Heterogeneous HW/SW acceleration of a video game in a reconfigurable MPSoC

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Motivation and Main Goals

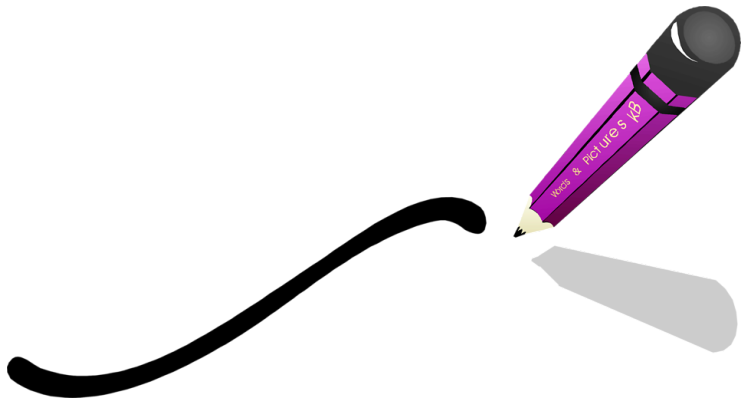
- Analyse the acceleration of a complex software application using an MPSoC.
- Evaluation of SDSoC and HLS tools.
- The use case is the DOOM game.

VIVADO®
HL*x* Editions

SDSoC™
Environment

Outline

1. Introduction
   - Heterogeneous systems and MPSoCs
   - Zynq UltraScale+ and ZCU102 platform
2. Development and methodology
   - Custom OS
   - DOOM Profiling
   - The `Stretch2x` function
     - FPGA implementation
     - Integration in Linux
3. Experimental Results
   - Speed-ups
   - Power Consumption
   - DOOM FPS
4. Conclusions and contributions



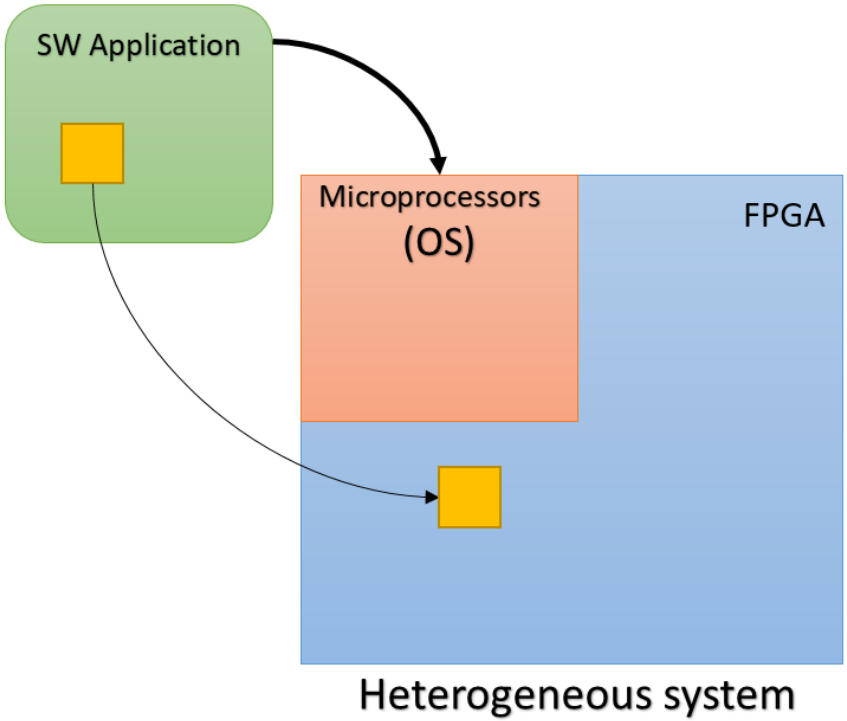
1.1. Heterogeneous systems and MPSoCs

- Heterogeneous $\longrightarrow$ sw/hw processing
- *Multi-Processor System-on-Chip* $\rightarrow$ Several elements

Software: Microprocessors (C/C++)

