How fast goes the light ?

Euro LLVM 2015

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The Architecture for the Digital World®

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Scope

- Speed of light: the fastest implementation of a function on a given cpu (Cortex-A57)
- The function under test is a typical image processing kernel:
  - Color space conversion from RGB to YIQ (see http://en.wikipedia.org/wiki/YIQ)

$$\begin{bmatrix} y \\ i \\ q \end{bmatrix} = \begin{bmatrix} Y_r & Y_g & Y_b \\ I_r & I_g & I_b \\ Q_r & Q_g & Q_b \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

- That's the most basic computation out there, so we'd better get it right…

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RGB2YIQ in C, with 16-bits integer coefficients

No aliasing

```
void rgb2yiq(uint8_t *restrict In, uint8_t *restrict Out, unsigned N) {
      for (unsigned pixel = 0; pixel < N; pixel++) {
            uint8_t r = *In++, g = *In++, b = *In++;

            uint8_t y = ((YR * r) + (YG * g) + (YB * b) + HALF_LSB) >> S;
            int8_t i  = ((IR * r) + (IG * g) + (IB * b) + HALF_LSB) >> S;
            int8_t q  = ((QR * r) + (QG * g) + (QB * b) + HALF_LSB) >> S;

            *Out++ = y, *Out++ = i, *Out++ = q;
      }
}
```

Matrix x vector

Rounding

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Expectations

- 9 or 10 coefficients loading
- 9 Multiply-accumulate
- Vectorization

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A first shot…

```
rgb2yiq_ref:
            cbz w2, .LBB0_3
            movz w8, #0x4c8b
            movz w9, #0x9646
            movz w10, #0x1d2f
            movn w11, #0x3b0e
            movn w12, #0x44ef
            movz w13, #0x33e2
            movz w14, #0x4c1d
.LBB0_2:
            ldrb w15, [x0]
            ldrb w16, [x0, #1]
            mul w18, w15, w8
            mul w3, w16, w9
            ldrb w17, [x0, #2]
            lsl w5, w15, #15
            sub w5, w5, w15
            mul w15, w15, w13
            mul w4, w17, w10
            add w18, w18, w3
            mul w3, w16, w11
            sub w16, w16, w16, lsl #15
            add w15, w15, w16
            add w16, w18, w4
            add w3, w5, w3
            mul w5, w17, w12
            add w16, w16, #8, lsl #12
            mul w17, w17, w14
            lsr w16, w16, #16
            add w18, w3, w5
            add w15, w15, w17
            add w17, w18, #8, lsl #12
            add w15, w15, #8, lsl #12
            lsr w17, w17, #16
            lsr w15, w15, #16
            strb w16, [x1]
            strb w17, [x1, #1]
            strb w15, [x1, #2]
            sub w2, w2, #1
            add x0, x0, #3
            add x1, x1, #3
            cbnz w2, .LBB0_2
.LBB0_3:
            ret
```

7 coefficients

2 strength reduced coefficients

Immediate half LSB

No multiply-accumulate, no vectorization !

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Performances (reference)

	Time	Code size	Data size (bytes)
First shot (reference)	1.0	1.0	0

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RGB2YIQ v2 : fight the compiler !

```
int Coeffs[3][3] = {{YR, YG, YB}, {IR, IG, IB}, {QR, QG, QB}};
int Half_LSB = HALF_LSB;

void rgb2yiq(uint8_t *restrict In, uint8_t *restrict Out, unsigned N) {
        int yr = Coeffs[0][0], yg = Coeffs[0][1], yb = Coeffs[0][2];
        int ir = Coeffs[1][0], ig = Coeffs[1][1], ib = Coeffs[1][2];
        int qr = Coeffs[2][0], qg = Coeffs[2][1], qb = Coeffs[2][2];
        int half_lsb = Half_LSB;

        for (unsigned pixel = 0; pixel < N; pixel++) {
                uint8_t r = *In++, g = *In++, b = *In++;

                uint8_t y = ((yr * r) + (yg * g) + (yb * b) + half_lsb) >> S;
                int8_t i  = ((ir * r) + (ig * g) + (ib * b) + half_lsb) >> S;
                int8_t q  = ((qr * r) + (qg * g) + (qb * b) + half_lsb) >> S;

                *Out++ = y, *Out++ = I, *Out++ = q;
        }
}
```

