High-Level Programming of FPGAs for Audio Real-Time Signal Processing Applications

Faust -> FPGA -> Sound

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https://ccrma.stanford.edu/~rmichon/talks/ccrma-colloq-oct22.pdf

Presentation Outline

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- 5 faculty, 4 PhD Candidates, 1 postdoc, 1 engineer, bunch of interns

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- The two main manufacturers of FPGAs are Xilinx/AMD and Altera/Intel.

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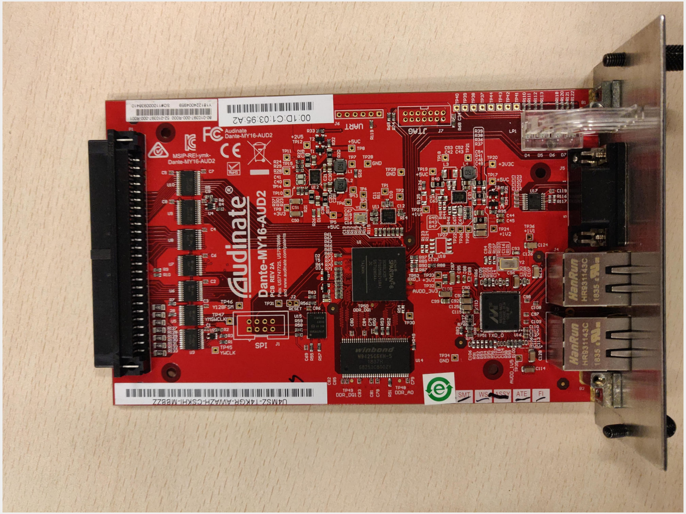
- Highly adapted to audio DSP algorithms with a high potential for parallelization (e.g., spatial audio, modal synthesis, etc.)
- FPGAs are already used at the heart of some high-end professional audio products.



Dante Audio Interface Based on a Xilinx Spartan 6

(this one was found in a CCRMA trashcan ;)). In this specific case, the power of the FPGA is exploited to interface with multiple audio codec chips in parallel and to compute a large number of audio channels.

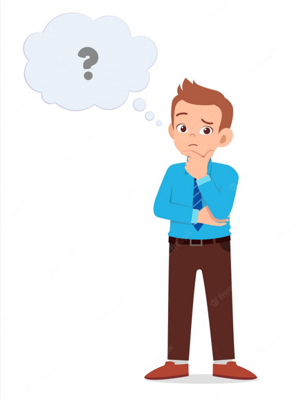
Novation Summit Keyboard

(this one was not found in a CCRMA trashcan ;)). In this specific case, the power of the FPGA is exploited to implement digital oscillators running at a very high audio sampling rate (about 24MHz), approximating analog...

Antelope Audio Synergy Core Series

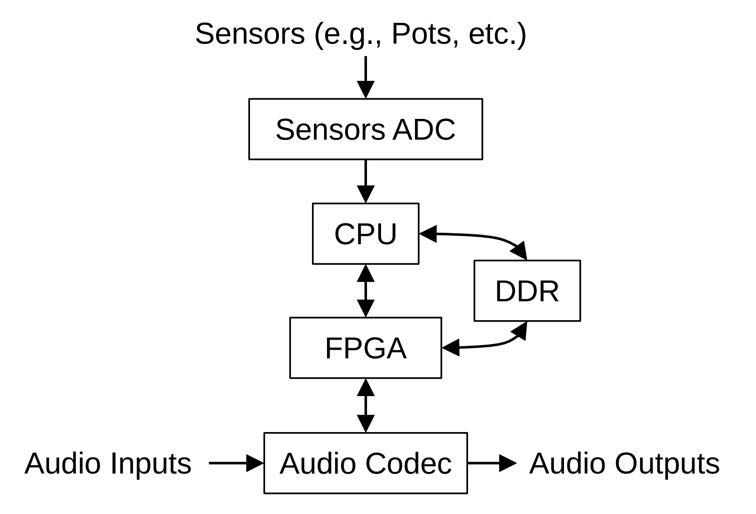
High-end audio interfaces and processors based on FPGAs. In this specific case, FPGAs are used for their computational power.

