# IMRT – the inverse problem and inverse planning

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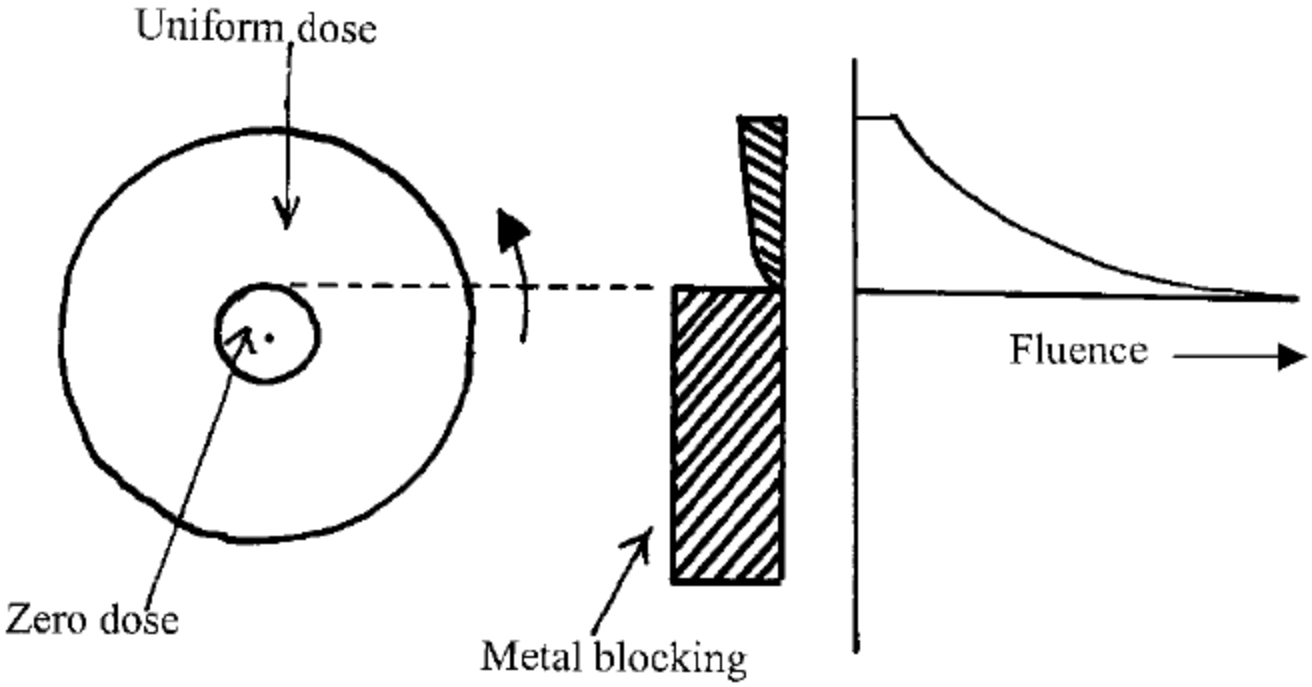
# Conflicts of interest

- Court receives funding from NIH, CPIRT, Varian and Elekta

# IMRT is 35 years old this year!

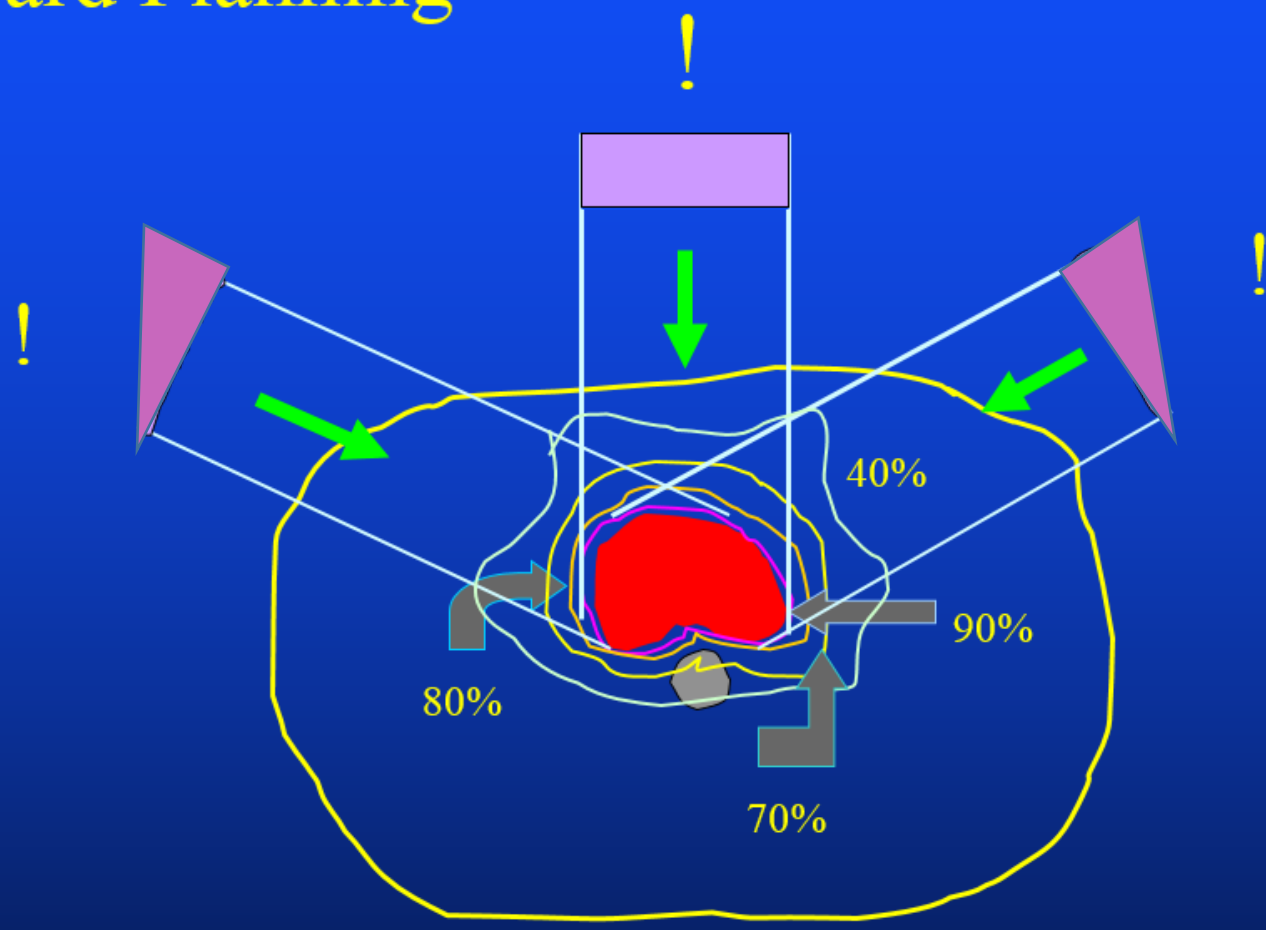



Brahme A, Roos JE, Lax I. Solution of an integral equation encountered in rotation therapy. Phys Med Biol1982;27:1221–9.

# Introduction to IMRT and the inverse problem

# Conventional Treatment Planning

## Forward Planning

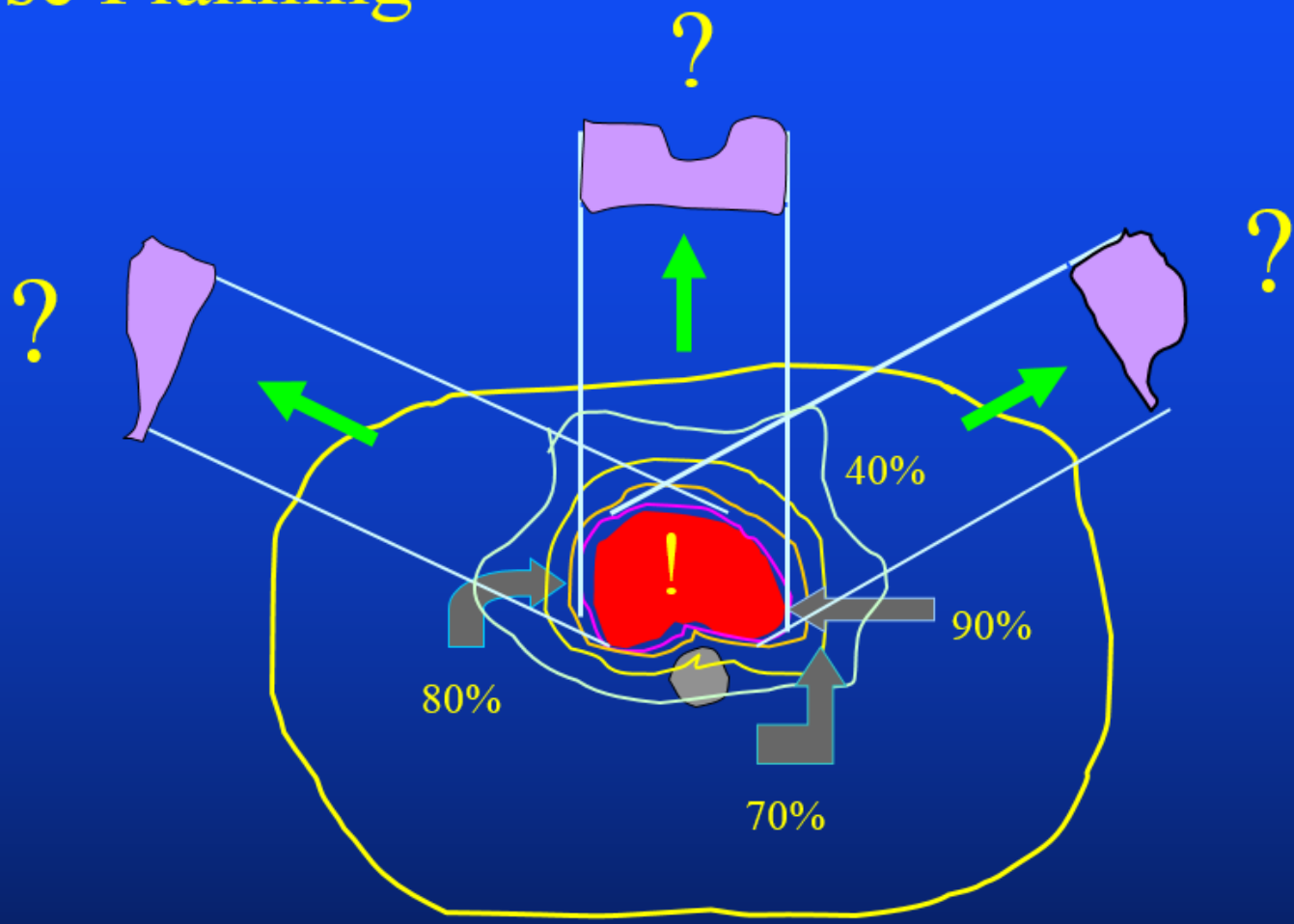





Slide from Charlie Ma

# IMRT Treatment Planning

## Inverse Planning



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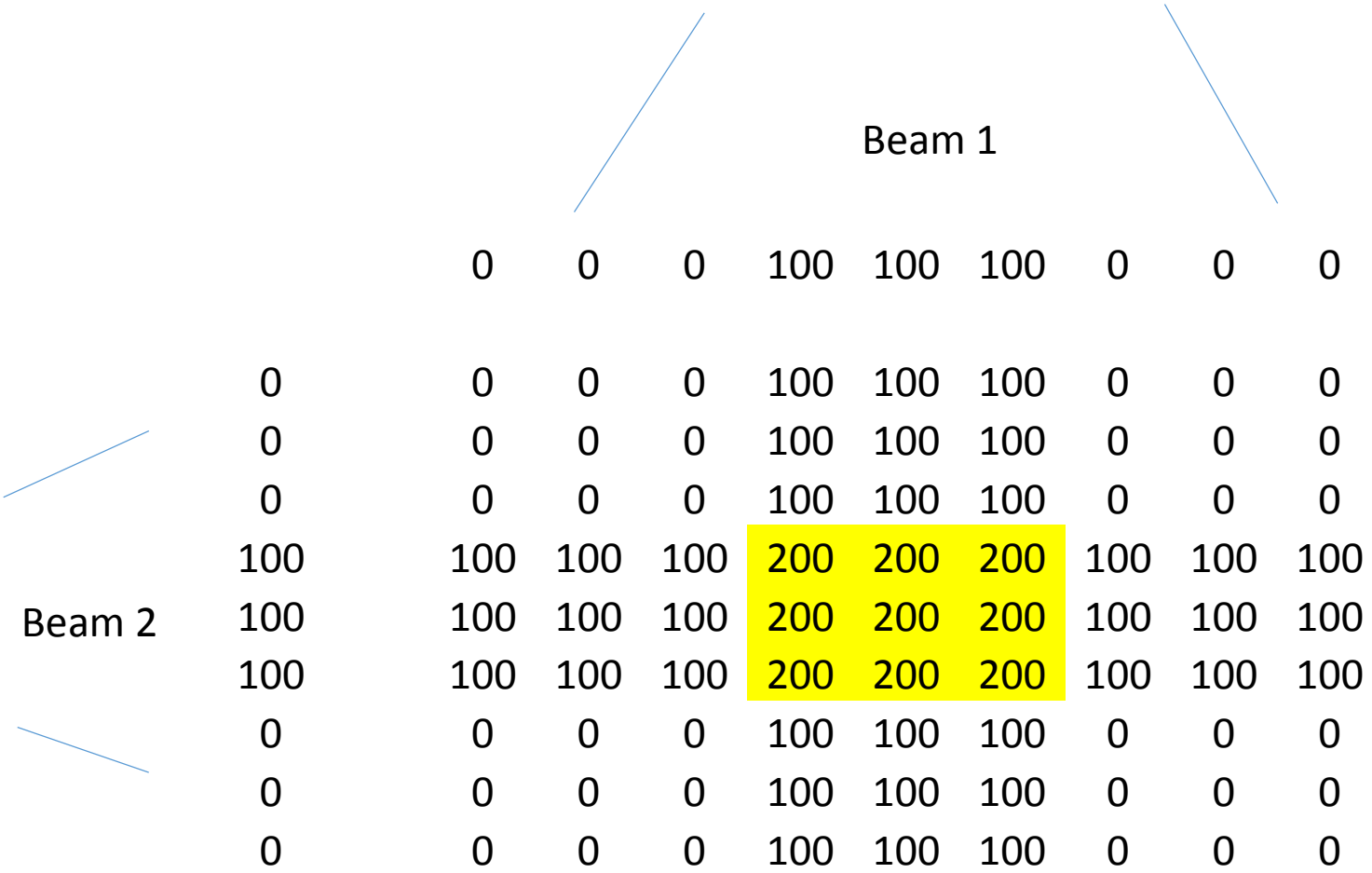
# Simple Example of Optimization

Assume that intensity's add and no attenuation




Based on slides by Peter Balter

# Simple Example of Optimization

If we have a critical structure we want to avoid we can lower the intensity of one or more of the beamlets that that cross that structure

Beam 1

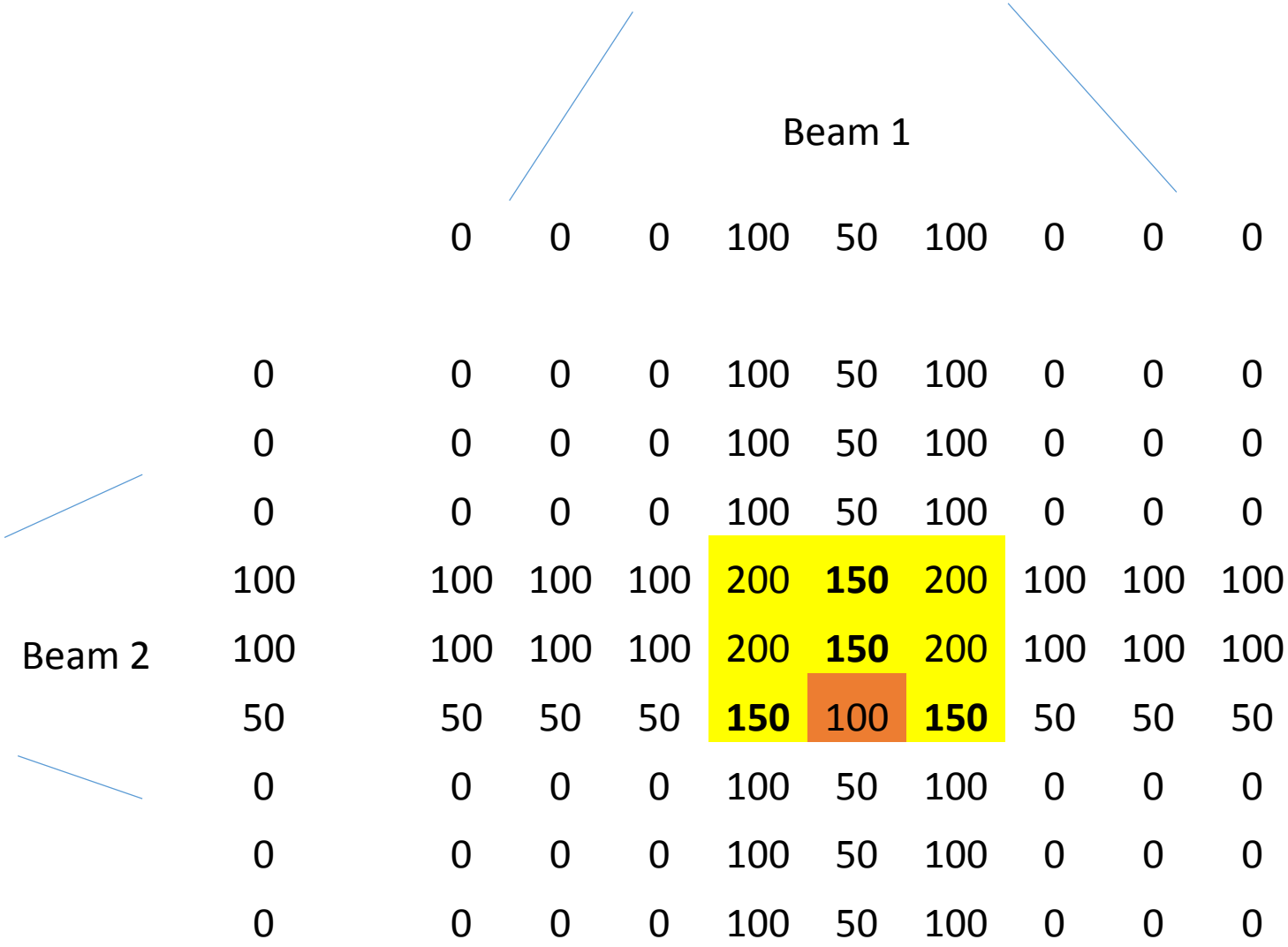
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0 | 0 | 100 | 100 | 100 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 100 | 100 | 100 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 100 | 100 | 100 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 100 | 100 | 100 | 0 | 0 | 0 |
| 100 | 100 | 100 | 100 | 200 | 200 | 200 | 100 | 100 | 100 |
| 100 | 100 | 100 | 100 | 200 | 200 | 200 | 100 | 100 | 100 |
| 100 | 100 | 100 | 100 | 200 | 200 | 200 | 100 | 100 | 100 |
| 0 | 0 | 0 | 0 | 100 | 100 | 100 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 100 | 100 | 100 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 100 | 100 | 100 | 0 | 0 | 0 |

Beam 2

Based on slides by Peter Balter

# Simple Example of Optimization

This results in a decrease in dose to the critical structure but also to other parts of the dose distribution.




Based on slides by Peter Balter

# Simple Example of Optimization

This underdose can be made up from other beamlets in other beams restoring dose to the target but resulting in dose inhomogeneity in the target, the more beam angles to more opportunity to achieve an optimal plan.

Beam 1

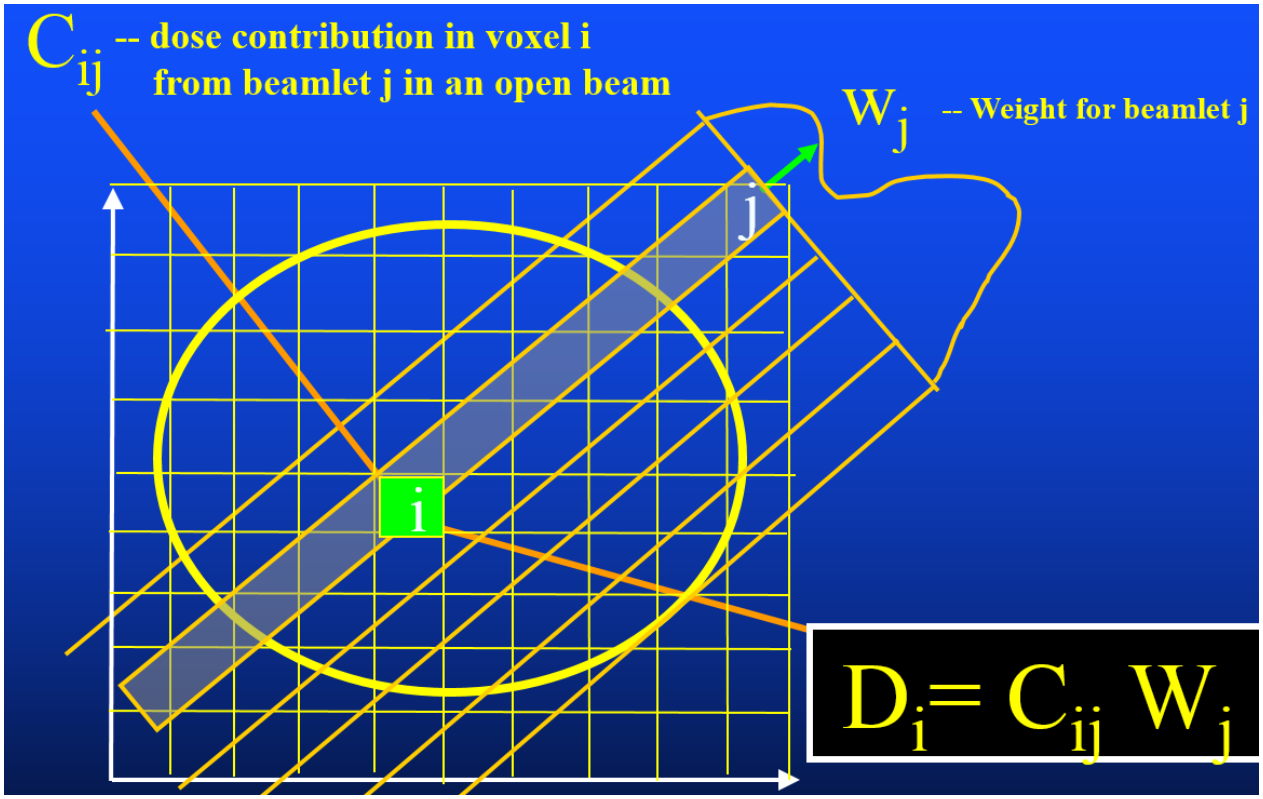
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0 | 0 | 100 | 50 | 100 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 100 | 50 | 100 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 100 | 50 | 100 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 100 | 50 | 100 | 0 | 0 | 0 |
| 150 | 150 | 150 | 150 | *250* | 200 | *250* | 150 | 150 | 150 |
| 150 | 150 | 150 | 150 | *250* | 200 | *250* | 150 | 150 | 150 |
| 50 | 50 | 50 | 50 | **150** | 100 | **150** | 50 | 50 | 50 |
| 0 | 0 | 0 | 0 | 100 | 50 | 100 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 100 | 50 | 100 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 100 | 50 | 100 | 0 | 0 | 0 |

Beam 2



Based on slides by Peter Balter

# Dose calculation




Multiple fields:

$$D_i = \sum_{j=1-n} C_{ij} W_j$$

Desired dose:

$$\mathbf{D}_0 = \mathbf{C}\mathbf{W}_0$$

Simplified:

$$\mathbf{D} = \mathbf{C}\mathbf{W}$$

Beamlet weight:

$$\mathbf{W}_0 = \mathbf{D}_0/\mathbf{C} = \mathbf{D}_0\mathbf{C}^{-1}$$

# Can we solve this?

- No
- Huge problem
- Degenerate problem – many solutions
- Ideal dose may not be achievable
- Many unknowns (>1000s beamlet weights)
- Conflicting requirements…..not all of which are clear
- Lots of structures……
- Etc….

