

Machine Learning:

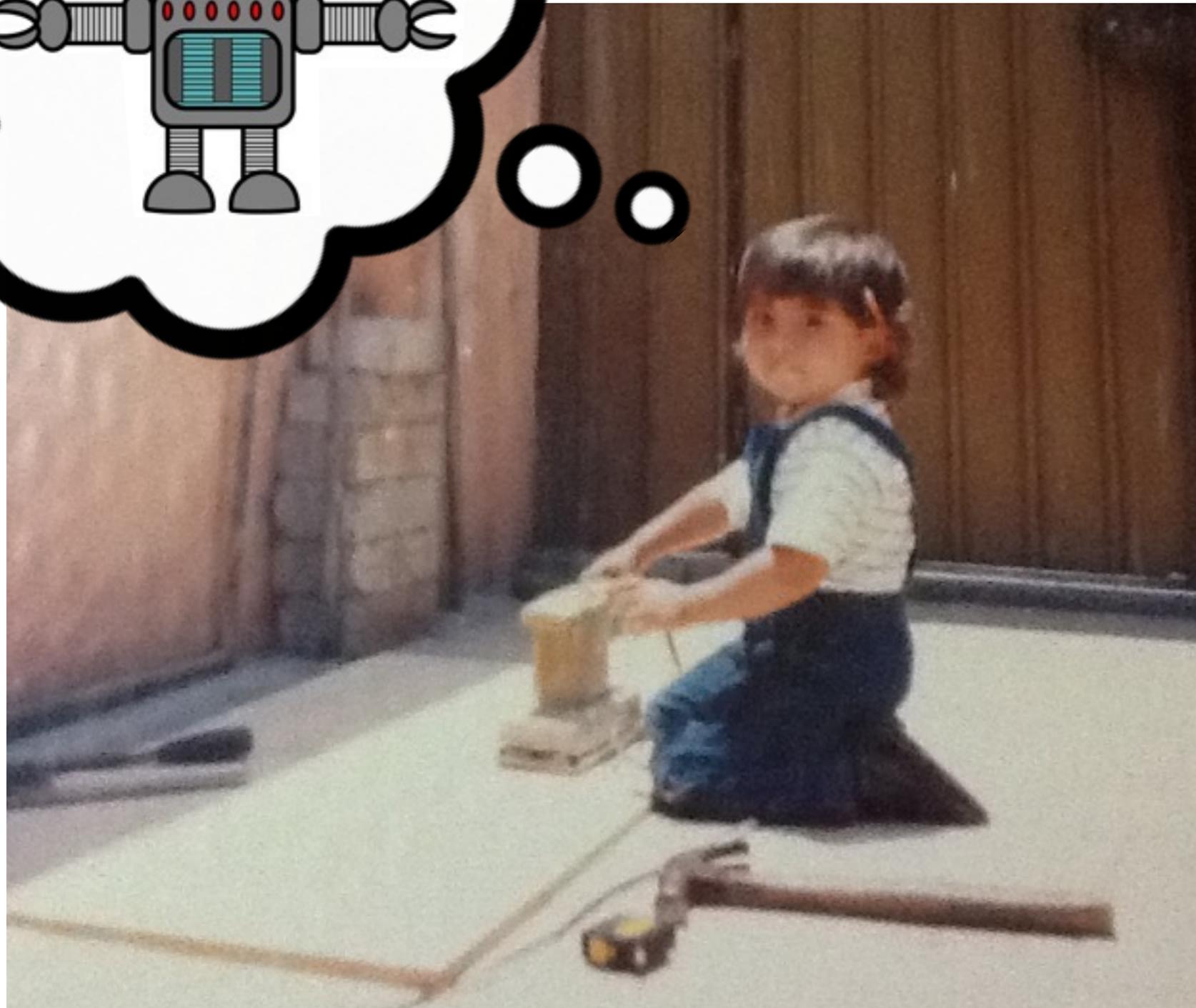
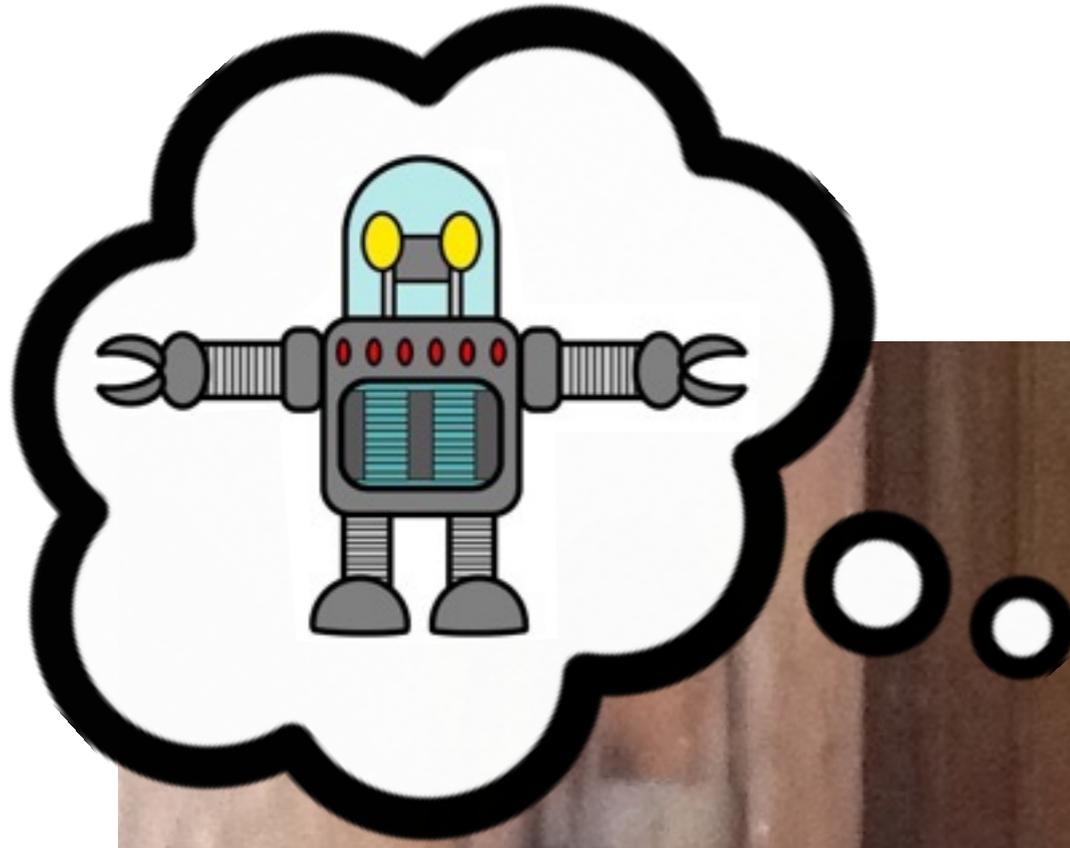
Who is teaching?

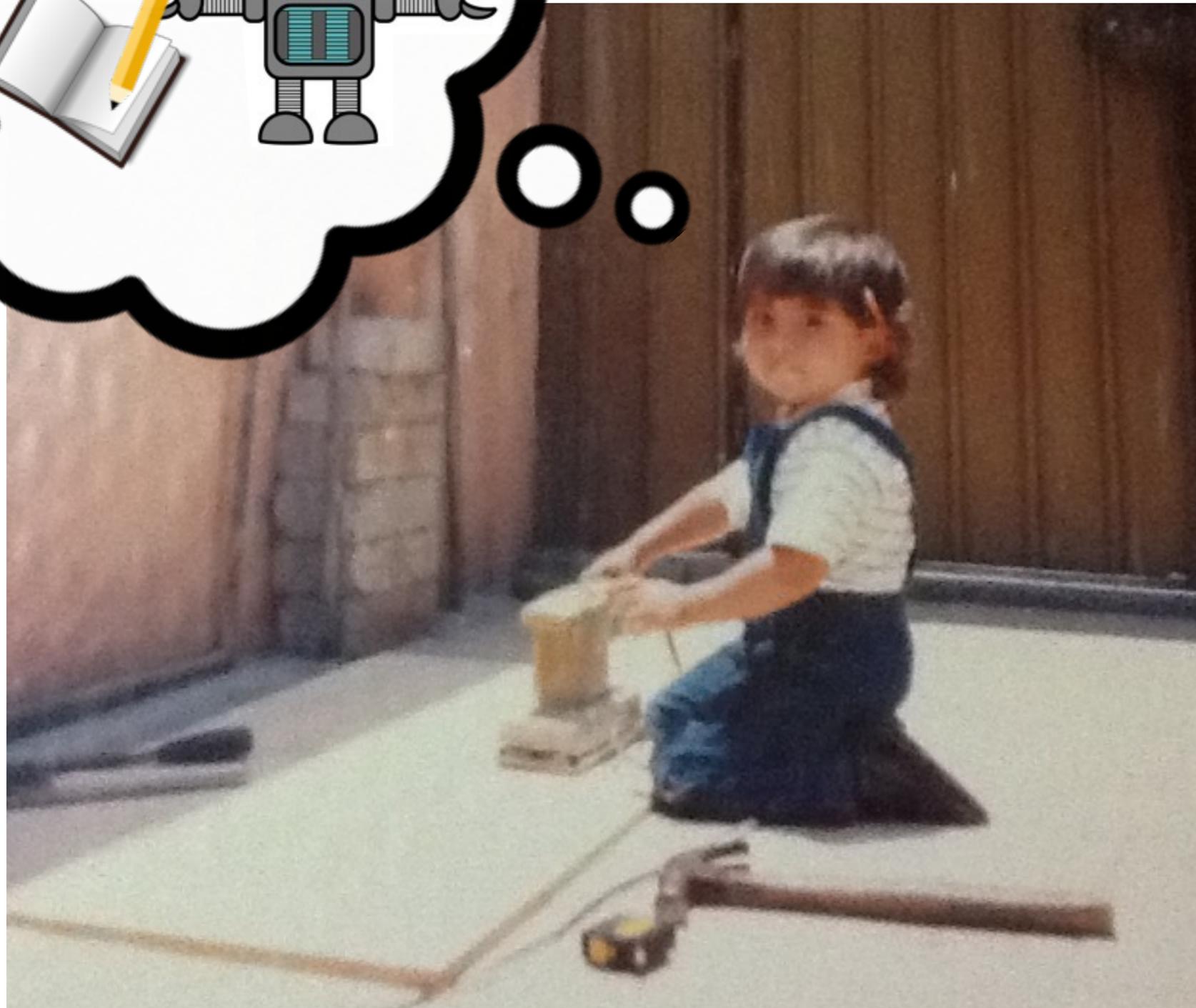
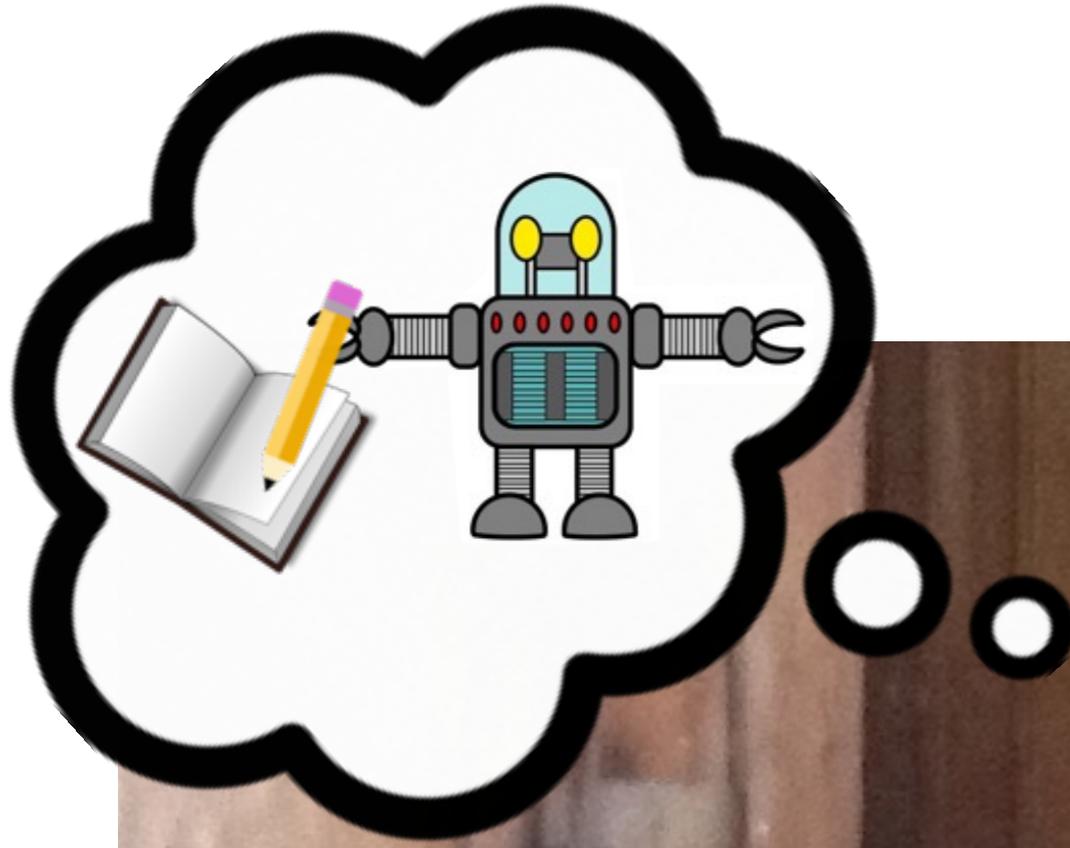
Daniel Pimentel-Alarcón

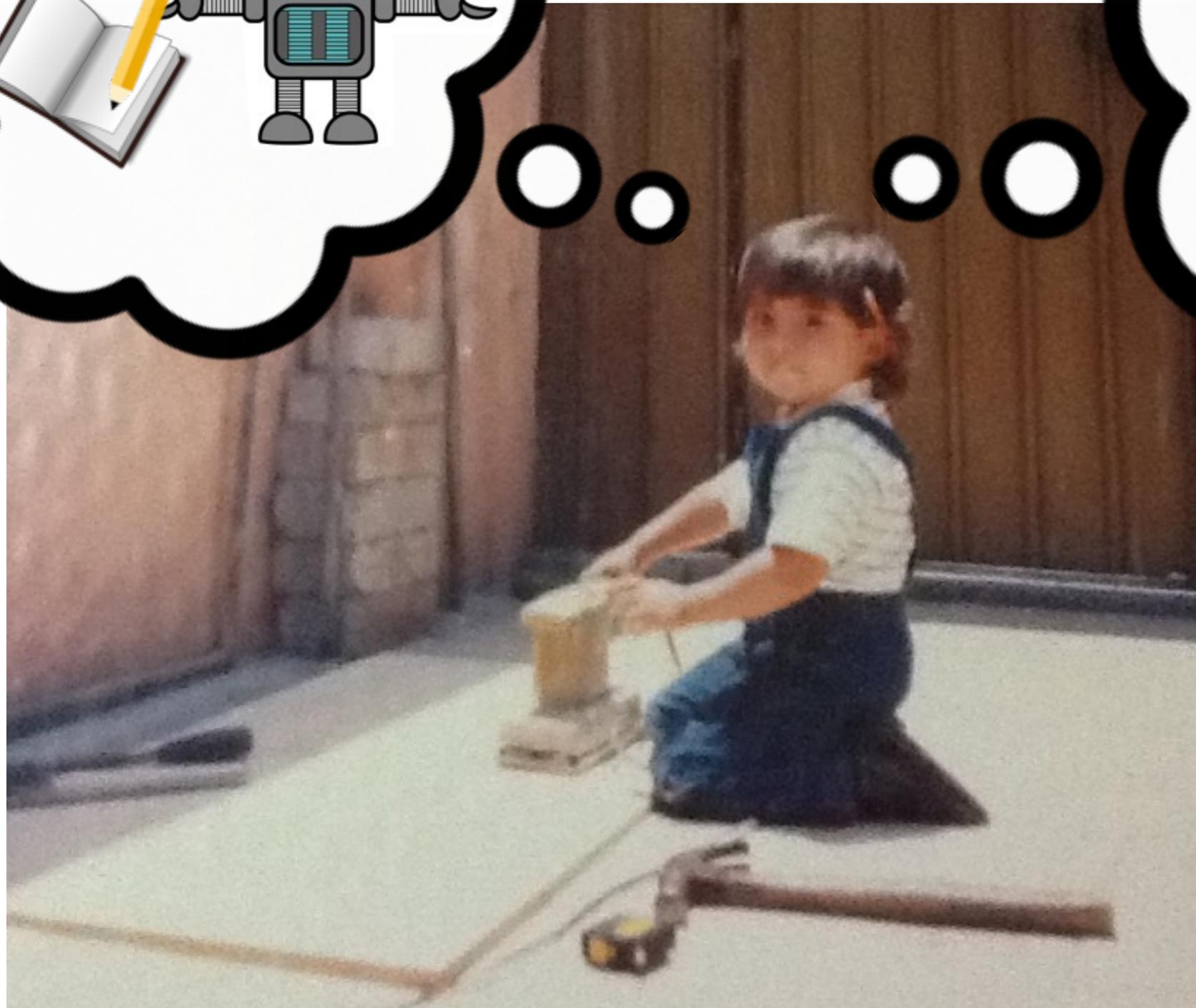
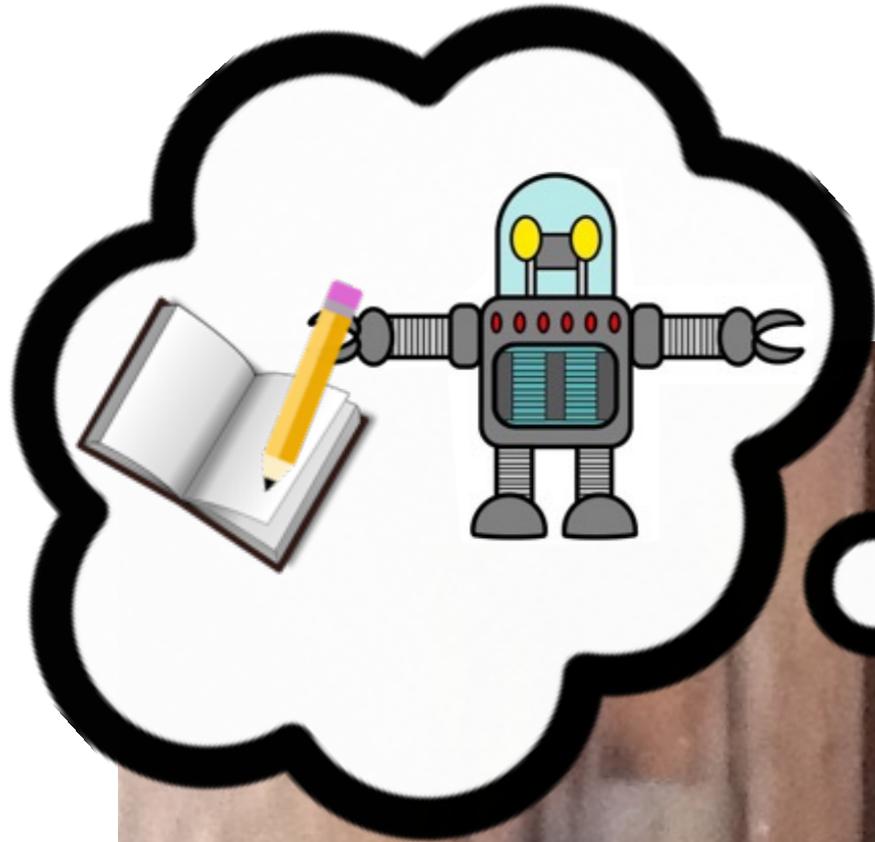
Georgia State University

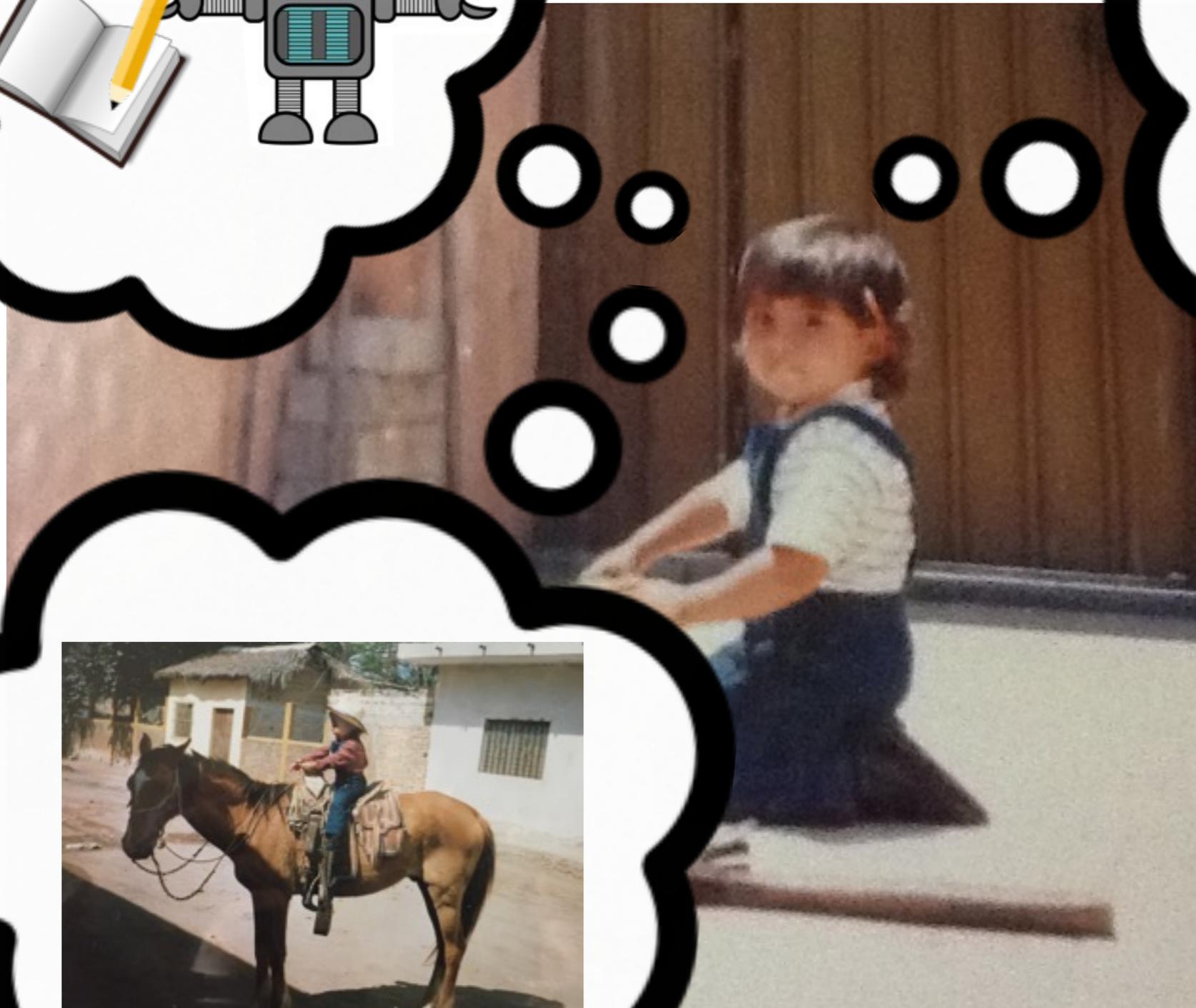
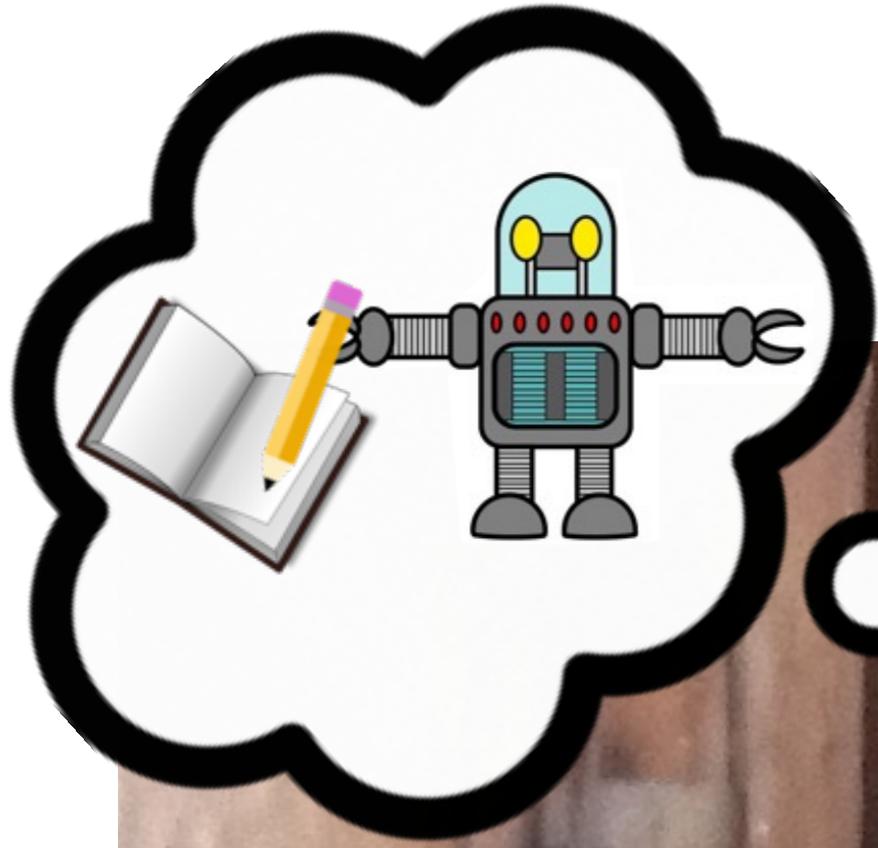
Georgia Statistics Day: Oct 9th, 2017

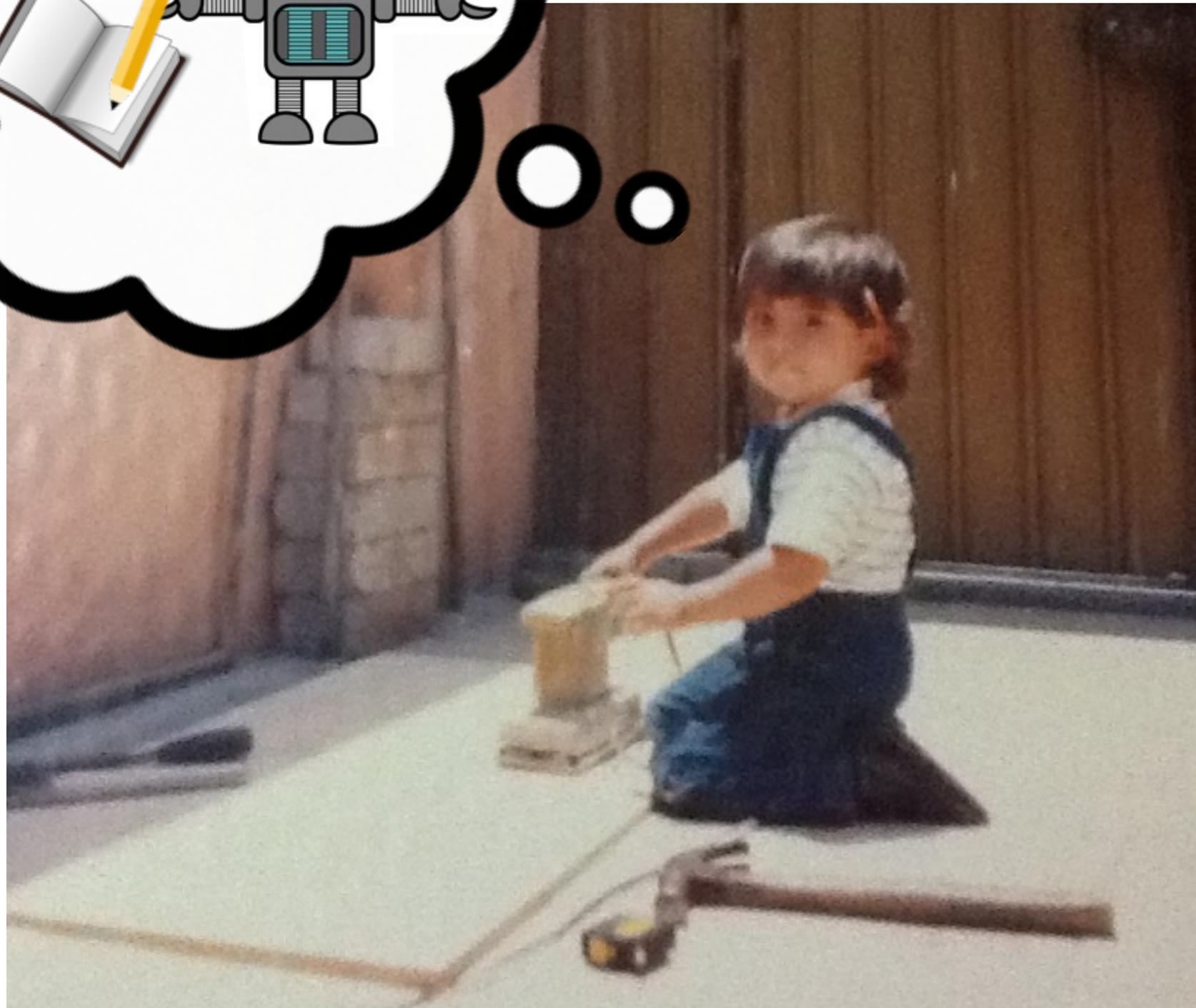
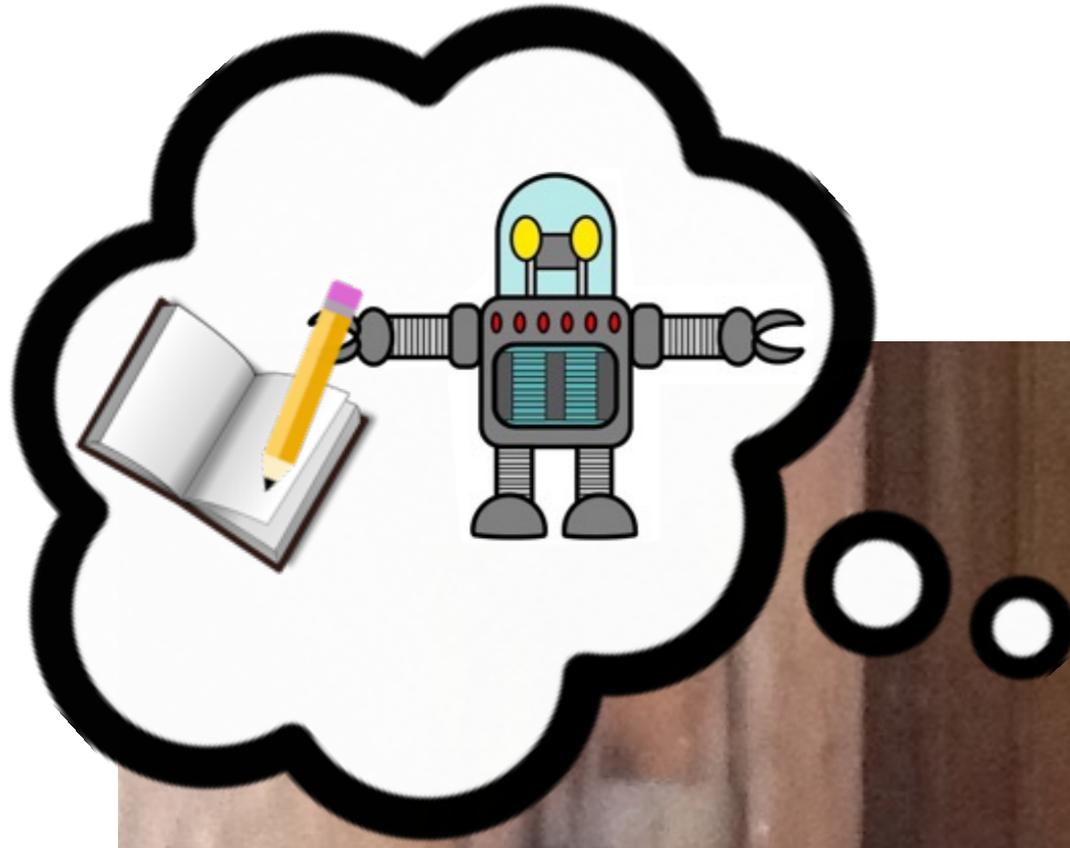


