IEEE IUS 2021
International Ultrasonics Symposium
Virtual Symposium | September 11 - 16, 2021
September 11-12: Short Courses || September 12-16: Technical Program

us4us®

IPPT PAN

Ultrasound Signal Processing with GPUs – Introduction to Parallel Programming

Ultrasound Hardware & Software

Presenter: Dr Marcin Lewandowski

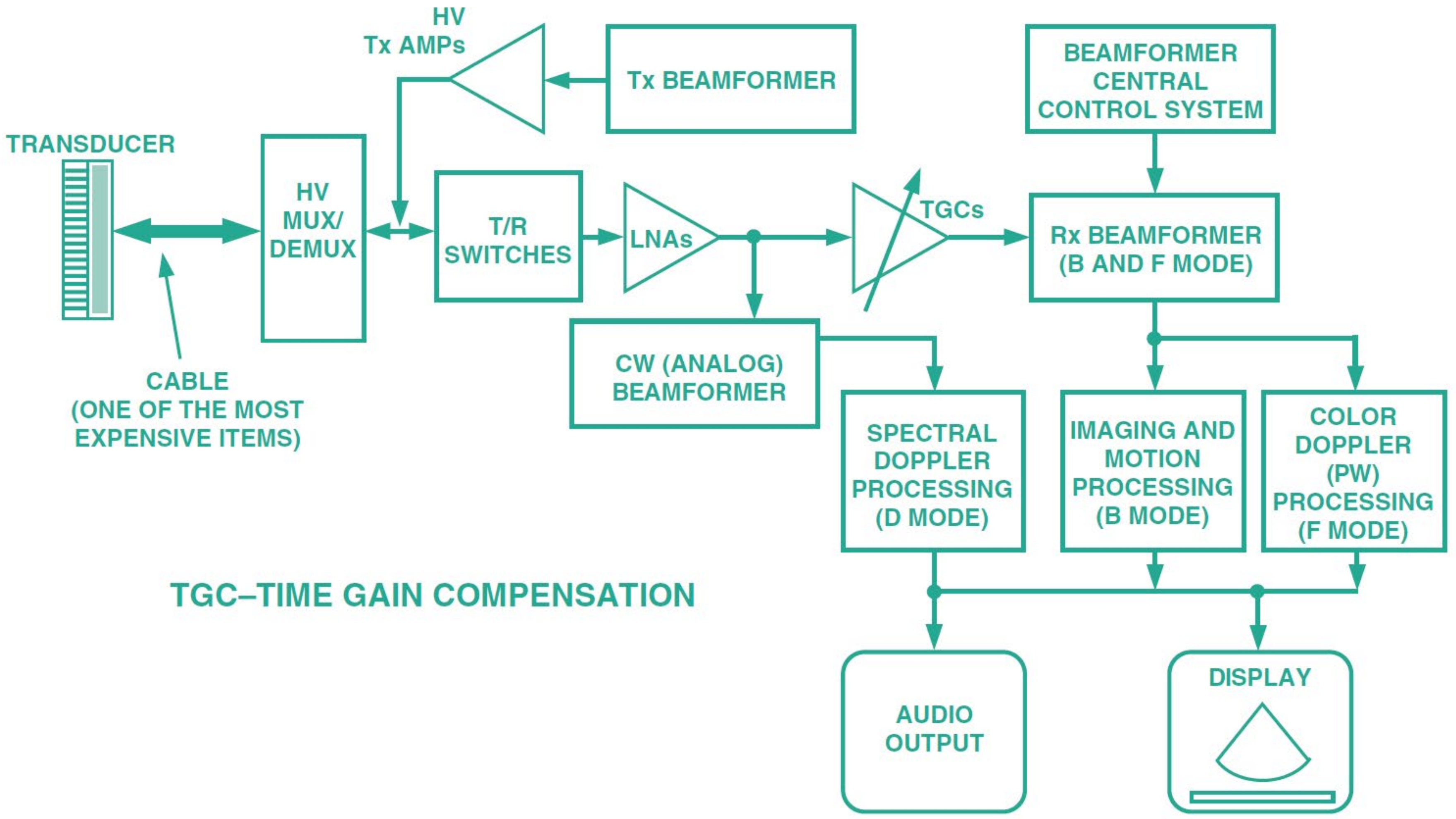
License / Attribution

- Materials for the short-course **„Ultrasound Signal Processing with GPUs – Introduction to Parallel Programming"** are licensed by us4us Ltd. the IPPT PAN under the Creative Commons Attribution-NonCommercial 4.0 International License.

- Some slides and examples are borrowed from the course **„The GPU Teaching Kit"** that is licensed by NVIDIA and the University of Illinois under the Creative Commons Attribution-NonCommercial 4.0 International License.
  - All the borrowed slides are marked with NVIDIA ILLINOIS

Ultrasound Systems

Ultrasound Scanner



Source: Eberhard Brunner, How Ultrasound System Considerations Influence Front-End Component Choice, Analog Dialogue 36-03 (2002)

What we need Ultrasound Research Systems for?

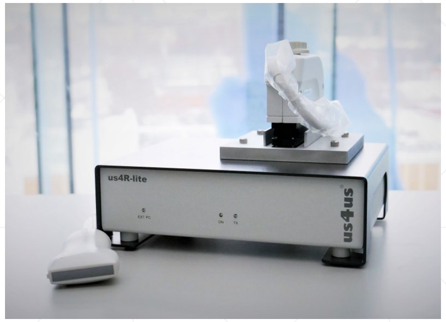
- **Applications**
  - Introducing new ultrasound modalities in Biomed, NDT (on-line/off-line)
    - Raw channel data acquisition (RF or I/Q)
  - Developing Demo systems (on-line)
  - Testing/evaluating new probes
- **Processing**
  - Off-line – acquire first, process later off-line
  - On-line – acquire and process in real-time
    - high-speed data transfer & computing resources are needed!
- **Features …**
  - Programmable TX/RX
  - High-level SDK (support for Matlab, Python)
  - High-performance processing for real-time

