# CS368 MATLAB Programming

## Lecture 2

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Based on lecture slides by Michael O'Neill and Beck Hasti

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# Quiz

## Admin

Room CS 368

Q1

add deadline to Canvas.

- Are you in room 168 Noland or on Zoom?
- $A$ : I don't know
- $B$ : 168 Noland
- $C$ : Zoom
- $D$ : Both

# Scalar Operations, Binary

## Code

- $x + y$ is $x + y$.
- $x - y$ is $x - y$.
- $x * y$ is $xy$.
- $x / y$ and $y \backslash x$ are $\frac{x}{y}$ .
- $x \hat{} y$ is $x^y$ .

# Scalar Operations, Unary

## Code

- *sqrt(x)* is $\sqrt{x}$ .
- *exp(x)* is $e^x$ .
- *log(x)* is natural log or $\ln(x)$, *log10(x)* is $\log_{10}(x)$.
- *sin(x)* with $x$ in radians, *sind(x)* with $x$ in degrees, *asin(y)* is $\arcsin(y)$ in radians, *asind(x)* is $\arcsin(y)$ in degrees.
- *cos(x)*, *cosd(x)*, *acos(y)*, *acosd(y)*.
- *tan(x)*, *tand(x)*, *atan(y)*, *atand(y)*.

# Scalar Operations, Unary Integer

## Code

- *round(x)* is rounding $x$ to nearest integer.
- *floor (x)* is $\lfloor x \rfloor$, largest integer $\leqslant x$.
- *ceil (x)* is $\lceil x \rceil$, smallest integer $\geqslant x$.
- *mod(x, y)* is $x \mod y$, or $x$ modulo $y$, the remainder when $x$ is divided by $y$, integer division, *x % y* does not work in MATLAB.

# Scalar Operations, Rounding

## Quiz

Q2

- $1.00001 + 1$
- $B$ : **2**
- $C$ : **2.00001**
- $D$ : **2.0000**

# Scalar Math Operations, Infinity

## Quiz

Q3

- *10 ^ 309*
- *B* : **1e+309**
- *C* : **1.0000e+309**
- *D* : **Inf**

$1.000 \times 10^{309}$

# Scalar Operations, Precision

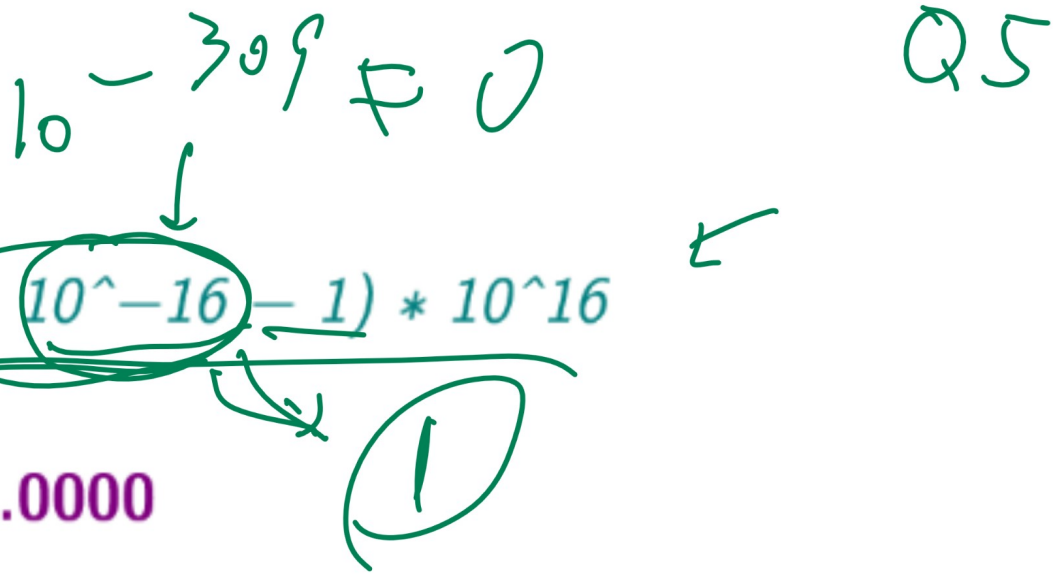
## Quiz

Q4

- *10 ^ −309*
- *B* : **1e-309**
- *C* : **1.0000e-309**
- *D* : **0**

# Scalar Operations, Numerical Instability

## Quiz



- $(1 + 10\text{^}{-16} - 1) * 10\text{^}16$
- $B$ : **0**
- $C$ : **0.0000**
- $D$ : **1**
- $E$ : **1.0000**

