

THE UNIVERSITY OF MICHIGAN VISIBLE HUMAN PROJECT (UMVHP)
QUARTERLY PROGRESS REPORT: Y2Q4



Ph.D.

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UMVHP: SECOND YEAR QUARTER FOUR REPORT
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YEAR 2 QUARTER 4 KNOWLEDGE ENGINEERING TEAM REPORT

ACCOMPLISHMENTS OF THE QUARTER JUST ENDED

The principal accomplishments of the quarter just ended were as follows:

1. Development of a prototype labeled display

Release 3.18 of EWSH, as demonstrated at the December 14 Annual Meeting in both PSC-driven and standalone modes, incorporates LABELING, one of the fundamental underlying informatic technologies required for NGI-enabled intelligent clients to serve the needs of students and researchers.

The EWSH labeling engine enhances `_filmstrips`, a display modality introduced in earlier quarterly reports, by using a new object type, `_curves_`. A typical curve might be the middle of the lumen of the aorta or one of its branches. Curves are not smooth, rather are lists of segmented polygons in the space of Eve. A label is loaded into a filmstrip (a sequence of sections of Eve constructed discretely by hand but "played back" continuously and automatically) as an object of type `.cur` (curve), often the centerline of some filmstrip constructed earlier, together with a text string, colors, and a screen location. EWSH filmstrips can have any number of labels (`.cur` inclusions) that are activated or deactivated under either user control or filmstrip editor control.

In the left EWSH window (the world view), the label can appear as a colored polygon in the correct location. Here it inhabits a scene of reference planes, anatomical surfaces, other curves, and the moving (filmstrip) section plane itself, under view control in the standard EWSH 7-df mode. In the right EWSH window (the section view), exactly those labels appear (1) for which the corresponding curve intersects the section window, and (2) that are active. For each such label, its text string appears at a convenient location in the window (which can be updated by the user), connected by a thin leader line to any point in the section at which the corresponding label curve intersects the section plane. A label can point to more than one location simultaneously. The text string appears and disappears as the corresponding curves intersect or cease to intersect the section plane (or as they are turned off under other toggle controls), and the leaders move dynamically as the section is advanced or rotated under filmstrip control.

The net effect is visually stunning and very powerful, both in scripted (filmstrip) and in unscripted (manually zoomed and tumbled) mode. The redundancy of the display, with 3D view at left and 2D section at right, seems exactly appropriate to the information-processing task the viewer is asked to perform. Planes, curves, and surfaces are woven together in two different dimensionalities in a very rich scheme of relationships.

2. Formal development of an advanced segmentation scheme

It will not have escaped the reader's attention that the type of label we just implemented makes strong assumptions about the intuitive topology the viewer is presumed to assign object labeled: something having a centerline. This is a common type of anatomical object, but only one such type.

During the just-ended quarter we have set a broader overall goal than this. The task is to produce a preliminary collection of segments of Eve that are topologically correct, that incorporate labeled substructures (surfaces incorporating curves, for instance, or curves incorporating labeled landmark points), and that are plausible in joint viewing both in 3D and in sections. In a preliminary classification of this collection, presented at the December 14 Annual Meeting, we proposed that the topologies of Eve's segments be considered under four headings:

- (1) standard simply-connected regions with smooth boundaries, such as convex or nearly convex blobs and tubular structures (perhaps with branches) -- the subtask on which we are currently focused;
- (2) objects that require a different geometry than that available from the actual image of Eve -- objects that span the saw kerfs, that are intermittently visible, that join heterogeneous objects sharing a cavity, that incorporate cavities of singular boundary, or that are assigned coordinates in systems of their own (concentric layering of tubes, parallel layers of the cerebral cortex);
- (3) objects that cannot be represented as manifolds-with-boundary in any consistent way (two-sided surfaces, forms that "taper off," sheets, blurred transitions down to the level of histology); and
- (4) a potentially rather long list of special cases (lungs, teeth, the spinal column, the cerebral cortex, the heart, fat, ... -- each of which has a quite distinctive list of conceptual problems).

