Astroid Optimization

With intensity modulated treatment plans the variety of possible dose distributions is quite large. Typically if a physician does not like a plan they will request it to be re-run. This requires the planner to input new constraints and objectives and a new plan to be run from the beginning of the optimization process. This is a time consuming process. Astroid eliminates this cycle using a Multi-Criteria Optimization (MCO) approach that allows planners and physicians to visualize the trade-offs of target volume coverage vs reduced dose to the OAR's in real time. MCO treatment planning is based on a set of Pareto optimized plans, where a plan is considered Pareto optimal if it satisfies all the constraints and none of the objectives can be improved without worsening at least one of the other objectives. So instead of creating just one plan, Astroid creates a set of optimal plans that satisfies the treatment plan constraints and puts an interactive exploration of the objectives at the planners and physicians fingertips via a unique, highly intuitive, solution navigation slider bar system.

Constraints play an important role in the optimization process, as they bound the solution space and ensure your navigation process is focused only on plans that meet your non-negotiable, highest priority dosimetric needs. It should be noted that if the *constraints* are too tight, there may be no feasible plans. However, if the *constraints* are too loose, too many solutions will exist and the navigation will be too broad to provide adequate resolution over the truly clinically useful plans. Therefore care should be taken to ensure appropriate constraints are set, which is facilitated using the Astroid *Feasibility* check feature. So while constraints supply hard limits, *objectives* are the negotiable goals, they do not have a hard level that must be obtained, but “pushing” them harder does result in benefit to the patient. The number and type of *objectives* chosen should be such that all the relevant trade-offs can be demonstrated and explored.

Feasibility and Constraints

After the *Constraints* have been entered, the user may start the *Feasibility* calculation by clicking *calculate* in the *Feasibility* block. The *Feasibility* calculation is based solely on the *constraints* and it should be used to ensure that is is possible to met the specified constraints. The *Feasibility* calculation may be an iterative processes in order to get appropriate constraints established for a particular plan. In other words, the user may need to enter one or more constraints, check the feasibility, then progressively tighten the constraints and re-check the feasibility until the plan is no longer feasible, then back-off to the last feasible values. It is recommended practice to start by obtaining a feasible plan utilizing only target *Constraints* then add OAR *Constraints* as desired. Remember, using a narrow range of constraints can improve the optimizer performance and improve the resolution of the solution navigation.

The user also needs to be aware of the impact of *Constraints* being set at the *Fraction Group* level versus the *Plan* level. For example, it is possible to have a *Constraint* set in the *Plan* level so that the whole dose to an OAR is given on one day and none on the other day. This could happen when there are two *Fraction Groups* and the OAR dose is not split between the two by using Fraction Group level constraints.

Running the Optimizer

The *Objectives*, as stated before are the negotiable goals where there may be no hard limit, but there is benefit to improving them. Astroid allows *Objectives* on both Targets and OAR's. *Objectives* can be placed on structures to either increase or decrease dose. The *Objectives* are the sole driving force guiding the MCO and it is important to recall from the discussion above that Astroid will only navigate to plans that are “optimal” in at least one objective (meaning again that this objective cannot be improved without another objective getting worse). Unlike *Constraints*, *Objectives* should be added all at once and there is no need to place them in any particular order (order is irrelevant). Additional information about *Objectives* can be found here. Since the MCO is finding a large set of optimal solutions the optimization can be a lengthy process. The following factors have the largest impact on the optimization run time:

- The number of points in the calculation grid
- The total number of spots from all beams

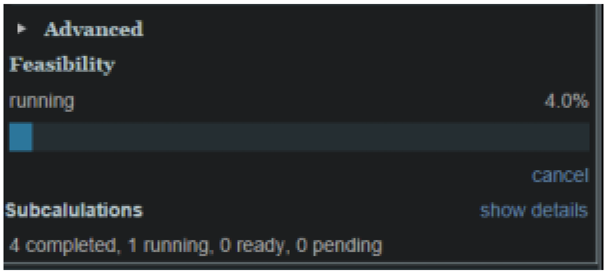
The number of calculation points and number of spots will have a direct impact on the calculation times meaning that increases in these values will also increase the MCO calculation time. The number of objectives does not always increase the overall run time of the calculation however, thanks to the parallelization that be achieved using the Astroid cloud services, though the number of objectives does impact the usable capacity of calculations that can run on the Astroid cloud. The speed and number of running calculations will depend on the availability and load on the Astroid cloud calculation servers. Each objective of the MCO calculation is computed on a separate thread of a calculation server, therefore understanding the usage of these servers can help users make decisions regarding resource usage for a given set of objectives. The Astroid MCO calculations are designed to use servers in CPU increments of 16 and the MCO calculations are posted to calculation servers as follows:

- 1-16 objectives: a single 16 core calculation will be issued, with an objective being run on each core
- 16-32 objectives: a single 32 core calculation will be issued, with an objective being run on each core
- >32 objectives: a single 32 core calculation will be issued, and the server will be responsible for balancing the load to achieve full CPU utilization

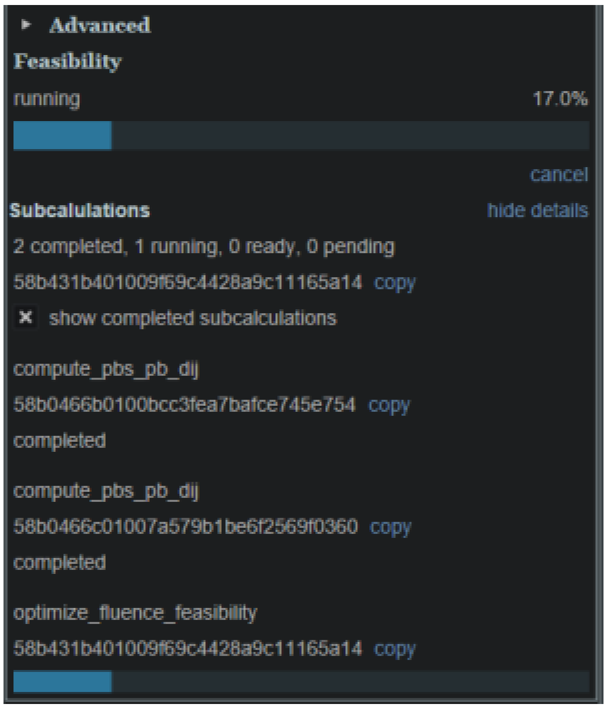
Understanding this pattern is important, as it can be seen that using less than 16 objectives generally will have minimal impact on MCO run-time and no impact on resource usage. Using between 17-32 objectives will use additional resources, but generally not impact run-time, but using >32 objectives will increase the MCO run-time without using additional resources.

Once all the desired *Objectives* are entered the MCO calculation is started just by clicking the *calculate* option in the *Navigation* block. It should be noted that the *Feasibility* will be re-checked if any of the *Constraints* have changed since the feasibility was last run. The MCO calculations will run in the cloud and the user can simply leave the Astroid application running and move on to other things while the calculations process. Please note that at this time the Astroid App should be left open in this state to ensure the calculations run to completion, however, users may open additional instances of Astroid and work on other plans while these calculations proceed (no performance issues should be encountered when using multiple instances since the “heavy” calculations are off-loaded to the cloud calculation servers).

During the calculation process the user may check to see the status of the calculations. The example below shows a Feasibility calculation that is 4% complete. As calculations finish the user will notice this number increasing.



By clicking on *Show Details* a detailed list of what calculations have been finished and which are running will be displayed. In the example below the dij's are completed and the Feasibility is currently running. In the detailed view if the user chooses *show completed subcalculations* they will be able to obtain the identification number of each calculation.

