LDC: The LLVM-based D Compiler

Using LLVM as backend for a D compiler

Kai Nacke

02/02/14

LLVM devroom @ FOSDEM´14

Agenda

- Brief introduction to D
- Internals of the LDC compiler
- Used LLVM features
- Possible improvements of LLVM

What is D?

- C-like syntax
- Static typing
- Supports many paradigms
  - Polymorphism, functional style, generics, contract programming
- Scales up to large projects
  - Modules, interfaces, unit tests
- Convenient and powerful features
  - Garbage collection, array slices, compile-time function execution (CTFE)

Code Examples

```
void main() {
    import std.stdio;

    writeln("Hello FOSDEM!");
}
```

```
import std.stdio;
import std.array;
import std.algorithm;

void main() {
    stdin.byLine(KeepTerminator.yes).
    map!(a => a.idup).
    array.
    sort.
    copy(stdout.lockingTextWriter());
}
```

```
module myalgo;

import std.traits;

T gcd(T)(T a, T b) pure
        if(isIntegral!T) {
    while (b) {
        auto t = b;
        b = a % b;
        a = t;
    }
    return a;
}

unittest {
    // CTFE
    enum val1 = gcd(3, 5);
    assert(val1 == 1);

    // No CTFE
    assert(gcd(25, 35) == 5);
}
```

Code Examples - hello

```d
void main() {
    import std.stdio;

    writeln("Hello FOSDEM!");
}
```

```d
import std.stdio;
import std.array;
import std.algorithm;

void main() {
    stdin.byLine(KeepTerminator.yes).
    map!(a => a.idup).
    ter());
```

```d
module myalgo;

import std.trai

T gcd(T)(T a, T
        if(isIn
    while (b) {
        auto t
        b = a % b;
        a = t;
    }
    return a;
}

unittest {
    // CTFE
    enum val1 = gcd(3, 5);
    assert(val1 == 1);

    // No CTFE
    assert(gcd(25, 35) == 5);
}
```

```d
void main() {
    import std.stdio;

    writeln("Hello FOSDEM!");
}
```

Code Examples - gcd

```d
module myalgo;

import std.traits;

T gcd(T)(T a, T b) pure if(isIntegral!T) {
    while (b) {
        auto t = b;
        b = a % b;
        a = t;
    }
    return a;
}

unittest {
    // CTFE
    enum val = gcd(3, 5);
    assert(val == 1);

    // No CTFE
    assert(gcd(25, 35) == 5);
}
```

Code Examples - sort

```
void main() {
    import std.stdio;

    writeln("
}
```

```
import std.stdio;
import std.array;
import std.algorithm;
```

```
module myalgo

import std.tr

T gcd(T)(T a,
        if(is
    while (b)
        auto
        b = a
        a = t
    }
    return a;
}

unittest {
    // CTFE
    enum val1
    assert(val1 == 1);

    // No CTFE
    assert(gcd(25, 35) == 5);
}
```

```
import std.stdio;
import std.array;
import std.algorithm;

void main() {
    stdin.byLine(KeepTerminator.yes).
    map!(a => a.idup).
    array.
    sort.
    copy(stdout.lockingTextWriter());
}
```

The case for D

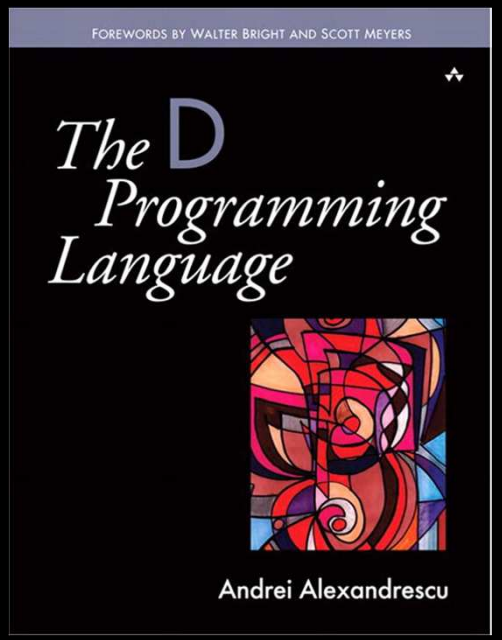
- 18th place on the TIOBE index
- Companies adopting D

