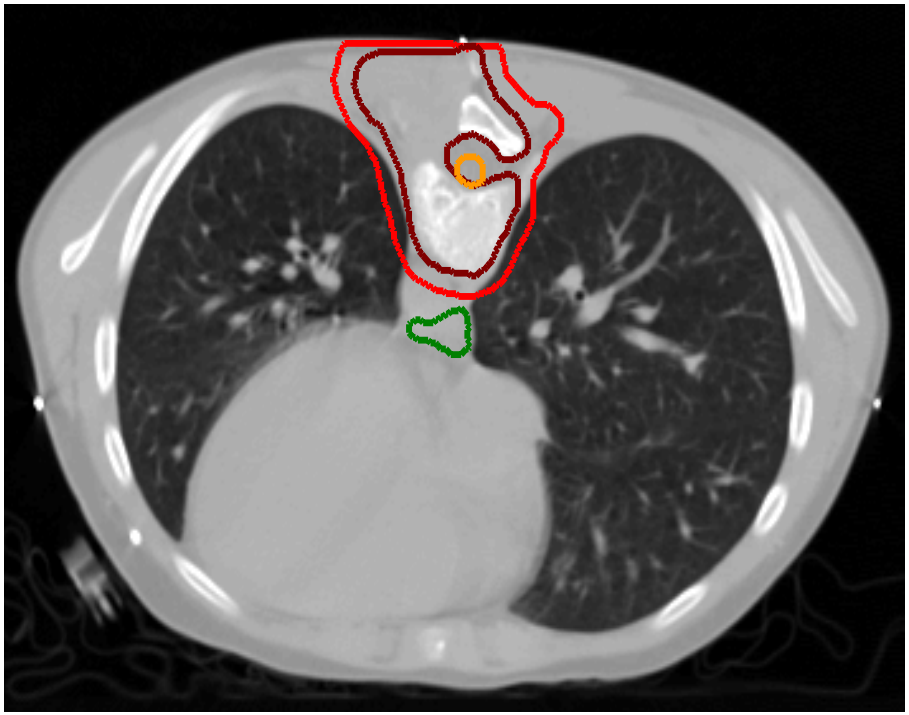
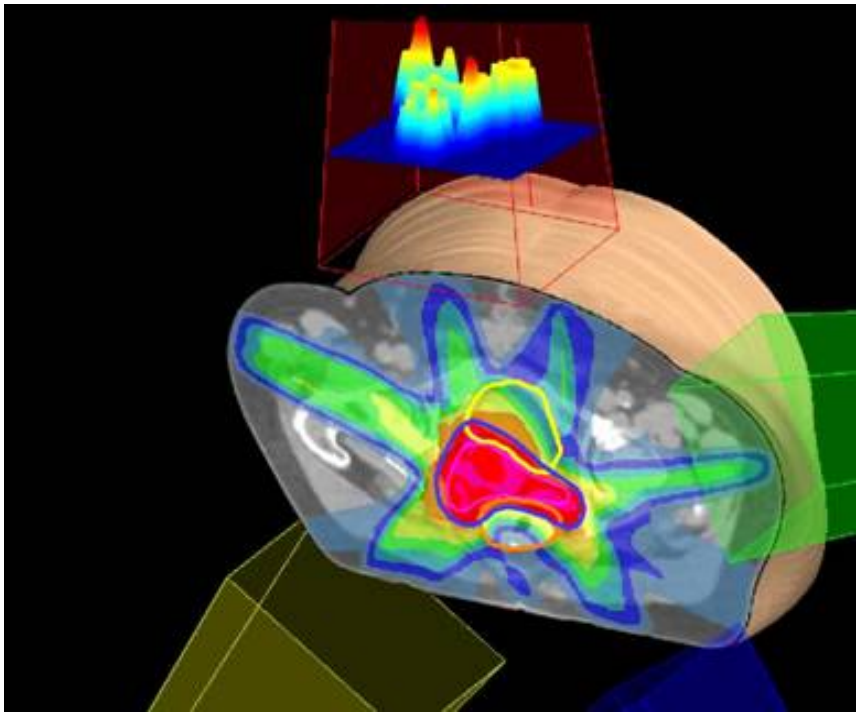
Optimization problems in Radiation Therapy and Medical Imaging

