Computer Aided Verification of Radiotherapy Treatment Plans

Juliana K Bowles, PhD[1] and Reshma Munbodh, PhD[2]

[1]School of Computer Science, University of St Andrews, Fife, St Andrews, United Kingdom
[2]Department of Radiation Oncology, Warren Alpert Medical School of Brown University, Providence, RI, USA

Purpose: Quality assurance (QA) in radiation oncology entails a multi-step verification of complex, high-technology treatments involving an inter-disciplinary team and multi-vendor software and hardware. Here, we extend our work on the pre-treatment physics chart review (TPCR) using a modular approach and formal methods from computer science to automatically identify logical inconsistencies in a patient's treatment plan and how they propagate.

Methods: The TPCR process was decomposed into modules, subprocesses and module-associated variables for input to the subprocesses. The checks in the subprocesses and their order were formalized as constraints in an activity workflow diagram. The TPCR process was converted into a Satisfiability Modulo Theory (SMT) problem and solvers were used to 1) detect and correct logical inconsistencies in the TPCR specification through an iterative learning approach and 2) detect logical inconsistencies in a proposed patient treatment plan automatically.

Results: The model for the TPCR process comprises 5 modules, 17 sub-processes and approximately 300 variables (~70 distinct). Modules comprise "Patient Manager", "Treatment Planning System", "Independent MU Calculation" and "Record and Verify". Subprocesses include "Dose Prescription", "Documents", "CT Integrity", "Anatomical Contours", "Beam Configuration", "Dose Calculation", "3D Dose Distribution Quality", "IMRT QA" and "Treatment Approval". We previously formulated our model to detect inconsistencies in the dose prescription, treatment modality and dose distribution. We have now extended the model to detect inconsistencies in additional areas including CT imaging, beam configuration, dose calculation and IMRT QA. Testing indicated that the solver successfully detected all inconsistencies in the specification of the TPCR process and in radiotherapy treatment plans automatically.

Conclusion: This work confirms that SMT solvers from computer science hold promise for automating the TPCR process and formalizing complex QA processes in radiation oncology and possibly other areas. The formalization and automation of these processes may lead to improved patient safety and increased clinical efficiency.

Keywords: Quality assurance, treatment planning, radiation therapy

Impact/Innovation: Currently, the pre-treatment physics chart review (TPCR) of radiotherapy treatment plans is mostly performed manually. Manual verification is time-consuming and prone to errors. We have formalized and automated the TPCR process. Our solution extends upon current solutions in the field by allowing us to not only identify errors but also their source, dependencies and how they propagate. This is expected to lead to improved patient safety and increased clinical efficiency both in terms of reduced patient delays, time saved in performing this task and the implementation of clinical procedures to reduce the occurrence of such errors.

Key results: We have used formal methods derived from computer science to decompose the TPCR process into tractable units, and automatically identify logical inconsistencies in a treatment plan, their source and how they propagate. The model for the TPCR process comprises 5 modules, 17 sub-processes and approximately 300 variables (~70 distinct). The TPCR process was converted into a Satisfiability Modulo Theory (SMT) problem and solvers were successfully used to 1) detect and correct logical inconsistencies in the specification of the TCPR process through an iterative learning procedure and 2) identify logical inconsistencies in a patient's radiotherapy treatment plan. The architecture of the implemented solution takes in customized checks, which represent current practice for a specific clinic. This allows us to replace the set of checks to suit the clinic where it should be deployed, thus making the solution easily adaptable for use in other clinics. Figure 1 illustrates the iterative nature of the solution development and Figure 2 shows the modular nature and constituents of the solution.

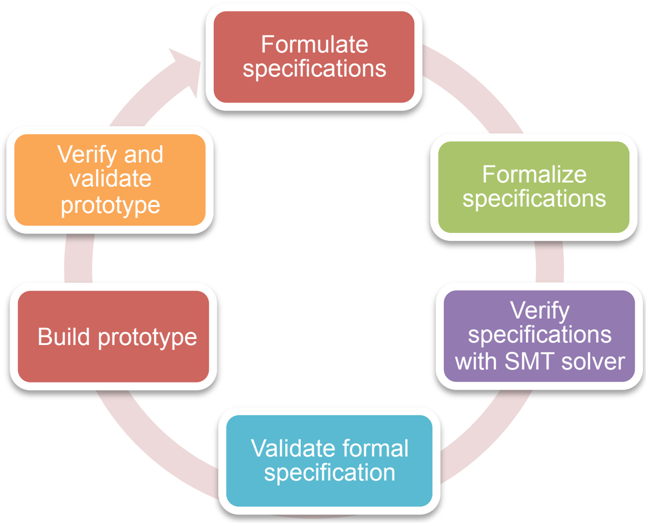

Figure 1: Iterative solution with feedback

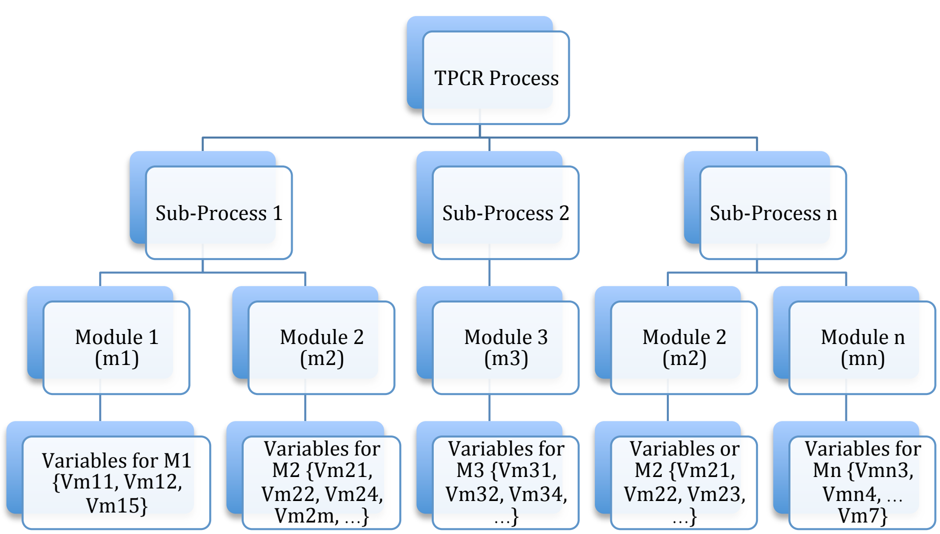

Figure 2: Breakdown of the TPCR process into sub-processes, modules and variables