# Scalar Math Operations, Numerical Instability Again

## Quiz

- $(1 - 1 + 10\hat{}{-16}) * 10\hat{}16$
- $B$ : **0**
- $C$ : **0.0000**
- $D$ : **1**
- $E$ : **1.0000**

# Numerical Instability

## Code

- The number of decimal places that is displayed can be changed.
- The number of decimal places that can be stored is fixed.

1. $\pi, e, \sqrt{2}$ etc are approximate values (accurate up to 16 decimal places).
2. Underflow may occur: numbers that are too close to 0 are stored as **0** .
3. Overflow may occur: numbers that are too large are stored as **Inf** .

# Vector Multiplication

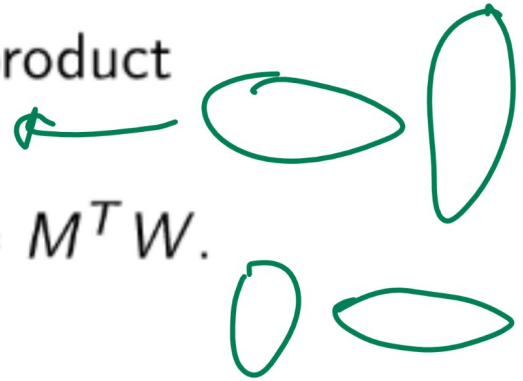
## Math

- $\begin{bmatrix} a \\ b \end{bmatrix} \odot \begin{bmatrix} c \\ d \end{bmatrix} = \begin{bmatrix} ac \\ bd \end{bmatrix}$ is the element-wise product.
- $\begin{bmatrix} a \\ b \end{bmatrix} \cdot \begin{bmatrix} c \\ d \end{bmatrix} = \begin{bmatrix} a & b \end{bmatrix} \begin{bmatrix} c \\ d \end{bmatrix} = ac + bd$ is the inner product, also called the dot product for matrices.
- $\begin{bmatrix} a \\ b \end{bmatrix} \otimes \begin{bmatrix} c \\ d \end{bmatrix} = \begin{bmatrix} a \\ b \end{bmatrix} \begin{bmatrix} c & d \end{bmatrix} = \begin{bmatrix} ac & ad \\ bc & bd \end{bmatrix}$ is the outer product.

# Vector Multiplication

## Code

- Suppose $M$ and $W$ are two row vectors having the same size.
- $M$ .* $W$ is the element-wise product $M \odot W$.
- $M * W'$ and *dot(M, W)* are the inner product $M \cdot W = MW^T$ .
- $M' * W$ is the outer product $M \otimes W = M^T W$.



# General Vector Operations

## Code

- Suppose $M$ and $W$ are two row vectors having the same size, and $c$ is a scalar.
- $M + W$ and $M - W$ are element-wise and also vector addition and subtraction.
- $M .\hat{} W$ and $M .\hat{} c$ are element-wise exponentiation.