Introduction





Introduction

Radiation therapy

Treatment planning and delivery

Radiotherapy planning process

1. Patient is diagnosed
2. CT scan is performed (possibly MRI, PET in addition)
3. Images are registered
4. Tumor volume and radiosensitive organs are delineated
5. A radiotherapy treatment plan is created
    - physician provides prescription dose
    - treatment planner chooses incident beam directions
    - determines radiation fields
    - calculates final dose distribution
    - physician reviews/approves plan
6. Treatment plan is converted into machine parameters
7. Some QA is performed, dose measurements
8. Treatment starts

This class

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Radiotherapy planning process

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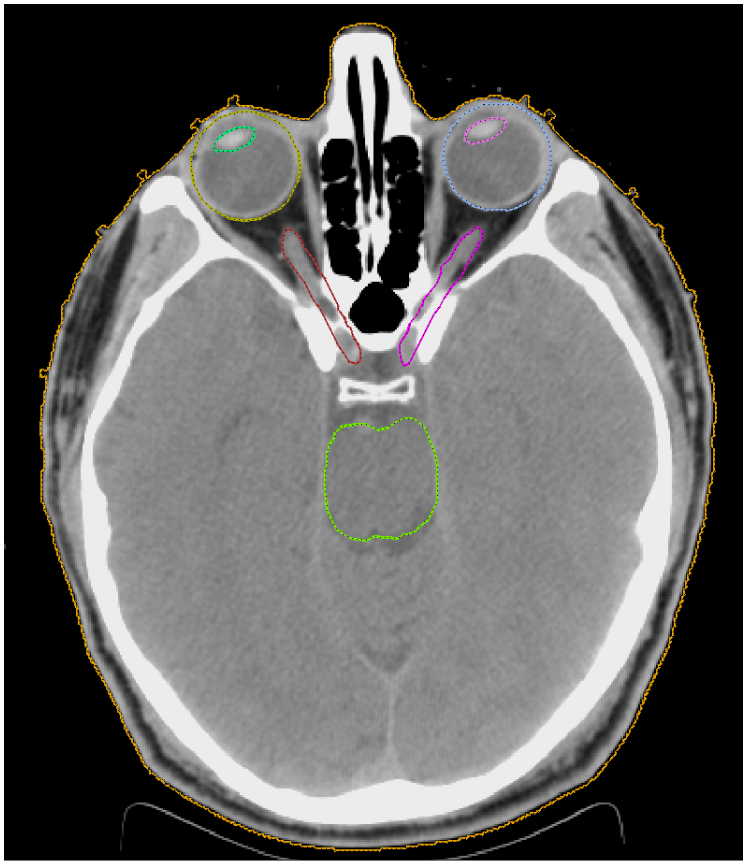
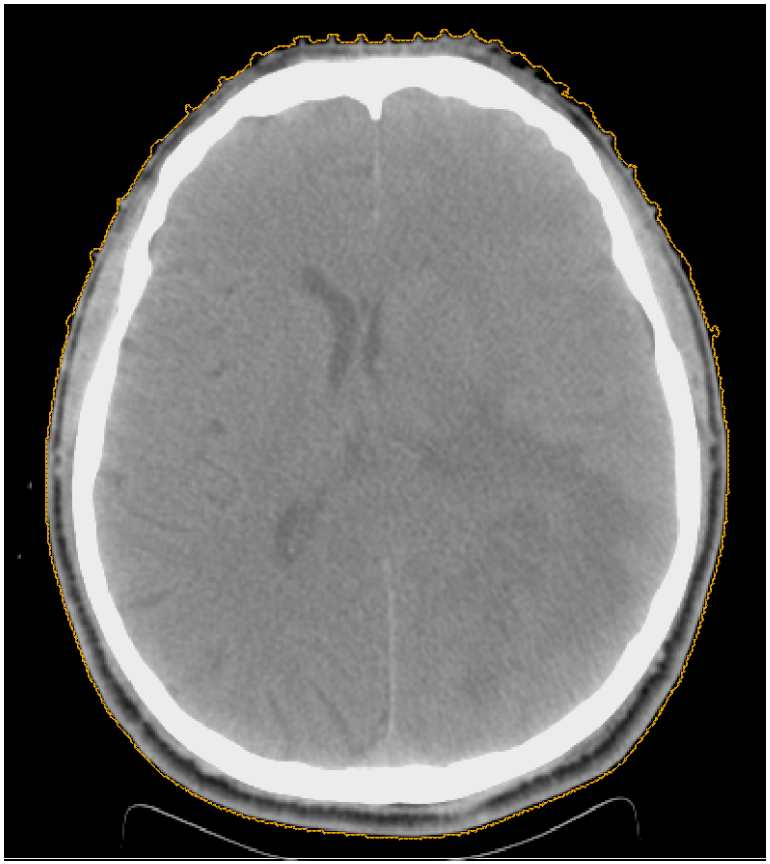
2. CT scan is performed





