Mobile Wireless Ultrasound with GPU Beamforming

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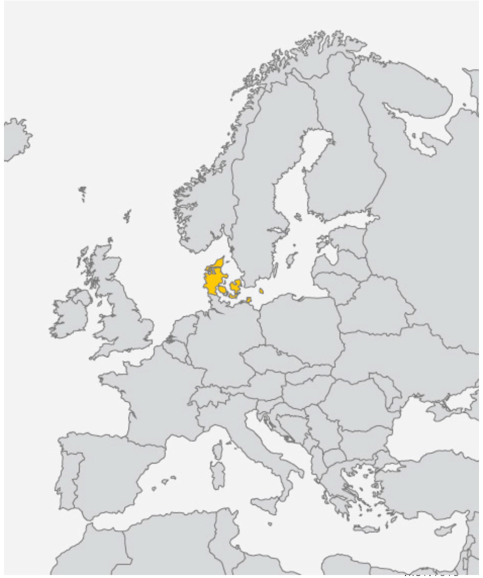
The Alexandra Institute

- Private not-for-profit company within IT
  - Technology transfer from University research through GTS institutes (Danish model)

- Application oriented research
- Consultancy for companies



FutureSonic

- " A new platform and business model for on-demand diagnostic ultrasound imaging"
- 2013-2018
- Budget: 23 mio US$

DTU

bk medical

MEGGITT

Højteknologifonden

Innovationsfonden
FORSKNING, TEKNOLOGI & VÆKST I DANMARK

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Joint work

- Center for Fast Ultrasound Imaging, Technical University of Denmark
  - Martin Christian Hemmsen
  - Borislav G. Tomov
  - Jørgen Arendt Jensen
- BK Medical
  - Carsten Kjær
- Computer Graphics Lab, Alexandra Institute
  - Thomas Kim Kjeldsen
  - Lee Lassen
  - Jesper Mosegaard

Presentation based on publications

T. Kjeldsen, L. Lassen, M. C. Hemmsen, C. Kjaer, B. G. Tomov, J. Mosegaard, and J. A. Jensen, “Synthetic aperture sequential beamforming implemented on multi-core platforms,” in *Proceedings of 2014 ieee international ultrasonics symposium*, 2014, pp. 2181-2184.

M. C. Hemmsen, T. Kjeldsen, L. Larsen, C. Kjaer, B. G. Tomov, J. Mosegaard, and J. A. Jensen, “Implementation of synthetic aperture imaging on a hand-held device,” in *Proceedings of 2014 ieee international ultrasonics symposium*, 2014, pp. 2177-2180.

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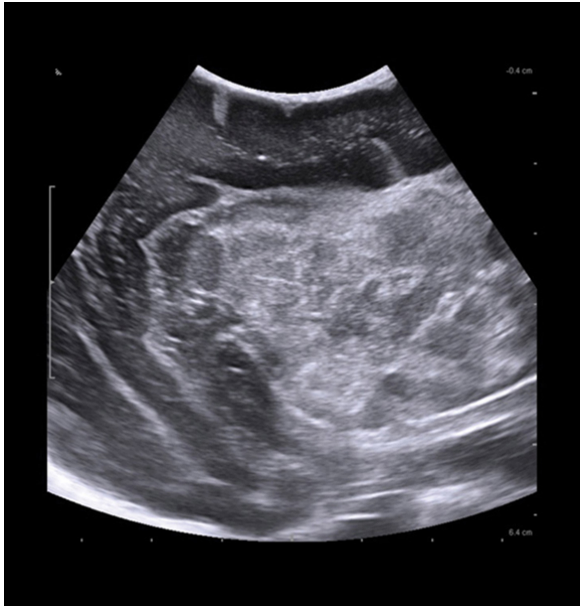
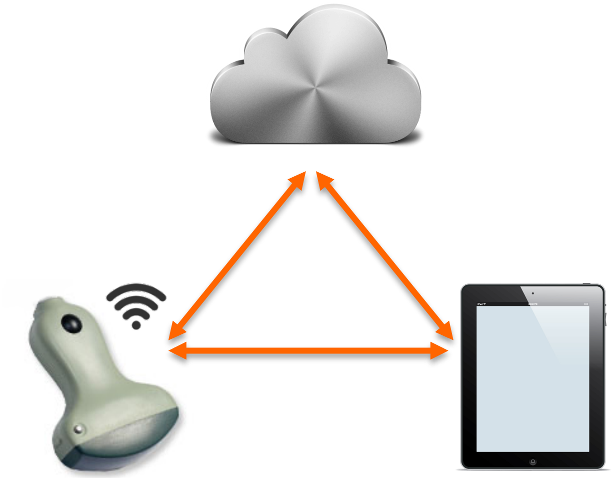
Medical Ultrasound



