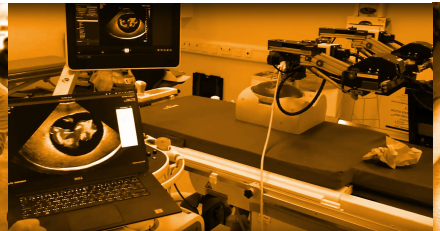
IOP Physical Acoustics Tutorial Day
8 Oct 2021

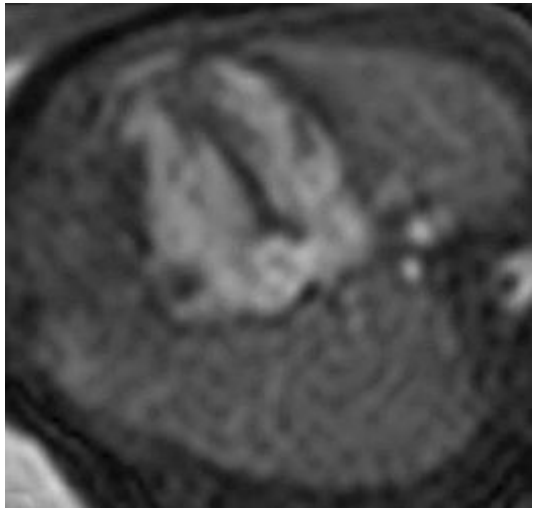
AI-enabled ultrasound imaging

from the lab to the clinic

Alberto Gomez, PhD

alberto.gomez@kcl.ac.uk | https://gomezalberto.github.io/





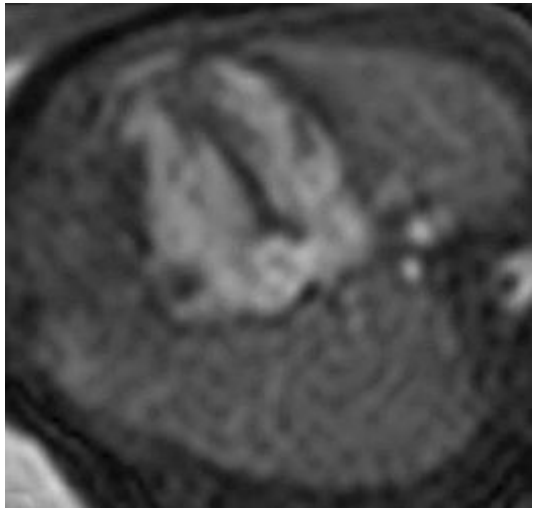
Which one is an ultrasound image?

a) Left

b) Right

c) Both

d) None



Which one is an ultrasound image?

a) Left

b) Right

c) Both

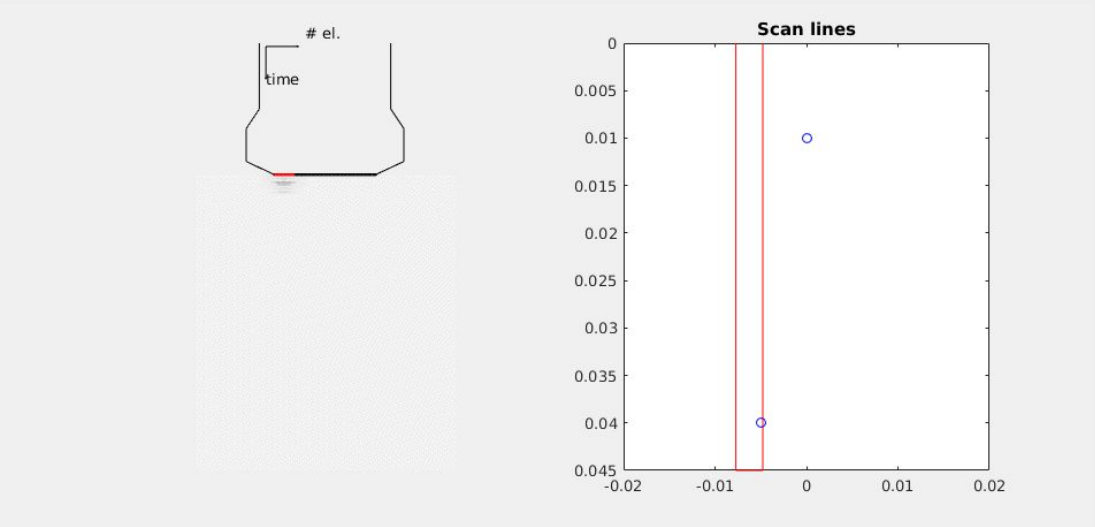
d) None

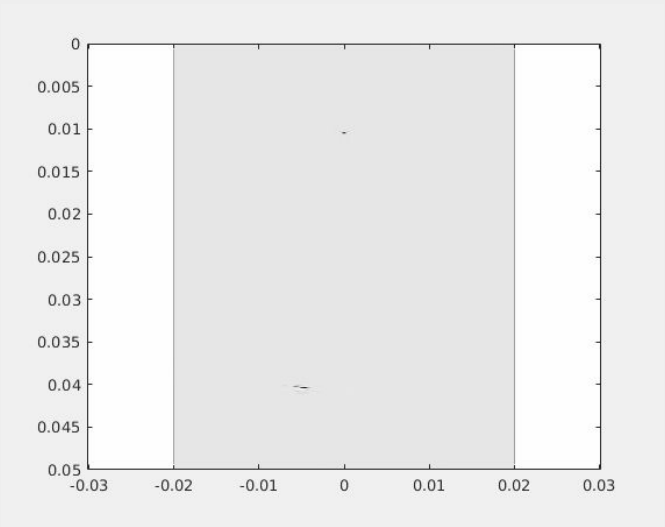
Outline

1. Medical ultrasound imaging
2. AI-enabled ultrasound
3. What could possibly go wrong?
4. Example application
5. Future trends