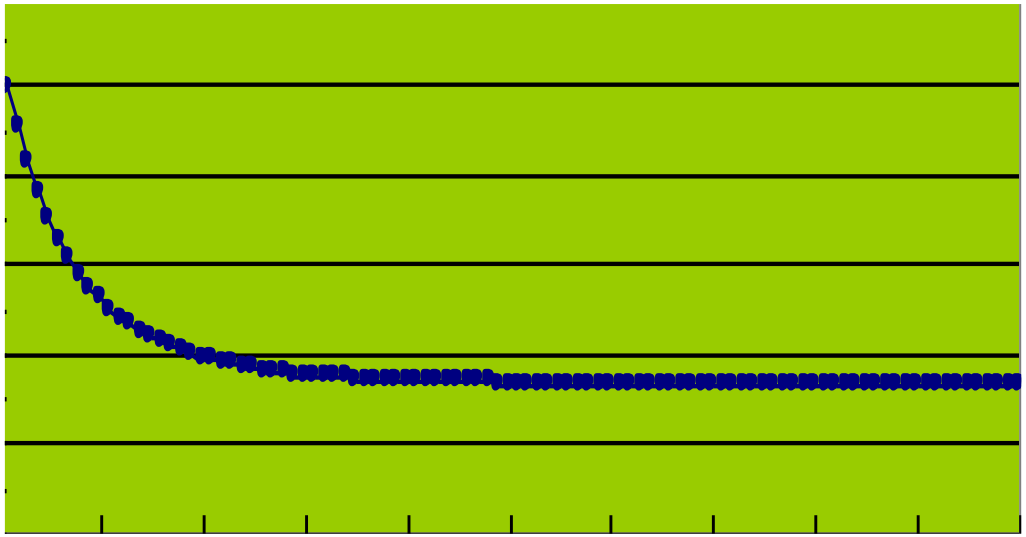
# What is meant by optimization?

- Not necessarily looking for the true optimum plan
  - Many constraints such as deliverability, type of radiation, beam geometry, planning time….
- Many a priori choices (reduce search space) – constrained optimization
  - Beam energy, gantry and collimator angles

A simple objective function:

$$O = \{D_0(1) - D_b(1)\}^2 + \{D_0(2) - D_b(2)\}^2 \ldots$$

Objective function, O



Iteration step

Partially based on slides from Charlie Ma

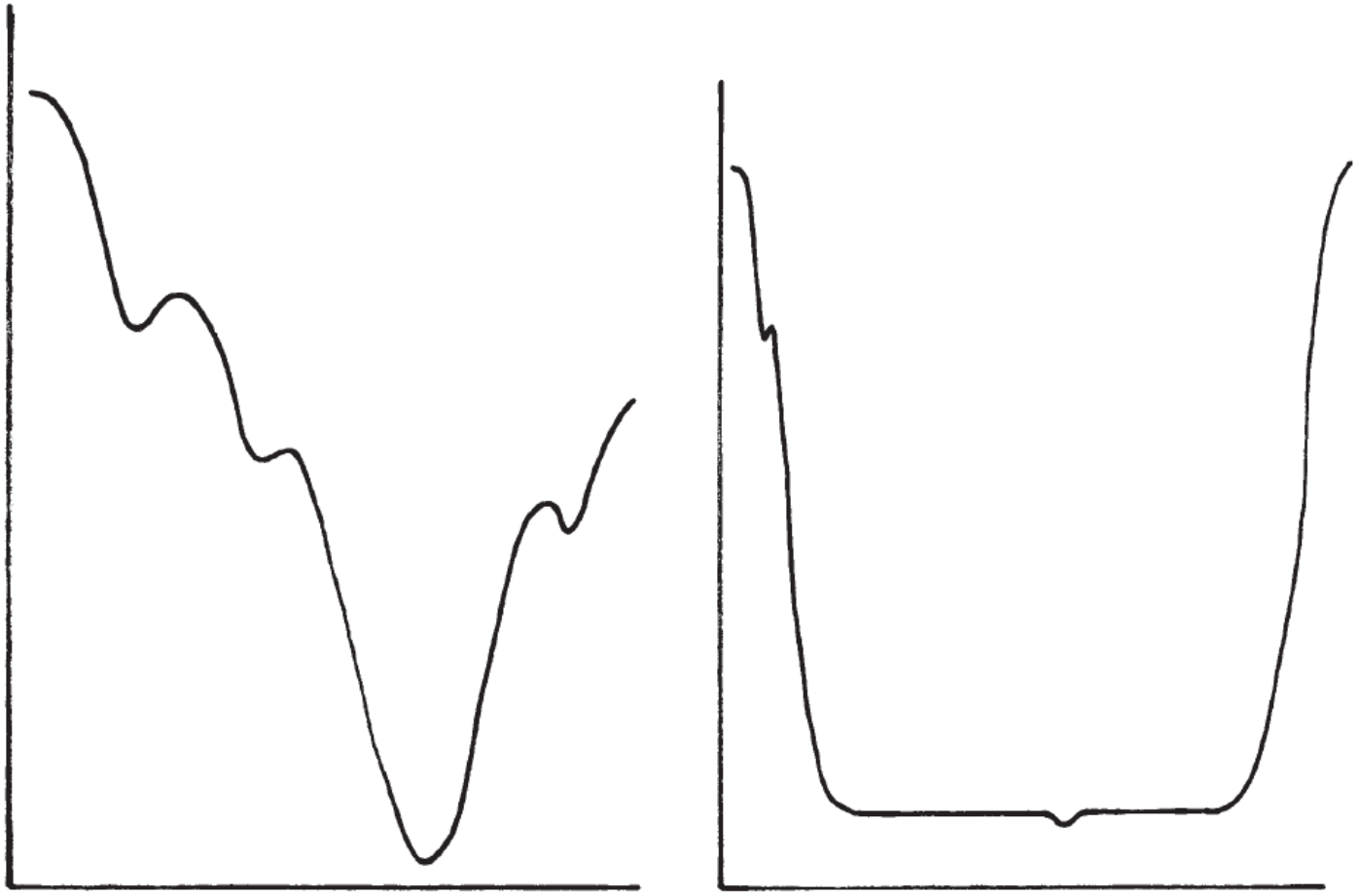
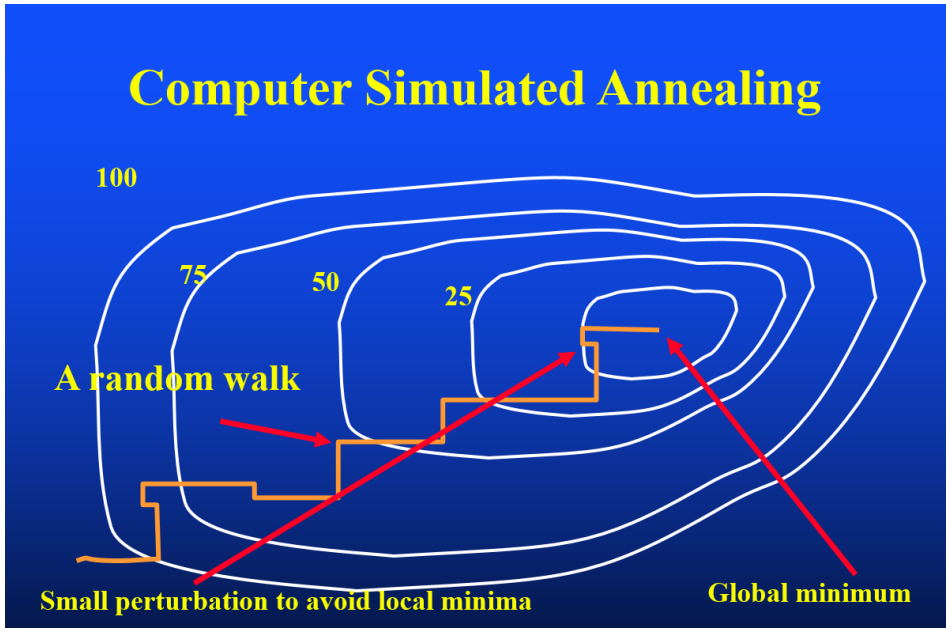
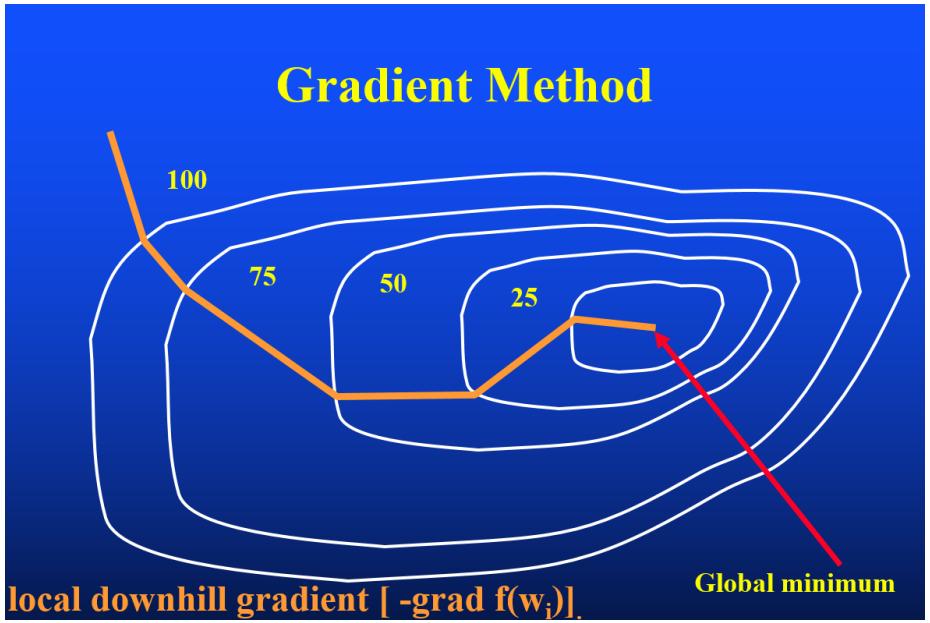



**Figure 4.** (a) The left graph shows a plot of a cost function for a problem with a well defined global minimum cost as well as several local minima. Cost is plotted on the vertical axis and position on the horizontal axis labels the particular stage of some iterative planning cycle. For example, the global minimum corresponds to having achieved the beams which deliver dose best matching the prescribed constraints. The very left hand position might represent the start of iteration when beams have not yet been properly formed. (b) The right graph conversely shows a cost function more typical of radiotherapy inverse planning problems. There is a wide plateau (basin) of beam arrangements all of which correspond to dose distributions that are much the same and best satisfy the planning constraints. There may be a small dip (global minimum) for the absolute best but continuing the iteration to find this might be futile when any position in the plateau would be acceptable.



From Webb, The British Journal of Radiology, 76 (2003), 678–689






Partially based on slides from Charlie Ma

# What needs to be in the cost function?

| | |
|---|---|
| Coverage | Good coverage of PTV<br>Look at 100% and 98% coverage |
| Hot Spots | ≤ 5% |
| Cord | < 46 Gy |
| Exp Cord | 50Gy isodose line shouldn't cross |
| Parotid | Mean dose ~ 26Gy |
| Uninvolved Larynx / post cricoid | < 60 Gy<br>(attempt to approach 50Gy) |
| Oral cavity | No hot spots outside volumes (≥60 Gy) and not hot spots in the mandible |

# Defining the prescription

(and cost functions)

# The prescription

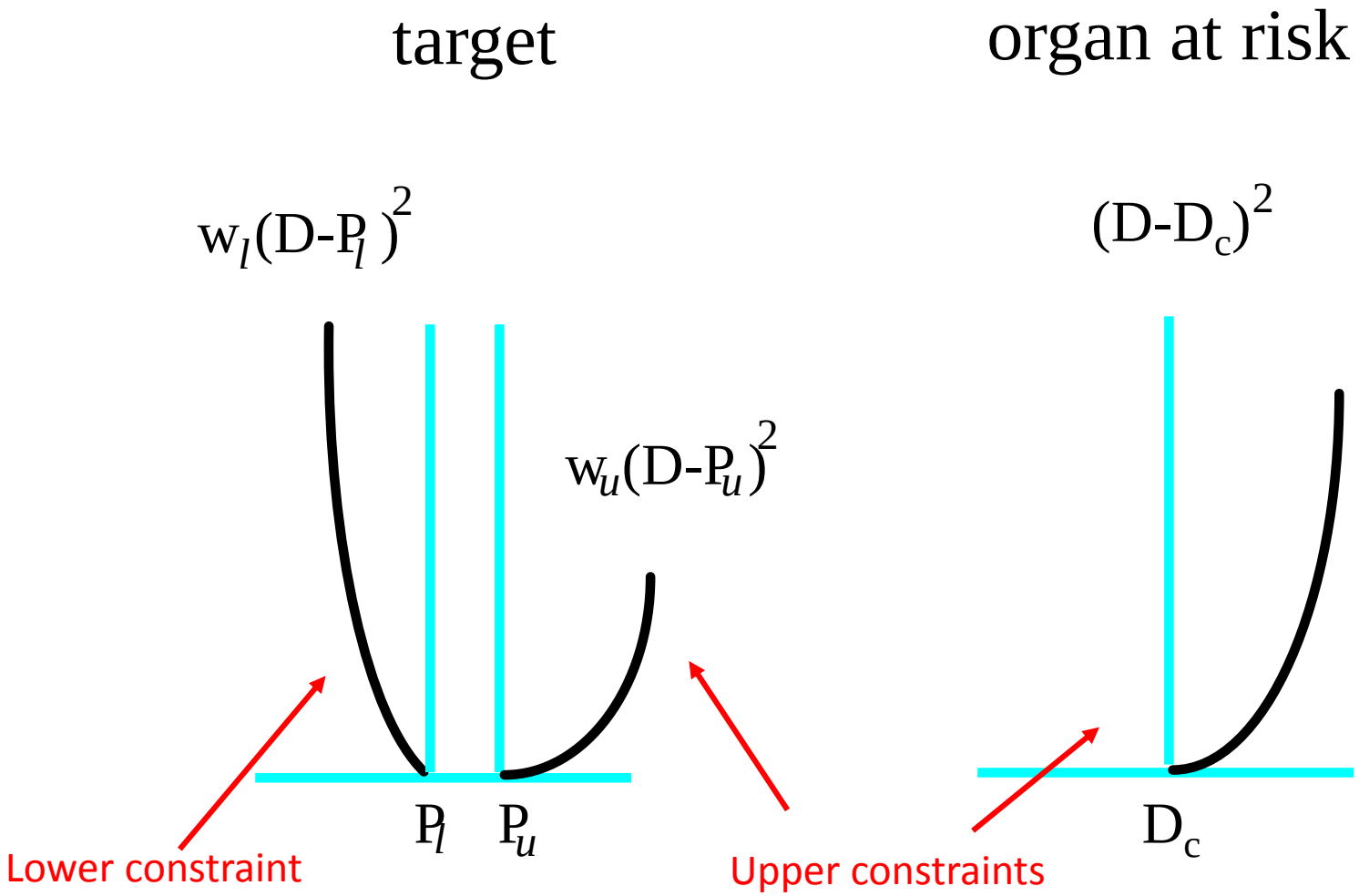
- The prescription defines the goals of the treatment.
- Target DVH
- Sensitive structure DVH
- Set goals, priorities, penalties

- The plan quality can be scored using either physical or biological criteria.

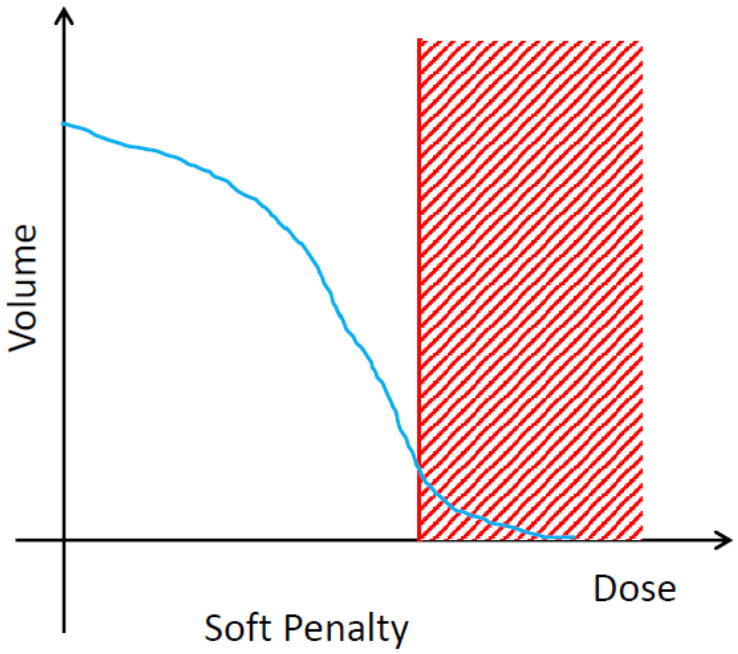
- It is difficult to reduce all of our treatment planning goals into a set of equations or a single scoring function

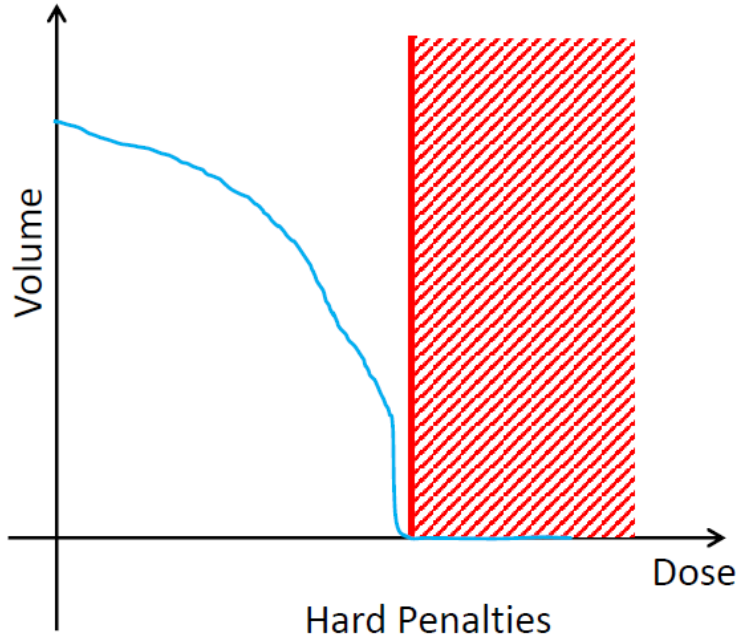
- Warning: no consistency expected in terminology used by different vendors!

# Types of Cost Functions




Based on a slide from Yakov Pipman



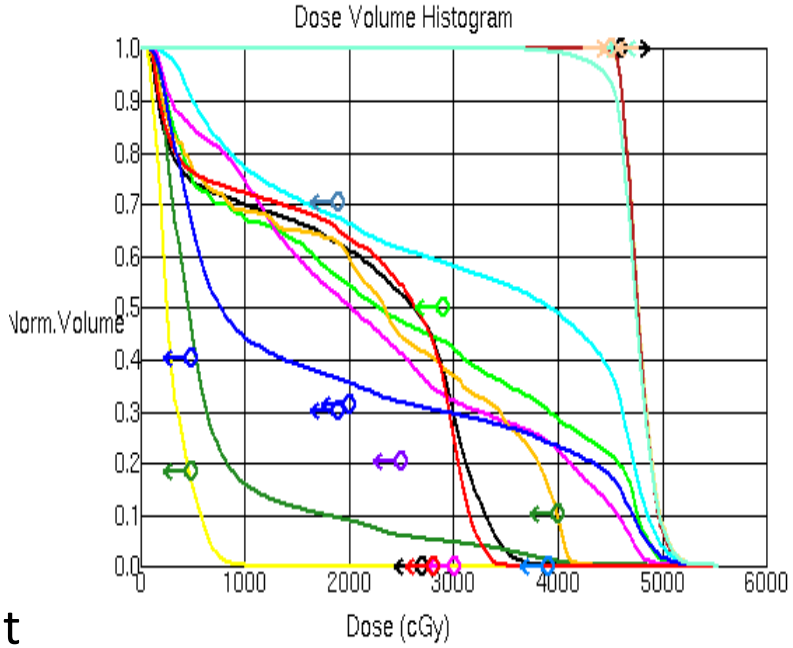




Objective (Pinnacle)

Constraint (Pinnacle)

# The Cost Function

- Cost functions are built based on objectives, there are a number of objective types possible.
  - Minimum Dose
  - Maximum Dose
  - DVH constraint no more than “x” % of the structure can exceed a dose of “y”.
  - Equivalent Uniform Dose
  - …
- Each objective can have a weighting factor
- If the weighing Factor is very high (infinite) that objective becomes a “Constraint” (in Pinnacle, at least)




| ROI | Type | Constrain | Target cGy | % Volume | % Variation | Weight | Objective Value |
|---|---|---|---|---|---|---|---|
| pPTV | Min Dose | | 4600 | | | 100 | 0.0806752 |
| pPTV | Uniform Dose | | 4600 | | | 8 | 0.0257317 |
| Cord PRV 3mm | Max Dose | | 2700 | | | 1.2 | 0.0171266 |
| Lt Lung T50 | Max DVH | | 490 | 18 | | 1 | 0.0345553 |
| fsRt Lung Avoid | Max DVH | | 1900 | 70 | | 1 | 0 |

# Minimum/Maximum Dose

Advantages

- Constraints can be used guarantee adequate dose uniformity in the tumor.
- Useful for serial structures such as the spinal cord.

Disadvantages

- Allowing small hot and/or cold spots are often provide a significant improvement in dose conformity.
- One point can dominate the optimization.
- If target and RAR are in close proximity, these constraints often cannot be satisfied.

