The Black Magic of Python Wheels

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Wheels/Black Magic FAQ

Q: But I’m not a witch?!

A: *Sometimes the greater good requires a little sacrifice.*

Topics

- Python packaging and distribution
- ELF (Executable and Linkable Format) files
- Dynamic vs. static linking

Outline

- A brief history of Python packaging and distribution
- An overview of the wheel
- Why we need native extensions
- How do native extensions even work, really?
  - What are `manylinux` and `auditwheel` for?
- How you can get involved

A Brief History of Python Packaging: Eggs

- Organically adopted (no guiding PEP)
- No standard → many incompatible implementations
- Designed to be directly importable, could include compiled Python (`.pyc` files)

Python Packaging Reinvented: The Wheel

- Adopted via PEP 427
- Follows the PEP 376 standard for distributions and PEP 426 standard for package metadata
- Designed for distribution, cannot include `.pyc` files (but may include other pre-compiled resources)

Wheels “make it easier to roll out” Python

- Pure wheels
  - Only contain Python code
  - May target a specific version of Python
- Universal wheels
  - Python 2/3 compatible pure wheels

```
pip install wheel
python setup.py bdist_wheel
```

Wheels “make it easier to roll out” Python

- Pure wheels
  - Only contain Python code
  - May target a specific version of Python
- Universal wheels
  - Python 2/3 compatible pure wheels
- Extension wheels
  - ???

Extensions without binary distributions

```
$ pip install --no-binary :all: cryptography
...
    c/_cffi_backend.c:2:10: fatal error: Python.h:
No such file or directory
     #include <Python.h>
              ^~~~~~~~~~
    compilation terminated.
    error: command 'x86_64-linux-gnu-gcc' failed
with exit status 1
$ sudo apt install python-dev  # get Python.h
```

Extensions without binary distributions

```
$ pip install --no-binary :all: cryptography

...
    c/_cffi_backend.c:15:10: fatal error: ffi.h: No
such file or directory
     #include <ffi.h>
              ^~~~~~~
    compilation terminated.
    error: command 'x86_64-linux-gnu-gcc' failed
with exit status 1

$ sudo apt install libffi-dev  # get ffi.h
```

Extensions without binary distributions

```
$ pip install --no-binary :all: cryptography

...
   build/temp.linux-x86_64-2.7/_openssl.c:498:10:
fatal error: openssl/opensslv.h: No such file or
directory
     #include <openssl/opensslv.h>
              ^~~~~~~~~~~~~~~~~~~~
    compilation terminated.
    error: command 'x86_64-linux-gnu-gcc' failed
with exit status 1

$ sudo apt install libssl-dev  # get opensslv.h
```

Extensions without binary distributions

```
$ time pip install --no-binary :all: cryptography
Successfully installed asn1crypto-0.24.0 cffi-
1.11.5 cryptography-2.3.1 enum34-1.1.6 idna-2.7
ipaddress-1.0.22 pycparser-2.19 six-1.11.0

real 0m16.369s
user 0m15.823s
sys  0m0.627s
```

Extensions with binary distributions

```
$ time pip install cryptography  # prebuilt binary

Successfully installed asn1crypto-0.24.0 cffi-
1.11.5 cryptography-2.3.1 enum34-1.1.6 idna-2.7
ipaddress-1.0.22 pycparser-2.19 six-1.11.0


real 0m1.088s
user 0m0.980s
sys  0m0.108s
```

What sort of black magic is this? ✨🔮

Extension Wheels are safe to `pip install`!

- Installing Python native extensions without wheels is painful
- Conda was developed to address this gap: why not use that?
  - Like eggs, Conda was not adopted by a PEP
  - Conda packages are not Python-specific, not supported by PyPI
  - Conda packages are not compatible with non-Conda environments
- Wheels are compatible with the entire Python ecosystem

What is a Python (Native) Extension?

- **Native:** the code was compiled specifically for my operating system
- **Extension:** this library extends Python's functionality with non-Python code
- **Example:** `cryptography`
  - It uses CFFI: the "C Foreign Function Interface" for Python

Python code is not just Python.

For Python to harness its full potential,
it must be able to depend on C libraries.

C is a compiled language

```c
// hello.c

#include<stdio.h>

int main(void) {
   puts("hello
         world");
}
```

```
# a.out (hexadecimal)

0000000 7f45 4c46 0201 0100
0000008 0000 0000 0000 0000
0000010 0300 3e00 0100 0000
0000018 5005 0000 0000 0000
0000020 4000 0000 0000 0000
...
```

ELF File

gcc hello.c

hexdump a.out

Hexes and ELFs

```
$ readelf -a a.out
ELF Header:
  Magic:   7f 45 4c 46 02 01 01 00
           00 00 00 00 00 00 00 00
  Class:             ELF64
  Data:              2's complement, little endian
  Version:           1 (current)
  OS/ABI:            UNIX - System V
  ABI Version:       0
  Type:              DYN (Shared object file)
  Machine:           Advanced Micro Devices X86-64
...
```