Radiotherapy planning process

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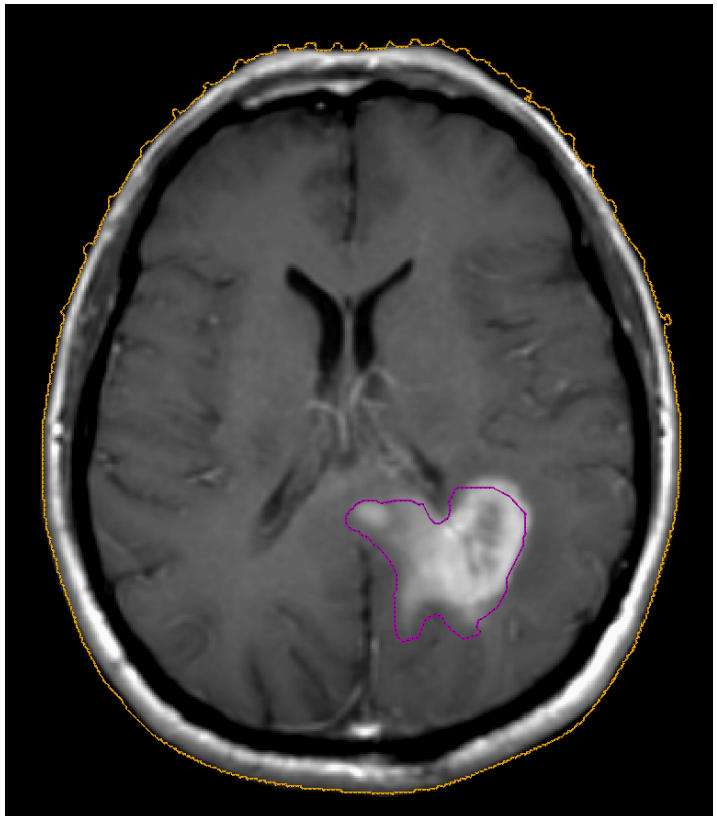
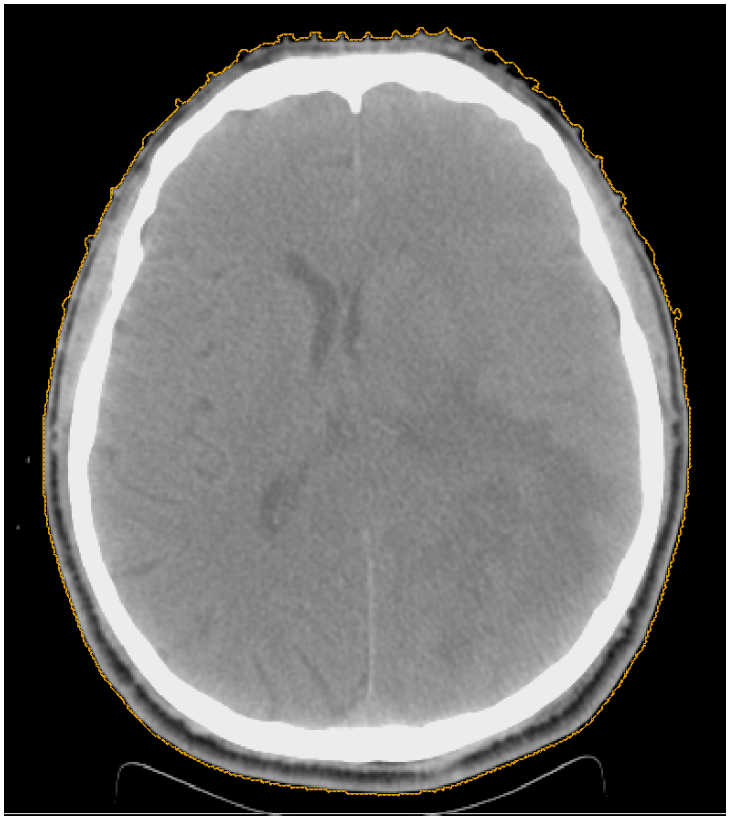