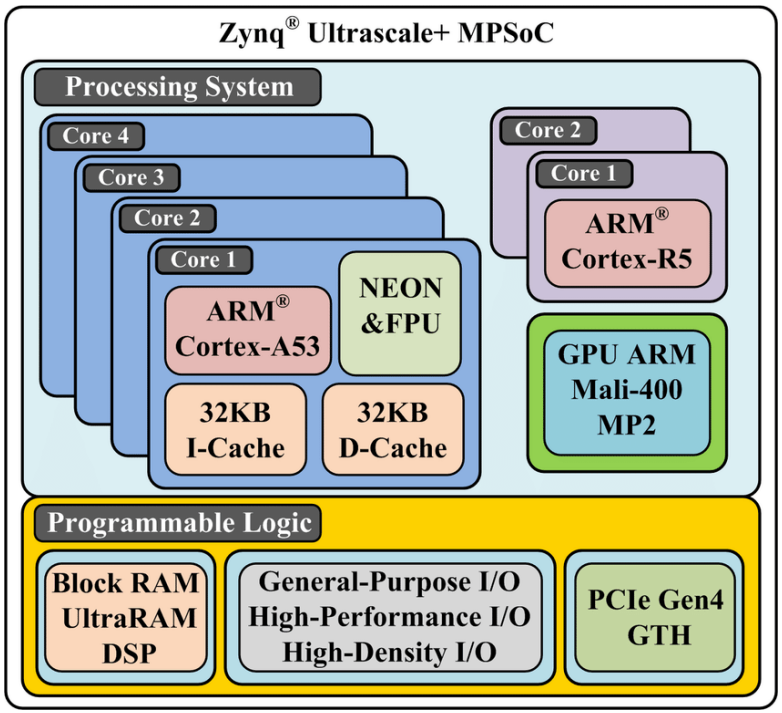
High Level Synthesis

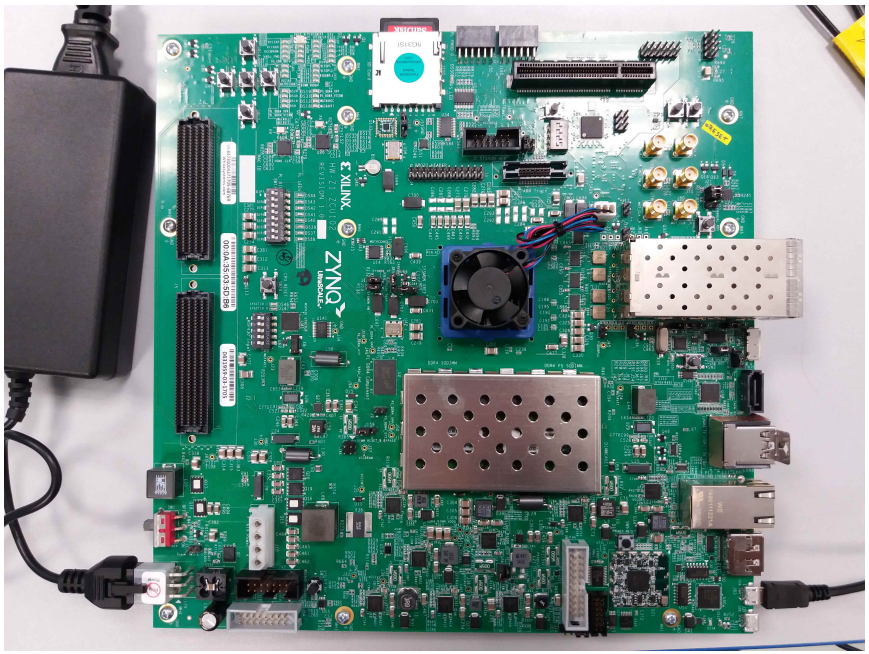
Hardware: FPGAs (VHDL/Verilog)



