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EDITORIAL

Moving from data, information, knowledge and models to wisdom-based decision making in the domain of Computer Assisted Radiology and Surgery (CARS)

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Introduction

This Editorial for an IJCARS Special Issue on a selection of CARS 2022 presentations tries to summarize what the CARS community might consider to be important, in order to move from the present relatively technical R&D focus to future priorities dedicated towards not only to maintain, but also on how to improve health-care services. In particular, some questions (what, why, how, who, where and when) are being addressed relating to data, information, knowledge, models and wisdom, specifically in the context of R&D endeavours in the domain of CARS. Possible questions are:

1. *What* are the issues in health care and specifically in the domain of CARS and what previous work can be built on?
2. *Why* do present and new concepts in certain health-care domains need to be revisited, revised and put into practice?
3. *How* can new concepts, for example relating to a model-guided medicine (MGM), be realised when applied to the OR and Hospital of the Future, specifically, or health care generally?
4. *Who* are the stakeholders, actors and beneficiaries of possible MGM realisations?
5. *Where* are the right places and situations for promoting and realising an MGM?
6. *When* can the different stages of MGM solution concepts be realised?

What are the issues in health care and specifically in the domain of CARS and what previous work can be built on?

One of the main issues in providing optimal health care is the complexity and variety of health-care situations and processes. CARS as a Congress and Journal addresses these phenomena and sees itself as a promoter of a model-centric (holistic) medicine to handle this complexity in order to enable intelligent decision-making in medical diagnosis and therapy. Appropriate R&D efforts for ICT support for an MGM have a long tradition in CARS. In principle, it is aimed at providing appropriate ICT methods and tools for an MGM within a continuum between the categories data, information, knowledge, models and wisdom, thereby enabling intelligent decision-making. To fulfil the label "Wisdom-based" decision-making, all five categories deserve equal attention, even if this is not obvious on first sight.

Why do present and new concepts in certain health-care domains need to be revisited, revised and put into practice?

The present and future health-care services have to correspond to new perceptions and derived needs presented by the four stakeholders in health care, specifically patients, physicians, R&D professionals as well as health-care providers. Methods and tools derived from structural mathematics and informatics allow new concepts to be devised and realised that try to address these needs. If applied appropriately, they are capable of handling the increase in complexity for the provision of health care in an intelligent manner.

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How can new concepts, for example relating to a model-guided medicine, be realised when applied to the OR and hospital of the future specifically, or health care generally?

Possible solution concepts based on new ICT methods, tools and architectures can serve as a base for a digital infrastructure for the CAM/CARS research community, thereby enabling applications of an MGM in clinical settings. Numerous scholarly publications, including also many in IJCARS, have addressed or relate to an MGM. They may be abstracted to five general phases for achieving a wisdom-based decision-making. As an example of a model building, ten specific steps to realise a patient-specific model-based medicine are given below**.**

In five phases from data-centric via model-centric to wisdom-centric medicine

1. In the **Data-centric** phase, it is critically important to select the right data items from the given domain of discourse (e.g. from medical records, signals, images, biomarkers, epidemiology, publications, guidelines, etc.). This phase sounds easy to realise but is intellectually very demanding. If the type of the source data is selected inappropriately, the four subsequent phases are likely to lead to faulty results, conclusions, vision or strategic decisions. Data is an important starting point but should not be dominant in the sense of "Can't see the forest for the trees", see Pearl and Brockman [1, 2].
2. In the **Information-centric** phase, data items are combined to information entities in a meaningful way. This phase should consider the logic on what data items should be combined in order to make plausible and verifiable statements. If necessary, a return to phase 1 and revisiting the data items may allow for some fine tuning in this phase.
3. The **Knowledge-centric** phase focuses on cause-effect relationships or any other correlations between information entities by means of an appropriate notation. Assignment of important ratings and impact factors relative to the domain of discourse can enhance the value of the knowledge statements significantly. This may then require to follow the loop back to the information-centric phase.
4. In the **Model-centric** phase, the focus is on selecting and combining all significant knowledge notations from a given domain of discourse into one or more structured models, see also flowchart in Fig. 1, "In 10 big steps to a modest PSM", here specifically on how to generate a Bayesian network. Other models may be derived from structural presentations relating to computational anatomy, physiology and pathology, clinical decision-making, machine learning, physical phenomena, software engineering, etc., as exemplified in the papers selected for this IJCARS Special Issue. A return to the knowledge- or information-centric phases may be necessary in order to enhance the fidelity of any of these models.
5. In the **Wisdom-centric** phase, emphasis is given on achieving a balanced decision-making process by selecting one, several or none of the available models in a domain of discourse, for example, by following the concept of a model-based medical evidence (MBME). "Balanced" refers to fairly considering all relevant stakeholders (and their domain models, if available!) in the given domain of discourse, e.g. different medical, scientific, ethical, economic, social, etc., point of views. It also refers to ensuring that none of the many possible sources of biases (more than 150!) unduly distorts the decision-making process.

