

The Beast programming language

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Abstract

This paper introduces a new compiled, imperative, object-oriented, C-family programming language, particularly inspired by C++ and D. Most notably, the language implements a new concept called *code hatching* (also a subject of this paper) that unifies templating, compile-time function execution, reflection and metaprogramming in general. The project also includes a proof-of-concept open-source compiler (more precisely transcompiler to C) called Dragon that demonstrates core elements of the language and the code hatching concept.

Keywords: Programming language — CTFE — code hatching — compile time — metaprogramming — ctime — Beast

Supplementary Material: [Git repository \(github.com/beast-lang/beast-dragon\)](https://github.com/beast-lang/beast-dragon)

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1. Introduction

There are two ways of how to approach introducing Beast – either it can be referred as a programming language designed to provide a better alternative for C++ programmers or as a programming language that implements the code hatching concept, which introduces vast metaprogramming and compile-time computing possibilities.

As a C++ alternative, the language provides syntax and functionality similar to C++, but adds features designed to increase coding comfort, code readability and safety. The most notable changes are:

- Instead of header/source files, Beast has modules with importing system similar to D or Java.
- Beast variables are const-by-default. As C++ has the `const` keyword to mark variables constant, Beast has `Type!` suffix operator to make variables not constant.
- References and pointers are designed differently. In Beast, references are rebindable and can be

used in most cases where C++ pointers would be used. Beast pointers are to be used only when pointer arithmetic is needed (or double indirection, as there cannot be references of references).

- The `#` character is a valid identifier character. It is used as a prefix for reflection or compiler-related properties and functions such as
`variable.#type`, `Type.#instanceSize` or
`var.#explicitCast(TargetType)`.

There are many smaller changes; those are (or will be) documented in the language reference and bachelor thesis text (both downloadable from the Git repository).

The main innovation of Beast is its *code hatching* concept that unifies formerly standalone concepts of templates, compile-time function execution (CTFE), compile-time reflection and metaprogramming in general (conditional compilation, etc.). The concept blurs borders between standard and templated functions, between code and *metacode* (in C++, an example of metacode would be preprocessor directives or template

42 declarations).

43 The D programming language, which Beast is in-
44 spired by the most, offers all of the functionality men-
45 tioned above, however the concepts are implemented
46 rather in the standalone way. Beast brings improve-
47 ment to the following aspects:

48 1. D has a dedicated template argument list similar
49 to C++ (the syntax is `!(args)` instead of `<args>`
50 and the `!` is omitted in declarations), making
51 compile-time parameters clearly separated from
52 runtime ones. Functions that differ only in one
53 parameter being compile-time (template) or not
54 have an extensively different syntax (as shown
55 in Figure 1).

56 Beast has one common parameter list for run-
57 time and compile-time parameters, resulting in
58 zero syntax difference between runtime and com-
59 pile-time parameters. It is even possible to use
60 parameters in a single function declaration to
61 work both as runtime or compile-time depend-
62 ing on the context – if the provided argument can
63 be evaluated at compile time, it is considered a
64 template parameter, otherwise it is considered
65 to be runtime (demonstrated in Figure 2).

66 2. The D programming language does not have
67 mutable compile-time variables, which makes
68 solving some problems impossible with iteration,
69 forcing programmers to use recursion (or
70 mixins), which often results in a hardly-readable
71 code (demonstrated in Figure 3). Beast supports
72 mutable compile-time variables (see Figure 4).

```
1 // D code
2 string format( Args ... )( string fmt,
3   Args args ) { ... }
4 string format( string fmt, Args ... )(
5   Args args ) { ... }
6
7 void main() {
8   auto rt = format( "%s, %i worlds",
9     "hello", 5 );
10
11   auto ct = format!( "%s, %i worlds" )(
12     "hello", 5 );
13 }
```

Figure 1. Usage of the `format` function in the D programming language (similar to `sprintf` in C). Second `format` definition and function call accept the `fmt` string as a template parameter, resulting in the string formatting code being generated at compile time.

```
1 String format( @autotime string fmt, auto
2   arg ... ) { ... }
3
4 Void main() {
5   auto rt = format( Console.readLine, "hello",
6     5 );
7
8   auto ct = format( "%s, %i worlds", "hello",
9     5 );
10 }
```

