MRO.ART
MODERN RADIATION ONCOLOGY

AI in modern Radiation Oncology

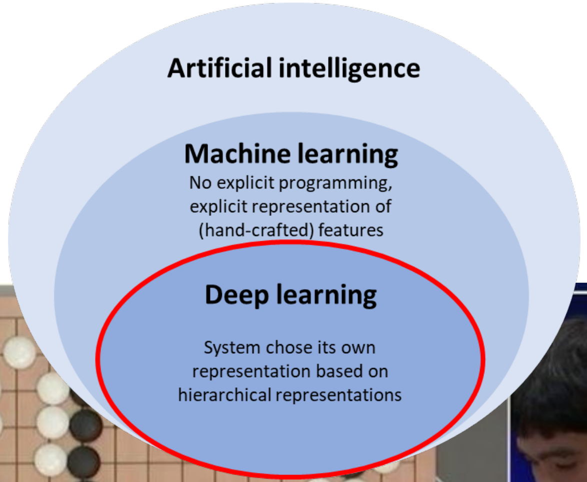
Deep Learning

a Physicist's perspective

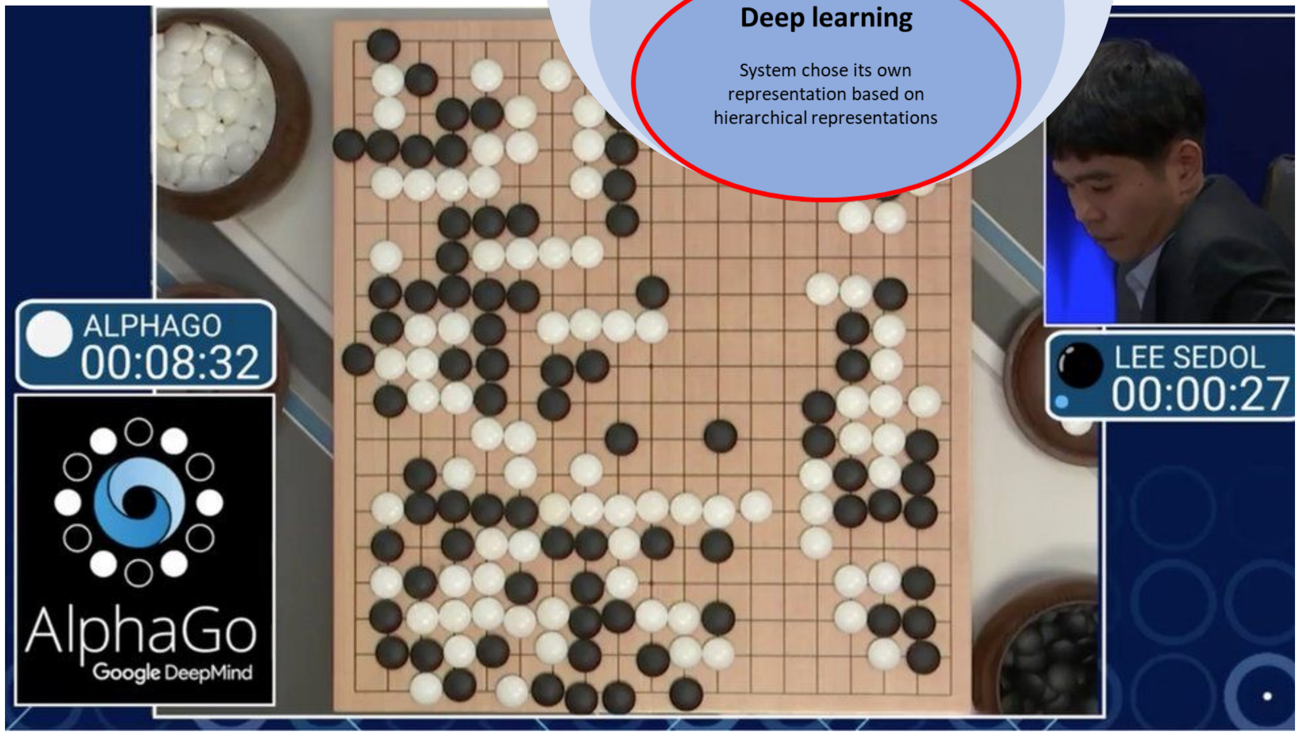
Gert Meijer

UMC Utrecht

The advent of Deep Learning in AI



1997

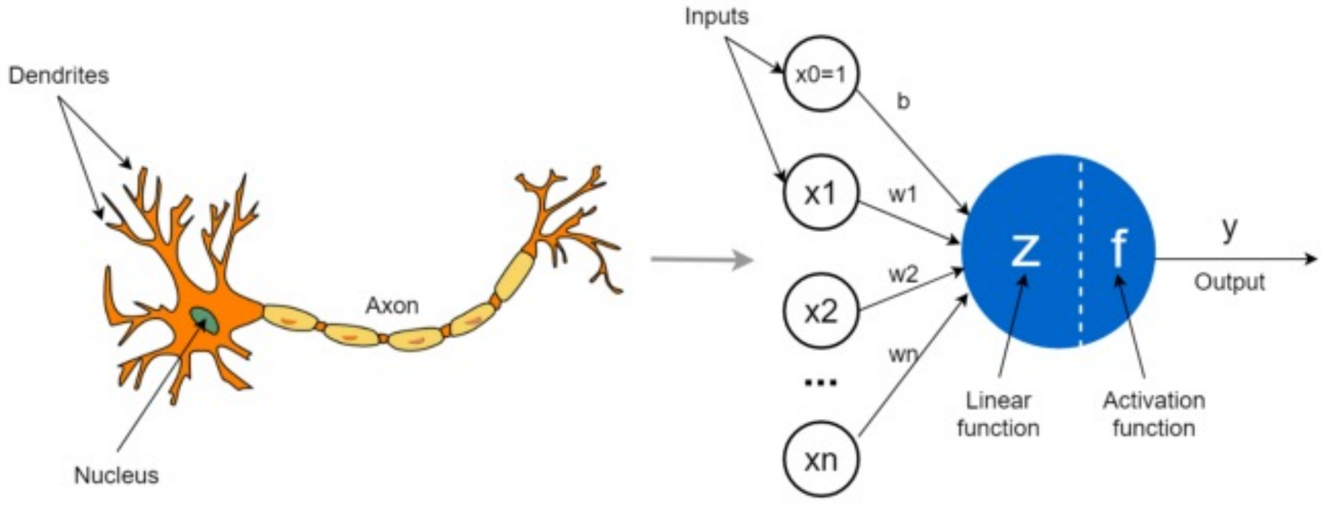


2016

What is deep learning?

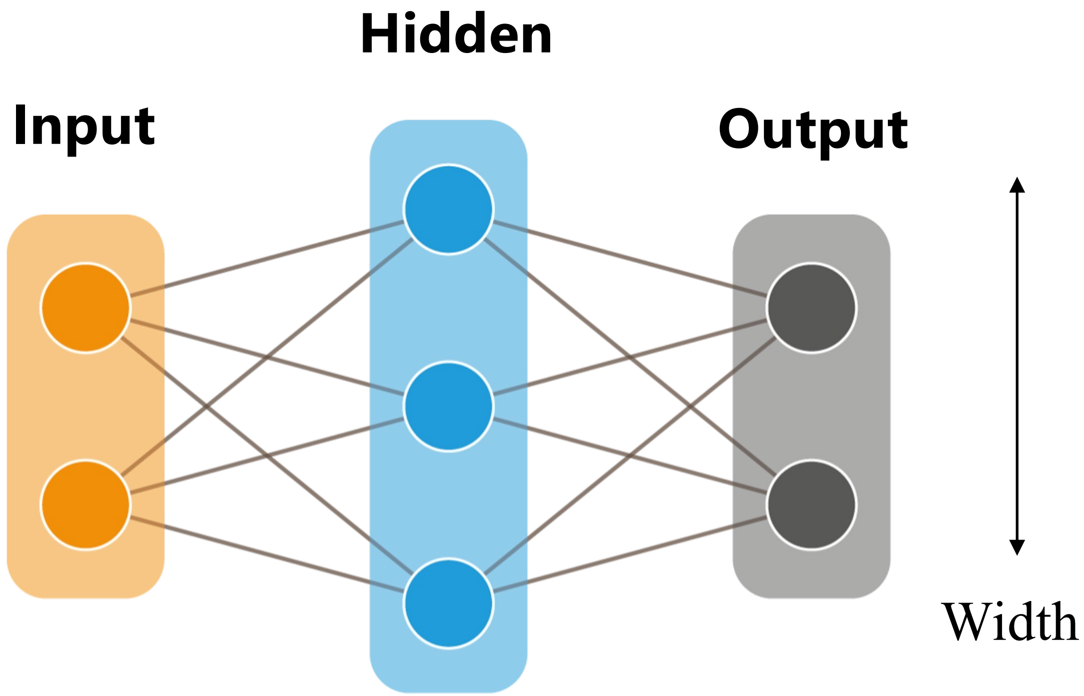
- Stacking of **artificial neurons** to increase the representation capacity

Artificial neuron



https://medium.com/swlh/a-study-of-artificial-neural-networks-ann-7e1f7f2ac891

Neural network



LeCun, Y., Bottou, L., Bengio, Y., & Haffner, P. (1998). Gradient-based learning applied to document recognition. Proceedings of the IEEE, 86(11), 2278-2324.