sociomantic

REMEDY

funkwerk
information technologies
Innovative information solutions

- Books about D



LDC =  +

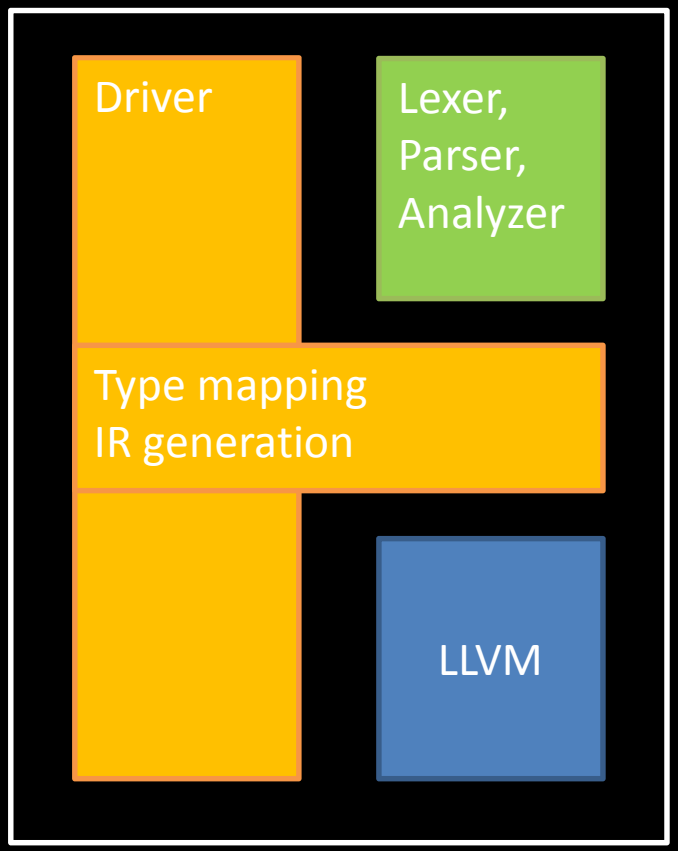
What about combining the D frontend with LLVM?

The idea is about 10 years old! The result is LDC.

Facts about LDC

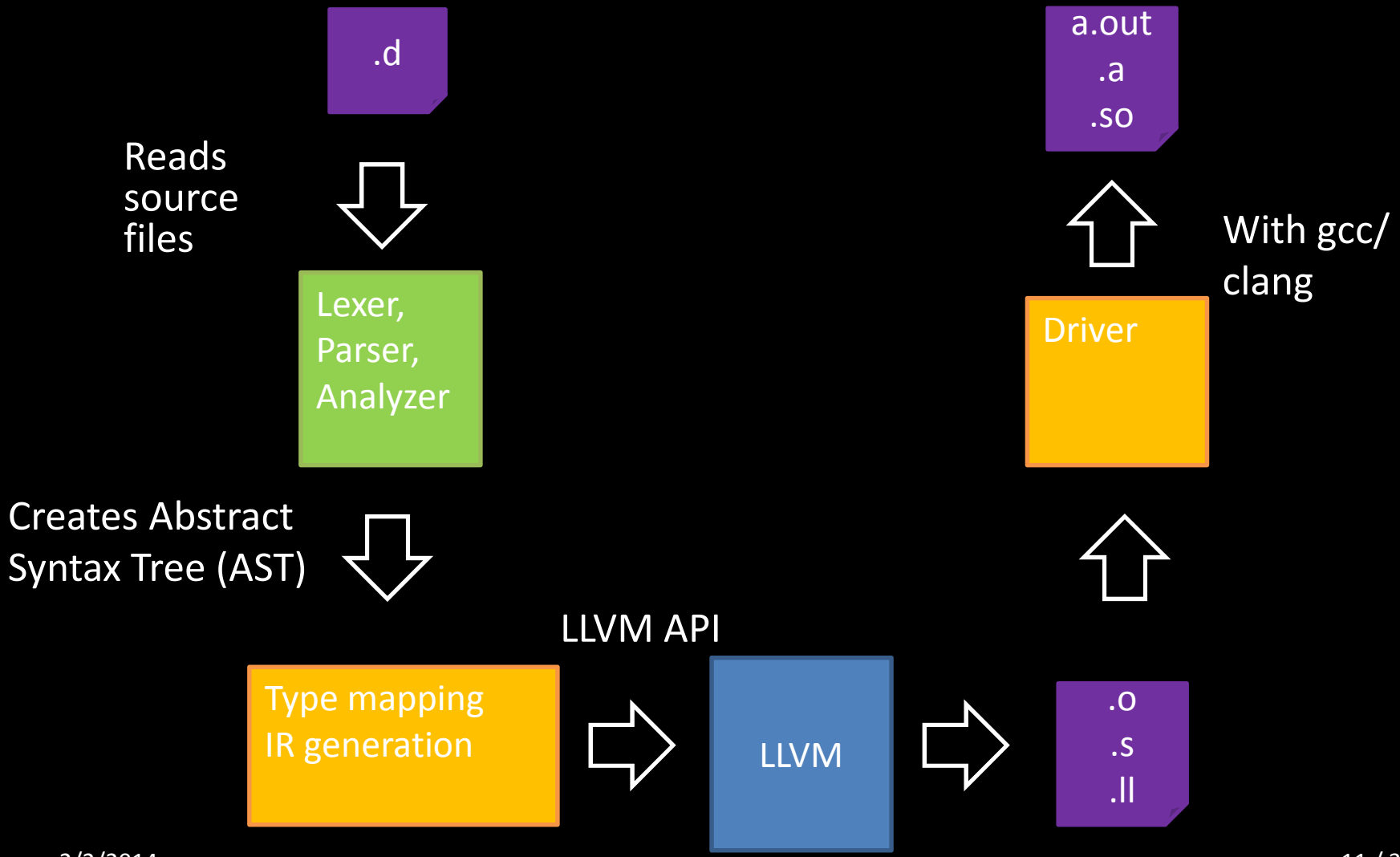
- Version 0.13.0 alpha recently announced
- Written in C++ (transition to D planned)
- Requires LLVM 3.1 or later
- Runs on most Posix-like x86/x86_64 OS‘s
  - Linux, OS X, FreeBSD, Mingw32
- Native Windows version depends on LLVM
- Port to Linux/PPC64 almost finished
- Work on port to Linux/ARM has started

