Robust biologically based optimization for intensity modulated radiotherapy (IMRT)

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What is IMRT?

- A technique used to deliver radiotherapy with increased target (tumour) dose conformality and/or better sparing of critical structures
- Beam intensity profiles are non-uniform
- Simultaneous dose increment to different target volumes in one treatment plan
- Treatment plans are derived by an inverse planning technique where an optimization problem is solved
- Objective functions and constraints are based on physical doses or biological effects

Past, current and future subprojects

- Uncertainties in biologically based objective functions
  - Use ”better” data
  - Sensitivity analysis
  - Robust optimization
- Machine optimization – realistic plan objectives
  - Deliverable-based optimization
  - Beam-angle optimization
- Multi-objective optimization
  - Increase the number of objectives in the problem
  - How many Pareto optimal solutions are needed in order to build a sufficient Pareto surface?

Robust optimization and IMRT History

- Most common: Geometric and dose calculation uncertainties
  - Due to positioning uncertainties and motion of the patients’ inner organs during and between treatment fractions
  - Treat the uncertain parameters as stochastic variables and use their expectation value and variance and/or a probability distribution of the stochastic variables in the definition of the optimization problem for IMRT
- Less common: Parameter uncertainty
  - Approaches so far …
    - Usage of biological margins
    - Optimization using a range of parameter values and average over the different solutions
    - Optimization using different probability distributions of parameter values incorporated in the objective function
    - Optimization over the expectation value for a nonconvex objective function

Robust optimization and IMRT
Present time and future prospects

- Present: Sensitivity analysis, or “What if” analyses
- Current project basis: Consider potentially uncertain parameters as stochastic variables
- A new robust optimization model: A Stochastic Program with Equilibrium Constraints (SMPEC)
- Robustness results are available for this model: The optimal solution varies continuously with the distribution; discretization approaches converge, and rapidly too
- Long-term goals: Allow planners to describe parameter uncertainties; provide practical robust multiobjective solutions that are deliverable; robustness visualization tools

Current resources and future needs

- Present:
  - two full-time PhD students + supervisors
  - with support from The Swedish Cancer Society & King Gustav V Jubilee Clinic Cancer Research Foundation resp. Chalmers Math
- Future needs for deliverable-based optimization:
  - improved dose calculation engine (assistant professor – position to be announced)
  - improved utilization of machine parameters (post-doc – position to be announced)

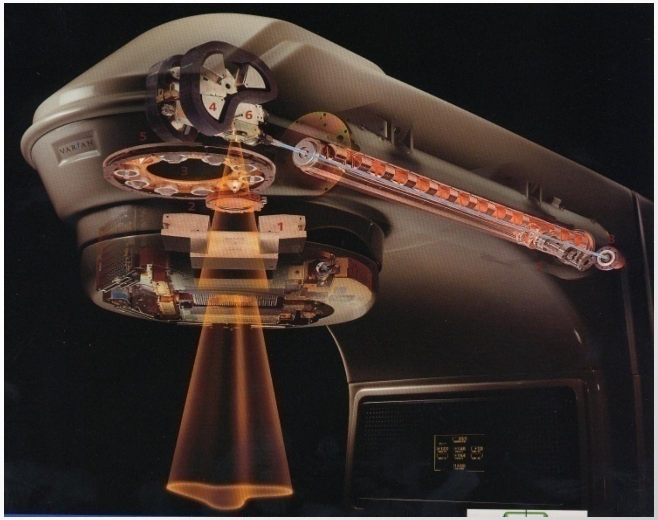
Thank You for your attention!

