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Adaptive fractionation on the MR-Linac: A reinforcement learning approach to exploit interfractional motion

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MR-Linac

- Hybrid device combining magnetic resonance (MR) imaging with radiation therapy (RT).
- State of the art technology with first patients treated in 2017[1]. In operation at USZ since April 2019.
- MRI provides soft-tissue contrast not visible in X-Ray scans.
- The device allows automated beam control by imaging during treatment. → Intrafractional motion control
- On-table dose delivery adaptations considering actual locations of target and organs at risk can be performed based on actual MR scans.
- No additional dose for imaging.

Interfractional motion

- In general, prescribed tumor doses are not delivered in one radiotherapy session but divided into several fractions.
- Fractionation allows normal tissue to recover between the sessions while still sufficiently damaging tumor tissue.
- The biological effect of ionizing radiation doses d_t delivered in fraction t can be modeled by the biological effective dose B, where ${}^{\alpha}/_{\beta}$ is a tissue specific constant :

$$B(\vec{d}) = \sum_{t=1}^{F} (d_t + \frac{d_t^2}{{}^{\alpha}/_{\beta}})$$

- Initial scans where tumor and organ at risk have been outlined do not precisely represent the daily setups on other days.
- Interfractional motion can be especially large in abdominal regions **(Fig.2)**. Therefore, treatment at the MR-Linac can be very beneficial.
- To quantify interfractional motion, the sparing factor δ is introduced, which is given by the ratio of dose delivered to the organ at risk and dose delivered to the tumor:

$$\delta = \frac{d_{OAR}}{d_T}$$

Adaptive fractionation

- Generally, fractionation is done by delivering the same amount of dose in each fraction.
- Adaptive fractionation deviates from this standard and adapts the dose to be delivered to the daily patient anatomy
- By delivering larger doses when tumor and organs at risk are far apart from each other, and lowering it when they are close, one can improve the radiotherapy treatment.
- The decision of what dose to apply in each fraction is a nontrivial problem as future patient anatomy is unknown.

Reinforcement learning solution

- To compute an optimal dose for each fraction, we apply the the framework of markov decision processes (MDP) and the dynamic programming algorithm.
- By observing the interfractional motion the future patient anatomy can be modelled.
- Based on a probability distribution of future patient anatomies $P(\delta)$ a dynamic programming algorithm (reinforcement learning) can be applied to calculate the optimal dose for each fraction by maximizing tumor dose and minimizing the dose delivered to the organs at risk.

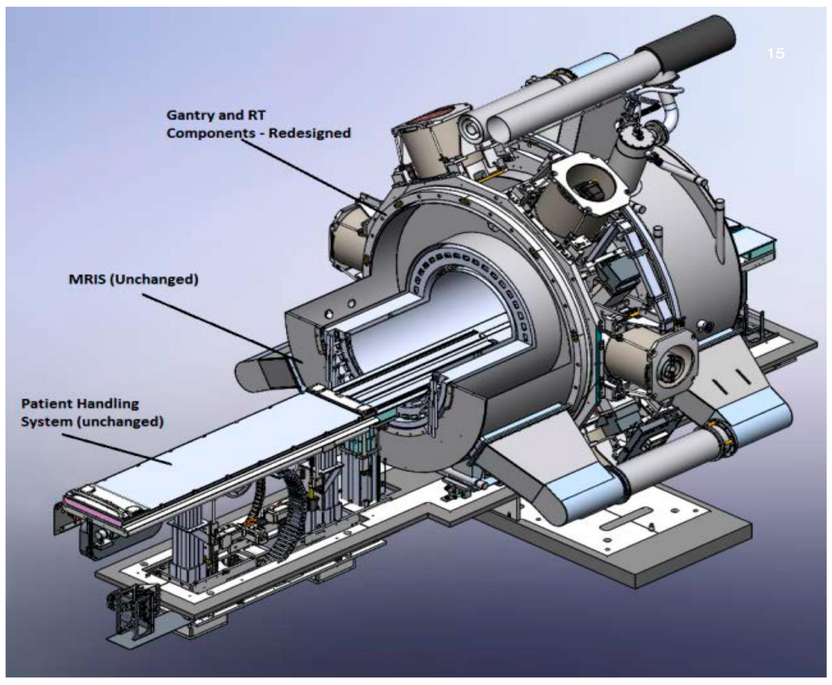

Fig.1: Schematic drawing of the ViewRay MRIdian Linac system. The Linac system is located inside the buckets shielding the parts from the static magnetic field and stopping RF noise.

Specifications[2]

- The MRIdian system is composed of a split superconducting magnet with a 28cm gap between the two magnet halves.
- A rotating gantry assembly placed at the gap holds all linac components which are mounted inside cylindrical shielding compartments.
- 0.35 T MRI with inplane resolution of 1.5mm x 1.5mm and slice thickness of 1.5mm and 3mm.
- Two-dimensional cine MR images can be acquired in one plane at four frames/s or in three planes at two frames/s, also during treatment. (resolution of 3.5mm x 3.5mm and slice thickness between 5mm and 7mm).
- Geometric accuracy of 1mm within 20cm and 2mm within 35cm from isocenter.
- 6MV linear accelerator with a dose rate of 600 cGy/min.