The architecture of LDC



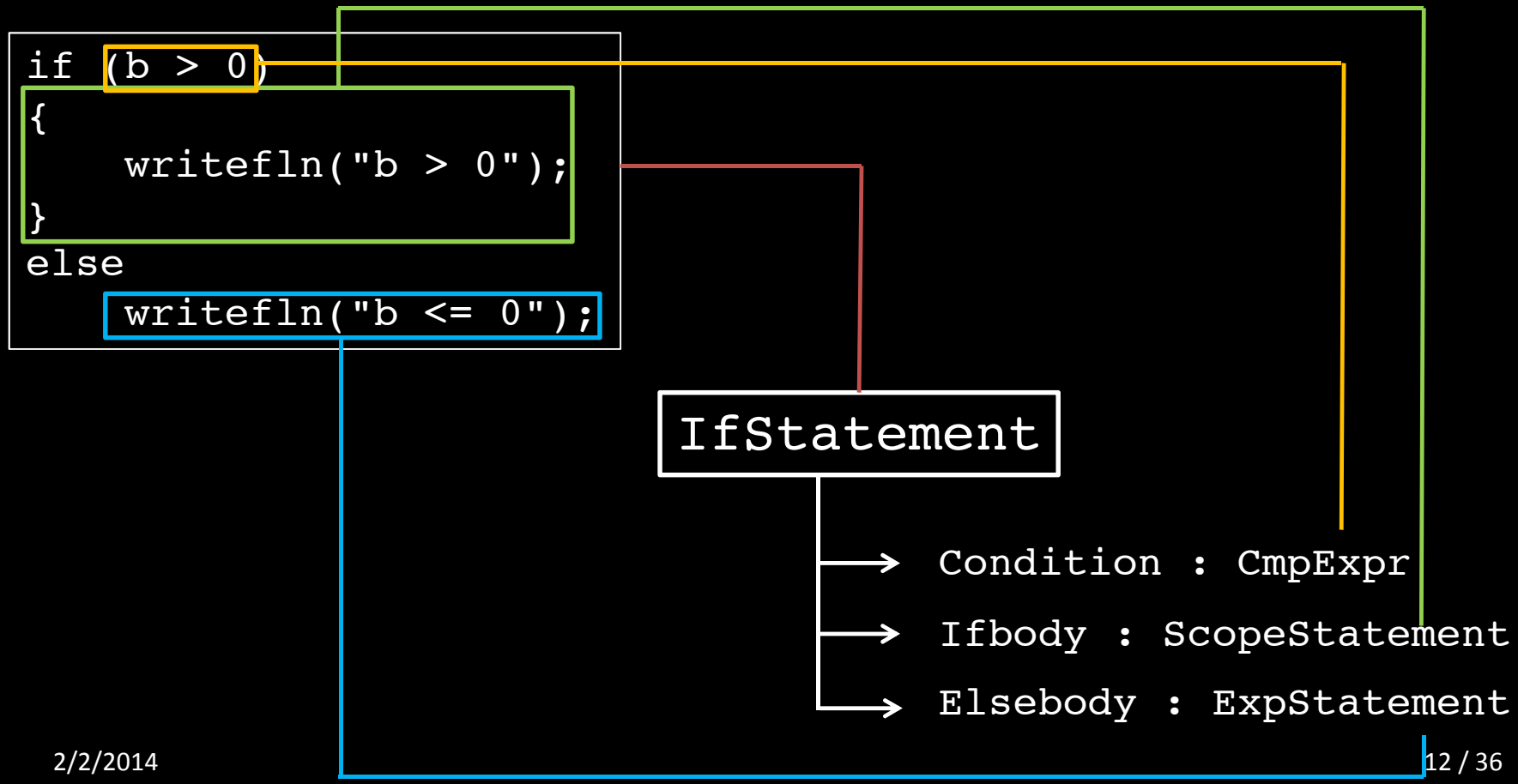
- Typical multi-pass compiler
  - Lexer, Parser, Analyzer from DMD
  - Type mapping and IR generation
  - Code generation with LLVM
- Illustrates Conway‘s law