Now if FPGAs are so great for audio, why don't we see more of them (both in the industry and in academia)?



Because they're extremely hard to program and their architecture is intrinsically low-level...

Basic Audio-FPGA System Architecture



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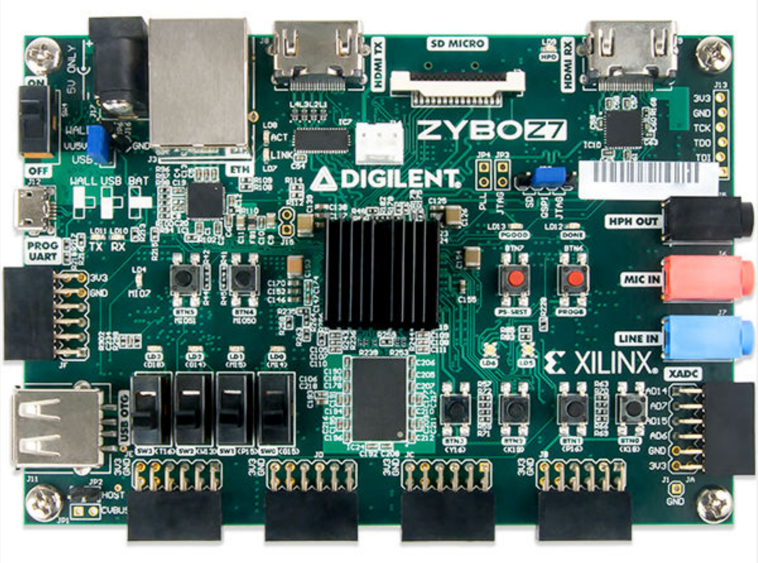
- Etc.

Dev Board Based on an FPGA: the Digilent Zybo Z7



Faust comes to the rescue!

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- Faust is open source: `https://faust.grame.fr`

- SyFaLa is an open-source tool developed by the Emeraude team allowing for the programming of Zybo Z7 and Ultracale Genesys FPGA-based boards with Faust: `https://github.com/inria-emeraude/syfala`

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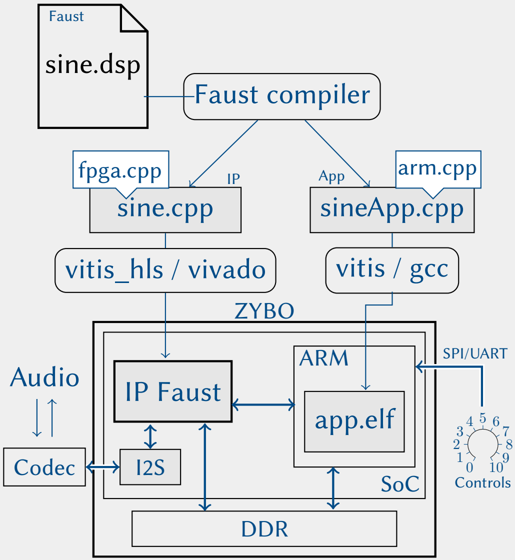
- Much more...

