Software bottlenecks for anatomical AI

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1. What is an image?

2. Software bottlenecks for AI research

3. What you can expect going forward

I do not have any conflict of interest to disclose.
What is an image?
What do you see on a medical image? [Zyg]
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1. Pixels
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1. Pixels
2. Anatomy
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1. Pixels  
2. Anatomy  
3. Function
What do you see on a medical image? [Zyg]

1. Pixels  
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Simplifying a bit, each level of analysis corresponds to a way of grouping pixels with their neighbors.
1st level: a pixel grid

$N_x \times N_y \times N_z$ array of pixels.

**Bitmap** images and volumes:
- .bmp, .png, .jpg
- Standard in **radiology**.

+ Ordered memory structure.
+ Explicit neighborhoods.
+ Fast **local** filters.

→ **Texture** analysis.
→ Organ **segmentation**.
→ Pattern **detection**.
2nd level: point clouds and 3D surfaces

$N_{\text{points}} \times 3$ array of $(x, y, z)$ coordinates.

**Clouds of points** ($\pm$ triangles):
- .svg
- Standard for video games.

+ Compact representation.
+ High precision geometry.
+ **Easy to deform.**

→ **3D visualization.**
→ Anatomical **atlas**.
→ **Shape** analysis.
3rd level: biomechanical and/or physiological model [Zyg]

Mechanical/biological model:
- Finite elements, networks.
- Standard for CAD.
- Prior knowledge.
- Robust to noise.
- Realistic behaviour.

→ Physiological interpretation.
→ Infer what cannot be seen (stress).
→ Simulate a surgery.

Volumetric mesh, graph of interactions.
Looking for the **neighbors** of a point in 3D space?

- **On a grid**: read adjacent memory cells.
- **With N points** \((x, y, z)\): computation of N distances.

Want to **rotate** a bone by 10°?

- **On a grid**: artifacts, loss of details, transfers between memory cells.
- **With N points** \((x, y, z)\): simple arithmetics on the coordinates.

Computational **speed** \(\iff\) Training on **large datasets**.
To summarize

AI = statistical regression method + relevant computational model.

In medical imaging, we represent patient data as:

1. A 2D or 3D pixel grid.
2. An array of \((x, y, z)\) coordinates.
3. A web of complex interactions.
4. All three at once!

In most cases, we define a large structured formula:

\[
\text{image} \xrightarrow{F} F(\text{image}) \simeq \text{diagnostic}
\]

\(F\) is a parametric computing architecture

\(\simeq \text{model} \) to fit \(\simeq \text{network} \) to train.
Software bottlenecks for AI research
The AI revolution is driven by gaming computers

Digital images and machine learning have been studied for decades. Breakthrough in 2010-15: using PlayStations to do science became easy.

Research effort at all levels towards:
- Increasingly powerful computers.
- Increasingly convenient software toolkits.
- Increasingly relevant models.

Spectacular results in a few applications ⟹ massive investments, industry + governments.

10,000 cores on a GPU.
Main motivation for AI in 2012-2022: **self-driving cars**.

Key challenges: **segment** the environment, **detect** other actors.

Two full software suites to manipulate **images as grids of pixels**:
- TensorFlow (Google)
- PyTorch (Facebook-Meta).
To go beyond prototypes, AI engineers need a full software suite

**Graphics:** Printer + Driver + **Photoshop** $\implies$ Illustrations

**Tabular data:** GPU + cuBLAS + PyTorch + TensorFlow $\implies$ “Classical” neural networks

**Pixel grids:** GPU + cuDNN + PyTorch + TensorFlow $\implies$ Convolutional neural networks

**Point clouds and graphs:** GPU + CUDA + ?? $\implies$ Geometric neural networks
For point clouds and graphs: work in progress

An ecosystem under construction:

- **KeOps**: since 2017
  - Fast learning with **point clouds**.

- **PyG**: since 2018
  - Fast learning with **graphs**.

- **Warp, FEniCSx and PhiFlow**: since 2018
  - Fast learning with **physics**.

- **PyVista and Vedo**: since 2019
  - **3D visualisation**.

- **scikit-shapes**: released soon
  - Easy **morphometrics**.
Conclusion

• **Gaming computers** (GPUs) are the workhorses of AI. A **full software suite** is required to rein in these machines.

• Since 2015, **medical imaging** rides a wave of investment from the **FAANG** for **natural** image processing.

  Breakthroughs: **segmentation**, **texture** analysis and lesion **detection**.

• What about **surgical** planning, **morphometrics**, **vascular** analysis…?

  An **investment in the numerical foundations** of the field is under way.
Zygote.

Solid 3d human foot and ankle model.