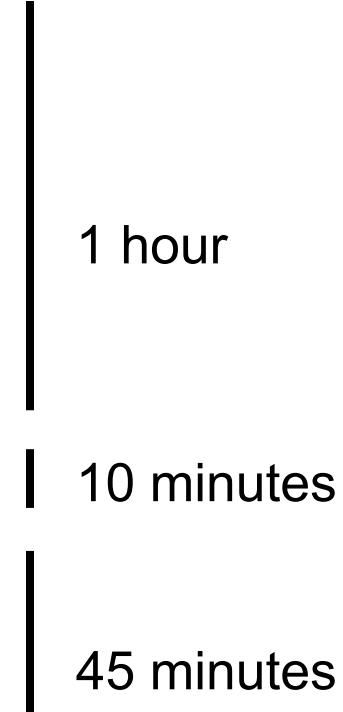


Artificial Intelligence Based Shape Representation

Nazli Tümer, Edwin Tay, Morteza Homayounfar

Department of Biomechanical Engineering
Faculty of Mechanical Engineering
Delft University of Technology (TU Delft)

Schedule

- Introduction
 - Shape Representation and Deep Learning
 - Crash Course on Deep Learning
 - Deep Learning for Geometry
 - (Visual) Foundation Models
 - Break
 - Git Version Control
 - Hands-on practical
- 

Who Are We?



Delft,
NL

ESB2025
Zürich, Switzerland

 BBioX



TU Delft – Mechanical Engineering
/ BioMechanical Engineering /
Biomaterials & Tissue Biomechanics

Who Are We?

BBioX Lab

<https://bbiox.github.io/index.html>



Nazli Tumer



PhD, Edwin Tay



PhD, Morteza Homayounfar



PhD, Sabrina Hörmann



PhD, Mohammad Mahmoodi



PhD, Sara Nuvoli

What Do We Do?

Bones Don't Lie:
What Does Bone Shape Tell Us
About Skeletal Diseases?



Bone Shape

Protect individuals against

OR

Play a role in the onset and progression of

Skeletal Diseases

What Do We Do?

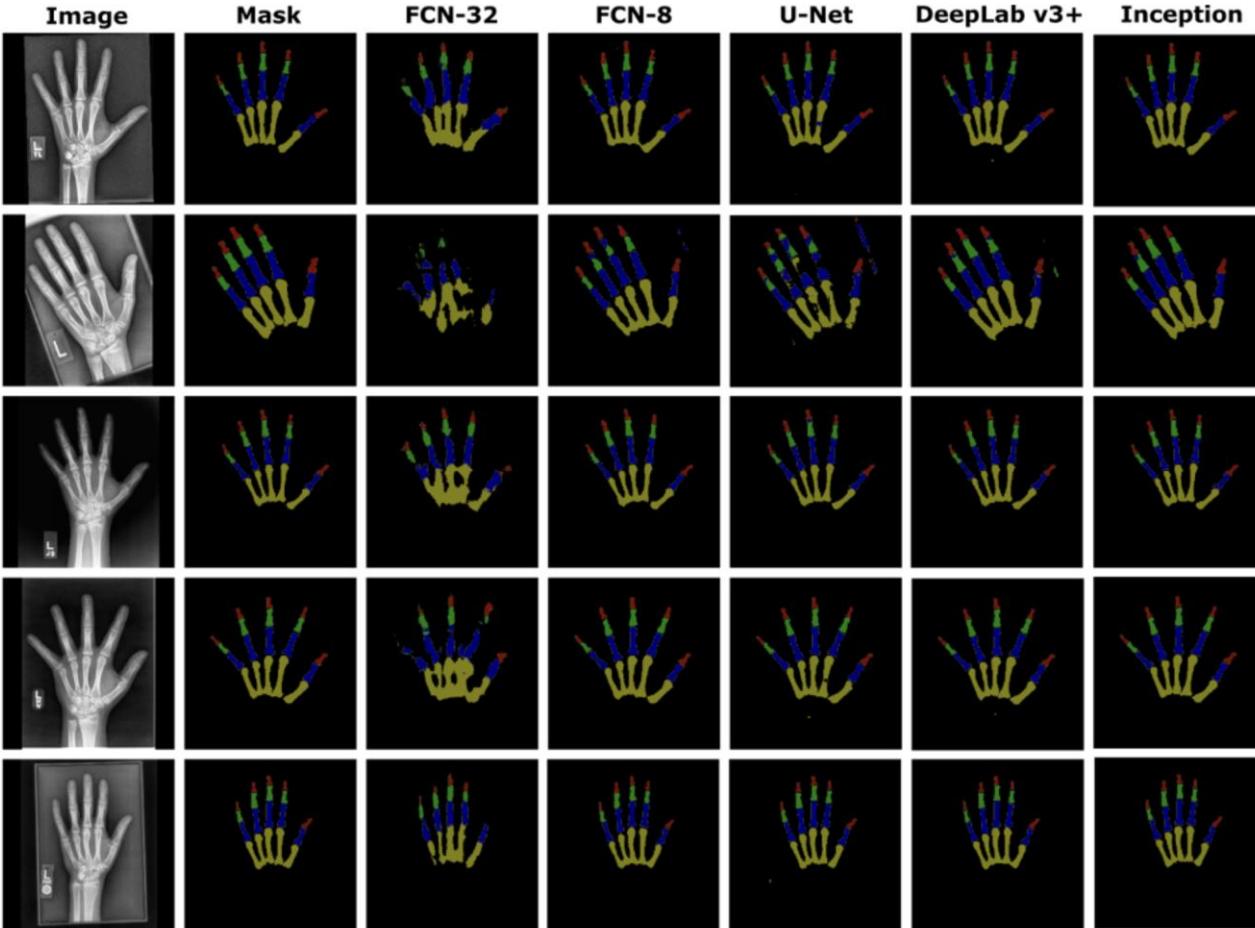


Mechanical forces
can influence
Normal or abnormal growth
and development
and affect
the size and shape
of our body parts

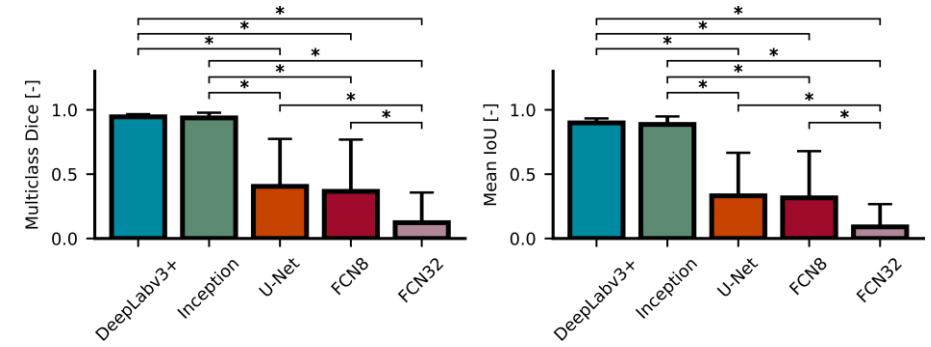
What Do We Do?

Use a combination of advanced:
data-driven, medical image processing,
computational and experimental approaches
**to study the biomechanics of the
(growing and developing) skeleton**

What Do We Do?

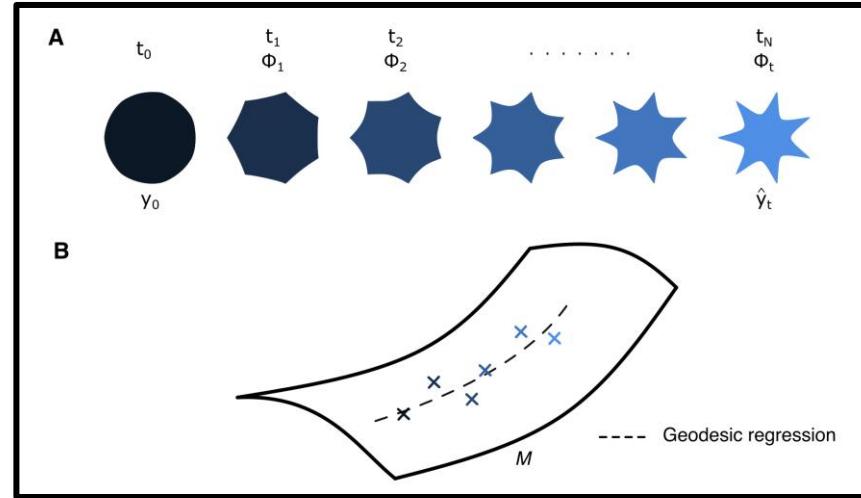
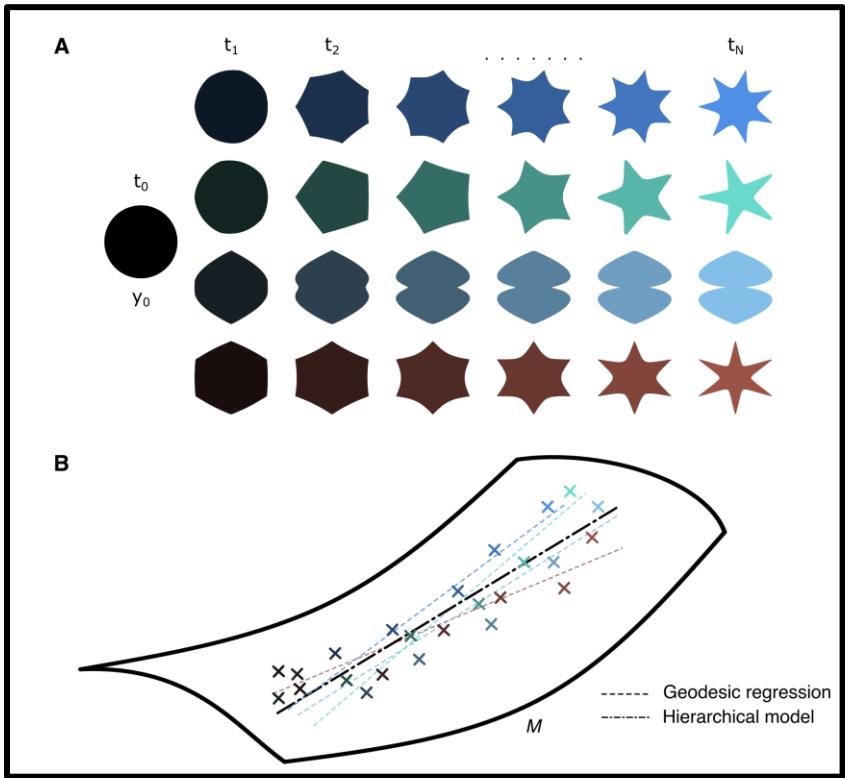


PhD, Edwin Tay



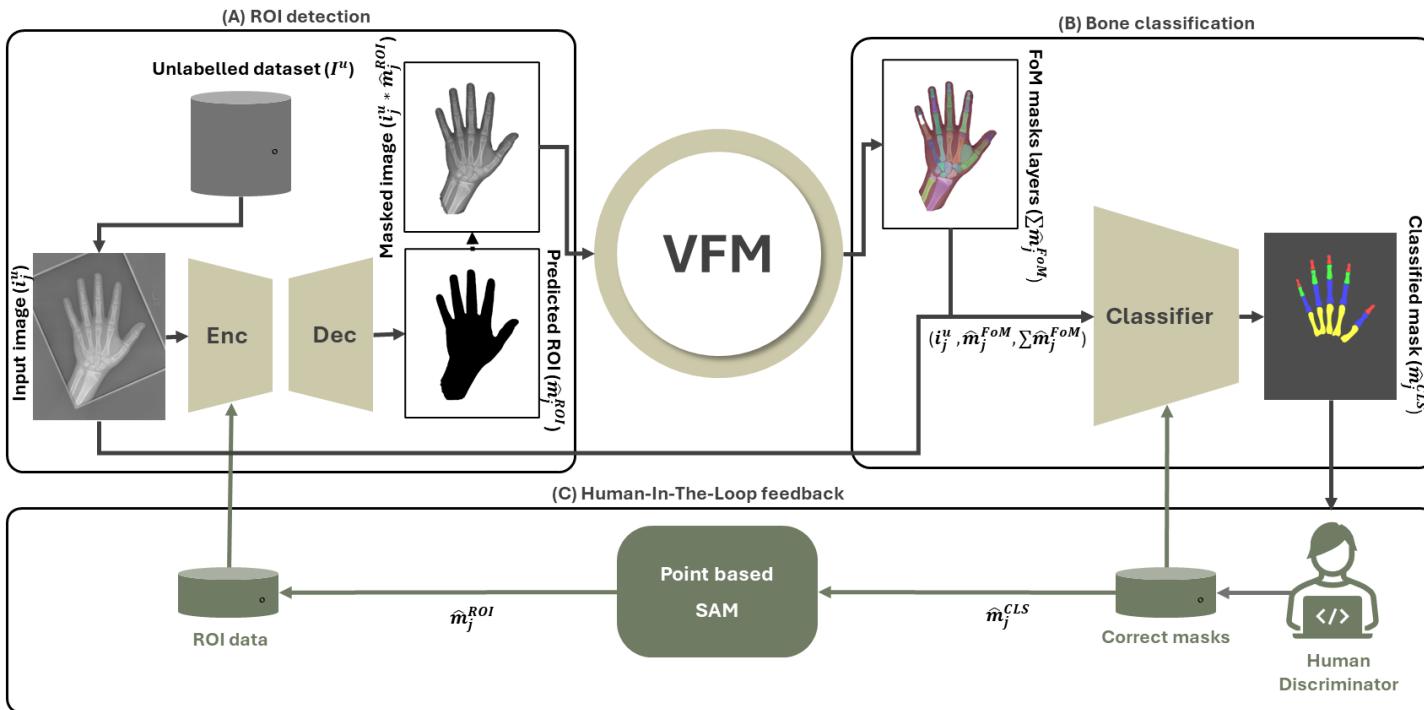
Tay, E., Zadpoor, A.A. and Tümer, N. (2025). Towards growth-accommodating deep learning-based semantic segmentation of pediatric hand phalanges. *Biomedical Signal Processing and Control*, 102, p.107338.

What Do We Do?



PhD, Edwin Tay

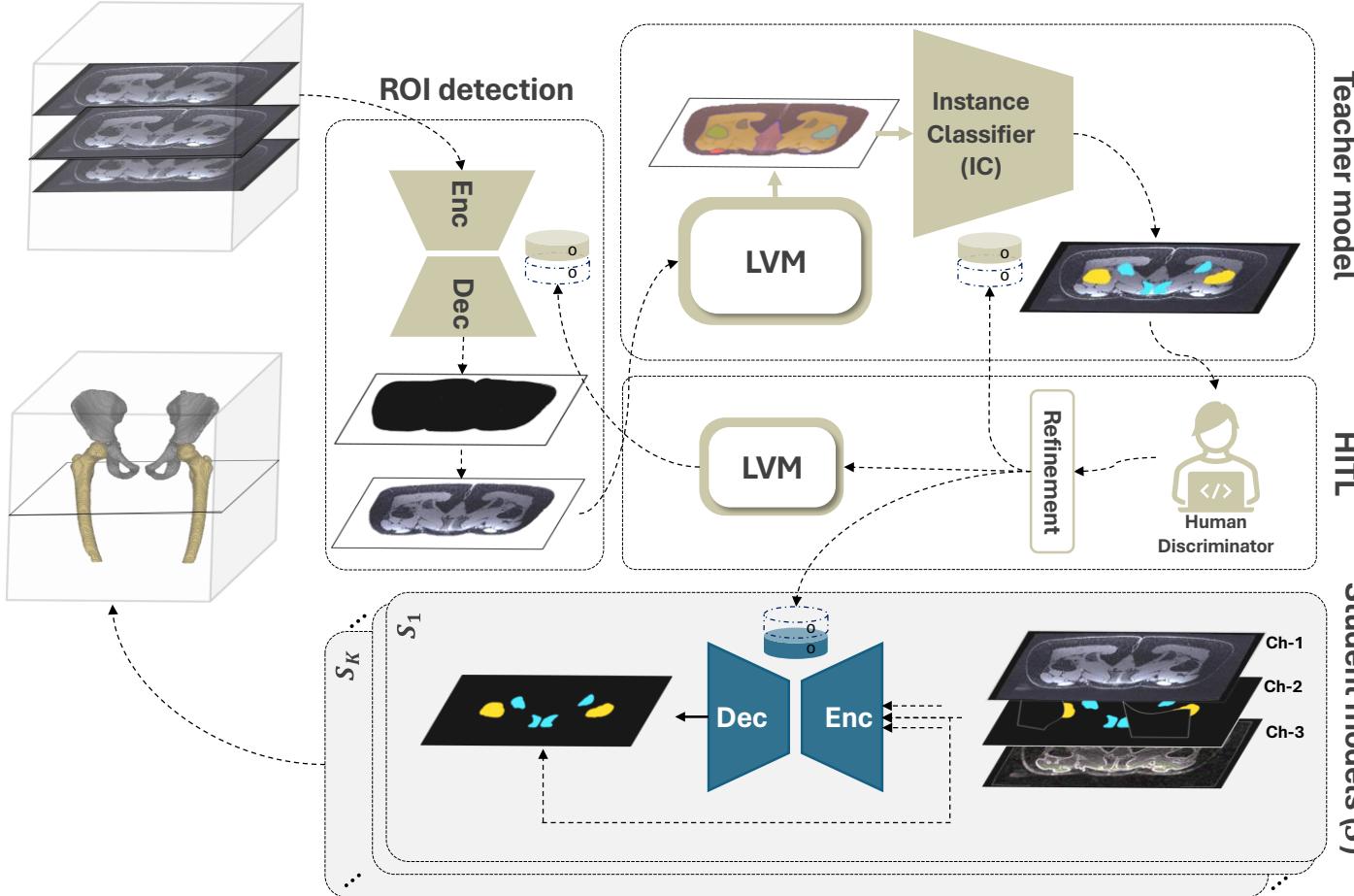
What Do We Do?



PhD, Morteza Homayounfar

Hands-on!

What Do We Do?



PhD, Morteza Homayounfar

What Do We Do?



PhD, Mohammad
Mahmoodi

A Mechanistic Study of Hip
Growth Development



PhD, Sabrina Hörmann

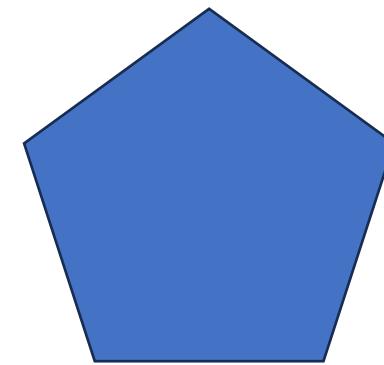
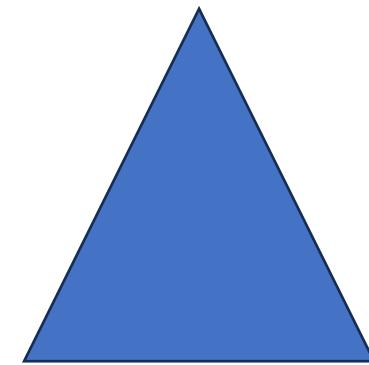
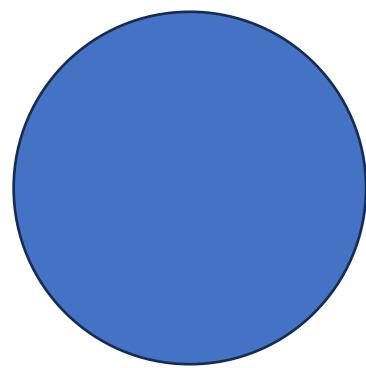
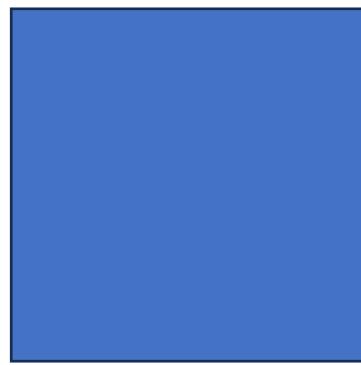
Estimation of knee joint forces in
different activities using personalized
musculoskeletal models and physics-
informed neural networks



PhD, Sara Nuvoli

Investigating Cellular Responses
to Local Structural Heterogeneity
and Mechanical Loading in
Engineered Cartilage Models

Shape Representation and Deep Learning



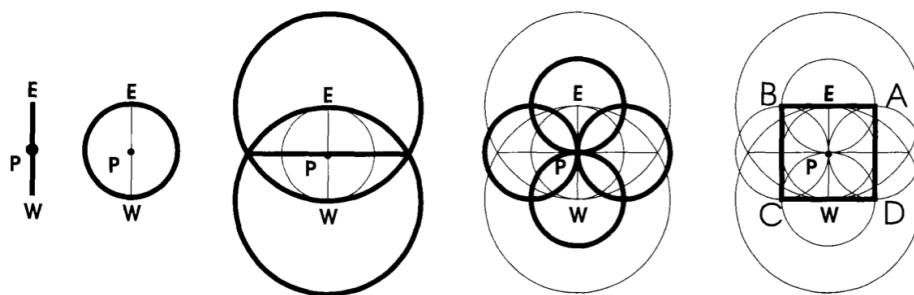
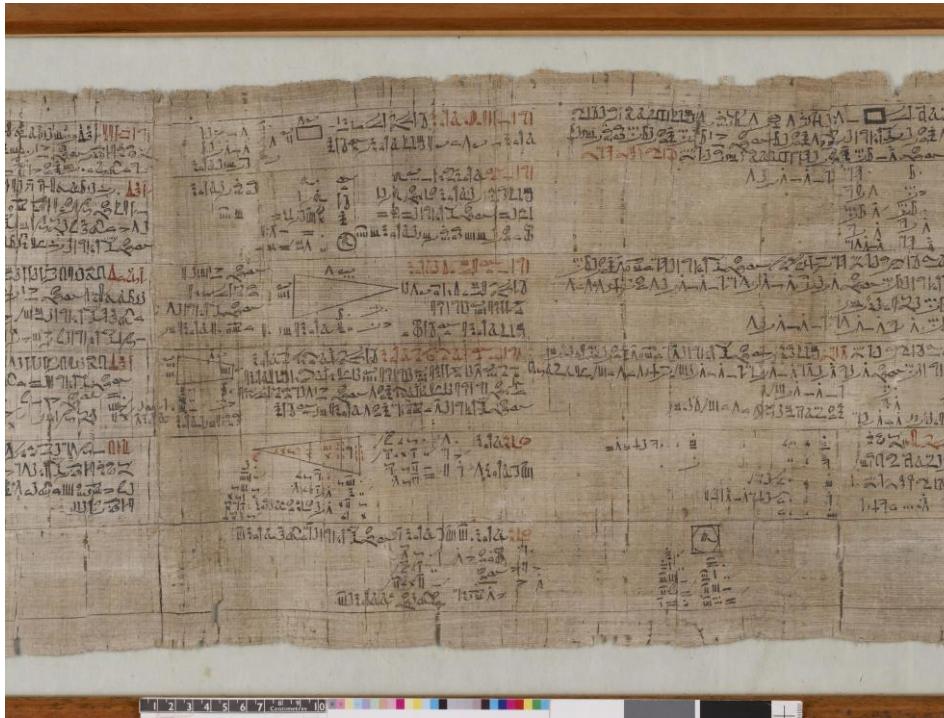
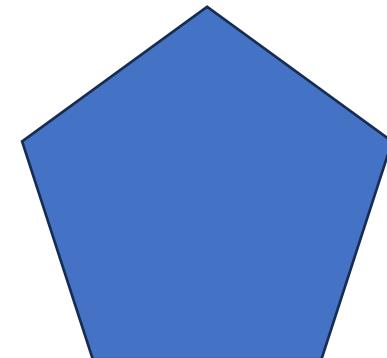
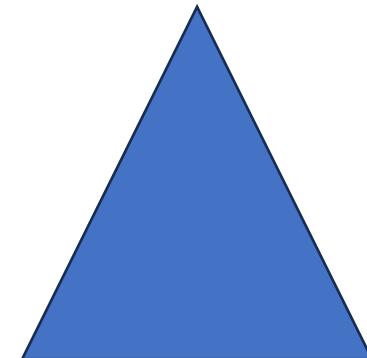
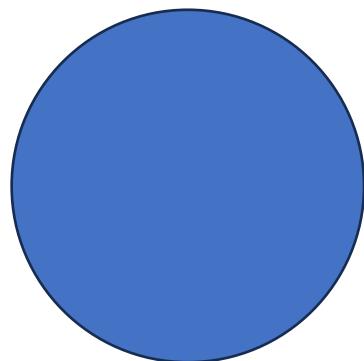
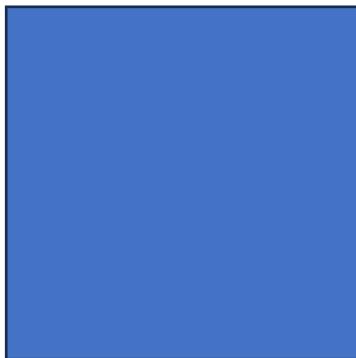


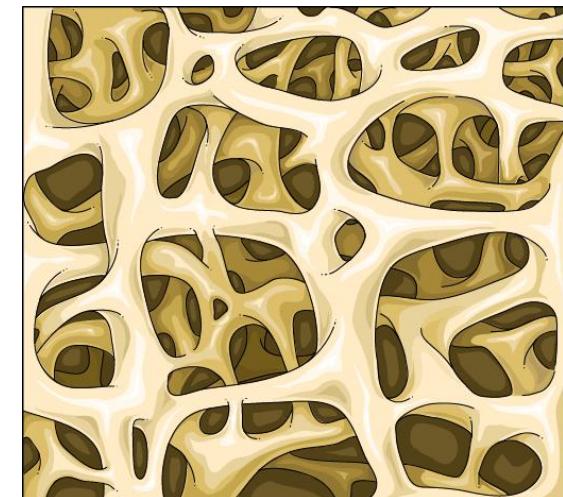
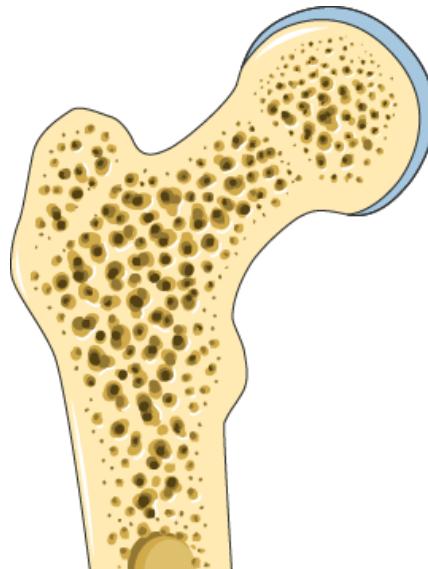
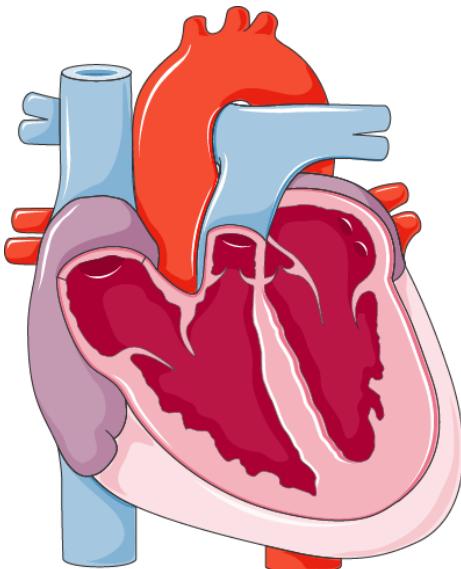
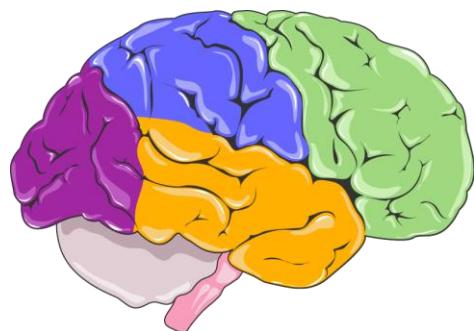
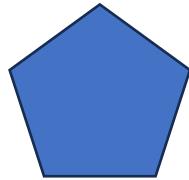
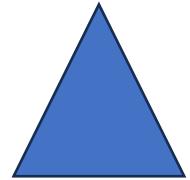
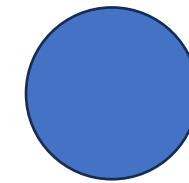
Figure 1: Steps for the construction of a square.

