Report Lab Assignment
Running x264 on Host Processor
Extracting and Accelerating Kernel on Co-processor

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Samenvatting

10 lines of Abstract text

1 Introduction

For the lab a computational intensive kernel has to be extracted from a `x264` software application, free software library for encoding video stream into H.236/MPEG-4 AVC format. The application is executed on a FPGA running a MicroBlaze host processor. By running the particular kernel on ρ-VEX co-processor, the execution time can be decreased by making use of hardware acceleration.

1.1 Getting Used to the Environment

The first lab is meant to get used to the project environment. A few input files are given to show the compile and run commands of the x264 application, by inserting a `.y4m` stream and creating a short `.mkv` movie. By adding the `gprof` flag to the compile command, a list is created of all functions ordered by their share of the total execution time (in percentage).

1.2 Detecting the Computationally Most Intensive Kernel

Profiling the x264 execution for the `.y4m` files that are provided by the lab leads to the ranking show in table 1.
Given these statistics, we decide to extract the `x264_pixel_satd_8x4 kernel`, since its share in execution time increases as the files become larger. This kernel evaluates the Sum of Transformed Differences between a 8x4 pixel block from the input stream and reference blocks using 4x4 transform (Hadamard???). DE EXECUTIETIJD IS VARIABEL, ELKE KEER DAT IK UITVOER MET GPROF OF TIME GEEFT IE ANDERE EXECUTIETIJDEN. DIT GETAL IS DUS NIET NAUWKEURIG.

1.3 Executing an Application on the Development Board and ρ-VEX

When executing `./configure`, a file is created for configuration of the application. However, the resulting `config.mak` file is made for applications running on the guest (Ubuntu). In order to configure for MicroBlaze, the `config.mak` file has to altered. All references to `m32` have to be removed and the `--DWORDS_BIGENDIAN`

Input fie	Execution time (in sec)	Share (in %)	Kernel name
eledream_32x18_1.y4m	0.02	100.00	x264_analyse_init_costs
		0.00	x264_free
		0.00	x264_cabac_encode_desicion_c
eledream_64x32_3.y4m	0.03	66.67	x264_analyse_init_costs
		33.33	x264_pixel_satd_4x4
		0.00	x264_pixel_satd_8x4
eledream_640x320_8.y4m	1.61	14.29	x264_pixel_satd_8x4
		11.80	x264_get_ref
		4.97	x264_pixel_satd_x4_16x16
eledream_640x320_32.y4m	8.54	20.61	get_ref
		13.23	x264_pixel_satd_8x4
		4.57	x264_pixel_satd_x4_8x8
eledream_640x320_128.y4m	29.86	17.48	get_ref
		14.17	x264_pixel_satd_8x4
		6.56	x264_pixel_satd_x4_16x16

Tabel 1: Chart with computationally most intensive kernels for each input stream.

flag has to be added to the `CFLAGS` variable. This has to be done everytime when configurating the application for MicroBlaze.
After doing this, the application now can be 'made' for MicroBlaze by first moving to the Scratchbox 2 environment for MicroBlaze and then execute the `make` command. Fig. 1 shows a block diagram of both the platforms.
In order to run the application on the MicroBlaze host processor, the `x264` executable must be compressed along with an input stream in a `tar.gz` file. This file can be put, via the FPGA host machine, on one of the three FPGAs using the `scp`, `ftp` and `put` command. For the programmer to connect to the development board, one must use the `ssh` and `telnet` command. See also fig 2.
For the first lab, the `satd_8x4` kernel has to be:

