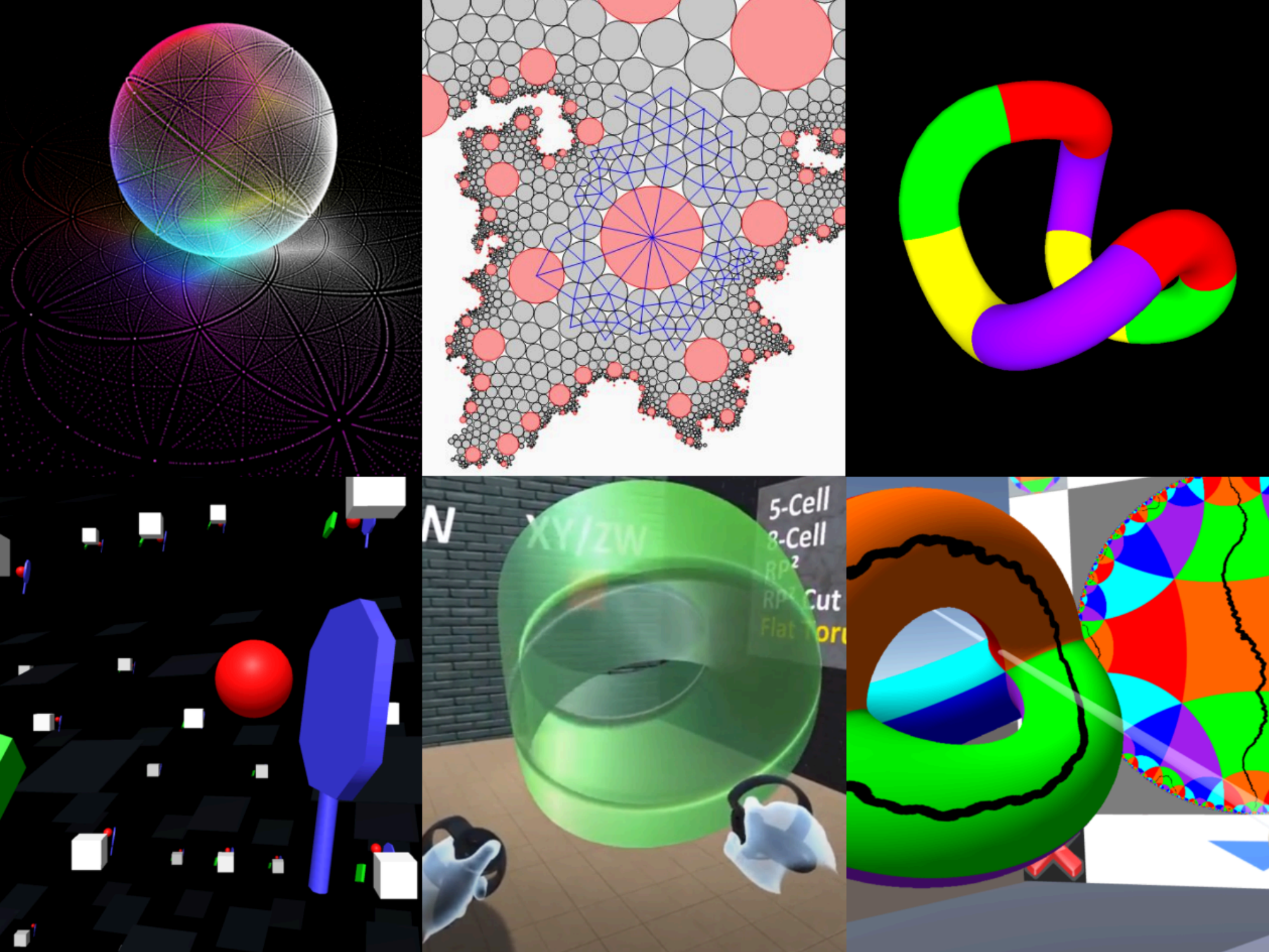
# Supervising undergraduate research in mathematical visualization

**David Dumas**

University of Illinois at Chicago

July 17, 2020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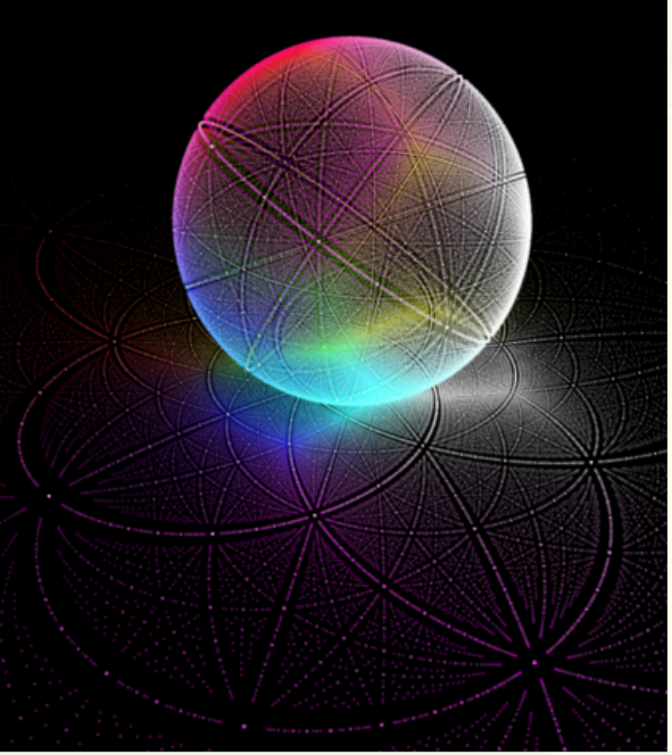
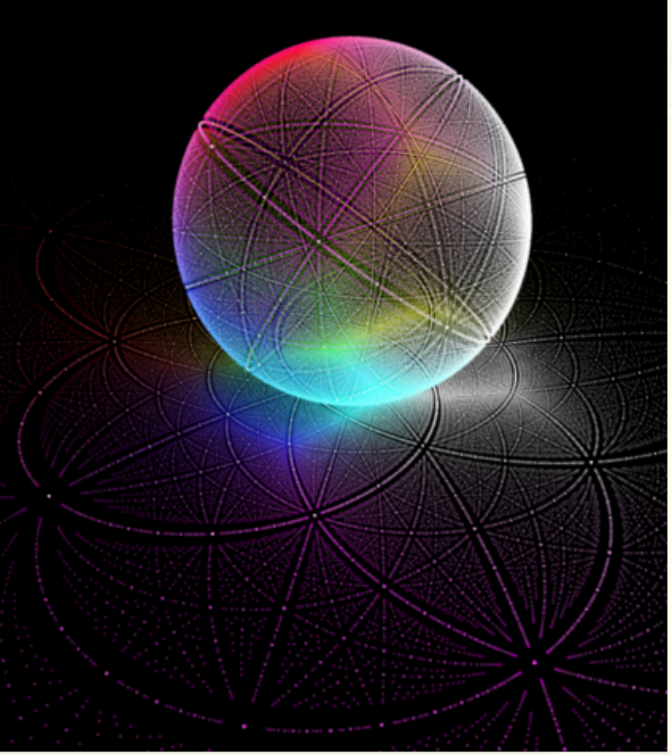


# Fall 2015
# Immersive Visualization of Data Sets in $S^3$

Angela George
Alexander Gilbert
Nathan Lopez (TA)
Jasmine Otto (TA)



