Emerging Data-Driven Approaches for Treatment Planning

Frontiers in AI and Its Applications in Medical Physics

Tom Purdie, PhD, MCCPM
Princess Margaret Cancer Centre

UNIVERSITY OF TORONTO

TECHNA

UHN Toronto General Toronto Western Princess Margaret Toronto Rehab

Disclosures

Method and System for Automated Planning of Radiation Therapy technology patented in PCT/CA2011/001130

Automated Quality Assurance (QA) and Planning technology patented in WO2014197994 A1

Receive royalties from RaySearch Laboratories for license of technology for Automated Breast Treatment Planning and Machine Learning-based Automated Treatment Planning

Have an equity interest in an AI healthcare startup, licensee of technology for Machine Learning-based for Automated Quality Assurance in Radiation Oncology

RaySearch Laboratories

Outline

Applications of Artificial Intelligence (AI) and Machine Learning (ML)

Machine Learning Architectures/Methods

- Convolution Neural Networks (CNNs) → U-Net
- Generative Adversarial Networks
- Reinforcement Learning
- Atlas Regression Forest

Open Knowledge Based Planning (KBP) Challenge

AI to Infer New Knowledge

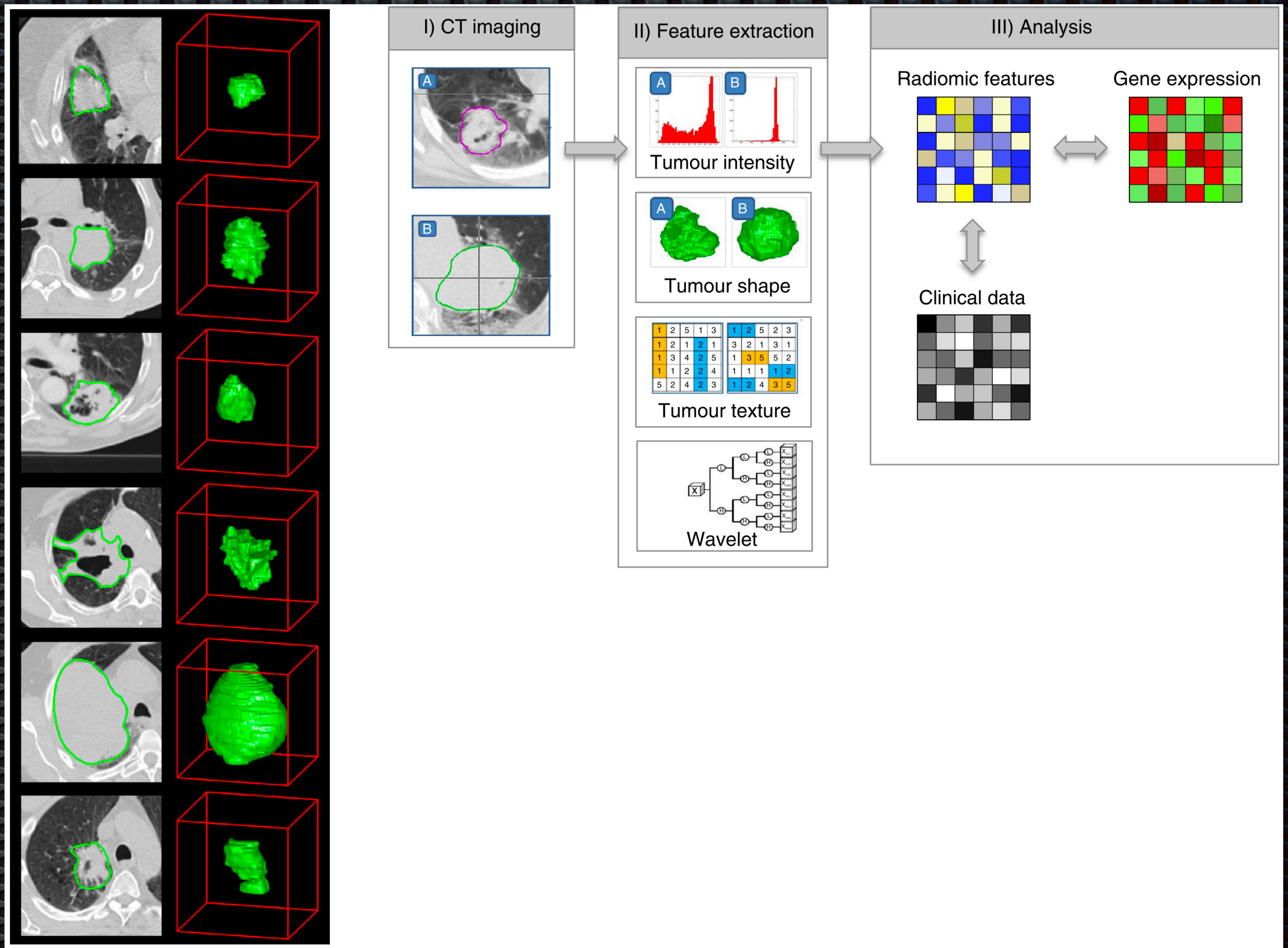
nature COMMUNICATIONS

ARTICLE

Received 25 Nov 2013 | Accepted 29 Apr 2014 | Published 3 Jun 2014 | Updated 7 Aug 2014 DOI: 10.1038/ncomms5006 OPEN

Decoding tumour phenotype by noninvasive imaging using a quantitative radiomics approach

Hugo J.W.L. Aerts[1,2,3,4,*], Emmanuel Rios Velazquez[1,2,*], Ralph T.H. Leijenaar[1], Chintan Parmar[1,2], Patrick Grossmann[2], Sara Carvalho[1], Johan Bussink[5], René Monshouwer[5], Benjamin Haibe-Kains[6], Derek Rietveld[7], Frank Hoebers[1], Michelle M. Rietbergen[8], C. René Leemans[8], Andre Dekker[1], John Quackenbush[4], Robert J. Gillies[9] & Philippe Lambin[1]



- AI recognizes complex data in images and can give quantitative metrics
- **Radiomics** → High throughput extraction of quantitative image features (non-human detectable) for biomarker discovery

Aerts et al. Nat Commun 2014

AI to Make Predictions → Replicate Human Tasks

LETTER

doi:10.1038/nature21056

Dermatologist-level classification of skin cancer with deep neural networks

Andre Esteva[1]*, Brett Kuprel[1]*, Roberto A. Novoa[2,3], Justin Ko[2], Susan M. Swetter[2,4], Helen M. Blau[5] & Sebastian Thrun[6]

[1]Department of Electrical Engineering, Stanford University, Stanford, California, USA. [2]Department of Dermatology, Stanford University, Stanford, California, USA. [3]Department of Pathology, Stanford University, Stanford, California, USA. [4]Dermatology Service, Veterans Affairs Palo Alto Health Care System, Palo Alto, California, USA. [5]Baxter Laboratory for Stem Cell Biology, Department of Microbiology and Immunology, Institute for Stem Cell Biology and Regenerative Medicine, Stanford University, Stanford, California, USA. [6]Department of Computer Science, Stanford University, Stanford, California, USA.
*These authors contributed equally to this work.

2 FEBRUARY 2017 | VOL 542 | NATURE | 115

AI algorithm tested for diagnosing skin lesions representing the most common and deadliest skin cancers with 21 board-certified dermatologists used as control

Bottom line

AI Algorithm matched the performance of dermatologists

AI to Create New Processes

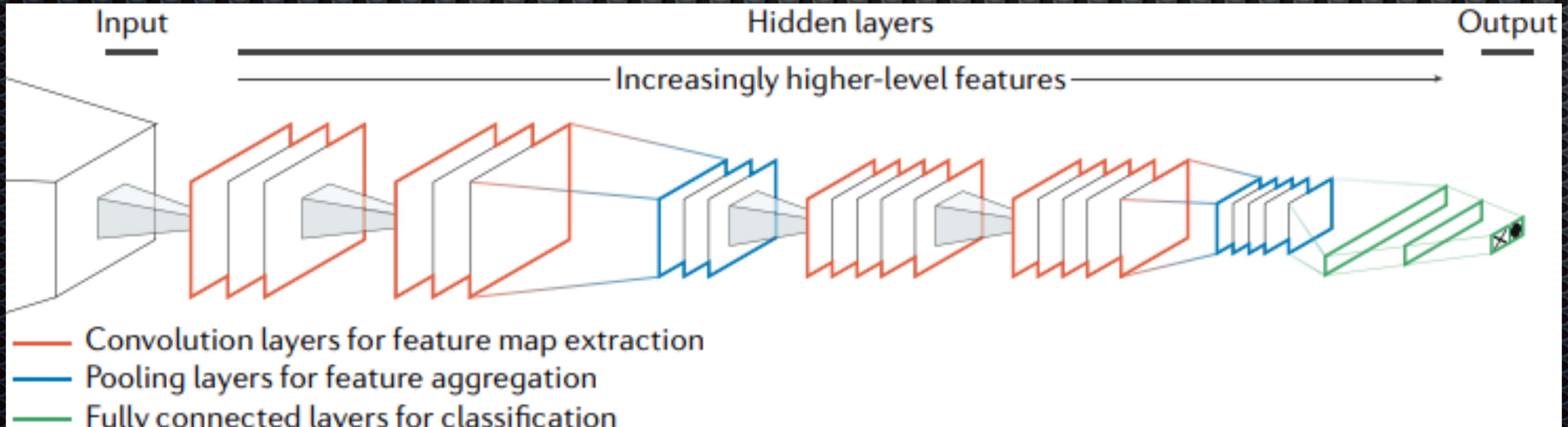
Dose Prediction for Automated Treatment Planning

The "Black Box"

Convolutional Neural Networks (CNNs)

- Learns from very complex data, like medical images
- Automatically generates relevant features in systematic way

Source: Machine Learning for Humans, Vishal Maini and Samer Sabri. https://medium.com/machine-learning-for-humans



Source: Hosny et al., Artificial Intelligence in radiology. Nat Rev Cancer 2018

Courtesy of Leigh Conroy

AI *for* the Clinic ➔ AI *in* the Clinic

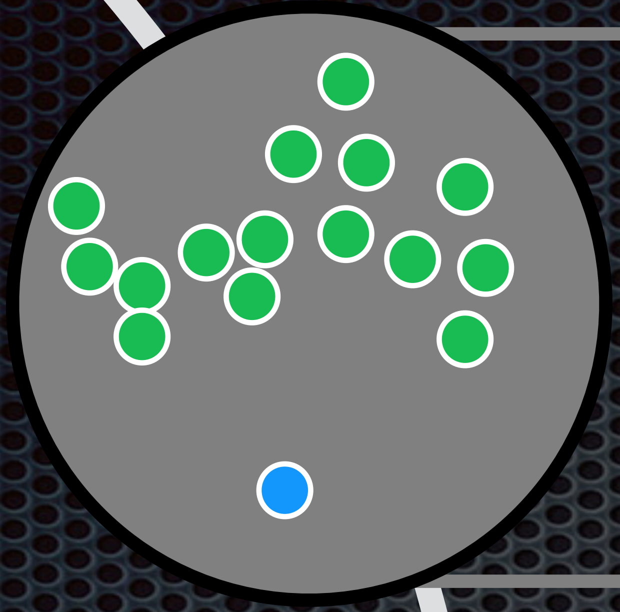
Tension between Accuracy and Interpretability

