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Editorial

Precision Imaging: more descriptive, predictive and integrative imaging

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ABSTRACT

Medical image analysis has grown into a matured field challenged by progress made across all medical imaging technologies and more recent breakthroughs in biological imaging. The cross-fertilisation between medical image analysis, biomedical imaging physics and technology, and domain knowledge from medicine and biology has spurred a truly interdisciplinary effort that stretched outside the original boundaries of the disciplines that gave birth to this field and created stimulating and enriching synergies. Consideration on how the field has evolved and the experience of the work carried out over the last 15 years in our centre, has led us to envision a future emphasis of medical imaging in Precision Imaging. Precision Imaging is not a new discipline but rather a distinct emphasis in medical imaging borne at the cross-roads between, and unifying the efforts behind mechanistic and phenomenological model-based imaging. It captures three main directions in the effort to deal with the information deluge in imaging sciences, and thus achieve wisdom from data, information, and knowledge. Precision Imaging is finally characterised by being descriptive, predictive and integrative about the imaged object. This paper provides a brief and personal perspective on how the field has evolved, summarises and formalises our vision of Precision Imaging for Precision Medicine, and highlights some connections with past research and current trends in the field.

1. The state of play and how we came to it

Medical image analysis has evolved over the past 40 years from being practically a sub-discipline at the cross-roads of image processing, computer vision, and pattern recognition, to become a distinct discipline of its own. Medical image analysis addresses exciting new challenges that emerged from close and creative dialogue with healthcare practitioners and biomedical researchers. This dialogue has generated novel and fundamental ideas that have been adopted back by its parent disciplines and has created a vibrant interdisciplinary community involving specialized meetings, tutorials and summer schools, and journals that top journal rankings in engineering, computer science, and mathematics in terms of impact factor. The introduction of the Medical Image Analysis journal in 1996 was not, correspondingly, an instance of "yet another journal". It was only in 1987, that the Medical Subject Heading (MeSH) concept 'Image Processing, Computer-Assisted was first adopted by the National Library of Medicine as a preferred concept. Also, 'Image Analysis, Computer-Assisted was then categorized as a narrow concept in MeSH terms. A PubMed query on Mar 30th 2016 by this term returns a total of 19,342 entries in this category in 1976–1995, and 161,948 entries in 1996–2015. These numbers show that the expansion of the field has been enormous, yet this evolution has been qualitative as much as quantitative (cf. Fig. 1).

In comparison with 20 years ago, the field of medical image analysis has made terrific progress both in terms of depth and breadth of the research carried out. Both the emerging methods and applications have been affected as much as the way in which we do research in medical image analysis. The first two decades (1976–1995) were dominated by what we know today as *image processing* and paralleled breakthrough developments in *image acquisition*. Scientific questions that marked this period tackled, for instance, image reconstruction, restoration, enhancement, filtering, visualization, and detection problems. The last two decades, however, have placed a greater stress on *image analysis* and *image understanding* thus addressing higher-level computational vi-