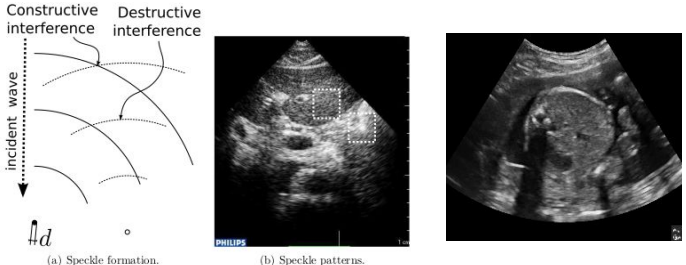
Medical ultrasound imaging

Ultrasound imaging in a nutshell





View-dependent image features (speckle) and artefacts (shadows, …)



(a) Speckle formation. (b) Speckle patterns.

[1] Gomez, A. "Full 3D blood velocity mapping and flow quantification from Doppler echocardiographic images." 2013.

Why is ultrasound so popular?

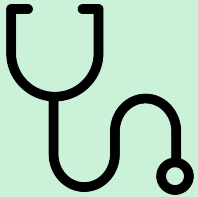
- ✓ Safe and comfortable
- ✓ Affordable (from < £2K)
- ✓ Portable
- ✓ Flexible
- ✓ Fast

Why is ultrasound so popular?

- ✓ Safe and comfortable
- ✓ Affordable (from < £2K)
- ✓ Portable
- ✓ Flexible
- ✓ Fast

BUT: ultrasound used only by specialists

Global need for non-specialist access ultrasound (US) imaging



General Practitioners (GP)

prescribe up to 45% **US** procedures

and

wait up to 1m for test[1]

[1]*NHS: DIDSR 2019-20*

Intensive Care Units (ICU)

Diagnostic change in >25% patients[2]

Unsuspected findings in >50% patients[3]

*(if using **US**)*

[2]*Zieleskiewicz, et al. JICM 2015,* [3]*Manno, et al. JASA 2012*

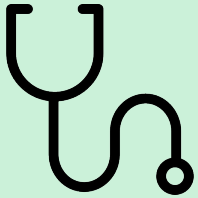
Low- and Middle- Income Countries (LMIC)

> 50% has no access to diagnostic imaging

US + X-Ray can cover 80% imaging need[4]

[4]*PAHO/WHO 2012*

Global need for non-specialist access ultrasound (US) imaging



General Practitioners (GP)

prescribe up to 45% **US** procedures

and

wait up to 1m for test[1]

Intensive Care Units (ICU)

Diagnostic change in >25% patients[2]

Unsuspected findings in >50% patients[3]

*(if using **US**)*

Low- and Middle- Income Countries (LMIC)

> 50% has no access to diagnostic imaging

US + X-Ray can cover 80% imaging need[4]

Issue is not cost or availability, but difficulty of operation!

[1]*NHS: DIDSR 2019-20*

[2]*Zieleskiewicz, et al. JICM 2015,* [3]*Manno, et al. JASA 2012*

[4]*PAHO/WHO 2012*

What are the main challenges?

- ✘ Difficult to interpret
- ✘ Difficult to acquire
- ✘ Difficult to measure
- ✘ Machine dependent
- ✘ Operator dependent
- ✘ Patient dependent

AI-enabled ultrasound imaging

What is AI anyways?

An umbrella term to encompass mathematical and computational methods to carry out tasks that would normally require human intelligence

It is ...

It is not ...

What is AI anyways?

An umbrella term to encompass mathematical and computational methods to carry out tasks that would normally require human intelligence

It is ...

- Artificial

It is not ...

- Intelligent

~~What is AI anyways?~~ What can AI do for us?

It can ...

- Solve repetitive tasks
- Extract discriminative features
- Classify
- Detect
- Localize
- Delineate
- Measure
- ...

It cannot ...

- Empathise
- Self-design
- Self-adapt to new tasks
- Self-deploy
- ...

~~What is AI anyways?~~ What can AI do for us?

It can ...

- Solve repetitive tasks
- Extract discriminative features
- Classify
- Detect
- Localize
- Delineate
- Measure
- ...

It cannot ...

- Empathise
- Self-design
- Self-adapt to new tasks
- Self-deploy
- ...

... (yet)

~~What is AI anyways?~~ What can AI do for us?

It can ...

- Solve repetitive tasks
- Extract discriminative features
- Classify
- Detect
- Localize
- Delineate
- Measure
- ...

It cannot ...

- Empathise
- Self-design
- Self-adapt to new tasks
- Self-deploy
- ...