Machine Prediction meets Human Judgement

Workflow Integration

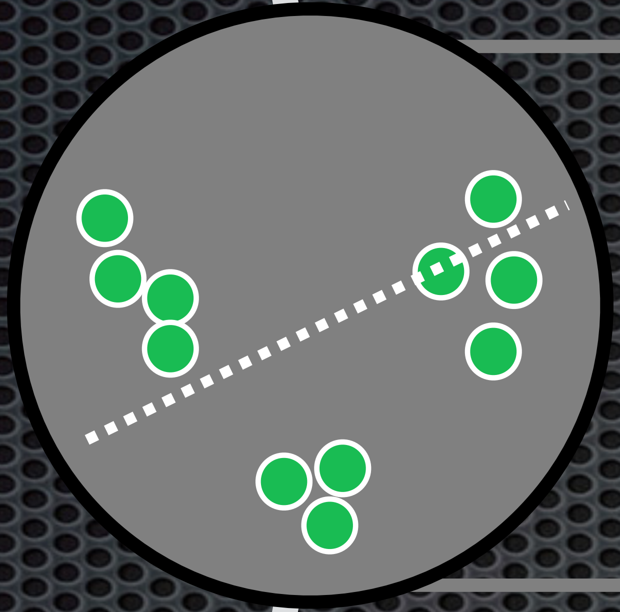
Courtesy of Leigh Conroy

Potential Sources of Error in Building AI Models



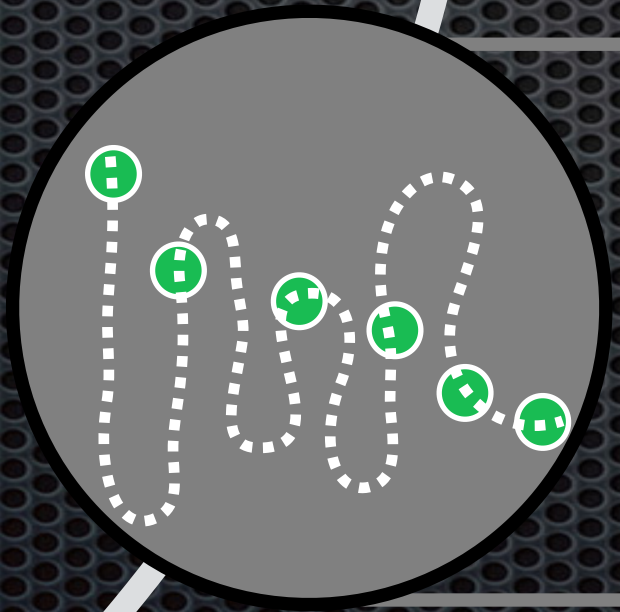
Class Imbalance & Outliers

Non-standard practice difficult to capture
Potential to confound model



Under-fitting

Lots of historical data… not collected for this purpose
Inaccurate assumptions/simplifications of the model



Over-fitting

Detect the signal, not the noise!
Less general and lacks inter-institutional applicability

Courtesy of Leigh Conroy

U-Net for Image Segmentation

U-Net: Convolutional Networks for Biomedical Image Segmentation

Olaf Ronneberger, Philipp Fischer, and Thomas Brox

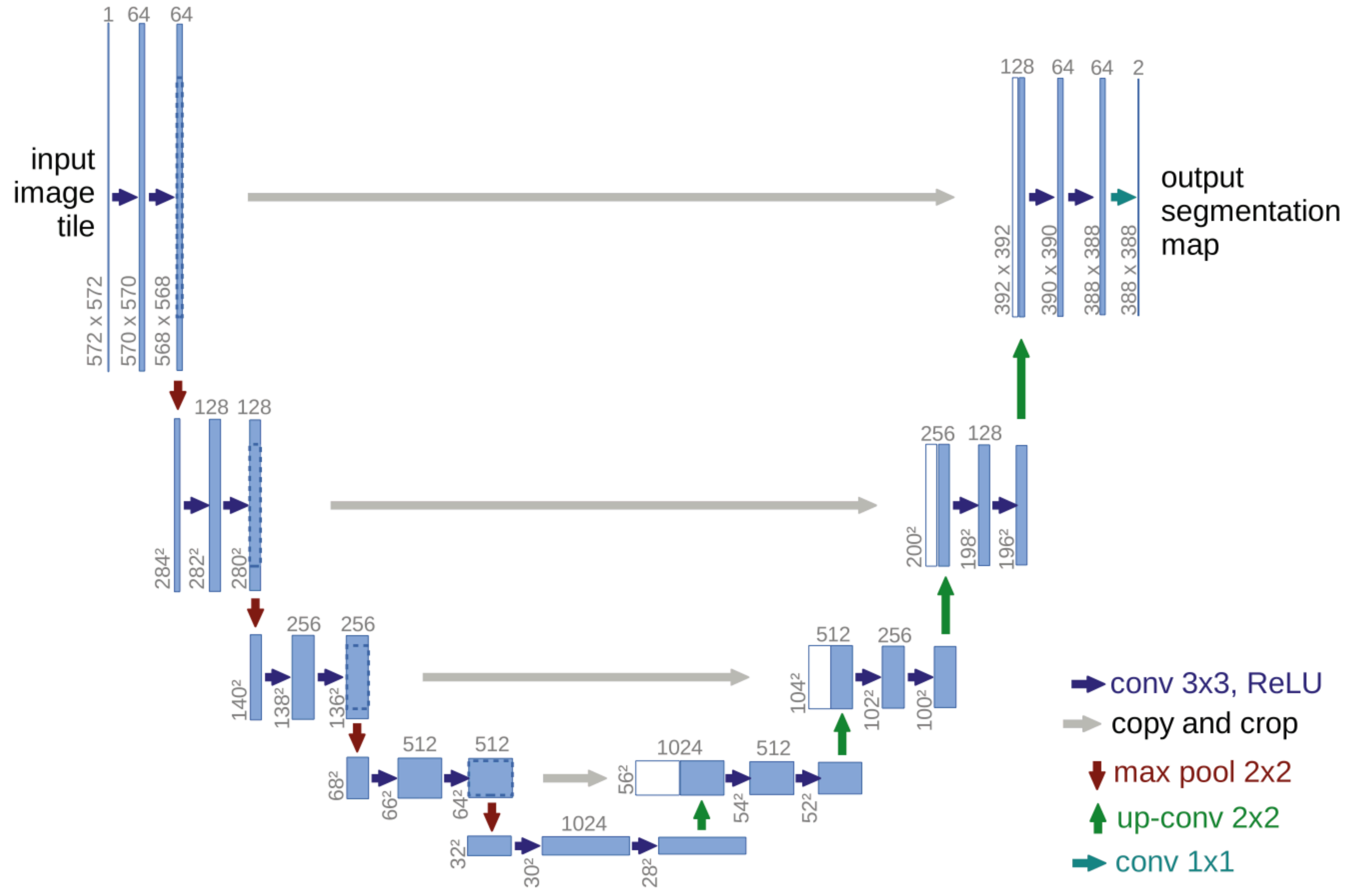
Computer Science Department and BIOSS Centre for Biological Signalling Studies,
University of Freiburg, Germany
ronneber@informatik.uni-freiburg.de
http://lmb.informatik.uni-freiburg.de/

Nassir Navab · Joachim Hornegger
William M. Wells · Alejandro F. Frangi (Eds.)

Medical Image Computing and Computer-Assisted Intervention – MICCAI 2015

18th International Conference
Munich, Germany, October 5–9, 2015
Proceedings, Part III

Springer



Dose Prediction: ResNet

Automatic treatment planning based on three-dimensional dose distribution predicted from deep learning technique

