



Visualization of the Boron Neutron Capture Therapy treatment planning process
by Cory Lee Albright

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Computer Science
Montana State University
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Abstract:

The focus of this thesis is the development of a visualization module (Sera3d) for the Simulated Environment for Radiotherapy Applications (SERA) software package, under development at Montana State University and the Idaho National Engineering and Environmental Laboratories.

In 1997, a highly efficient particle tracking method was developed to speed the Monte Carlo transport calculations, which simulate the neutron/boron interactions in the anatomical geometry. The new particle tracking method required a uniform volume element (univel) description of the geometry. The uniformity allowed for fast tracking through highly efficient indexing schemes and integer-based arithmetic operations. The adoption of the univel descriptions resulted in the restructuring of the software package.

With the restructuring of the older software package into SERA, and the advances in computer graphics hardware, the addition of a visualization module was undertaken to provide a visual understanding of all aspects of the proposed treatment plan.

The three dimensional rendering in Sera3d is built on the OpenGL graphics library, while all of the user interfaces and components were developed using the Motif toolkit in an X11 window environment.

The univel geometry description provides great storage flexibility; virtually any anatomical structure can be represented. Sera3d is constructed with this flexibility mind, allowing the three dimensional reconstruction of any region stored with this univel description.

Sera3d also provides various tools for further examination of the region reconstruction. Multiple rendering windows, each through a different camera, as well as full model rotation capabilities provide views from any angle. Two clipping planes are provided along each of the three major orthogonal axes, offering a direct look into the interior of the geometry. Likewise, varying the values of region transparency allow views into the inner regions. Through the use of texture mapping, an image slice can be inlaid in any arbitrary direction within the reconstruction. This inclusion of the original data allows further confirmation of the surface geometry. Additionally, a camera view along the beam line is provided, as well as image slices perpendicular to the beam line.

One of the unique elements of this system is that the same surface rendering methods used to display the reconstructed anatomical objects are used to display the isodose contours. This provides for a striking presentation of the radiation dose data and also provides a useful tool for the clinician in developing an efficacious treatment plan.

A second method for displaying the dose data is colorwashing the medical image volume with the isodoses.

This thesis includes the visual results of the applied techniques, as well as visions for the further integration of Sera3d into the SERA software package.

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APPROVAL

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

The focus of this thesis is the development of a visualization module (Sera3d) for the Simulated Environment for Radiotherapy Applications (SERA) software package, under development at Montana State University and the Idaho National Engineering and Environmental Laboratories.

In 1997, a highly efficient particle tracking method was developed to speed the Monte Carlo transport calculations, which simulate the neutron/boron interactions in the anatomical geometry. The new particle tracking method required a uniform volume element (univel) description of the geometry. The uniformity allowed for fast tracking through highly efficient indexing schemes and integer-based arithmetic operations. The adoption of the univel descriptions resulted in the restructuring of the software package.

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One of the unique elements of this system is that the same surface rendering methods used to display the reconstructed anatomical objects are used to display the isodose contours. This provides for a striking presentation of the radiation dose data and also provides a useful tool for the clinician in developing an efficacious treatment plan. A second method for displaying the dose data is colorwashing the medical image volume with the isodoses.

This thesis includes the visual results of the applied techniques, as well as visions for the further integration of Sera3d into the SERA software package.

BACKGROUND INFORMATION

Boron Neutron Capture Therapy

Boron Neutron Capture Therapy (BNCT) is a treatment modality engineered for selectively irradiating certain tumor types. The patient is injected with a drug containing a stable isotope of boron, B-10, which is capable of accumulating in the tumor tissue. When irradiated with low energy (thermal) neutrons, a B-10 atom will react with a neutron (neutron capture). This capture results in the splitting of the B-10 nucleus which releases an alpha particle and a lithium nucleus directed opposite each other with significant energy. This reaction is very damaging to cells within approximately 14 micrometers, roughly the diameter of one or two cells. Thus tissue damage is very localized to areas with B-10 loaded cells.

Glioblastoma multiforme (GBM) accounts for about 80% of all malignant gliomas, and continues to be the most intractable brain tumor. It is diagnosed in approximately 7000 people in the United States each year. GBM is characterized by the highly infiltrative growth of dendrils. Surgical removal of the tumor without considerable loss of healthy tissue is not achievable due to the dendrils, and an incomplete removal often results in regrowth of the tumor. Conventional therapies are not sufficiently tumor specific and thus produce extensive damage to the normal brain tissue when given in doses high enough to adequately address the infiltrating GBM cells.

