Gotta Prove Fast

Building an Ecosystem for Effortless Native Compilation of Tactics

Sebastian Ullrich | 2022/01/22

The Lean 4 Project [de Moura & Ullrich 2021]

Provide a fully extensible theorem proving frontend

Erase the boundary between built-in and custom syntax/tactics/...
by reimplementing >75% of Lean in Lean itself

Make Lean an efficient, general-purpose programming language

Compiling Tactics – *How?*

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- A Just-In-Time Compiler? LLVM JIT?
  - + run tactic with native performance in the same file
  - – re-compile tactic in every importing file...?
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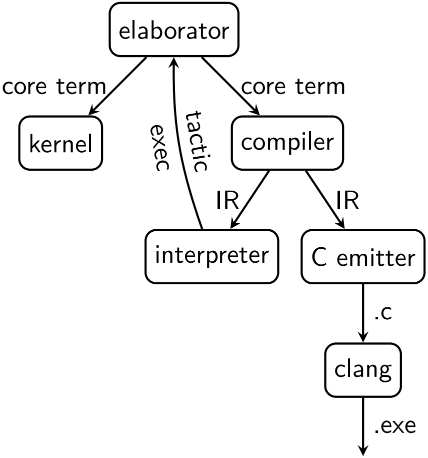
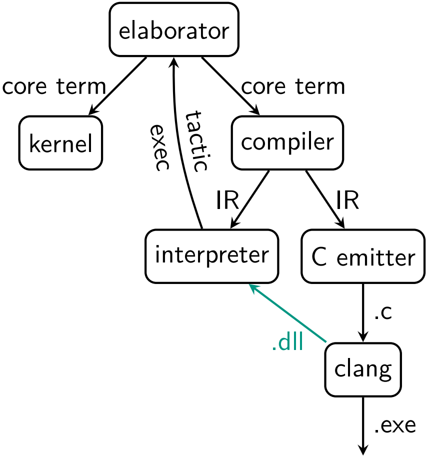
- reuse Ahead-Of-Time toolchain for stand-alone Lean programs
  - + much simpler... hopefully!
  - + benefits stand-alone use case as well
  - – should probably use the interpreter in the same file

Lean 4 Compilation Pipeline



Lean 4 Compilation Pipeline



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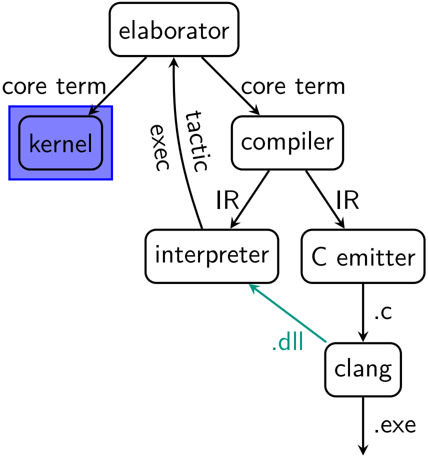
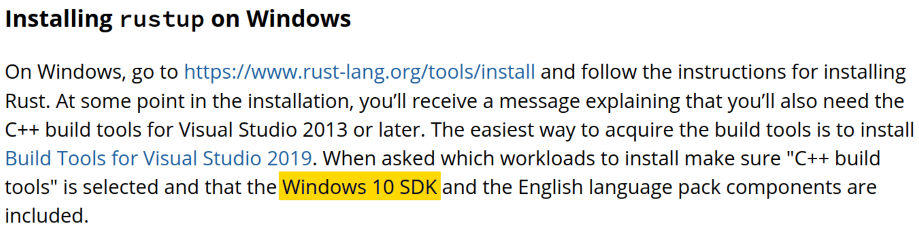


NB: The Trusted Code Base is unaffected!

So You Want to Build a Native Binary



Installing `rustup` on Windows

On Windows, go to https://www.rust-lang.org/tools/install and follow the instructions for installing Rust. At some point in the installation, you'll receive a message explaining that you'll also need the C++ build tools for Visual Studio 2013 or later. The easiest way to acquire the build tools is to install Build Tools for Visual Studio 2019. When asked which workloads to install make sure "C++ build tools" is selected and that the Windows 10 SDK and the English language pack components are included.