Jiawei Fan* and Jiazhou Wang*
Department of Radiation Oncology, Fudan University Shanghai Cancer Center, Shanghai 200032, China
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Zhi Chen*
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Chaosu Hu, Zhen Zhang, and Weigang Hu[a)]
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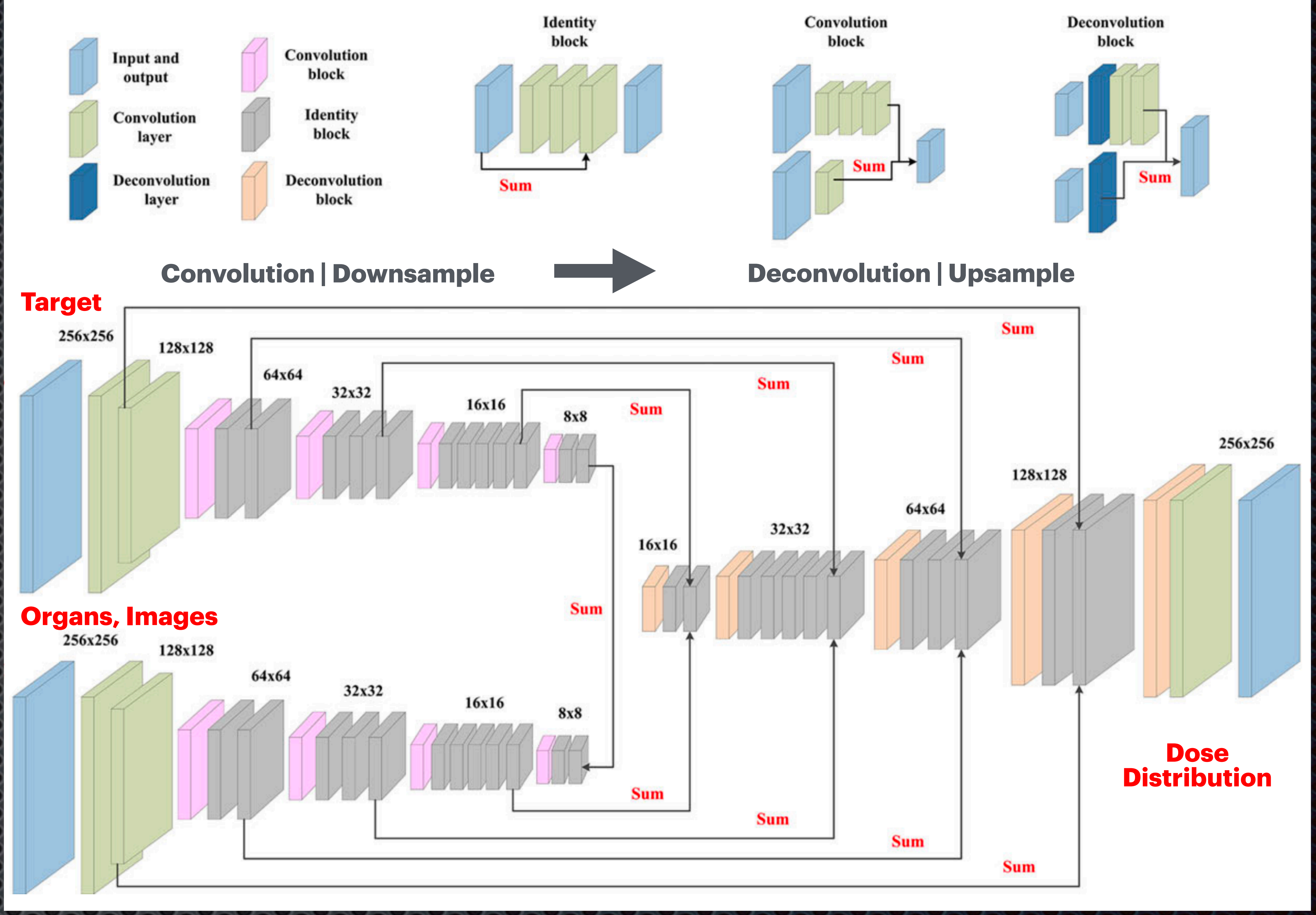
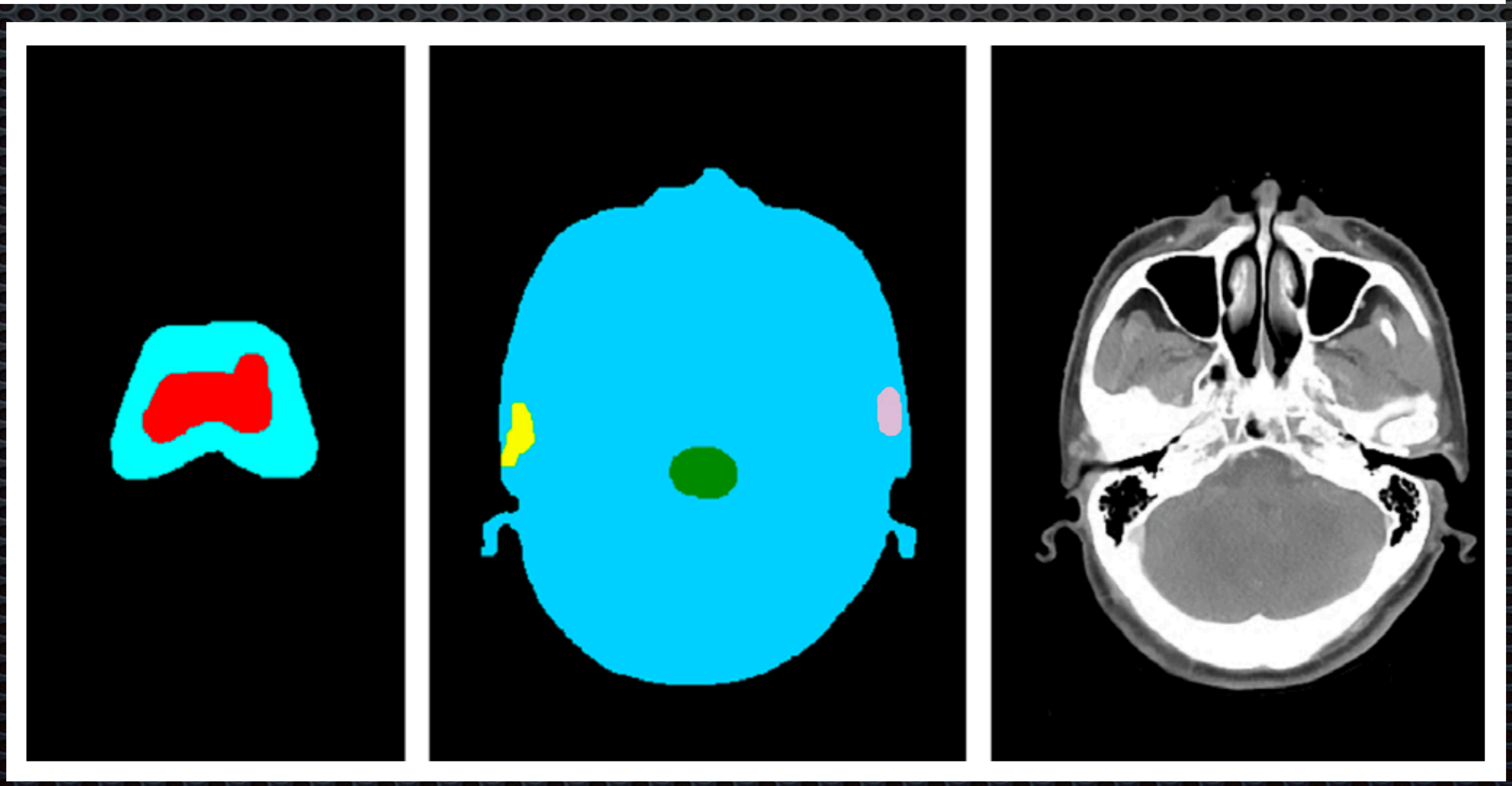
370 Med. Phys. 46 (1), January 2019 0094-2405/2019/46(1)/370/12

370





Dose Prediction: DoseNet

IOP Publishing   Phys. Med. Biol. 63 (2018) 235022 (11pp)   https://doi.org/10.1088/1361-6560/aaef74

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8 November 2018

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4 December 2018

PAPER

DoseNet: a volumetric dose prediction algorithm using 3D fully-convolutional neural networks

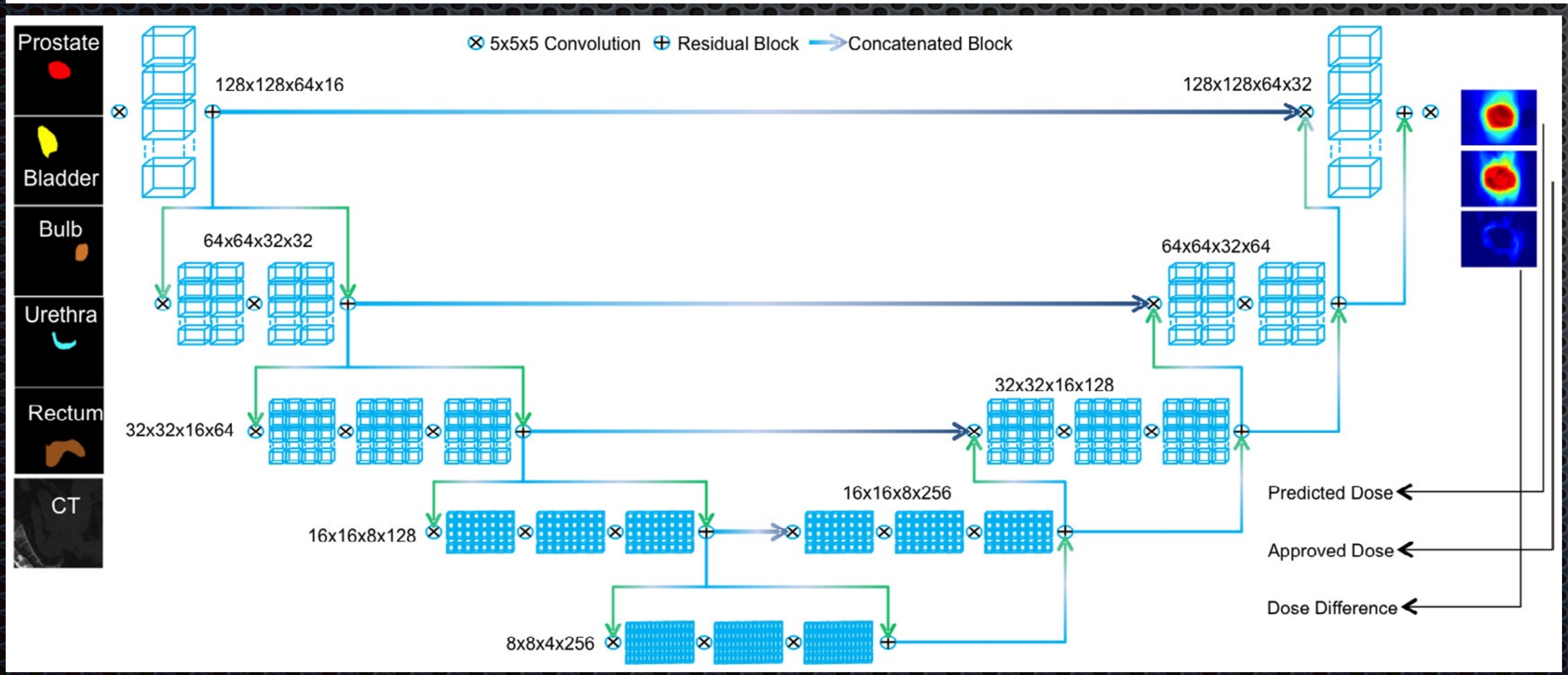
Vasant Kearney[1], Jason W Chan[1], Samuel Haaf, Martina Descovich and Timothy D Solberg

Department of Radiation Oncology, University of California, San Francisco, CA 94115, United States of America

[1] These two authors contributed equally.

E-mail: vasant.kearney@ucsf.edu

Keywords: dose prediction, convolutional neural networks, knowledge based planning, radiation oncology, machine learning, automated treatment planning, deep learning



Dose Prediction

IOP Publishing Phys. Med. Biol. 64 (2019) 065020 (15pp) https://doi.org/10.1088/1361-6560/ab039b

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31 January 2019

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PAPER

3D radiotherapy dose prediction on head and neck cancer patients with a hierarchically densely connected U-net deep learning architecture

Dan Nguyen[1], Xun Jia, David Sher, Mu-Han Lin, Zohaib Iqbal, Hui Liu and Steve Jiang

