THE LINUX FOUNDATION
OPEN SOURCE SUMMIT

Optimizing Zlib on Arm:
The power of NEON

Adenilson Cavalcanti
ARM - San Jose (California)

@adenilsonc

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Why zlib?

Zlib

Used everywhere (libpng, Skia, freetype, **cronet**, Firefox, Chrome, linux kernel, android, iOS, JDK, git, etc).

Old code base released in 1995.

Written in K&R C style.

Context

Lacks any optimizations for ARM CPUs.

Problem statement

Identify potential optimization candidates and verify positive effects in Chromium.

Previous art

- Cloudflare
- Intel
- Zlib-ng

Before deepening the fork...

- Performed some benchmarking.
- Contacted each project.
- Mixed results (1 project never replied back).

Before forking...

- Performed some benchmarking.
- Contacted each project.
- Mixed results (1 project never replied back).

None focused on **decompression*** or had ARM specific optimizations.

*Important for a Web Browser.

Meet Mr. Parrot

PNGs rely on zlib

- Transparent.
- Pre-filters.
- High-res.

Source: https://upload.wikimedia.org/wikipedia/commons/3/3f/ZebraHighRes.png

Parrots are not created equal

Original: 2.7MB

Palette: 0.8MB

Zopfli: 2.6MB

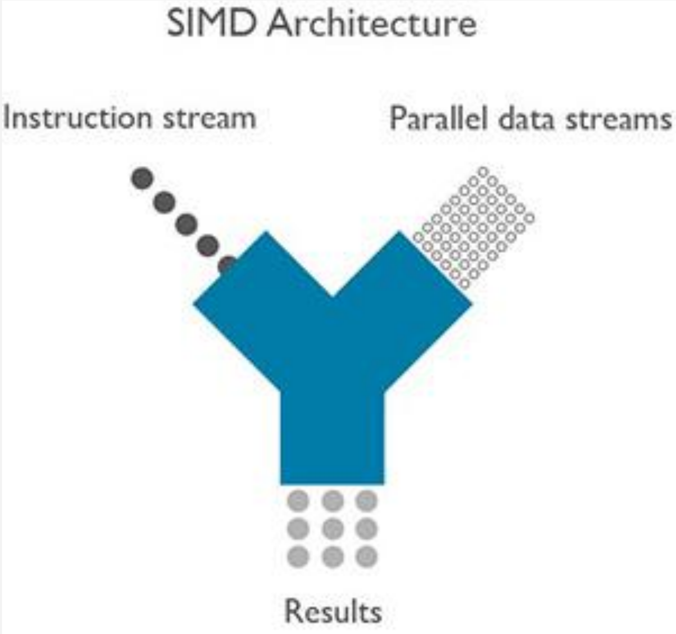
Perf to the rescue

```
== Image has pre-compression filters (2.7MB) ==
Lib     Command     SharedObj          method                         CPU (%)
zlib    TileWorker  liblink           inflate_fast .................. 1.96
zlib    TileWorker  libblnk           adler32 ....................... 0.88
blink   TileWorker  liblink           ImageFrame::setRGBAPremultiply .. 0.45
blink   TileWorker  liblink           png_read_filter_row_up........... 0.03*

== Image was optimized using zopfli (2.6MB) ==
Lib     Command     SharedObj          method                         CPU (%)
zlib    TileWorker  liblink           inflate_fast .................. 3.06
zlib    TileWorker  libblnk           adler32 ....................... 1.36
blink   TileWorker  liblink           ImageFrame::setRGBAPremultiply .. 0.70
blink   TileWorker  liblink           png_read_filter_row_up........... 0.48*


== Image has no pre-compression filters (0.9MB) ==
Lib     Command     SharedObj          method                         CPU (%)
libpng  TileWorker  liblink           cr_png_do_expand_palette ........ 0.88
zlib    TileWorker  liblink           inflate_fast .................. 0.62
blink   TileWorker  liblink           ImageFrame::setRGBAPremultiply .. 0.49
zlib    TileWorker  libblnk           adler32 ....................... 0.31
```

NEON: Advanced SIMD

(Single Instruction Multiple Data)

NEON



- Optional on ARMv7.
- Mandatory on ARMv8.