http://www.bkmed.com/products_en.htm

Mobile transducer



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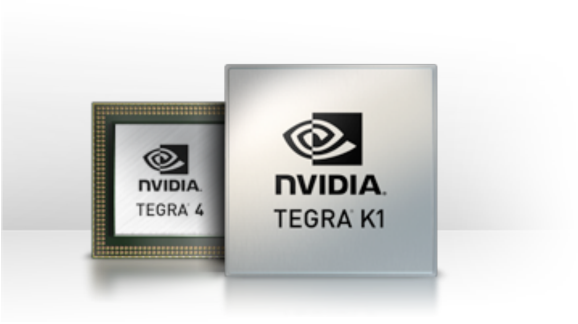
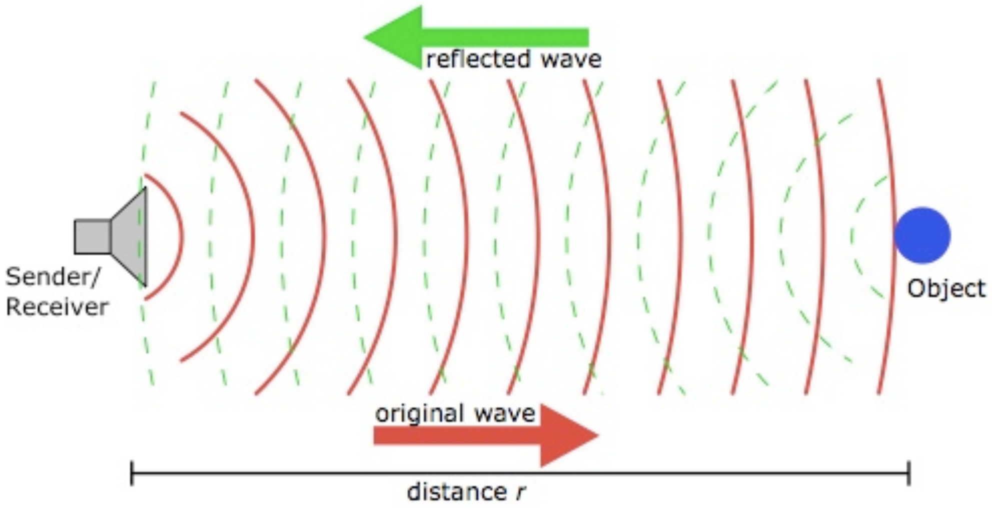
Leveraging disruptive technology



Ultrasound

- From acoustic (pressure) waves to images

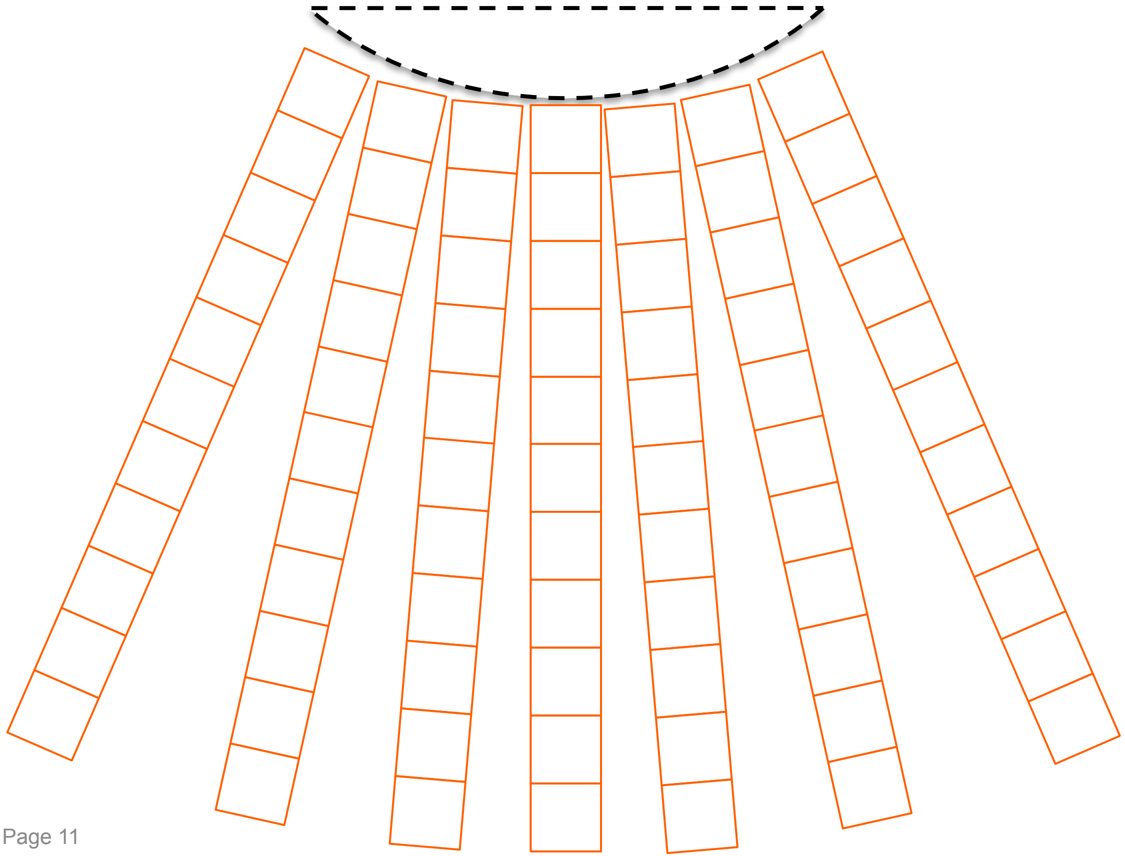


Medium	Velocity (m/sec)
Fat	1450
Water	1480
Soft tissue	1540
Kidney	1560
Blood	1570
Muscle	1580
Bone	4080

