Inside Spirit X3

Redesigning Boost.Spirit for C++11

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Agenda

- Quick Overview
- Parser Combinator
- Let’s Build a Toy Spirit X3
- Walk-through Spirit X3

What's Spirit

- A object oriented, recursive-descent parser and output generation library for C++
  - Implemented using template meta-programming techniques
  - Syntax of Parsing Expression Grammars (PEGs) directly in C++, used for input and output format specification
- Target grammars written entirely in C++
  - No separate tools to compile grammar
  - Seamless integration with other C++ code
  - Immediately executable

Spirit X3

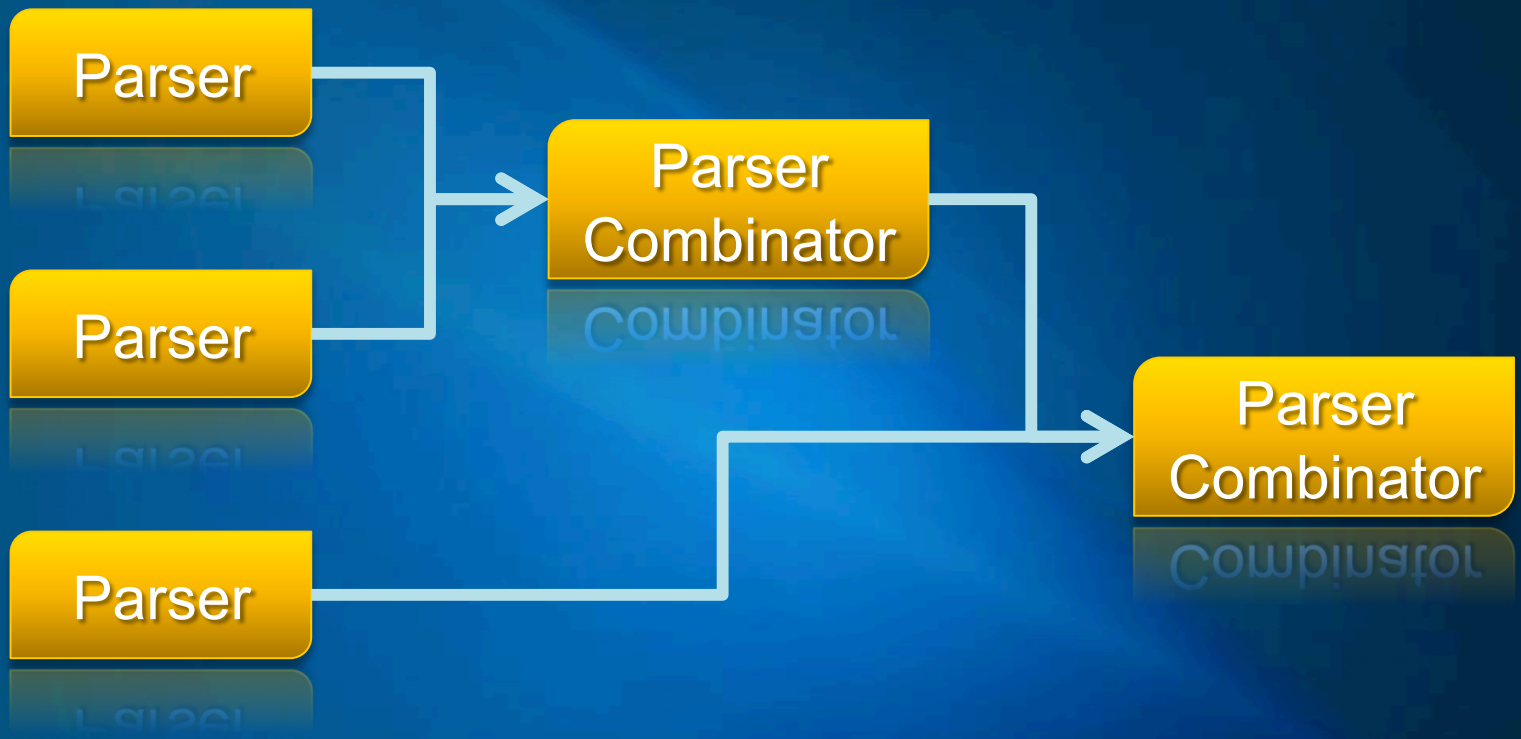
- Experimental
- C++11
- Hackable, simpler design
- Minimal code base and dependencies
  - MPL
  - Fusion
  - Phoenix?
  - Proto?
- Better error handling
- Faster compile times