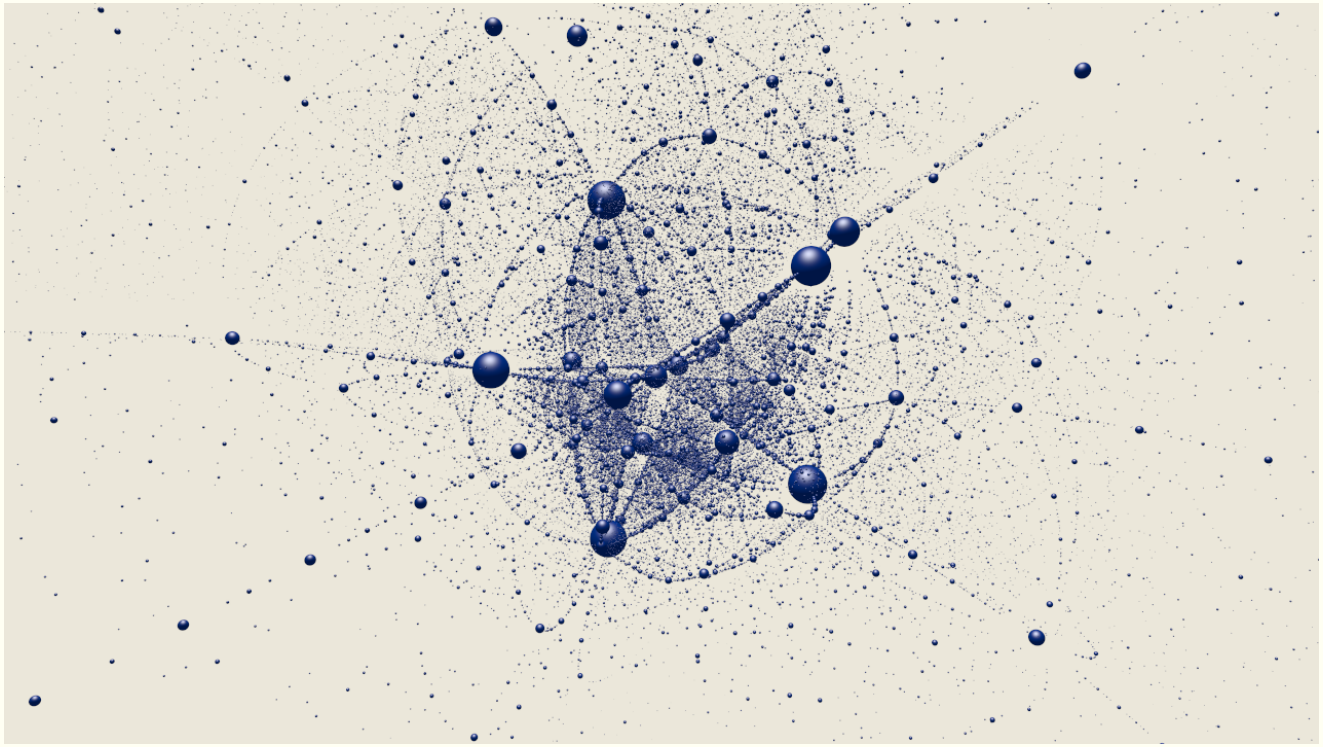
# Fall 2015 & Summer 2016
# Immersive Visualization of Data Sets in $S^3$


Angela George
Alexander Gilbert
Nathan Lopez (TA)
Jasmine Otto (TA)

Galen Ballew
Alexander Gilbert

# 2015: Immersive visualization

Idea: Interactive real-time view of data from the PML visualization project (w/F. Guéritaud)



(These are point clouds in $S^n$. Sometimes, $n = 3$.)

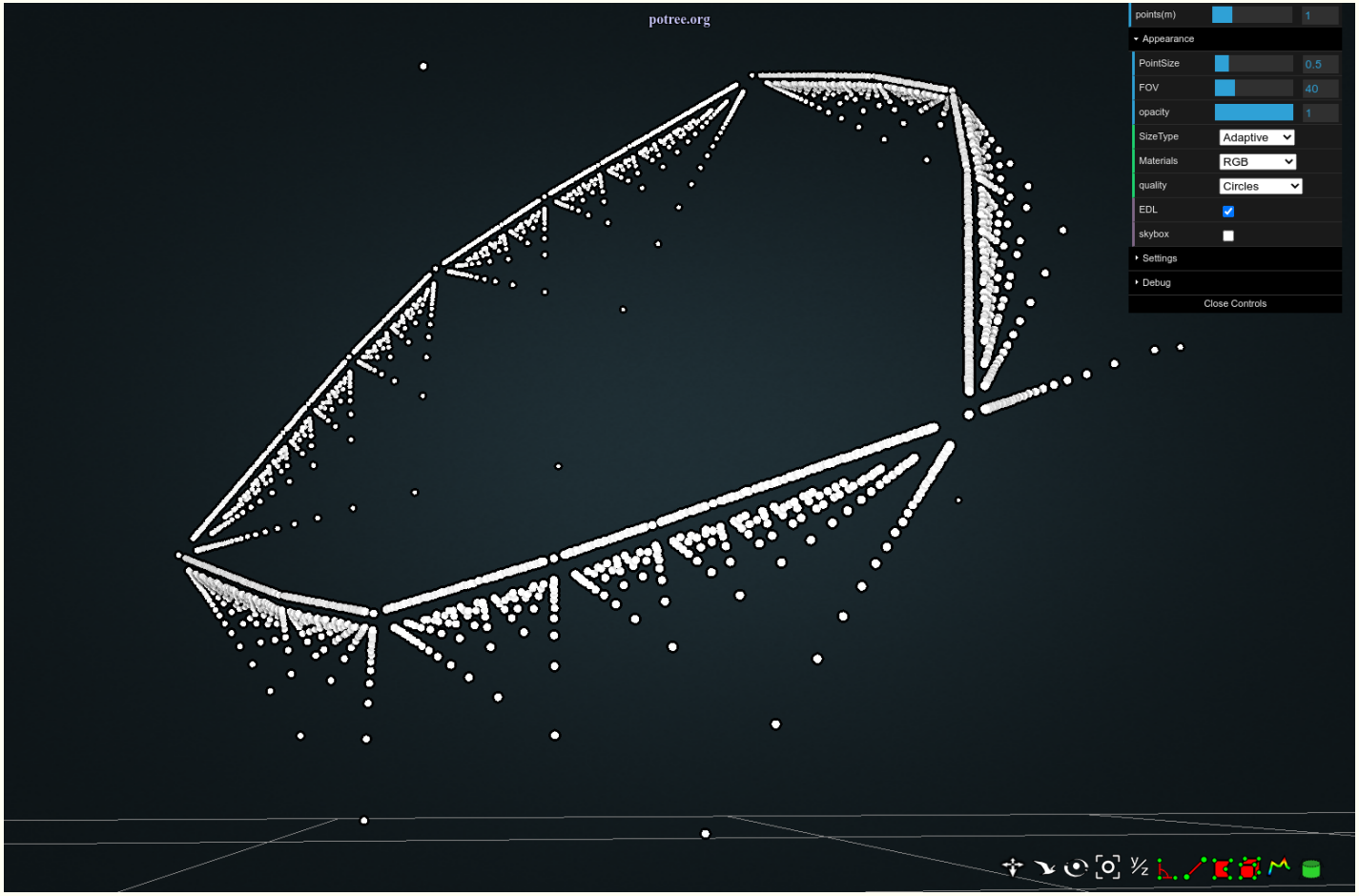
# 2015: Immersive visualization

Structure:

- Supervision
- Separate projects
- Free choice of language, tools
- Lectures about PML

