

Overview

- Finding the most beneficial treatment
- Mastering the degrees of freedom
- The computer aided planning process
 - posing and solving an optimization problem
 - interactivity
- Organ motion
- Demonstrations
 - Direct machine parameter optimization
 - Dose tracking

Finding the most beneficial treatment

- Prescribing a treatment
 - target definition / delineation
 - dose based (DVH, min, mean, max ...)
 - biological models (TCP, NTCP)
 - geometrical uncertainties
- Realizing the prescription
 - external photon beams
 - ...
- Other considerations
 - robustness to organ motion (geometrical uncertainties)
 - robustness to delivery errors
 - delivery time

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Mastering the degrees of freedom

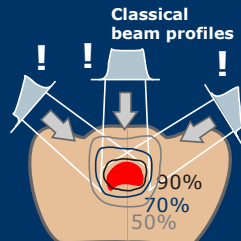
- External photon beams parameters
 - number of beams
 - beam orientations (angles and isocenter)
 - collimator configuration (MLC & jaw sequence)
 - (intensity modulation)
- Degrees of freedom
 - several thousand exist
 - a handful are utilized with conventional techniques

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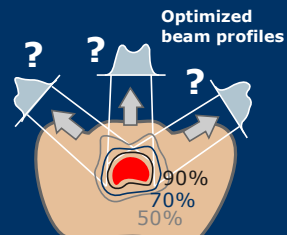
Computer aided planning

Conventional treatment planning



- Standard beam configurations
- "What is the resulting dose?"
- Plan modification by trial-and-error
- Simple beam profiles (uniform or wedge shaped)

Inverse treatment planning



- Explicit requirements on the desired dose distribution
- "Find the best possible beam configuration!"
- Leads to an optimization problem
- Best solution with non-uniform beams

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Posing an optimization problem

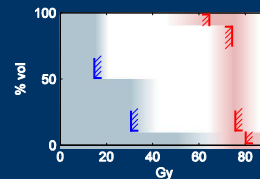
- Distill the full knowledge of the physician and/or planner into a small set of numbers
 - quadratic penalty functions
 - biological models
- Define the rules that drive the optimization
 - minimize the objective while fulfilling the constraints
- Define which degrees of freedom are open for optimization, and provide initial values for them
- Launch the optimization process and obtain the optimal solution

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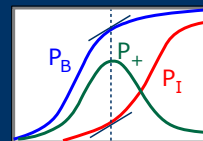
Optimization functions

- Weighted sum of quadratic penalty functions
 - Dose volume criteria (at most 70% of the volume to receive 45 Gy)
 - Equivalent uniform dose



Quadratic penalties

- Biological models
 - Tumor control probability (TCP, P_B)
 - Normal tissue complication probability (NTCP, P_I)
 - Probability for complication free tumor control (P_+)



Biological models

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Constraints

- Give absolute precedence to some physical criterion, i.e. max dose to a critical structure. No need to care about function weights.
- Perform lexicographic (prioritized) optimization:
 - first achieve target coverage
 - without losing target coverage, minimize dose to critical structures
 - similarly, minimize dose to other organs at risk
 - similarly, minimize integral dose
- Explore the Pareto efficient frontier
- Define biological optimization problems

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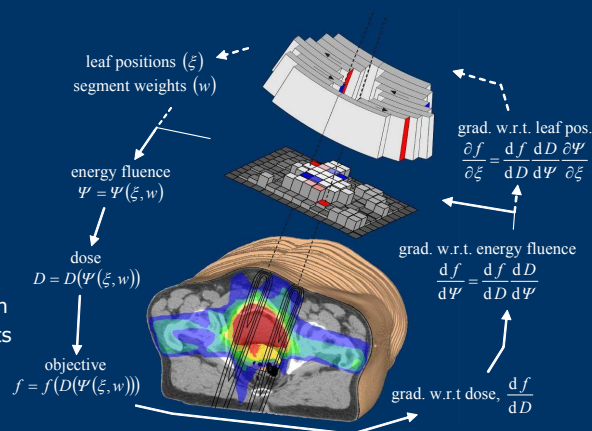


Optimization variables

- Intensity modulation
 - initial guess is a uniform fluence over the target
 - needs subsequent sequencing
- Direct step-and-shoot optimization
 - initial guess obtained through a brief intensity modulation
- Gantry angle optimization
 - local optimization based on the initial angles given by the user

Computational flow

- Search direction
 - current gradient
 - estimated curvature
 - accumulated information
 - fulfill linearized constraints
- Line search
 - minimize merit function
 - incorporates constraints as penalties
- Optimize intensity modulation or machine parameters



Intensity modulation problems

Problem "Over-optimization":

Optimizing in many iterations generates jagged profiles that are hard to convert to machine settings (MLC sequence)