# Mean Dose

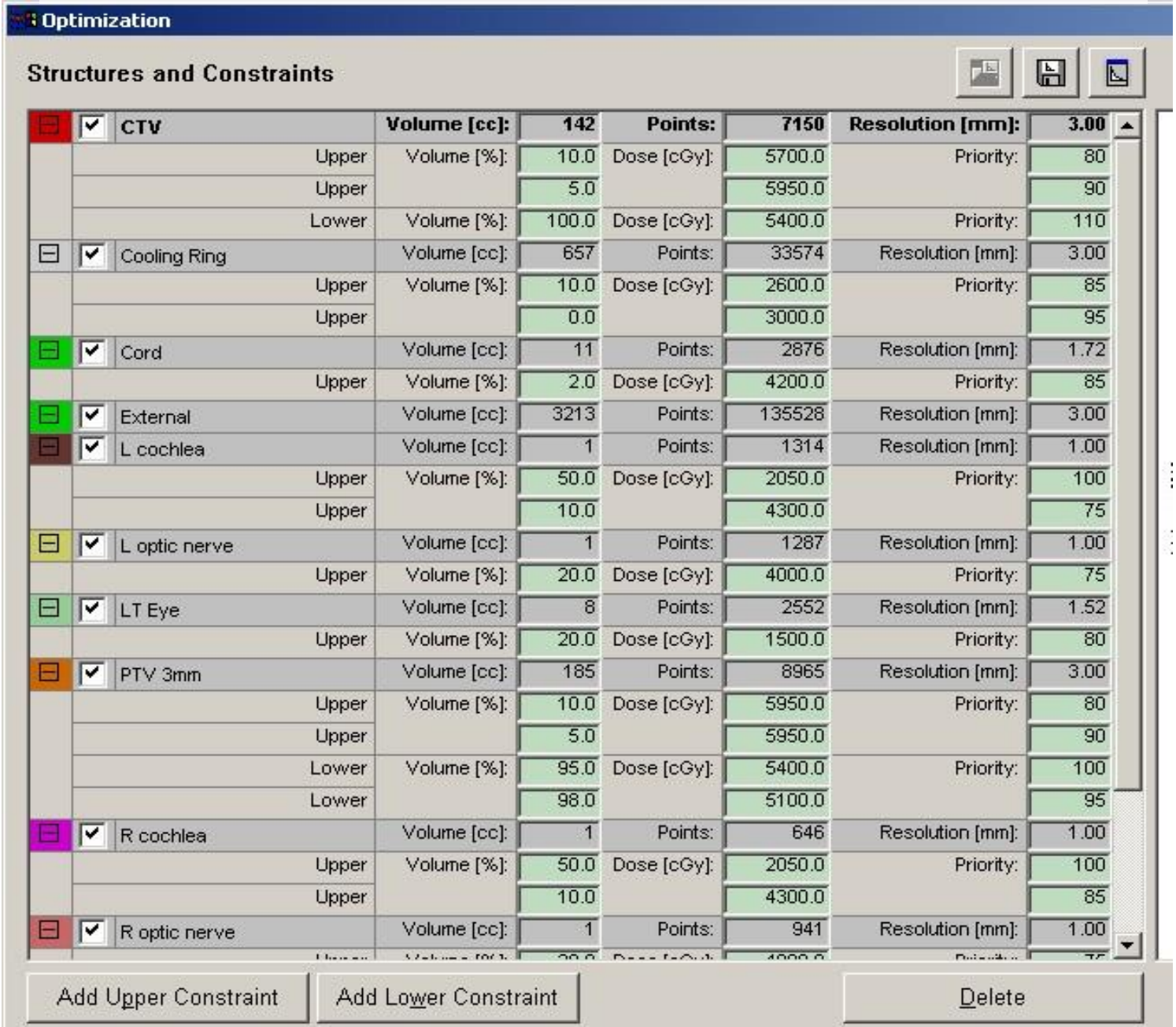
## Advantages

- Easy to formulate.

## Disadvantages

- Of limited value for most sensitive structures.
- Dramatically different dose distributions can have the same mean dose.

# Setting constraints




Eclipse screen shot

# Biological Objective Functions and Constraints

# Biological Objectives/Constraints

- Biological objective functions and constraints are outcome related.
- Biological models are used to predict treatment outcome.
- Tumor Control Probability (TCP).
- Normal Tissue Complication Probability (NTCP).
- Uncomplicated TCP (UTCP or P+).
- Equivalent Uniform Dose (EUD).

# Equivalent Uniform Dose (EUD)

- Two dose distributions are equivalent if the corresponding biological/clinical outcomes are equivalent
- Normal structures and targets.

$$EUD = \left( \sum_{i=1} v_i D_i^a \right)^{\frac{1}{a}}$$

*Niemierko A. Med Phys, 26(6), 1999.

# Equivalent Uniform Dose (EUD)

| Structure (Source) | End-point | a |
|---|---|---|
| **Chordoma base of skull (MGH)** | Local control | -13 |
| **Squamous cc (Brenner)** | Local control | -13 |
| **Melanoma (Brenner)** | Local control | -10 |
| **Breast (Brenner)** | Local control | -7.2 |
| **Parotids (Eisbruch)** | Salivary function (<25%) | <0.5 |
| **Parotids (Chao)** | Salivary function (<25%) | 0.5 |
| **Liver (Lawrence)** | Liver failure | 0.6 |
| **Liver (Dawson)** | Liver failure | 0.9 |
| **Lung (Kwa)** | Pneumonitis | 1.0 |
| **Lung (Emami)** | Pneumonitis | 1.2 |
| **Kidney (Emami)** | Nephritis | 1.3 |
| **Liver (Emami)** | Liver failure | 2.9 |
| **Heart (Emami)** | Pericarditis | 3.1 |
| **Bladder (Emami)** | Symptomatic contracture | 3.8 |
| **Brain (Emami)** | Necrosis | 4.6 |
| **Colon (Emami)** | Obstruction/perforation | 6.3 |
| **Spinal cord (Powers)** | White matter necrosis | 13 |
| **Esophagus (Emami)** | Perforation | 18 |
| **Spinal cord (Schultheiss)** | Paralysis | 20 |

Example values – no guarantees!

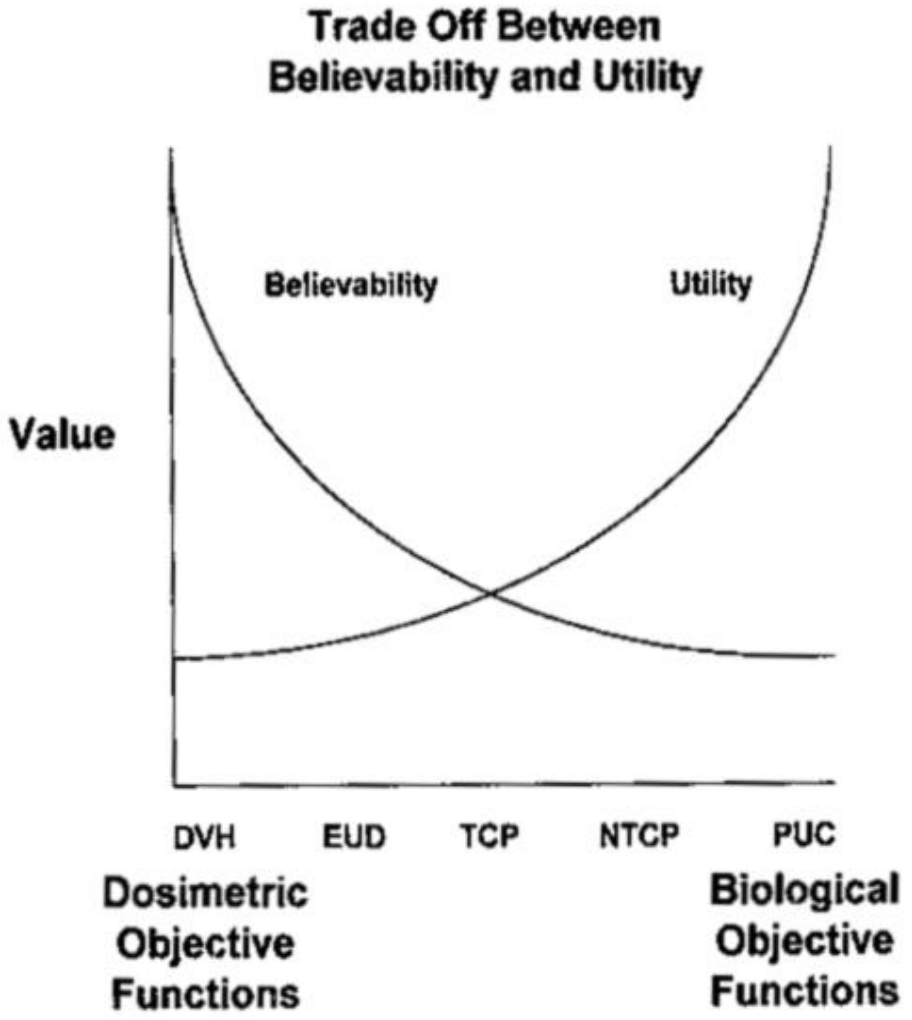
# Biological Objectives/Constraints

Advantages

- Our goal is to improve patient outcome, and this is precisely what is modeled with these techniques.

Disadvantages

- Because of uncertainties in the parameters included in the models, the accuracy of the models is often called into question.





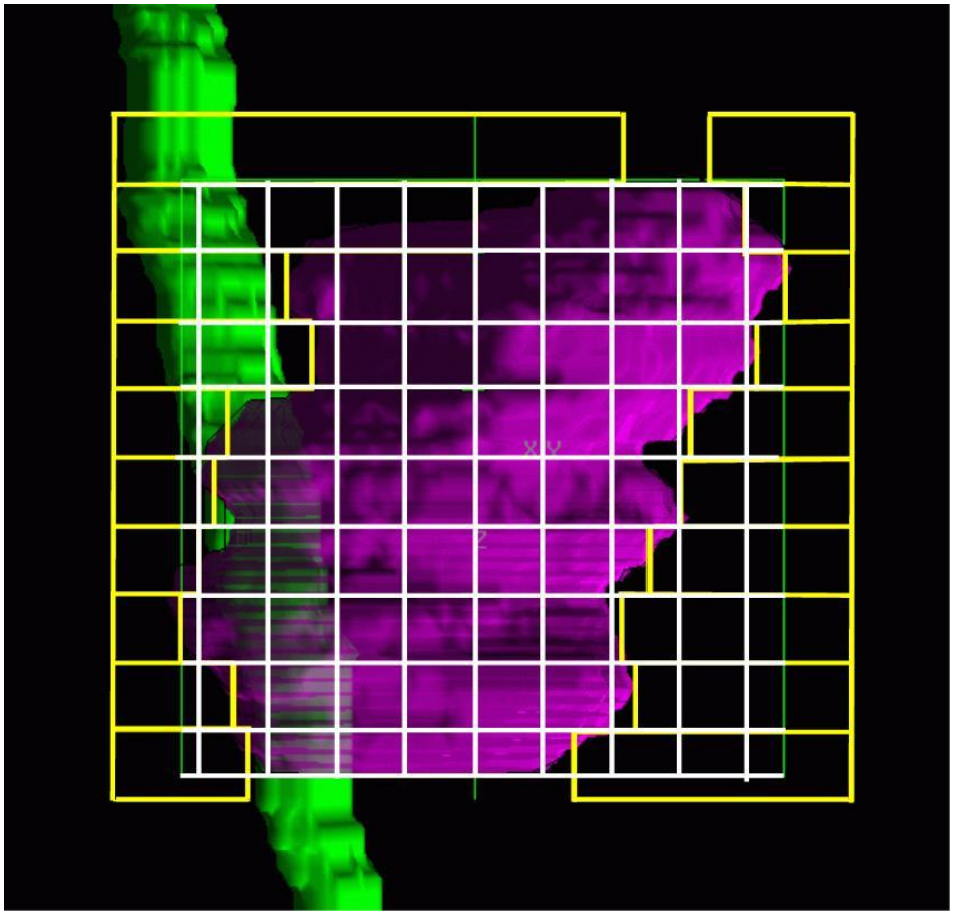

Based on a slide from David Shephard

# Plan Optimization
# Fixed Field IMRT

- Beamlet based optimization
- Direct aperture optimization

# The Beamlet Model

Before an IMRT optimization, each beam is divided into a number of smaller beamlets (pencil beams), and the corresponding dose distributions are computed.

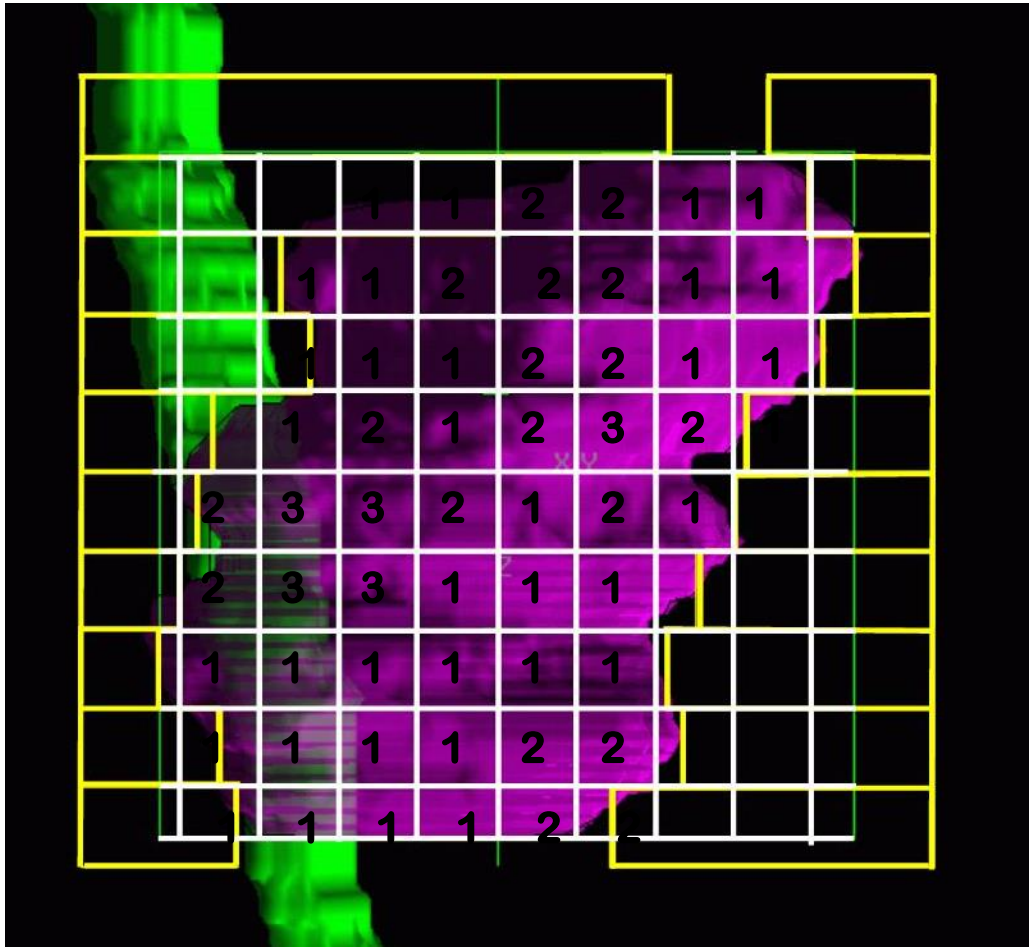


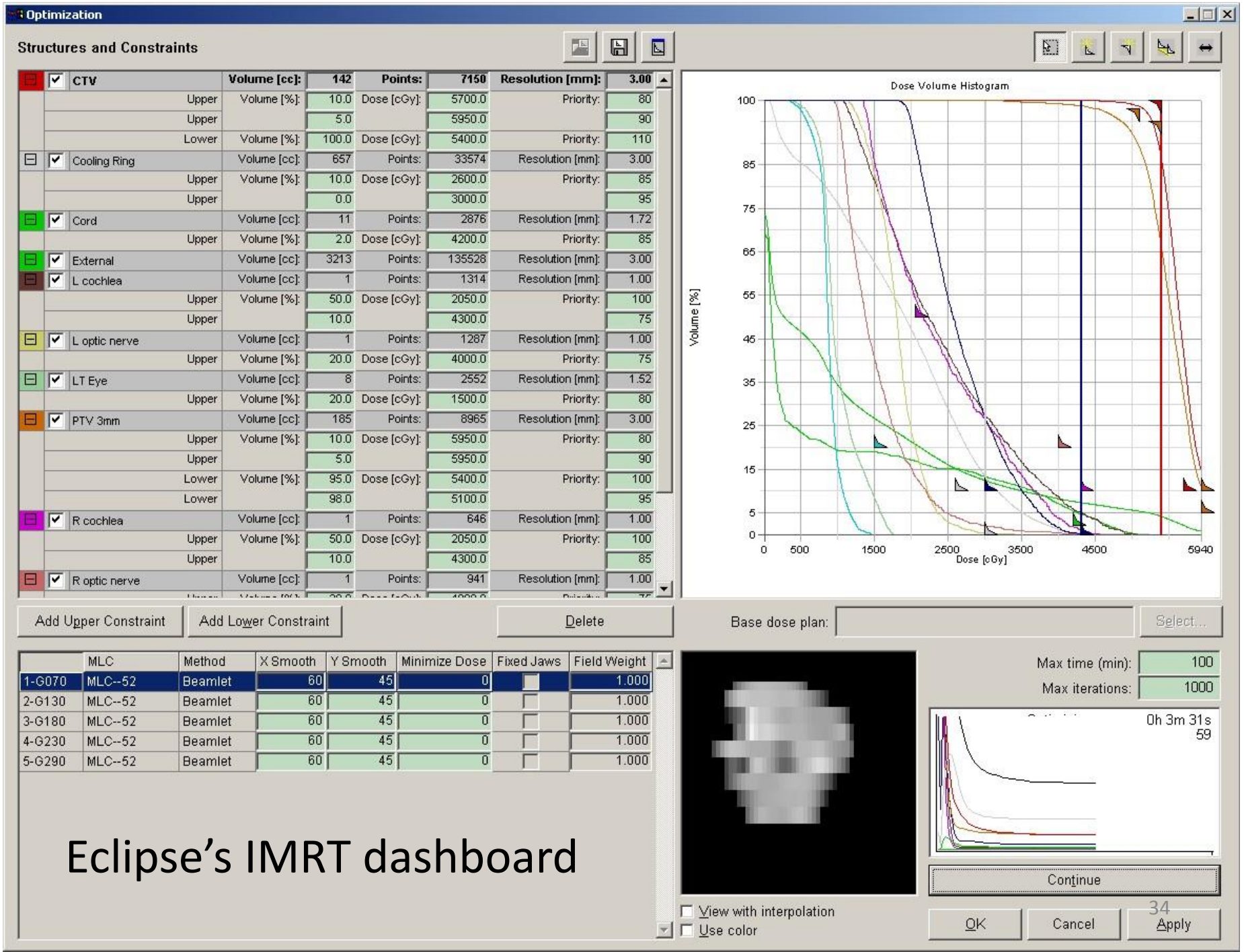


Slide from David Shephard

# Beamlet-Based Inverse Planning

Beamlet weights are optimized to produce an optimized fluence map for each beam direction.



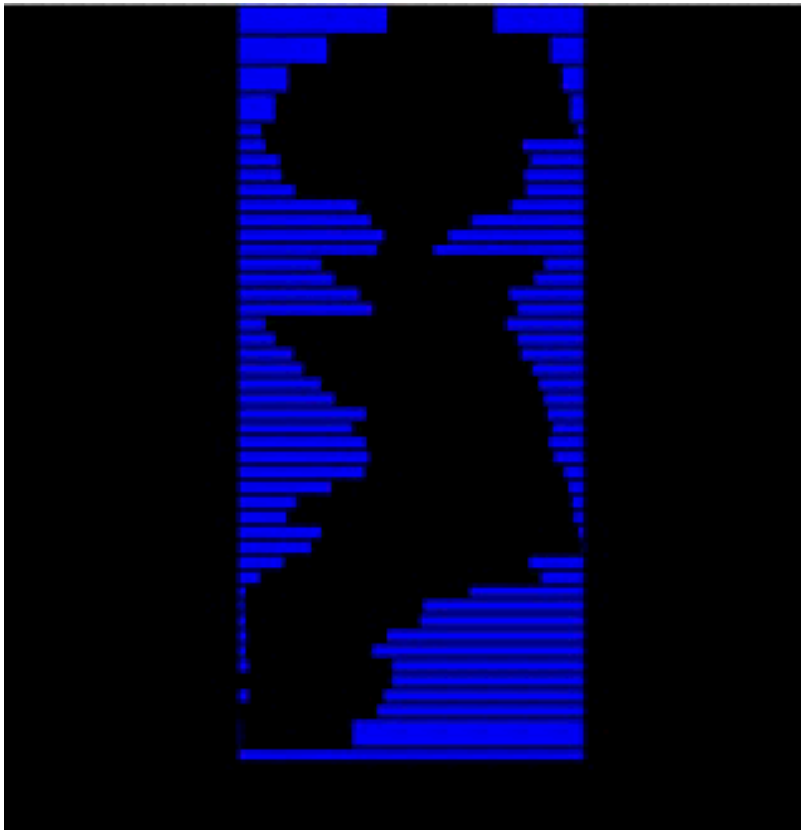



# Eclipse's IMRT dashboard

# Leaf sequencing

# Intensity Modulation

- Step and shoot MLC
  - The intensity pattern developed by the TPS is converted into a finite number of segments
  - For each segment the MLCs leaves are set and the beam is on for a determined amount of time
  - The summation of all the segments is equal to the planned intensity
- Pinnacle

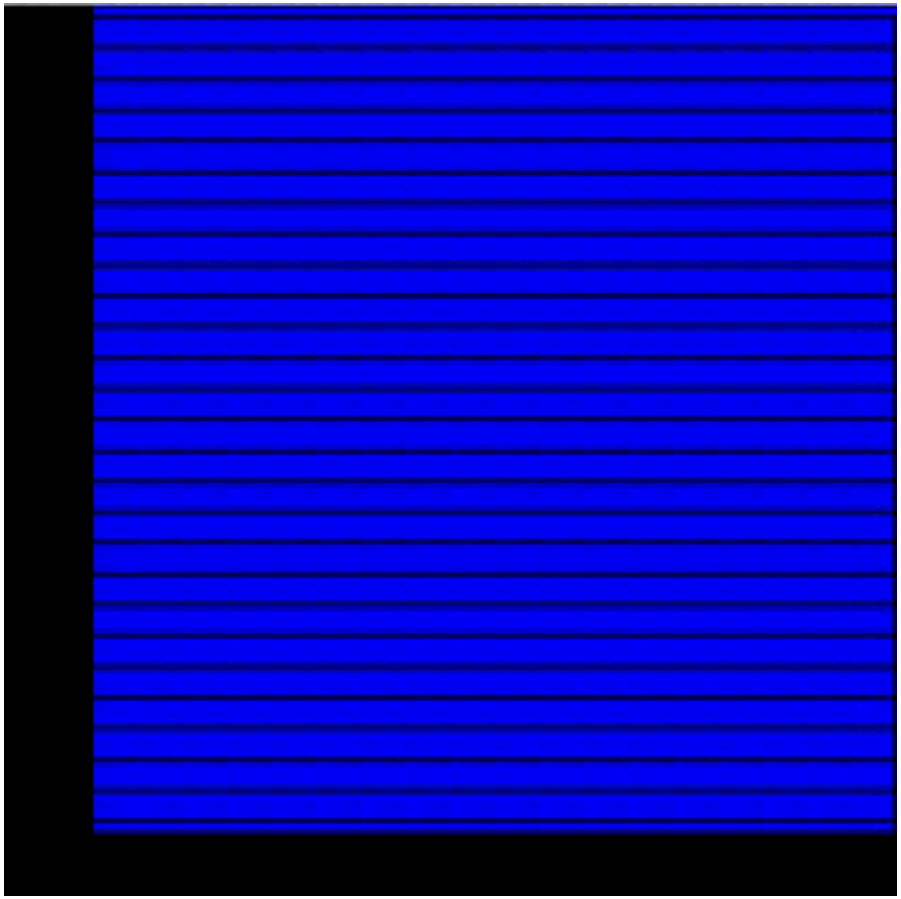




Slide from Peter Balter

# Intensity Modulation

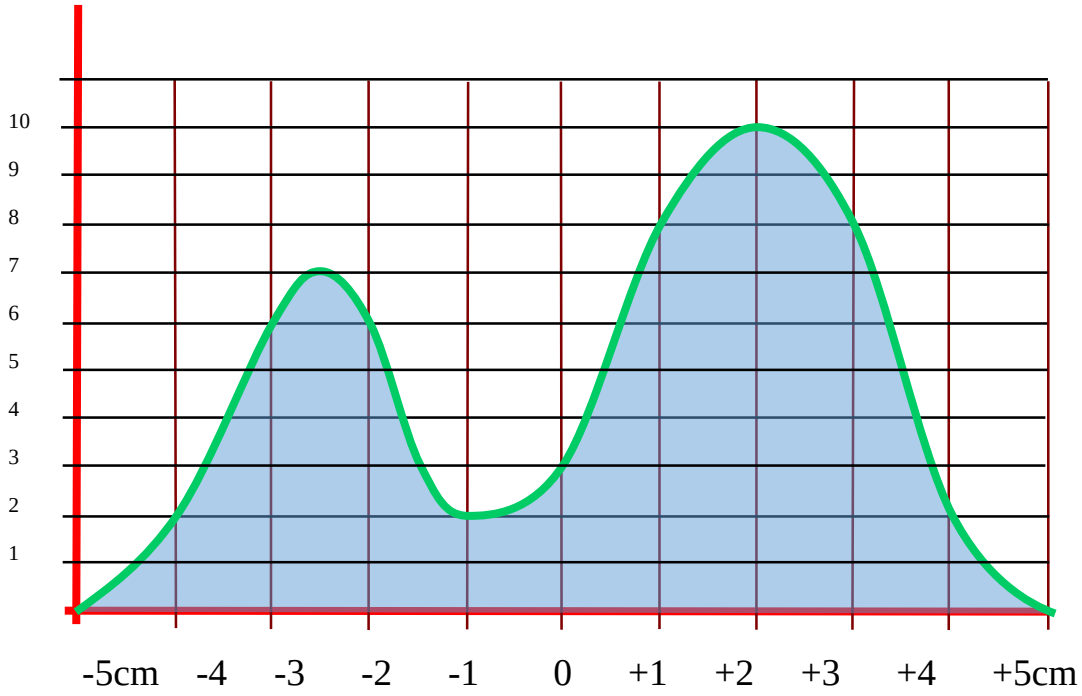
- Sliding Window MLC
  - MLC leaves move continuously while the treatment machine is on
  - The field is divided into a number of control points that have target positions for each leaf at each fraction amount of dose delivered
  - The linac modulates leaf speed, then dose rate to ensure the targets for each control point are within tolerance values.