Registers

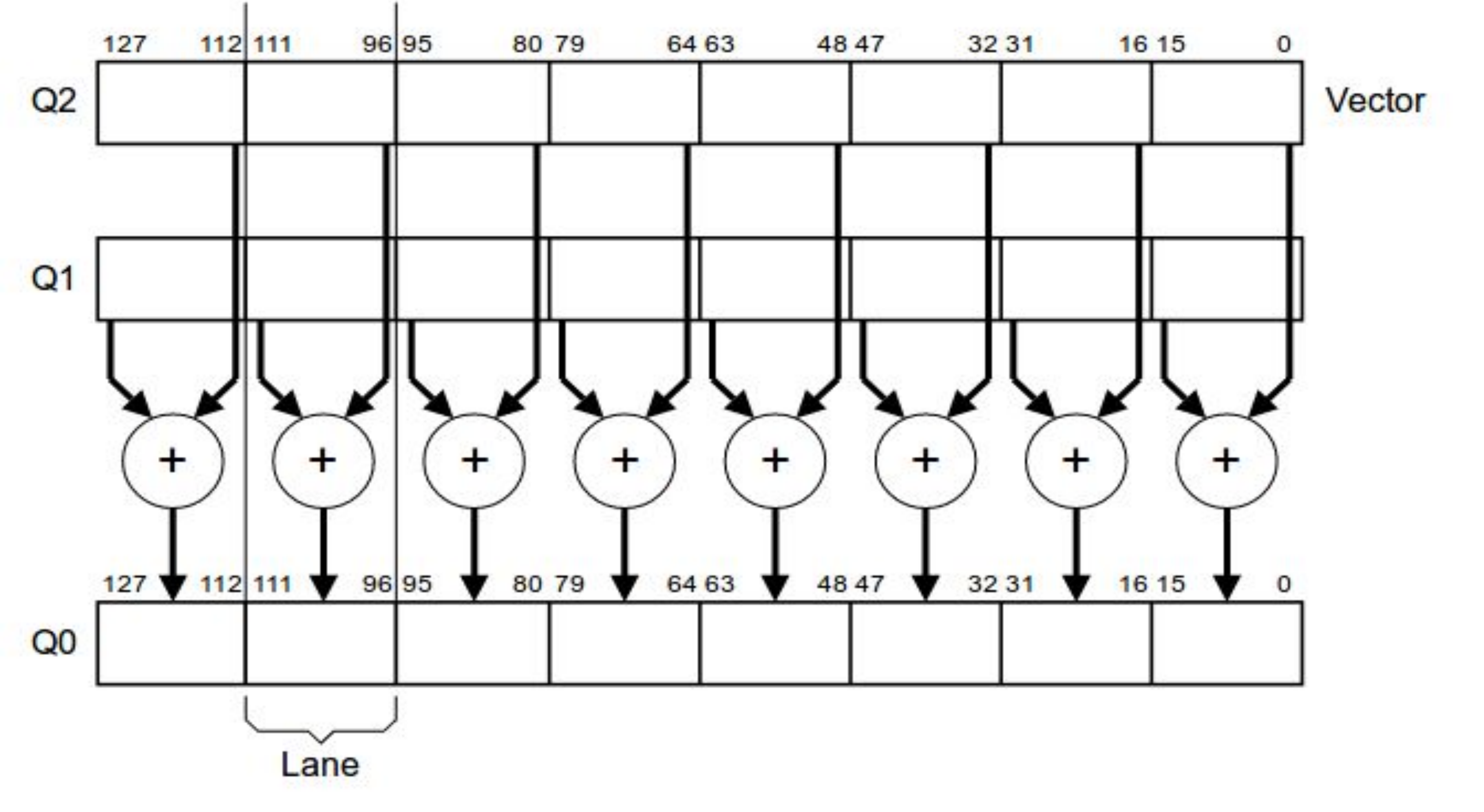
ARMv7

- 16 registers@128 bits: Q0 - Q15.
- 32 registers@64bits: D0 - D31.
- Varied set of instructions: load, store, add, mul, etc.

ARMv8

- 32 registers@128 bits: Q0 - Q31.
- 32 registers@64bits: D0 - D31.
- 32 registers@32bits: S0 - S31.
- 32 registers@8bits: H0 - H31.
- Varied set of instructions: load, store, add, mul, etc.

An example: VADD.I16 Q0, Q1, Q2



Entropy & Compression

Entertaining definition

https://www.youtube.com/watch?v=l49MHwooaVQ

Formal definition

Shannon Entropy

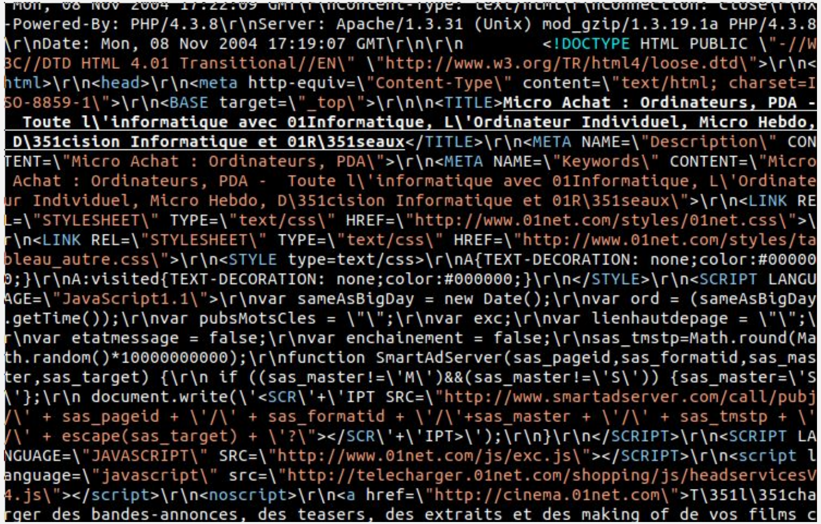
$$H = -\sum_{i} p_i \log_b p_i$$

Where:
p_i: probability of character *i* appearing in the stream of characters.

https://en.wiktionary.org/wiki/Shannon_entropy

Practical explanation

a) HTML



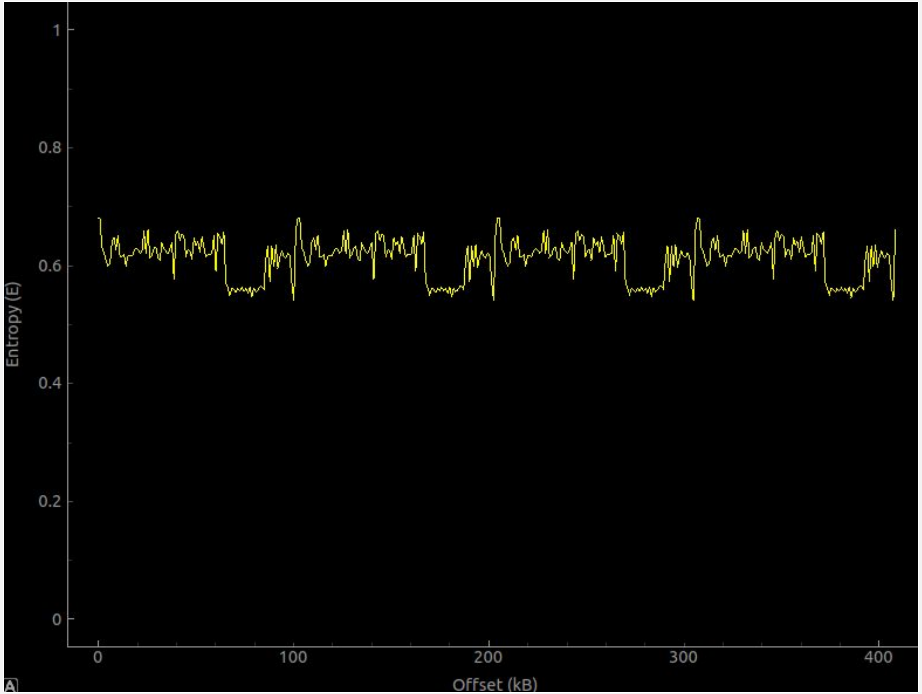
```
Mon, 08 Nov 2004 17:22:09 GMT\r\nContent-Type: text/html\r\nConnection: close\r\nX
-Powered-By: PHP/4.3.8\r\nServer: Apache/1.3.31 (Unix) mod_gzip/1.3.19.1a PHP/4.3.8
\r\nDate: Mon, 08 Nov 2004 17:19:07 GMT\r\n\r\n        <!DOCTYPE HTML PUBLIC \"-//W
3C//DTD HTML 4.01 Transitional//EN\" \"http://www.w3.org/TR/html4/loose.dtd\">\r\n<
html>\r\n<head>\r\n<meta http-equiv=\"Content-Type\" content=\"text/html; charset=I
SO-8859-1\">\r\n<BASE target=\"_top\">\r\n\r\n<TITLE>Micro Achat : Ordinateurs, PDA -
 Toute l\'informatique avec 01Informatique, L\'Ordinateur Individuel, Micro Hebdo,
 D\351cision Informatique et 01R\351seaux</TITLE>\r\n<META NAME=\"Description\" CON
TENT=\"Micro Achat : Ordinateurs, PDA\">\r\n<META NAME=\"Keywords\" CONTENT=\"Micro
 Achat : Ordinateurs, PDA -  Toute l\'informatique avec 01Informatique, L\'Ordinate
ur Individuel, Micro Hebdo, D\351cision Informatique et 01R\351seaux\">\r\n<LINK RE
L=\"STYLESHEET\" TYPE=\"text/css\" HREF=\"http://www.01net.com/styles/01net.css\">\
r\n<LINK REL=\"STYLESHEET\" TYPE=\"text/css\" HREF=\"http://www.01net.com/styles/ta
bleau_autre.css\">\r\n<STYLE type=text/css>\r\nA{TEXT-DECORATION: none;color:#00000
0;}\r\nA:visited{TEXT-DECORATION: none;color:#000000;}\r\n</STYLE>\r\n<SCRIPT LANGU
AGE=\"JavaScript1.1\">\r\nvar sameAsBigDay = new Date();\r\nvar ord = (sameAsBigDay
.getTime());\r\nvar pubsMotsCles = \"\";\r\nvar exc;\r\nvar lienhautdepage = \"\";\
r\nvar etatmessage = false;\r\nvar enchainement = false;\r\nsas_tmstp=Math.round(Ma
th.random()*10000000000);\r\nfunction SmartAdServer(sas_pageid,sas_formatid,sas_mas
ter,sas_target) {\r\n if ((sas_master!=\'M\')&&(sas_master!=\'S\')) {sas_master=\'S
\'};\r\n document.write(\'<SCR\'+\'IPT SRC=\"http://www.smartadserver.com/call/pubj
/\' + sas_pageid + \'/\' + sas_formatid + \'/\'+sas_master + \'/\' + sas_tmstp + \'
/\' + escape(sas_target) + \'?\"></SCR\'+\'IPT>\');\r\n}\r\n</SCRIPT>\r\n<SCRIPT LA
NGUAGE=\"JAVASCRIPT\" SRC=\"http://www.01net.com/js/exc.js\"></SCRIPT>\r\n<script l
anguage=\"javascript\" src=\"http://telecharger.01net.com/shopping/js/headservicesV
4.js\"></script>\r\n<noscript>\r\n<a href=\"http://cinema.01net.com\">T\351l\351cha
rger des bandes-annonces, des teasers, des extraits et des making of de vos films c
```

