_('+') > multiplicative_expr)
        |    (char_('-') > multiplicative_expr)
        )
    ;
```

Error Handling

Expect Directive

```
auto const additive_expr_def =
    multiplicative_expr
    >> *(   (char_('+') >> expect[multiplicative_expr])
        |   (char_('-') >> expect[multiplicative_expr])
        )
    ;
```

Error Handling

Expectation Failure

```
template <typename Iterator>
struct expectation_failure : std::runtime_error
{
public:

    expectation_failure(Iterator where, std::string const& which);
    ~expectation_failure() throw();

    std::string which() const;
    Iterator const& where() const;

    /*...*/
};
```

Defining a Grammar

Decorators: Annotations and Error Handlers

```
struct unary_expr_class : annotation_base {};
struct primary_expr_class : annotation_base {};
struct function_call_class : annotation_base {};

struct expression_class :
    annotation_base, error_handler_base {};
```

Error Handling

Error Handler

```
// X3 Error Handler Utility
template <typename Iterator>
using error_handler = x3::error_handler<Iterator>;

// tag used to get our error handler from the context
struct error_handler_tag;

struct error_handler_base
{
    error_handler_base();

    template <typename Iterator, typename Exception, typename Context>
    x3::error_handler_result on_error(
        Iterator& first, Iterator const& last
      , Exception const& x, Context const& context);

    std::map<std::string, std::string> id_map;
};
```

Error Handling

error_handler_base::on_error

```
template <typename Iterator, typename Exception, typename Context>
inline x3::error_handler_result
error_handler_base::on_error(
    Iterator& first, Iterator const& last
  , Exception const& x, Context const& context)
{
    std::string which = x.which();
    auto iter = id_map.find(which);
    if (iter != id_map.end())
        which = iter->second;

    std::string message = "Error! Expecting: " + which + " here:";
    auto& error_handler = x3::get<error_handler_tag>(context).get();
    error_handler(x.where(), message);
    return x3::error_handler_result::fail;
}
```

Error Handling

error_handler_base constructor

```
inline error_handler_base::error_handler_base()
{
    id_map["expression"] = "Expression";
    id_map["additive_expr"] = "Expression";
    id_map["multiplicative_expr"] = "Expression";
    id_map["unary_expr"] = "Expression";
    id_map["primary_expr"] = "Expression";
    id_map["argument_list"] = "Argument List";
}
```

Annotations

Annotating the AST with the iterator position

```
struct annotation_base
{
    template <typename Iterator, typename Context>
    void on_success(Iterator const& first, Iterator const& last
      , ast::operand& ast, Context const& context);

    template <typename T, typename Iterator, typename Context>
    inline void on_success(Iterator const& first, Iterator const& last
      , T& ast, Context const& context);
};
```

Annotations

annotation_base::on_success

```cpp
template <typename T, typename Iterator, typename Context>
inline void
annotation_base::on_success(Iterator const& first, Iterator const& last
  , T& ast, Context const& context)
{
    auto& error_handler = x3::get<error_handler_tag>(context).get();
    error_handler.tag(ast, first, last);
}
```

Annotations

annotation_base::on_success

```
template <typename Iterator, typename Context>
inline void
annotation_base::on_success(Iterator const& first, Iterator co
  , ast::operand& ast, Context const& context)
{
    auto& error_handler
        = x3::get<error_handler_tag>(context).get();

    auto annotate = [&](auto& node)
    {
        error_handler.tag(node, first, last);
    };

    ast.apply_visitor(
        x3::make_lambda_visitor<void>(annotate));
}
```

Error Handling

Bad Syntax

```
foo(123, $%)
```

Error Message

```
In file bad_arguments.fun, line 1:
Error! Expecting: ')' here:
foo(123, $%)
_______^_
```

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Attribute Parsing vs Semantic Actions

Avoid semantic actions! Generate ASTs instead.

- Imperative semantic actions are ugly warts in an elegant declarative grammar.
- Semantic actions look even uglier and verbose in X3 with native C++ lambda.
- Use semantic actions only to facilitate the generation of an attribute.
- If you really can't avoid semantic actions, at least make them side-effect free. Back tracking can cause havoc when actions are called multiple times.

Attribute Parsing vs Semantic Actions

Avoid semantic actions! Generate ASTs instead.

- Imperative semantic actions are ugly warts in an elegant declarative grammar.
- Semantic actions look even uglier and verbose in X3 with native C++ lambda.
- Use semantic actions only to facilitate the generation of an attribute.
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Printing the AST