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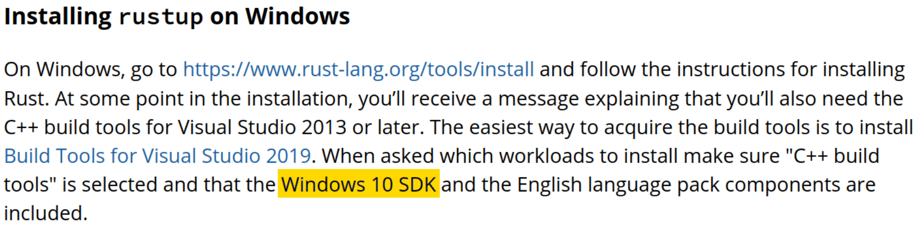

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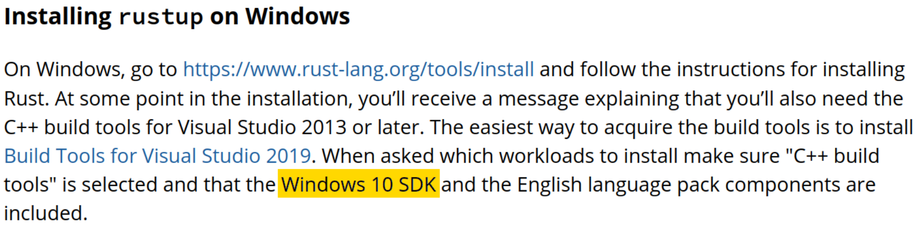

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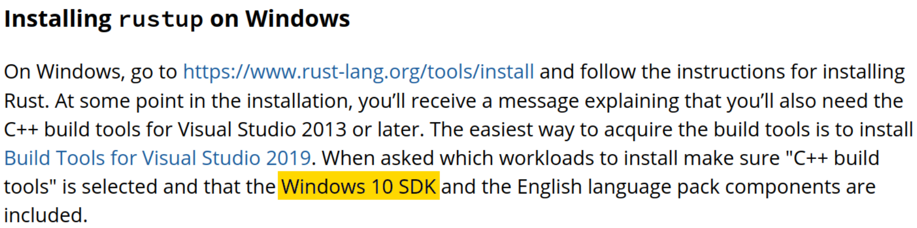

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We need effortless setup *not requiring root*!

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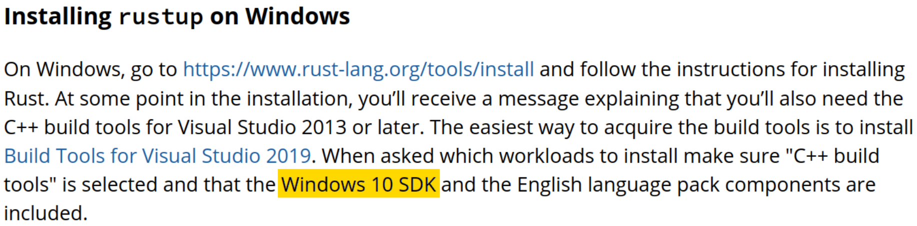

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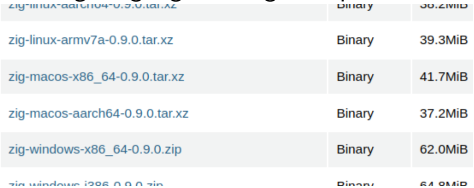
The *Zig* language manages to provide small, self-contained toolchains for many platforms



zig-linux-aarch64-0.9.0.tar.xz	Binary	38.2MiB
zig-linux-armv7a-0.9.0.tar.xz	Binary	39.3MiB
zig-macos-x86_64-0.9.0.tar.xz	Binary	41.7MiB
zig-macos-aarch64-0.9.0.tar.xz	Binary	37.2MiB
zig-windows-x86_64-0.9.0.zip	Binary	62.0MiB
zig-windows-i386-0.9.0.zip	Binary	64.8MiB

Assembling a Native Compilation Pipeline

LLVM comes with many necessary parts:

- a C compiler
- basic C headers
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- a linker (good macOS support since LLVM 13)
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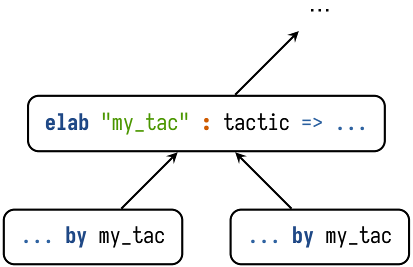
  - Windows:
    ```
    cp /clang64/x86_64-w64-mingw32/lib/lib{m,bcrypt,mingw32,moldname,mingwex,msvcrt,pthread,advapi32,shell32,user32,k
    ```