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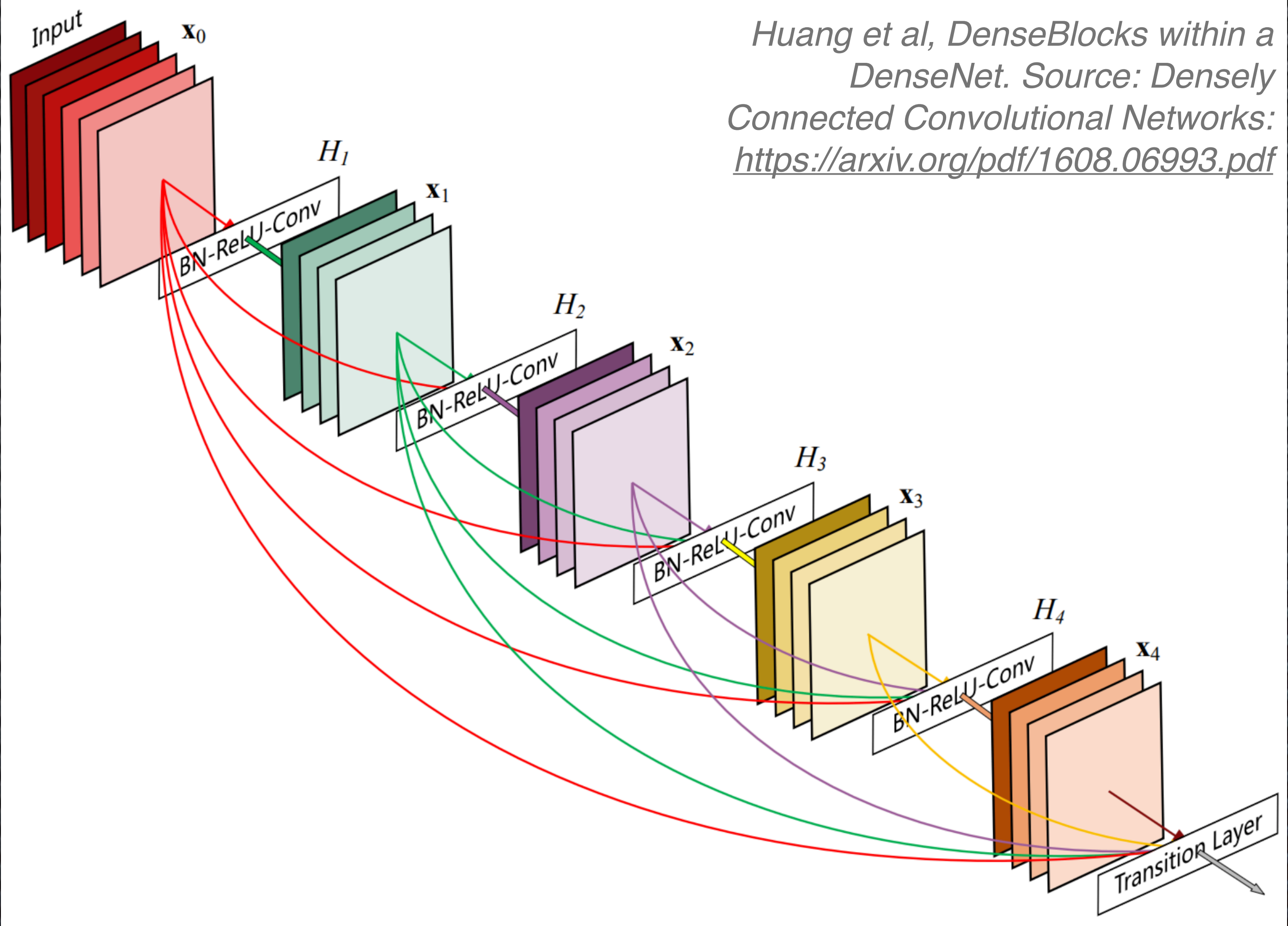
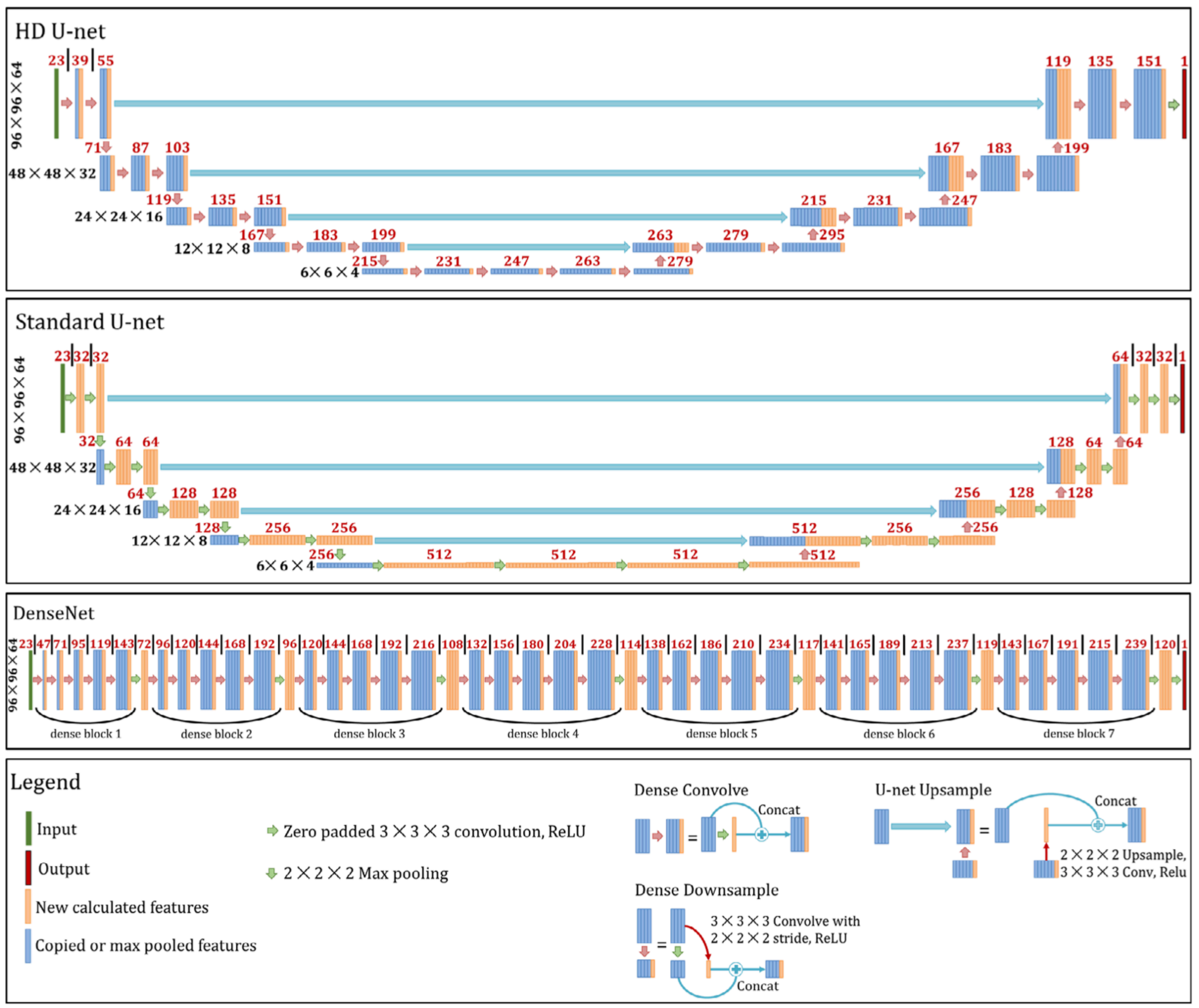
Keywords: radiation therapy, deep learning, artificial intelligence, dose prediction, head and neck cancer, U-net, DenseNet



Huang et al, DenseBlocks within a DenseNet. Source: Densely Connected Convolutional Networks: https://arxiv.org/pdf/1608.06993.pdf



U-Net for Dose Prediction:

www.nature.com/scientificreports

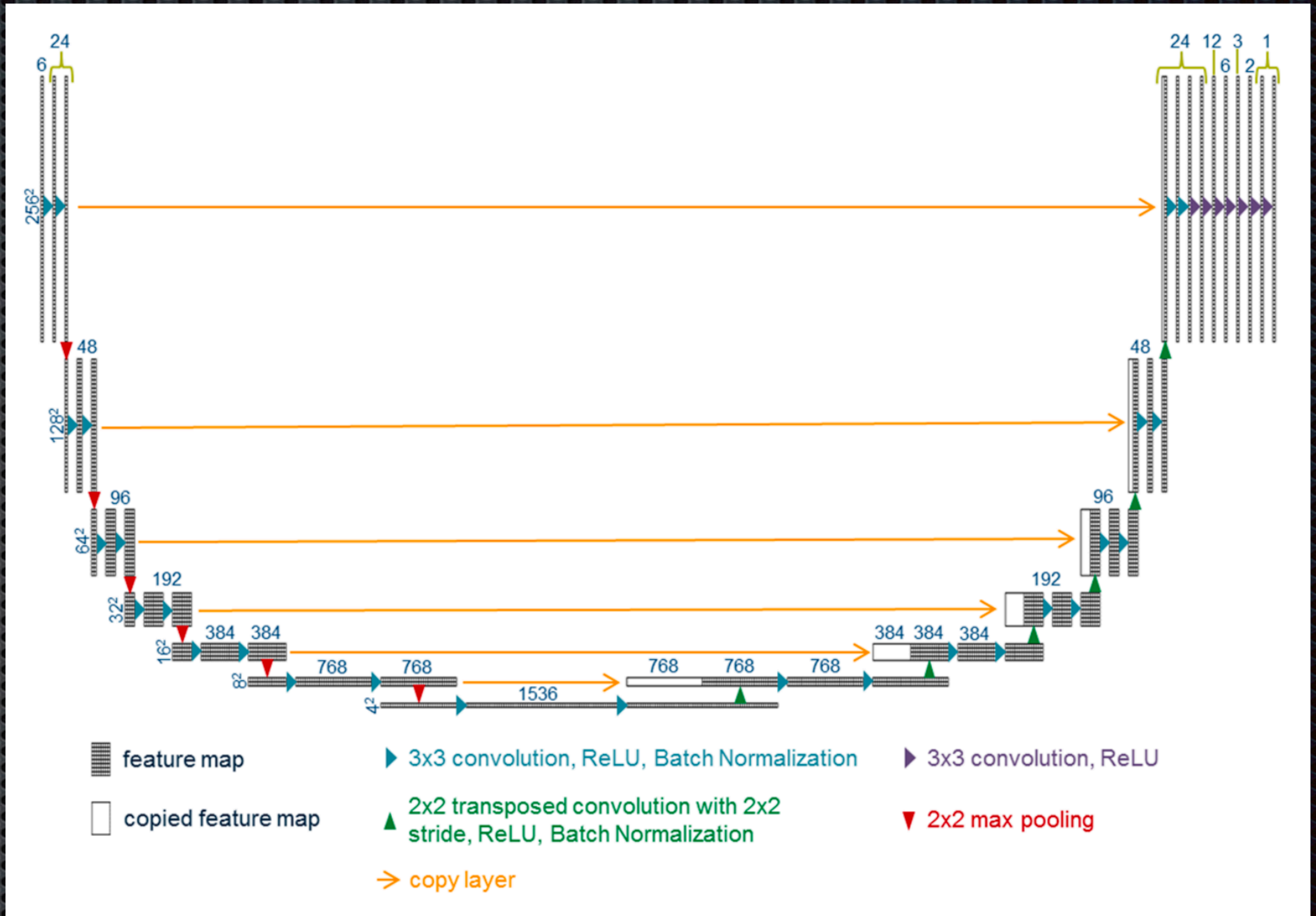
SCIENTIFIC REPORTS

OPEN

A feasibility study for predicting optimal radiation therapy dose distributions of prostate cancer patients from patient anatomy using deep learning

Received: 30 May 2018
Accepted: 13 November 2018
Published online: 31 January 2019

Dan Nguyen, Troy Long, Xun Jia, Weiguo Lu, Xuejun Gu, Zohaib Iqbal & Steve Jiang



Generative Adversarial Networks (GAN) for Dose Prediction

Knowledge-based automated planning with three-dimensional generative adversarial networks