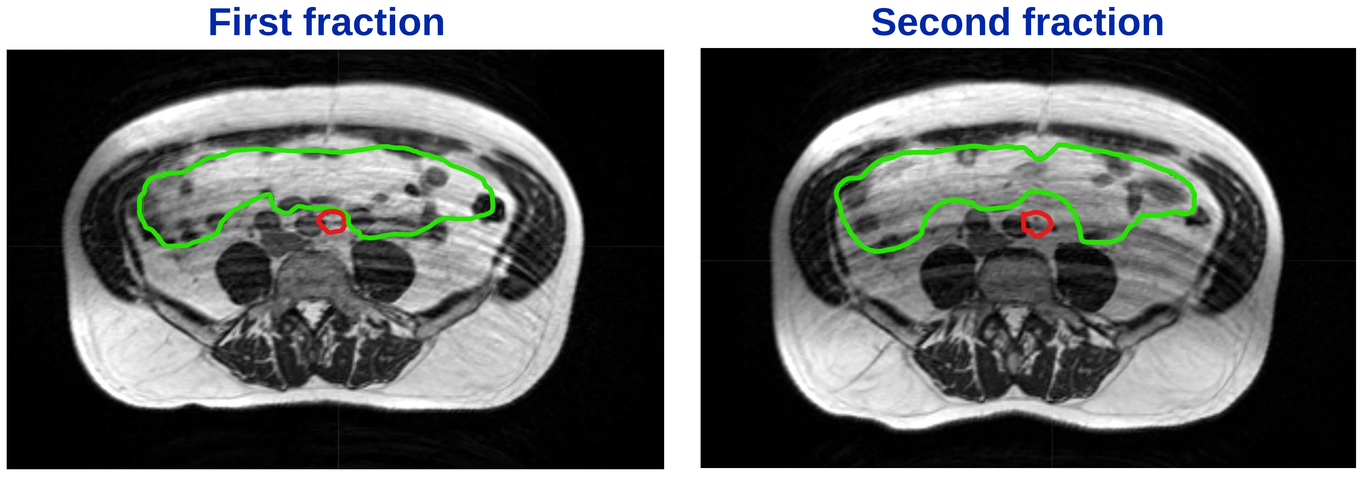

Fig.2: Visualized interfractional motion of a patient at the MR-Linac. The organ at risk, the bowel, is outlined in green while the tumor is outlined in red.

Markov model of the problem

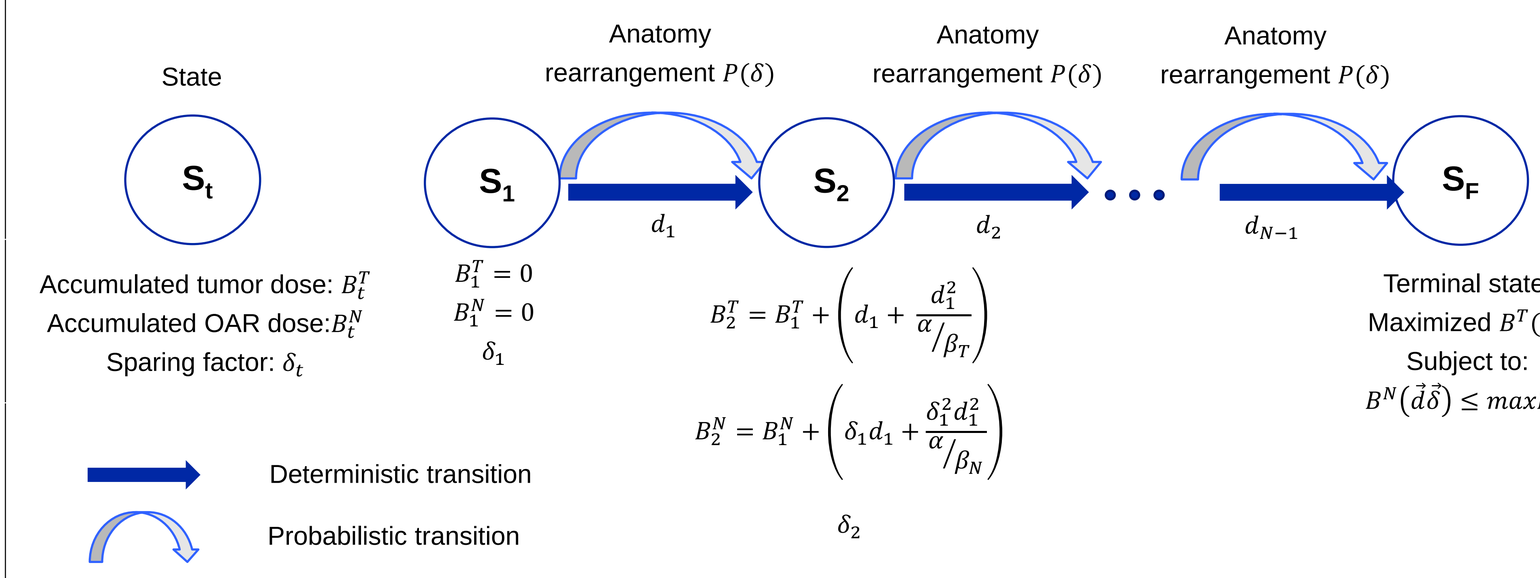

Fig.3: Visualization of the adaptive fractionation problem. The transition of the "dose states" is determined by the delivered doses *d* and is deterministic, given the patient anatomy. The transition of the "anatomy state" instead is probabilistic. The future sparing factors, relating to the distances between tumor and organs at risk, cannot be predicted accurately but are described by a probability distribution $P(\delta)$ that assigns a probability for all sparing factors.

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References

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2. Klüter, S. Technical design and concept of a 0.35 t mr-linac.Clinical and Translational Radiation Oncology18, 98–101 (2019).