b) JPEG

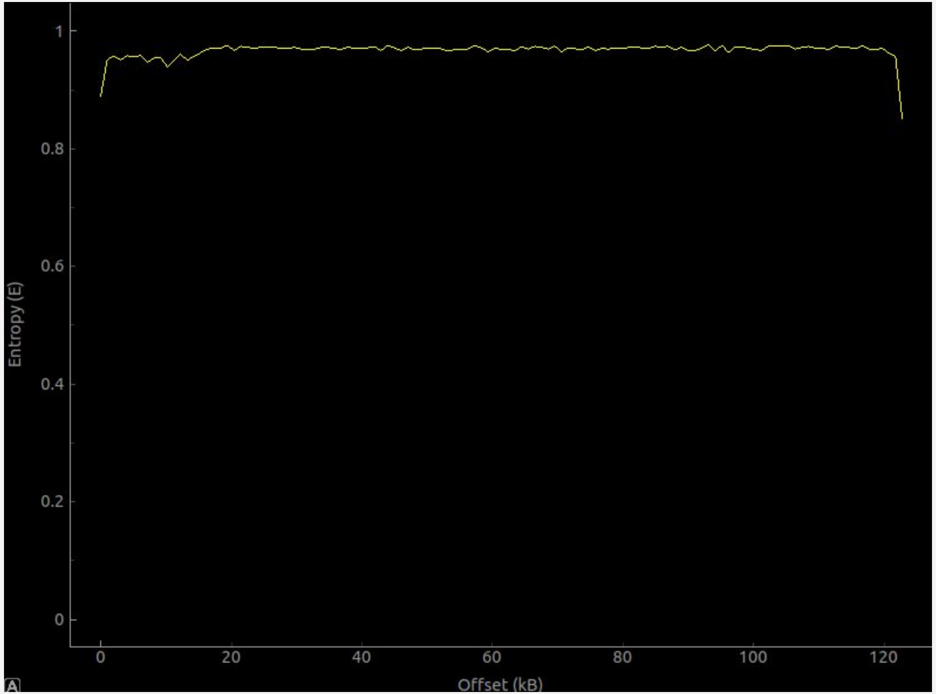
Practical visualization

./binwalk -E file

a) HTML: 0.68



b) JPEG: 0.95



Decompression optimizations

Adler-32 checksum

$$A = 1 + D_1 + D_2 + ... + D_n \pmod{65521}$$

$$B = (1 + D_1) + (1 + D_1 + D_2) + ... + (1 + D_1 + D_2 + ... + D_n) \pmod{65521}$$

$$= n \times D_1 + (n-1) \times D_2 + (n-2) \times D_3 + ... + D_n + n \pmod{65521}$$

$$Adler\text{-}32(D) = B \times 65536 + A$$

https://en.wikipedia.org/wiki/Adler-32

Adler-32 simplistic implementation

```c
// From: https://en.wikipedia.org/wiki/Adler-32
const int MOD_ADLER = 65521;
unsigned long naive_adler32(unsigned char *data,
                            unsigned long len)
{
    uint32_t a = 1, b = 0;
    unsigned long index;

    for (index = 0; index < len; ++index) {
        a = (a + data[index]) % MOD_ADLER;
        b = (b + a) % MOD_ADLER;
    }

    return (b << 16) | a;
}
```