Who are the stakeholders, actors and beneficiaries of possible MGM realisations?

Given the four stakeholders to be patients, physicians, R&D professionals and health-care providers, they can be instrumental to establish multidisciplinary and international R&D groups who can contribute to the MGM solution concepts and their validation in clinical settings. An MGM network of clinical and research centres may be interlinked by means of a horizontal and vertical infrastructure, thereby providing an ICT platform for MGM research, services and management, see Fig. 2.

Where are the right places and situations for promoting and realising an MGM?

It can be observed that in recent years an increase in awareness and activities towards an MGM is taking place in various research institutions worldwide. Work towards new concepts is mainly carried out in specific think tanks and workshops, but increasingly also presented in congresses and scholarly publications. A considerable amount of work still needs to be done, however, before a physical realisation of MGM in horizontal and vertical integrated network of research and clinical centres is possible.

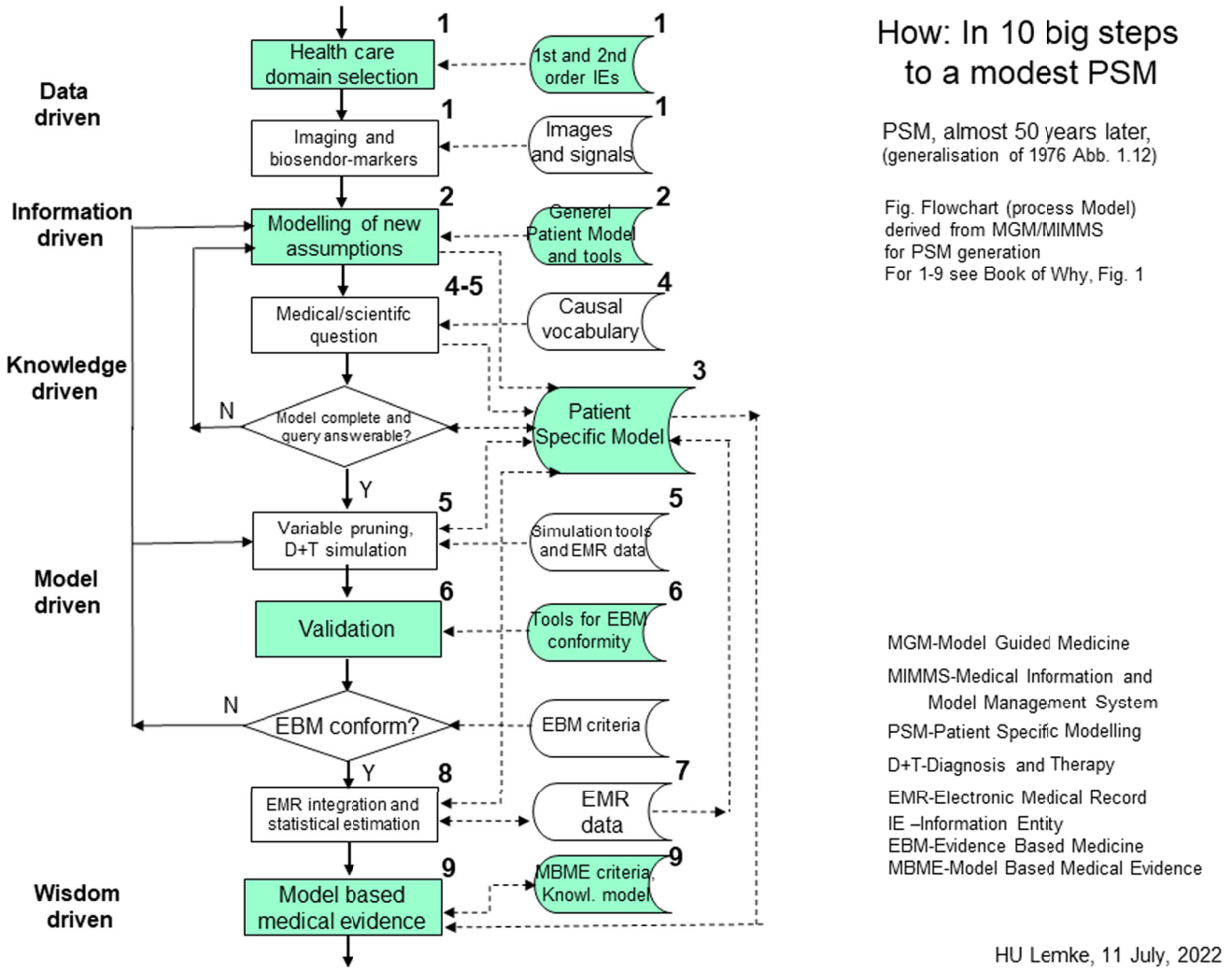

Fig. 1 In ten big steps to a modest PSM (patient-specific model)

When can the different stages of MGM solution concepts be realised?

In order to realise the solution concepts, different stages and time horizons need to be considered, stretching over a period of 10–20 years with a focus of addressing questions and viewpoints of the four stakeholders in health care. Assuming that the next few years will see a significant reshaping of the health-care system, not only because of demographic, economic and political reasons, but also because of the introduction of intelligent technologies, CARS with a focus on MGM, in which machine intelligence is an implicit component, is destined to play a major role in this development.

Selected CARS 2022 presentations (manuscripts) that could be considered to be in line with the above observations and concepts

It is not fair or appropriate to apply the six questions and five phases in the How question to all submitted manuscripts for CARS 2022. Only a subset of the Questions and the How phases are typically considered in the IJCARS review process. A small selection of papers which relate to various aspects of modelling towards one of the five application areas considered for the IJCARS special issue, e.g. computational anatomy, physiology and pathology, clinical decision-making, machine learning, physical phenomena, and software engineering, are listed below.