1.2. Zynq UltraScale+ and ZCU102 platform

- The device → Zynq UltraScale+ MPSoC
- The board → ZCU102 Evaluation Kit



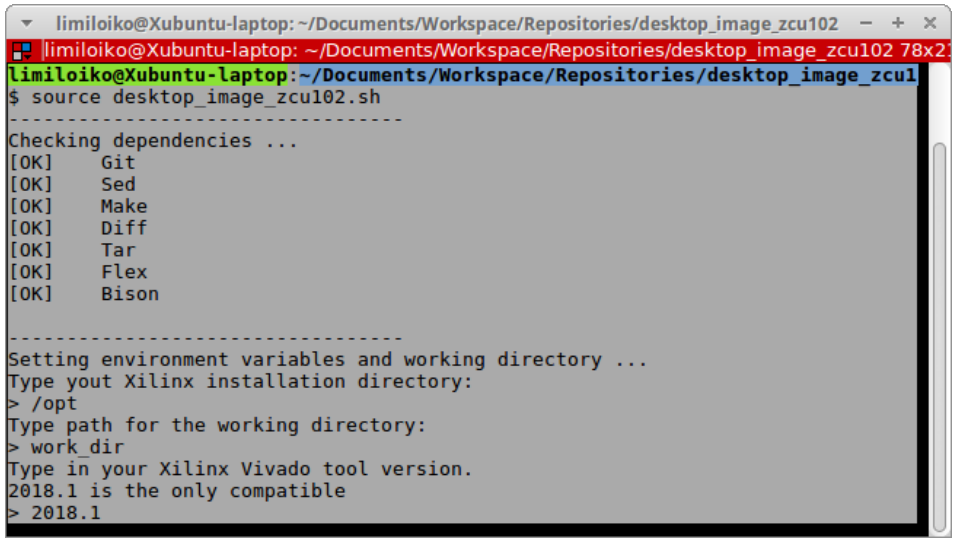


2.1. Custom OS

- Limitations using tools to generate the OS (PetaLinux/Yocto).

$$\text{Limitations} \begin{cases} \text{Desktop environment} \rightarrow \texttt{MALI GPU Drivers} \\ \text{Package Manager} \end{cases}$$

- Each element is built with the required features.
- `Bash` script that generates the SD Card image.



2.2. DOOM Profiling

- The profiling is performed to identify the task that uses the CPU the most.
- `Gprof` Linux tool is used.
- The results are similar: `I_Stretch2x` $\rightarrow$ **37.67%**

- Amdahl's Law theoretical speedup:

$$S = \frac{1}{(1-p) + \frac{p}{s_i}}$$

$$S_{max} = \lim_{s \to \infty} \frac{1}{(1-0.3767) + \frac{0.3767}{s}} = \mathbf{1.604}$$

/home/limiloiko/Documents/Workspace/tfm_doom/Project_Resources/profiling/crispy-doom/sw/gprof_sv

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Flat profile:

Each sample counts as 0.01 seconds.

% time	cumulative seconds	self seconds	calls	self s/call	total s/call	name
37.67	1.10	1.10	424	0.00	0.00	I_Stretch2x
13.70	1.50	0.40	122262	0.00	0.00	R_DrawSpan
13.01	1.88	0.38	2	0.19	0.19	GenerateStretchTa
12.33	2.24	0.36	484435	0.00	0.00	R_DrawColumn
3.42	2.34	0.10	272	0.00	0.01	D_PageDrawer
3.08	2.43	0.09	224	0.00	0.00	V_DrawFilledBox
3.08	2.52	0.09	11232	0.00	0.00	R_RenderSegLoop
3.08	2.61	0.09	1	0.09	0.09	Chip__Setup
2.40	2.68	0.07	5465	0.00	0.00	V_DrawPatch
1.37	2.72	0.04	943598	0.00	0.00	R_MakeSpans
0.86	2.75	0.03	432327	0.00	0.00	R_GetColumn
0.68	2.77	0.02	1102083	0.00	0.00	FixedMul
0.51	2.78	0.02	125	0.00	0.00	R_GenerateLookup
0.34	2.79	0.01	74537	0.00	0.00	R_DrawMaskedColum
0.34	2.80	0.01	26142	0.00	0.00	Z_ChangeTag2
0.34	2.81	0.01	16379	0.00	0.00	R_MaybeInterpolat
0.34	2.82	0.01	14601	0.00	0.00	R_PointOnSide
0.34	2.83	0.01	1648	0.00	0.00	BuildNewTic
0.34	2.84	0.01	1530	0.00	0.00	FindNearestColor
0.34	2.85	0.01	820	0.00	0.00	P_PlayerThink

