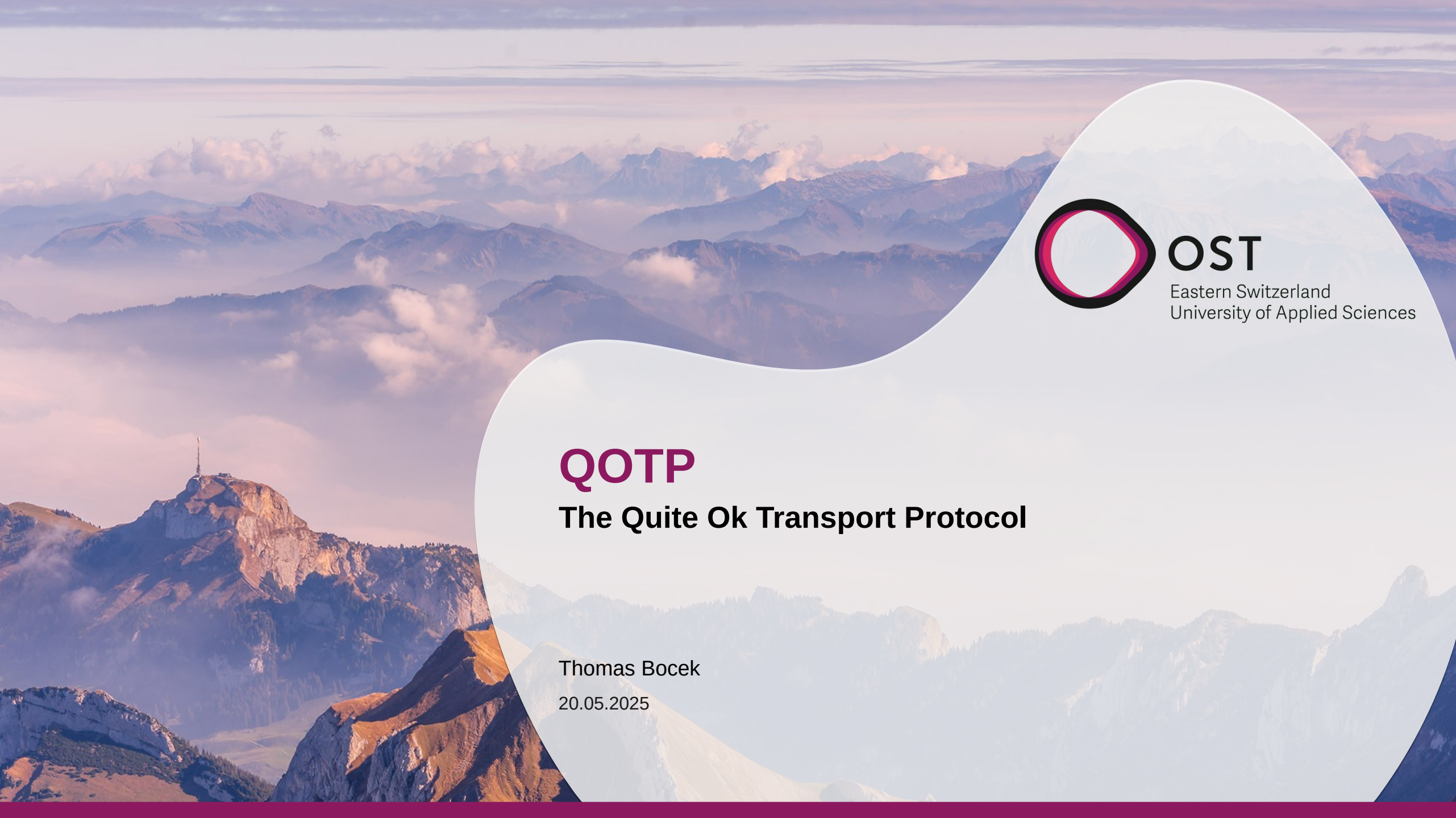

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QOTP

The Quite Ok Transport Protocol

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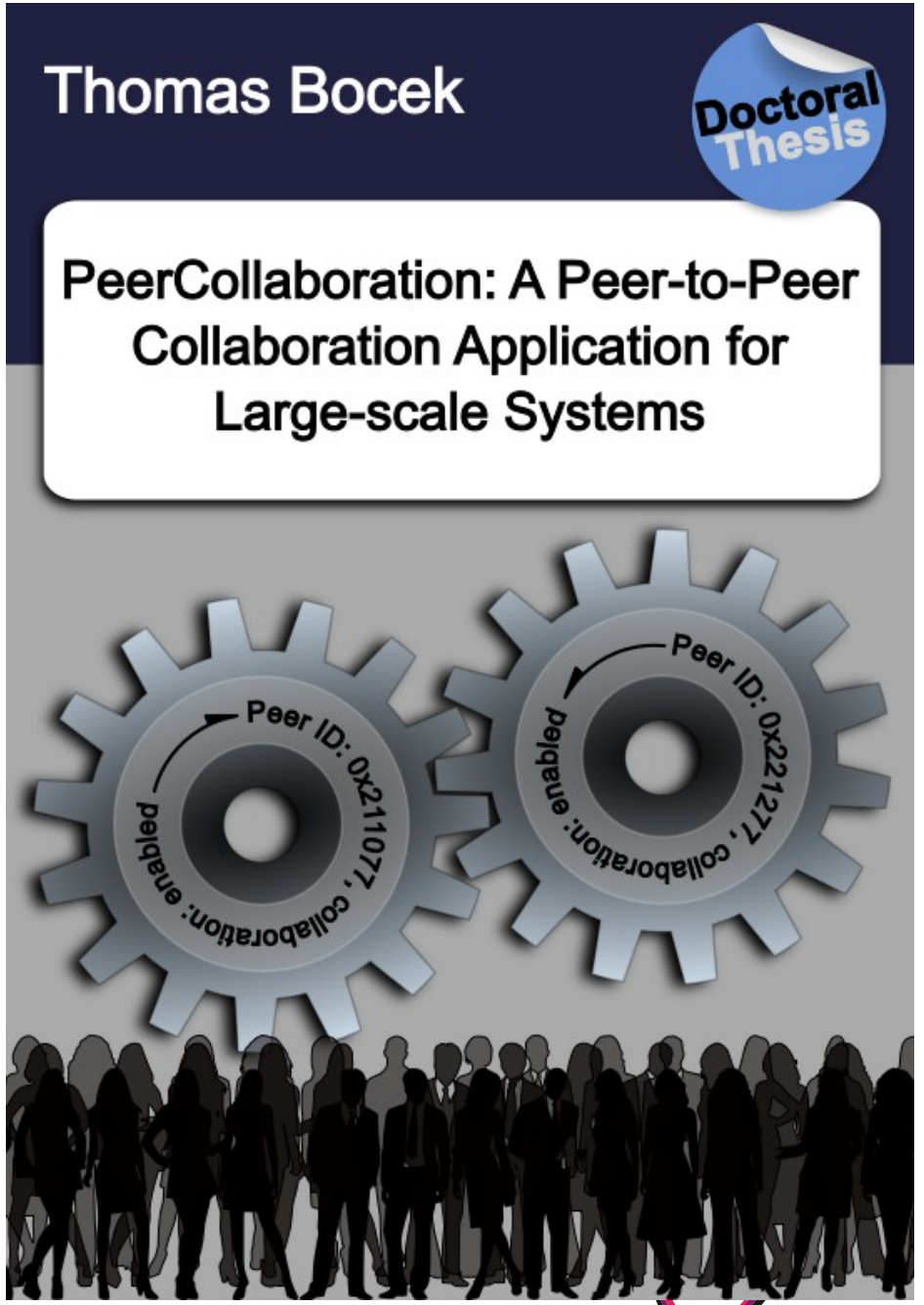
20.05.2025

PhD Topic

- Included TomP2P, a DHT implemented in Java
  - Used TCP, but TCP has many issues…
  - Not P2P friendly (hole-punching) – predict sequence numbers (besides predicting ports)
  - “too many open files in system”, 2 files per TCP connection

```
draft  /tmp  ulimit -n
1024
```

  - “time wait state” - TCP connection termination process → port exhaustion - issues with many short lived connections



Alternatives?

- KCP - no encryption, GFCP - a KCP variant, UDT - unmaintained
- utp4j - Micro Transport Protocol for Java – handed over to tribler (Delft University of Technology)
  - 0-RTT Protocol in Golang [link]
  - ATP – A P2P Protocol [link]
  - P2P Library in Golang (BA) [link]
- QUIC – complexity, good for low latency, but can be slow (receiver-side processing overhead)