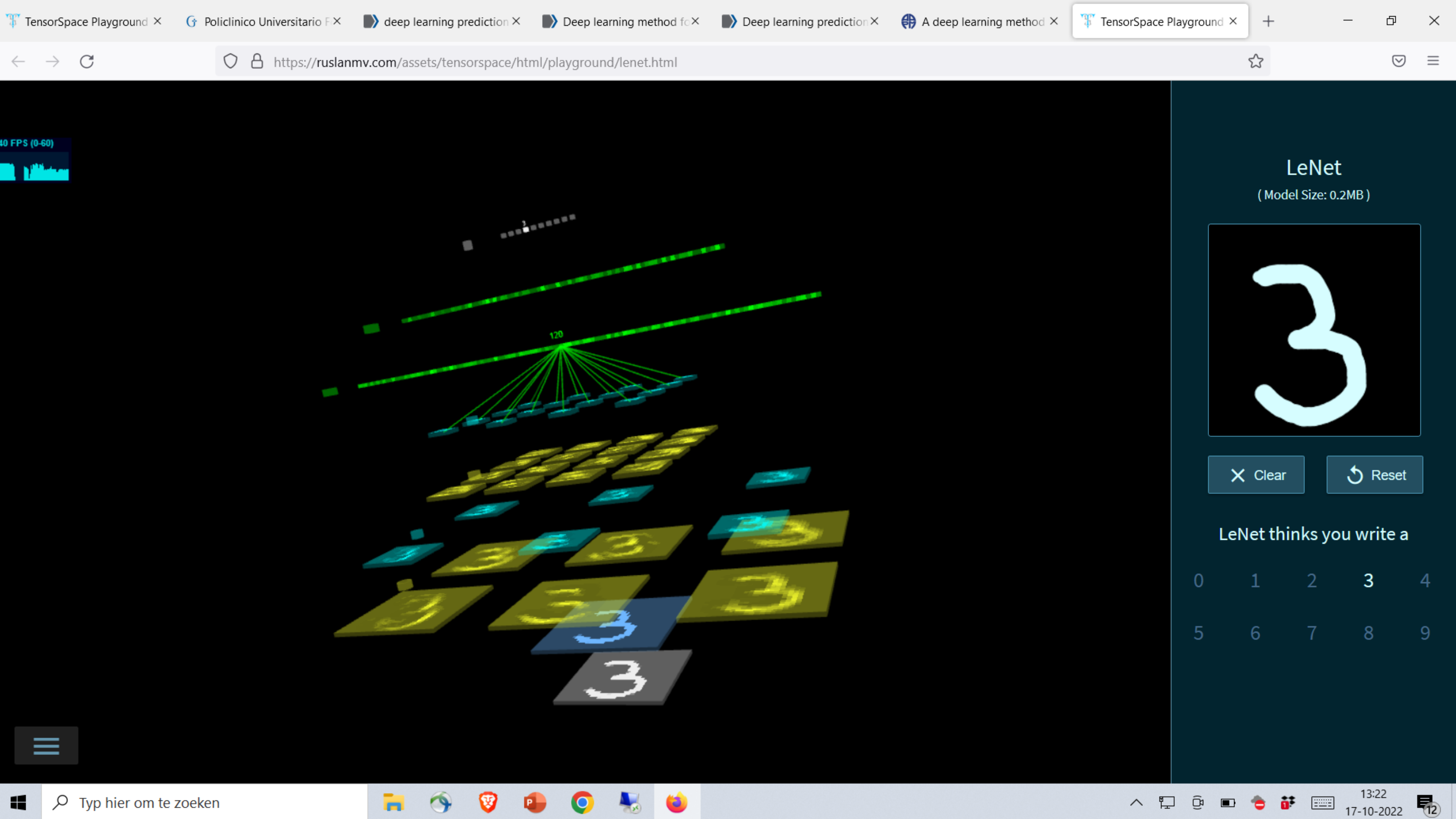
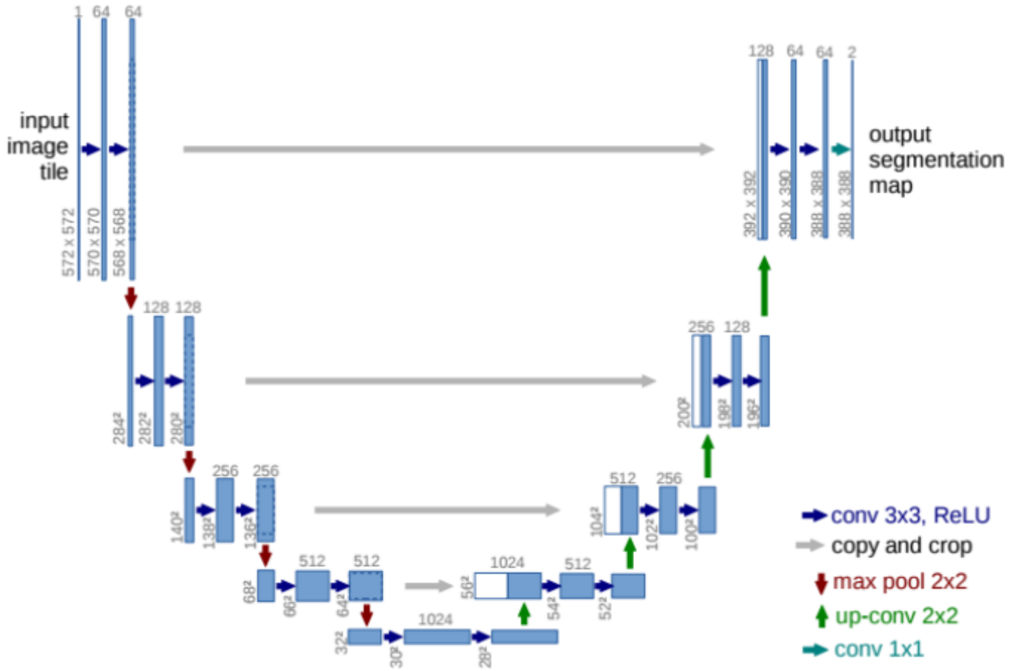

TensorSpace Playground
Policlinico Universitario F
deep learning prediction
Deep learning method fo
Deep learning prediction
A deep learning method
TensorSpace Playground
https://ruslanmv.com/assets/tensorspace/html/playground/lenet.html
40 FPS (0-60)
120
LeNet
(Model Size: 0.2MB)
Clear
Reset
LeNet thinks you write a
0 1 2 3 4
5 6 7 8 9
Typ hier om te zoeken
13:22
17-10-2022

Image -> Image

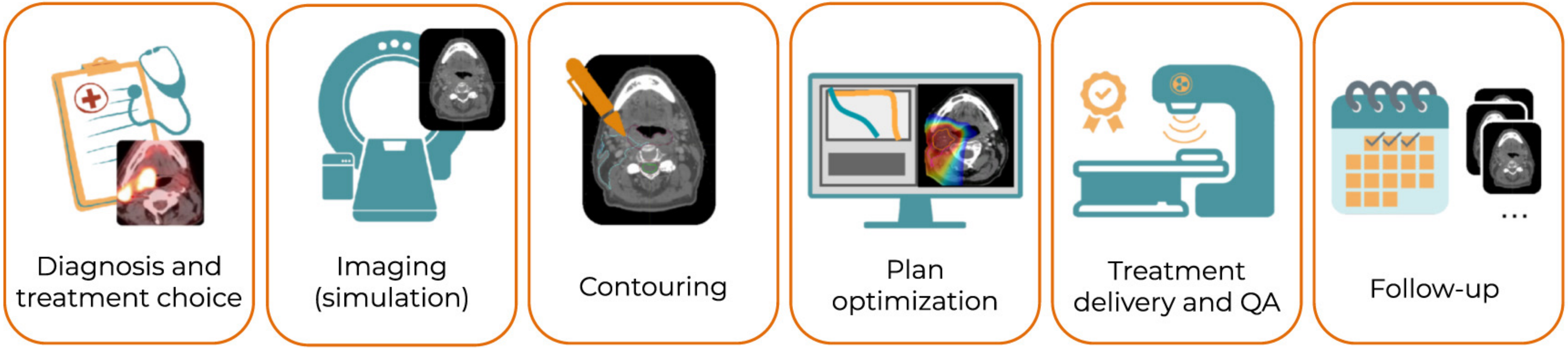
Encoder-decoder architecture: U-Net

- Contracting path
  - Obtain encoding at multiple levels
- Expanding path
  - Combine encodings
  - Decode into segmentations



Ronneberger, O., Fischer, P., & Brox, T. (2015). U-net: Convolutional networks for biomedical image segmentation. In MICCAI (pp. 234-241). Springer, Cham.

The role of imaging in IGRT (and MRgRT)