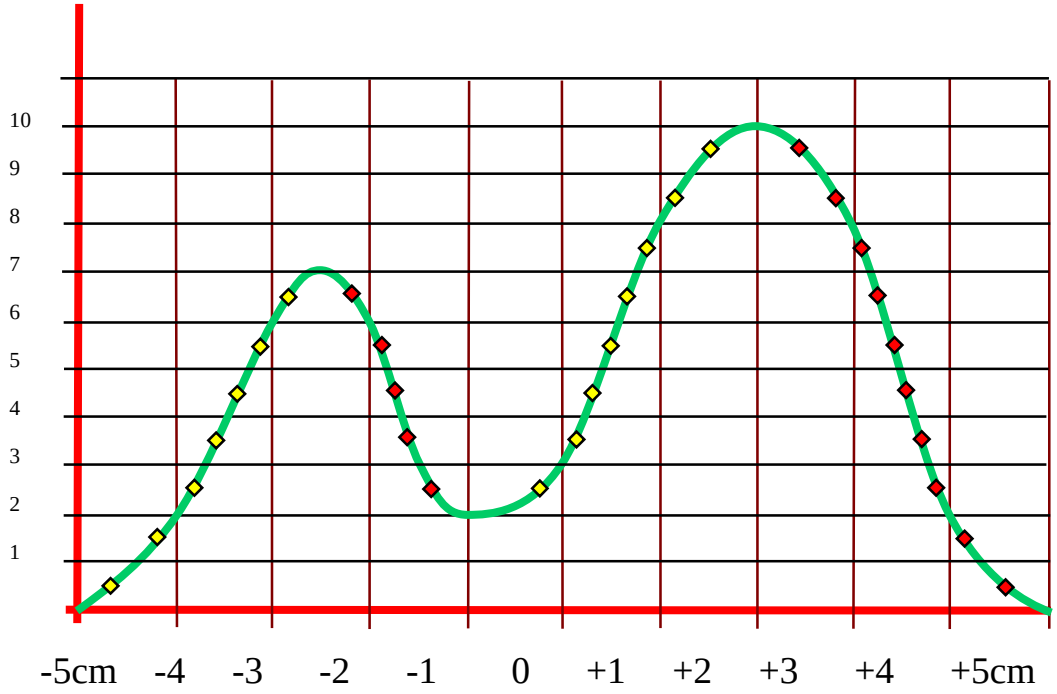
Slide from Peter Balter

# How Can We Make Any Intensity Shape with an MLC?






Slide from Chen Chui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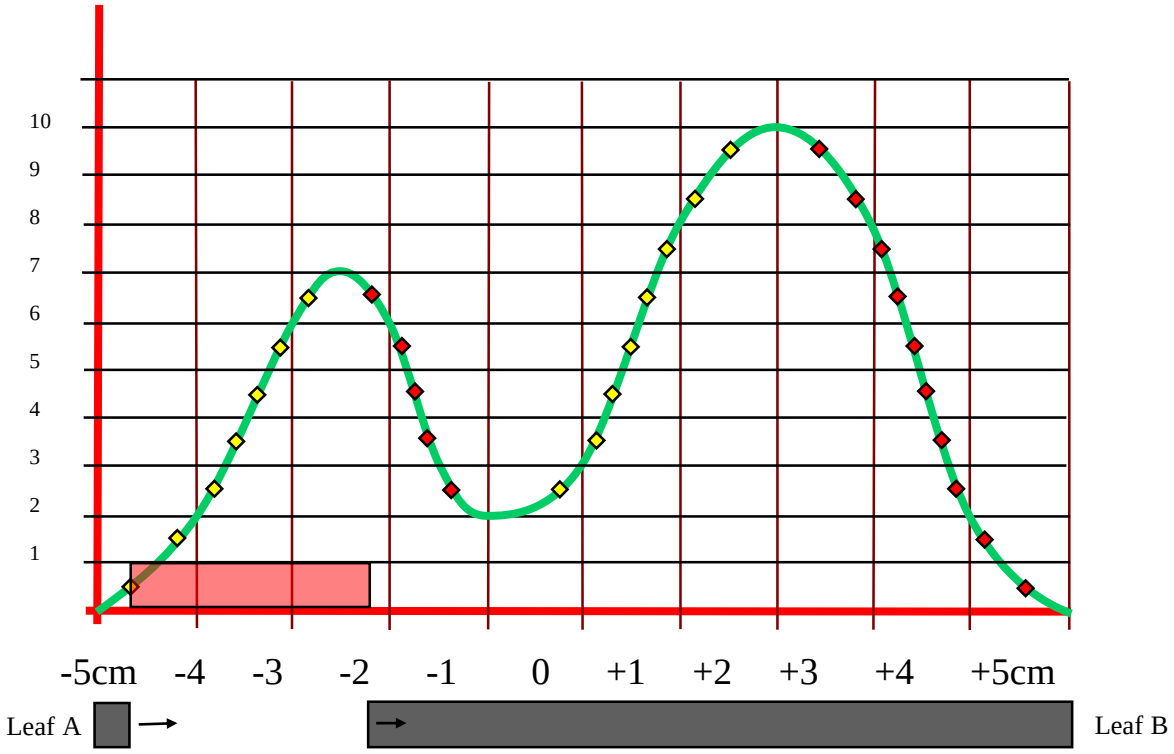
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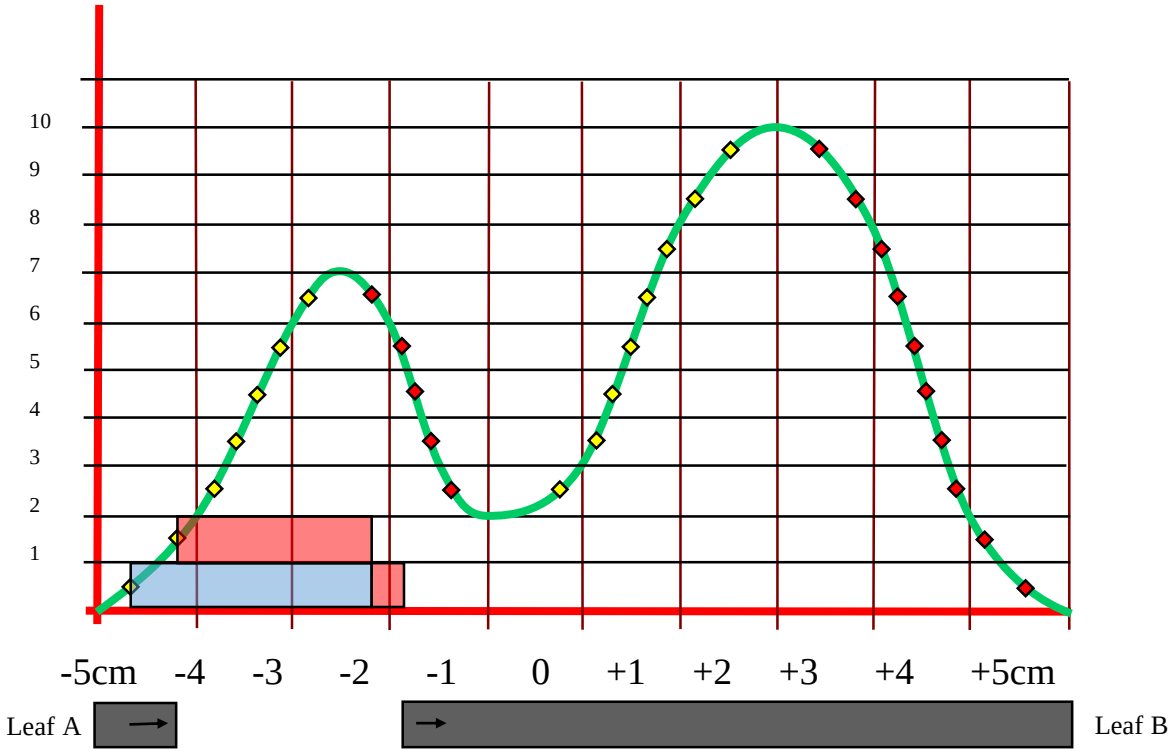
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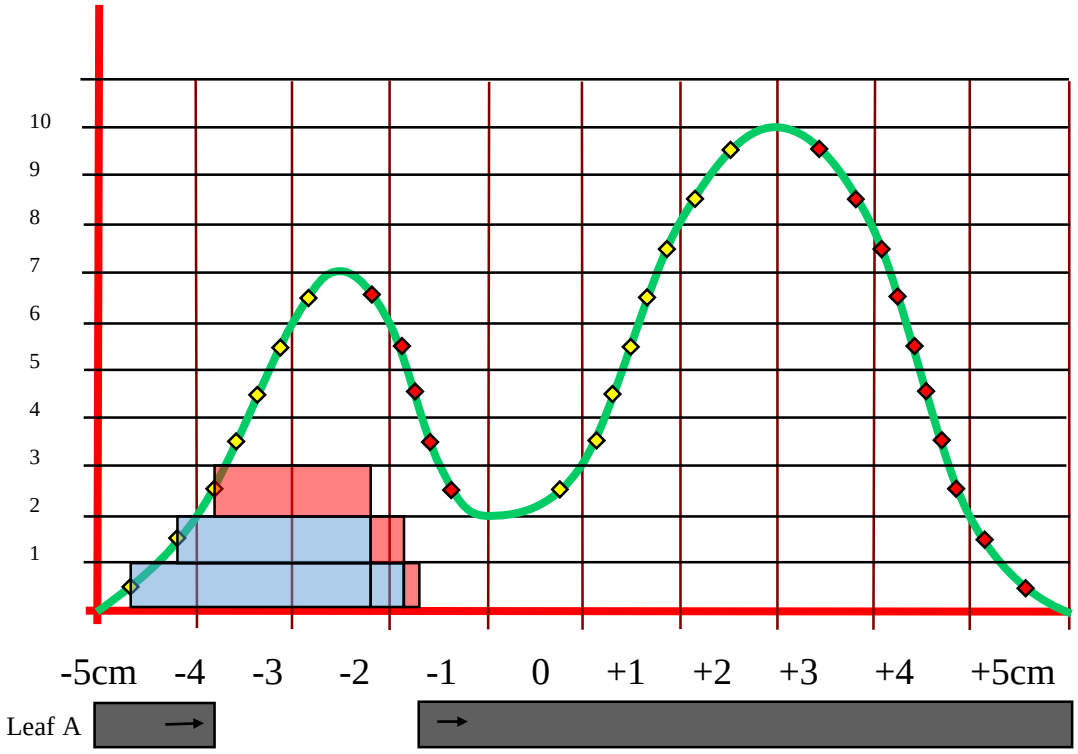
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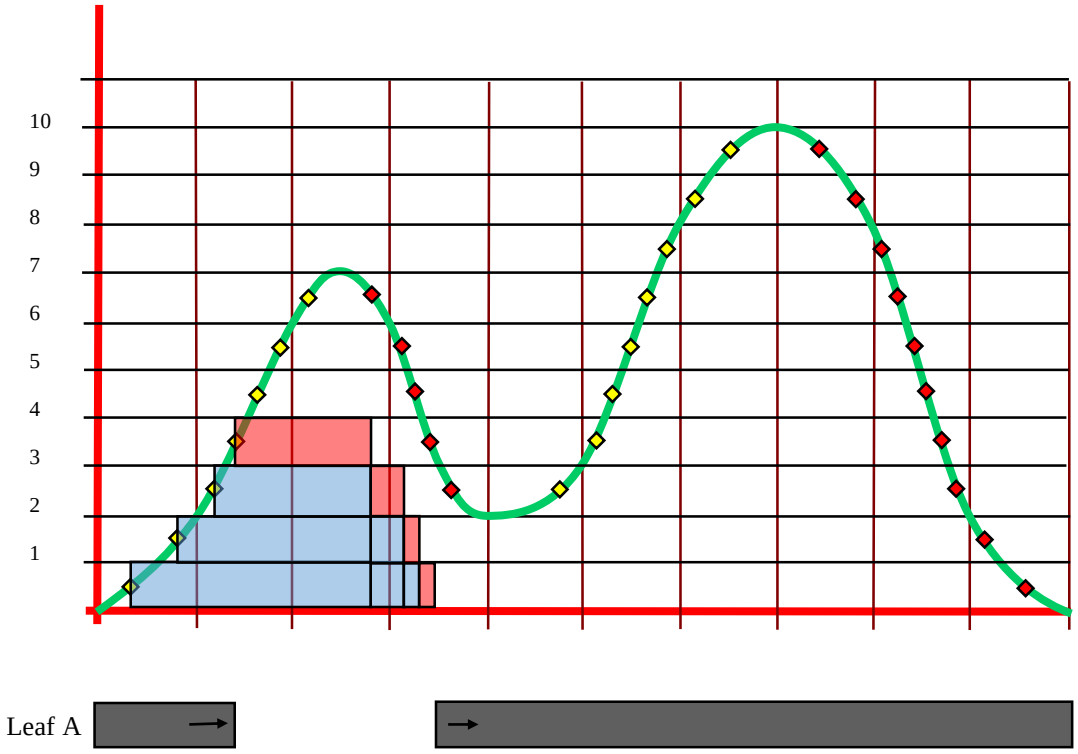
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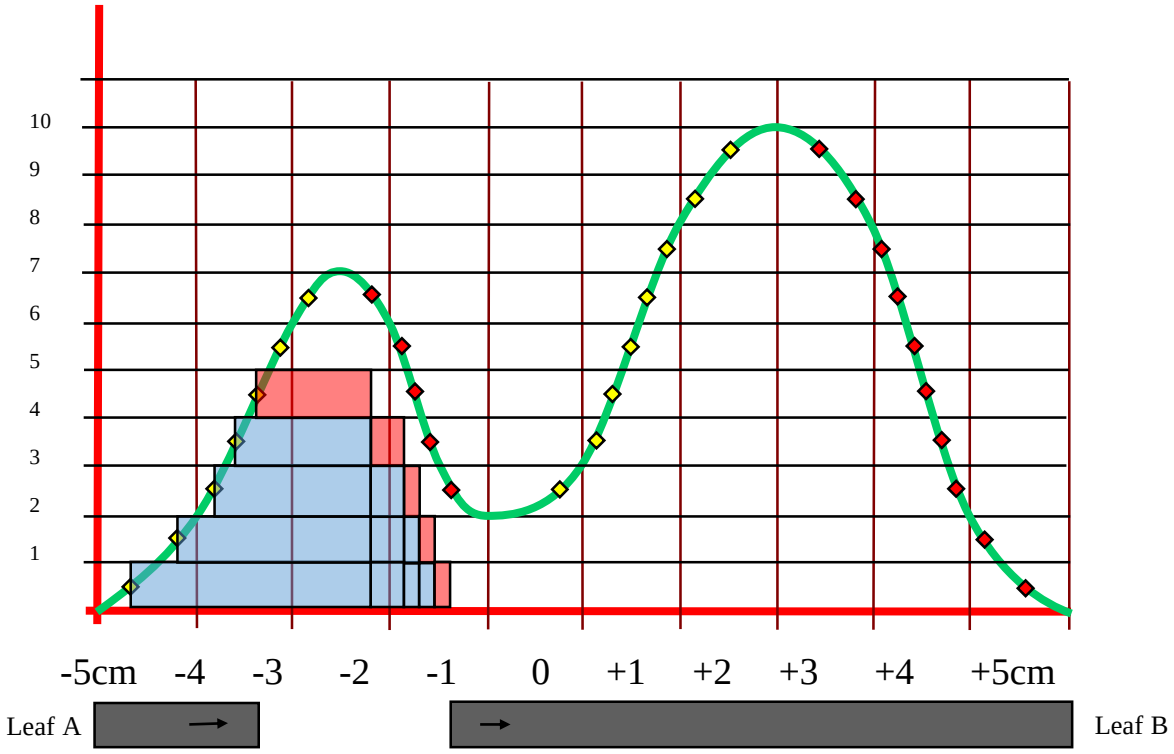
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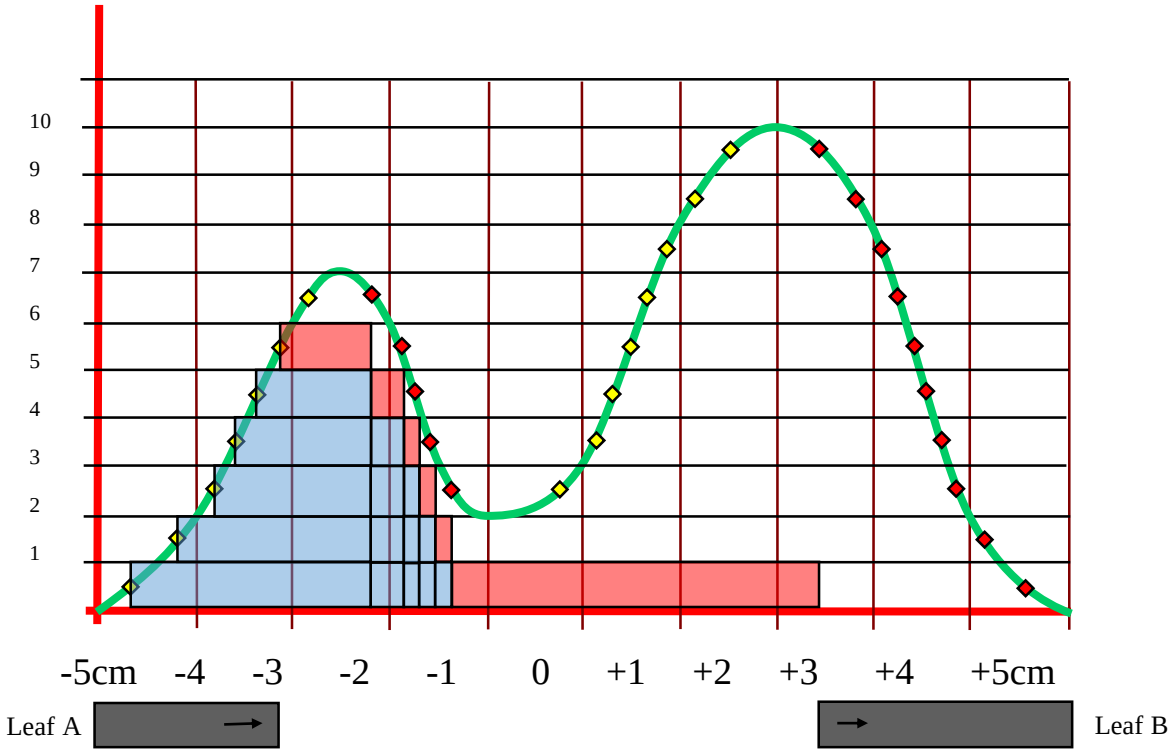
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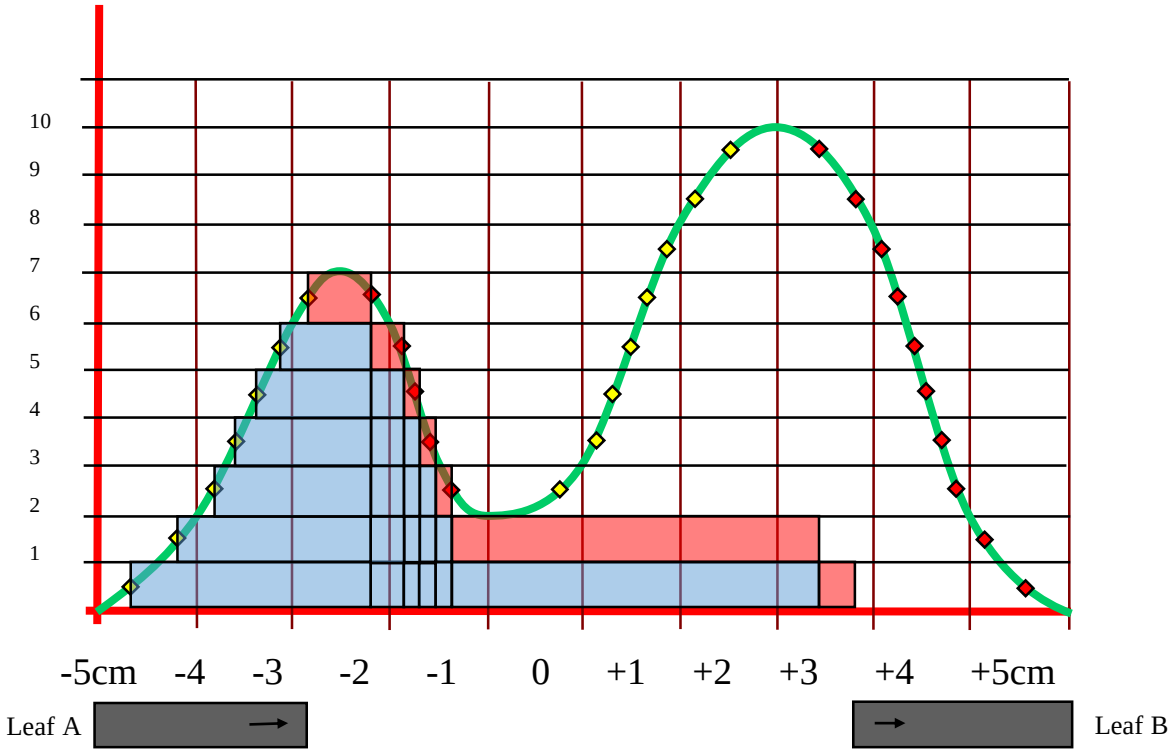
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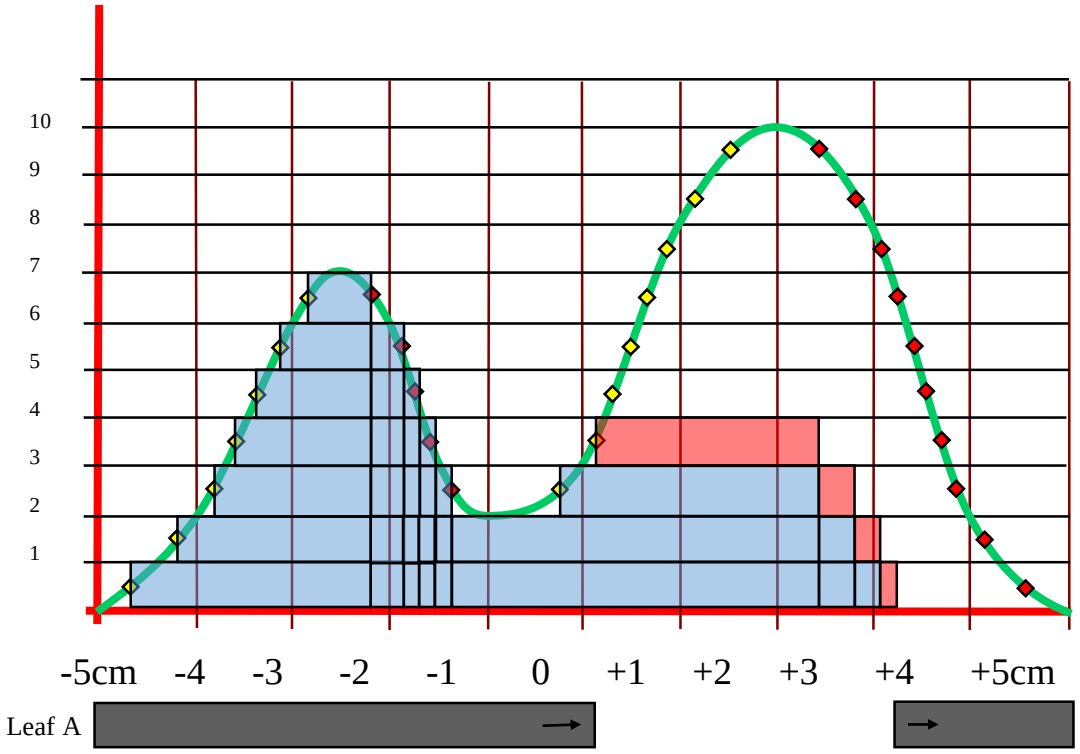
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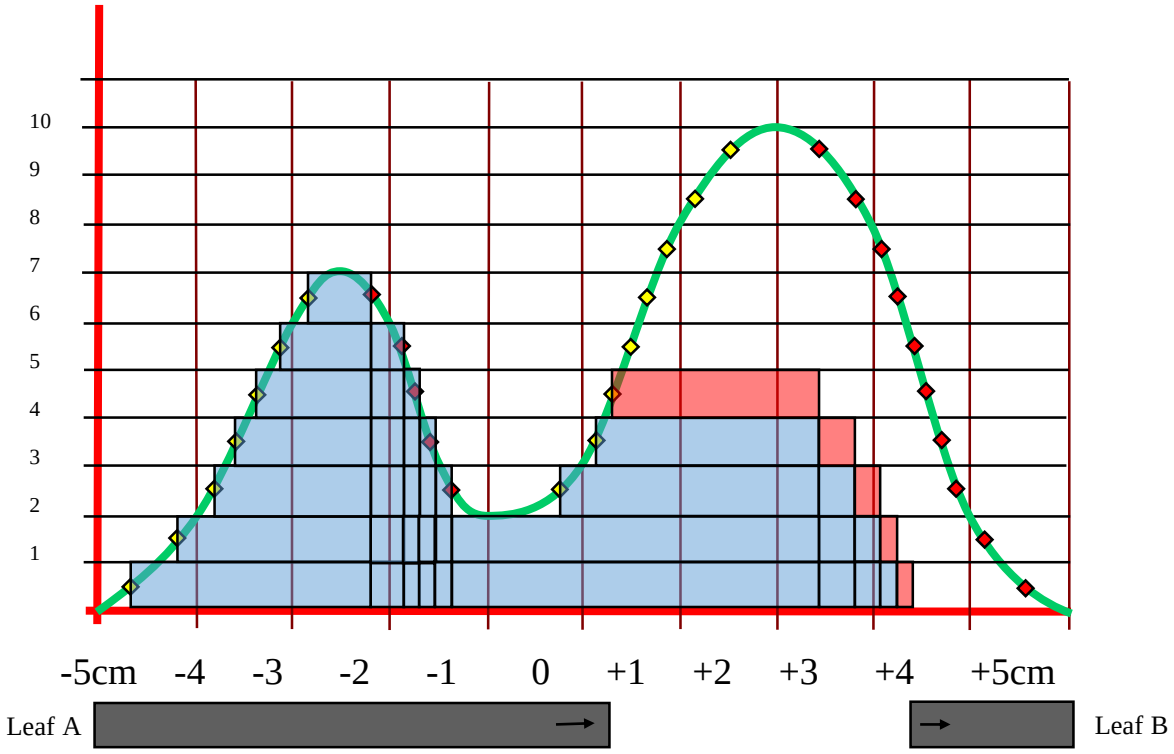
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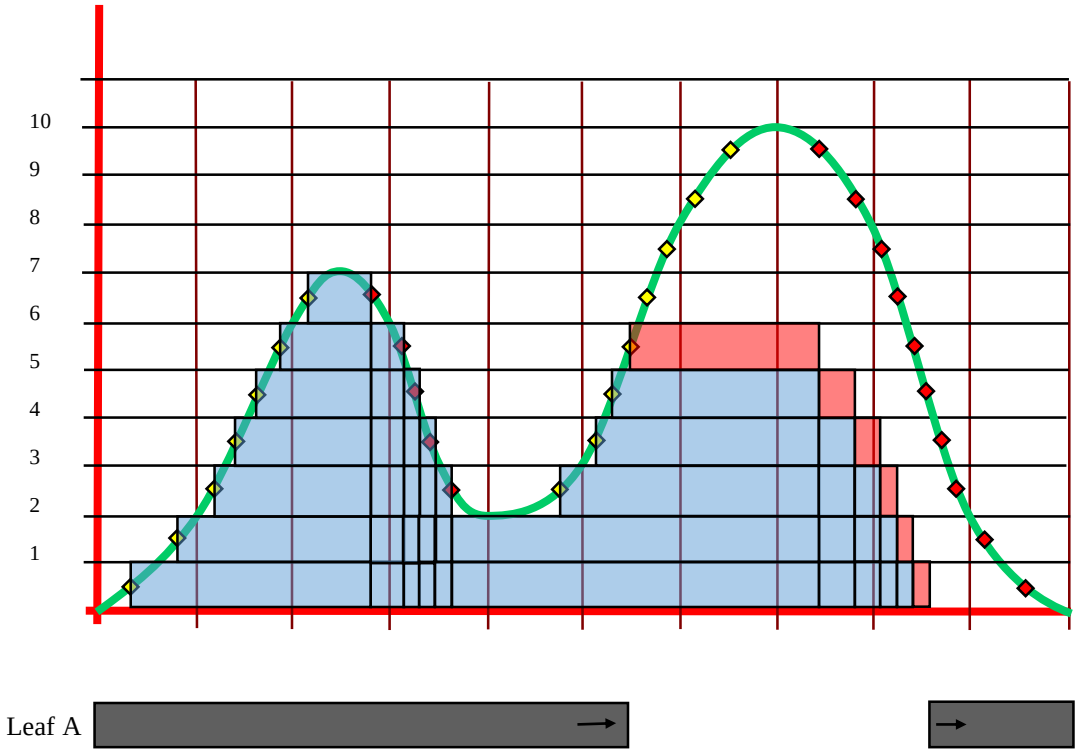
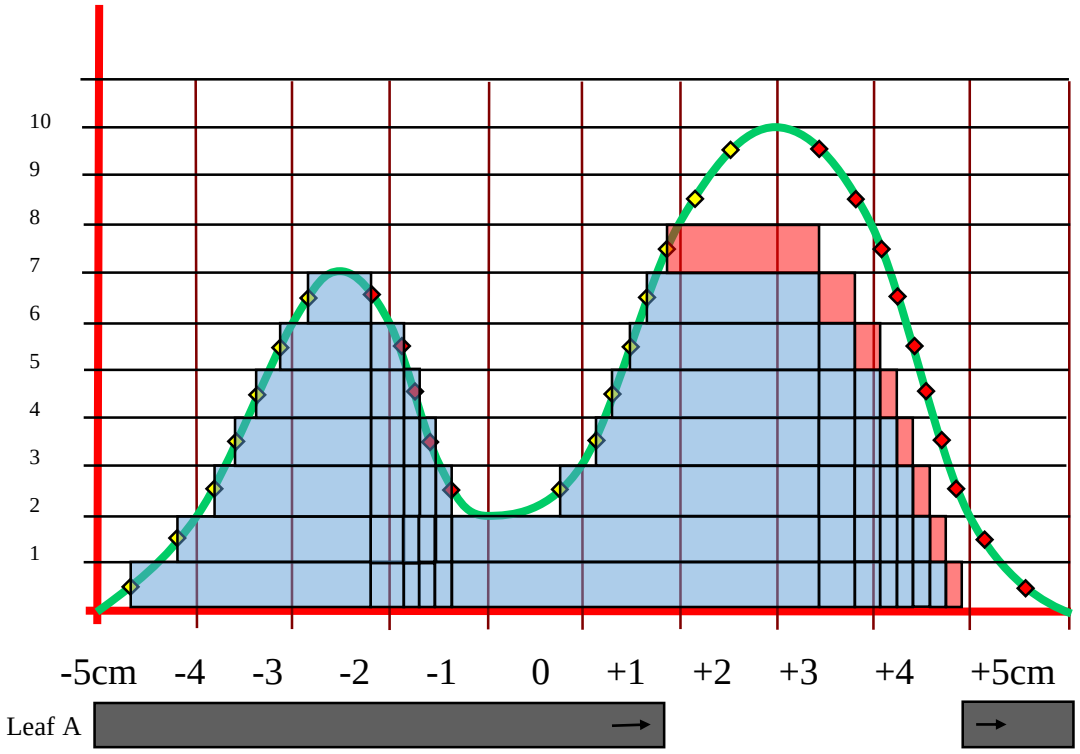
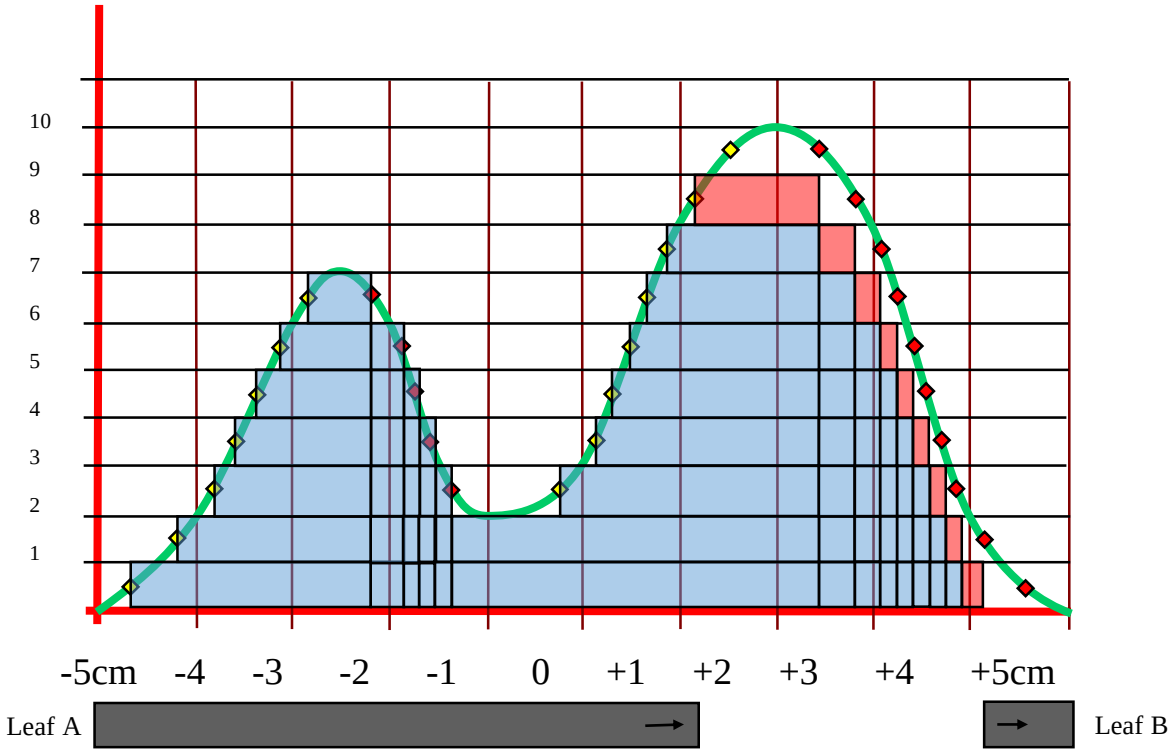
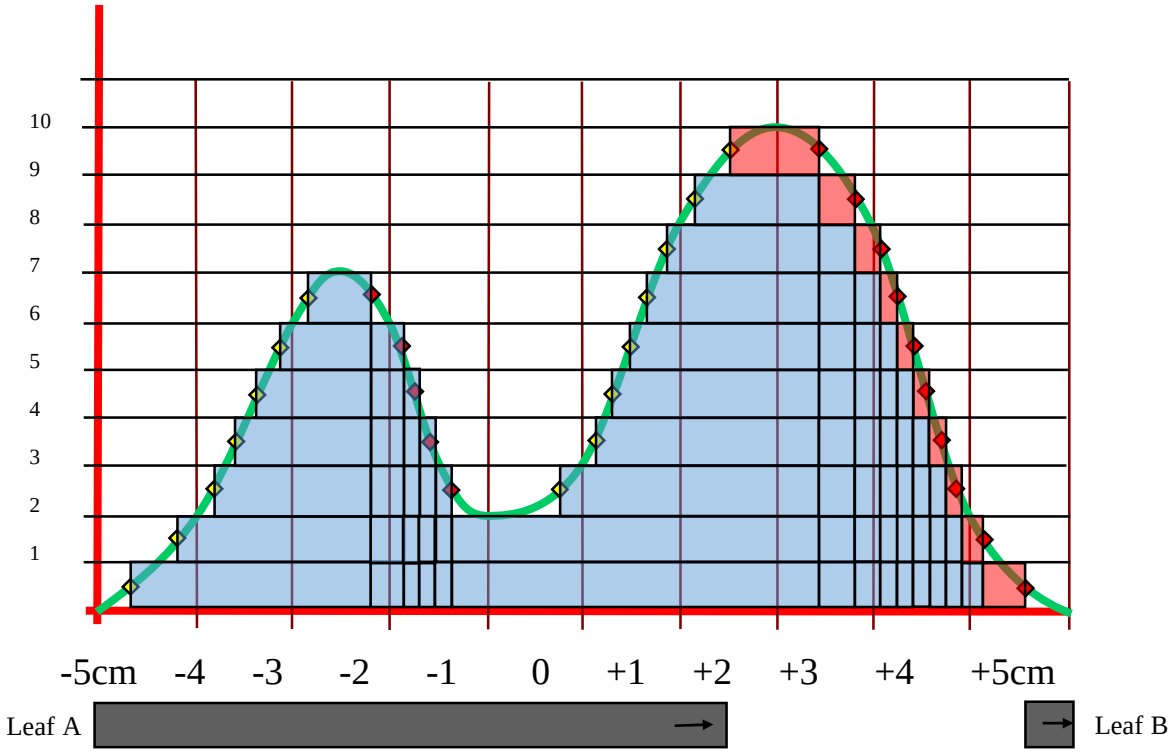
Leaf B

