Experiences with Adopting ANARI in Existing Visualization Applications

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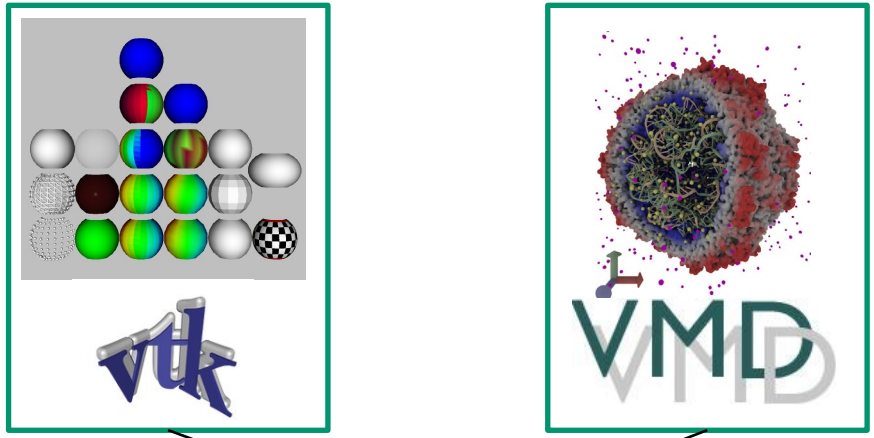
ANARI™

Analytic Rendering API

Portable access to live rendering systems



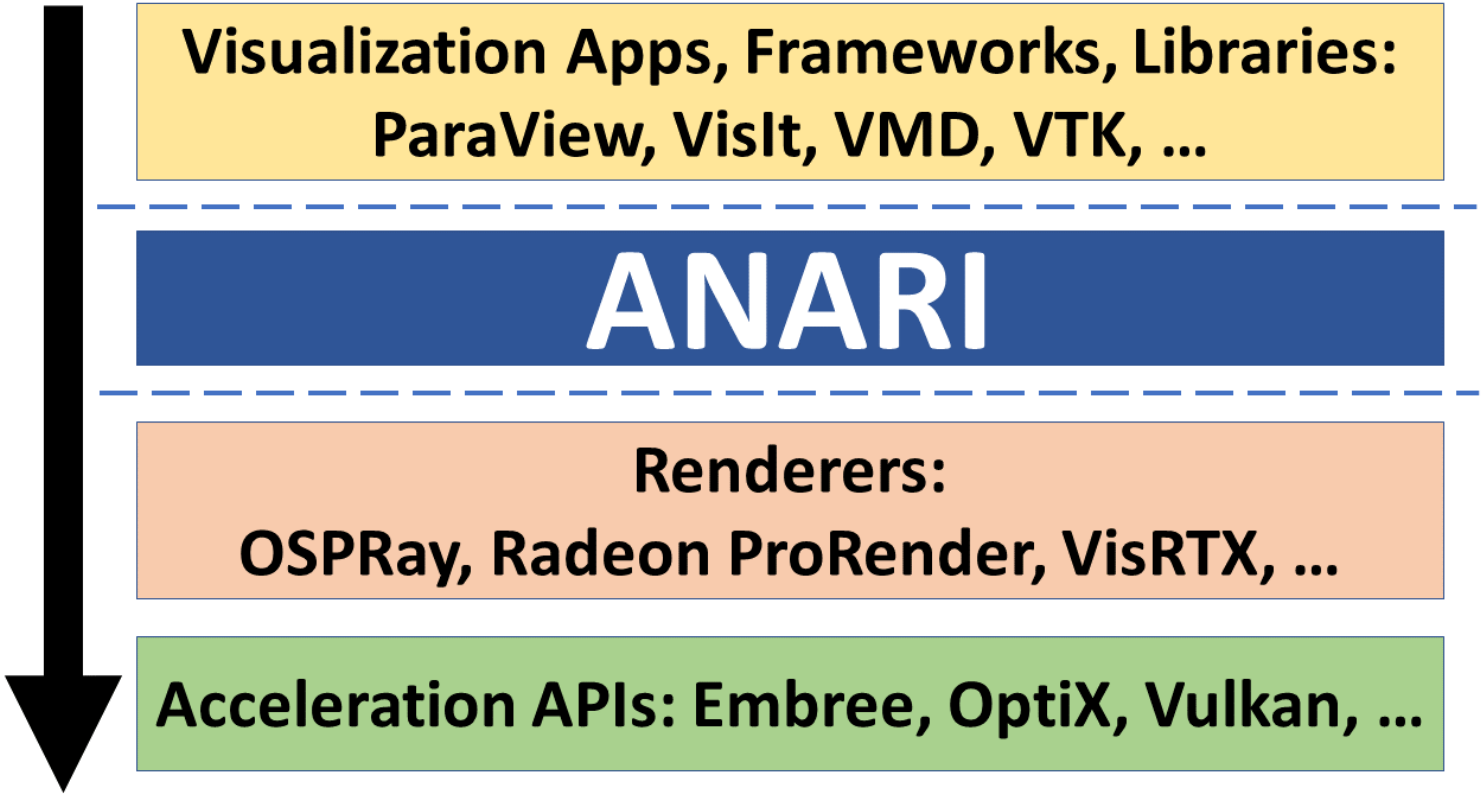
- Specification development ongoing
- Exploratory implementations
- Identifying friction points

- Anyone welcome to join!

https://www.khronos.org/anari

KHRONOS GROUP

ANARI API Position Within Visualization Stack



ANARI: A 3D Rendering Interface Standard. J. E. Stone, K. Griffin, J. Amstutz, D. DeMarle, W. Sherman, J. Günther. Computing in Science and Engineering, 2022.