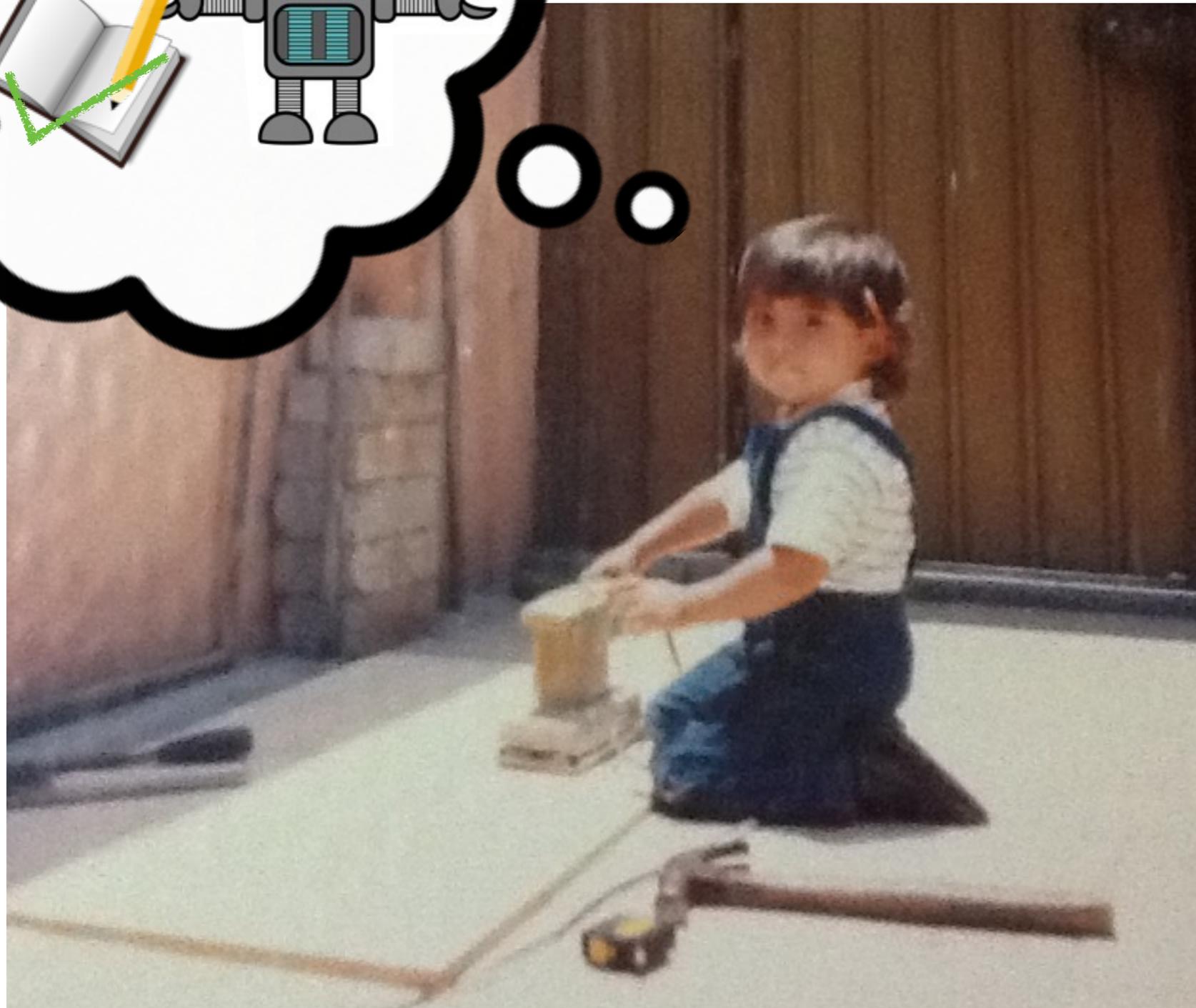
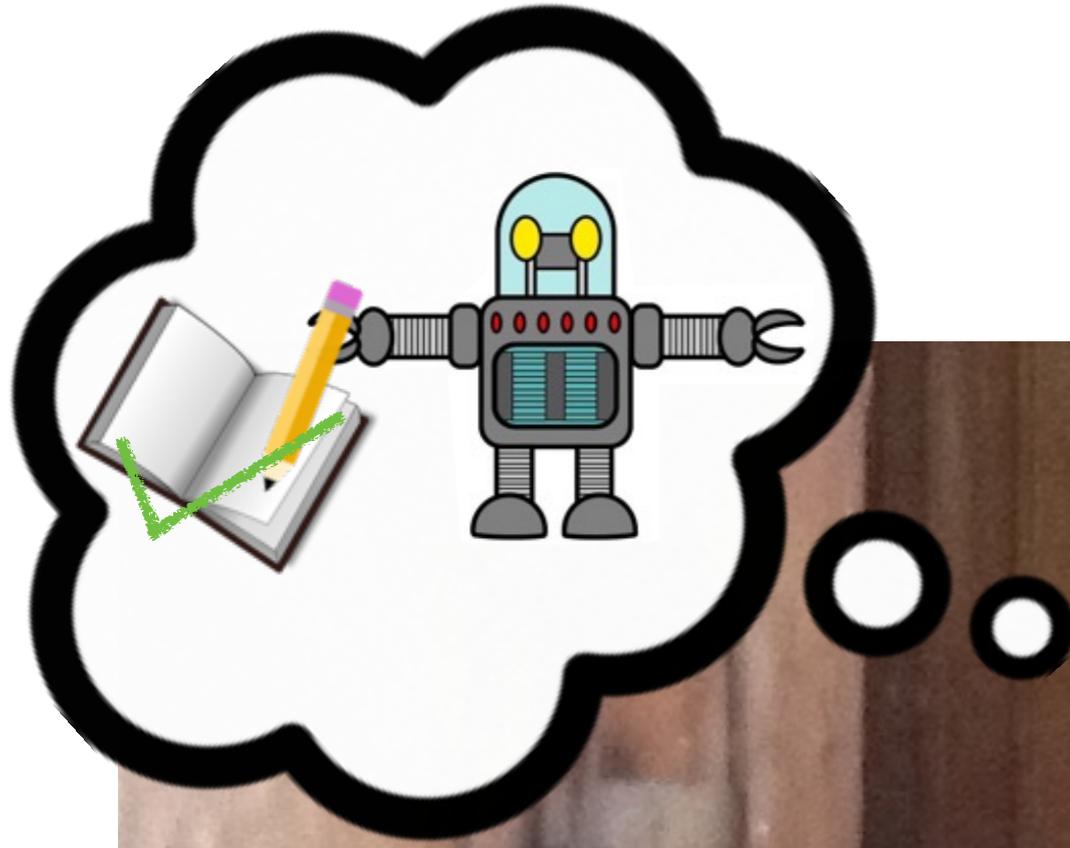


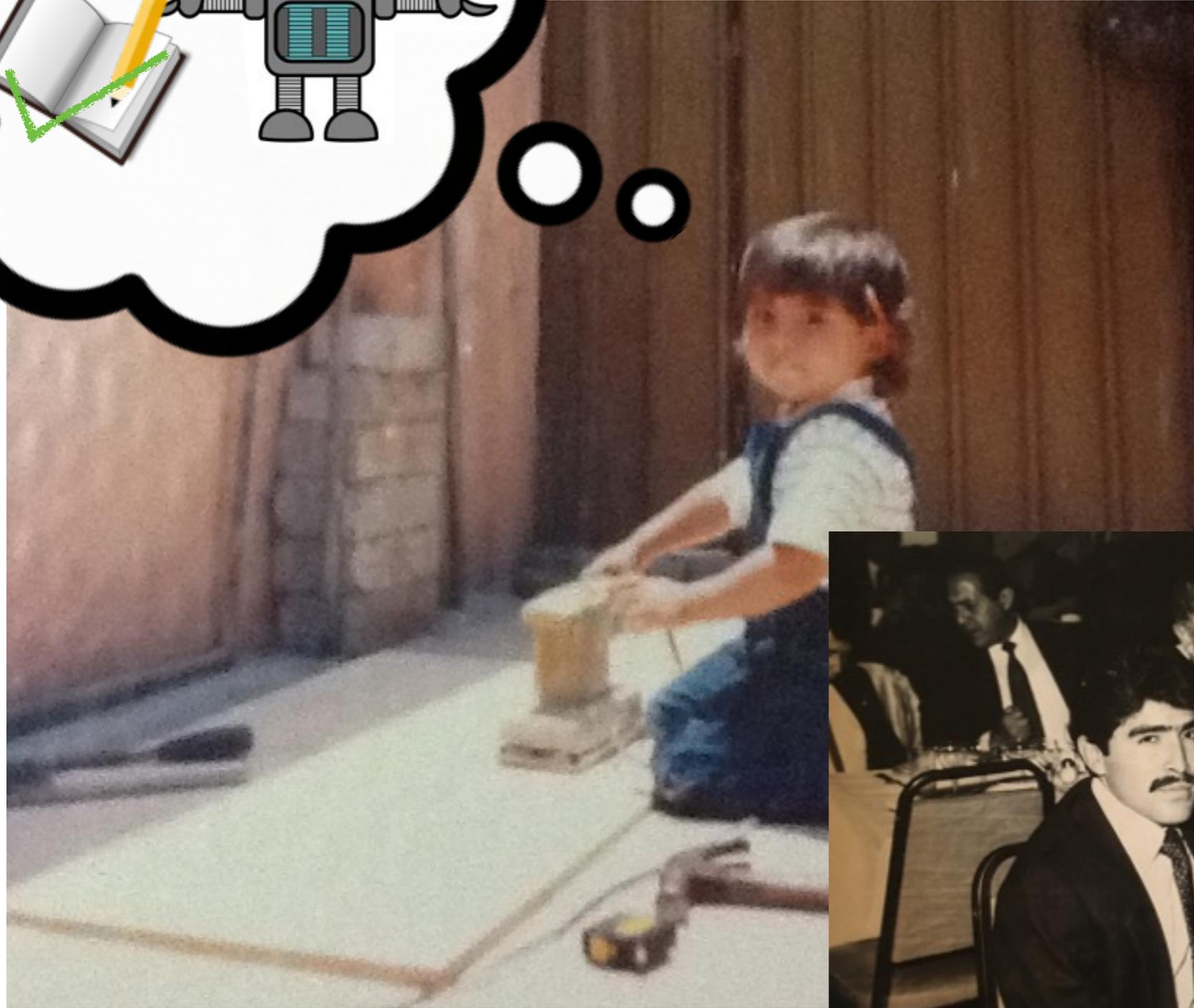
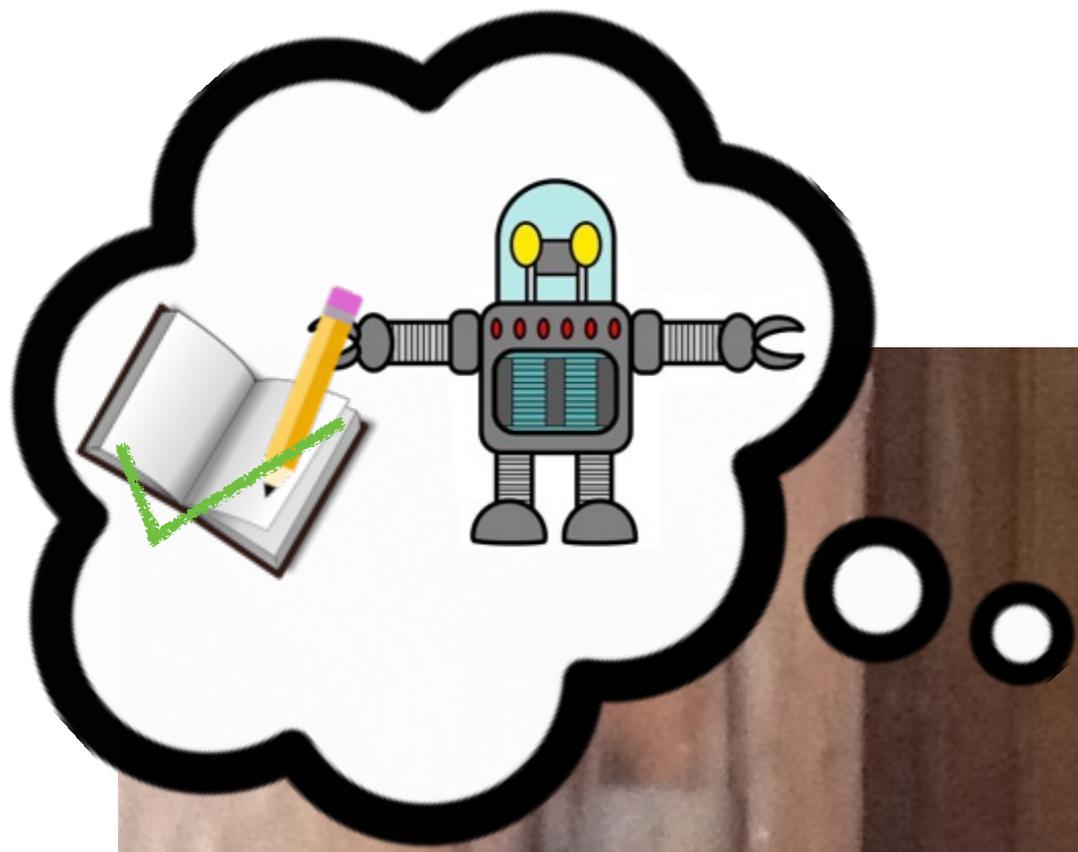






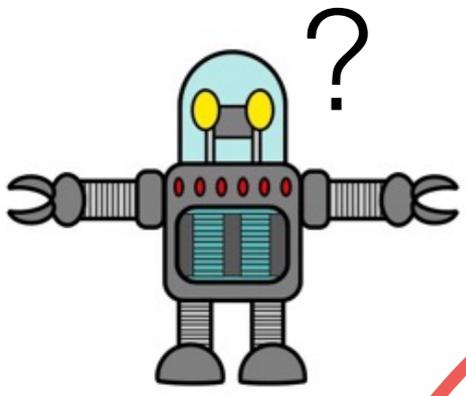


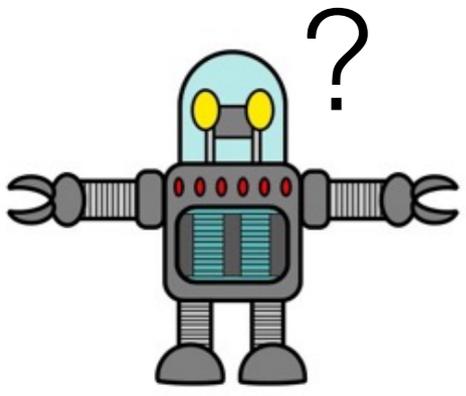








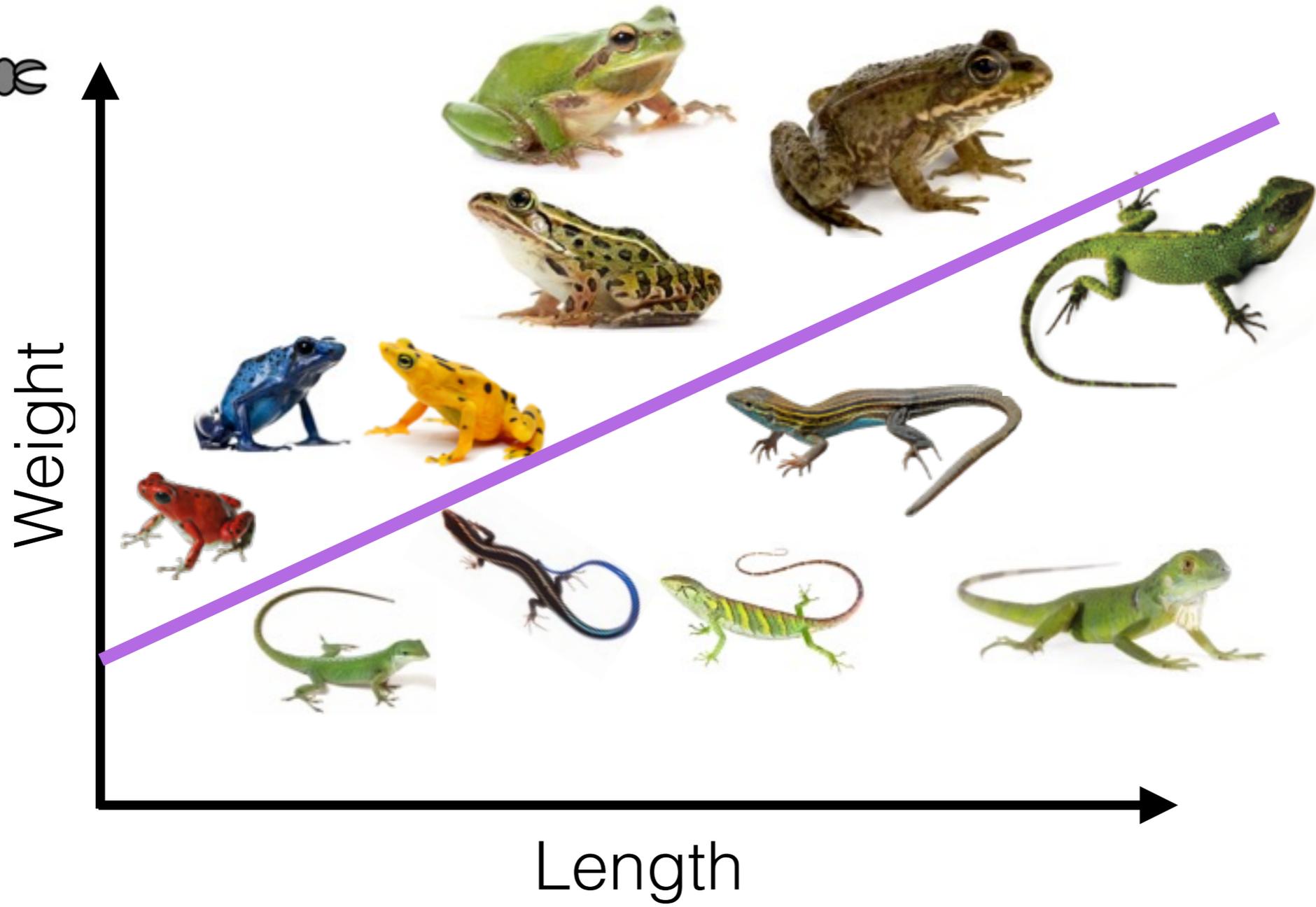
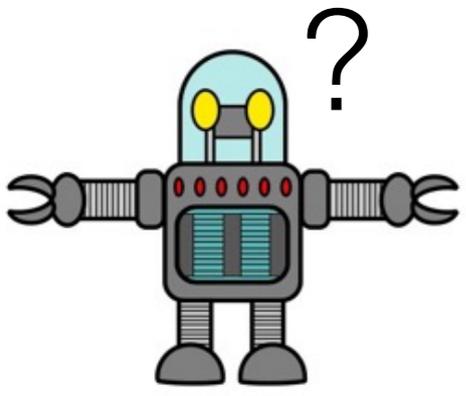


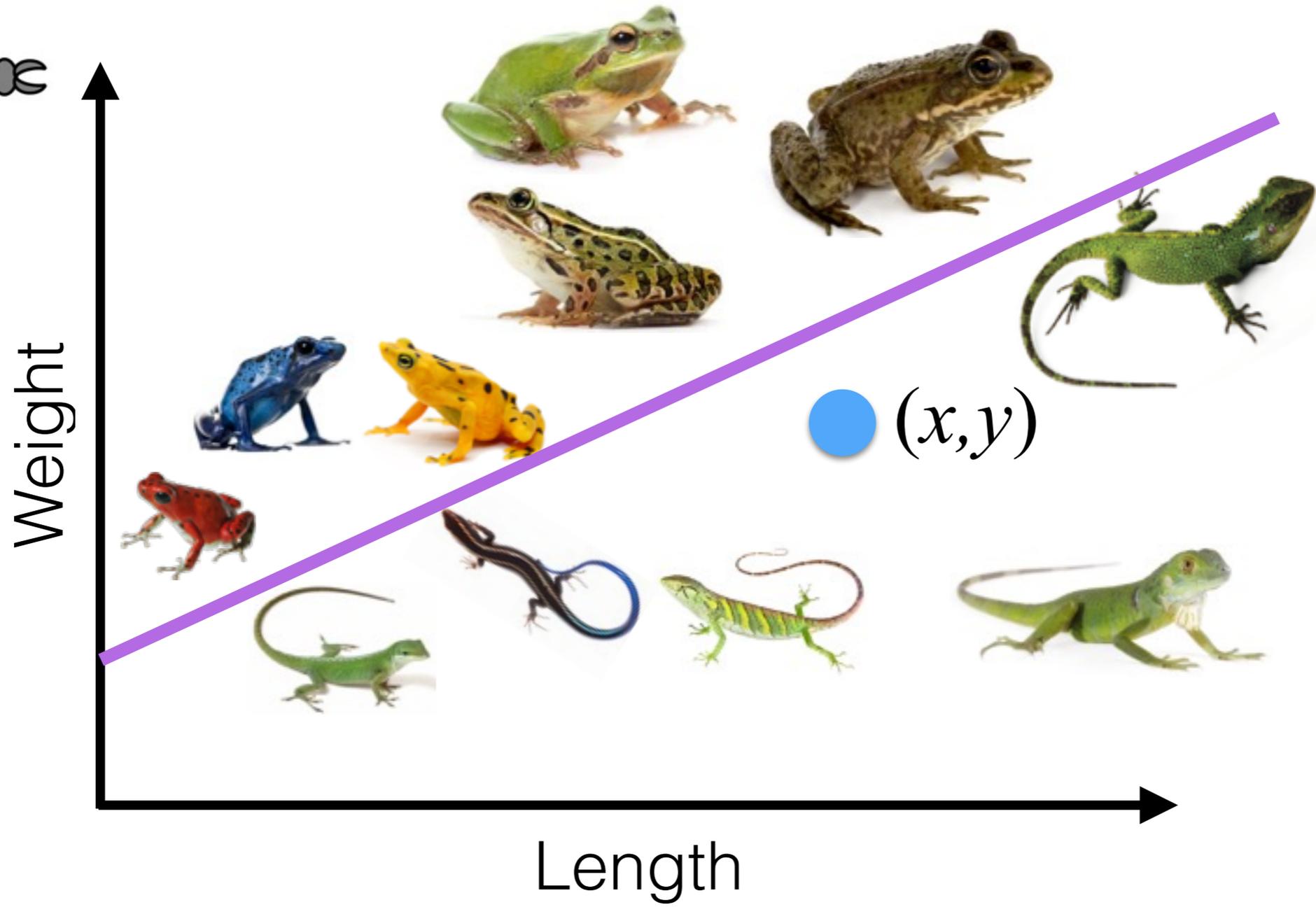
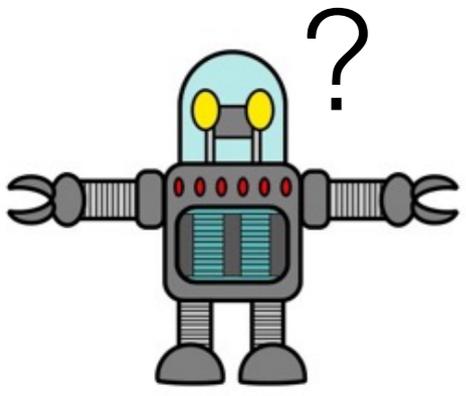


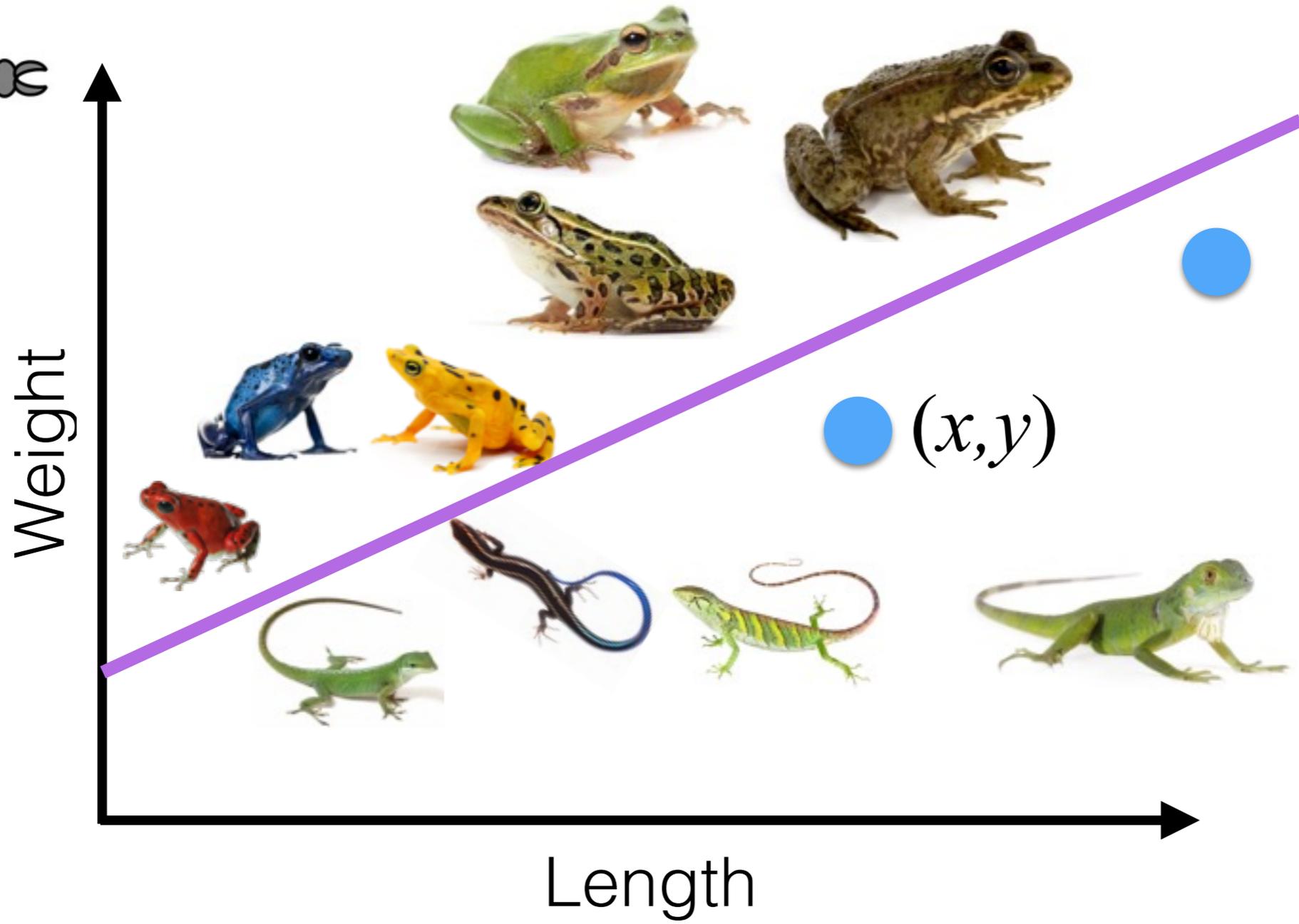
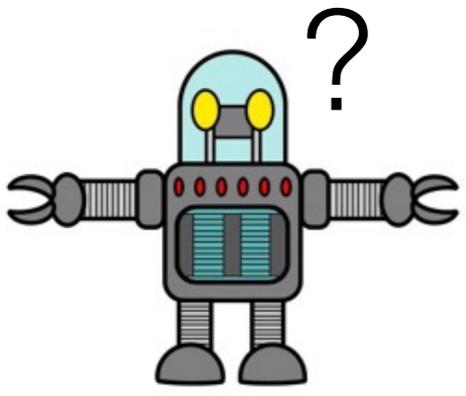
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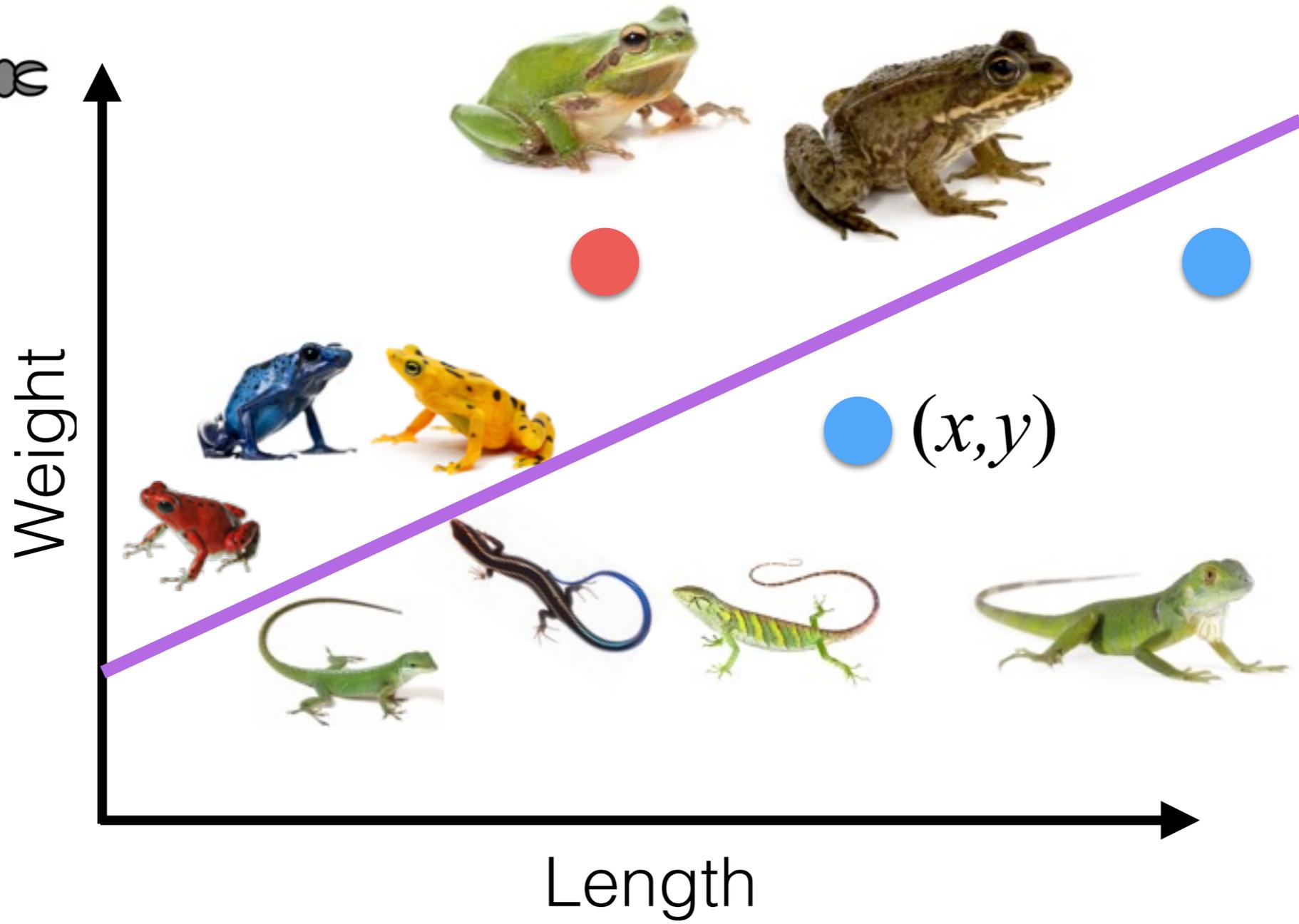
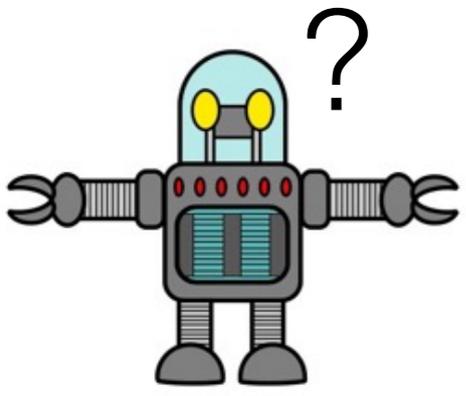