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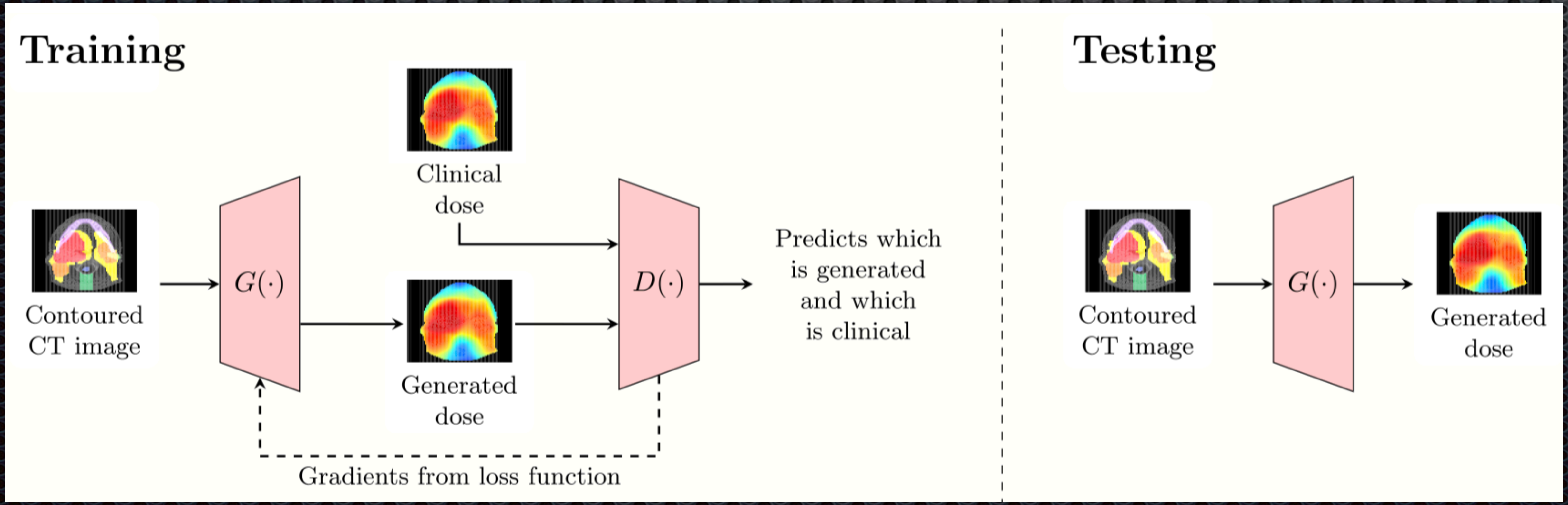
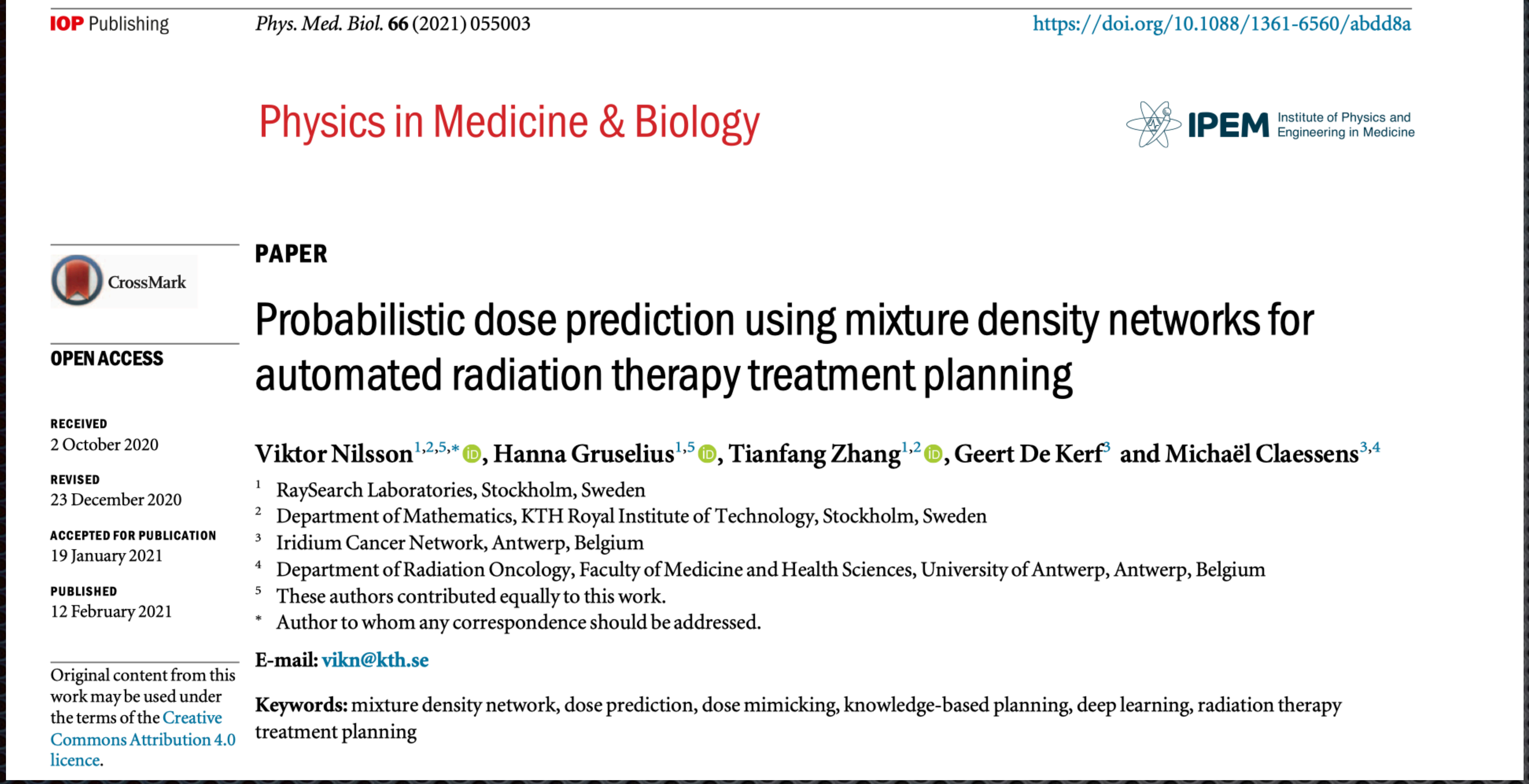
297 Med. Phys. 47 (2), February 2020 0094-2405/2020/47(2)/297/10 **297**



Mixed Density Networks for Dose Prediction


IOP Publishing Phys. Med. Biol. 66 (2021) 055003 https://doi.org/10.1088/1361-6560/abdd8a

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PAPER

Probabilistic dose prediction using mixture density networks for automated radiation therapy treatment planning

Viktor Nilsson[1,2,5,*], Hanna Gruselius[1,5], Tianfang Zhang[1,2], Geert De Kerf[3] and Michaël Claessens[3,4]

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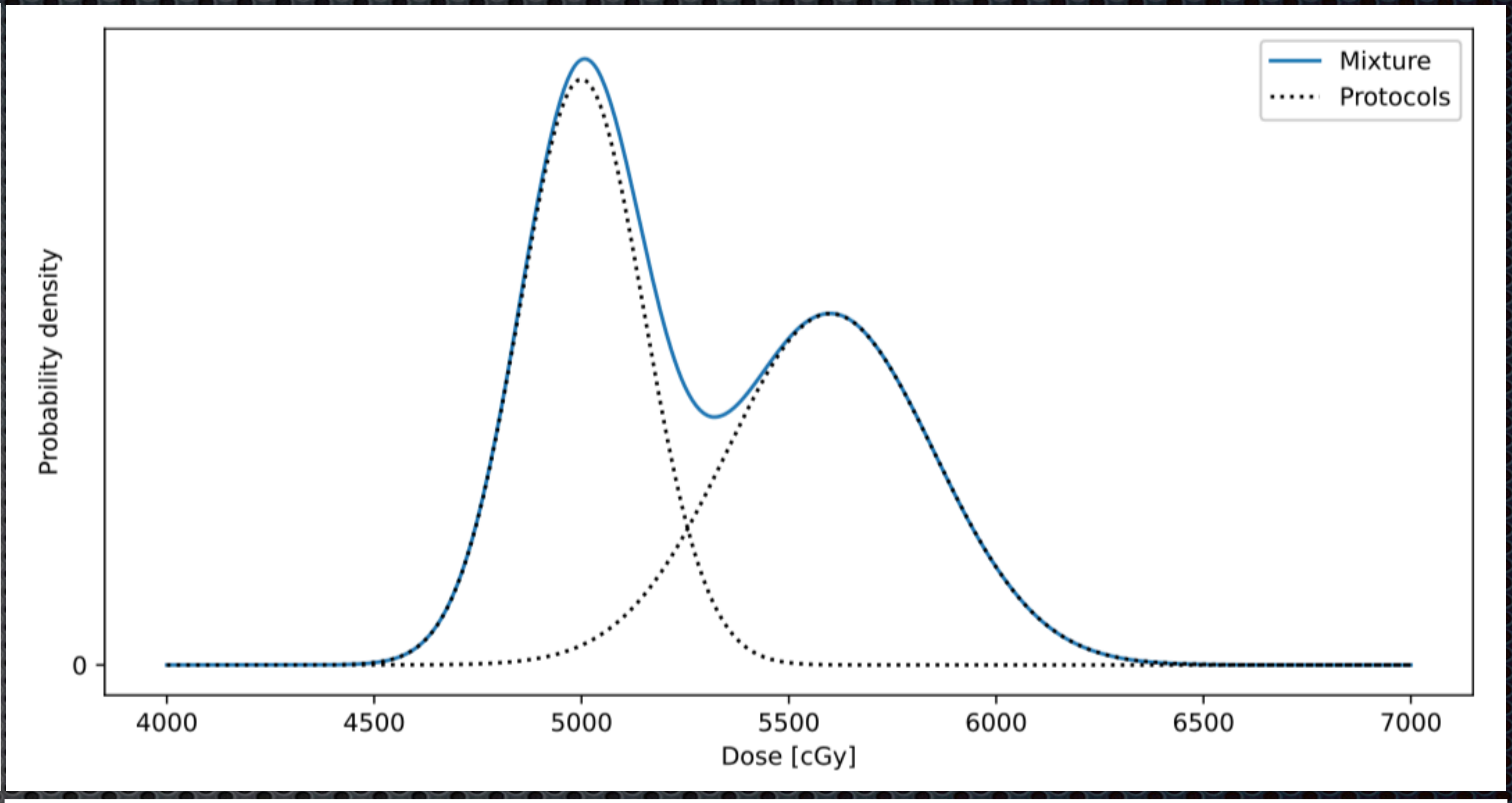
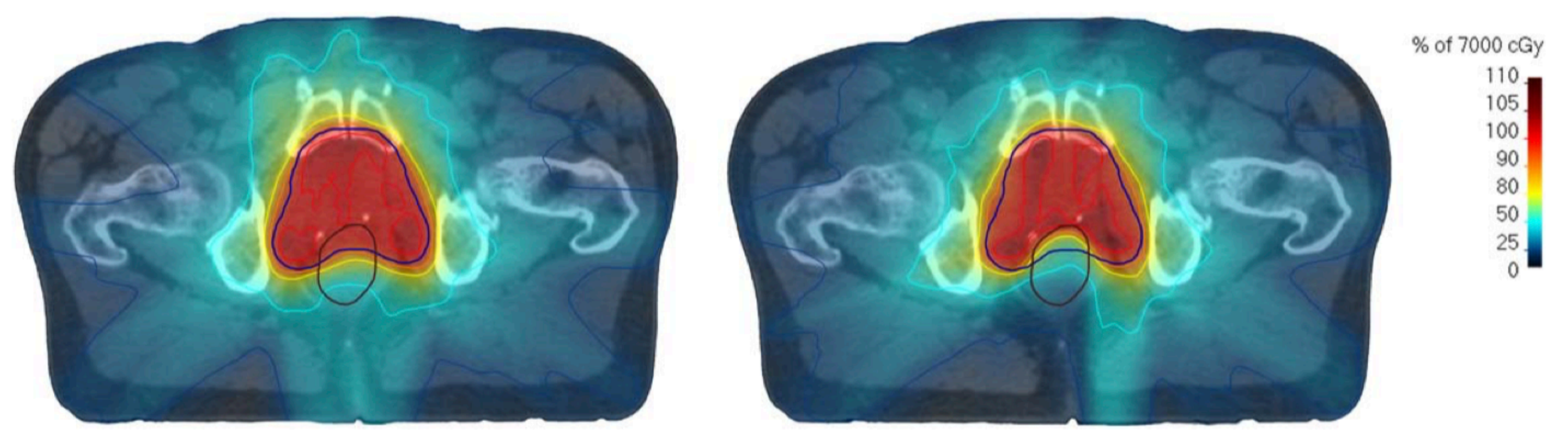
Keywords: mixture density network, dose prediction, dose mimicking, knowledge-based planning, deep learning, radiation therapy treatment planning