- Study of shapes, geometry, and form have been relevant for millennia!
- How we represent and describe shapes is always changing, depending on our purpose

Shape Descriptions



Anatomical Shapes



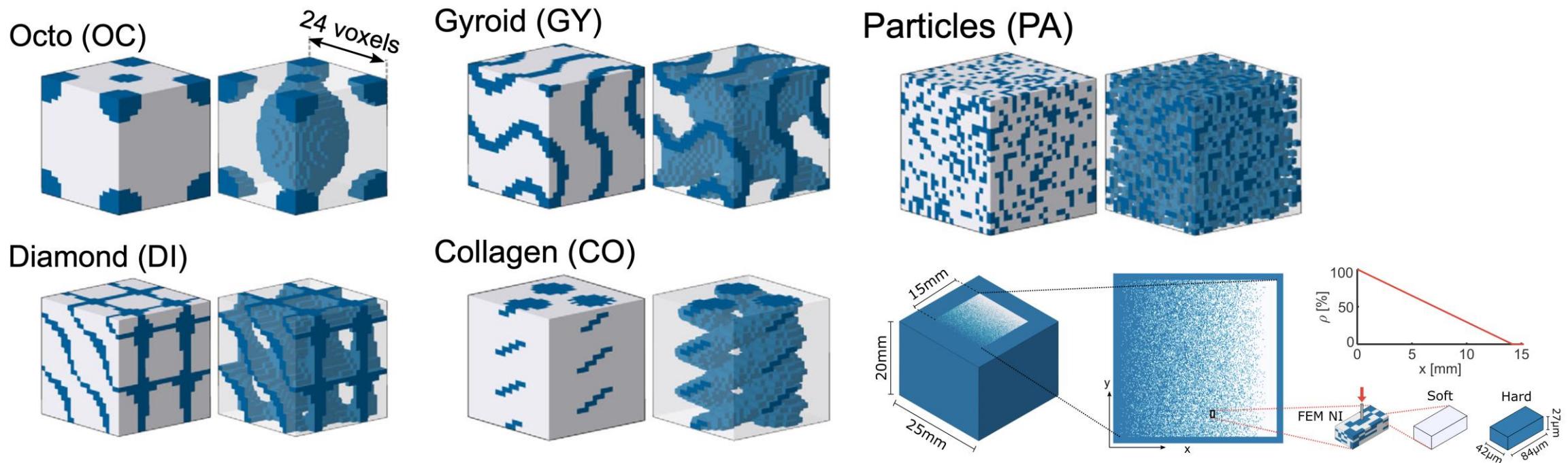
How can we represent complex structures?

Shape Representation Mediums

- Voxel-based
- Surface-based
 - Point cloud
 - Surface meshes
- Implicit surfaces
- Deformation-based

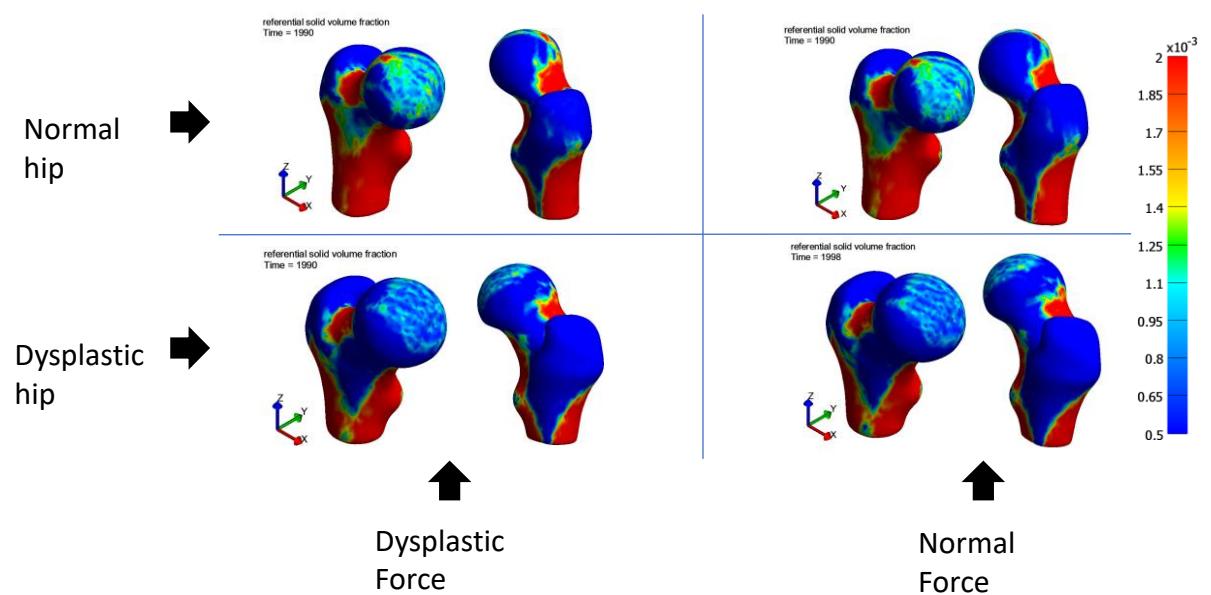
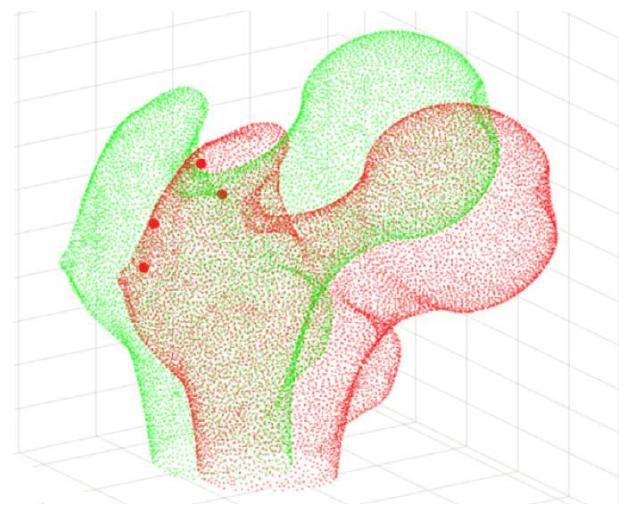
Shape Representation Mediums

- Voxel-based



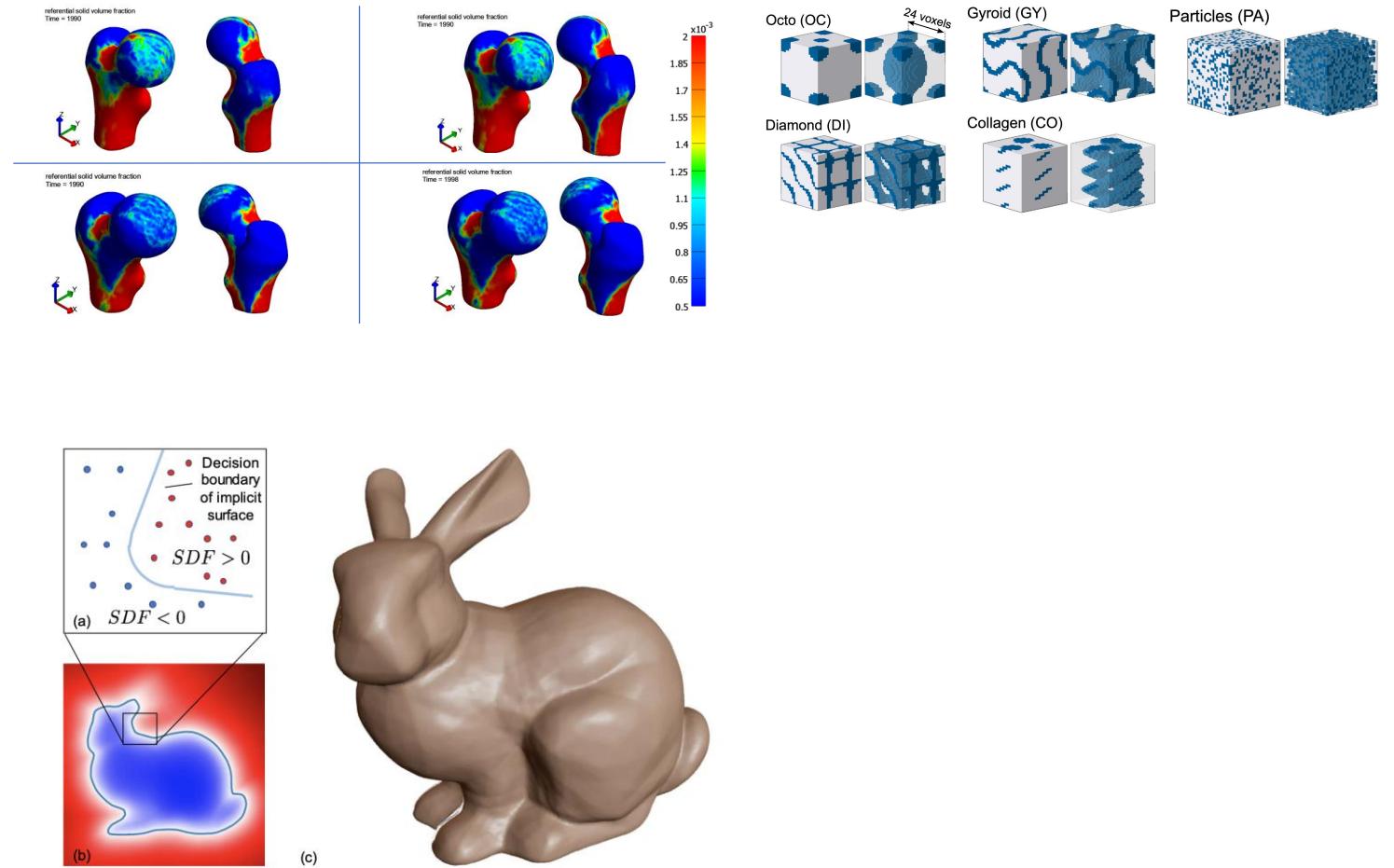
Shape Representation Mediums

- Voxel-based
- **Surface-based**
 - Point cloud
 - Surface meshes



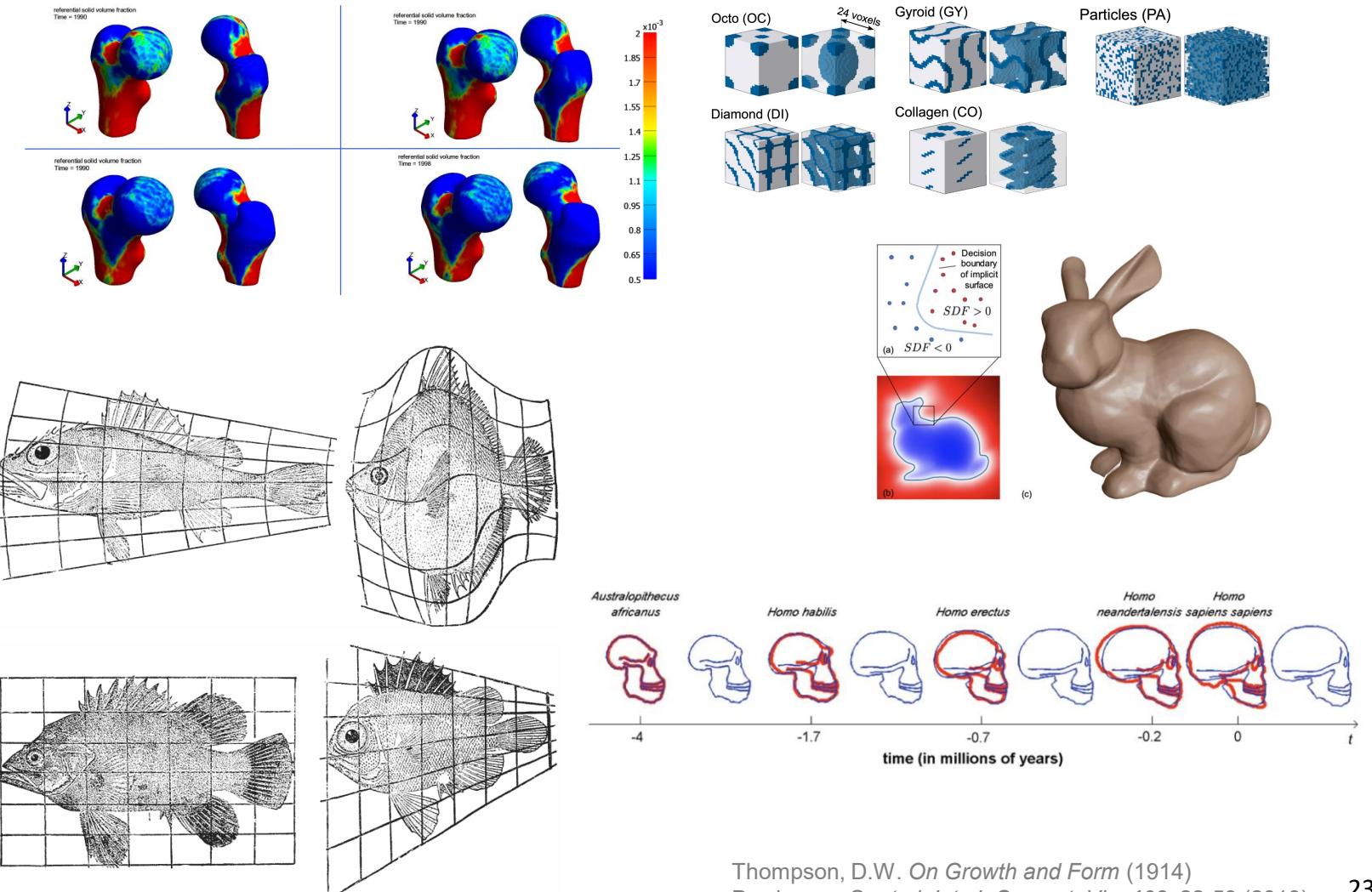
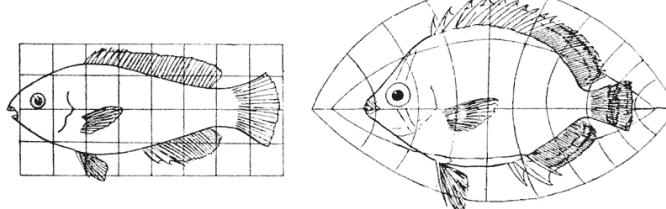
Shape Representation Mediums

- Voxel-based
- Surface-based
 - Point cloud
 - Surface meshes
- **Implicit surfaces**



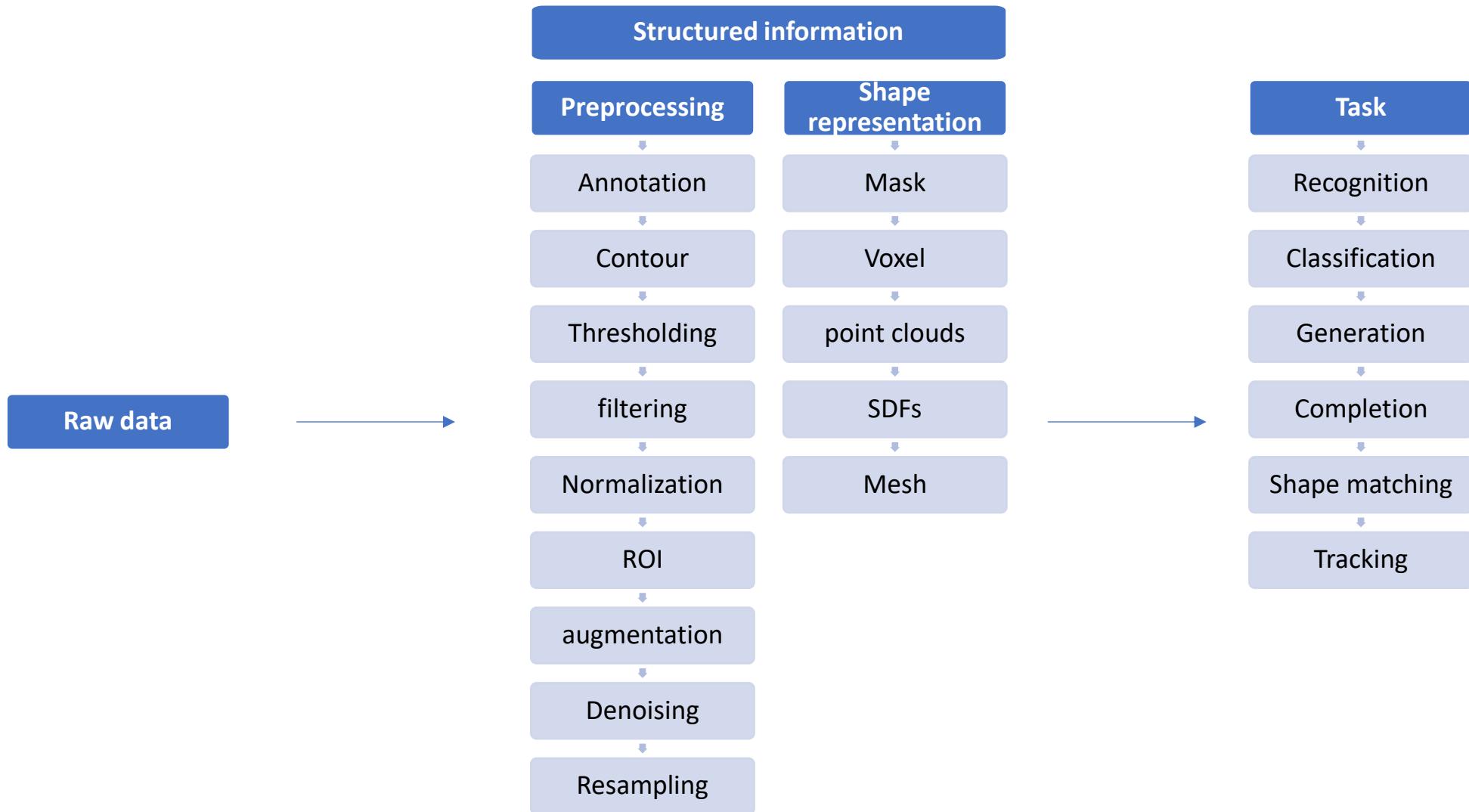
Shape Representation Mediums

- Voxel-based
- Surface-based
 - Point cloud
 - Surface meshes
- Implicit surfaces
- Deformation-based



Why Does This Matter?





Example Pipeline

- How do we analyse the shape of hand phalanges bones?



Example Pipeline

- How do we analyse the shape of hand phalanges bones?

Raw data



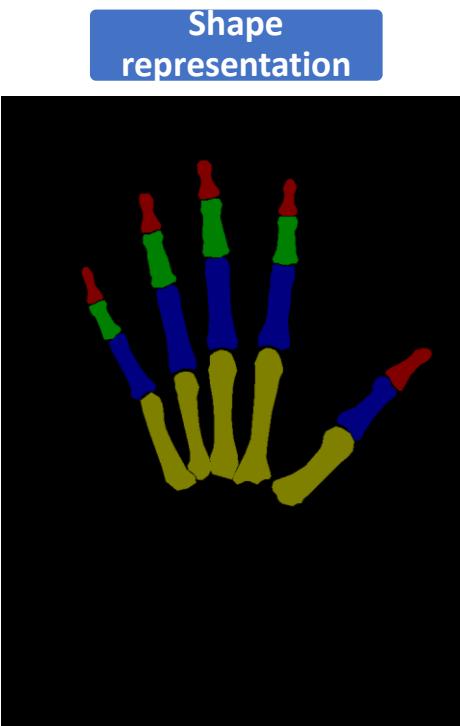
Preprocessing

Example Pipeline

- How do we analyse the shape of hand phalanges bones?



Preprocessing

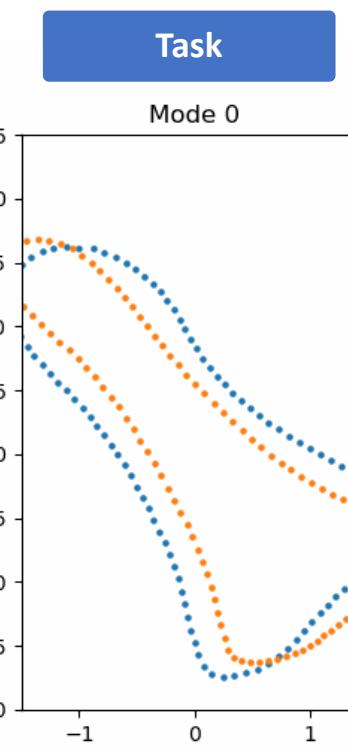
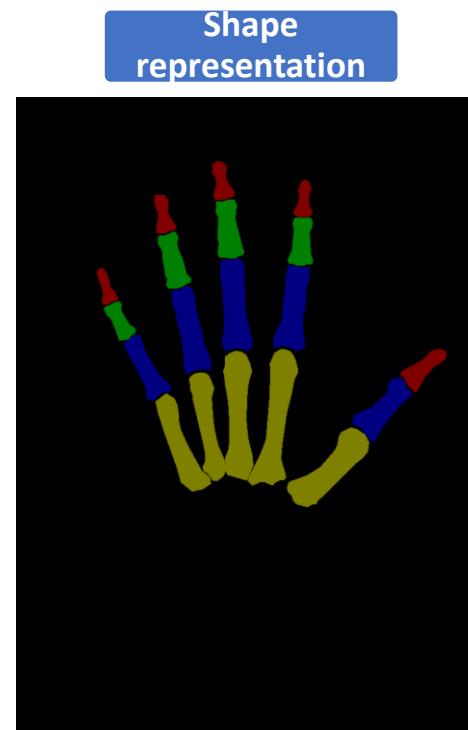


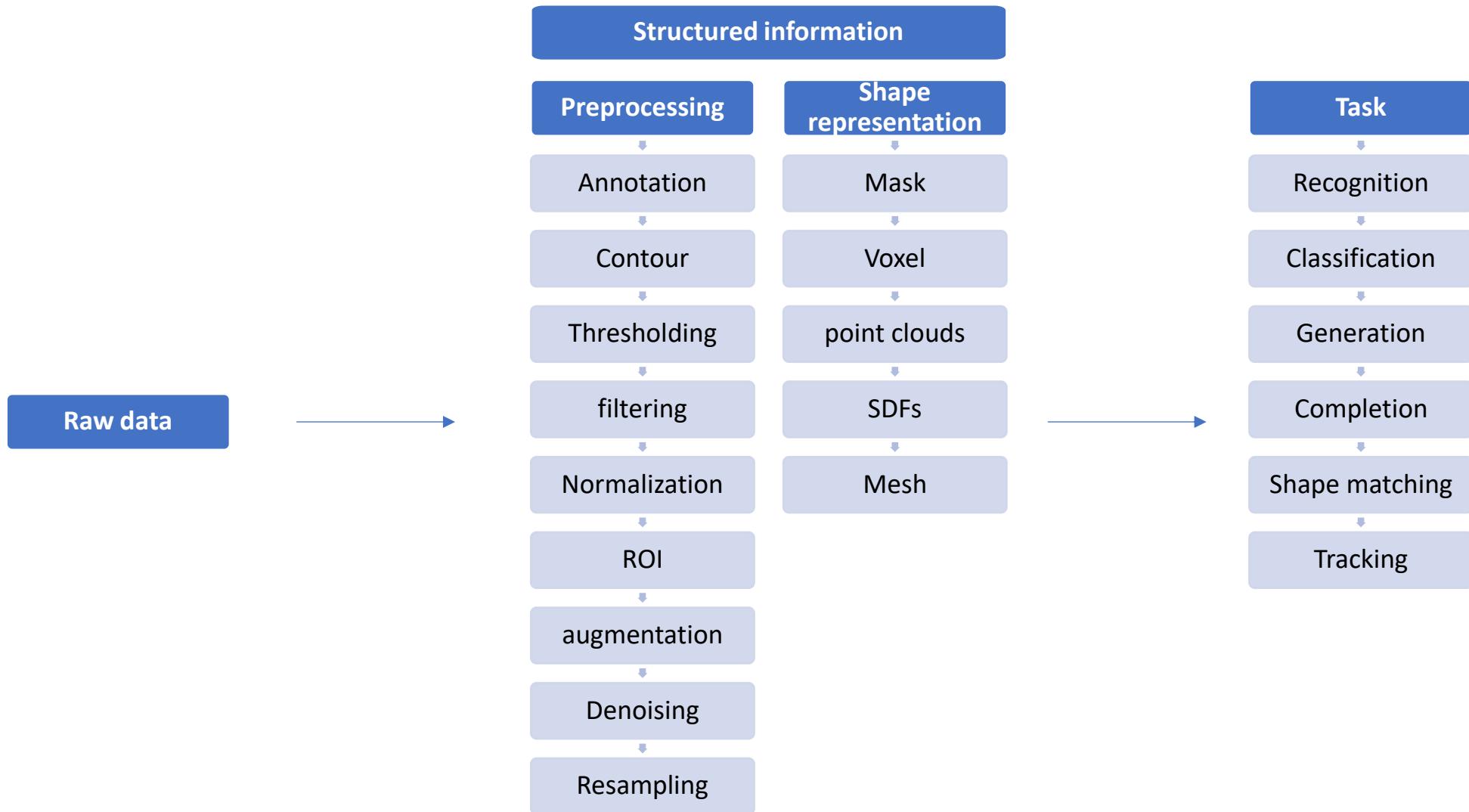
Example Pipeline

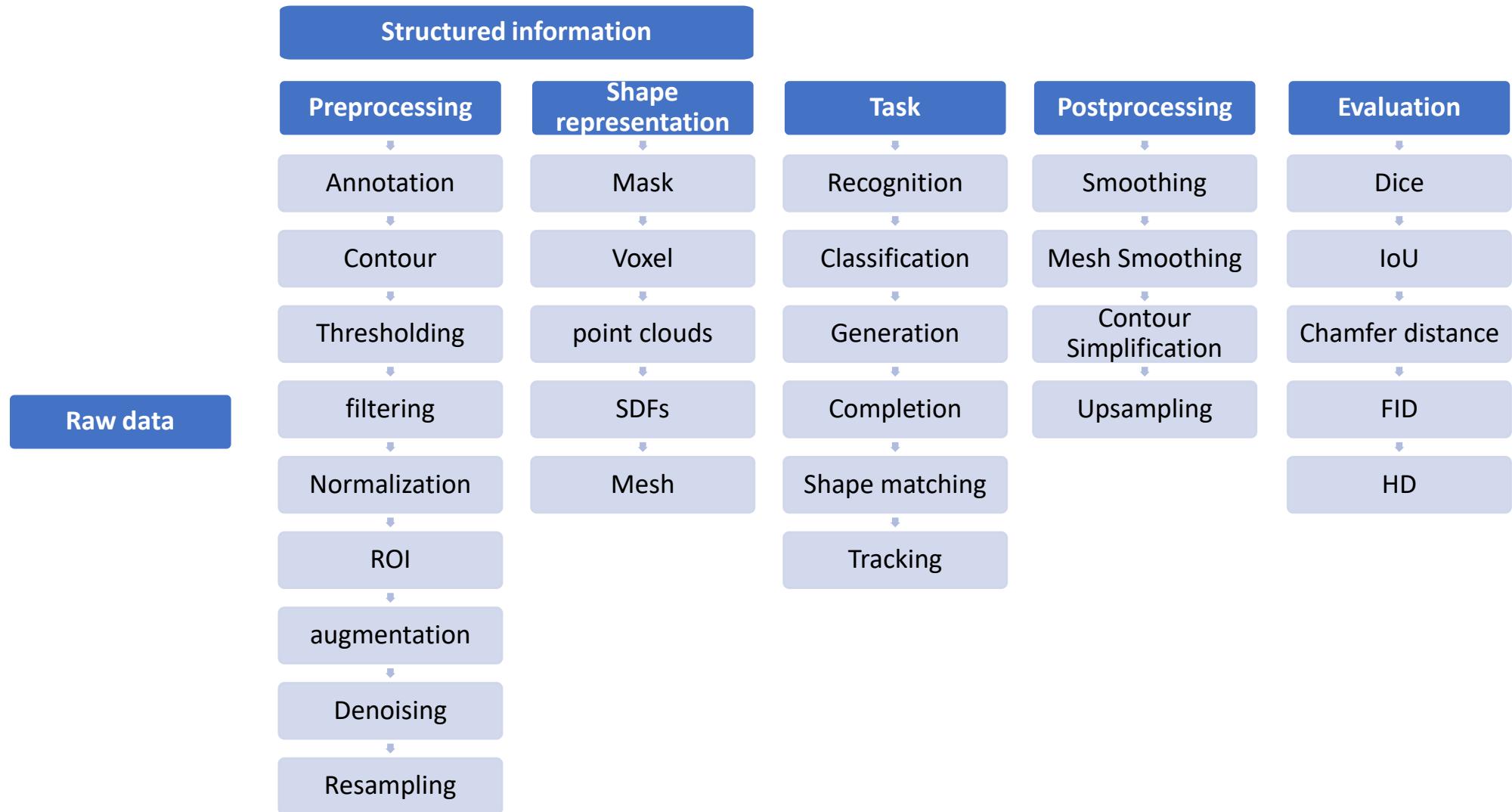
- How do we analyse the shape of hand phalanges bones?