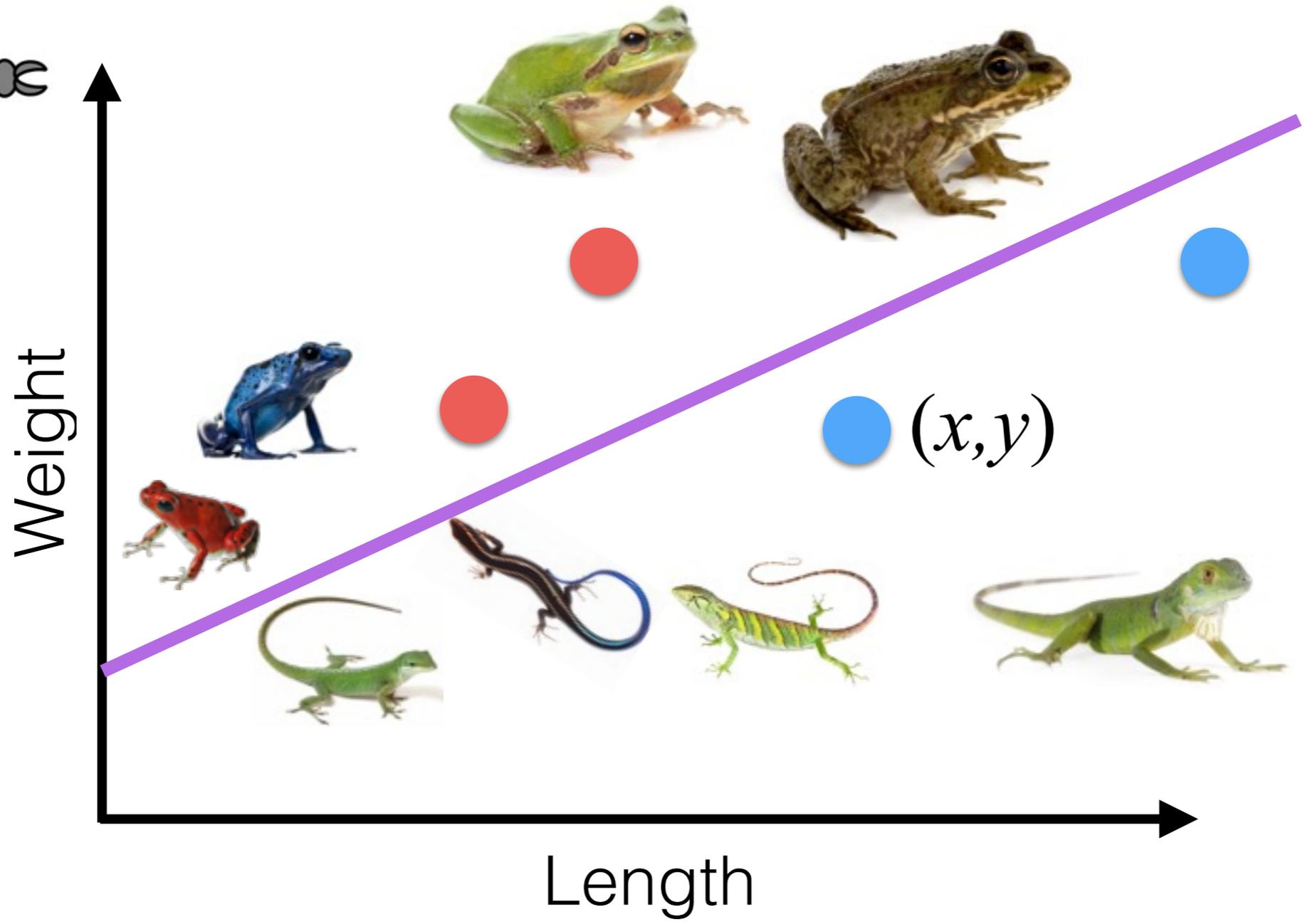
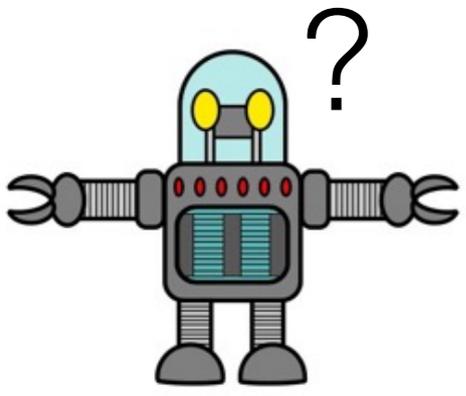
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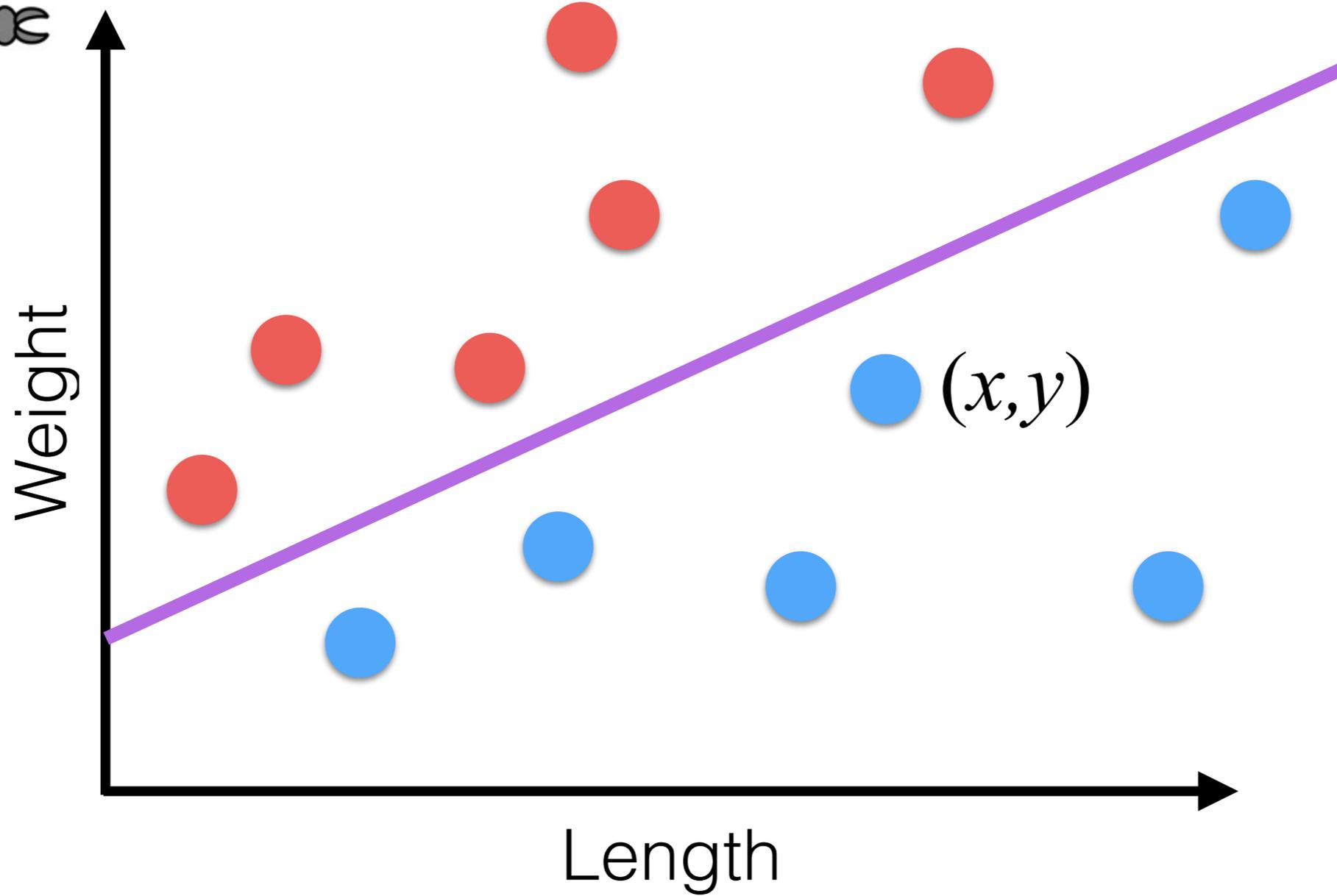
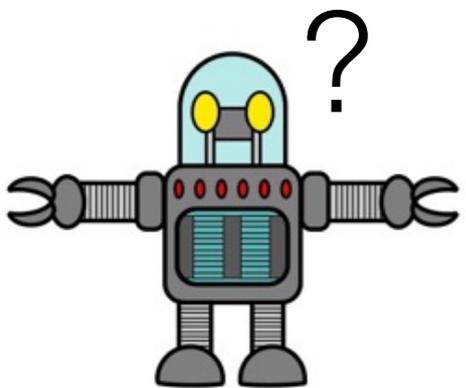


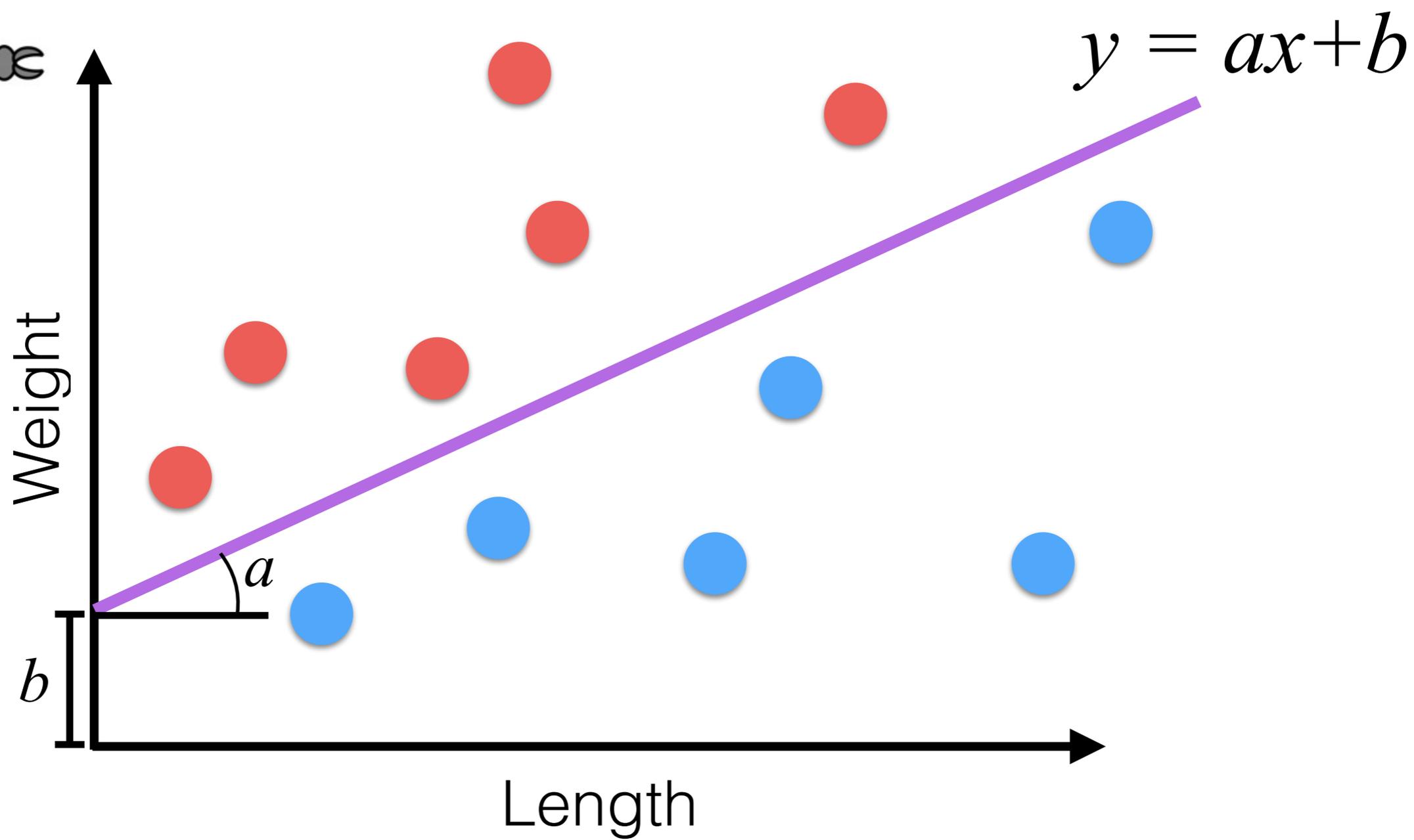
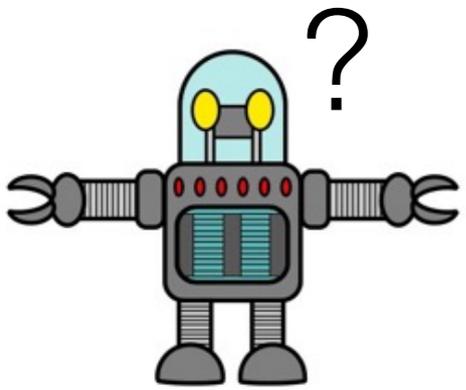


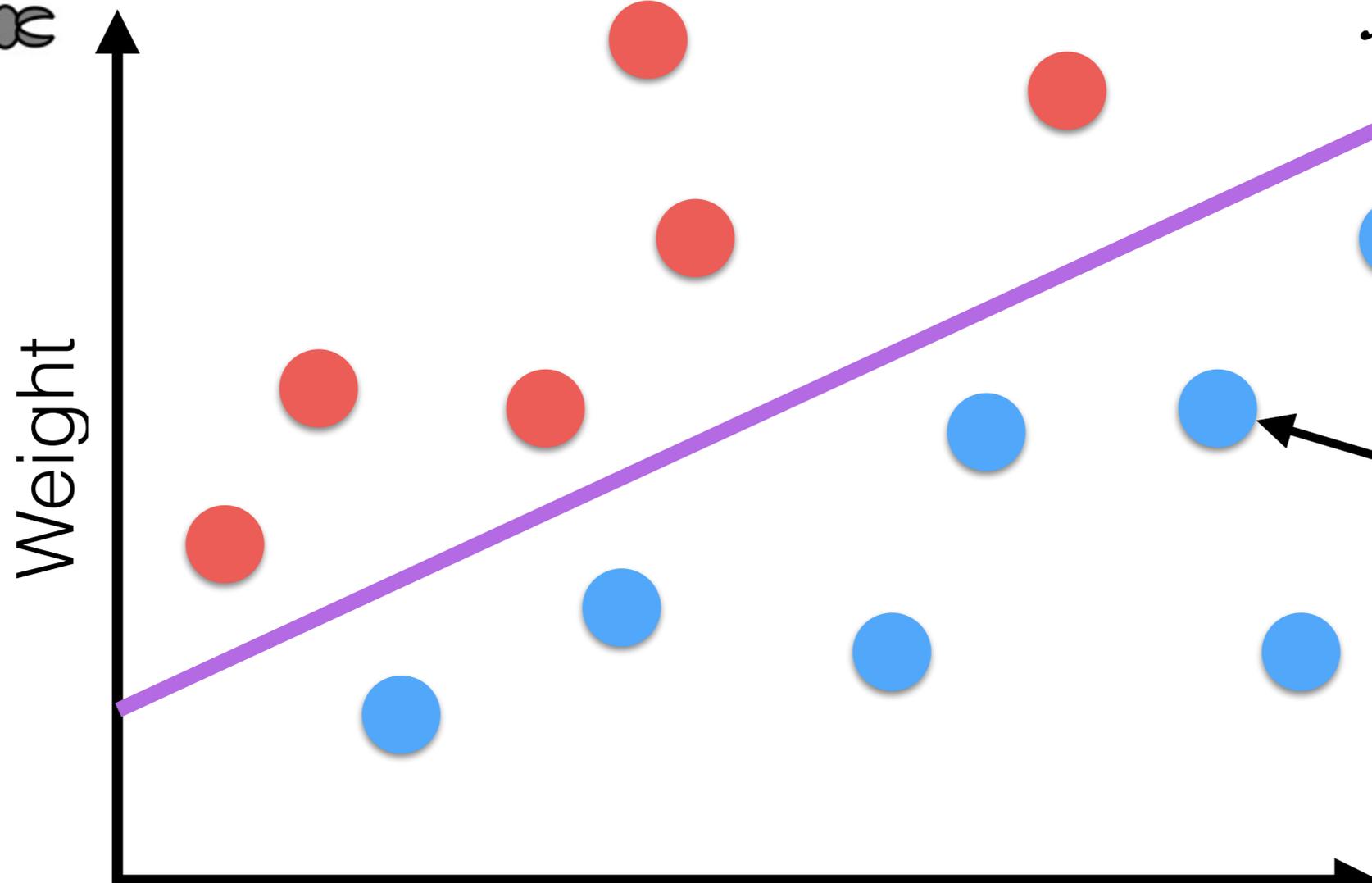
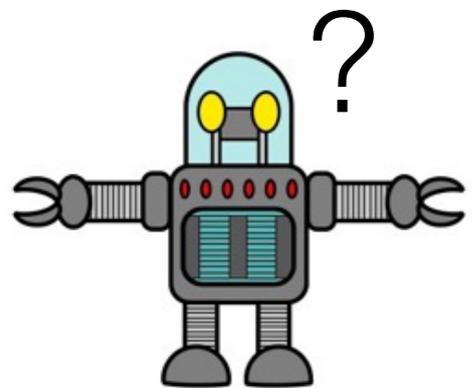












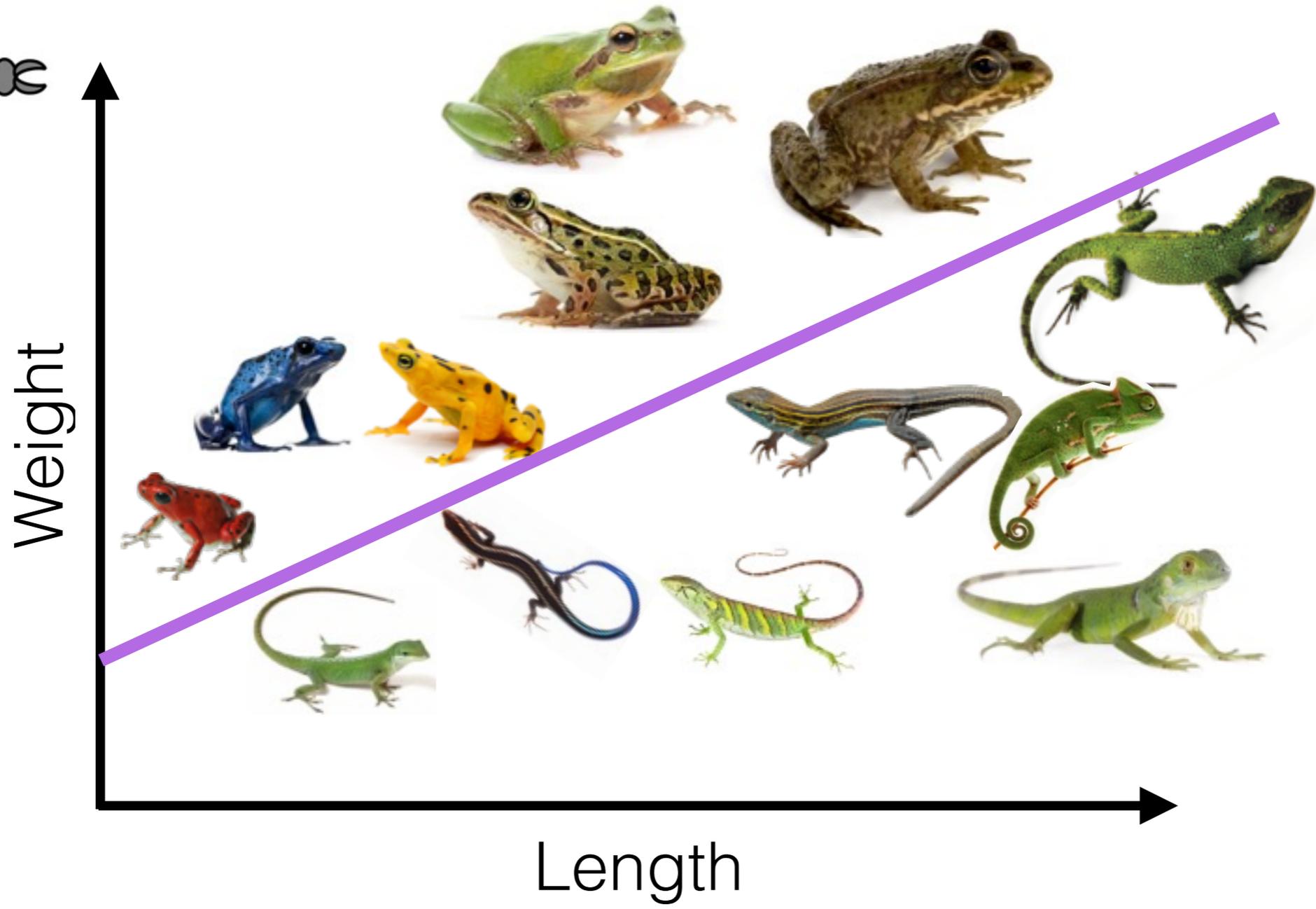
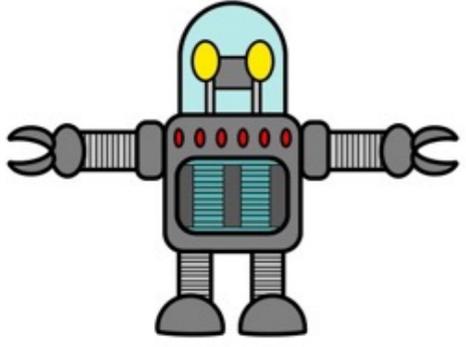
$$y = ax + b$$

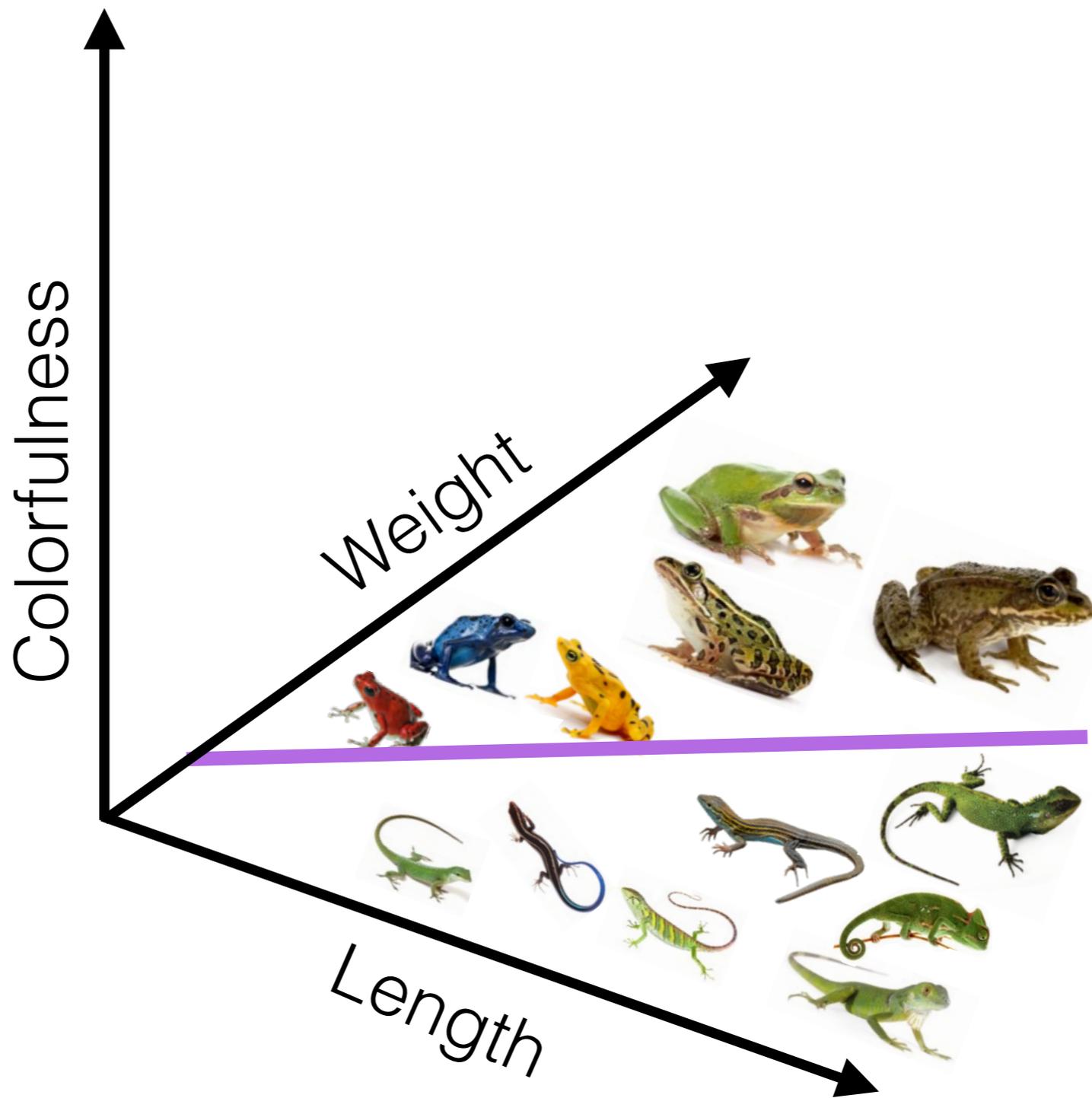
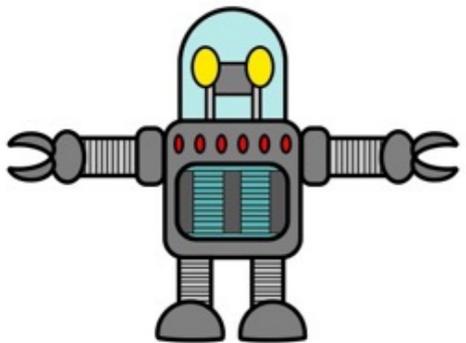