Deep Learning for Automated Fluence Map Generation

IOP Publishing   *Phys. Med. Biol.* **65** (2020) 175014   https://doi.org/10.1088/1361-6560/aba5eb

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PAPER

Automatic IMRT planning via static field fluence prediction (AIP-SFFP): a deep learning algorithm for real-time prostate treatment planning

Xinyi Li[1], Jiahan Zhang[1], Yang Sheng[1], Yushi Chang[1], Fang-Fang Yin[1], Yaorong Ge[2], Q Jackie Wu[1] and Chunhao Wang[1,3]

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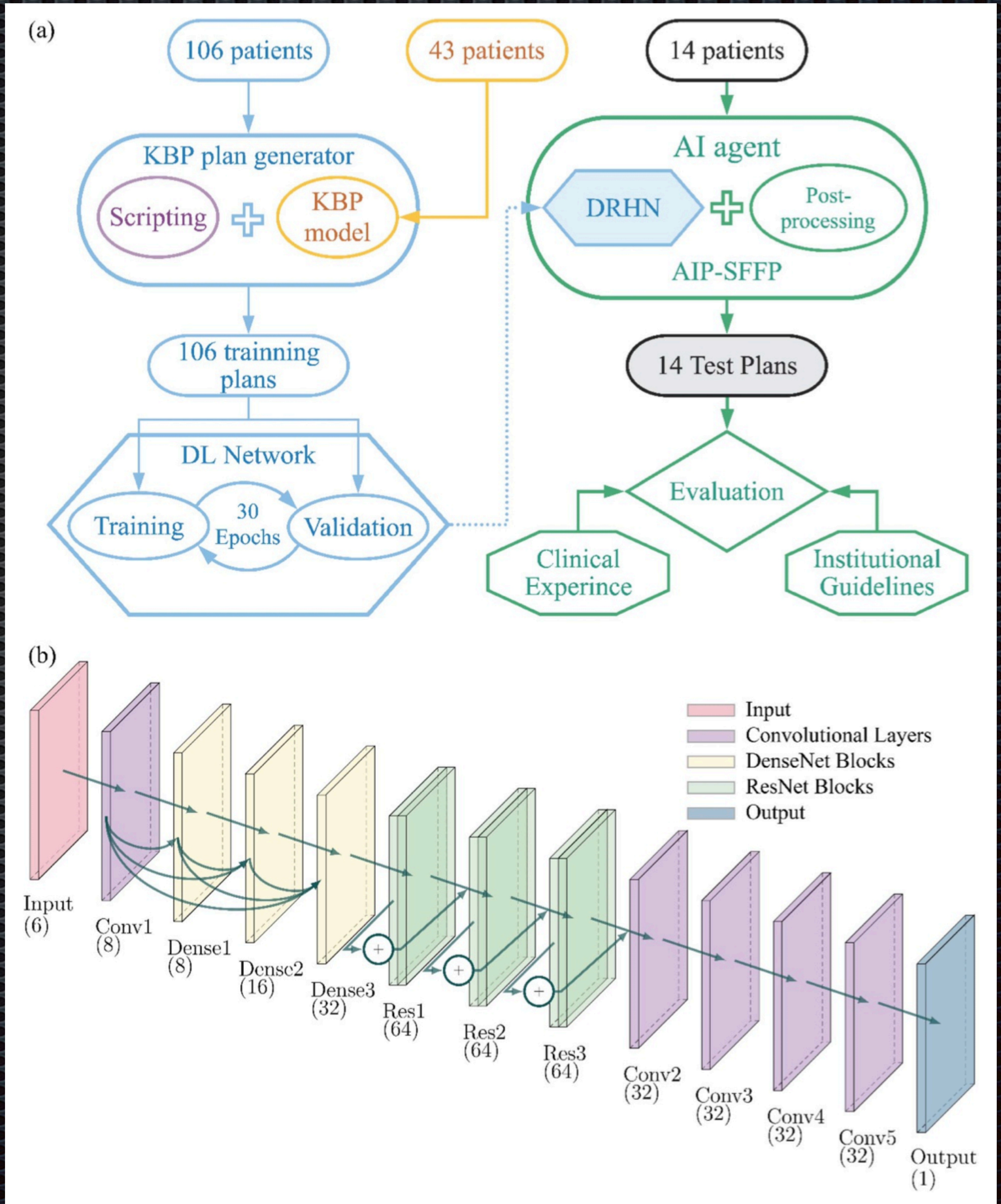
Keywords: auto-planning, deep learning, prostate, IMRT



Reinforcement Learning

Operating a treatment planning system using a deep-reinforcement learning-based virtual treatment planner for prostate cancer intensity-modulated radiation therapy treatment planning

Chenyang Shen[a)]
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Xun Jia[a)]
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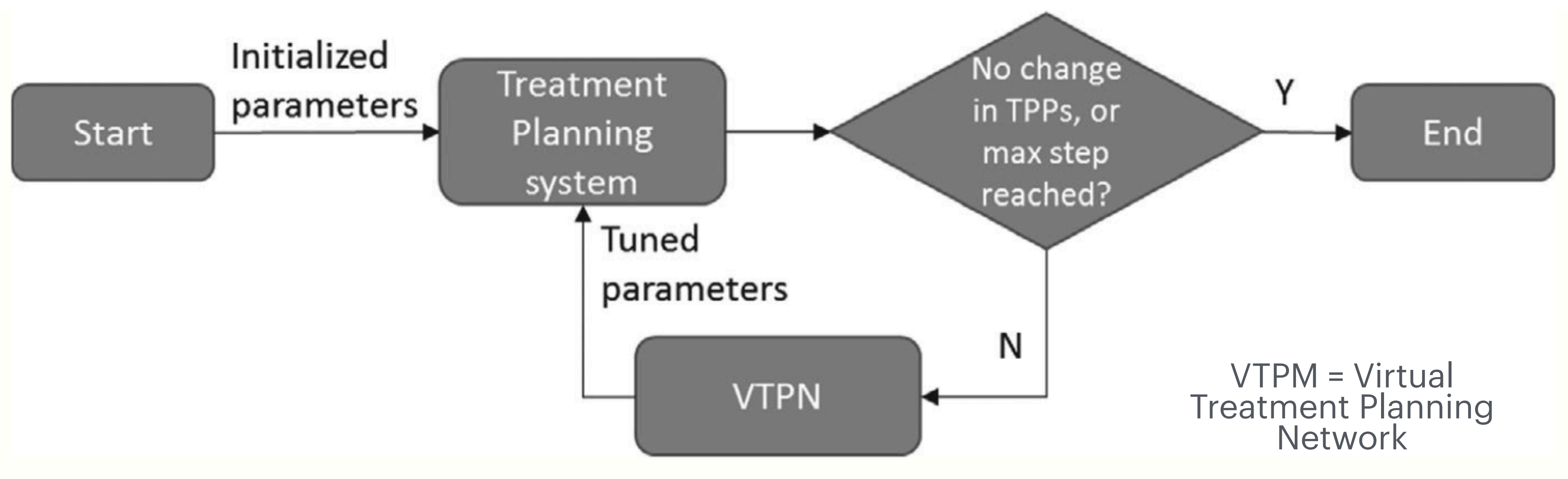
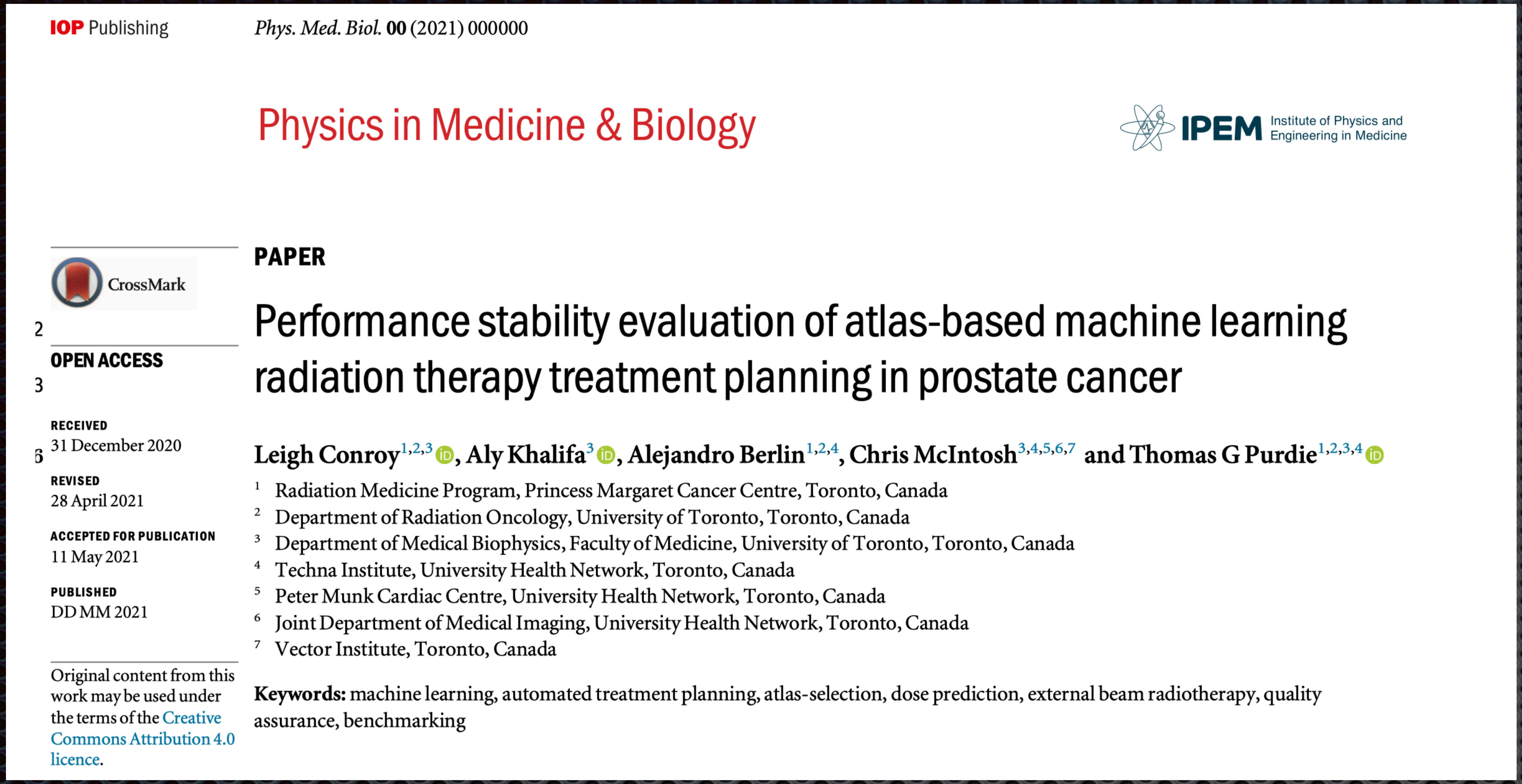