Comparison of API Abstraction Levels

OSPRay

ANARI

OpenGL <= 2.x

OpenGL >= 3.x

OptiX <= 6.x

OptiX >= 7.0

Embree

Vulkan

NVIDIA APIs

Intel APIs

Open Standards APIs

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VMD – “Visual Molecular Dynamics”

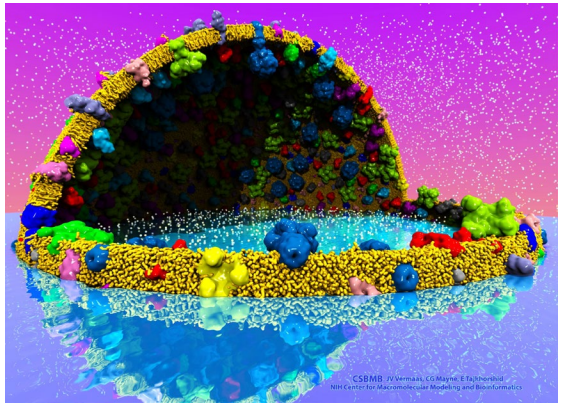
100,000 active users worldwide

Visualization and analysis of:

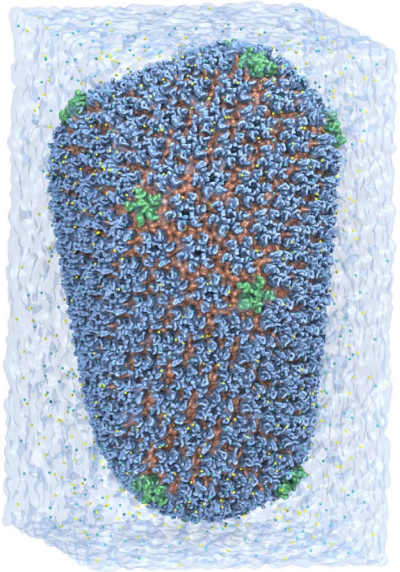
- Molecular dynamics simulations
- Lattice cell simulations
- Quantum chemistry calculations
- Cryo-EM densities, volumetric data

User extensible scripting and plugins

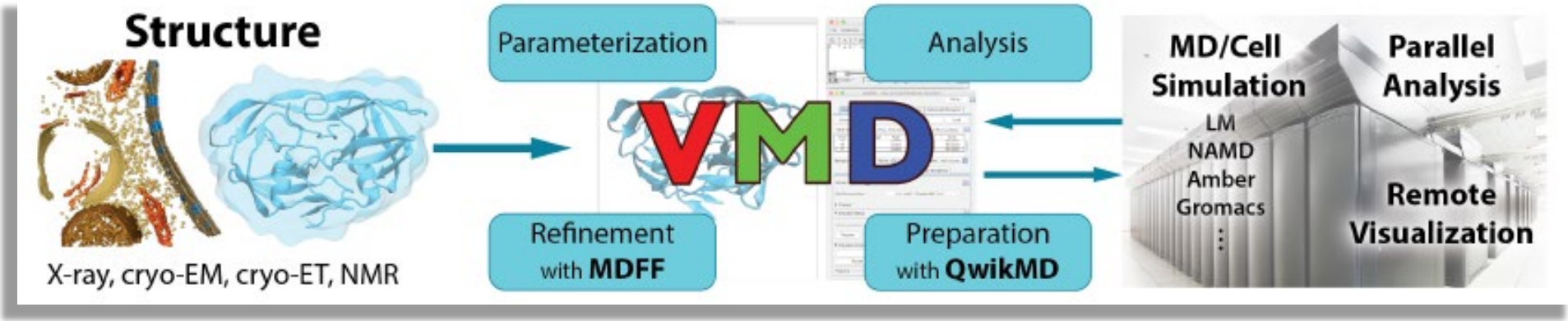
http://www.ks.uiuc.edu/Research/vmd/



Cell-Scale Modeling

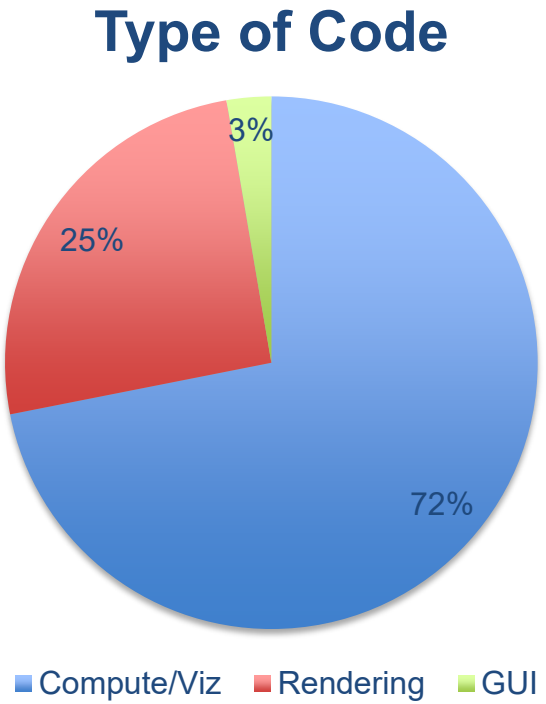


MD Simulation



VMD Software Decomposition

- Rendering code is 25% core VMD lines of code
  - 358,000 LoC total
  - 92,000 LoC rendering!
- Need to evolve VMD toward higher level rendering abstractions

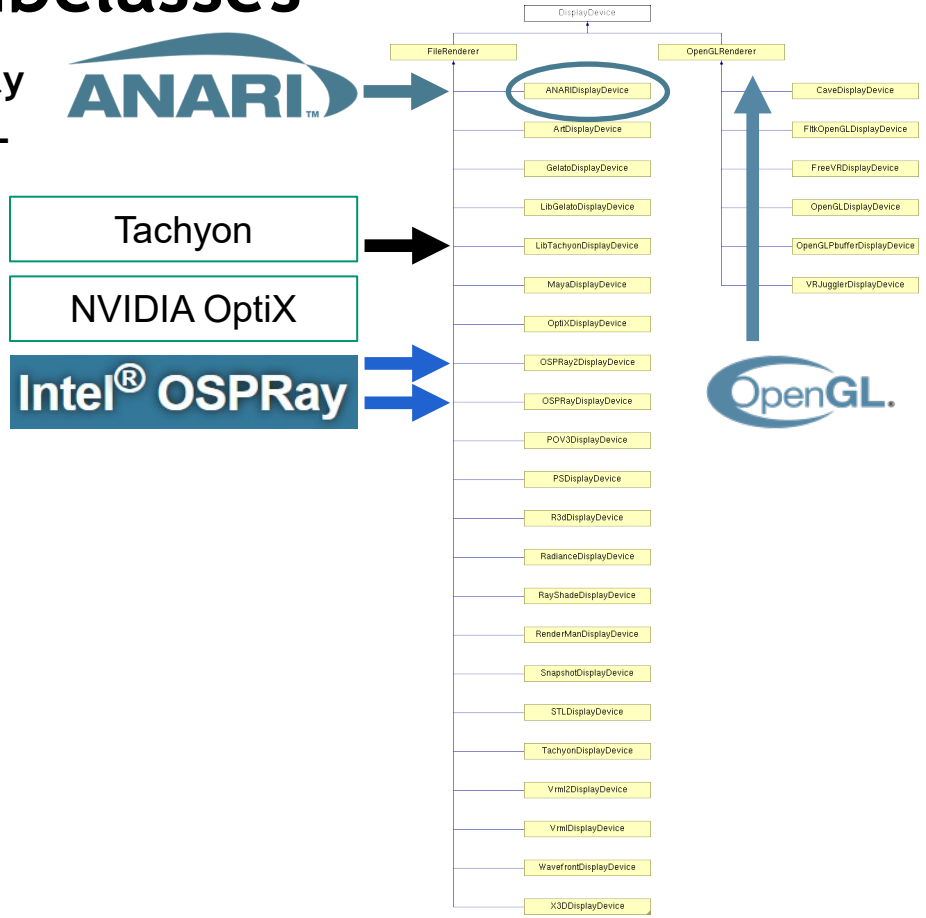


VMD Rendering Code

- 92,000 lines in total
- Roughly 20,000 are high level abstractions
- Remaining ~72,000 lines are various (internal) full rendering engines and their support code
- Tremendous **specialized expertise required** to write and maintain renderers **anywhere close to current state-of-the-art**