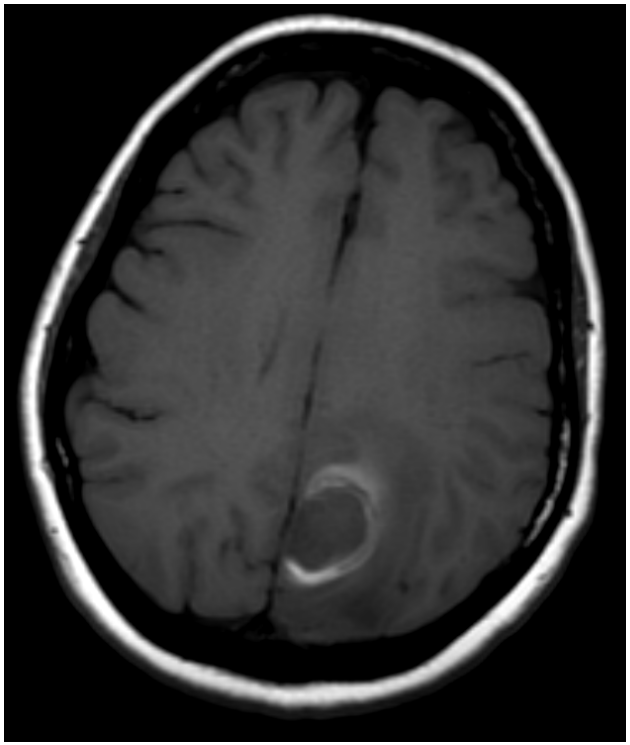
T1 weighted MRI



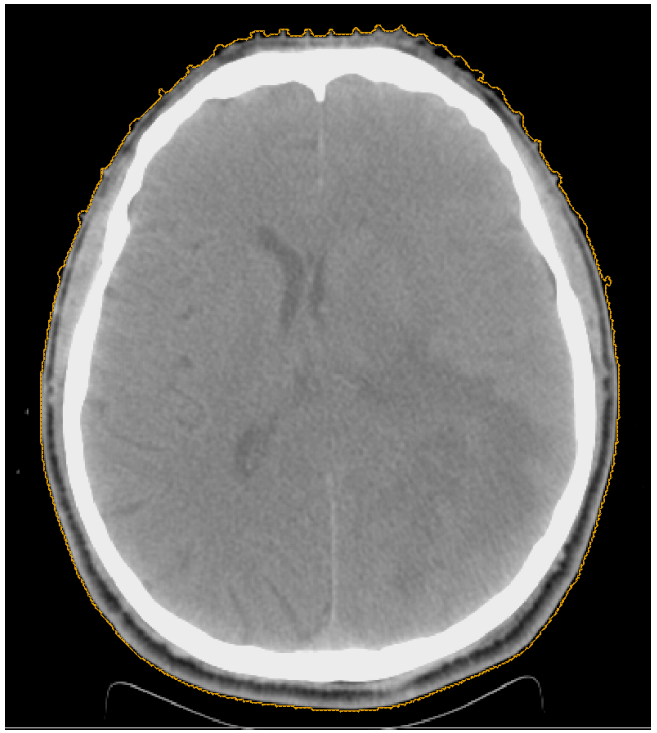
CT

Radiotherapy planning process

1. Patient is diagnosed
2. CT scan is performed (possibly MRI, PET in addition)
3. CT and MRI images are registered



translation
rotation
deformation



Radiotherapy planning process

1. Patient is diagnosed
