Visualization of C++ Template Metaprograms[1]

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Contents

1. Introduction
2. Templight
3. Debugger
4. Visualizer
5. Conclusion

C++ Templates

- Different from Java / C# generics
  - Java / C#: type erasure
  - C++: instantitation
- Mainly used for libraries: STL, etc.
- Templates are skeletons, code generated on demand
- Possibility for specialisation
- Recursive templates are ok

C++ Template Metaprogram - example

```
template <int N>
struct Factorial
{
  enum { Value = N * Factorial<N-1>::Value};
};
template <>
struct Factorial<0>
{
  enum { Value = 1 };
};

int main()
{
  std::cout << Factorial<5>::Value;
}
```

C++ Template Metaprogram features

- Executed at compilation-time
- Functional paradigm
- Why we used them:
  - optimalizations of runtime programs, expression templates
  - static interface checking, concept checking
  - compile-time code adoption, active libraries
  - embedding DSLs
- Turing complete

Motivation

- Metaprogramming is side effect of template construct
- Template syntax is not helpful
- Compiler interprets metaprograms at compilation-time
- No user input, trivial printouts, etc.
- Maintenance is hopeless

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C++ template metaprogram code comprehension tools are essential

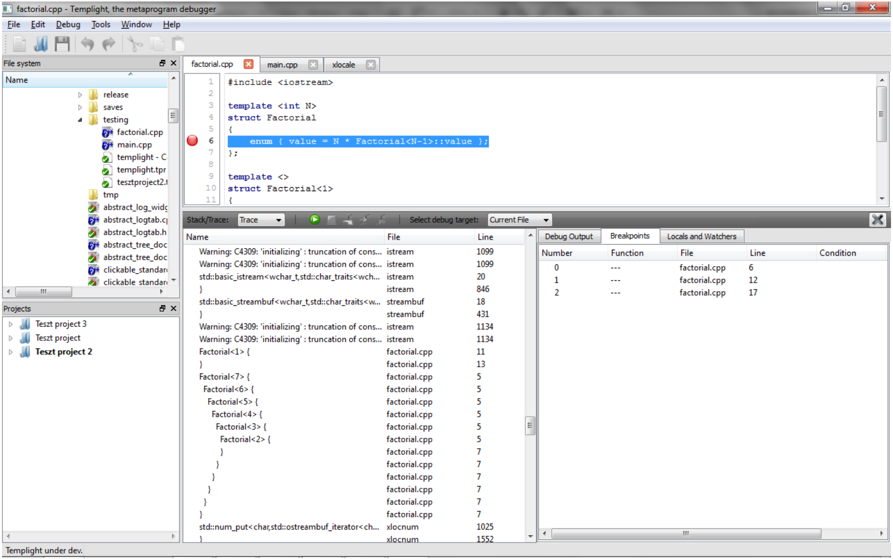
Templight

- Lightweight parser using boost wave and spirit
- Instruments template classes/functions injecting begin/end markers
- Markers emit compilation warnings on instantiation
- Collects warnings generating a "stack-trace"
- Post-mortem way
- Take advantage of compiler dependent implementation details (e.g. *memoization*)

Debugger

- Based on Templight
- GUI is based on QT
- Implements "usual" debugger features:
  - Breakpoints, continue
  - Step in/out/over
  - Locals, watch
- Backward execution

Screenshot



```
#include <iostream>

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

template <>
struct Factorial<1>
{
```