3. Other improvements to Edgewarp

Over the course of the quarter a goodly number of other improvements have been installed in EWSH for the convenience of users and toolbuilders alike. These improvements include a reordering of the chad retrieval list to operate in center-out order rather than right-to-left (so that the crosshairs of the section serve rather as a fovea of the browser's detailed attention); the appearance of curves as a data type for objects analogous to surfaces (the substrate for labels, see above); the inclusion of a toggle-switched network interface for control of one copy of EWSH by another copy at any other location; the incorporation of the 3D worldview parameters into save files; and a release-specific Help text file that is itself on-line by button press (and that contains more detail about all of these extensions).

PLANS FOR QUARTERS Y3Q1 and Y3Q2

1. COMPRESSED CHADS

Early in the next quarter a new chad server is expected to come online from our PSC site. The server will supply Eve's contents at a variety of rates, under client (browser) control, corresponding to either lossless or lossy conditions. This will permit, for instance, very fast dynamic exploration of volumes adjacent to a feature of interest, followed by refinement of the image once the sectioning plane is static. EWSH will be extended to incorporate PSC-supplied software for decompression; eventually all chads will be sent in compressed form. Estimates of the speed improvements thus afforded run upward of tenfold, which will greatly ease the hardware requirements of implementing these browsers for collections of users in multi-seat pods, such as anatomy students sharing a wireless network.

2. A SYSTEM OF LABELED FILMSTRIPS

The success of our prototype labeling engine, as demonstrated on 12/14, suggests that now is the right time to assign some effort to actual production of teaching modules in this medium. Working with Dr. Bookstein, a small number of anatomists and anatomy instructors will assemble a library of filmstrips corresponding to one or more of the usual teaching modules at our medical school. For instance, a set of about 40 such filmstrips, all displaying the same branching .cur structures, could implement a tour of the major arteries of Eve's

pelvis. Specific curricular content of this task will be determined in consultation with the faculty of our anatomy testbeds.

3. ALTERNATE INTERFACES

The interface of EWSH is controlled not by its kernel but by a user-accessible file of TCL/TK commands. Over the next quarter, we intend to generate alternate versions of this interface that reversibly conceal some of the more specialized buttons (such as those handling landmark locations) in submenus. We will also produce a generalized capability for starting EWSH in any arbitrary state, as, for instance, by hotlink from a browser in some other project data resource.

4. ADDITIONAL SPECTRA

Additional channels of information about Eve are expected to come on-line during the next year. These include the remaining channels of raw data (CT and MR imagery), as registered at PSC, and also information arising from computationally intense processing of the full color image, such as local gradient intensities, divergence of intensity, or other convoluted differential operators. We will prototype facilities for importing these additional spectra into the EWSH object world and toggling between various forms of sectional displays for them.

5. OTHER SEGMENTATION TYPES AND LABELING STYLES

As noted above, our current filmstrip/labeling facility is convenient mainly for objects of a very small number of structural forms, specifically, blobs and tubes. Over the next two quarters we intend to select a small number of additional segmentation types for analogous developments. One promising such candidate might be the `_heterogeneous lumen_`, as exemplified by the ureter-bladder junction or the spinal column itself, where objects of different histology and topology share a submanifold. (For the ureter, the lumen is continuous at the bladder wall; for the spinal column, a stack of blocks corresponding to the separate vertebrae share a lumen with a continuous cylindrical cavity running for many tens of centimeters.) Another will likely be the surface that does not contain a volume, but that may incorporate embedded curves (as, for instance, the peritoneum incorporates the crease of the pouch of Douglas).

SPECIAL CASES OF SEGMENTATION: SURFACES OF EVE

GOAL: SURFACES THAT ARE

- Labeled
- Hotlinked
- Topologically correct
 - both in isolation and in joint display
- Aggregable and disaggregable
- Textured
- Landmarked by points and curves, themselves labeled ,and
- Plausible in arbitrary section and in situ, for hundreds of entities from Terminologia Anatomica

In other words, scenes of multiple surfaces and sections viewed cleverly in combinations should resemble pages of a competently prepared, though Simplified anatomy atlas.

WHAT WE'VE GOT TODAY

- Three gigavoxels of RGB Eve
- Terminologia Anatomica
- hundreds or thousands of traced contours in widely separated cardinal sections
- some voxels pointing into TA
- a nearly complete outer surface (skin)
- some coarsely meshed polyhedral surface renderings

WHAT ELSE WE NEED IN ORDER TO BEGIN:

- The easy regions
 - Ice
 - Blood?
 - Cortical bone?
- • Many additional contours **from filmstrips**
 - They must be supplied by a strategy different from what is currently in place: not multiple objects in inappropriate (cardinal) planes, but one structure at a time traced in one, or (preferably) two pencils of appropriate planes
- Landmark points and curves ad libitum
 - (incidence constraints on the surface)

BASIC TOOLS NEEDED:

- Region to surface tool
 - marching cubes?

