#### MAT 552

Introduction to

Lie Groups and Lie Algebras

Claude LeBrun Stony Brook University

February 23, 2021

$$e_1 = 1, e_2 = i, e_3 = j, e_4 = k$$

$$e_1 = \mathbf{1}, \quad e_2 = \mathbf{i}, \quad e_3 = \mathbf{j}, \quad e_4 = \mathbf{k}$$

$$\mathbf{i}^2 = \mathbf{j}^2 = \mathbf{k}^2 = -\mathbf{1}$$

$$e_1 = 1, e_2 = i, e_3 = j, e_4 = k$$

$$\mathbf{i}^2 = \mathbf{j}^2 = \mathbf{k}^2 = -\mathbf{1}$$

$$\mathbf{i}\mathbf{j}=-\mathbf{j}\mathbf{i}=\mathbf{k}$$

$$e_1 = 1, e_2 = i, e_3 = j, e_4 = k$$

$$i^{2} = j^{2} = k^{2} = -1$$
$$ij = -ji = k$$
$$jk = -kj = i$$

$$e_1 = 1, e_2 = i, e_3 = j, e_4 = k$$

$$i^{2} = j^{2} = k^{2} = -1$$
$$ij = -ji = k$$
$$jk = -kj = i$$
$$ki = -ik = j$$

$$e_1 = 1, e_2 = i, e_3 = j, e_4 = k$$

$$e_1 = \mathbf{1}, \quad e_2 = \mathbf{i}, \quad e_3 = \mathbf{j}, \quad e_4 = \mathbf{k}$$

Quaternionic conjugation

$$\overline{t \mathbf{1} + u \mathbf{i} + v \mathbf{j}, + w \mathbf{k}} = t \mathbf{1} - u \mathbf{i} - v \mathbf{j}, -w \mathbf{k}$$

$$e_1 = 1, e_2 = i, e_3 = j, e_4 = k$$

Quaternionic conjugation

$$\overline{t \mathbf{1} + u \mathbf{i} + v \mathbf{j}, + w \mathbf{k}} = t \mathbf{1} - u \mathbf{i} - v \mathbf{j}, -w \mathbf{k}$$

Notice that

$$\overline{q}q = q\overline{q} = \|q\|^2 := \|q\|^2 \mathbf{1}$$

$$e_1 = 1, e_2 = i, e_3 = j, e_4 = k$$

Quaternionic conjugation

$$\overline{t \,\mathbf{1} + u \,\mathbf{i} + v \,\mathbf{j}, + w \,\mathbf{k}} = t \,\mathbf{1} - u \,\mathbf{i} - v \,\mathbf{j}, -w \,\mathbf{k}$$

Notice that

$$\overline{q}q = q\overline{q} = \|q\|^2 := \|q\|^2 \mathbf{1}$$

So any  $q \neq 0$  has multiplicative inverse

$$q^{-1} = \frac{1}{\|q\|^2}\overline{q}.$$

$$e_1 = 1, e_2 = i, e_3 = j, e_4 = k$$

Quaternionic conjugation

$$\overline{t \mathbf{1} + u \mathbf{i} + v \mathbf{j}, + w \mathbf{k}} = t \mathbf{1} - u \mathbf{i} - v \mathbf{j}, -w \mathbf{k}$$

Notice that

$$\overline{q}q = q\overline{q} = \|q\|^2 := \|q\|^2 \mathbf{1}$$

So any  $q \neq 0$  has multiplicative inverse

$$q^{-1} = \frac{1}{\|q\|^2}\overline{q}.$$

Also notice that conjugation satisfies

 $\overline{q_1 q_2} = \overline{q_2} \ \overline{q_1}$ 

•  $U(1) = S^1$ 

• 
$$\mathbf{U}(1) = S^1$$
  
 $\mathfrak{u}(1) = \mathbb{R}$ 

• 
$$\mathbf{U}(1) = S^1$$
  
 $\mathfrak{u}(1) = \mathbb{R}$ 

•  $\mathbf{SO}(n) = \{n \times n \mid \mathbb{R}\text{-matrices } \mathbf{A} \mid \mathbf{A}^t \mathbf{A} = \mathbf{I}, \det \mathbf{A} = 1\}$ 