Ultrasound Research Systems


	SARUS	ULA-OP 256	UARP	SonixTouch	Verasonics (Vantage 256)	us4R-lite™	us4R™
Channels	Up to 1024 Tx/Rx	Up to 256 Tx/Rx	Up to 256 Tx/Rx	128 Tx/Rx	256 Tx/Rx	256Tx / 64Rx	1024Tx / 256Rx
Tx Voltage	Up to 200 V_{pp}	Up to 200 V_{pp}	Up to 200 V_{pp}	Up to 50 V_{pp}	3 to 190 V_{pp}	Up to 180V_{pp}	Up to 180V_{pp}
Tx Frequency	1 to 30 MHz	1 to 20 MHz	0.5 to 15 MHz	1 to 20 MHz	0.5 to 20 MHz (standard config.)	1 to 30MHz	1 to 30MHz
Tx Type	Linear	Linear	5-Level	3-Level	3-Level	3-Level	3-Level
ADC	70 MHz @ 12 bits programmable downsampling with filtration	78 MHz @ 12 bits programmable downsampling	programmable sampling rate up to 80 MHz @ 12 bits	80 MHz @ 10 bits/ 40 MHz @ 12 bits	programmable sampling rate up to 62.5 MHz @ 14 bits	65 MHz @ 14-bits	65 MHz @ 14-bits or 80 MHz @ 12-bits
RAM Buffer	128 GB	80 GB	16 GB	16 GB	16 GB	8 GB	32 GB
Connection to PC	sixty-four 1Gb/s Ethernet links coupled through four 10Gb/s optical links	USB 3.0	PCIe 3.0	USB 2.0	PCIe 3.0 x8	Thunderbolt-3 or PCIe 3.0 x8	PCIe 3.0 x16 or Dual PCIe 3.0 x16
Real-time PROCESSING:	**FPGA**	**FPGA / DSP**	**FPGA**	**FPGA**	**FPGA / CPU**	**CPU / GPU**	**CPU / GPU**

Source: E. Boni, A. C. H. Yu, S. Freear, J. A. Jensen and P. Tortoli, "Ultrasound Open Platforms for Next-Generation Imaging Technique Development," in *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 65, no. 7, pp. 1078-1092, July 2018, doi: 10.1109/TUFFC.2018.2844560

us4R-lite™



- A low-cost, portable ultrasound platform for research & educational applications
- 256 TX / 64 RX – optimized for Plane-Wave
- High-speed data interfaces:
  - Thunderbolt-3 (2.5GB/s)
  - PCIe gen3 x8 (6GB/s)
- GPU-ready using external PC/notebook with GPU or optional embedded NVIDIA Jetson TX2
- ARRUS™ SDK for Windows / Linux
  - open-source!
  - optimized for real-time data acquisition and software processing.

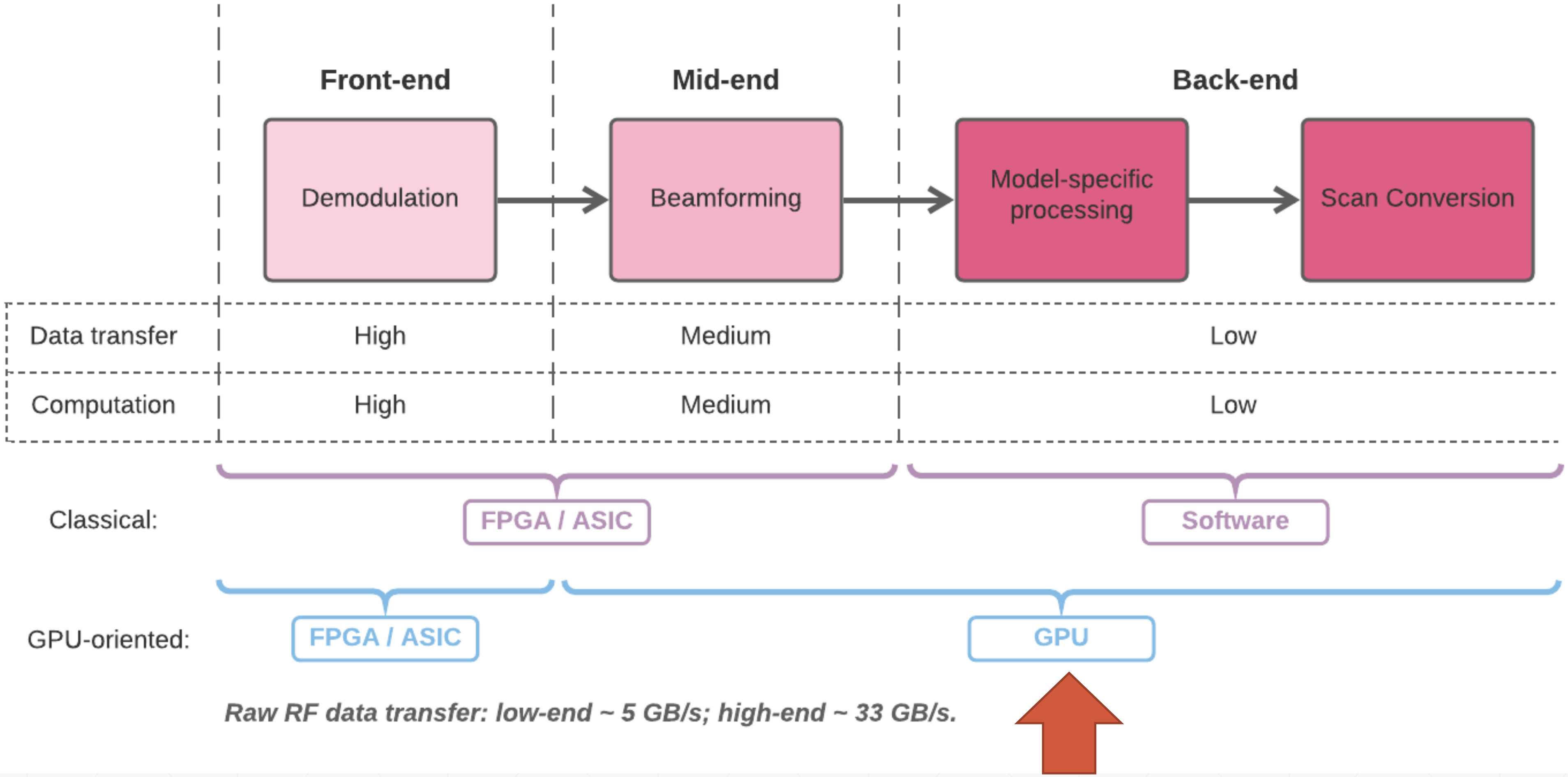
us4R™

- High-performance ultrasound research platform
- Up to 1024 TX / 256 RX (support for 2D/3D)
- High-speed data interfaces:
  - single PCIe gen3 x16 (12GB/s)
  - dual PCIe gen3 x16 (24GB/s)
- Versatile – possible integration with various hardware:
  - GPU and multi-GPU (Nvidia, AMD, Intel)
  - PCIe FPGA Accelerator cards (Altera, Xilinx)
- ARRUS™ SDK for Windows / Linux
  - open-source!
  - optimized for real-time data acquisition and software processing.