Preprocessing







Rule-Based vs. Learning-Based

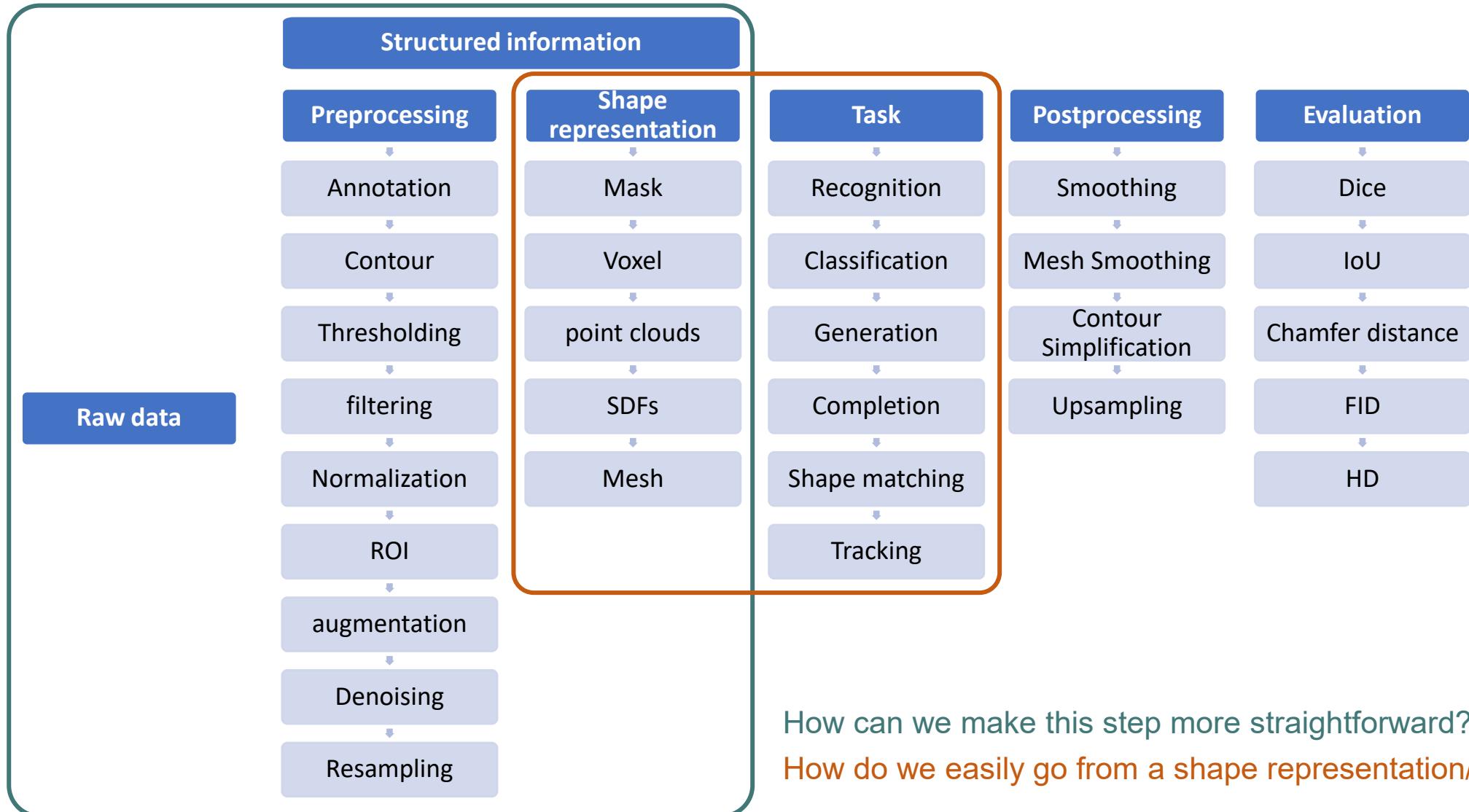
- Rule-based relies on heuristic and/or deductive steps in an extensive pipeline



Rule-Based vs. Learning-Based

- Rule-based relies on heuristic and/or deductive steps in an extensive pipeline
- Learning-based relies on identifying patterns from data





How can we make this step more straightforward?

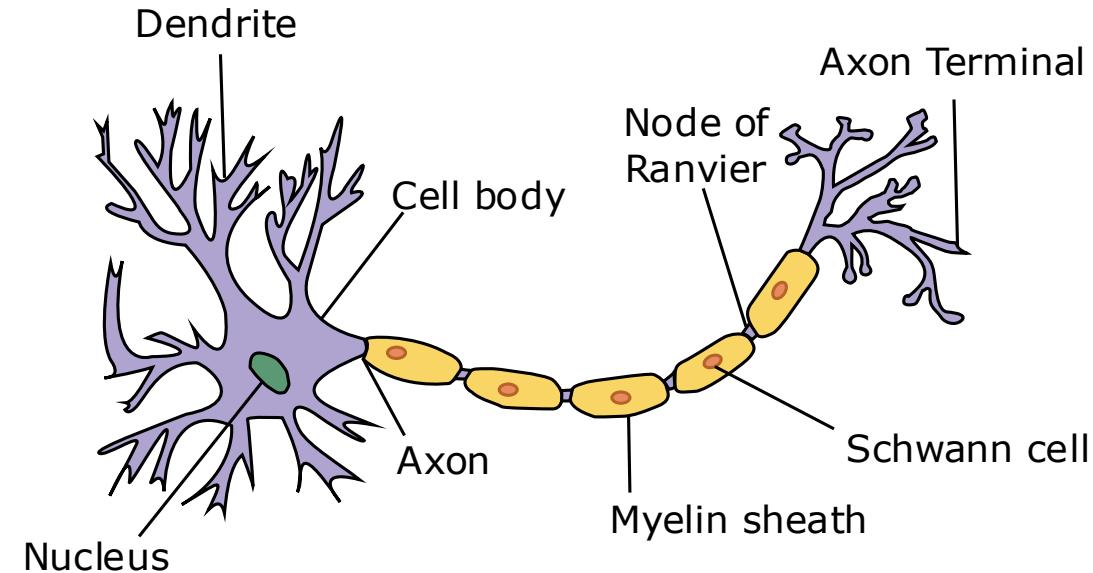
How do we easily go from a shape representation/data to task?

Intermezzo

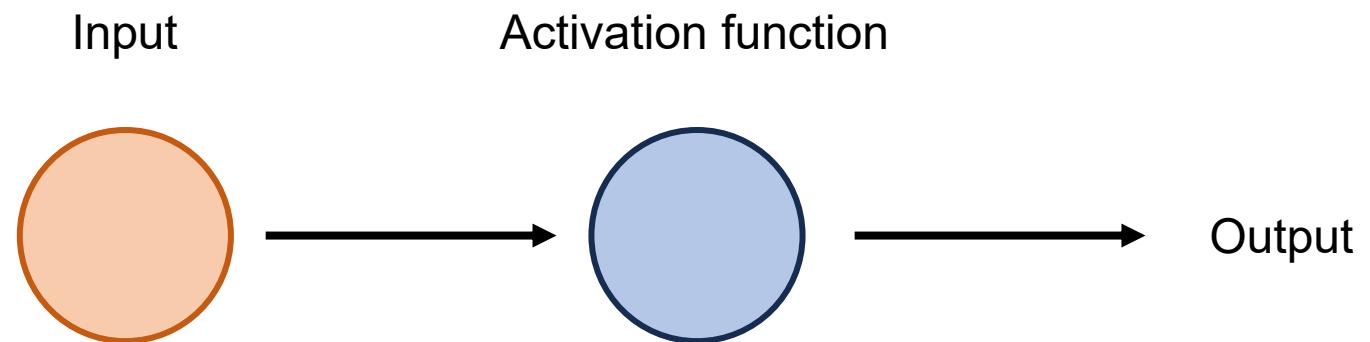
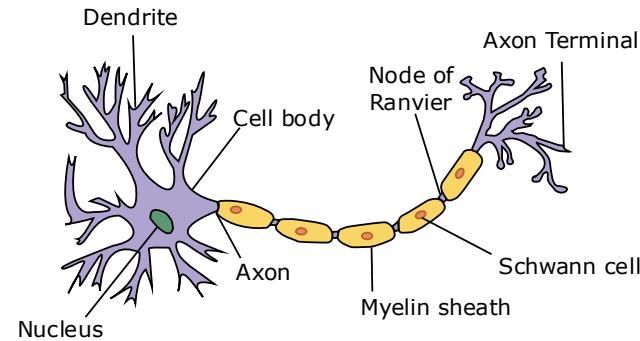
Crash Course in Deep Learning

Deep Learning 101

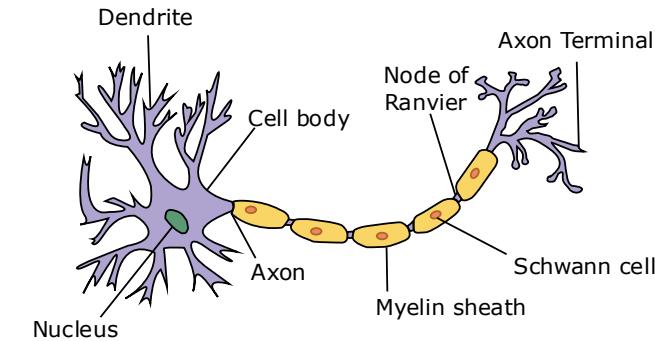
- Neurons



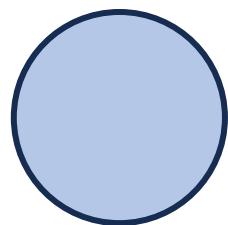
Deep Learning 101



Deep Learning 101



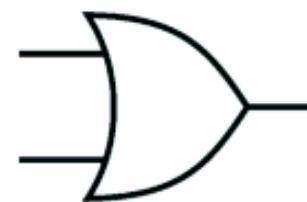
Activation function



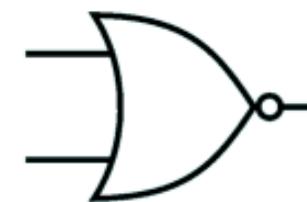
AND



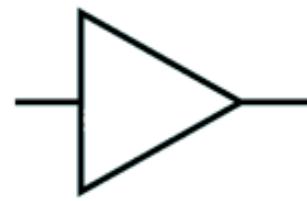
NAND



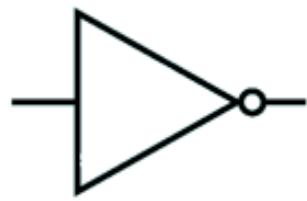
OR



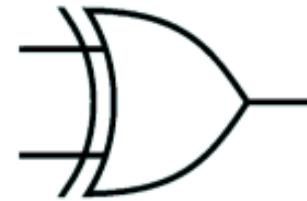
NOR



BUFFER



NOT



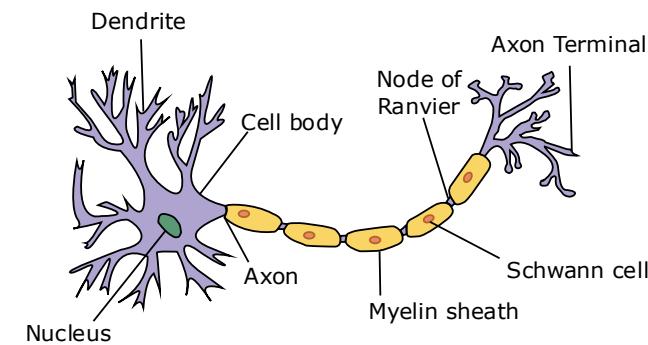
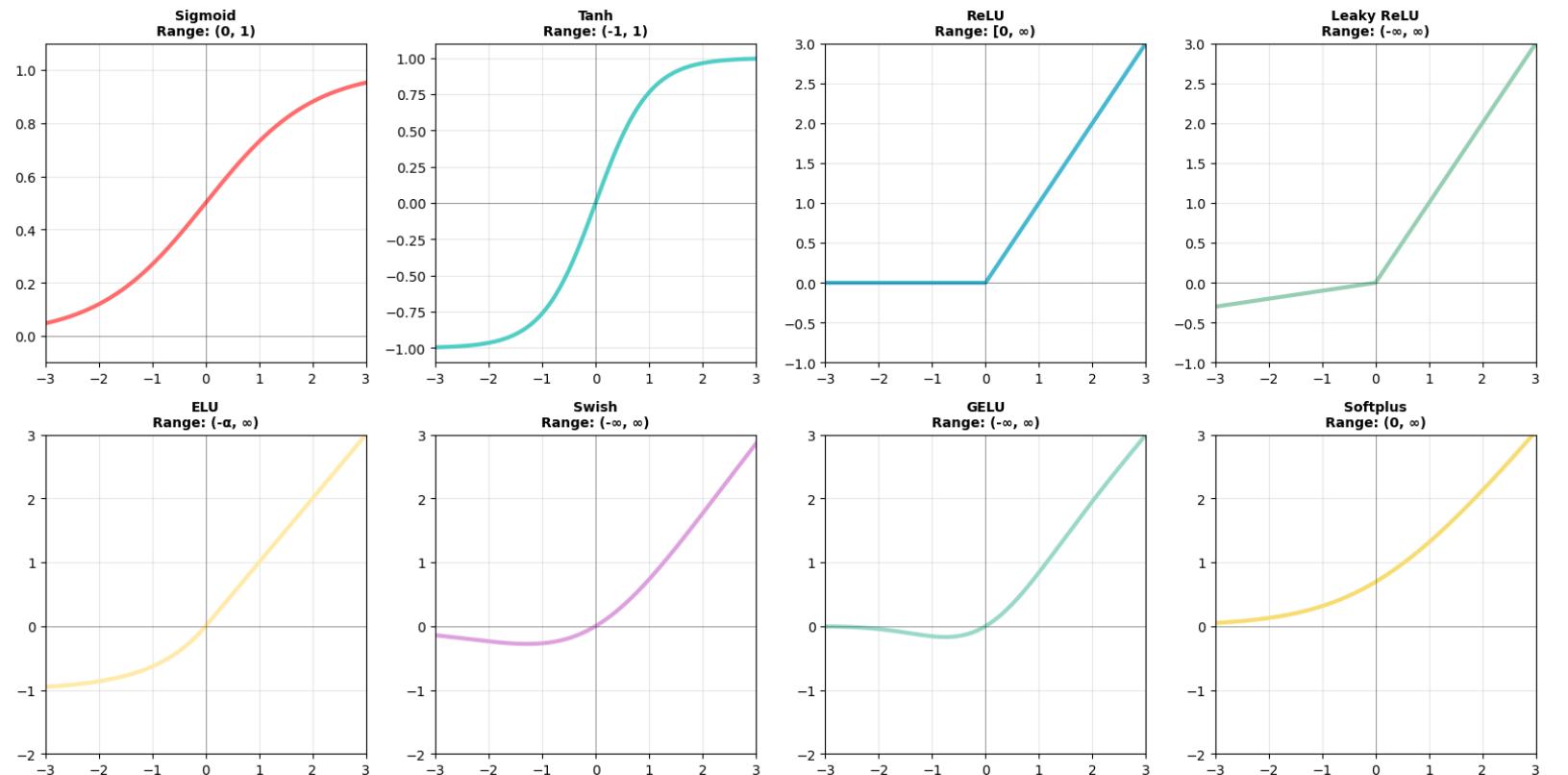
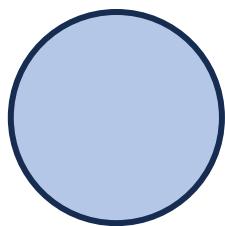
XOR



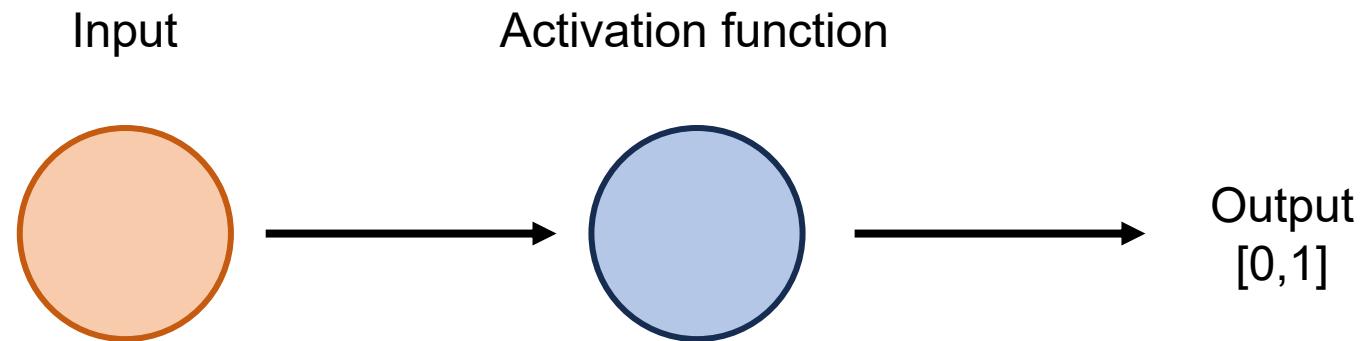
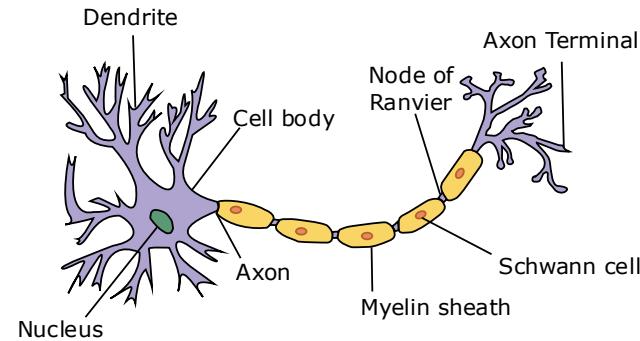
XNOR

Deep Learning 101

Activation function

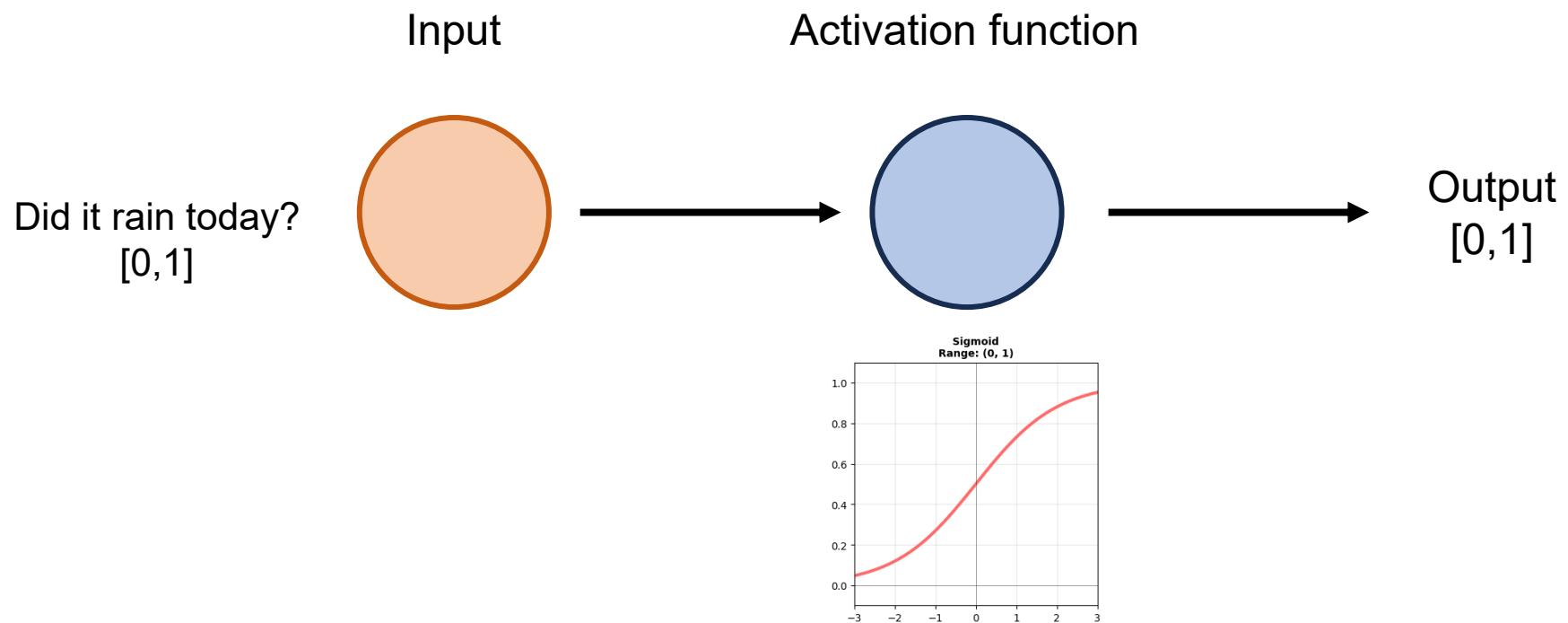
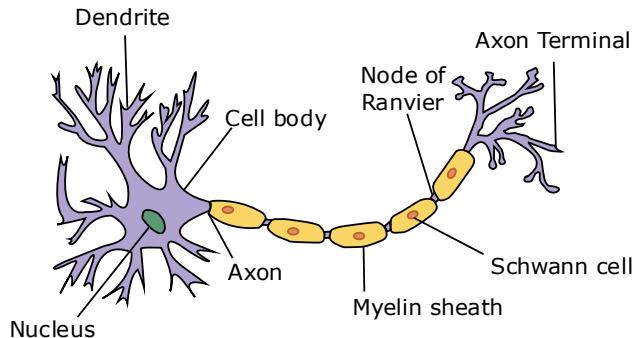


Deep Learning 101



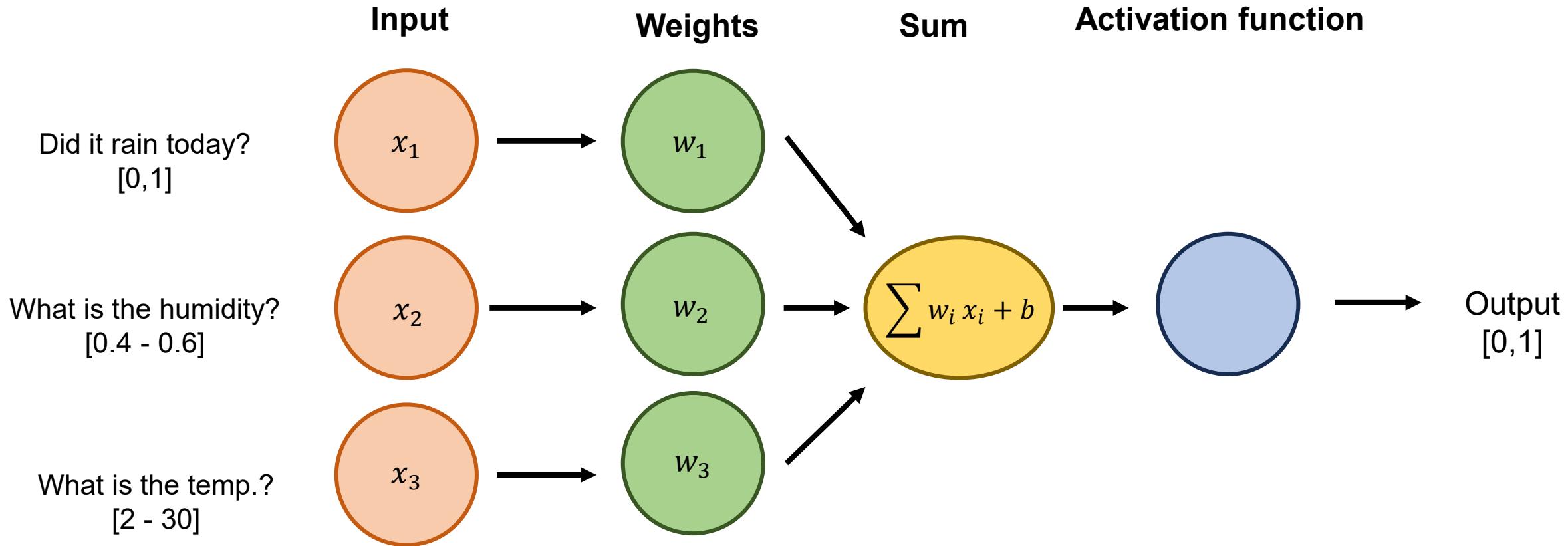
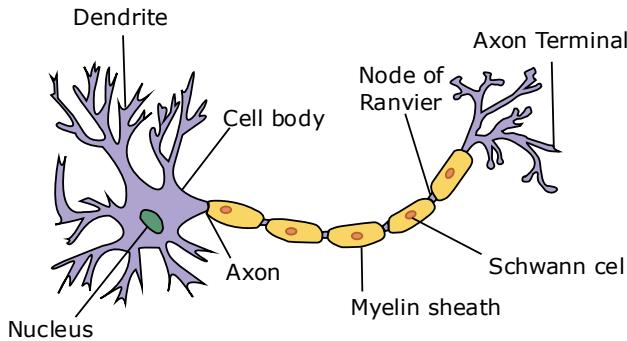
Will it rain tomorrow?

Deep Learning 101

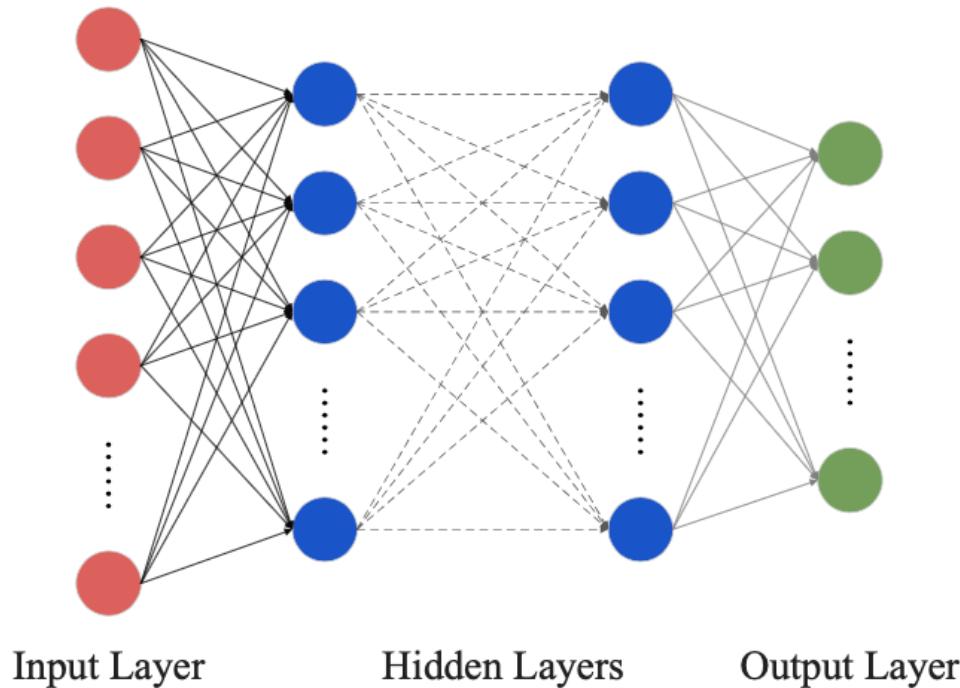


Will it rain tomorrow?

Deep Learning 101



Deep Learning 101



Will it rain tomorrow?