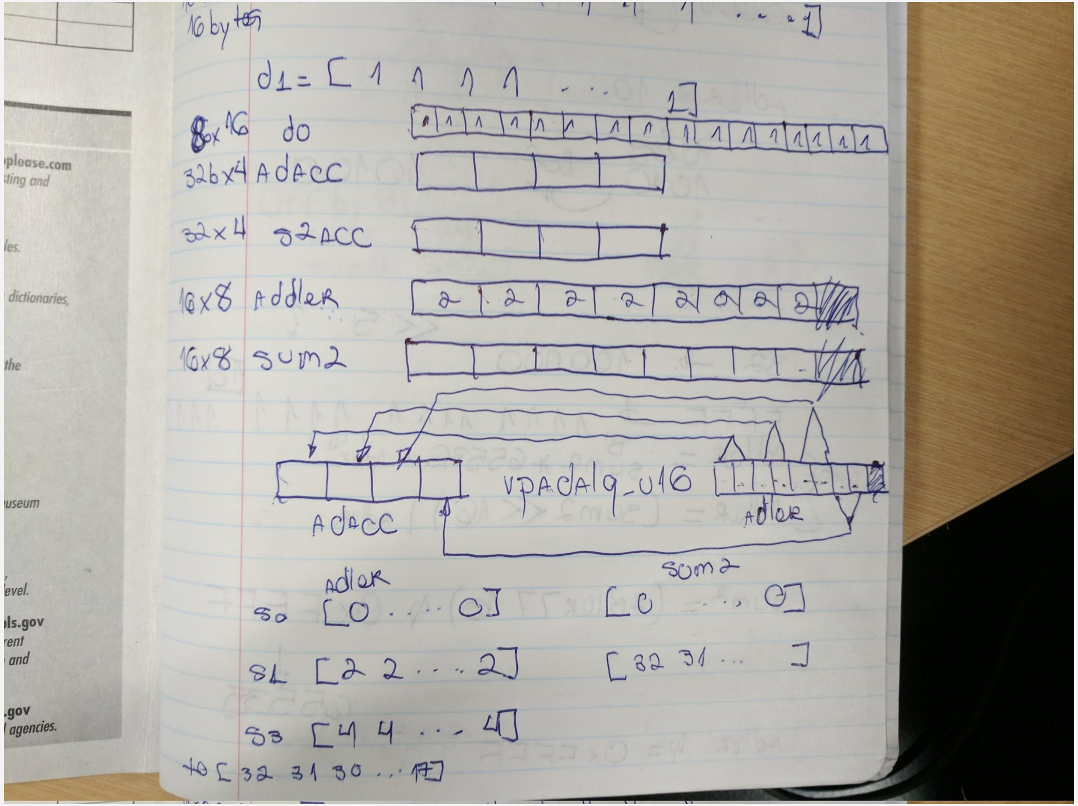
https://en.wikipedia.org/wiki/Adler-32

Adler-32: problems

- Zlib's Adler-32 was more than **7x faster** than naive implementation.
- It is hard to vectorize the following computation:

```
void accum(uint32_t *pair, const unsigned char *buf,
           unsigned int len)
{
    unsigned int i;
    for (i = 0; i < len; ++i) {
        pair[0] += buf[i];
        pair[1] += pair[0];
    }
}
```

Adler-32: technical drawing (Jan 2017)



Adler-32

‘Taps’ to the rescue

```
static void NEON_accum32(uint32_t *s, const unsigned char *buf,
                         unsigned int len)
{
    static const uint8_t taps[32] = {
        32, 31, 30, 29, 28, 27, 26, 25,
        24, 23, 22, 21, 20, 19, 18, 17,
        16, 15, 14, 13, 12, 11, 10, 9,
        8, 7, 6, 5, 4, 3, 2, 1 };

    uint32x2_t adacc2, s2acc2, as;
    uint8x16_t t0 = vld1q_u8(taps), t1 = vld1q_u8(taps + 16);

    uint32x4_t adacc = vdupq_n_u32(0), s2acc = vdupq_n_u32(0);
    adacc = vsetq_lane_u32(s[0], adacc, 0);
    s2acc = vsetq_lane_u32(s[1], s2acc, 0);

    while (len >= 2) {
        uint8x16_t d0 = vld1q_u8(buf), d1 = vld1q_u8(buf + 16);
        uint16x8_t adler, sum2;
        s2acc = vaddq_u32(s2acc, vshlq_n_u32(adacc, 5));
        adler = vpaddlq_u8(       d0);
        adler = vpadalq_u8(adler, d1);
        sum2 = vmull_u8(      vget_low_u8(t0), vget_low_u8(d0));
        sum2 = vmlal_u8(sum2, vget_high_u8(t0), vget_high_u8(d0));
        sum2 = vmlal_u8(sum2, vget_low_u8(t1), vget_low_u8(d1));
        sum2 = vmlal_u8(sum2, vget_high_u8(t1), vget_high_u8(d1));
        adacc = vpadalq_u16(adacc, adler);
        s2acc = vpadalq_u16(s2acc, sum2);
        len -= 2;
        buf += 32;
    }
```

Assembly:
https://godbolt.org/g/KMeBAJ

Adler-32: Intel got some love too!

author Noel Gordon <noel@chromium.org> Fri Sep 29
committer Commit Bot <commit-bot@chromium.org> Fri Sep 29
tree a25de9dd3212b49c1d903e72289e424b72127c3e
parent 6baf6221674f5a075f12f83e4262a4751b5d445b [diff]

zlib adler_simd.c

Add SSSE3 implementation of the adler32 checksum, suitable for both large workloads, and small workloads commonly seen during PNG image decoding. Add a NEON implementation.

Speed is comparable to the serial adler32 computation but near 64 bytes of input data, the SIMD code paths begin to be faster than the serial path: 3x faster at 256 bytes of input data, to ~8x faster for 1M of input data (~4x on ARMv8 NEON).

For the PNG 140 image corpus, PNG decoding speed is ~8% faster on average on the desktop machines tested, and ~2% on an ARMv8 Pixel C Android (N) tablet, https://crbug.com/762564#c41

Update x86.{c,h} to runtime detect SSSE3 support and use it to enable the adler32_simd code path and update inflate.c to call x86_check_features(). Update the name mangler file names.h for the new symbols added, add FIXME about simd.patch.

Ignore data alignment in the SSSE3 case since unaligned access is no longer penalized on current generation Intel CPU. Use it in the NEON case however to avoid the extra costs of unaligned memory access on ARMv8/v7.

NEON credits: the v_s1/s2 vector component accumulate code was provided by Adenilson Cavalcanti. The uint16 column vector sum code is from libdeflate with corrections to process NMAX input bytes which improves performance by 3% for large buffers.