Software Defined Ultrasound

Systems Architecture

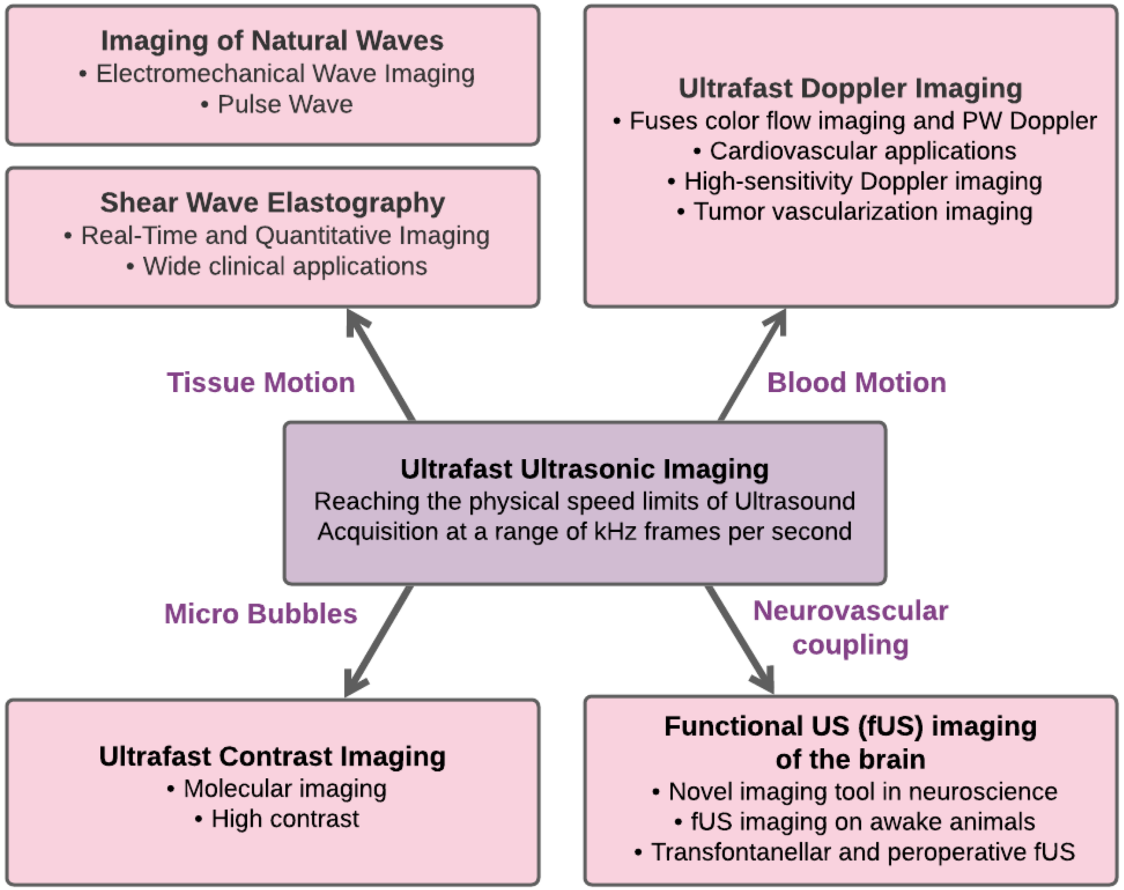
Ultrasound processing chain



SOFTWARE BEAMFORMING

Software-Defined Ultrasound (SDU)

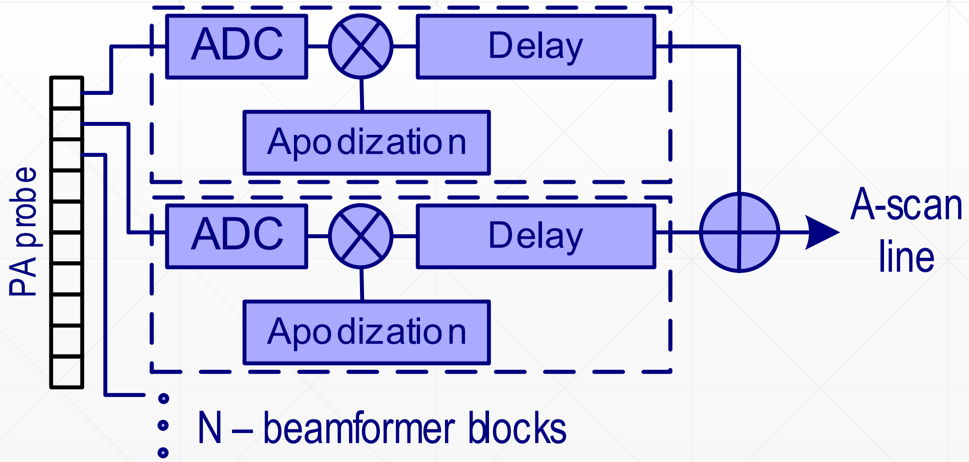
- Software-Defined Ultrasound is a new paradigm of applying full software processing to raw ultrasound echo signals (RF or I/Q).
- Instead of a fixed (usually hardware-based) processing pipeline, we can have a fully programmable and extensible software framework.
- Thanks to the high-performance GPU technology, now, we can implement advanced parallel processing algorithms in real-time.
- us4us® ultrasound platforms have been designed to provide real-time streaming of raw RF data for Software-Defined Ultrasound processing.
- Ultrafast acquisition technology with parallel processing enables implementation of novel multi-modal technologies.

