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

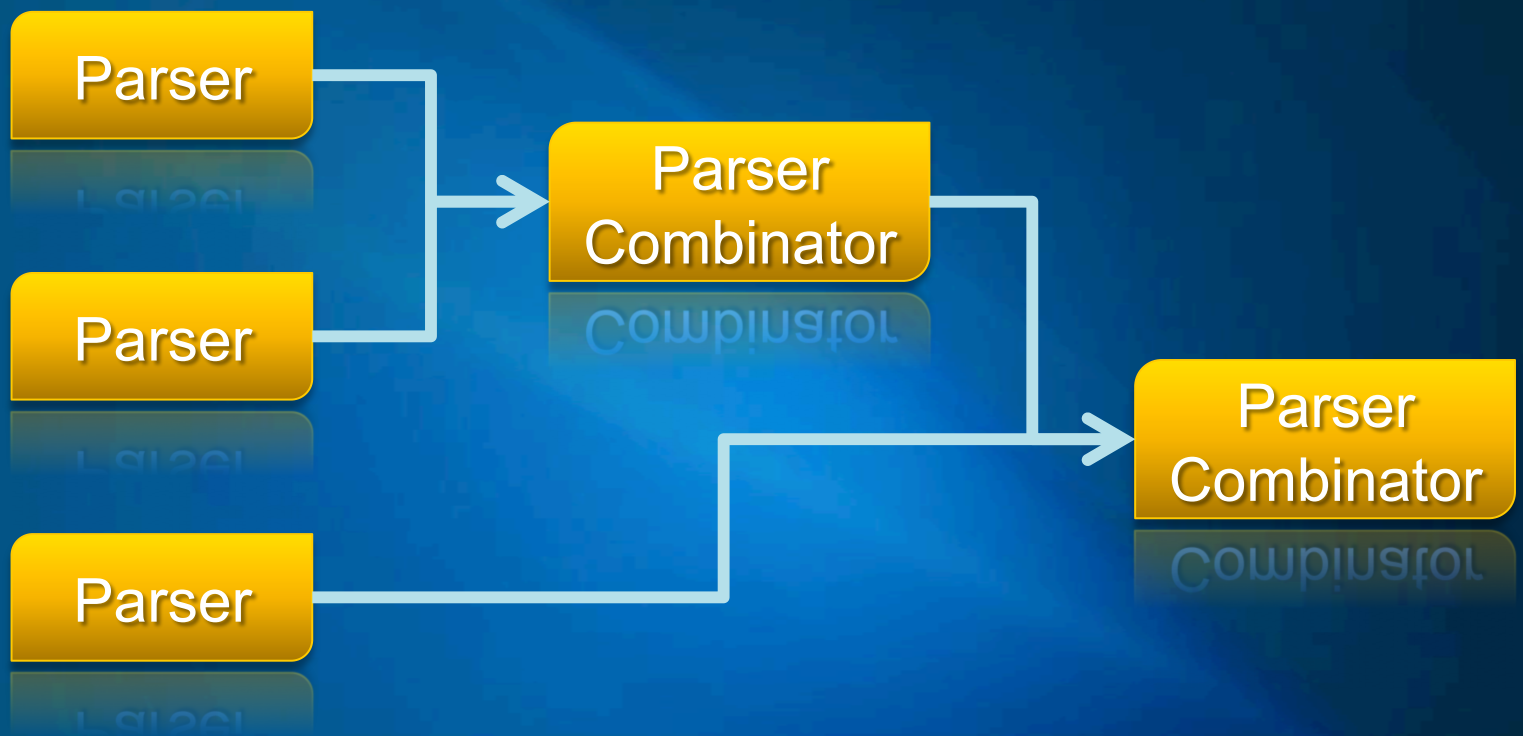
SpiritX3: TOTAL : 4.27 secs

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

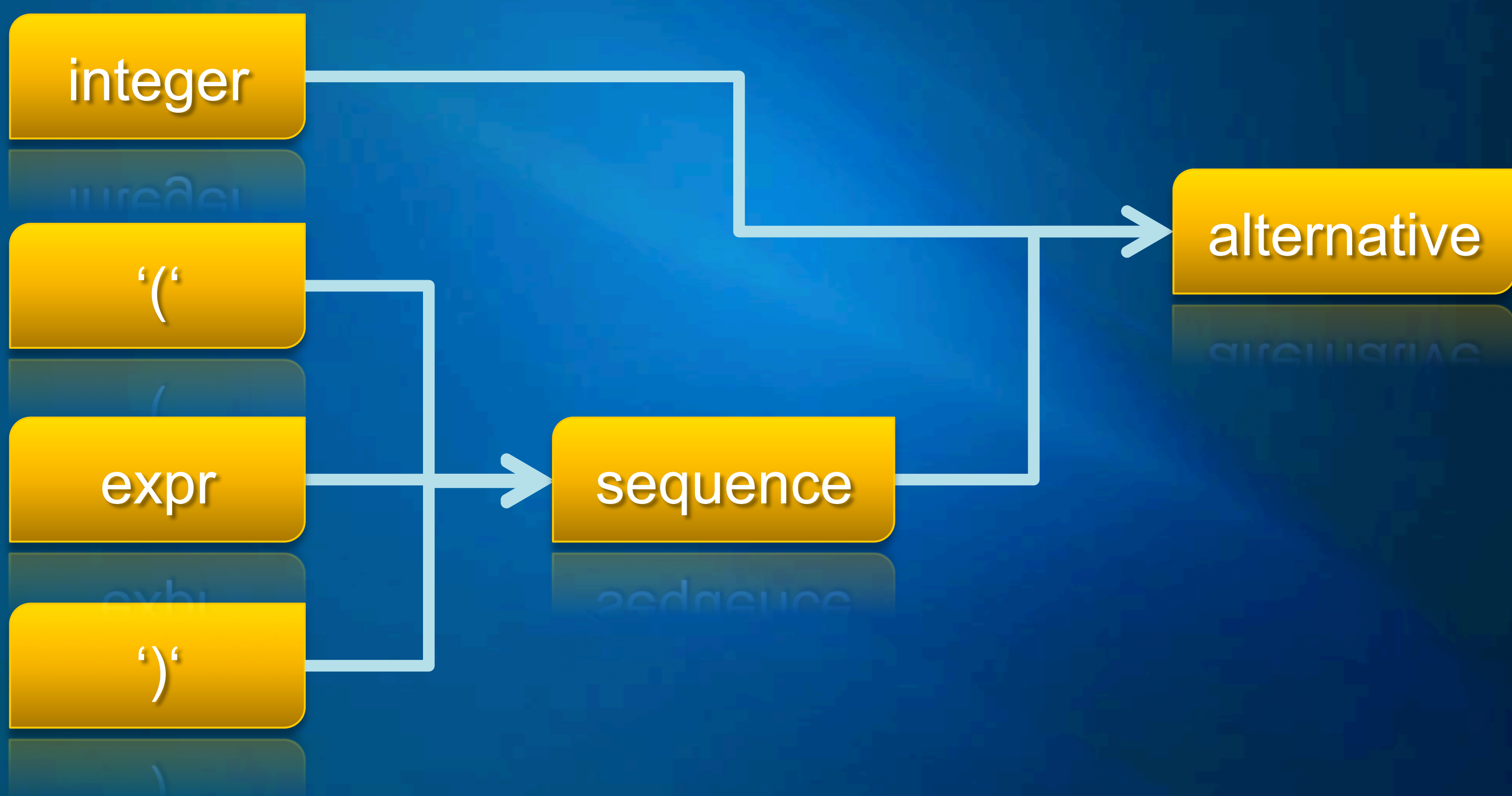