Deep Learning 101

- What does model ‘training’ mean?
 - Update weights and biases to minimize a **loss function**

$$L(y, \hat{y}) = \frac{1}{N} \sum_{i=1}^N (y_i - \hat{y}_i)^2$$

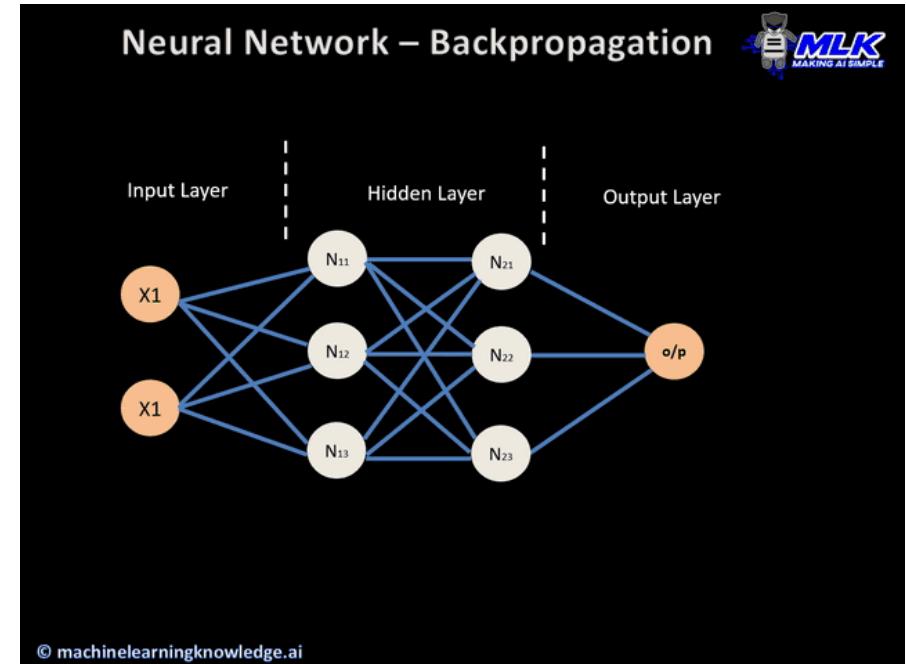
Mean Square Error

$$L(y, \hat{y}) = - \sum_{i=1}^N y_i \log(\hat{y}_i)$$

Cross-entropy

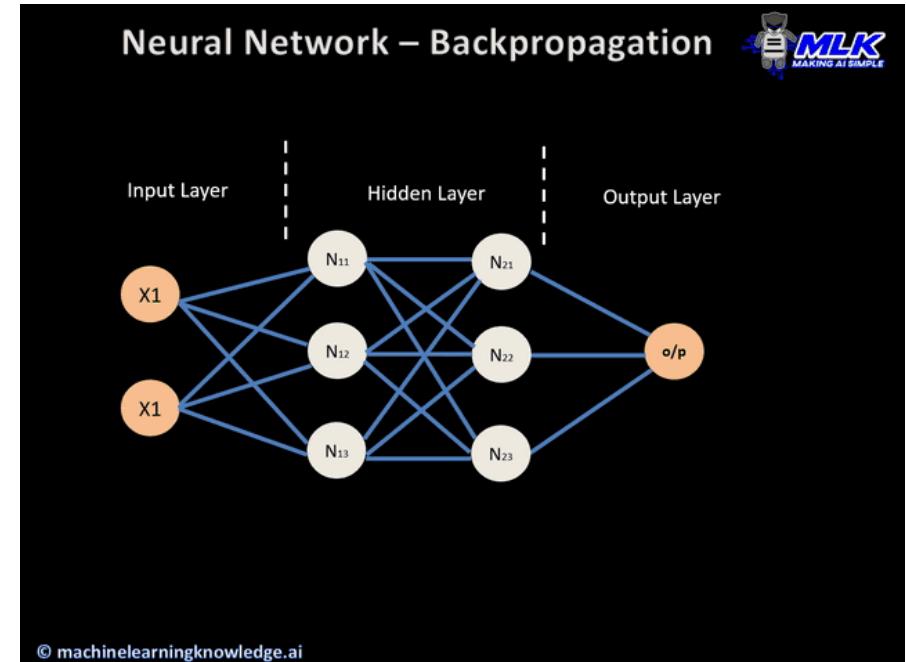
$$L(y, \hat{y}) = -\alpha(1 - \hat{y})^\gamma \log(\hat{y})$$

Focal loss



Deep Learning 101

- What does model ‘training’ mean?
 - Update weights and biases to minimize a **loss function**
- How are these parameters updated?
 - Using optimizers!
 - Algorithms which update parameters based computed loss gradients



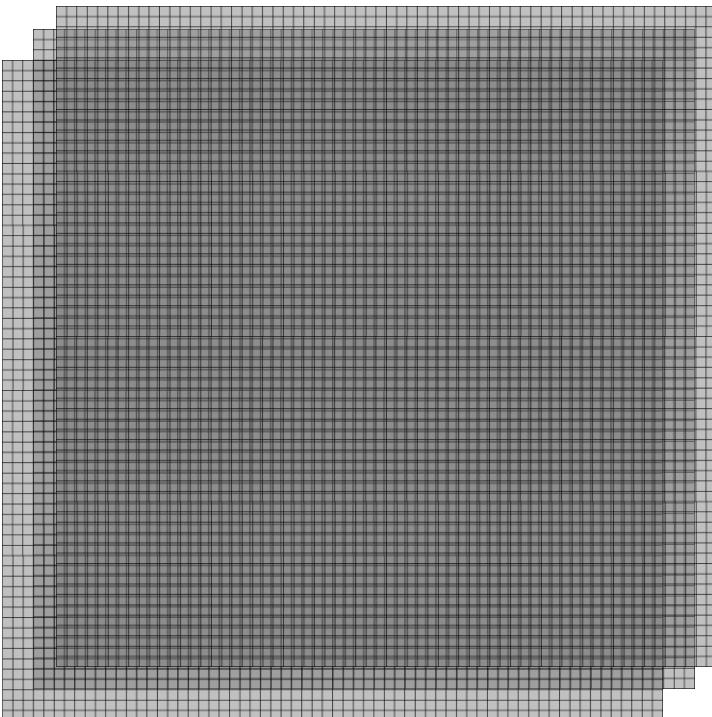
Deep Learning 101

- What about images?

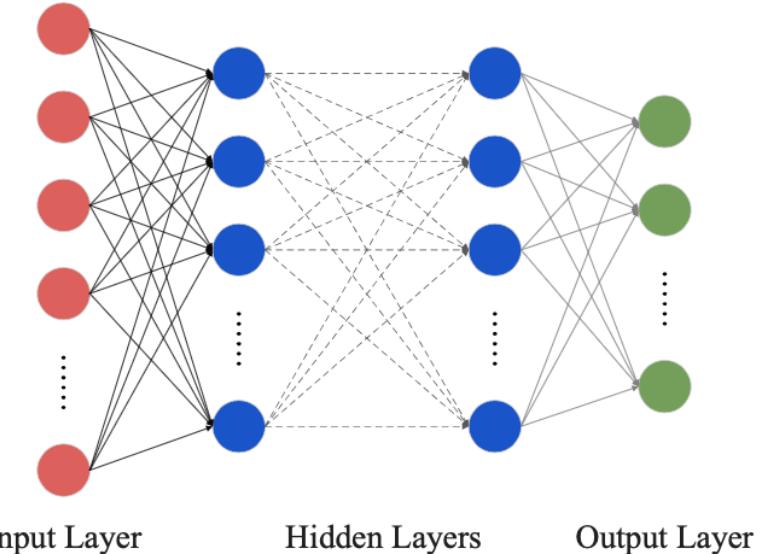


Deep Learning 101

- What about images?

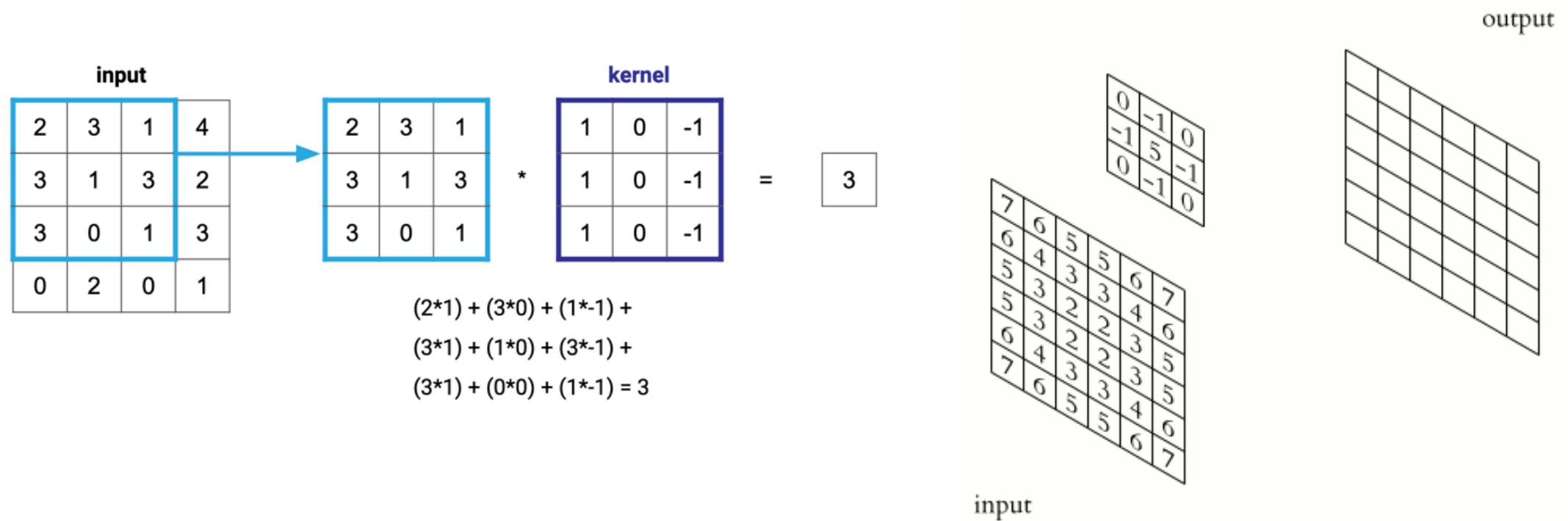


$64 \times 64 \times 3$
With 100 hidden units
 $= 1,228,800$ parameters to learn!



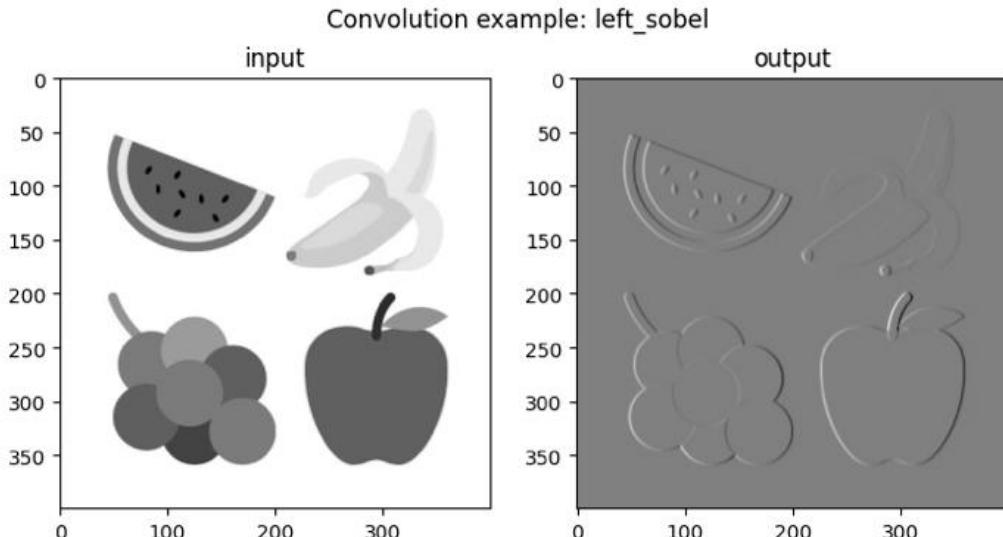
Deep Learning 101

- Convolutions (sliding window)



Deep Learning 101

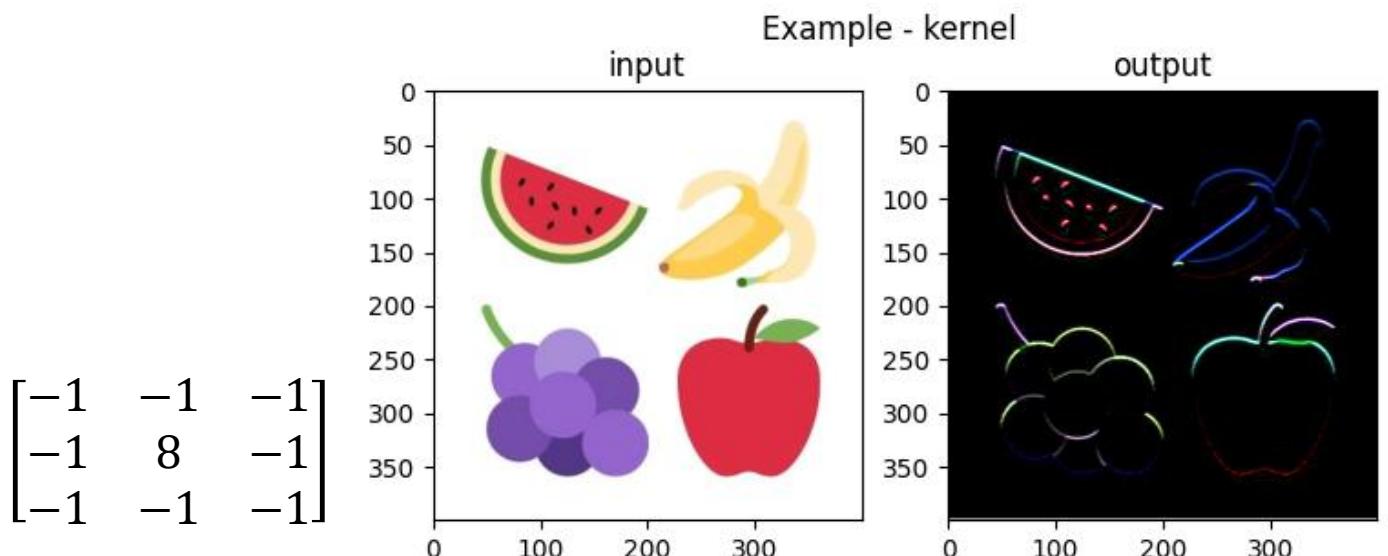
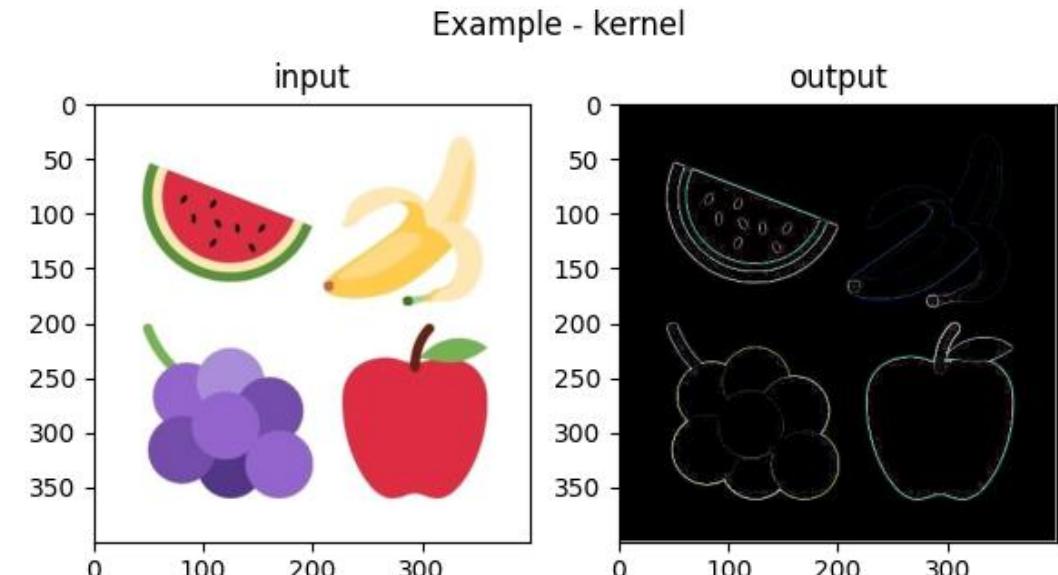
- Convolutions (sliding window)



$$\begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

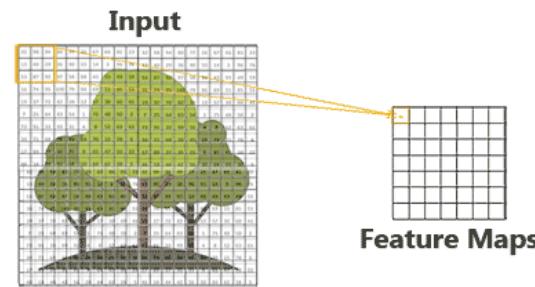
$$\begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$



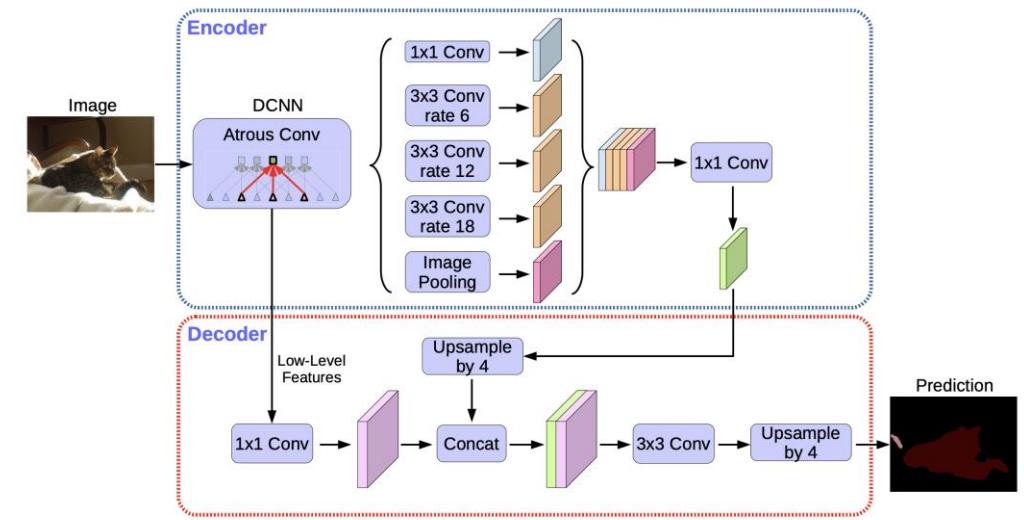
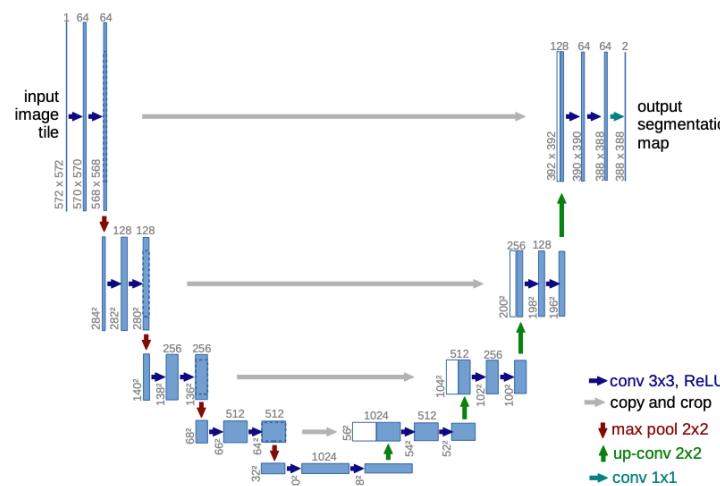
Deep Learning 101

- Neurons vs. convolutional layers
 - Now we are learning convolutional filters (kernel parameters) rather than node weights



Deep Learning 101

- Architectures
 - Specific arrangement of layers, connections, optimizer, and loss function(s) for a specific task.



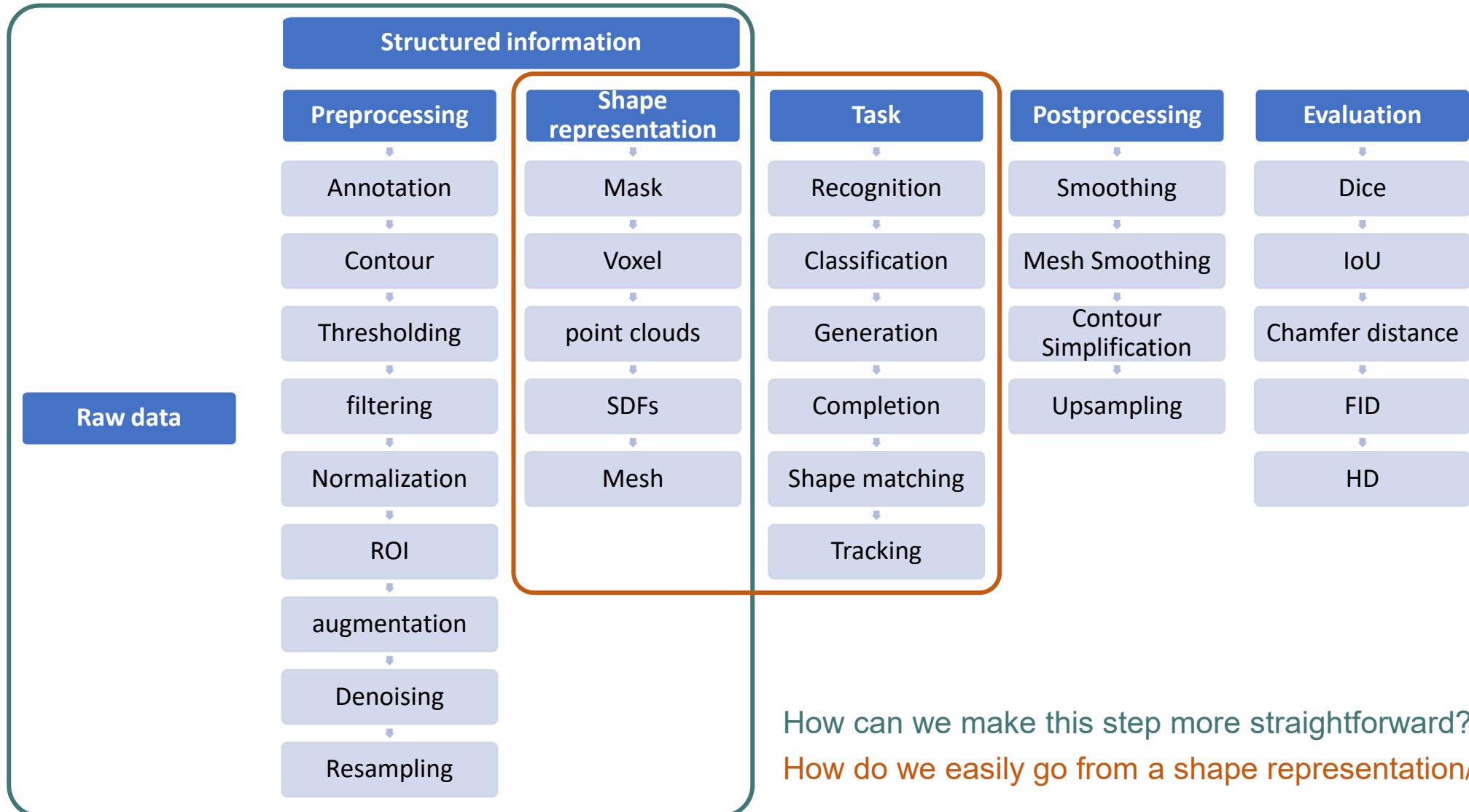
Deep Learning 101

- Practical considerations
 - Hardware: What GPU to get?
 - Tensorflow vs PyTorch?



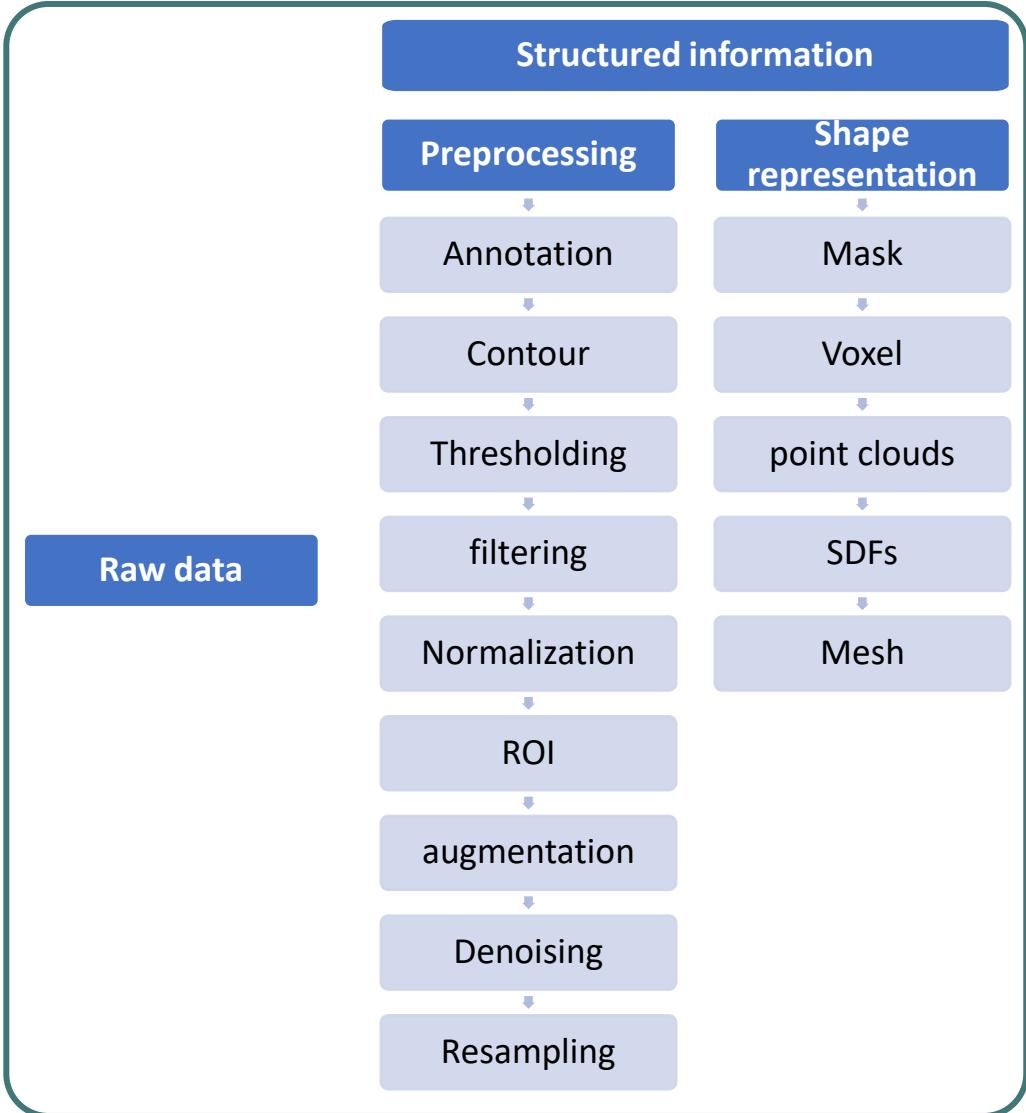
Deep Learning for Geometry

How can deep neural networks learn representations from geometry?
What does that enable?



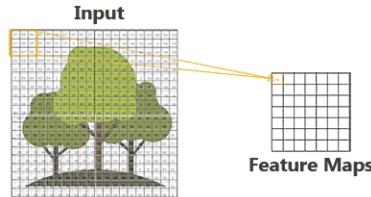
How can we make this step more straightforward?

How do we easily go from a shape representation/data to task?