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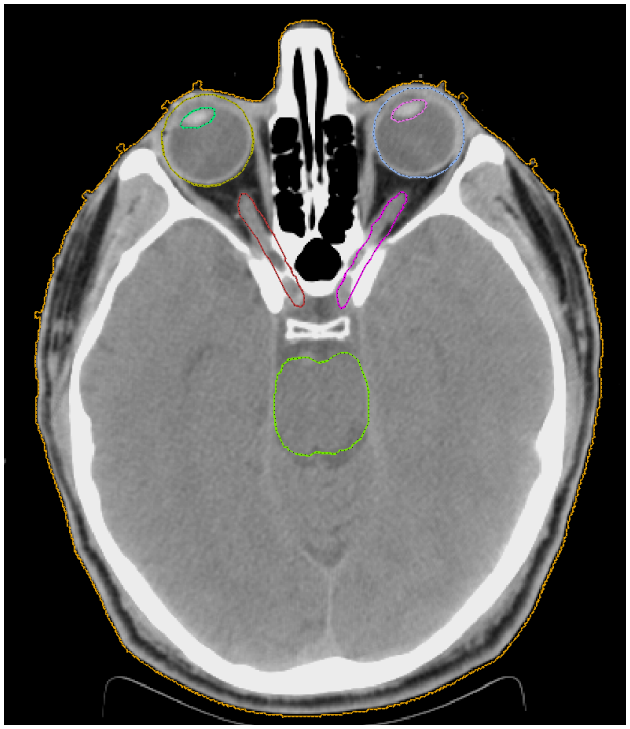
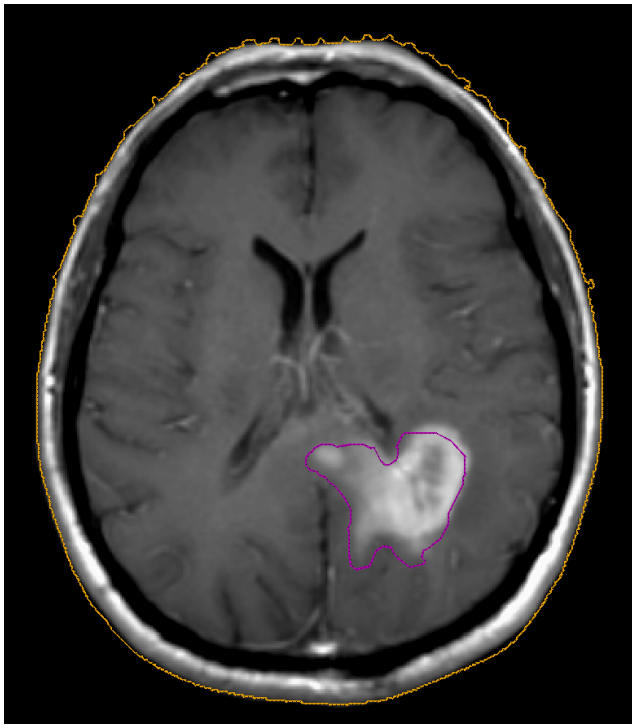
4. Tumor volume and radiosensitive organs are segmented





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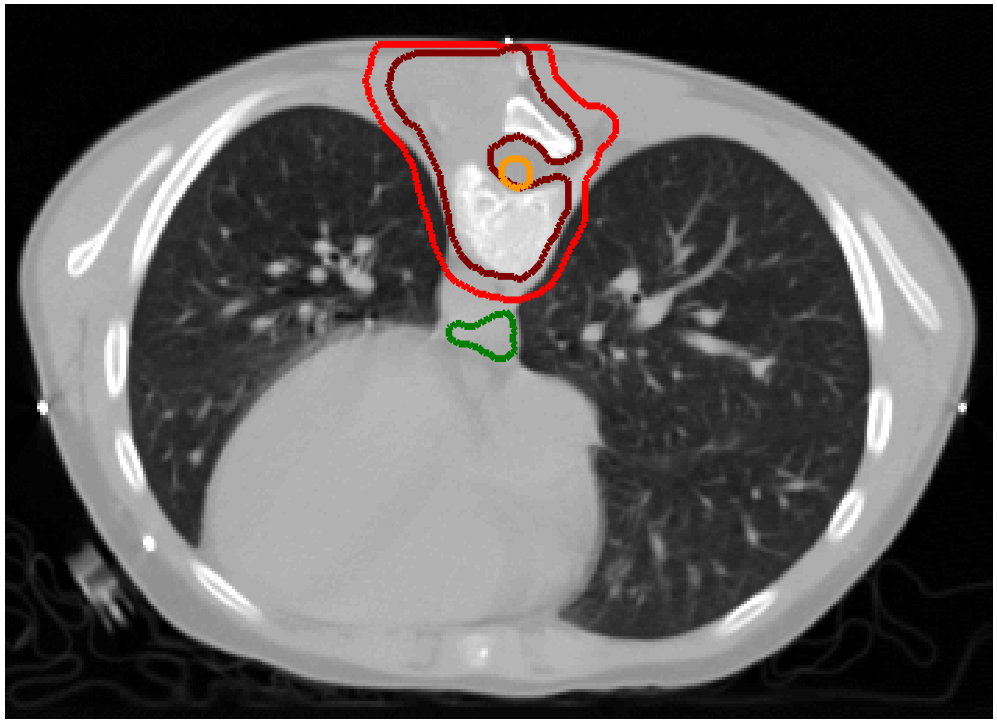

- some things can be automated

  e.g. Lung
  (great contrast on CT)