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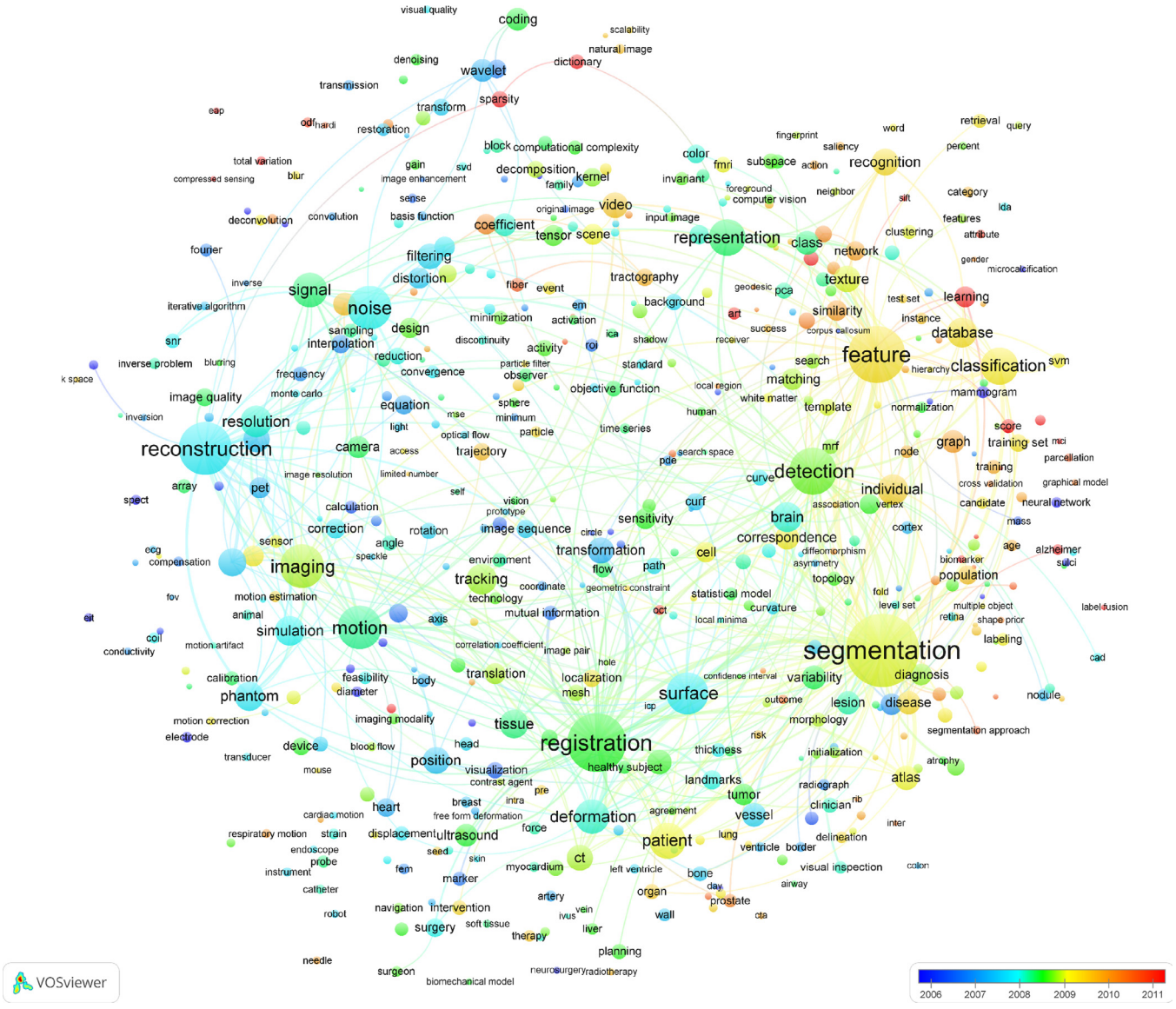

Fig. 1. Network visualization based on clusters of key-phrases in titles and abstracts of the top ranking journals and conferences in our field corresponding to the MeSH term 'Image Processing, Computer-Assisted'. Circles represent concepts, radii are proportional to their frequency, and links encode the top 200 strongest normalized co-occurrences. Colour coding relates to the average publication date of the associated articles. The results correspond to the period 1996–2015 and include ca. 10,012 publications from PubMed on Mar 30th 2016.

sion tasks connected with image interpretation. Key challenges addressed have been pattern and shape analysis, non-rigid registration and tissue deformation analysis, high-dimensional (e.g. vector, tensor) image analysis and registration, multi-scale and multi-resolution modeling and analysis, to name just a few. This period witnessed also important developments in machine learning (e.g. graphical models, deep learning, transfer learning) and new computing hardware (e.g. distributed computing and graphical processing units) that enabled complex data-driven approaches to flourish. Computational imaging emerged as an ever more intimate cross-fertilization between electrical engineering, computer science, and mathematics to which additional disciplines like mechanical engineering, physics, medicine and biology helped further by providing inspiration or priors from domain knowledge. This confluence of disciplines spurred a host of new methodological developments but also a new way to think and work together across disciplines, an aspect that has also radically changed over the past 40 years. Up to the 90s, it was common to illustrate newly proposed methods working on a handful of medical images; it was then rare to find medical image analysis groups within healthcare institutions. Consequently, the dialogue between people doing image processing at the time and those eventually being the recipients of the technology was not as fluid as nowadays. A number of groups around the world led a major transformation in this regard (e.g. the Wolfson Image Analysis Unit at the Medical School of the University of Manchester, the Surgical Planning Lab at the Harvard Medical School, the Imaging Sciences Institute in University Medical Centre Utrecht at Utrecht University, the Medical Imaging Research Center at KU Leuven, the Computational Imaging Science Group based at Guy's Hospital in London, the Image Processing and Analysis group at Yale University, or various groups at the interface between image acquisition, medical robotics and image analysis at Johns Hopkins University, to name a few). These groups spearheaded a different approach to medical image analysis that highlighted the understanding and focus on clinical translation without compromising the scientific rigor and