# 2015: Immersive visualization

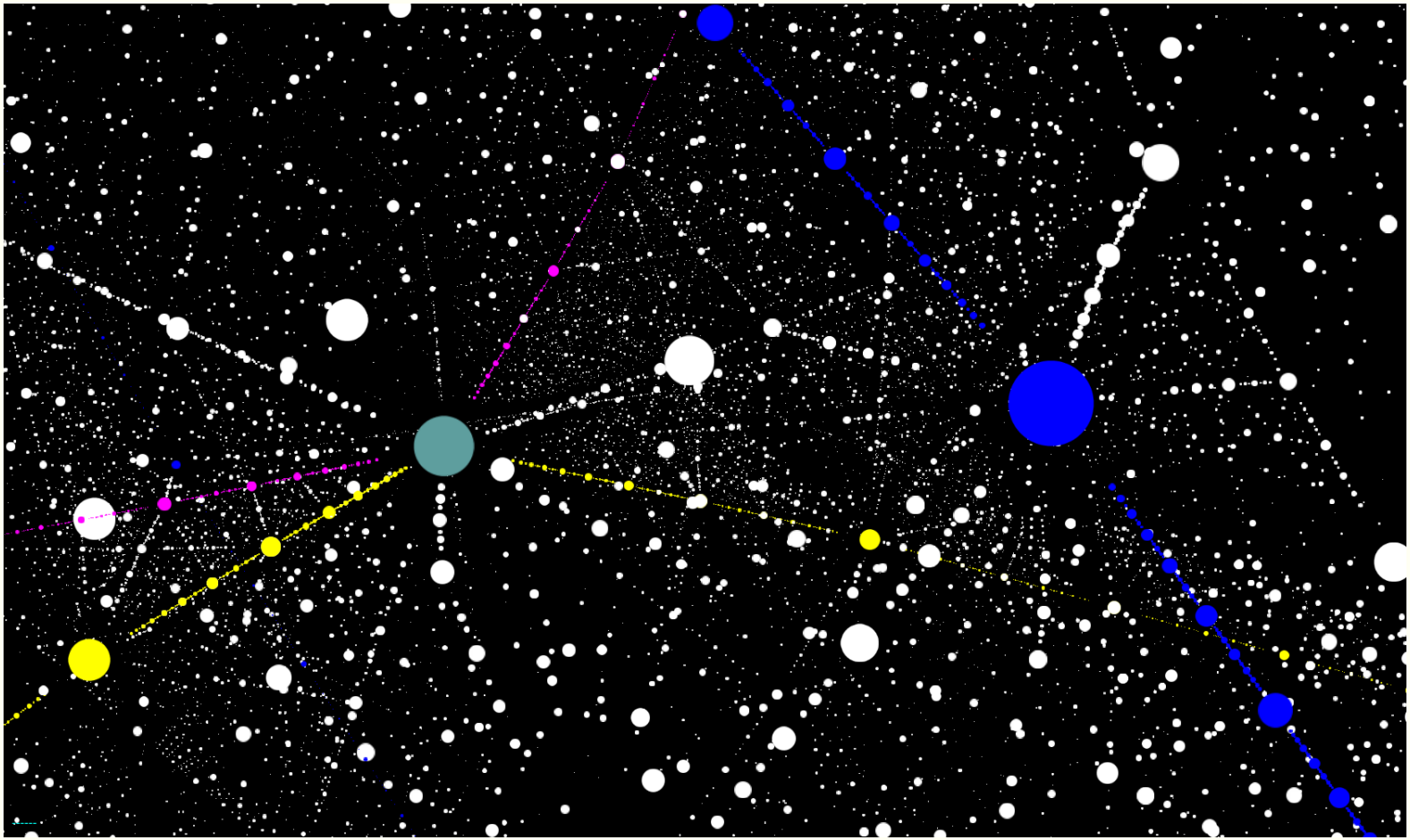
Result (George): WebGL PML dataset viewer




Built with potree Javascript library

# 2015: Immersive visualization

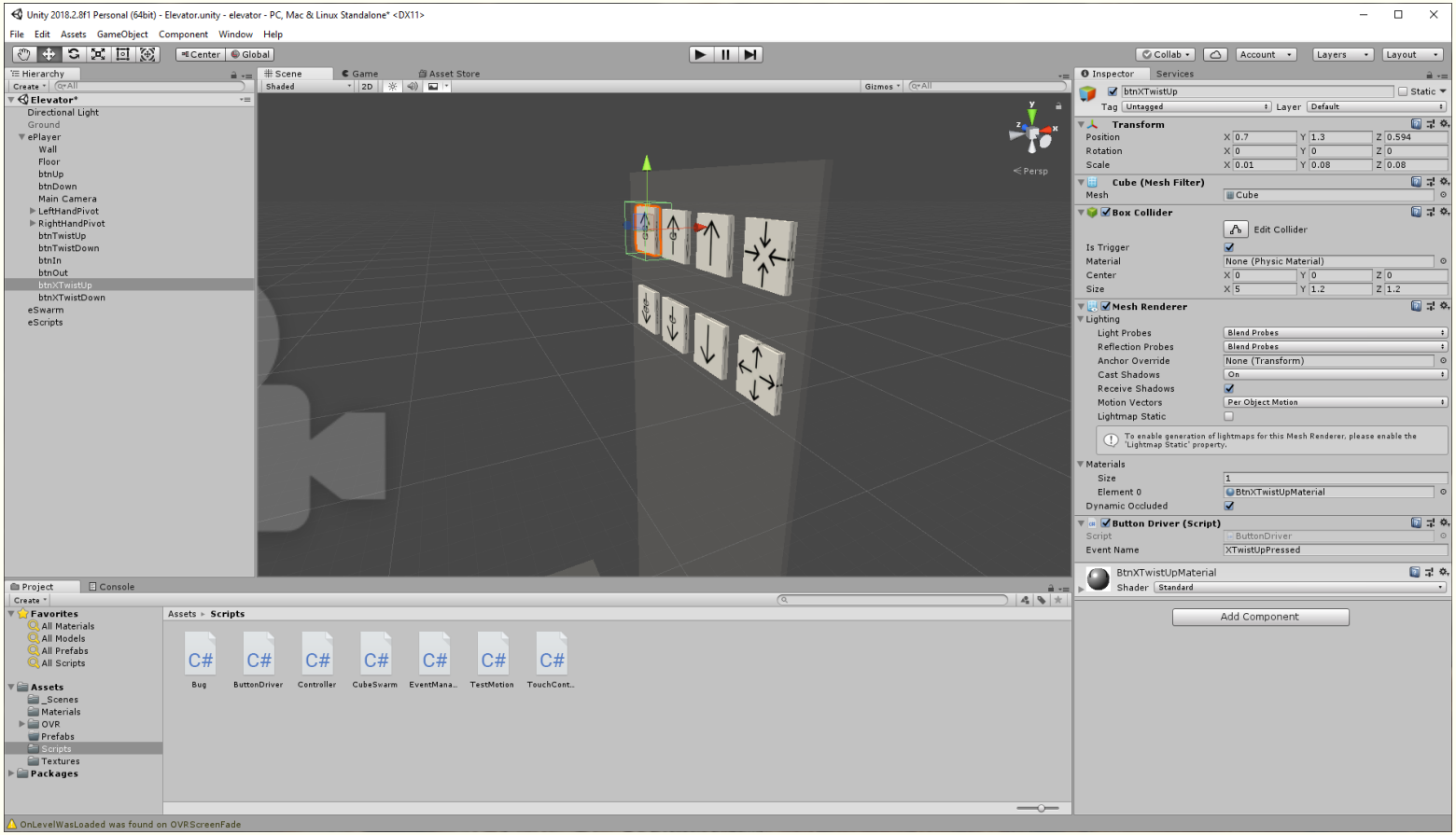
Result (Gilbert): First person PML dataset viewer



Built with Unity (in C#)

# Unity

Popular 3D engine often used for game dev
(Pseudo-WYSIWYG 3D graphics app IDE)

