Using Extruded Volumes to Visualize Time-series Datasets

Nick Schultz
Oregon State University
nick.schultz@live.com

Mike Bailey
Oregon State University
mjb@cs.oregonstate.edu

Introduction

Viewing time-series datasets gives users a unique perspective and allows them to identify patterns and trends over time. This chapter shows a visualization technique that involves a process of time-extrusion to view an "animation" over time in a single image.

This project's goals were to visualize simulation data created by the Envision software [Bolte2007]. Envision is a software tool to project the impacts of land-use decisions into the future. To show how the simulation progressed, snapshots were presented of the landscape side by side which allowed the viewer to compare the images. The following figure is a visualization showing a 50 year simulation in 10 year increments using this side-by-side technique.

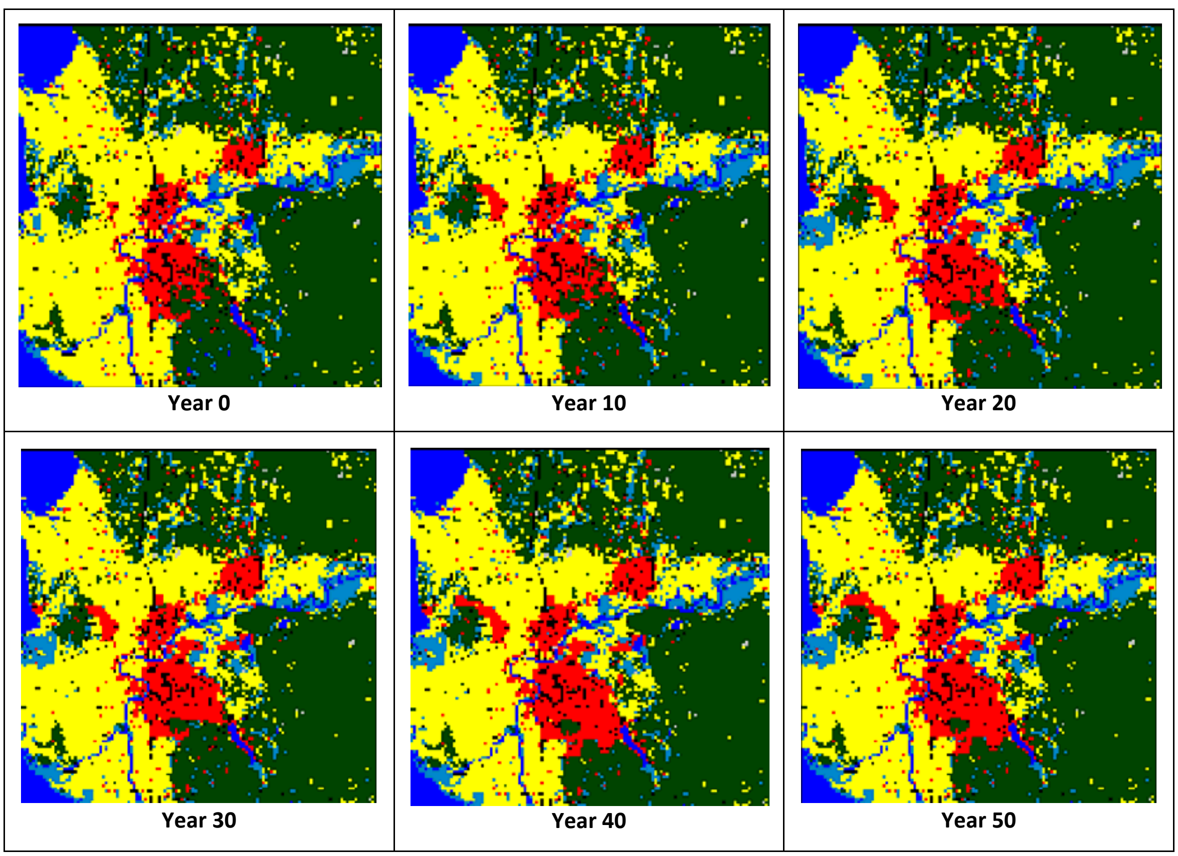


Figure 1. Sequential 10-year snapshots. Source: Envision Skagit 2060 Project.

Viewing the changes between these snapshots proved to be a difficult task. While individual times can be observed, recognizing trends between the time-slices is problematic. We found that we could use a crossed-eye fusion technique to detect changes between two images. However, the extent of the technique was limited as only two images can be crossed at a time.

We also developed a visualization tool to display animations that blended between various years. This worked well when comparing a short series, say 2 to 5 years, as the viewer could see regions of the dataset fading from one color to another. However, as the duration of the visualization increased, it became more challenging to compare the current frame with the entire animation. Thus, discerning patterns over time becomes a difficult task.

Project Description

Envision

Envision is a software framework for constructing alternative future scenario simulations, and is the main source of data used for the visualizations. Envision allows users to simulate the interactions between Actors (decision-makers, such as county officials, city planners), Policies (descriptions of the constraints on the Actors, such as laws and/or usage goals), and the Landscape (environment metrics). Users are typically concerned with the resulting Landscape and shape Policies to try to conform to an ideal environment, such as increased wetlands.

The data is typically composed of polygons with associated attributes describing the Landscape. To visualize this data, the user can rasterize the polygons with the interested environment metrics (Land Use/Land Cover, Population Density) perform a color transfer function to produce a 2D image. These images can then be compiled into an animation to show the changes of the Landscape as the simulation progresses.

Simulation data from the Envision Skagit 2060 Project was used as a testing dataset [Skagit2011]. The project's purpose is to develop and implement a 50-year plan to protect and enhance the Skagit and Samish watersheds' (located in northern Washington) environments. Envision will be used to simulate four different alternative future scenarios. The outcome of these simulations will help shape recommendations to the county government's comprehensive plans and policies addressing land use planning, economic development, environment protection and natural resource conservation.

Tools Used

Data preparation was scripted in Perl, utilizing shape file rasterization utilities from the Geospatial Data Abstraction Library [Gdal2011]. The volume visualization software's user interface is based on GLUI 2.01 and has a custom range slider control developed by Mike Bailey and John Rapp. The range slider allows the user to define the width of a selection range and use the slider to drag it. The Open Source project, FreeImage Library, is used to support importing multiple image types [FreeImage2011]. For the sake of simplicity, the OpenGL Mathematics [Riccio2011] library provided mathematical classes and functions similar to those provided by OpenGL Shading Language (GLSL).

Methodology

The derivation of the term "time-extruded volumes" comes from the fact that the features created within these volumes look similar to extruded objects. Stacking each sequential slice of time from a time-series dataset on top of each other creates a volume. Data that does not change over time creates time-extruded columns within the volume. If the data changes, it results in either a growing, shrinking, or disappearing column. Viewing these columns in a 3D environment provides an intuitive visualization of the trends in a dataset.

This visualization of time-series data involved three major steps: 1. data extraction and preparation into a 3D data volume, 2. rendering the volume, and 3. Implementation of user interface tools for data manipulation.

Data Extraction and Preparation

To gather simulation data, the scenario was first run in Envision. Envision offers the ability to export a snapshot of the Landscape in yearly increments. The exported polygonal data are in ESRI shape files (.shp).

To ease development, the decision was made to rasterize the shape files as a pre-process to the visualization. Adding a pre-process simplified the importation process of the program. A Perl script was developed that utilized the GDAL utility "gdal_rasterize" to create TIFF images rasterized with the raw attribute values. To take advantage of the multiple cores in modern machines, calls were made to the utility in parallel. After rasterizing the shape files, images were then cropped to 256x256 or 512x512.

To import the image layers, the FreeImage library was used to load the images into a 3D array. Each layer in the X-Y plane of the array represented a yearly time slice of the data. The entire dataset was then loaded into the graphics card as a 3D texture. Since the images had been rasterized into raw data values, the 3D texture was filled with floating point data instead of color values. This gave greater flexibility as color transfer functions could be applied on the fly within the fragment shader.

Envision creates essentially two types of data: categorical (discrete) and continuous data. Categorical data can be thought of as storing labels instead of continuous scalar values. Interpolating labels does not have a meaning. Therefore, categorical data must be interpolated using nearest interpolation, selecting the label closest to the sampling point.