Target & organs-at-risk definition

CT MRI PET

CT-equivalent for estimating dose distribution in pt

CT MRI

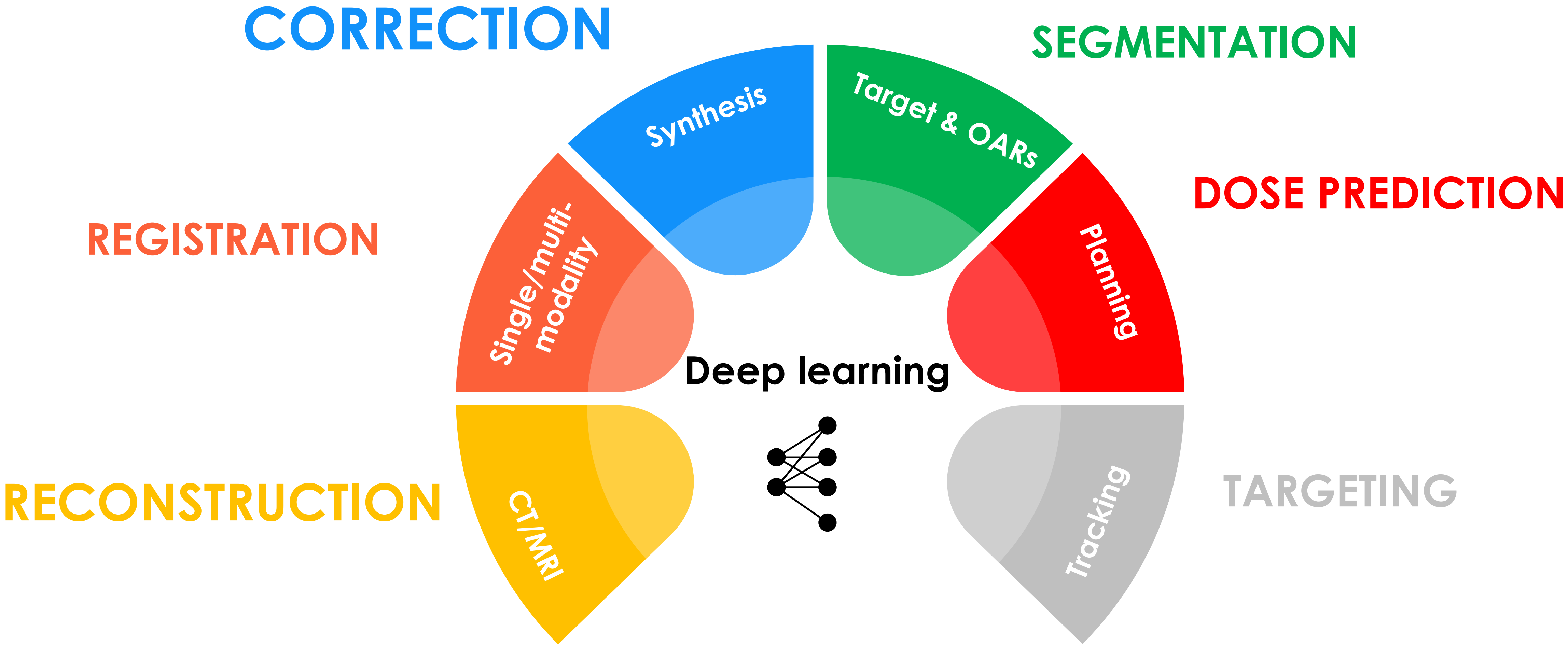
Accurate positioning
Motion management

CT MRI CBCT

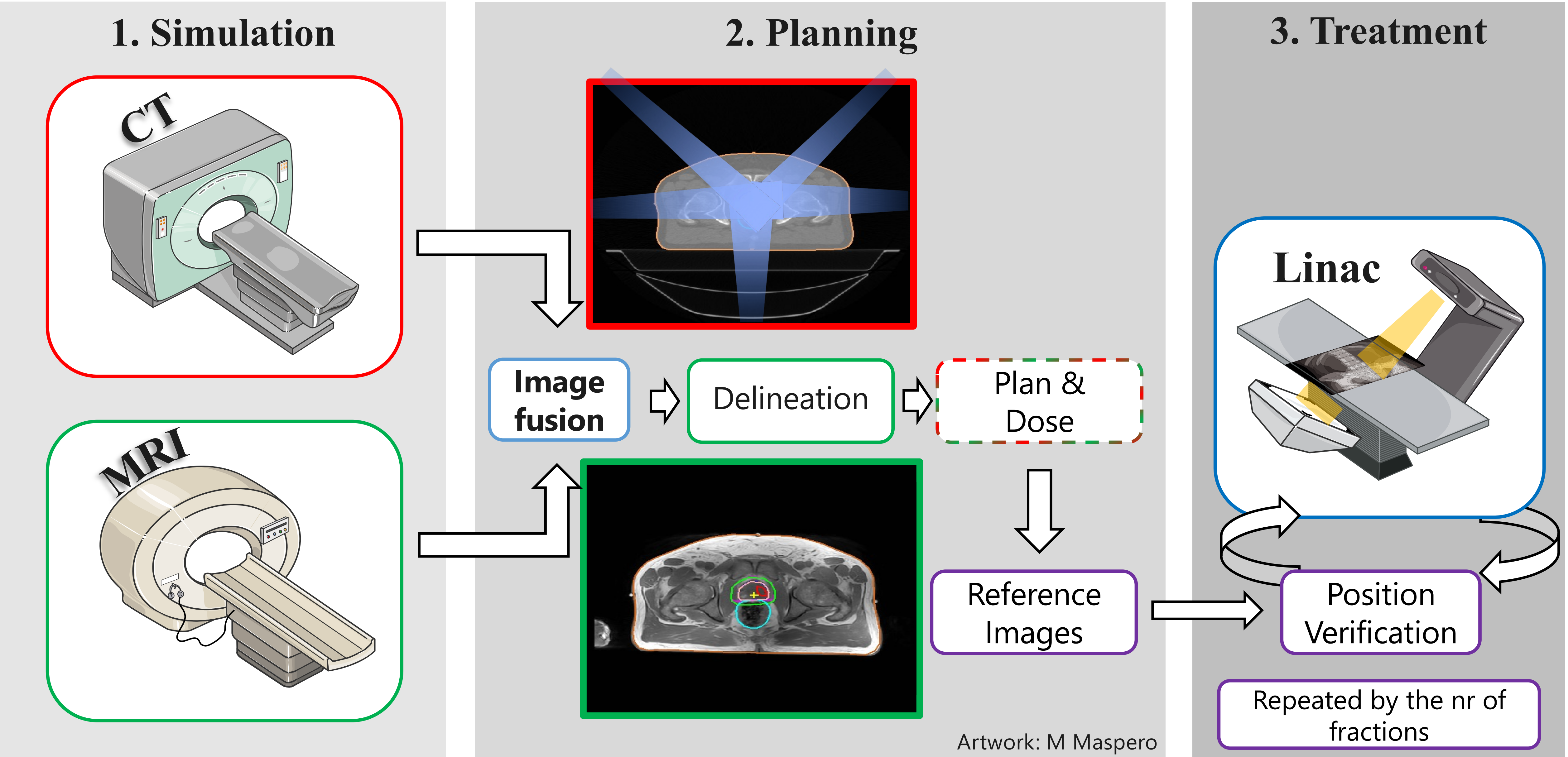
Response assessment

CT MRI PET

Adapted from Barragan-Montero PMB 202

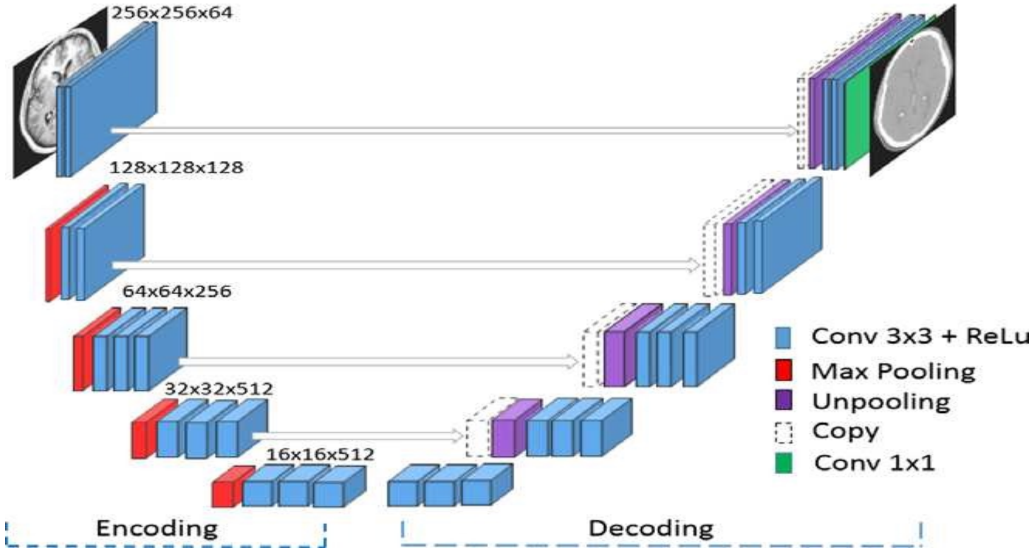

CORRECTION
SEGMENTATION
Synthesis
Target & OARs
DOSE PREDICTION
REGISTRATION
Single/multi-modality
Planning
Deep learning
RECONSTRUCTION
CT/MRI
Tracking
TARGETING

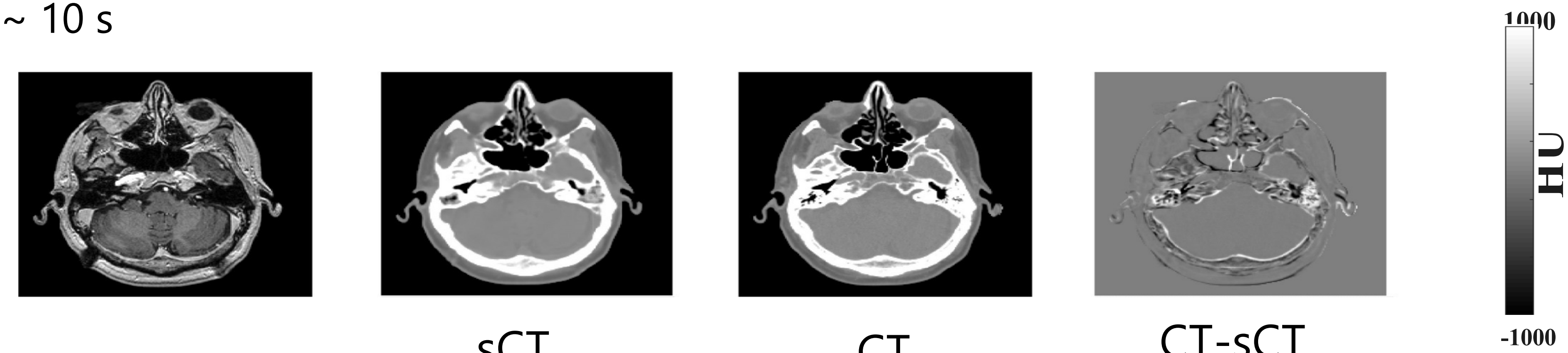
A Radiotherapy workflow...



Brain: first application

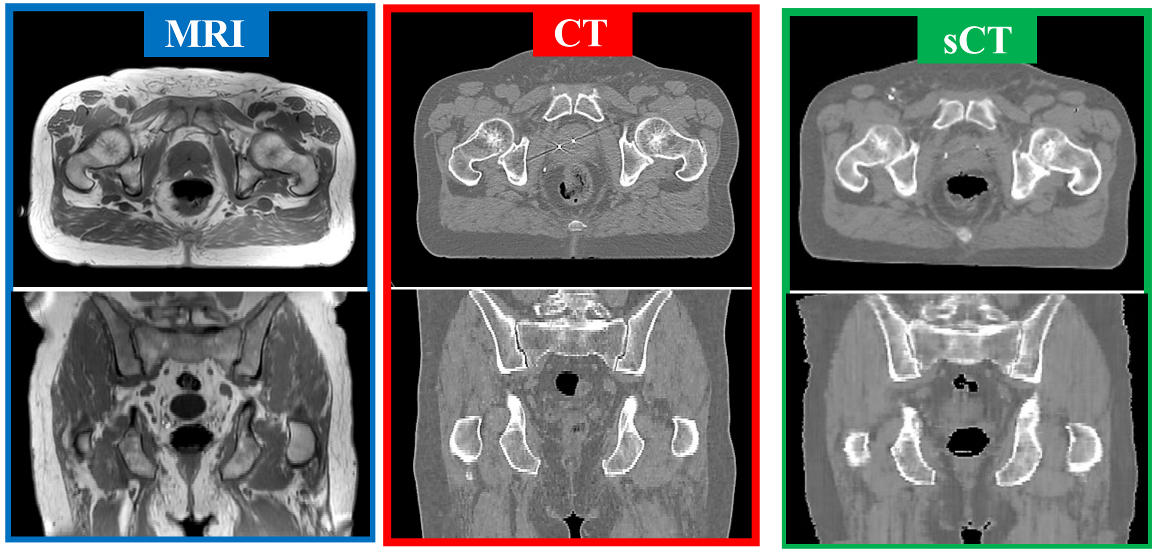
- **Subjects** 18 pts: CT & MR rig reg
- **Methods**
  - 2D U-net
- **Results**
  - MAE 85±17 HU
    vs 95±17 HU [atlas]
  - sCT ~ 10 s



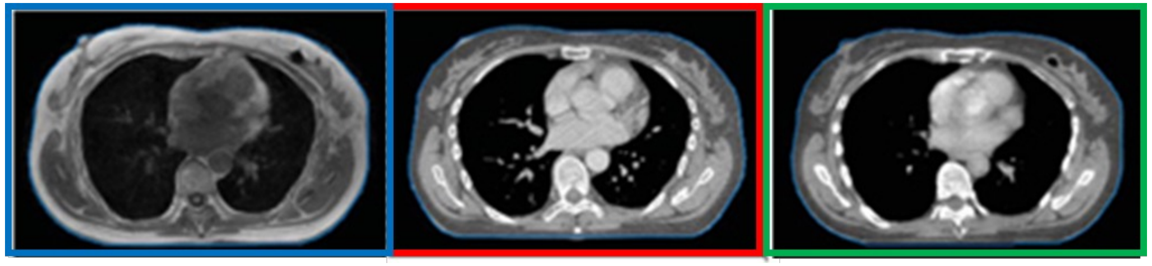


sCT CT CT-sCT

Han X 2017 Med Phys 44(4) https://doi.org/10.1002/mp.12155 ;



