3D Bolus Reconstruction Workflow

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Summary: Reconstruct the 3D shape and motion of a contrast-enhanced solid or liquid bolus from XROMM data (biplanar videoradiography). Workflow uses custom Autodesk Maya scripts and allows the user to quantify in vivo bolus volume.

1. **Download/install required materials**
    a. Autodesk Maya (preferably version 2020 or later)
    b. Maya Bonus Tools (needed for volume calculation)
    c. J.D.'s custom Maya scripts
        i. `Snap`, `calcPolyVolume`, and `createBolusRig` are required
2. **Set up scene**
    a. Create Maya scene and import X-ray cameras (via XROMM shelf → Xcam)
        i. If desired, create lights in scene to optimize image/bolus contrast
    b. In each camera view, ensure "Wireframe on shaded" is enabled (Panel -> Shading -> wireframe on shaded)
        i. This will ensure we can see the 2D outline of the bolus as well as the X-ray image behind it
    c. Set viewport to "smooth shade all" with texture maps (press "6")
    d. Set the time slider/window to the frame range of interest
3. **Create 2D bolus outline**
    a. In either Xcam view, go to your preferred start frame (i.e., beginning of frame range of interest)
    b. Select "Create Polygon" tool (from "Mesh Tools" dropdown of Modeling workspace)
    c. Left click to place vertices and create and outline of the bolus
        i. *Be sure to*:
            1. Place them in order (as in a loop)
            2. Place an adequate number of vertices for the desired bolus resolution (the number of vertices is conserved across all frames and not editable later)
    d. When all vertices are placed, press enter/return to create the polygon.
    e. Give the polygon object a name (i.e., bolus_cam1)
    f. Apply a new lambert to the polygon (long right click, "assign new material") and set it to be completely transparent.
        i. With the "wireframe on shaded" on, we should still be able to see its outline
4. **Create 3D rig**
    a. Select (Shift+left click; in order) (1) the new bolus polygon, then (2) the camera plane immediately behind it
    b. In the MEL command line, run `createBolusRig;`
        i. A series of locators and two new groups should appear in the outliner
        ii. The visible set of locators are the 'controllers' for the vertices of the polygon; these are what you will move/keyframe to animate the bolus silhouette.

        iii. Note that the rig is set up such that the polygon's vertices are constrained to the image plane; while the vertex controllers are free to move wherever, the vertices themselves won't leave the image plane.
    c. The function will also create a 3D version of the bolus model, for each camera plane. Hide this (select, then press "h") until you are done with step 6/7.

5. **Repeat steps 3 and 4 in the other Xcam.**
6. **Keyframe vertex control (locator) positions**
    a. Upon creation, the locators and 2D shape will likely be offset from their original position on the image plane--this is normal. The easiest way to adjust is to select all of the vertex controllers at once (in the outliner) and translate them together.
        i. Importantly--only ever translate the locators in the plane of the xcam (when using the translate tool, click and hold the middle square, rather than individual axes.) As described in 4 iii, the vertices are constrained--but moving the controllers off the image plane can introduce annoying alignment issues
    b. When you've adjusted the bolus shape to look good, select all of the controllers, and press "s" the keyframe hotkey.
    c. Advance forward 5-25 frames, and adjust all of the controllers to fit the bolus silhouette. Once it looks good, select all of the controllers and set another keyframe.
        i. I recommend erring on the side of larger initial gaps between successive keyframes. Then you can scrub back through the interpolated frames and assess when/where additional keyframes are needed.
7. **Repeat step 6 for other Xcam, if you haven't yet**
8. **Calculate intersection of two camera planes**
    a. Un-hide (select, "h") the two 3D bolus models that you hid when you first ran `createBolusRig;`
    b. Select both of them at once (shift select) and perform an "Intersection" Boolean operation (Modeling workspace → Mesh → Booleans → Intersection)
        i. You should now see the bolus in 3D
    c. The bolus model is dynamic, in that you can refine the vertex keyframes at any point, and the changes will be reflected in the 3D bolus model
        i. A consequence of this is that step 8 could just as well be performed prior to any keyframes being set
9. **Calculate bolus volume**
    a. Turn the Poly volume heads up display (Bonus Tools → Poly Volume)
    b. Decide what frame range you wish to run the calculation on
    c. Select the 3D bolus model, and run `calcPolyVolume(`*`startframe`*`,`*`endframe`*`);` where startframe and endframe are just frame numbers (e.g., `calcPolyVolume(550,1000);`)
    d. The volume data (in units of the calibration object, cubed (likely cm^3)) will be stored in a new locator as its X-position.
        i. You can then visualize the volume in the graph editor, or export using the XROMM exp function as you would with any other data stored in a locator.