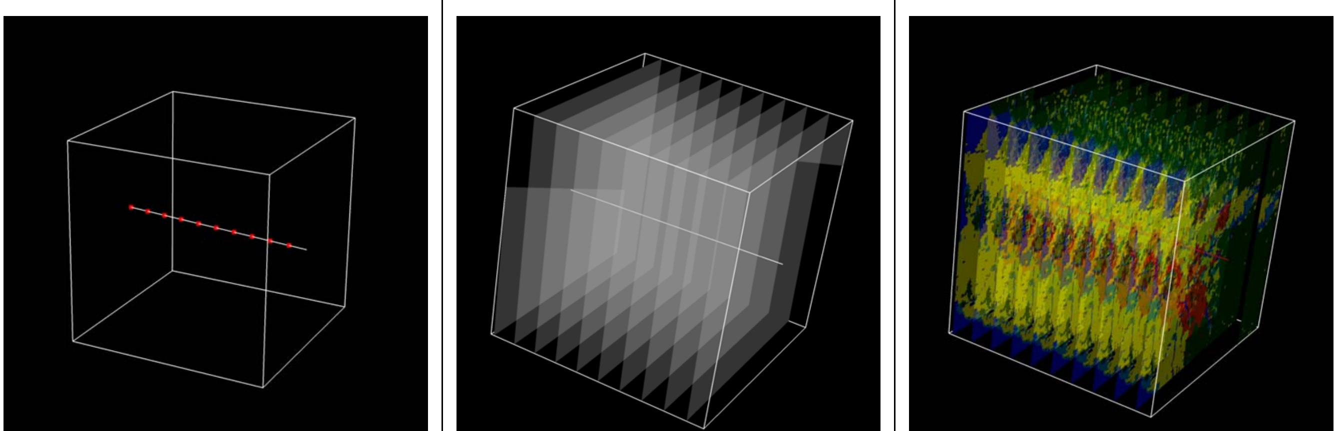
Rendering Techniques

The volume rendering was implemented using texture mapping on parallel planes. Quad slicing, the drawing of 2D quads with texture coordinates that are within the volume texture, provided a way to sample the volume. The appearance of a volume was reproduced by stacking these slices together. Alpha blending was used to provide a translucent effect and gave the ability to peer into the volume. Due to depth testing, the slices needed to be drawn in a back-to-front fashion to avoid being z-culled and to make blending work.

A single 3D texture was used to hold the data. This let us use any number of slices and gave us the ability to trilinearly interpolate sample points between voxels. Drawing the slices such that they were perpendicular to the viewing direction eliminated artifacts that would have been created with axis-aligned slices.

The quads were generated on the fly with a geometry shader that accepted GL_POINTS as inputs and then output sets of two GL_TRIANGLE_STRIPs to create quads. The geometry shader created a view-aligned quad centered at the incoming point. Performing the quad calculation in the shader program moved the calculation onto the more powerful graphics hardware. This also reduced the number of vertex coordinates needed to transfer to the graphics hardware.

Figure 2a shows the effect of the geometry shader. First, a set of points on the view vector are submitted to the graphics pipeline in a back to front order. Figure 2b then shows the result of the geometry shader with texture mapping turned off. Finally, Figure 2c shows the final result with texture mapping turned on.



a. Input is an array of GL_POINTS | **b. Output one quad slice per point** | **c. Shaded result**

Figure 2. An example visualizing the programmable graphic shader. In this example, 11 points were submitted to the graphics pipeline.

When the cube dimensions were made the same as the texture dimension (1.0x1.0x1.0), both the vertex and texture coordinates occupied the same space. This simplified calculations and eliminated the need to send any texture coordinates to the graphics card. Instead they were computed in the geometry shader. User-defined clip planes were used to slice into the volume to view surfaces within the volume.

Visualization User Interface

Having the ability to manipulate and filter the volumetric data empowers users with the ability to visualize and explore their data effectively. Initially, several types of visualization tools were implemented to assist users with are trying to accomplish.

Slicing Tool

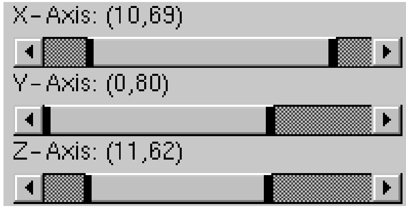


Figure 3. Slicing Tool interface.

Figure 3 shows a simple set of range slider tools used to control the clipping planes. The clipping plane controls are double-ended and allowed the ability to control the slicing on either side of the volume's axis. With these sliders, the user can narrow the scope of the visualization. As the user adjusts the sliders, the labels are updated with the selected viewing ranges.

Slicing within the Z-Axis range slider reveals a new time slice and can be used to determine at what time events occur in the time-series. Slicing with either the X or Y axis range sliders traverses spatially through the dataset in the respective directions.

Alpha Control Tools

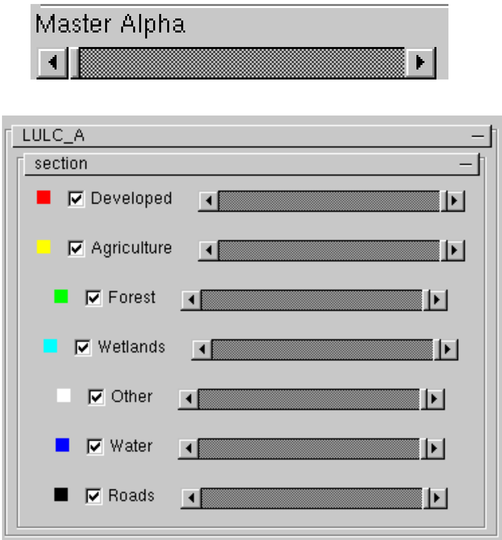


Figure 4. Master Alpha slider [top] and Category Alpha slider [bottom] interfaces.

The alpha controls are a set of sliders that control the transparency values of the voxels. Figure 4 shows an example of the Master Alpha and Category Alpha sliders. The Master Alpha slider allows the user to change the overall opacity of the entire volume, allowing the viewer to look through the volume with varying degrees of transparency.

The Category sliders are then used to control the alpha values of individual categories of data. This allows users to individually adjust the opacity of categories such that only their data of interest strongly appears in the volume. The independent slider feature was only implemented for Categorical data.

Additionally, the checkboxes allow the quick enabling or disabling of features within the volume. Colored boxes were also implemented in GLUI to give a data legend for the user.

Highlighter Tool

The Highlighter Tool allows the user to quickly highlight a specific data category as an opaque white. A picture of the user interface is shown in Figure 5. Used in conjunction with the Master Alpha slider, the user can shade the volume as transparent and then use the highlighter to quickly visualize various categories in the volume.

The advantage to using an opaque white is that it gives the user an obvious indication of the highlighted voxels and reduces the error of misinterpreting blended colors. The user also has the option of either viewing the rest of the volume in the original color transfer function, or in the monochrome equivalent. The latter produces visualizations similar to an X-Ray image.

Figure 5. Highlighter Tool interface.

Transitioning Tool

The Transitioning Tool allows the user to see when, where, and to what value the data is changing. Figure 6 shows an example of the tool's interface. The interface is formulated in a way that allowed the user to specify a question for the visualization to answer. The user first selects which direction they want the voxels to be highlighted. Transitioning "to" shows the voxels whose next time-step transitions into the selected category. Transitioning "from" shows the voxels whose previous time-step was classified as the selected category. For example, Figure 6 asks to "Show the voxels that transition to the Agriculture category at the next time-slice." The following figure illustrates the concept of the Transitioning tool.

Figure 6. Transitioning Tool interface.

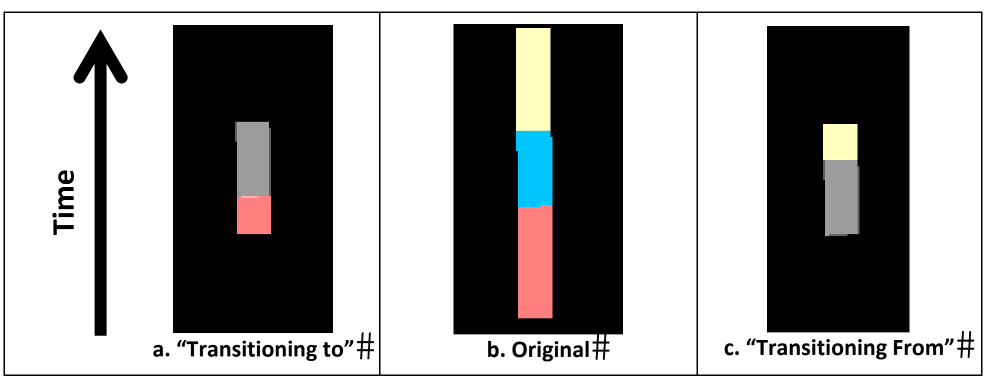


Figure 7. Example describing the applications of Transitioning Tool.

Figure 7b shows the original voxel data with three data values. The Figure 7a shows the "voxel transitioning to the blue value." As shown, the blue value is now highlighted as a translucent white and the last voxel that transitioned -to-the "blue value" is colored fully opaque. Alternatively, the Figure 8c displays "voxel transitioning from the blue value." The "blue value" is still a translucent white; however the first voxel that has transitioned -from- the selected value is colored fully opaque.

Applying this visualization technique across the entire volume essentially gives the effect of a 3D scatter plot. Viewing the highlighted voxels gives insight into the dataset, in particular to what the voxels are changing into.

Orienteer Tool

To orient the user as to where they are viewing the volume, an "XYZ" axis is drawn as an overlay to show from which angle the user is viewing the data. Figure 8 shows an example of the Orienteer. The blue axis represents time, whereas the green and red axes represent the 2D spatial coordinate system (usually latitude and longitude, respectively). The arrows of the orienteer point in the positive direction. For example, time increases in the direction of the blue arrow.