Calculator PEG Grammar

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 ‘)’

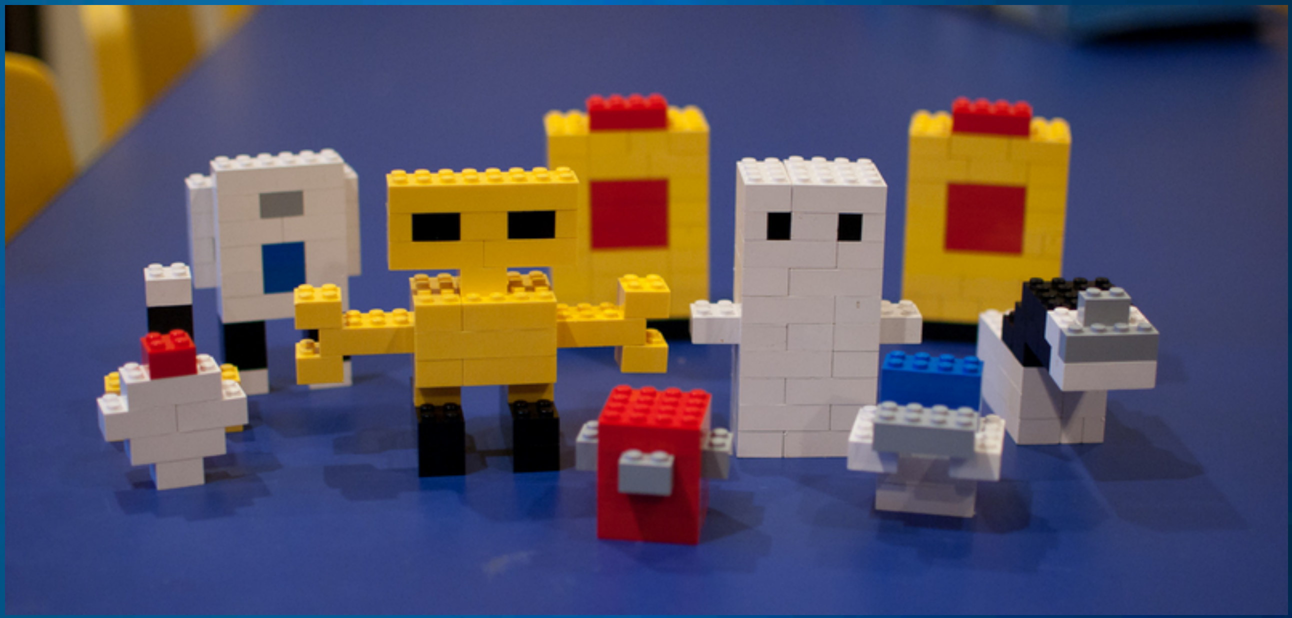


Parser Composition

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