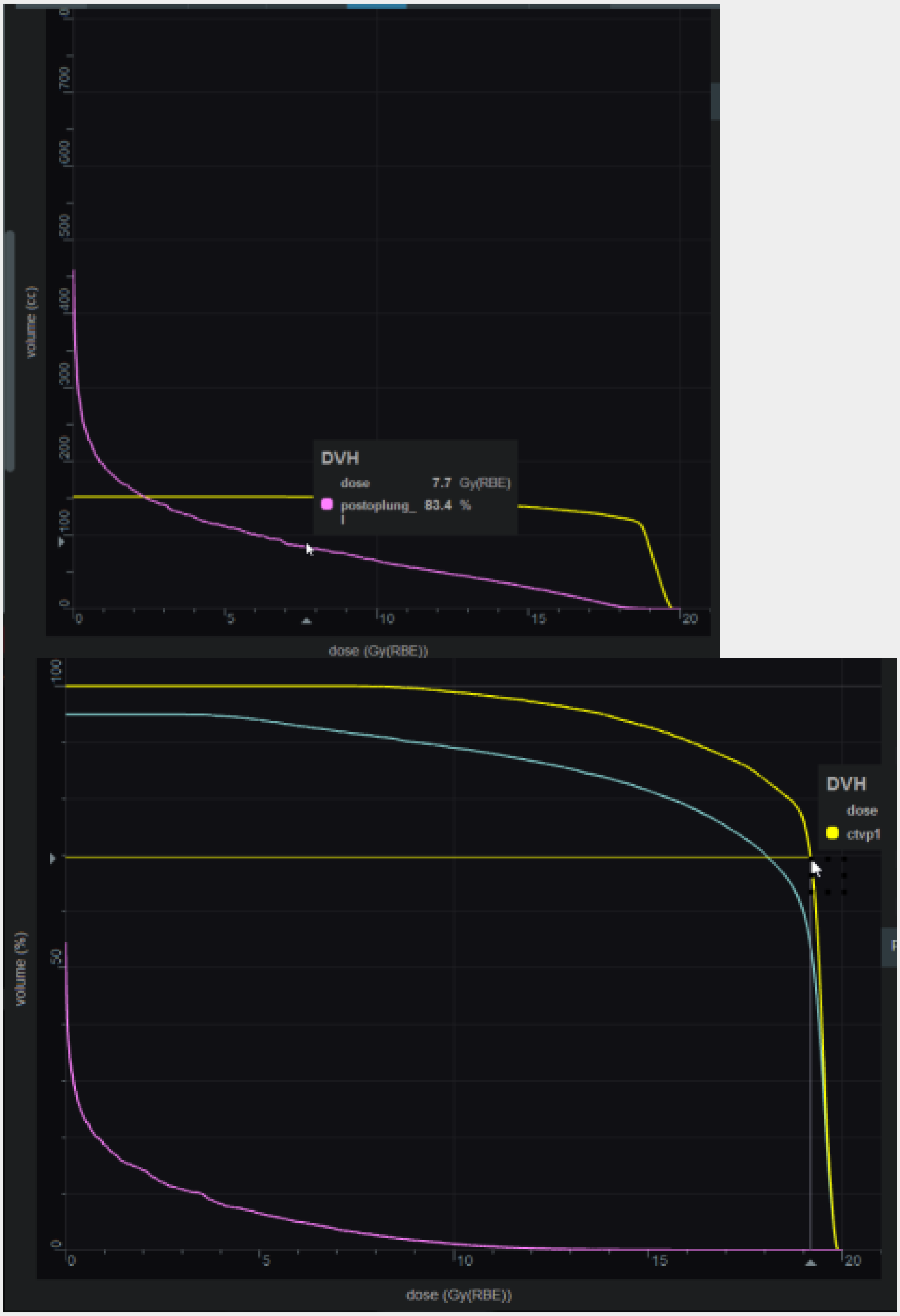


Dose Normalization and Display

The user has many options for how the dose is displayed in Astroid. The options for controlling the display of the dose are on the right hand side of the display under *Dose Options*. The *Dose Options* provide controls over the DVH type (relative or absolute volume), the colors and scaling of the display dose, the type of dose display shown (colorwash, isolines, or isobands), as well as the scope of dose to display (full plan, single fraction group, or individual beam dose).