- Surface to region tool
 - must be capable of surgery, e.g. dura of the brain
- Branching tube builder
 - the four principal vascular systems
- Mesh refinement tool
 - colored active surfaces
 - Sethian-type stuff?
 - flexible geometry of constraints
- Composite (heterogeneous) region tool
 - joints
 - vessels inside organs and other co-occupancies
- Systems tool

ADDITIONAL TOOLS I:

Changing Geometry •Poking holes (sphincters, stomata, foramina)

- Sewing up holes (ureters bladder)
- Radially in tubes (lumen/endo/epi)
- By layers in sheets (e.g., cortex)
- Inflating cavities (ice, cotton, nothing)
- The saw kerfs
- Linking the intermittently visible
 - disappearances and partial volumes in 1 or 2 dimensions
- Nonvascular branching (e.g., pancreas?)
- Invisible separatrices (muscle to muscle, cranial bone to bone)

ADDITIONAL TOOLS II:

Failures of Dimension

- Doubly labeled surfaces (default is singly labeled)
- Improper or fractal edges (ligaments, cranial bones)
- Transition regions (e.g., muscle to ligament)
- “Squished stuff” (e.g. ovaries)
- Sheets (peritoneum, palmar aponeurosis, retina?)
- Curves (small nerves, vessels, ligaments)
- Tapering with change of dimension
 - surfaces sheets,
 - cones curves

ADDITIONAL TOOLS III:

Special Cases (a few from a very long list)}

- lungs
- teeth

- spinal column
- cerebral cortex
- kidney calyx
- Eve's own anomalies
- heart
- fat
- tears during preparation, ice damage
- etc.

YEAR 2 QUARTER 4 PSC VISIBLE HUMAN SUBCONTRACT STATUS REPORT

1) Description of progress towards completion of quarterly milestones & deliverables:

Major work during this quarter has produced improved control functions in the volume browser, a rapid turnaround mesh construction facility and more efficient data storage mechanisms at the server. Additional production work has continued to produce surface models, to improve WEB100 auto tuning facilities and to maintain operation of the volume and mesh servers.

Previous versions of the PSC Volume Browser have used a public domain widget set to implement control functions. This was adequate to bring up the basic functionality relatively quickly but had a number of shortcomings in adaptability to some of the specialized features for our Visible Human application. The primary user controls have now been reimplemented with a custom widget design and secondary controls, such as segmentation, are being moved to this new system during the next quarter.

From the user perspective, this change eliminates the separate flying control panels and attaches controls to the specific viewing window that they manipulate. The new mechanism avoids some of the sluggish behaviors of the earlier controls and provides direct one button access to the most common functions with popup windows to control secondary operations. All of the previous control functions are still provided but the visual appearance is greatly improved including color coding, and logarithmic zoom for both the slice and context windows. The context window zoom is particularly useful to see the 3D form of mesh models. These models can now be displayed both as shaded surfaces with user selected transparency or as explicit wire frame views and with label retrieval from the anatomy database.

Earlier problems specific to the Mac G4 have been fixed so the Volume Browser now runs from exactly the same source code and with identical visual appearance across all Mac OS X, Windows, Linux and Unix platforms. Additional features have been added to provide better user feedback of orientation and position. This includes a navigational trackball display to show the orientation of the current cutting plane along with a gaze direction indicator in the context window. Gaze

direction is currently shown as an arrow representing the viewing vector but this may change as we receive alternative suggestions from users.

Specific features have been added to the system to support the University of Michigan Visible Human kiosk under the leadership of Geri Pelok. The kiosk had the requirement to operate in the Apple Mac environment and to support linkage with the web and with the University of Michigan anatomy database. Part of this was done by providing hooks for remote operation of PSC VB by receiving commands from the database. This same mechanism was also used to prototype the collaborative operation mode that was demonstrated at the December meeting. The collaborative mode lets multiple VB users share a single session, currently with a single "master", whereby interactive commands from the master user are collected at the server and broadcast to the other "slaved" users in the same session. Each of the slaved clients then reproduces the actions and views of the master at what ever rate can be supported by their specific hardware and network connection. This facility will be extended to support remote demonstrations and teaching modes and should eventually be applicable to Edgewarp. Our implementation based on exchange of commands back through the server rather than directly from peer to peer is to provide central logging facilities as well as a common switching interface to control sets of user sessions. Part of this work has additional support from the PSC collaboratory tools grant from NCRR.