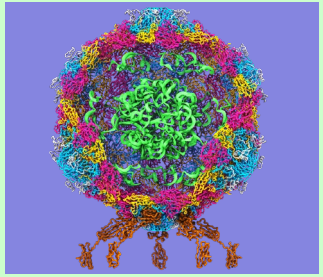
VMD DisplayDevice Subclasses

- **Interactive display renderer originally written using Silicon Graphics IRIS GL**
- **C++ DisplayDevice subclasses**
  - Ease support for new interactive or offline/batch renderers
  - CAVE VR displays
  - Desktop windowed OpenGL
  - Interactive ray tracing
  - Heavily used for coupling VMD to offline/batch renderers



VMD Molecular Structure Data and Global State

Scene Graph



Graphical Representations

- DrawMolecule
- Non-Molecular Geometry

User Interface Subsystem

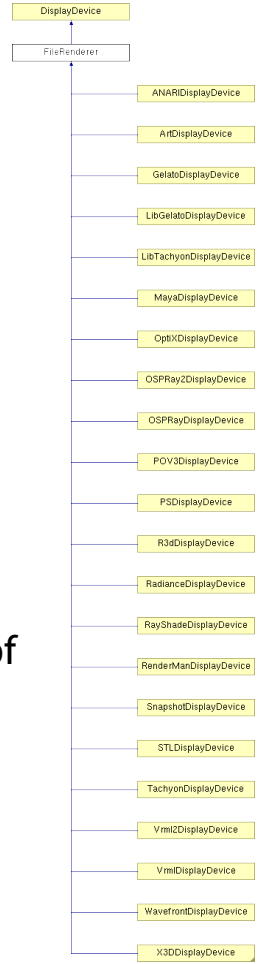
- Tcl/Python Scripting
- Mouse + Windows
- VR Input “Tools”

Display Subsystem

- VMDDisplayList
- DisplayDevice
- OpenGLDisplayDevice
- FileRenderer
- Windowed OpenGL GPU
- OpenGL Pbuffer GPU
- Tachyon CPU RT
- TachyonL-OptiX GPU RT Batch + Interactive

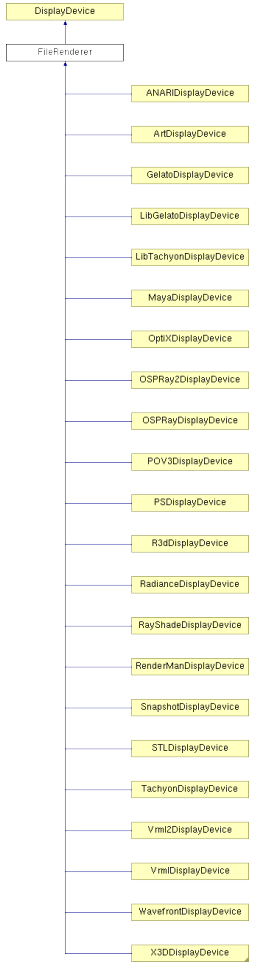
VMD Offline Renderer Subclasses

- **20,000+ lines of code in 22+ *FileRenderer* subclasses**
  - Every implementation is different despite the common VMD class hierarchy they operate within
  - Development, debugging, testing, and maintenance are all very costly in time and require significant expertise
- **VMD scheme to reduce programming complexity:**
  Subclasses implement virtual methods for features supported by their associated back-end renderer
  - Unimplemented virtual methods revert to superclass implementations:
  - Provide emulation / alternative / workarounds, e.g. triangulation of spheres, cylinders, cones
  - Runtime warning for anything that remains unimplemented in the scene



VMD ANARI Offline Renderer Subclass

- **VMD C++ sublasses and virtual methods simplify porting and incremental bringup of new renderers**
  - Emulation of missing features always comes at a performance or memory cost, but for offline renderers, these are reasonable trade-offs
  - Differences in shading and material properties tend to remain an area where different renderers still diverge and have a unique “look”
- **ANARI has been EASY to implement incrementally within the VMD offline rendering framework**
  - Added virtual method for material handling
  - Incrementally add virtual methods for geometric primitive types associated with ANARI subtypes
  - **NEXT: better integration of ANARI with VMD’s methods for geometric instancing**