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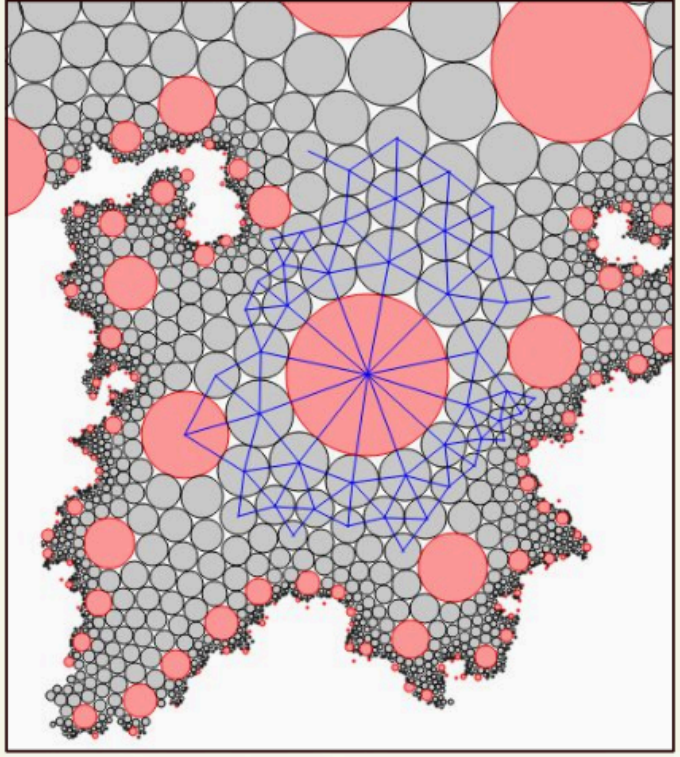
# 2015: Immersive visualization

Things I learned:

- A semester is very short
- Not knowing Javascript, WebGL, C#, or Unity led to me giving well-intentioned bad advice
- Trying to teach about PML was too amibitious



# Summer 2016
# Circle Packing Visualization

Kimberly Kim
Jacob Lewis
Ellie Dannenberg (TA)