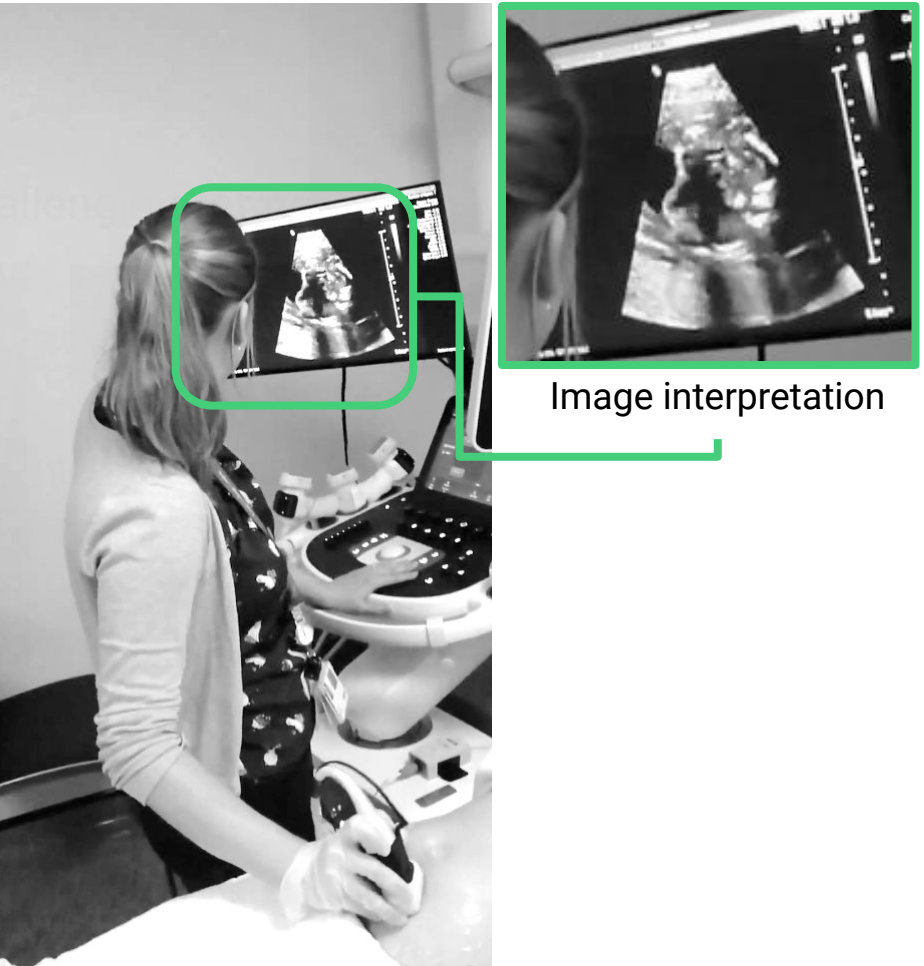
... (yet)

Worry not! This is plenty to address our current challenges!

Understanding challenges with ultrasound imaging

Understanding challenges with ultrasound imaging

Understanding challenges with ultrasound imaging



Understanding challenges with ultrasound imaging

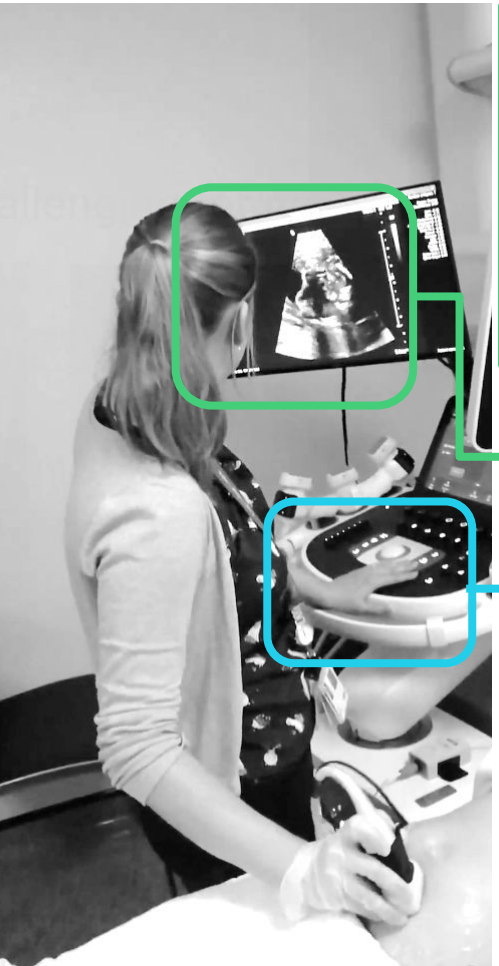


Image interpretation

Machine operation

Understanding challenges with ultrasound imaging

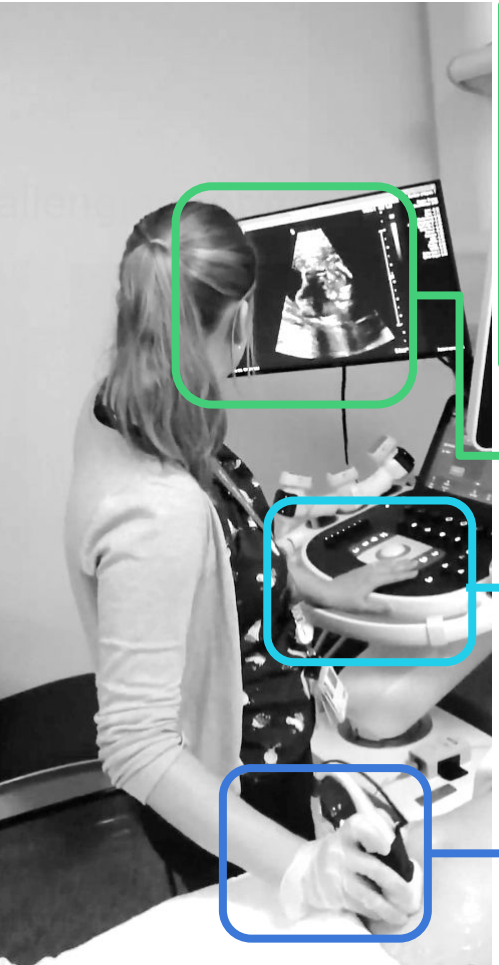


Image interpretation

Machine operation

Transducer operation

Understanding challenges with ultrasound imaging

Image interpretation

Machine operation

Transducer operation

The patient!

- Normally awake
- “Exposed”
- Collaborative
- ...