https://bugs.chromium.org/p/chromium/issues/detail?id=688601

fast_chunk

- Second candidate in the perf profiling was **inflate_fast**.
- Very **high level** idea: perform long loads/stores in the byte array.
- Average **20% faster**!
- Shipping on M62.
- Original patch by Simon Hosie.

```
+                     */
+                    out = chunkcopy_safe(out, from, len, limit);
                 }
             }
             else {
-                from = out - dist;          /* copy direct from output */
-                do {                        /* minimum length is three */
-                    *out++ = *from++;
-                    *out++ = *from++;
-                    *out++ = *from++;
-                    len -= 3;
-                } while (len > 2);
-                if (len) {
-                    *out++ = *from++;
-                    if (len > 1)
-                        *out++ = *from++;
-                }
+                /* Whole reference is in range of current output.  No
+                   range checks are necessary because we start with room
+                   for at least 258 bytes of output, so unroll and roundoff
+                   operations can write beyond `out+len` so long as they
+                   stay within 258 bytes of `out`.
+                 */
+                out = chunkcopy_lapped_relaxed(out, dist, len);
             }
```

https://bugs.chromium.org/p/chromium/issues/detail?id=697280

CRC-32

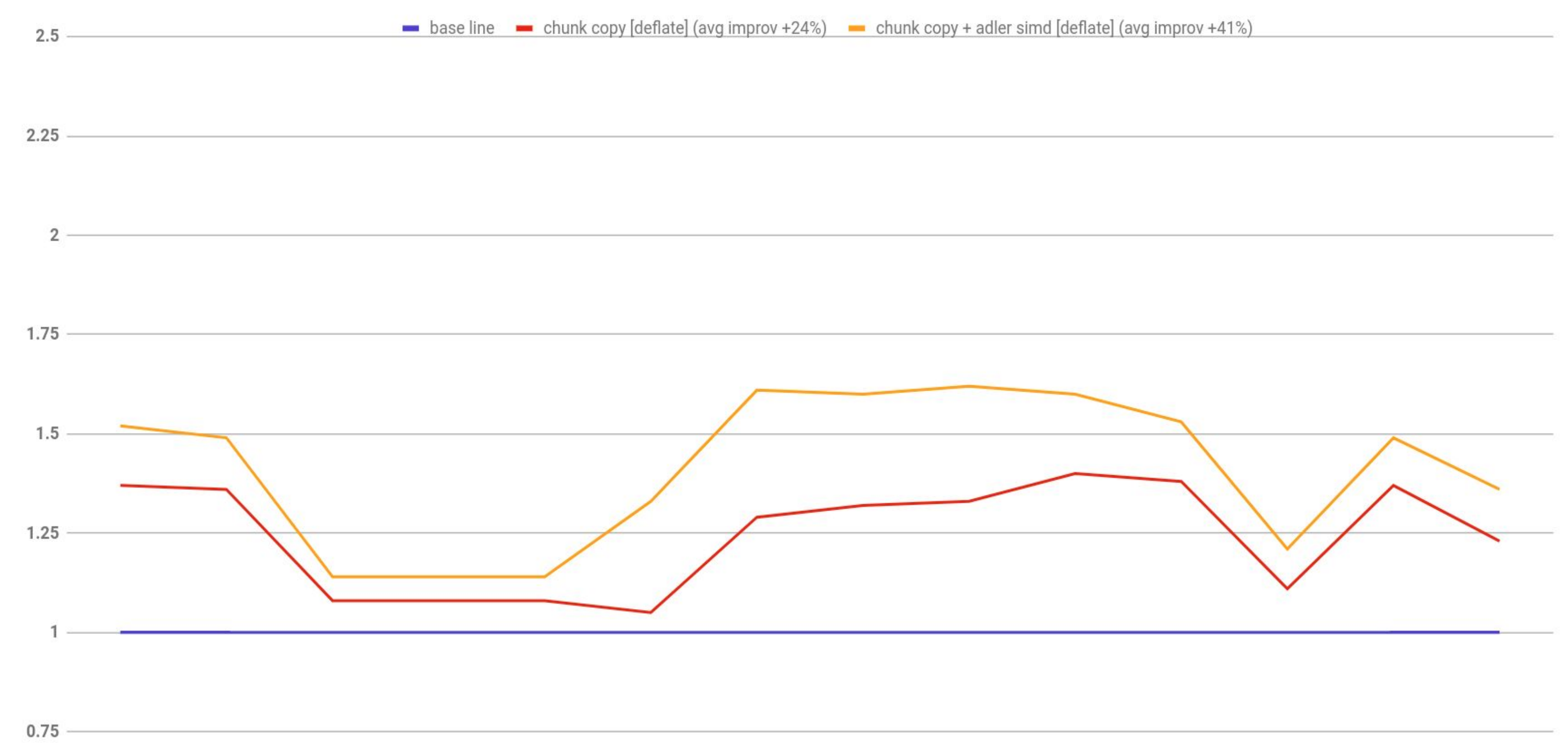
- YMMV on PNGs (from 1 to 5%).
- Remember it is used while **decompressing** web content (29% boost for gzipped content).
- ARMv8-a has a crc32 instruction (from 3 to 10x faster than zlib's crc32 C code).
- Shipping on M66.