# General Vector Operations, Unary

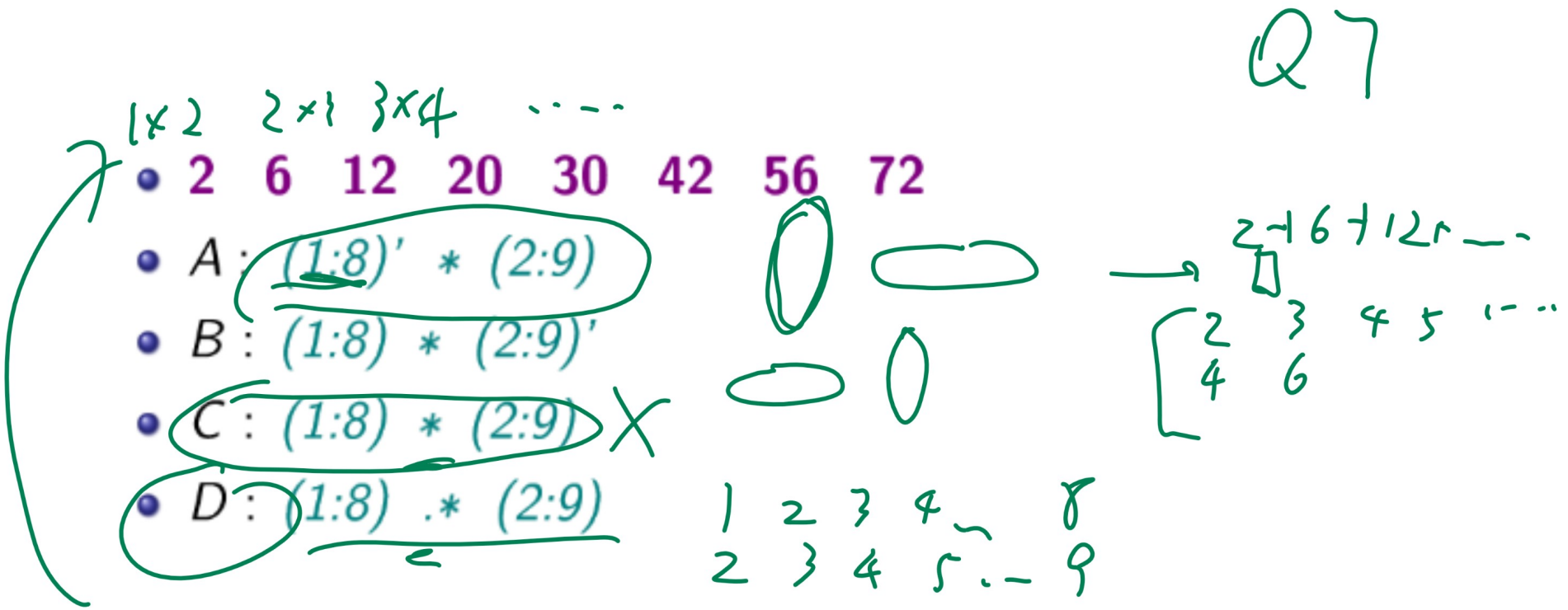
## Code

- Most of the built-in unary operations are element-wise when applied to vectors.
- For example, the square root function can be applied element-wise to vectors directly.

1. *sqrt ([a b c])* is $\begin{bmatrix}\sqrt{a} & \sqrt{b} & \sqrt{c}\end{bmatrix}$.
2. *[a b c] .^ 0.5* is also $\begin{bmatrix}\sqrt{a} & \sqrt{b} & \sqrt{c}\end{bmatrix}$.
3. *[a b c] ^ 0.5* results in an error.

# Vector Operations, Multiplication

## Quiz



# Vector Operations, Exponentiation

## Quiz

Q8

$2^0$ $2^1$ $2^2$ ..... $2^7$

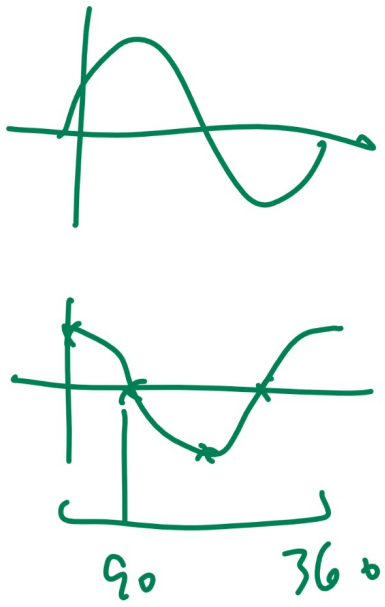
- **1 2 4 8 16 32 64 128**
- A : *(0:7) ^ 2*
- B : *(0:7) .^ 2*
- C : *2 ^ (0:7)*
- D : *2 .^ (0:7)*