Compiling Tactics – *Where?*



...

```
elab "my_tac" : tactic => ...
```

```
... by my_tac
```

```
... by my_tac
```

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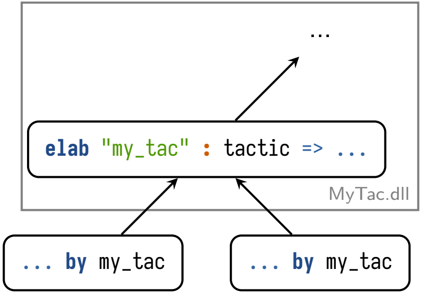

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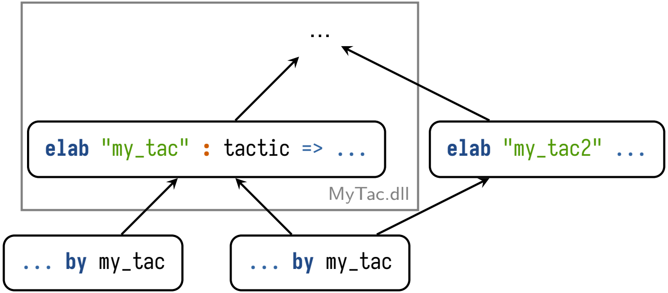

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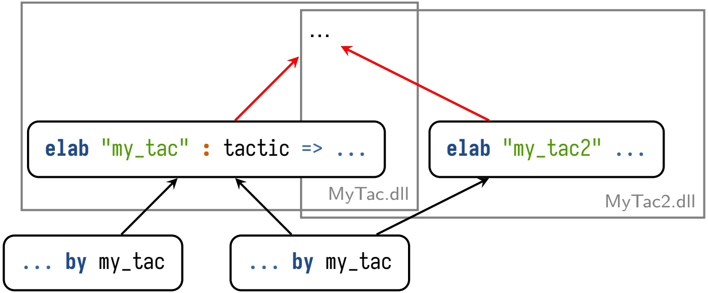

Must *partition* modules into shared libraries to avoid duplicate symbols

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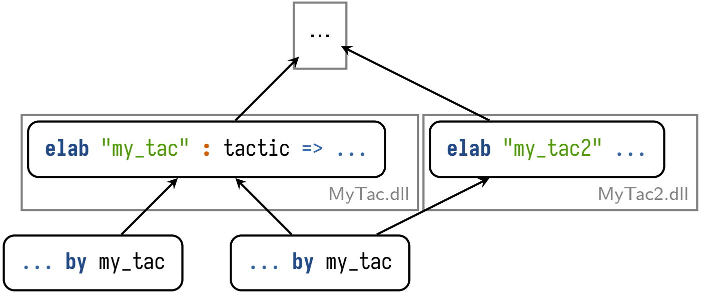

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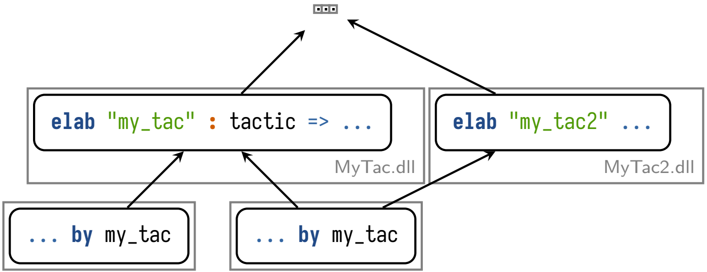
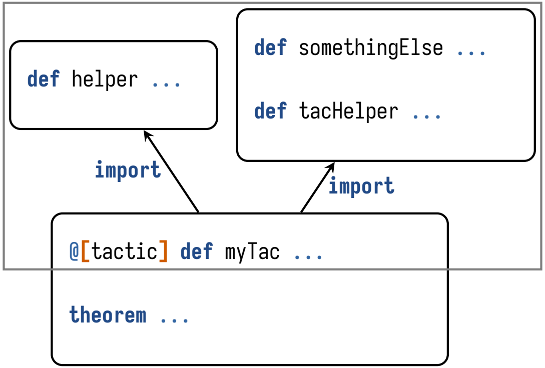