calc4.cpp example
SpiritX3: TOTAL : 4.27 secs
Spirit2: TOTAL : 10.00 secs

Parser Combinator

- A Parser is a function
  - A character parser
  - A numeric parser
- Parsers can be composed to form higher order *parser* functions
  - E.g. a sequence parser accepts two parsers and returns a composite parser
  - Such a higher order *parser* function is called a Parser Combinator. A Parser Combinator accepts several parsers as input and returns a composite parser as result

Parser Combinator



Parser Combinator

- Primitives (plain characters, uint_, etc.)

```
bool match_char(char ch)
        { return ch== input(); }
```

- Sequences

```
bool match_sequence(F1 f1, F2 f2)
        { return f1() && f2(); }
```

- Alternatives

```
bool match_alternative(F1 f1, F2 f2)
        { return f1() || f2(); }
```

- Modifiers (kleen, plus, etc.)

```
bool match_kleene(F f)
        { while (f()); return true; }
```

- Nonterminals (factor, term, expr)

```
bool match_rule()
        { return match_rhs(); }
```

Parsing Expression Grammar

- Formal grammar for describing a formal language in terms of a set of rules used to recognize strings of this language
  - Does not require a tokenization stage
- Similar to Extended Backus-Naur Form (EBNF)
- Unlike (E)BNF, PEG's are not ambiguous
  - Exactly one valid parse tree for each PEG
- Any PEG can be directly represented as a recursive-descent parser
- Different Interpretation as EBNF
  - Greedy Loops
  - First come first serve alternates

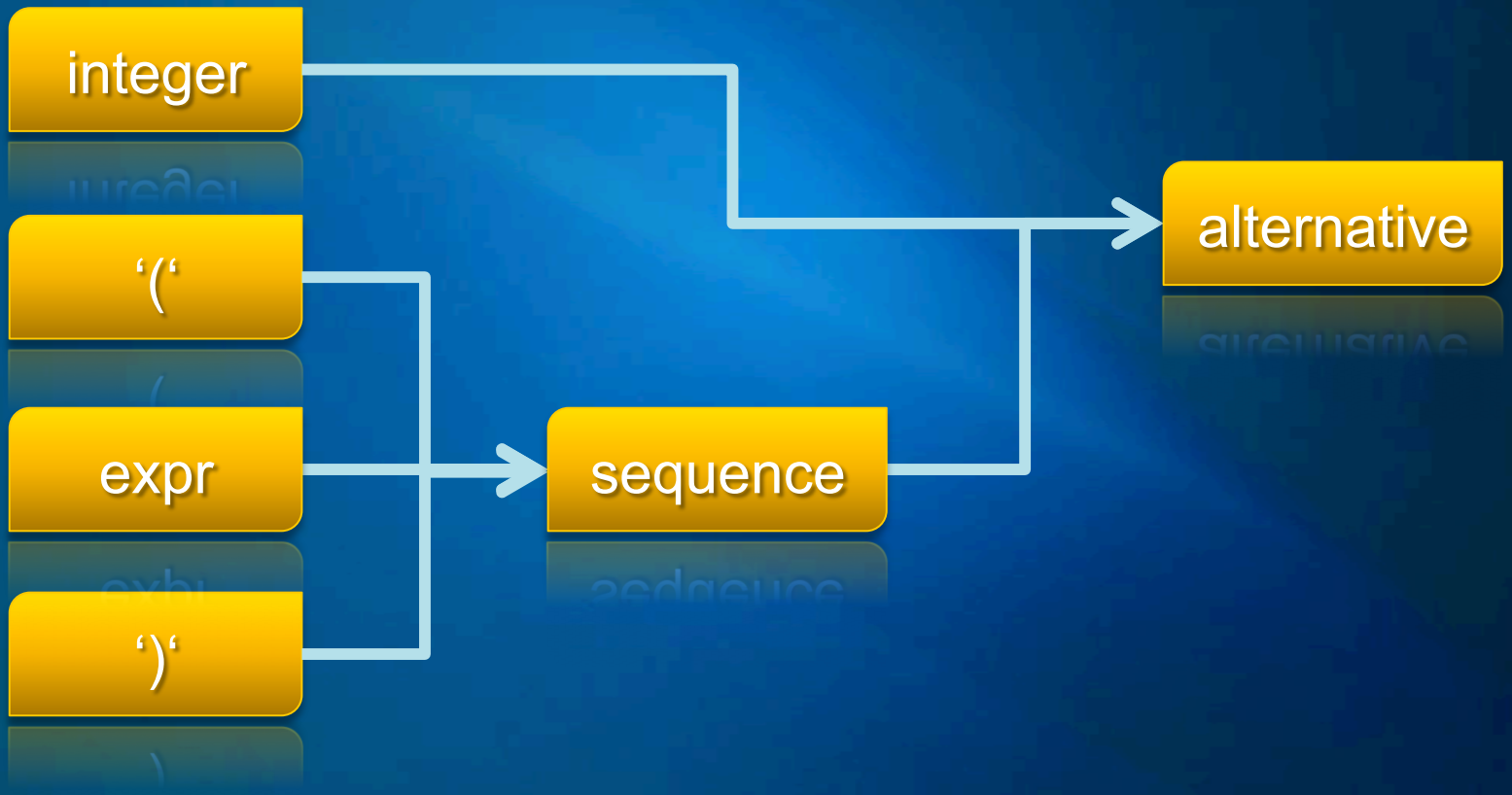
Calculator PEG Grammar

```
factor  ←  integer  /  '('  expr  ')'
term    ←  factor (('*'  factor)  /  ('/'  factor))*
expr    ←  term (('+' term)  /  ('-'  term))*
```