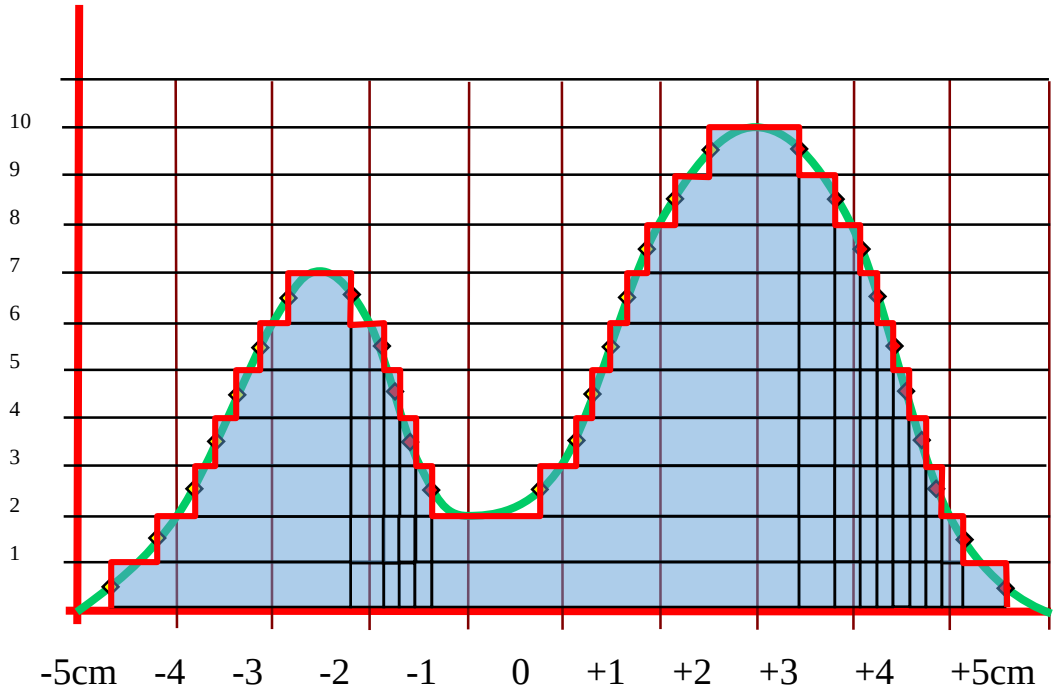

10
9
8
7
6
5
4
3
2
1
Leaf A


10
9
8
7
6
5
4
3
2
1
-5cm
-4
-3
-2
-1
0
+1
+2
+3
+4
+5cm
Leaf A


10
9
8
7
6
5
4
3
2
1
-5cm
-4
-3
-2
-1
0
+1
+2
+3
+4
+5cm
Leaf A
Leaf B


10
9
8
7
6
5
4
3
2
1
-5cm
-4
-3
-2
-1
0
+1
+2
+3
+4
+5cm
Leaf A
Leaf B

# Done!



# From Optimized Intensity Map to Treatment Leaf Sequencing

- The optimized treatment plan is not immediately ready for delivery.
- A leaf sequencing algorithm needs to be applied to translate the each optimized (theoretical) fluence map into a set of deliverable aperture shapes.
- The constraints imposed by the multileaf collimator are accounted for in the leaf sequencing step.
- Final plan dose distribution changes
- This is the approach taken by Eclipse for dynamic IMRT.
- It was the approach used by Pinnacle for step-and-shoot IMRT (older versions)



Based on a slide from David Shephard

# Direct aperture optimization

(DAO)

# Direct Aperture Optimization (DAO)

1. Inverse planning technique where the aperture shapes and weights are optimized simultaneously.
2. All of the MLC delivery constraints are included in the optimization
3. The number of aperture per beam angle is specified in the prescription.

# Direct aperture optimization: A turnkey solution for step-and-shoot IMRT

D. M. Shepard, M. A. Earl, X. A. Li, S. Naqvi, and C. Yu
*University of Maryland School of Medicine, Department of Radiation Oncology, 22 South Greene St., Baltimore, Maryland 21201-1595*

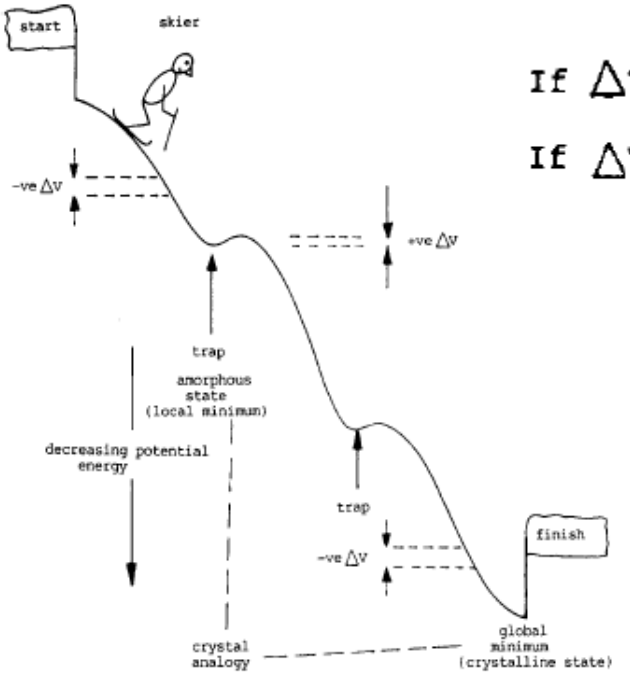
(Received 26 September 2001; accepted for publication 12 March 2002; published 13 May 2002)

IMRT treatment plans for step-and-shoot delivery have traditionally been produced through the optimization of intensity distributions (or maps) for each beam angle. The optimization step is followed by the application of a leaf-sequencing algorithm that translates each intensity map into a set of deliverable aperture shapes. In this article, we introduce an automated planning system in which we bypass the traditional intensity optimization, and instead directly optimize the shapes and the weights of the apertures. We call this approach "direct aperture optimization." This technique allows the user to specify the maximum number of apertures per beam direction, and hence provides significant control over the complexity of the treatment delivery. This is possible because the machine dependent delivery constraints imposed by the MLC are enforced within the aperture optimization algorithm rather than in a separate leaf-sequencing step. The leaf settings and the aperture intensities are optimized simultaneously using a simulated annealing algorithm. We have tested direct aperture optimization on a variety of patient cases using the EGS4/BEAM Monte Carlo package for our dose calculation engine. The results demonstrate that direct aperture optimization can produce highly conformal step-and-shoot treatment plans using only three to five apertures per beam direction. As compared with traditional optimization strategies, our studies demonstrate that direct aperture optimization can result in a significant reduction in both the number of beam segments and the number of monitor units. Direct aperture optimization therefore produces highly efficient treatment deliveries that maintain the full dosimetric benefits of IMRT. © *2002 American Association of Physicists in Medicine.* [DOI: 10.1118/1.1477415]

Key words: IMRT, inverse treatment planning, optimization, intensity modulation

# Simulated Annealing

- DAO uses simulated annealing, an optimization technique using random sampling techniques.
- The term simulated annealing derives from the roughly analogous physical process of heating and then slowly cooling a substance to obtain a strong crystalline structure.
- In each simulation, a minima of the cost function corresponds to this ground state of the substance.
- The basic principle is that by allowing occasional ascent in the search process, we might be able to escape the trap of local minima.