Must *partition* modules into shared libraries to avoid duplicate symbols
... or simply generate one library per module (& package)

Compiling Tactics – *Unless?*

Compiling definitions that are never executed is wasteful



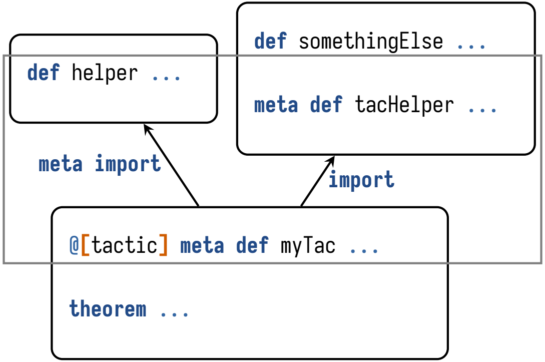
```
def helper ...
```

```
def somethingElse ...

def tacHelper ...
```

```
@[tactic] def myTac ...

theorem ...
```

Compiling Tactics – *Unless?*

Compiling definitions that are never executed is wasteful – *phase separation* [Flatt 2002] could tell us where the metaprograms are



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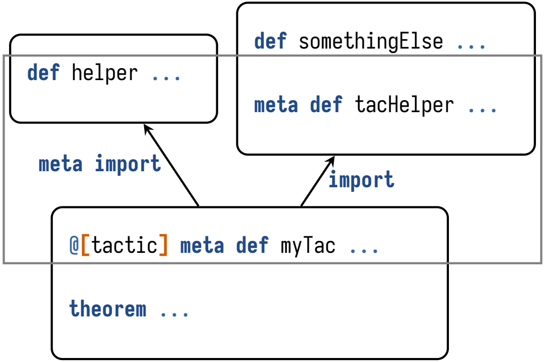

```
def helper ...
```

```
def somethingElse ...

meta def tacHelper ...
```

```
@[tactic] meta def myTac ...

theorem ...
```

Bonus points if changing `helper` does not recompile `myTac` – *separate compilation!*

Summary

Today:

- Effortless native tactic compilation by coordinating the compiler, build system, and interpreter
- A stand-alone LLVM toolchain is *possible*

For the future:

- Scalability questions such as to number and size of shared libraries remain to be seen
- We want a better module/compilation unit system[1]

de Moura, Leonardo and Ullrich, Sebastian (2021). “The Lean 4 Theorem Prover and Programming Language”. In: CADE.

Flatt, Matthew (2002). “Composable and Compilable Macros: You Want It When?” In: ICFP.

[1] `https://github.com/leanprover/lean4/issues/416`

Relevant Pull Requests

- *Build & distribute release builds with Zig as stand-alone C compiler* (abandoned)
  `https://github.com/leanprover/lean4/pull/659`
- *Bundle LLVM on all platforms* (merged)
  `https://github.com/leanprover/lean4/pull/795`
- *Simple, opt-in precompilation scheme*
  `https://github.com/leanprover/lean4/pull/949`

Early mathlib4 Benchmarks (Warm ccache)

```
  diff [s]           drv
----------  -------  ----------------------------------------
  -0.0976    -12.4%  Mathlib.Tactic.Lint.Simp
  -0.0882     -3.6%  Mathlib.Data.List.Basic
  -0.0812     -6.6%  Mathlib.Init.Data.Int.Order
  +0.0745   +100.0%  Mathlib.Mathport.Syntax-dynlib
  +0.0697   +100.0%  Mathlib.Data.Prod-dynlib
  +0.069    +100.0%  Mathlib.Init.Data.List.Lemmas-dynlib
  +0.069    +100.0%  Mathlib.Data.UInt-dynlib
  +0.0687   +100.0%  Mathlib.Data.ByteArray-dynlib
  +0.0686   +100.0%  Mathlib.Data.Fin.Basic-dynlib
  +0.0684   +100.0%  Mathlib.Tactic.NormNum-dynlib
  +0.0682   +100.0%  Mathlib.Tactic.Ring-dynlib
  +0.0681   +100.0%  Mathlib.Data.Subtype-dynlib
  +0.068    +100.0%  Mathlib.Data.Option.Basic-dynlib
...
  +7.84      +16.5%  total
```