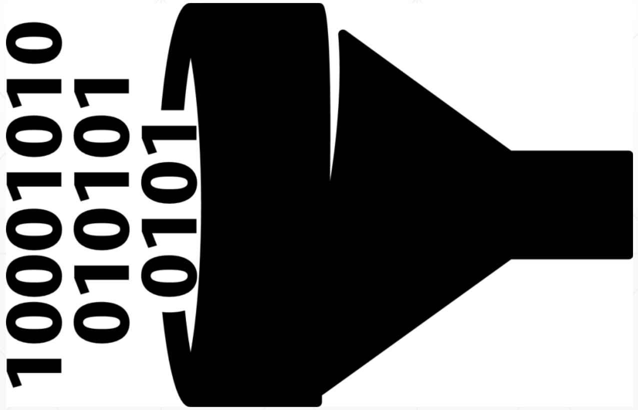


Adopted from: M. Tanter, M. Fink, Ultrafast Imaging in Biomedical Ultrasound, IEEE TUFFC 61(1):102-119, DOI: 10.1109/TUFFC.2014.6689779, 2014

Classical approach – Beamforming

- A classical Beamforming approach
  – Fixed hardware-based image reconstruction
- Line-by-line acquisition and processing
- N:1 data reduction (N signals are delayed and summed together)

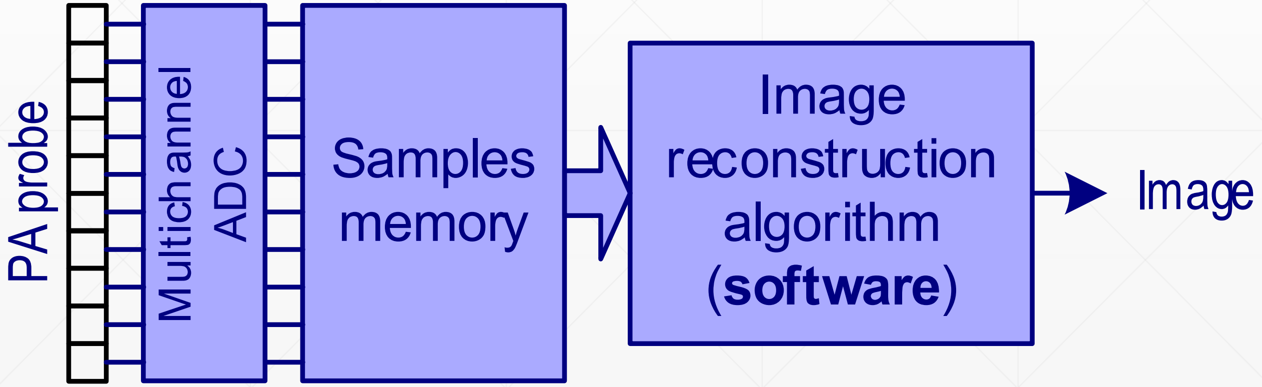




DATA REDUCTION
N:1

Software Defined Ultrasound – features

- A fully programmable TX/RX
- A fully software-programmable signal processing chain
- Direct access and processing of raw channel data / ultrasound echoes
- Imaging based on the Synthetic Aperture Focusing Technique:
  - Depth-independent imaging
  - Ultrafast methods (1000s FPS v.s. 10s FPS for classical Beamforming)
  - Advanced ultrasound modalities/algorithms (e.g. Doppler vector flow)



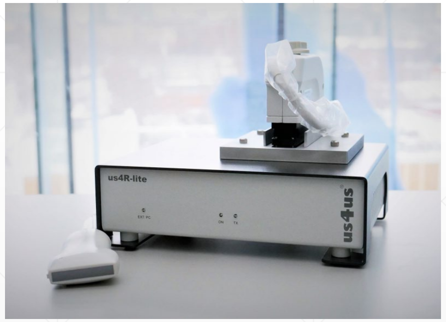
us4us® Software Architecture

Application

us4us ARRUS SDK*
(C/C++, Matlab, Python)

Parallel Processing API
(CUDA, OpenCL, OneAPI, etc.)