# Vector Operations, Trig Operations

## Quiz

Q9

- **1 0 -1 0 1 0 -1 0**
- $A$ : *round(sind((0:7) * 180))*
- $B$ : *round(cosd((0:7) * 180))*
- $C$ : *round(sind((0:7) * 90))*
- $D$ : *round(cosd((0:7) * 90))*



# Matrix Multiplication

## Math

- $\begin{bmatrix} a & b \\ c & d \end{bmatrix} \odot \begin{bmatrix} e & f \\ g & h \end{bmatrix} = \begin{bmatrix} ae & bf \\ cg & dh \end{bmatrix}$ is the element-wise product.
- $\begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} e \\ f \end{bmatrix} = \begin{bmatrix} ae + bf \\ ce + df \end{bmatrix}$ and

  $\begin{bmatrix} e & f \end{bmatrix} \begin{bmatrix} a & b \\ c & d \end{bmatrix} = \begin{bmatrix} ea + fc & eb + fd \end{bmatrix}$ are matrix products.
- $\begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} e & f \\ g & h \end{bmatrix} = \begin{bmatrix} ae + bg & af + bh \\ ce + dg & cf + dh \end{bmatrix}$ is also the matrix product.

# Matrix Multiplication

## Code

- Suppose $M$ and $W$ are two matrices.
- $M$ .* $W$, when $M$ and $W$ have the same size, is the element-wise product $M \odot W$.
- $M * W$, when number of columns of $M$ is the same as the number of rows of $W$, is the matrix product $MW$.

# General Matrix Operations, Binary

## Code

- Suppose $M$ and $W$ are two matrices, and $c$ is a scalar.
- $M + W$ and $M - W$ are element-wise and also matrix addition and subtraction.
- $M .* W$ is element-wise, and $M * W$ is matrix multiplication.
- $M ./ W$ and $W .\backslash M$ are element-wise, and $M / W$ and $W \backslash M$ find the matrix $X$ such that $MX = W$, the solution of systems of linear equations. More details in a later lecture.
- $M .\hat{} W$ and $M .\hat{} c$ are element-wise, and $M \hat{} c$ is matrix exponentiation.

M .^ 2 ≠ M ^ 2 = M * M

# General Matrix Operations, Unary

## Code

- Most of the built-in unary operations are element-wise when applied to matrices.
- For example, the square root function can be applied element-wise to matrices directly.

1. *sqrt ([a b; c d])* is $\begin{bmatrix} \sqrt{a} & \sqrt{b} \\ \sqrt{c} & \sqrt{d} \end{bmatrix}$.
2. *[a b; c d] .^ 0.5* is also $\begin{bmatrix} \sqrt{a} & \sqrt{b} \\ \sqrt{c} & \sqrt{d} \end{bmatrix}$.
3. *[a b; c d] ^ 0.5* is the actual square root of the matrix, it finds a matrix $\begin{bmatrix} e & f \\ g & h \end{bmatrix}$ such that $\begin{bmatrix} e & f \\ g & h \end{bmatrix} \begin{bmatrix} e & f \\ g & h \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix}$.

# Matrix Operations, Multiplication

## Quiz

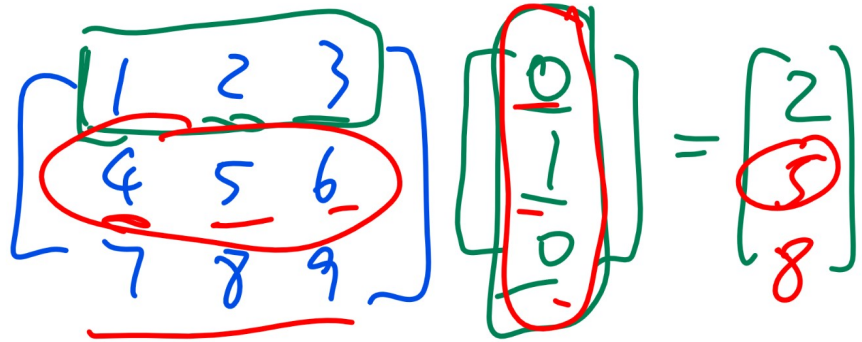
- (What is the second column of $\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}$?)

