Software bottlenecks for anatomical AI

GEST AI Webinar, online

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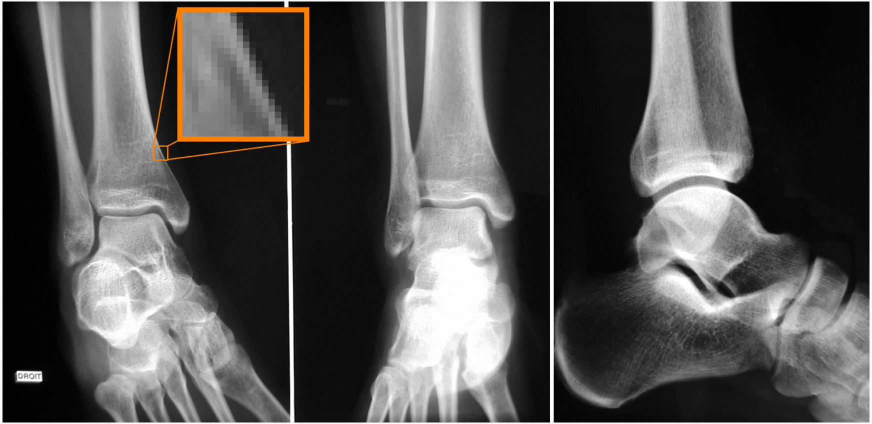
What is an image?

What do you see on a medical image? [Zyg]

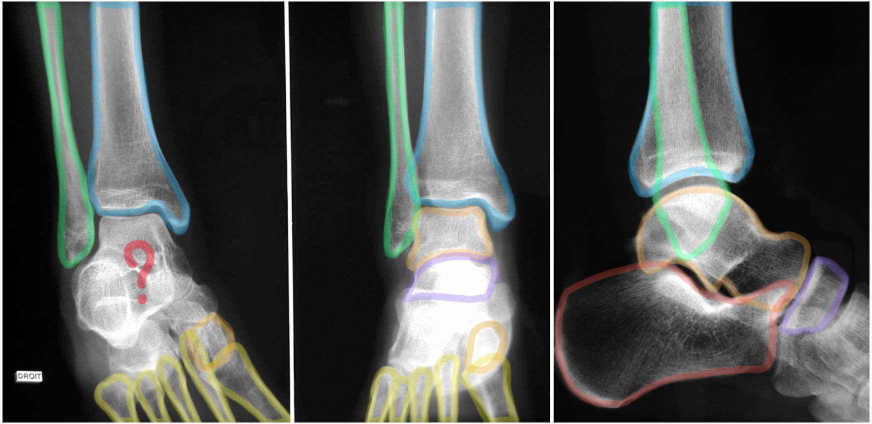
What do you see on a medical image? [Zyg]

1. Pixels



What do you see on a medical image? [Zyg]

1. Pixels
2. Anatomy

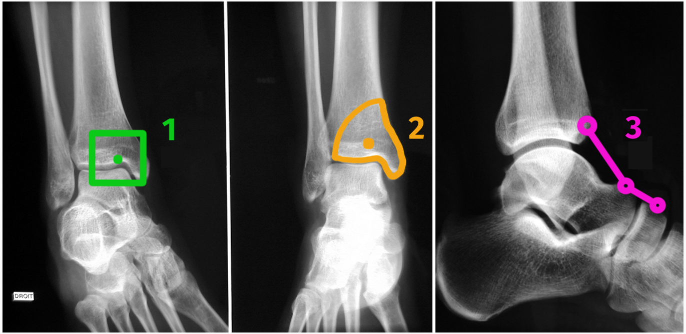


What do you see on a medical image? [Zyg]

1. Pixels
2. Anatomy
3. Function

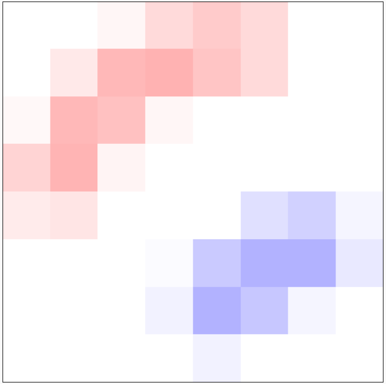
What do you see on a medical image? [Zyg]

1. Pixels 2. Anatomy 3. Function



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.

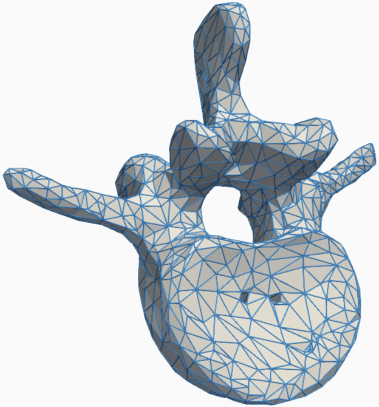
Bitmap images and volumes:

- `.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**.