Understanding challenges with ultrasound imaging

Image interpretation

Machine operation

Transducer operation

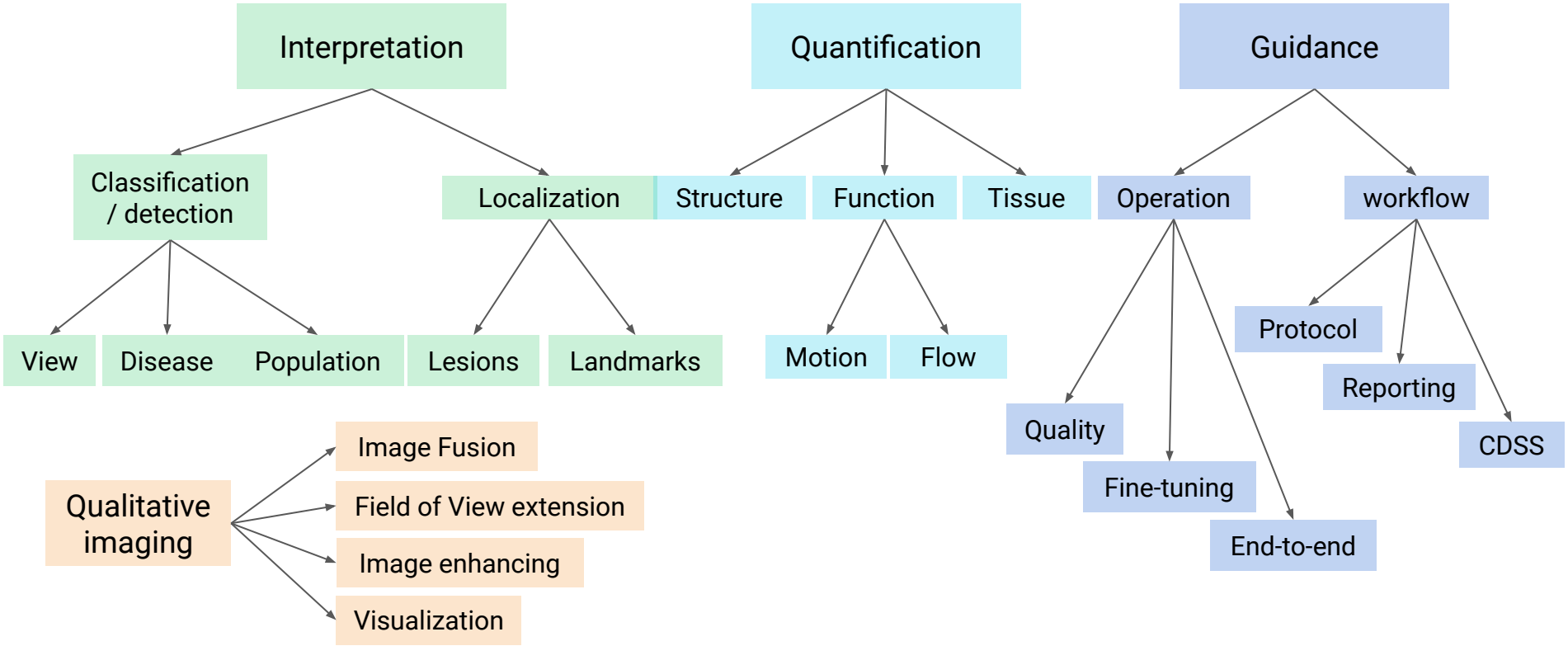
The patient!

- Normally awake
- “Exposed”
- Collaborative
- ...

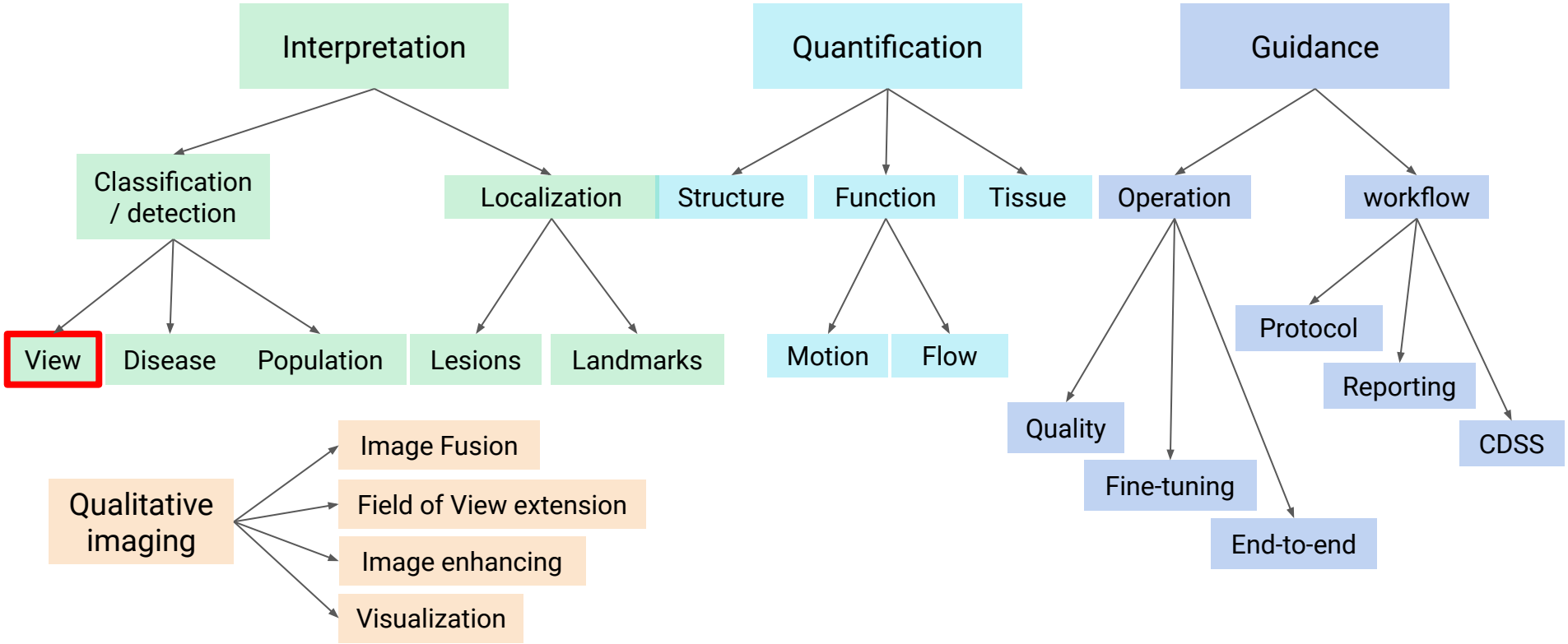
Reporting results

- Tedious
- Partial
- Lack of QC
- ...