The linear accelarator (LINAC) and the multileaf collimator (MLC)

- The beam is divided into small rectangular cells called beamlets
- The treatment region of the patient is divided into boxed shaped cells called voxels
- The absorbed dose (Gray) in a voxel scale linearly with the beam intensities

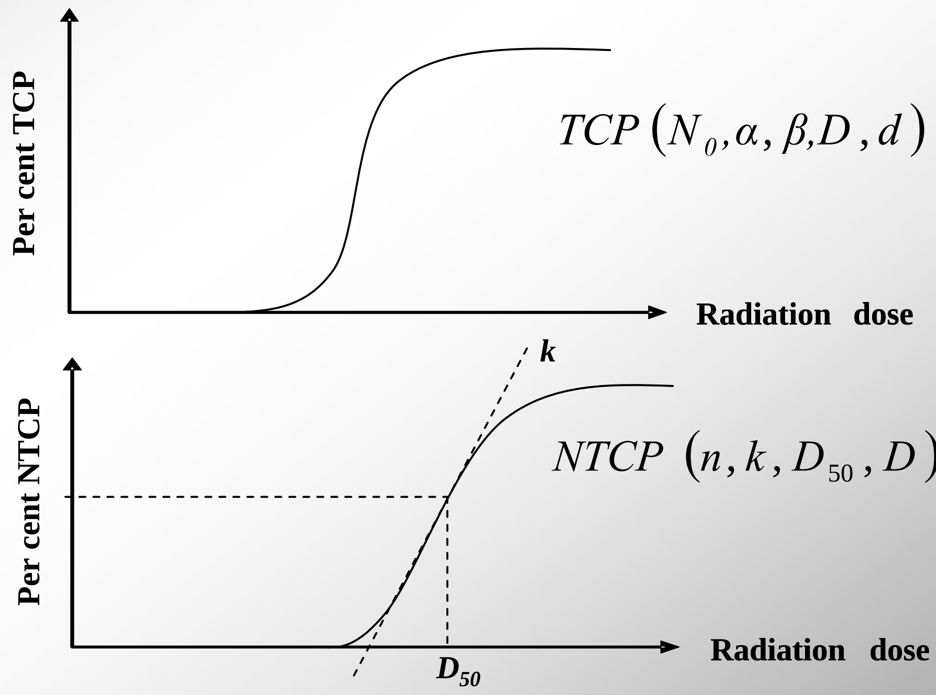
$$d_i = \sum_{\forall j} K_{ij} x_j$$

- 30-40 pairs of 1cm thick (MLC) leafs are located in the head of the LINAC and are moving dynamically during the delivery of an IMRT treatment



Models that account for radiobiological factors

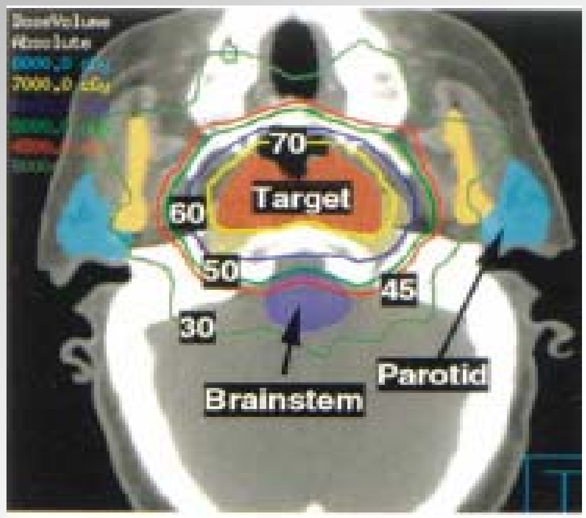
- The models give the probability that a specific end-point will occur at a given point of time
- TCP describes the tumour control probability
- NTCP describes the normal tissue complication probability
- The EUD (gEUD) model give the (generalized) uniform equivalent dose based on a tissue's volume effect



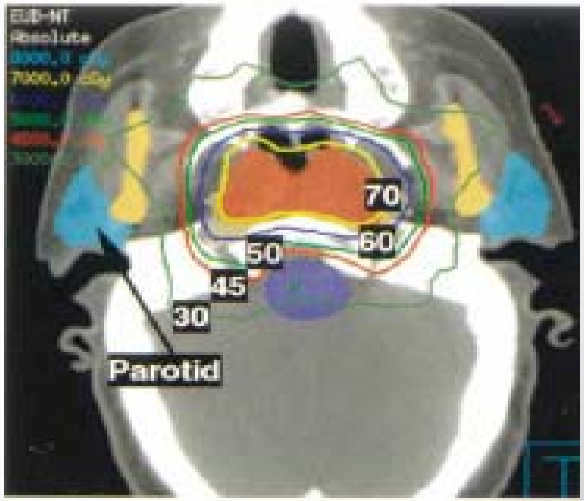
$$gEUD(\mathbf{d}, a) = \left(\frac{1}{N} \sum_{i=1}^{N} d_i^{\,a} \right)^{\frac{1}{a}} \Rightarrow \begin{cases} a < 0 : d_{min} \\ a \approx 1 : d_{mean} \\ a >> 1 : d_{max} \end{cases}$$