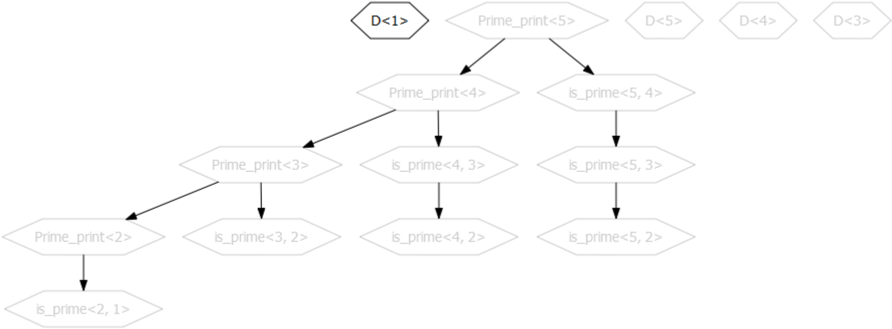
Name	File	Line
Warning: C4309: 'initializing' : truncation of cons...	istream	1099
Warning: C4309: 'initializing' : truncation of cons...	istream	1099
std::basic_istream<wchar_t,std::char_traits<wch...	istream	20
}	istream	846
std::basic_streambuf<wchar_t,std::char_traits<w...	streambuf	18
}	streambuf	431
Warning: C4309: 'initializing' : truncation of cons...	istream	1134
Warning: C4309: 'initializing' : truncation of cons...	istream	1134
Factorial<1> {	factorial.cpp	11
}	factorial.cpp	13
Factorial<7> {	factorial.cpp	5
Factorial<6> {	factorial.cpp	5
Factorial<5> {	factorial.cpp	5
Factorial<4> {	factorial.cpp	5
Factorial<3> {	factorial.cpp	5
Factorial<2> {	factorial.cpp	5
}	factorial.cpp	7
}	factorial.cpp	7
}	factorial.cpp	7
}	factorial.cpp	7
}	factorial.cpp	7
}	factorial.cpp	7
std::num_put<char,std::ostreambuf_iterator<ch...	xlocnum	1025
}	xlocnum	1552

Number	Function	File	Line	Condition
0	---	factorial.cpp	6	
1	---	factorial.cpp	12	
2	---	factorial.cpp	17	

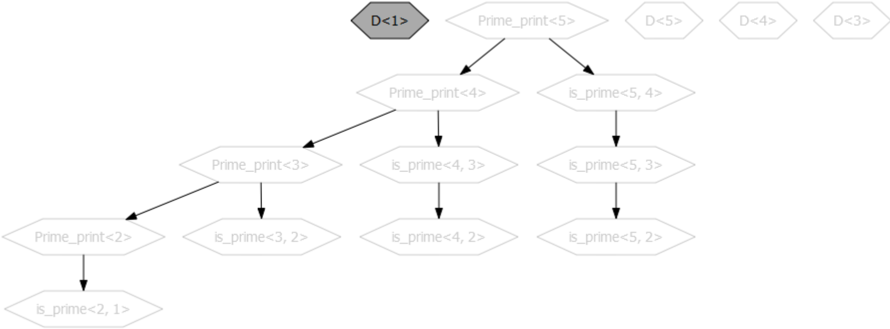
Visualizer

- Based on Templight
- Transform the instantiation chain into a directed graph:
  - nodes: types generated from templates
  - edges show the instantiation requests
- Show corresponding code
- Filter out irrevelant nodes
- Export to png, jpg etc,

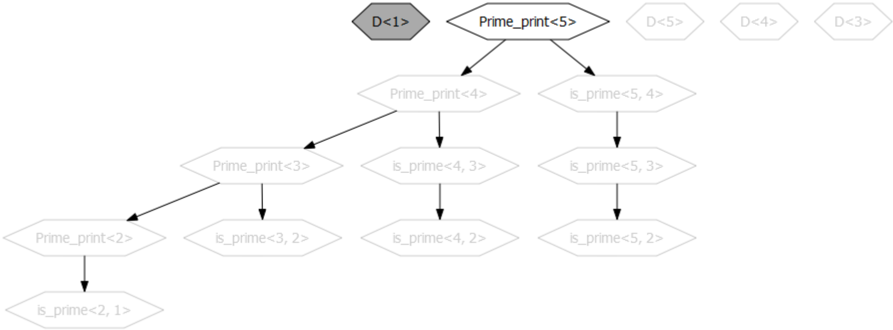
Unruh Example Demonstration



Unruh Example Demonstration



Unruh Example Demonstration



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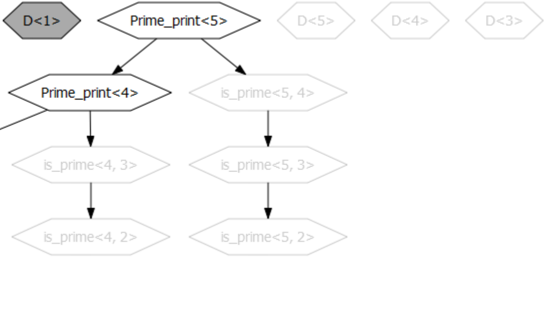