us4R™



us4R-lite™

GPU

CPU

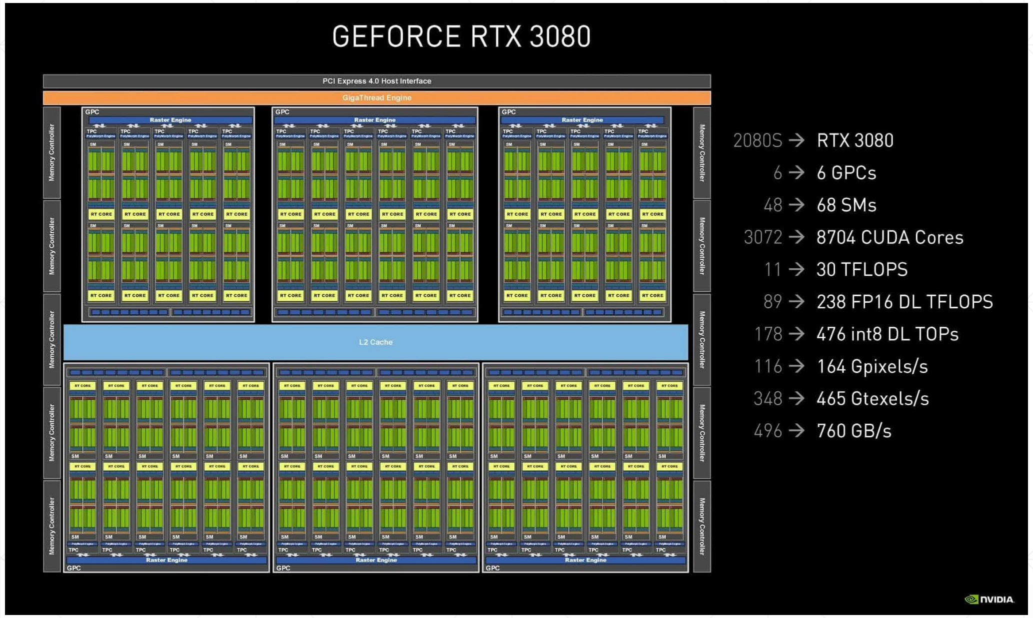
VPU, SoC, …

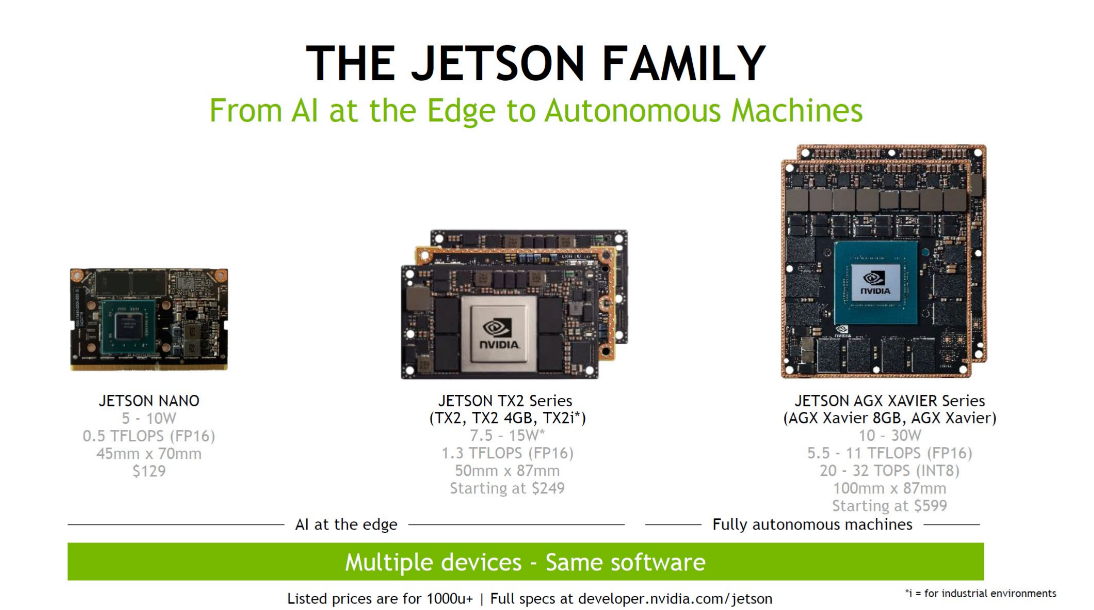
FPGA

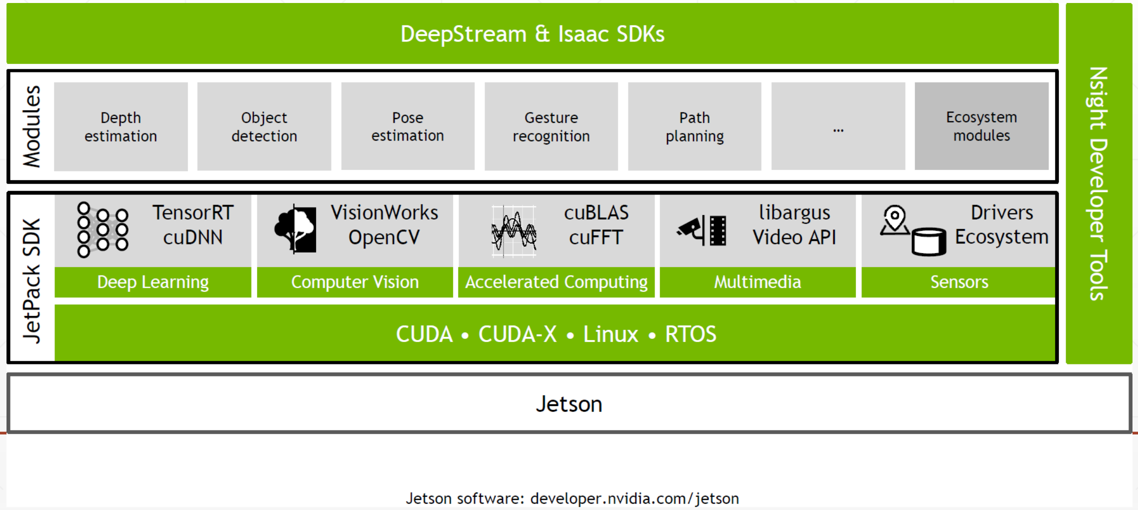
*Windows & early Linux support

GPU processing

NVIDIA GPU ecosystem

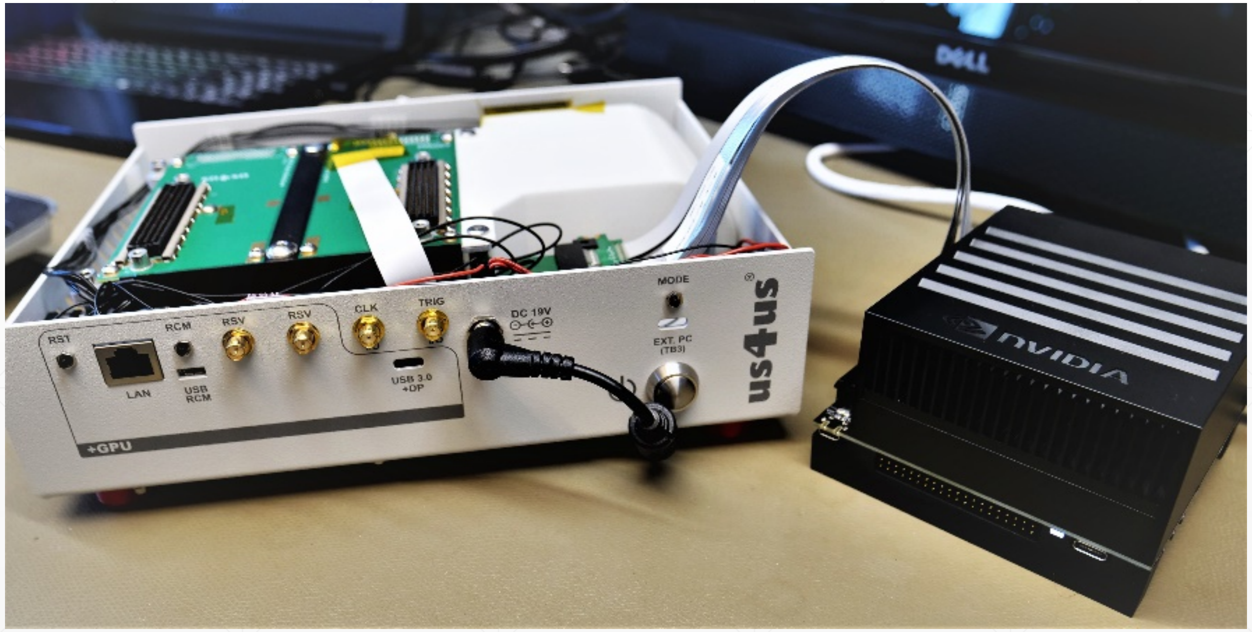






us4R-lite™ with NVIDIA Xavier

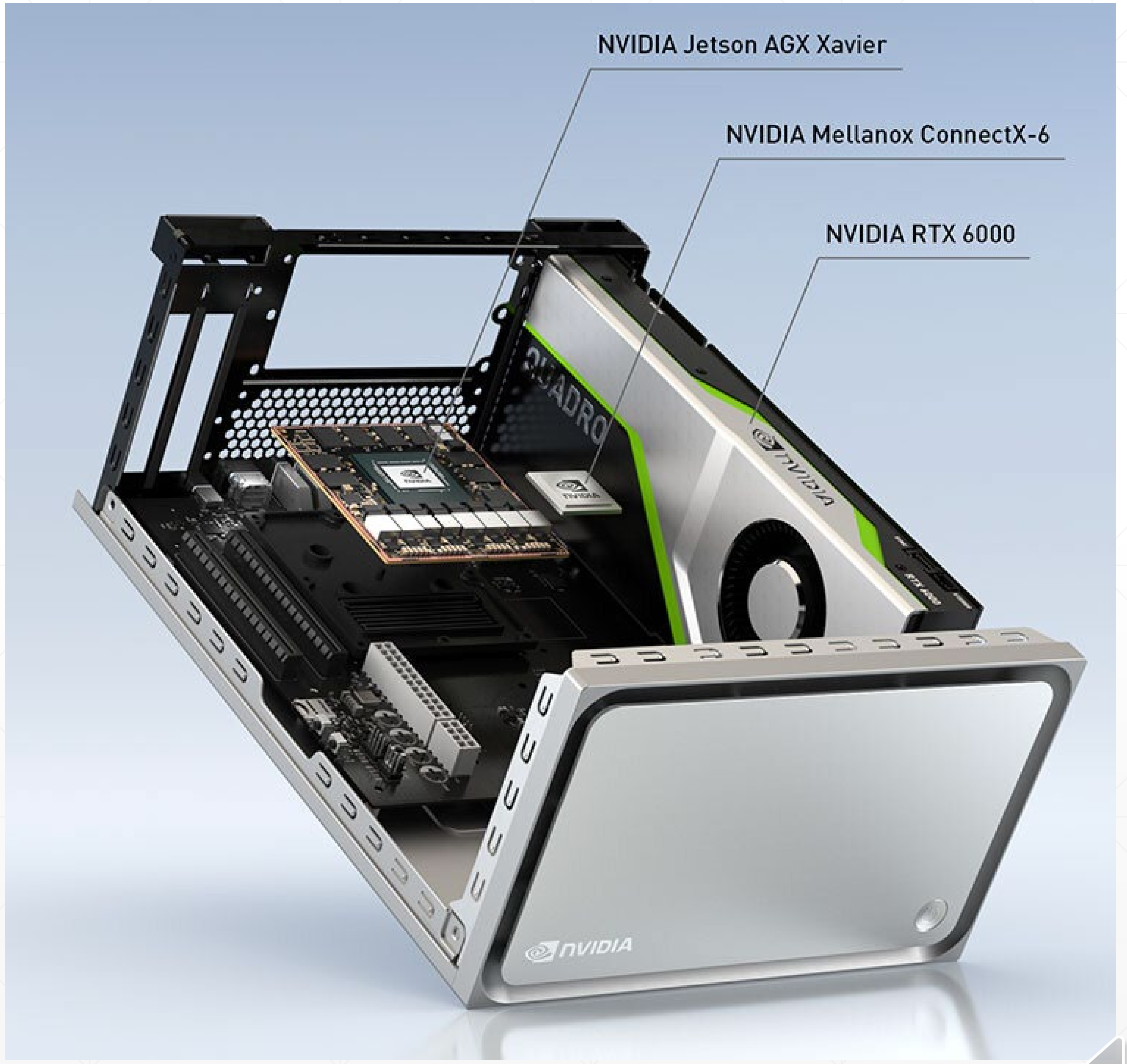
- We have executed a feasibility study of integrating us4R-lite™ platform with NVIDIA Jetson AGX Xavier™.
  - The Jetson AGX Xavier module delivers up to 32 TOPS of AI performance and benefits from NVIDIA's rich set of AI tools and workflows, enabling developers to train and deploy neural networks quickly.
- We envision integrating the Xavier in the next revision of the us4R-lite™ systems.



NVIDIA Clara AGX