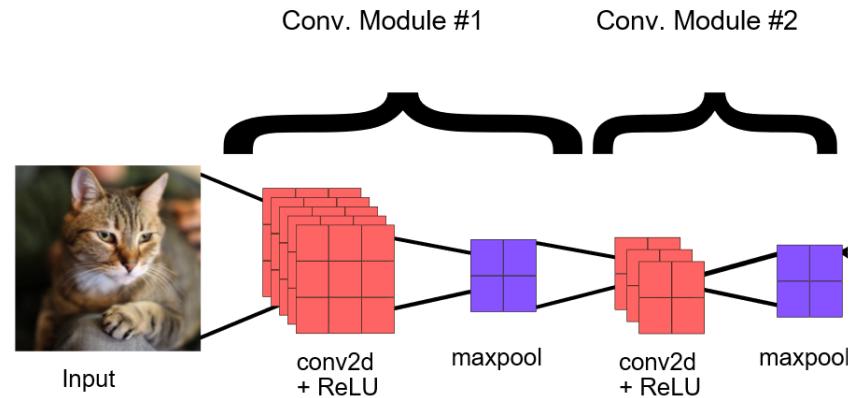
Feature extraction

- Use trained networks to extract representations from data



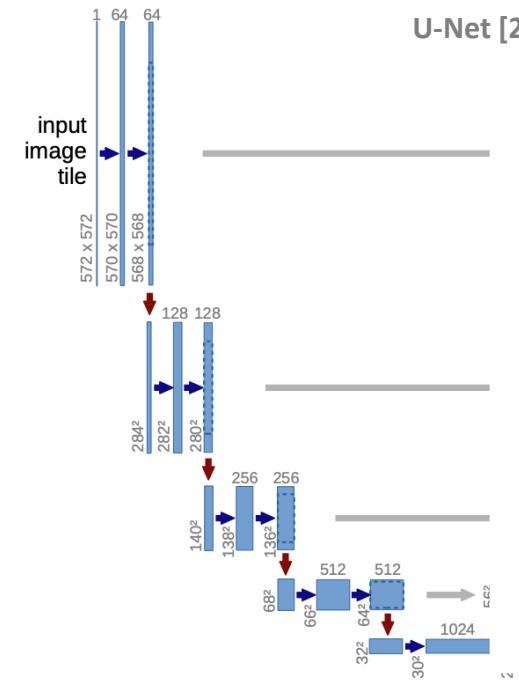
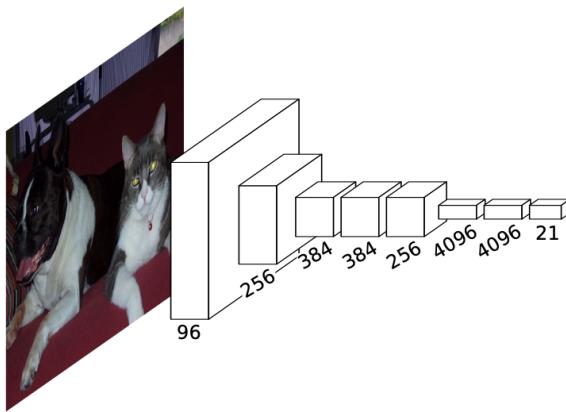
Feature Extraction

- Images
 - Use convolutions to extract representations from data
 - Use extracted features for some purpose after, e.g., classification



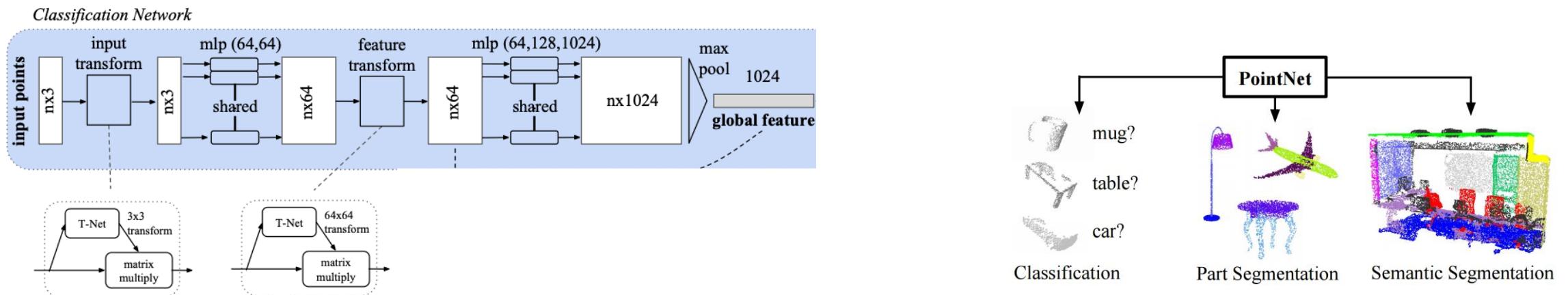
Feature Extraction

- Images
 - Use convolutions to extract representations from data
 - Use extracted features for some purpose after, e.g., segmentation



Feature Extraction

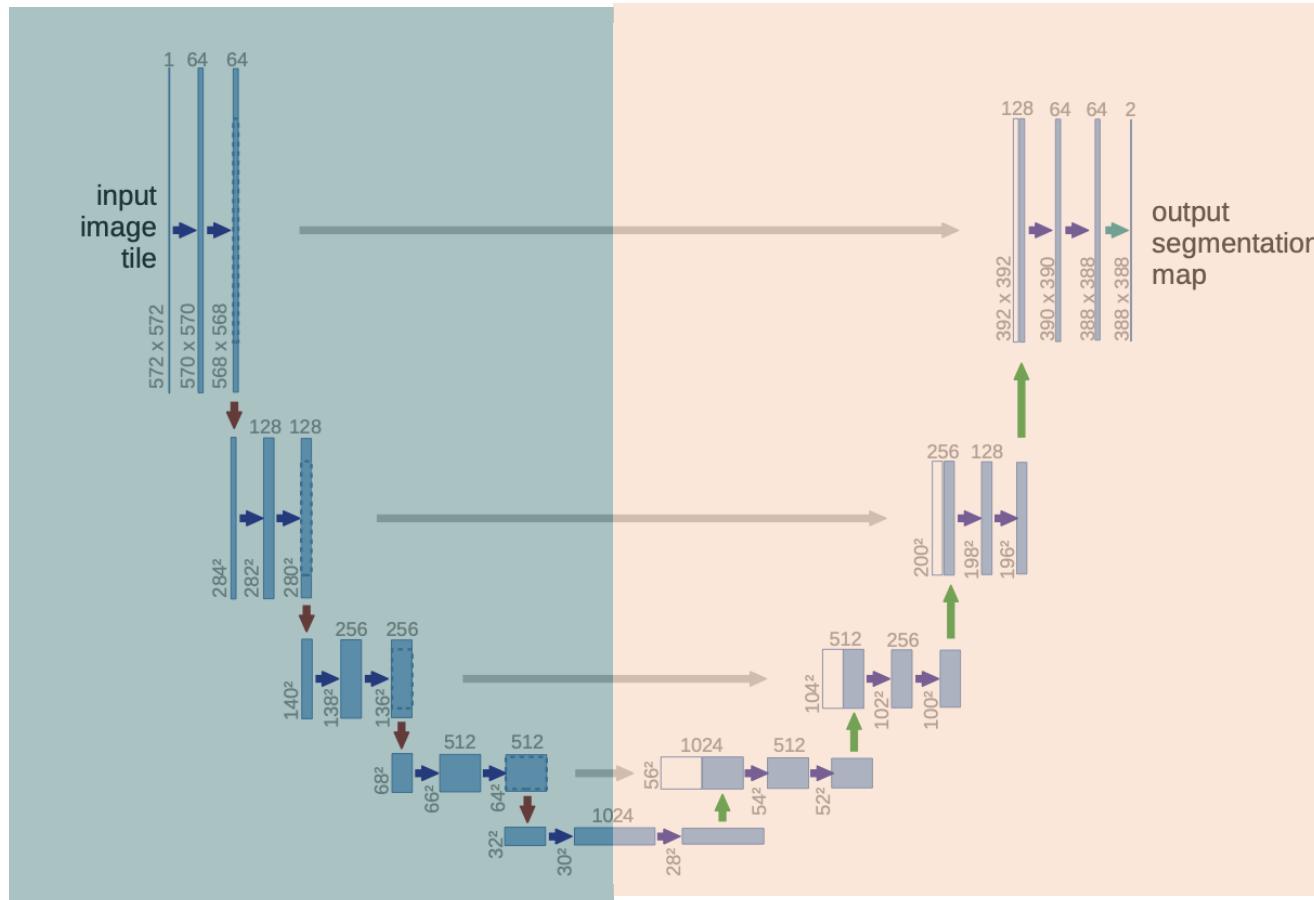
- Point clouds
 - PointNet, uses MLPs and operates directly on point clouds to extract useful features



Feature Extraction

- Encoder-decoder structure

Encoder
a.k.a. feature extractor



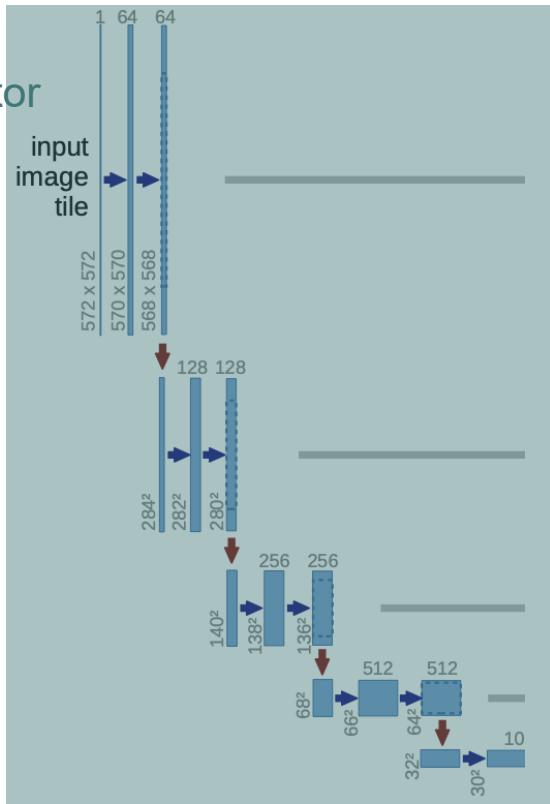
Decoder
Use features for a task

Feature Extraction

- Encoder-decoder structure

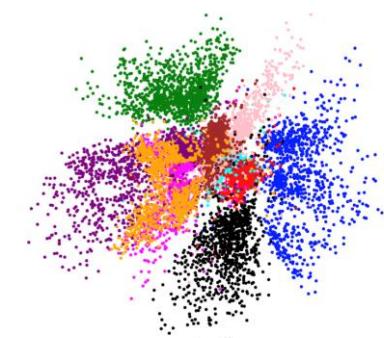
Encoder

a.k.a. feature extractor



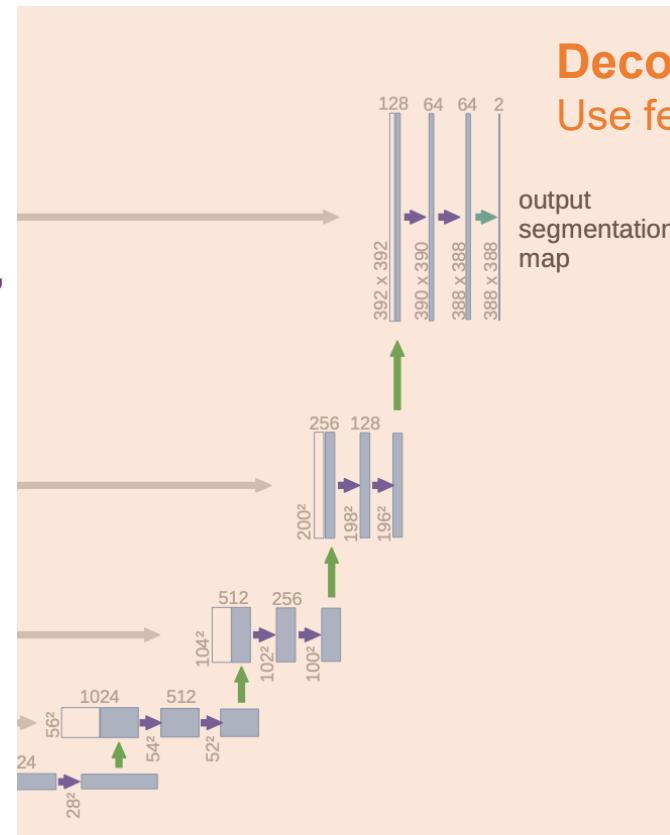
Latent space

a.k.a. latent embeddings,
latent variables, latent
parameters, latent
features



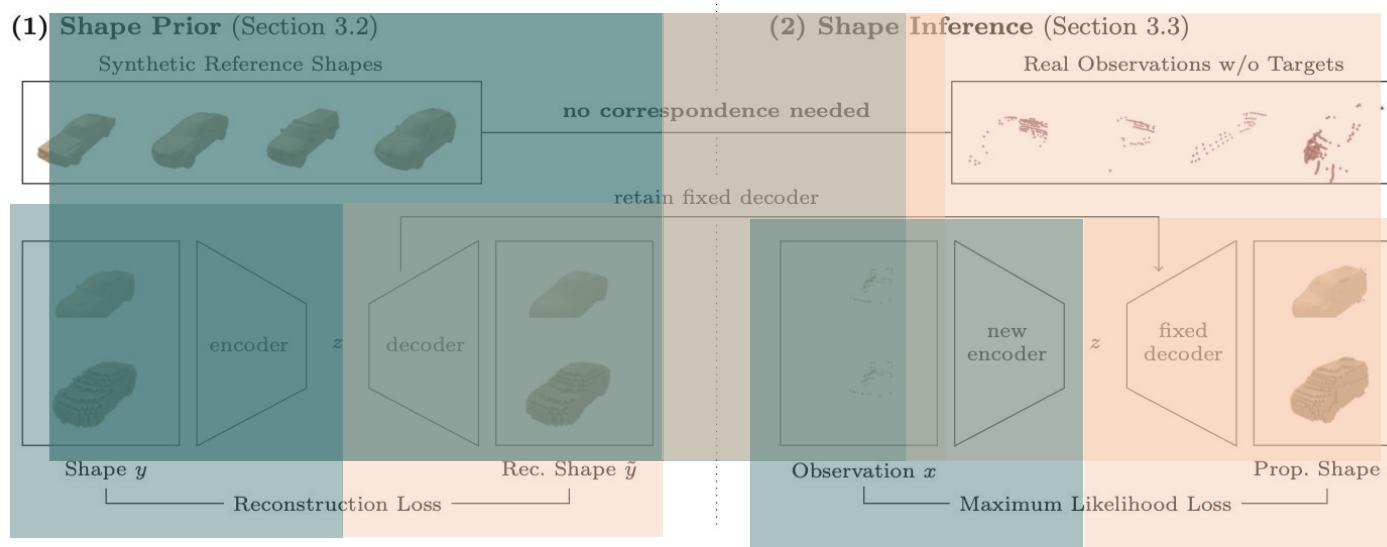
Decoder

Use features for a task



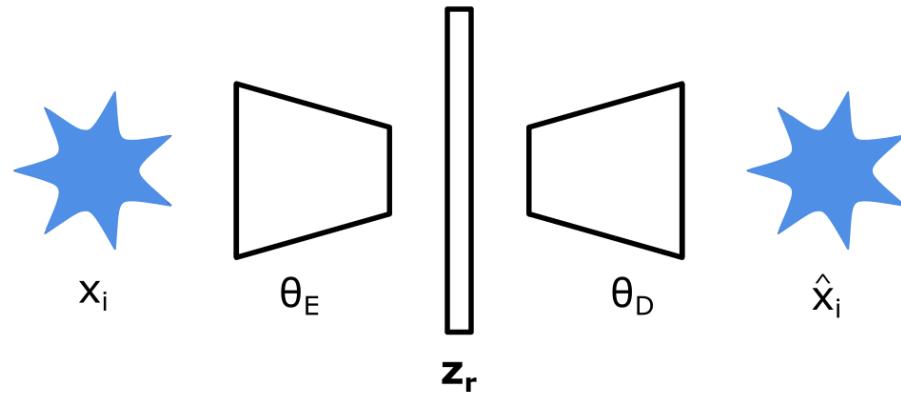
Feature Extraction

- Use extracted ‘features’ for many applications
 - Classification
 - Segmentation
 - Shape completion



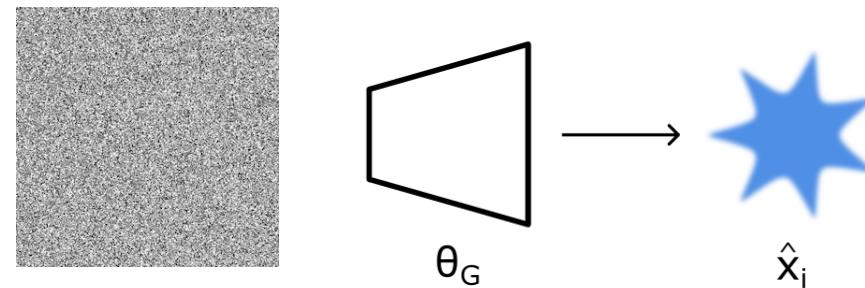
Feature Extraction

- Use extracted ‘features’ for many applications
 - Classification
 - Segmentation
 - Shape completion
 - Generative frameworks

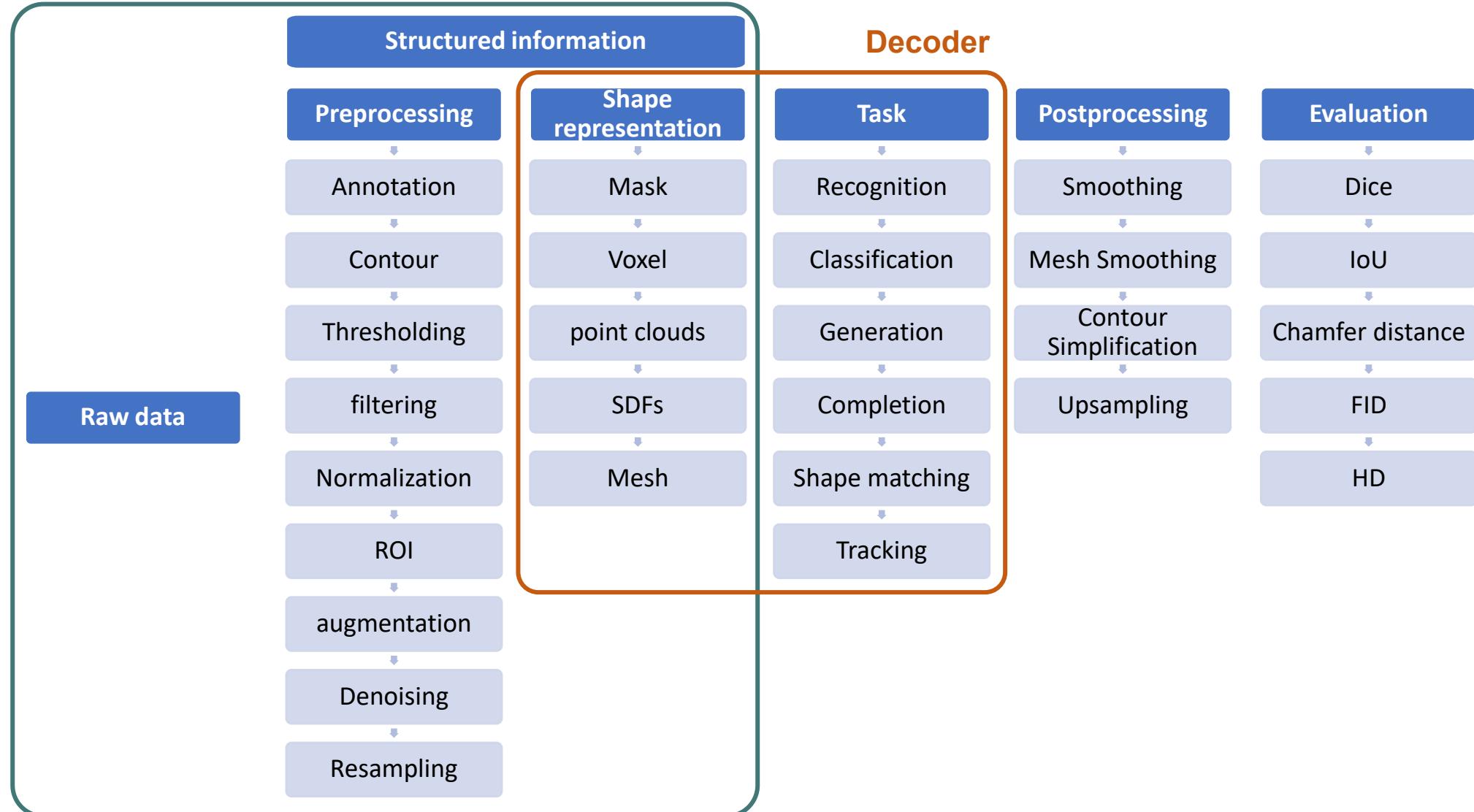


Feature Extraction

- Use extracted ‘features’ for many applications
 - Classification
 - Segmentation
 - Shape completion
 - Generative frameworks
 - And many many more...



Encoder

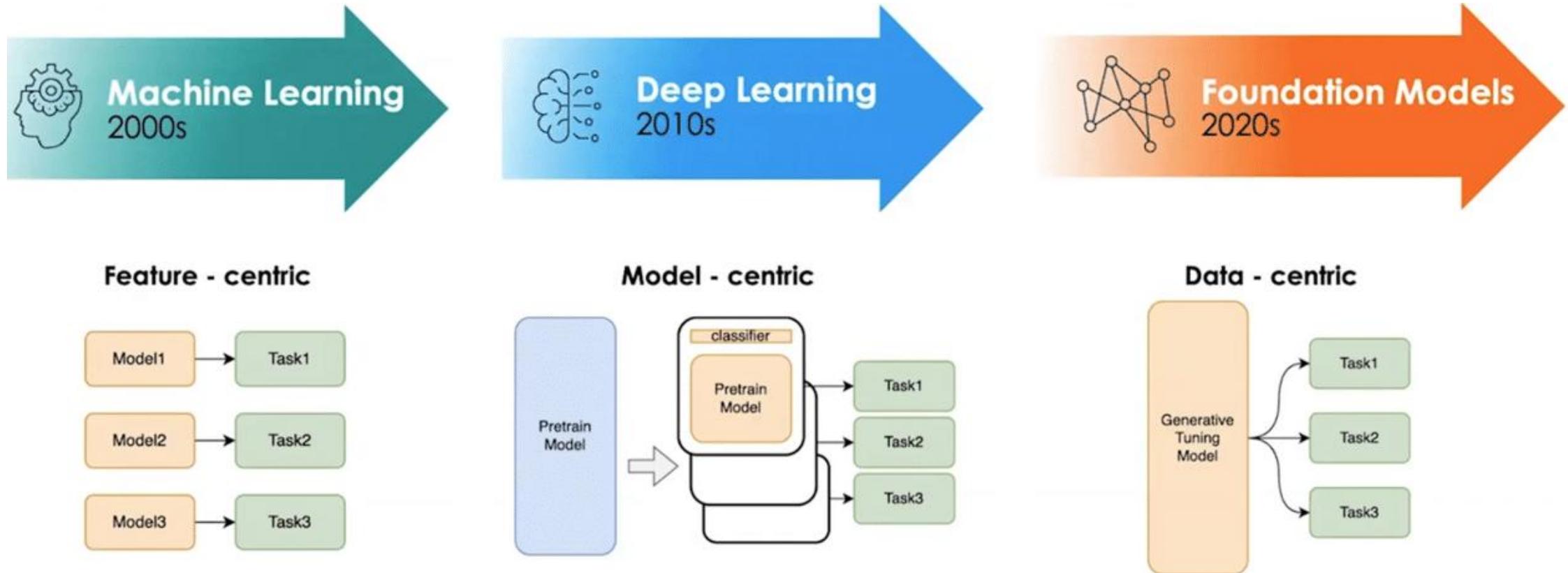


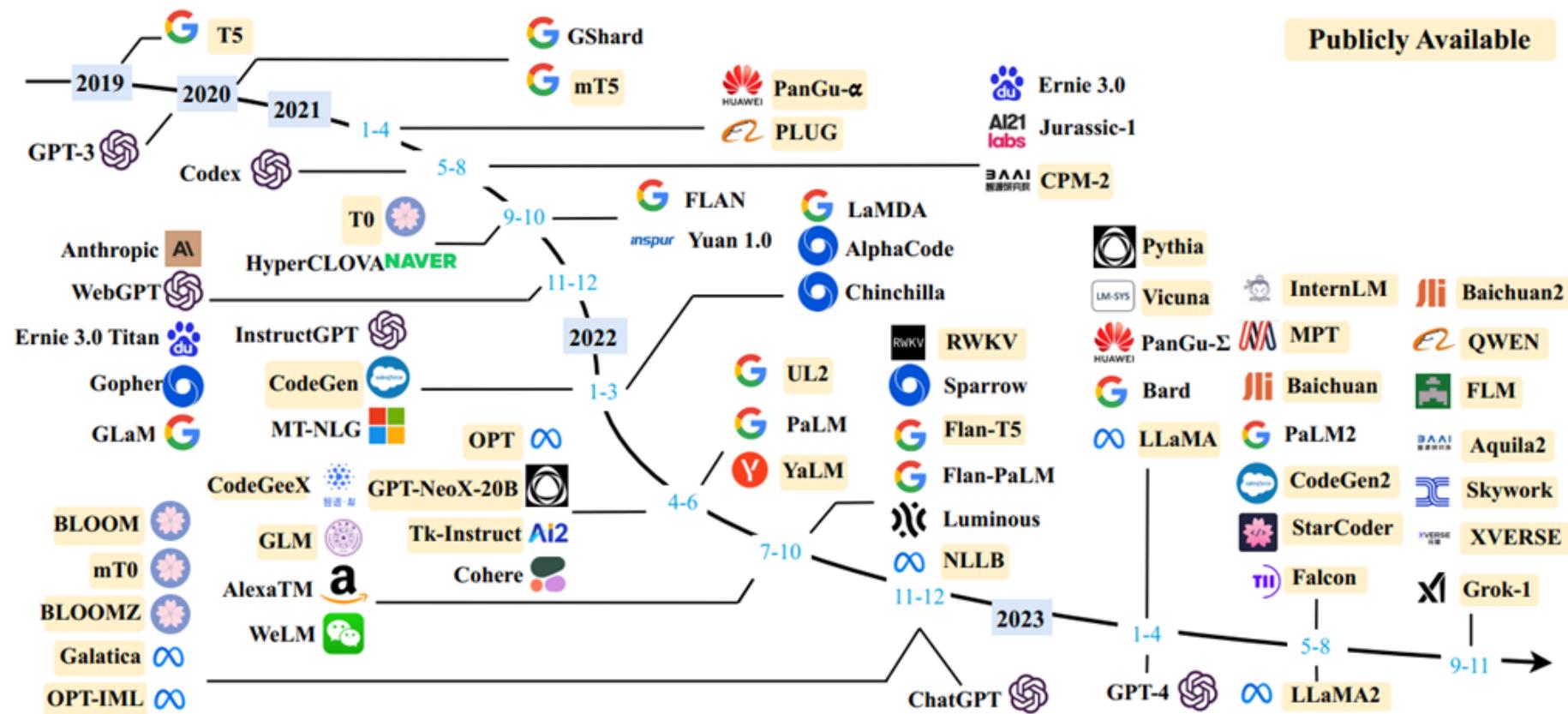
Limitations

- What is still missing?
 - Training from scratch is expensive
 - What architecture do I pick?
 - How much data is enough data?

Expertise is still needed; rules are still necessary!
Can we go further and make things simpler?

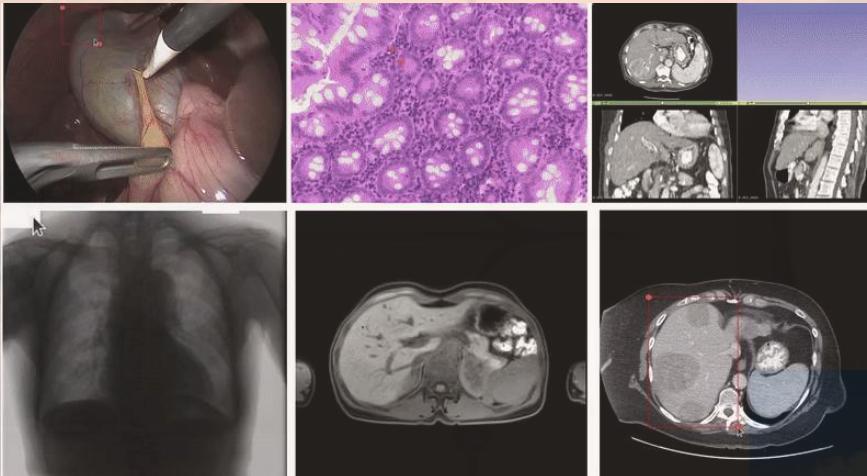
A New Era of AI: Foundation Models





Visual Foundation Models (VFM)

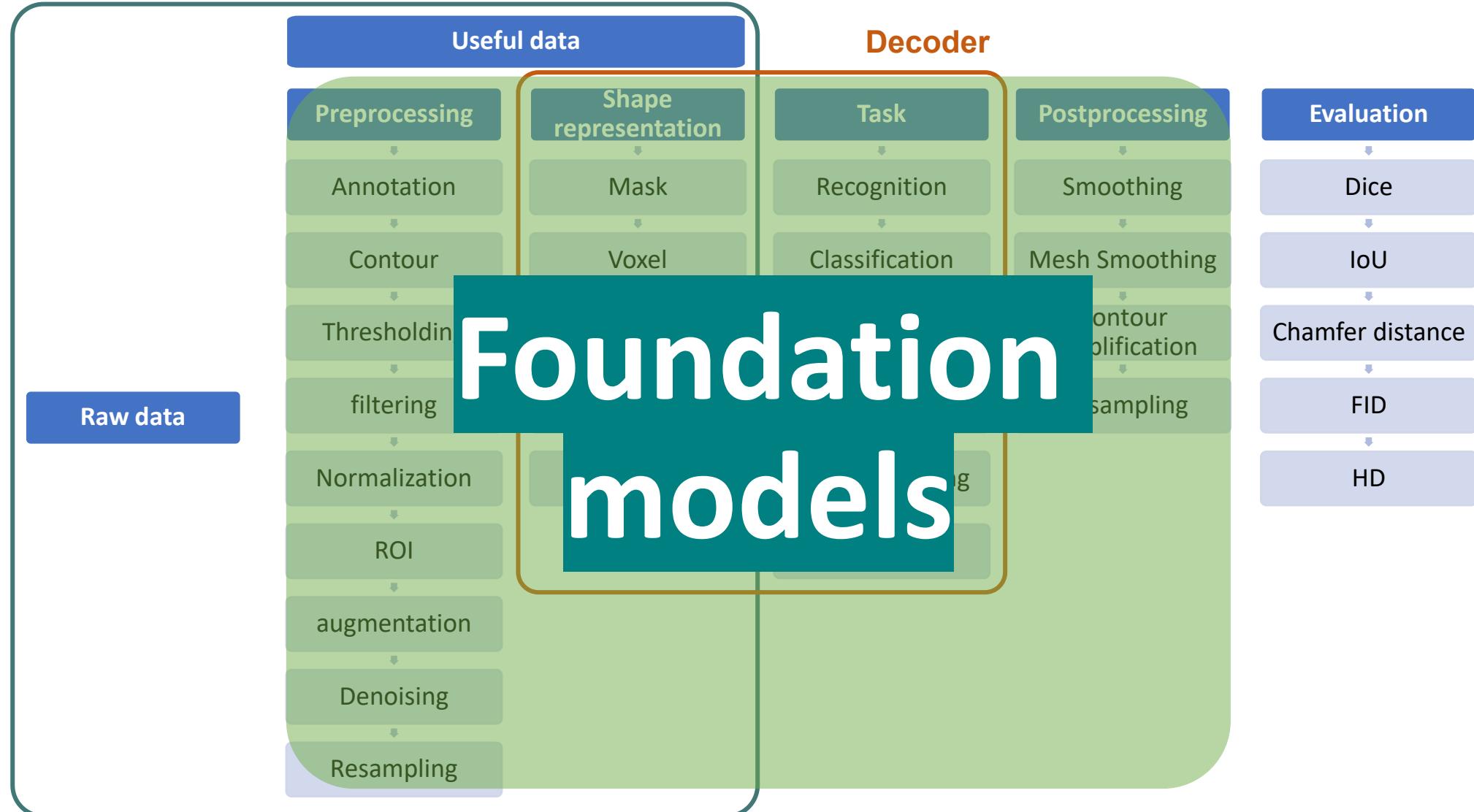
Segment Anything Model (SAM)