Figure 2. Beast code corresponding to D code in Figure 1. On line 4, the `fmt` argument cannot be evaluated at compile time, resulting in it being considered a runtime parameter. On line 6, the argument can be evaluated at compile time, resulting in it being treated as `@ctime` (compile-time, template) and in string formatting code being generated at compile time.

```
1 // D code
2 template memberTypes1( Type ) {
3   alias memberTypes1 = helper!( __traits(
4     allMembers, Type ) );
5
6   template helper( string[] members ) {
7     static if( members.length )
8       alias helper = TypeTuple!(
9         typeof( __traits( getMember, Type,
10           members[ 0 ] ) ),
11         helper!( member[ 1 .. $ ] ) );
12     else
13       alias helper = TypeTuple!();
14   }
15
16   template memberTypes2( Type ) {
17     mixin( {
18       string[] result;
19
20       foreach( memberName; __traits(
21         allMembers, Type ) )
22         result ~=
23           "typeof( __traits( getMember, Type,
24             %s ) )"
25             .format( memberName );
26
27       return "TypeTuple!( %s )".format(
28         result.joiner( ", " ) );
29     } )();
30   }
31 }
```

Figure 3. Two approaches of writing a 'function' returning a `TypeTuple` (compile-time analogy to an array) of types of members of given type `Type` in the D programming language. First approach uses recursion, second one mixins.

```

1 | @ctime Type[] memberTypes( Type T ) {
2 |     Type[]! result;
3 |
4 |     foreach( auto member; T.#members )
5 |         result ~= member.#type;
6 |
7 |     return result;
8 | }

```

Figure 4. Beast function corresponding to D 'functions' from Figure 3. The function returns array of types of members of given type τ .

2. Principles of code hatching

The code hatching concept is based on a simple idea – having a classifier for variables whose value is deducible during compile time. In Beast, those variables are classified using the @ctime decorator (usage @ctime Int x;). Local @ctime variables can be mutable; because Beast declarations are not processed in order as they are declared in source code, order of evaluation of expressions modifying static @ctime variables cannot be decided; that means that static @ctime variables cannot be mutable. All @ctime variable manipulations are evaluated at compile time.

@ctime variables can also be included within a standard code (although their mutation can never depend on non-@ctime variables or inputs).

```

1 | @ctime Int z = 5;
2 |
3 | Void main() {
4 |     @ctime Int! x = 8;
5 |     Int! y = 16;
6 |     y += x + z;
7 |     x += 3;
8 | }

```

Figure 5. Example of mixing @ctime and non-@ctime variables in Beast

The concept of variables completely evaluable at compile time brings a possibility of having type variables (only @ctime, runtime type variables cannot be effectively done in compiled, statically typed languages). As a consequence, class and type definitions in general can be considered @ctime constant variables (thus first-class citizens).

```

1 | Void main() {
2 |     @ctime Type! T = Int;
3 |     T x = 5;
4 |     T = Bool;
5 |     T b = false;
6 | }

```

Figure 6. Example of using type variables in Beast

Having type variables, templates can be viewed as functions with @ctime parameters, for example class templates can be viewed functions returning a type.

With @ctime variables, generics, instead of being a standalone concept, become a natural part of the language.

```

1 | auto readFromStream( @ctime Type T, Stream!?
   |     stream )
2 | {
3 |     T result;
4 |     stream.readData( result.#addr,
   |         result.#sizeof );
5 |     return result;
6 | }
7 |
8 | Void main() {
9 |     Int x = readFromStream( Int, stream );
10 | }

```

Figure 7. Example of a function with @ctime parameters in Beast

Adding compile-time reflection is just a matter of adding compiler-defined functions returning appropriate @ctime data.

