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AI and Healthcare: towards a Digital Twin?

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AI & Healthcare : Towards a Digital twin?

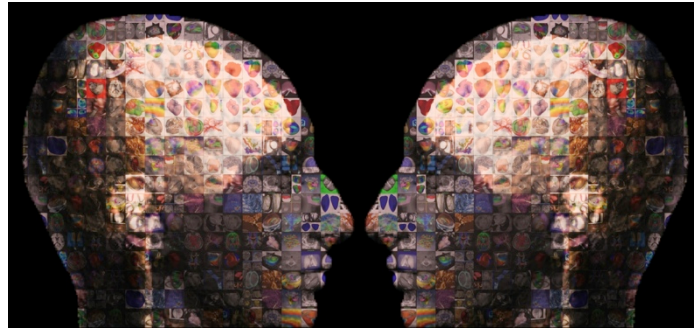
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Abstract—The "Personalized Digital Patient" or "Digital Twin" is a digital representation of the patient's anatomy and physiology based on models whose parameters can be learnt automatically from real or simulated medical images and additional clinical, biological, behavioral, and environmental data. Advanced algorithms can then use the learnt parameters to serve the three pillars of digital medicine: computerized assistance to diagnosis, prognosis and therapy. The presentation will illustrate these points and insist on the importance of geometrical, statistical and biophysical modeling of life and imaging processes.

REFERENCES

Journal Articles (selection 2016-2018)

1. Qiao Zheng, Hervé Delingette, Nicolas Duchateau, and Nicholas Ayache. 3D Consistent & Robust Segmentation of Cardiac Images by Deep Learning with Spatial Propagation. *IEEE Transactions on Medical Imaging*, 2018.
2. Rocio Cabrera Lozoya, Benjamin Berte, Hubert Cochet, Pierre Jaïs, Nicholas Ayache, and Maxime Sermesant. Model-based Feature Augmentation for Cardiac Ablation Target Learning from Images. *IEEE Transactions on Biomedical Engineering*, 2018.
3. Nicolas Duchateau, Maxime Sermesant, Hervé Delingette, and Nicholas Ayache. Model-based generation of large databases of cardiac images: synthesis of pathological cine MR sequences from real healthy cases. *IEEE Transactions on Medical Imaging*, 37:755-766, 2018.
4. Sophie Giffard-Roisin, Hervé Delingette, Thomas Jackson, Jessica Webb, Lauren Fovargue, Jack Lee, Christopher A Rinaldi, Reza Razavi, Nicholas Ayache, and Maxime Sermesant. Transfer Learning from Simulations on a Reference Anatomy for ECGI in Personalised Cardiac Resynchronization Therapy. *IEEE Trans. On Biomedical Engineering*, 20, 2018.
5. Pietro Gori, Olivier Colliot, Linda Marrakchi Kacem, Yulia Worbe, Alexandre Routier, Cyril Poupon, Andreas Hartmann, Nicholas Ayache, and Stanley Durrleman. Double diffeomorphism: combining morphometry and structural connectivity analysis. *IEEE Transactions on Medical Imaging*, 2018.
6. Fanny Orhac, Frédérique Frouin, Christophe Nioche, Nicholas Ayache, and Irene Buvat. Validation of a method to compensate multicenter effects affecting CT radiomic features. *Radiology*, 2018.
7. Fanny Orhac, P.-A Mattei, C. Bouveyron, and N Ayache. Class-specific Variable Selection in High-Dimensional Discriminant Analysis through Bayesian Sparsity. *Journal of Chemometrics*, 2018.
8. Thomas Demarcy, Clair Vandersteen, Nicolas Guevara, Charles Raffaelli, Dan Gnansia, Nicholas Ayache, and Hervé Delingette. Automated analysis of human cochlea shape variability from segmented microCT images. *Computerized Medical Imaging and Graphics*, 59:1 - 12, 2017.
9. Sophie Giffard-Roisin, Thomas Jackson, Lauren Fovargue, Jack Lee, Hervé Delingette, Reza Razavi, Nicholas Ayache, and Maxime Sermesant. Non-Invasive Personalisation of a Cardiac Electrophysiology Model from Body Surface Potential Mapping. *IEEE Transactions on Biomedical Engineering*, 64(9):2206 - 2218, September, 2017.
10. Pietro Gori, Olivier Colliot, Linda Marrakchi-Kacem, Yulia Worbe, Cyril Poupon, Andreas Hartmann, Nicholas Ayache, and Stanley Durrleman. A Bayesian Framework for Joint Morphometry of Surface and Curve meshes in Multi-Object Complexes. *Medical Image Analysis*, 35:458-474, 2017.
11. Bishesh Khanal, Nicholas Ayache, and Xavier Pennec. Simulating Longitudinal Brain MRIs with known Volume Changes and Realistic Variations in Image Intensity. *Frontiers in Neuroscience*, 2017.
12. Loïc Le Folgoc, Hervé Delingette, Antonio Criminisi, and Nicholas Ayache. Sparse Bayesian registration of medical images for self-tuning of parameters and spatially adaptive parametrization of displacements. *Medical Image Analysis*, 36:79 - 97, 2017.
13. Roch Molléro, Xavier Pennec, Hervé Delingette, Alan Garny, Nicholas Ayache, and Maxime Sermesant. Multifidelity-CMA: a multifidelity approach for efficient personalisation of 3D cardiac electromechanical models. *Biomechanics and Modeling in Mechanobiology*, pp 1-16, 2017.