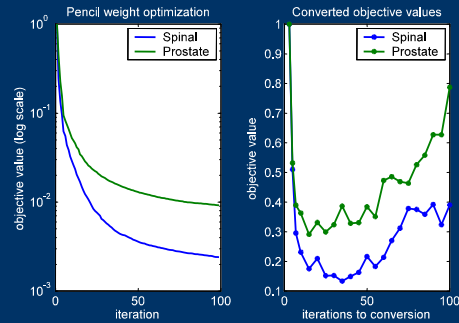
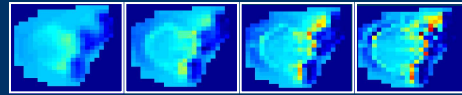
Cause:

Pencil weight optimization problems are ill-conditioned

Solution:

- Use a Quasi-Newton method with diagonal initial Hessian estimate
- Optimize no more than 25-40 iterations before conversion

3 iter 10 iter 25 iter 100 iter

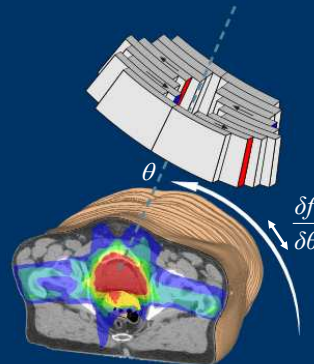


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Gantry angle optimization

- Gantry angles and other beam modifiers (fluence, DSS) are optimized simultaneously.
- The optimization is gradient based and local, but may find solutions far away from the initial point when necessary.
- Exploiting the extra degree of freedom may allow for fewer beams and/or fewer segments, with maintained plan quality.



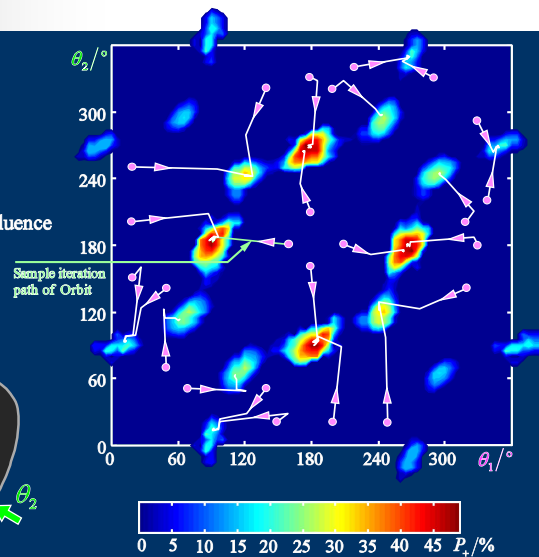
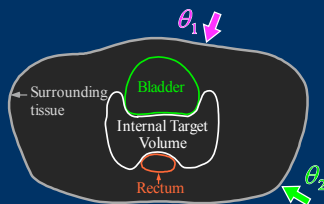
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Gantry angle optimization

For each (θ_1, θ_2) , the following optimization problem is solved:

$$\begin{cases} \text{maximize } P_+(\xi; \theta_1, \theta_2) \\ \text{where } \xi = \begin{bmatrix} \mathcal{E}_1 \\ \mathcal{E}_2 \end{bmatrix} \\ \text{and } \mathcal{E}_i = \text{discretized therapeutic fluence} \\ \text{for beam } i \end{cases}$$



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Interactivity

- Defining a perfect optimization problem is practically impossible
- Most algorithms involved in solving the problem have some imperfections
 - global optimality cannot be guaranteed
 - memory and CPU limits the speed and accuracy
- Speed and efficiency of the user interaction is a key issue
- Evolving to more sophisticated problem descriptions and algorithms
 - Multi criteria optimization
 - Sensitivity analysis

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Robustness to organ motion

- Due to organ motion, different doses will be delivered each day.
- The accumulated dose will be a smeared out version of the nominal dose.
- The dose delivered to a specific patient is dependent on the stationary error, and the magnitude of the random errors
- ORBIT uses a stochastic model to compute the accumulated dose in a number of patients.



dose point of view



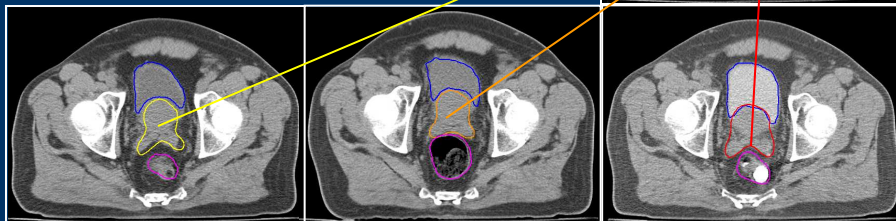
organ point of view

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Prostate movement

- It is well-known that the prostate moves considerably.
- Gastro-intestinal induced motion.
- Translation mainly in the AP direction.
- Rotation around the LR-axis.
- Data from William Beaumont Hospital



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Summary

- Problem definition
 - objectives and constraints
- Optimization variables (degrees of freedom)
 - intensity modulation, machine parameters
- Algorithms
 - dose computation
 - MLC sequencing
 - optimization algorithm
- Interactivity
 - toward a more responsive and intelligent counterpart