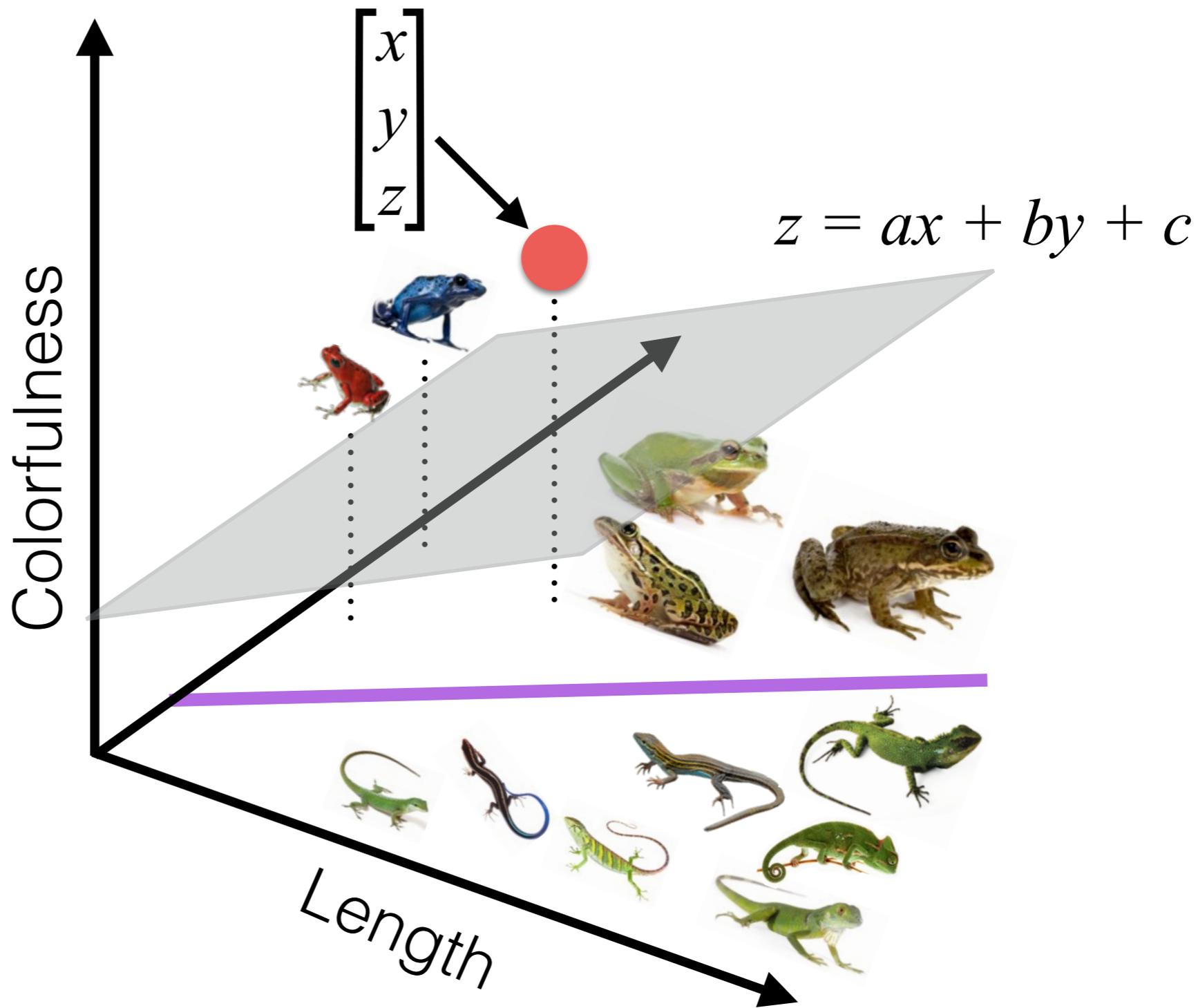
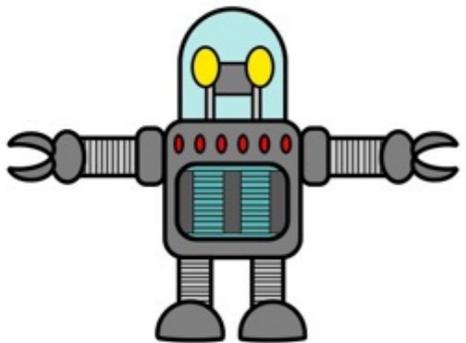
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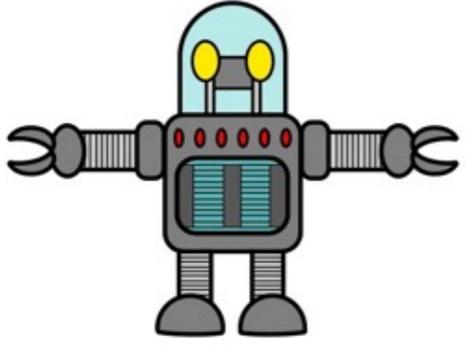
Length

Weight







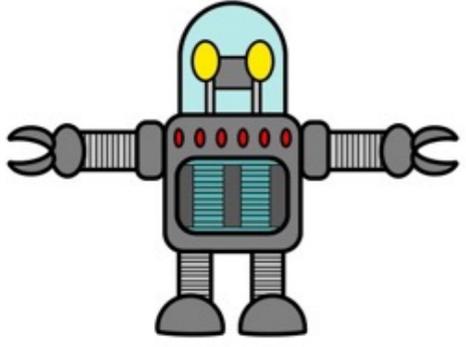


$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

Length

Weight

Colorfulness

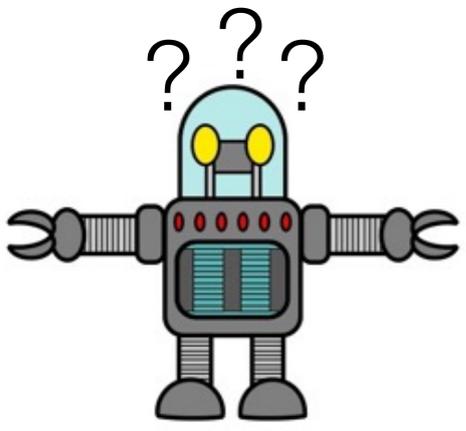

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

Length

Weight

Colorfulness



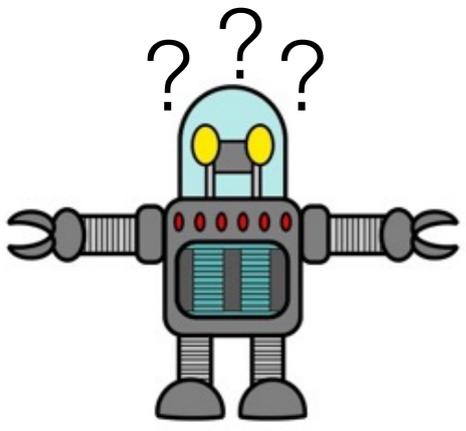

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

Length

Weight

Colorfulness





w
x
y
z

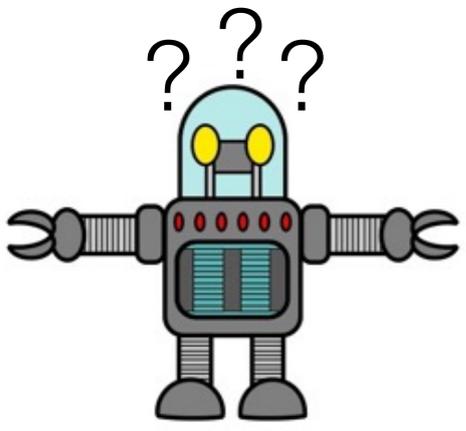
Diet

Length

Weight

Colorfulness





w
x
y
z

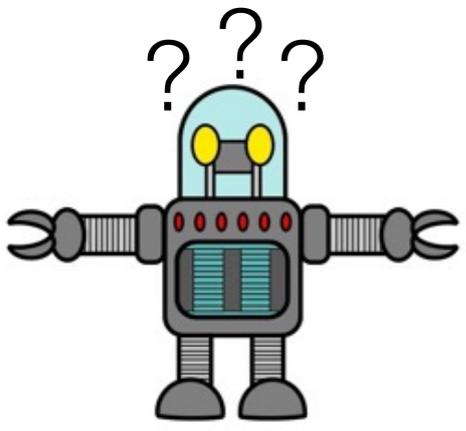
Diet

Length

Weight

Colorfulness





w
x
y
z

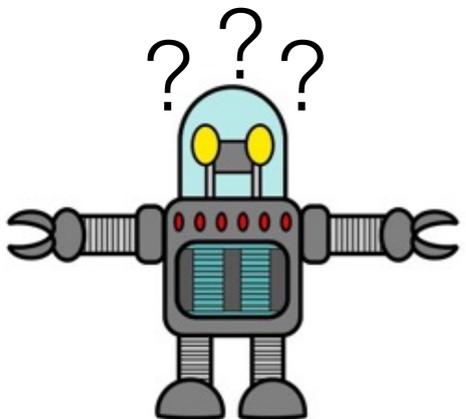
Diet

Length

Weight

Colorfulness





w
 x
 y
 z

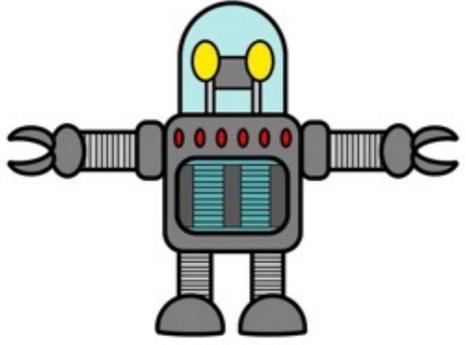
Diet

Length

Weight

Colorfulness



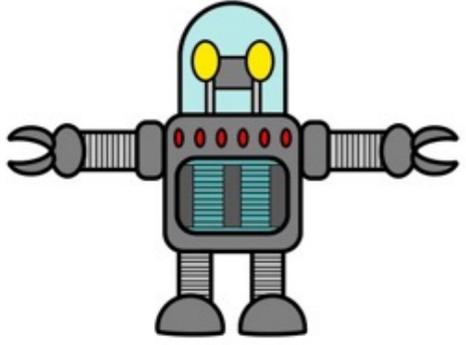

$$\begin{bmatrix} w \\ x \\ y \\ z \end{bmatrix}$$

Diet

Length

Weight

Colorfulness



v
 w
 x
 y
 z

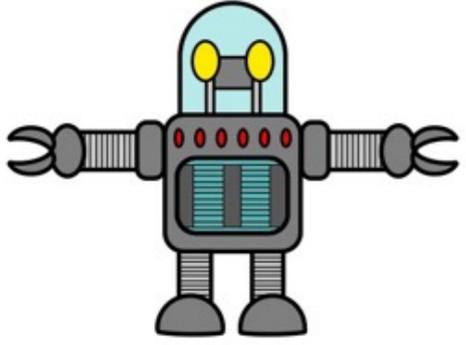
Fins

Diet

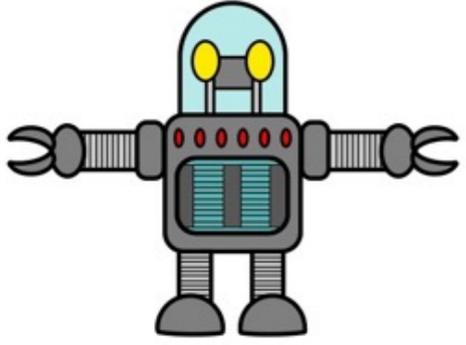
Length

Weight

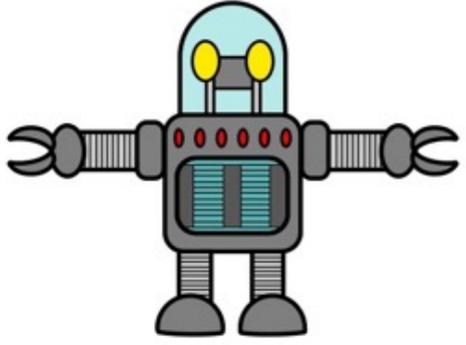
Colorfulness



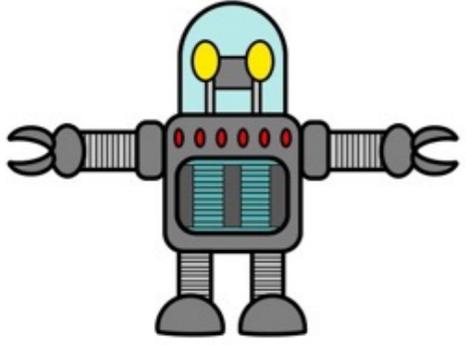
x_1	Fins
x_2	Diet
x_3	Length
x_4	Weight
x_5	Colorfulness



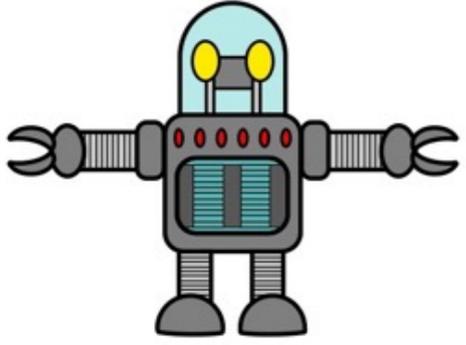
x_1	Fins
x_2	Diet
x_3	Length
x_4	Weight
x_5	Colorfulness
x_6	Eggs



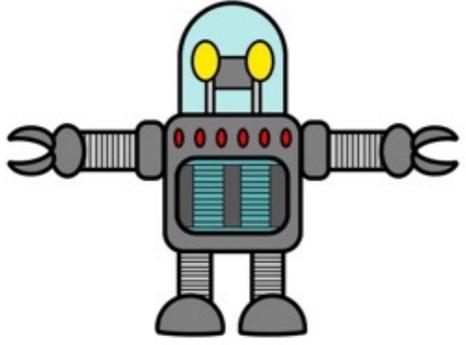
x_1	Fins
x_2	Diet
x_3	Length
x_4	Weight
x_5	Colorfulness
x_6	Eggs
x_7	Mammal



x_1	Fins
x_2	Diet
x_3	Length
x_4	Weight
x_5	Colorfulness
x_6	Eggs
x_7	Mammal
x_8	Gene 1

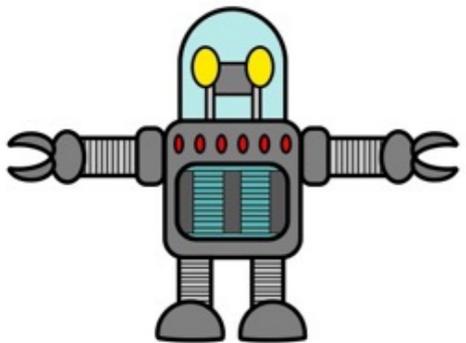


x_1	Fins
x_2	Diet
x_3	Length
x_4	Weight
x_5	Colorfulness
x_6	Eggs
x_7	Mammal
x_8	Gene 1
\vdots	
x_N	Gene M



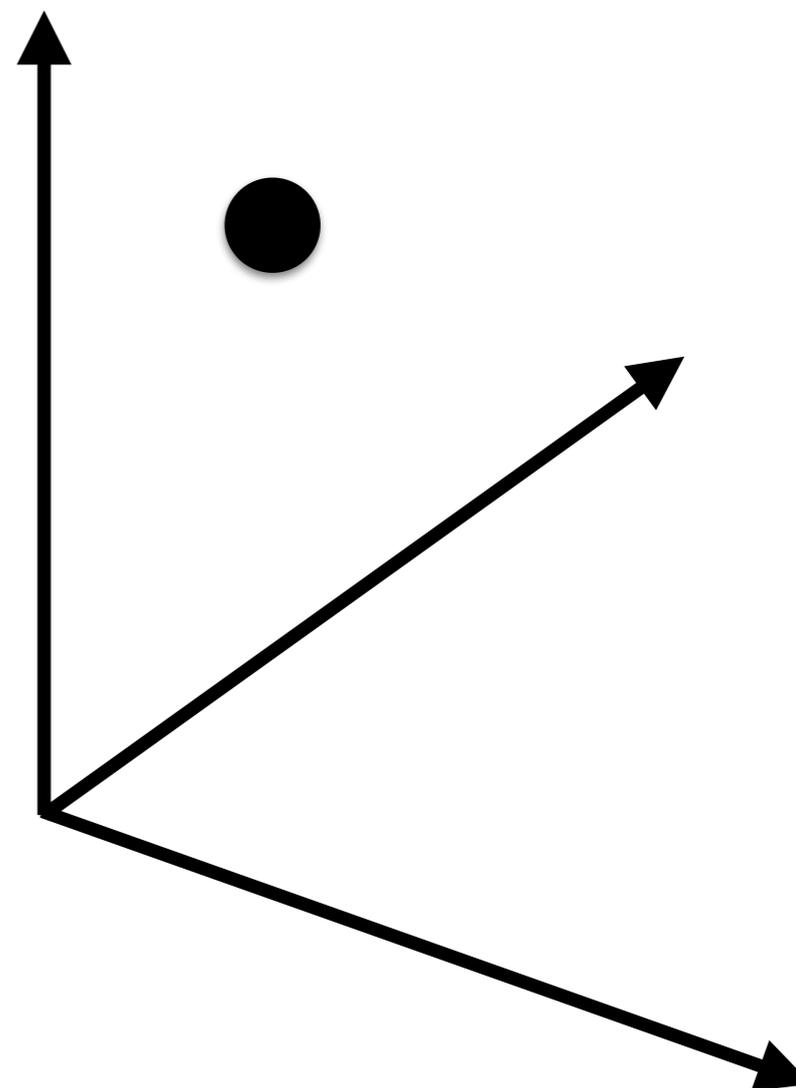
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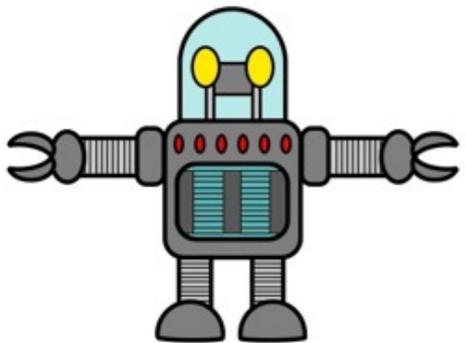
x_1	Fins
x_2	Diet
x_3	Length
x_4	Weight
x_5	Colorfulness
x_6	Eggs
x_7	Mammal
x_8	Gene 1
\vdots	
x_N	Gene M



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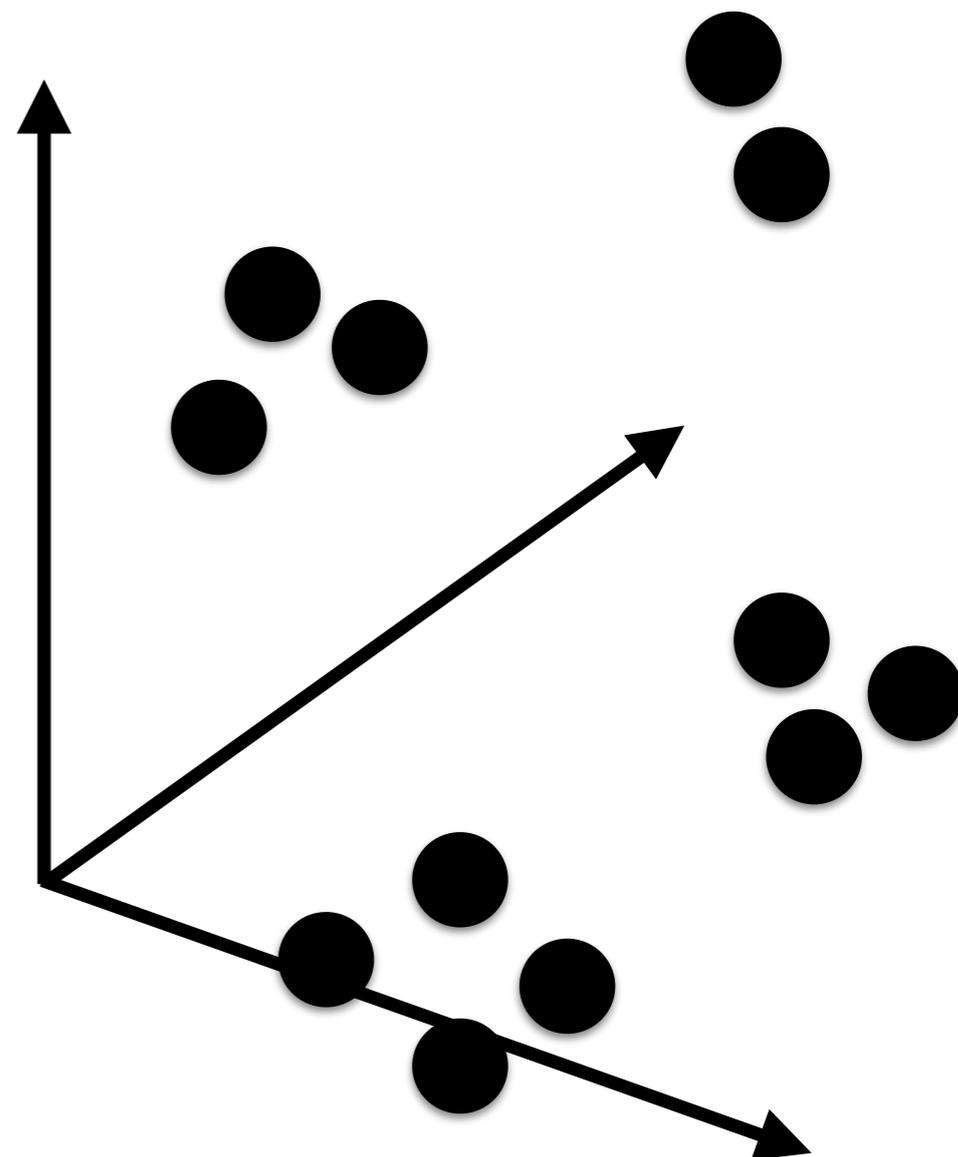
- x_1 Fins
- x_2 Diet
- x_3 Length
- x_4 Weight
- x_5 Colorfulness
- x_6 Eggs
- x_7 Mammal
- x_8 Gene 1
- \vdots
- x_N Gene M

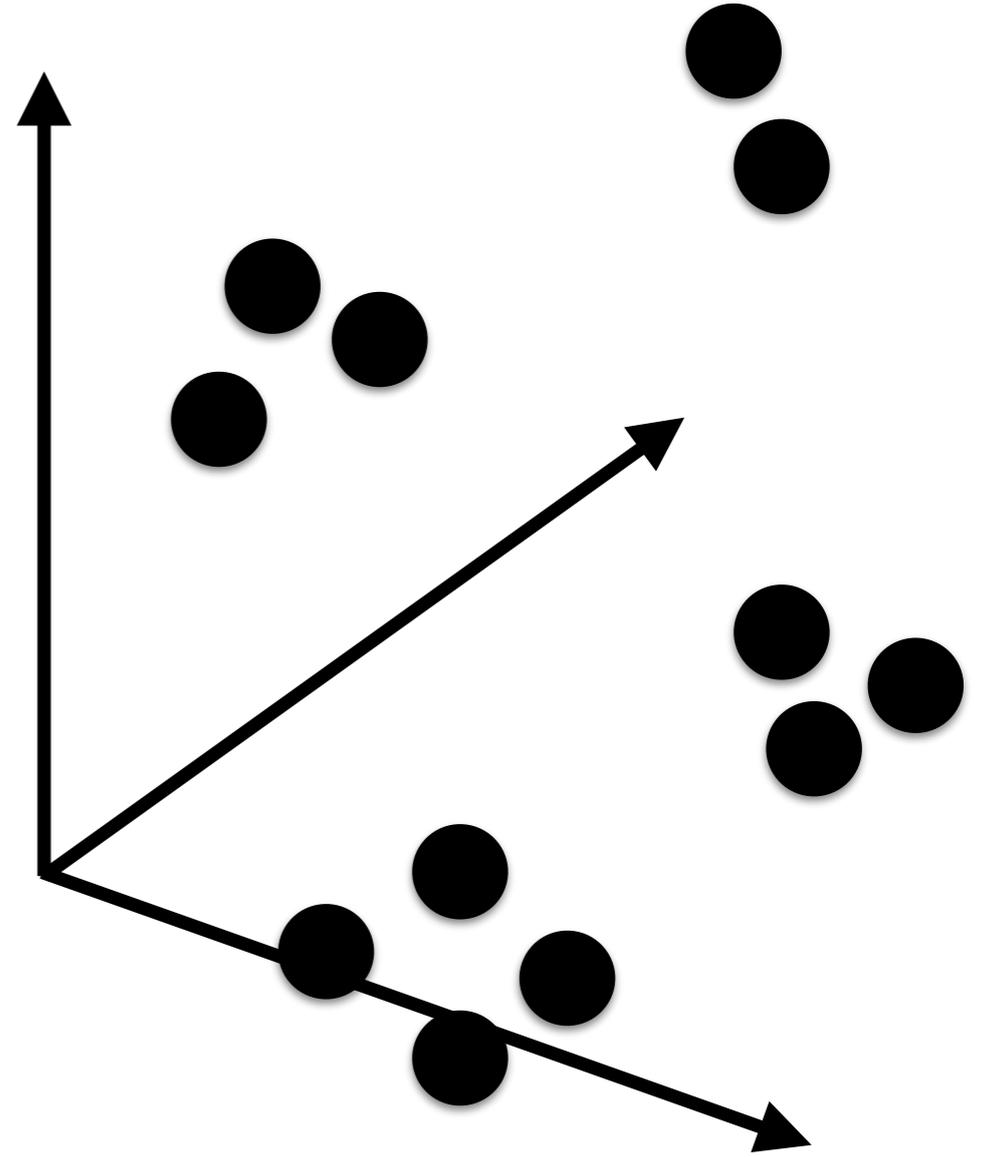
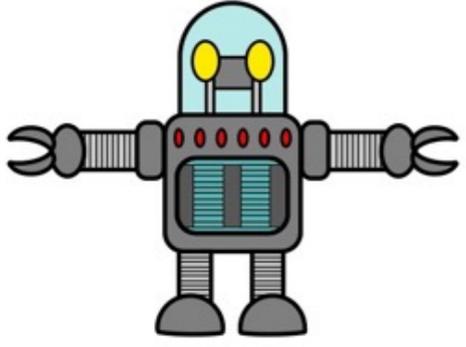


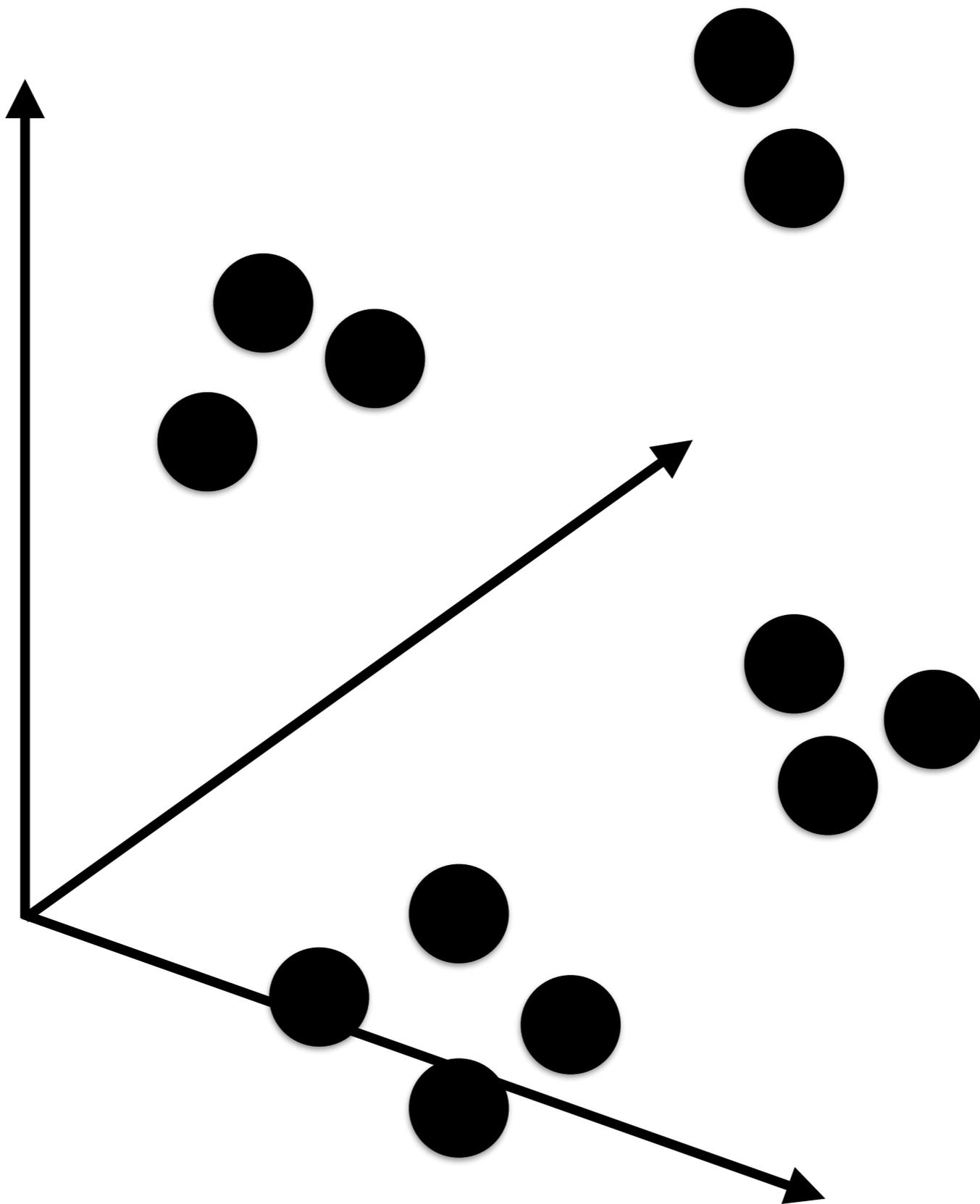
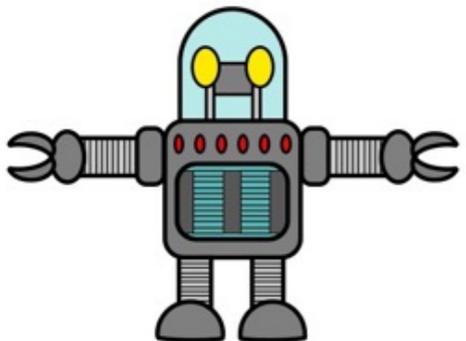