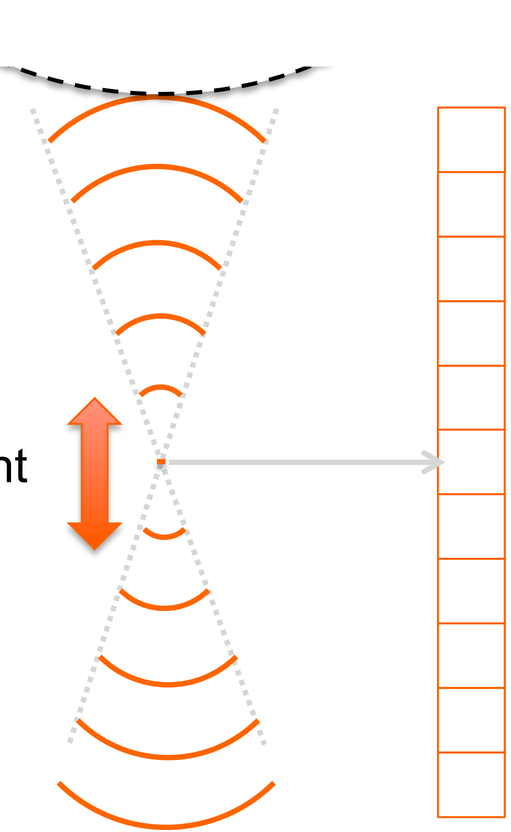
http://www.sensorwiki.org/doku.php/sensors/ultrasound

Beamforming to reconstruct images

Shooting for a number of scanlines



Dynamic Receive beamforming



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Beamforming

- Traditional beamforming requires a high data bandwidth.
- A typical system could have 128 channels and use a 12-bit 40 MHz sampling system.
- This generates $128 \times 40 \times 10^6$ Hz $\times$ 2B = 9.54 GB/s

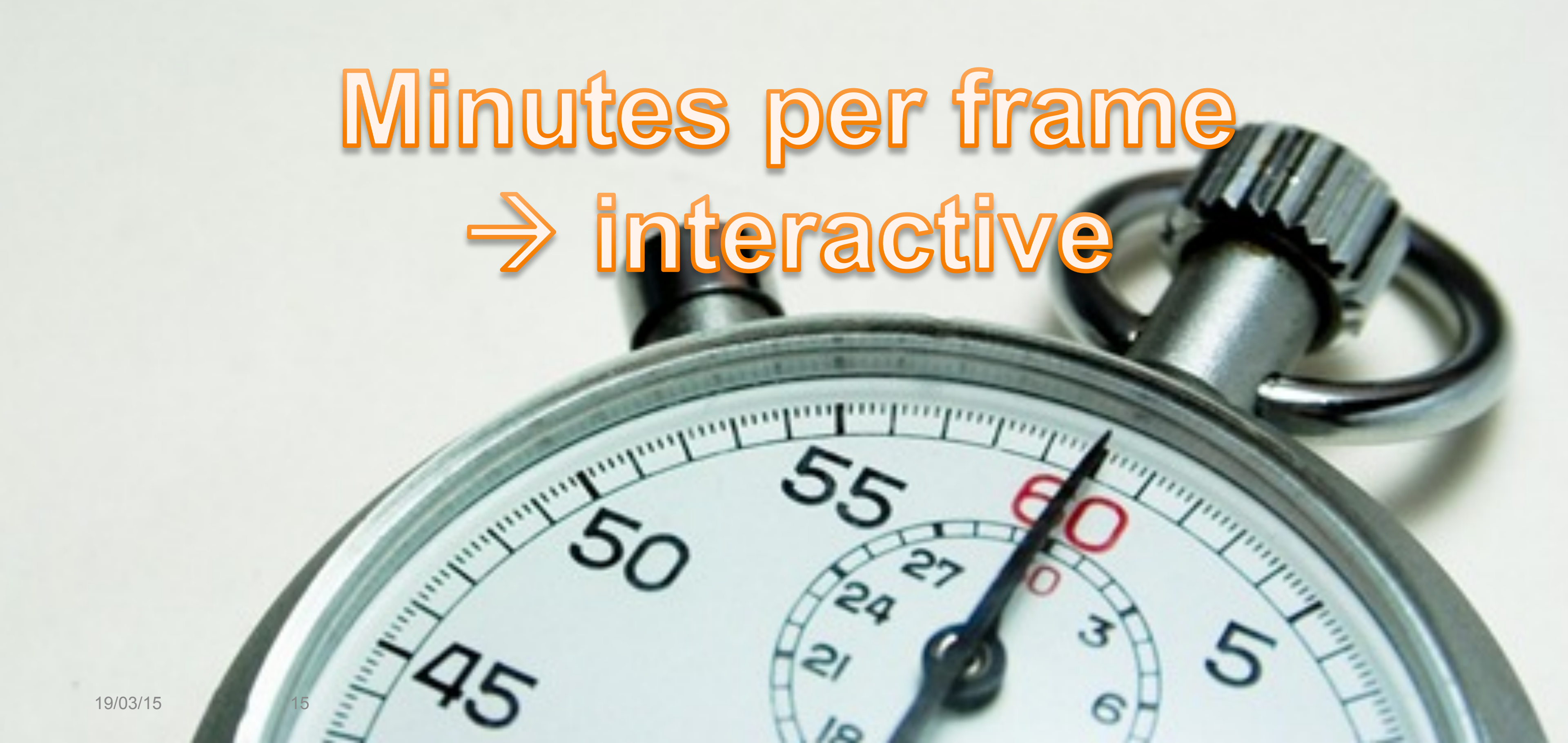
~10 GB/s

SASB – dual beamforming

- Simple first stage
  - Single focal point for both transmit and receive
- Advanced second stage
  - combining information from multiple first stage focused scan lines
- Reduction in data-transfer requirement
  - Reduced by a factor of receive elements (192)