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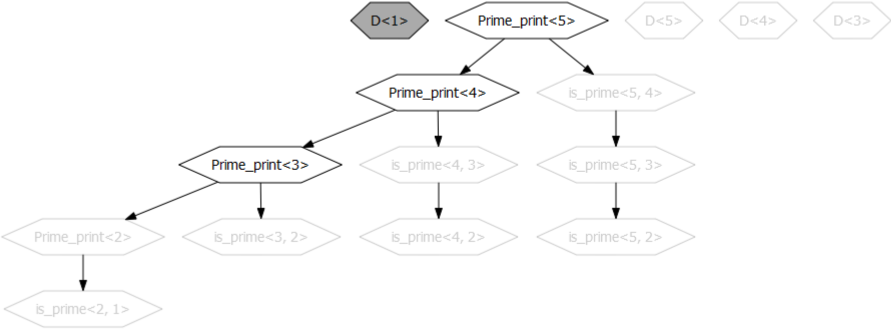

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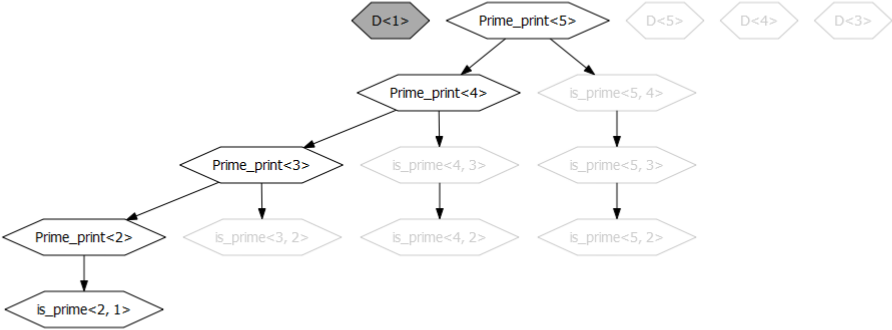

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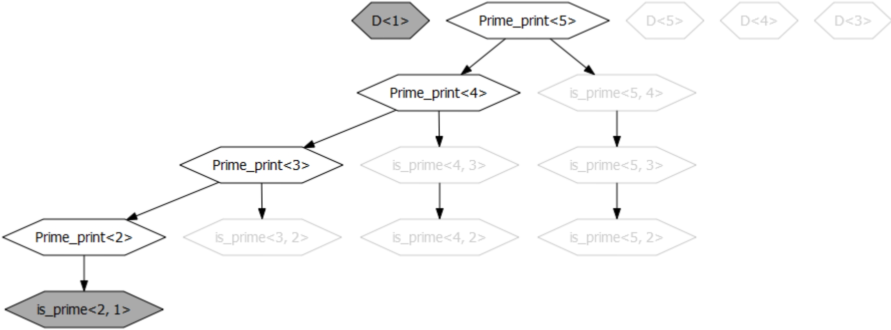

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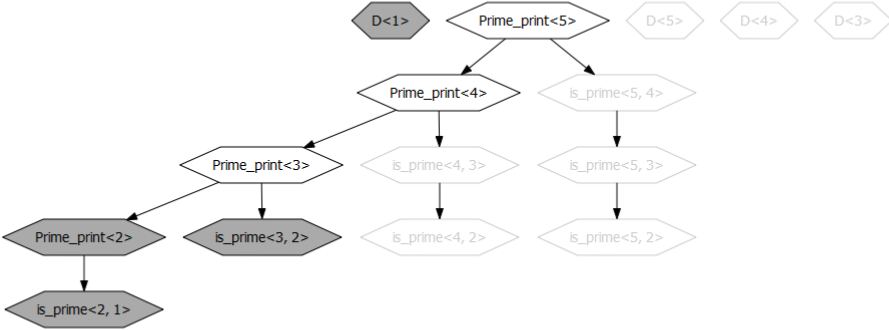