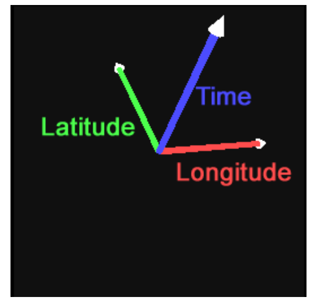


Figure 8. The Orienteer

Test Setup

To show the usability of this project, two actual datasets from recent simulation studies were used. The first dataset was generated from Envision and focused on Skagit County in the state of Washington. The "Plan Trend" scenario was used, which simulates the current trends and activities within the region. The simulation begins in 2007 and continues through the year 2060. For the purpose of this study, visualization of the LULC_A attribute will be used. LULC stands for "Land use/Land Cover" and is used to classify sections of land into types. Major land types used in this study included Developed, Agriculture, and Forest, and Wetlands.

The second dataset was generated from a MC1 simulation and focused on the Apache-Sitgreaves National Forest in Arizona. The vegetation maps were generated by Dr. David Conklin for a project funded by the Western Wildland Environmental Threat Assessment Center, USDA Forest Service Joint Venture Agreements PNW 09-JV-11261900-003. The data values represent the potential vegetation type produced by MC1 for cells on a 30 arc-second grid. This particular output came from a run for the years 2009-2100, using future climate data from the MIROC general circulation model under the A2 emissions scenario, as produced for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

The difference between these two datasets allowed testing of the visualizer with two different levels of complexity. The Envision Skagit 2060 Project contained data with few (seven) categories and a relatively small amount of change between time-slices. The Apache-Sitgreaves Study had a total of 26 categories, all of which transition at a rate higher than the first dataset.

Results and Discussion

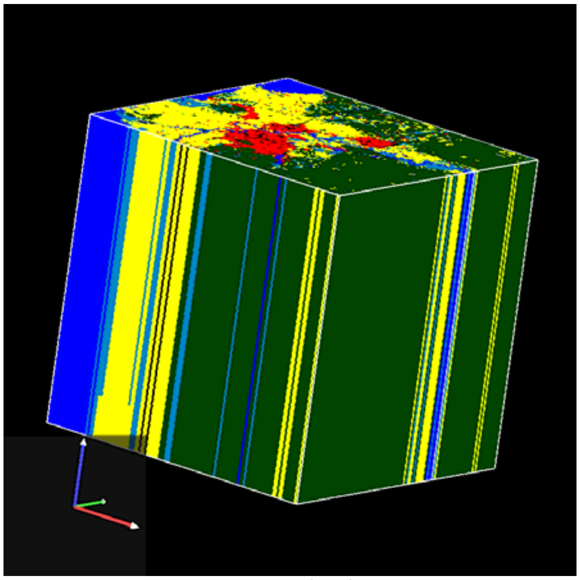
The following images were rendered on a Dell XPS L502x laptop with an Intel Core i7 2720QM @ 2.20GHz, 8GB of DDR3 memory, and an NVIDIA GeForce GT 540M graphics card. At a rendering resolution of 600x60 pixels, 400 volume slices displayed at a rate of 40 frames per second. With 1700 slices, the display rate was nine frames per second.

Skagit Study Area: LULC_A

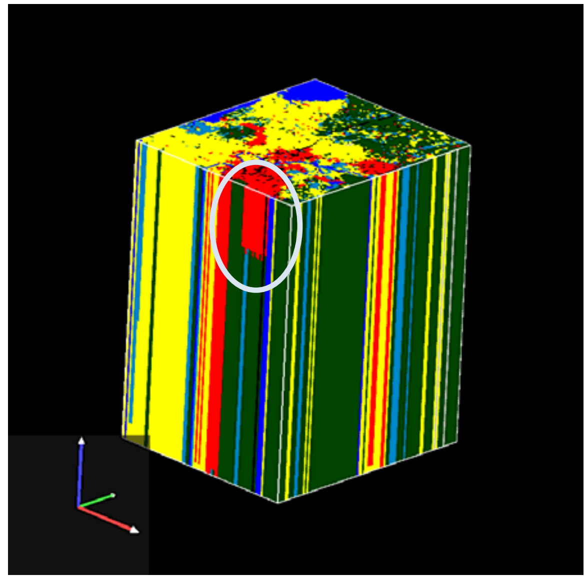
Figure 9a shows the time-series data represented in a volume without any slicing or filtering. As shown, viewing the data in a volume is the 3D equivalent of the 2D images as previously available. Instead of viewing a single slice of time, there are three planes: X-Y plane, X-Z plane, and Y-Z plane, where X and Y represents the latitude and longitude respectively and the Z axis represents time. Therefore, images parallel to the X-Y plane show the original 2D images. The X-Z and Y-Z planes show the values of a particular point over time. These viewing planes made it possible to visualize any trends or patterns over time in the simulation. If a particular spatial location does not change over time, a column is extruded through the visualization.

By using clipping planes, the volume can be sliced to reveal new surfaces. Using the range sliders to manipulate the clipping planes achieves the effect of animating through various 2D slices as we have previously done. Traversing through the volume, we can look for slices that show trends in the data. For example, in Figure 9b, it was easy to locate a fairly widespread creation of the Developed category towards the end of the simulation.

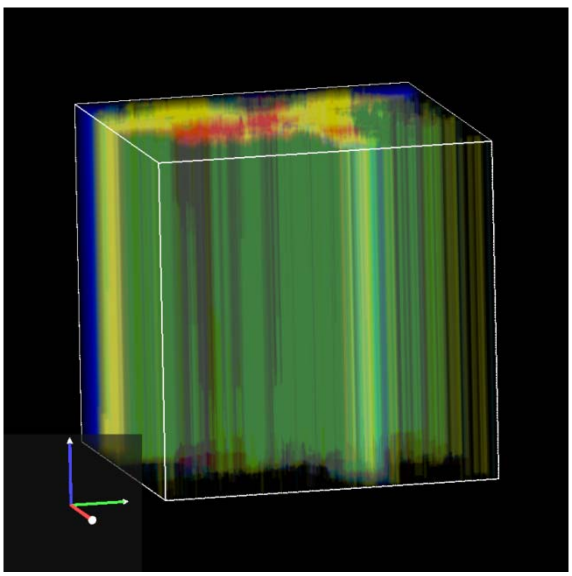
However, just this technique alone still lacks the ability to show what the previous frame looked like. Therefore, any trends or patterns perpendicular to the slicing planes are not easily recognized. In order to view inside the volume, the transparency of the volume was adjusted by using the Alpha Controls. Figure 9c shows a uniform transparency added to all categories in the volume. Since the volume is now translucent, the time-extruded columns are no longer two dimensional but appear to have depth. Viewing into the volume gives the user a context of the data. This allows the entire set of three dimensional columns to be viewed and be able to spatially compare them with other columns within the volume. By increasing the opacity of the Developed land voxels as shown in Figure 9d, the user had a better view of the extruded columns.