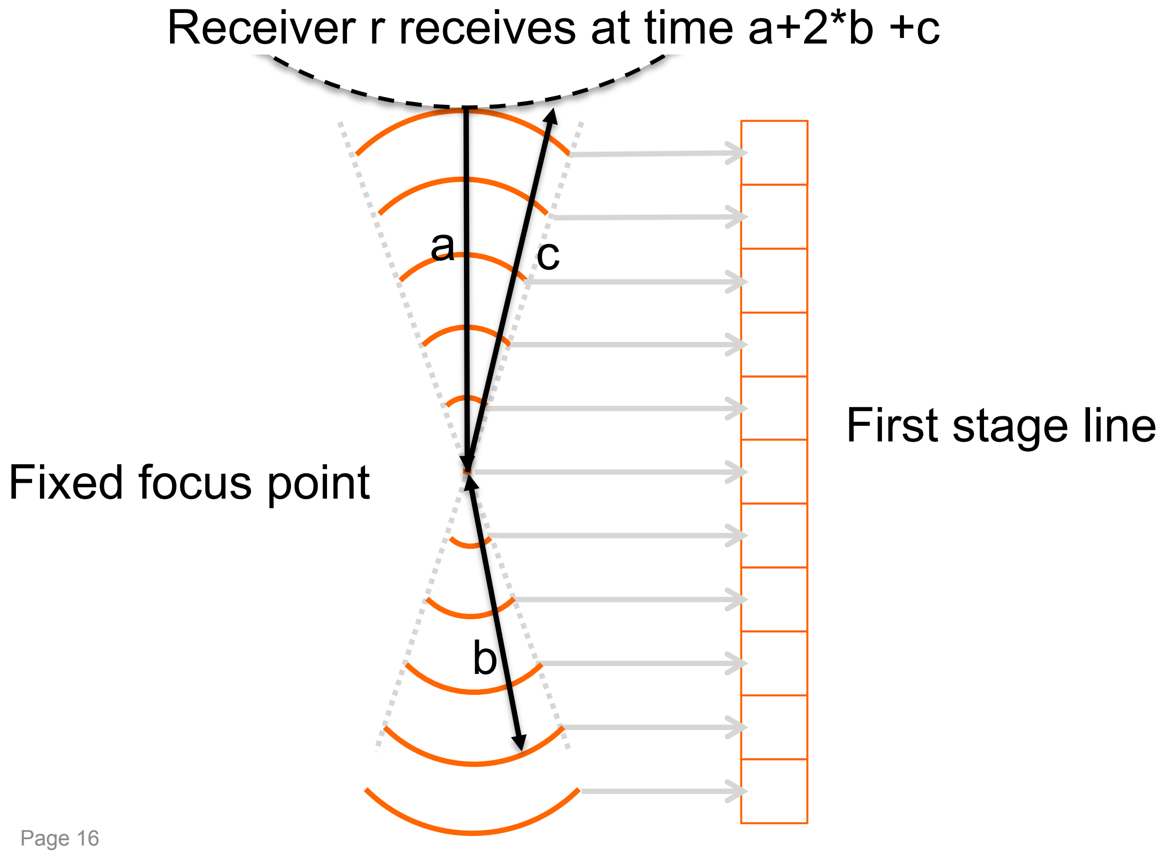
M. C. Hemmsen, J. M. Hansen, and J. A. Jensen, "Synthetic Aperture Sequential Beamformation applied to medical imaging using a multi element convex array transducer," in EUSAR , Apr. 2012, pp. 34–37.