- $\mathbf{U}(1) = S^1$  $\mathfrak{u}(1) = \mathbb{R}$
- $\mathbf{SO}(n) = \{n \times n \quad \mathbb{R}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^t \mathbf{A} = \mathbf{I}, \text{ det } \mathbf{A} = 1 \}$  $\mathfrak{so}(n) = \{n \times n \quad \mathbb{R}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^t = -\mathbf{A} \}$

- $\mathbf{U}(1) = S^1$  $\mathfrak{u}(1) = \mathbb{R}$
- $\mathbf{SO}(n) = \{n \times n \quad \mathbb{R}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^t \mathbf{A} = \mathbf{I}, \text{ det } \mathbf{A} = 1 \}$  $\mathfrak{so}(n) = \{n \times n \quad \mathbb{R}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^t = -\mathbf{A} \}$

•  $\mathbf{SU}(n) = \{n \times n \quad \mathbb{C}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^*\mathbf{A} = \mathbf{I}, \ \det \mathbf{A} = 1\}$ 

- $\mathbf{U}(1) = S^1$  $\mathfrak{u}(1) = \mathbb{R}$
- $\mathbf{SO}(n) = \{n \times n \quad \mathbb{R}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^t \mathbf{A} = \mathbf{I}, \text{ det } \mathbf{A} = 1 \}$  $\mathfrak{so}(n) = \{n \times n \quad \mathbb{R}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^t = -\mathbf{A} \}$
- $\mathbf{SU}(n) = \{n \times n \quad \mathbb{C}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^*\mathbf{A} = \mathbf{I}, \text{ det } \mathbf{A} = 1\}$  $\mathfrak{su}(n) = \{n \times n \quad \mathbb{C}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^* = -\mathbf{A}, \text{ tr } \mathbf{A} = 0\}$

- $\mathbf{U}(1) = S^1$  $\mathfrak{u}(1) = \mathbb{R}$
- $\mathbf{SO}(n) = \{n \times n \quad \mathbb{R}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^t \mathbf{A} = \mathbf{I}, \text{ det } \mathbf{A} = 1 \}$  $\mathfrak{so}(n) = \{n \times n \quad \mathbb{R}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^t = -\mathbf{A} \}$
- $SU(n) = \{n \times n \quad \mathbb{C}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^*\mathbf{A} = \mathbf{I}, \text{ det } \mathbf{A} = 1\}$  $\mathfrak{su}(n) = \{n \times n \quad \mathbb{C}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^* = -\mathbf{A}, \text{ tr } \mathbf{A} = 0\}$
- $\mathbf{Sp}(n) = \left\{ n \times n \quad \mathbb{H}\text{-matrices } \mathbf{A} \mid \quad \overline{\mathbf{A}^t}\mathbf{A} = \mathbf{I} \right\}$

- $\mathbf{U}(1) = S^1$  $\mathfrak{u}(1) = \mathbb{R}$
- $\mathbf{SO}(n) = \{n \times n \quad \mathbb{R}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^t \mathbf{A} = \mathbf{I}, \text{ det } \mathbf{A} = 1 \}$  $\mathfrak{so}(n) = \{n \times n \quad \mathbb{R}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^t = -\mathbf{A} \}$

• 
$$\mathbf{SU}(n) = \{n \times n \quad \mathbb{C}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^*\mathbf{A} = \mathbf{I}, \text{ det } \mathbf{A} = 1\}$$
  
 $\mathfrak{su}(n) = \{n \times n \quad \mathbb{C}\text{-matrices } \mathbf{A} | \quad \mathbf{A}^* = -\mathbf{A}, \text{ tr } \mathbf{A} = 0\}$ 

• 
$$\mathbf{Sp}(n) = \left\{ n \times n \quad \mathbb{H}\text{-matrices } \mathbf{A} \mid \quad \overline{\mathbf{A}^{t}}\mathbf{A} = \mathbf{I} \right\}$$
  
 $\mathfrak{sp}(n) = \left\{ n \times n \quad \mathbb{H}\text{-matrices } \mathbf{A} \mid \quad \overline{\mathbf{A}^{t}} = -\mathbf{A} \right\}$