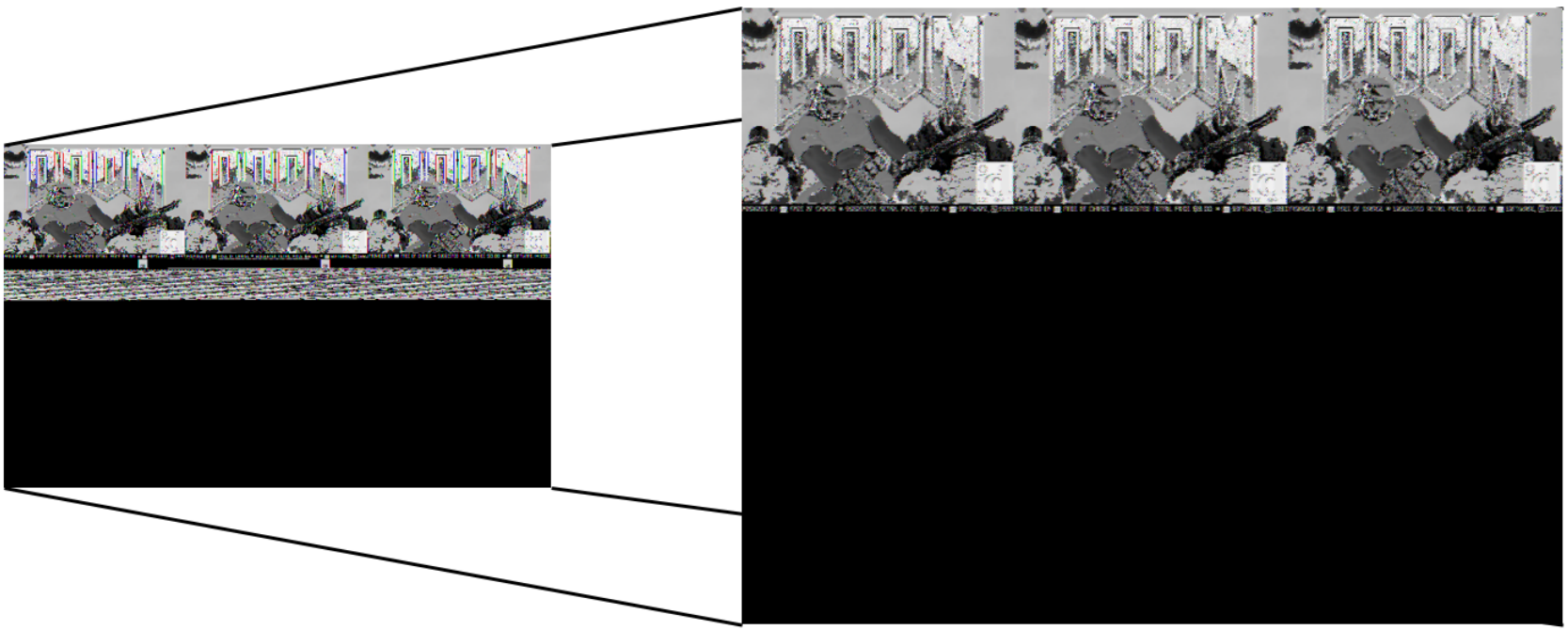
2.3. The `Stretch2x` function

- Adapts the resolution of the input frame.