- An embedded AI computer and software developer framework for medical devices
- Designed to boost development of Software-Defined Ultrasound solutions
- Built for real-time AI and advanced signal processing on high-throughput streaming data

Find out more Clara AGX for healthcare here.



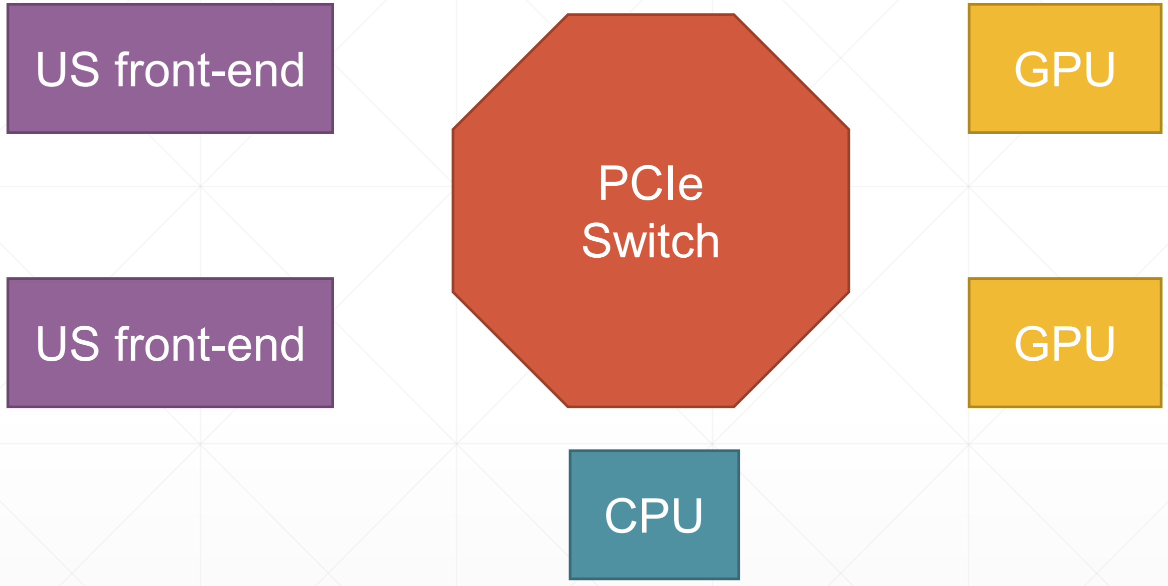
us4R-lite™ and Clara AGX integration

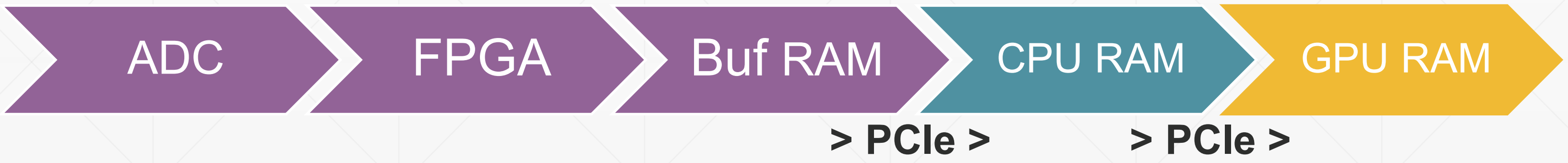
- We have now successfully integrated NVIDIA Clara AGX with our smaller system in a laboratory setting.
- Our immediate plans include integration of low-level software to enable integration with NVIDIA machine learning libraries.
- In future, we plan to fully integrate Clara AGX with both the us4R™ and the us4R-lite ™ and make these available to our clients for purchase alongside corresponding software.