$\rightarrow$ **3D visualization**.
$\rightarrow$ Anatomical **atlas**.
$\rightarrow$ **Shape** analysis.

3rd level: biomechanical and/or physiological model [Zyg]

Volumetric mesh,
graph of interactions.

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.

Strengths and weaknesses of these image formats

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** $\Longleftrightarrow$ 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**:

$$\text{image} \xrightarrow{\text{F}} \text{F}\,(\text{image}) \simeq \text{diagnostic}$$

F is a parametric computing **architecture**
$\simeq$ **model** to fit $\simeq$ **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**.

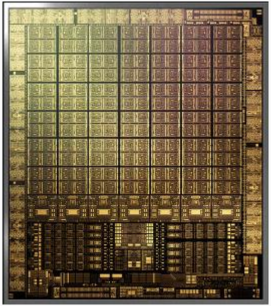
Breakthrough in 2010-15 : using **PlayStations** to do **science** became **easy**.

Research effort at all levels towards:

- Increasingly powerful **computers**.
- Increasingly convenient **software toolkits**.
- Increasingly relevant **models**.

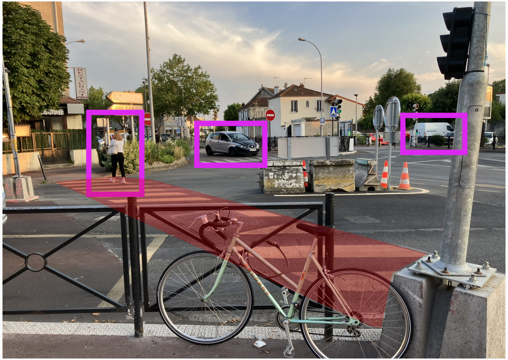
Spectacular results in a few applications

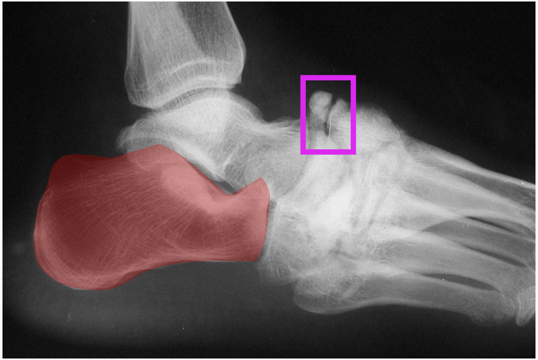
$\Longrightarrow$ massive **investments**, industry + governments.



10,000 cores on a GPU.

For grid images: a mature ecosystem





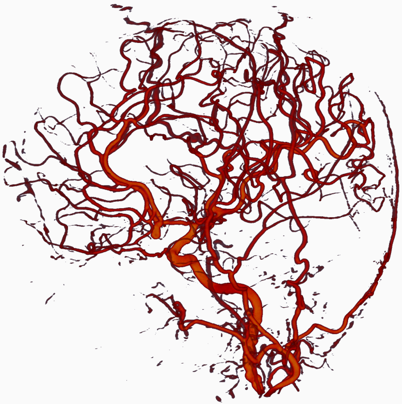
Main motivation for AI in 2012-2022: **self-driving cars**.

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

Two full software suites to manipulate **images as grids of pixels**:

TensorFlow (Google) and PyTorch (Facebook-Meta).

For point clouds and graphs: work in progress

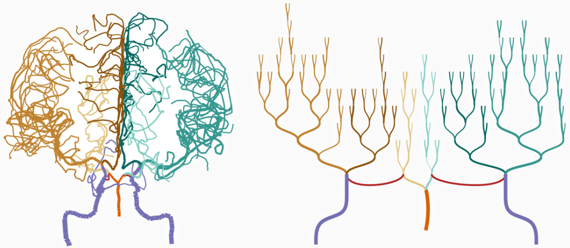


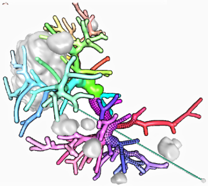
Brain arterial network.
How do we **process this object**?

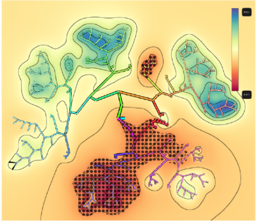
An ecosystem under construction:

- **KeOps** : since 2017
  - Fast learning with **point clouds**.
- **PyG** : since 2018
  - Fast learning with **graphs**.
- **Warp**, **FEniCSx** and **Taichi** : since 2018
  - Fast learning with **physics**.
- **PyVista** and **Vedo** : since 2019
  - **3D visualisation.**
- **scikit-shapes**: in 2025
  - Easy **morphometrics.**

Towards “intelligent” maps of vessel networks? [EMML22]







Some examples of **“vessel maps”** that are currently available.
We are working to **adapt** them to the requirements of interventional radiologists.

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.

References

References i

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