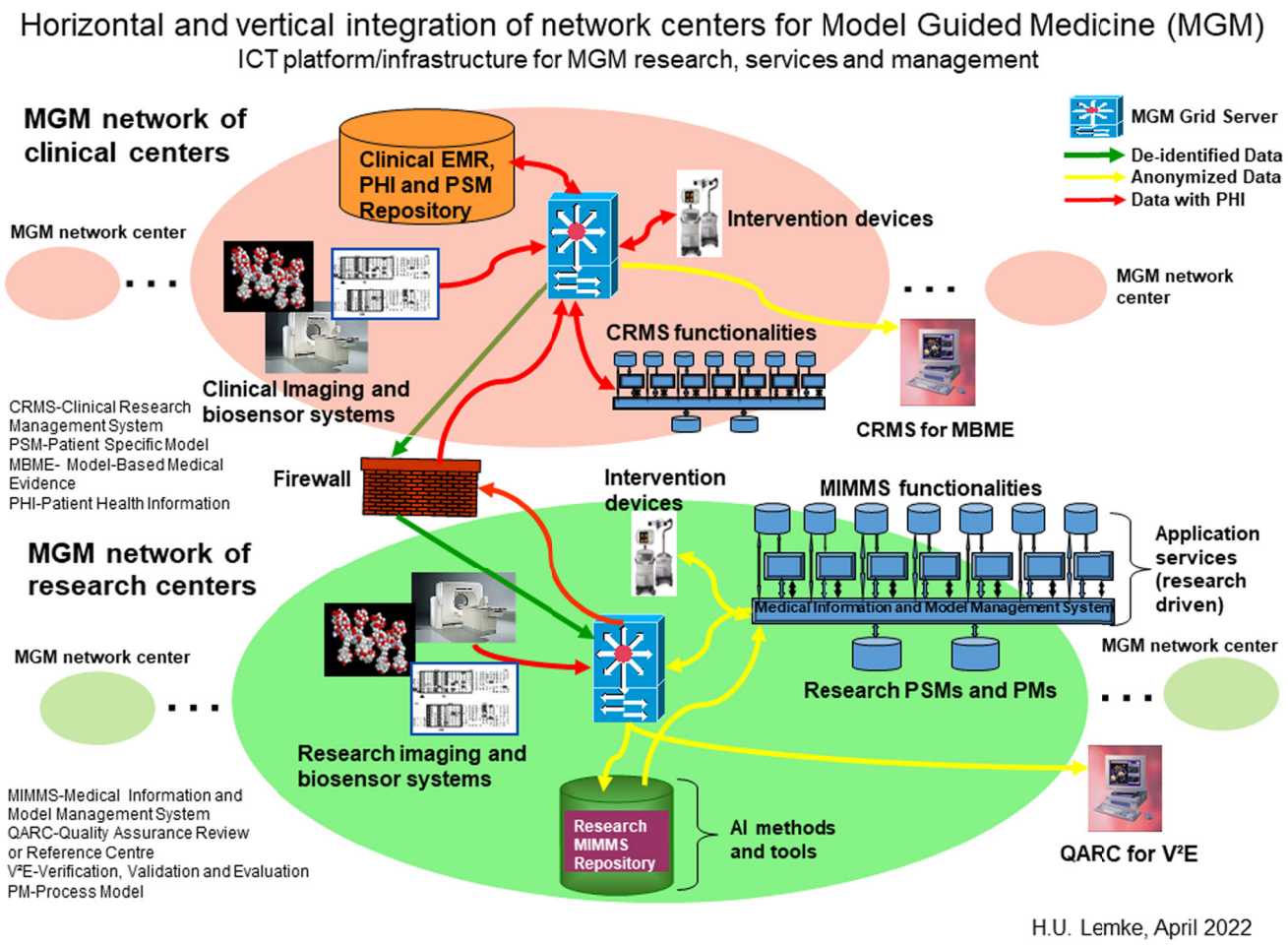

Fig. 2 Horizontal and vertical integration of network centres for MGM

Computational models of anatomy, physiology and pathology, e.g. FEM, CFD

- Comparison of rhinomanometric and computational fluid dynamic assessment of nasal resistance with respect to measurement accuracy, N. Schmidt, J. Brüning, H. Behrbohm, L. Goubergrits, T. Hildebrandt
- Biomechanical analysis of laminectomy, laminoplasty, posterior decompression with instrumented fusion, and anterior decompression with fusion for the kyphotic cervical spine, N. Nishida, M. Mumtaz, S. Tripathi, A. Kelkar, Y. Kumaran, T. Sakai, V.K. Goel
- Augmented reality navigation with ultrasound-assisted point cloud registration for percutaneous ablation of liver tumours, L. Ma, H. Liang, B. Han, S. Yang, X. Zhang, H. Liao
- 3D localization from 2D X-ray projection, D. Bertsche, V. Rasche, W. Rottbauer, I. Vernikouskaya
- Fibre tract segmentation for intraoperative diffusion MRI in neurosurgical patients using tract-specific orientation atlas and tumour deformation modelling, F. Young, K. Aquilina, C. Clark, J. Clayden
- 3D localization of vena contracta using Doppler ICE imaging in tricuspid valve interventions, H. Nisar, D. Fakim, D. Bainbridge, E.C.S. Chen, T. Peters
- Design and validation of a phantom for transcranial ultrasonography, D. Leonov, M. Kodenko, D. Leichenco, A. Nasibullina, N. Kulberg
- Towards intraoperative tissue classification: exploiting signal feedback from an ultrasonic aspirator for brain tissue differentiation, N. Bockelmann, D. Schetelig, D. Kesslau, S. Buschschlüter, F. Ernst, M.M. Bonsanto
- Characterization of blood-mimicking fluids for echocardiography imaging of ventricular septal defects, S. Amouri, G. Tibamoso Pedraza, I. Navarro, M.-J. Raboisson, C. Lapierre, J. Miró, L. Duong
- A patient-specific multi-modality abdominal aortic aneurysm imaging phantom, C.D. Little, E.C. Mackle, E. Maneas, D. Chong, D Nikitichev, J. Constantinou, J. Tsui, G. Hamilton, R. Rakhit, T. Mastracci, A.E. Desjardins