SyFaLa Toolchain Overview



Typical Example of a Faust Program Running On an FPGA Through SyFaLa

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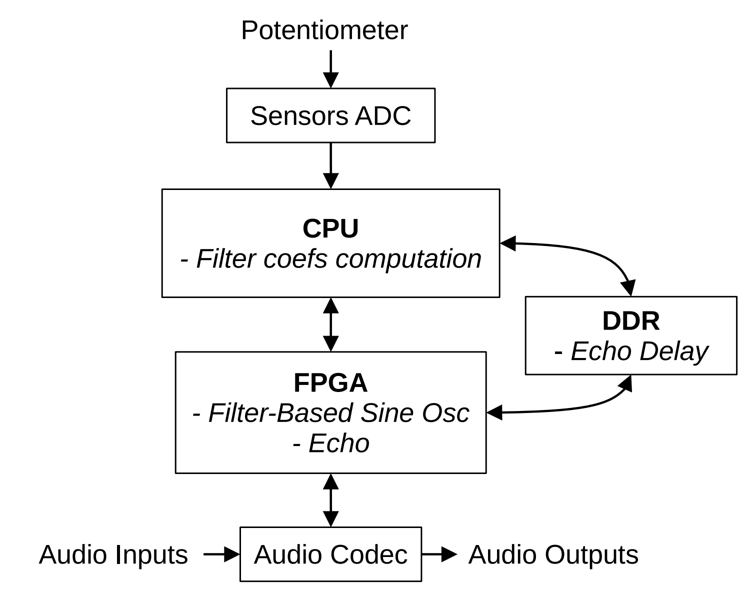
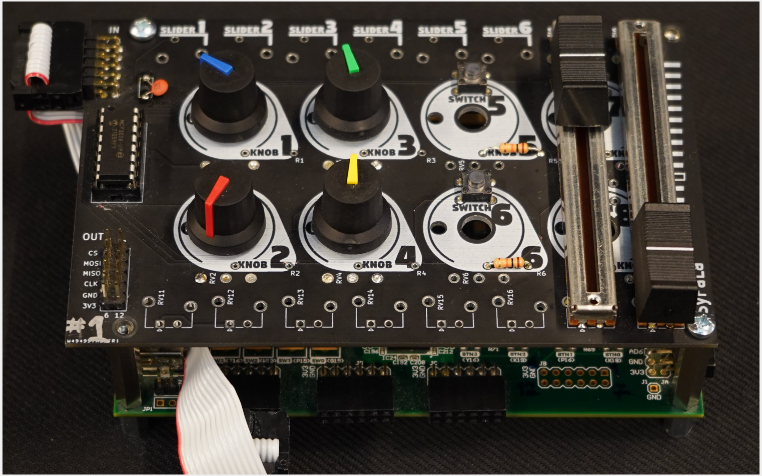
- The `freq` parameter here is controlled by a hardware potentiometer connected to the the sensor ADC.


Potentiometer
Sensors ADC
CPU
- Filter coefs computation
DDR
- Echo Delay
FPGA
- Filter-Based Sine Osc
- Echo
Audio Inputs
Audio Codec
Audio Outputs

Modular Control Interface: the "Popophone"



Sister board provided as part of SyFaLa. It is based on a TI sensor ADC and it can host various controllers: push buttons, rotary and linear potentiometers, etc.

Performances, Applications, and Research Avenues

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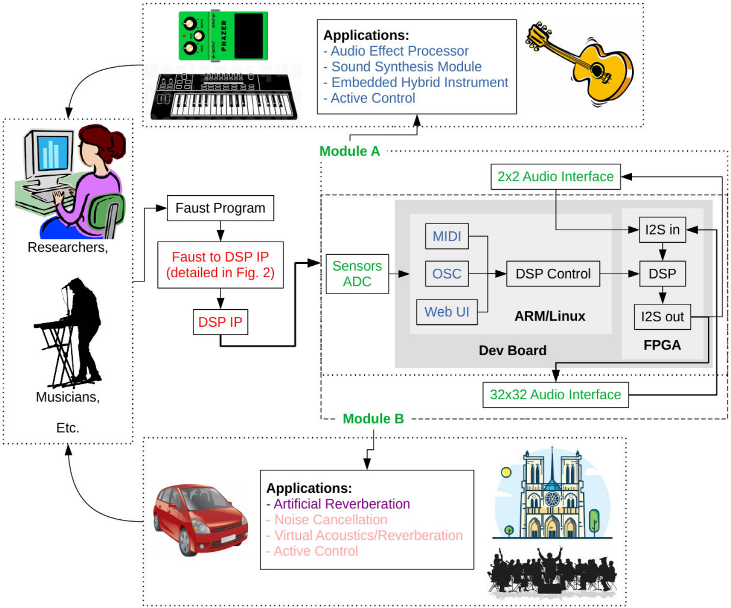
- Most applications enabled by such performances are related to active acoustic control (e.g., augmented instruments, noise cancellation, room acoustics, etc.).