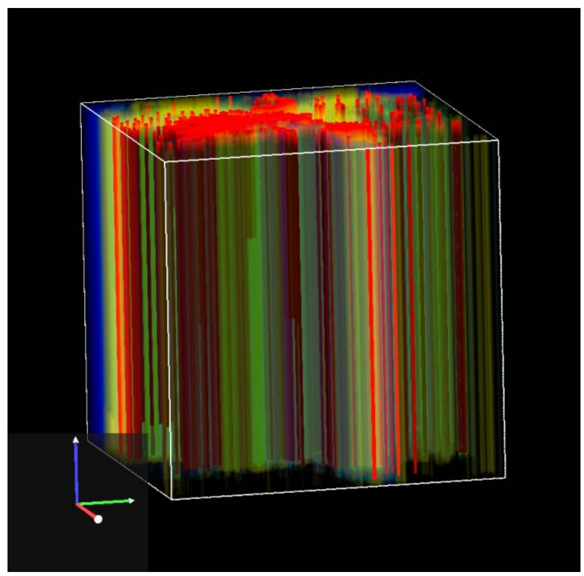
a. Original Volume



b. Clipped Volume



c. Overall transparency applied



d. Independent alpha applied: Developed

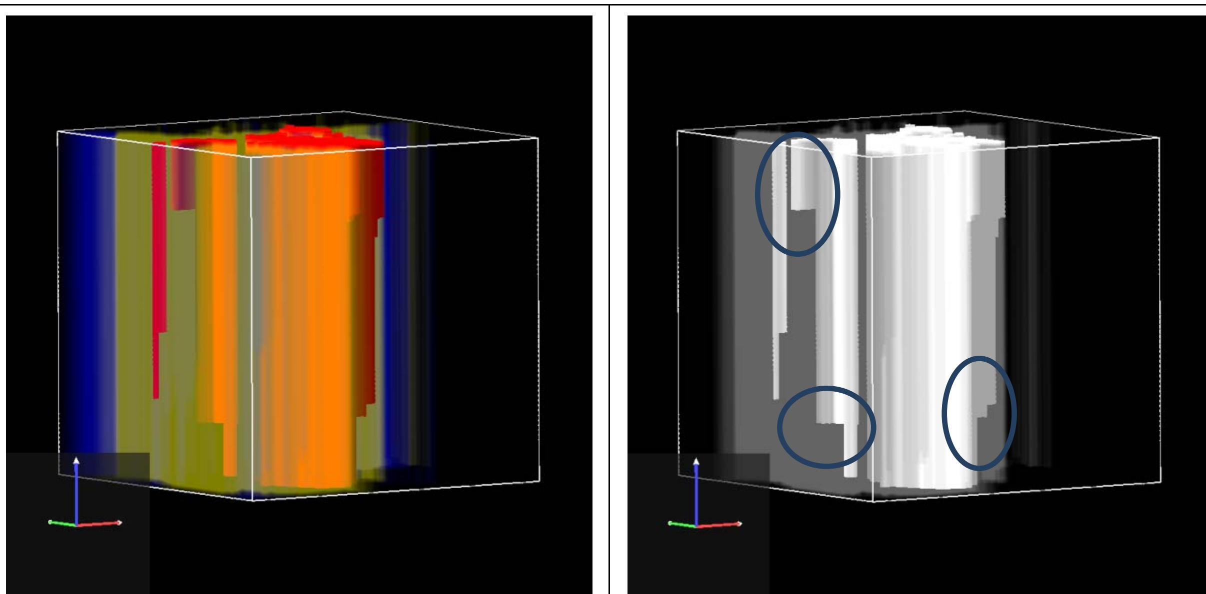
Figure 9. Snapshots of the time-extruded volume. Source: Envision Skagit 2060 Project.

LULC_A			
Developed	Agriculture	Forest	Wetlands
Other	Water	Roads	

Figure 10 shows a transparent time-extruded volume with the Developed voxels rendered opaque. Figure 10b shows the volume with the Monochrome Highlighter Tool enabled. The circled areas of the screenshot highlight the areas where development has been introduced. The visualization shows that as time progresses large sections of the screen shot change to developed lands and stay developed for the duration of the study.

The highlighter function was then used to color the selected category to an opaque white. Figure 11a highlights the wetlands in a monochrome coloring scheme. As shown in this figure, the majority of the wetlands are maintained throughout the simulation, as the three dimensional columns stretch over the entire volume. Columns that terminate within the volume represent wetlands that have been converted into another land type. The two columns marked in the figure indicate that a wetland has been eliminated.

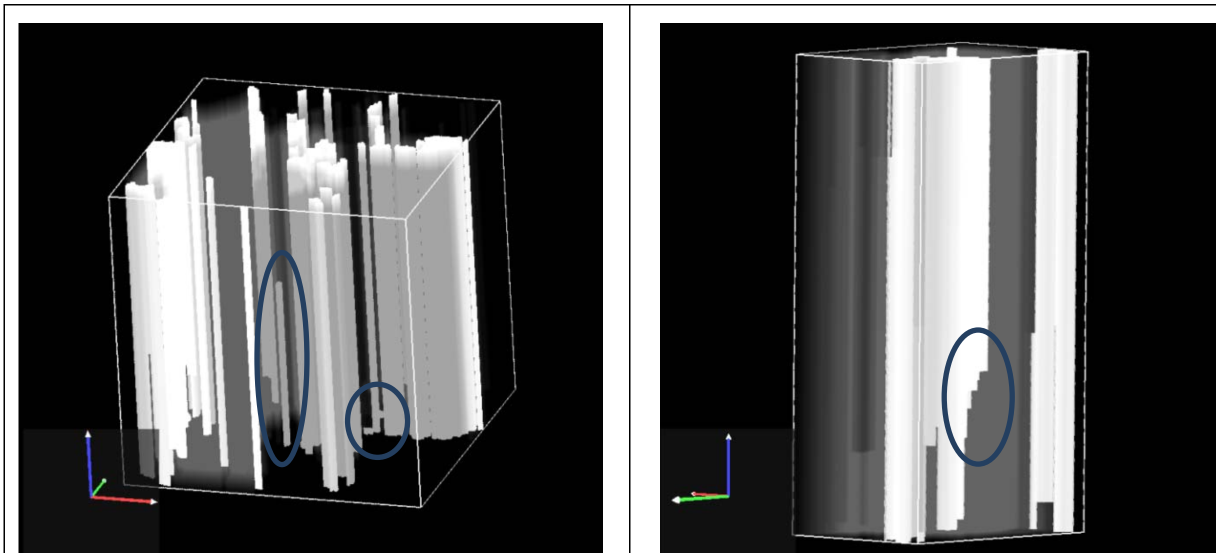
Figure 11b shows the same volume, however from a different viewing angle and cropped to show the western region of the study. This view shows wetlands were created fairly early in the simulation as they did not exist at the bottom of the volume. These areas are highlighted with a circle. The visualization also shows that once created, the wetlands continued to exist to the end of the study. Additionally, as the simulation progressed, the volume of the columns grew, indicating a growing trend.



a. Independent alpha applied: Developed

b. Monochrome Highlighter applied: Developed

Figure 10. Viewing the volume with interest of the Developed category. Source: Envision Skagit 2060 Project.



a. Monochrome Highlighter applied: Wetlands

b. Monochrome Highlighter with clipping: Wetlands

Figure 11. Viewing the volume with intrerst of the Wetlands category. Source: Envision Skagit 2060 Project.

LULC_A							
	Developed		Agriculture		Forest		Wetlands
	Other		Water		Roads		

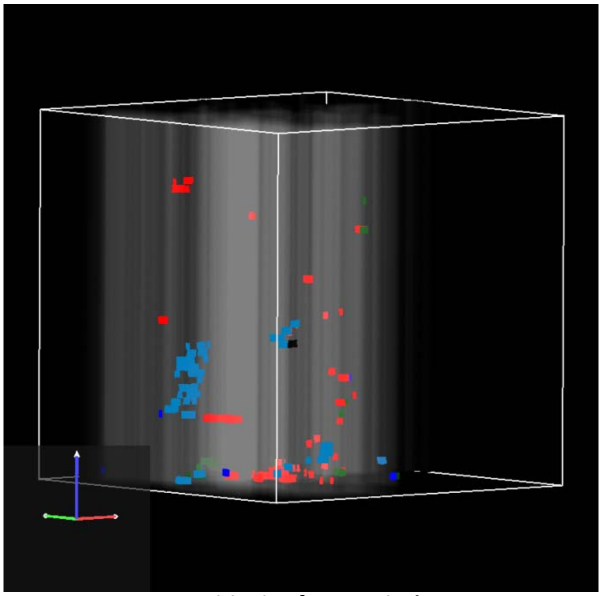
Figure 12 shows the Transitioning Tool in action. Specifically it shows the “from” transitioning of selected categories. These visualizations can be thought of as the loss of a particular category to the voxel shown. For example, the loss of Agriculture to wetlands or the loss of forest to developed land. This ability to show the loss of one category to another is important when attempting to find patterns and trends over an increased period of time.

Figure 12a shows all voxels that have previously transitioned from an Agriculture land type. With this tool, the user is quickly able to determine spatially where, at what time in the simulation, and to what type the Agriculture voxels transition to. With the transitioning tool enabled, we are able to see that Agriculture voxels had mostly transitioned into either Wetlands or Developed voxels.

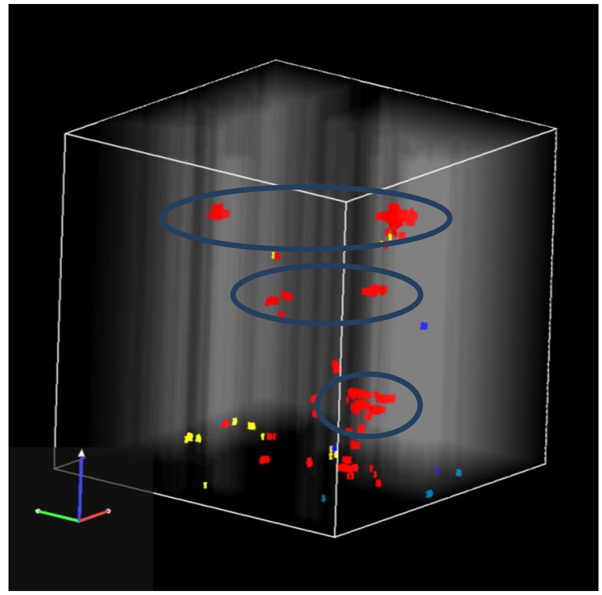
Figure 12b shows voxels that have transitioned from Forest. In this example, we can see that the majority of transitioned Forest voxels have turned into the Developed type. The three circled areas represent short periods of time where the majority of the voxels transitioned.

Figure 12c is slightly different then 12a and 12b. When Figure 12c is viewed with the Transitioning tool, the lack of colored voxels indicated that the selected data category rarely transitions. This distinguishes this screen shot from the others by its ability to either help validate the dataset or raise questions for concern. Figure 12c indicates that developed land rarely tends to transition. This sounds reasonable as it is expected that Developed regions will remain Developed. However, interestingly enough the few small voxels that made a transition changed from Developed land to Agriculture. This could possibly represent an error in the data, as this transition contradicts current data, trends, and intuition.