Maspero et al. 2018, Phys Med Biol 63(18):185001



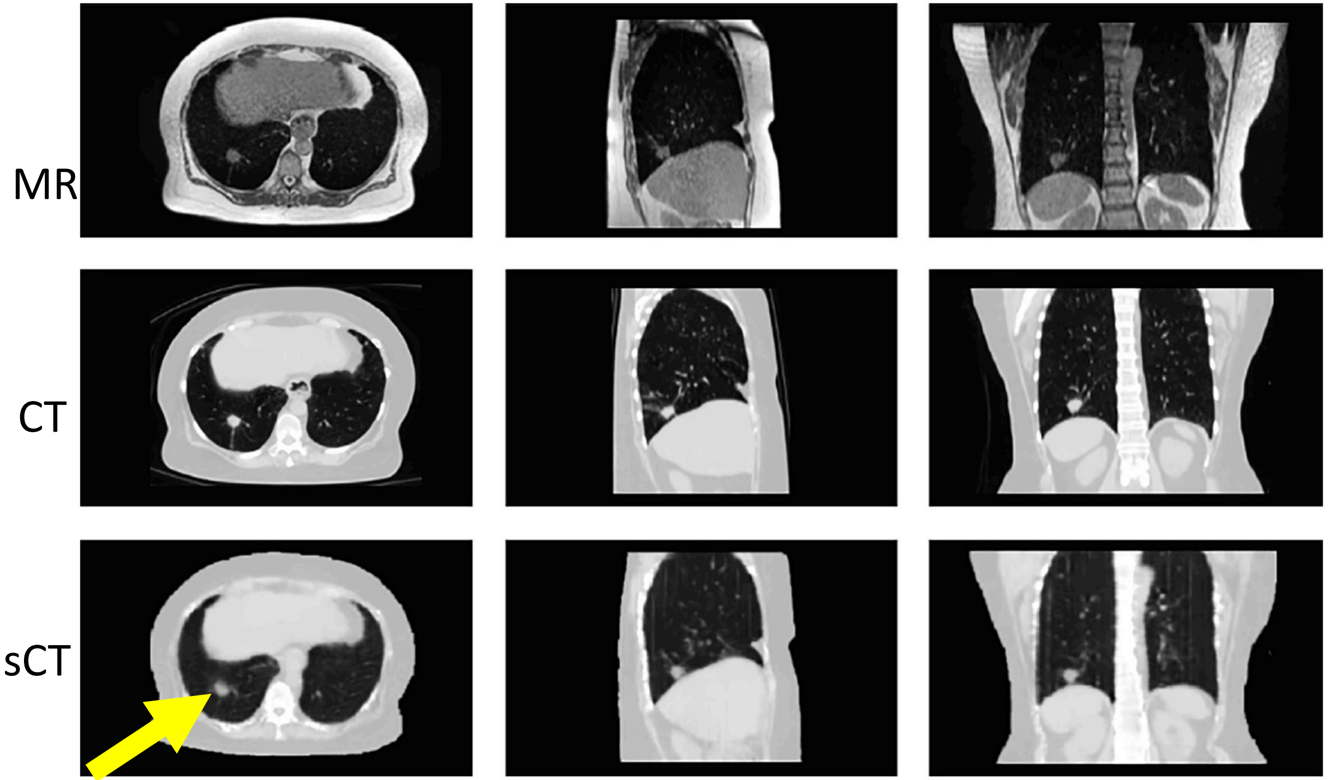
Groot Koerkamp ML et al. Phys Med Biol. 2021 Apr 66(85)

Original Article

A deep learning approach to generate synthetic CT in low field MR-guided radiotherapy for lung cases

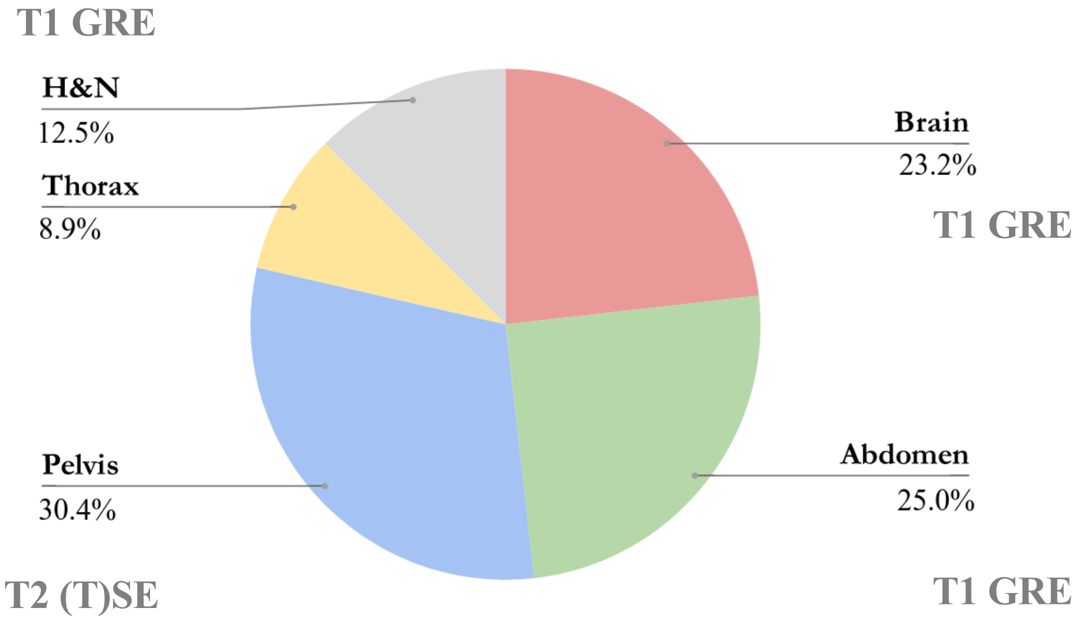
Jacopo Lenkowicz [a], Claudio Votta [a,b,*], Matteo Nardini [a], Flaviovincenzo Quaranta [b], Francesco Catucci [b], Luca Boldrini [a], Marica Vagni [a], Sebastiano Menna [b], Lorenzo Placidi [a], Angela Romano [a], Giuditta Chiloiro [a], Maria Antonietta Gambacorta [a], Gian Carlo Mattiucci [b,c], Luca Indovina [a], Vincenzo Valentini [a,c], Davide Cusumano [a,b]

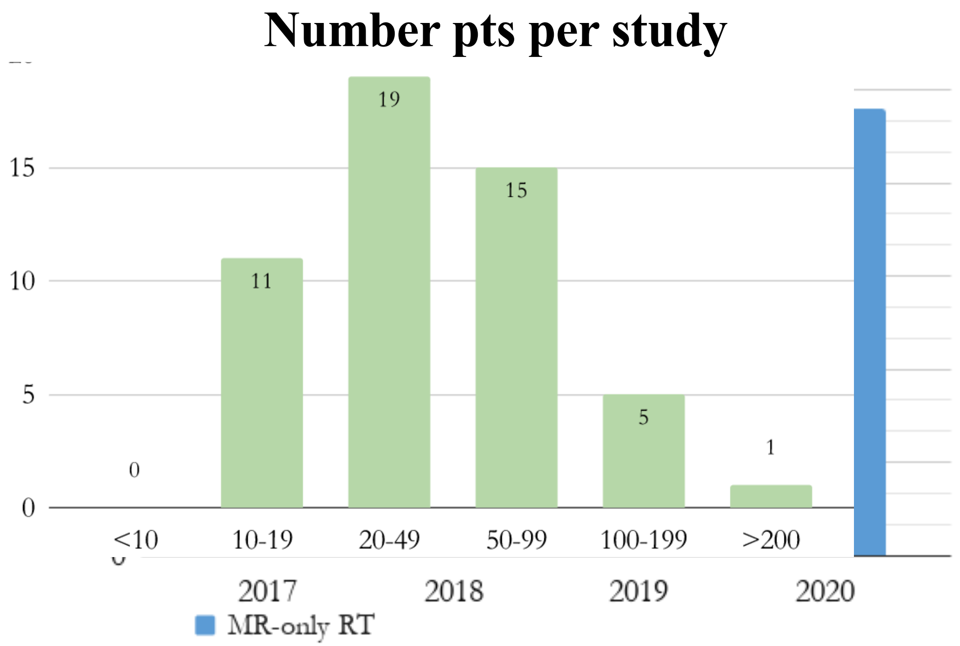
[a] Fondazione Policlinico Universitario "Agostino Gemelli" IRCCS, Rome; [b] Mater Olbia Hospital, Olbia (SS); and [c] Università Cattolica del Sacro Cuore, Rome, Italy



Lenkowicz *et al.* R&O 2022

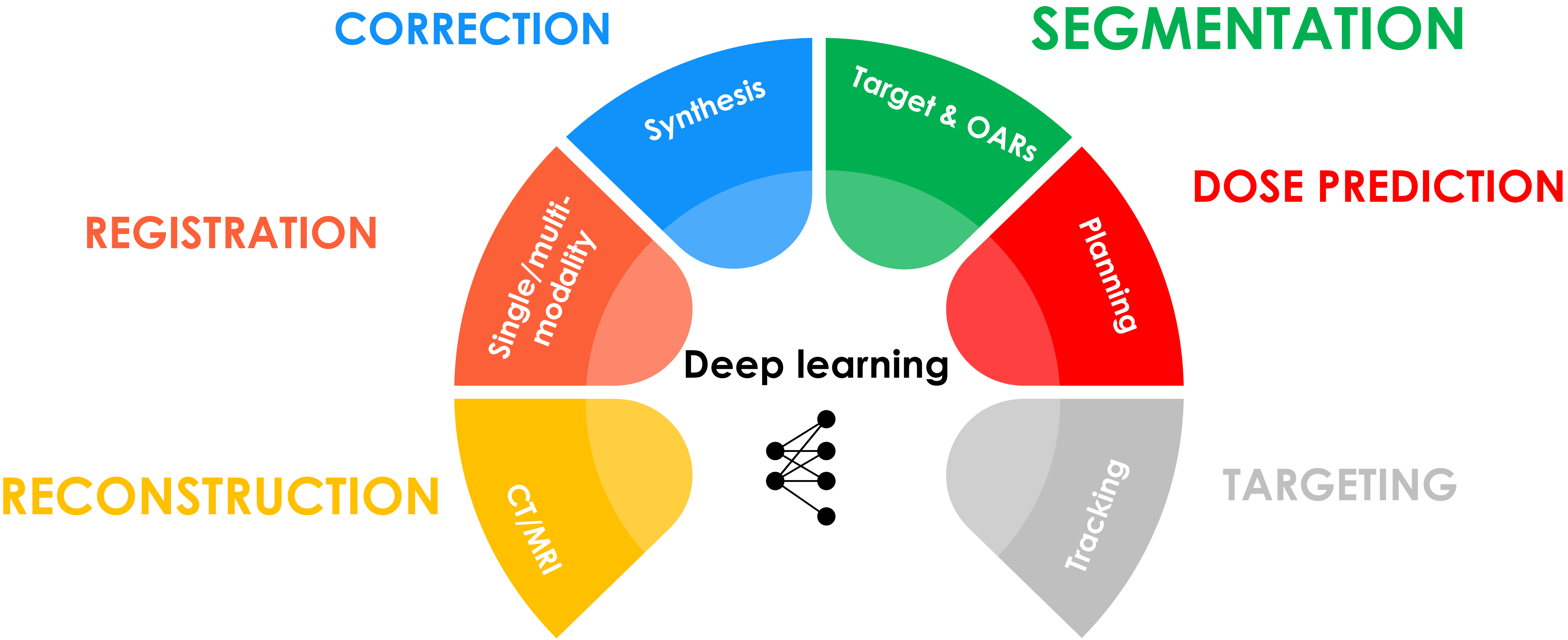
sCT generation with deep-learning <2021





- >50 studies, first multi-centers
- Synthetic CT can be used for dose calculations
- Four commercial products with DL → clinically available and implemented in simulation, still simpler solutions are adopted for MRgRT