# 2016: Circle packing

Idea: Build app to display circle packing $\mathbb{CP}^1$ structures E. Dannenberg and I computed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⋮

```
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⋮

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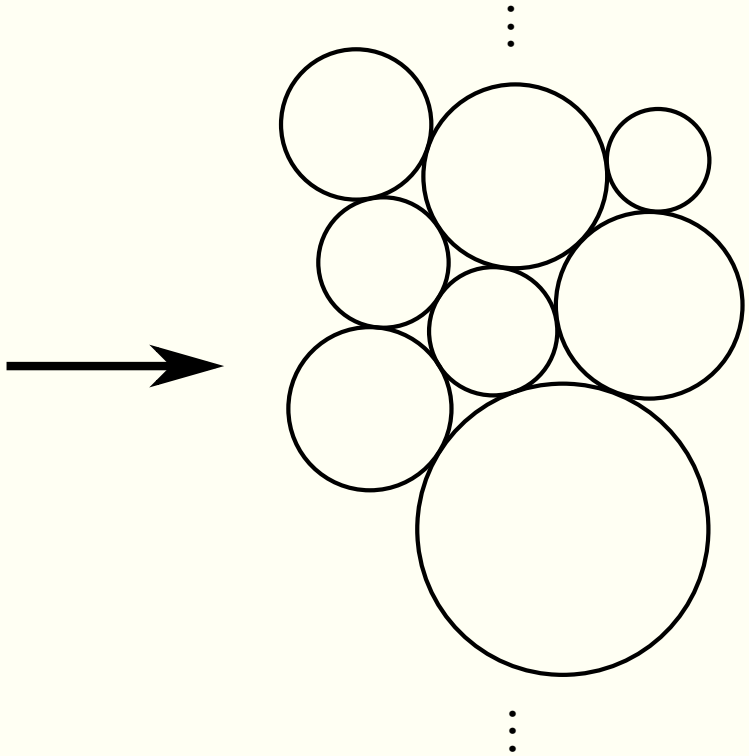


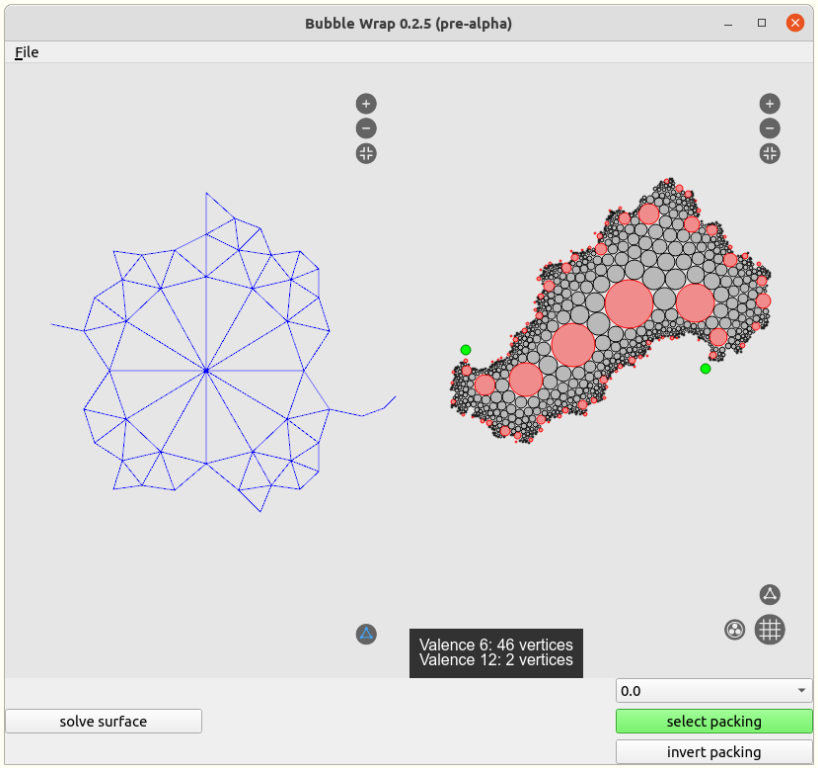
# 2016: Circle packing

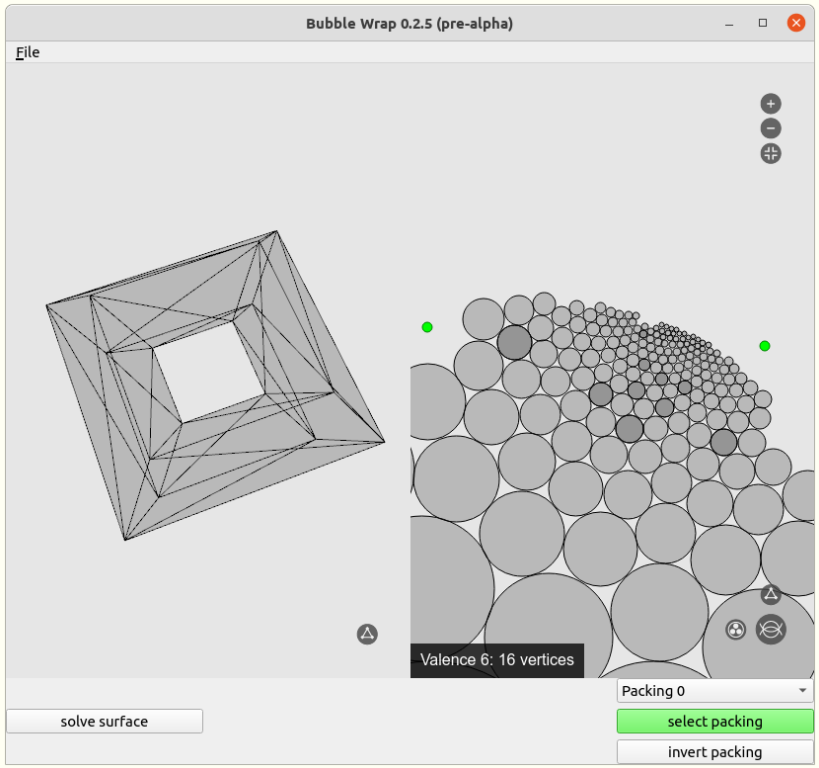
Structure:

- Supervision
- Python
- Students collaborated on a single project
- Lectures about Möbius transformations and circle packings

# 2016: Circle packing

Result: Bubble Wrap, a Python+Qt application

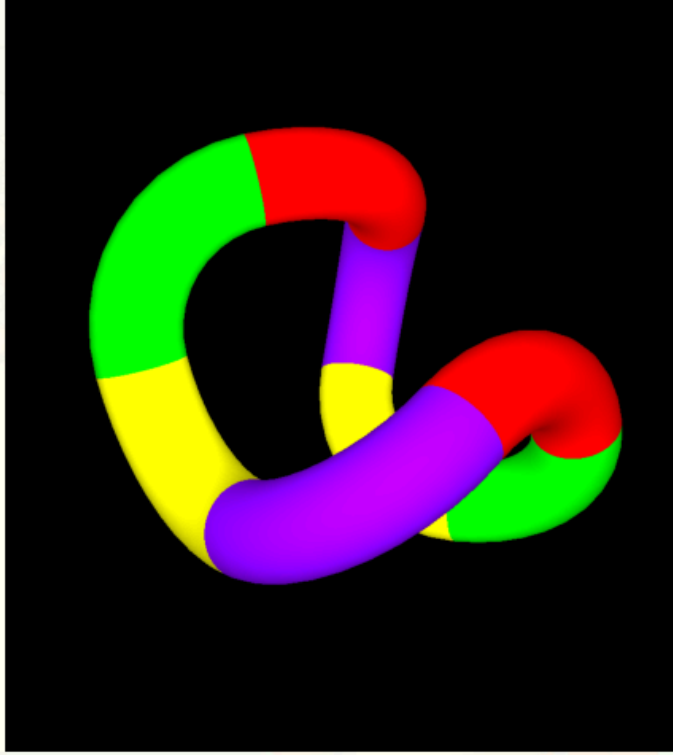


# 2016: Circle packing

Things I learned:

- Version control (git): challenge, payoff
- Python GUI development headaches
- Helpful to have <u>some</u> code for students to look at



# Fall 2016
# Tangle Toy Moduli

Sarah Ather
Rolando Medellin

# 2016: Tangle toy moduli

Idea: Visualize moduli space of the 8-arc tangle toy

Following a 2015 preprint of K. Rafi and G. Zhang

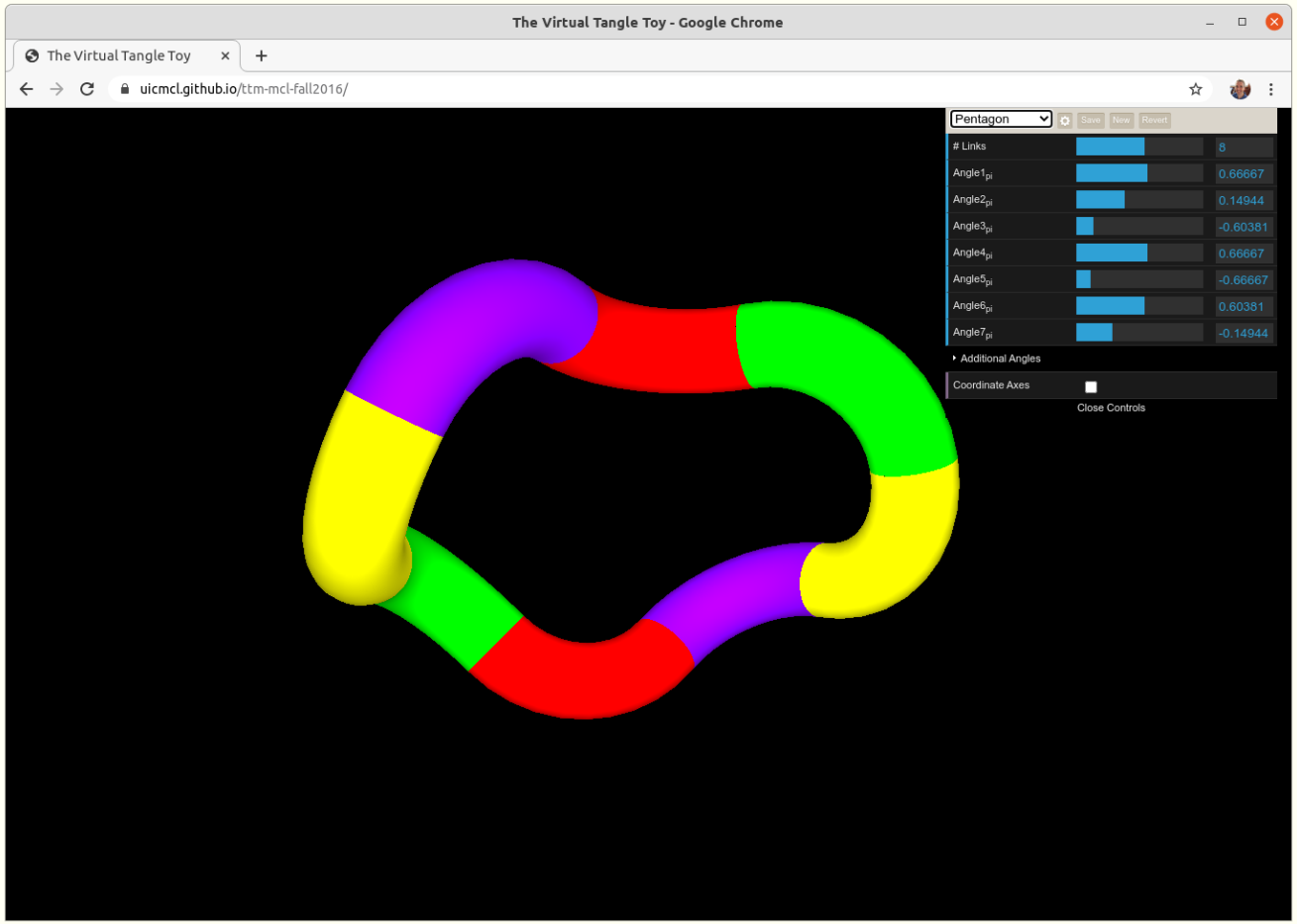
# 2016: Tangle toy moduli

Structure:

- Supervision
- Javascript + WebGL
- Lectures on linear algebra and 3D graphics
- One 90-minute meeting per week

# 2016: Tangle toy moduli

Result: WebGL Tangle Toy




Can rotate joints, but not constrained to be closed

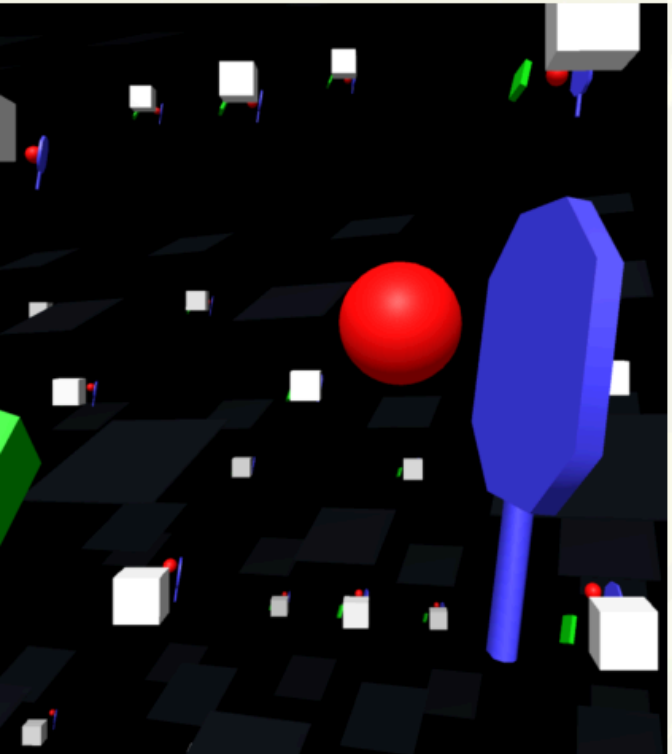
# 2016: Tangle toy moduli

Things I learned:

- The “just works everywhere” aspect of HTML+JS+WebGL is very powerful