Algorithmic engineering

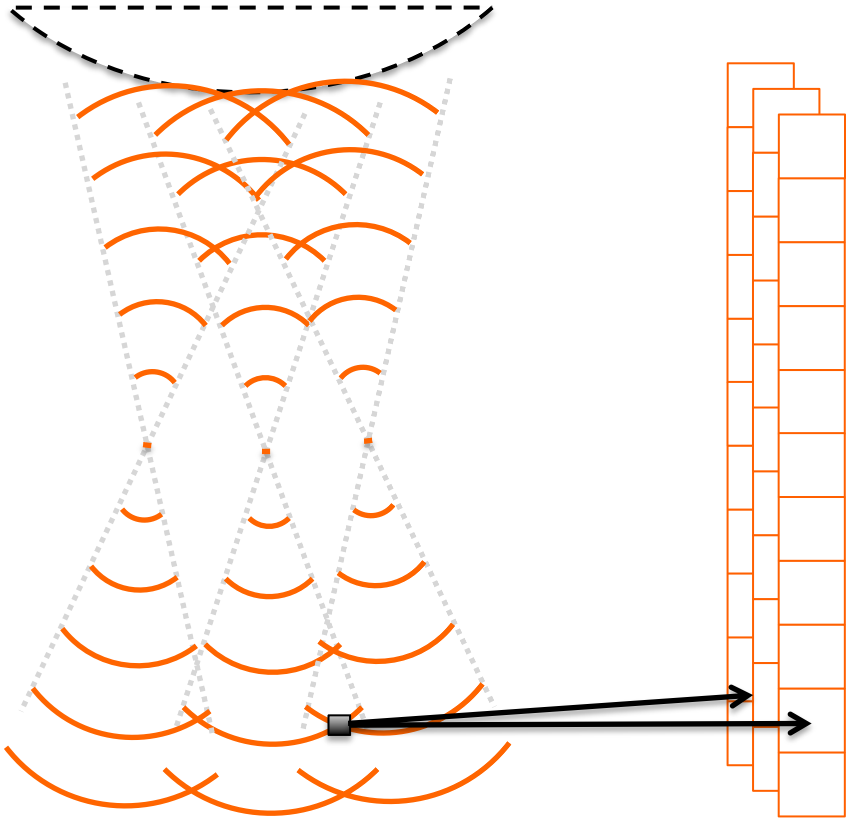


Minutes per frame → interactive

1. stage: Fixed focus transmit and receive



2. stage: reconstruct focus



1. Find index scanline entries
2. Add contribution

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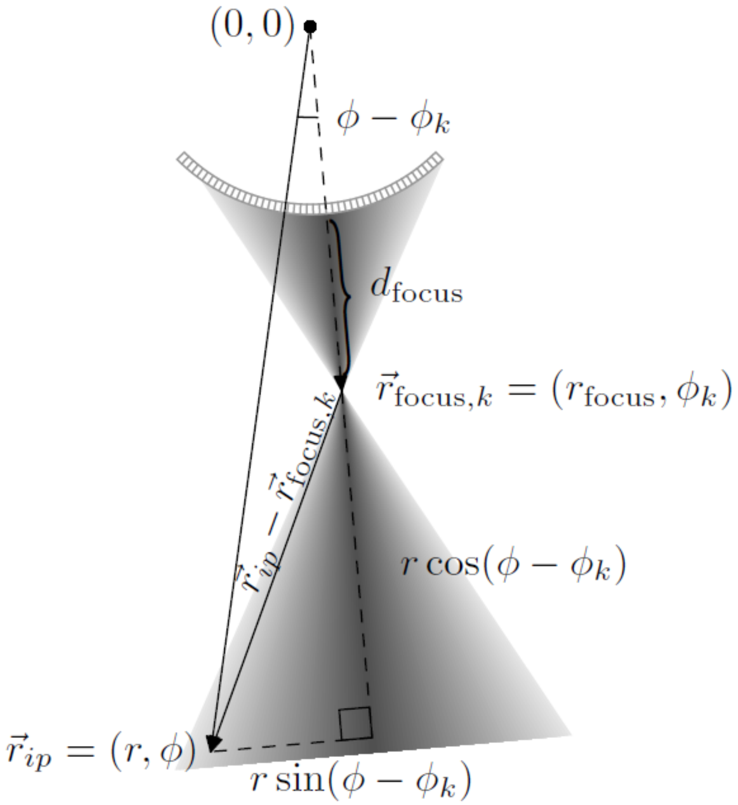
The math behind it



$$I(r,\phi) = \sum_{k=0}^{N_l - 1} W(r, |\phi - \phi_k|) s_k(t(r, \phi - \phi_k))$$

$$t(r,\phi) = \frac{2}{c}\left(d_{\text{focus}} \pm \sqrt{r^2 + r_{\text{focus}}^2 - 2 r r_{\text{focus}} \cos\phi}\right)$$

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Pseudo code

```
for all image samples p with polar coordinates (i,j)
    for all first stage scanlines k
        a = calculateWeight(i,k)
        d = calculateDelay(i,k)
        s = getScanline(d,k)
    l(i,j) += a*s
```