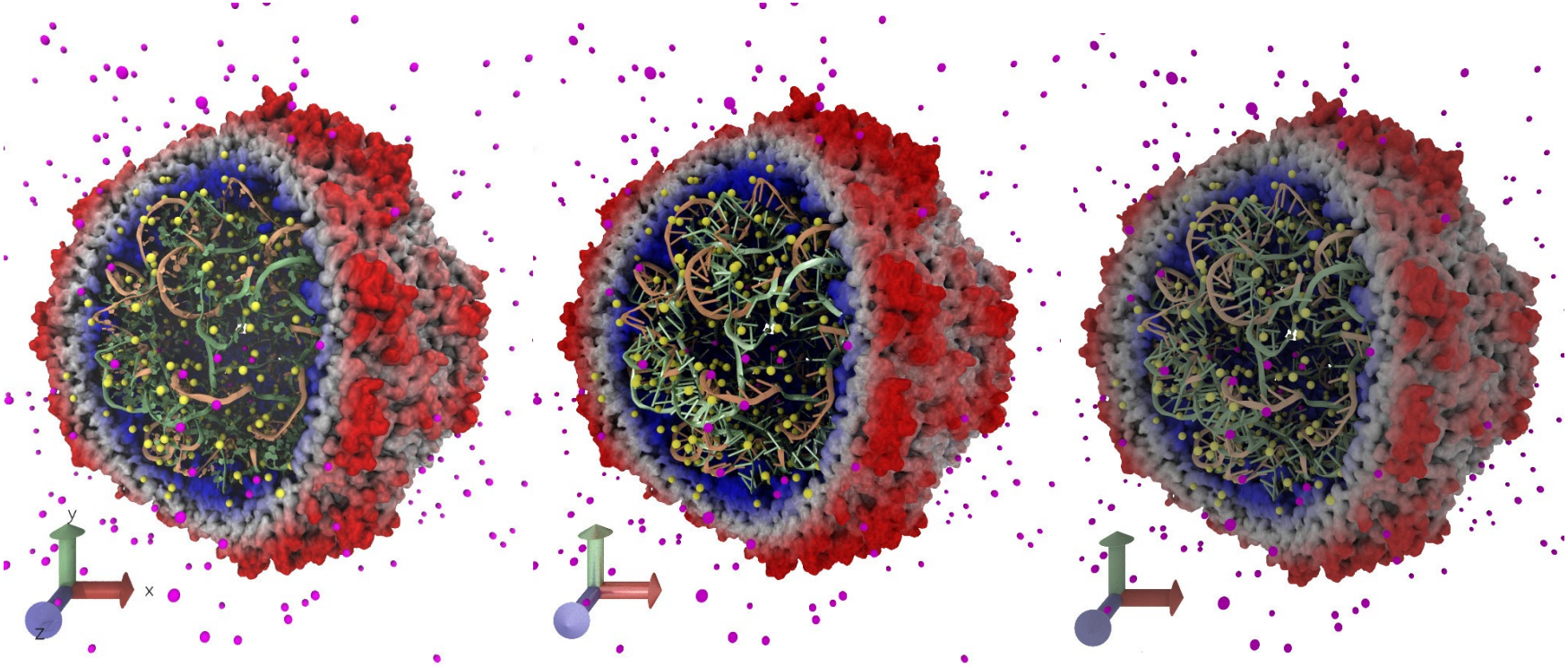


VMD Examples from Early In-Progress ANARI Impls.

Tachyon Ray Tracer (AO)

OSPRay Path Tracer

OptiX Path Tracer



```
// Use the 'example' library if not overridden, this is where the impl(s) come from
const char *libname = "example";
if (getenv("ANARI_LIBRARY"))
  libname = getenv("ANARI_LIBRARY");
ANARILibrary lib = anariLoadLibrary(libname, statusFunc, NULL);
ANARIDevice dev = anariNewDevice(lib, "default");
if (!dev) {
  printf("\n\nERROR: could not load default device in example library\n");
  return -1;
}
anariCommit(dev, dev);

// .... abridged application code ...

// create and setup camera
ANARICamera camera = anariNewCamera(dev, "perspective");
float aspect = imgSize[0] / (float)imgSize[1];
anariSetParameter(dev, camera, "aspect", ANARI_FLOAT32, &aspect);
anariSetParameter(dev, camera, "position", ANARI_FLOAT32_VEC3, cam_pos);
anariSetParameter(dev, camera, "direction", ANARI_FLOAT32_VEC3, cam_view);
anariSetParameter(dev, camera, "up", ANARI_FLOAT32_VEC3, cam_up);
anariCommit(dev, camera); // commit camera object to indicate mods are done
```

Figure 11. Example ANARI API calls required to load and instantiate an ANARI "device" implementation, and to create a perspective camera, and set its associated parameters.

ANARI: A 3D Rendering Interface Standard. J. E. Stone, K. Griffin, J. Amstutz, D. DeMarle, W. Sherman, J. Günther. Computing in Science and Engineering, 2022.

```
ANARISurface gen_knot(ANARIDevice dev, float *coords, float *colors,
                      int numpts, float radius, ANARIMaterial mat) {
  ANARIGeometry spheres = anariNewGeometry(dev, "sphere");
  ANARIArray1D array;
  array = anariNewArray1D(dev, coords, 0, 0, ANARI_FLOAT32_VEC3, numpts, 0);
  anariCommit(dev, array);
  anariSetParameter(dev, spheres, "vertex.position", ANARI_ARRAY1D, &array);
  anariRelease(dev, array); // we are done using this handle

  anariSetParameter(dev, spheres, "radius", ANARI_FLOAT32, &radius);

  ANARIArray1D cols = anariNewArray1D(dev, colors, 0, 0, ANARI_FLOAT32_VEC4, numpts, 0);
  anariSetParameter(dev, spheres, "vertex.color", ANARI_ARRAY1D, &cols);
  anariCommit(dev, spheres);

  ANARISurface surface = anariNewSurface(dev);
  anariSetParameter(dev, surface, "geometry", ANARI_GEOMETRY, &spheres);
  anariSetParameter(dev, surface, "material", ANARI_MATERIAL, &mat);
  anariCommit(dev, surface);
  anariRelease(dev, spheres); // we are done using this handle

  return surface;
}
```

Figure 12. ANARI API calls that add an array of spheres to the scene, adapted from the knot example.

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```
// The world to be populated with renderable objects
ANARIWorld world = anariNewWorld(dev);

// Set the material rendering parameters
ANARIMaterial mat = anariNewMaterial(dev, "matte");
// route the primitive/vertex colors to the material's color input
anariSetParameter(dev, mat, "color", ANARI_STRING, "color");
anariCommit(dev, mat);

// generate surface geometry
int numsurfs = 0;
ANARISurface surfs[2] = { 0 };
surfs[numsurfs++] = gen_knot(dev, coords, colors, numpts, 0.33f, mat);
surfs[numsurfs++] = gen_floor(dev, 200.0f, 3.5f, 200.0f, mat);
anariRelease(dev, mat);

// put the surfaces directly onto the world
ANARIArray1D array = anariNewArray1D(dev, surfs, 0, 0, ANARI_SURFACE, numsurfs, 0);
anariCommit(dev, array);
anariSetParameter(dev, world, "surface", ANARI_ARRAY1D, &array);
anariCommit(dev, world); // finalize the completed world
for (int i=0; i<numsurfs; i++)
  anariRelease(dev, surfs[i]);
anariRelease(dev, array);

// setup renderer and associated params...
ANARIRenderer rend = anariNewRenderer(dev, "default"); // could use pathtracer, etc
float bgColor[4] = {1.f, 1.f, 1.f, 1.f}; // white
anariSetParameter(dev, rend, "backgroundColor", ANARI_FLOAT32_VEC4, bgColor);
anariCommit(dev, rend); // finalize renderer