$$640x400 \rightarrow 1280x960$$

$$\text{Width } x2 = 1280$$

$$\text{Height } x2.4 = 960$$

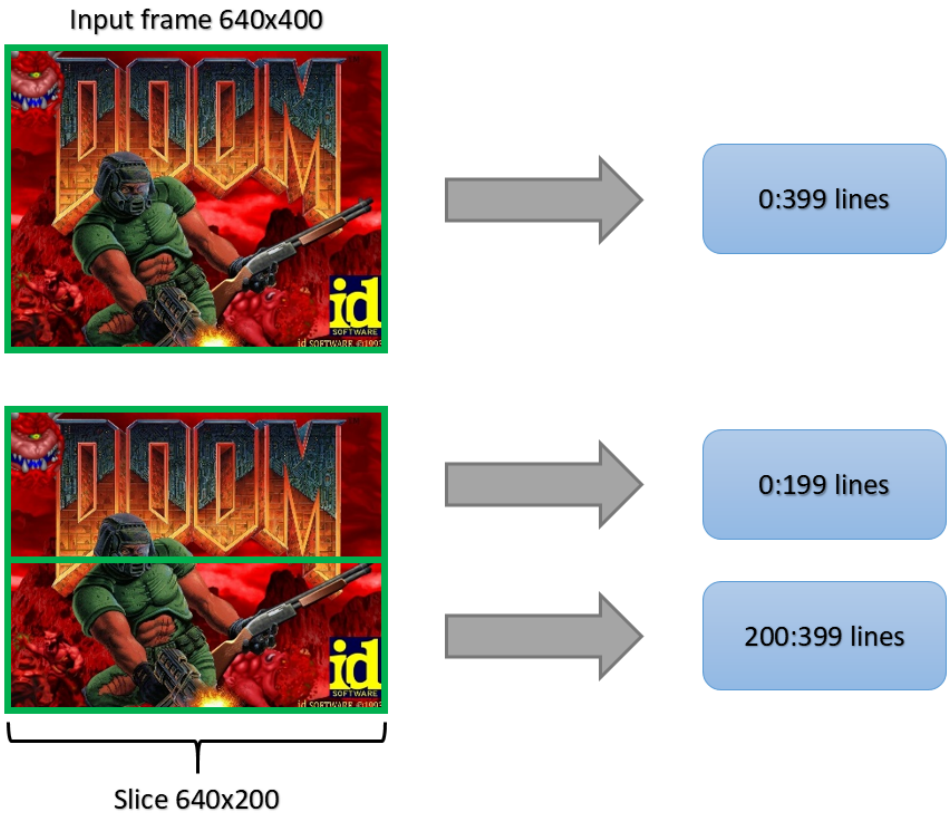


Input 640x400

Output 1280x960

2.3.1. FPGA implementation

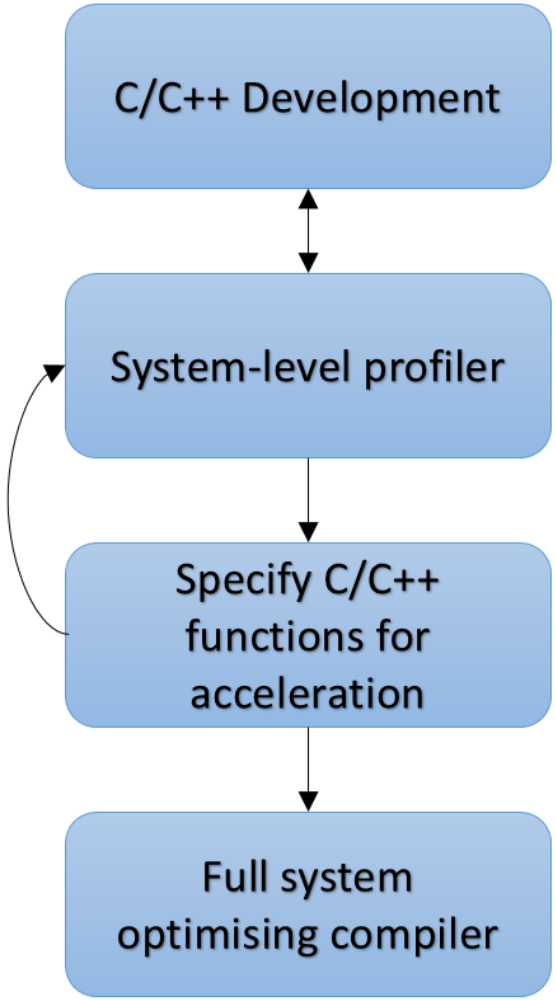
- Vivado HLS (*High-Level Synthesis*) tool is used.
- The use of global variables are removed and the function arguments are adapted.



- The image is split into slices.
- The HW function is instanced many times.
- Less data is processed by each module.

2.3.2. Integration in Linux

- Xilinx tool to generate Linux applications.
- It generates *stub* functions that handle the HW interfaces.
- Use of the SDSoC tools to:
  1. Create single executables to measure speedups.
  2. Generate the C shared library for the integration in DOOM.



3. Experimental Results

- Different ways to implement the function:
  1. N° modules: 1, 2, 4, 5, 8.
  2. HW frequency: 100, 150, 200, 300 MHz.
- The main characteristics that are measured are:

Speed-up

The comparison between the time it takes respect to software.

Energy consumption

The energy consumption of the platform.

3.1. Speed-ups

Table 1: Speed-ups for each HW setup

Nº	100 MHz	150 MHz	200 MHz	300 MHz
1	0.67	0.99	1.38	1.37
2	1.35	1.87	2.43	2.56
4	2.40	3.20	3.96	4.11
5	2.59	3.60	4.37	4.53
8	3.30	4.13	4.74	4.83

- ↑ nº → More parallelism
- ↑ MHz → Faster
- Amdahl's Law:

$$S = \frac{1}{(1 - 0.3767) + \frac{0.3767}{4.83}} = \mathbf{1.47}$$

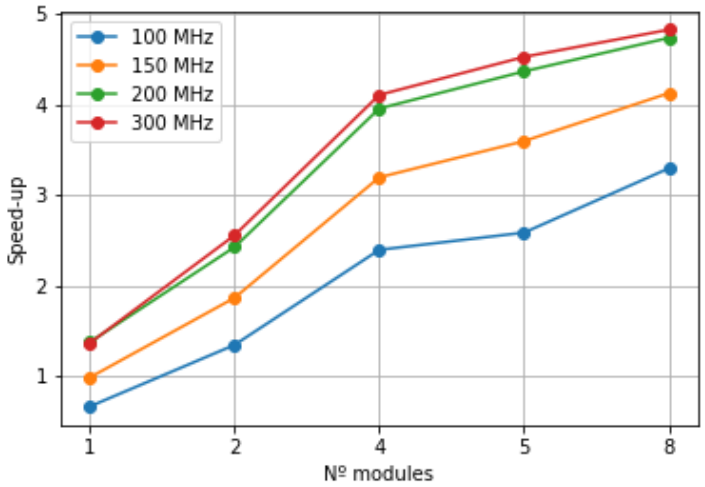


Figure 1: Speed-ups

3.2. Power Consumption

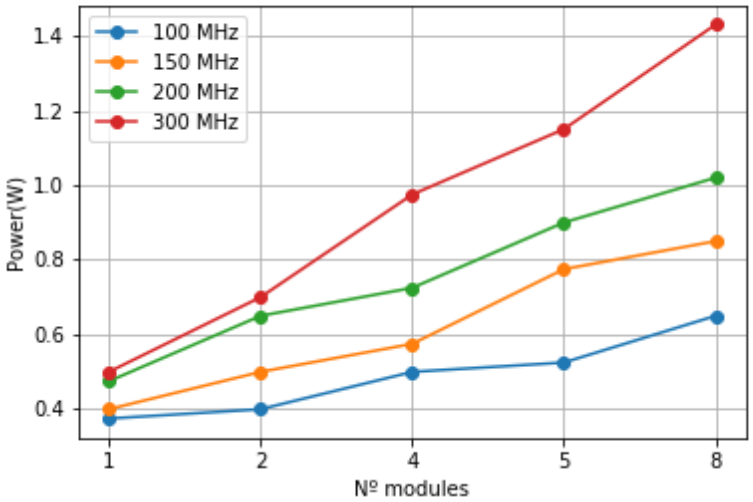


Figure 2: FPGA Power consumption

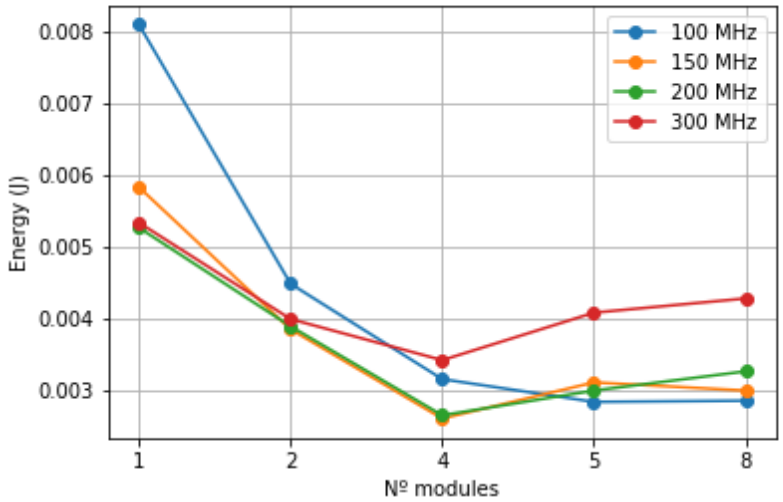


Figure 3: Energy consumption

- It increases using:
  1. More modules.
  2. Higher frequencies.

$$\text{Most efficient} \begin{cases} 4 \text{ modules} \\ 150 \text{ MHz} \end{cases}$$

$$S = \frac{1}{(1 - 0.3767) + \frac{0.3767}{3.20}} = \mathbf{1.35}$$

3.3. DOOM FPS

- Using the stub functions generated by the SDSoC.
- The SW gives **55 FPS**

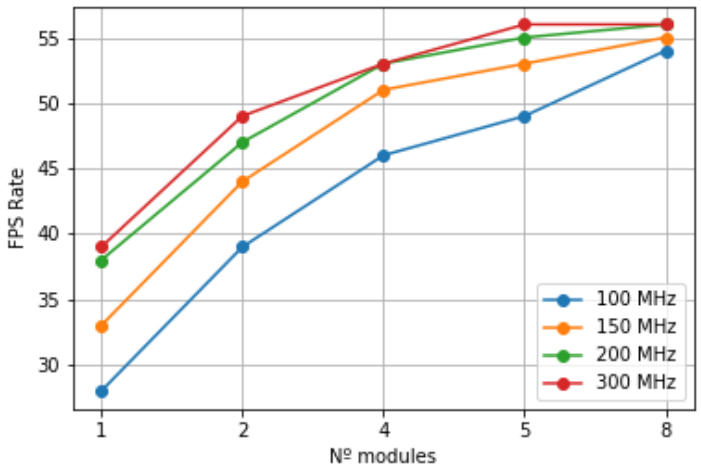


Figure 4: Game FPS rate

- ✗ FPS ratio can not be used.
- ✓ The CPU is released of the execution of this function.
- ✓ The CPU consumption is zero.