```
struct printer
{
    typedef void result_type;

    printer(std::ostream& out)
        : out(out)
    {}

    void operator()(ast::nil) const { BOOST_ASSERT(0); }
    void operator()(double ast) const;
    void operator()(ast::operation const& ast) const;
    void operator()(ast::signed_ const& ast) const;
    void operator()(ast::expression const& ast) const;
    void operator()(ast::function_call const& ast) const;

    std::ostream& out;
};
```

Printing the AST

```
void printer::operator()(double ast) const
{
    out << ast;
}

void printer::operator()(ast::operation const& ast) const
{
    switch (ast.operator_)
    {
        case '+': out << " + "; break;
        case '-': out << " - "; break;
        case '*': out << " * "; break;
        case '/': out << " / "; break;

        default:
            BOOST_ASSERT(0);
            return;
    }
    boost::apply_visitor(*this, ast.operand_);
}
```

Printing the AST

```
void printer::operator()(ast::expression const& ast) const
{
    if (ast.rest.size())
        out << ’(’;
    boost::apply_visitor(*this, ast.first);
    for (auto const& oper : ast.rest)
        (*this)(oper);
    if (ast.rest.size())
        out << ’)’;
}
```

Printing the AST

```
void printer::operator()(ast::function_call const& ast) const
{
    out << ast.name;
    if (ast.arguments.size())
        out << '(';
    bool first = true;
    for (auto const& arg : ast.arguments)
    {
        if (first)
            first = false;
        else
            out << ", ";
        (*this)(arg);
    }
    if (ast.arguments.size())
        out << ')';
}
```

The Interpreter

```
class interpreter
{
public:

    typedef std::function<
        void(x3::position_tagged, std::string const&)>
    error_handler_type;

    template <typename ErrorHandler>
    interpreter(ErrorHandler const& error_handler);

    template <typename F>
    void add_function(std::string name, F f);

    float eval(ast::expression const& ast);

private:

    std::map<
        std::string
      , std::pair<std::function<double(double* args)>, std::size_t>
    >
    fmap;

    error_handler_type error_handler;
};
```

The Interpreter

```
// Add some functions:
interp.add_function("pi", []{ return M_PI; });
interp.add_function("sin", [](double x){ return std::sin(x); });
interp.add_function("cos", [](double x){ return std::cos(x); });
```

The Interpreter

```
sin(45 * (pi / 180))
```

The Interpreter

```
template <typename F>
inline void interpreter::add_function(std::string name, F f)
{
    static_assert(detail::arity<F>::value <= detail::max_arity,
        "Function F has too many arguments (maximum == 5).");

    std::function<double(double* args)> f_adapter = detail::adapter_function<F>(f);
    fmap[name] = std::make_pair(f_adapter, detail::arity<F>::value);
}
```

The Interpreter

```
double interpreter_impl::operator()(double lhs, ast::operation const& ast) const
{
    double rhs = boost::apply_visitor(*this, ast.operand_);
    switch (ast.operator_)
    {
        case '+': return lhs + rhs;
        case '-': return lhs - rhs;
        case '*': return lhs * rhs;
        case '/': return lhs / rhs;

        default:
           BOOST_ASSERT(0);
           return -1;
    }
}
```

The Interpreter

```
double interpreter_impl::operator()(ast::function_call const& ast) const
{
    auto iter = fmap.find(ast.name);
    if (iter == fmap.end()) {
        error_handler(ast, "Undefined function " + ast.name + '.');
        return -1;
    }

    if (iter->second.second != ast.arguments.size()) {
        std::stringstream out;
        out << "Wrong number of arguments to function " << ast.name << " ("
            << iter->second.second << " expected)." << std::endl;

        error_handler(ast, out.str());
        return -1;
    }

    // Get the args
    double args[detail::max_arity];
    double* p = args;
    for (auto const& arg : ast.arguments)
        *p++ = (*this)(arg);

    // call user function
    return iter->second.first(args);
}
```