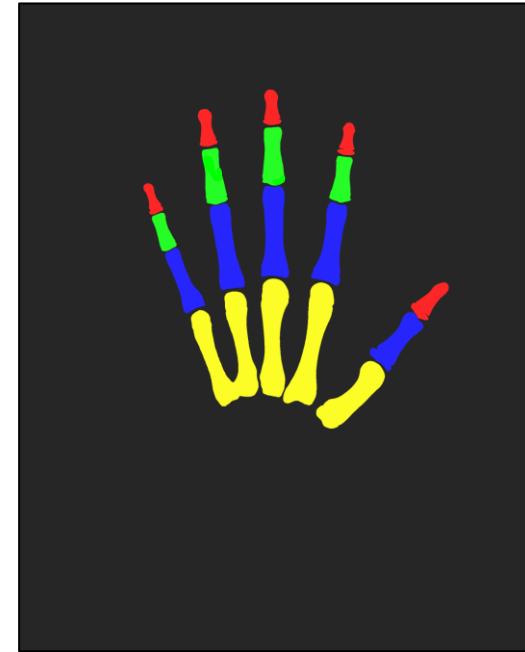
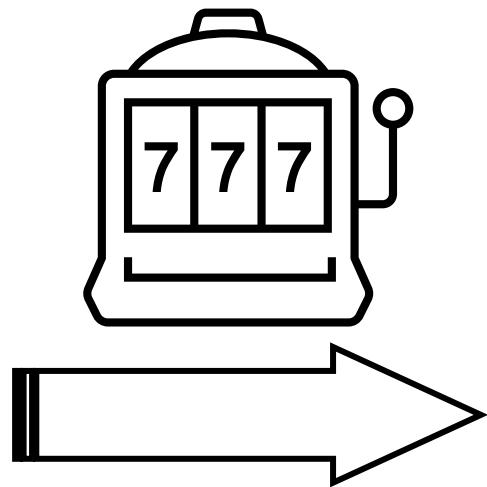
SAM

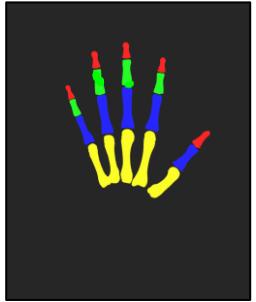
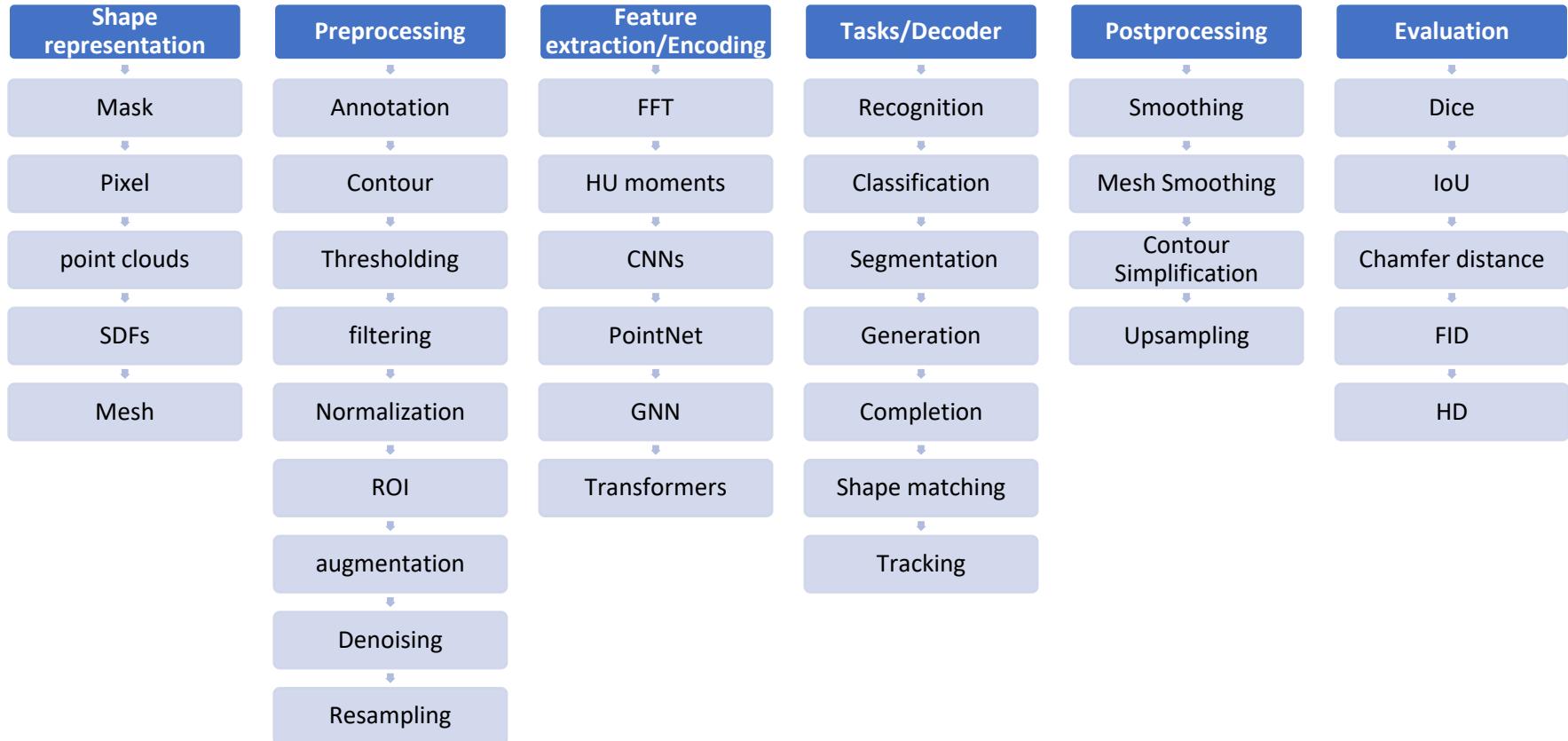


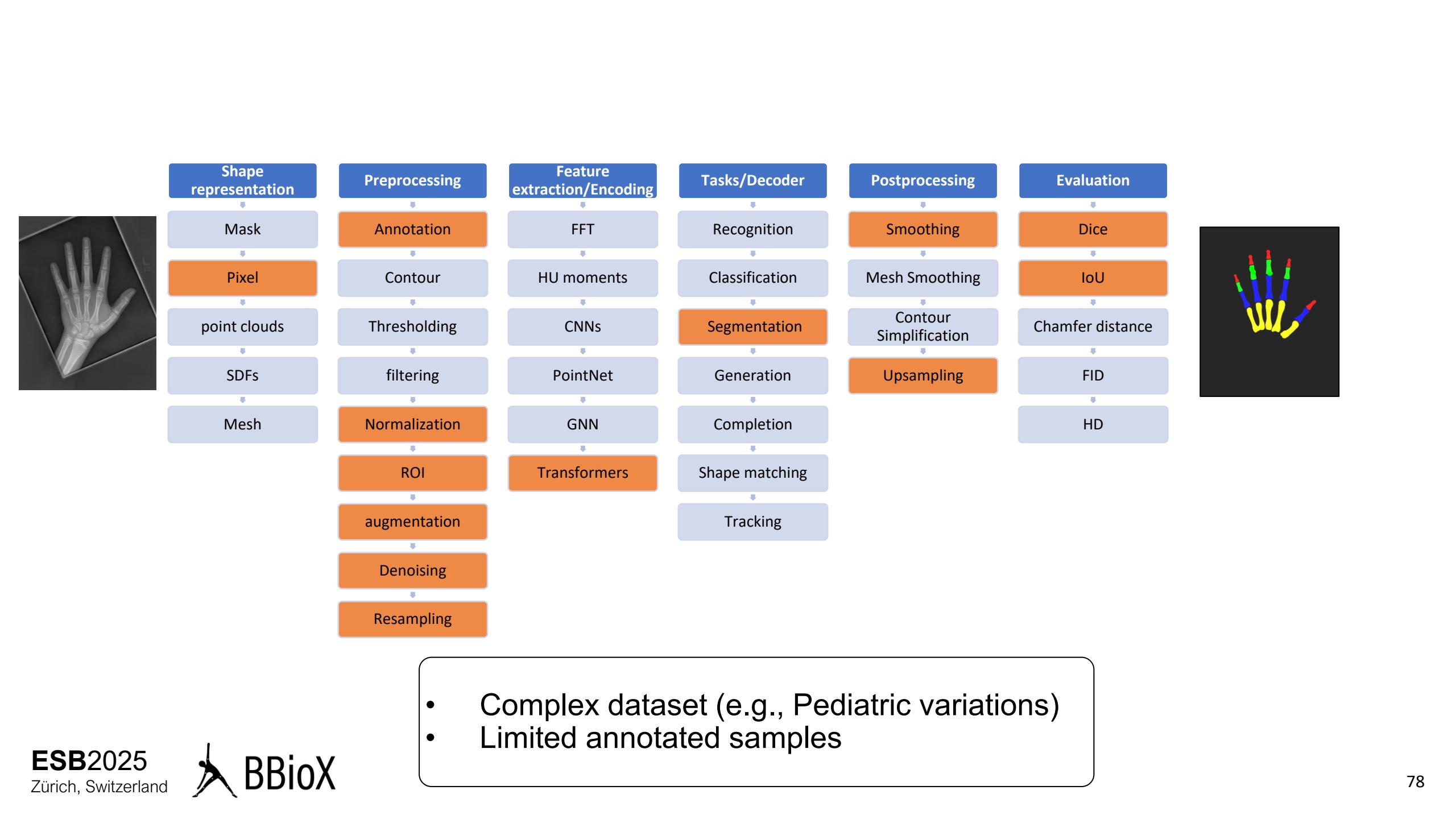
Encoder



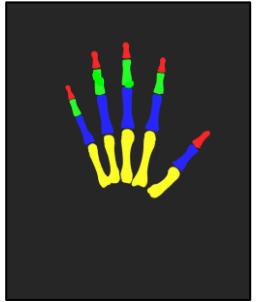
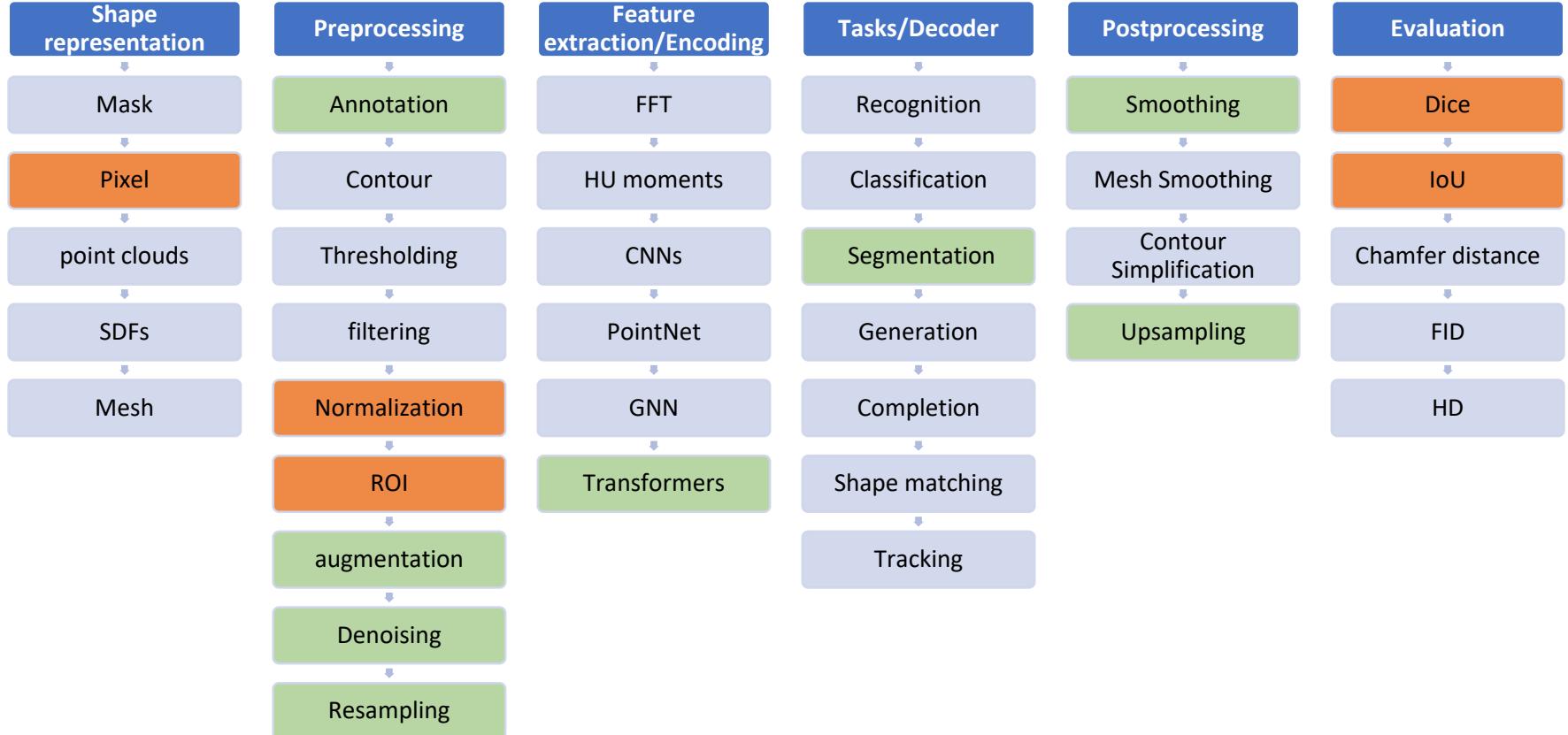
2D Pipeline