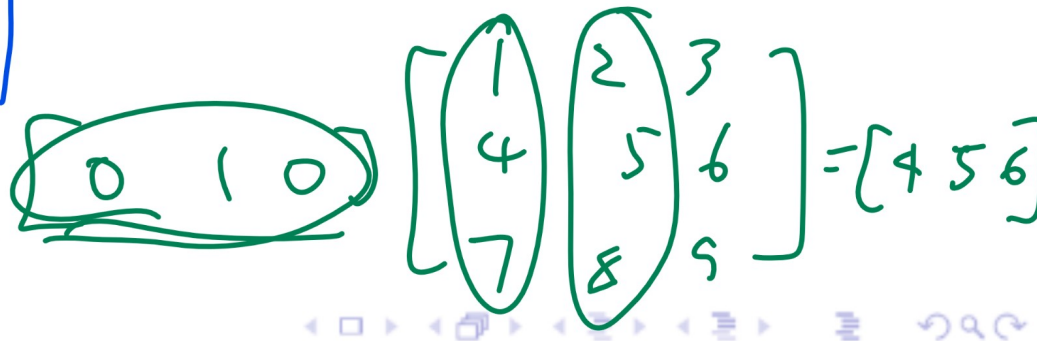
Q 10

- **2**
- **5**
- **8**

1. $m = [1\ 2\ 3;\ 4\ 5\ 6;\ 7\ 8\ 9]$;
   - ~~A~~ : $m * [0\ 1\ 0]$
   - B : $m * [0;\ 1;\ 0]$
   - C : $[0\ 1\ 0] * m$
   - ~~D~~ : $[0;\ 1;\ 0] * m$

$A * B \neq B * A$





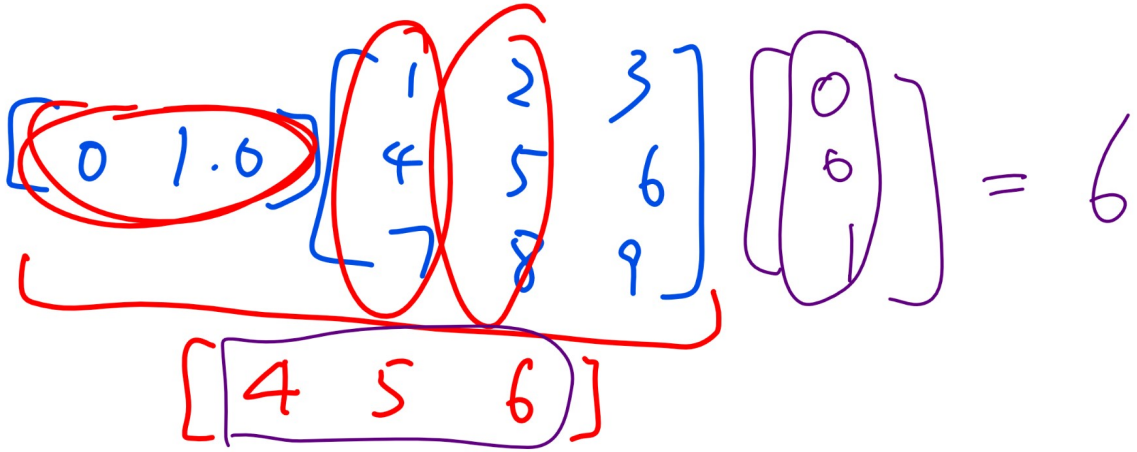
# Matrix Operations, Multiplication Again