// create and setup frame
ANARIFrame frame = anariNewFrame(dev);
anariSetParameter(dev, frame, "size", ANARI_UINT32_VEC2, imgSize);
ANARIDataType fbFormat = ANARI_UFIXED8_RGBA_SRGB;
anariSetParameter(dev, frame, "color", ANARI_DATA_TYPE, &fbFormat);
anariSetParameter(dev, frame, "renderer", ANARI_RENDERER, &rend);
anariSetParameter(dev, frame, "camera", ANARI_CAMERA, &camera);
anariSetParameter(dev, frame, "world", ANARI_WORLD, &world);
anariCommit(dev, frame);

// render and accumulate frames
for (int frames = 0; frames < 100; frames++) {
  anariRenderFrame(dev, frame); // launch async frame rendering...
  anariFrameReady(dev, frame, ANARI_WAIT); // wait for async frame completion...
}
```

Figure 13. ANARI example scene setup and rendering loop, adapted from the knot example.

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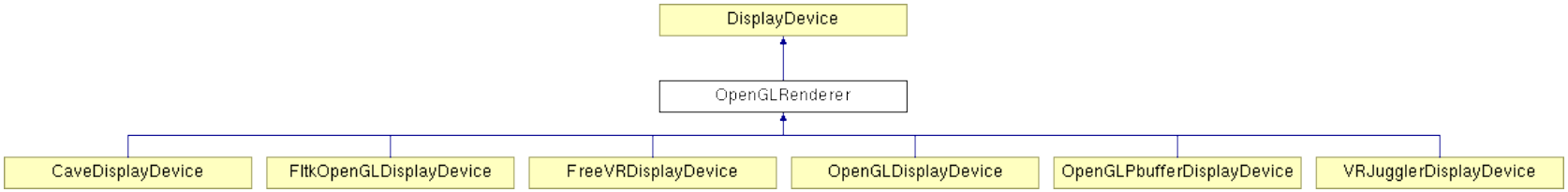
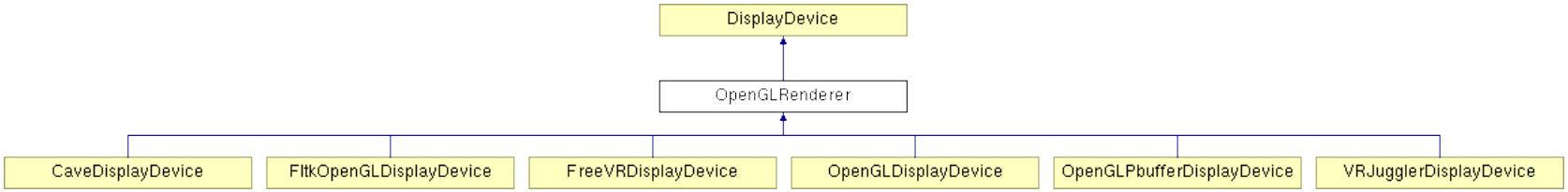
VMD Interactive Renderer Subclasses

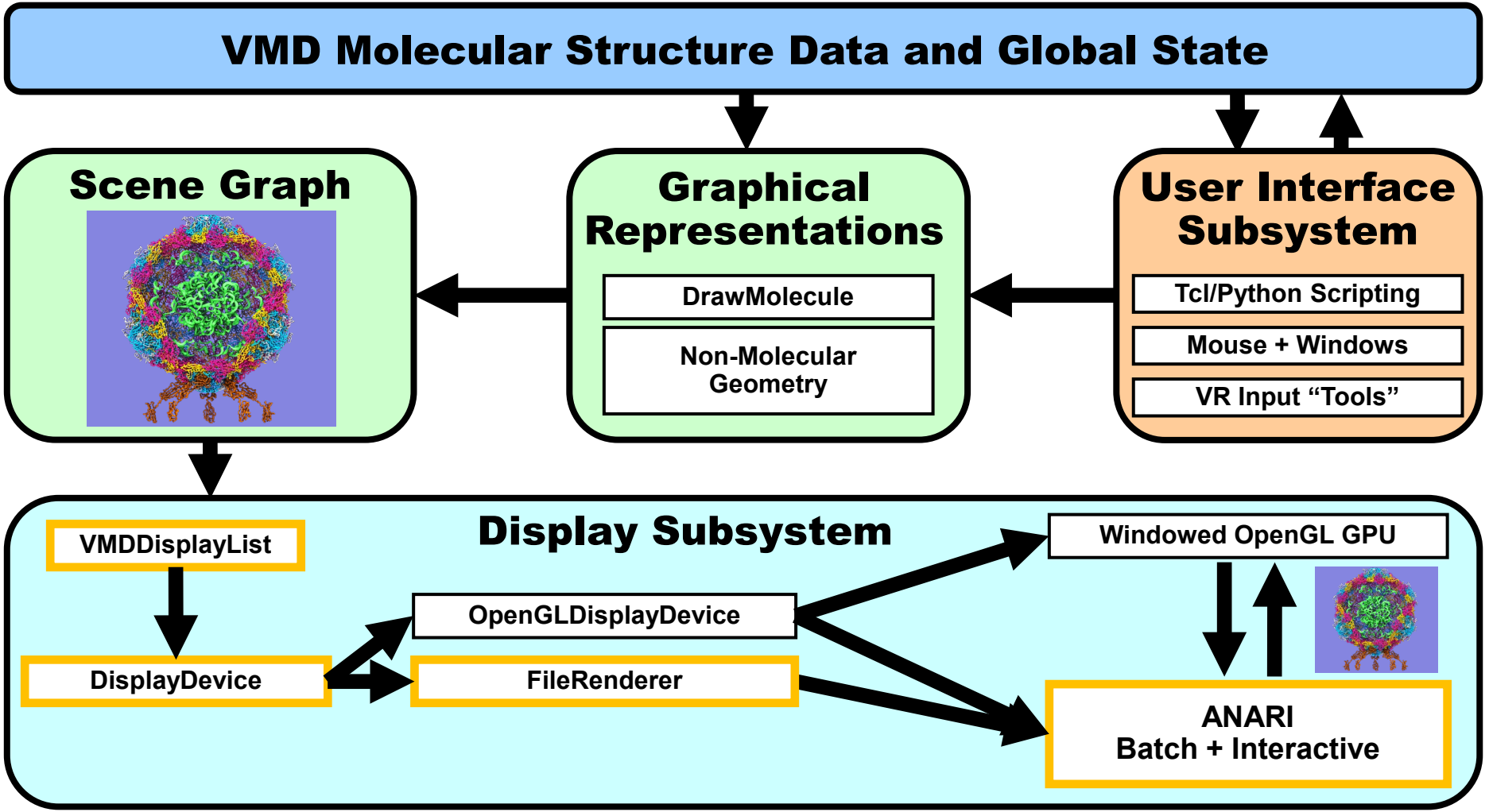
- **Current VMD hierarchy branches off from an OpenGL renderer class (several omitted in the figure below)**
  - Interactive ray tracing engines (RTRT), real-time video streaming variations and various VR display subclasses
  - RTRT mode only uses OpenGL for windowed image presentation
  - Subclasses “piggyback” on the OpenGL superclass methods, and apply further specialization
  - Performance is critical, so there’s no emulation of missing features, geometric primitives



VMD Interactive Renderer Subclasses