Atlas Regression Forests

Training

McIntosh, Purdie *Phys Med Biol*, 2017

Input Data Variations on Automated Planning



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PAPER

Performance stability evaluation of atlas-based machine learning radiation therapy treatment planning in prostate cancer

Leigh Conroy[1,2,3], Aly Khalifa[3], Alejandro Berlin[1,2,4], Chris McIntosh[3,4,5,6,7] and Thomas G Purdie[1,2,3,4]

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[2] Department of Radiation Oncology, University of Toronto, Toronto, Canada
[3] Department of Medical Biophysics, Faculty of Medicine, University of Toronto, Toronto, Canada
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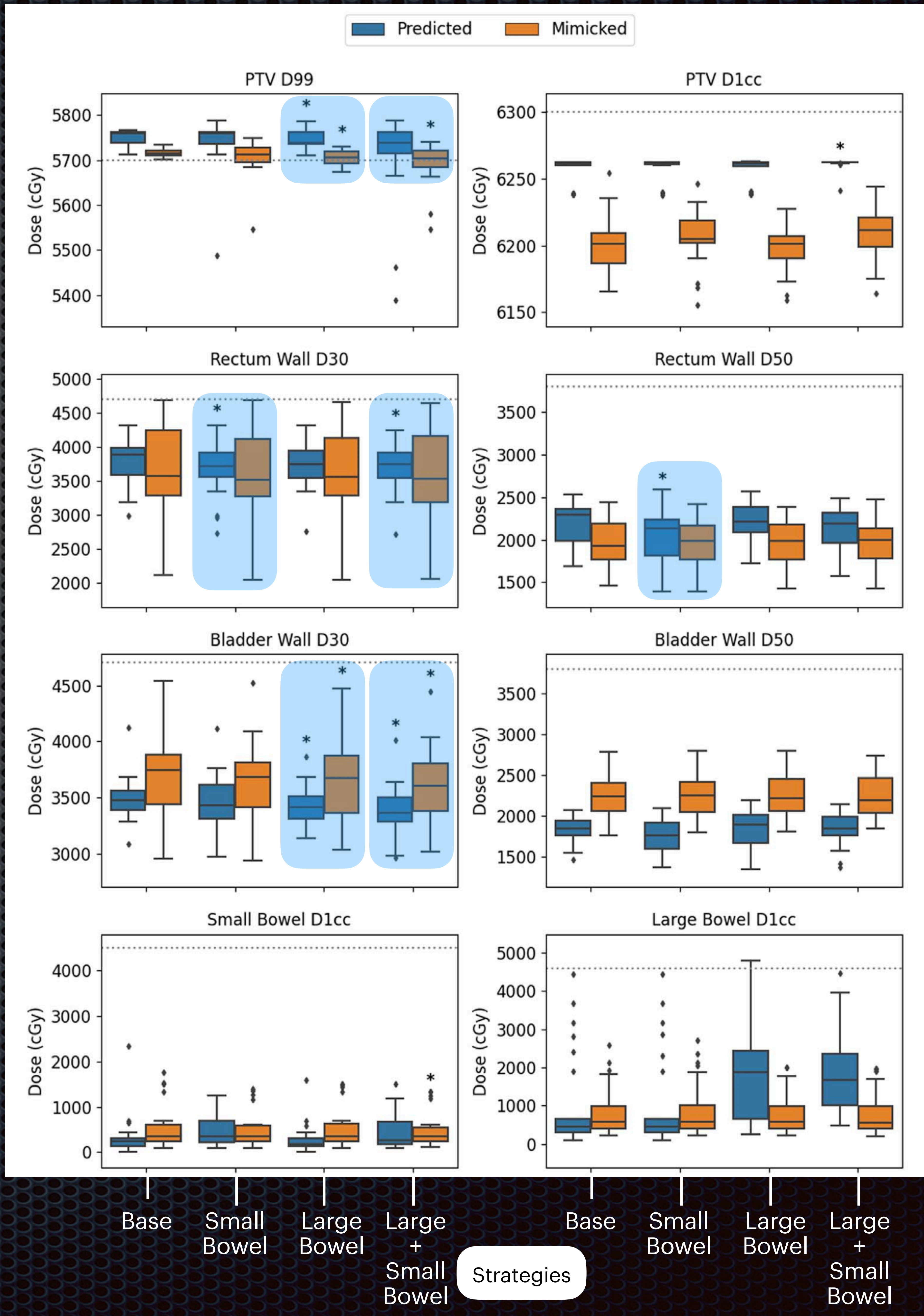
Keywords: machine learning, automated treatment planning, atlas-selection, dose prediction, external beam radiotherapy, quality assurance, benchmarking



AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE

Improving Health Through Medical Physics

The Open Knowledge-Based Planning Challenge (OpenKBP)

An AAPM Grand Challenge

The aim of the OpenKBP Challenge is to advance fair and consistent comparisons of dose prediction methods for knowledge-based planning (KBP). Participants of the challenge will use a large dataset to train, test, and compare their prediction methods, using a set of standardized metrics, with those of other participants.

TH-F-TRACK 5-3 (Thursday, 7/29/2021) 4:30 PM - 5:30 PM [Eastern Time (GMT-4)]

An International Validation of Knowledge-Based Planning

Aaron Babier

UC San Diego

UNIVERSITY OF TORONTO

UHN Princess Margaret Cancer Centre

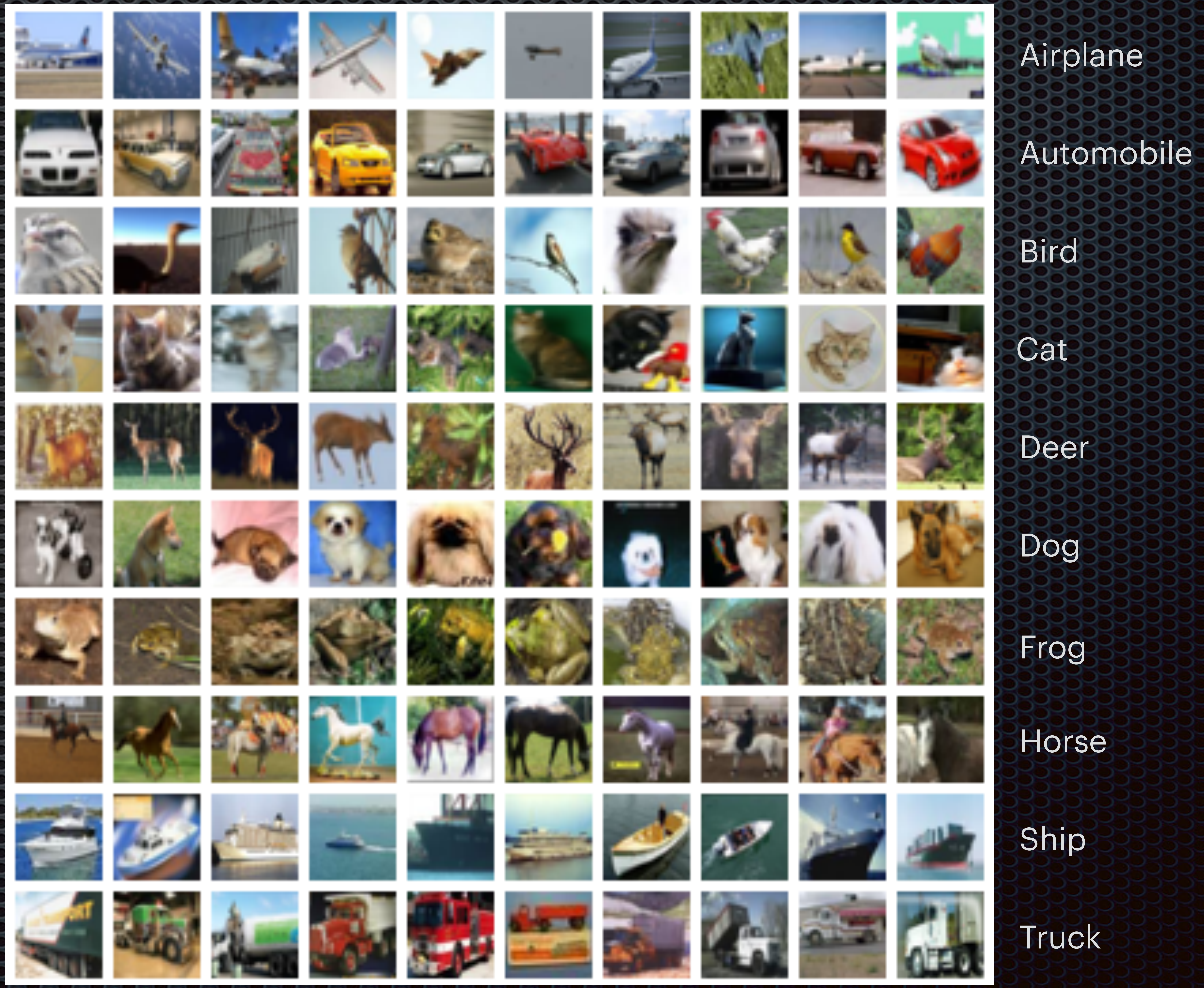
Open Knowledge-Based Planning (OpenKBP) Challenge