- many organs are hard

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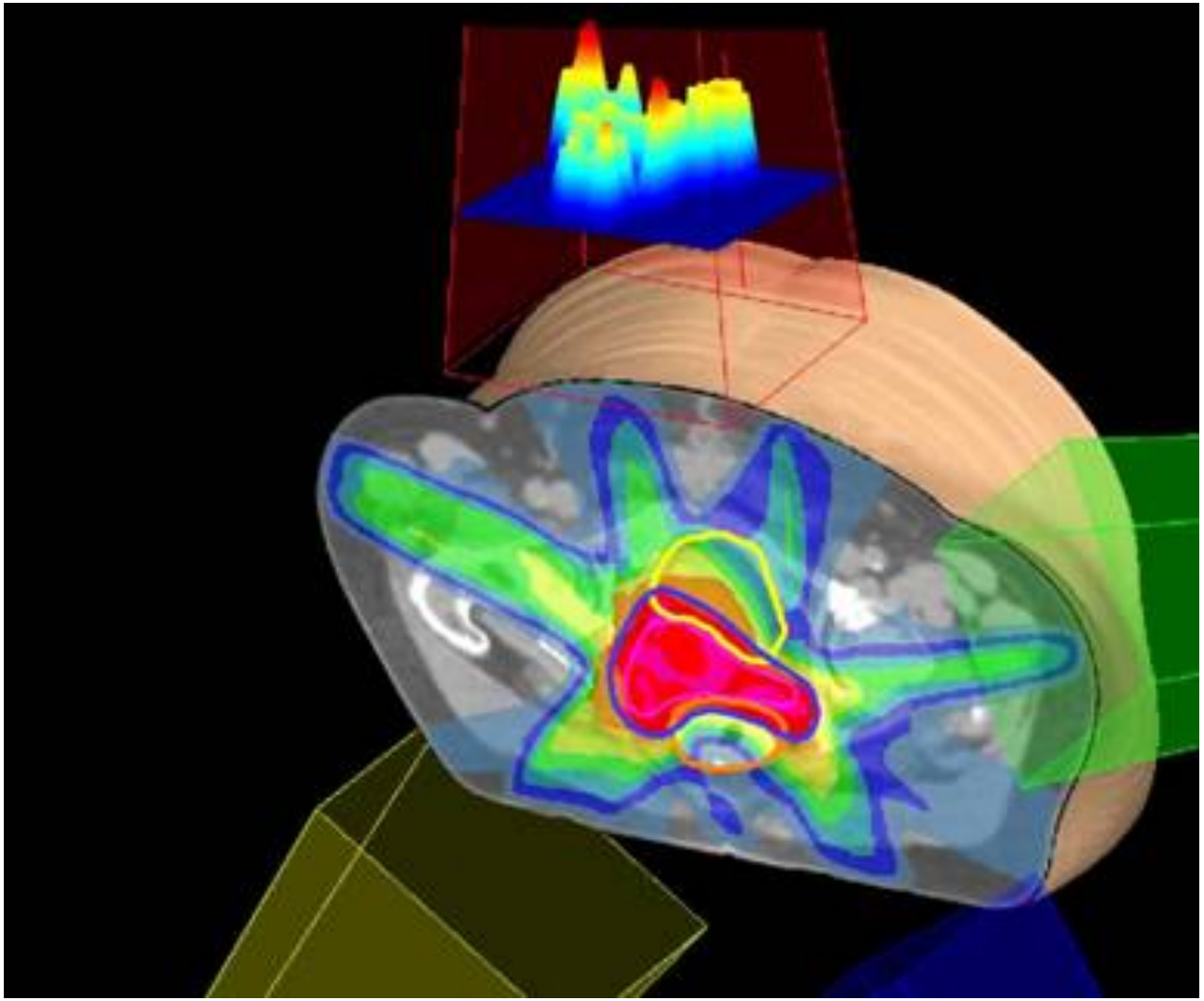
Radiotherapy planning process