- A recursive descent parser is a top-down parser built from a set of mutually-recursive functions, each representing one of the grammar elements
- Thus the structure of the resulting program closely mirrors that of the grammar it recognizes

Parser Composition

factor ← integer / ‘(‘ expr ‘)’

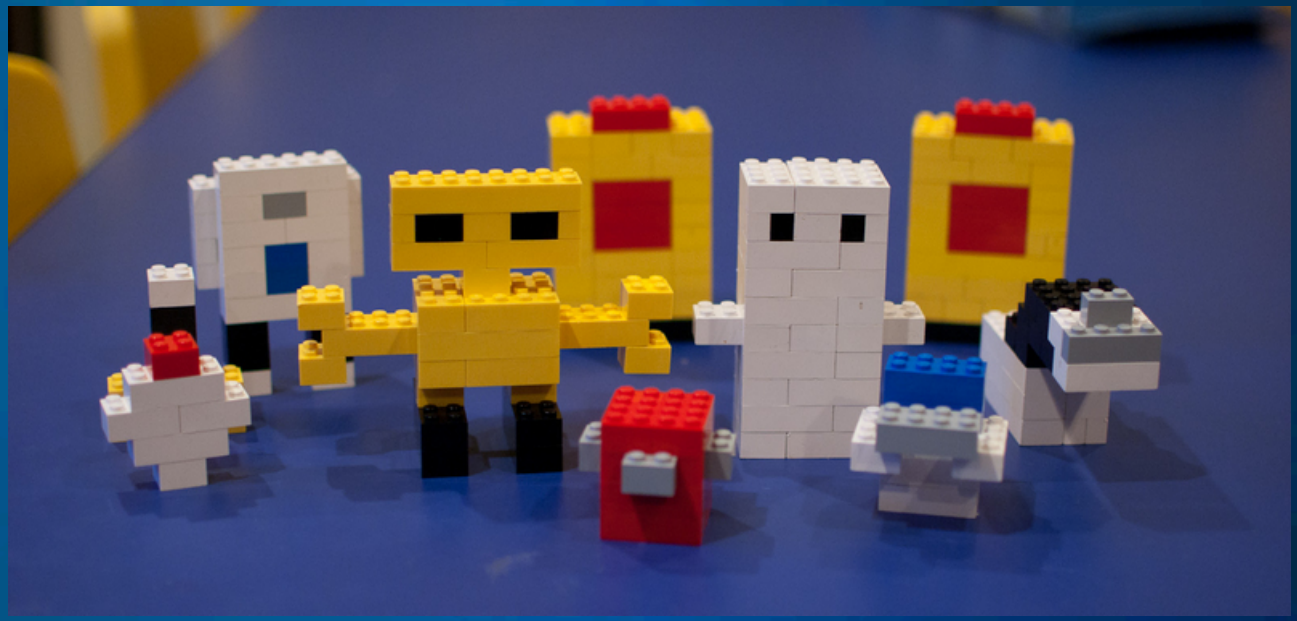


Parser Composition

factor ← integer / '(' expr ')'

```
bool match_fact()
{
   return     match_integer() ||
      (
                 match_char( '(' )
         &&      match_expr()
         &&      match_char( ')' )
      );
}
```

Let’s build a toy Spirit X3



The Parser Base Class

```
namespace boost { namespace spirit { namespace x3
{
    template <typename Derived>
    struct parser
    {
        Derived const& derived() const
        {
            return *static_cast<Derived const*>(this);
        }
    };
}
```

The parse member function

```
template <typename Iterator, typename Context>
bool parse(
    Iterator& first,
    Iterator last,
    Context const& ctx) const
```

Postconditions

- Upon return from p.parse the following post conditions should hold:
  - On a successful match, first is positioned one past the last matching character.
  - On a failed match, first is restored to its original position prior to entry.
  - No post-skips: trailing skip characters will not be skipped.

Our First Primitive Parser

```
template <typename Char>
struct char_parser : parser<char_parser<Char>>
{
   char_parser(Char ch) : ch(ch) {}

   template <typename Iterator, typename Context>
   bool parse(Iterator& first, Iterator last, Context const& ctx) const
   {
      if (first != last && *first == ch)
      {
         ++first;
         return true;
      }
      return false;
   }

   Char ch;
};
```

char_ ET

```
template <typename Char>
inline char_parser<Char> char_(Char ch)
{
    return char_parser<Char>(ch);
};
```

Our First Composite Parser

```
template <typename Left, typename Right>
struct sequence_parser : parser<sequence_parser<Left, Right>>
{
    sequence_parser(Left left, Right right)
      : left(left), right(right) {}

    template <typename Iterator, typename Context>