https://bugs.chromium.org/p/chromium/issues/detail?id=709716

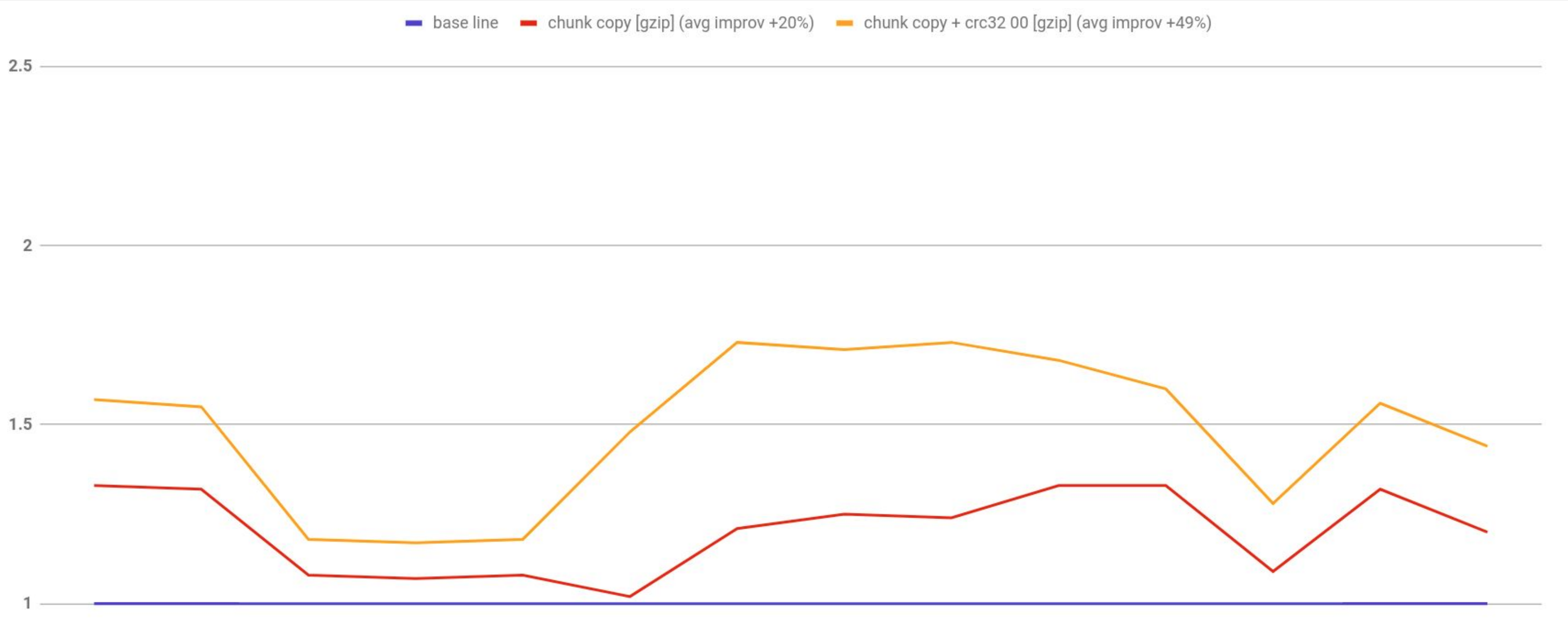
Results: Chromium’s zlib*

* c-zlib

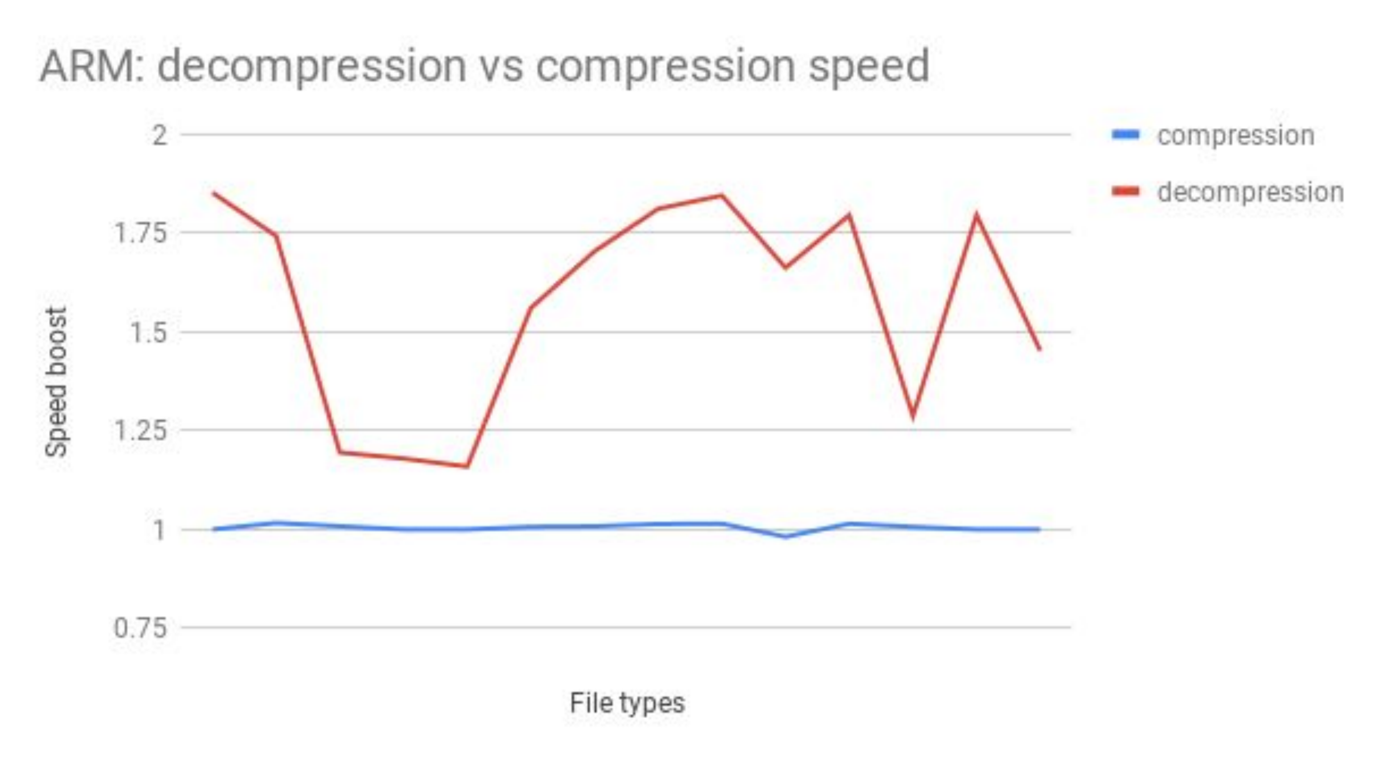
Arm: zlib format 1.4x