Software Defined Ultrasound

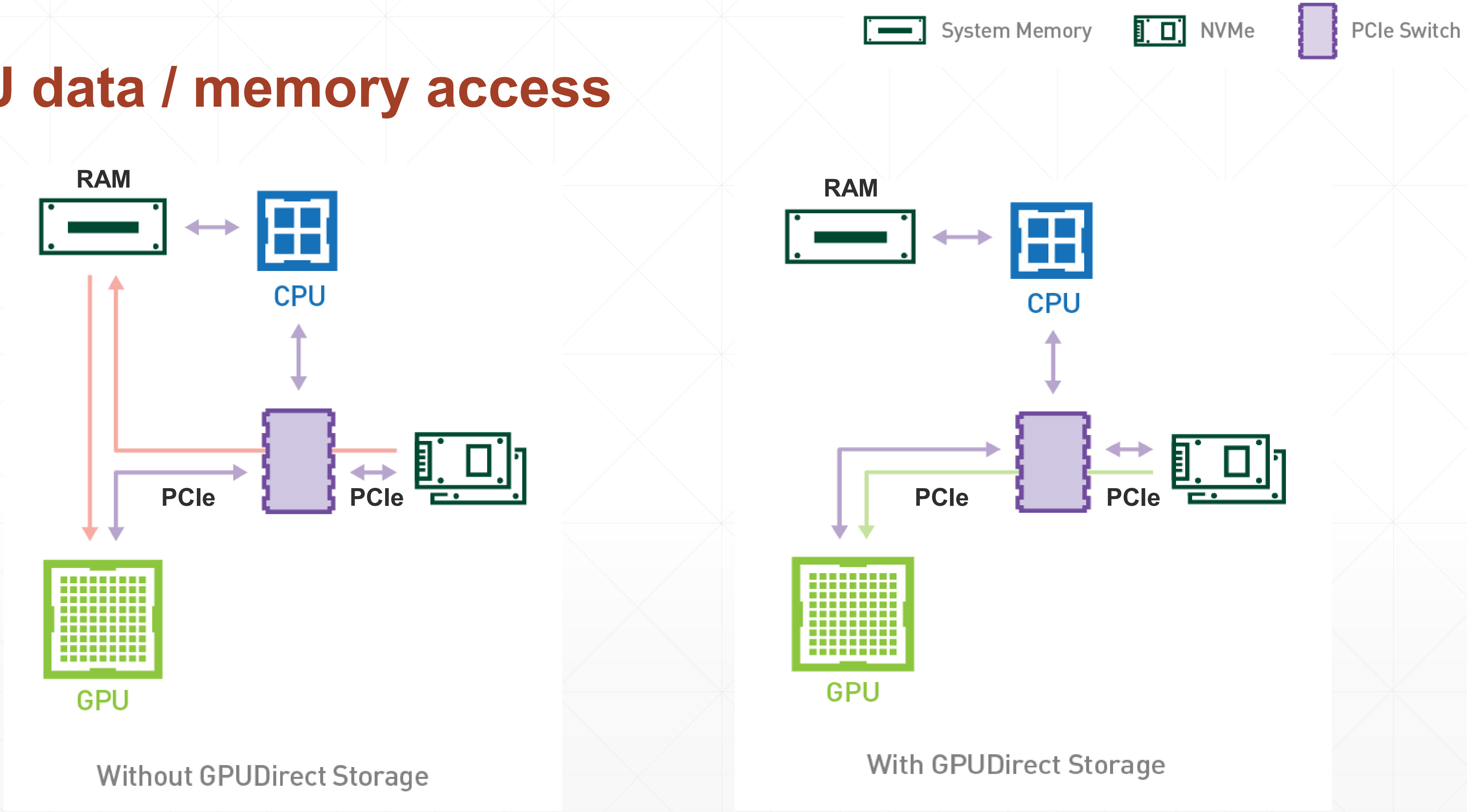
Applications

Data Flow


US front-end
US front-end
PCIe Switch
GPU
GPU
CPU

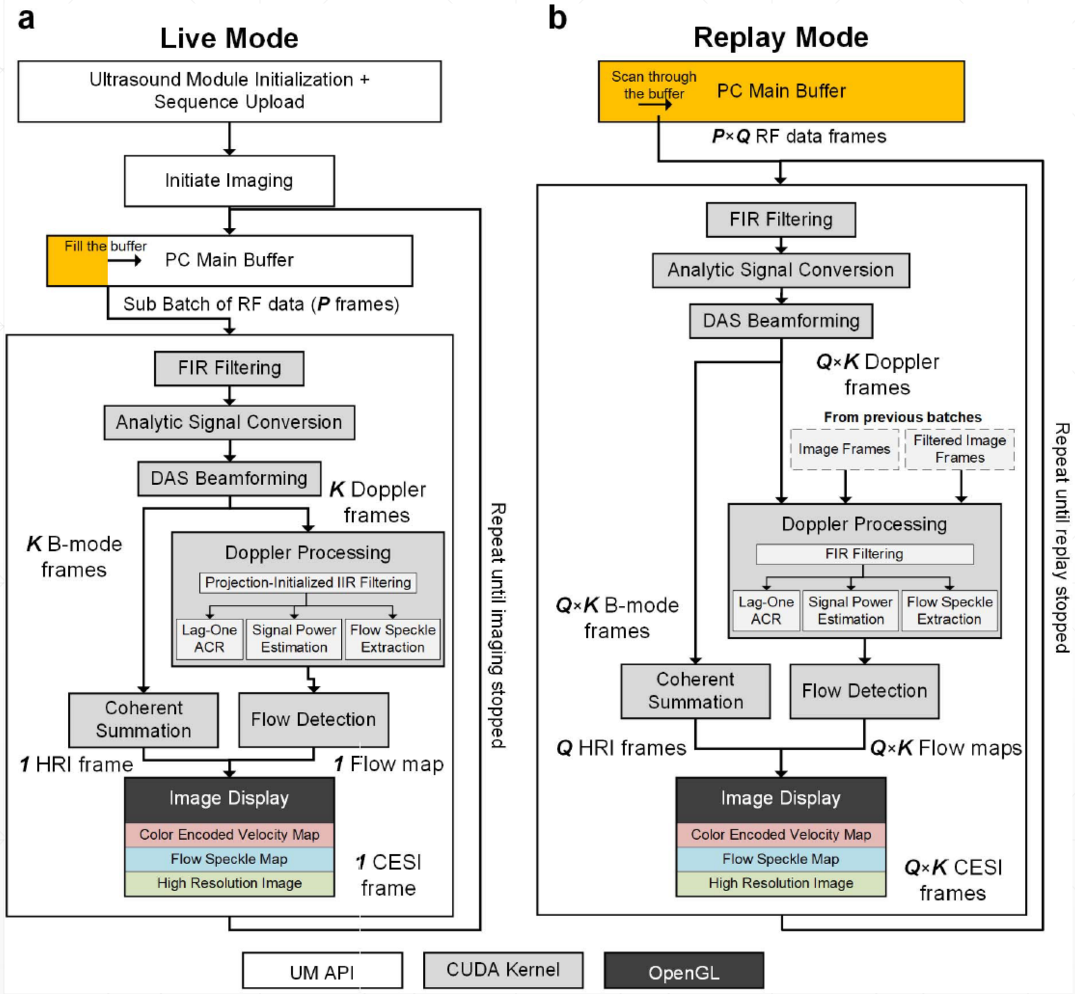

ADC
FPGA
Buf RAM
CPU RAM
GPU RAM
> PCIe >
> PCIe >

GPU data / memory access



Source: https://developer.nvidia.com/blog/gpudirect-storage/

Advanced ultrafast acquisition and GPU processing

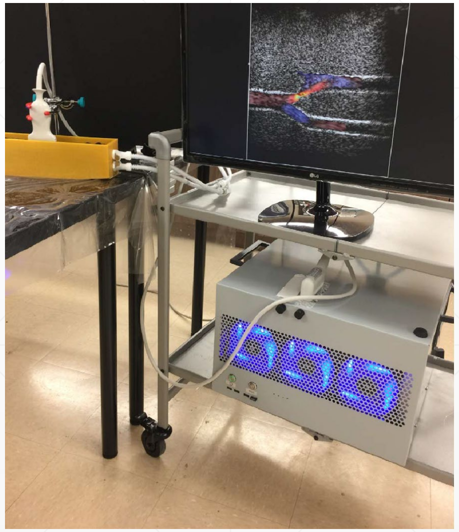


Source: B.Y.S. Yiu, M. Walczak, M. Lewandowski, A.C.H. Yu, Live Ultrasound Color-Encoded Speckle Imaging Platform for Real-Time Complex Flow Visualization In Vivo. IEEE TUFFC, 2019 Apr;66(4):656-668. doi: 10.1109/TUFFC.2019.2892731

On a single Nvidia GTX-1080 card!

Scenario (PRF)	Imaging Depth	Center Freq.	Sampling Freq.	Samples /Channel	Data/s
Superficial (10 kHz)	2 cm	15 MHz	50 MHz	1299	4.6 GB/s*
Carotid (10 kHz)	4 cm	6 MHz	25 MHz	1299	4.6 GB/s*
Kidney (5 kHz)	8 cm	10 MHz	25 MHz	2598	4.6 GB/s*
Heart (4 kHz)	18 cm	3 MHz	25 MHz	5845	4.3 GB/s#

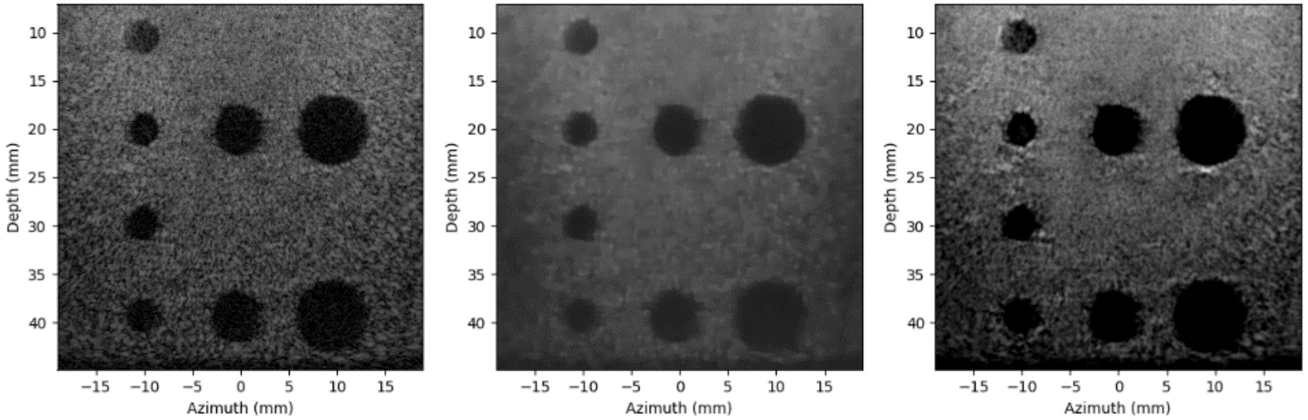
*Assuming the use of a 192-element linear array and 2 bytes per data sample
Assuming the use of a 96-element phased array and 2 bytes per data sample