14. Chloé Audigier, Tommaso Mansi, Hervé Delingette, Saikiran Rapaka, Tiziano Passerini, Viorel Mihalef, Marie-Pierre Jolly, Raoul Pop, Michele Diana, Luc Soler, Ali Kamen, Dorin Comaniciu, and Nicholas Ayache. Comprehensive Pre-Clinical Evaluation of a Multi-physics Model of Liver Tumor Radiofrequency Ablation. *International Journal of Computer Assisted Radiology and Surgery*, 2016.
15. Nicholas Ayache. Medical Imaging Informatics: Towards a Personalized Computational Patient. *IMIA Yearbook of Medical Informatics*, 25(Suppl. 1):S8-S9, 2016
16. Nicholas Ayache and James Duncan. 20th anniversary of the medical image analysis journal (MedIA). *Medical Image Analysis*, 33:1-3, 2016
17. Rocio Cabrera-Lozoya, Benjamin Berte, Hubert Cochet, Pierre Jaïs, Nicholas Ayache, and Maxime Sermesant. Image-based Biophysical Simulation of Intracardiac Abnormal Ventricular Electrograms. *IEEE Transactions on Biomedical Engineering*, 2016.
18. Zhong Chen, Rocio Cabrera-Lozoya, Jatin Relan, Manav Sohal, Anoop Shetty, Rashed Karim, Hervé Delingette, Jaswinder Gill, Kawal Rhode, Nicholas Ayache, Peter Taggart, Christopher Aldo Rinaldi, Maxime Sermesant, and Reza Razavi. Biophysical modelling predicts ventricular tachycardia inducibility and circuit morphology: A combined clinical validation and computer modelling approach. *Journal of Cardiovascular Electrophysiology*, 27(7):851-860, 2016.
19. Nicolas Cordier, Hervé Delingette, Matthieu Lê, and Nicholas Ayache. Extended Modality Propagation: Image Synthesis of Pathological Cases. *IEEE Transactions on Medical Imaging*, 2016.
20. Dan Gnansia, Thomas Demarcy, Clair Vandersteen, Charles Raffaelli, Nicolas Guevara, Hervé Delingette, and Nicholas Ayache. Optimal electrode diameter in relation to volume of the cochlea. *European Annals of Otorhinolaryngology, Head and Neck Diseases*, 133, Supplement 1:S66-S67, 2016.
21. Pietro Gori, Olivier Colliot, Linda Marrakchi-Kacem, Yulia Worbe, Fabrizio De Vico Fallani, Mario Chavez, Cyril Poupon, Andreas Hartmann, Nicholas Ayache, and Stanley Durrleman. Parsimonious Approximation of Streamline Trajectories in White Matter Fiber Bundles. *IEEE Transactions on Medical Imaging*, 2016.
22. Mehdi Hadj-Hamou, Marco Lorenzi, Nicholas Ayache, and Xavier Pennec. Longitudinal Analysis of Image Time Series with Diffeomorphic Deformations: A Computational Framework Based on Stationary Velocity Fields. *Frontiers in Neuroscience*, 2016.
23. Bishesh Khanal, Marco Lorenzi, Nicholas Ayache, and Xavier Pennec. A biophysical model of brain deformation to simulate and analyze longitudinal MRIs of patients with Alzheimer's disease. *NeuroImage*, 134:35-52, 2016.
24. Loïc Le Folgoc, Hervé Delingette, Antonio Criminisi, and Nicholas Ayache. Quantifying Registration Uncertainty with Sparse Bayesian Modelling. *IEEE Transactions on Medical Imaging*, 2016.
25. Matthieu Lê, Hervé Delingette, Jayashree Kalpathy-Cramer, Elizabeth R Gerstner, Tracy Batchelor, Jan Unkelbach, and Nicholas Ayache. MRI Based Bayesian Personalization of a Tumor Growth Model. *IEEE Transactions on Medical Imaging*, 35(10):2329-2339, 2016.
26. Matthieu Lê, Hervé Delingette, Jayashree Kalpathy-Cramer, Elizabeth R Gerstner, Tracy Batchelor, Jan Unkelbach, and Nicholas Ayache. Personalized Radiotherapy Planning Based on a Computational Tumor Growth Model. *IEEE Transactions on Medical Imaging*, 2016.
27. Matthieu Lê, Jan Unkelbach, Nicholas Ayache, and Hervé Delingette. Sampling Image Segmentations for Uncertainty Quantification. *Medical Image Analysis*, 34:42-51, 2016.
28. Anant S. Vemuri, Stéphane Nicolau, Adrien Sportes, Jacques Marescaux, Luc Soler, and Nicholas Ayache. Inter-Operative Biopsy Site Relocalization in Endoluminal Surgery. *IEEE Transactions on Biomedical Engineering*, 63(9):1862-1873, 2016.