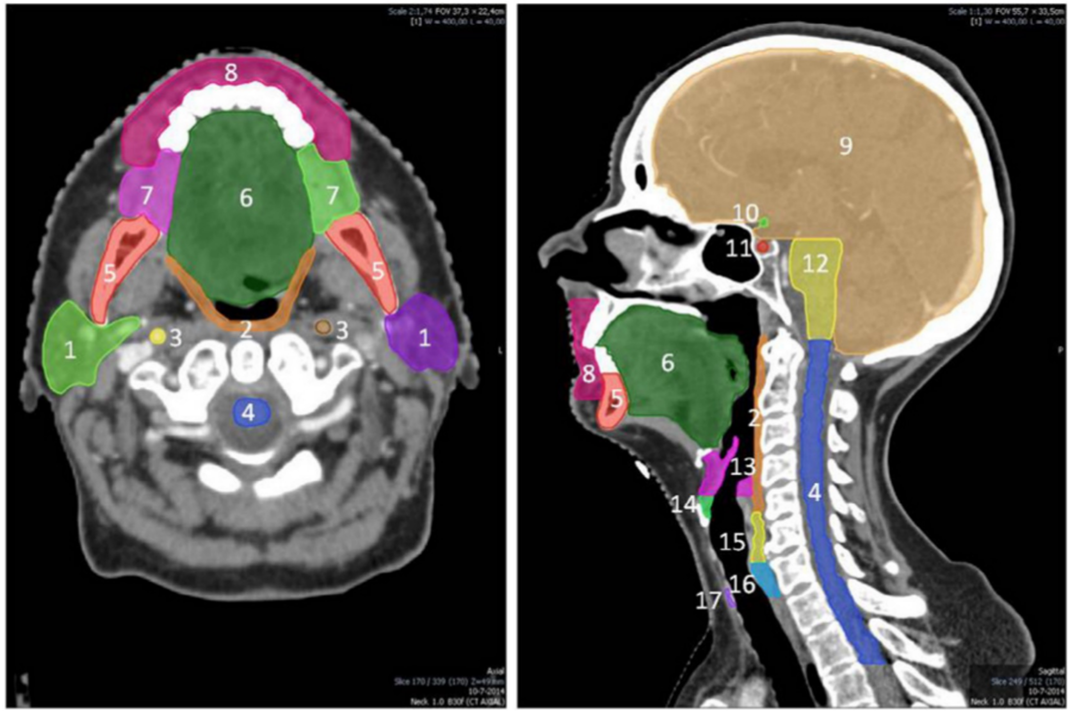
Spadea MF & Maspero M et al. Med Phys 2021


CORRECTION
SEGMENTATION
REGISTRATION
DOSE PREDICTION
RECONSTRUCTION
TARGETING
Synthesis
Target & OARs
Single/multi-
modality
Planning
CT/MRI
Tracking
Deep learning

Contouring in RT

Segmenting OARs and targets

- Laborious and time-consuming
- Impacting personnel availability
- Limiting step in adaptive RT



Brouwer Radiother Oncol 2015

OAR on MRI prostate

First segmentation project 2018…

Motivation

MRI-based software was not available

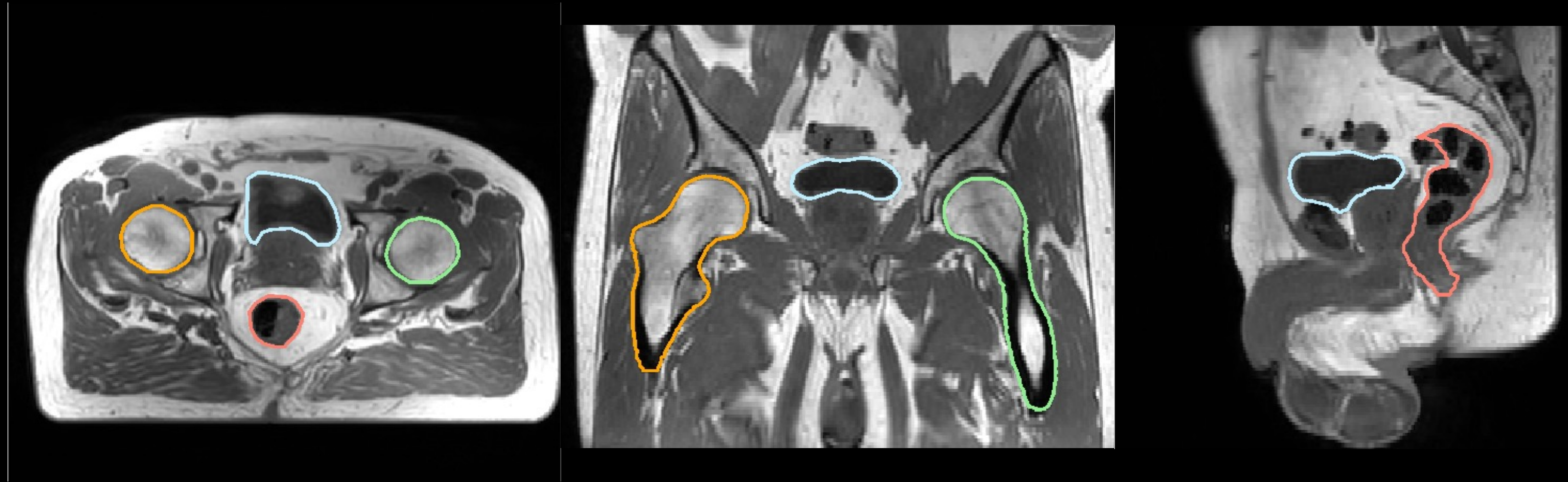
Savenije *et al. Radiation Oncology* (2020) 15:104
https://doi.org/10.1186/s13014-020-01528-0

Radiation Oncology

RESEARCH Open Access

Clinical implementation of MRI-based organs-at-risk auto-segmentation with convolutional networks for prostate radiotherapy

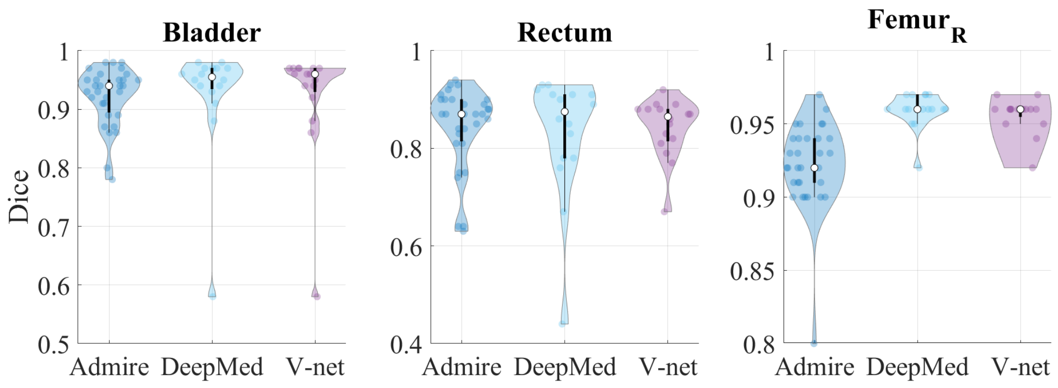
Mark H. F. Savenije[1,2†], Matteo Maspero[1,2*†], Gonda G. Sikkes[1], Jochem R. N. van der Voort van Zyp[1], Alexis N. T. J. Kotte[1], Gijsbert H. Bol[1] and Cornelis A. T. van den Berg[1,2]

