Meta<Fun> - Towards a Functional-Style Interface for C++ Template Metaprograms*

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- Template Metaprogramming
- Metaprogramming & Functional Programming
- A Functional TMP interface
- Example: Lazy data types
- Evaluation

C++ Template Metaprogramming I

- Template:
  - `list<int>, list<double>`
  - Tool for generic programming
  - Unconstrained (in current standard)
  - Concepts (in C0x)
- Implementation
  - Instantiation (in compile-time)
  - Specialization
  - Pattern-matching
- Compile-time algorithms
  - Recursions, conditional statements => Turing-completeness

C++ TMP: an example

```
template <int N>
struct Factorial
{
  enum { value = N*Factorial<N-1>::value };
};

template <>
struct Factorial<1>
{
  enum { value = 1 };
};

int main()
{
  int r = Factorial<5>::value;
}
```

Application areas of TMP

- Concept checking
- Expression templates
- Compile-time code adaptation
- Compiler construction
- Active libraries
- Language embedding
- etc

TMP is Functional

- Referential transparency
  - no mutable variables
  - no loops
- Pattern matching
- Higher order TMPs
- Lazyness?

Motivation

- Terrible syntax
- Terrible diagnostics
- Metaprogramming in itself is difficult and ugly
- Most metaprograms are handcrafted
- Non-functional style libraries (like boost::mpl)
- Hard to debug
- Hard to predict the development process

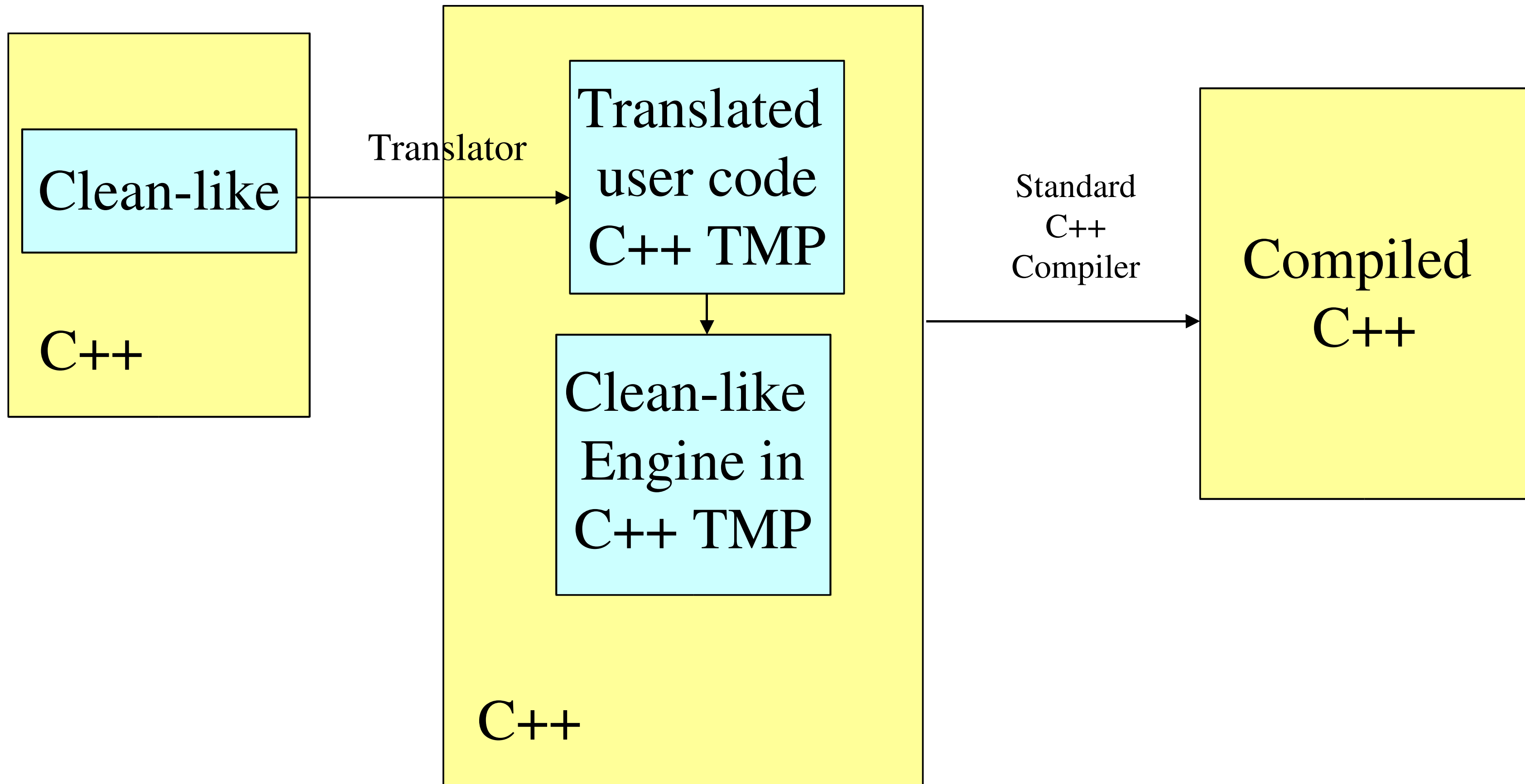
- Aim: C++ template metaprogramming interface which explicitly expresses the programmer's intentions