The FAST Project: Faust -> FPGA -> Active Control of Acoustics

- FAST gathers the strength of GRAME-CNCM, INSA Lyon, INRIA, and LMFA.
- FAST is funded by the French National Agency for Research (ANR).
- 2 PhDs, 1 PostDoc, many interns

https://fast.grame.fr/



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- Opens the door to audio latency way below $1\mu s$ and to potentially some new ways to approach audio DSP.
- This is an ongoing project: we have a working DAC, we're now working on the ADC.

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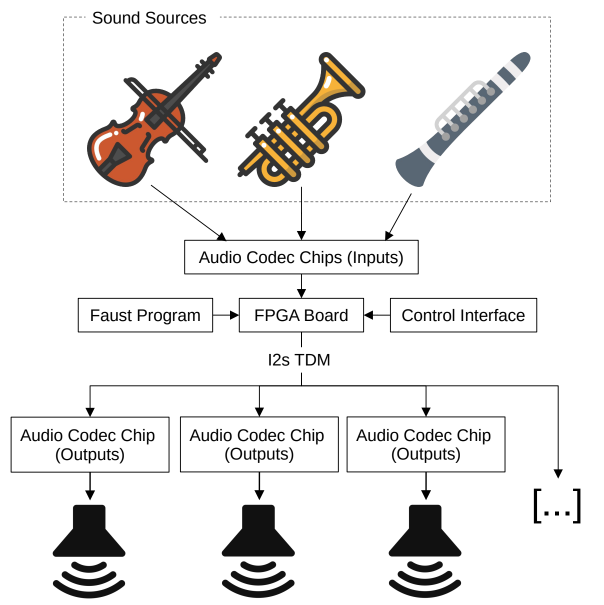
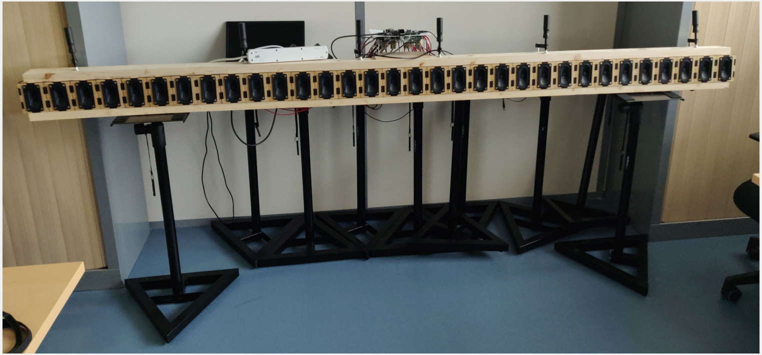
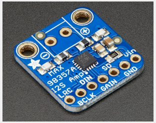
- Initial experiments show that the main bottleneck is the potential number of memory accesses done by the system in DDR rather than actual computational power. Hence, algorithm with small memory footprints can run without a problem.

- A large number of audio codec chips are connected to the FPGA using i2s TDM.
- The FPGA is fully programmable in Faust (i.e., Wave Field Synthesis, Ambisonics, etc.).
- Sound sources are provided to the system as analog audio inputs.
- The system is controlled using a laptop connected to the FPGA, OSC, etc.





Prototype of a SyFaLa-based WFS system (programmed in Faust) using cheap ($6, well $3 a year ago lol) Adafruit i2s amplifiers (MAX98357A):



- **Best measured round-trip latency using an audio codec:** $11\mu s$
- **Best theoretical round-trip latency using built-in $\Sigma\Delta$ ADC and DAC:** 100ns
- **Theoretical maxim number of audio inputs and outputs on a Zybo Z7-20 using audio codecs:** 480x480 (more than 1000x1000 on a Genesys board)
- **Maximum number of biquads running on a Zybo Z7-20 (intermediate range FPGA):** 150

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- Working more on spatial audio (i.e., PLASMA project, WFS, ambisonics, FPGA-based ambisonic microphone, etc.).

Thanks! :)

DSP seminar on Friday (Oct. 28th) on "Compiling Audio DSP for FPGAs Using the Faust Programming Language and High Level Synthesis"

Send your questions to: `romain.michon@inria.fr`

More @: `https://team.inria.fr/emeraude`

Slides @: `https://ccrma.stanford.edu/~rmichon/talks/ccrma-colloq-oct22.pdf`