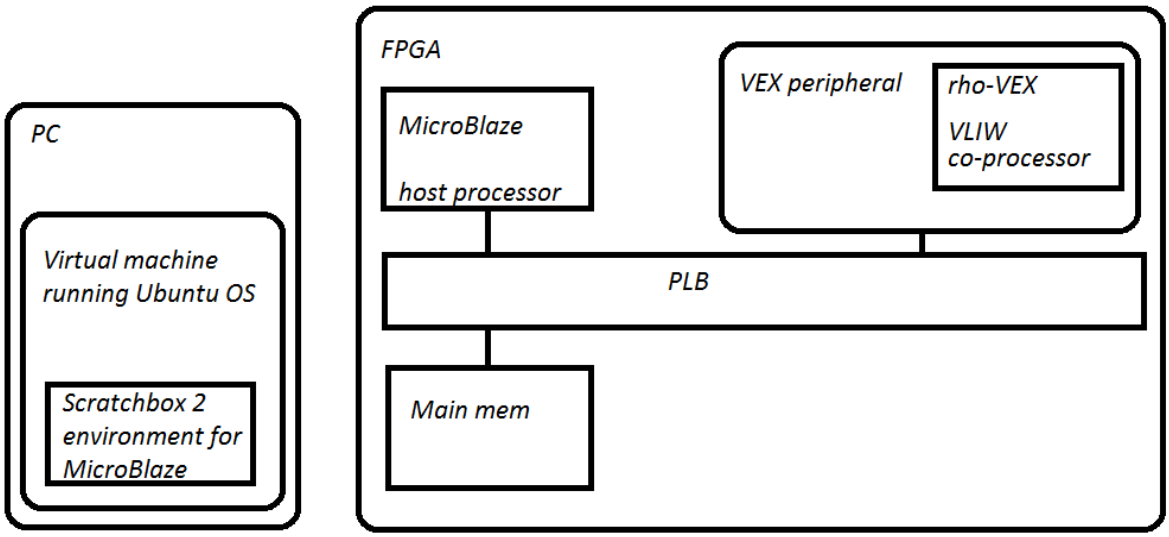
- extracted into a separate file
- supplemented to a proper .c file which can be compiled and run using the ρ-VEX
- included in the makefile that creates a bytecode and bytedata file of the kernel
- debugged

Looking back, the debugging part has been chasing us all the way through the lab. Not only did we suffer from bugs in our source code, the ρ-VEX itself did also have shortcomings that had to be circumvented by downloading several fixes, competing for FPGA availability and break downs of the entire host machine due to unsufficient capacity for the amount of students.

2 Approach

Our extracted kernel can be found in appendix A. In order to make the extracted kernel qualified for compilation and execution, a few things have to be altered. First, the new file has to be recognized by the `makefile` in the rovex-examples directory. By executing `make byte−` command two files are created:

- `bytecode`, containing all the intstructions to be executed by the ρ-VEX
- `bytedata`, containing the pixels of the input stream