- **Implementation of ANARI in the interactive hierarchy is FAR simpler than what was done historically for IRIS GL, OpenGL, Vulkan, etc…**
- **Primary consideration going forward is ensuring maximally efficient use of ANARI objects, so that ANARI back-end implementations can:**
  - Use high-performance data transfer/caching methods, particularly on GPU accelerated back-ends
  - Maintain persistent data structures for unchanging scene components
  - Minimize geometry acceleration structure (BVH) (re)builds
  - Exploit efficient internal methods for object instancing




VMD Molecular Structure Data and Global State
Scene Graph
Graphical Representations
DrawMolecule
Non-Molecular Geometry
User Interface Subsystem
Tcl/Python Scripting
Mouse + Windows
VR Input "Tools"
Display Subsystem
VMDDisplayList
DisplayDevice
OpenGLDisplayDevice
FileRenderer
Windowed OpenGL GPU
ANARI
Batch + Interactive

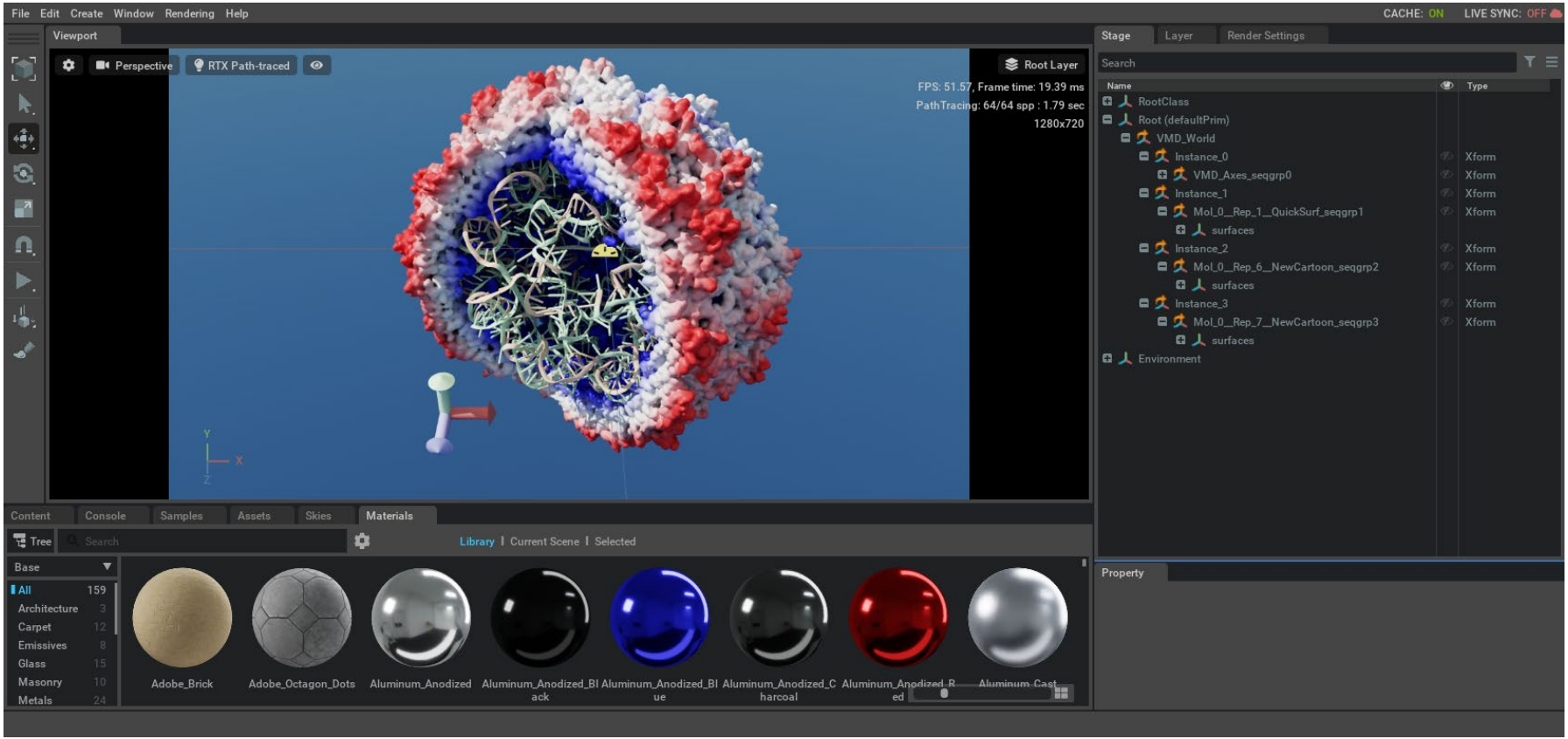
ANARI VMD Integration Experiences

- **ANARI 1.0 (provisional) includes complete coverage of key required camera, light, and geometry subtypes for molecular visualization**
- **Special VMD-specific materials will be an interesting challenge**
  - VMD will likely co-evolve to exploit ANARI opportunities
  - VMD could adopt support for industry standard materials that get exposed in ANARI either as core features or extensions
- **Early ANARI devices that implement the geometric subtypes needed by VMD already do well as offline renderers, both rendering performance and memory use are acceptable**