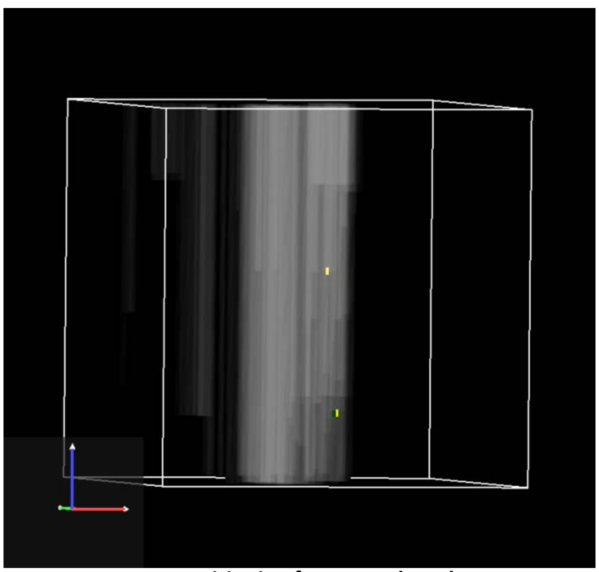
Figure 12d shows voxels transitioning from Wetlands to different land categories. The primary transition is of Wetlands to Developed land. However, also shown in the visualization are a few areas of Wetland to Agriculture, Wetlands to Forest and one area of Wetlands to Water.



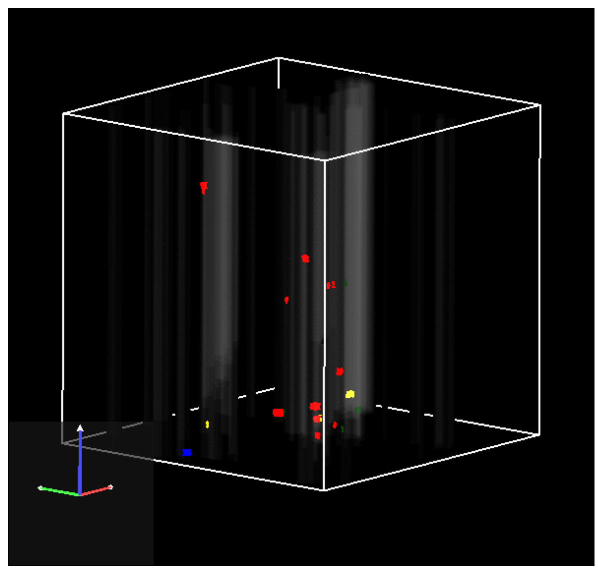
a. Transitioning from Agriculture



b.Transitioning from Forest



c.Transitioning from Developed



d. Transitioning from Wetlands

Figure 12. Transitioning Tool applying "from" transitioning. The transparent white voxels represent the selected category. The opaque colored voxels represent voxels whose next time-step transitioned to the selected category. Source: Envision Skagit 2060 Project.

LULC_A			
Developed	Agriculture	Forest	Wetlands
Other	Water	Roads	

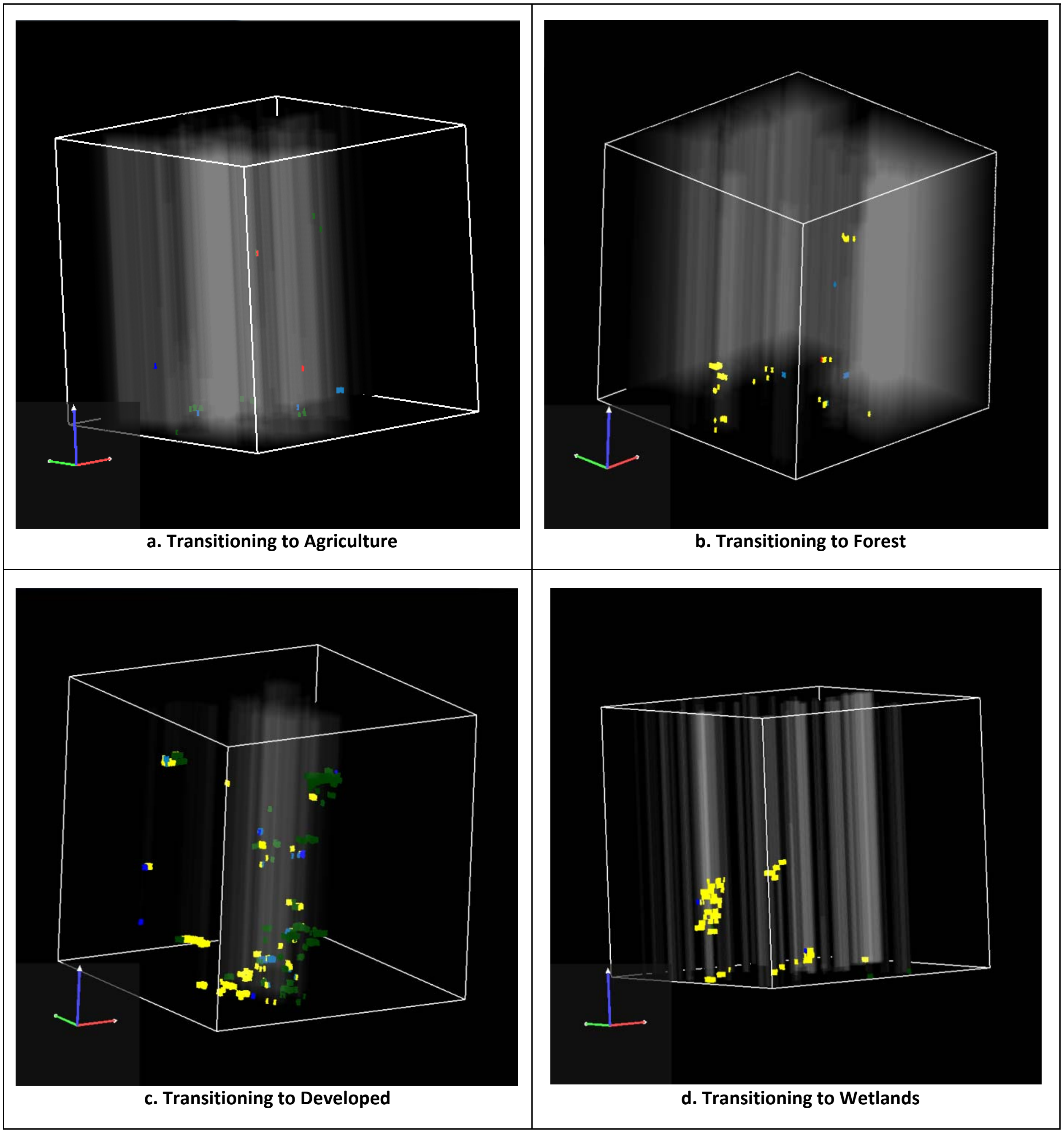
The next figure, Figure 13, also displays the Transitioning Tool in action, however instead of representing the "from" transition, the "to" transition is shown. These visualizations can be thought of as the gain of

the selected category, rather than the loss shown in the previous example (Figure 12). For instance, the transition of Agriculture to Forest is shown as well as Wetlands to Developed land. Data displayed in this new visualization not only show the addition of types of land, but also give the viewer a clear representation of when the transition was made and where, a tool that was not previously available.
In Figure 13a only a small amount of data is shown transitioning to agriculture. The few colored voxels that are represented are transitioning from forest to Agriculture and wetlands to Agriculture. Although on first glance there appears to be little information in this screen shot, the lack of information could raise concerns or questions as to why there appears to be a limited transition to agricultural land in the time period shown in this data set.

Figure 13b also contains only a selected amount of information. The few colored voxels shown made a transition from agricultural lands to Forest. Also noticeable is the lack of transition represented later in the simulation. Only a few voxels transition to forest from Agriculture, compared to many more in the beginning of the simulation.

Figure 13c is different from the previous two by containing more data. The transitions made were from agricultural lands to Developed as well as Forest land to Developed. Perhaps the most interesting aspect of this particular frame is the diversification over time. At the beginning of the visualization a mix of Agriculture and forest are shown transitioning to Developed lands, however towards the end of the simulation, the majority of land changing to Developed is Forest, not Agriculture.

The final figure, 13d shows the transition of the voxels to Wetlands. As stated before, wetlands have been a particular focus in this study and are extremely important to show throughout the visualization. Figure 13d shows an almost exclusive transition from Agriculture to Wetlands. Although there are a few small areas with a transition from Forest to Agriculture, the major trend shown is a loss of Agriculture to Wetlands.



a. Transitioning to Agriculture

b. Transitioning to Forest

c. Transitioning to Developed

d. Transitioning to Wetlands

Figure 13. Transitioning Tool applying “to” transitioning. The opaque colored voxels represent voxels whose previous time-step transitioned to the selected category. Source: Envision Skagit 2060 Project.