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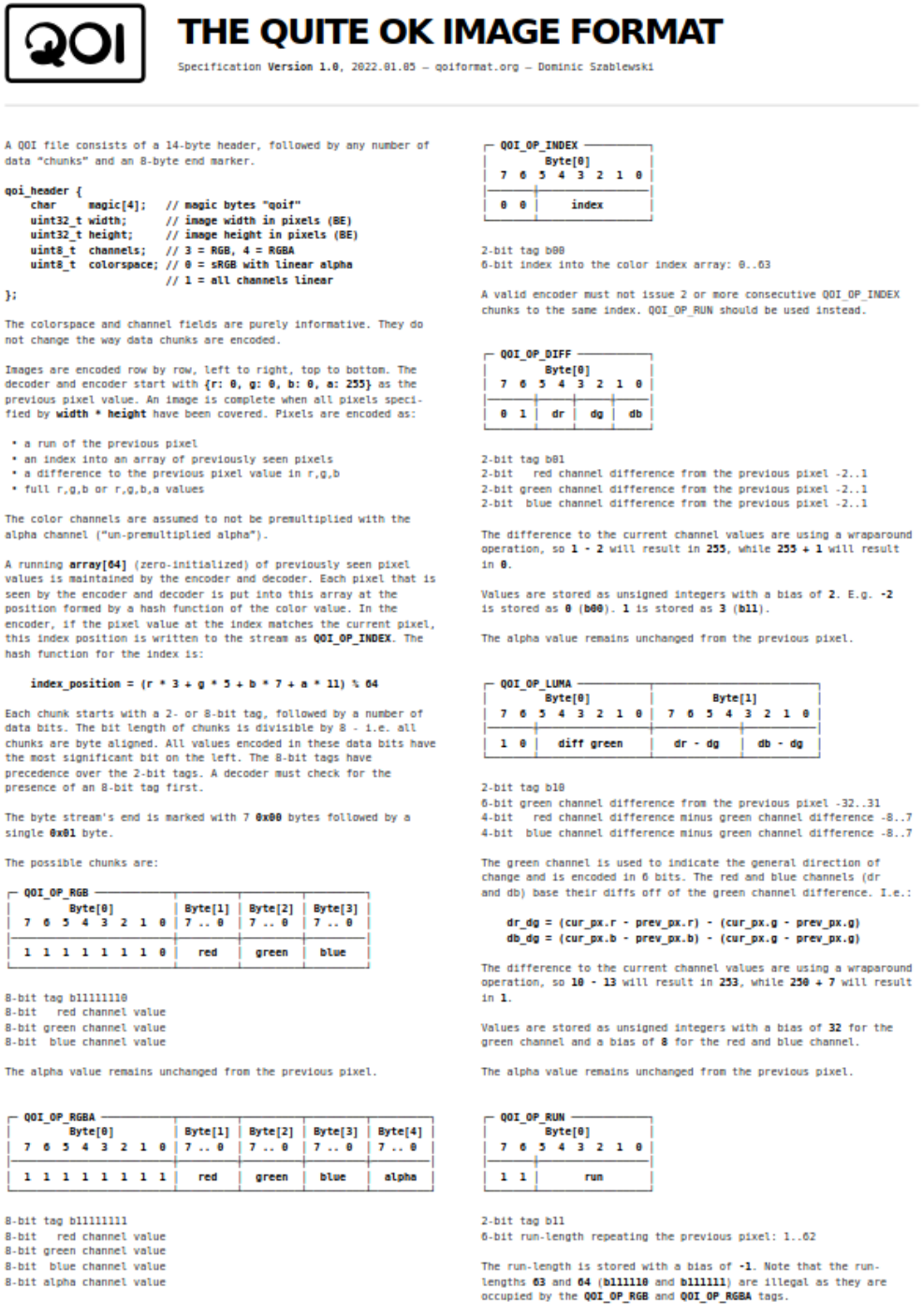
Complexity

- I like simple solutions, *e.g.*,
- QOI – simpler version of PNG
  - Encoder / decoder in 300 loc
  - PNG generates smaller images [link], QOI is much faster
  - Specification: 1 page
    - QOI – RLE
    - PNG – dictionary based compression with Huffman coding, 92 pages
  - Compression not much worse, but much simpler



QOI

THE QUITE OK IMAGE FORMAT

Specification **Version 1.0**, 2022.01.05 – qoiformat.org – Dominic Szablewski

A QOI file consists of a 14-byte header, followed by any number of data "chunks" and an 8-byte end marker.

```
qoi_header {
    char     magic[4];   // magic bytes "qoif"
    uint32_t width;      // image width in pixels (BE)
    uint32_t height;     // image height in pixels (BE)
    uint8_t  channels;   // 3 = RGB, 4 = RGBA
    uint8_t  colorspace; // 0 = sRGB with linear alpha
                         // 1 = all channels linear
};
```

The colorspace and channel fields are purely informative. They do not change the way data chunks are encoded.