- Can host live demo with GitHub pages
- Fewer, longer meetings work well

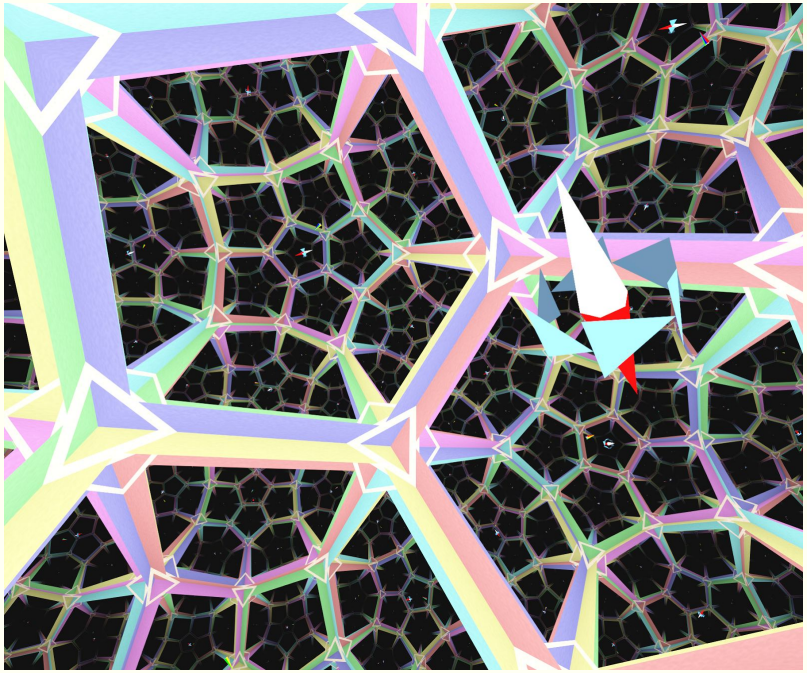
# Spring 2017
# Hyperbolic Racquetball

Horalia Armas
Brandon Reichman
Hai Tran (TA)



# 2017: Hyperbolic racquetball

Idea: One-player VR racquetball in a hyp manifold



Screenshot of *Curved Spaces* by Jeff Weeks

+


Photo by Donna Pool (CC BY-NC-ND)

Use it to teach about hyperbolic geometry, multiply-connected spaces, etc.

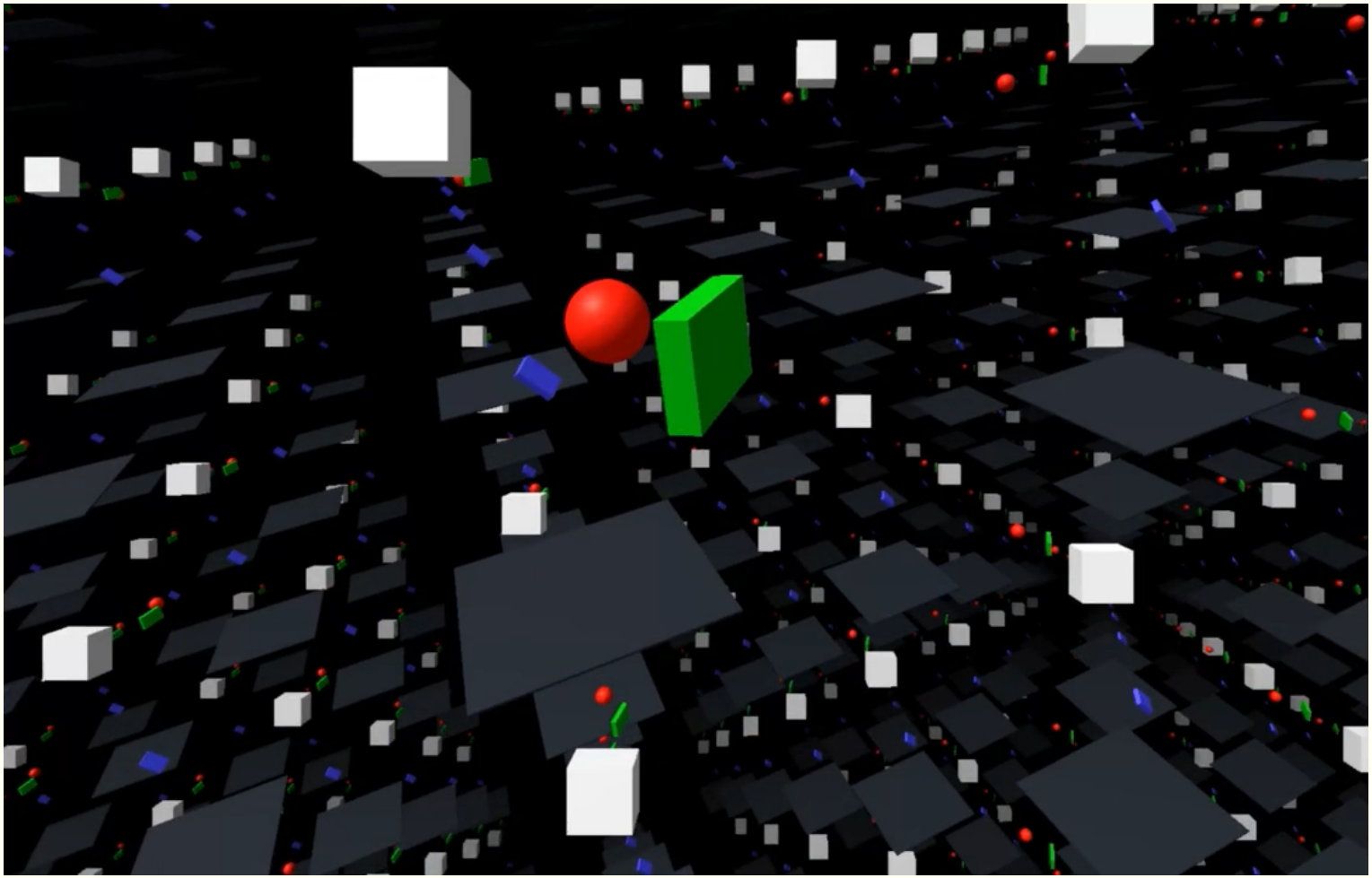
# 2017: Hyperbolic racquetball

Structure:

- Collaboration
- Unity + Oculus VR
- Template program (basic)
- Programming meetings (w/ TA) and project meetings (all)

# 2017: Hyperbolic racquetball

Result: ManifoldBall



VR racquetball in the 3-torus and other Euclidean orbifolds

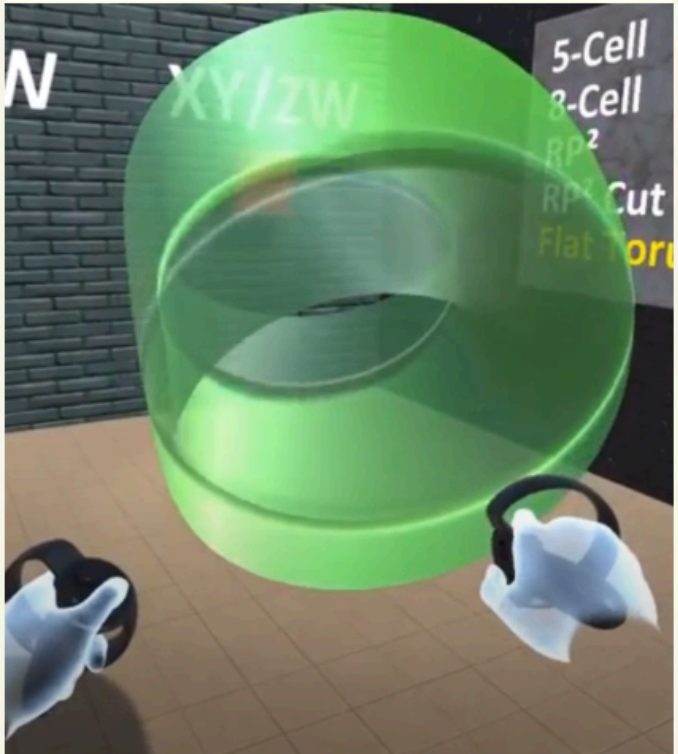
# 2017: Hyperbolic racquetball

Things I learned:

- Graphics programming (shaders, Unity internals)
- VR motion sickness
- Plans were wildly ambitious; fallback goal important

# Fall 2017
# Visualizing 4D with VR

Brandon Reichman



# 2017: 4D VR

Result: 4DVR viewer for surfaces in $\mathbb{R}^4$

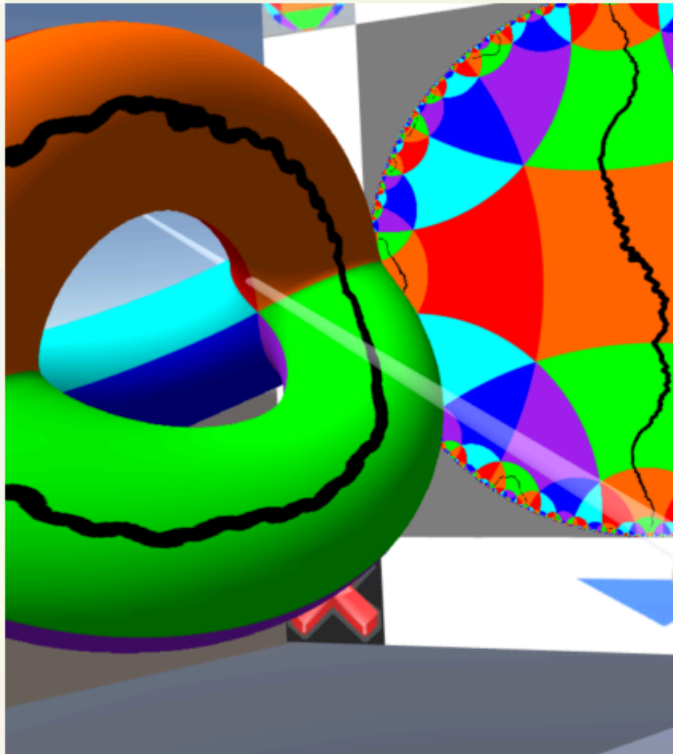
# 2017: 4D VR

Things I learned:

- Fast progress when no tutorial needed

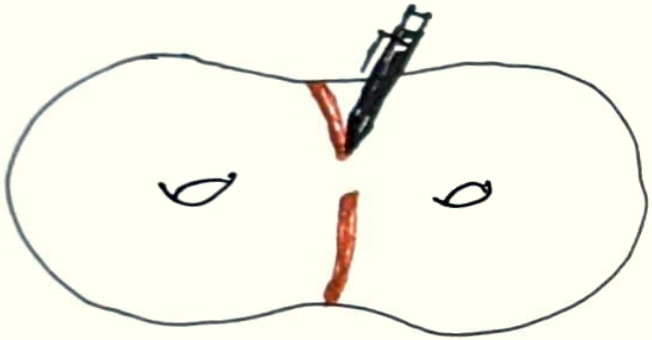
# Fall 2018
# Slicing Surfaces in VR

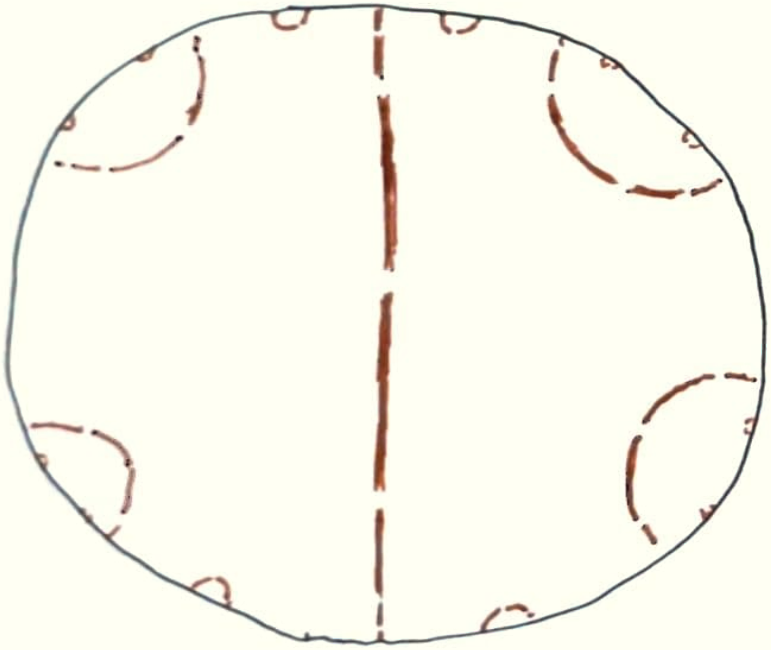
Alexander Adrahtas
Alexander Guo
Gregory Schamberger



# 2018: Slicing surfaces

Idea: VR tool for simultaneous drawing/cutting on genus two surface and its universal cover