AI-enabled ultrasound imaging (*after image formation*)

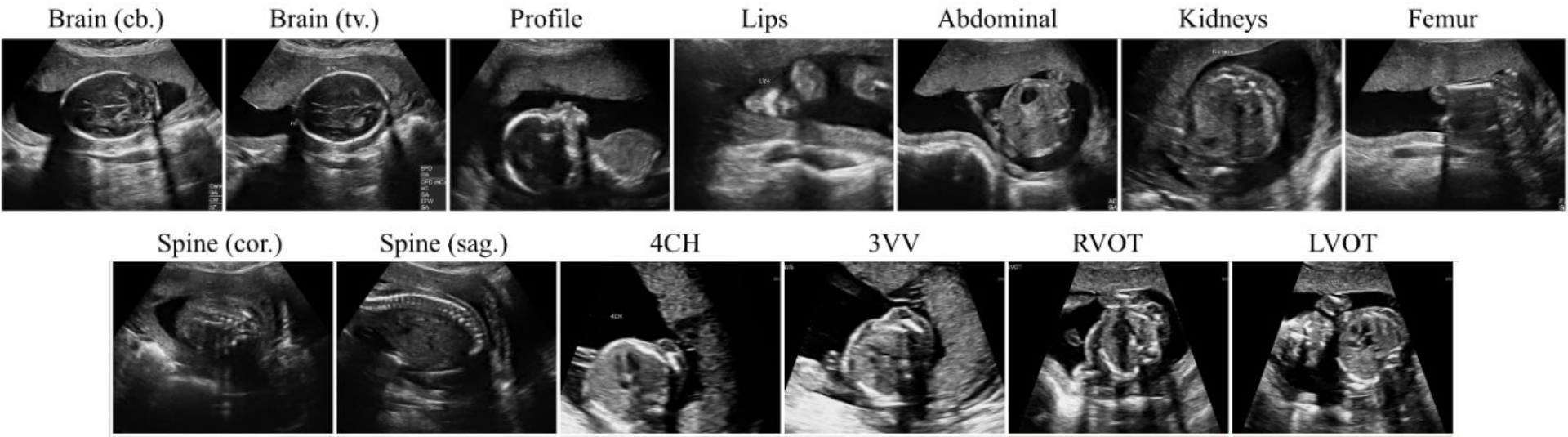


AI-enabled ultrasound imaging (*after image formation*)



Standard view detection in fetal ultrasound screening

The problem: illustration



Baumgartner, C. F., et al. "SonoNet: real-time detection and localisation of fetal standard scan planes in freehand ultrasound." IEEE transactions on medical imaging 36.11 (2017): 2204-2215.

Standard view detection in fetal ultrasound screening

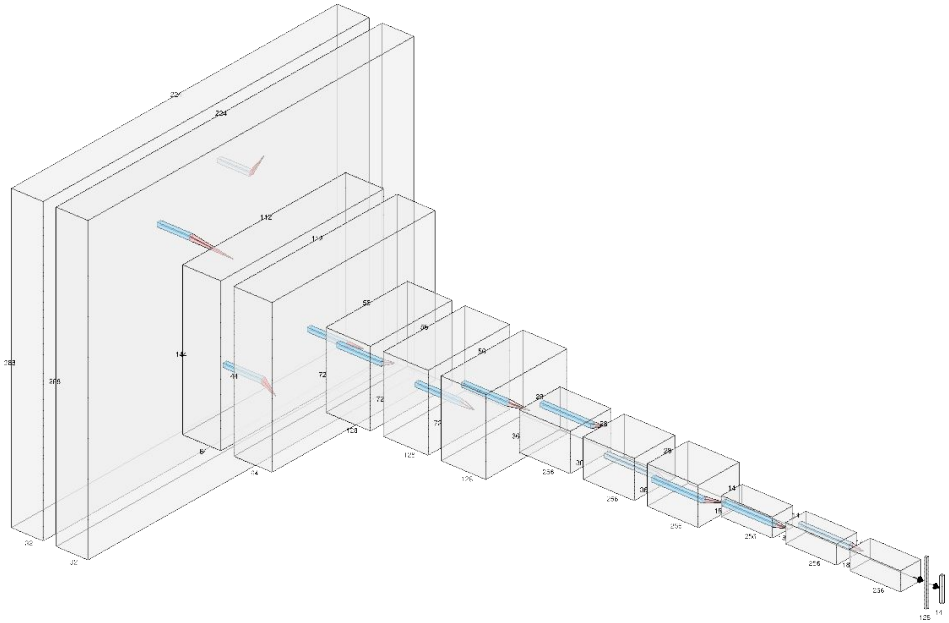
Data

- 7 year long project
- Recruiting up to 10K patients (~2K samples/class)
- Storing **DICOM** and **video data**
- From video to training data → **Do not underestimate!**

Baumgartner, C. F., et al. "SonoNet: real-time detection and localisation of fetal standard scan planes in freehand ultrasound." IEEE transactions on medical imaging 36.11 (2017): 2204-2215.