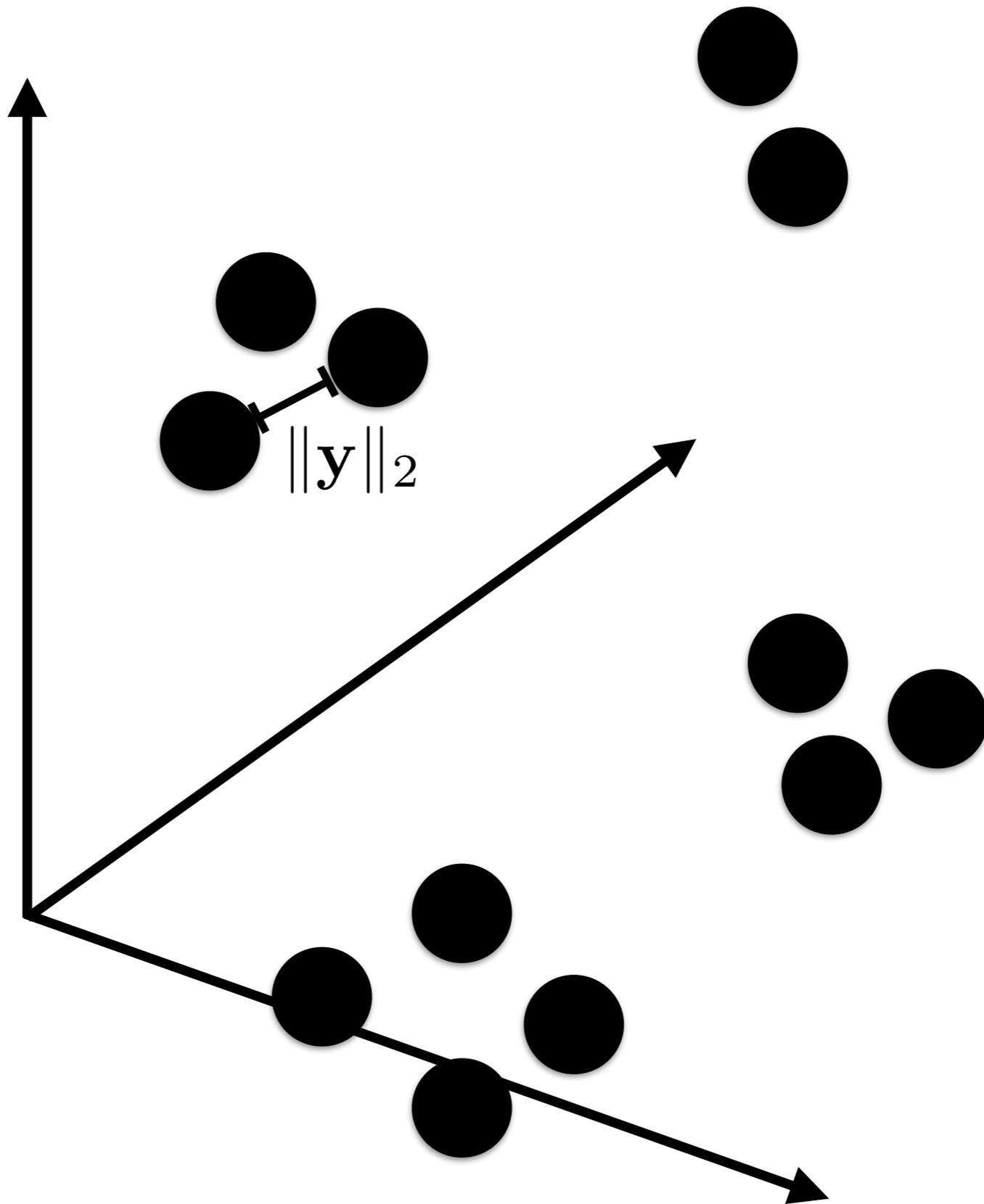
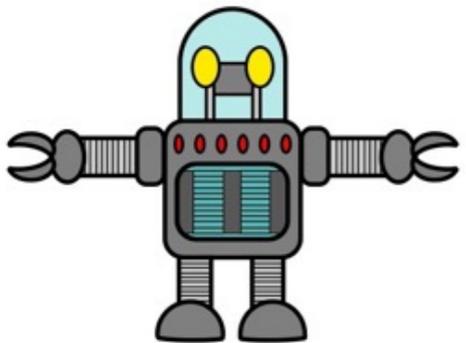
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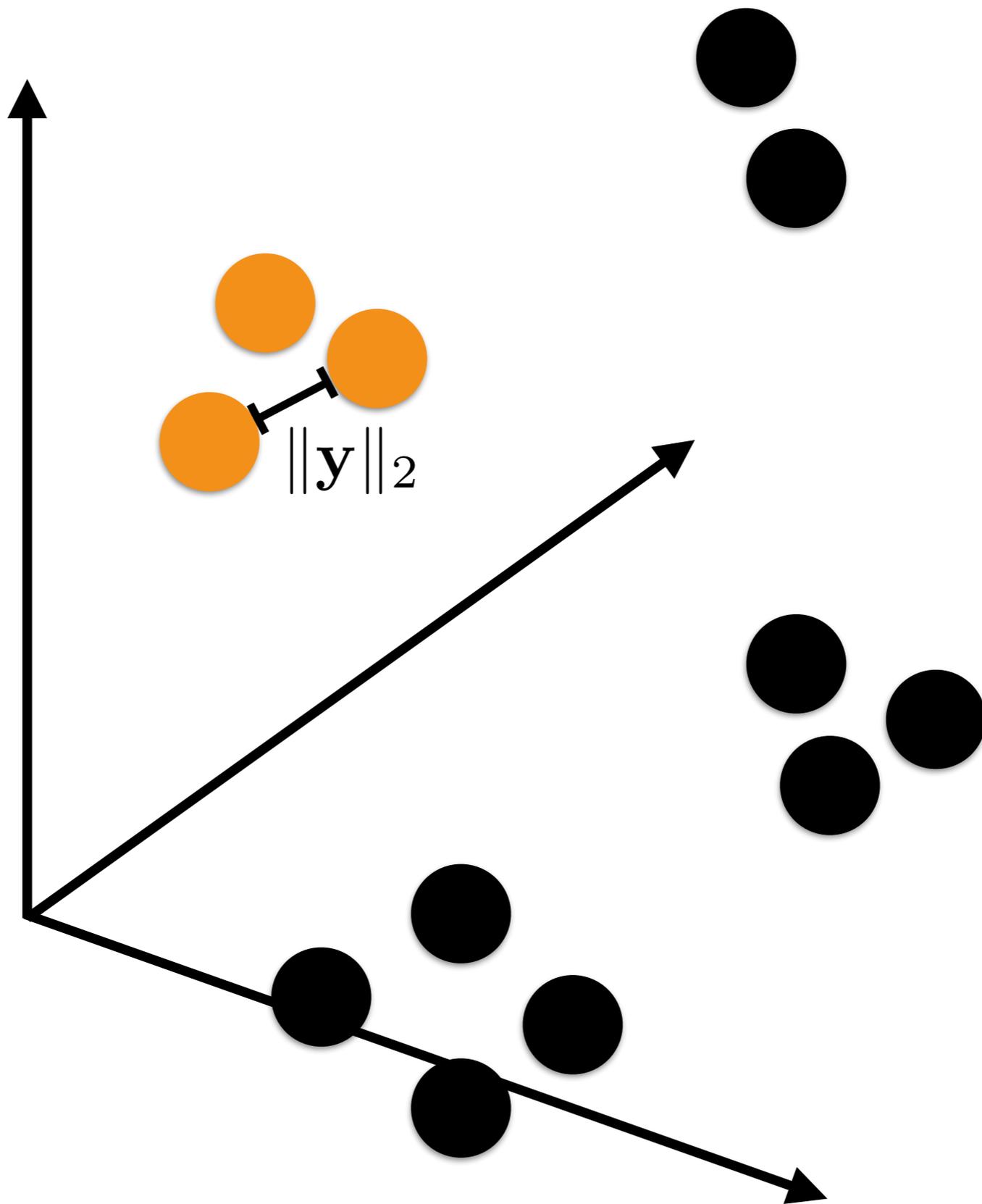
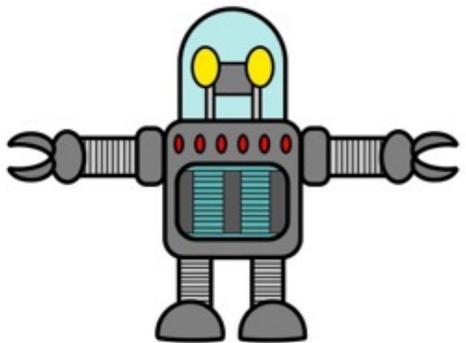
- x_1 Fins
- x_2 Diet
- x_3 Length
- x_4 Weight
- x_5 Colorfulness
- x_6 Eggs
- x_7 Mammal
- x_8 Gene 1
- \vdots
- x_N Gene M

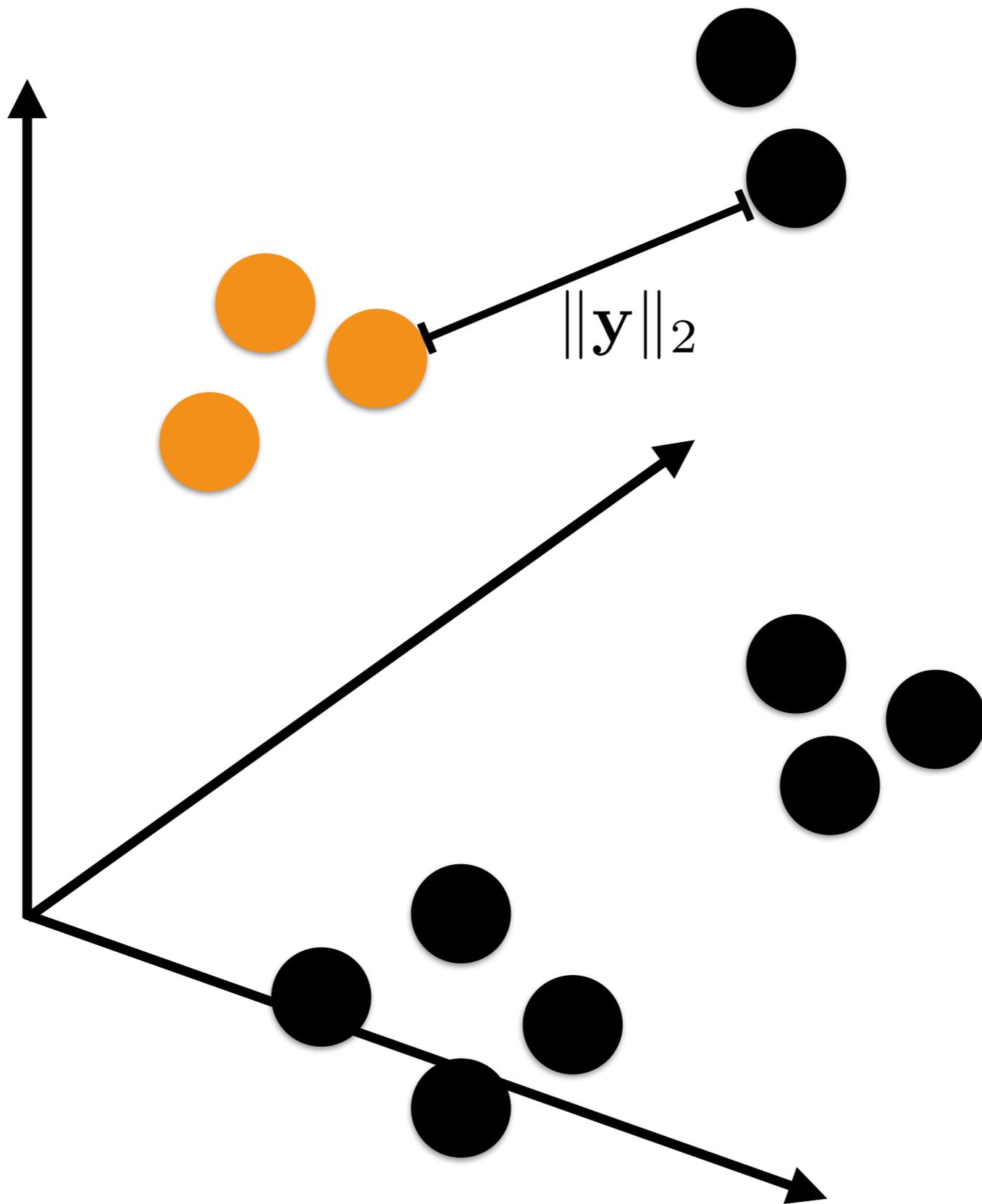
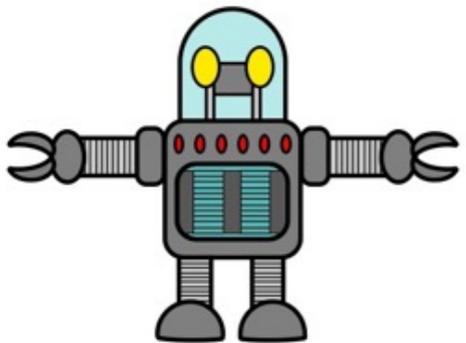


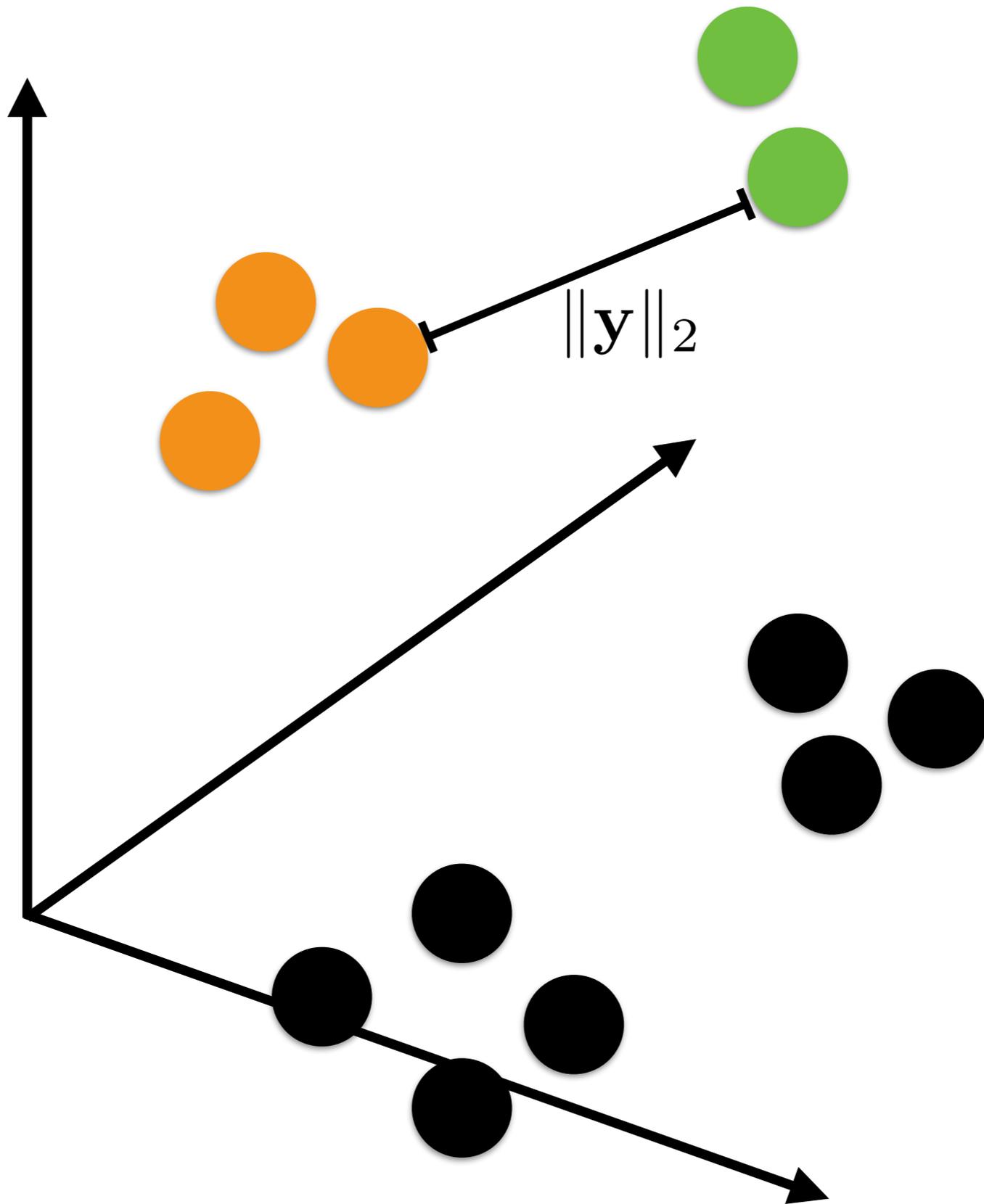
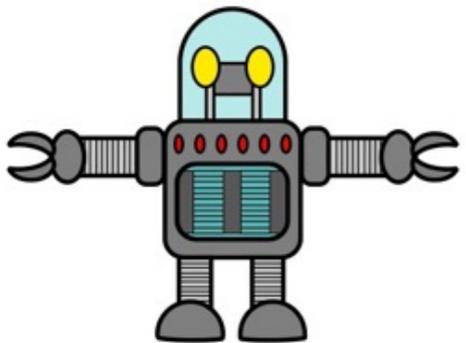


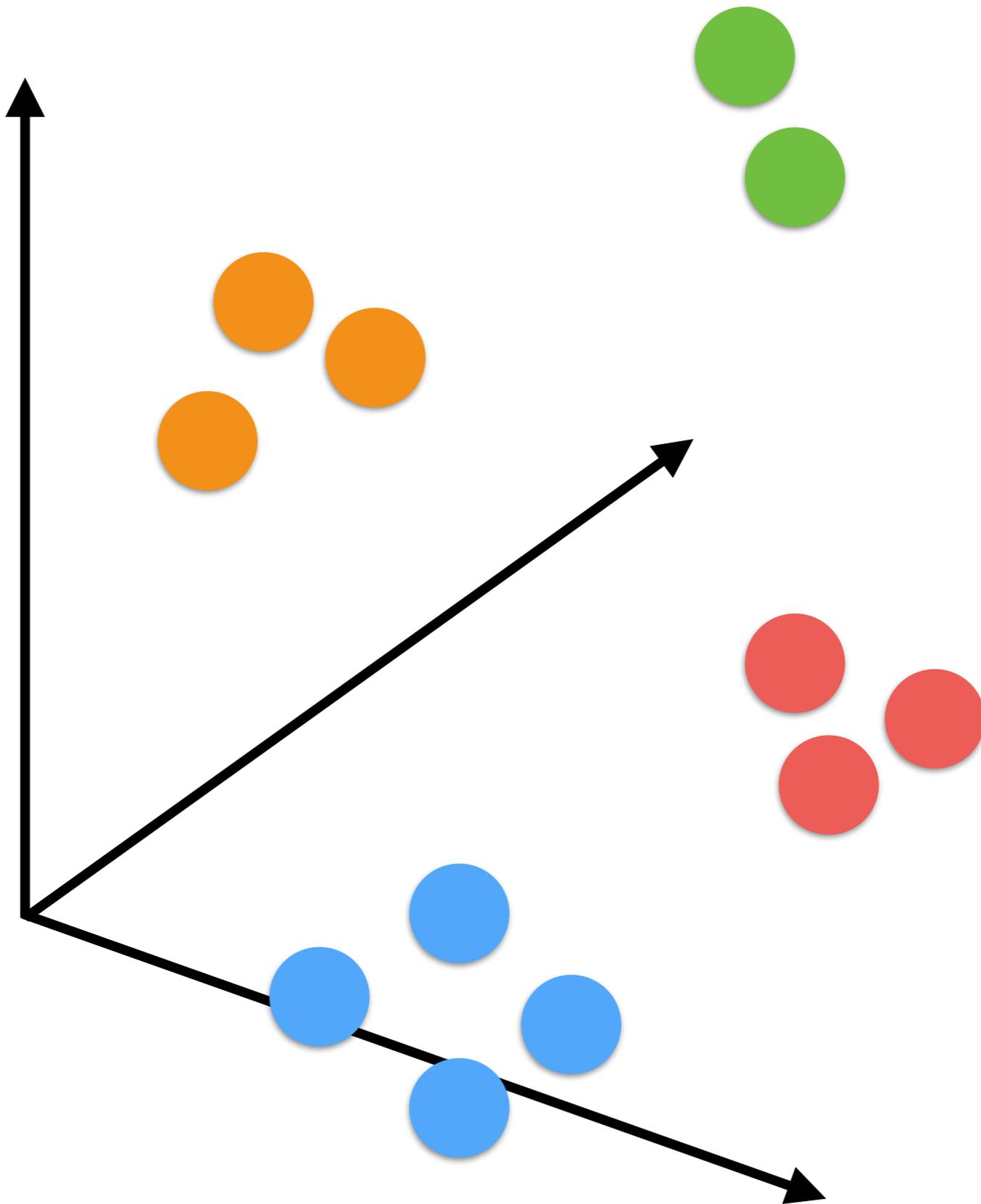
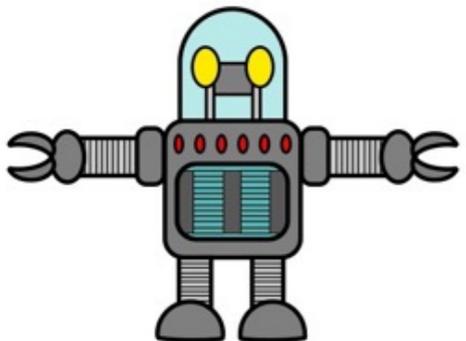


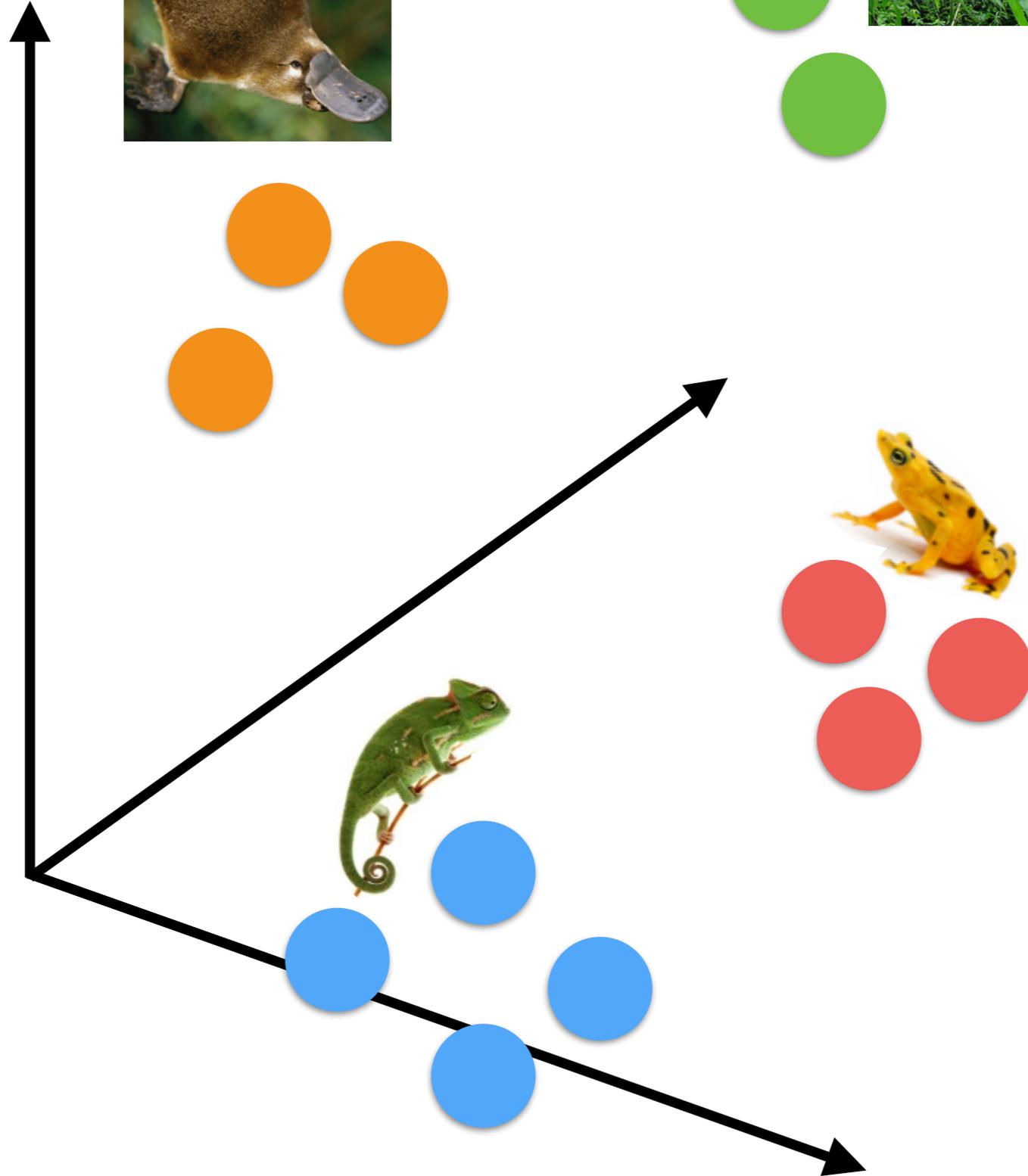
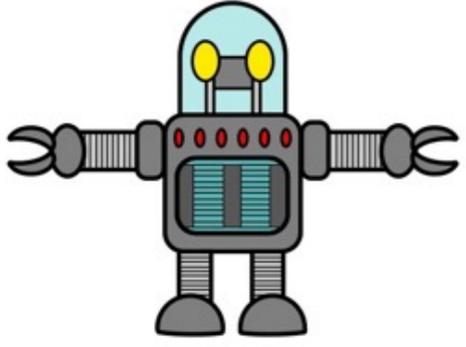






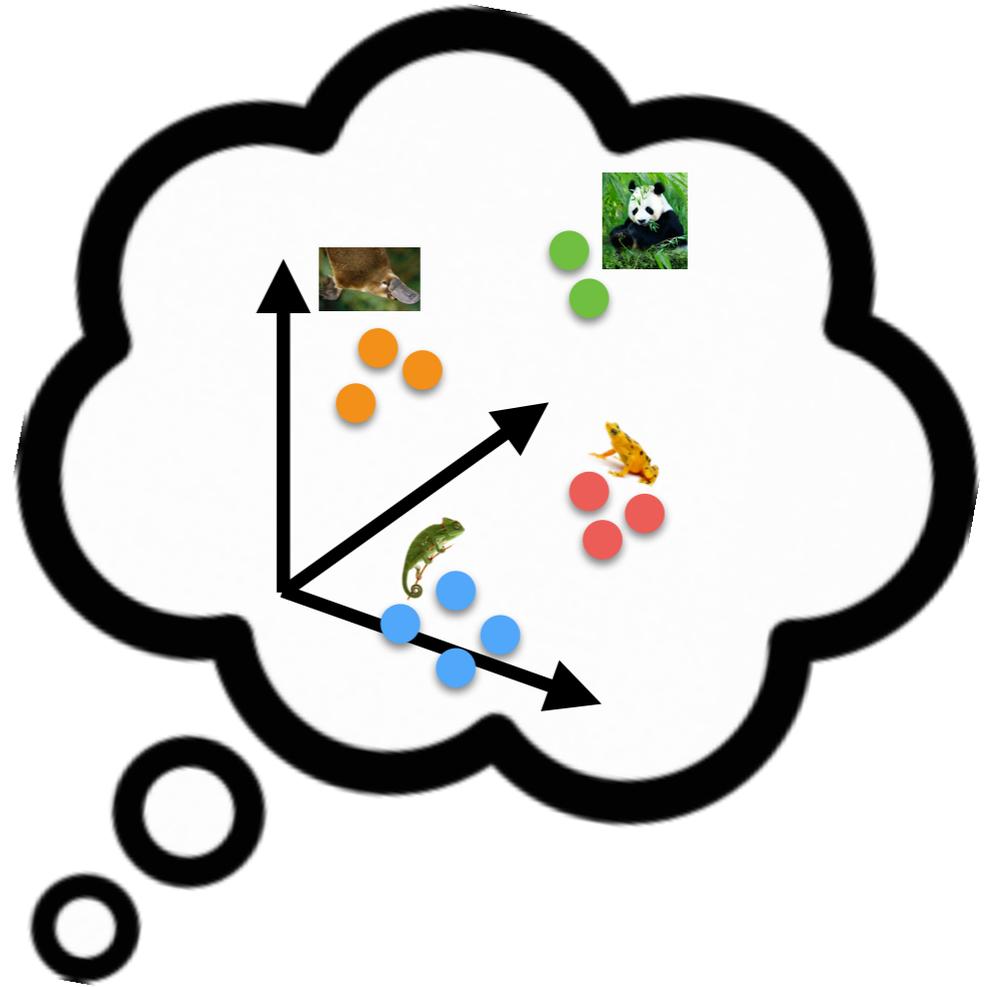
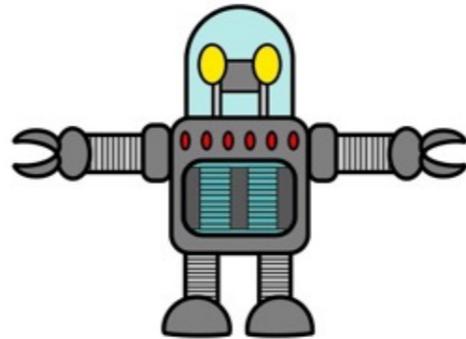








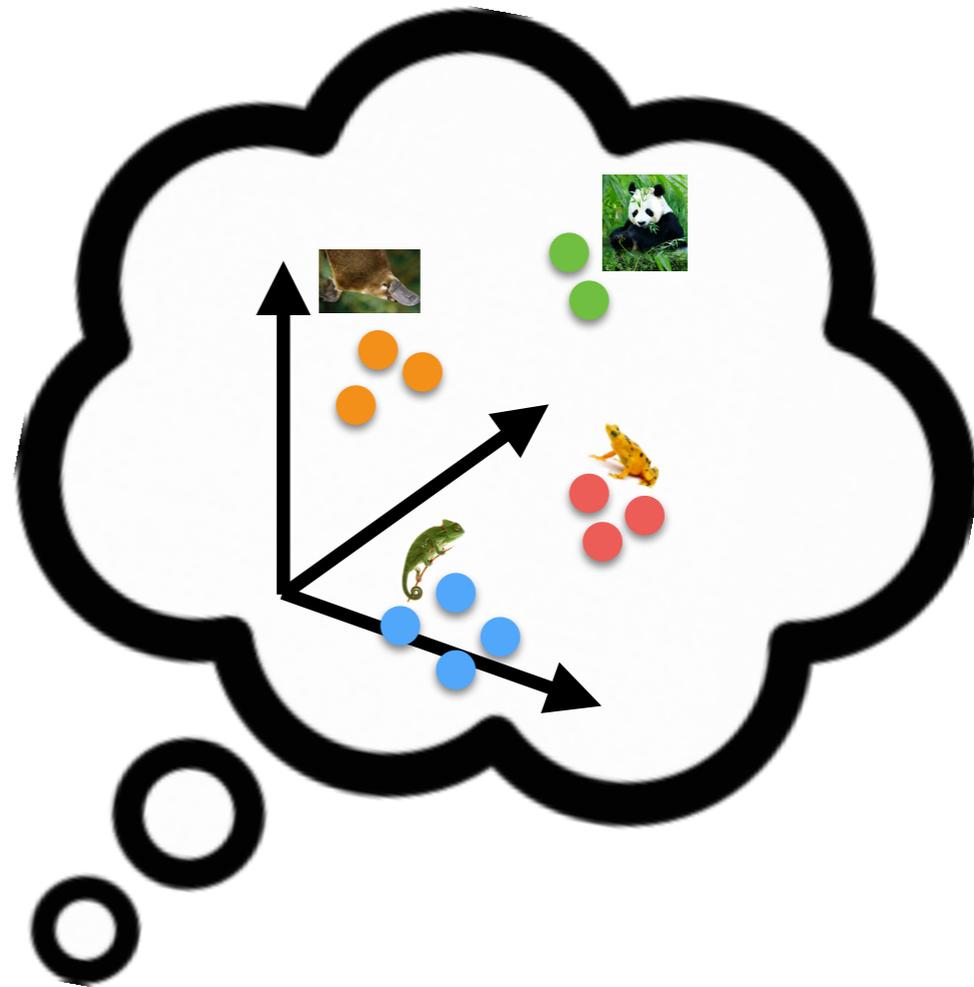
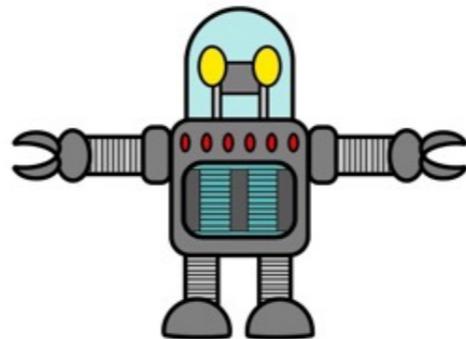
$$\|y\|_2$$