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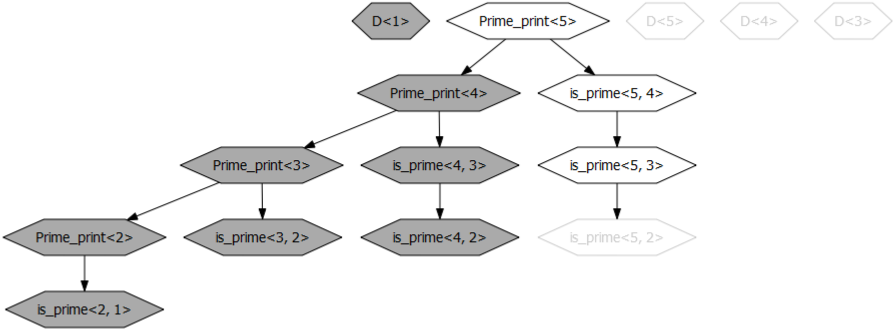

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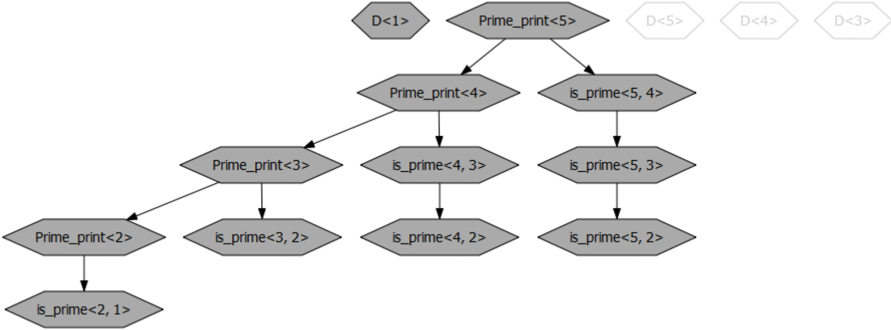

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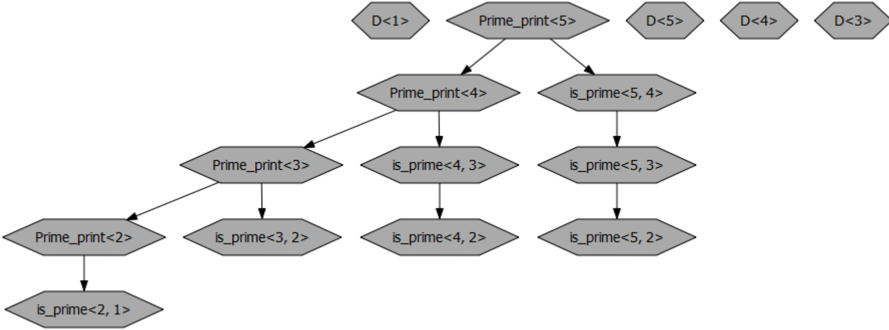

Conclusion

- It is hard to understand and maintain C++ template metaprograms
- Visualization of programs is essential
- We have created a basic framework called *Templight*
- We have developed a graphical user interfaced post-mortem debugger
- We have implemented a tool to visualize the C++ template metaprograms as graphs

Controversial

```
template <int p, int i>
struct is_prime {
  enum {
    prim = (p==2) ||
           (p%i) &&
           is_prime<(i>2?p:0),i-1>::prim
  };
};
template<>
struct is_prime<0,0> {
  enum {prim=1};
};
template<>
struct is_prime<0,1> {
  enum {prim=1};
```

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C++ source is the assembly of template metaprogram.

We have to use high level functional programming languages, like Haskell, to write metaprograms, and **generate** C++ source.

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Thank you for attention