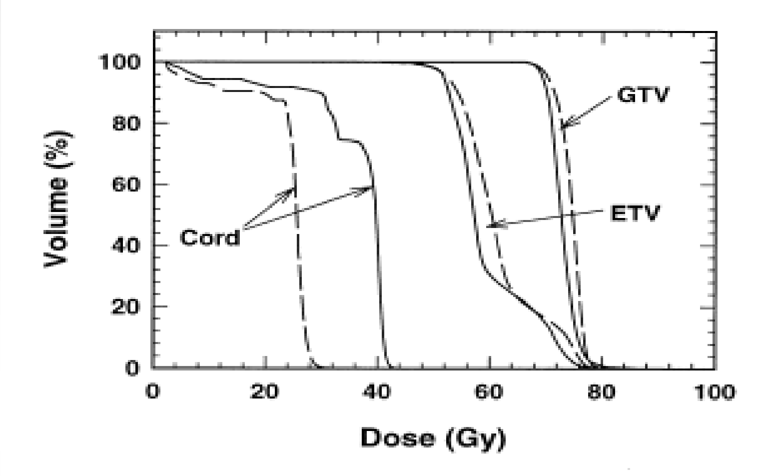
The gain with biological over physical optimization

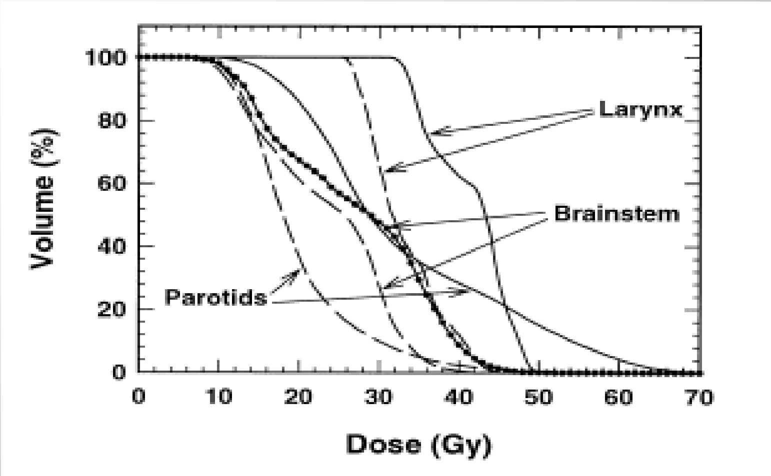
Physically based optimization



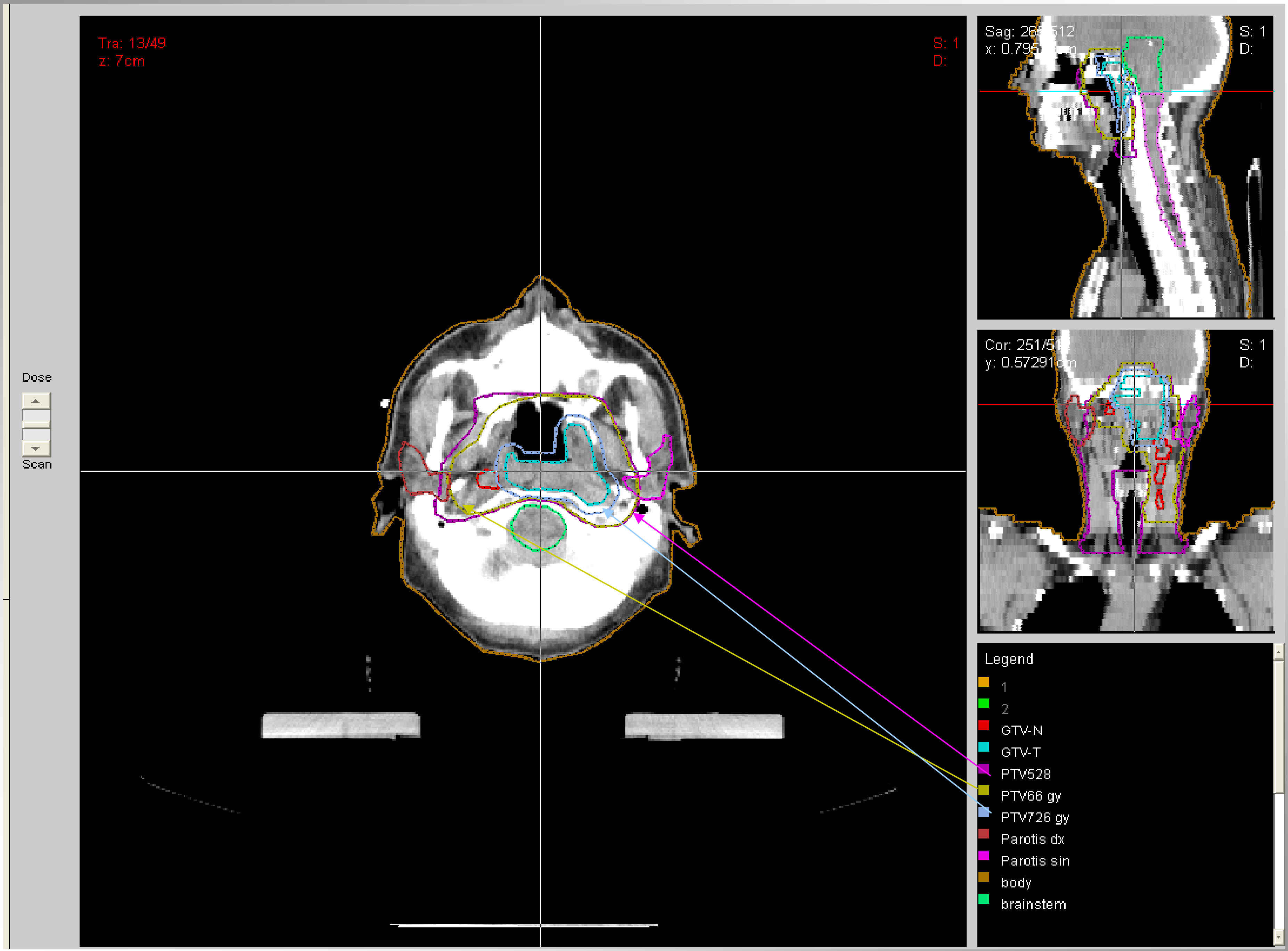
Biologically based optimization





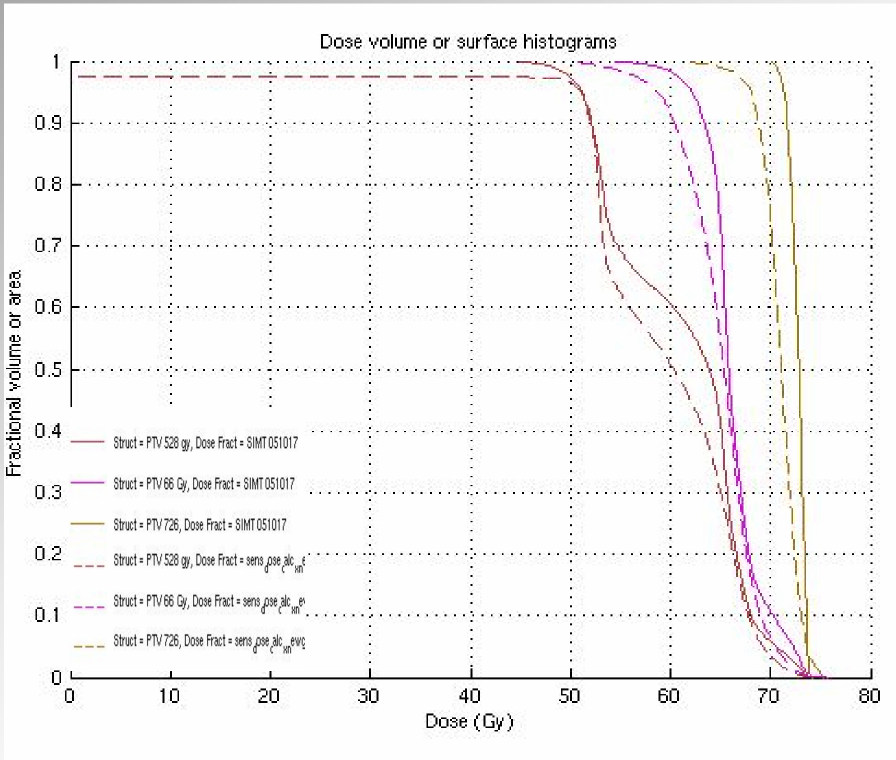


Wu et al: *Optimization of intensity-modulated radiotherapy plans based on the equivalent uniform dose*. Int. J. Radiation Oncology Biol. Phys. 52(1), pp 224-235, 2002.