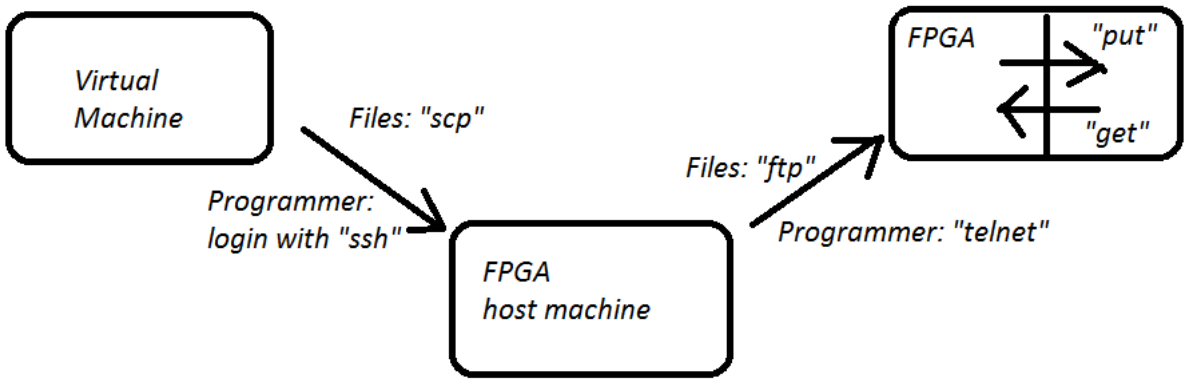


Figuur 1: Block diagram of the Virtual Machine and the ERA platform

Second, some type definitions have to be made. Originally, `pixel_satd_8x4` resides in the `pixel.c` file of the x264 application. When extracting this kernel, all prior knowledge is lost and has to be defined again. Then, in order to make the kernel compile and run on the ρ-VEX, the development board has to be reset and started. `Bytecode` has to be written to the instruction memory (`rex-imemory`) and `bytedata` to the data memory (`rvex-dmemory`). Finally, the calculated result should be returned to the host. Figure X shows the ρ-VEX memory layout for our kernel.

2.1 Adjusting the `makefile`

In order to make the makefile recognize the extracted kernel, the file can simply be added to the `EXECUTABLES`. Other files are already in the `makefile` (e.g. `adpcm`), but these can be removed since we will not need them for our application. An important issue is the difference between logical memory and physical memory. While the first address of a logical memory is obviously zero, the physical memory can have the first part of the register being occupied by the operating system. For the ρ-VEX, the first address which is allowed to be (over)written is 120. Thus, when writing for example the result of the kernel to the logical address '0', it actually should be written to the physical address '120' of the data memory. This can be done using `__DATA_START` to indicate the start address.
Despite the fact that this is a rather simplistic operation, it took us some struggling to have this action confirmed as correct. For example, we were told to remove the `AUTOINLINE` flag which resulted in a lot of wrong hexdumps. Also, half way the lab a fix has been made to eliminate the issue of the logical and physical addresses. All references to `__DATA_START` had to be removed again, which felt like we had wasted lots of time. Unfortunately, we still had major problems getting the application to run correctly. As it turned out, the fix had only affected the 'home' directory. In order to avoid conflicting files, we had created a separate folder named 'lab2' from where we executed the application. Due to this, the fix did not reach our code and thus did not eliminate the start address issue.



Figuur 2: Ubuntu commands for putting files on and navigating to the FPGAs

2.2 Type Definition

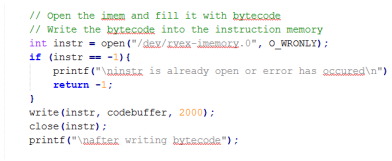
As stated earlier, an extracted kernel is unable to obtain information from previous code. Consequently, all parameters have to be pre-defined. Table 2 shows all required type definitions.

Parameter	Type definition	Motivation
`intptr_t`	`unsigned int`	This parameter represents the stride, which cannot be <0
`pixel`	`unsigned char`	Pixels are made out of bytes, which have 8 bits (like a `char`)
`sum_t`	`short int`	Same type definition as in the source code (16 bits)
`sum2_t`	`long int`	Same type definition as in the source code (32 bits)
`BIT_DEPTH`	defined as 8	Also in the source code, plus the kernel handles pixels (bytes)
`BIT_PER_SUM`	(8 * `sizeof(sum_t)`)	Also predefined as in the source code, being 8 as well

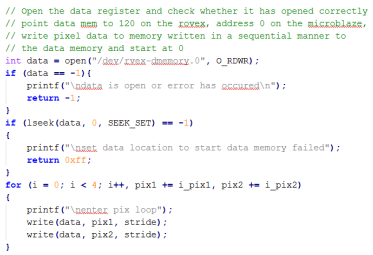
Tabel 2: Type definitions in the extracted kernel file.