4. Conclusions and contributions

Conclusions:

- The nowadays development tools are used:
  - Vivado HLS
  - SDSoC Tools
- The final acceleration of the game (**1.47**) is near the theoretical (**1.604**).
- The complexity of the DOOM game has prevented the overall acceleration.

Contributions:

- The custom Linux-based system.
- The generation of a hw IP and DSE.
- The implementation to split the image into different slices in the game.

The End

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PL vs PS

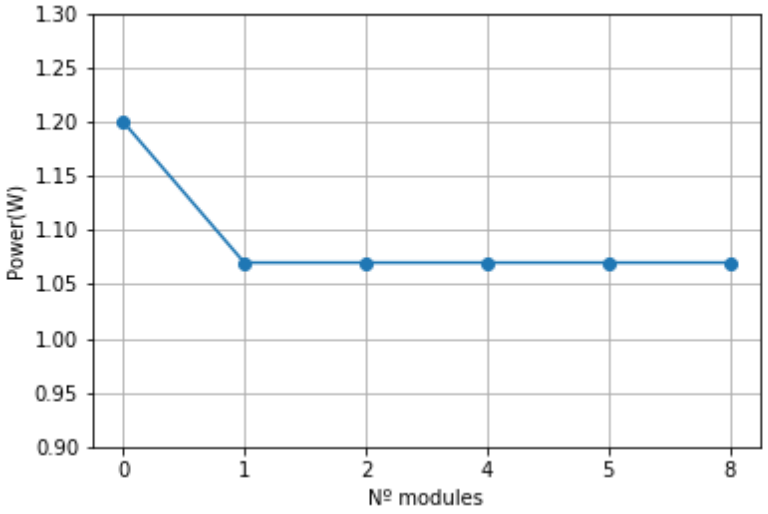

Figure 5: PS power consumption

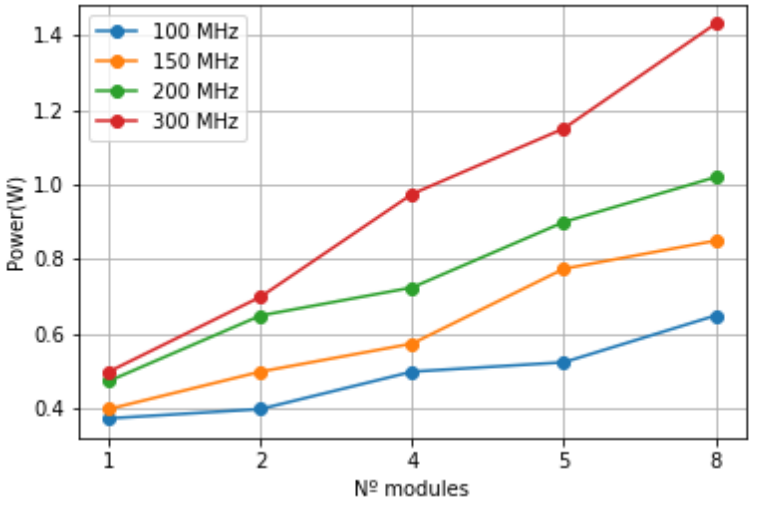

Figure 6: PL power consumption

Hardware profiling

/media/limiloiko/946b6880-69b8-4c23-a407-a65272d3fc5d/home/linaro/Doom/crispy/crispy-doom/log_gp

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Flat profile:

