* Title
* Agenda
* Section Title
  + Rotations in 2D with Matrices
* 2D Rotation Matrix
* Matrix-Vector Matrix Multiplication
* Resulting Equations
* Section Title
  + Rotations in 2D with Complex Numbers
* Complex numbers with i
* Complex number multiplication
* Resulting Equation
* Compare 2D Rotation Equations with Matrices and Complex Numbers
* Section Title
  + Rotations in 3D with Matrices
* 3D Rotation Matrices
* 3D Rotation Matrix
* Matrix-Vector Rotation Multiplication
* Resulting Equations
* Statement
  + That is only one way to rotate in space
* Section Title
  + Quaternions
* Define a Quaternion
* Quaternion Arithmetic
  + Quaternions work very similar to vectors
    - Importantly they share similar definitions for dot and cross products
* Define a conjugate
  + The conjugate of a quaternions is defined as
* Polar Representation Definition
  + - The conjugate is
  + This represents a 4th dimensional rotation about the 3D axis (x, y, z) by θ
* Question
  + Why did we skip the 3rd Dimensional Rotation?
* We need to do a 4th Dimensional Rotation and then “undo” the rotation about 2 of the 4 axes while doing another about the other 2
* This brings in the 3-Dimensional Rotation definition for Quaternions
* For example,
  + A rotation about the axis (0,1,0) by 180 degrees would look like
* To generalize this
  + Quaternion
    - Represents part of a rotation about u by angle θ
  + Quaternion
    - Represents a point in 3D space
  + The rotation definition is
  + Which reduces down to
* This is how we can rotate with Quaternions, however, to avoid Gimbal Lock we have to implement certain strategies with how we use them.
* Section Title
  + Combining Quaternions
  + Importantly, multiple Quaternion rotations can be combined into a single rotation to be applied to be applied
* Given two Quaternion rotations
* The combination of the two will be
  + Where
* This definition does create 2 cases where the rotation axis is undefined
  + But both of these are cases where no rotation is occurring and as such any rotation by those angles in unnecessary
* If used incorrectly, using combination to compose quaternion rotations can still result in Gimbal Lock, however, that is only if the approach of defining a rotation about the x, y, and z Euler axes and then combining those is used
* The better way to use Quaternions is for whatever is being rotated to have a Quaternion which defines its current orientation and then combine that with a given rotation before applying that to an object
  + Using this strategy will significantly reduce the chances that gimbal lock will occur