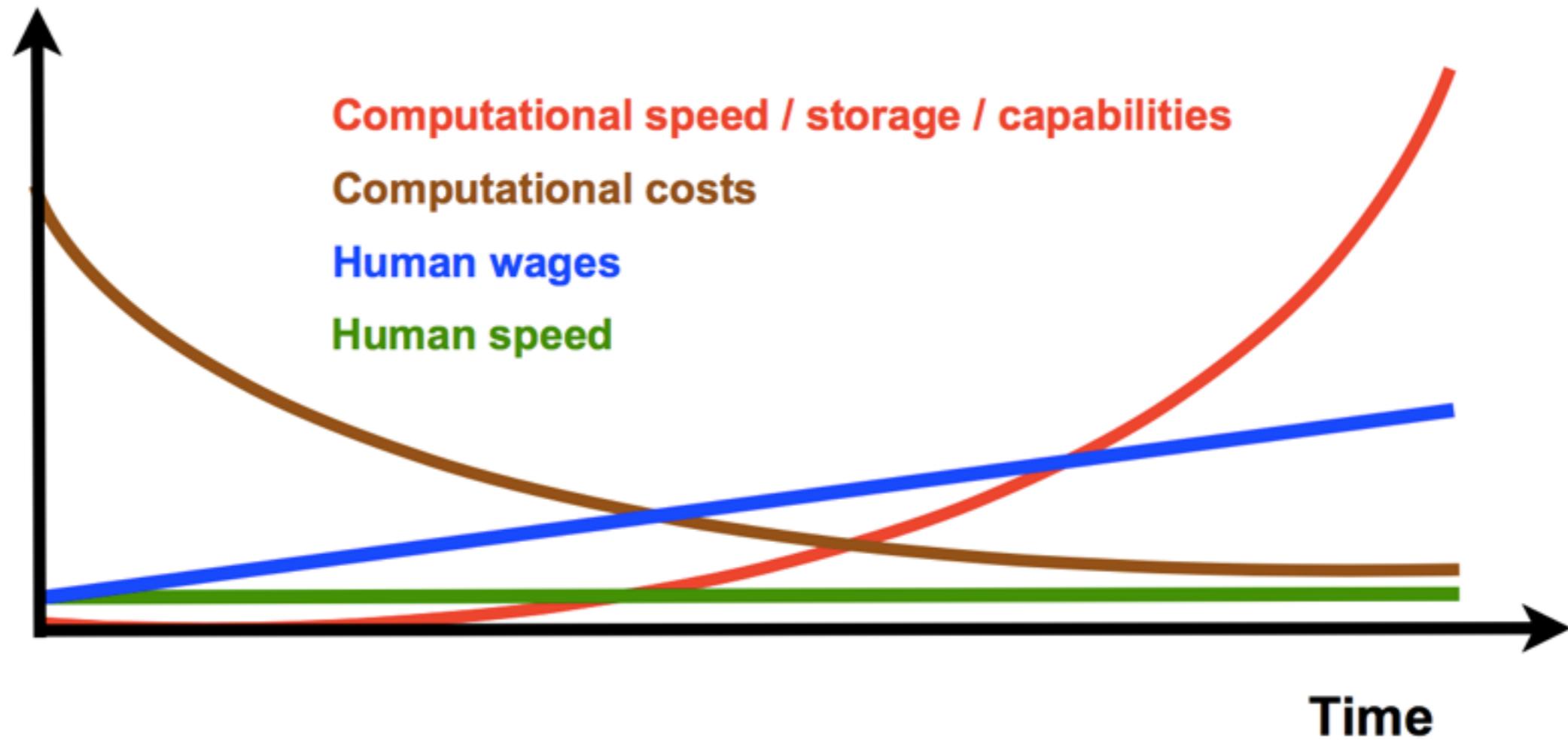
So, what did we do?



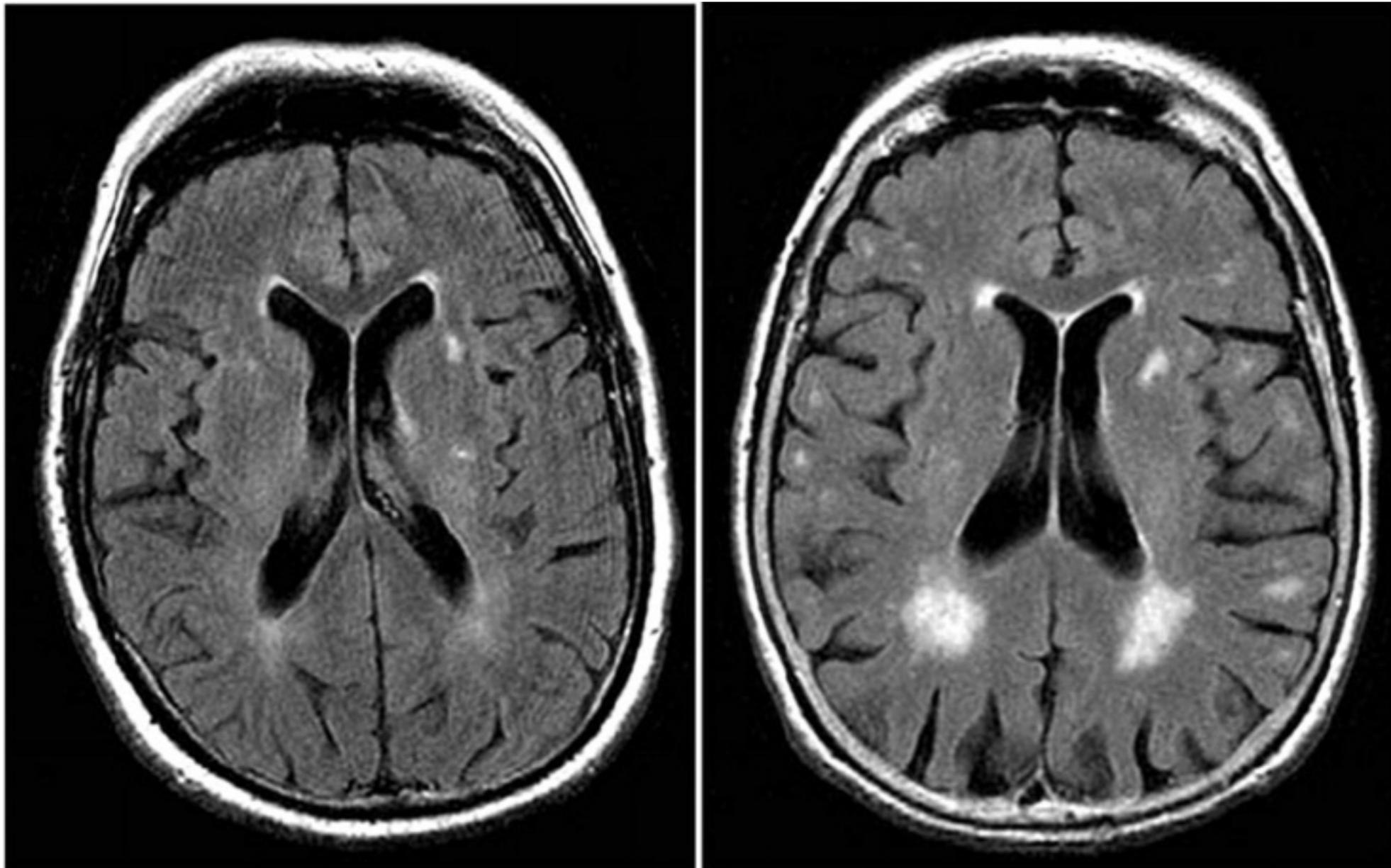
$$\|\mathbf{y}\|_2$$



So, my robot can classify a few animals. Cool. So what?



Here is why the big fuzz about
Machine Learning



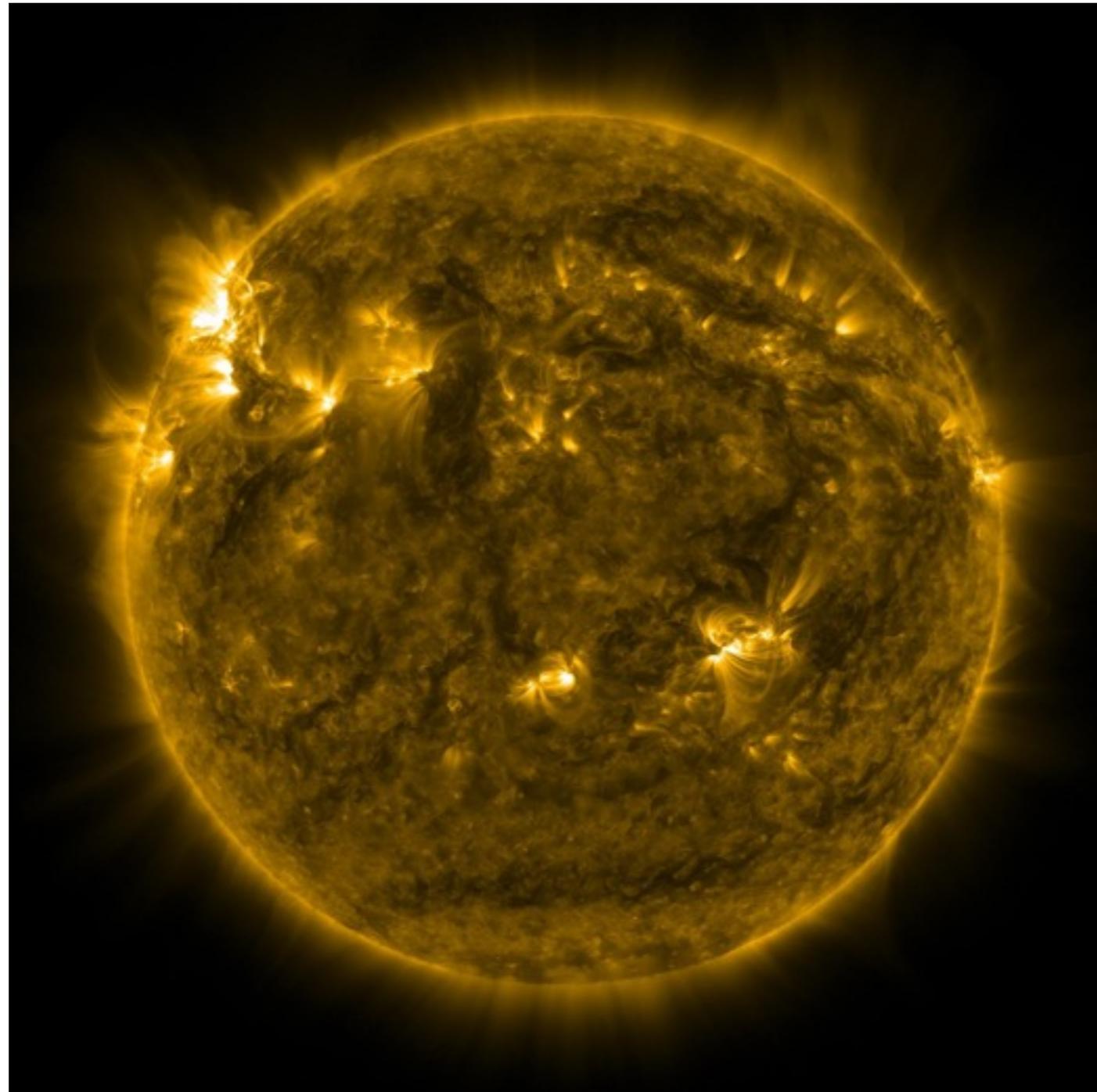
Which one has Alzheimer?



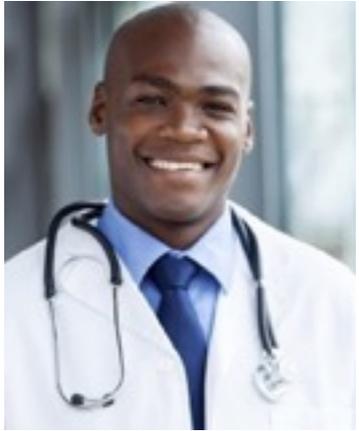
Who is commmitting a crime?



Who is commmitting a crime?

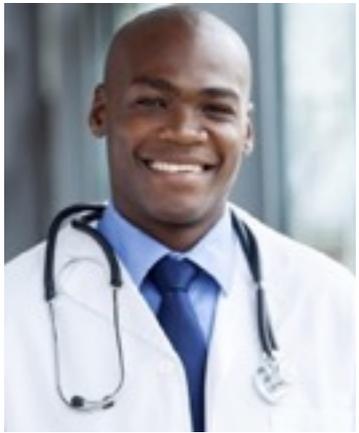


When will a flare hit the earth?

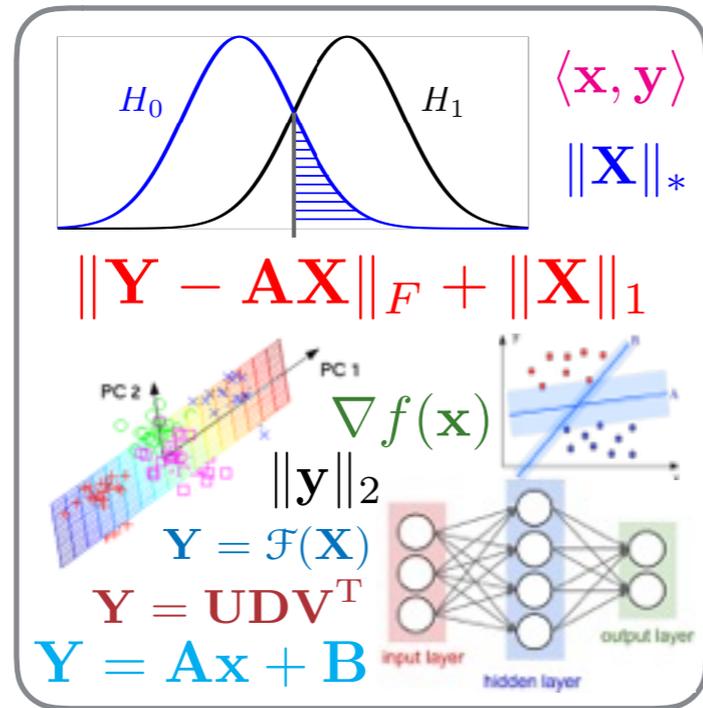


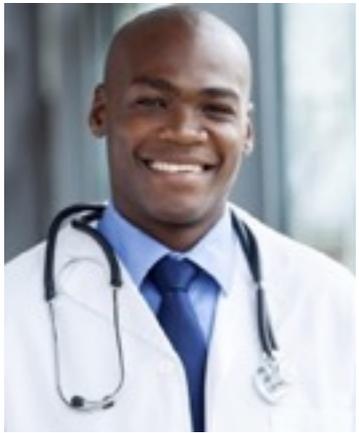
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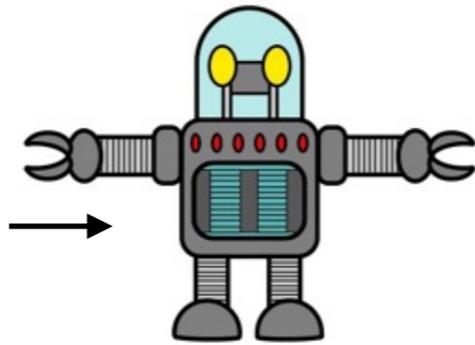
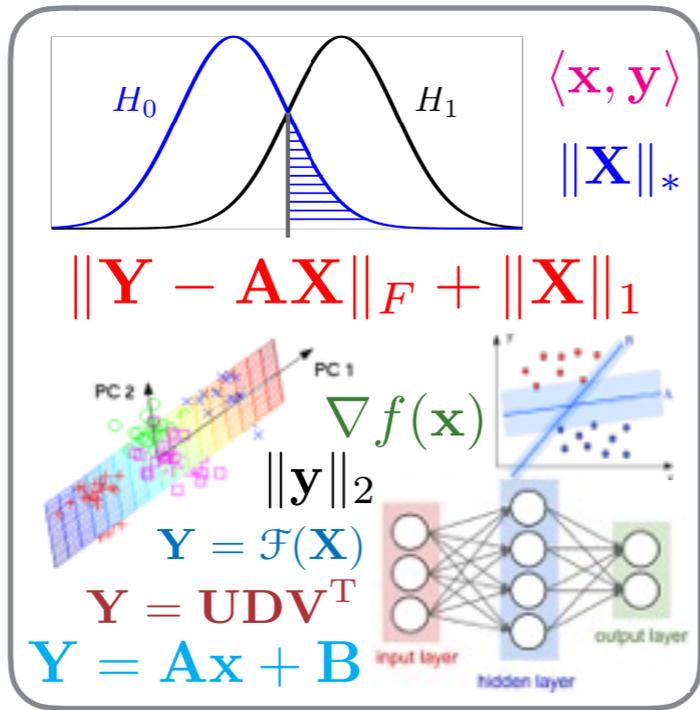


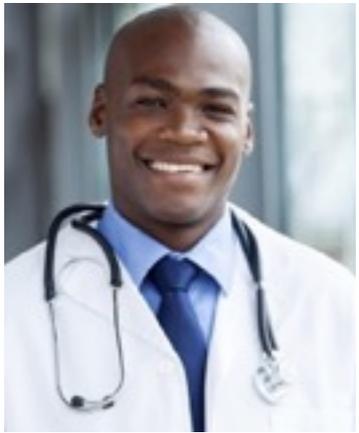
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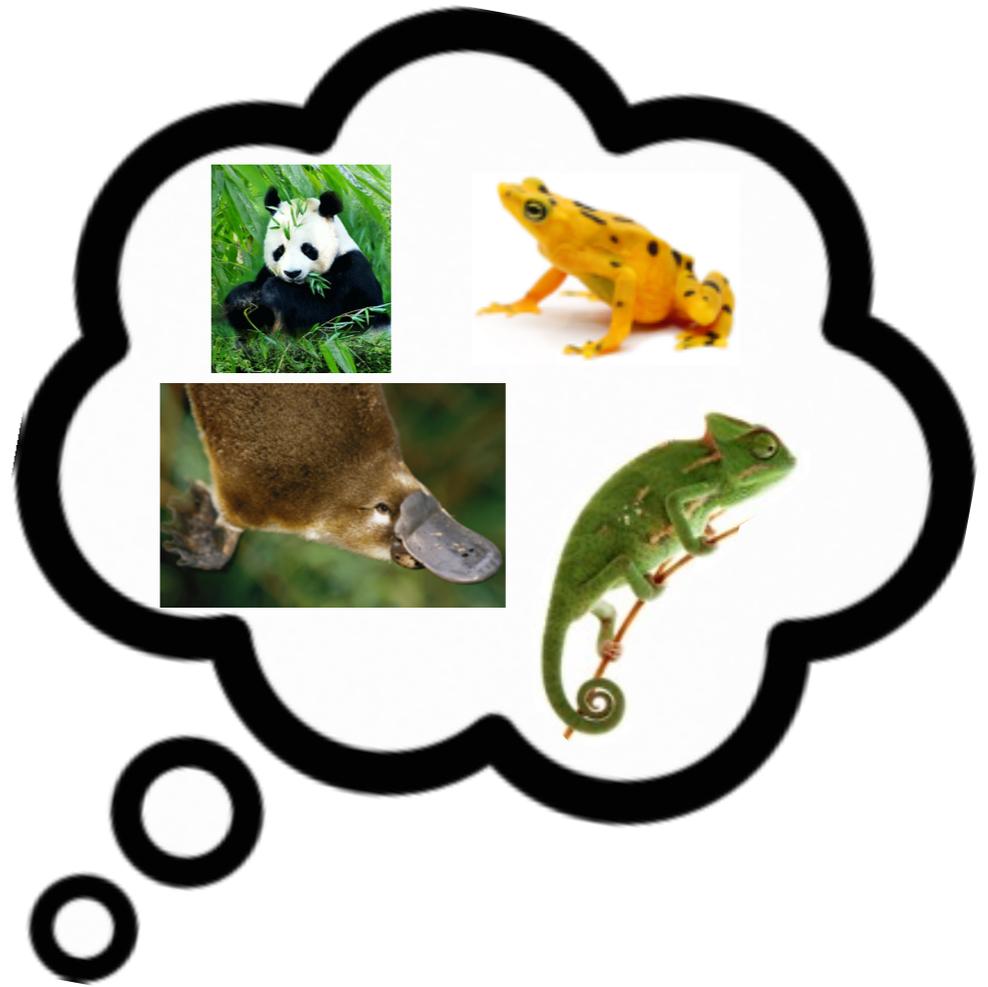
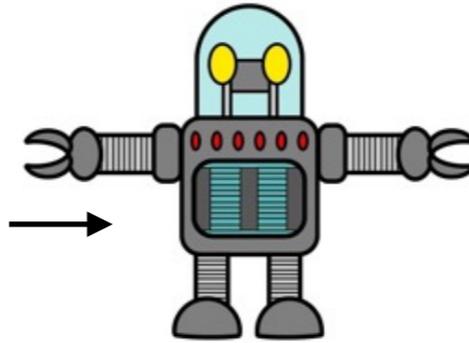
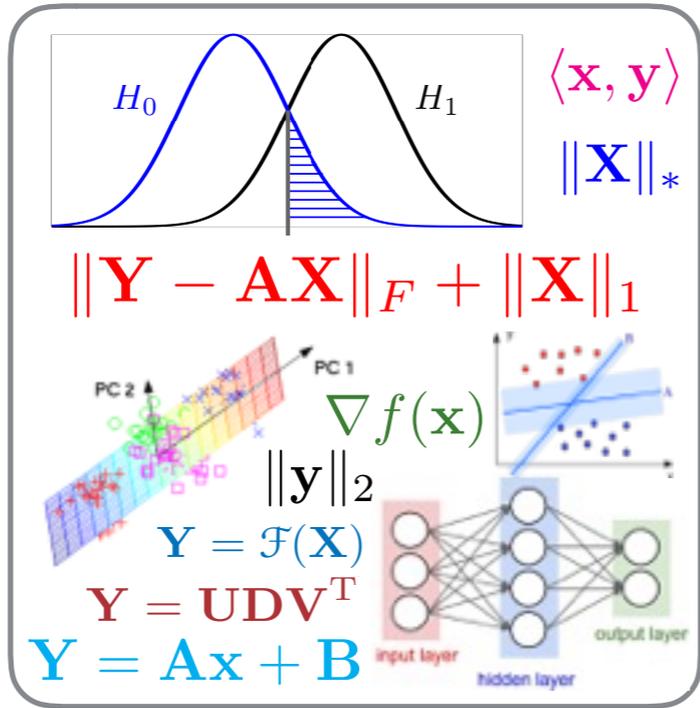


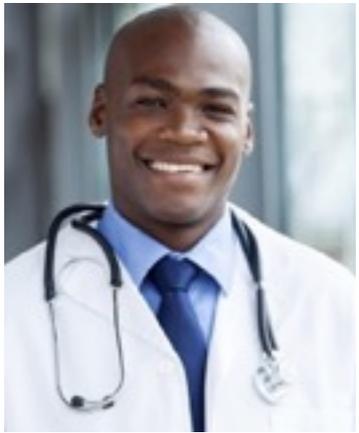
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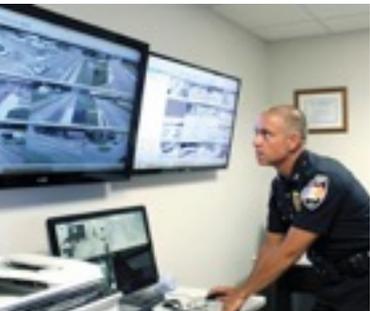


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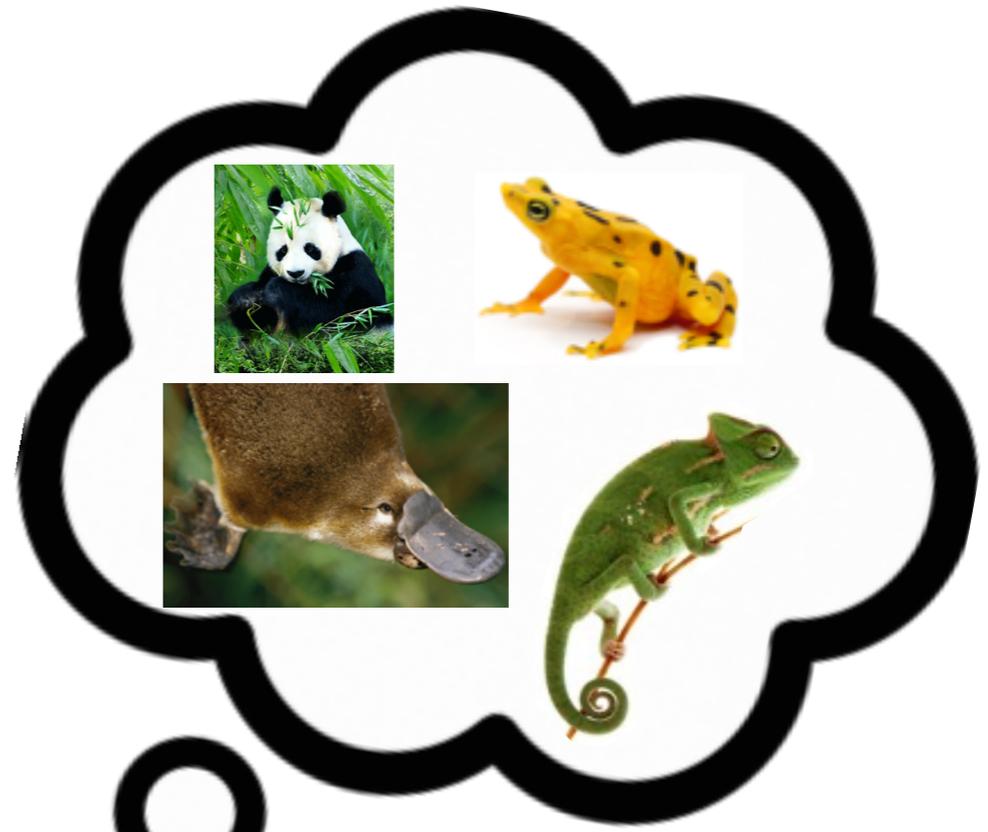
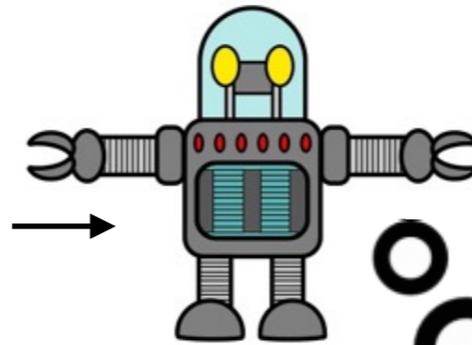


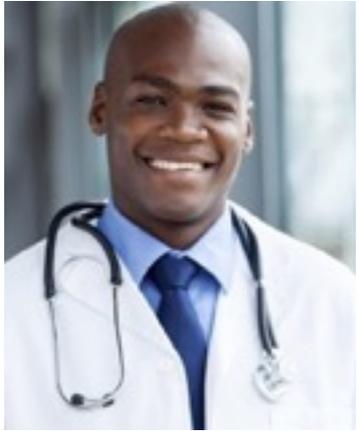
$\langle \mathbf{x}, \mathbf{y} \rangle$
 $\|\mathbf{X}\|_*$