Place coefficients in memory

Make sure it does not alias with `In` or `Out`, and is hoisted of the loop

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Second try…

```
rgb2yiq:
        stp x20, x19, [sp, #-16]!
        cbz w2, .LBB0_3
        adrp x16, Coeffs
        add x16, x16, :lo12:Coeffs
        adrp x17, Half_LSB
        ldp w8, w9, [x16]
        ldp w10, w11, [x16, #8]
        ldp w12, w13, [x16, #16]
        ldp w14, w15, [x16, #24]
        ldr w16, [x16, #32]
        ldr w17, [x17, :lo12:Half_LSB]
.LBB0_2:
        ldrb w18, [x0]
        ldrb w3, [x0, #1]
        mul w5, w3, w9
        madd w7, w18, w8, w17
        ldrb w4, [x0, #2]
        mul w19, w3, w12
        mul w3, w3, w15
        mul w6, w4, w10
        add w5, w7, w5
        madd w7, w18, w11, w17
        madd w18, w18, w14, w17
        add w7, w7, w19
        mul w19, w4, w13
        add w18, w18, w3
        mul w3, w4, w16
        sub w2, w2, #1
        add x0, x0, #3
        add w4, w5, w6
        add w5, w7, w19
        add w18, w18, w3
        lsr w3, w4, #16
        strb w3, [x1]
        lsr w4, w5, #16
        lsr w18, w18, #16
        strb w4, [x1, #1]
        strb w18, [x1, #2]
        add x1, x1, #3
        cbnz w2, .LBB0_2
.LBB0_3:
        ldp x20, x19, [sp], #16
        ret
```

9 coefficients
+ half lsb

3 MACs !

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Performances (lower is better)

	Time	Code size	Data size (bytes)
First shot (reference)	1.0	1.0	0
Second try	1.03	1.0	40

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Let's ignore the compiler…

```
rgb2yiq:
        cbz w2, .LBB0_3
        adrp x16, Coeffs
        add x16, x16, :lo12:Coeffs
        adrp x17, Half_LSB
        ldp w8, w9, [x16]
        ldp w10, w11, [x16, #8]
        ldp w12, w13, [x16, #16]
        ldp w14, w15, [x16, #24]
        ldp w16, [x16, #32]
        ldp w17, [x17, :lo12:Half_LSB]
.LBB0_2:
        ldrb w3, [x0]
        ldrb w4, [x0, #1]
        ldrb w5, [x0, #2]

        madd w6, w3, w8, w17
        madd w6, w4, w9, w6
        madd w6, w5, w10, w6

        madd w7, w3, w11, w17
        madd w7, w4, w12, w7
        madd w7, w5, w13, w7

        madd w18, w3, w14, w17
        madd w18, w4, w15, w18
        madd w18, w5, w16, w18

        lsr w6, w6, #16
        lsr w7, w7, #16
        lsr w18, w18, #16

        strb w6, [x1]
        strb w7, [x1, #1]
        strb w18, [x1, #2]

        add x0, x0, #3
        add x1, x1, #3
        sub w2, w2, #1
        cbnz w2, .LBB0_2
.LBB0_3:
        ret
```

Load coefficients

Multiply-add

Shift

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Performances (lower is better)

	Time	Code size	Data size (bytes)
First shot (reference)	1.0	1.0	0
Second try	1.03	1.0	40
Hand written straight asm (scalar)	0.94	0.80	40

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Performances (lower is better)

	Time	Code size	Data size (bytes)
First shot (reference)	1.0	1.0	0
Second try	1.03	1.0	40
Hand written straight asm (scalar)	0.94	0.80	40
Hand written scheduled asm (scalar)	0.79	0.80	40