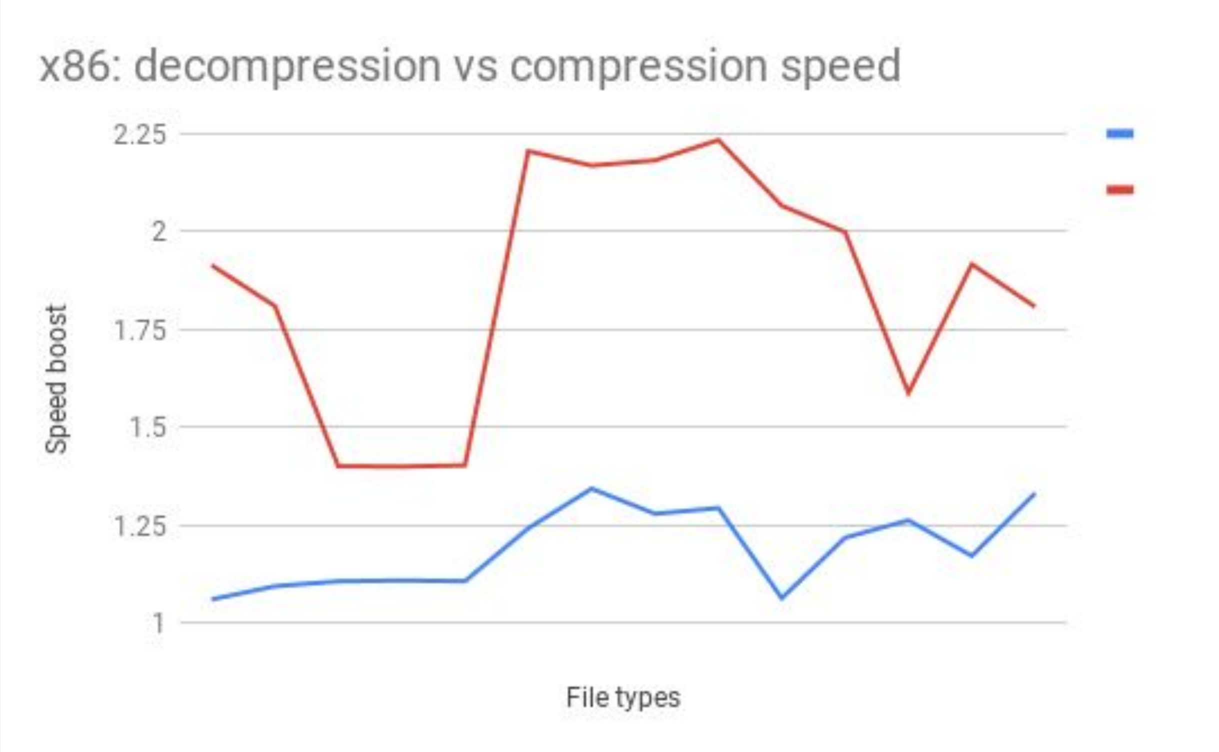
Arm: gzip format 1.5x



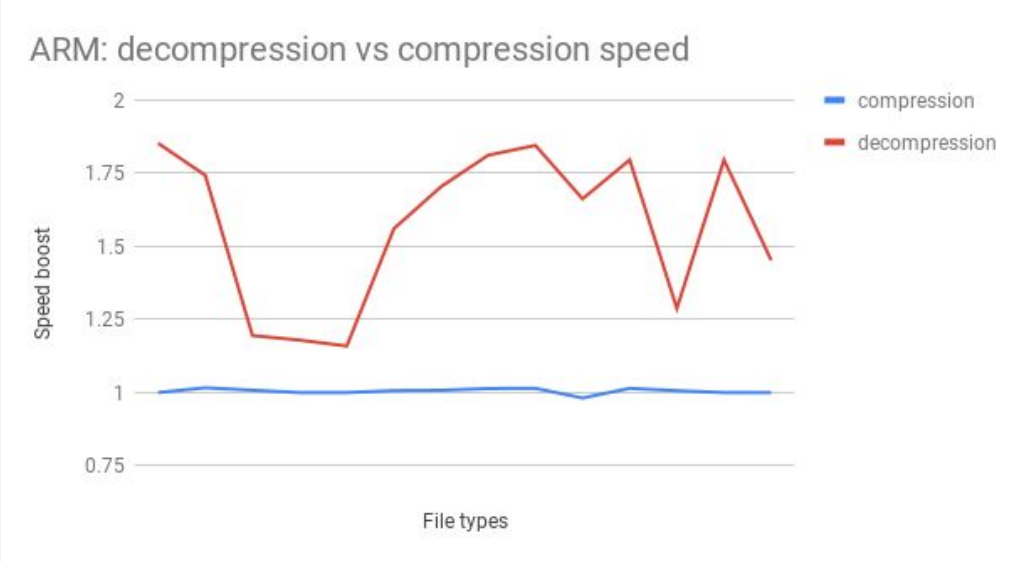
Arm: c-zlib X Vanilla

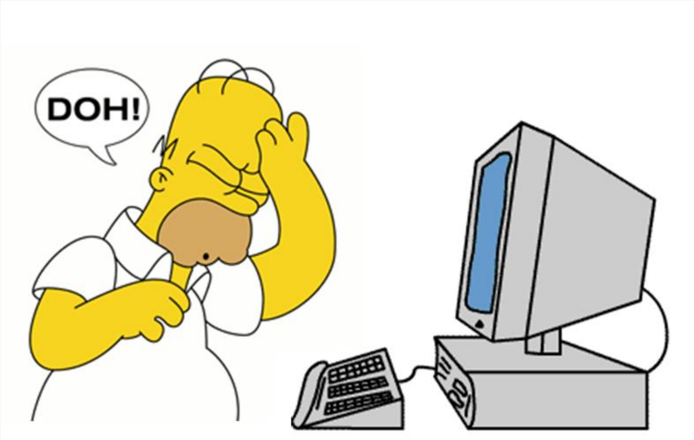


x86: c-zlib X Vanilla



We were missing **compression**...