LULC_A			
Developed	Agriculture	Forest	Wetlands
Other	Water	Roads	

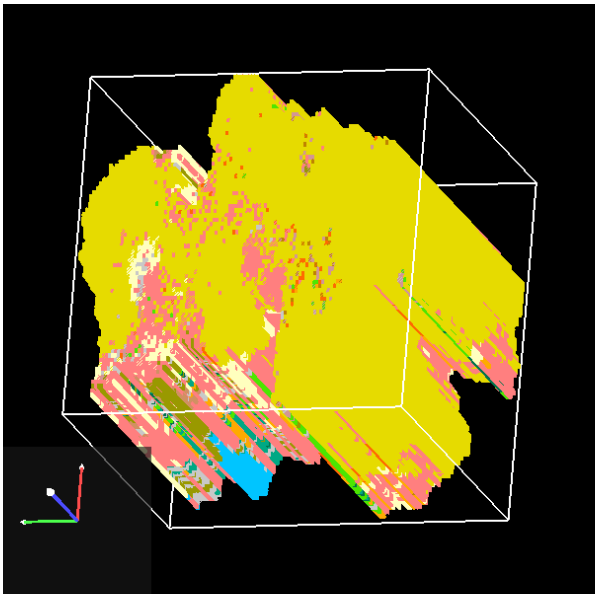
Apache-Sitgreaves National Forest Study Area: Vegetation Type

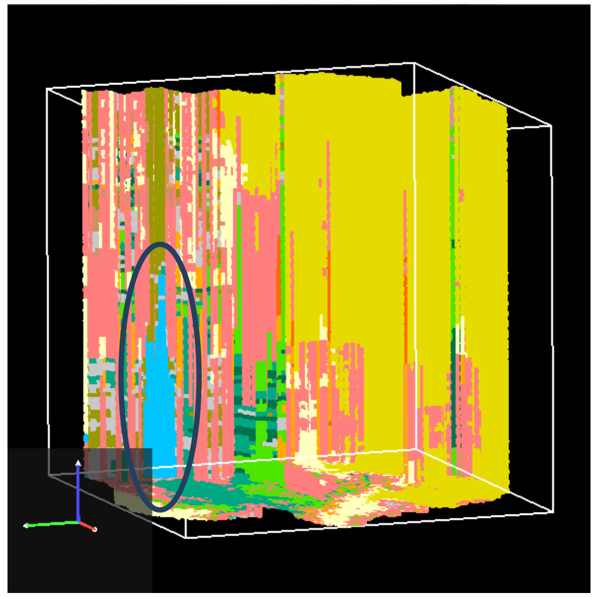
Figure 14a shows the time-series data represented in a volume without any slicing or filtering. The viewing angle in Figure 14a shows that the majority of the vegetation ultimately transitioned to C4 Grassland. The second most prevalent vegetation type shown was temperate shrub land. At the bottom of the volume, the viewer sees a prevalent area of subalpine forest. Rotating the volume as shown in Figure 14b gives the viewer a new perspective of the entire duration of the simulation. The circled region in Figure 14b visualized the eradication of the subalpine forest vegetation type.

Figure 15 represents the volume with an overall transparency applied. Figure 15a shows a uniform transparency. On the right side of the simulation, a large region is shown to primarily contain one vegetation type. Although other vegetation types are visible in a few columns, C4 Grassland dominates the right side of the volume. Alternatively, the left side shows a diverse array of vegetation types. A large green region toward the bottom left is viewable and represents a patch of forest type. Additionally as time progresses, the forest type gradually disappears into what appears to be Coniferous Xeromorphic Woodland.

Figure 15b shows an independent alpha applied to the temperate needleleaf forest category, shading it opaque. Decreasing the transparency of the selected category gives the viewer a clear view of one particular vegetation type. In this example, the Temperate Needleleaf Forest type has been chosen, and presents a new perspective on the same data viewed not only in Figure 15a, but Figure 14a and 14b as well. In Figure 15a, the right side of the volume appears to be dominated by C4 Grassland. However, when the Temperate Needleleaf Forest type is made opaque, the visualization changes and the C4 Grassland vegetation type is not viewed as a continuous block, as much of the area also contains Temperate Needleleaf Forest. This ability to highlight one vegetation type is important because it allows the viewer to see the same material from a variety of viewpoints.

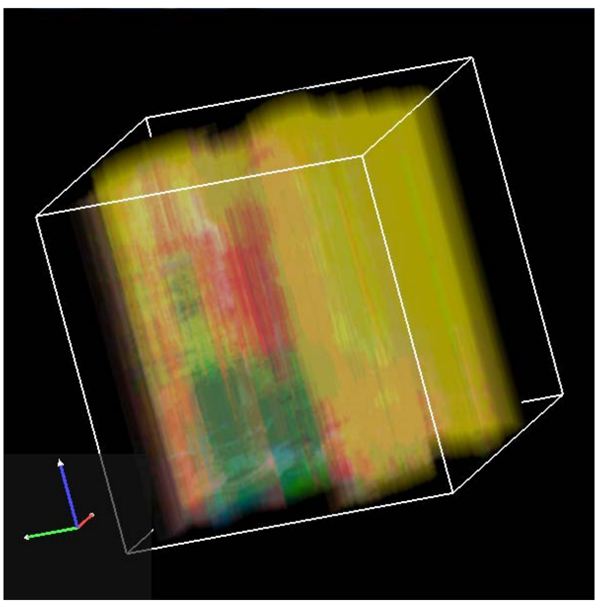
Additionally, a portion of Figure 15b is highlighted by a circle in the bottom right. This circle shows an intriguing aspect of the simulation where the temperate needleleaf forest vegetation type exists for several years and then completely disappears only to reappear and continue for the rest of the simulation. This sudden fluctuation is interesting and could contain important information about the changes taking place during that time period.

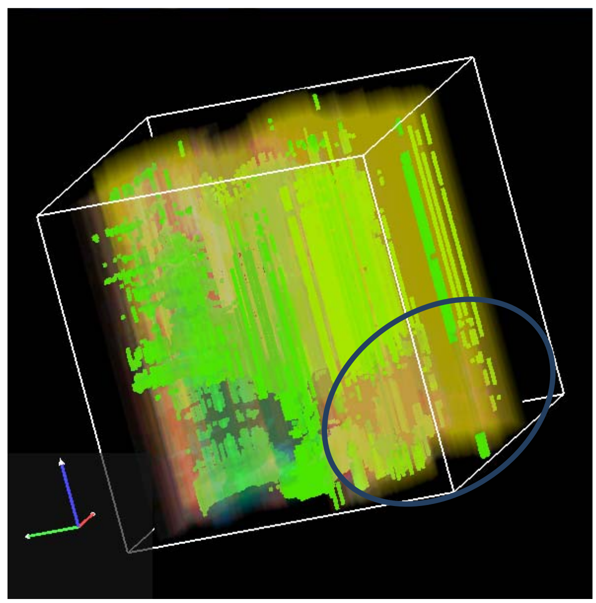




a. Original Volume | b. Original Volume

Figure 14. Source: Dave Conklin





a. Overall transparency applied | b. Independent Alpha applied: Temperate Needleleaf Forest

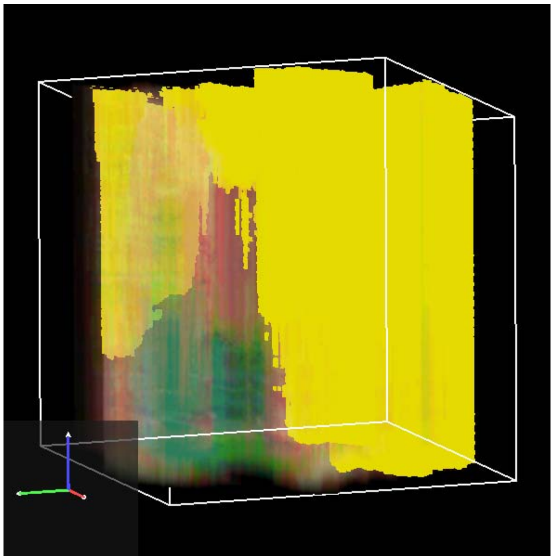
Figure 15. Source: Dave Conklin

Vegetation Type			
ice aka barren	temperate warm mixed forest	temperate desert	coniferous xeromorphic woodland
tundra aka alpine	temperate needleleaf woodland	subtropical needleleaf forest	
subalpine forest	temperate deciduous broadleaf woodland	subtropical shrubland	subalpine meadow
maritime needleleaf forest	temperate cool mixed woodland	C4 grassland	water
temperate needleleaf forest	temperate warm mixed woodland	subtropical	natural barren
temperate deciduous broadleaf forest	temperate shrubland	tropical	developed
temperate cool mixed forest	C3 grassland	cool needleleaf forest	