Meta<Fun>

- Aim: C++ template metaprogramming interface which explicitly expresses the programmer's intentions

- Embedded functional-style interface for C++ Template Metaprograms
- Embedded language example: Clean
  - Pure functional language based on graph rewriting with outermost tree reduction
  - Lazy evaluation

Structure of Meta<Fun>



Components of Meta<Fun>

- Clean-TMP translator
  - Work in progress
- Clean-like metaprogram library
  - Separating the user-written code from the graph-rewriting engine
  - Equivalent semantics to Clean programs
  - Library based on standard C++
  - Portable

An example: Sieve

```
take 0 xs = []
take n [x:xs] = [x:take (n-1) xs]

sieve [prime:rest] = [prime : sieve (filter prime rest)]
filter p [h:tl] | h rem p == 0  = filter p tl
                                = [h : filter p tl]
filter p [] = []

Start = take 10 (sieve [2..]) ->
take 10 ([2, sieve (filter 2 [3..])]) ->
[2, take 9 (sieve (filter 2 [3..]))] ->
[2, take 9 (sieve [3, filter 2 [4..])] ->
[2, take 9 [3, sieve (filter 3 (filter 2 [4..]))] ->
[2, 3, take 8 (sieve (filter 3 (filter 2 [4..]))) ->
............
```

Sieve: translated code

```
template <int p, int x, class xs>
struct filter<p, Cons<x,xs> >
{
    typedef typename
     if_c< x%p==0, Filter<p,xs>, Cons<x,filter<p,xs> > >::type right;
};

template <class xs>
struct sieve
{
    typedef NoMatch right;
};

template <int p, class xs>
struct sieve<Cons<p,xs> >
{
    typedef Cons<p,sieve<filter<p,xs> > > right;
};
```