Based on suggestion of M. Duchin

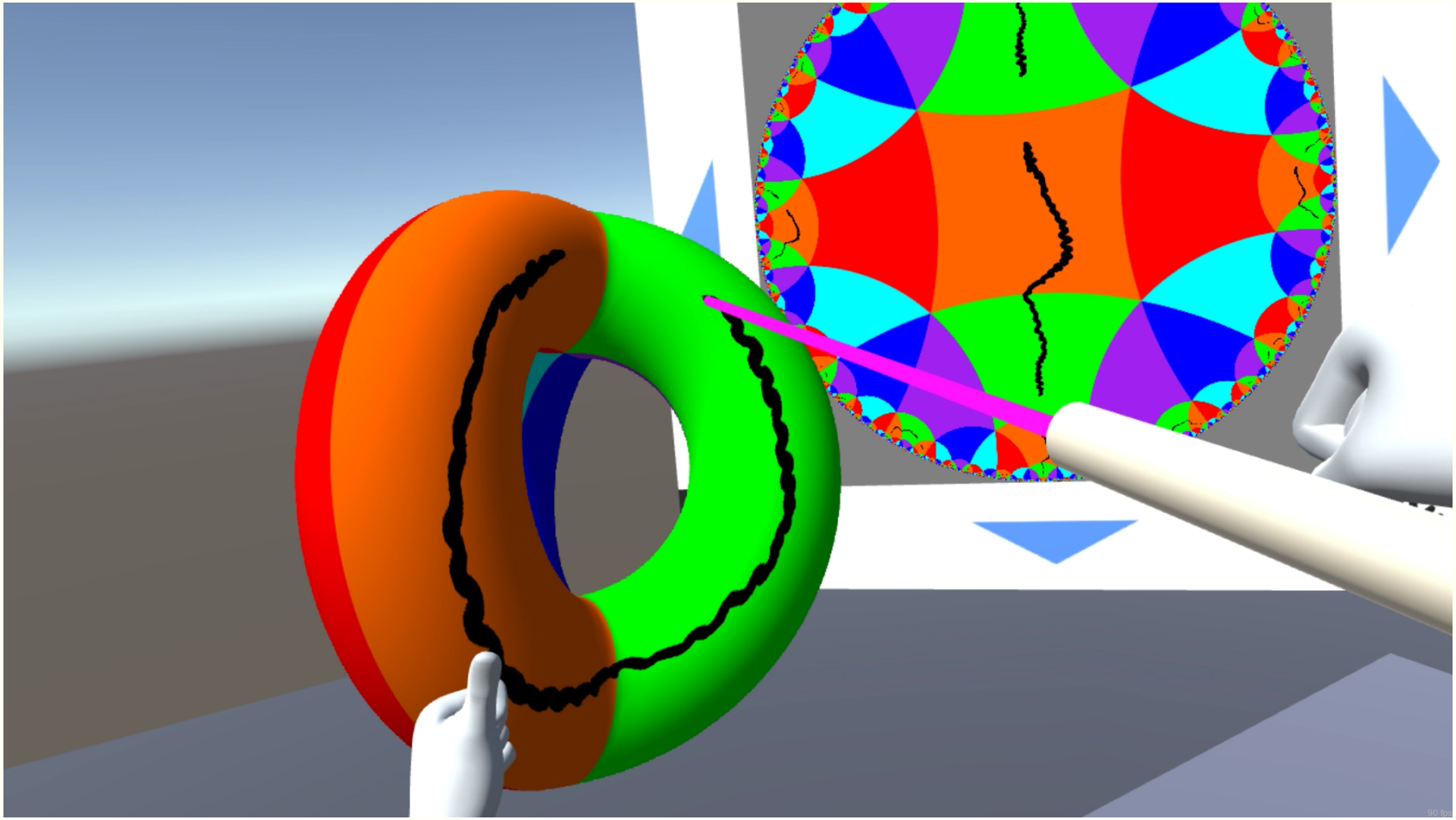
# 2018: Slicing surfaces

Structure:

- Collaboration
- Extensive prep work: built non-VR MVP
- Required extensive programming background
- Long weekly meetings

# 2018: Slicing surfaces

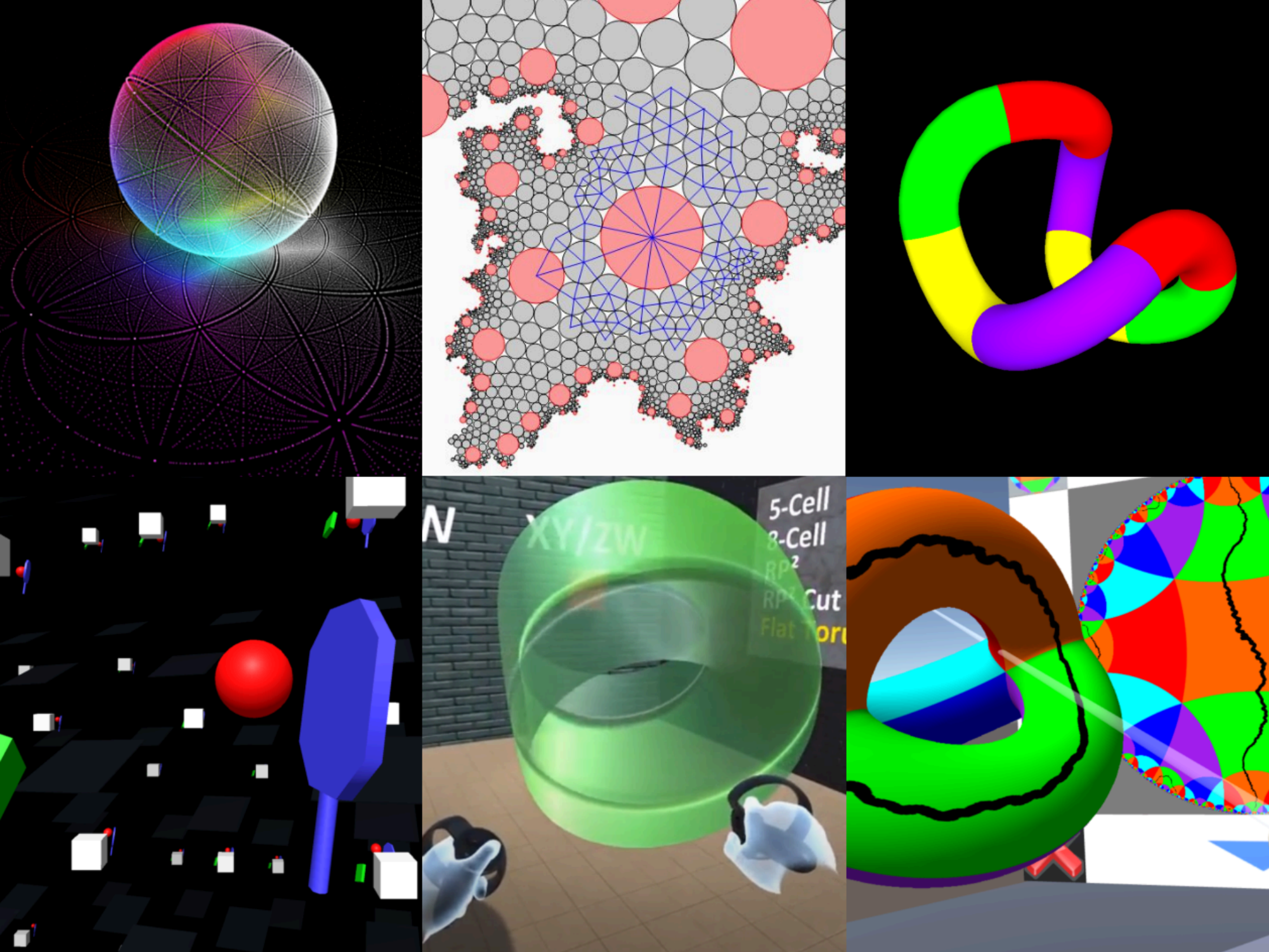
Result: GenusLab



# 2018: Slicing surfaces

Things I learned:

- More 3D graphics (e.g. order independent transparency)
- VR controls are hard to get right
- Providing a large amount of starting code creates its own challenges


5-Cell
8-Cell
Cut

# Some conclusions

- Right amount of structure can maximize student potential
- Avoid all-or-nothing goals
- Important to remember everyone has other activities

# VR for undergrad projects

After several projects, I'm ambivalent.

- Novelty (+)
- Power (+)
- Complexity (-)
- Small audience (-)

Alternative: WebGL first, then add WebVR/WebXR?

# Unity for undergrad projects

After several projects, I'm ambivalent.

- Lowers barrier to entry (++)
- Vast feature set (+/-)
- C# (+/-)
- Takes some low-level control away (-)
- Moving target (-)

# Unity for undergrad projects

If the goal is to build a 3D graphics application in an undergraduate project, using a 3D engine deserves consideration.

Perhaps Unreal Engine? (I haven’t tried it.)

Increasingly, I see the size of the potential audience as an important consideration.

# Future plans

Definitely

- Web-target projects (HTML+JS+WebGL etc.)
- Projects that start with a MVP