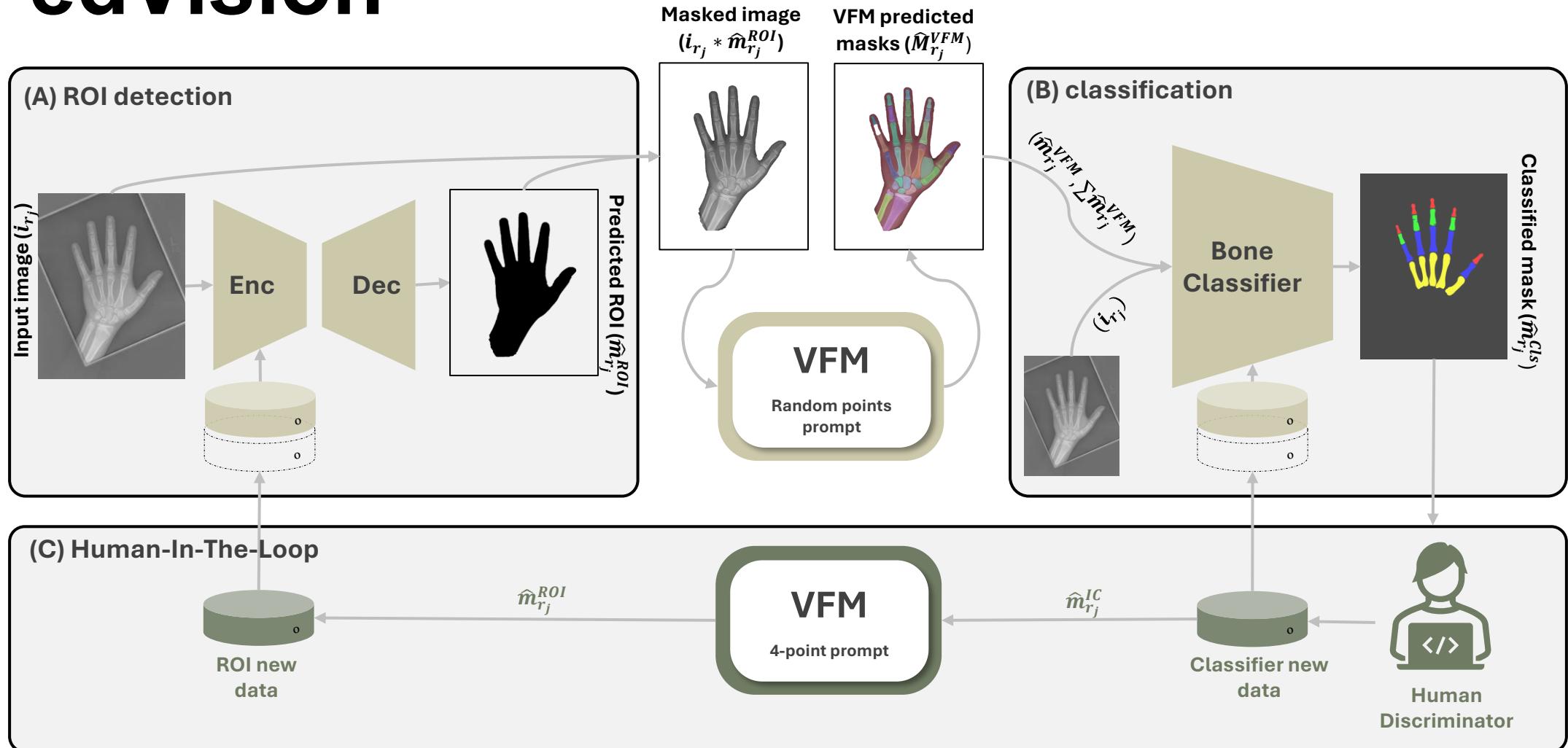




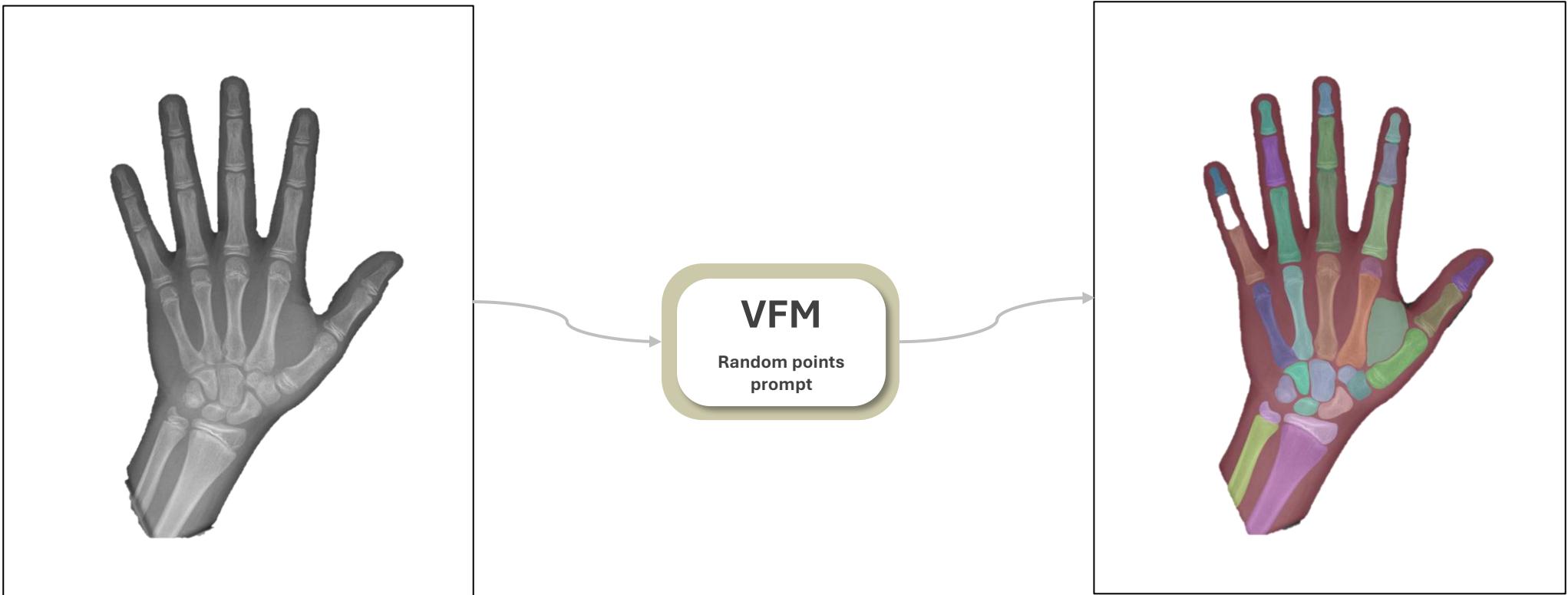


VFM

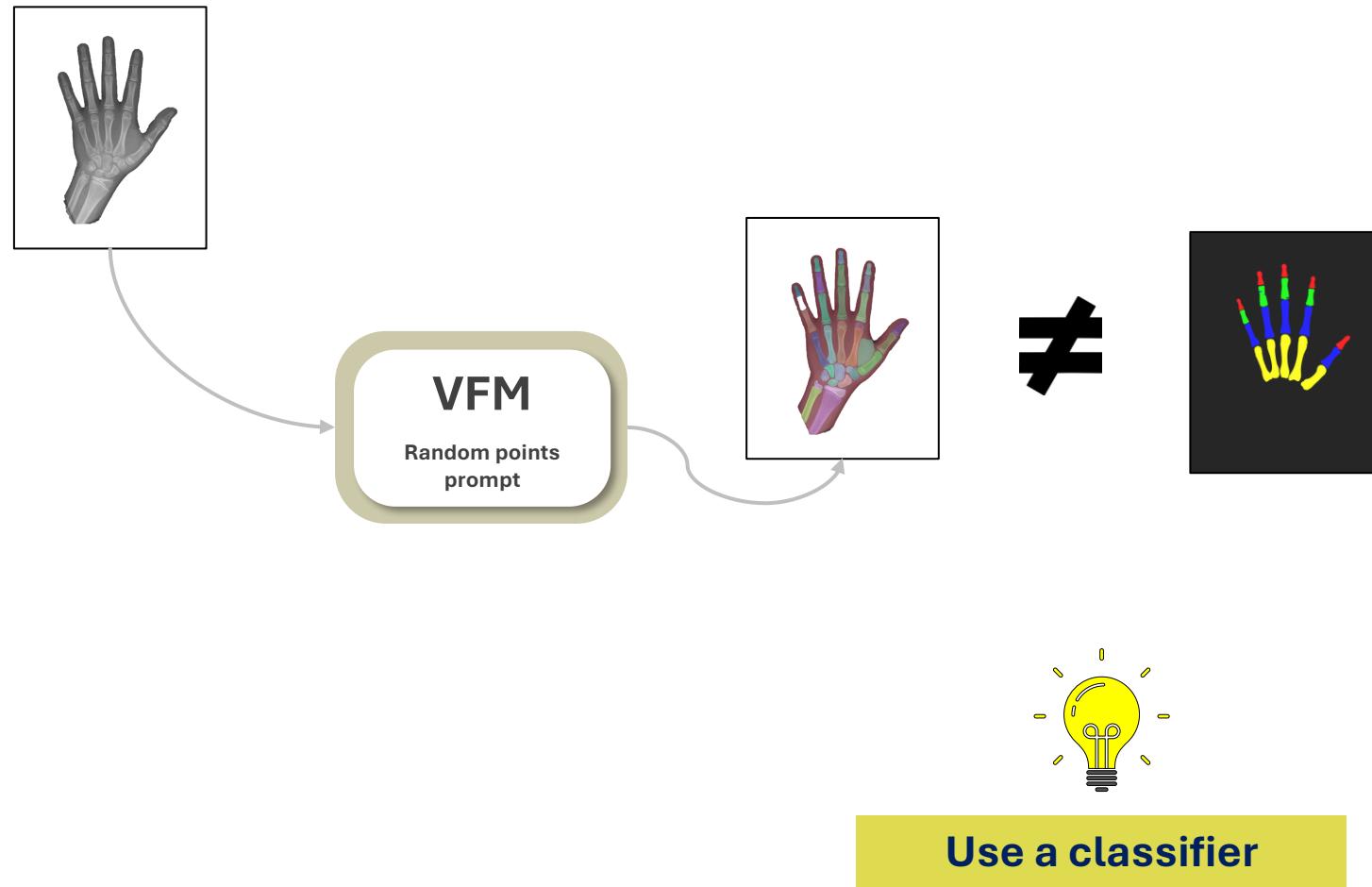
PedVision



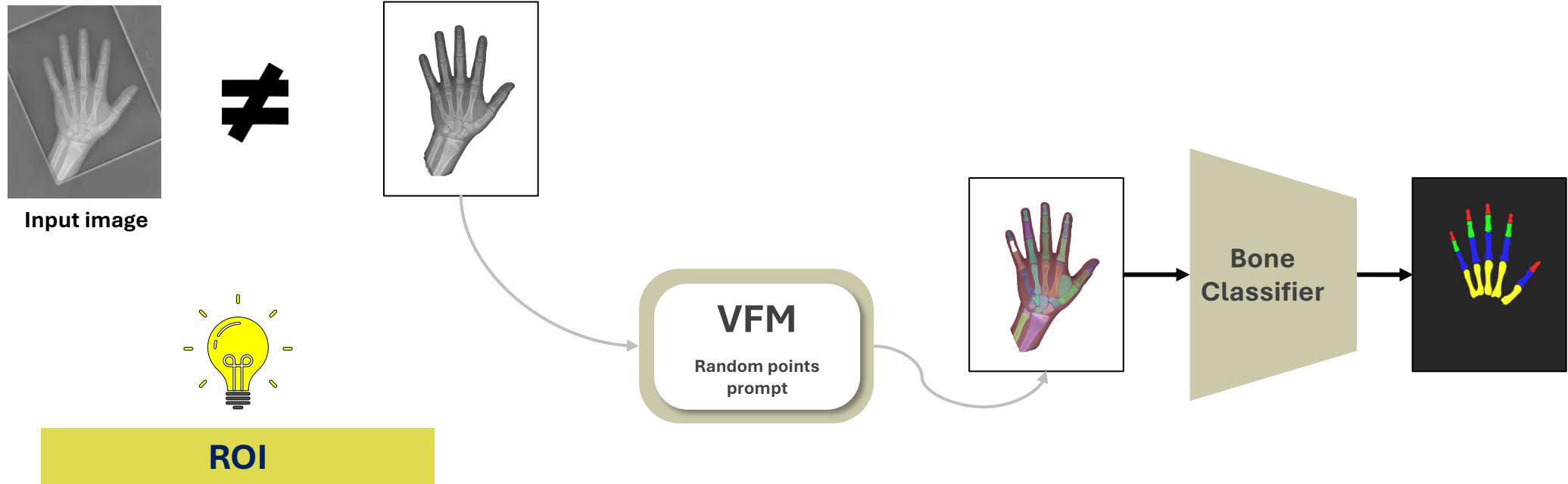
2D Pipeline - PedVision



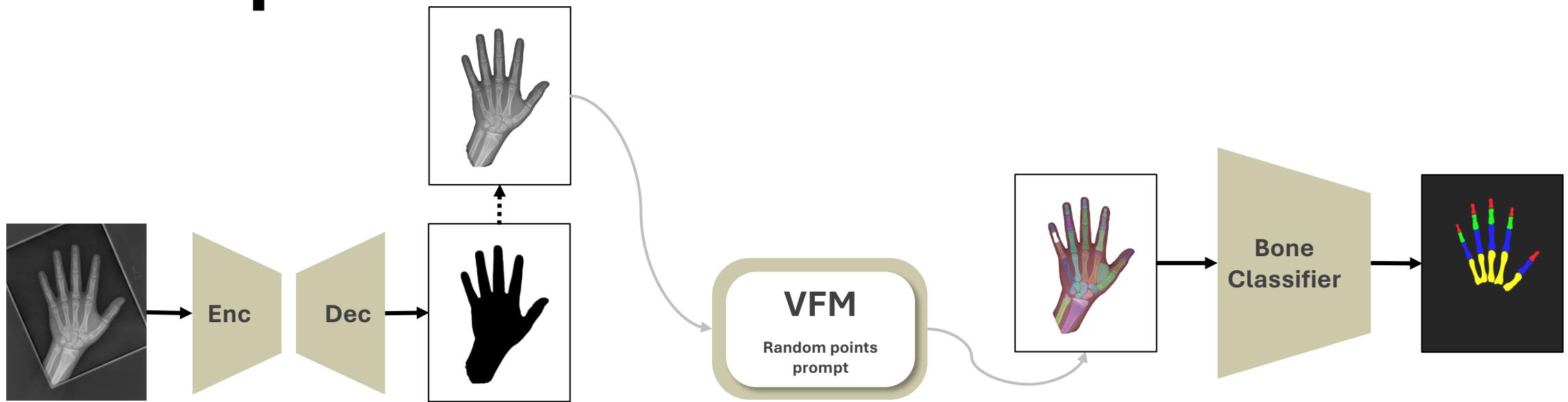
2D Pipeline - PedVision



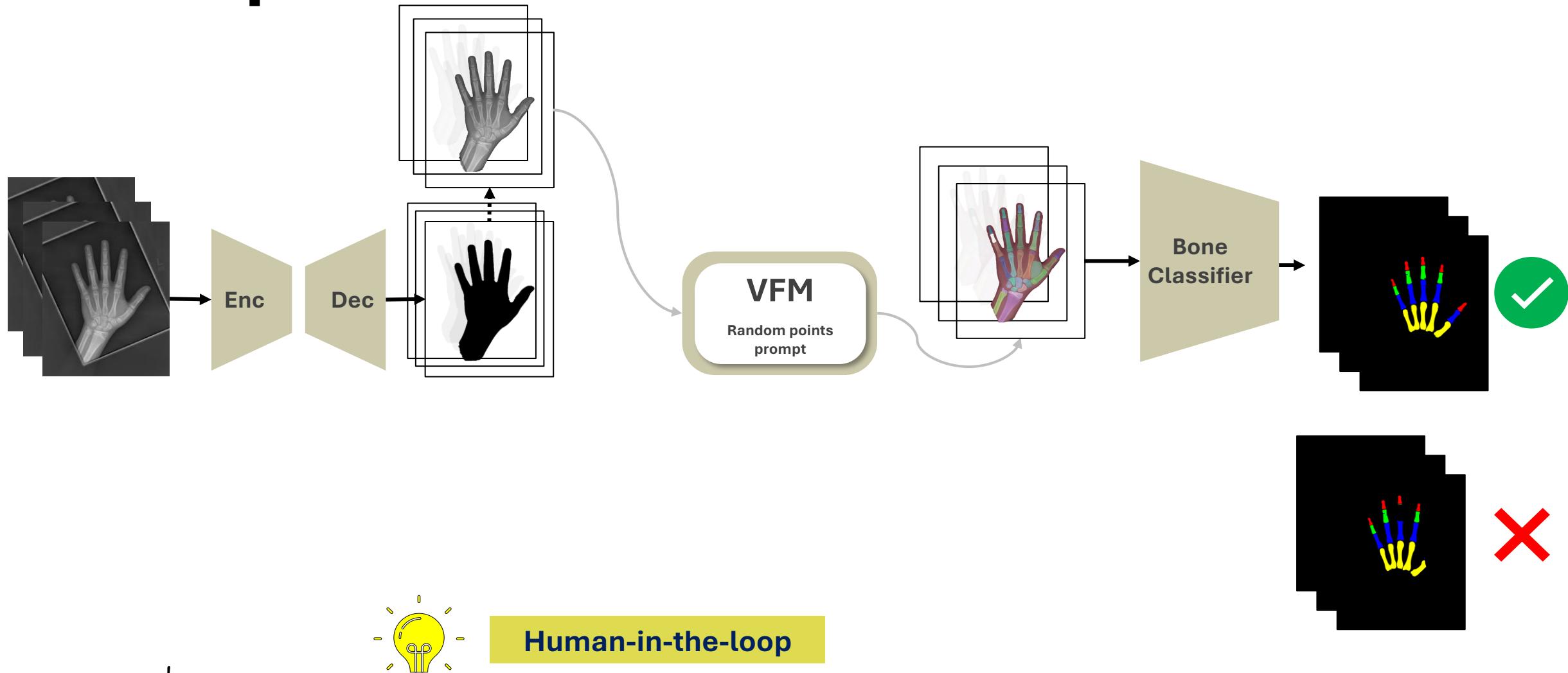
2D Pipeline - PedVision



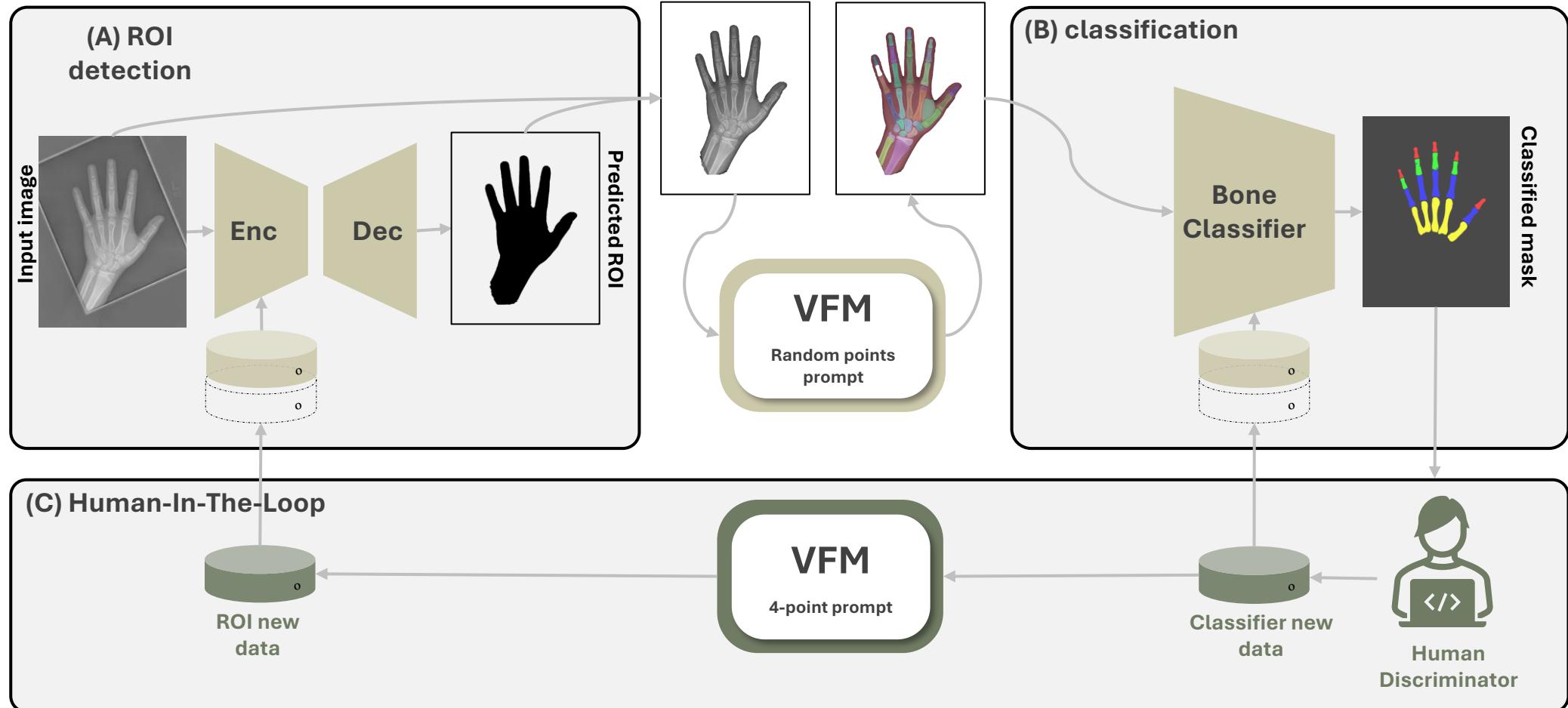
2D Pipeline - PedVision



2D Pipeline - PedVision



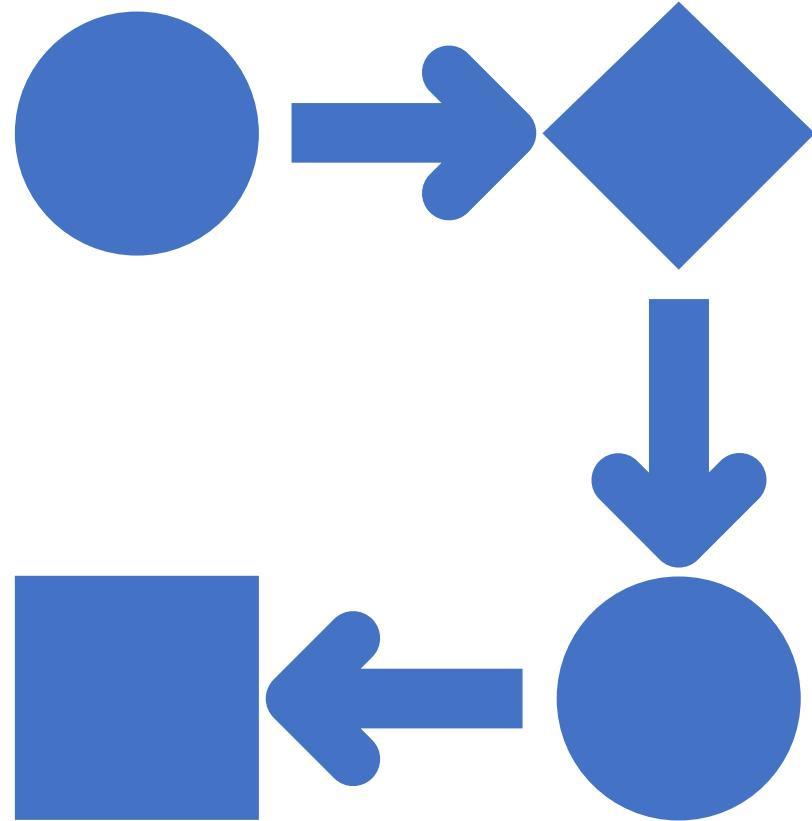
2D Pipeline - PedVision



Homayounfar, M., Bierma-Zeinstra, S., Zadpoor, A.A. and Tümer, N.,
Pedvision: A Manual-Annotation-Free and Age Scalable Segmentation
Pipeline for Bone Analysis in Hand X-Ray Images. Available at SSRN
5050535.

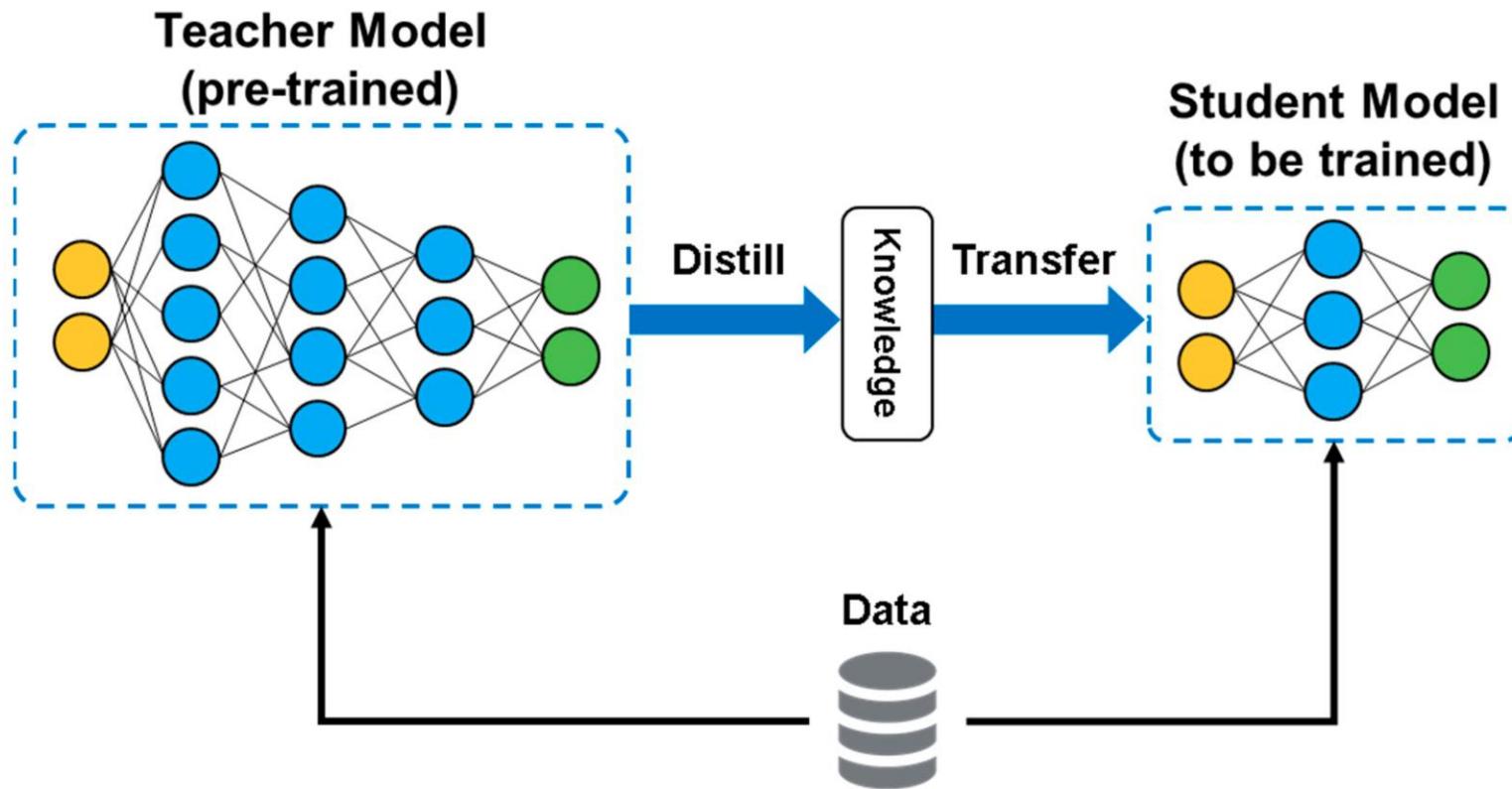
What VFM based pipelines brings us?
Flexibility, generalization, and robustness?

Hands-on!

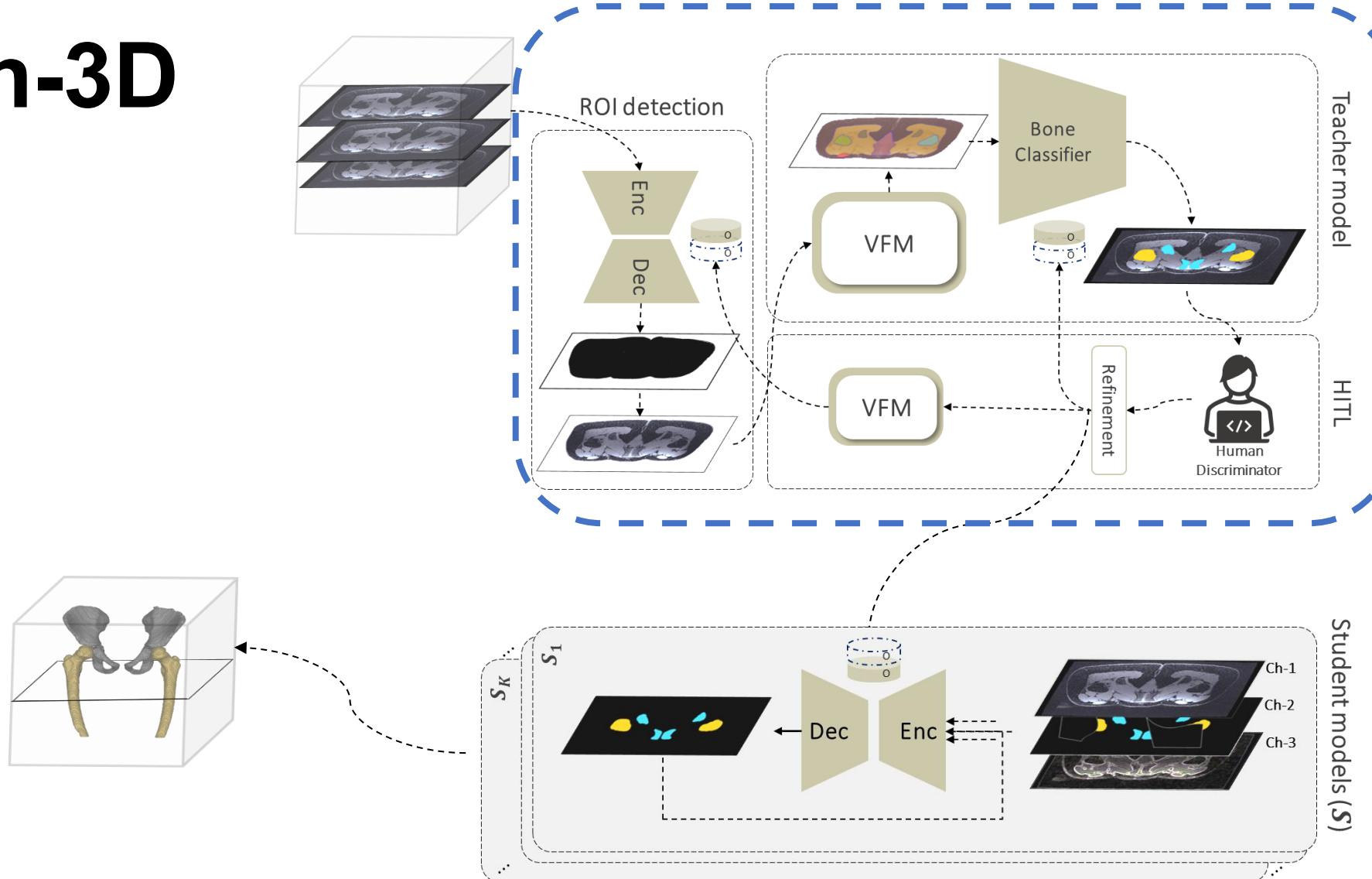


Any Limitations with VFM-Based Pipelines?

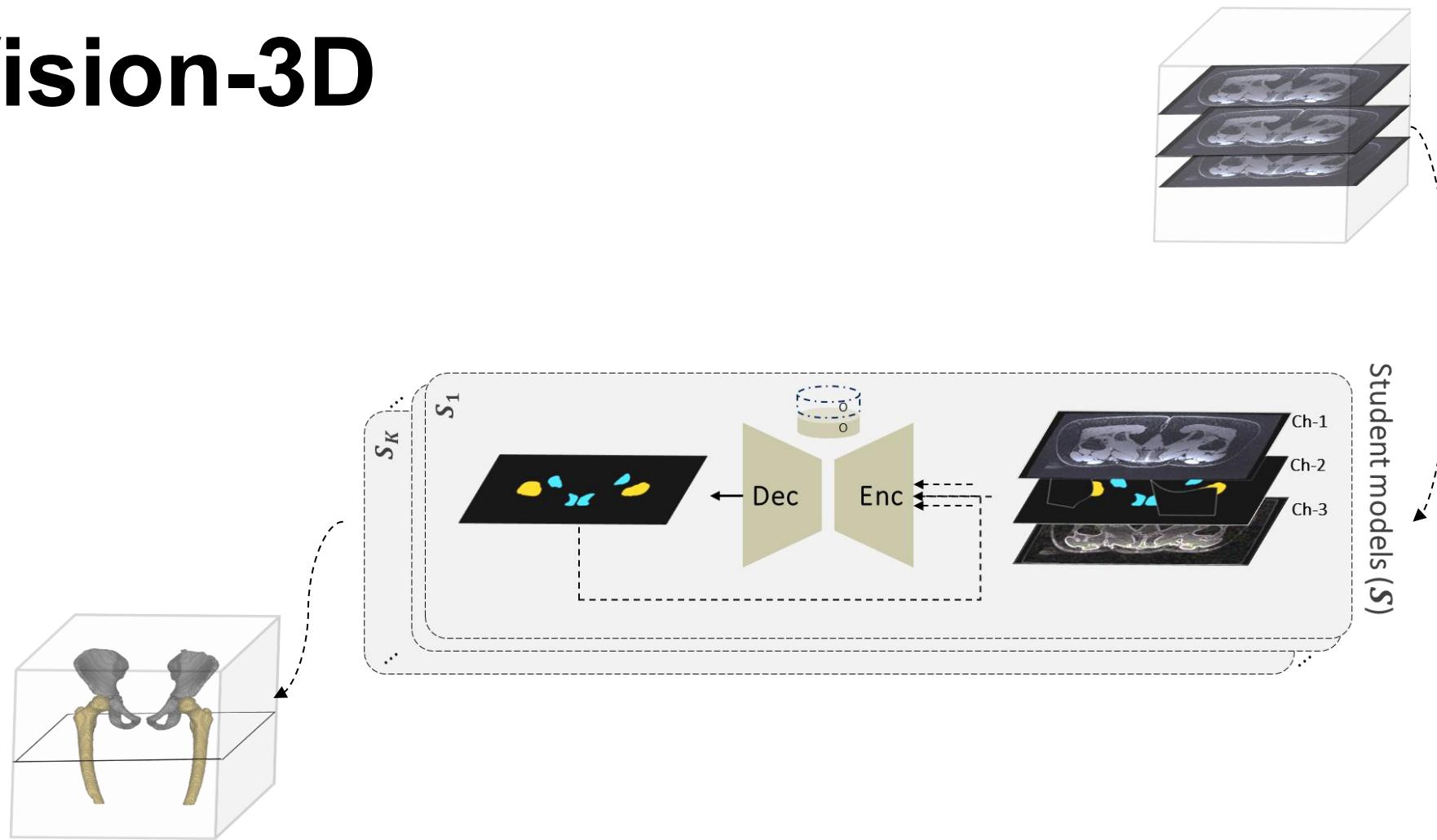
Teacher-Student Models



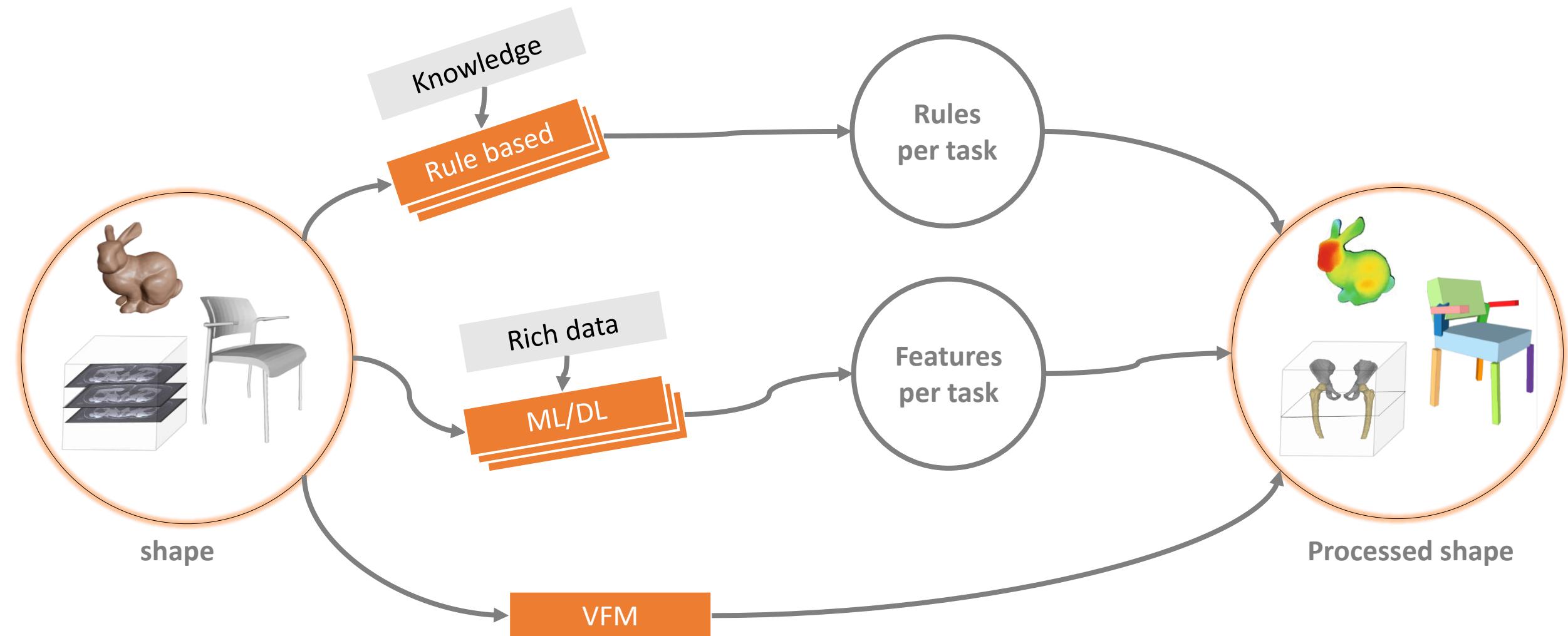
PedVision-3D



PedVision-3D



What we talked...



BREAK

[https://github.com/BBioX
/esb25_workshop_bbiox](https://github.com/BBioX/esb25_workshop_bbiox)



Version Control

A Short Introduction

Keep Track of Versions...

Mybeautifulproject-ver01.zip 

Mybeautifulproject-2025-02-01.zip 

Mybeautifulproject-yesworking.zip 

Mybeautifulproject-2024-09-02.zip 

Mybeautifulproject-2024-myadditions.zip 

...

Many more files like these

Do You Recognize Some of Them?

“It broke ... hopefully I have a working version somewhere?”

“Where is the latest version?”

“Which version are you using?”

“Which version did the authors use in the paper I am trying to reproduce?”

“Found a bug! Since when was it there?”

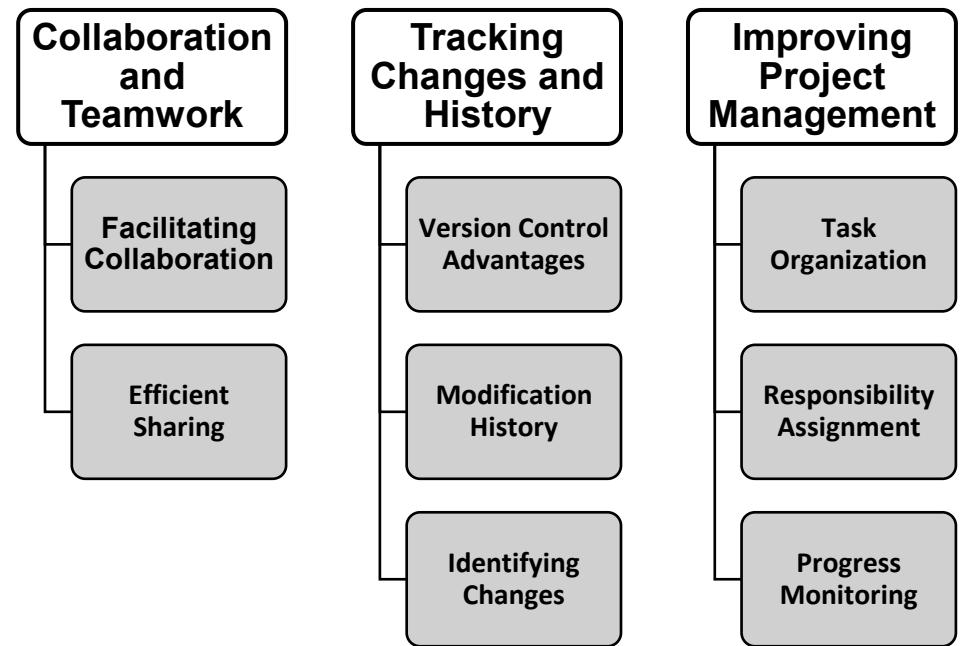
“I am sure it used to work. When did it change?”

“My laptop is gone. Have I lost all my code?”



Why Version Control?

- Track changes in code over time
- Collaborate without overwriting each other's work
- Roll back to previous versions if needed



Meet Git and GitHub

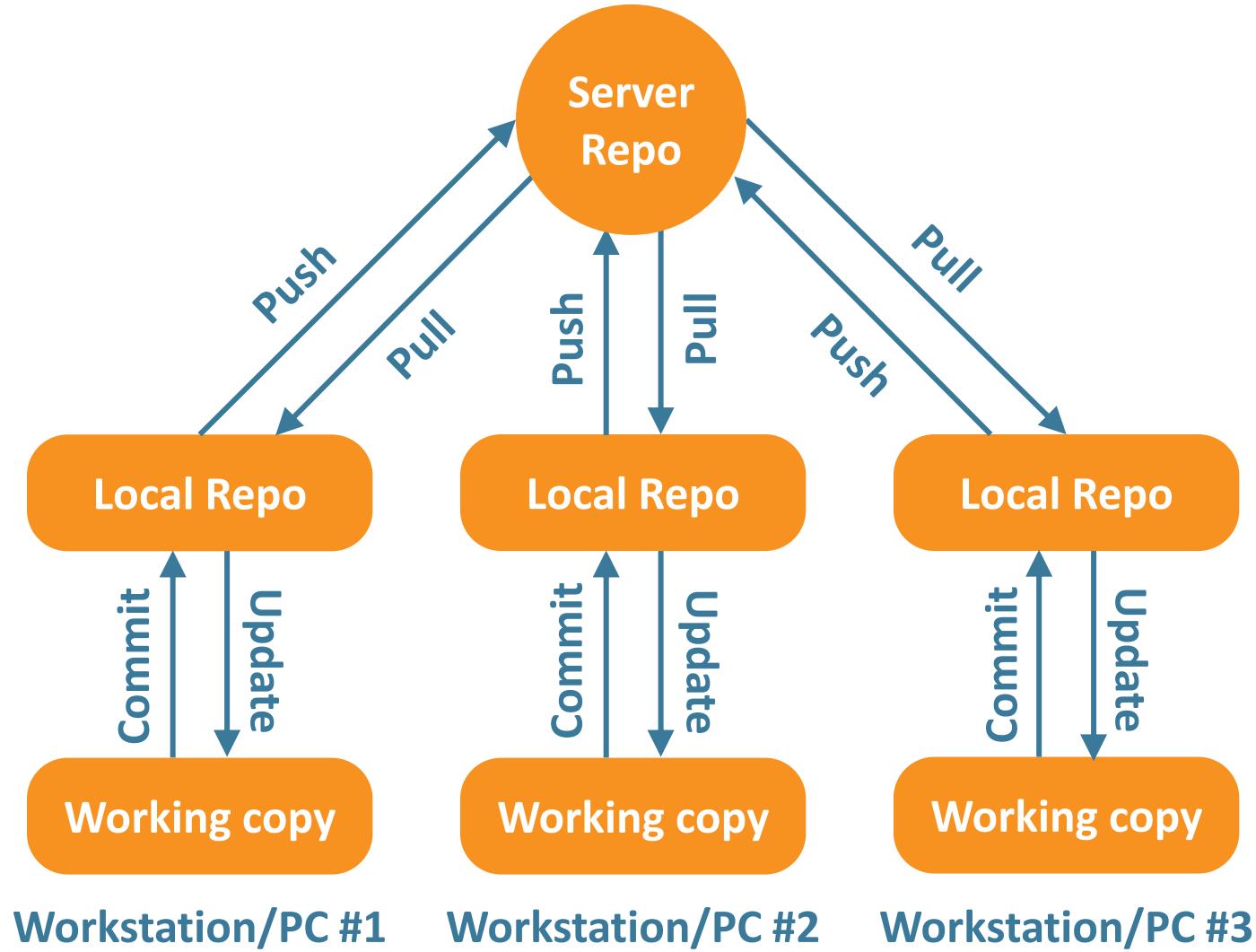
- **Git** is all about keeping track of changes (code history)

Why Git?