## Quiz

Q 11

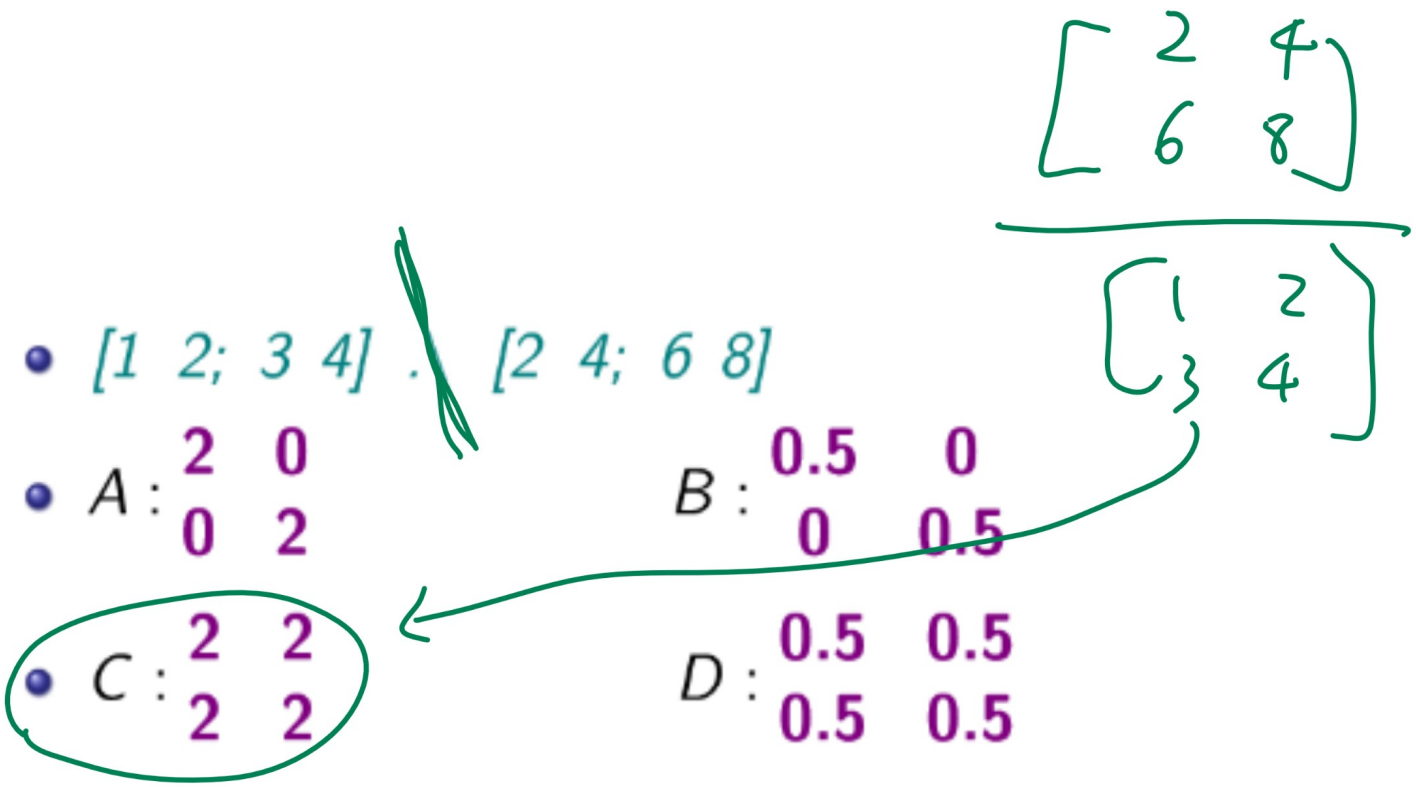
- (What is the row 2, column 3 entry of $\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}$?)
- **6**

1. $m = [1\ 2\ 3;\ 4\ 5\ 6;\ 7\ 8\ 9];\ ei = [0;\ 1;\ 0];\ ej = [0;\ 0;\ 1];$
   - $A : ei' * m * ej$
   - $B : ej' * m * ei$
   - $C : ei' * ej * m$
   - $D : m * ei * ej'$



# Matrix Operations, Division

## Quiz



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