    bool parse(Iterator& first, Iterator last, Context const& ctx) const
    {
        return left.parse(first, last, ctx)
            && right.parse(first, last, ctx);
    }

    Left left;
    Right right;
};
```

Sequence ET

```
template <typename Left, typename Right>
inline sequence_parser<Left, Right> operator>>(
    parser<Left> const& left, parser<Right> const& right)
{
    return sequence_parser<Left, Right>(
        left.derived(), right.derived());
}
```

Another Composite Parser

```
template <typename Left, typename Right>
struct alternative_parser : parser<alternative_parser<Left, Right>>
{
    alternative_parser(Left left, Right right)
        : left(left), right(right) {}

    template <typename Iterator, typename Context>
    bool parse(Iterator& first, Iterator last, Context const& ctx) const
    {
        if (left.parse(first, last, ctx))
            return true;
        return right.parse(first, last, ctx);
    }

    Left left;
    Right right;
};
```

Alternative ET

```
template <typename Left, typename Right>
inline alternative_parser<Left, Right> operator|(
    parser<Left> const& left, parser<Right> const& right)
{
    return alternative_parser<Left, Right>(
        left.derived(), right.derived());
}
```

Simple Rules

```
auto abc =
        char_('a')
    >>  char_('b')
    >>  char_('c')
    ;

auto a_or_bc =
        char_('a')
    |   ( char_('b') >> char_('c') )
    ;
```

But how about Recursion?

- I want a rule that parses these inputs:
  - “x”
  - “ax”
  - “aax”
  - “aaaaax”
- In other words: I want zero or more ‘a’s followed by an ‘x’
- No, we don’t have the Kleene star yet ;-)

But how about Recursion?

```
auto const x = char_('x') | ax;
auto const ax = char_('a') >> x;
```

But how about Recursion?

```
auto const x = char_('x') | ax;
auto const ax = char_('a') >> x;
```

Nonterminals

- The rule is a polymorphic parser that acts as a named placeholder capturing the behavior of a PEG expression assigned to it.
- Naming a PEG expression allows it to be referenced later and makes it possible for the rule to call itself.
- This is one of the most important mechanisms and the reason behind the word “recursive” in recursive descent parsing.