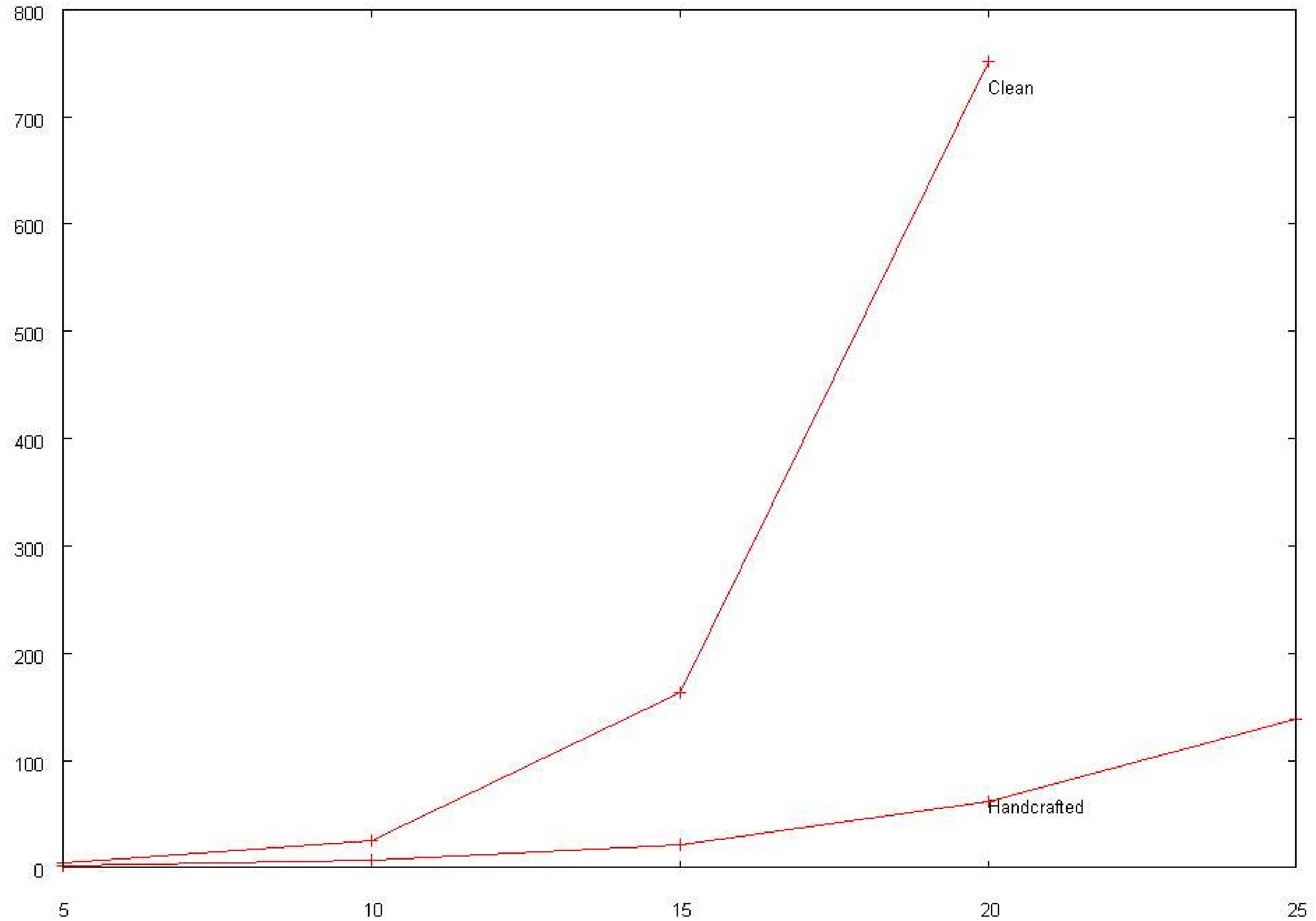
Lazy list and Sieve

```
template <int r>
struct EnumFrom
{
    typedef Cons<r, EnumFrom<r+1> > right;
};

take<10,sieve<EnumFrom<2> >
take<10,Cons<2,sieve<filter<2,EnumFrom<3> > > >
Cons<2,take<9,sieve<filter<2,EnumFrom<3> > > > >
Cons<2,take<9,sieve<3,filter<2,EnumFrom<4> > > > >
Cons<2,take<9,Cons<3,sieve<filter<3,EnumFrom<4> > > > > >
Cons<2,3,take<8,filter<3,filter<2,EnumFrom<4> > > > >
…………
```

The engine

```
template <class T1, template <class> class Expr>
struct Eval<Expr<T1> >
{
    typedef typename
        if_c<is_same<typename Expr<T1>::right,NoMatch>::value,
        typename
            if_c<!Eval<T1>::second,
                Expr<T1>,
                Expr<typename Eval<T1>::result>
            >::type,
            typename Expr<T1>::right
        >::type result;

    static const bool second =
        !(is_same<typename Expr<T1>::right,NoMatch>::value &&
        !Eval<T1>::second);
};
```

Compilation times



Related/Future work

- C++ Template Metaprogram Libraries
  - Loki (Alexandrescu 2000)
  - boost::mpl (Gurtovoy, Abrahams, 2002)
    - Incl: TMP Lambda
- Runtime functional library
  - fc++ (McNamara, Smaragdakis, 2000)
- Func – C++ template mapping
  - From Haskell type classes to C++ concepts (Zalewski, Priesnitz, Ionescu, Botta, Schupp, 2007)

- Closer to Clean syntax
- Order of rules (priorities)
- Optimizations

Conclusion

- C++ Template Metaprogramming is emerging
- Functional-style programming
- Current syntax is unsuitable and source of errors
- Functional syntax would better express the programmers' intensions
- Meta<Fun> - a portable way to achieve the goals
- Lazy data types – a proof of concepts
- Many open questions

Functional interface

```
BEGIN_CLEAN(sievesum10)

take 0 xs = []
take n [x:xs] = [x:take (n-1) xs]

sieve [prime:rest] = [prime : sieve (filter prime rest)]
filter p [h:tl] | h rem p == 0  = filter p tl
                                = [h : filter p tl]
filter p [] = []

Start = sum ( take 10 (sieve [2..]) )

END_CLEAN

static const int prime10 = cleanstart(sievesum10);
```

Thank you!
Questions?

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