If $\Delta V < 0$ accept grain

If $\Delta V > 0$ accept grain with probability $\exp(-\Delta V/kT)$
(T is temperature; k is Boltzmann's constant)

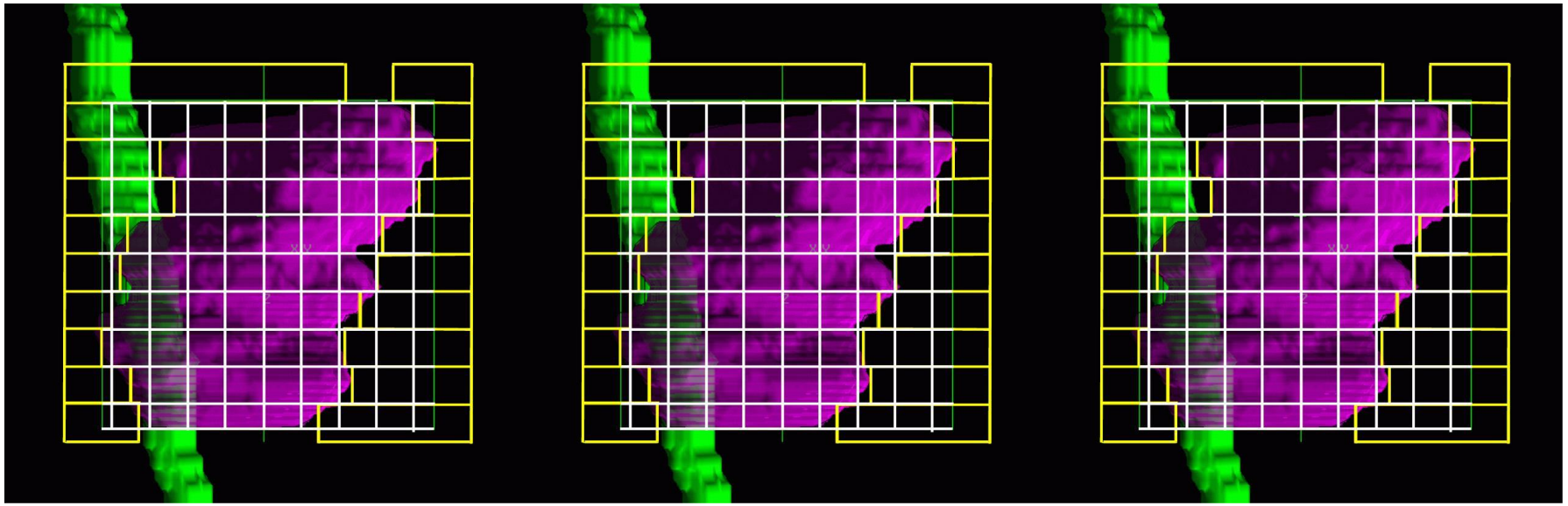
Figure from Webb – the first person to introduce SA to radiotherapy in the late 80's

# DAO Optimization via Simulated Annealing

1) Pick a parameter (leaf position, aperture weight) randomly
2) Change the parameter by a random amount
3) Calculate objective function based on the new dose distribution
4) Objective function lower: accept change
5) Objective function higher: accept change with certain probability

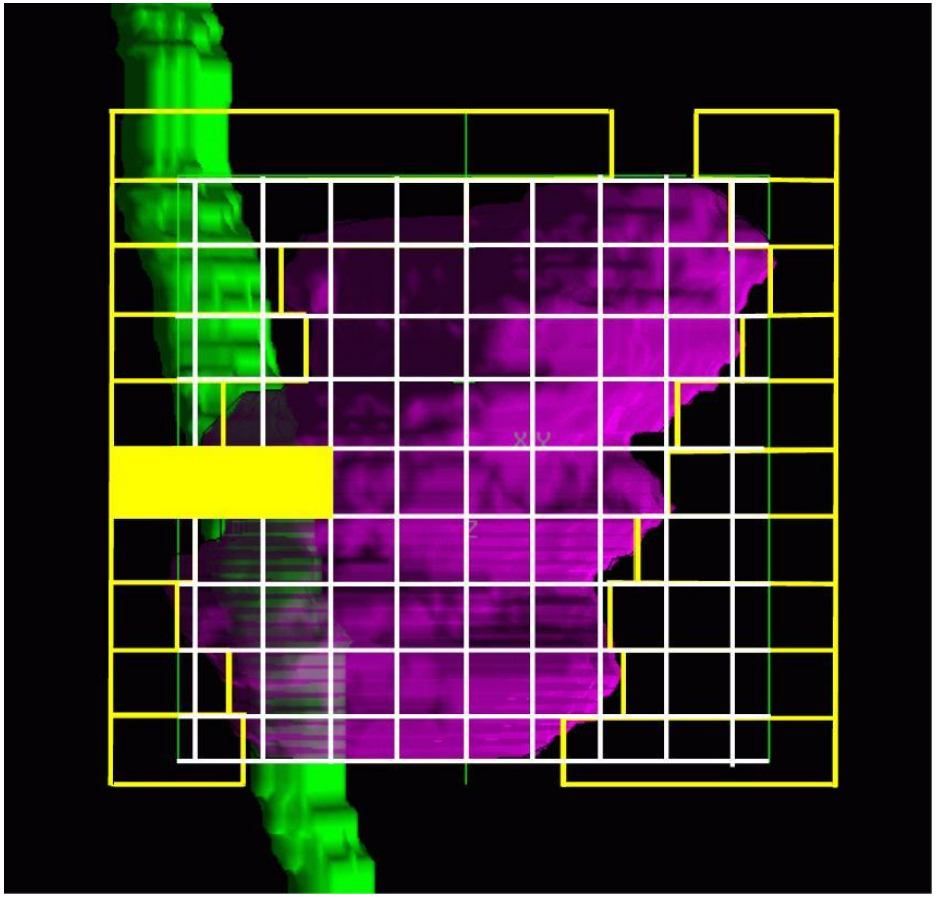
# Prescription: 3 apertures per angle

## Begin with 3 identical copies



# Pick an Parameter and Make a Change

Aperture 1
Leaf pair 6
Left leaf position
Move leaf in 2cm



## Keep or Reject the Change

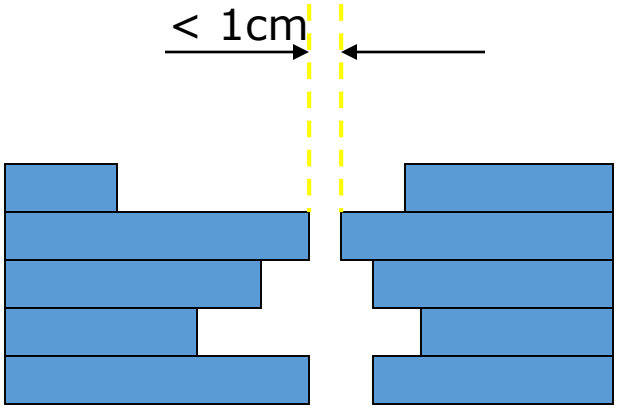
Based on:

1. MLC constraints.
2. Cost function & Annealing Rules.

# MLC Constraints

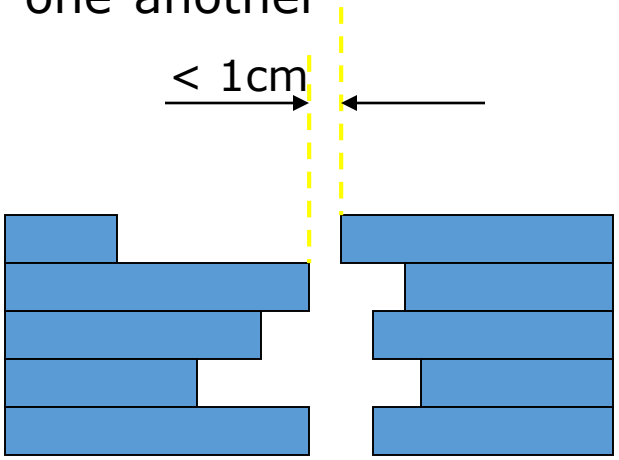
Some sample Elekta constraints:

1) Opposed leaves cannot come closer than 1-cm from one-another



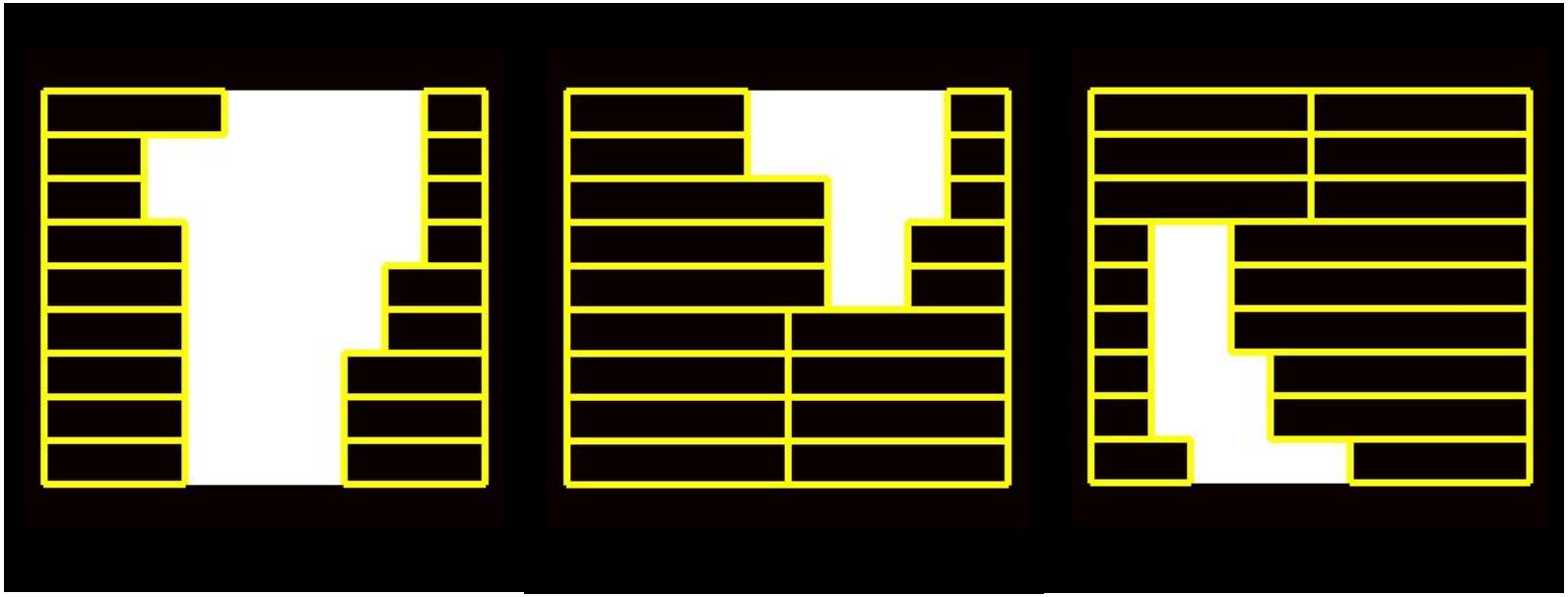

Not allowed

2) Opposed-adjacent leaves cannot come closer than 1-cm from one-another



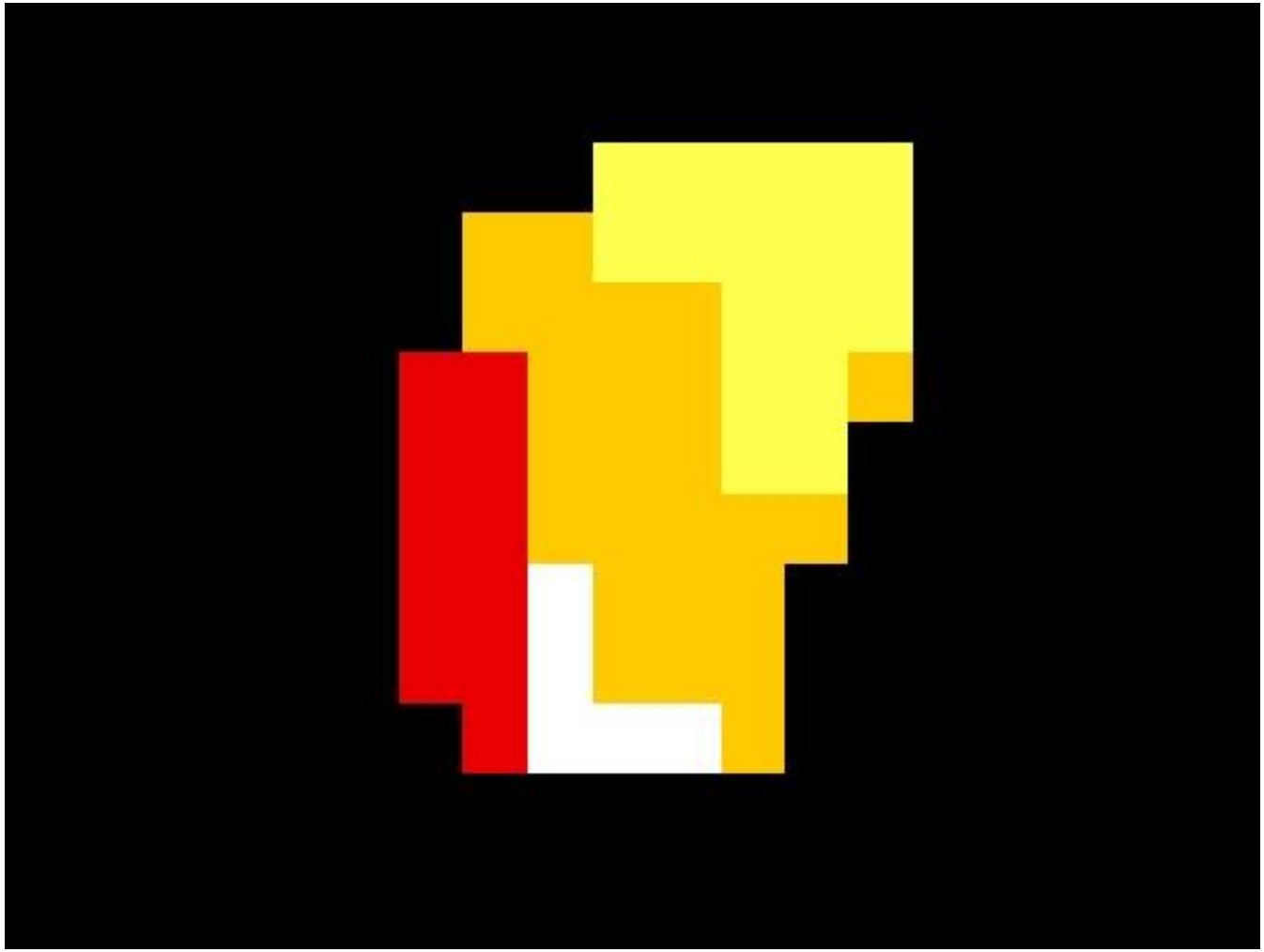

Not allowed

# After numerous iterations...



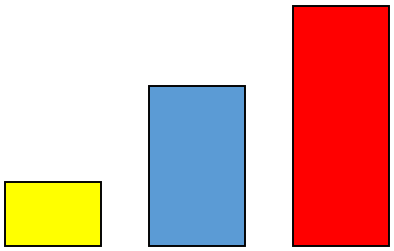
Add them up along with their weights…

# Final intensity map from DAO

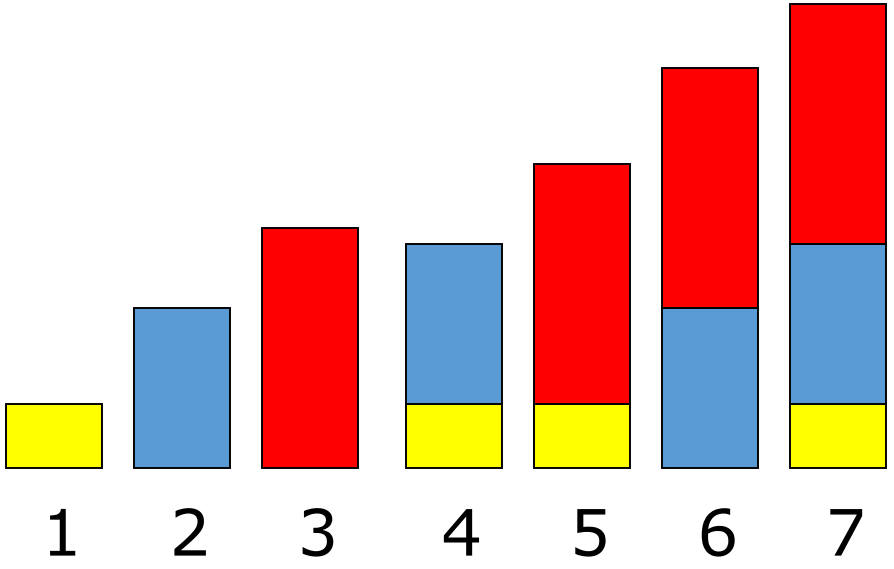


# Small number of apertures can produce large number of intensity levels

Example:  3 apertures/angle



3 separate weights



Small number of apertures can produce large number of intensity levels

$$N_n = 2^n - 1$$

$N$ = Number of intensity levels
$n$ = Number of apertures

For 3 apertures, 7 intensities
For 4 apertures, 15 intensities
For 5 apertures, 31 intensities
For 6 apertures, 63 intensities

# Volume-Modulated Arc Therapy

VMAT

# Volumetric modulated arc therapy: IMRT in a single gantry arc

Karl Otto[a)]
*Vancouver Cancer Centre, BC Cancer Agency, Vancouver, British Columbia V5Z 4E6, Canada*

(Received 25 June 2007; revised 21 September 2007; accepted for publication 5 November 2007; published 26 December 2007)

In this work a novel plan optimization platform is presented where treatment is delivered efficiently and accurately in a single dynamically modulated arc. Improvements in patient care achieved through image-guided positioning and plan adaptation have resulted in an increase in overall treatment times. Intensity-modulated radiation therapy (IMRT) has also increased treatment time by requiring a larger number of beam directions, increased monitor units (MU), and, in the case of tomotherapy, a slice-by-slice delivery. In order to maintain a similar level of patient throughput it will be necessary to increase the efficiency of treatment delivery. The solution proposed here is a novel aperture-based algorithm for treatment plan optimization where dose is delivered during a single gantry arc of up to 360 deg. The technique is similar to tomotherapy in that a full 360 deg of beam directions are available for optimization but is fundamentally different in that the entire dose volume is delivered in a single source rotation. The new technique is referred to as volumetric modulated arc therapy (VMAT). Multileaf collimator (MLC) leaf motion and number of MU per

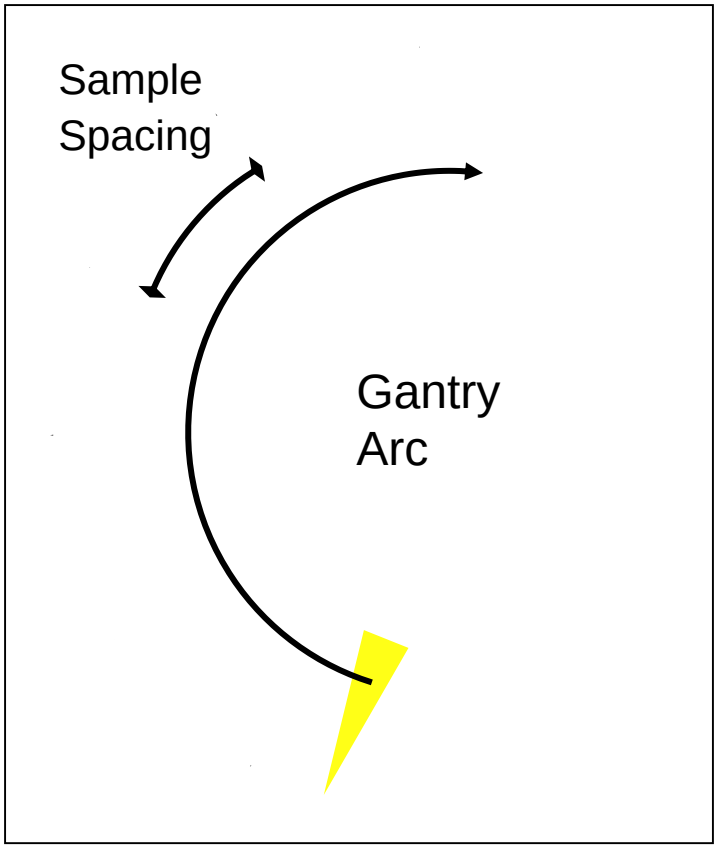
**Med. Phys. 35 (1), January 2008**

# Eclipse VMAT

- In Otto's paper, he used DAO to produced IMAT plans.
- Two key innovations:
  1. Focused on a single arc approach with more control points in the single arc. Termed "VMAT".
  2. Progressive sampling was used to improve the speed of the algorithm.
- This is the approach utilized in Eclipse

# Dynamic Source Model

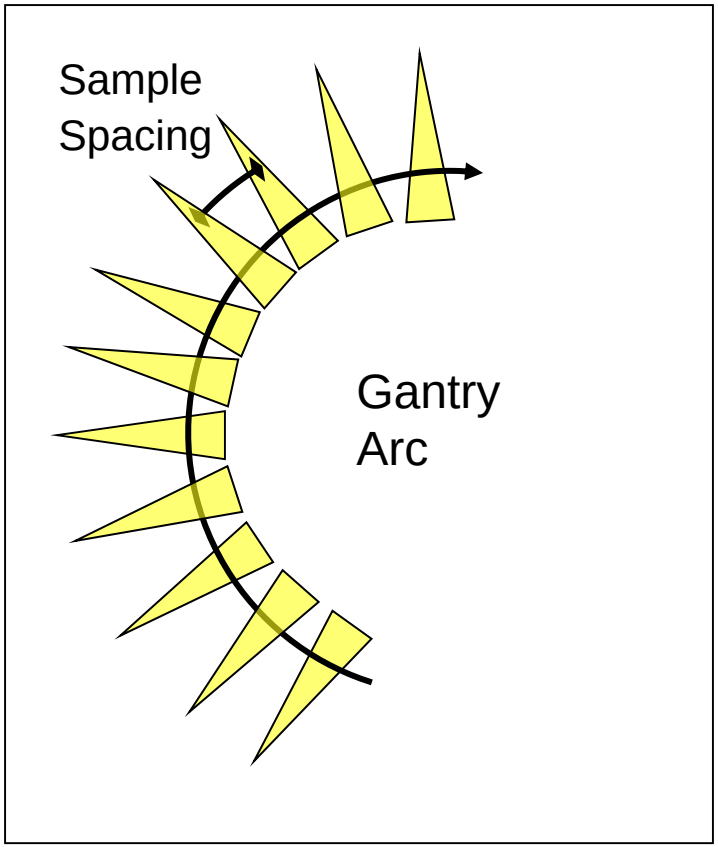
| Sampling | Flexibility | Accuracy |
|---|---|---|
| Coarse | √ | X |




Courtesy of Karl Otto

# Dynamic Source Model

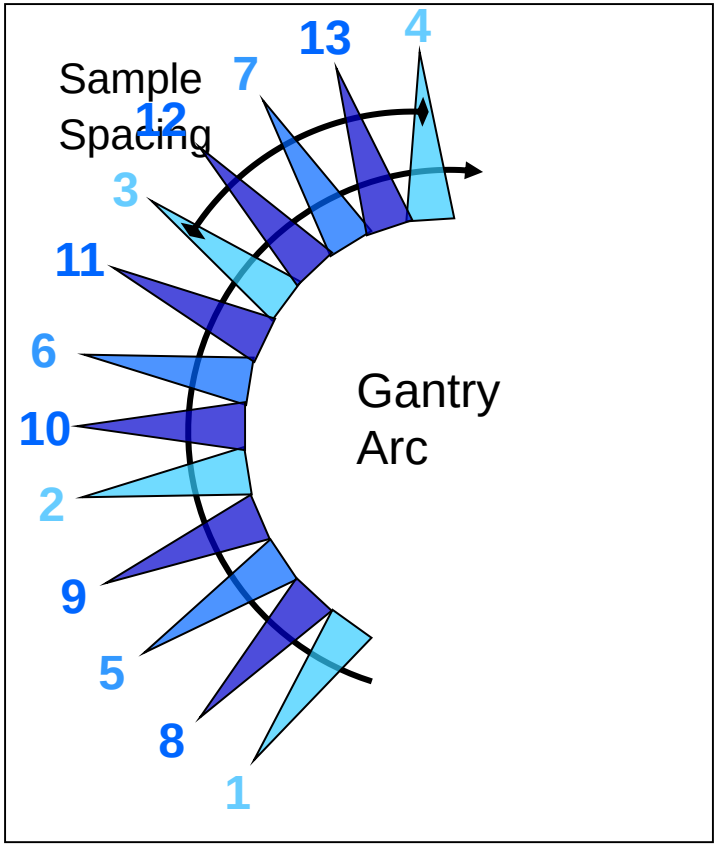
| Sampling | Flexibility | Accuracy |
|---|---|---|
| Coarse | √ | X |
| Fine | X | √ |




Courtesy of Karl Otto

# Progressive Sampling

| Sampling | Flexibility | Accuracy |
|---|---|---|
| Coarse | √ | X |
| Fine | X | √ |
| Progressive | √ | √ |




