Application of Robust Optimization in Lung Cancer Treatment

Timothy Chan
Massachusetts Institute of Technology

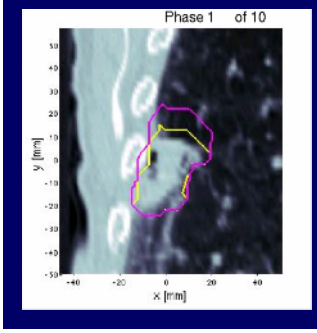
Joint with
Alexei Trofimov (MGH), Christian Vrancic (U Heidelberg),
John Tsitsiklis (MIT), Thomas Bortfeld (MGH)

AAPM Annual Meeting
July 23, 2007

Outline

- Motion uncertainty
- Relationship between motion and probability density functions
- Robust optimization (Goldilocks approach)
- Comparison of approaches

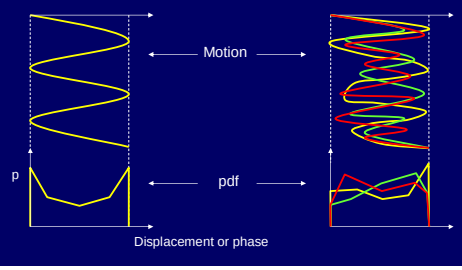
How do we ensure that we generate "good" plans in the face of uncertainty?



- What exactly is the uncertainty here?
- Not just the motion, but the possible *irregularities in the motion* itself.
- A "good" plan guarantees tumor coverage while minimizing healthy tissue dose

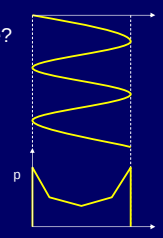
Existence of probabilities doesn't necessarily imply uncertainty

- Could be a natural expression of physical phenomena: regular motion leads to a pdf
- However, uncertain motion may lead to many pdfs



4D optimization approach

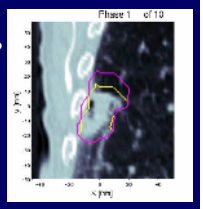
- Construct an intensity map that takes into account (de-convolution) one pdf associated with the motion. This undoes the blurring effect of motion.
- What does the 4D approach assume?
- Assumptions:
  - Reproducibility/stability of motion
  - Takes into account *EXACTLY ONE* pdf
  - "Best case"



5

ITV-like approach

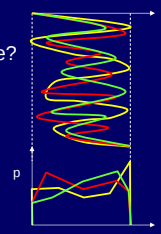
- Construct an intensity map that achieves ITV coverage
- We say it is "ITV-like", since we consider anatomical voxels, and not geometric voxels
- What does the ITV approach assume?
- Assumptions:
  - Totally unstable motion
  - Takes into account *ALL* pdfs
  - "Worst case"



6

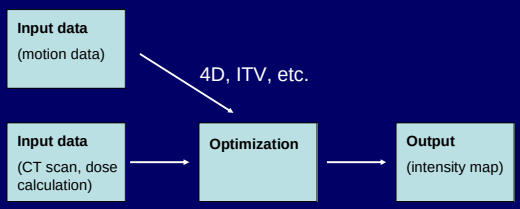
Robust (Goldilocks) approach

- Construct an intensity map that takes into account *some* amount of motion uncertainty (some family of pdfs), but not all pdfs.
- What does the robust approach assume?
- Assumptions:
  - Motion pdf within some error bounds
  - Takes into account *SOME* pdfs
  - "Not too hot, not too cold"