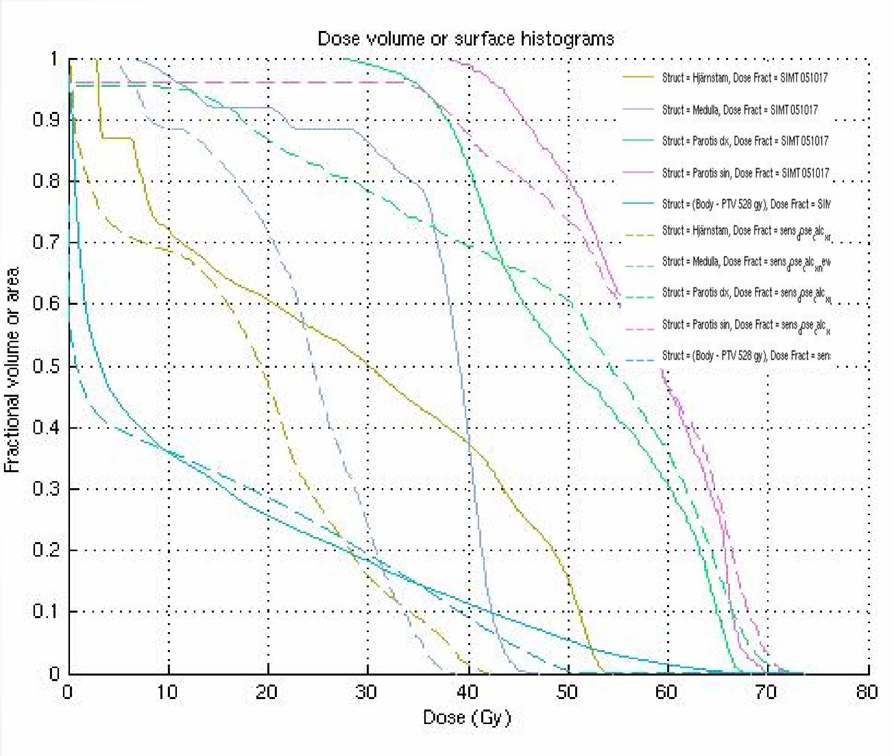


Tra: 13/49
z: 7cm
S: 1
D:
Dose
Scan
S: 1
D:
Cor: 251/5
y: 0.57291 cm
S: 1
D:
Legend
1
2
GTV-N
GTV-T
PTV528
PTV66 gy
PTV726 gy
Parotis dx
Parotis sin
body
brainstem

DVH



Dose volume or surface histograms
Fractional volume or area
Dose (Gy)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
Struct = PTV 528 gy, Dose Fract = SIMT 051017
Struct = PTV 66 Gy, Dose Fract = SIMT 051017
Struct = PTV 726, Dose Fract = SIMT 051017



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20
30
40
50
60
70
80
Struct = Hjärnstam, Dose Fract = SIMT 051017
Struct = Medulla, Dose Fract = SIMT 051017
Struct = Parotis dx, Dose Fract = SIMT 051017
Struct = Parotis sin, Dose Fract = SIMT 051017

Multicriteria optimization
Pareto navigator