Standard view detection in fetal ultrasound screening

Creating a CNN model



- Feature extraction
  - (Conv → BN → ReLU)
- Adaptation layer
  - (Linear → ReLU)
- Classification layer
  - Softmax

~12M learnable parameters!

(vs ~200M pixels in the dataset)

Baumgartner, C. F., et al. "SonoNet: real-time detection and localisation of fetal standard scan planes in freehand ultrasound." IEEE transactions on medical imaging 36.11 (2017): 2204-2215.

Standard view detection in fetal ultrasound screening

Training the model

- Split your data into Train / Validate / Test
- Use data augmentation (does it need to be realistic?)
- Use regularization?
- Train until convergence?

Baumgartner, C. F., et al. "SonoNet: real-time detection and localisation of fetal standard scan planes in freehand ultrasound." IEEE transactions on medical imaging 36.11 (2017): 2204-2215.

Standard view detection in fetal ultrasound screening

Results (I)

Baumgartner, C. F., et al. "SonoNet: real-time detection and localisation of fetal standard scan planes in freehand ultrasound." IEEE transactions on medical imaging 36.11 (2017): 2204-2215.

Standard view detection in fetal ultrasound screening

Results (II)

TABLE VI
RETRIEVAL ACCURACY FOR SONONET-32

Class	Accuracy %	Class	Accuracy %
Brain (Cb.)	96.36	Spine (cor.)	95.65
Brain (Tv.)	100.00	Spine (sag.)	96.23
Profile	97.73	4CH	95.00
Lips	92.59	3VV	81.90
Abdominal	88.99	RVOT	73.08
Kidneys	78.38	LVOT	78.50
Femur	96.70	**Average**	**90.09**

Network	Precision	Recall	F1-score
SonoNet-64	**0.806**	0.860	**0.828**
SonoNet-32	0.772	0.843	0.798
SonoNet-16	0.619	**0.900**	0.720
SmallNet	0.354	0.864	0.461

Baumgartner, C. F., et al. "SonoNet: real-time detection and localisation of fetal standard scan planes in freehand ultrasound." IEEE transactions on medical imaging 36.11 (2017): 2204-2215.

Standard view detection in fetal ultrasound screening

Right.

But:

- ~20% false positives
- Exam ~20min = 36k frames
- We could end up with 7.2K frames that need to be manually discarded...

What could possibly go wrong?

What could go wrong?

- Your solution does not solve an actual problem
- An alternative solution already is good enough
- You don’t have an interface that users can actually use
- Users do not want / like to use your solution
- ...

A recipe for success

1. Start by identifying a problem, not a solution
2. Asses to what extent / accuracy the problem needs to be solved
3. Investigate existing work: does it solve your problem already?
4. Think about how far you would like to go, before you start

A recipe for success

1. Start by identifying a problem, not a solution
2. Asses to what extent / accuracy the problem needs to be solved
3. Investigate existing work: does it solve your problem already?
4. Think about how far you would like to go, before you start
5. **Now you may creatively think about new techniques to address the problem**

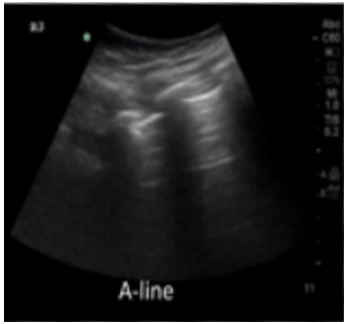
A recipe for success

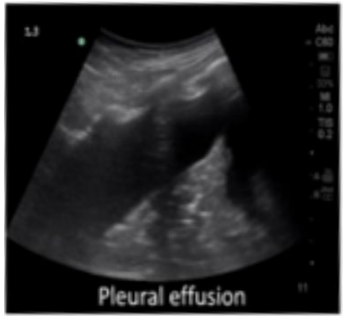
1. Start by identifying a problem, not a solution
2. Asses to what extent / accuracy the problem needs to be solved
3. Investigate existing work: does it solve your problem already?
4. Think about how far you would like to go, before you start
5. Now you may creatively think about new techniques to address the problem
6. **Expose your work frequently to constructive criticism by experts and stakeholders**

A successful example

Assisted lung ultrasound image interpretation

- **Problem**

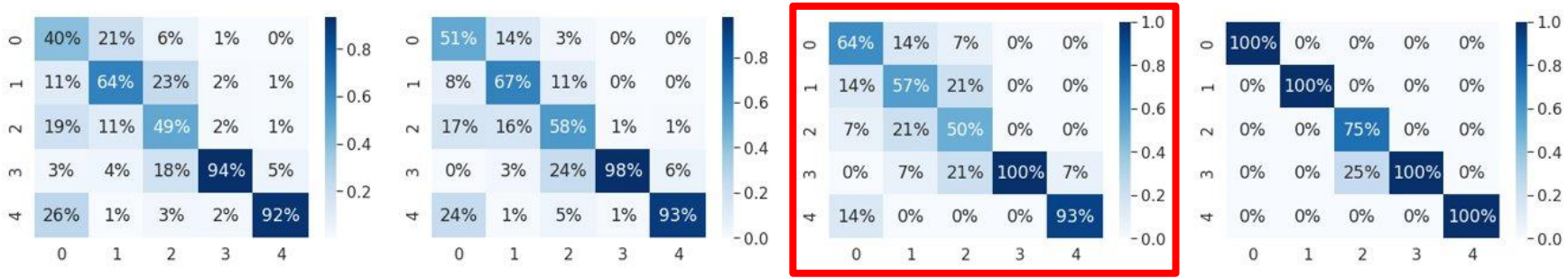




Assisted lung ultrasound image interpretation

✓ **Problem**: Lung ultrasound images are useful to manage critical patients, but difficult to interpret.