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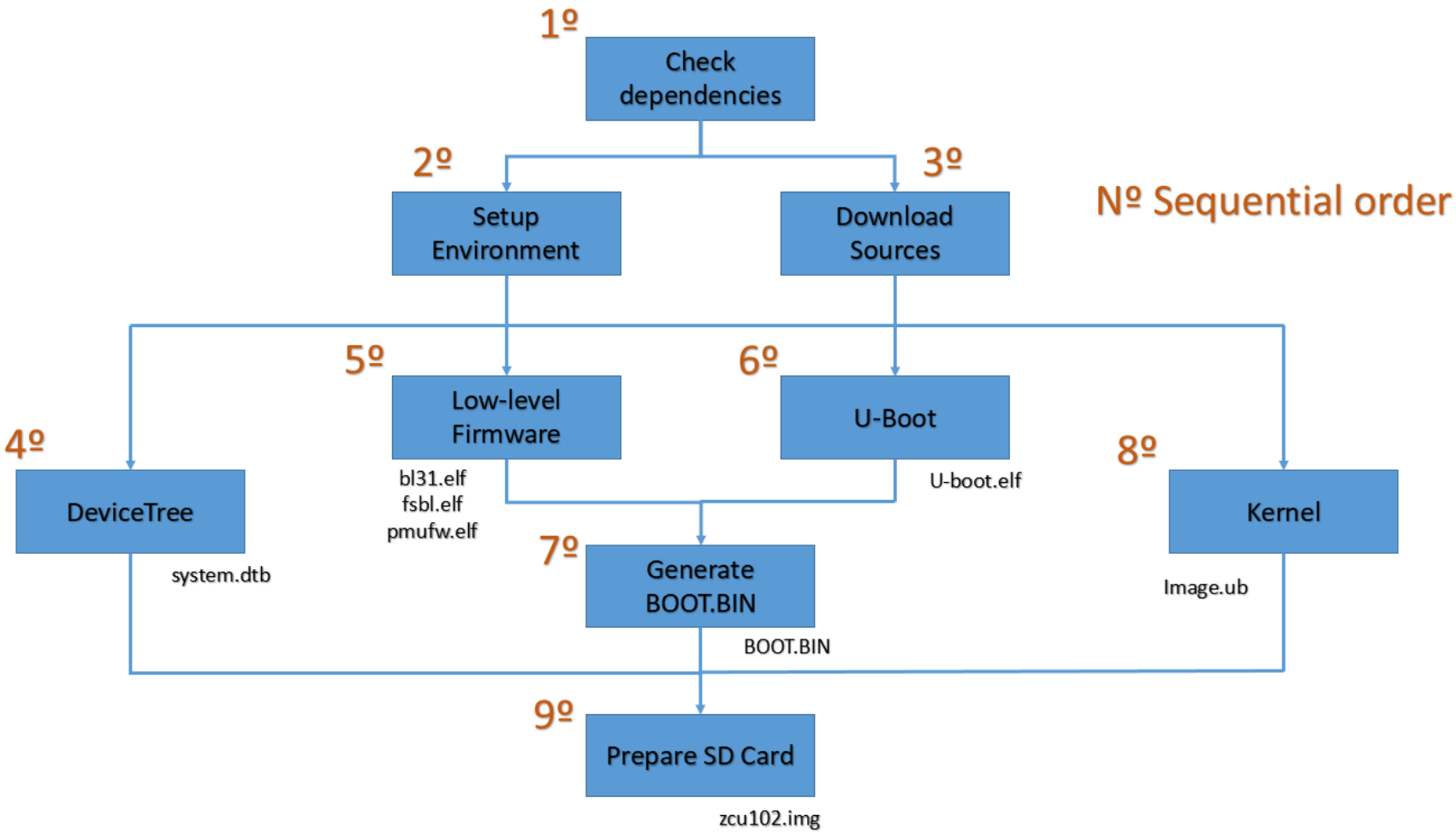
% time	cumulative seconds	self seconds	calls	self s/call	total s/call	name
28.06	1.77	1.77	1842757	0.00	0.00	R_DrawColumn
27.66	3.51	1.74	482295	0.00	0.00	R_DrawSpan
9.86	4.13	0.62	50086	0.00	0.00	R_RenderSegLoop
5.72	4.49	0.36	2	0.18	0.18	GenerateStretchTa
4.93	4.80	0.31	1026	0.00	0.00	V_DrawFilledBox
2.23	4.94	0.14	4032427	0.00	0.00	R_MakeSpans
2.23	5.08	0.14	1053	0.00	0.01	D_PageDrawer
1.75	5.19	0.11	1713868	0.00	0.00	R_GetColumn
1.59	5.29	0.10	1609184	0.00	0.00	Z_ChangeTag2
1.43	5.38	0.09	1	0.09	0.09	Chip__Setup
1.11	5.45	0.07	4741790	0.00	0.00	FixedMul
1.11	5.52	0.07	1592869	0.00	0.00	W_CacheLumpNum
1.11	5.59	0.07	125566	0.00	0.00	R_AddLine
1.11	5.66	0.07	1018	0.00	0.00	R_DrawPlanes
0.95	5.72	0.06	50061	0.00	0.00	R_StoreWallRange
0.95	5.78	0.06	23165	0.00	0.00	V_DrawPatch
0.87	5.83	0.06	391955	0.00	0.00	R_PointToAngle
0.64	5.87	0.04	69178	0.00	0.00	R_CheckBBox
0.64	5.91	0.04	19260	0.00	0.00	R_DrawSprite
0.48	5.94	0.03	226084	0.00	0.00	R_DrawMaskedColum

Hardware profiling



SDSoC Tools

SDSoC™ Environment

- Xilinx tool to generate Linux applications.
- It generates *stub* functions that handle the HW interfaces.