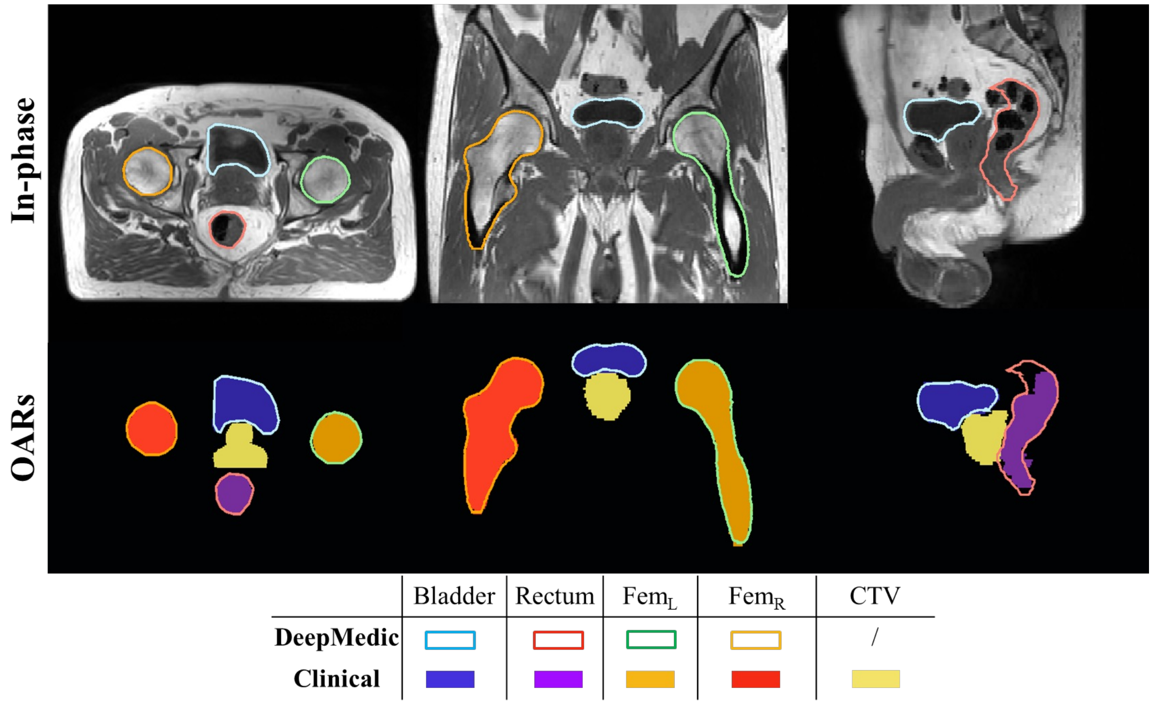


$Prostate_{MRI}$
Bladder
Rectum
$Femur_{R/L}$
Prostate

Savenije M & Maspero M Radiat Oncol 2020

Results: quantitative comparison



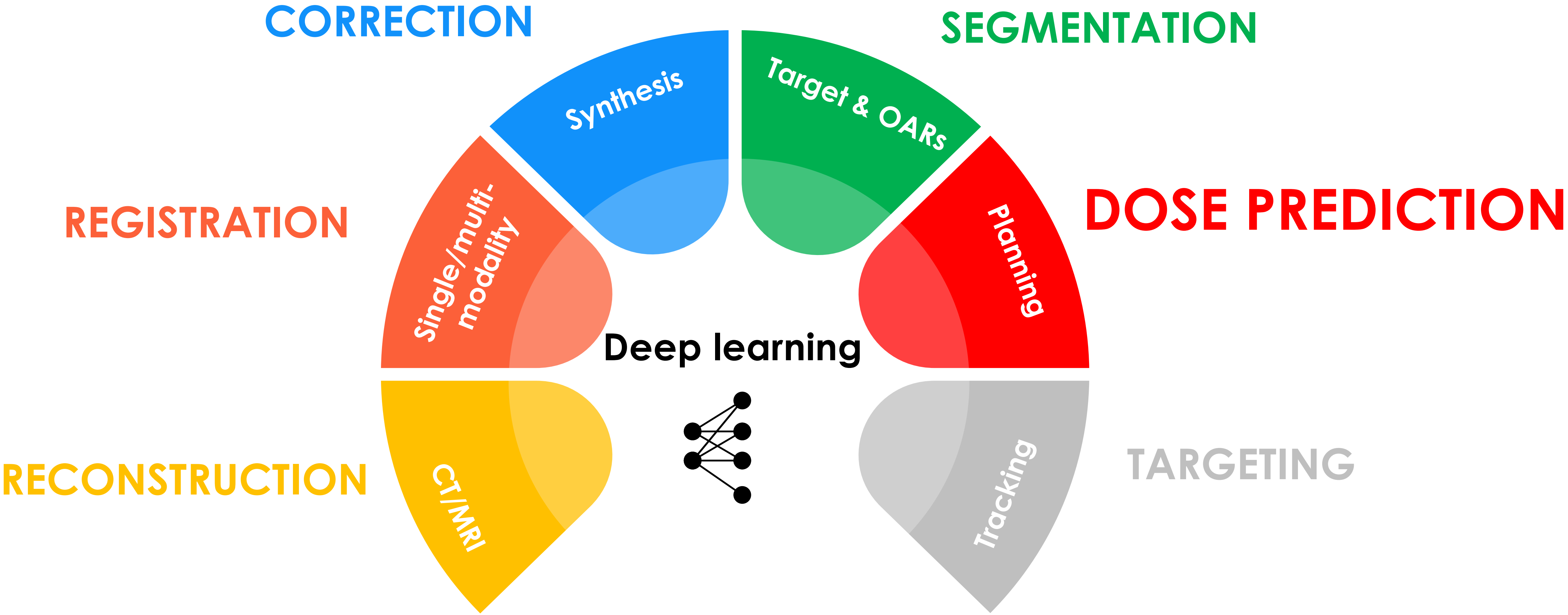


DL outperformed atlas-based solutions

Savenije M & Maspero M Radiat Oncol 2020

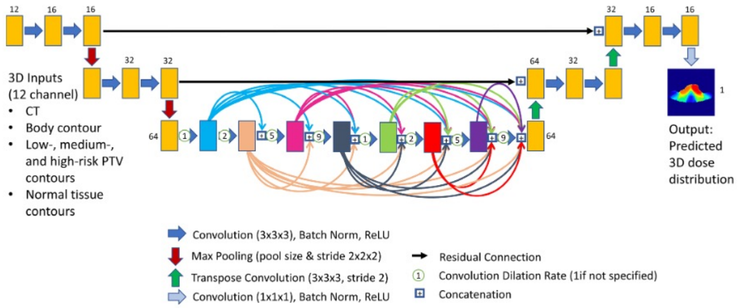
Overview company with DL-based segmentation

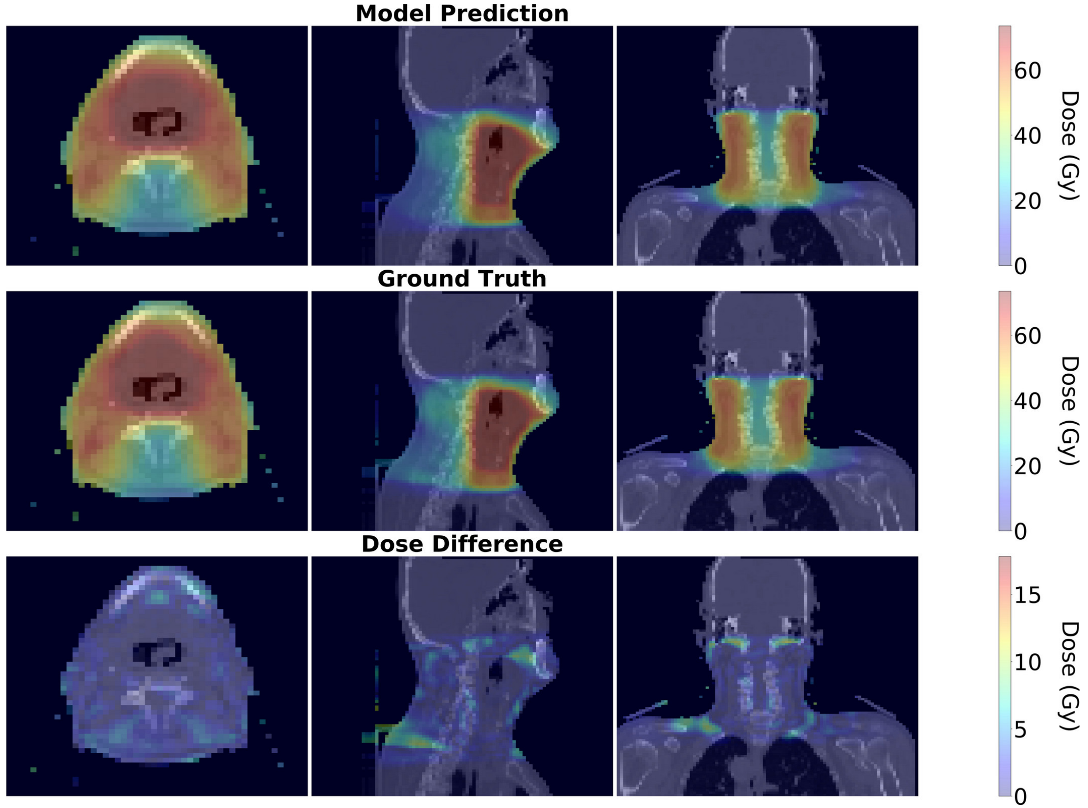
- CARINA
- DEEP VOXEL
- Limbus AI
- MEDCOM visions. innovations. solutions.
- mim SOFTWARE
- MIRADA The Imaging Software People
- MVISION - AI for Precision Radiotherapy -
- PHILIPS
- RAD formation
- RaySearch Laboratories
- SIEMENS Healthineers
- SPECTRONIC MEDICAL
- SYNAPTIQ COLLECTIVE INTELLIGENCE
- THERAPANACEA Reinventing cancer care through AI


CORRECTION
Synthesis
SEGMENTATION
Target & OARs
REGISTRATION
Single/multi-modality
DOSE PREDICTION
Planning
Deep learning
RECONSTRUCTION
CT/MRI
TARGETING
Tracking

DL used for dose prediction

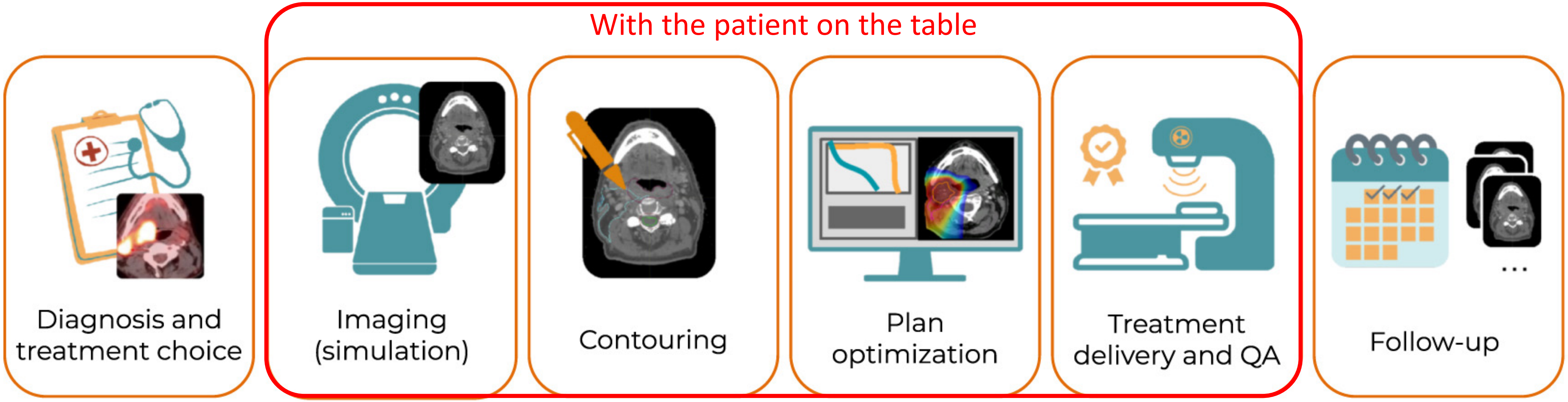
Dr. Nuria Jornet
OMICS &AI in H&N cancer





Medical Physics, Volume: 48, Issue: 9, Pages: 5567-5573, First published: 22 June 2021, DOI: (10.1002/mp.14827)