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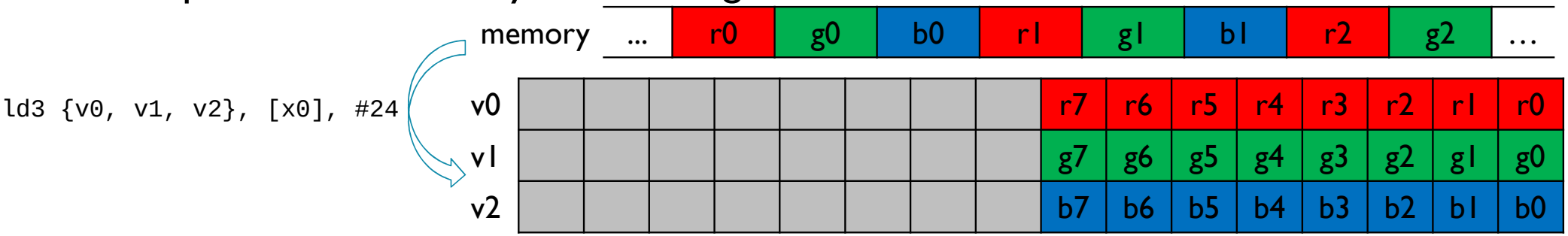
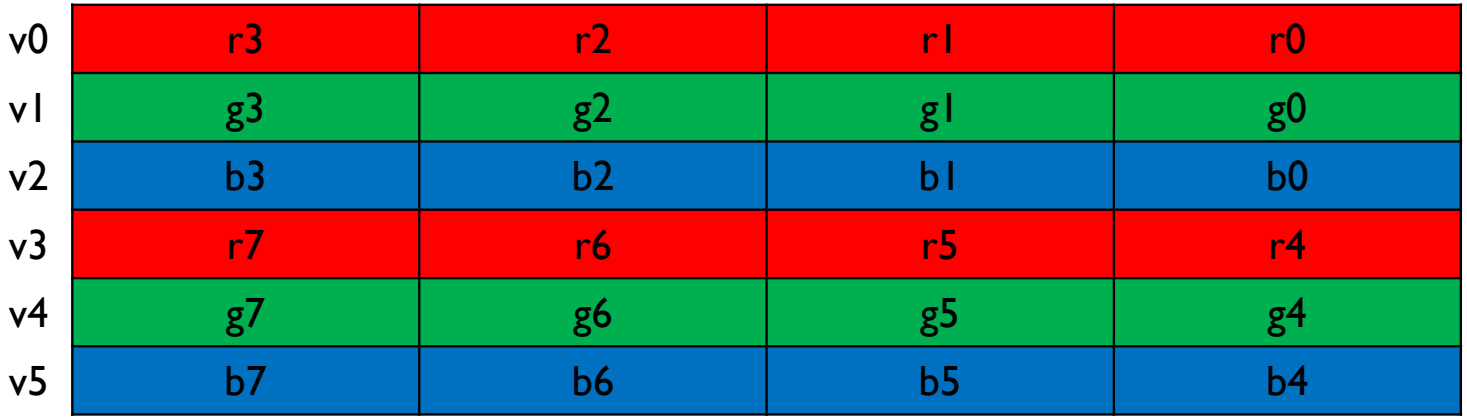
What about vectorization ?

1. Load 8 pixels from memory to neon registers



2. Expand to 32 bits (`uxtl, uxtl2`)



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What about vectorization (cont.)

3. Bunch of `mul` / `mla` with the coefficients
4. Round shift right the y, i, q results to 16bits (`rshrn`, `rshrn2`)

v0	y7	y6	y5	y4	y3	y2	y1	y0
v1	i7	i6	i5	i4	i3	i2	i1	i0
v2	q7	q6	q5	q4	q3	q2	q1	q0

5. Extract and compact the 8LSB from the y, i, q results (`xtn`)

v0									y7	y6	y5	y4	y3	y2	y1	y0
v1									i7	i6	i5	i4	i3	i2	i1	i0
v2									q7	q6	q5	q4	q3	q2	q1	q0

6. And store with `st3 {v0, v1, v2}, [x1], #24`

memory	...	y0	i0	q0	y1	i1	q1	y2	i2	...

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Performances (lower is better)

	Time	Code size	Data size (bytes)
First shot (reference)	1.0	1.0	0
Second try	1.03	1.0	40
Hand written straight asm (scalar)	0.94	0.80	40
Hand written scheduled asm (scalar)	0.79	0.80	40
Hand written asm (vector)	0.49	1.88	48

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Thank you !

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