The selective delivery of radiation dose from BNCT lends itself well to the problematic dendrils of GBM. Because of the abnormally high growth rate of the cancerous cells, they take in more of the Boron compound than normal brain cells. With a higher count of B-10 in the tumor cells, a more selective radiation dose is achieved.

This selective radiation dose allows the adequate treatment of the infiltrated dendrils with minimal damage to normal tissue.

BNCT at MSU/INEEL

Since 1991, Montana State University (MSU) and the Idaho National Engineering and Environmental Laboratory (INEEL) have been developing treatment planning software for BNCT.

The early version of this software package was called Boron Neutron Capture Therapy Radiation Treatment Planning Environment (BNCT_RTPE). Segmented regions of interest derived from the medical images were fit into Non Uniform Rational B-Splines (NURBS) surfaces. In 1997, a new fast particle tracking method through uniform volume elements (univels) provided a significant speed increase in the tracking calculations, and thus the univel based region representations were adopted.

Development commenced on a new and improved treatment planning system called Simulation Environment for Radiotherapy Applications (SERA), which was based upon the univel representation.

The new package now consists of separate software modules: SeraImage, SeraModel, Sera3d, SeraDose, SeraCalc, SeraPlot and SeraPlan. The modules provide the necessary functions to conduct a complete BNCT treatment plan.

Treatment Planning Process with SERA

The first step in the planning process is to obtain the diagnostic images either with Magnetic Resonance Imaging (MRI) or Computed Tomography (CT). Next, the first

module of the software, SeraImage reads the medical slices, for certain formats, and converts them into an internal format used by the other modules.

The second and most time consuming step of the process is segmenting the images into regions of interest such as scalp, skull, brain, target, and tumor. SeraModel provides manual and semi-automatic tools for segmenting. The segmented images are then stacked into a univel (uv/uvh) file representing the treatment volume.

At this point, Sera3d, the visualization module can reconstruct the segmented regions as well as the medical slices into a 3-dimensional rendering. The Sera3d module will be the focus of this thesis.

The next step in the process is to run the treatment plan simulation with SeraCalc. SeraCalc is a Monte Carlo simulation, which tracks millions of particle paths through the regions and calculates the radiation doses associated with the treatment.

At this point, the radiation doses to the regions are available and can be superimposed over the original 2-dimensional medical images with SeraDose. For a 3-dimension view of the doses, Sera3d provides the region surfaces colorwashed with the dose contours, as well as dose contour surfaces.

SeraPlot and SeraPlan provide dose depth plots and dose volume histograms to assist in the treatment verification.

OpenGL

Sera3d uses the OpenGL graphics library for the 3-dimensional rendering. OpenGL was introduced in 1992, and has become the industry's most widely used and supported 2D and 3D graphics application programming interface (API) [10]. It is a vendor-neutral graphics standard, guided by the OpenGL Architecture Review Board, an

independent consortium. OpenGL has proven itself in stability and portability, producing consistent visual results on a wide variety of platforms.

INTRODUCTION

Problem Statement

The SERA software package has a large amount of data to process in developing a treatment plan. The univel regions are stored in one large 3-dimensional array, at the same resolution as the original medical images. A two millimeter image set of a human head produces around 128 slices, each being 256 x 256 pixels, resulting in around 8,388,608 univels. When the medical images are included there are over 16 million data points.

There are also many different elements of the treatment plan included in the visualization. Reconstruction of the segmented regions, superimposed with the original medical images provides the model for the treatment plan. The patient's model must then be orientated in the path of the beam. The orientation determines the success of the simulation. Finally, the results of the simulation in the form of radiation isodose contours provide the verification of the proposed treatment plan. All of these aspects of the treatment need to be included in the visualization process with Sera3d.

The following sections discuss the techniques used to visually reconstruct the large amount of data, as well as the various tools provided for investigation.

REGION RENDERING

The rendering of the labeled (segmented) regions stored in the block of data went through two phases, each a different approach at extracting the region boundaries for display.

Phase I

The first technique used for determining the region boundaries was through the use of a region tracing algorithm. The region tracing algorithm was applied to each 2-dimensional slice that contained the current region, returning the points on the outer boundary for that region. The advantage of using a region tracing program was that the boundary points were returned in an orderly fashion and consistent between slices, which was needed for a smooth NURBS surface representation which will be discussed shortly. The region tracing algorithm had some difficult obstacles to overcome.