- **How well do ICU staff do? How good is good enough?**
  - Virtual seminar on LUS training
  - Beginner (44%), intermediate (43%), advanced (12%), expert(1%)



Beginners (69%) Intermediate (72%) Advanced (73%) Experts (93%)

Assisted lung ultrasound image interpretation

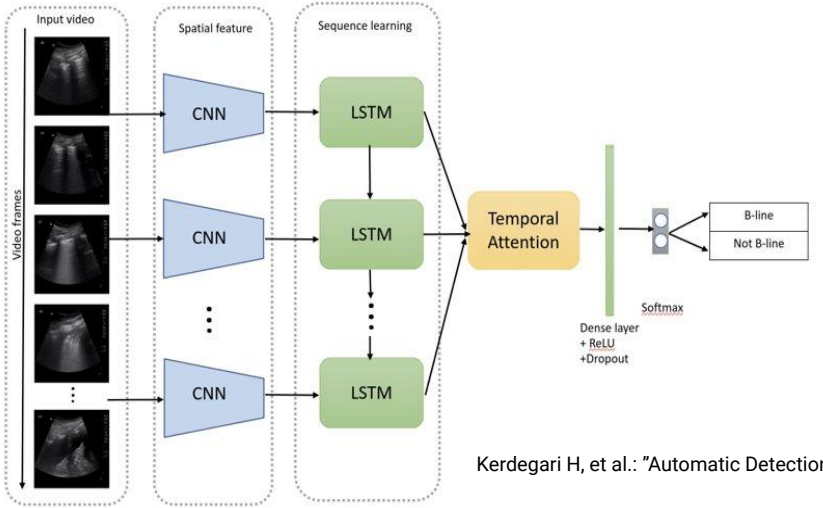
- ✓ **Problem**: Lung ultrasound images are useful to manage critical patients, but difficult to interpret.
- ✓ **How well do ICU staff do? How good is good enough?** >73%
- **What methods are out there to solve this problem?**
  a. Very little work on automated LUS
  b. Mostly related to covid -not suitable for the patient group of interest
  c. Some related work on B-line detection on LUS - close enough!

Assisted lung ultrasound image interpretation

- ✓ **Problem**: Lung ultrasound images are useful to manage critical patients, but difficult to interpret.
- ✓ **How well do ICU staff do? How good is good enough?** >73%
- ✓ **What methods are out there to solve this problem?** - classification, B-line detection
- **How far do we want to go?**
  - Show potential benefit?
  - Prototype?
  - Clinical trial?
  - Commercial product?

Assisted lung ultrasound image interpretation

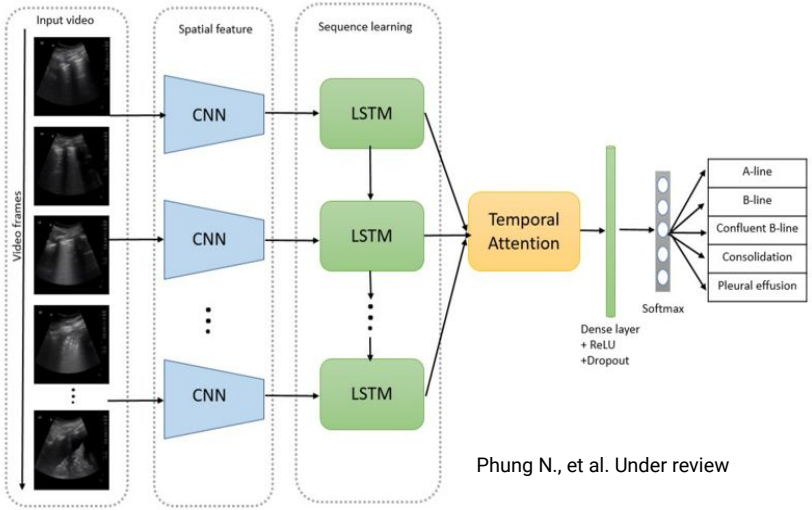
- ✓ **Problem**: Lung ultrasound images are useful to manage critical patients, but difficult to interpret.
- ✓ **How well do ICU staff do? How good is good enough?** >73%
- ✓ **What methods are out there to solve this problem?** - classification, B-line detection
- ✓ **How far do we want to go?** - Prototype
- **Think about the solution**
  - Extend current methods to do 5-class classification



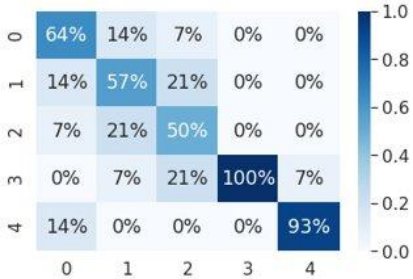
Kerdegari H, et al.: "Automatic Detection of B-lines in Lung Ultrasound Videos from Severe Dengue Patients", IEEE ISBI2021.