USPlatform (us4us, Poland)

us4R-lite™ with NVIDIA Clara AGX for Deep-Learning

- After successfully integrating Clara AGX with the us4R-lite system, we performed a test-case of real-time imaging using a neural network for despeckling and image enhancement.
  - Ultrasound raw data acquisition transfer rate: **3.2 GB/s**
  - Signal processing throughput for 64 PWI: **67 fps** // NN Despeckling: **57 fps** // MimickNet post-processing: **57 fps**



LOOK:

- IUS-2021 presentation: [“Integration of Ultrasound Research System with AI Workstation NVIDIA Clara AGX”]
- NVIDIA Clara AGX us4R-lite Ultrasound Container >> https://ngc.nvidia.com/catalog/containers/nvidia:clara-agx:agx-us4us-ultrasound

Implementation based on Dongwoon Hyun et al., Beamforming and Speckle Reduction Using Neural Networks, IEEE TUFFC, doi:10.1109/TUFFC. 2019.2903795.

And NOW …

- You almost made it 😅
- There are another exciting Exercises:
  - CUDA streams & Processing

- Probably, you run out of coffee by now …
- We have a few case-studies (<u>believe me, they are worth seeing</u>):
  - Doppler processing
  - Color-encoded speckle imaging platform for real-time complex flow visualization in-vivo