$\| \mathbf{Y} - \mathbf{A}\mathbf{X} \|_F + \|\mathbf{X}\|_1$

PC2
PC1
 $\nabla f(\mathbf{x})$
 $\|\mathbf{y}\|_2$
 $\mathbf{Y} = \mathcal{F}(\mathbf{X})$
 $\mathbf{Y} = \mathbf{U}\mathbf{D}\mathbf{V}^T$
 $\mathbf{Y} = \mathbf{A}\mathbf{x} + \mathbf{B}$

input layer
hidden layer
output layer

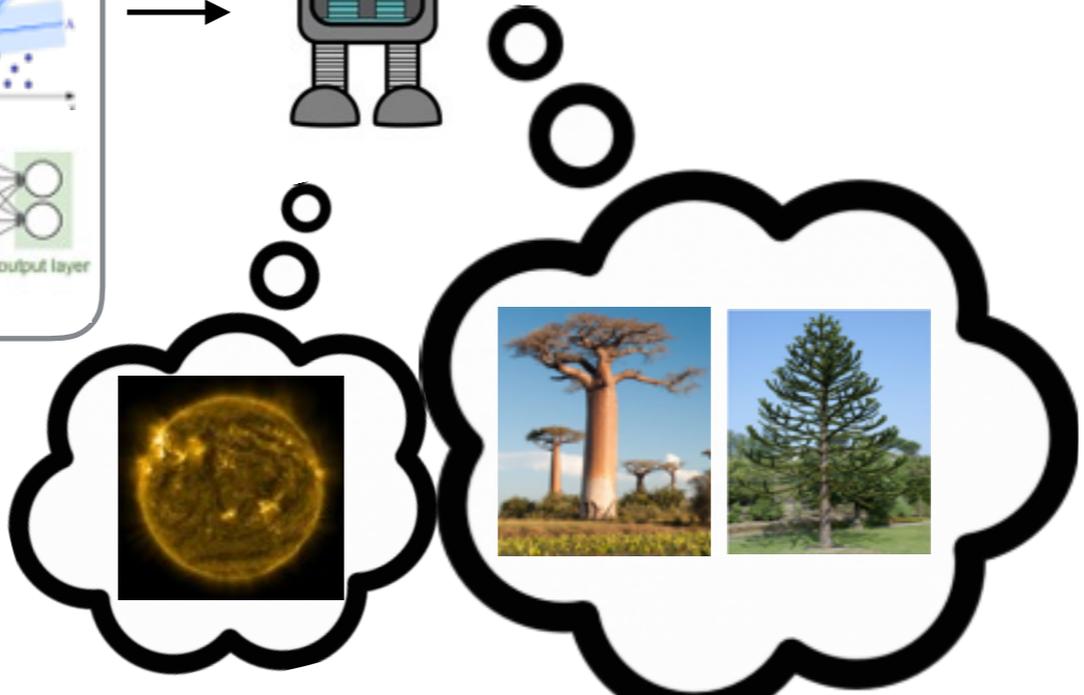
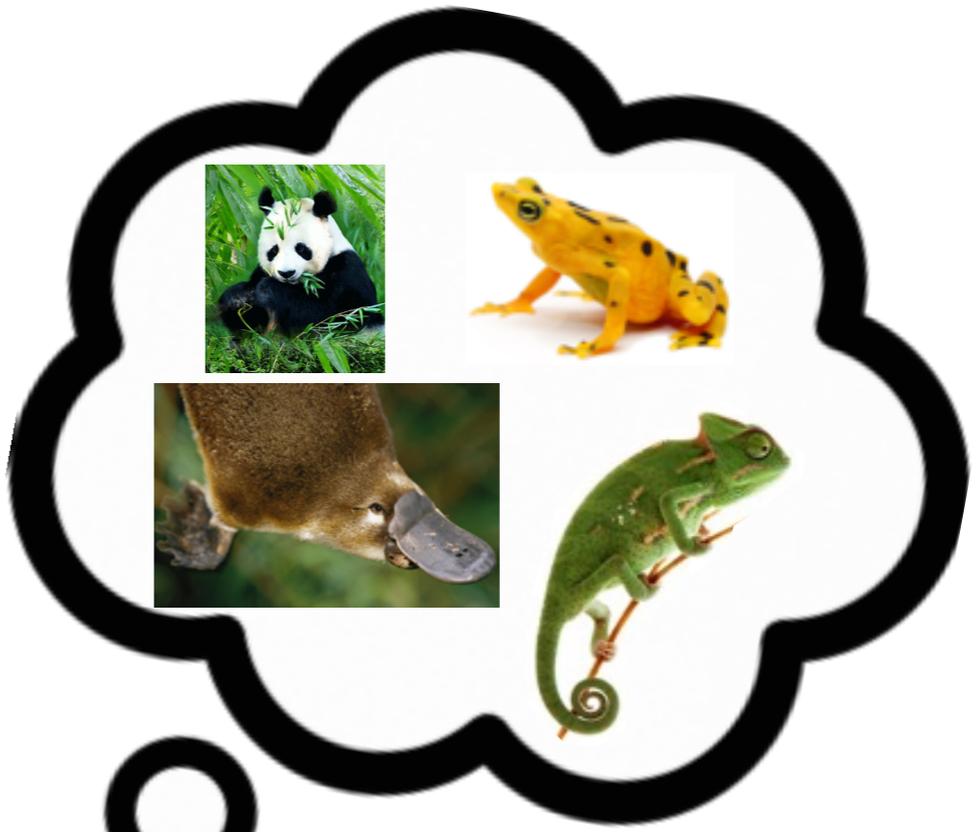
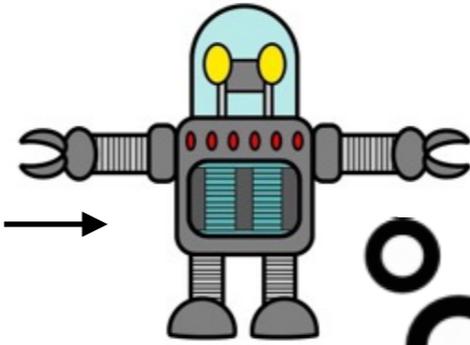


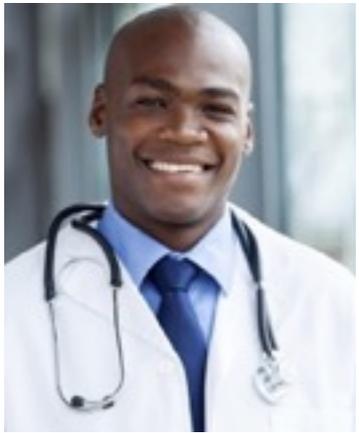


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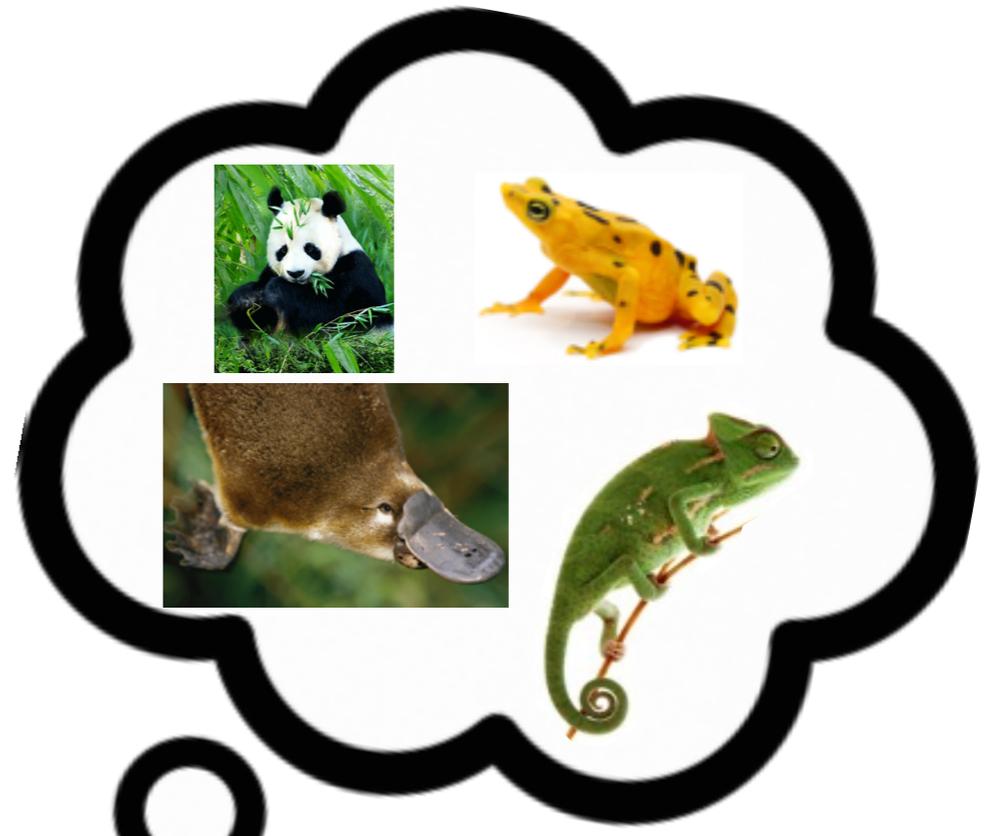
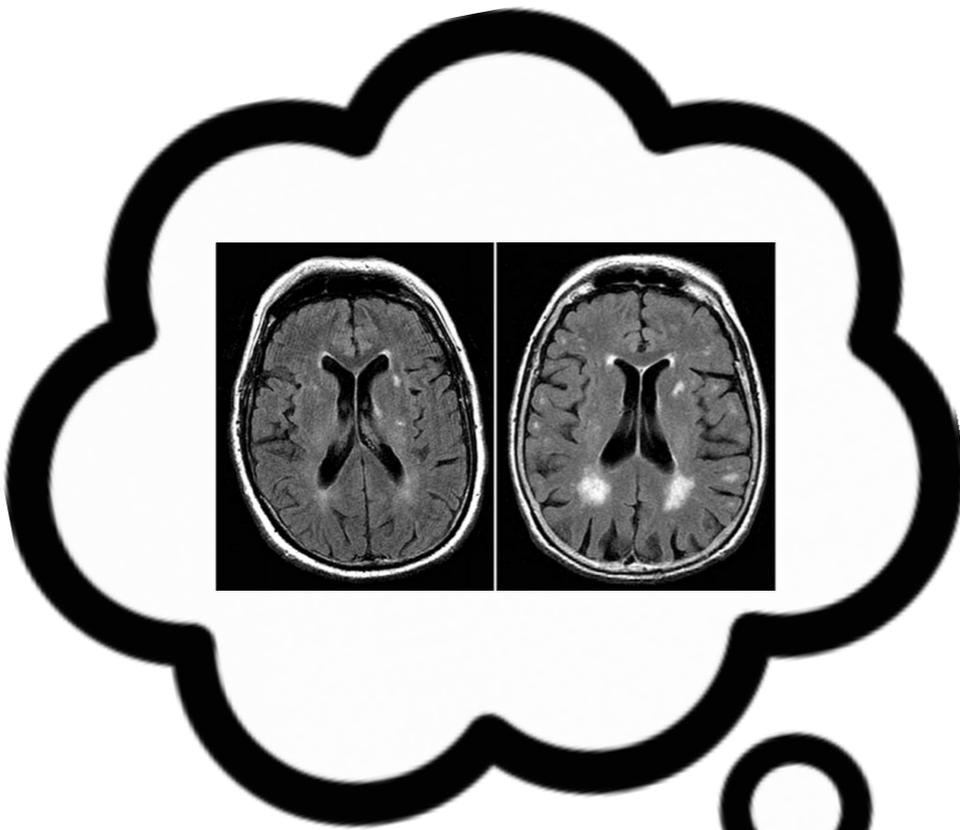


H_0 H_1 $\langle \mathbf{x}, \mathbf{y} \rangle$
 $\|\mathbf{X}\|_*$
 $\|\mathbf{Y} - \mathbf{A}\mathbf{X}\|_F + \|\mathbf{X}\|_1$
 PC2 $\nabla f(\mathbf{x})$ $\|\mathbf{y}\|_2$
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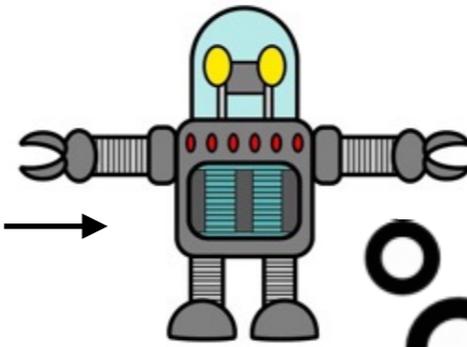


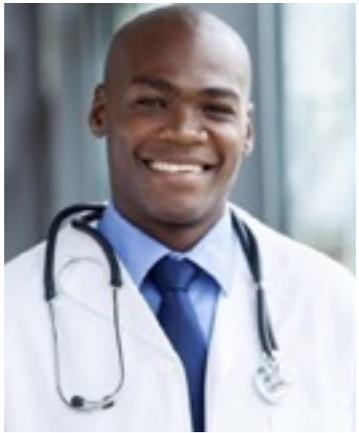


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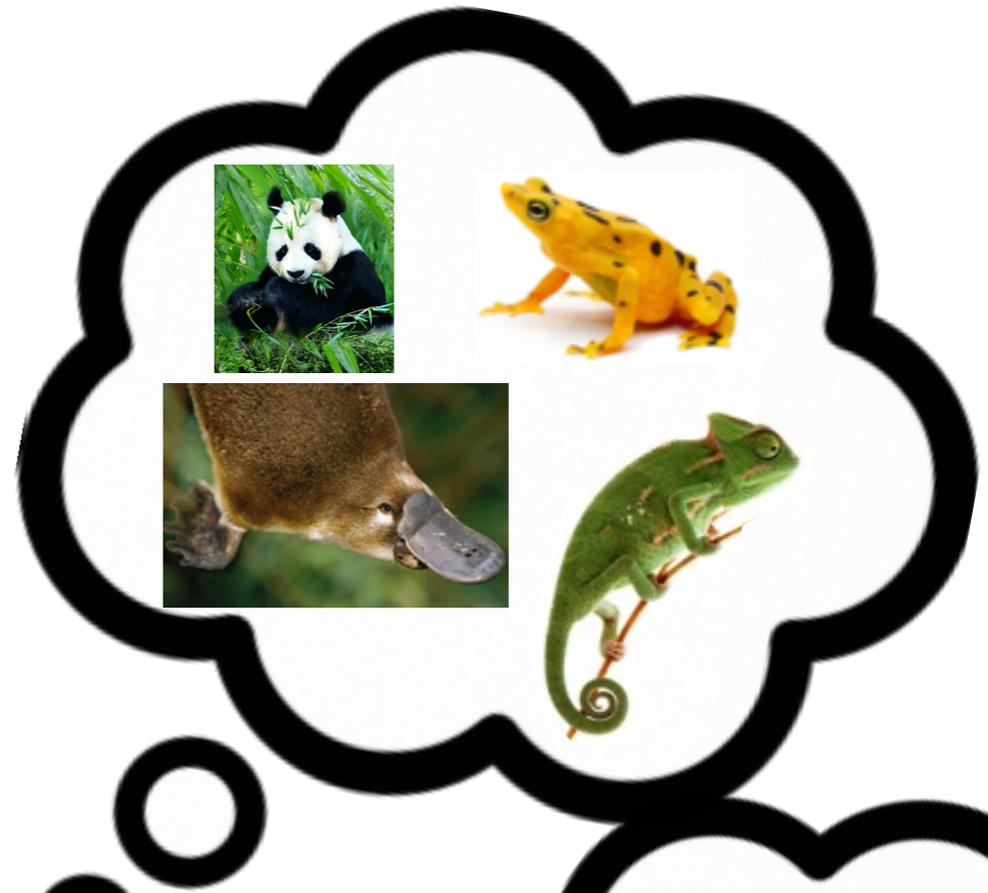
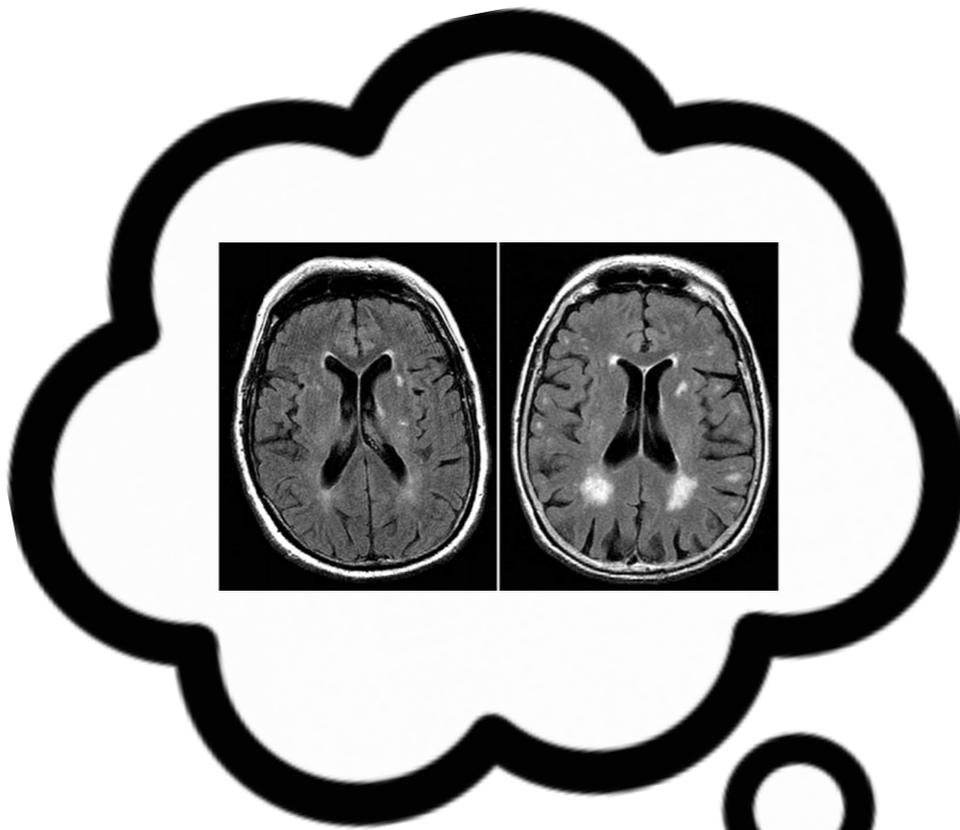
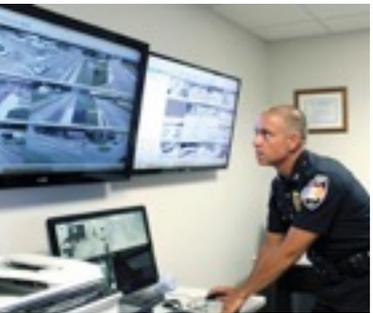


$\langle \mathbf{x}, \mathbf{y} \rangle$
 $\|\mathbf{X}\|_*$
 $\| \mathbf{Y} - \mathbf{A}\mathbf{X} \|_F + \|\mathbf{X}\|_1$
 $\nabla f(\mathbf{x})$
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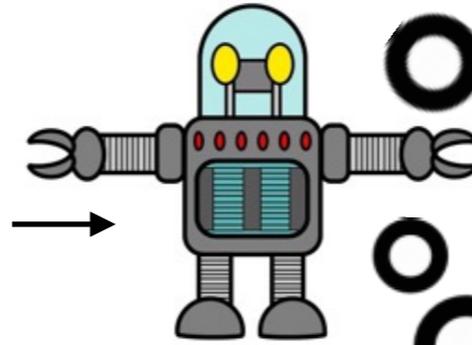


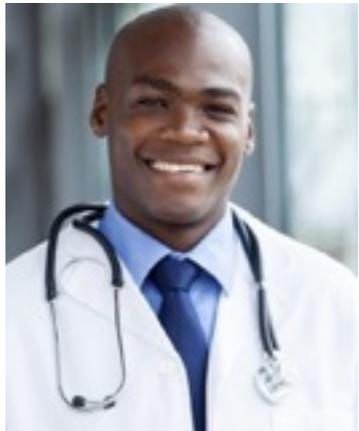


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$\langle \mathbf{x}, \mathbf{y} \rangle$
 $\|\mathbf{X}\|_*$
 $\| \mathbf{Y} - \mathbf{A}\mathbf{X} \|_F + \|\mathbf{X}\|_1$
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 $\mathbf{Y} = \mathbf{A}\mathbf{x} + \mathbf{B}$



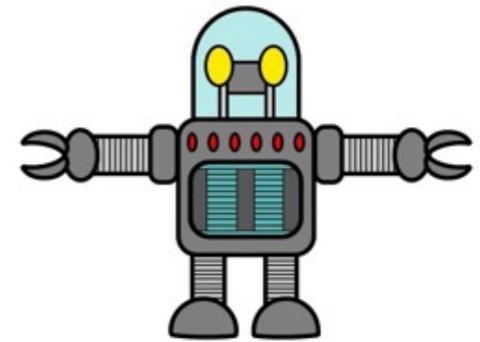


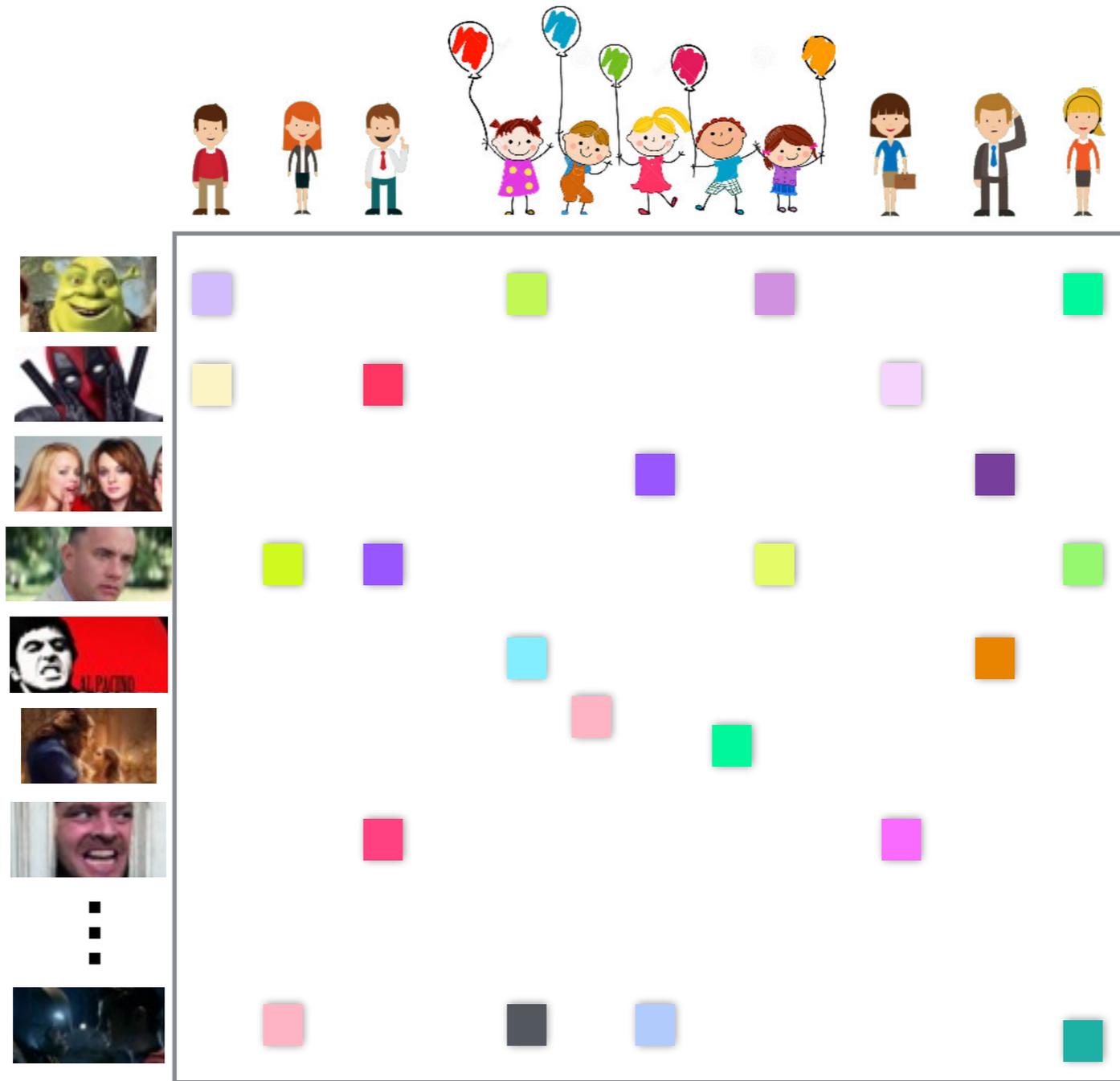
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Statistics
Probability
Vector Spaces
Optimization
Analysis
Algebra
Math

Parallelization
Storage
Speed
Algorithms
Hardware
Networks
Data Acquisition
Parameter Tuning
Training
Coding





Textbook Example

Recommender Systems



User i



Romance



Comedy

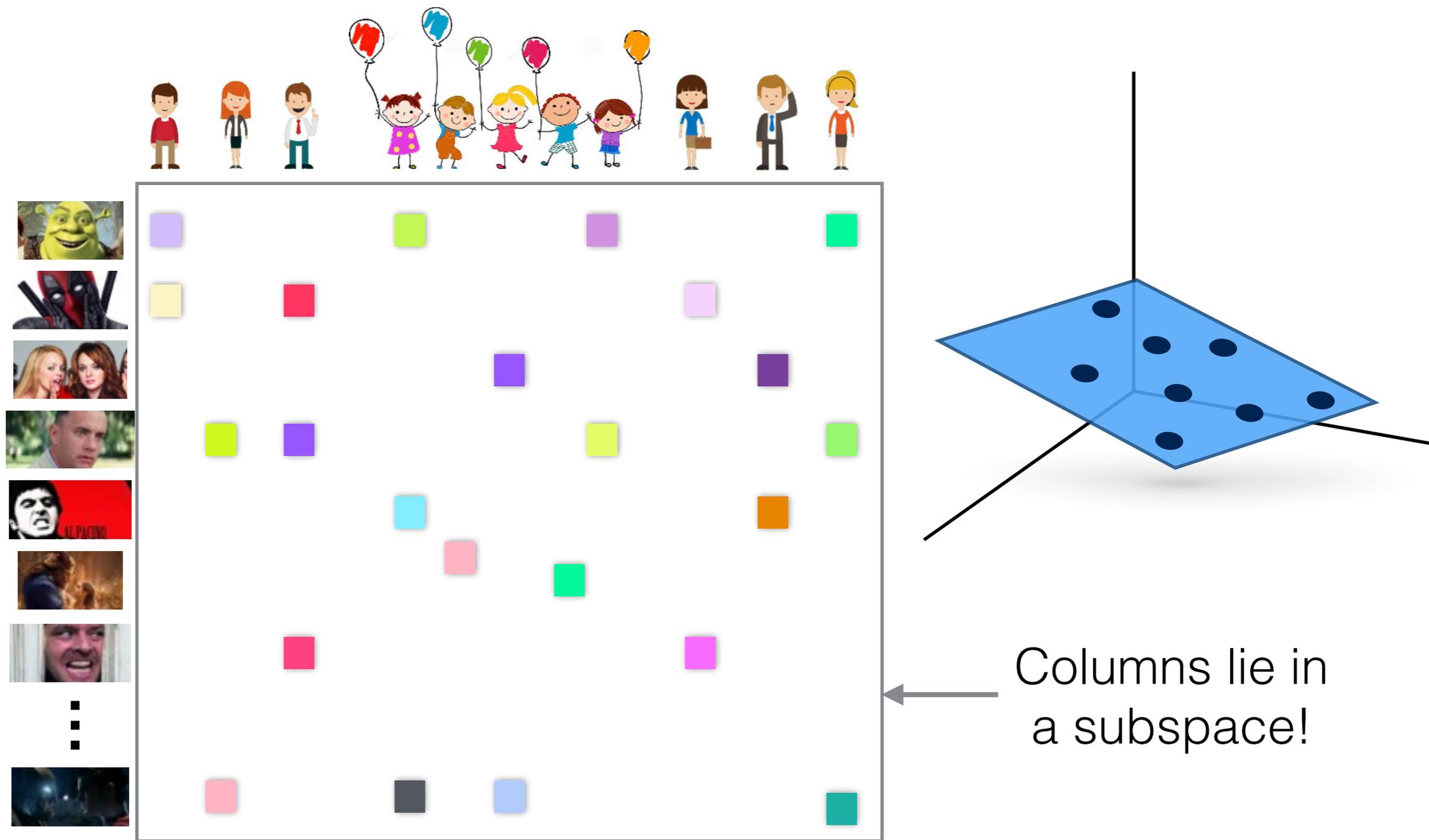


Action



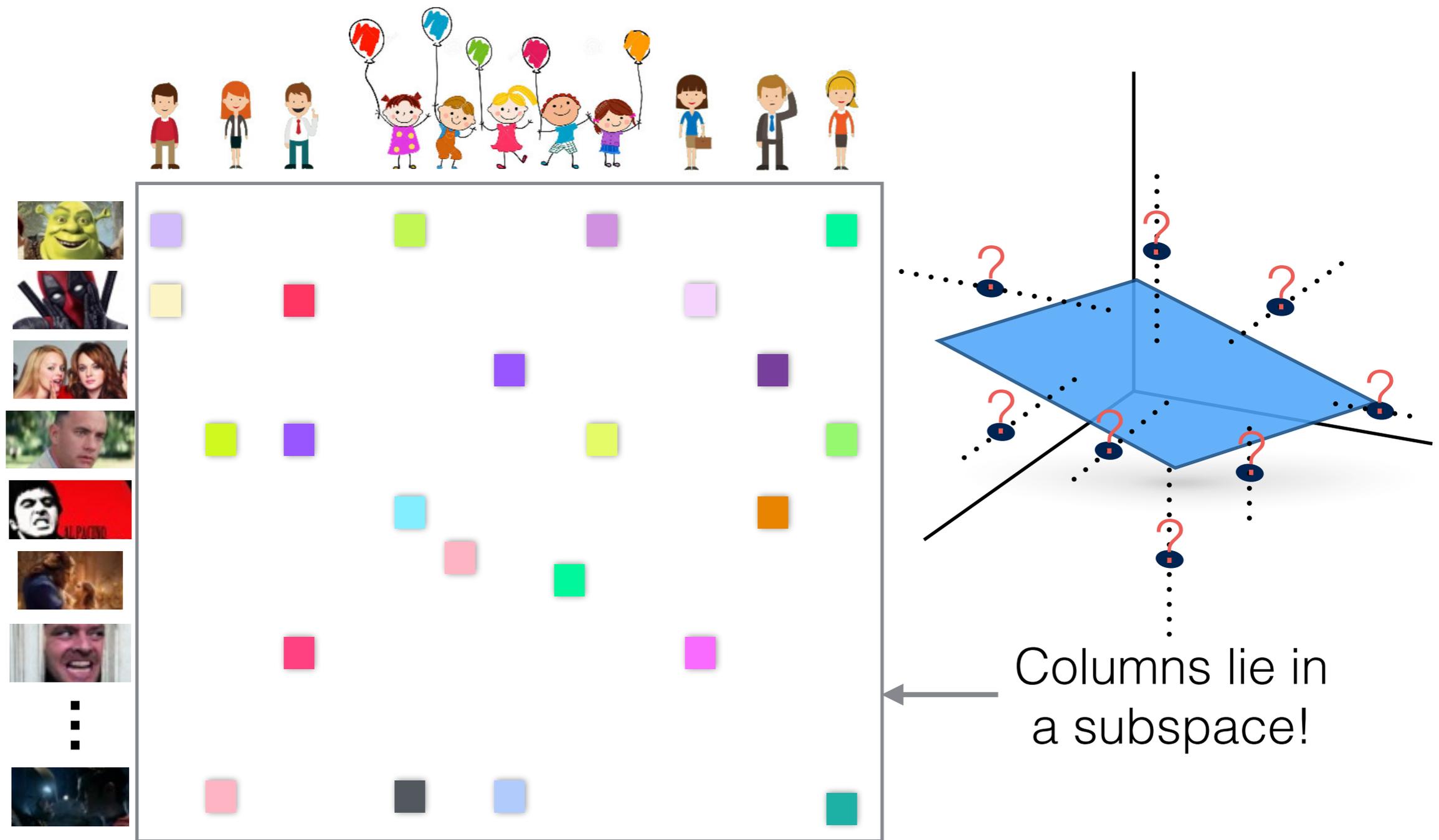
Horror





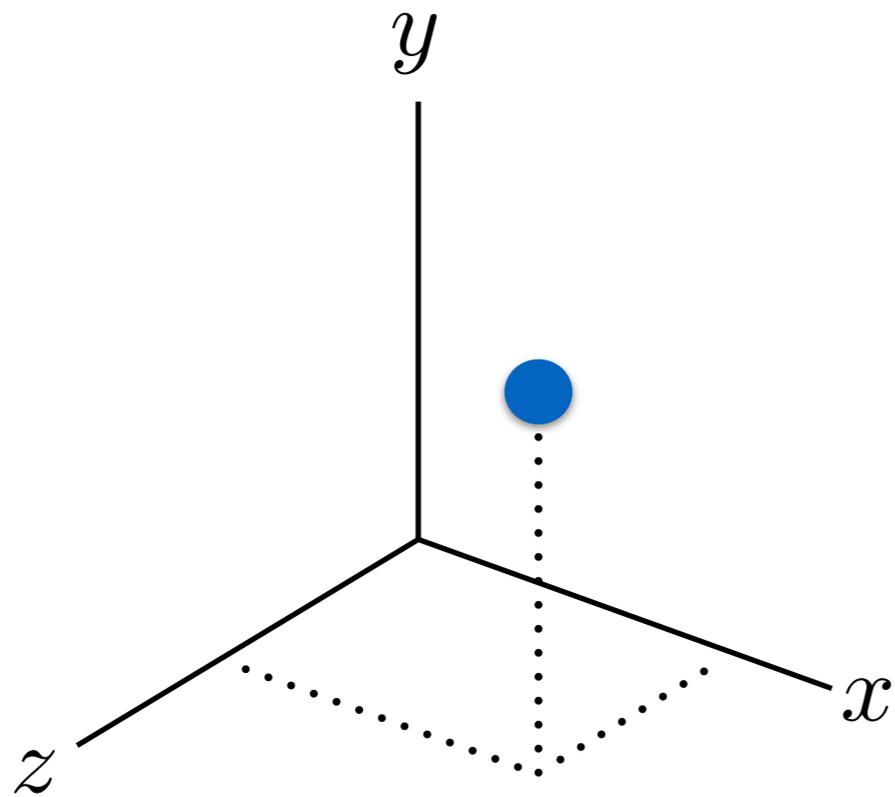
We want to find this Subspace!