We are receiving and processing an increasing number of anatomy markups from the Michigan team. Nearly all of these are now produced using the segmentation features from the PSC VB. Many of these have been sent back to PSC by depositing files using DocShare but that process is now greatly improved by a prototype surface server. In this new process, markups using PSC VB are directly routed back to the surface server (currently on the same machine as the volume server) where additional computational power can be applied to process the data and derive a meshed surface. The mesh is then linked to the Michigan anatomy data base and also sent back to the original user. The surface can then be seen in the PSC VB environment just like any other production mesh. This gives the segmentation user rapid feedback to evaluate the quality of their segmentations and immediately identify problem areas needing more detail.

Some of the programs used for segmentation and surface construction include Powercrust (Amenta et. al.), Cocone (Dey et. al.), Optimal Tiling (Meyers et. al.), Isosurf (Treece et. al.), and Qslim (Garland). This entire process is adequate for many types of surface but still has shortcomings in a number of areas. We have

done a preliminary examination of the Insight Toolkit to see if any of its components would help to fill the gaps in the existing process. However, the learning curve with the Insight Tools is very long and the complexity and limitations (such as memory) to their use prevent their immediate application. Rather, a number of the enhancements we have already had in development should cover the existing problem areas.

We continue to make server improvements toward the stated goal of supporting 40 simultaneous and independent users from a single server. Although the Compaq ES-40 located in PSC's machine room continues to be the primary volume data server, operation of the server has now been demonstrated on a Sun UltraSparc running at Michigan as well as a 4 processor 4Gbyte Itanium machine here at PSC. The code should now be entirely portable to any 64bit architecture running Linux/Unix and supporting large memory mapped files. The 64-bit requirement is dependent on overall data set size. Most 32-bit systems have a file size and process memory limit of either 2Gbytes or 4Gbytes. A 64 bit system with memory mapping is more than adequate to operate with multi terabyte data sets given sufficient disk space and a large enough memory to hold roughly a 20% working set.

The Compaq ES-40 volume server has been entirely stable over the past year with only a few hours of unplanned hardware down time in March and a brief outage during a software swap in November. We will have 2 days of downtime for new upgrades during January. In addition to the RGB Visible Female data, which we have been using during all of 2001 this machine also hosts the female CT data and a portion of the 70mm male film scans. We will bring up the remainder of the 70mm data after doing slice registration. Service of the 70mm data has shown the capability to work with non-cubic voxels with no additional code changes.

Our data compression techniques are currently able to maintain the female RGB data in 3Gbytes of actual server memory. We are extending the compression to improve support for highly compressed lossy delivery at ratios greater than 10:1 together with seamless flow through of lossless data at 3:1 for static viewing and segmentation. To date we have operated the compression with just one or the other of these modes but want to finish the full integration before finally turning off the uncompressed service.

Operation at much higher effective compression ratios for dynamic navigational imagery is being implemented using the embedding techniques that are currently applied to some of the highest compression ratio static images using SPHIT and

JPEG2000. Those methods cannot directly support the arbitrary viewing orientations that we need for Visible Human navigation. However, by attaching an extra priority tag to each data chunk and downloading in multiple passes with client cooperation we can achieve a similar effect. The result is a reallocation of network bandwidth to concentrate on the regions of highest visual significance while not transmitting new representations of regions with minimal feature content.

Networking improvements continue to come from our use of the WEB100 tools applied to the volume server. The open source release of the tools will take place in February and our use of the tools for the Visible Human work has helped that project uncover several issues relating to multiprocessor support. In addition to the additional help we receive from that NSF supported work we also receive results from the related NET100 project supported by the DOE. (See <http://www.net100.org/> and <http://www.web100.org/>)

Finally, we have recently revised the PSC Visible Human web pages located at "<http://vhserv.psc.edu:8000/>" to a more graphical interface using the Pittsburgh black and gold color scheme. The old web pages are still available as a link from the new pages as some users still need and use the original web based orthogonal and volume retrieval hooks. This work was done by our student assistant William Ford, who also provides additional help with anatomical aspects of our VH work.