Courtesy of Karl Otto

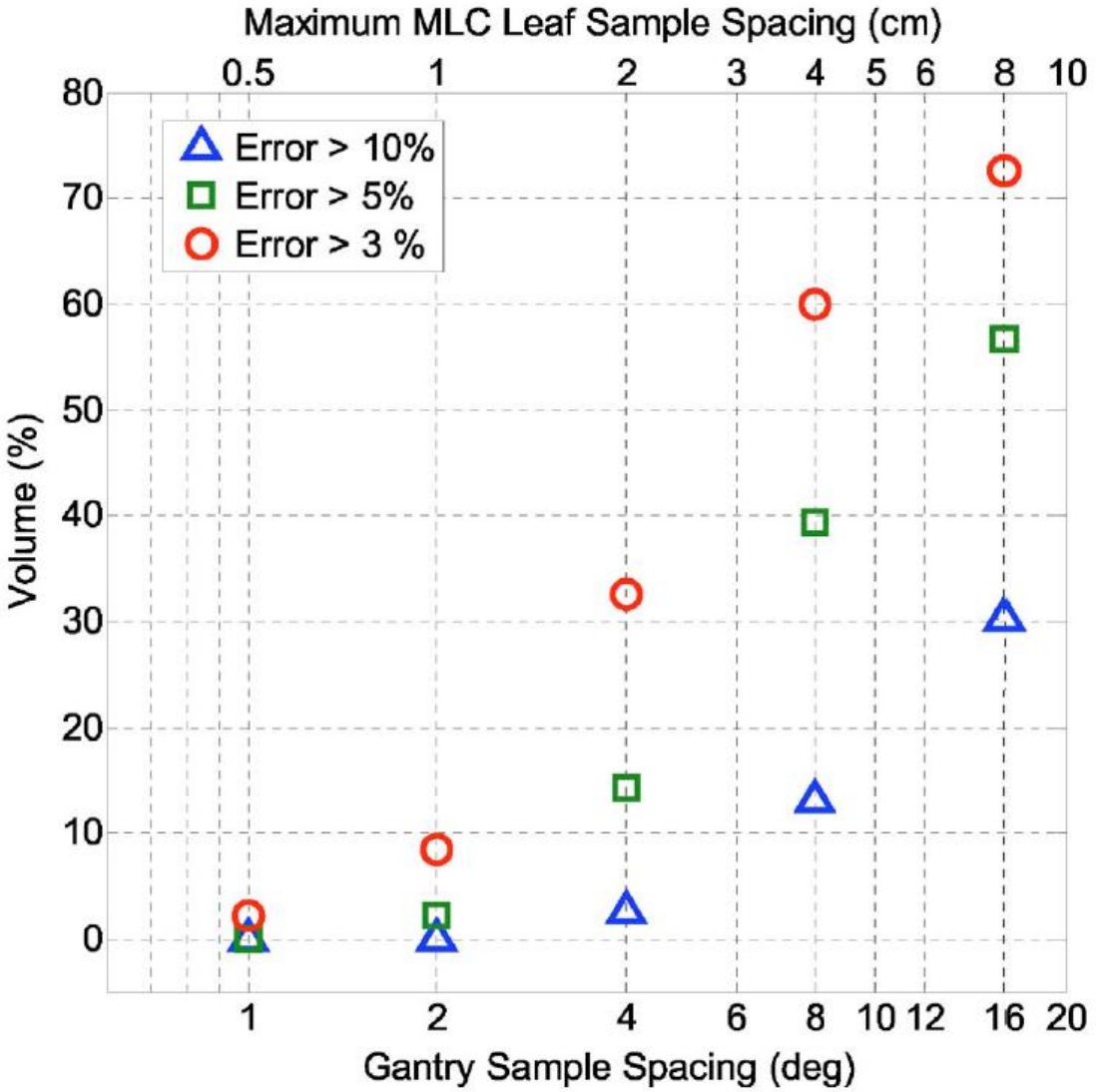
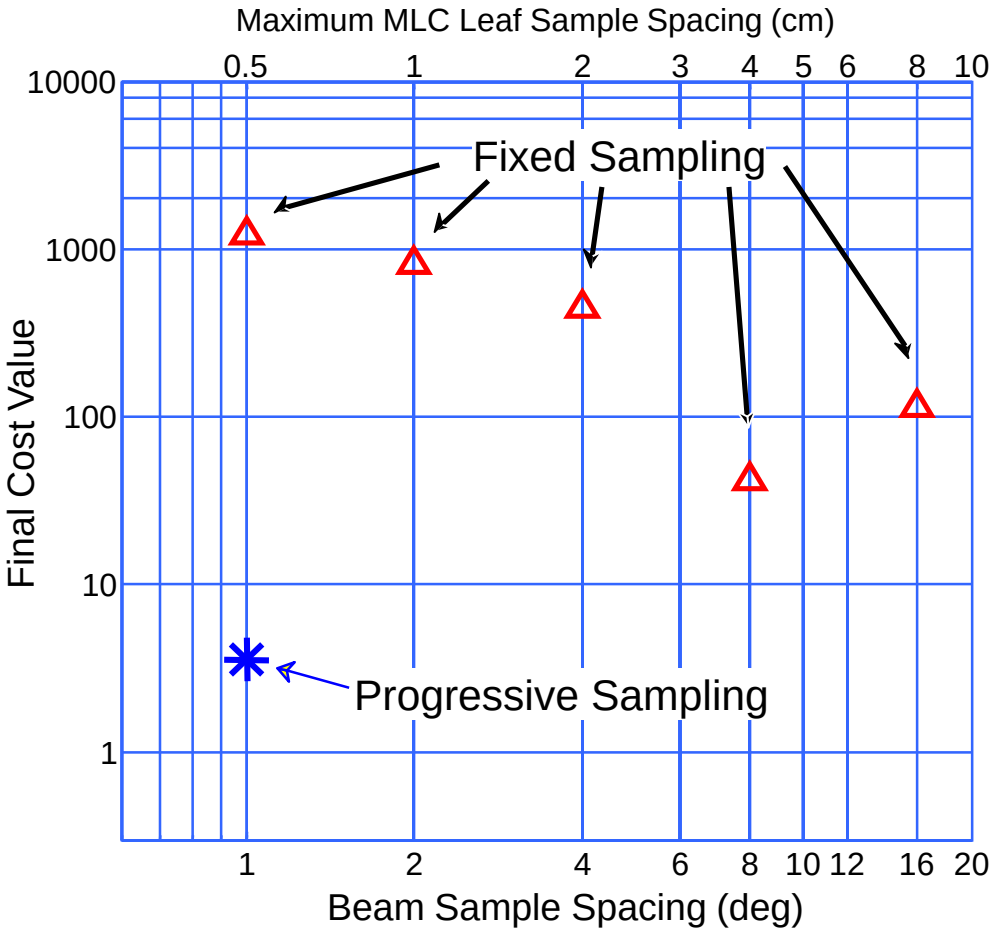


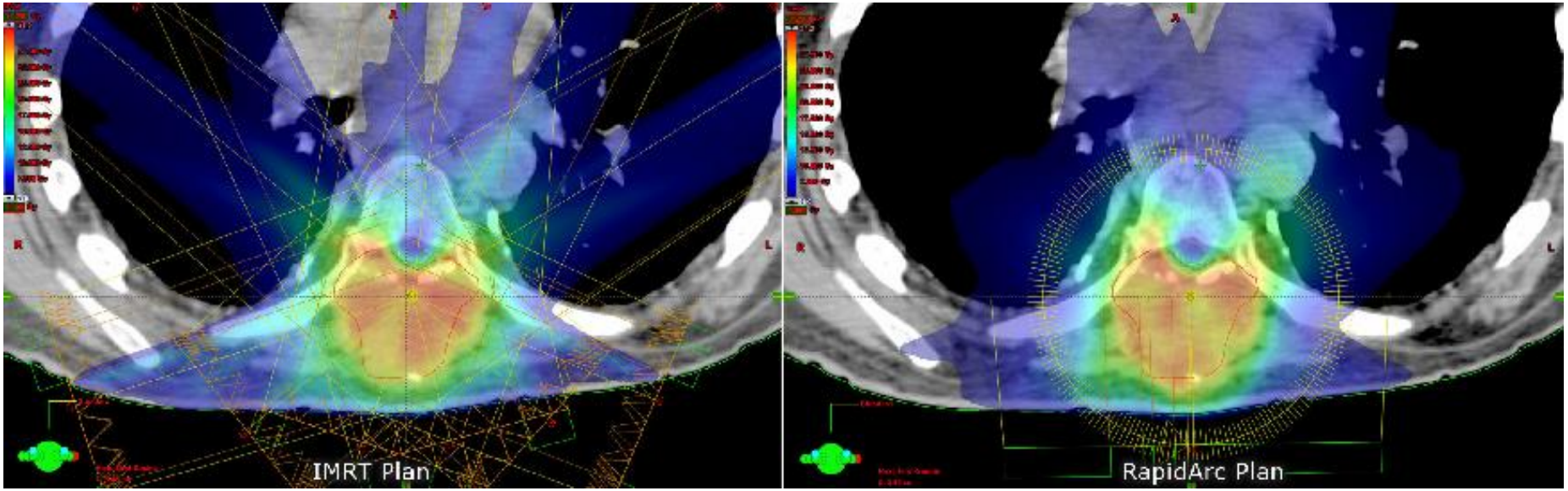

FIG. 2. The percentage volume (target and critical structures) exceeding 10%, 5%, and 3% dose error is shown as a function of the gantry and maximum MLC leaf sample spacing.

# Progressive Sampling




Courtesy of Karl Otto

# Varian Eclipse




- Planning is performed using Direct Aperture Optimization.
- Typical plan uses 1 arc with 177 control points.
- For some cases, multiple arcs are use to improve the plan quality or provide adequate coverage of large targets.

# SmartArc Optimization (Philips)

1. Beams are generated at the start and the stop angles and at 24° increments from the start angle.
2. A fluence map optimization is performed.
3. The fluence maps are sequenced and filtered so that there are only 2 control points per initial beam angle.
4. These control points are distributed to adjacent gantry angles and additional control points are added to achieve the desired final gantry spacing.
5. All control points are processed to comply with the motion constraints of VMAT.
6. The DMPO algorithm is applied with an aperture based optimization that takes into account all of the VMAT delivery constraints.
7. The jaws are conformed to the segments based on the characteristics of the linac.



Courtesy of Philips Medical

# Treatment planning is an art

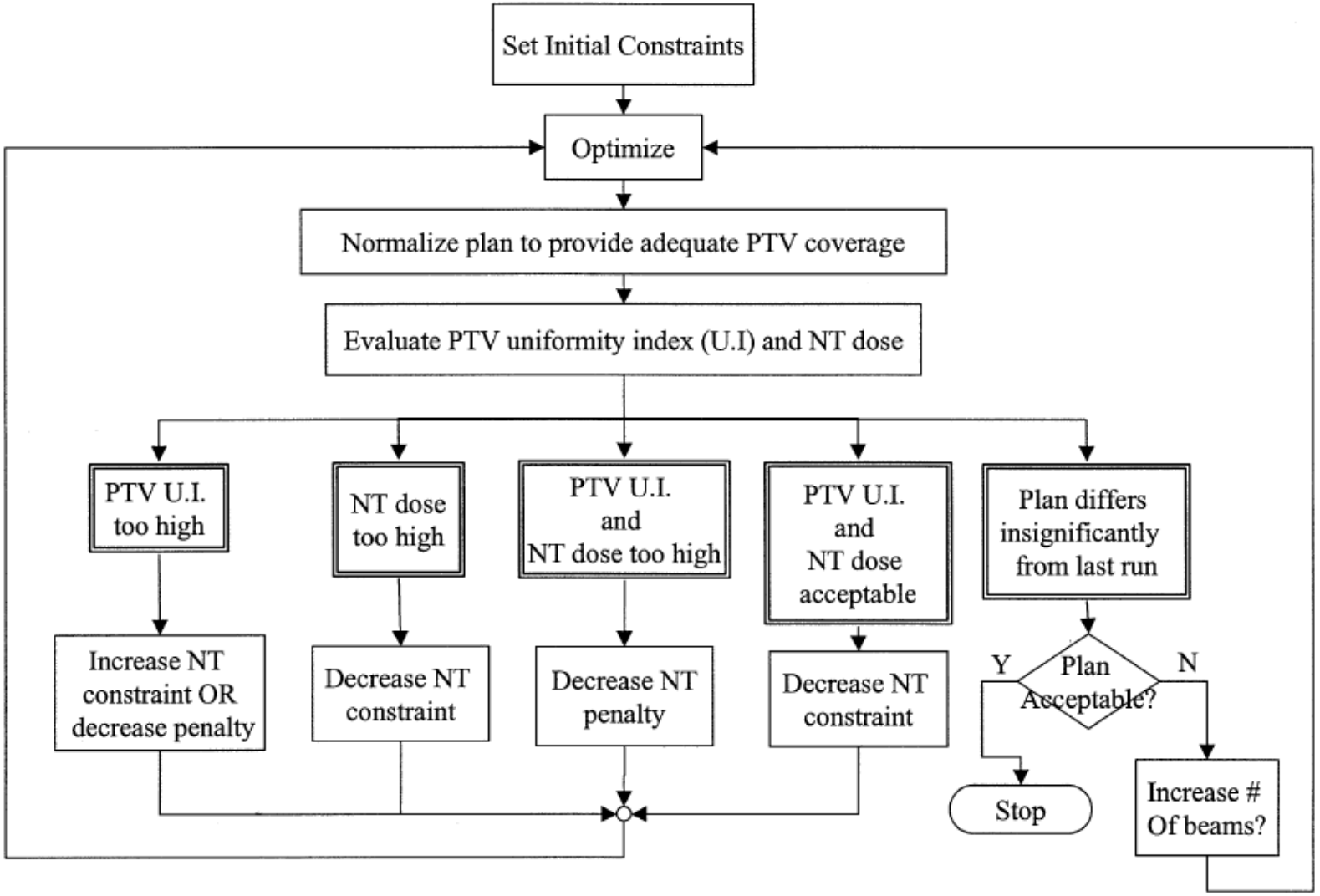


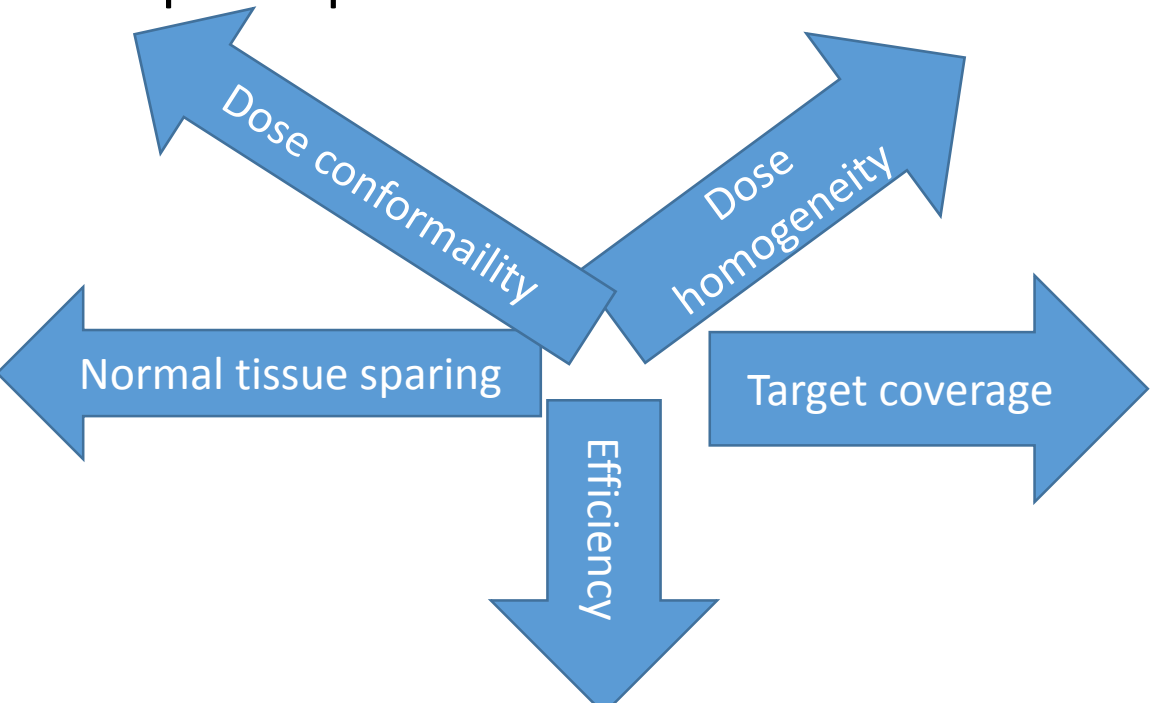



Figure from Hunt et al, IJROBP 54(3), 953-962, 2002

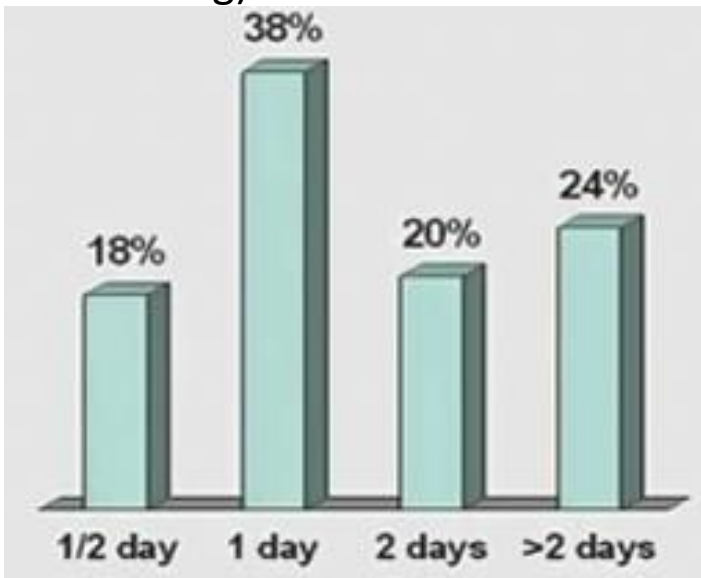
# Multi-criteria optimization (MCO)

# IMRT planning process is complex

- Long planning time
- Not clear which knobs to turn
- Tradeoffs unclear
- Clinician's judgment indirect (the process does not encourage physician participation




Time for IMRT planning for a complex case (excluding contouring)

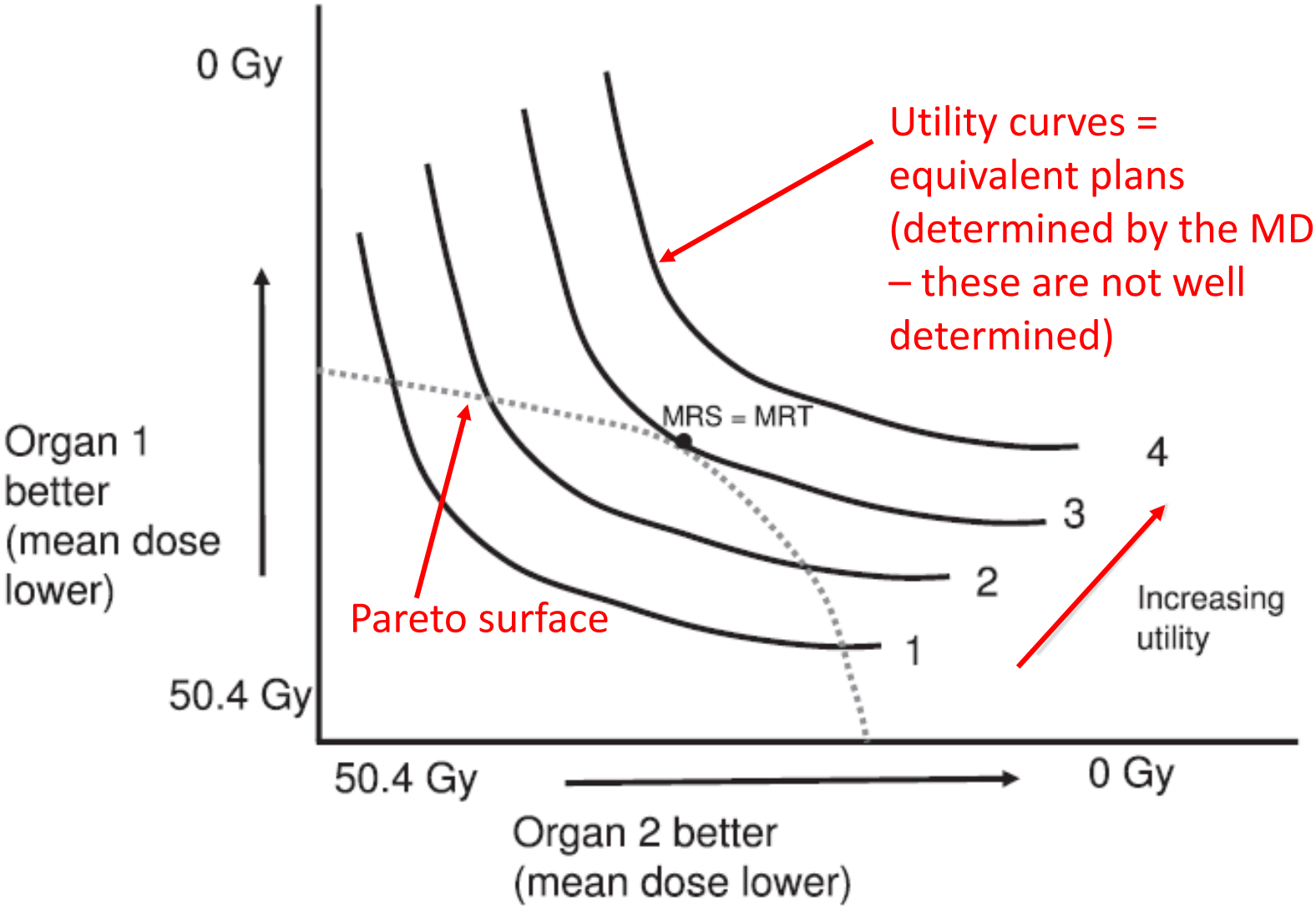



N=167, ASTRO 2004



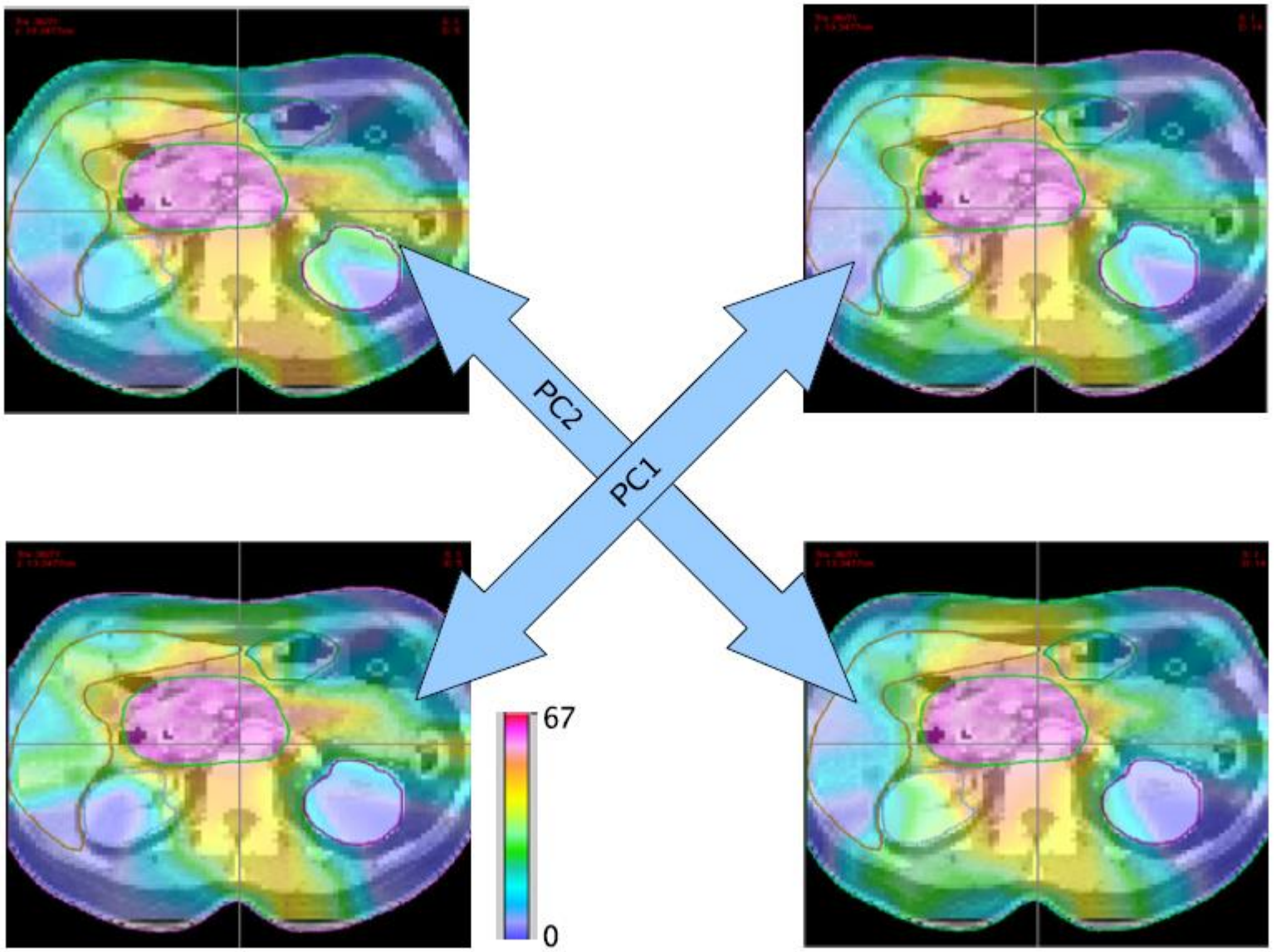
Based on slides by Thomas Bortfeld

# Pareto surface (or the Possibility Frontier)






Craft et al, IJROBP 82, e83-e90, 2012




- PC1: Liver and stomach vs. left and right kidneys
- PC2: Right kidney and stomach vs. left kidney and liver