2.3 Communication between the MicroBlaze and the ρ-VEX

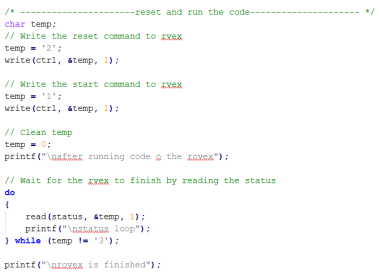
In order to delegate the `satd_8x4` kernel from the MicroBlaze to the ρ-VEX, both the environments need to communicate with each other. When executing the `x264` application, the MicroBlaze has to load the instructions of the extracted kernel into the instruction memory of the ρ-VEX and the data (for which the SATD has to be evaluated) into the data memory. This is when the source code of `x264` becomes involved. The `pixel_satd_8x4 kernel`, which is residing in the `pixel.c` file of the application, needs to be overwritten. Instead of calculating the SATD, it should send the instructions and input to the ρ-VEX. The commands **??** and **??** are therefore added to the `pixel.c` file of the `x264` application. These pixels are written at physical address 120, the first address on the ρ-VEX that is not set apart for communication between the driver and the ρ-VEX. Also, an empty pixel is written after `bytedata` in order to make space for writing the result.
To control the ρ-VEX from the x264 application, the control memory should also be written. By first setting the control to `'2'`, the ρ-VEX is being reset. It can then be started by writing `'1'` to control, telling the ρ-VEX to start calculating the satd of the two pixels. While calculating, the status of the ρ-VEX can be checked in a `while`-loop by reading the status variable of the status memory (`rvex-smemory`). When the `satd` kernel is finished, the result can be read from the data memory. See also 3c.



(a) Bytecode



(b) Bytedata



(c) Reset, set and get the status of the ρ-VEX

Figuur 3: Commands for reading from and writing to the ρ-VEX

2.4 Result Hyphothesis

By having the computational intensive kernel being run concurrently on a co-processor, one could expect an overal speedup of the application. A problem is, however, that the `bytecode` and `bytedata` have to be sent to the ρ-VEX every time the kernel is being called. `Bytedata` contains two new pixels of which the SATD has to be calculated, `bytecode` the kernel instructions. Because of this constant data traffic between the MicroBlaze and the ρ-VEX we don't think the intended speed up is achieved.
The reason that `bytecode` has to be sent every time the kernel is called, is that the three FPGAs are shared among a lot of students. When running their application concurrently, the instruction memory is constantly overwritten by another group. If there was a one-to-one setup, `bytecode` could have to been placed in `main.c`, written tot the `imemory` of the ρ-VEX once when starting the application.

3 Implementation

The approach described in the previous section wasn't implemented in a day, obviously.
*** ervaringen!! ***