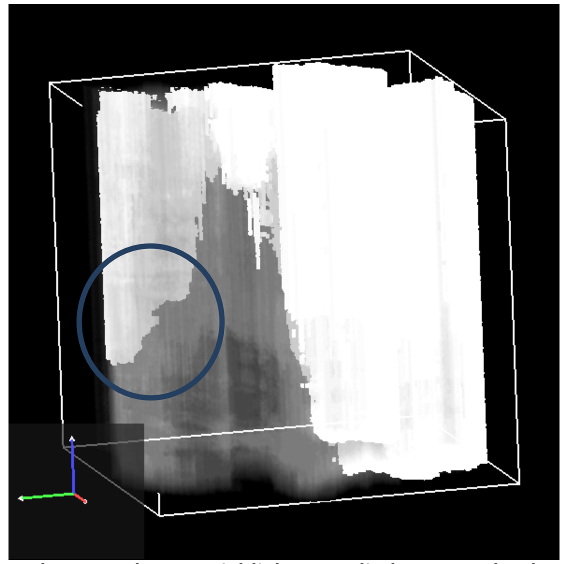
Figures 16’s and 17’s focus is primarily on the vegetation type C4 Grassland, an attribute considered important by the study group. Figure 16 is similar to Figure 14 in that it highlights a specific vegetation type and creates an opaque shading. Figure 16a applies an independent Alpha to C4 Grassland presented to the viewer in bright yellow. As seen in Figure 16, C4 Grassland is prevalent throughout the volume; however with the application of an opaque shading to the vegetation type, C4 is shown as even more of a dominant vegetation type, especially towards the end of the study.

In Figure 16b a monochrome highlighter was applied. This eliminates all color blending of the visualization making the selected attribute more pronounced. Additionally, a section at the bottom left is highlighted with a circle. A region of C4 Grassland appears and begins the growing trend of an increased amount of C4 Grassland vegetation.

Figure 17 is similar to Figures 12 and13 where a transition “to” and “from” a certain land or vegetation type is shown. In this visualization C3 Grassland and temperate shrubland made a transition to C4 Grassland. However, this figure shows that the frequency of transitions is much higher in this data set than as shown in Figure 13. With a high rate of transitions to C4 Grassland, the visualization appears as a 3D scatter plot showing the voxels that have transitions to C4 Grassland. In Figure 17a, a circled section of C4 Grassland appeared abruptly and starts the trend of C4 Grassland prevalence. This new volume in Figure 17b shows that C4 Grassland was not making a transition from multiple vegetation types, but was transitioning only from C3 Grassland in that area.

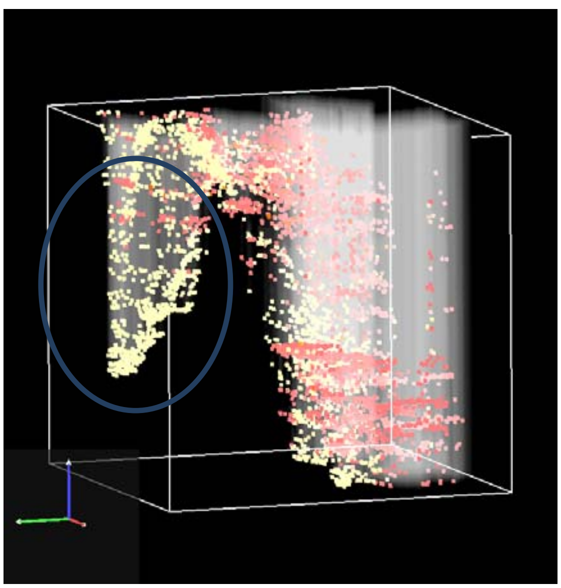


a. Independent Alpha applied: C4 Grassland

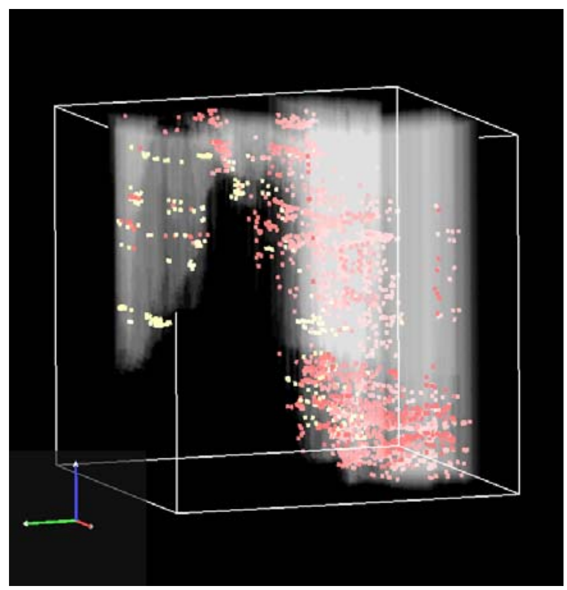


b. Monochrome Highlighter applied: C4 Grassland

Figure 16. Time-extruded volumes with C4 Grassland as the focus. Source: Dave Conklin



a. Transitioning to C4 Grassland



b. Transitioning from C4 Grassland

Figure 17. Transitioning Tool enabled with C4 Grassland selected. Source: Dave Conklin

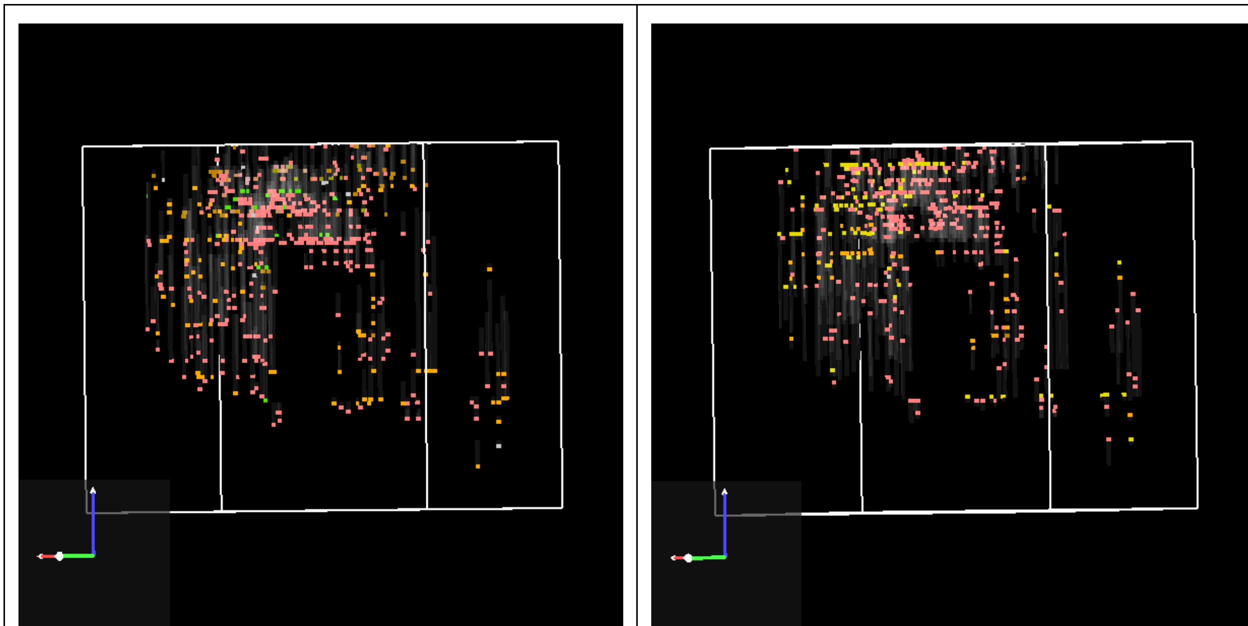
Vegetation Type			
ice aka barren	temperate warm mixed forest	temperate desert	coniferous xeromorphic woodland
tundra aka alpine	temperate needleleaf woodland	subtropical needleleaf forest	
subalpine forest	temperate deciduous broadleaf woodland	subtropical shrubland	subalpine meadow
maritime needleleaf forest	temperate cool mixed woodland	C4 grassland	water
temperate needleleaf forest	temperate warm mixed woodland	subtropical	natural barren
temperate deciduous broadleaf forest	temperate shrubland	tropical	developed
temperate cool mixed forest	C3 grassland	cool needleleaf forest	

Figure18a shows the voxels transitioning to the Coniferous Xeromorphic Woodland category from temperate shrubland as well as Temperate Needleleaf Woodland . Although the transition to Coniferous Xeromorphic Woodland is shown throughout the data set the majority of the transitions take place towards the end of the simulation.

Figure 18b shows the voxels transitioning from the Coniferous Xeromorphic Woodland to Temperate Needleleaf Woodland and C4 Grassland, as well as Temperate Shrubland. The transitions happen at different points in the data set. At the beginning of the simulation, the majority of transitions from Coniferous Xeromorphic Woodland is to Temperate Shrubland, however later in the visualization it appears to be transforming to C4 Grassland and Temperate Shrubland.