Three implementations

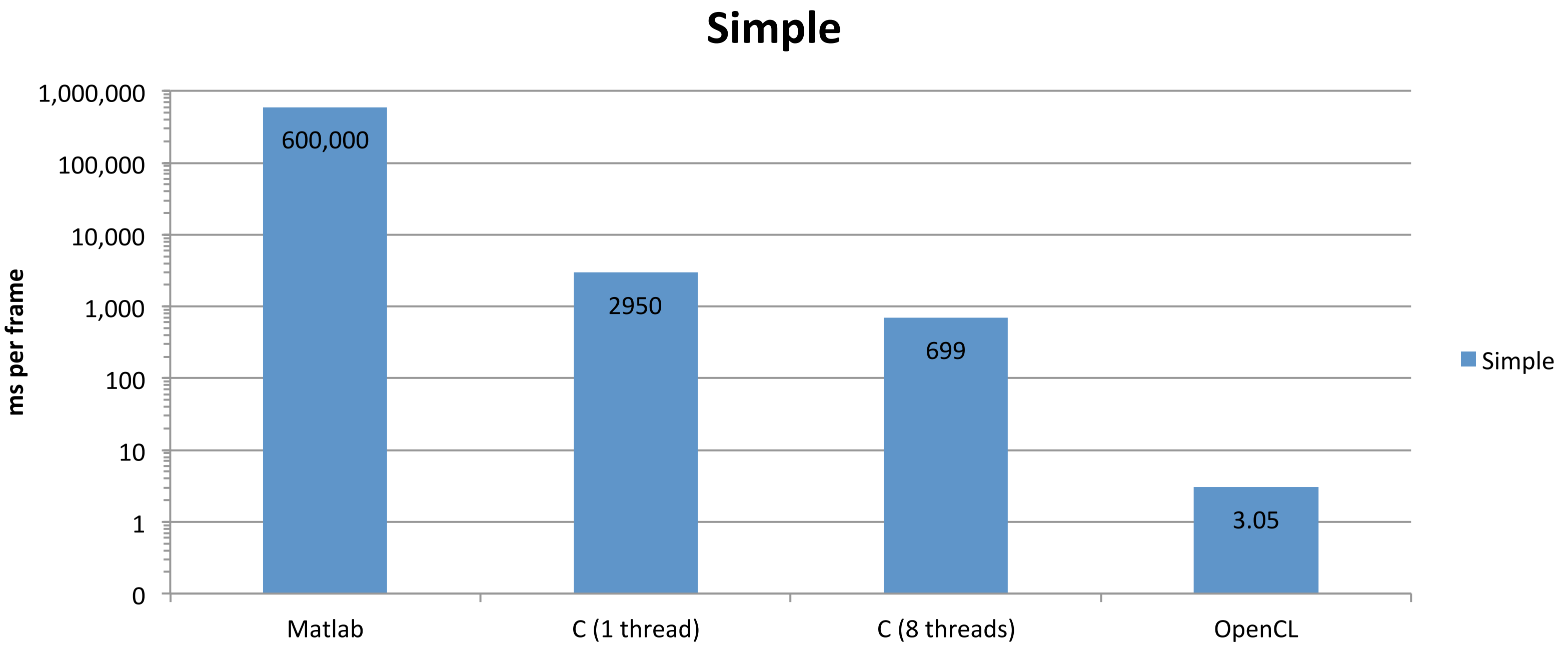
OpenCL

OpenGL®

C++

AVX
Multithreaded

Benchmark, simple implementation



Intel Core i7 2600
Nvidia GTX 680 GPU

Algorithmic optimization

- Sampling the beamforming directly in the scan line sample locations

$$I(r,\phi) = \sum_{k=0}^{N_l-1} W(r, |\phi - \phi_k|) s_k(t(r, \phi - \phi_k))$$

$$I(r_i,\phi_j) = W_{i0} s_j(t_{i0}) + \sum_{k'=1}^{N(r_i)} W_{ik'} \left[s_{j+k'}(t_{ik'}) + s_{j-k'}(t_{ik'}) \right]$$

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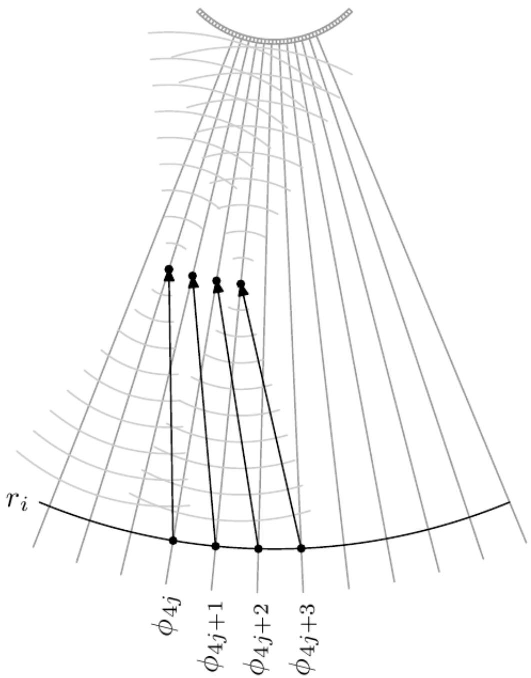
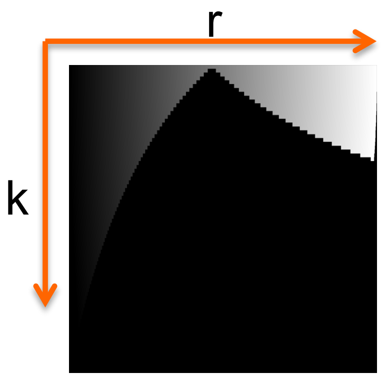
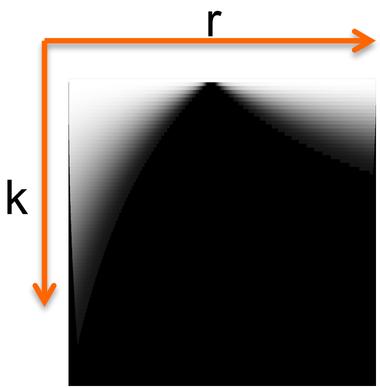
Weights and delays precalculated





Delays



Apodization

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Pseudo code

```
l = 0
for all image samples p with polar coordinates (i,j)
    for all first stage scanlines k - up to N(r_i)
        a = getWeight(i,k)
        if a=0 then break
        d = getDelay(i,k)
        s = getScanline(d,j+k)
        l(i,j) += a*s
        if (k>0) then
            s = getScanline(d,j-k)
            l(i,j) += a*s
```