The last quarter, as every Fall season, has been a time for a number of demonstrations and presentations. In addition to demonstrations at various University of Michigan functions we gave demonstrations at the November SC2001 conference in Denver, the October Applied Imagery and Pattern Recognition Workshop in Washington and the Advancing Pathology Informatics, Imaging, and the Internet Conference (APIII) in Pittsburgh. A scientific session presentation at APIII on the application of techniques for volumetric imaging applied to pathology received an honorable mention award.

1A) Summary of main year 2 developments:

In summary, during project year 2 we have been able to produce operating versions of all of the initially specified system components including visualization, segmentation, surface construction, volume server, mesh server and networking components. Networked service of the Visible Female data from PSC has been operating with no significant problems for the entire year. This has provided support for Edgewarp and PSC Volume Browser development and a number of public demonstrations across the country. The overall system now consists of a

number of services from PSC tied together with an anatomy database running at Michigan. The main PSC based servers include the volume data server, voxel identity server, mesh data server and surface construction server. Each of these is implemented to handle even larger data sets as they may become available by the simple addition of memory and disk at the server. The protocol and client codes (VB and Edgewarp) would remain unchanged in scaling up to volumes as much as 10 times the current Visible Female.

2) Problems encountered during this quarter:

There have been no new equipment or technical problems during the quarter. Some limitations remain in the area of segmentation and model construction due to the use of existing tools for short-term production. We continue work towards the solution of those limitations but this is a complex and extensive task. A major problem area continues to be time allocation and particularly the level of effort devoted to short term demonstrations or work arounds for system components which are under development but not yet complete in final form. This frequently has the effect of delaying the final planned solutions. It is essential to have the final solutions in place with adequate time for testing, tuning and evaluation before the end of the project.

3) Resolution of problems:

We are continuing to try to balance the ongoing production and support work together with the frequent demands for demonstrations incorporating special features and the important long-term developments. There has not been a complete resolution to this problem but during this final project year it is increasingly critical that the major areas be completed as most demonstrations can now be based on project work already completed rather than special request features.

4) Goals for the next quarter & action plan for their completion:

We will be continuing PSC Volume Browser development to support use by anatomy students during the spring term. This involves further implementation of requests and suggestions from users at Michigan. Additional work is being done to enhance and streamline the user driven segmentation capabilities. Students will be testing these functions with a new code release which incorporates the new control functions, position indicators and other facilities implemented during this quarter.

The anatomy team has now begun to work on the circulatory system and has asked for additional computational segmentation tools for this task. We will be providing color and texture based extensions to the segmentation facilities to help with this work. The mesh compute server which was prototyped during this past quarter will also be more tightly linked to VB segmentation tools and user identification logging and similar production features will be added. This will make it easier for multiple users to produce and exchange surface models as well as provide tracking of the source for the main production models.

Additional improvements continue with the networking, compression and user logging aspects of the server. Since multiple data sets are now available from the server we will be making measurements to help improve the memory residency of these additional data volumes. We will also release an update to the client server protocol to allow prioritized data retrieval based on visual importance level. This will improve the effective compression ratio during volume navigation while still providing lossless viewing of static slices for detailed study and for user driven segmentation. Recent server and VB logging facilities together with student use during the new term will let us tune the tradeoffs of memory based lossy compression for rapid navigation and migration of the larger lossless compression overlay from disk. Once we can retire the uncompressed service, which is still the primary delivery vehicle, nearly all of the VH data over both the male and female data sets for both RGB and CT imagery will fit in the 4GByte server memory. VB logging will also provide information about the frequency of use of principle plane views vs. off axis views that will be used for further server tuning and analysis by the user interface group. We will also be implementing a collaboratory control panel to provide convenient multi group use of the collaboratory interaction facility that was prototyped and shown at the quarterly meeting.

A major area of new effort for the quarter is initial implementation of raycast and stereoscopic viewing. Although this was not part of the original proposal there has been considerable interest in this area and requests by the Michigan team. Preliminary work has been done to produce static raycast images along the principle planes. This is being generalized to produce a series of many of projections over sequential angles which will be stacked into the existing volume server structure but as a separate data set. Additional controls will be built into the Volume Browser to display this data both in rotating image form or with displaced eye views for stereo fusion.