# Future plans

Likely

- Supervision-only projects
- Summer or year-long projects
- Video/image projects

# Future plans

Probably not

- Projects with ambitious goals in both programming and learning research-level math
- Projects focused on building GUI software

# Observation

I use skills learned while supervising these projects in my personal research.

# Links

- Immersive visualization (2015)
  - Project page [http://mcl.math.uic.edu/fall-2015-projects/]
- Circle packing visualization (2016)
  - Project page [http://mcl.math.uic.edu/summer-2016-projects/]
  - Source [https://github.com/daviddumas/bubble-wrap/]
- Tangle toy moduli (2016)
  - Project page [http://mcl.math.uic.edu/fall-2016-projects/#TTM]
  - Virtual tangle toy [https://uicmcl.github.io/ttm-mcl-fall2016/]
- Hyperbolic racquetball (2017)
  - Project page [http://mcl.math.uic.edu/spring-2017-projects/] (includes ManifoldBall download links)
  - Source [https://github.com/uicmcl/manifoldball/]
  - Video [https://www.youtube.com/watch?v=K6k6mYd5164]

# Links

- Visualizing 4D with VR (2017)
  - Project page [http://mcl.math.uic.edu/fall-2017-projects/] (includes 4DVR download links)
  - Source [https://github.com/Brandon-Reichman/4DVR/]
- Slicing surfaces in VR (2018)
  - Project page [http://mcl.math.uic.edu/fall-2018-projects/#destop] (includes GenusLab download links)
  - Source [http://github.com/uicmcl/genuslab-vr/]

# Thank you.

**David Dumas**

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https://dumas.io