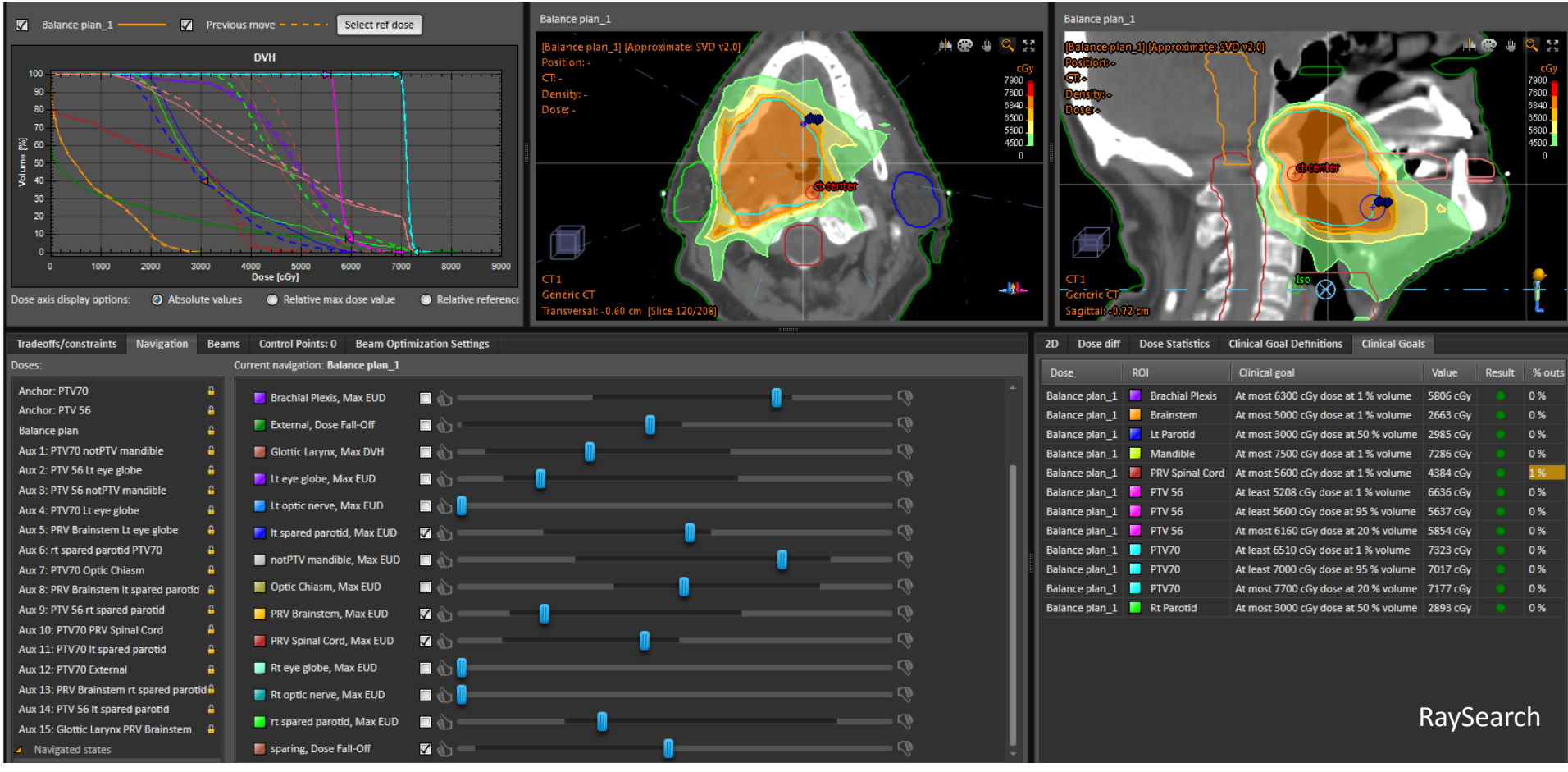
Spalke et al, PMB 54, 3741-3754, 2009

# MCO PLANNING (PARETO OPTIMIZATION) - RAYSEARCH

Pareto-optimality, “efficient”:

“You cannot make anybody better off without making someone else worse off”

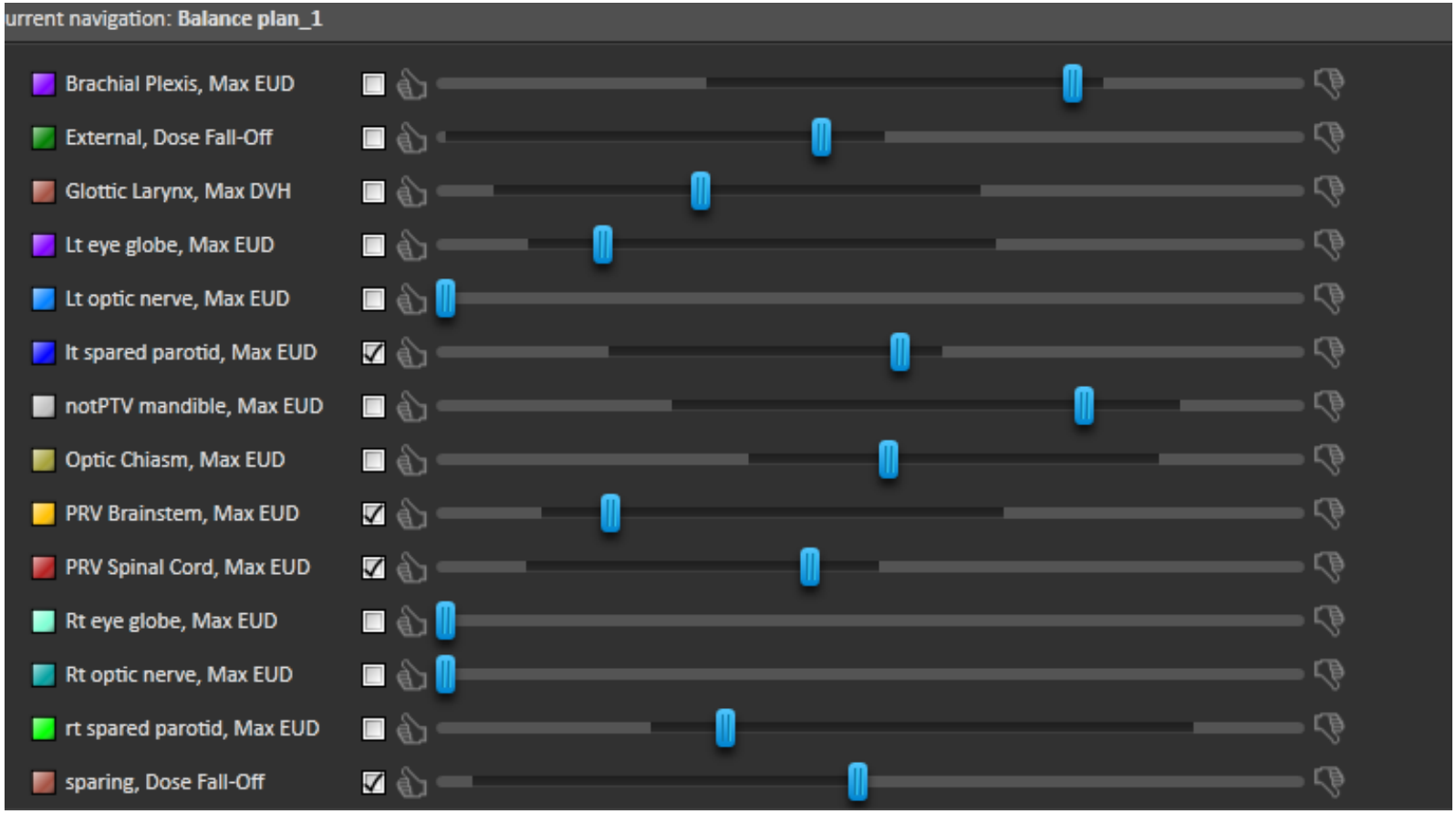
Vilfredo Pareto, born 1848 (Paris) – died 1923 (Geneva)
Industrialist, Sociologist, Economist, Philosopher
Taught in Lausanne, lived in Céligny near Geneva



# MCO PLANNING (PARETO OPTIMIZATION) - RAYSEARCH

Pareto-optimality, “efficient”:

“You cannot make anybody better off
without making someone else worse off”

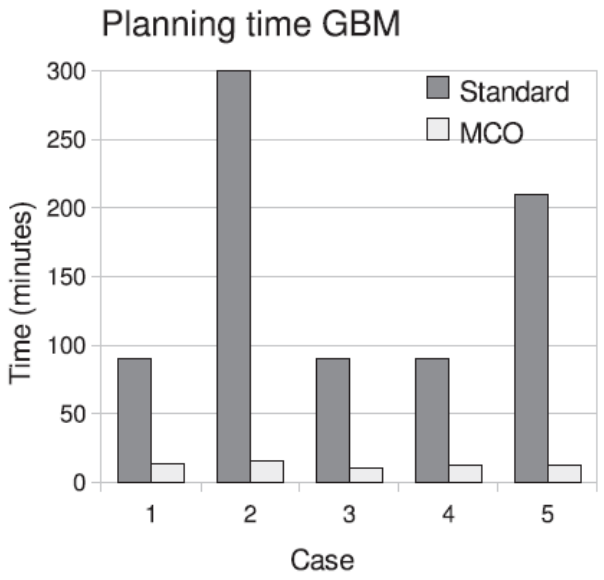


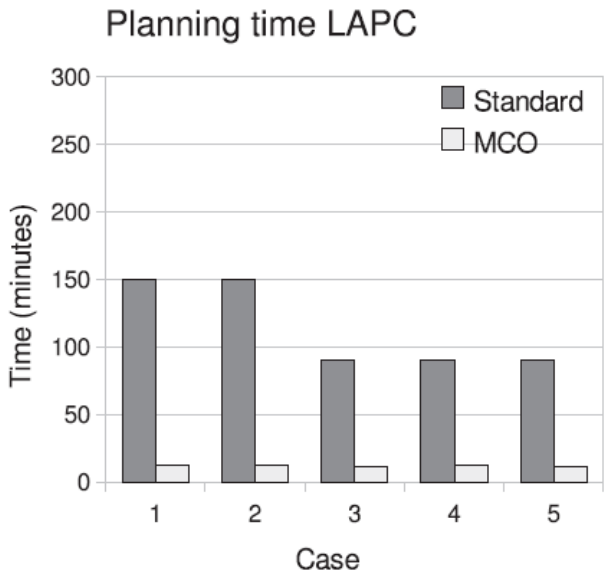

RaySearch

# Increased physician involvement Reduced planning time

| Parameter | Planner time (min) | Physician time (min) |
|---|---|---|
| GBM: Standard | $156 \pm 95.8$ | $5.0 \pm 2.5$ |
| GBM: MCO | $12.4 \pm 1.8$ | $8.2 \pm 2.8$ |
| LAPC: Standard | $114 \pm 32.9$ | $4.5 \pm 2.7$ |
| LAPC: MCO | $11.6 \pm 0.6$ | $9.0 \pm 2.2$ |

GBM = glioblastoma; LAPC = locally advanced pancreatic cancer;






Craft et al, IJROBP 82, e83-e90, 2012

# Technique comparison

# Technique comparison: MU/cGy

Pinnacle, DAO

Eclipse

| | Beam Modulation Factors [MU/Gy] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Conformal Radiotherapy | | | Step-and-Shoot IMRT | | | Dynamic IMRT | | | VMAT | | |
| Cancer Site | No. | Mean | SD | No. | Mean | SD | No. | Mean | SD | No. | Mean | SD |
| Breast | 60 | 139 | 21 | | | | 47 | 249 | 66 | 8 | 238 | 73 |
| Cervical | 35 | 114 | 17 | | | | 69 | 736 | 292 | 20 | 262 | 63 |
| Esophagus | 48 | 113 | 13 | 18 | 303 | 94 | 9 | 707 | 197 | 7 | 197 | 41 |
| Head and neck | 32 | 137 | 55 | 21 | 392 | 152 | 147 | 763 | 277 | 49 | 230 | 76 |
| Lung | 55 | 126 | 35 | 25 | 336 | 78 | 79 | 586 | 188 | 53 | 267 | 61 |
| Prostate | 39 | 113 | 7 | 25 | 362 | 45 | 25 | 713 | 238 | 63 | 289 | 57 |
| Rectum | 33 | 142 | 18 | 26 | 495 | 135 | 10 | 883 | 400 | 4 | 177 | 38 |

- Dynamic IMRT is less MU-efficient than step-and-shoot or VMAT



McCarroll et al, Journal of Global Oncology 2017

# Technique comparison: Treatment time

Eclipse

Pinnacle, DAO

| Activity | Average Time Required (minutes) | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | Conformal Radiotherapy | | | |
| | | | | | Cobalt-60 | | |
| | Linac VMAT | Linac Dynamic IMRT | Linac Step-and-Shoot IMRT | Linac | Y1* | Y5 | Y8 |
| Setup | 3.21 | 3.21 | 3.21 | 3.21 | 3.21 | 3.21 | 3.21 |
| Image guidance | 2.33 | 2.33 | 2.33 | 2.33 | 2.33 | 2.33 | 2.33 |
| Mechanical motion | 0.50 | 1.00 | 2.56 | 1.00 | 1.00 | 1.00 | 1.00 |
| Beam-on | 2.00 | 1.86 | 0.93 | 0.40 | 1.03 | 1.74 | 2.58 |
| Total | 8.04 | 8.41 | 9.03 | 6.95 | 7.57 | 8.28 | 9.12 |

NOTE. All data assume that multileaf collimators were used. Data are averaged across the top nine cancer sites for which radiotherapy is indicated in the eight African countries for which data were available.

Abbreviations: IMRT, intensity-modulated radiotherapy; Linac, linear accelerator; VMAT, volumetric-modulated arc therapy.

*Y indicates year of use of the cobalt-60 unit (ie, Y1 indicates year 1 of use).



McCarroll et al, Journal of Global Oncology 2017

# End on a happy thought:

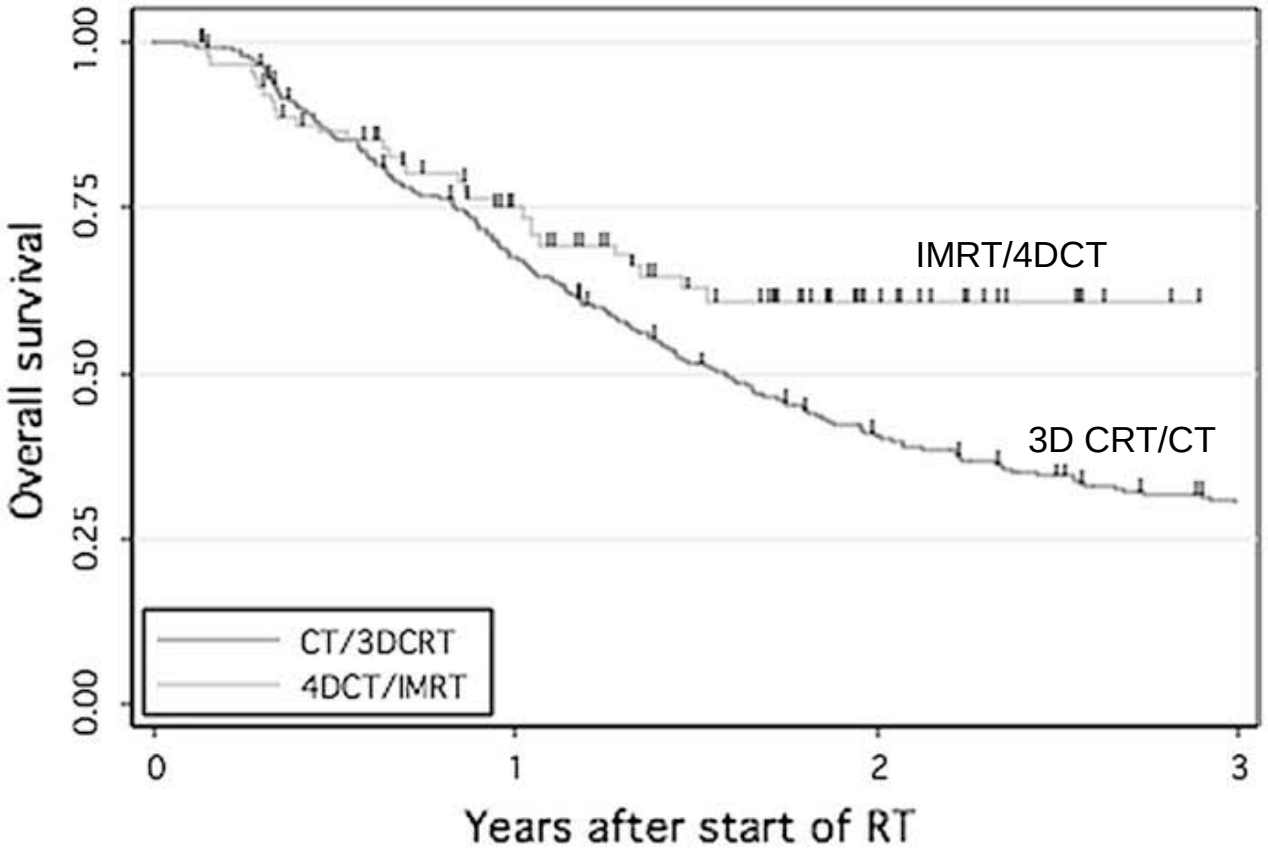
Int J Radiat Oncol Biol Phys. 2009 Jun 8. [Epub ahead of print]

**Influence of Technologic Advances on Outcomes in Patients With Unresectable, Locally Advanced Non-Small-Cell Lung Cancer Receiving Concomitant Chemoradiotherapy.**

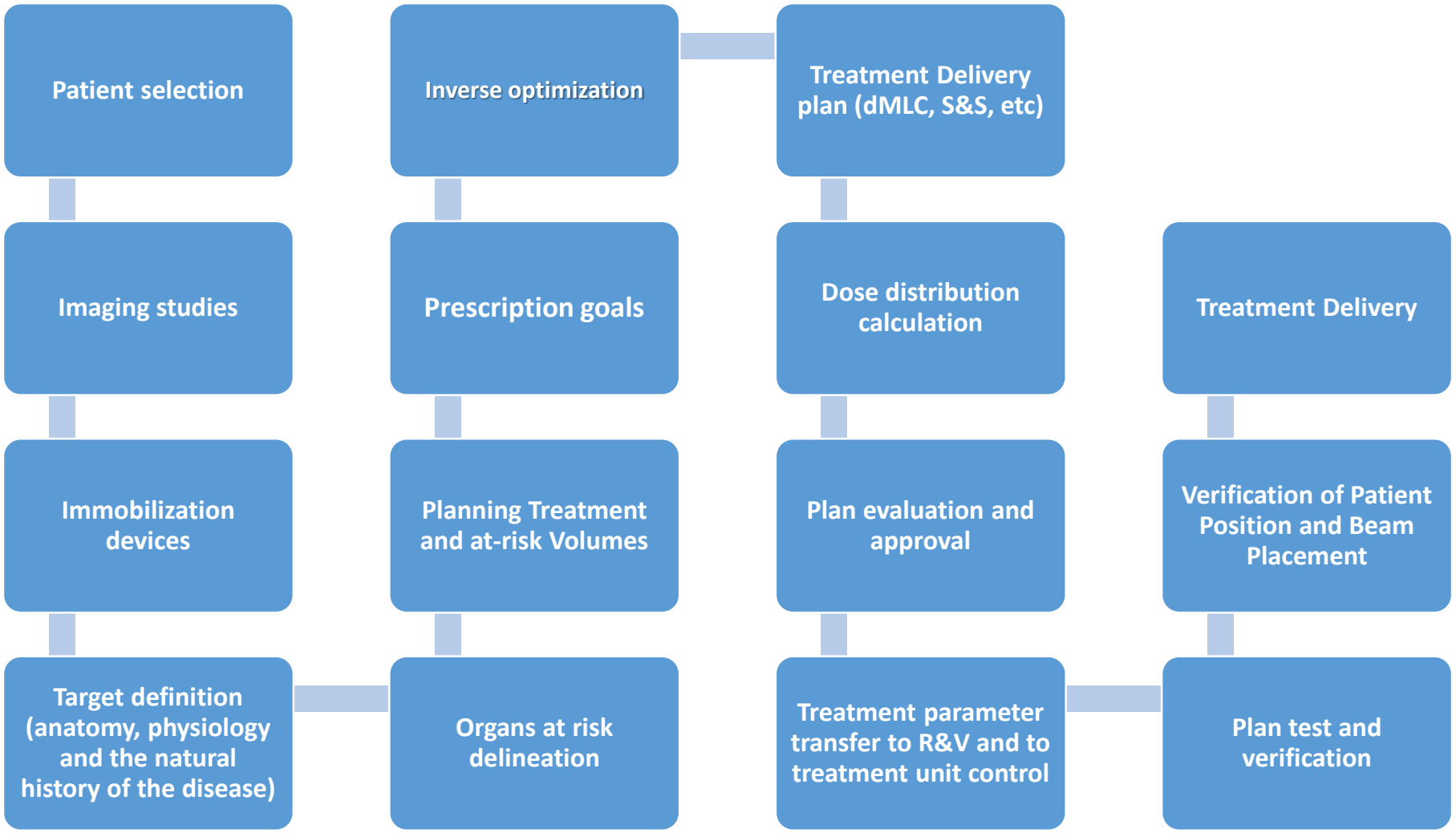
Liao ZX, Komaki RR, Thames HD Jr, Liu HH, Tucker SL, Mohan R, Martel MK, Wei X, Yang K, Kim ES, Blumenschein G, Hong WK, Cox JD.

Department of Radiation Oncology, The University of Texas M. D. Anderson Cancer Center, Houston, TX.

- The combination of
  - IMRT
  - IGRT
  - 4DCT
- Increased
  - Local control
  - Overall Survival
- Decreased
  - Pneumonitis



# The Radiotherapy Process - IMRT






Slide from Yakov Pipman