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, ...)

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\(^1\)

**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\(^4\)

\(^1\) NHS: DIDS 2019-20
\(^2\) Zieleskiewicz, et al. JICM 2015
\(^3\) Manno, et al. JASA 2012
\(^4\) 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

Intensive Care Units (ICU)

Diagnostic change in >25% patients
Unsuspected findings in >50% patients (if using US)

Low- and Middle- Income Countries (LMIC)

> 50% has no access to diagnostic imaging
US + X-Ray can cover 80% imaging need

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

1 NHS: DIDS 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
<table>
<thead>
<tr>
<th>It can ...</th>
<th>It cannot ...</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Solve repetitive tasks</td>
<td>● Empathise</td>
</tr>
<tr>
<td>● Extract discriminative features</td>
<td>● Self-design</td>
</tr>
<tr>
<td>● Classify</td>
<td>● Self-adapt to new tasks</td>
</tr>
<tr>
<td>● Detect</td>
<td>● Self-deploy</td>
</tr>
<tr>
<td>● Localize</td>
<td>● ...</td>
</tr>
<tr>
<td>● Delineate</td>
<td></td>
</tr>
<tr>
<td>● Measure</td>
<td></td>
</tr>
<tr>
<td>● ...</td>
<td></td>
</tr>
</tbody>
</table>
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

The patient!

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

Image interpretation
Machine operation
Transducer operation
Understanding challenges with ultrasound imaging

The patient!
- Normally awake
- “Exposed”
- Collaborative
- ...

Reporting results
- Tedious
- Partial
- Lack of QC
- ...

Image interpretation
Machine operation
Transducer operation
AI-enabled ultrasound imaging (after image formation)

- **Interpretation**
  - Classification / detection
  - Localization
  - Structure
  - Function
  - Tissue
  - View
  - Disease
  - Population
  - Lesions
  - Landmarks

- **Quantification**
  - Motion
  - Flow

- **Guidance**
  - Operation
  - Protocol
  - Reporting
  - CDSS
  - Quality
  - Fine-tuning
  - End-to-end

- **Qualitative imaging**
  - Image Fusion
  - Field of View extension
  - Image enhancing
  - Visualization

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

- Interpretation
  - Classification / detection
  - View
    - Disease
    - Population
    - Lesions
    - Landmarks
  - Localization
  - Structure
  - Function
  - Tissue

- Quantification
  - Motion
  - Flow

- Guidance
  - Operation
  - workflow
  - Protocol
  - Reporting
  - CDSS

- Qualitative imaging
  - Image Fusion
  - Field of View extension
  - Image enhancing
  - Visualization
Standard view detection in fetal ultrasound screening

The problem: illustration

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!

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)

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?

Standard view detection in fetal ultrasound screening

Results (I)

Standard view detection in fetal ultrasound screening

Results (II)

<table>
<thead>
<tr>
<th>Class</th>
<th>Accuracy %</th>
<th>Class</th>
<th>Accuracy %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain (Cb.)</td>
<td>96.36</td>
<td>Spine (cor.)</td>
<td>95.65</td>
</tr>
<tr>
<td>Brain (Tv.)</td>
<td>100.00</td>
<td>Spine (sag.)</td>
<td>96.23</td>
</tr>
<tr>
<td>Profile</td>
<td>97.73</td>
<td>4CH</td>
<td>95.00</td>
</tr>
<tr>
<td>Lips</td>
<td>92.59</td>
<td>3VV</td>
<td>81.90</td>
</tr>
<tr>
<td>Abdominal</td>
<td>88.99</td>
<td>RVOT</td>
<td>73.08</td>
</tr>
<tr>
<td>Kidneys</td>
<td>78.38</td>
<td>LVOT</td>
<td>78.50</td>
</tr>
<tr>
<td>Femur</td>
<td>96.70</td>
<td>Average</td>
<td><strong>90.09</strong></td>
</tr>
</tbody>
</table>

---

**TABLE VI**

Retrieval accuracy for **SonoNet-32**

<table>
<thead>
<tr>
<th>Network</th>
<th>Precision</th>
<th>Recall</th>
<th>F1-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>SonoNet-64</td>
<td><strong>0.806</strong></td>
<td>0.860</td>
<td><strong>0.828</strong></td>
</tr>
<tr>
<td>SonoNet-32</td>
<td>0.772</td>
<td>0.843</td>
<td>0.798</td>
</tr>
<tr>
<td>SonoNet-16</td>
<td>0.619</td>
<td><strong>0.900</strong></td>
<td>0.720</td>
</tr>
<tr>
<td>SmallNet</td>
<td>0.354</td>
<td>0.864</td>
<td>0.461</td>
</tr>
</tbody>
</table>

---

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. Assess 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. Assess 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. Assess 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%)
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

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
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

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

Clinical acceptability [16]

Interaction and usability [18,19]

Quantification [17]

[17] Wheeler, G., ... and Gomez, A. IPCAI 2019
[18] Deng, S., ... and Gomez, Euroecho 2019
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

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!
Acknowledgements

King's College London
Hamideh Kerdegari
Nhat Phung
Miguel Xochicale
Gavin Wheeler
Shujie Deng
Julia Schnabel
Veronika Zimmer

Oxford University Clinical Research Unit
Robert Wright
Jo Hajnal
Laura Peralta
Reza Razavi
Andy King
Silvia Giampieri
Nicolas Toussaint
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:

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