The online RT workflow

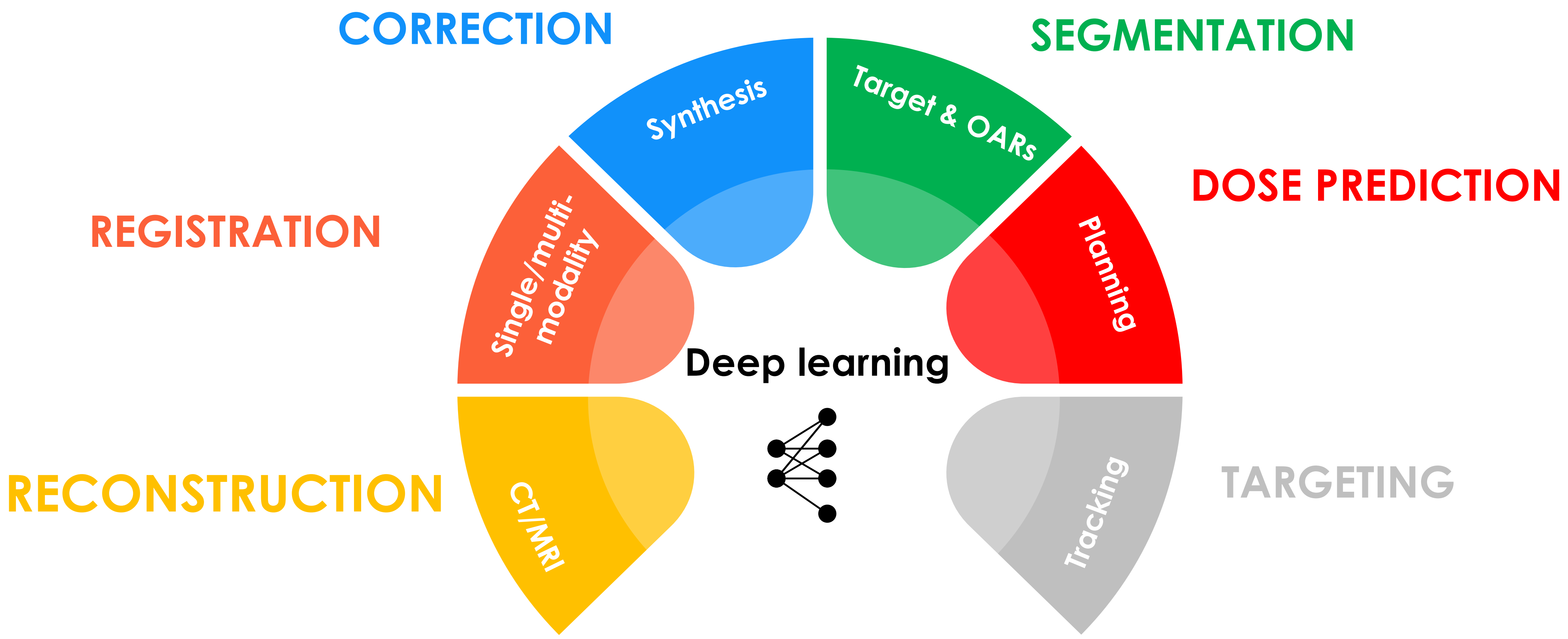


Adapted from Barragan-Montero PMB 2022

Current fraction = 40-55 min*

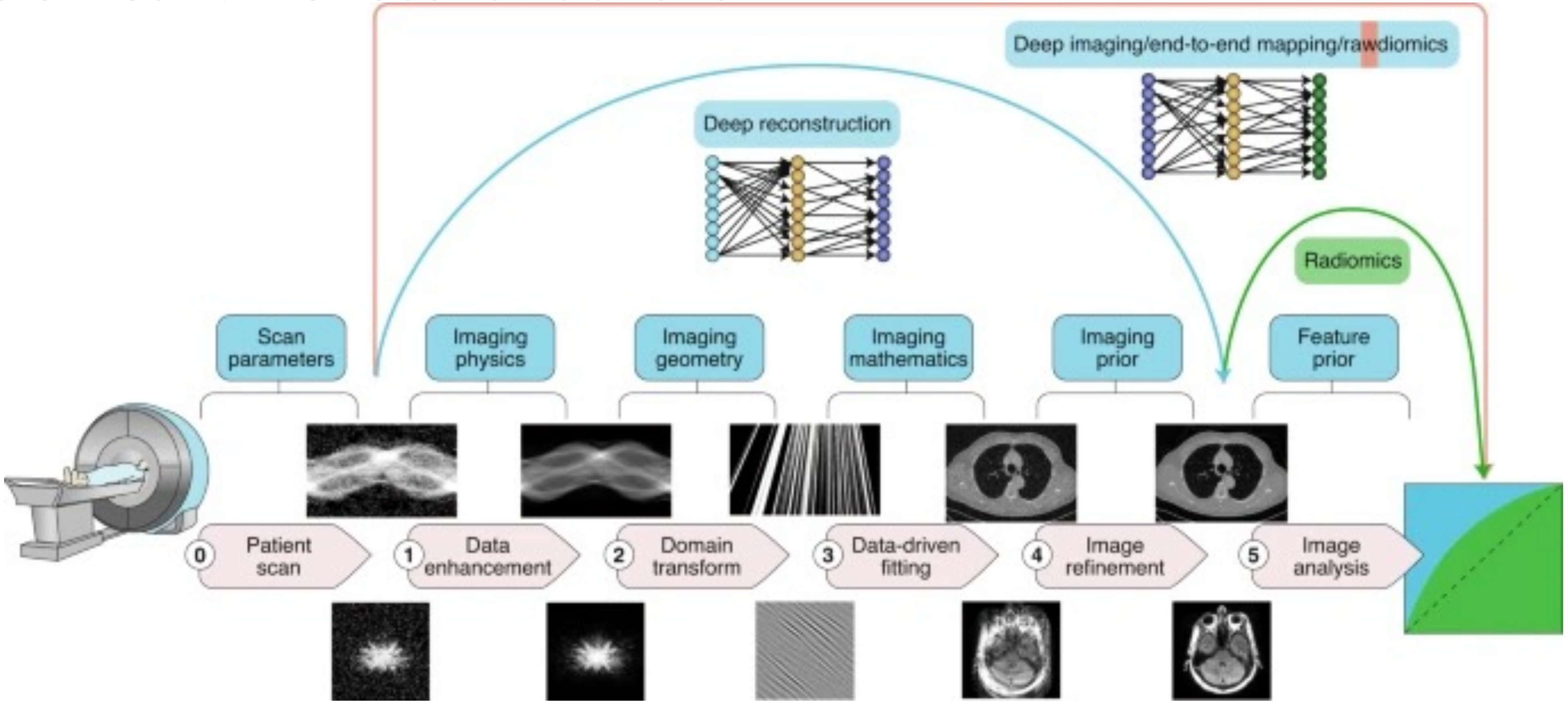
Desired = < 15 min → in-line with standard RT

*Gungor Prat radiat Oncol 2021

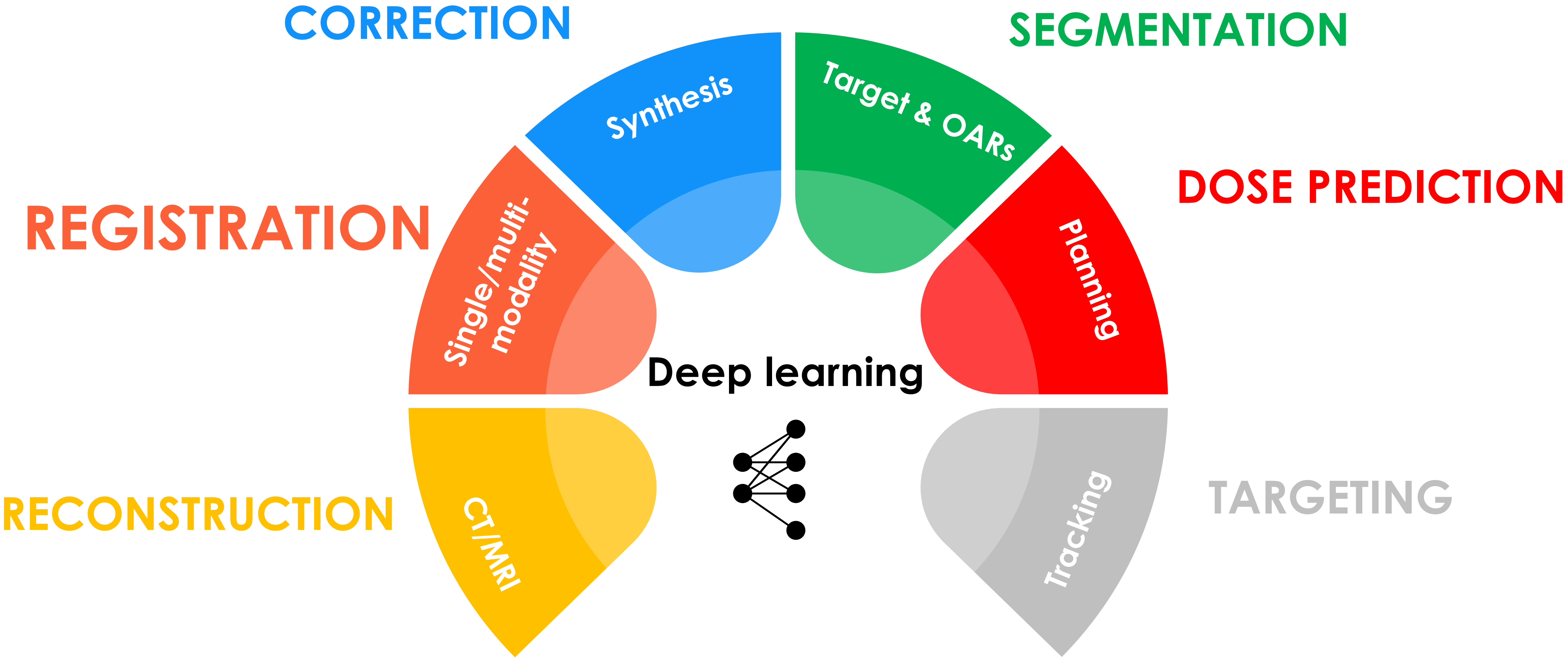

CORRECTION
SEGMENTATION
Synthesis
Target & OARs
DOSE PREDICTION
REGISTRATION
Single/multi-
modality
Planning
Deep learning
RECONSTRUCTION
CT/MRI
Tracking
TARGETING

Increasing image quality with DL reconstruction

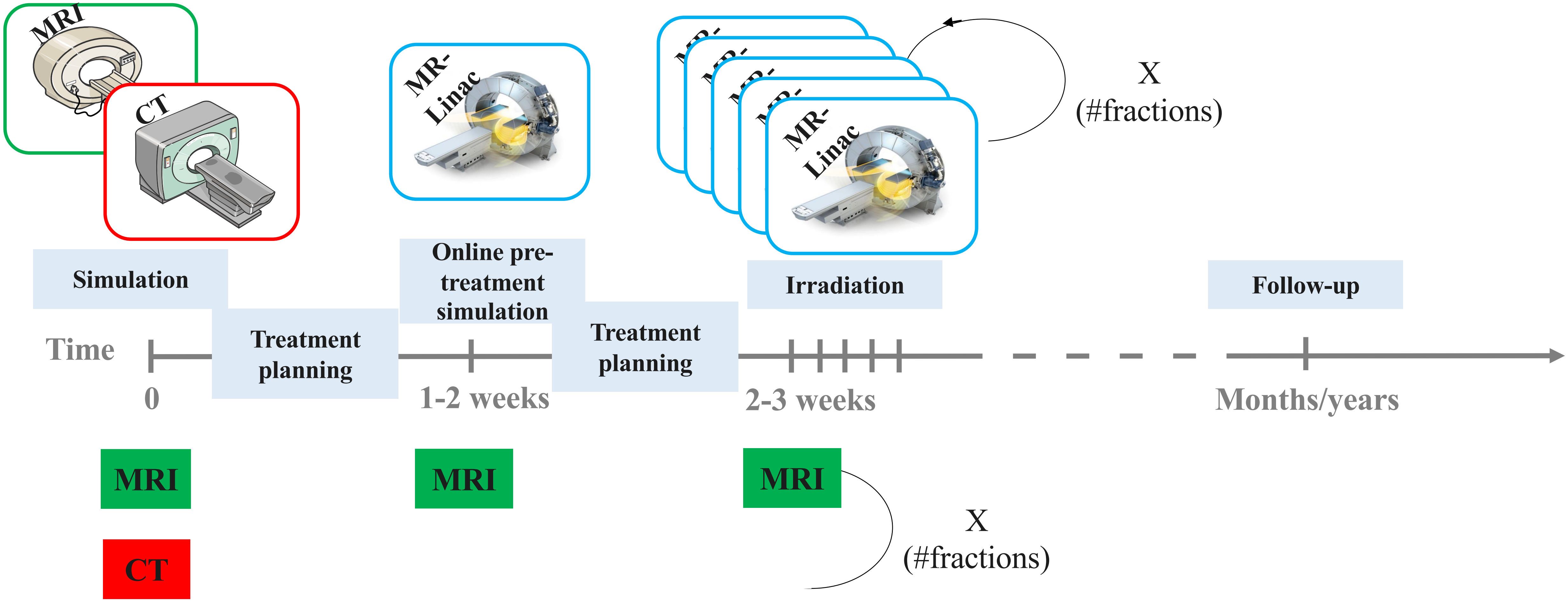
- DL as a way to incorporate priors
- Capable of real-time reconstructions



Wang, G., et al. *Nat Mach Intell* 2020

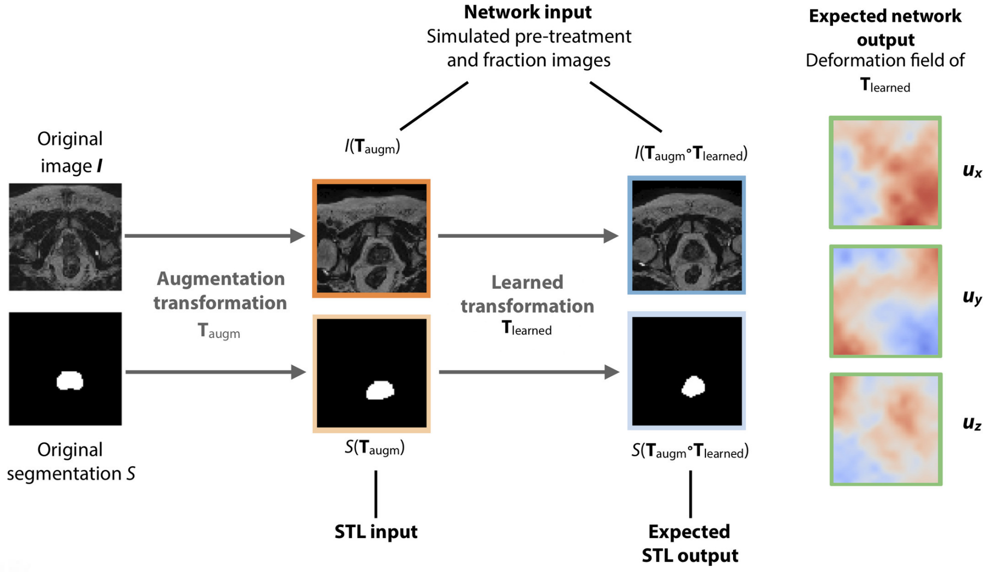

CORRECTION
Synthesis
SEGMENTATION
Target & OARs
REGISTRATION
Single/multi-
modality
DOSE PREDICTION
Planning
Deep learning
RECONSTRUCTION
CT/MRI
TARGETING
Tracking