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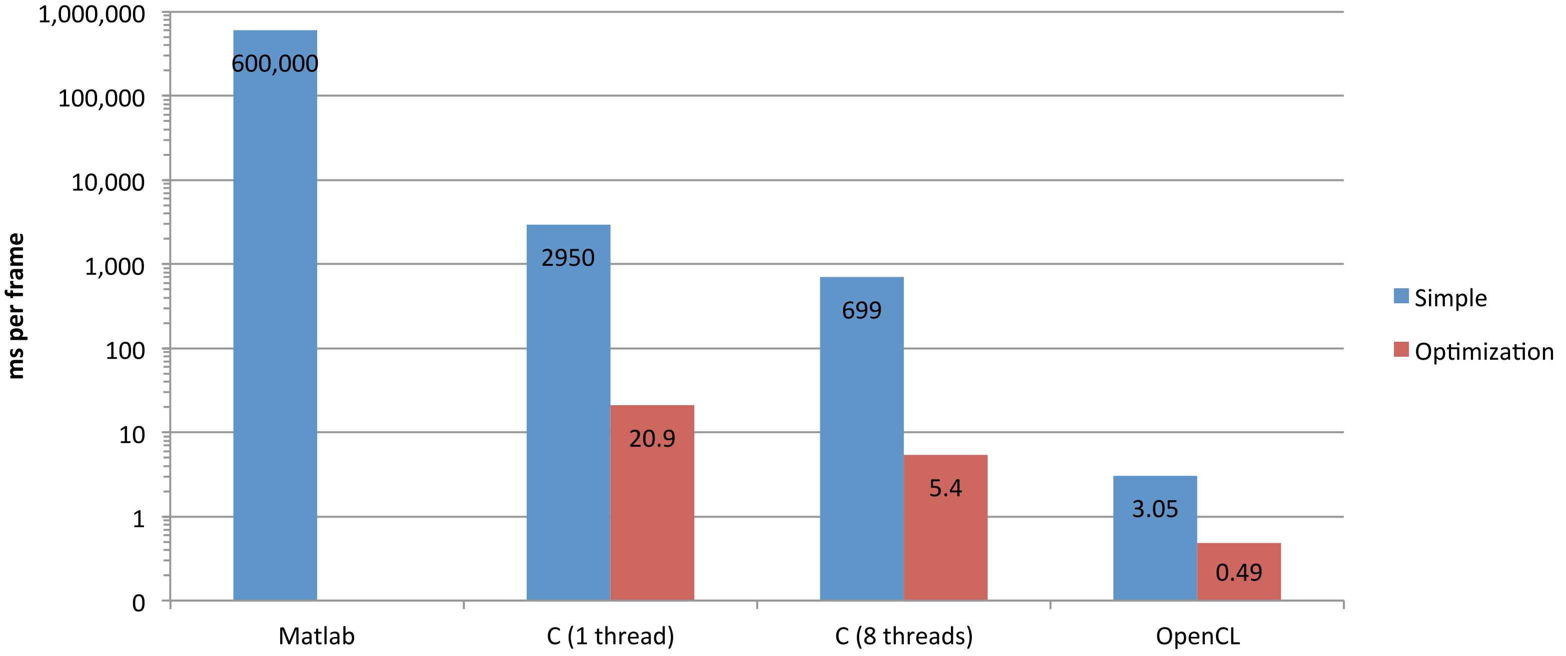
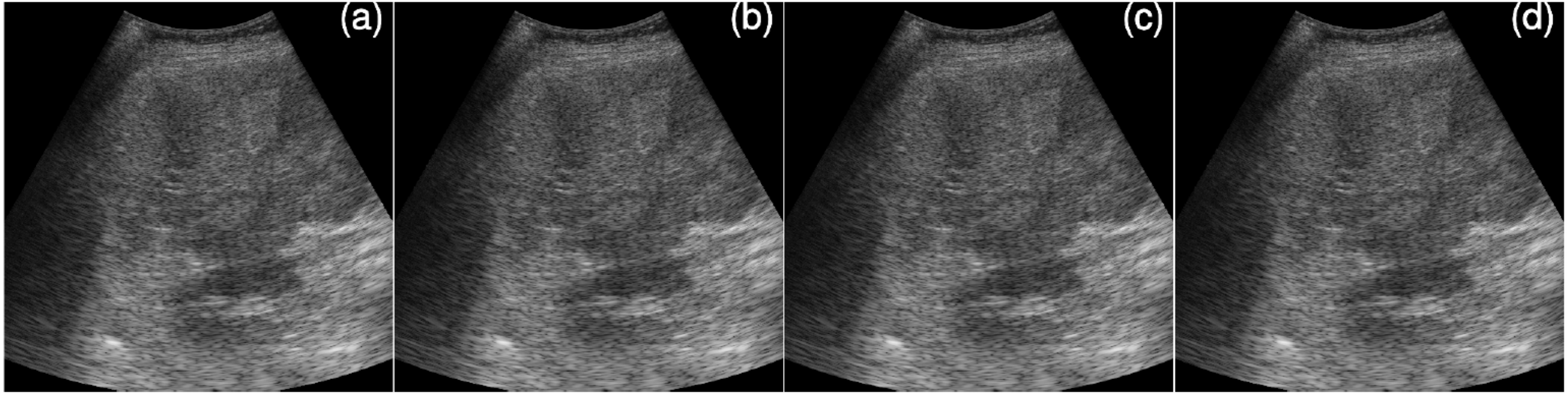
Benchmark, Optimization



Intel Core i7 2600
Nvidia GTX 680 GPU

Resulting image quality



Matlab	SIMD/Multicore	OpenGL	OpenCL
RMSE	0.0044	0.0042	0.0040
PSNR	47.23dB	47.79dB	48.01dB