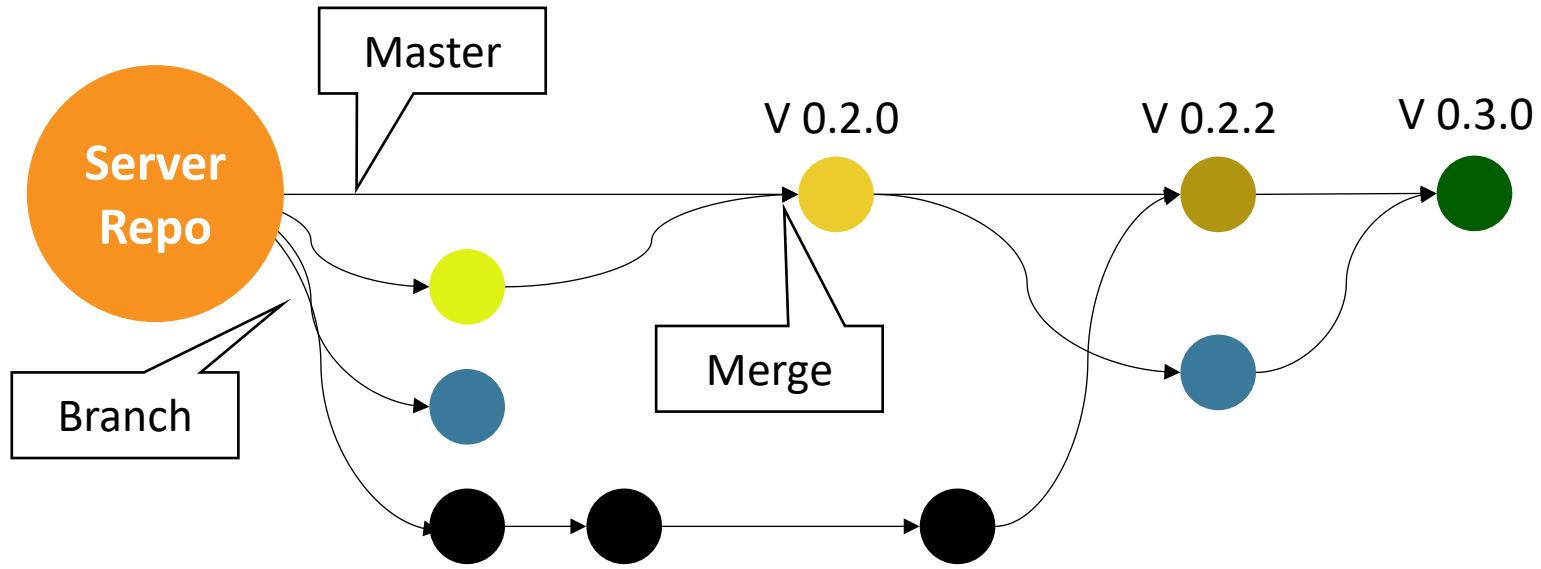
- Easy to set up, popular, distributed, and important platforms such as **GitHub**, GitLab, and Bitbucket build on top of Git.
- **GitHub** is a platform to host and collaborate on Git repositories online
- Version control for your models, collaboration with teammates and the broader research community, access to state-of-the art AI repositories, and integration with Colab, VS Code and other AI tools.

Key Terms and Concepts in GitHub

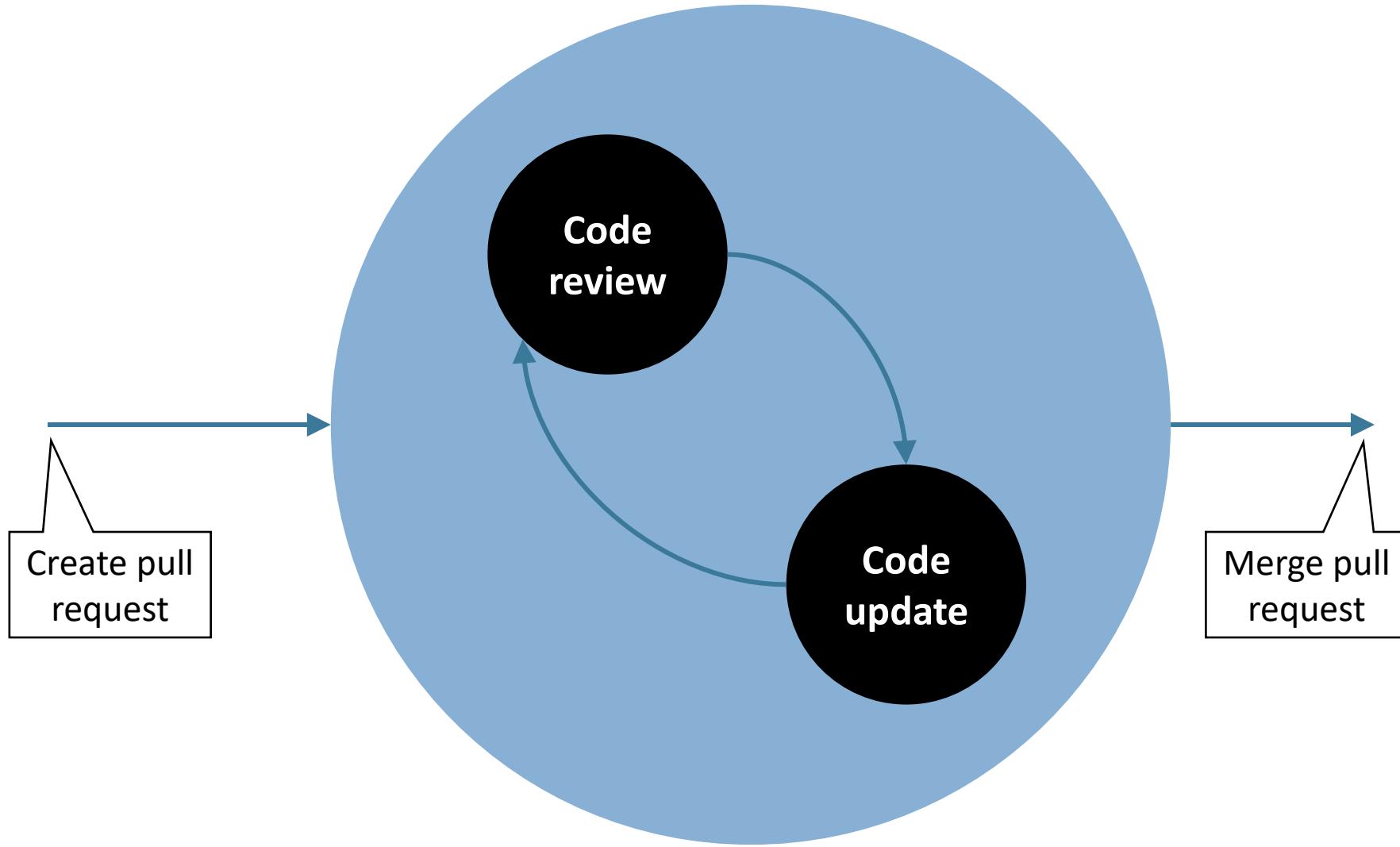
GitHub Keywords, Commit, Push,...



Master, Branch, Merge, and Versions



Pull Requests and Code Reviews



Other Tools and Features

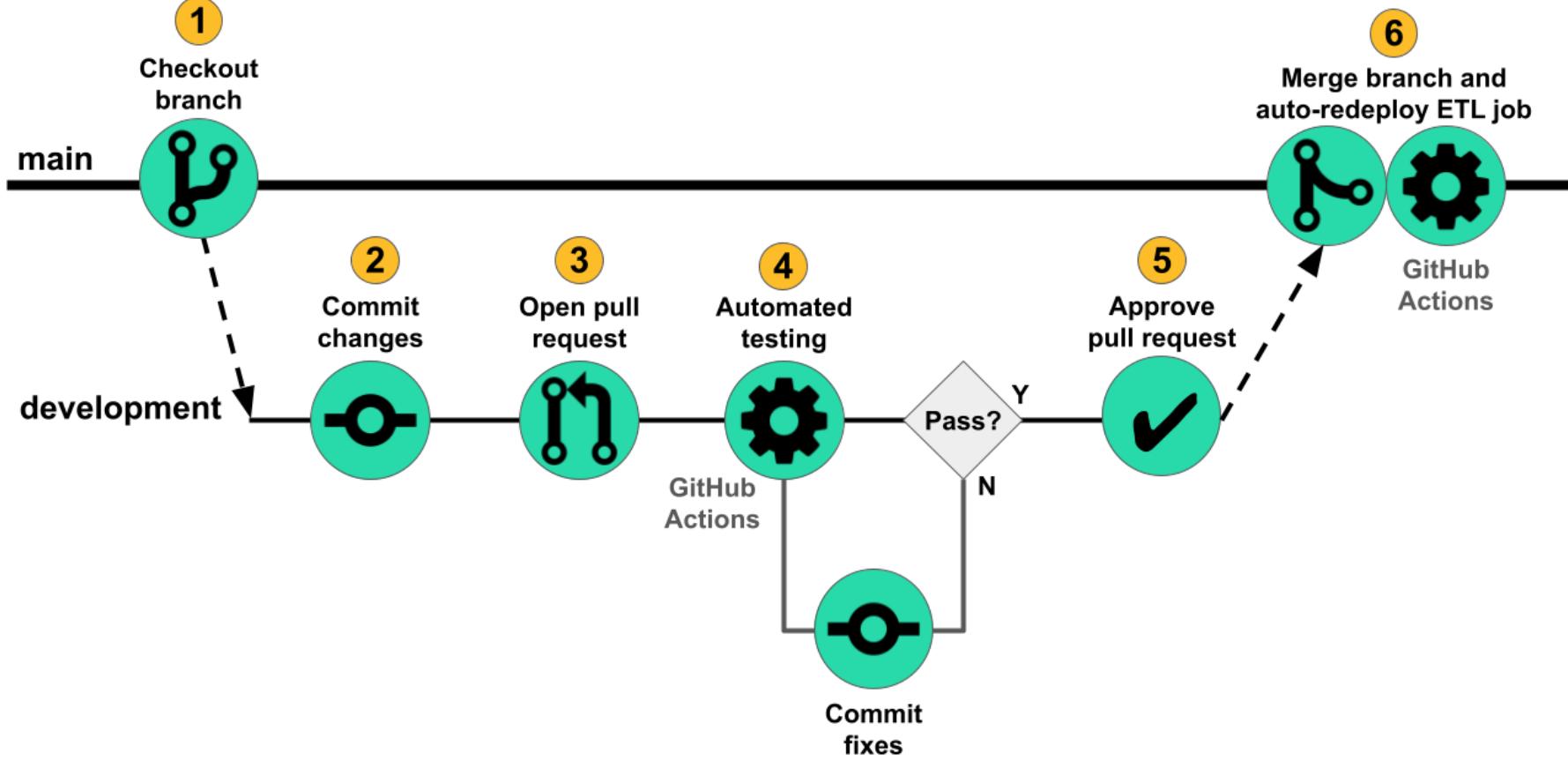
Issues and Project Boards

OctoArcade Invaders

The Plan Game loop Backlog Standup New view

Title	Team	Status	Assignees	Sub-issue progress
Prototype 3 2 of 3 67%				
1 Game brief and go-no-go	Producers 🎬	Complete ✅	inesvibe	29%
2 Engine prototype (physics, rendering)	Engine 🚀	Complete ✅	artur and mp56	
3 Initial concept art	Art 🌈	Complete ✅	rajqlfow	
+ Add item				
Beta 5 1 of 5 25%				
4 Integrate with Leaderboard Service	Game 📊	Not Started ⏱	magnusflare	
5 Creative design update to aliens for variety	Art 🌈	Planning 📈	robbota45	
6 Updates to alien, beam, and cannon sprites	Art 🌈	Building 🛠	vastibot	29%
7 Update to collision logic	Engine 🚀	Building 🛠	pavbez	40%
8 Improve alien respawn rate	Game 📊	Complete ✅	anasazon	
+ Add item				
Launch 6				
9 Interviews with media outlets	Producers 🎬	Not Started ⏱	baddias	Launch 🚀
10 Save score across levels	Game Loop 📊	Not Started ⏱	lokalhosst09	Launch 🚀

GitHub Actions for Automation



ultralytics / yolov5

Type to search

Code Issues 246 Pull requests 31 Discussions Actions Projects Wiki Security Insights

yolov5 Public Sponsor Watch 370 Fork 17k Star 54.2k

master 10 Branches 10 Tags Go to file Add file Code

glenn-jocher Update links.yml (#13620) 79c4c31 · 4 days ago 2,905 Commits

File	Commit Message	Time
.github	Update links.yml (#13620)	4 days ago
classify	Bump slackapi/slack-github-action from 2.0.0 to 2.1.0 in /.git...	last month
data	Use uv for pip installs (#13586)	last month
models	Bump slackapi/slack-github-action from 2.0.0 to 2.1.0 in /.git...	last month
segment	Bump slackapi/slack-github-action from 2.0.0 to 2.1.0 in /.git...	last month
utils	Bump slackapi/slack-github-action from 2.0.0 to 2.1.0 in /.git...	last month
.dockerignore	Add .git to .dockerignore (#8815)	3 years ago
.gitattributes	git attrib	5 years ago
.gitignore	Update CoreML exports to support newer *.mlpackage outp...	11 months ago
CITATION.cff	Update LICENSE to AGPL-3.0 (#11359)	2 years ago
CONTRIBUTING.md	Fix comet (#13561)	2 months ago
LICENSE	Update LICENSE to AGPL-3.0 (#11359)	2 years ago
README.md	Update YOLOv5->Comet ML READMEs (#13560)	2 months ago

About

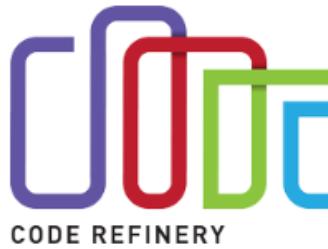
YOLOv5 🚀 in PyTorch > ONNX > CoreML > TFLite

docs.ultralytics.com

ios machine-learning deep-learning
ml pytorch yolo object-detection
coreml onnx tflite yolov3 yolov5
ultralytics

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Security policy
Cite this repository
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54.2k stars
370 watching
17k forks
Report repository

Releases 10

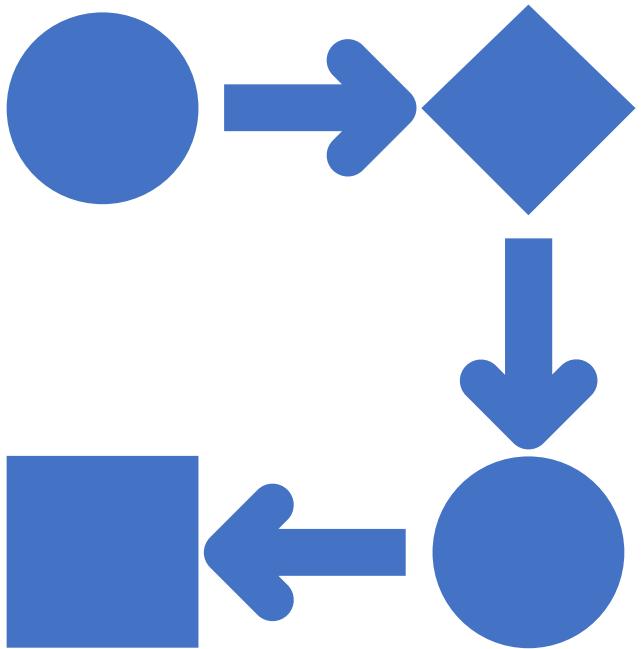


<https://coderefinery.org>

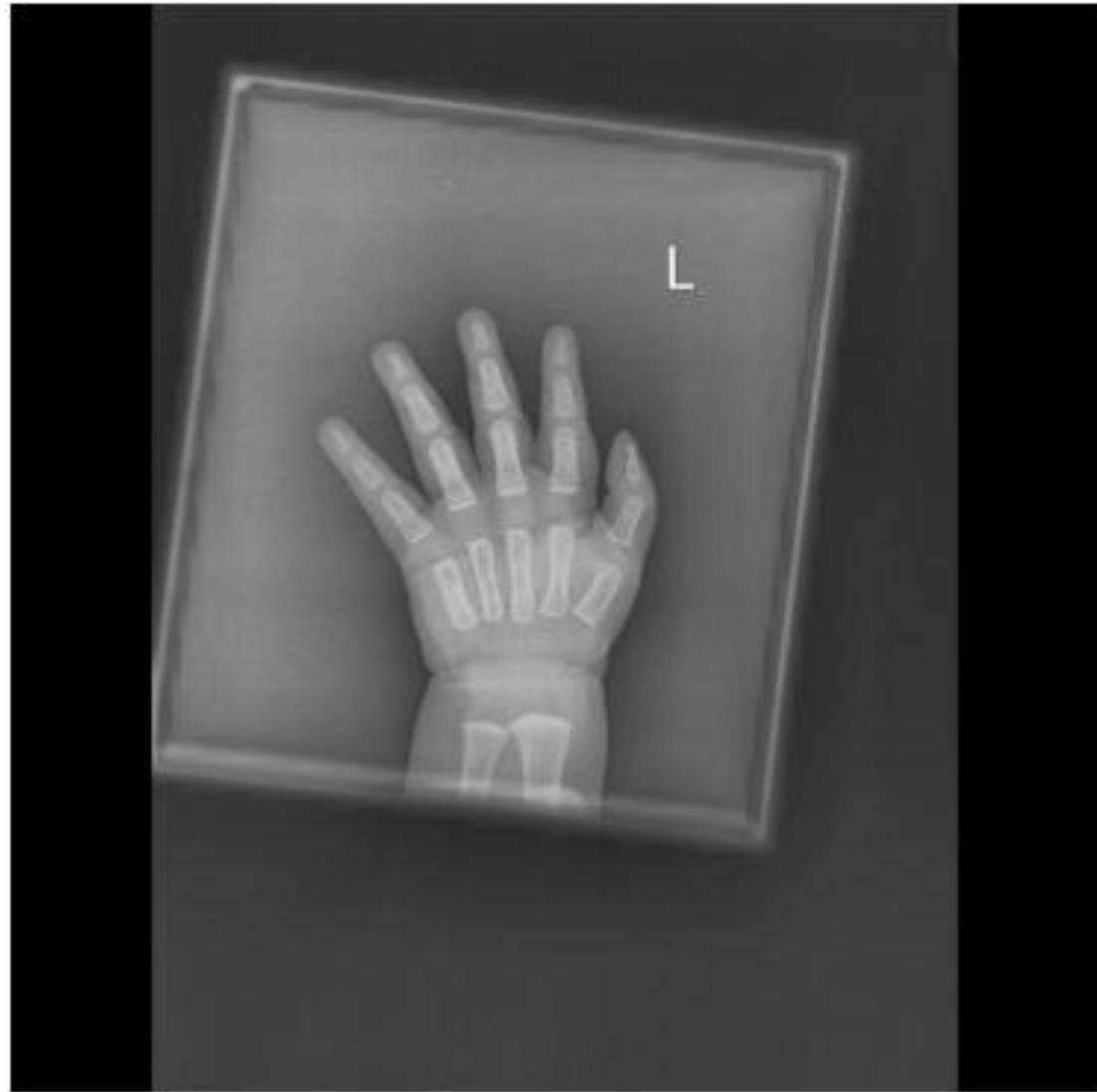
A hub for FAIR research software practices
Trainings in FAIR research software development

Hands-on

What VFM based pipelines brings us?
Flexibility, generalization, and robustness?

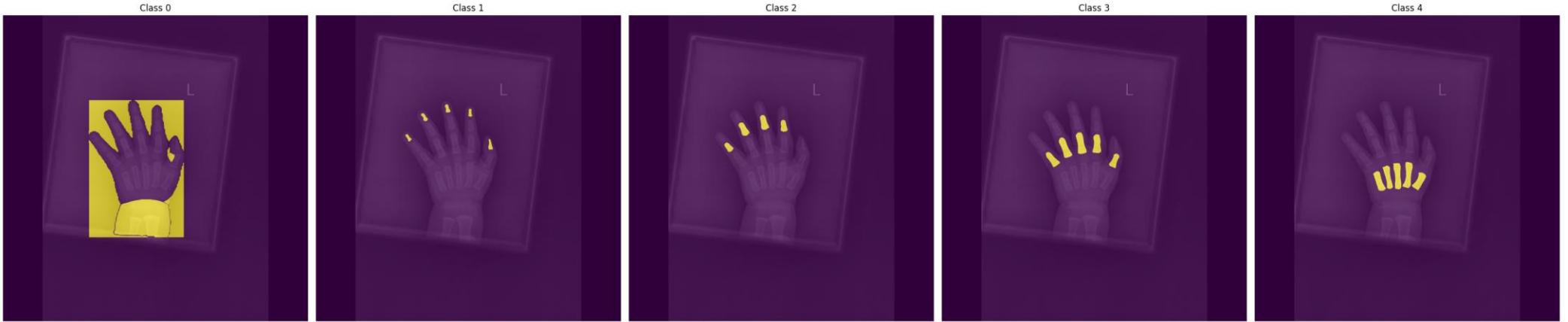


PedVision

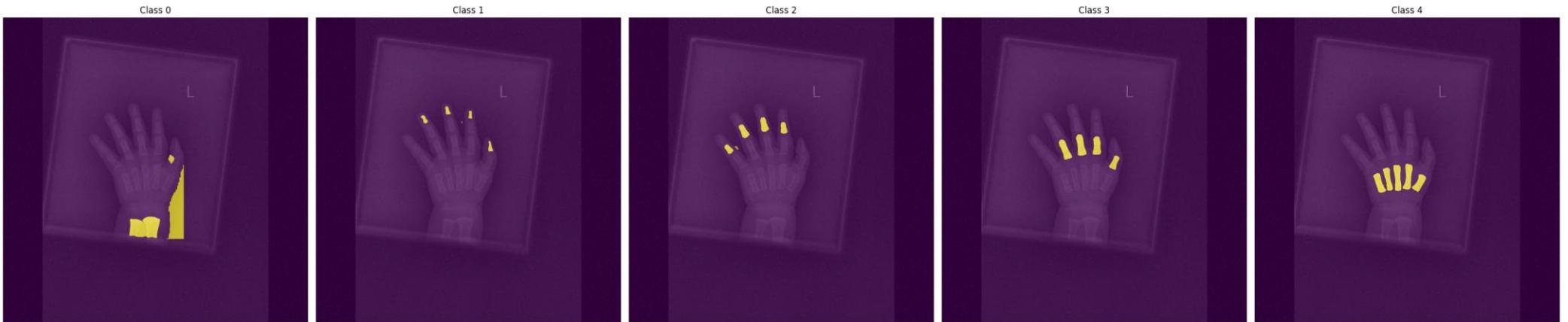


PedVision

Original Image
Prediction



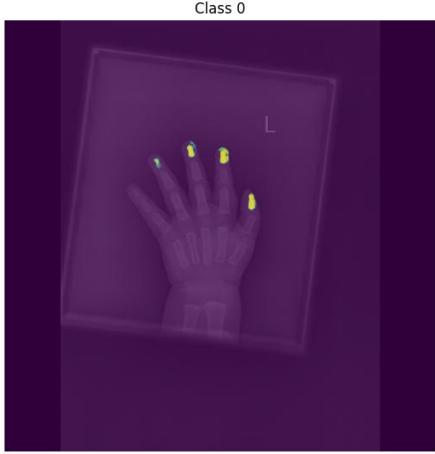
Salt & Pepper
30% Prediction



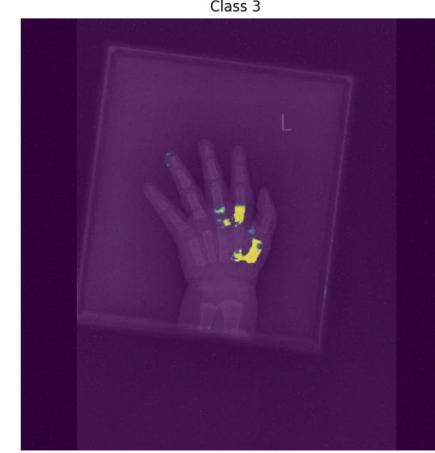
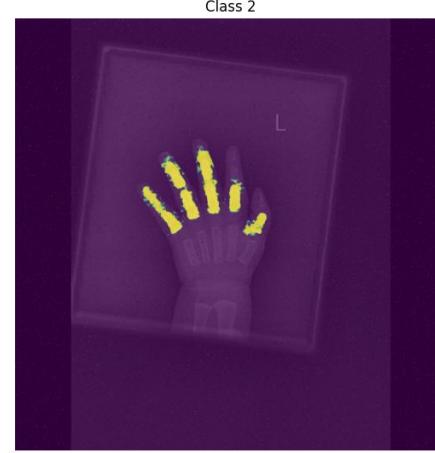
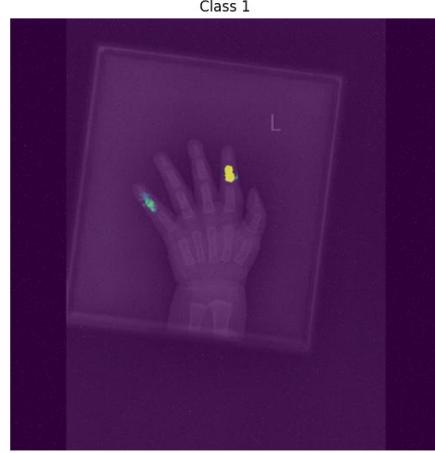
Non-VFM

SegFormer-B3

Original Image
Prediction



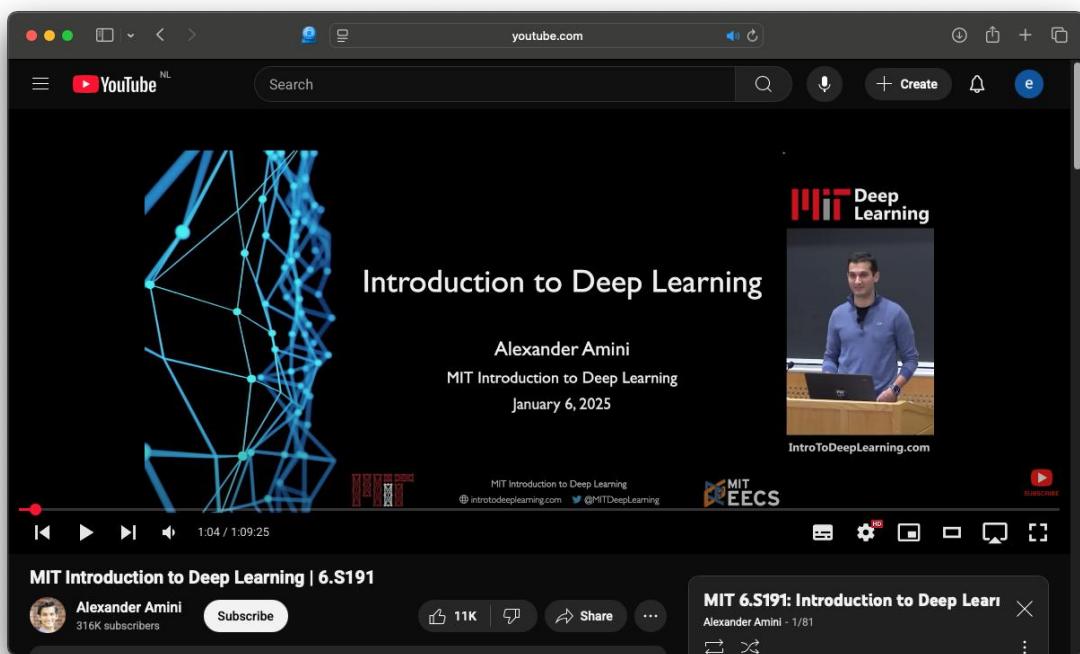
Salt & Pepper
30% Prediction



Take Home Messages

- **Shape Representation** – The choice of how you represent shape directly influences your pipeline.
- **Deep Learning** – Allows you to move from raw data to task-specific outcomes without relying on hand-crafted rules.
- **Foundation Models** – Powerful, pre-trained feature extractors that reduce the need to train models from scratch.
- **Version Control** – Essential to keep track of projects with multiple collaborators spanning several years.

Further resources



visionbook.mit.edu

Foundations of Computer Vision

AUTHORS
[Antonio Torralba](#), [Phillip Isola](#), and [William Freeman](#)

You can buy the print version of this book [here](#).

Published by *The MIT Press*
Cambridge, Massachusetts
London, England

Preface
Dedicated to all the pixels.

About this Book
This book covers foundational topics within computer vision, with an image

Table of contents
[Preface](#)
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[What Do We Not Cover?](#)
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ESB2025
Zürich, Switzerland

A portrait of ir. Edwin Tay, a young man with glasses and a floral shirt.

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A QR code for Google Scholar.A portrait of Dr. ir. Nazli Tümer, a woman with shoulder-length brown hair.

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