Closer look at data flow



Abstract Syntax Tree from Frontend

- Frontend generates fully decorated AST



AST

- Frontend already lowers some statements

```
scope(exit) { ... }
/* stmts */
```

```
try { /* stmts */ }
finally { ... }
```

```
foreach (a; 1..10) {
    /* stmts */
}
```

```
for (int key = 1;
     key < 10; ++key) {
    /* stmts */
}
```

- Simplifies IR generation
- Complicates generation of debug info

IR generation

- IR is generated with a tree traversal
- Uses visitor provided by frontend
  - New code, it is different in current release
- IR is attached to main entities
  - Example: FuncDeclaration <- IrFunction
- Generated IR could be improved

IR generation example - if

```
int a;

if (a > 0)
    ...
else
    ...
```

```
  %tmp = load i32* %a
  %tmp1 = icmp sgt i32 %tmp, 0
  br i1 %tmp1, label %if,
               label %else

if:
  ...
  br label %endif

else:
  ...
  br label %endif

endif:
```

IR generation example - for

```
for (int i = 0;
     i < a.length;
     ++i)
    {
        ...
    }
```

```
 ...
  br label %forcond

forcond:
  ...
  br i1 %tmp6,
     label %forbody,
     label %endfor

forbody:
  ...
  br label %forinc

forinc:
  ...
  br label %forcond

endfor:
```

Type mapping

- Mapping of simple types

```
byte  / ubyte
short / ushort
int   / uint
long  / ulong
float
double
real
```

```
i8
i16
i32
i64
float
double
x86_fp80 / ppc_fp80 / double
```

- Mapping of type bool

```
bool
```

```
i8
```

- Use of `i1` for bool turned out to be wrong!

Type mapping

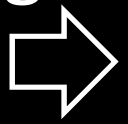
- Static arrays are mapped to LLVM arrays

```
int[5]
```

```
[5 x i32]
```

- Dynamic arrays are mapped as anonymous structs with length and pointer to data

```
int[]
```



```
{ i64, i32* }
```

- Associative arrays are opaque to the compiler

```
int[string]
```

```
i8*
```

Type mapping

- Structs are mapped to LLVM structs

```
struct {
    byte a;
    byte b;
    short c;
}
```

```
type {
    i8,
    i8,
    i16
}
```

- Classes are structs with a vtable and a monitor

```
class {


    long a;
}
```

```
type {
    %type.ClassA.__vtbl*,
    i8*,
    i64
}
```

- Padding is added if required

D-specific LLVM passes

- LLVM knows nothing about D and its runtime library!
- Adding D-specific knowledge to LLVM helps to optimize the code
- Currently these passes are available
  - GarbageCollect2Stack
  - SimplifyDRuntimeCalls
  - StripExternals

D-specific LLVM passes

- GarbageCollect2Stack
  - Tries to turn a GC allocation into a stack allocation
  - Useful for closures

```
int b = 5;
foreach (int i; 0..10)
{
    apply(a => b*a, i);
    b = 2*b;
}
```

- Requires memory allocation for nested frame
- Can be turned into alloca if memory does not escape function
- Based on PointerMayBeCaptured
- Conservative in loops, can be improved