Network and server operating system upgrades which were postponed from the previous quarter due to scheduling difficulties will be completed.

5) Next quarter needs:

Acquisition of equipment for stereoscopic viewing to help with production of 3D raycast views and stereo surfaces.

YEAR 2 QUARTER 4 NURSING TESTBED REPORT

Deborah S. Walker, DNSc, CNM, FNP

Update 12/14/01

The University of Michigan School of Nursing faculty and students continue to enthusiastically support the work of the Visible Human Project. Significant progress was made this quarter in several areas.

1. Ongoing projects:

A. School of Nursing (SON) wiring/network upgrade:

To test and take full advantage of the academic content created by the Visible Human Project (VHP), the School of Nursing's (SON) network infrastructure needs to be upgraded from 10mbs Ethernet to 100mbs Fast Ethernet. The new networking standard for all classrooms is Cat5e wiring with a 2-port data jack. Network closet upgrades will include upgraded fiber and one 24-port 100mbs Ethernet switch.

B. Devoted space for Visible Human software testing

Room designated for VH space: 400 N. Ingalls, Rm. 1224. This will allow for a private, quiet, space, separate from the classrooms to obtain user feedback.

C. Surveying student's learning needs/preferences and styles

Focus groups/ Student Learning styles

Student learning styles

Learning styles survey developed with other members of the UIT

Approx. 40 undergraduate nursing students surveyed 12/12/01

Results currently being analyzed

D. Manuscript development and revision-

Submitted to JAMIA

Returned with revise and resubmit

Revisions made

Manuscript resubmitted 11/01

(Copy attached)

YEAR 2 QUARTER 4 iVOXEL BROWSER

Alex Ade
University of Michigan
Progress Report
Year 2, Quarter 4

Progress this quarter

1. Kiosk development and network code
2. Intrepid Stereo Viewer / Software
3. Foreign Language (Chinese) input software
4. PSC Server running on UM equipment
5. Database development

1. Kiosk Development

- Network code was written and tested to support web based control of both VB and Edgewarp applications.
- Users click on a URL, querying the database for state information.
- Info is passed to the browsers which then update their scene (new slice, models, etc.).
- User sessions are maintained in the database.

2. Intrepid Stereo Viewer

- Modifications were made to the Java based browsers to support stereo display.
- Right and Left eye views are merged by the Intrepid device to display realistic 3D stereo views.
- Stereo visualization of Slices, Models, and Volume Renderings are possible.
- A native application was written to display high resolution 3D models.

3. Foreign Language Input

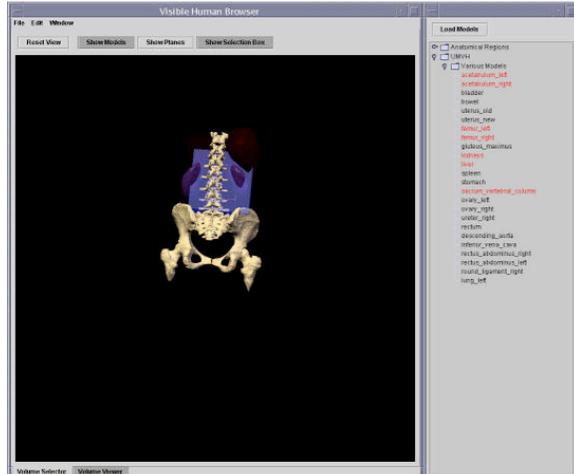
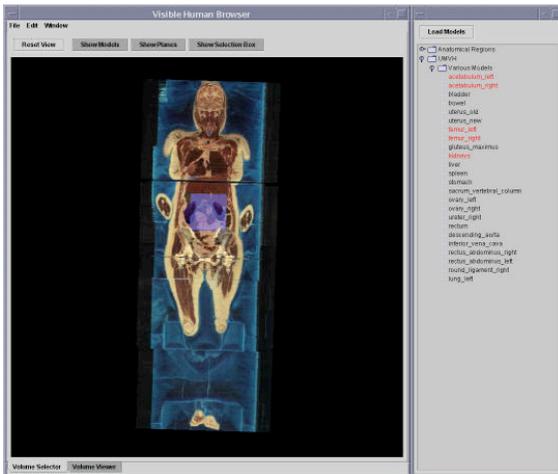
- Middleware software to support Anatomist's entry and editing of foreign language terms (Chinese) into the database.
- Web based querying and input.