Clinical decision-making models, e.g. Bayesian

- A system for real-time multivariate feature combination of endoscopic mitral valve simulator training data, R. Fuchs, K.M. Van Praet, R. Bieck, J. Kempfert, D. Holzhey, M. Kofler, M. A. Borger, S. Jacobs, V. Falk, T. Neumuth
- Deep learning-based classification of DSA image sequences of patients with acute ischaemic stroke, B.J. Mittmann, M. Braun, F. Runck, B. Schmitz, T.N. Tran, A. Yamlahi, L. Maier-Hein, A.M. Franz
- Clinical decision support models for oropharyngeal cancer treatment: design and evaluation of a multi-stage knowledge abstraction and formalization process, J. Gaebel, S. Mehlhorn, A. Oeser, A. Dietz, T. Neumuth, M. Stoehr

Machine learning models, e.g. CNN

- Use of deep learning to predict postoperative recurrence of lung adenocarcinoma from preoperative CT, Y. Sasaki, Y. Kondo, T. Aoki, N. Koizumi, T. Ozaki, H. Seki
- Real-time automatic tumour segmentation for ultrasound-guided breast-conserving surgery navigation, Z. Hu, P.V. Nasute Fauerbach, C. Yeung, T. Ungi, J. Rudan, C.J. Engel, P. Mousavi, G. Fichtinger, D. Jabs
- Explainability of deep neural networks for MRI analysis of brain tumours, R.A. Zeineldin, M.E Karar, Z. Elshaer, J. Coburger, C.R. Wirtz, O. Burgert, F. Mathis-Ullrich
- Deep learning-based instrument detection for intraoperative robotic assistance, J. Badilla-Solórzano, S. Spindeldreier, S. Ihler, N.C. Gellrich, S. Spalthoff
- Training deep neural networks with noisy clinical labels: towards accurate detection of prostate cancer in US data, G. Javadi, S. Samadi, S. Bayat, S. Sojoudi, A. Hurtado, W. Eshumani, S. Chang, P. Black, P. Mousavi, P. Abolmaesumi

Physical phenomena models, e.g. electromagnetic, implants

- Development and validation of a method for automated 3D thorax model generation and surface-electrode positioning based on handheld video footage, N. Dussel, R. Fuchs, A.W. Reske, T. Neumuth
- Intraoperative compensation of magnetic field distortions for fluoroscopic and electromagnetic hybrid navigation, M. Cavaliere, P. Cantillon-Murphy
- Evaluation of virtual handles for dental implant manipulation in virtual reality implant planning procedure, H.-R. Rantamaa, J. Kangas, M. Jordan, H. Mehtonen, J. Mäkelä, K. Ronkainen, M. Turunen, O. Sundqvist, I. Syrjä, J. Järnstedt, R. Raisamo
- Spatio-temporal reconstruction method of carotid artery ultrasound from freehand sonography, H. Liang, G. Ning, S. Dai, L. Ma, J. Luo, X. Zhang, H. Liao

Software engineering models

- NousNav: a low-cost neuronavigation system for deployment in lower resource settings, E. Léger, S. Horvath, J.-C. Fillion-Robin, D. Allemang, S. Gerber, P. Juvekar, E. Torio, S. Pujol, T. Kapur, S. Pieper, R.S. Bardsley, S. Frisken, A. Golby

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