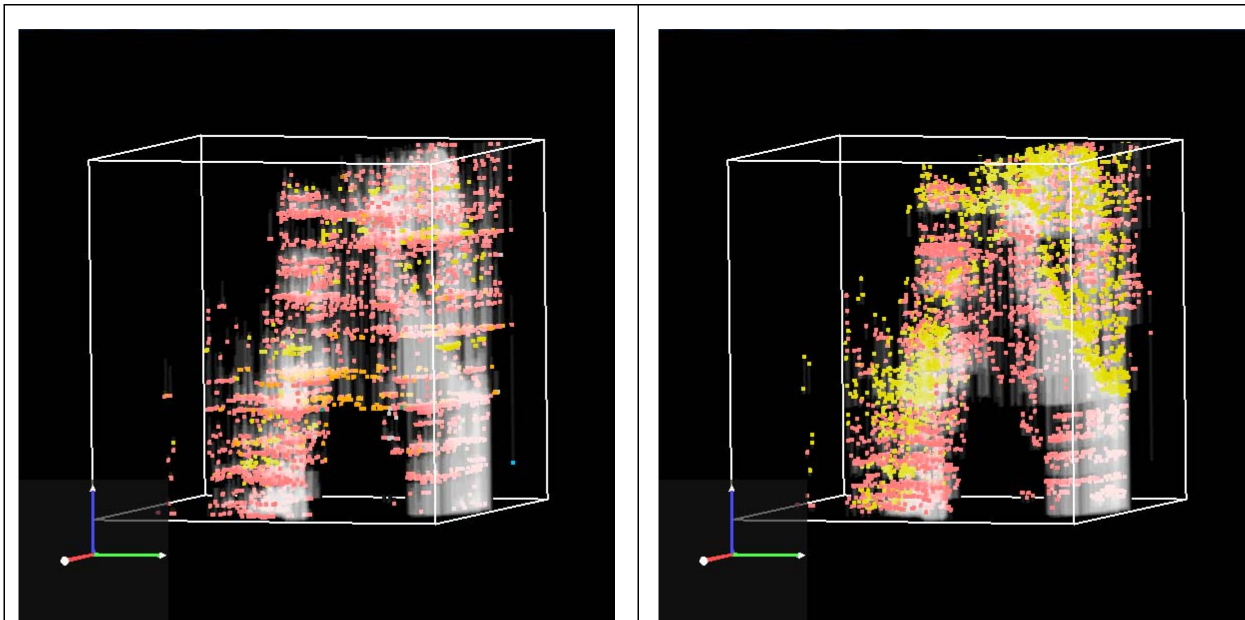
Figure 19a represents the voxels transitioning to C3 Grassland from Temperate Shrubland and Temperate Needleleaf Woodland. The data appears to show that roughly ever y five years the C3 Grassland transitions into Temperate Shrubland and then transitions back to C3 Grassland. This episodic feature lasts throughout the entire simulation as seen by the horizontal grouping of voxels along the same time plane.

Figure 19b shows the voxels transitioning from C3 Grassland. The data shows that the transition is primarily taking place from temperate scrubland and C4 Grassland. This volume reemphasizes the episodic nature of the C3 Grassland transitioning in and out with temperate shrubland. When compared, Figures 19a and 19b show that more C3 Grassland is transitioning to C4 Grassland than C4 Grassland to C3 Grassland. This occurrence demonstrates that once the transition to C4 Grassland is made, the transition is more likely to be permanent.



a. Transitioning to Coniferous Xeromorphic Woodland | b. Transitioning from Coniferous Xeromorphic Woodland

Figure 18. Transitioning Tool enabled with Coniferous Xeromorphic Woodland selected. Source: Dave Conklin



a. Transitioning to C3 Grassland | b. Transitioning from C3 Grassland

Figure 19. Transitioning Tool enabled with C3 Grasslands selected. Source: Dave Conklin

Vegetation Type			
ice aka barren	temperate warm mixed forest	temperate desert	coniferous xeromorphic woodland
tundra aka alpine	temperate needleleaf woodland	subtropical needleleaf forest	
subalpine forest	temperate deciduous broadleaf woodland	subtropical shrubland	subalpine meadow
maritime needleleaf forest	temperate cool mixed woodland	C4 grassland	water
temperate needleleaf forest	temperate warm mixed woodland	subtropical	natural barren
temperate deciduous broadleaf forest	temperate shrubland	tropical	developed
temperate cool mixed forest	C3 grassland	cool needleleaf forest	

Future Work

For this project, the major type of data was Categorical. Thus, the tools created were geared more towards Categorical data and less towards Continuous data. Tools such as the Highlighter and Transitioning Tools have yet to be implemented for continuous data. Completing these tools will require further research on setting threshold values, as well as implementing a user interface. In the meantime, Continuous data can be converted into Categorical data by utilizing multiple RangedBins.

When viewers are able to freely rotate the volume, giving them a sense of depth, they can then determine where various columns/voxels are located within the volume. However, viewing a screenshot does not offer any ability for interaction, forcing the viewer to use other visual cues to determine depth. Applying highlights and shadows to the voxels can provide information about the column's dimensions and depth.

We have just started using stereoscopic displays to alleviate some of the display clutter. Stereo vision allows the user to better comprehend the visualizations as they are better able to visually perceive depth, and thus better understand the spatial and temporal relationships among changes in the dataset. Figure 20 shows some of the preliminary results.

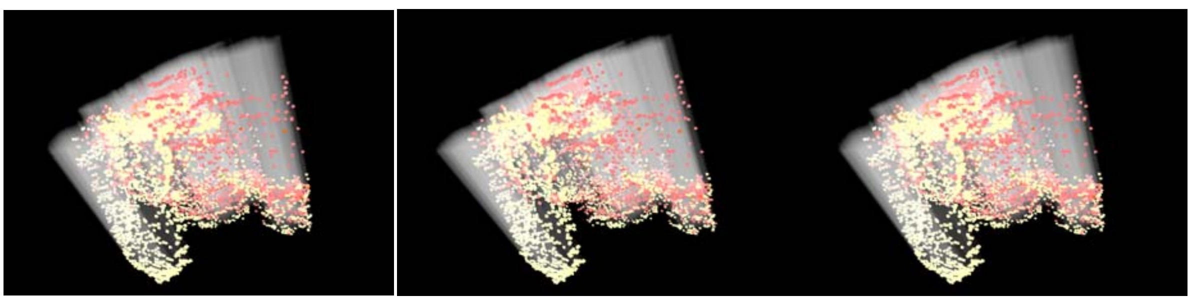


Figure 20. Stereo views. If you can free (i.e., parallel) view, look at the left two images. If you are better at crossing your eyes, look at the right two.

For continuous data, the gradient computed at a specific voxel can be used as the normal vector for a light shading algorithm. However, deriving a gradient from Categorical Data does not result in a useful normal vector – an alternative method of deriving the normal vectors will need to be developed. One approach would be to create isosurfaces from the volume data and extract the normal vectors from the generated triangular geometry. This visual cue might give the viewer a better sense of depth of the highlighted regions. Therefore, the user would have a better estimation of the location of the columns within the volume and a better understanding of a screenshot.

Conclusion

This work presented a technique of visualizing time-series data through the process of time-extrusion. With this technique, the visualization of time-series datasets is given to users in a unique perspective that allows for the identification of patterns and trends over time. However, this technique is dependent on the accompanying tools such as the Transitioning Tool and Highlighting tool. Empowering users with these tools gives them the ability to explore their data in a way not available before. Continuation in direction of improving the screenshot aspect of this work should be considered, as providing intuitive visualizations without depth is difficult.

References

Bell1988 — Bell, Gavin. *A virtual trackball implementation.* [Source Code] s.l. : Silicon Graphics, 1988. http://www.opengl.org/resources/code/samples/glut_examples/examples/.

Bolte2007 — Bolte, John P., et al., Modeling biocomplexity – actors, landscapes and alternative futures. *Environmental Modelling & Software.* May 2007, Vol. 22, 5, pp. 570-579.

Conklin2011 — Conklin, David. *personal communication.* [Dataset] Corvallis : Conservation Biology Institute, 2011.

Engel2006 — Engel, Klaus, et al., *Real-Time Volume Graphics.* Wellesley, MA : A K Peters, Ltd., 2006.

FreeImage2011 — *FreeImage Open Source Image Library 3.15.0.* [Software Library] s.l. : The FreeImage Project, 2011. http://freeimage.sourceforge.net/.

Gdal2011 — *GDAL - Geospatial Data Abstraction Library 1.8.0.* [Software Library] s.l. : Open Source Geospatial Foundation, 2011. http://www.gdal.org/.

Mcreynolds1997 — McReynolds, Tom and Blythe, David**,** *Programming with OpenGL: Advanced Rendering.* 1997. SIGGRAPH.

Skagit2011 — Envision Skagit 2060. [Online] Department of Biological & Ecological Engineering, Oregon State University, 2011. [Cited: May 11, 2011.] http://envision.bioe.orst.edu/StudyAreas/Skagit/Skagit.html.

Riccio2011 — Riccio, Christophe. *OpenGL Mathematics 0.9.1.0.* [Software Library] s.l. : G-Truc Creation, 2011. http://glm.g-truc.net/.