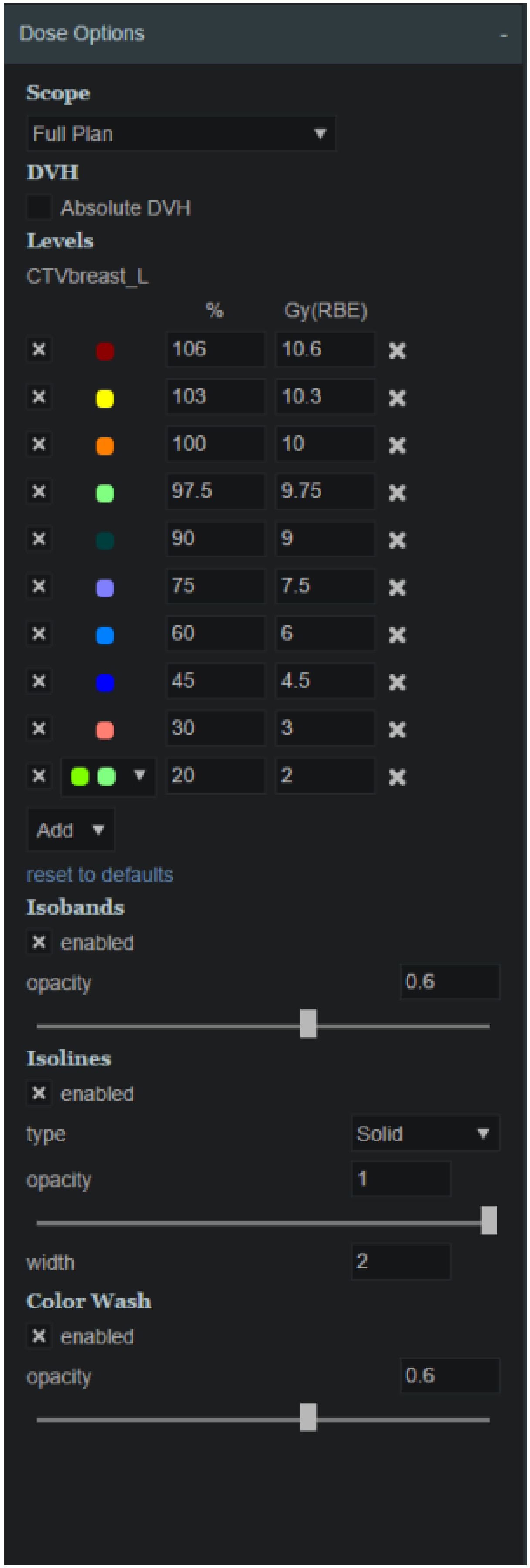
Dose Volume Histogram (DVH)

The planner has the option of viewing the dose for the DVH in relative volume (dose per percentage of the volume) or in absolute volume (dose per cc of the structure) using the *Absolute DVH* option. The user may also hover over any area of the DVH curve to obtain the dose and percentage of a given structure or click on one or more lines to start tracking the cursor value for the lines.



Dose Display Normalization

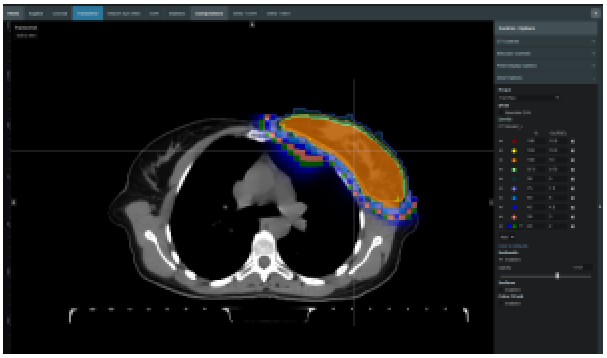
As in the DVH the user has multiple options for displaying the dose. The user may change the percentage isodose line and its corresponding Gy they would like displayed. This is done by entering the appropriate numbers in the boxes under *Levels*. The user may turn on and off specific levels by clicking on the *X* to the left of the line. The user also can choose to view the dose as either isobands, isolines, color wash or combinations of these. The user may use the sliders to set the opacity for each of these as well. They may choose the line width and whether it is solid, dashed or dotted for isolines.



Note: When in a sliced image display containing dose, slice scrolling positions will be based on the smallest voxel size of the calculation grid. For any sliced image displays that do not show dose, scrolling positions will be based on the CT image slice thicknesses directly.

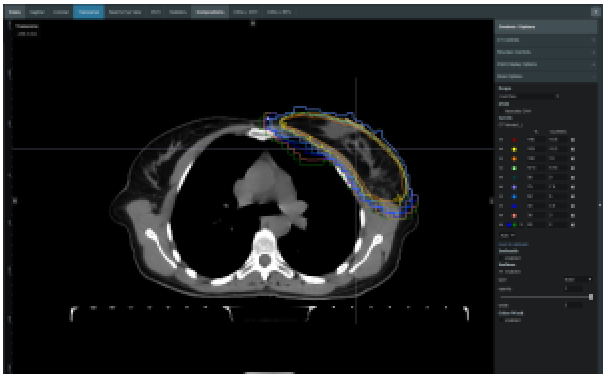
Isobands

Isobands are an interpolation of dose from isodose line to isodose line. Isobands take a range of interpolated dose and fills it in with color.