Spirit-2 and Spirit-Classic style

- Uses type-erasure
  - Abstract class with virtual functions
  - Boost or std function

```
rule<Iterator> x, ax;
x = char_('x') | ax;
ax = char_('a') >> x;
```

Problems with type-erasure

- All template parameters for parse should be known before hand.
  - Hence the rule needs to know the “scanner” type (Spirit-Classic) and the Iterator type (Spirit-2).
- Code bloat
  - The virtual functions force instantiations even if, in the end, they are not really used. Same with Boost or std function.
- Prevents optimizations
  - The virtual function is an opaque wall. In general, compilers cannot see beyond this opaque wall and cannot perform optimizations.

X3 style

- Does not use type-erasure
- Inspired by Spirit-Classic *Subrules*
  - Taken to the next level with the help of C++11 facilities that were not available at the time (e.g. auto and variadic templates)
  - V2 and Classic subrules are compile time monsters with its heavy reliance on expression templates

The Context

- Allows functions to efficiently access data from other stack frames
  - Caller sets up a Context
  - Callee retrieve the Context as needed
- On demand (pull vs. push)
- Data can be polymorphic
- Efficient alternative to passing arguments to functions
- Data can cross multiple stack frames
- Allows multiple contexts to be linked up

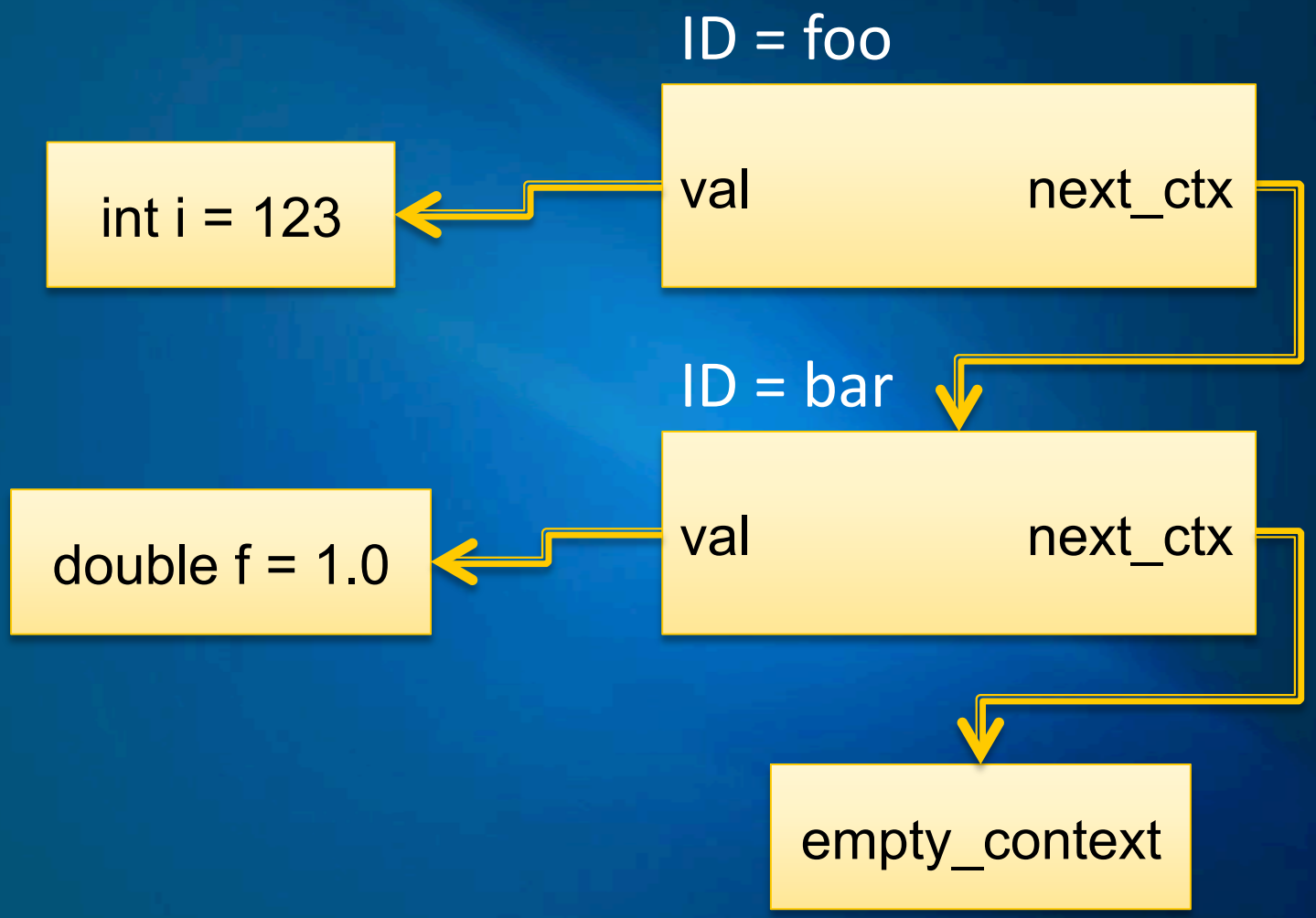
The Context

```
template <typename ID, typename T, typename NextContext>
struct context
{
    context(T const& val, NextContext const& next_ctx)
        : val(val), next_ctx(next_ctx) {}

    T const& get(mpl::identity<ID>) const
    {
        return val;
    }

    template <typename Identity>
    decltype(std::declval<NextContext>().get(Identity()))
    get(Identity id) const
    {
        return next_ctx.get(id);
    }

    T const& val;
    NextContext const& next_ctx;
};
```