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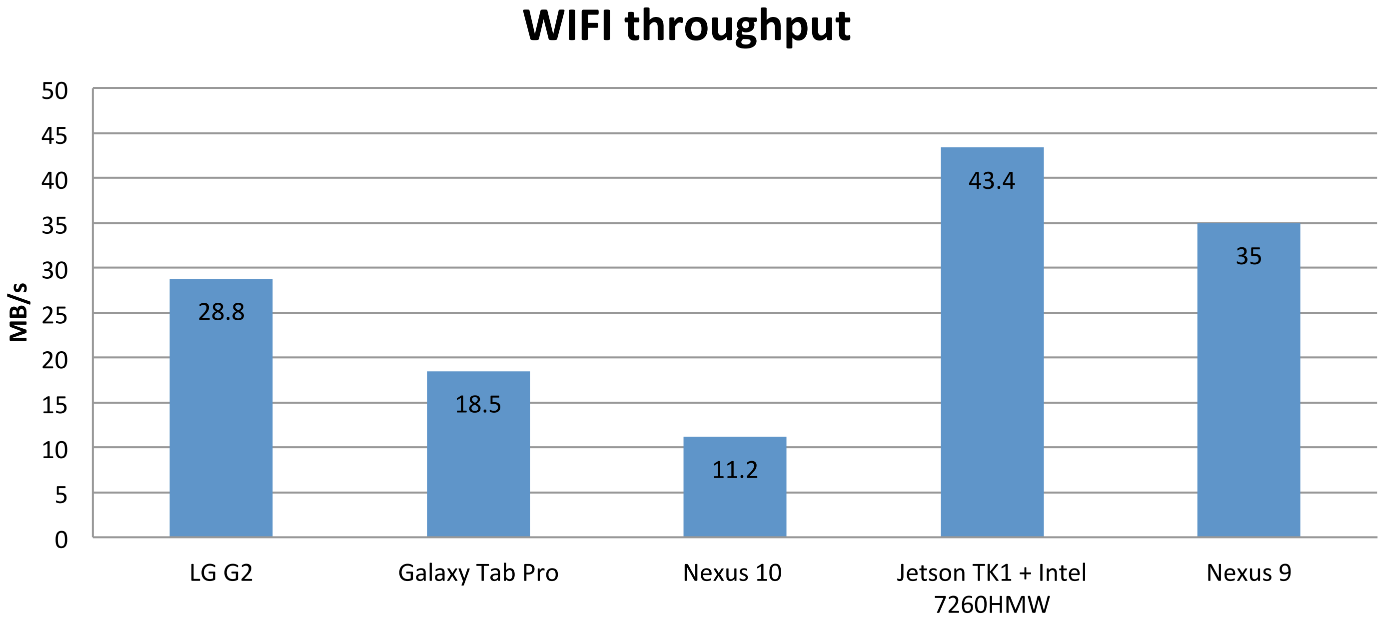
Going mobile (OpenGL ES 3.0)

Mobile hardware

	LG G2	Samsung Galaxy Tab	Samsung Nexus 10	Nvidia Jetson TK1	HTC Nexus 9
SoC	Snadragon 800	Exynos 5	Exynos 5220	Tegra K1	Tegra K1
GPU	Adreno 300	Mali T628	Mali T604	Kepler	Kepler
Screen	1920x1080	2560x1600	2560x1600	1920x1080	2048x1536
OS	Android	Android	Android	Linux4Tegra	Android

Mobile WIFI capabilities

- Need 25.3 MB/s → IEEE 802.11ac



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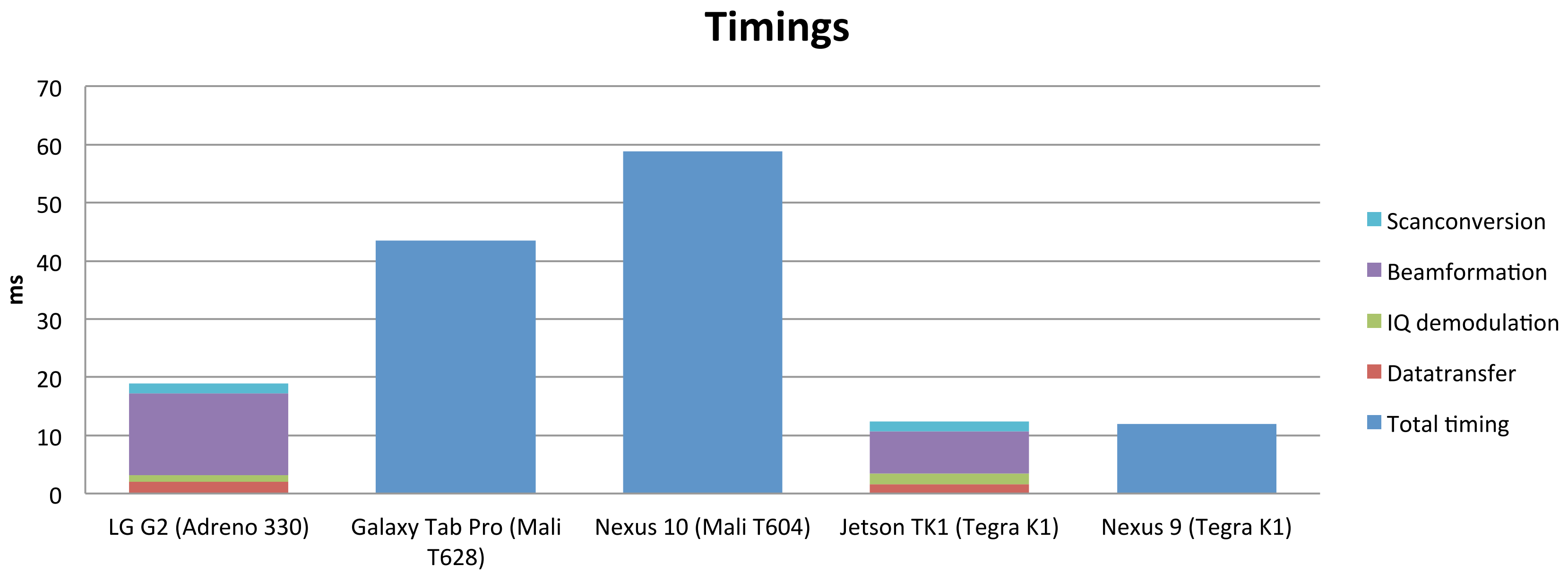
Mobile performance



Going mobile, Nexus 9

Digital or wireless?

Thank you for your attention

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