Images are encoded row by row, left to right, top to bottom. The decoder and encoder start with **{r: 0, g: 0, b: 0, a: 255}** as the previous pixel value. An image is complete when all pixels specified by **width * height** have been covered. Pixels are encoded as:

- a run of the previous pixel
- an index into an array of previously seen pixels
- a difference to the previous pixel value in r,g,b
- full r,g,b or r,g,b,a values

The color channels are assumed to not be premultiplied with the alpha channel ("un-premultiplied alpha").

A running **array[64]** (zero-initialized) of previously seen pixel values is maintained by the encoder and decoder. Each pixel that is seen by the encoder and decoder is put into this array at the position formed by a hash function of the color value. In the encoder, if the pixel value at the index matches the current pixel, this index position is written to the stream as **QOI_OP_INDEX**. The hash function for the index is:

```
index_position = (r * 3 + g * 5 + b * 7 + a * 11) % 64
```

Each chunk starts with a 2- or 8-bit tag, followed by a number of data bits. The bit length of chunks is divisible by 8 - i.e. all chunks are byte aligned. All values encoded in these data bits have the most significant bit on the left. The 8-bit tags have precedence over the 2-bit tags. A decoder must check for the presence of an 8-bit tag first.

The byte stream's end is marked with 7 **0x00** bytes followed by a single **0x01** byte.

The possible chunks are:

QOI_OP_RGB

Byte[0]	Byte[1]	Byte[2]	Byte[3]
7 6 5 4 3 2 1 0	7 .. 0	7 .. 0	7 .. 0
1 1 1 1 1 1 1 0	red	green	blue

8-bit tag b11111110
8-bit red channel value
8-bit green channel value
8-bit blue channel value

The alpha value remains unchanged from the previous pixel.

QOI_OP_RGBA

Byte[0]	Byte[1]	Byte[2]	Byte[3]	Byte[4]
7 6 5 4 3 2 1 0	7 .. 0	7 .. 0	7 .. 0	7 .. 0
1 1 1 1 1 1 1 1	red	green	blue	alpha

8-bit tag b11111111
8-bit red channel value
8-bit green channel value
8-bit blue channel value
8-bit alpha channel value

QOI_OP_INDEX

Byte[0]
7 6 5 4 3 2 1 0
0 0 | index

2-bit tag b00
6-bit index into the color index array: 0..63

A valid encoder must not issue 2 or more consecutive QOI_OP_INDEX chunks to the same index. QOI_OP_RUN should be used instead.

QOI_OP_DIFF

Byte[0]
7 6 5 4 3 2 1 0
0 1 | dr | dg | db

2-bit tag b01
2-bit red channel difference from the previous pixel -2..1
2-bit green channel difference from the previous pixel -2..1
2-bit blue channel difference from the previous pixel -2..1

The difference to the current channel values are using a wraparound operation, so **1 - 2** will result in **255**, while **255 + 1** will result in **0**.

Values are stored as unsigned integers with a bias of **2**. E.g. **-2** is stored as **0** (**b00**). **1** is stored as **3** (**b11**).

The alpha value remains unchanged from the previous pixel.

QOI_OP_LUMA

Byte[0]	Byte[1]
7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0
1 0 | diff green	dr - dg | db - dg

2-bit tag b10
6-bit green channel difference from the previous pixel -32..31
4-bit red channel difference minus green channel difference -8..7
4-bit blue channel difference minus green channel difference -8..7

The green channel is used to indicate the general direction of change and is encoded in 6 bits. The red and blue channels (dr and db) base their diffs off of the green channel difference. I.e.:

```
dr_dg = (cur_px.r - prev_px.r) - (cur_px.g - prev_px.g)
db_dg = (cur_px.b - prev_px.b) - (cur_px.g - prev_px.g)
```

The difference to the current channel values are using a wraparound operation, so **10 - 13** will result in **253**, while **250 + 7** will result in **1**.

Values are stored as unsigned integers with a bias of **32** for the green channel and a bias of **8** for the red and blue channel.

The alpha value remains unchanged from the previous pixel.

QOI_OP_RUN

Byte[0]
7 6 5 4 3 2 1 0
1 1 | run

2-bit tag b11
6-bit run-length repeating the previous pixel: 1..62

The run-length is stored with a bias of **-1**. Note that the run-lengths **63** and **64** (**b111110** and **b111111**) are illegal as they are occupied by the **QOI_OP_RGB** and **QOI_OP_RGBA** tags.

Transport protocol?

- Can we build a QOTP?
  - Opinionated – make reasonable assumptions
  - IMHO: low complexity - better than a few % more performance
- QOTP
  - Based on previously gained knowledge
- Good project also to test GenAI
  - Which tools work good, which not?
  - Fast prototyping: e.g., experimented with RLE / Bitmaps for ACK encoding...