The @ctime decorator can also be used on more syntactical constructs than just variable definitions:

- @ctime code blocks are entirely performed at compile time.
- @ctime branching statements (if, while, for, etc.) are performed at compile time (not their bodies, just branch unwrapping).
- @ctime functions are always executed at compile time and all their parameters are @ctime.
- @ctime expressions are always evaluated at compile time.
- @ctime class instances can only exist as @ctime variables (for instance, Type is a @ctime class)

To make the code hatching concept work, it is necessary to ensure that @ctime variables are truly evaluable at compile time. That is realized by the following rules. Their deduction can be found in author's bachelor thesis [1] (downloadable from the Github repository).

1. @ctime variables cannot be data-dependent on non-@ctime variables.
 - (a) Data of non-@ctime variables cannot be assigned into @ctime variables.
 - (b) It is not possible to change @ctime variables declared in a different runtime scope; for example it is not possible to change @ctime variables from a non-@ctime if body if they were declared outside it.
2. Static (non-local) @ctime variables must not be mutable.
3. If a variable is @ctime, all its member variables (as class members) are also @ctime.

4. If a reference/pointer is @ctime, the referenced data is also @ctime.
5. @ctime variables can only be accessed as constants in a runtime code.
6. @ctime references/pointers are cast to pointers/references to constant data when accessed from runtime code.
7. A non-@ctime class cannot contain member @ctime variables.

```

1 Void main() {
2     @ctime if( true )
3         println( "Hello, %s!".format( "world" ) );
4     else
5         println( "Nay! );
6
7     @ctime for( Int! x = 0; x < 3; x ++ )
8         print( x );
9
10    print( @ctime "Goodbye, %s!".format(
11        "world" ) );
12 }
13 // Is processed into:
14 Void main() {
15     println( "Hello, %s!".format( "world" ) );
16     print( 0 );
17     print( 1 );
18     print( 2 );
19     print( "Goodbye, world!" );
20 }

```

Figure 8. Example usage of the @ctime decorator in Beast

References

- [1] Daniel Čejchan. Compiler for a new modular programming language, 2017.
- [2] D programming language, c1999-2017.
- [3] Nim programming language, c2015.
- [4] The crystal programming language, c2015.
- [5] Ante: The compile-time language, 2015.
- [6] The zig programming language, 2015.

```

1 class C {
2
3     @public:
4         Int! x; // Int! == mutable Int
5
6     @public:
7         // Operator overloading, constant-value
8         // parameters
9         Int #opBinary(
10             Operator.binPlus,
11             Int other
12         )
13         {
14             return x + other;
15         }
16
17     enum Enum {
18         a, b, c;
19
20         // Enum member functions
21         Enum invertedValue() {
22             return c - this;
23         }
24     }
25
26     String foo( Enum e, @ctime Type T ) {
27         // T is a 'template' parameter
28         // 'template' and normal parameters are in
29         // the same parentheses
30         return e.to( String ) + T.#identifier;
31     }
32
33     Void main() {
34         @ctime Type T! = Int; // Type variables!
35         T x = 3;
36
37         T = C;
38         T! c := new auto(); // C!? - reference to
39         // a mutable object, := reference
40         // assignment operator
41         c.x = 5;
42
43         // Compile-time function execution, :XXX
44         // accessor that looks in parameter type
45         @ctime String s = foo( :a, Int );
46         stdout.writeln( s );
47
48         stdout.writeln( c + x ); // Writes 8
49         stdout.writeln(
50             c.#opBinary.#parameters[1].type.#identifier
51         ); // Compile-time reflection
52     }
53 }

```

Figure 9. Beast features showcase (currently uncompileable by the proof-of-concept compiler)

3. Existing solutions

Beast is inspired by the D Programming Language [2]. Differences between Beast and D are described in Section 1.

Among imperative compiled languages, there are no other well-established programming languages with such metaprogramming capabilities. However, recently several new programming language projects introducing compile-time capabilities emerged – for example Nim [3], Crystal [4], Ante [5] or Zig [6]. From the list, Zig is the most similar language to Beast. Author of Beast and the code hatching concept was not aware of existence of Zig during the language design, so the two languages emerged independently.

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