- **Early experiences with real-time interactive rendering shows that the ANARI back ends will work very well for static scenes**
- **VMD ANARI implementation for interactive fully dynamic scene geometry (simulation "trajectory" time series playback, etc) is in early stages:**
  - Teaching VMD how to selectively create/destroy individual ANARI scene elements to facilitate higher interactive renderings when only a small part of a scene evolves dynamically

ANARI VMD Integration Experiences

- **Integration with specific types of back-end devices/renderers:**
  - ANARI devices that use OpenGL require special consideration related to OpenGL context sharing or management
  - ANARI devices using other APIs (Intel Embree, NVIDIA CUDA+OptiX, Vulkan, …) haven't **yet** required special handling since they insulate of internal state, threading, and context management
  - ANARI USD device makes use of ANARI "name" tags on the various ANARI objects, enabling the tags to be visible in GUI treeview displays of scene contents
    - Required a little finesse to convert VMD-internal scene component names into something usable in an outboard GUI/renderer combo
    - Enables VMD scenes to retain scientifically relevant object, group, instance name tags within tools like NVIDIA Omniverse Create

VMD+NVIDIA Omniverse Using ANARI USD Impl.



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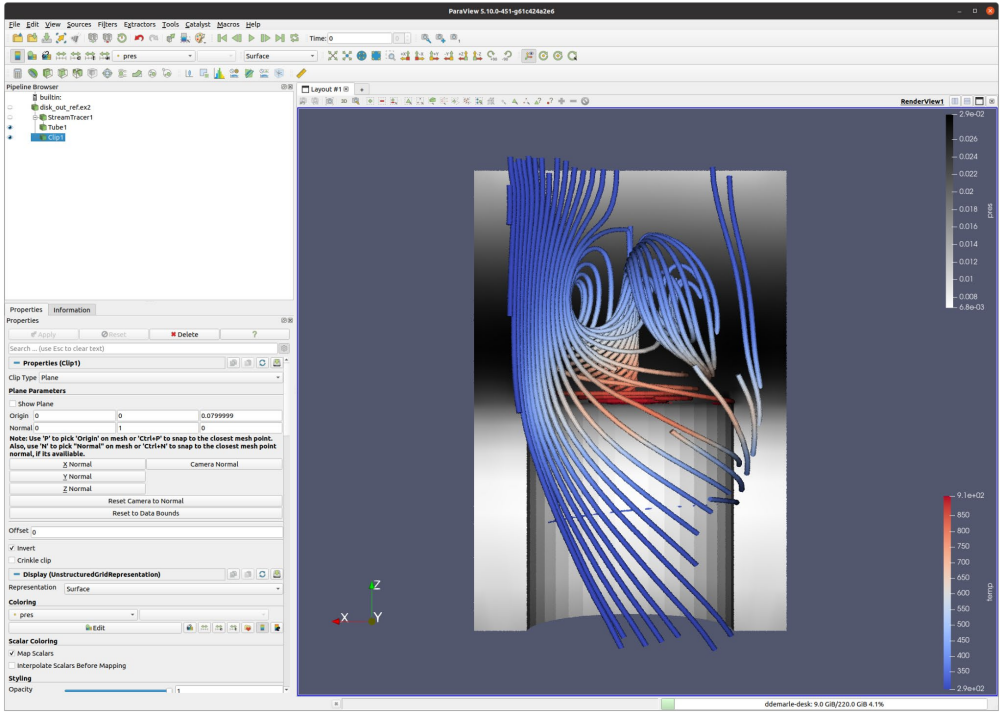
ANARI Developer Tools

- **Special ANARI "devices" for debugging and API tracing**
- **Debug device interposed in-between active back-end device/renderer and application**