Peer-Reviewed Conference Articles (selection 2018)

1. Luigi Antelmi, Nicholas Ayache, Philippe Robert, and Marco Lorenzi. Multi-Channel Stochastic Variational Inference for the Joint Analysis of Heterogeneous Biomedical Data in Alzheimer's Disease. In *Understanding and Interpreting Machine Learning in Medical Image Computing Applications*, 2018.
2. Julian Krebs, Tommaso Mansi, Boris Mailhé, Nicholas Ayache, and Hervé Delingette. Unsupervised Probabilistic Deformation Modeling for Robust Diffeomorphic Registration. In *Deep Learning in Medical Image Analysis (MICCAI workshop)*, Granada, Spain, September 2018.
3. Clement Abi Nader, Nicholas Ayache, Philippe Robert, and Marco Lorenzi. Alzheimer's Disease Modelling and Staging through Independent Gaussian Process Analysis of Spatio-Temporal Brain Changes. In *Machine Learning in Clinical Neuroimaging (MLCN) workshop*, Granada, Spain, 2018
4. Fanny Orhac, Olivier Humbert, Sarah Boughdad, Maud Lasserre, Michael Soussan, Christophe Nioche, Nicholas Ayache, Jacques Darcourt, Frédérique Frouin, and Irène Buvat. Validation of a harmonization method to correct for SUV and radiomic features variability in multi-center studies. In *SNMMI Annual Meeting*, Philadelphia, United States, June 2018.
5. Wen Wei, Emilie Poirion, Benedetta Bodini, Stanley Durrleman, Nicholas Ayache, Bruno Stankoff, and Olivier Colliot. Learning Myelin Content in Multiple Sclerosis from Multimodal MRI through Adversarial Training. In *MICCAI 2018 -- 21st International Conference On Medical Image Computing & Computer Assisted Intervention*, volume 11072, Granada, Spain, September 2018.
6. Wen Wei, Emilie Poirion, Benedetta Bodini, Stanley Durrleman, Olivier Colliot, Bruno Stankoff, and Nicholas Ayache. FLAIR MR Image Synthesis By Using 3D Fully Convolutional Networks for Multiple Sclerosis. In *ISMRM-ESMRMB 2018 - Joint Annual Meeting*, Paris, France, pages 1-6, June 2018

Submitted Articles (selection 2018-2019)

1. Pawel Mlynarski, Hervé Delingette, Antonio Criminisi, and Nicholas Ayache. 3D Convolutional Neural Networks for Tumor Segmentation using Long-range 2D Context. Under review.
2. Pawel Mlynarski, Hervé Delingette, Antonio Criminisi, and Nicholas Ayache. Deep Learning with Mixed Supervision for Brain Tumor Segmentation. Under review.
3. Raphaël Sivera, H Delingette, M Lorenzi, X Pennec, and N Ayache. A model of brain morphological changes related to aging and Alzheimer's disease from cross-sectional assessments. Under review.
4. Qiao Zheng, Hervé Delingette, and Nicholas Ayache. Explainable cardiac pathology classification on cine MRI with motion characterization by semi-supervised learning of apparent flow. Under review
5. Julian Krebs, Hervé Delingette, Boris Mailhé, Nicholas Ayache, and Tommaso Mansi. Learning a Probabilistic Model for Diffeomorphic Registration. Note: Under review.