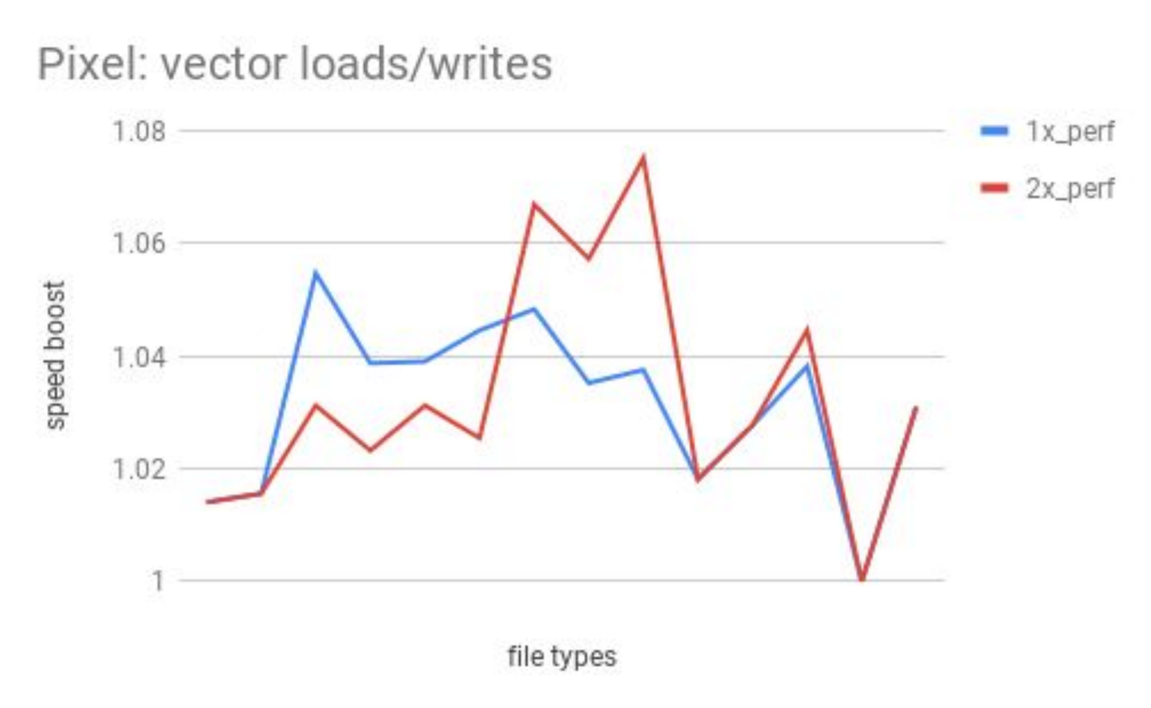




Bonus: Compression on Arm

Slide-hash: NEON

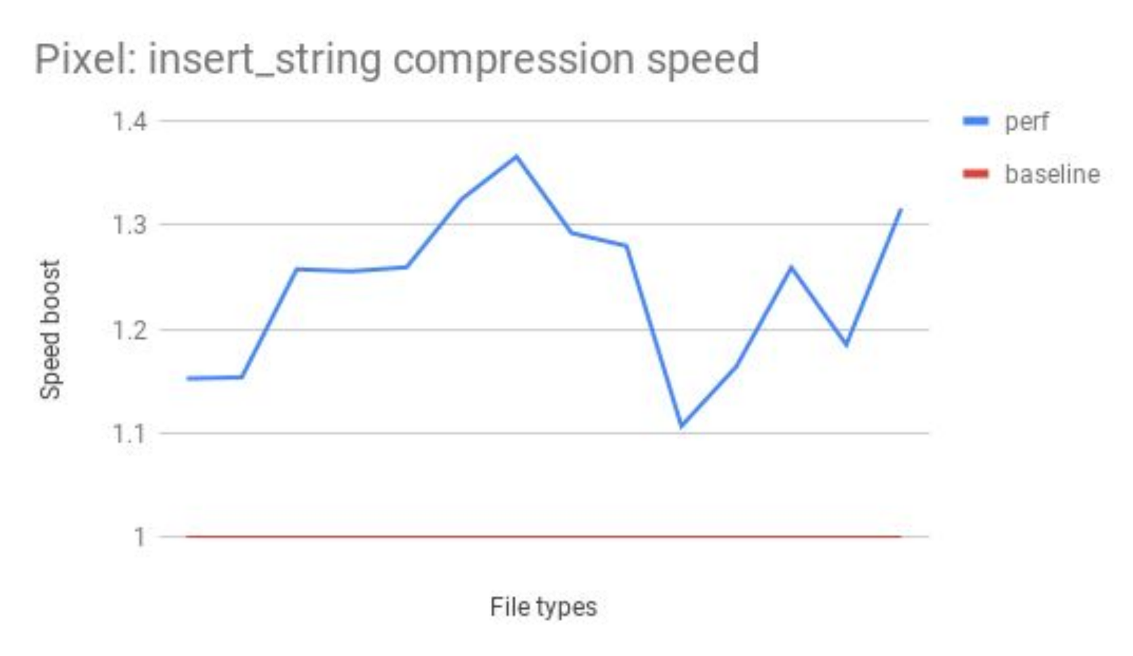
- Using NEON instruction vqsubq.
- Works on 8x 16bits chunks.
- Perf gain of 5%.



https://chromium-review.googlesource.com/1136940

insert-string: crypto CRC-32

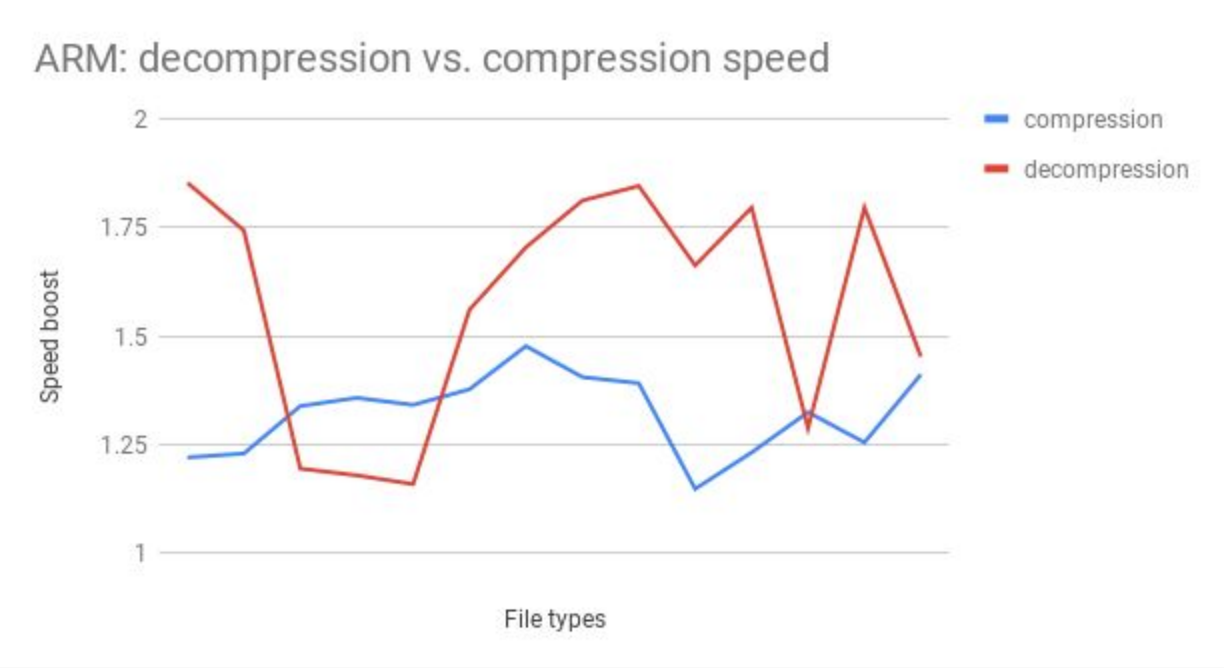
- Using ARMv8-a instruction crc32.
- Works on 1x 32bits chunks.
- Perf gain of 24%.



https://chromium-review.googlesource.com/c/chromium/src/+/1173262

Arm: current state

- Compression: average 1.36x faster, but 1.4x faster for HTML.
- Decompression: average 1.6x faster (gzip), but 1.8x faster for HTML.



Conclusions

Conclusions

- There is plenty of life left even in an old code base.
- NEON optimizations can yield a *huge* impact.
- It pays up to work in a lower layer.
- OSS love: Intel got it too.

Chromium's zlib: c-zlib

- Decompression: 1.7x to 2x faster.
- Compression: 1.3x to 1.4x faster.
- Both ARM & x86 are supported.
- Highly tested (i.e. cronet, fuzzers).
- Widely deployed (over 1 billion users).
- Open to performance & security patches.

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Zlib users should consider moving to Chromium’s zlib.

Resources

a) Slides: https://goo.gl/vaZA9o
b) Performance benchmarks: https://goo.gl/qLVdvh
c) Code:
https://cs.chromium.org/chromium/src/third_party/zlib/

Final words

“This is how the open-source model works: building upon the work of others is far more efficient than rewriting everything.”

Jean-loup Gailly (zlib author)

https://slashdot.org/story/00/03/10/1043247/jean-loup-gailly-on-gzip-go-and-mandrake

Questions

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