Treatment planning for

IMRT

Intensity – modulated radiotherapy

Radiotherapy planning process

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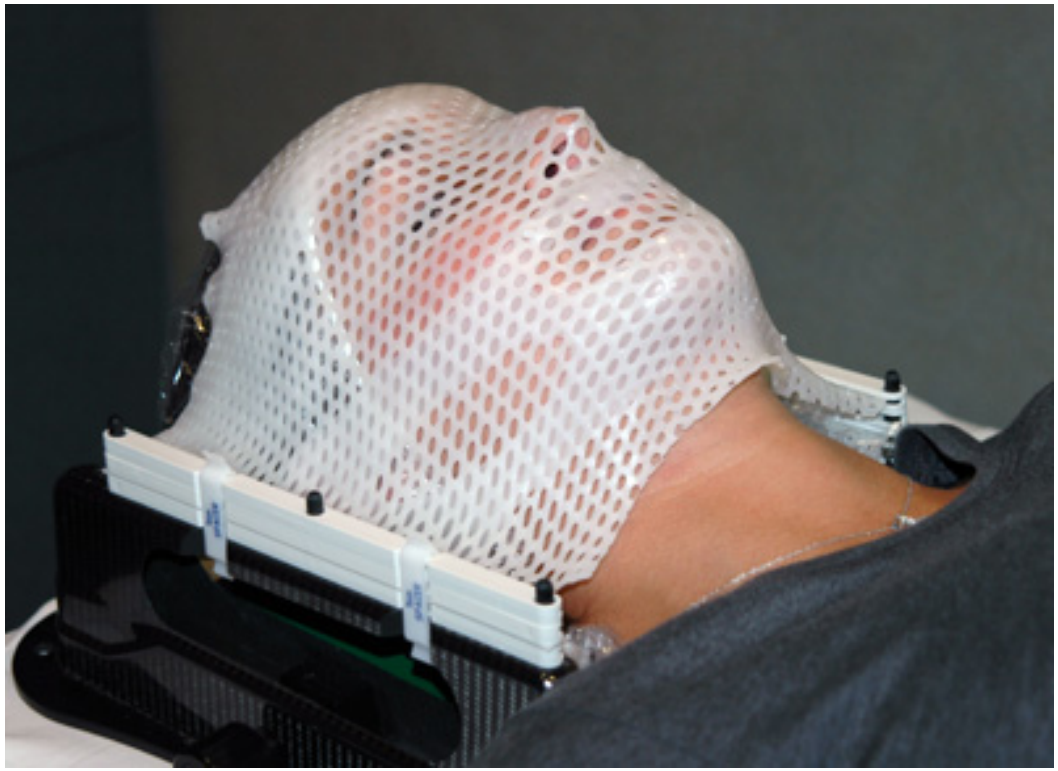
Radiotherapy treatment process

1. Patient enters the treatment room
2. Patient is positioned relative to the treatment beam
    - position lasers
    - X-ray imaging
    - fixation devises



Radiotherapy treatment process

2. Patient is positioned relative to the treatment beam
3. Patient is irradiated over 6 weeks / 30 fractions

Linac

Radiotherapy treatment process

Cyber knife

Adaptive radiotherapy

Goal: account for geometric variations of the patient

- setup error
- internal inter-fraction organ motion (prostate)
- intra-fraction motion (respiratory motion, lung, liver)

1. Cone beam CT in treatment position
2. Fast CT reconstruction
3. Registration to planning CT
4. (Automated segmentation)
5. Setup correction
6. (Treatment plan adaptation)

➔ ideally, every step should be real time

This class

Three blocks

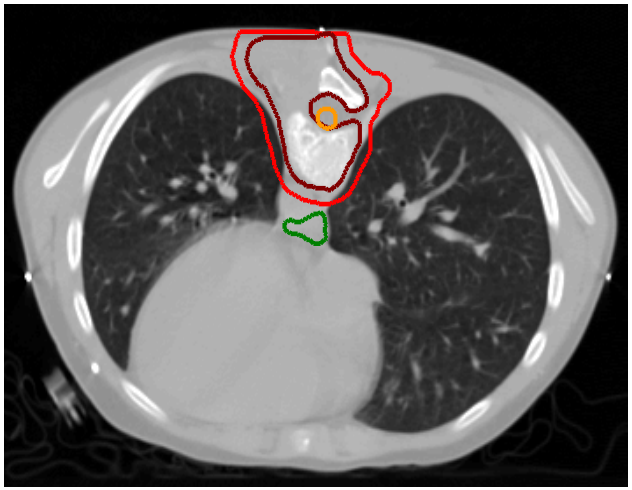
1. CT reconstruction
2. Image registration and segmentation
3. Treatment plan optimization

Syllabus

1. Introduction / planar CT reconstruction (analytic method)
2. Cone beam CT reconstruction (analytic method)
3. Image registration – rigid, affine
4. Image registration – multimodality
5. Deformable image registration 1
6. Deformable image registration 2
7. Treatment plan optimization 1
8. Treatment plan optimization 2
9. Treatment planning system demo
10. Adaptive planning
11. Biological planning
12. TBD