The Empty Context

```
struct empty_context
{
   struct undefined {};
   template <typename ID>
   undefined get(ID) const
   {
      return undefined();
   }
};
```

The Context


ID = foo
val
next_ctx
int i = 123
ID = bar
val
next_ctx
double f = 1.0
empty_context

Example Context Usage

```
struct foo_id;

template <typename Context>
void bar(Context const& ctx)
{
      std::cout << ctx.get(mpl::identity<foo_id>()) << std::endl;
}

void foo()
{
   int i = 123;
   empty_context empty_ctx;
   context<foo_id , int, empty_context> ctx(i, empty_ctx);
   bar(ctx);
}
```

Example Context Usage

```
struct foo_id;

template <typename Context>
void bar(Context const& ctx)
{
      std::cout << ctx.get(mpl::identity<foo_id>()) << std::endl;
}

void foo()
{
   int i = 123;
   empty_context empty_ctx;
   context<foo_id , int, empty_context> ctx(i, empty_ctx);
   bar(ctx);
}
```

The Rule Definition

```
template <typename ID, typename RHS>
struct rule_definition : parser<rule_definition<ID, RHS>>
{
    rule_definition(RHS rhs)
        : rhs(rhs) {}

    template <typename Iterator, typename Context>
    bool parse(Iterator& first, Iterator last, Context const& ctx) const
    {
        context<ID, RHS, Context> this_ctx(rhs,  ctx);
        return rhs.parse(first, last, this_ctx);
    }

    RHS rhs;
};
```

The Rule

```
template <typename ID>
struct rule : parser<rule<ID>>
{
    template <typename Derived>
    rule_definition<ID, Derived>
    operator=(parser<Derived> const& definition) const
    {
        return rule_definition<ID, Derived>(definition.derived());
    }

    template <typename Iterator, typename Context>
    bool parse(Iterator& first, Iterator last, Context const& ctx) const
    {
        return ctx.get(mpl::identity<ID>()).parse(first, last, ctx);
    }
};
```

The main parse function

```
template <typename Iterator, typename Derived>
inline bool parse(parser<Derived> const& p, Iterator& first, Iterator last)
{
    empty_context ctx;
    return p.derived().parse(first, last, ctx);
}
```

Our Recursive Rule X3 style

```
rule<class x> const x;
auto const ax = char_('a') >> x;
auto const start =
    x = char_('x') | ax;
```