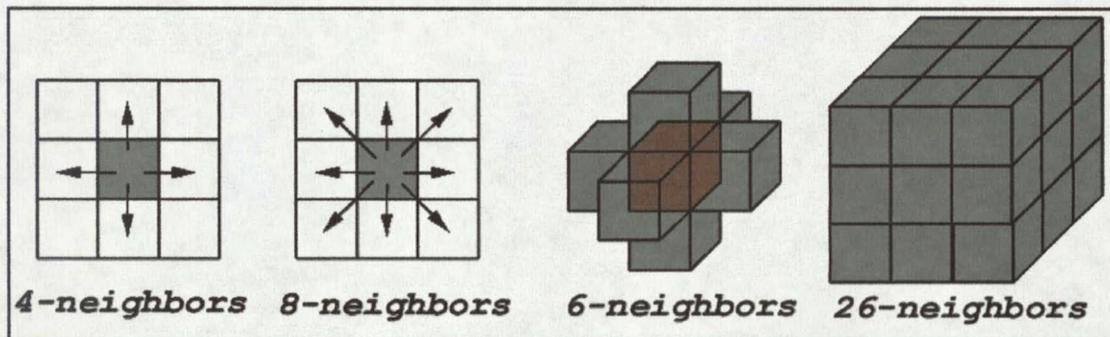


Figure 1: 2D pixel neighbors, 3D univel neighbors

To begin tracing a region trace on a given slice, a starting pixel for the region must first be determined. This was accomplished by a quick scanline pass to the first occurrence of the region in the slice. From this starting pixel, the algorithm would look at its 8-neighbors (Figure 1) to find the first neighbor that was a 4-neighbor (Figure 1) border pixel. A 4-neighbor border point is a pixel that has a 4-neighbor containing a

different value; thus it is bordering another region. The algorithm would then save this pixel, mark it as “visited”, and continue walking around the region's border until the starting pixel was reached. This approach quickly encountered several obstacles. Due to the great freedom in segmenting regions with the SeraModel module, it is not uncommon to have sharp corners, discontinuous pixels, or even disjoint pieces of the region on a given slice. An example is seen in Figure 2, with a sharp corner or dead end, and a discontinuous pixel.

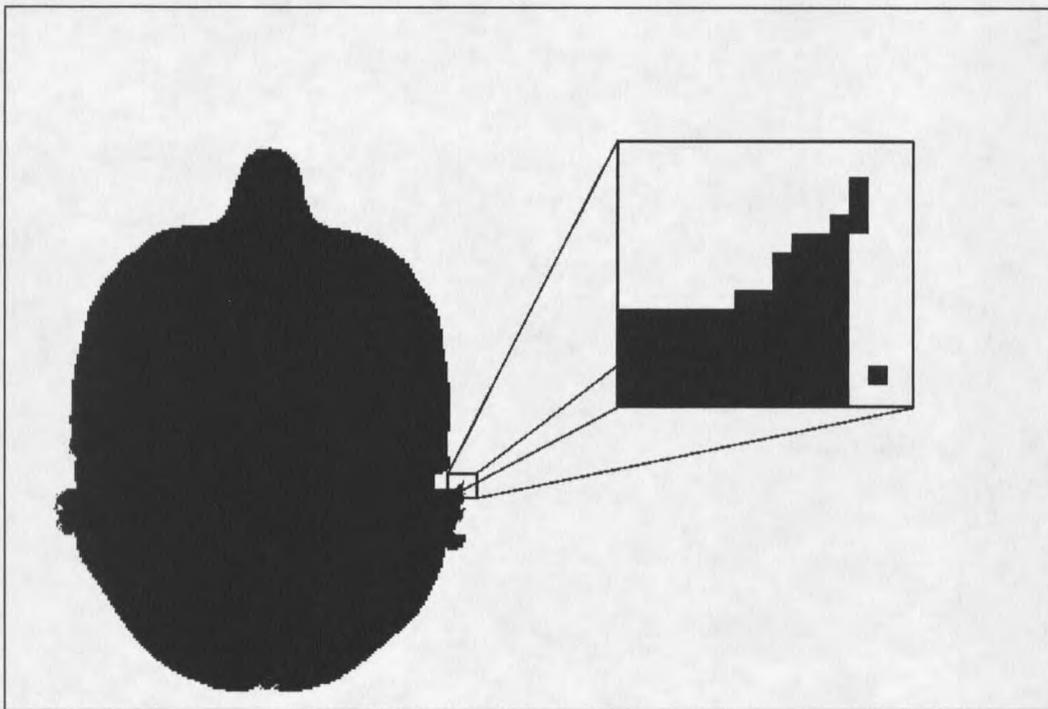


Figure 2: Region Tracing Problem Case

When the tracing algorithm encountered a sharp corner such as a line of pixels, it would walk right out to the end and be unable to turn around due to its marking of visited pixels. Thus the algorithm would stop and return an incomplete border trace. To overcome this problem, a stack was introduced to the tracing algorithm. Now when the algorithm reached a point at which it had more than one border pixel to advance to, it