D-specific LLVM passes

- SimplifyDRuntimeCalls
  - Replaces/optimizes calls of D runtime, mainly for arrays
  - Framework copied from SimplifyLibcalls
- StripExternals
  - Removes body of functions declared as available_externally
  - Used as support for global dead code elimination (GlobalDCE)

Porting to new platforms

- Required LLVM features
  - Thread-local storage (TLS)
  - Exception handling
  - Anonymous structs
- Nice to have
  - Inline assembler
  - Debug symbols
  - Some intrinsics
- Features are not supported by all LLVM targets

Porting to new platforms

- Common problems found in LLVM
  - TLS is not implemented / partially implemented / buggy
  - Wrong relocation generated
    - Most of the time TLS relocations
- E.g. on Linux/ARM – missing R_ARM_TLS_LDO32

```
localhost tmp # /build/work/ldc/bin/ldc2 -g hello.d
/usr/lib/gcc/armv7a-hardfloat-linux-gnueabi/4.8.2/../../../
../armv7a-hardfloat-linux-gnueabi/bin/ld: /build/work/ldc/r
untime/../lib/libphobos-ldc-debug.a(random-debug.o)(.debug_
info+0x31): R_ARM_ABS32 used with TLS symbol _D3std6random1
7unpredictableSeedFNdZk6seededb
```

Porting to new platforms

- Recommendation for porting

  Always use LLVM trunk!

- A new port can improve quality of LLVM
  - E.g. PowerPC64: 17 bug reports

- Many interesting platforms are yet unsupported (MIPS, AArch64, Sparc, ...)

Inline ASM

- LDC supports DMD-style ASM on x86/x86_64

```
 asm { naked;
    mov RAX, 8;
    mov RAX, GS:[RAX];
    ret;
}
```

- Inline assembler requires parsing of statements and construction of constraints
- Naked functions are translated to modul-level inline assembly
- Is not inlined by default

Inline ASM

- LLVM ASM is supported on all platforms via a special template

```
import ldc.llvmasm;

return __asm!(void*)("movq %gs:8, %rax", "={rax}");
```

- Prefered way because it can be inlined
- No debug info generated

Inline IR

- IR can be inlined via a special template

```
pragma(LDC_inline_ir)
    R inlineIR(string s, R, P...)(P);

void* getStackBottom(){
 return inlineIR!(`
            %ptr = inttoptr i64 %0 to i64 addrspace(256)*
            %val = load i64 addrspace(256)* %ptr, align 1
            %tmp = inttoptr i64 %val to i8*
            ret i8* %tmp`,
          void*, ulong)(8);
}
```

- Be aware that IR is not platform independent!

Inline IR

- Example translates to (EH removed)

```
_D3thr14getStackBottomFZPv:
        movq   %gs:8, %rax
        retq
```

- Useful to access IR features which are otherwise not available (e.g. shufflevector)
- Best result because of tight integration with LLVM
- No debug info generated

Attributes

- Used to change LLVM function attributes

```
import ldc.attribute;

@attribute("alwaysinline")
void func() {
   // ...
}
```

- Some attributes require more work
- Experimental feature, not yet finished

Integrating AdressSanitizer

- Integrate sanitizer passes into compile
  - opt is used as blueprint
- Add new option
  - `-sanitize=address`
- Add attribute `SanitizeAddress` to every function definition

Integrating AdressSanitizer

- Compile runtime library with new option
- Still missing: runtime support
  - Own allocator with GC
  - Use gcstub/gc.d instead
- Produces some aborts in unit tests on Linux/x86_64
- Evaluation of reports not complete

Better ABI support

- Frontend must have intimate knowledge of calling convention
- Degree of implementation of attributes varies
  - PPC64: Good
  - Win64: Needs more work (byval with structs)
- LDC uses an abi class to encapsulate the details for each supported platform
- Improvement: more complete implementation

Better ABI support

- Improvement: Implement helper for C ABI lowering in LLVM
- It is the default ABI in LLVM and every major language needs this
- Think of the effort required for MSC ABI in Clang
- Even better: Abstract the details away

Better Windows support

- No exception handling on native Windows
  - Most wanted feature by LDC users!
  - I am working on the implementation
  - There is already a Clang driver in PR18654
- No CodeView debug symbols
  - COFF line number support added recently
  - I started to work on this topic (a year ago...)

Looking for contributors

If you want to have fun with

- ... a cool language
- ... a friendly community
- ... hacking LLVM

then start contributing to LDC today!

http://forum.dlang.org/group/digitalmars.D.ldc

https://wiki.dlang.org/LDC

https://github.com/ldc-developers