Hexes and ELFs

```
$ readelf -a a.out
...
Program Headers:
  Type        Offset               VirtAddr             PhysAddr
              FileSiz              MemSiz               Flags  Align
  INTERP      0x0000000000000238 0x0000000000000238 0x0000000000000238
              0x000000000000001c 0x000000000000001c  R      0x1
      [Requesting program interpreter: /lib64/ld-linux-x86-64.so.2]
```

ELF interpreter

Hexes and ELFs

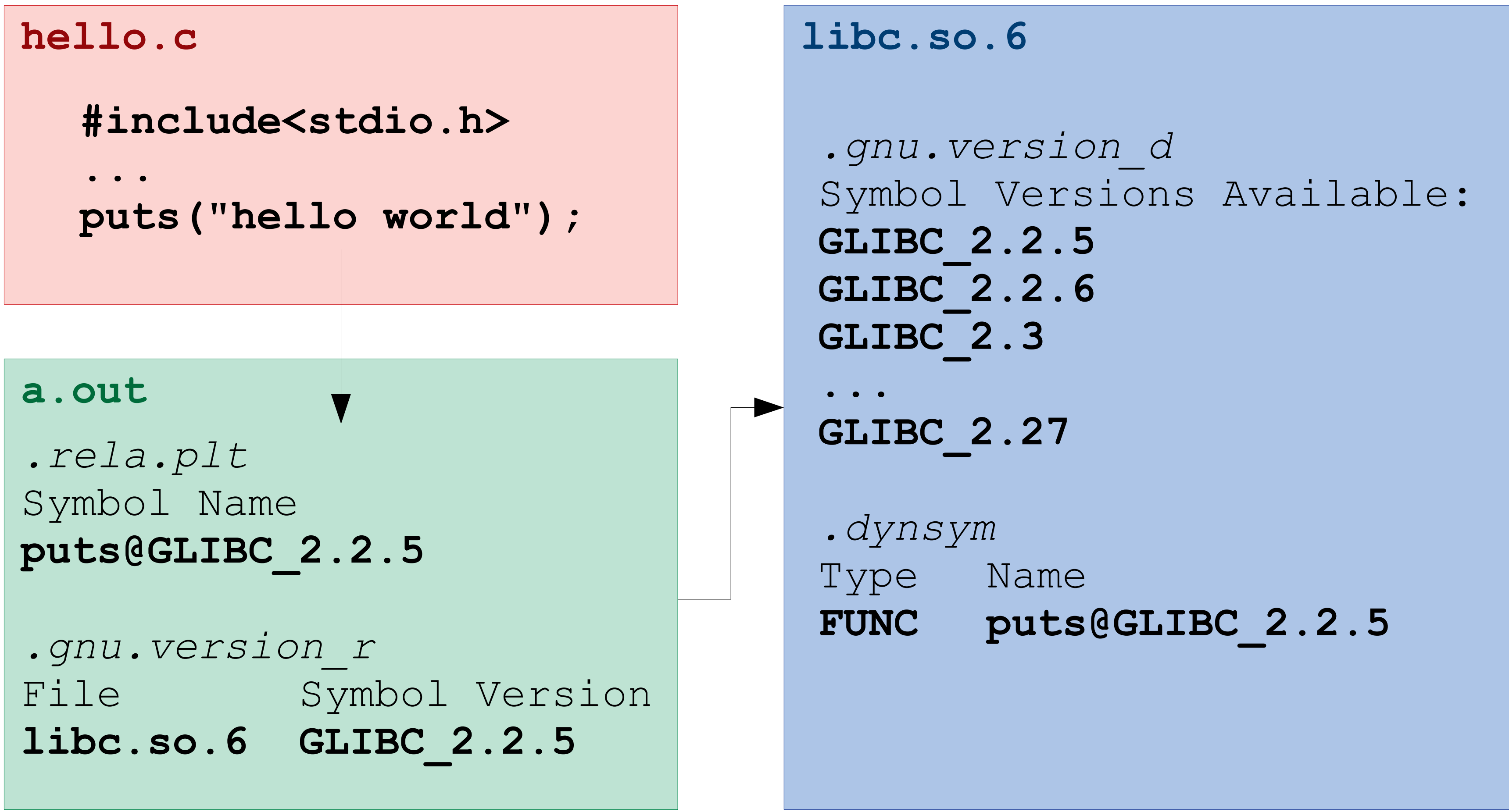
```
$ readelf -a a.out
...
Relocation section '.rela.plt' at offset
0x4d0 contains 1 entry:
  Offset          Info           Type
000000200fd0  000200000007 R_X86_64_JUMP_SLO
  Sym. Value     Sym. Name + Addend
0000000000000000 puts@GLIBC_2.2.5 + 0
```

Symbol Version

Hexes and ELFs

```
$ readelf -a a.out
...
Version needs section '.gnu.version_r' contains
1 entry:
 Addr: 0x00000000000003f0  Offset: 0x0003f0  Link: 6
(.dynstr)
  000000: Version: 1  File: libc.so.6  Cnt: 1
  0x0010:    Name: GLIBC_2.2.5  Flags: none  Version: 2
```

Symbol Versions in Action



What happens when we run this?