- QOTP Features
  - Always encrypted
    - First message – no perfect forward secrecy if data in 1st msg
    - Endpoints identified by
      - Main: IP/Port/PubKey, get PubKey out-of-band e.g., from DNS
      - Backup: IP/Port, get PubKey in first message, no data in 1st msg
  - 0-RTT, but prevent amplification attacks
    - First packet is always full MTU
  - Streams
    - Simple stream teardown FIN/FINACK and timeouts
    - **No built-in keep alive**
  - ~ 2.4k LoC

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Security

- QUIC – Security built-in (TCP no security)
- TLS 1.3
  - Key Exchange Algorithms - secp256r1, secp384r1, secp521r1, X25519, X448
  - Symmetric Encryption + Integrity – AES_128_GCM_SHA256, AES_256_GCM_SHA384, CHACHA20_POLY1305_SHA256
  - Digital Signatures – RSA-PSS-RSAE-SHA256, RSA-PSS-RSAE-SHA384, RSA-PSS-RSAE-SHA512, ecdsa_secp256r1_sha256, ecdsa_secp384r1_sha384, ed25519, ed448
  - Key Derivation – HKDF-SHA256, HKDF-SHA384
  - TLS: 9 primary RFCs and 48 extensions and informational RFCs, totalling 57 RFC [wikipedia]
- QOTP – Security built-in
- X25519, CHACHA20_POLY1305_SHA256
  - Ideally 1 page PDF as QOI

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Comparison

- Format – space efficient
- Short header / long header
  - Handshake + retry to prevent amp attacks
- Variable-Length Fields
  - Connection Id 8-20 bytes
- Optional fields
  - SACK / ACK, token, RCV window
- Uses 1-4 bytes nonce are transferred for reordering, uses interally 62bit

- Format - simplicity
  - 1 header:
    - Handshake with full MTU to prevent amp attacks
  - No variable length fields, 1 optional field
  - Uses 6 bytes nonce, always

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Complexity

- Big save: 6 bytes nonce vs. 24 bytes nonce [source]
  - 24 bytes nonce easier to implement, 12/6 leaks information → double encrypt saves 18 bytes overhead per paket ~1.3%

```
// NonceSize is the size of the nonce used with the standard variant of this
// AEAD, in bytes.
//
// Note that this is too short to be safely generated at random if the same
// key is reused more than 2³² times.
NonceSize = 12

// NonceSizeX is the size of the nonce used with the XChaCha20-Poly1305
// variant of this AEAD, in bytes.
NonceSizeX = 24
```

- 2-layer ChaCha20-Poly1305 encryption
  - 1st for payload using sequence-based nonce (6 bytes, 48bit, on overflow, new ep. Keys)
    - Encrypts payload, payload min size 8 bytes
  - 2nd for the sequence number itself
    - First 24 bytes from initial encryption serves as nonce to encrypt sequence number with XchaCha20-Poly1305
    - Encrypts 6 byte nonce, not using MAC, as already in 1st encryption - prevents traffic analysis
    - QUIC uses XOR masking...
  - Decryption works in reverse
  - ~60 loc complexity

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Design Choices

- No delayed Ack – 1 ACK = 1 packet
  - TCP and QUIC have this to reduce overhead with multi ACKs
  - QOTP: overhead - 1 packet with ACK, 74 bytes
  - Simpler: otherwise to measure time you need to know delay from other side
- Do we need flow control?
  - Yes, rcv window sent all the time vs only when changes – 6/8 bytes vs simplicity
- **Congestion control: WIP**
  - Bottleneck Bandwidth and Round-trip propagation time (BBR)
  - Goal: same aggressiveness as TCP / QUIC

- qh://
  - Quite Ok HTTP on top of QOTP
  - No Let's encrypt
    - Key material via DNS TXT record
  - Certificates needed?
    - Yes/no, but **never** for encryption, for signatures
      - Where to put? `Trailer: Signature, Certificate`
      - Streaming? `Transfer-Encoding: chunked`
    - No need for Oracles in the blockchain world → JSON signed by qh:// if certificate provided
      - How to access?
  - Other questions: QPACK or zstd for header compression?

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Ultimate Goal

- Make SPA great again (single page application)
  - 1st packet: GET request
  - 1st reply: compressed HTML/Javascript in ~1.3KB with relevant Fetch requests
  - 2.. reply packets: data/layout
- Make SPAs load faster
  - SPA simplify backend and frontend development

- PrevelteKit
  - Server-Side Pre Rendering (SSPR) with hydration / jdom
  - **TODO**: extract relevant Fetch requests, add to front of the 1st reply

Questions?

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