4. PSC Voxel Server

- Worked with Art Wetzel at PSC to provide local voxel server to UM team.
- Currently running on a Sun Enterprise E 250 server.

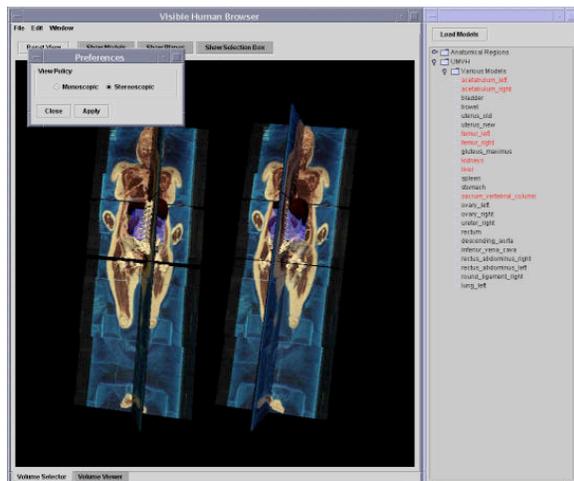
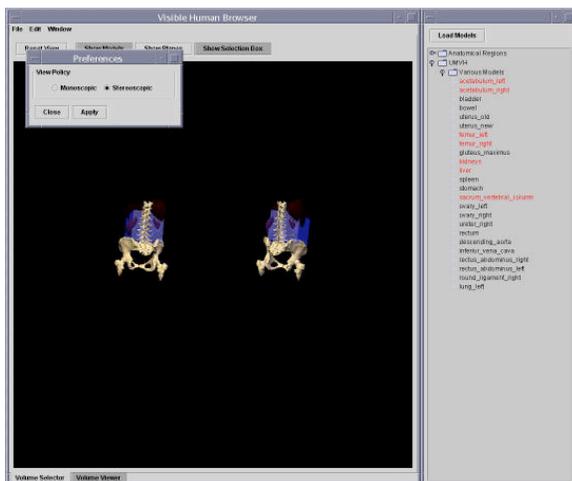
5. Database Development

- Over 7000 Terminologia Anatomica terms are now available via the UMVH database.
- Structural relationships.
- Foreign Languages.
- Web based querying and editing.

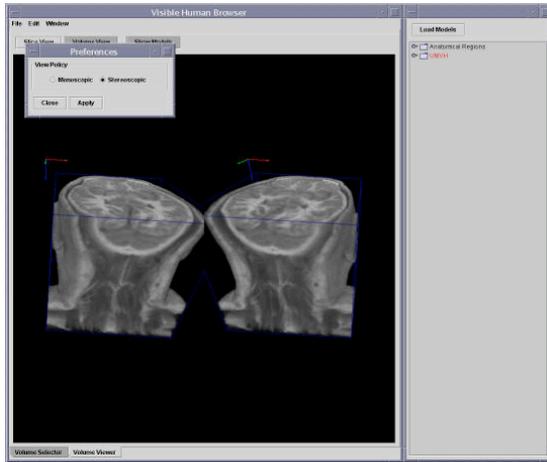


Java Browser - selection and model view

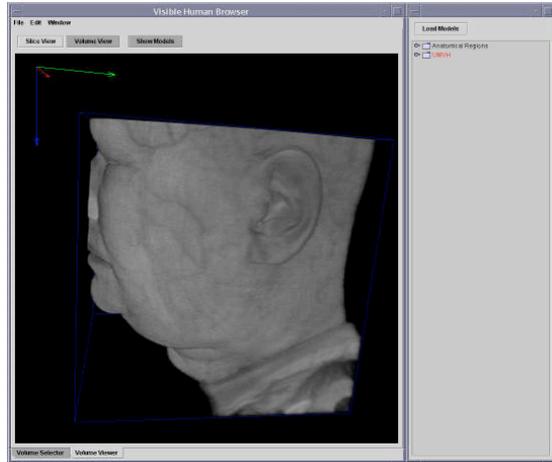
Java Browser - model view II



Java Browser - stereo model view
stereo model view II



Java Browser -



Java Browser - stereo volume view
view

Java Browser - volume