A Extracted kernels `pixel_satd_8x4` and `pixel_satd_4x4`

```
// Defining types for the expected input arguments
// changed intptr_t to int instead of unsigned int and sum2 from us long to us int
typedef unsigned int intptr_t;
typedef unsigned char pixel;
typedef unsigned short sum_t;
typedef unsigned long sum2_t;

// Define an inputarray that points to the start of the data memory
pixel datamem[128];

// BIT_DEPTH is 8 always, so if else statement is removed
#define BIT_DEPTH 8

// #define BITS_PER_SUM (8 * sizeof(sum_t))
#define BITS_PER_SUM (8 * sizeof(sum_t))

// HADAMARD4 function exported from the original pixel.c file
#define HADAMARD4(d0, d1, d2, d3, s0, s1, s2, s3) {\
    sum2_t t0 = s0 + s1;\
    sum2_t t1 = s0 - s1;\
```

```
    sum2_t t2 = s2 + s3;\
    sum2_t t3 = s2 - s3;\
    d0 = t0 + t2;\
    d2 = t0 - t2;\
    d1 = t1 + t3;\
    d3 = t1 - t3;\
}

// abs function exported from the original pixel.c file
static sum2_t abs2(sum2_t a);

// x264_pixel_satd_8x4 exported from the original pixel.c file
int x264_pixel_satd_8x4();

// x264_pixel_satd_4x4 exported from the original pixel.c file
int x264_pixel_satd_4x4();

char main()
{
    // run the x264_pixel_satd_8x4 by passing on the pixel values.
    int result, i;
    result = 0;
    i = 0;

    // calculate the result
    if (datamem[0x40] == 0x44)
    {
        result = x264_pixel_satd_4x4();
    }
    else if (datamem[0x40] == 0x84)
    {
        result = x264_pixel_satd_8x4();
    }
    else result = 0xdead;


    // clean result array
    for (i = 0; i < 4; i++)
    {
        datamem[i] = 0x00;
    }

    // write result in reverse endianess
    datamem[0x00] = (result >> 24) & 0xFF;
    datamem[0x01] = (result >> 16) & 0xFF;
    datamem[0x02] = (result >> 8) & 0xFF;
    datamem[0x03] = result & 0xFF;

    // DEBUG
    // datamem[0x40] = 0xfe;
    // datamem[0x41] = 0xed;

    return 0;
}

static sum2_t abs2(sum2_t a)
{
    sum2_t s = ((a>>(BITS_PER_SUM-1))&(((sum2_t)1<<BITS_PER_SUM)+1))*((sum_t)-1);
    return (a+s)^s;
}

int x264_pixel_satd_8x4()
{
        sum2_t tmp[4][4];
        sum2_t a0, a1, a2, a3;
```

```
    sum2_t sum = 0;
    int i = 0;

    // Strides are set values and do not have to be given as input arguments
    // Stride is 16 to compute 2 rows of 8 bytes of pixel array elements
    intptr_t stride = 16;

    // Pointer to data memory
    pixel* datapoint = datamem;

    // Adjust the for loop so it can fetch data from data memory
    for(i = 0; i < 4; i++, datapoint += stride)
    {
        a0 = (datapoint[0] - datapoint[8]) + ((sum2_t)(datapoint[4] - datapoint[12]) << BITS_PER_SUM);
        a1 = (datapoint[1] - datapoint[9]) + ((sum2_t)(datapoint[5] - datapoint[13]) << BITS_PER_SUM);
        a2 = (datapoint[2] - datapoint[10]) + ((sum2_t)(datapoint[6] - datapoint[14]) << BITS_PER_SUM);
        a3 = (datapoint[3] - datapoint[11]) + ((sum2_t)(datapoint[7] - datapoint[15]) << BITS_PER_SUM);
        HADAMARD4( tmp[i][0], tmp[i][1], tmp[i][2], tmp[i][3], a0,a1,a2,a3 );
    }
    for(i = 0; i < 4; i++ )
    {
        HADAMARD4( a0, a1, a2, a3, tmp[0][i], tmp[1][i], tmp[2][i], tmp[3][i] );
        sum += abs2(a0) + abs2(a1) + abs2(a2) + abs2(a3);
    }
    return (((sum_t)sum) + (sum>>BITS_PER_SUM)) >> 1;;
}

int x264_pixel_satd_4x4()
{
    sum2_t tmp[4][2];
    sum2_t a0, a1, a2, a3, b0, b1;
    sum2_t sum = 0;
    int i = 0;

        // Strides are set values and do not have to be given as input arguments
    // Stride is 8 to compute 2 rows of 4 bytes of pixel array elements
    intptr_t stride = 8;

    // Pointer to data memory
    pixel* datapoint = datamem;

    // instead of 8x4 method, it writes per 4 bytes
    for( i = 0; i < 4; i++, datapoint +=stride )
    {
        a0 = datapoint[0] - datapoint[4];
        a1 = datapoint[1] - datapoint[5];
        b0 = (a0+a1) + ((a0-a1)<<BITS_PER_SUM);
        a2 = datapoint[2] - datapoint[6];
        a3 = datapoint[3] - datapoint[7];
        b1 = (a2+a3) + ((a2-a3)<<BITS_PER_SUM);
        tmp[i][0] = b0 + b1;
        tmp[i][1] = b0 - b1;
    }
    for( i = 0; i < 2; i++ )
    {
        HADAMARD4( a0, a1, a2, a3, tmp[0][i], tmp[1][i], tmp[2][i], tmp[3][i] );
        a0 = abs2(a0) + abs2(a1) + abs2(a2) + abs2(a3);
        sum += ((sum_t)a0) + (a0>>BITS_PER_SUM);
    }
    return sum >> 1;
}
```