- OS parses "magic ELF" text
- OS invokes the ELF interpreter specified by the binary
- ELF interpreter loads any required files with valid versions
- ELF interpreter relocates the program code and dependencies in memory so that it can run
- This is called *dynamic linking*

Q: That all sounds really complex. Couldn’t I just include all the code I need in my output binary?

A: Sure! That’s called *static linking*.

Q: ...then why doesn’t everyone just do that??

Dynamic vs. Static Linking

- Pros: Dynamic
  - Less storage space used
  - One copy of a library = one upgrade
- Cons: Dynamic
  - Complex
  - Needs some kind of dependency management
- Cons: Static
  - More storage space used
  - May store many copies of one library
- Pros: Static
  - Simple
  - Dependencies are bundled with your programs

Conclusion: Static linking is great, but should be used sparingly.

…so…

What if we "used it sparingly" to build Python extensions for easier distribution?

But that might not work! What if my C standard library is too old to run your binary?

...so...

What if we made sure to statically link against symbol versions that are maximally compatible?

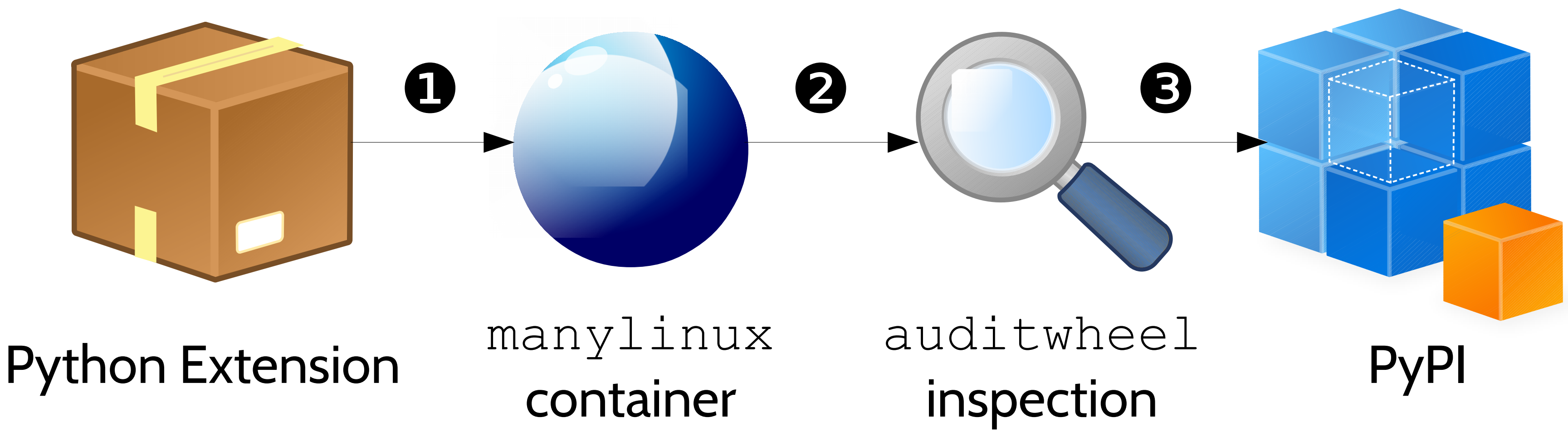
Q: How can we ship compiled Python extensions compatible with as many systems as possible?

A: Static linking (`manylinux`) and symbol versioning (`auditwheel`).

What are `manylinux` and `auditwheel`?

- PEPs 513 and 571 define a set of permitted libraries and their symbol versions for Linux systems
  - "Many" Linux systems are compatible with this standard
- `manylinux` is both the name of the policy and a Docker image
  - `manylinux1` (PEP 513): CentOS 5, i386/amd64 architectures
  - `manylinux2010` (PEP 571): CentOS 6, i386/amd64 architectures
- `auditwheel` is a tool to enforce the symbol policies

Wheel Builder's Pipeline for Linux



❶ Add your code, dependencies to the `manylinux` Docker image and build against your supported Python versions/architectures

❷ Inspect the built wheel with `auditwheel` for compliance

❸ Upload to PyPI!

Want in on the magic?

- Help us build wheels!
  - Feedback enthusiastically welcomed ✨
- pythonwheels.com
  - See what packages already build wheels
  - Find examples for how to build yours (including Windows, OS X)
- github.com/pypa/python-manylinux-demo
  - Simple demo to learn Linux wheelbuilding


Questions?

Thanks to:

Two Sigma Investments, LP
Nelson Elhage, Paul Kehrer, Donald Stufft

Talk resources: https://hashman.ca/pygotham-2018

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