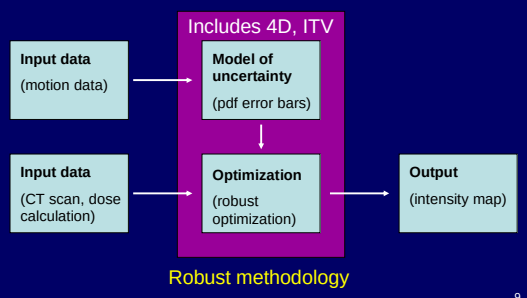
7

Sketch of traditional approach



8

Sketch of robust approach



9

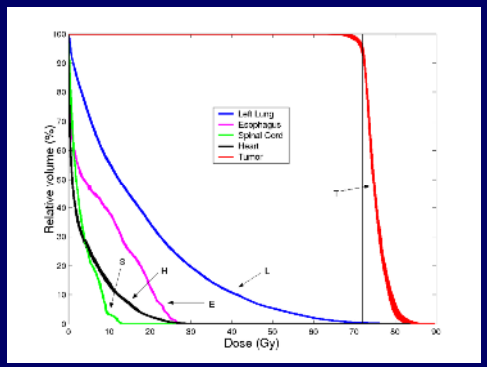
Lung Case

- Tumor in left lung
- Critical structures: left lung, esophagus, spinal cord, heart
- Approx. 100,000 voxels, 1600 beamlets
- Minimize dose to healthy tissue
- Lower bound and upper bound on dose to tumor

- Simulate delivery of optimal solution with 52 “realized pdfs”

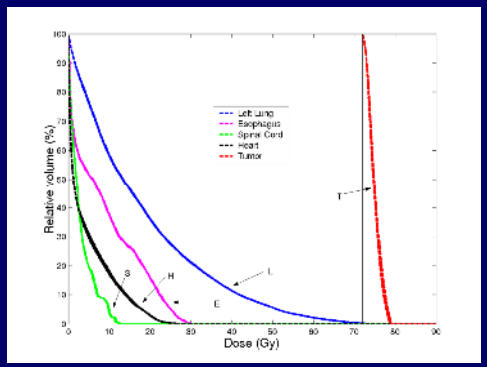
10

4D (one pdf) DVH



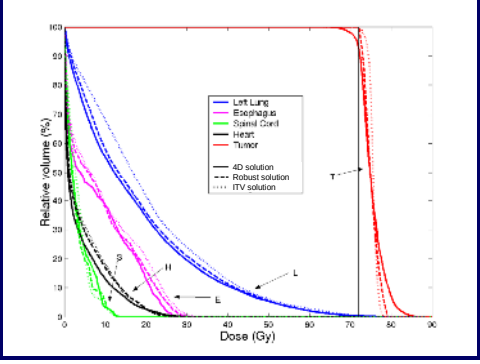
11

Robust DVH



12

Comparison of approaches



13

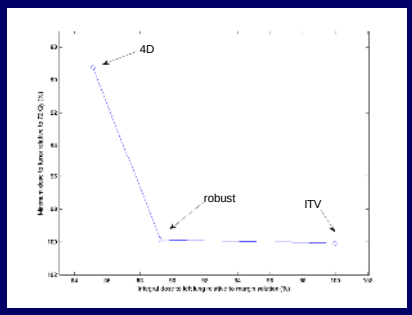
Numerical results

	4D (one pdf)	Robust (some pdfs)	ITV (all pdfs)
Minimum dose in tumor*	89.25 %	99.87 %	100.07 %
Total dose to left lung	85.11 %	89.27 %	100.00 %

* Relative to minimum dose requirement

14

A multi-objective perspective



15

Continuum of Robustness

4D (one pdf) — Robust (some pdfs) — ITV (all pdfs)

No Uncertainty — Some Uncertainty — Complete Uncertainty

- Can prove this mathematically
- Flexible tool allowing planner to modulate his/her degree of conservatism based on the case at hand

16

Takeaways

- Not just breathing motion, but *breathing motion uncertainty*
- Robust optimization gives us a continuum of options to deal with various levels of uncertainty
- Patient belongs somewhere in this continuum
- Model the patient, and the robust framework comes up with the right treatment in the continuum

17

Some future directions for Robust Optimization

- Experiments with linac and detector array
  - SU-FF-T-224
- Use in conjunction with other strategies
  - SU-DD-A3-6
- Application to uncertainties in IMPT
  - MO-D-M100J-3
- Individualization, adaptation, other sites
  - This session!

18