  - Catch common ANARI programming mistakes:
    - Catch/warn on bad ANARI parameter strings
    - Use of uncommitted ANARI object
    - Leaked ANARI object (fail to make release calls)
    - Warnings for redundant commits
- **ANARI API Tracing:**
  - Capture+log all ANARI API calls and arrays, data, to disk files
  - Use captured API trace to (with some editing) create standalone compilable source code to replay API sequence and associated data
- **Future ideas?:**
  - Includable ANARI-specific profiling tag macros for popular performance analysis tools

Examples from In-Progress ANARI Impls.



ParaView visualization rendered with ANARI OSPRay back-end.

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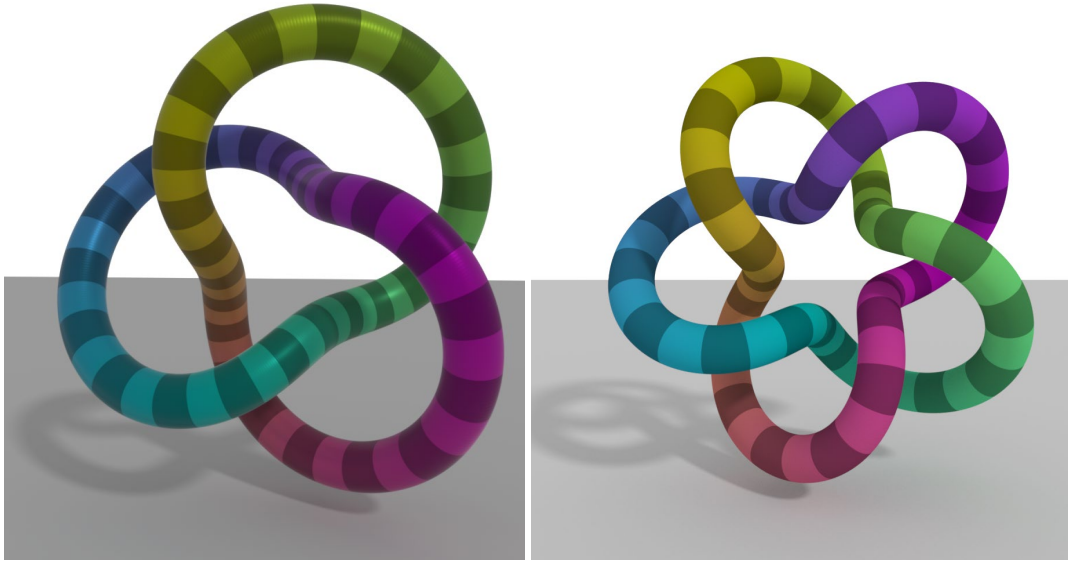
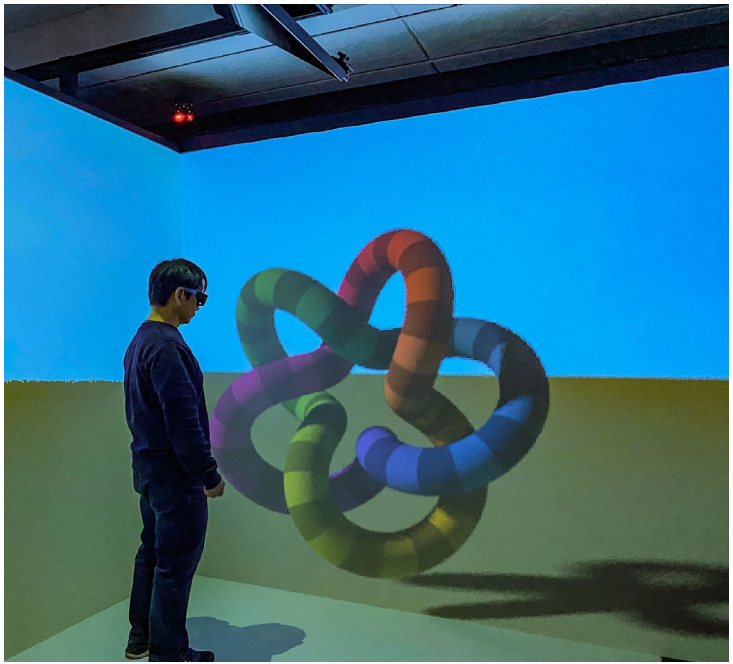


Knots drawn using ANARI sphere primitives with OSPRay back-end.



CAVE VR Display at NIST

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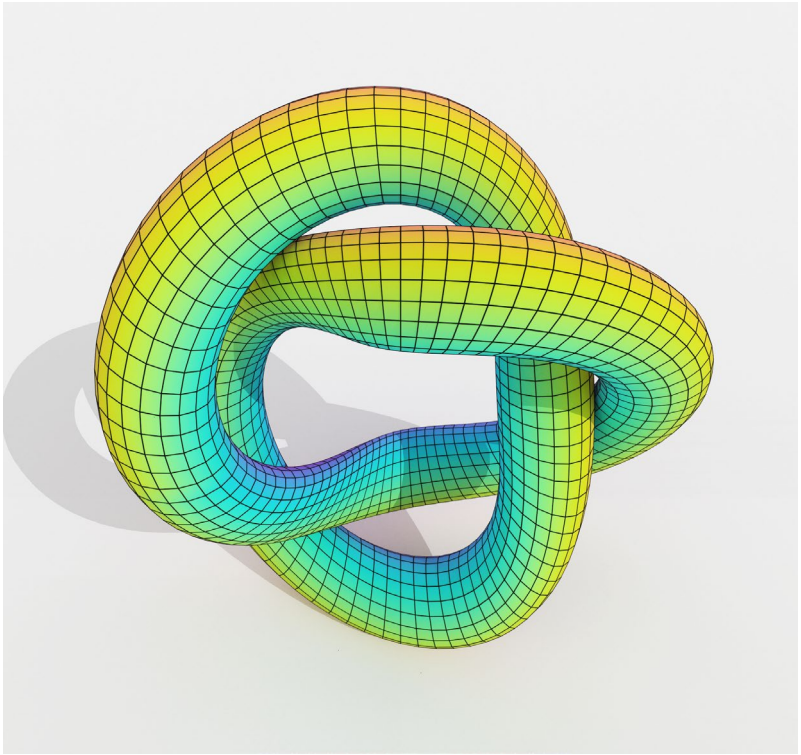

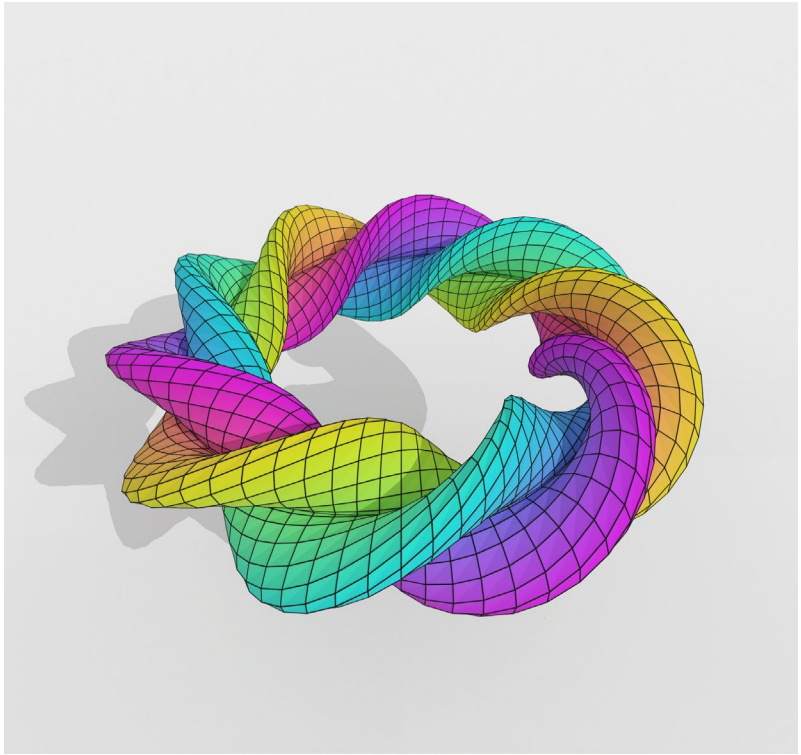

Parametric Surfaces with ANARI VisRTX back-end.

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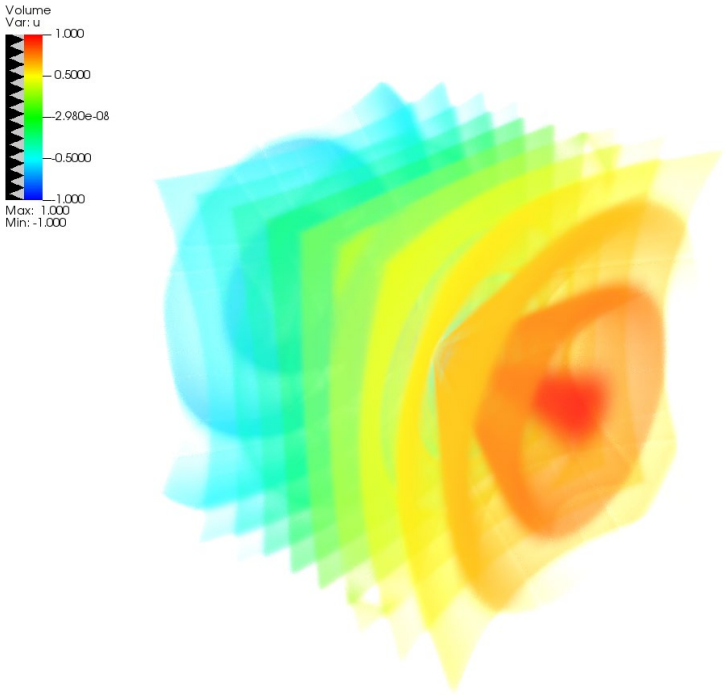
Examples from In-Progress ANARI Impls.



VisIt distributed memory MPI volume rendering using the ANARI VisRTX back-end, with IceT image compositing.

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Examples from In-Progress ANARI Impls.

San Miguel scene using ANARI VisRTX back-end.

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Q&A Panel