CT reconstruction

… is an inverse problem

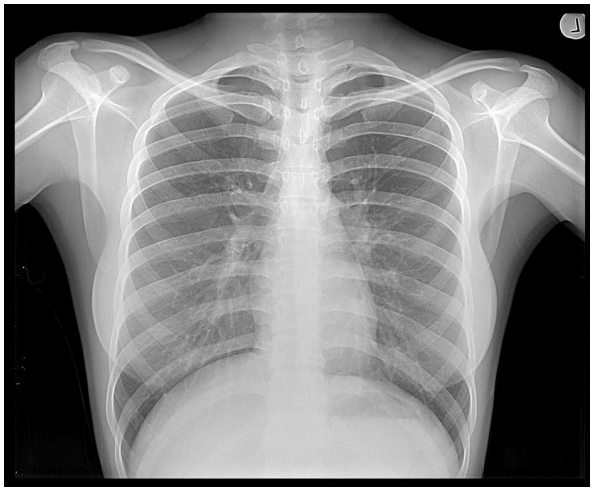


forward problem

(DRR calculation)

inverse problem

(CT reconstruction)

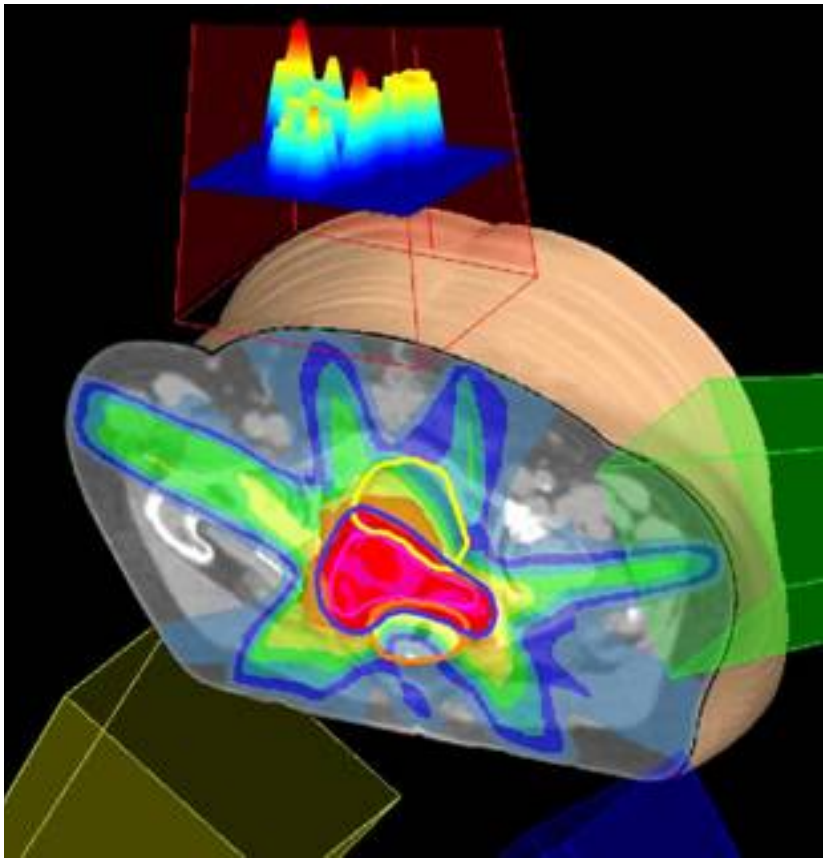


3D CT image

2D X-ray images

Treatment planning

… can be viewed as an inverse problem



2D intensity profiles

forward problem
(dose calculation)

inverse problem
(IMRT planning)

3D dose distribution

Optimization

Optimization is common theme:

$$\underset{x}{\text{minimize}} \quad \sum_i \left(f\left(x, A_i\right) - y_i \right)^2$$

f – model of the observation

x – optimization variables / parameters of the model (to be determined)

A – problem data (given)

y – observation / goal (given)

Optimization

CT reconstruction:

$$\underset{x}{\text{minimize}} \sum_i \left(f\left(x, A_i\right) - y_i \right)^2$$

f – imaging model (physics)

$$f\left(x, A_i\right) = A_i \cdot x$$

x – CT image (absorption coefficient for every voxel)

A – problem data (geometry)

y – X-ray images (measured)

Optimization

Treatment planning:

$$\underset{x}{\text{minimize}} \quad \sum_i \left(f\left(x, A_i\right) - y_i \right)^2$$

y – prescribed dose

f – Dose deposition model

$$f\left(x, A_i\right) = A_i \cdot x$$

$$= \sum_j A_{ij} \cdot x_j$$

x – intensity of radiation beams

A – patient geometry, beam parameters

Optimization

Image registration:

$$\underset{x}{\text{minimize}} \sum_{i} \left(f\left(x, A_i\right) - y_i \right)^2$$

f – coordinate transformation function

x – parameters of transformation matrix (rotation, translation)

A – second image to be registered

y – reference image