AAPM Grand Challenge 2020 Open Source Dataset

OpenKBP Challenge is the first competition for knowledge-based planning (KBP)

Open source, highly curated datasets (e.g., ImageNet →) are staples of thriving artificial intelligence driven fields

Used public and private data sources and augmented public data with new plans for OpenKBP release



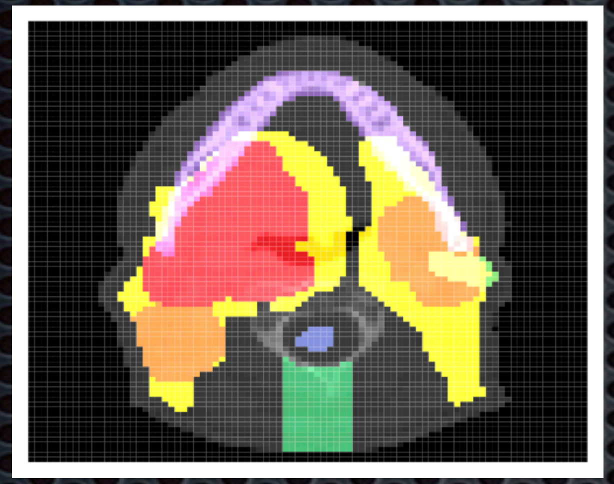
Applied Optimization Lab, University of Toronto

Open Knowledge-Based Planning (OpenKBP) Challenge

AAPM Grand Challenge 2020 Competition

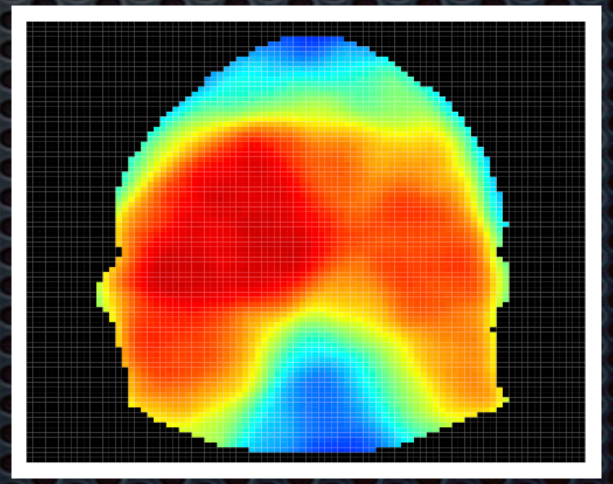
Objective
Implement the most accurate KBP dose prediction method on a large open-access dataset

Evaluation
All models are trained on the same data, and evaluated with standard metrics



Planning CT + ROIs

Dose Prediction Method



Predicted Dose

Applied Optimization Lab, University of Toronto

Courtesy of Aaron Babier and Tim Chan

Open Knowledge-Based Planning (OpenKBP) Challenge

AAPM Grand Challenge 2020 Competition

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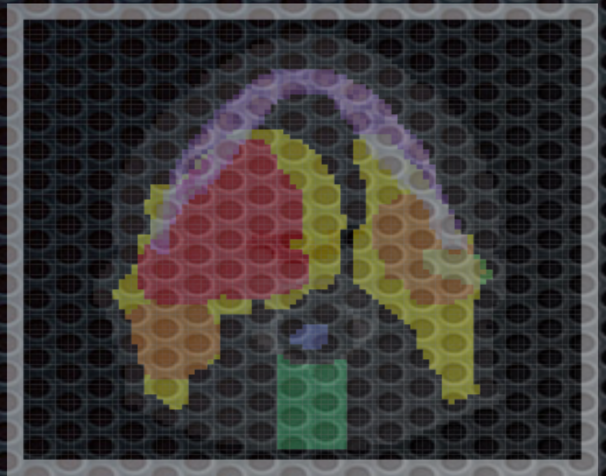
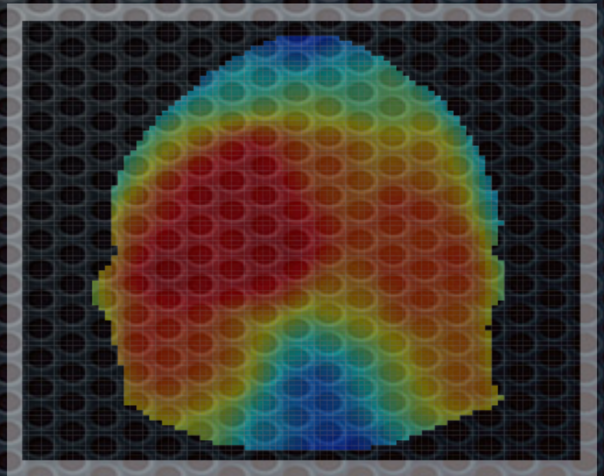


Planning CT + ROIs

Dose Prediction Method



Predicted Dose

Validation phase
Each team's best validation submission was displayed on a public leaderboard

Testing Phase
Each team made <u>one</u> submission to the testing phase
Winners determined based on the one submission
Scores were blinded until competition closed

Applied Optimization Lab, University of Toronto

Courtesy of Aaron Babier and Tim Chan

Challenge Leaderboard Streams

	3D Leaderboard	DVH Leaderboard
Ranking	Lowest average error	
Ground Truth	Plan dose distribution	Plan DVH
Error Measure	Mean absolute error voxel-by-voxel	Mean absolute error at dose volume metrics
3D stream	✓	✓
DVH stream	✗	✓

Applied Optimization Lab, University of Toronto

Courtesy of Aaron Babier and Tim Chan

Challenge Participants

	Registration	Active in Validation	Active in Testing
Total participants	195	73	54
Total teams	129	44	28
Number of submissions	---	1750	28

New interest to research community

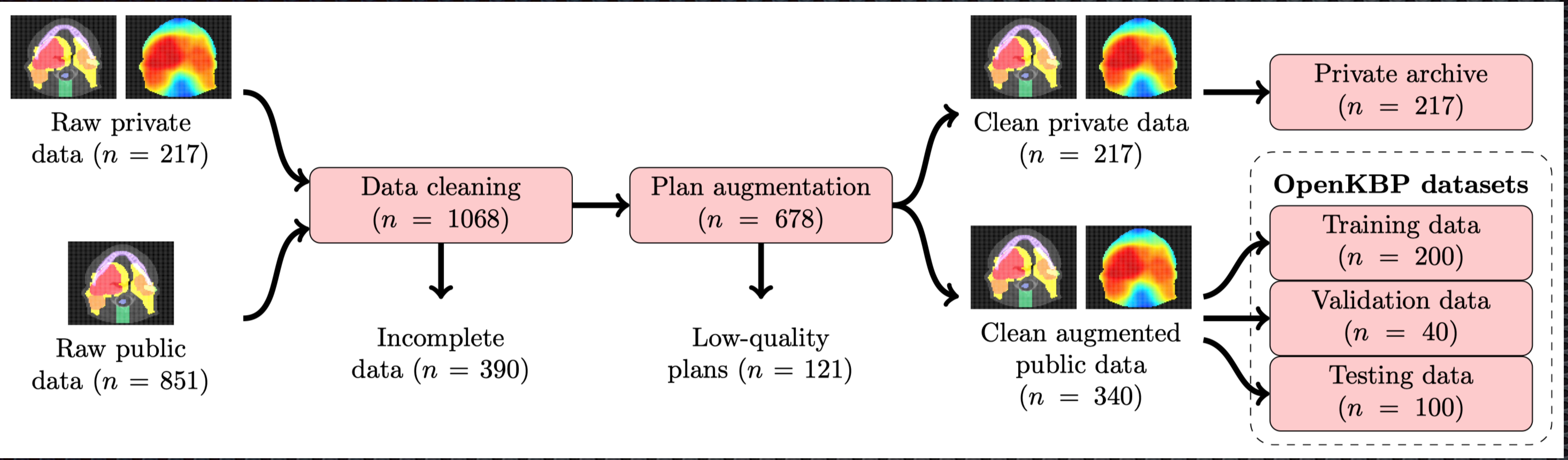
57%
say primary research is Not "Medical Physics"

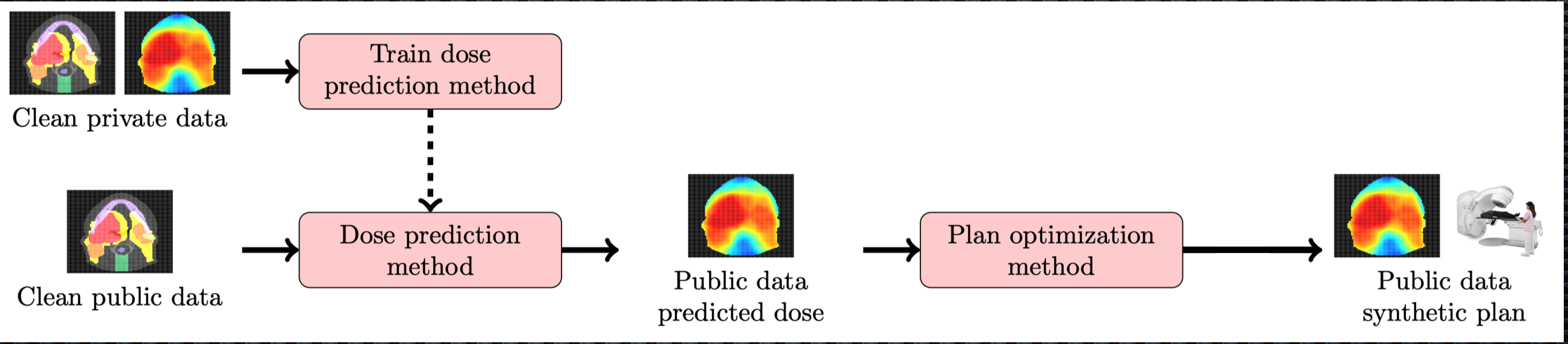
62%
say NEVER done KBP research before

Applied Optimization Lab, University of Toronto

Courtesy of Aaron Babier and Tim Chan

Data → Curation | Generation | Augmentation





TH-F-TRACK 5-3 (Thursday, 7/29/2021) 4:30 PM - 5:30 PM [Eastern Time (GMT-4)]

An International Validation of Knowledge-Based Planning

Aaron Babier

Courtesy of Aaron Babier and Tim Chan

Summary

Machine Learning → Dose Prediction

Machine Learning Architecture/Methods:

- Convolution Neural Networks → U-Net
- Generative Adversarial Networks
- Atlas Regression Forest
- Reinforcement Learning

Open Knowledge-Based Planning (OpenKBP) Challenge

- Voxel-based dose prediction
- DVH prediction