Assisted lung ultrasound image interpretation

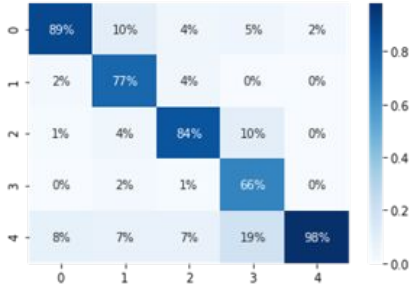
- ✓ **Problem**: Lung ultrasound images are useful to manage critical patients, but difficult to interpret.
- ✓ **How well do ICU staff do? How good is good enough?** >73%
- ✓ **What methods are out there to solve this problem?** - classification, B-line detection
- ✓ **How far do we want to go?** - Prototype
- **Think about the solution**
  - Extend current methods to do 5-class classification



Phung N., et al. Under review



Advanced (73%)



Proposed (83%)

Assisted lung ultrasound image interpretation

- ✓ **Problem**: Lung ultrasound images are useful to manage critical patients, but difficult to interpret.
- ✓ **How well do ICU staff do? How good is good enough?** >73%
- ✓ **What methods are out there to solve this problem?** - classification, B-line detection
- ✓ **How far do we want to go?** - Prototype
- ✓ **Think about the solution** - 5 class extension - 85%

Now, analyse the method critically, put it to test in challenging & realistic conditions

https://github.com/gomezalberto/pretus

Gomez, A. et al, "PRETUS: A plug-in based platform for real-time ultrasound imaging research", 2021 - arXiv:2109.0651

Future trends

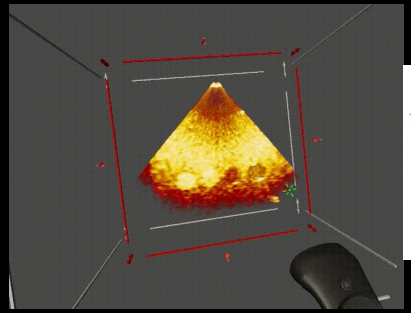
Overview: where ultrasound is getting hot

- **Novel applications,** e.g. AI-assisted interaction in virtual reality for surgery planning

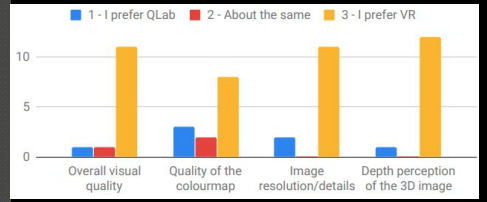
- **Novel US systems**, e.g. handheld devices and multi-transducer

AI-assisted interaction in VR for surgery planning

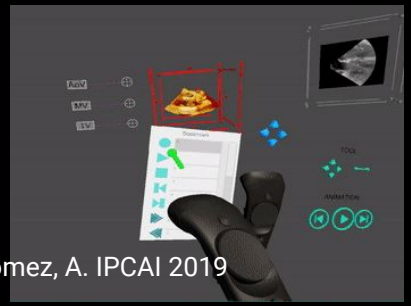
Quantification [17]

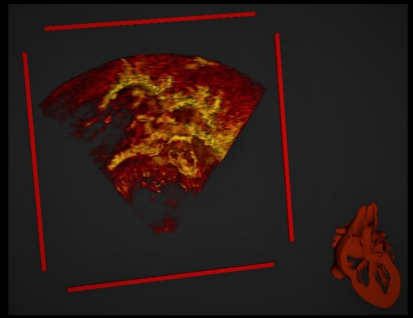


Clinical acceptability [16]



Interaction and usability [18,19]





[16] Wheeler, G,... and Gomez, A. Health Tech Lett. 2018 [17] Wheeler, G., … and Gomez, A. IPCAI 2019

[18] Deng, S,... and Gomez, Euroecho 2019 [19] Munroe, A. et al MIUA 2021

New US systems

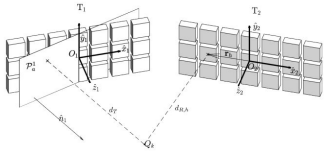
Handheld devices

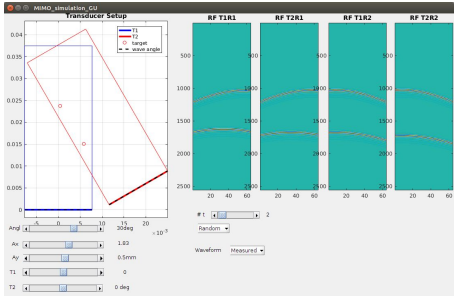
- Mobile devices with high computing power enable AI in system

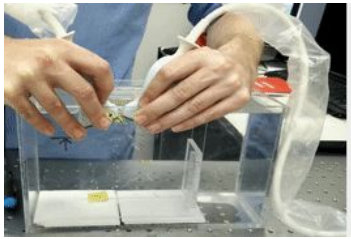
- Cloud computing enables affordable AI-enabled mobile tech

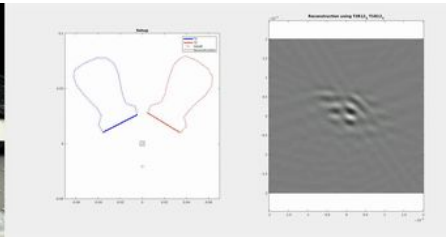
Advent of multi-transducer technology

- Coherent multi-transducer allows to resolve flexible geometry
- Might be key to enabling wearable imaging









Peralta, L., Gomez, A., et al IEEE TUFFC 2019

Take home messages

- Ultrasound imaging is very powerful but also challenging to use
- AI can help make it more accessible
- It is crucial to identify and understand the problems to solve
- The future of AI-enabled US is very bright and expanding!

alberto.gomez@kcl.ac.uk
https://gomezalberto.github.io/

Acknowledgements

King's College London

Hamideh Kerdegari

Nhat Phung

Miguel Xochicale

Gavin Wheeler

Shujie Deng

Julia Schnabel

Veronika Zimmer

Robert Wright

Jo Hajnal

Laura Peralta

Reza Razavi

Andy King

Silvia Giampieri

Nicolas Toussaint

Oxford University Clinical Research Unit

Louise Thwaites

Sophie Yacoub

London Evelina Children's Hospital

John Simpson

Kuberan Pushparajah

Natasha Stephenson

Imperial College London

Bernhard kainz

Daniel Rueckert

University of Seville

Isra Valverde

Universitat Pompeu Fabra

Oscar Camara

Funded by:

Thanks!