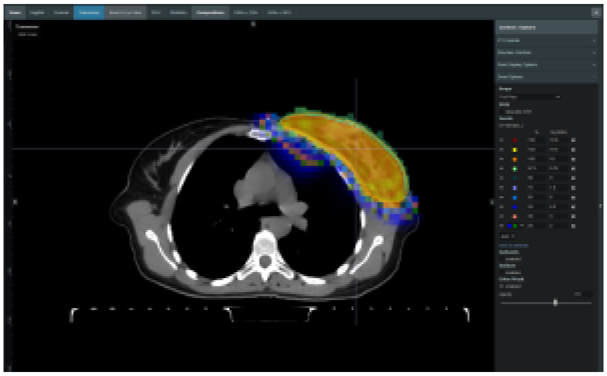
Isoline

Isoline display either the absolute or relative isodose line in the form of a single line. These are lines that pass through the points of equal dose.



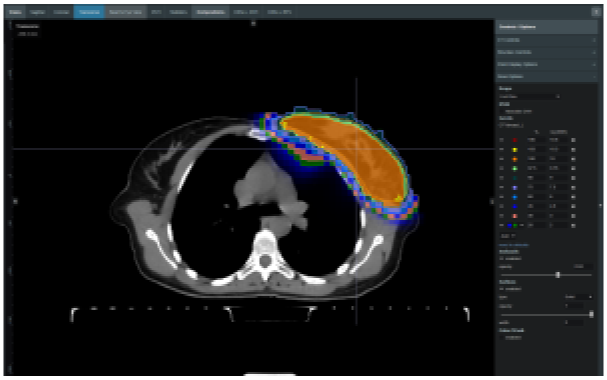
Color Wash

Color Wash demonstrates the raw dose across a range. It shows the raw dose across an area.



Combination

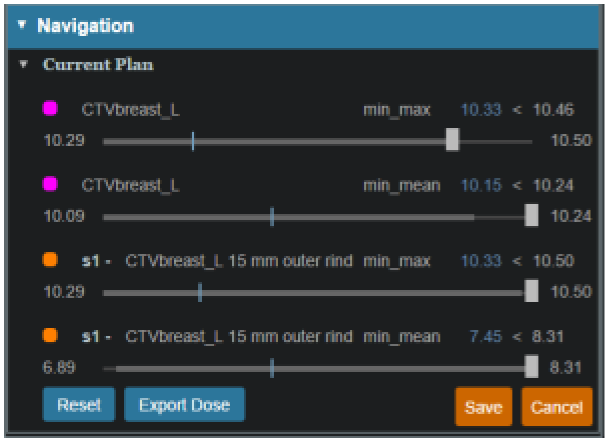
The user does have the ability to combine multiple representations. Below shows a combination of Isobands and Isolines



Navigating the Solutions

Once the plan has been calculated the *Navigation* block will become active. This block contains entries for all the active objectives and under each objective is a slider bar. This slider bar allows the user to adjust the importance of an objective and to see, in real time, how the change will affect the dose to the patient.

The Navigation Sliders should provide an intuitive process for finding the optimal plan, but by gaining a complete understanding of the Navigation Sliders users will be better equipped to quickly reach their plan goals. On each slider there are two vertical bars. The thick white bar is the user controlled slider handle and it represents the worst value of an objective that the user wants to allow (note sliders for minimize objectives will slide to the left and sliders for maximize objectives will slide to the right). Simply stated, the objective will not go past this limit. The thin blue bar denotes the actual current value of the objective. Astroid calculates this value by balancing the solution over the available ranges of each objective. It should now be clear that moving a slider does **not** directly set an objective, but rather it places limits on the allowable range of an objective. It is this feature that makes navigating the solution space very clear and effective.



The blue and white numbers to the upper right of each slider correlate to the objective value for the current plan and the objective limit based on the slider position, respectively. The numbers at the end of each slider bar denote the overall range for the objective value (i.e worst and best possible values). The main slider horizontal bar is also separated into two sections. The thicker, lighter grey horizontal bar is the range or window that the objective is currently limited to stay within (it is limited due to the positioning of the other sliders by the user). The user will notice as they drag the slider handle (white bar) on one objective, this light grey area will change on some of the other sliders. This allows the user to know the limits they have to work in and the impacts (trade-offs) that one objective is having on the others.

Fix Me! Add some details of how to adjust and why (need to discuss with MGH??)

All of these adjustments are able to be done without running a new plan as would needed to be done in traditional treatment planning systems. This allows the user to look at many different solutions in a short amount of time.

If the user does not like the adjustments they have made to the structure objective slider they may hit the *Reset* button in the bottom left corner to reset all the objectives to their last saved state. It the user does like the adjustment that was made they may choose the *Save* button in the bottom right hand corner. This will save the objectives at their current position. The *Cancel* button will close the *Navigation* block in its current state.

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