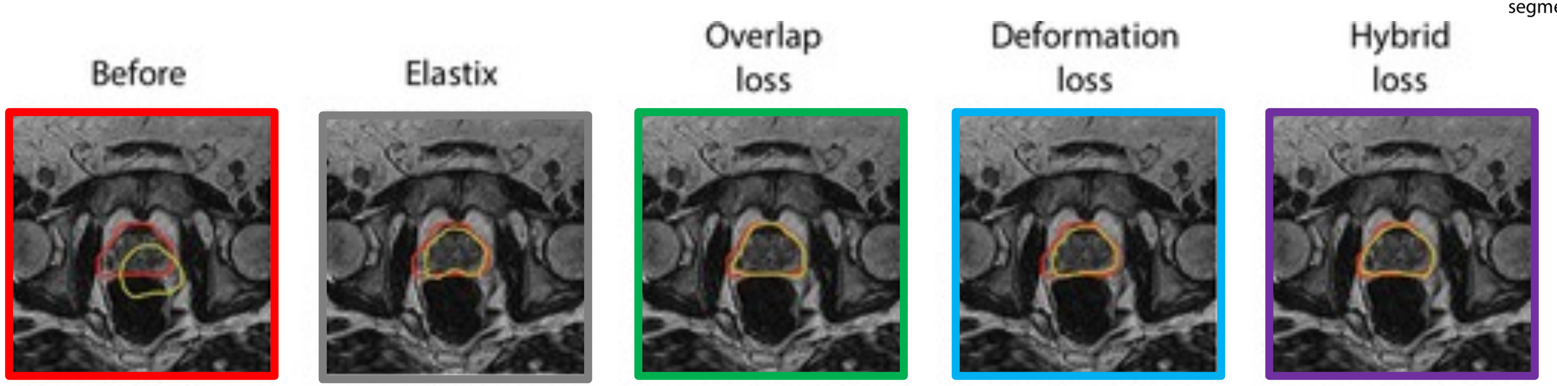
Contour propagation for Online adaptive RT

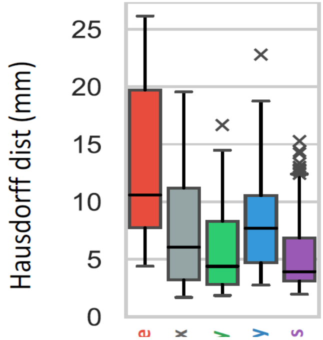


Contour propagation for MRgRT prostate

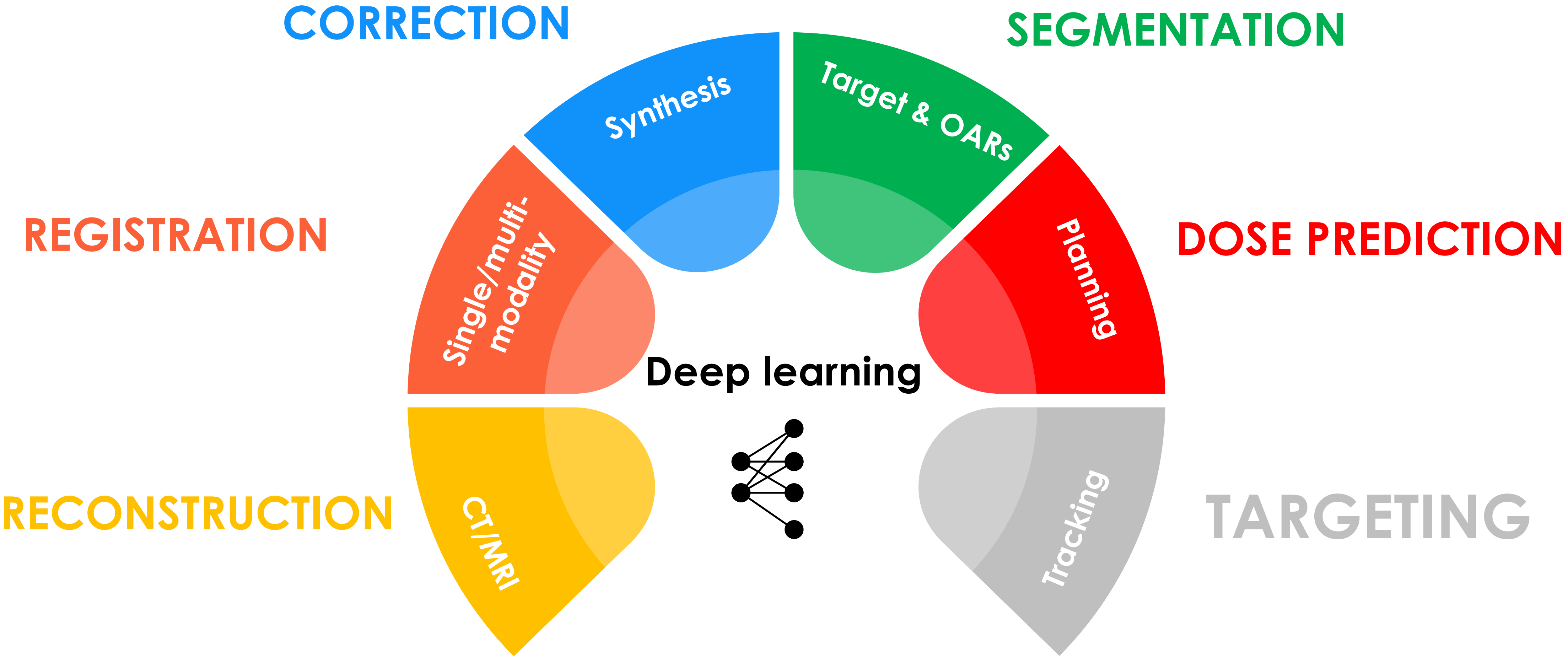
- Registration from pre-treatment to daily fraction for the target
- Comparison of weakly vs strongly supervised or **Hybrid**
- Deep learning outperforming classical registration





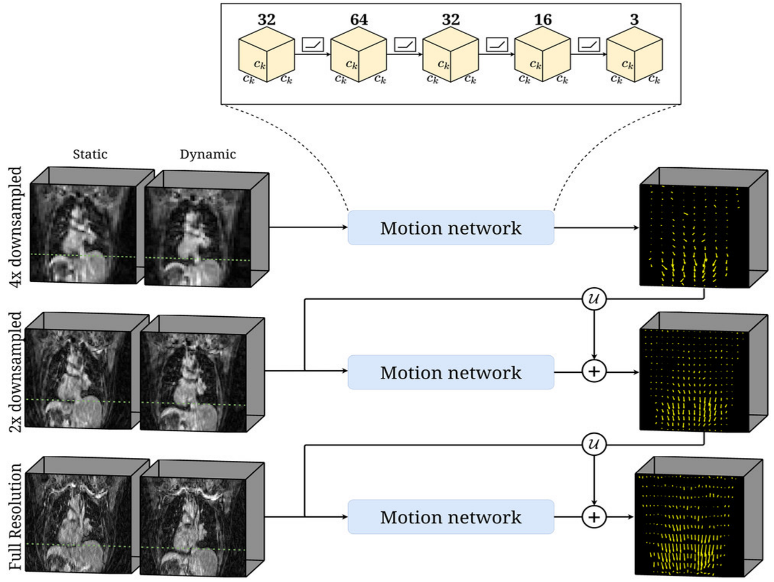


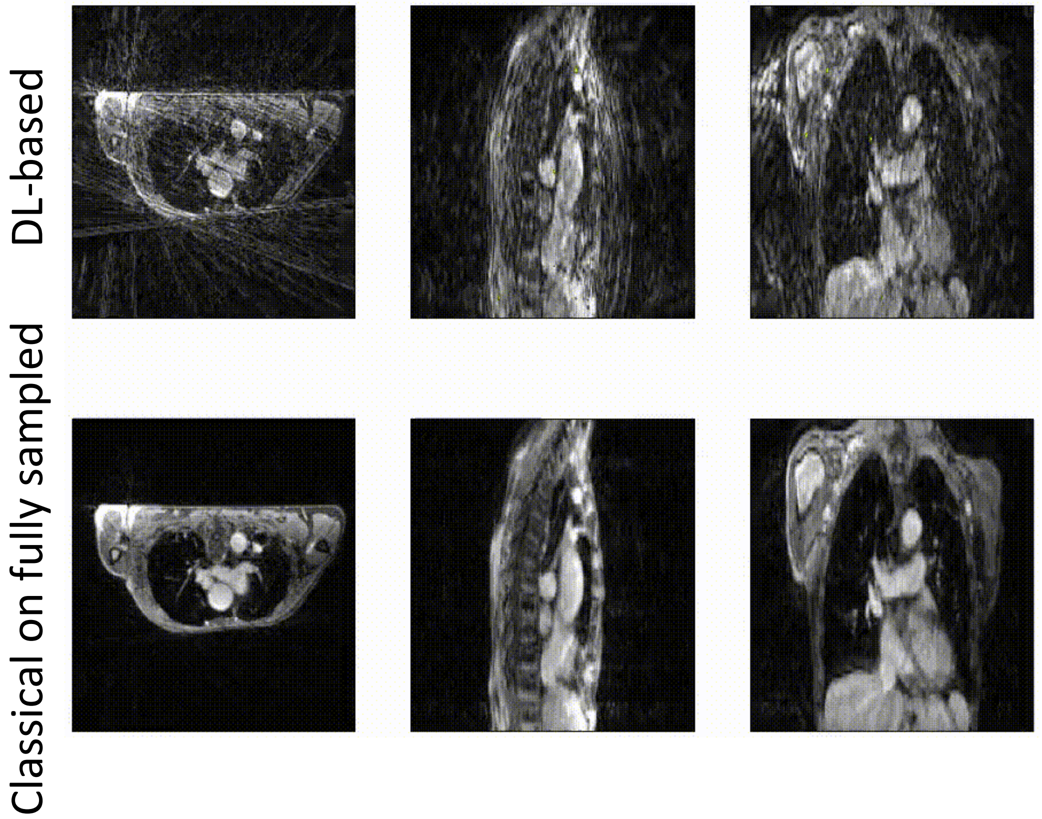
Eppenhof K et al. Med Phys 2020


CORRECTION
SEGMENTATION
REGISTRATION
DOSE PREDICTION
RECONSTRUCTION
TARGETING
Synthesis
Target & OARs
Single/multi-modality
Planning
CT/MRI
Tracking
Deep learning

Real time 3D motion estimation

- Undersample 4D MRI
- Multi-resolution approach
  - → registration = 30 ms in 3D
  - → manage to deal with artifacts
  - → 1.5 mm mean error





Terpstra M et al. Med Phys 2021

Conclusions

- **DL applications have found solid ground in Radiation Oncology workflows**
  - **Image segmentation**
  - **Image synthesis**
  - **Dose prediction**
  - **Image reconstruction**
  - **Deformable image registration**

- **Training is slow (need lots of data for each task)**
- **Inference is *fast***

- **Increase use of DL in online adaptive workflows**

Acknowledgments: Matteo Maspero