High-performance numerical methods supporting radiation therapy treatment planning (11w2035)

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1 Overview of the Field

The projected increase in the incidence and mortality of thoracic and abdominal cancers is an important health concern for Canadians. For many diseases, radiation therapy is a proven treatment modality, and nearly half of all cancer patients receive radiation therapy, either as the sole treatment or combined with surgery and/or systemic pharmaceutical agents, e.g. chemotherapy. Important technological advances, such as Intensity Modulated Radiation Therapy (IMRT), have solidified or expanded the role of radiation therapy in improving control of cancers, notably for head and neck cancers and prostate cancer. For disease in the thorax and abdomen –in aggregate terms, cancers with the highest mortality rate– however, the effectiveness of radiotherapy has been drastically limited by the sensitivity of non-tumour lung and liver tissues, and confounded by the technical challenges due to breathing-related organ movement and patient setup uncertainty. Thus, there is a marked need for improving state-of-the-art radiotherapy planning and delivery methods.

Since the state-of-the-art radiation therapy treatment planning process typically involves highly complex computer-assisted mathematical modeling to support near-optimal decision making, it is impossible to address such a need without adequate advancements in associated mathematical models and high-performance numerical methods, carefully integrating those with existing and emerging radio-therapeutic technologies.

2 Recent Developments and Open Problems

Of particular interest is minimizing negative effects of uncertainties that are inherently present during the radiation treatment planning phase. As we improve our medical imaging capabilities, highly tailored to the shape and position of the cancer treatments minimize the radiation dose to healthy tissue, but also create a greater risk of a geometric miss of the disease if cancer moves. So, without effective targeting and adequate accounting of these uncertainties during the mathematical modeling and treatment planning phases, there is a risk of damaging healthy tissues indiscriminately, thus failing to control the disease, especially using high-precision technologies like IMRT, which in turn nowadays become almost ubiquitously present in clinics.

The above mentioned uncertainties may be targeted at several distinct phases of treatment planning and delivery, for example, by developing novel medical imaging techniques that provide more accurate biological information to planners (e.g., PET/CT combination), by providing information on present organ and tumor locations and consequently allowing for real-time intervention during the treatment delivery (e.g., gating), and finally, by informing the underlying numerical models about the anticipated uncertainties a-priori during the treatment planning phase to enable the delivery of *robust* near-optimal radiation treatment (e.g., robust optimization of IMRT plans).

As the radiation treatment modalities become more advanced and complex, a concurrent treatment planning challenge is to formulate the associated treatment planning model that carefully captures the desired clinical objectives and yet remains computationally tractable, that is, possible to optimize over in short time alloted under clinical planning scenario and with limited computational and human resources.

All of the above provides both challenges and excellent opportunities to develop a truly collaborative scientific framework that would ultimately enhance state-of-the-art standards for cancer treatment and management.

3 Presentation Highlights

Radiation therapy treatment planning, besides acquiring the initial medical imaging data and setting proper clinical objectives, involves formulating a mathematical model for treatment delivery, and, subsequently, exploring the model's control variable space (numerically) in search of a (near) optimal treatment plan. The workshop was focused on the following principal components of this process: (1) (clinically) adequate modeling, (2) numerical optimization methods, and (3) implementation.

The workshop led participants on a guided tour of state-of-the-art radiation therapy, opening with some clinical insights into the problem (presented by a radiation oncologist, Princess Margaret Hospital, and the chair of medical physics, Memorial Sloan-Kettering Cancer Center – two world-leading cancer treatment and research centers). The opening was followed by presentations given by a number of distinguished applied mathematicians and computer scientists primarily working in the area of optimization. An important component of the workshop was a presentation by an industrial research scientist from Elekta, one of the commercial leaders in radiation therapy products, on the challenges in the field as seen by the product developers.

In addition, the first day of the workshop was concluded by a networking and poster session where some of the more junior attendees had a chance to present their work and the floor was opened to a more informal discussions.

4 Scientific Progress Made

During the workshop, primarily, during the panel discussion, a number of concrete projects were proposed for collaborative research, and potential research groups were identified; these include

1. GPU-supported Monte-Carlo-based accurate dose computation engine,
2. data-mining for clinically "good" and "bad" treatment plans,
3. constructing and exploring the Pareto-space of non-dominated treatment plans,
4. real-time GPU-supported treatment plan re-optimization.

Presently, we are investigating the viability of these research directions.

5 Outcome of the Meeting

This was a first event within the envisioned series of once-in-two-years workshops on high-performance numerical methods supporting radiation therapy treatment planning. The intent is to grow these workshops into regular series of intense collaborative research events that bring together a diverse group of applied mathematics, medical physics and radiation oncology researchers, as was reconfirmed during the BIRS workshop in March of 2011. First and foremost we target a creation of a truly active, interdisciplinary and sustainable research framework addressing the problems in the field of optimal radiation therapy treatment planning.

The main goal of the proposed workshop series is to determine and regularly update a set of integrated strategic directions for development and collaboration in high-performance numerical methods and models that support optimal radiation therapy treatment planning – an interdisciplinary area that brings together researchers and practitioners in applied mathematics and operations research, medical physics, and radiation oncology. We believe that the goal may be achieved by bringing together leading experts in the area and a selected group of post-doctoral fellows and graduate students in the collaborative environment. Consequently, 2011 BIRS workshop served an important milestone towards radical advancement in the state-of-the-art standards of radiotherapy treatment planning.