Problem is: data is *incomplete*!



We want to find this Subspace!

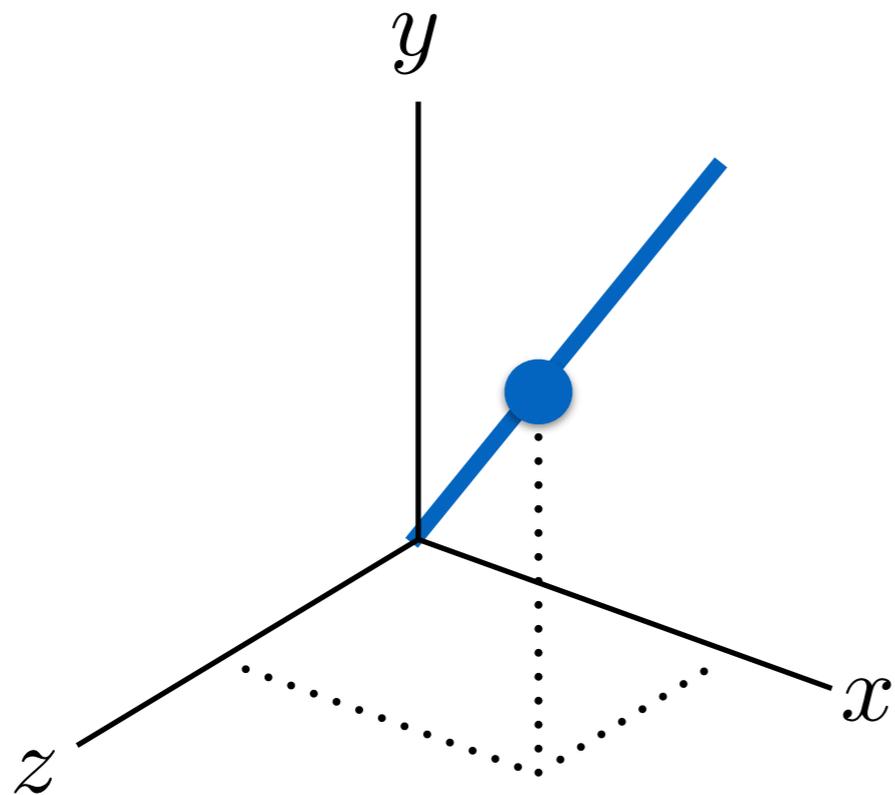
Problem is: data is *incomplete*!



$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix}$$

An example of the challenges

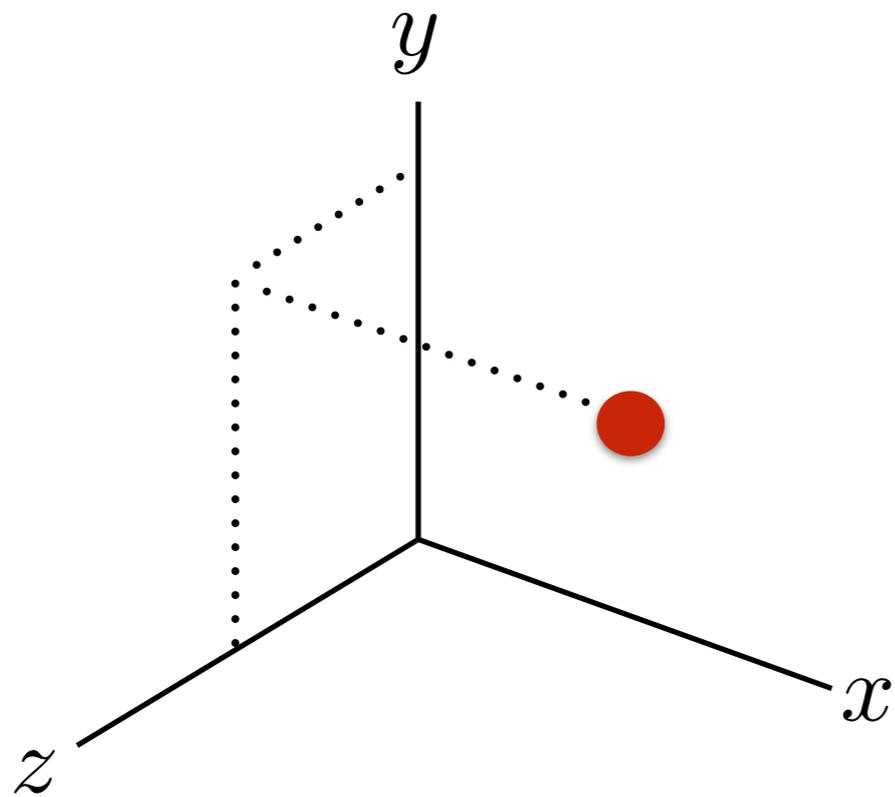
Missing data



$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix}$$

An example of the challenges

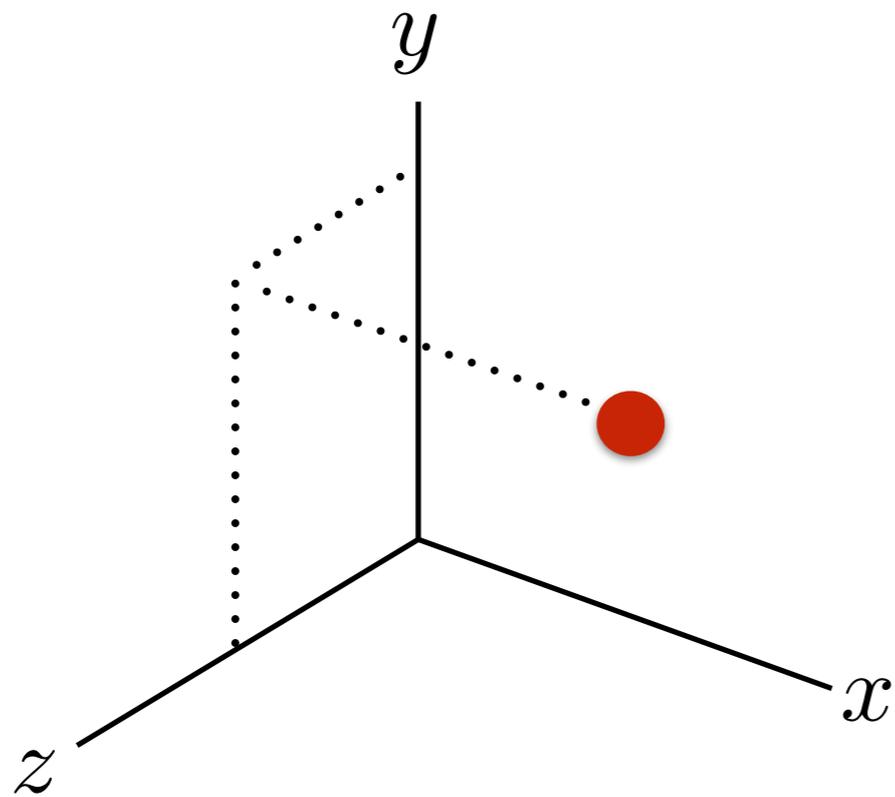
Missing data



$$\begin{bmatrix} \cdot \\ y_1 \\ z_1 \end{bmatrix}$$

An example of the challenges

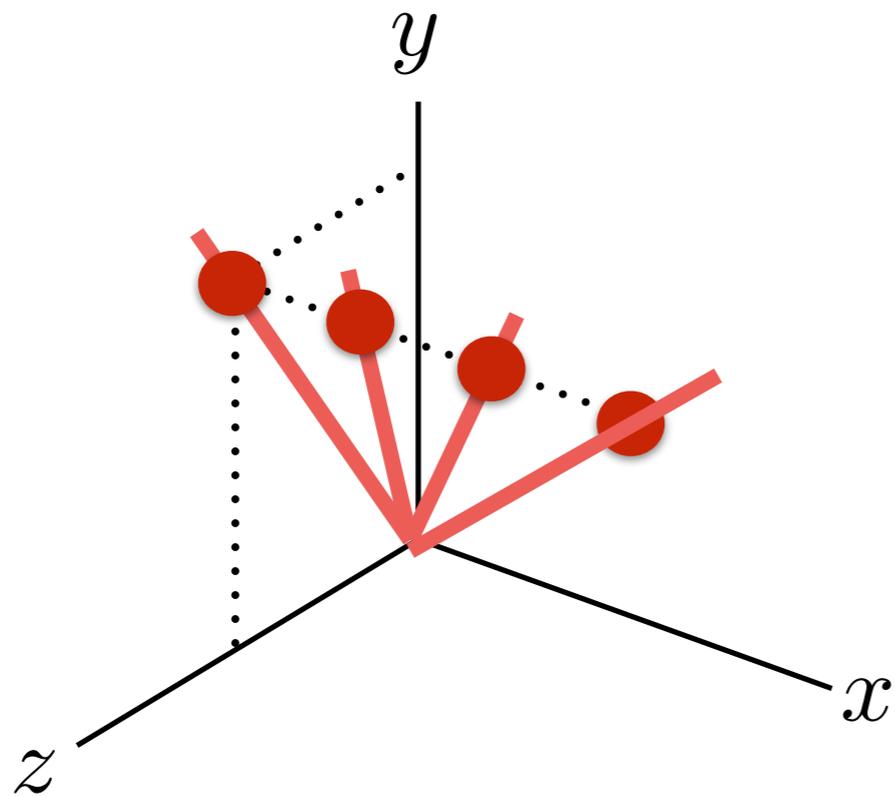
Missing data



$$\begin{bmatrix} \cdot \\ y_1 \\ z_1 \end{bmatrix}$$

An example of the challenges

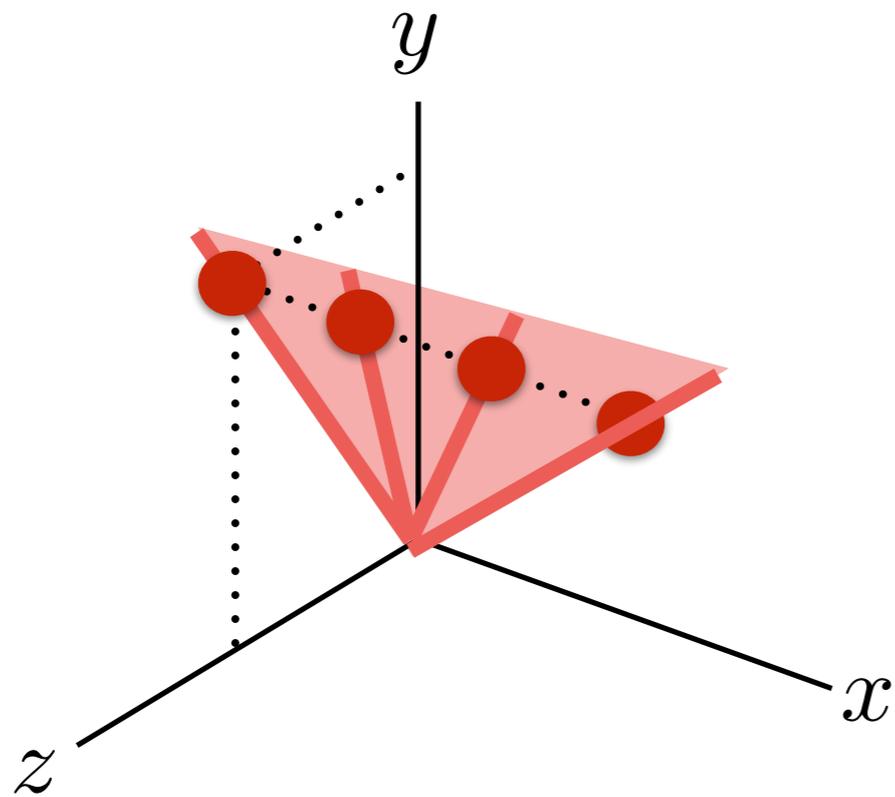
Missing data



$$\begin{bmatrix} \cdot \\ y_1 \\ z_1 \end{bmatrix}$$

An example of the challenges

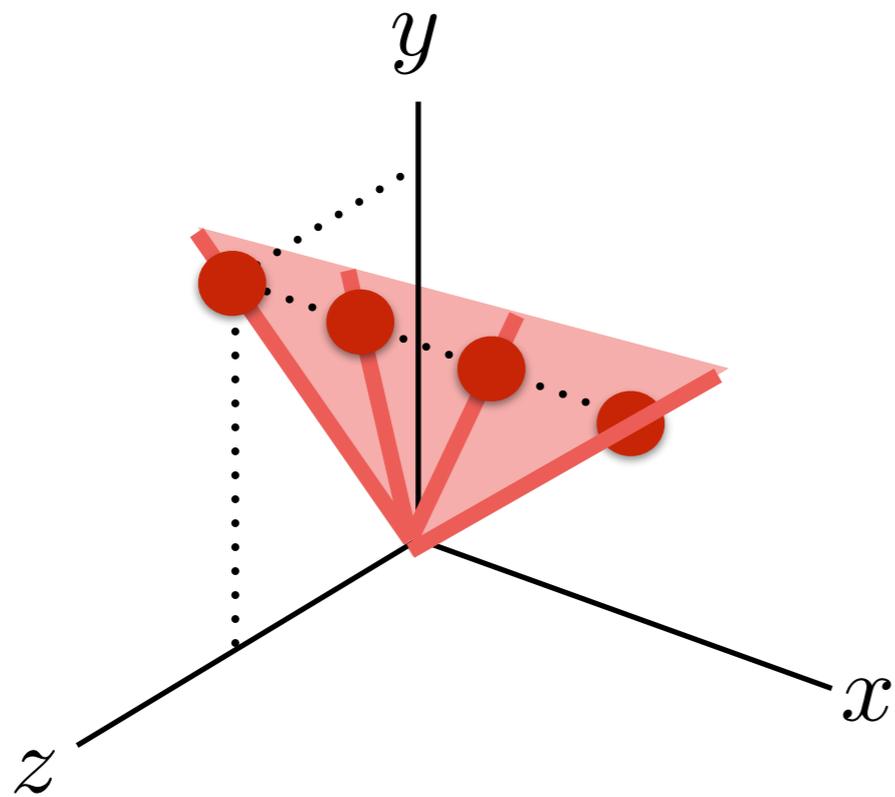
Missing data



$$\begin{bmatrix} \cdot \\ y_1 \\ z_1 \end{bmatrix}$$

An example of the challenges

Missing data

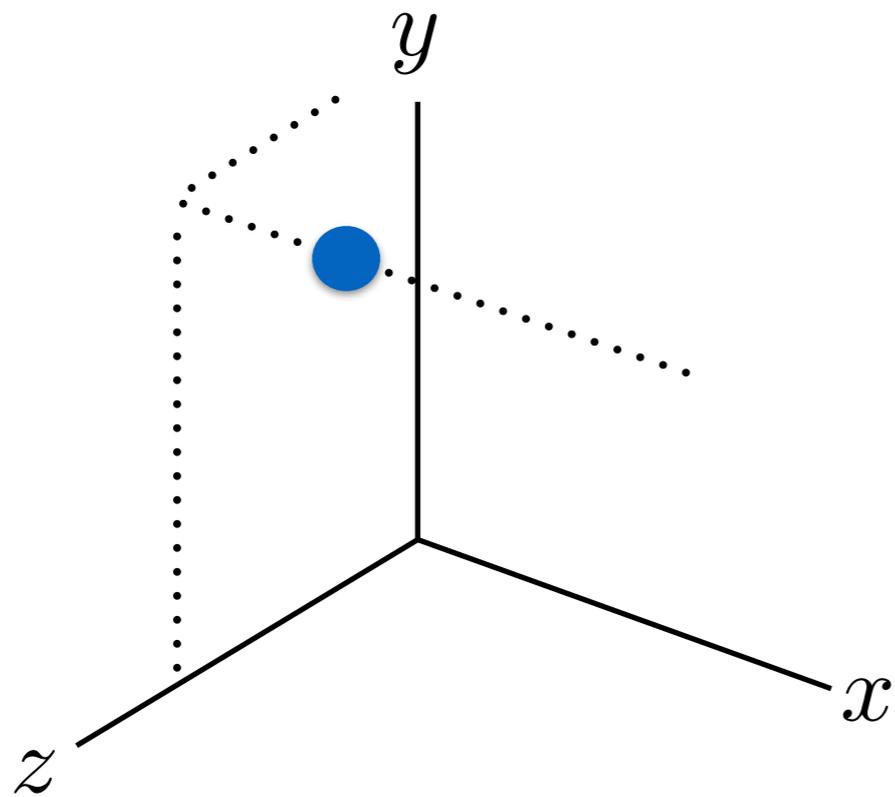


This column imposes *1* restriction on what the subspace may be

$$\begin{bmatrix} \cdot \\ y_1 \\ z_1 \end{bmatrix}$$

An example of the challenges

Missing data

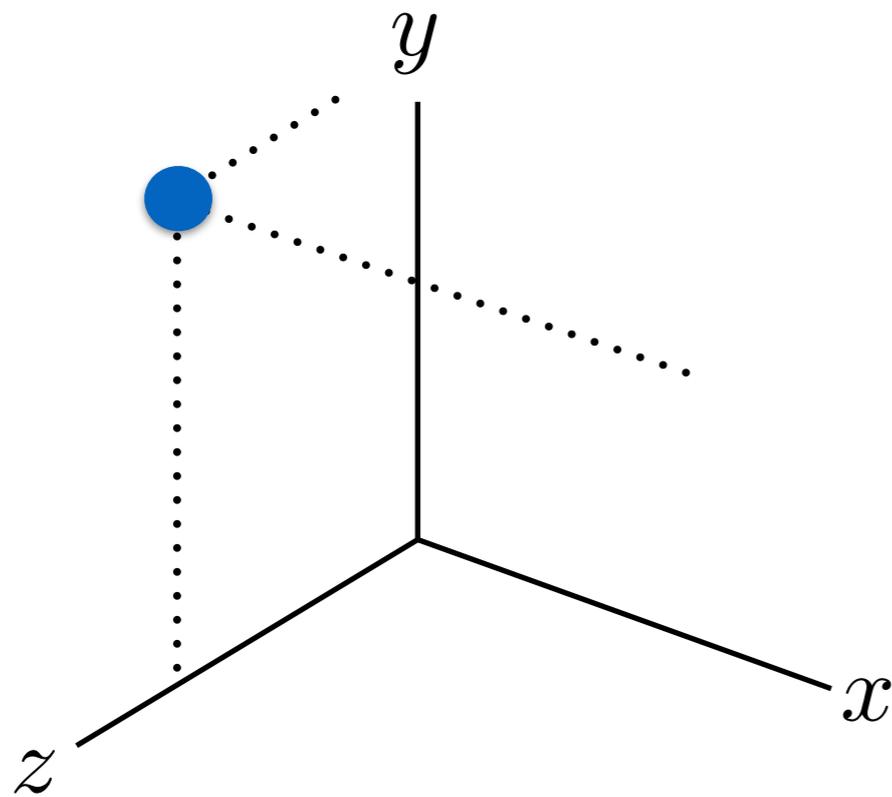


New column imposes *1* restriction on what the subspace may be

$$\begin{bmatrix} \cdot & \cdot \\ y_1 & y_2 \\ z_1 & z_2 \end{bmatrix}$$

An example of the challenges

Missing data

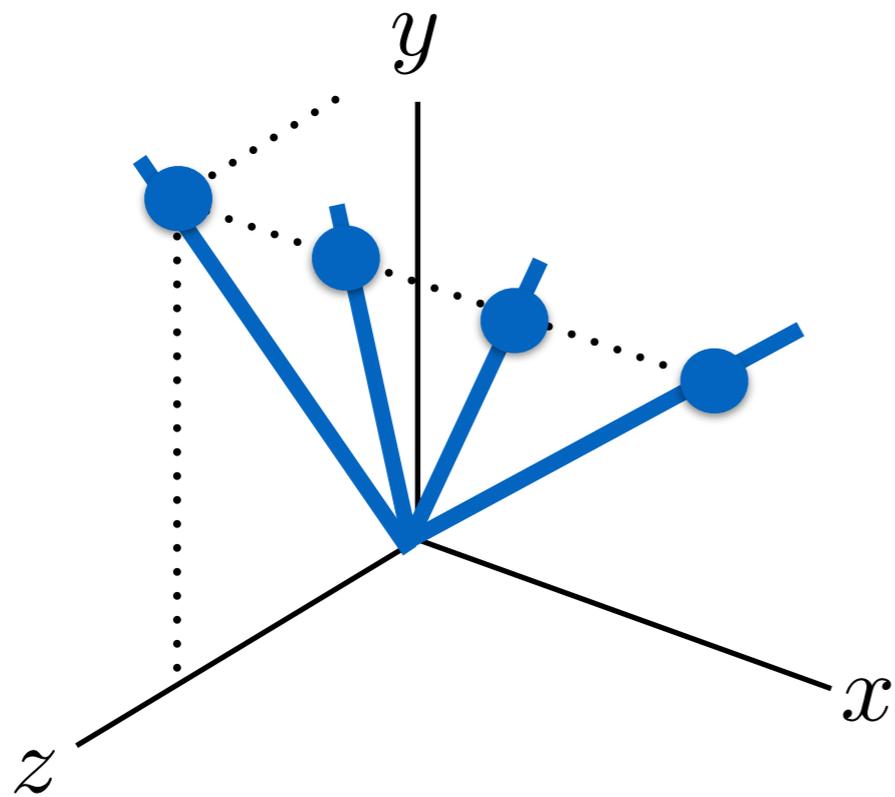


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$$\begin{bmatrix} \cdot & \cdot \\ y_1 & y_2 \\ z_1 & z_2 \end{bmatrix}$$

An example of the challenges

Missing data

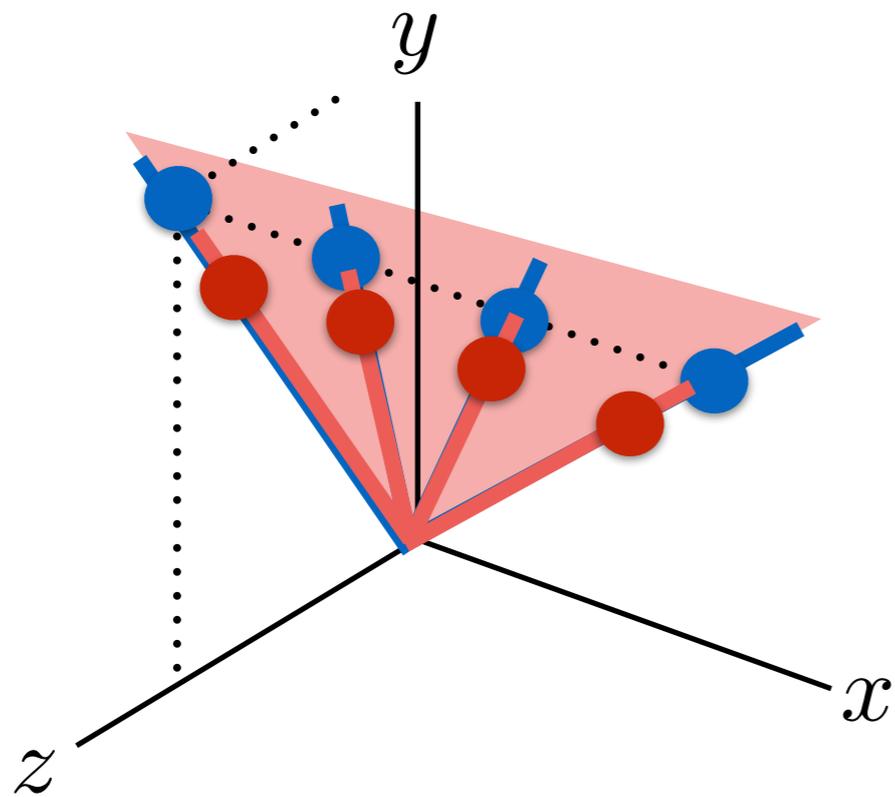


New column imposes *1* restriction on what the subspace may be

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An example of the challenges

Missing data

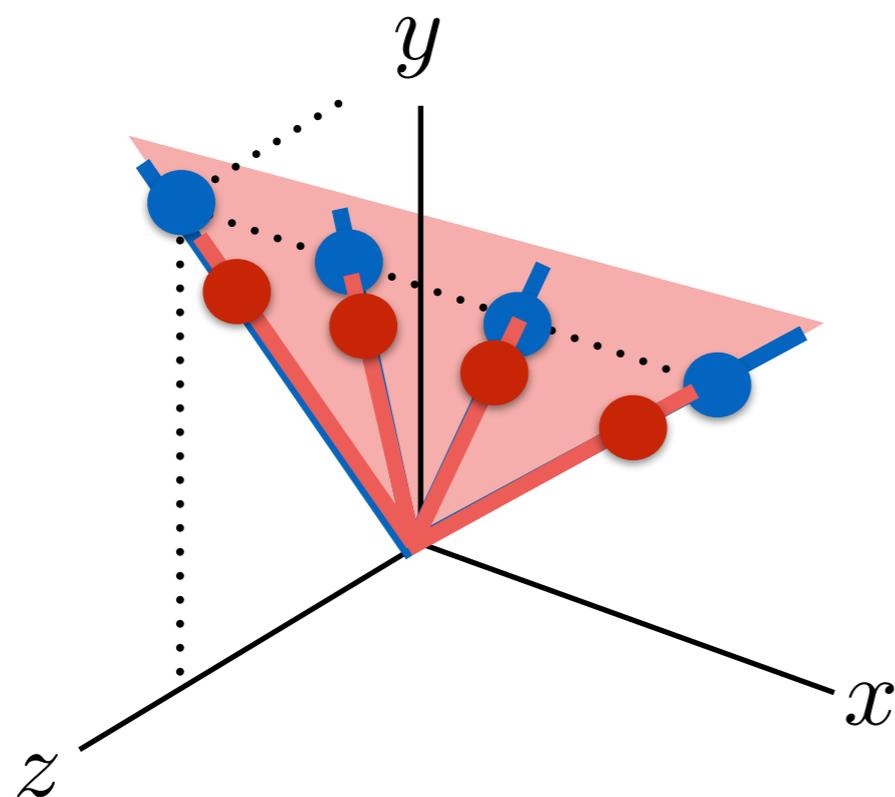


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$$\begin{bmatrix} \cdot & \cdot \\ y_1 & y_2 \\ z_1 & z_2 \end{bmatrix}$$

An example of the challenges

Missing data



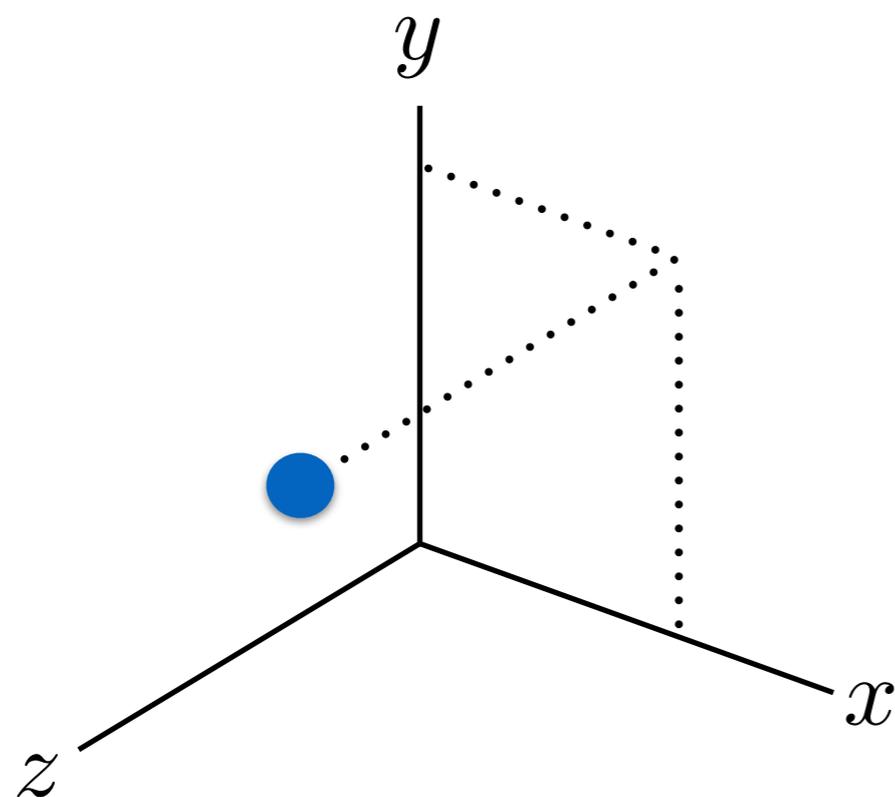
New column imposes *1* restriction on what the subspace may be

$$\begin{bmatrix} \cdot & \cdot \\ y_1 & y_2 \\ z_1 & z_2 \end{bmatrix}$$

New restriction may be redundant!

An example of the challenges

Missing data



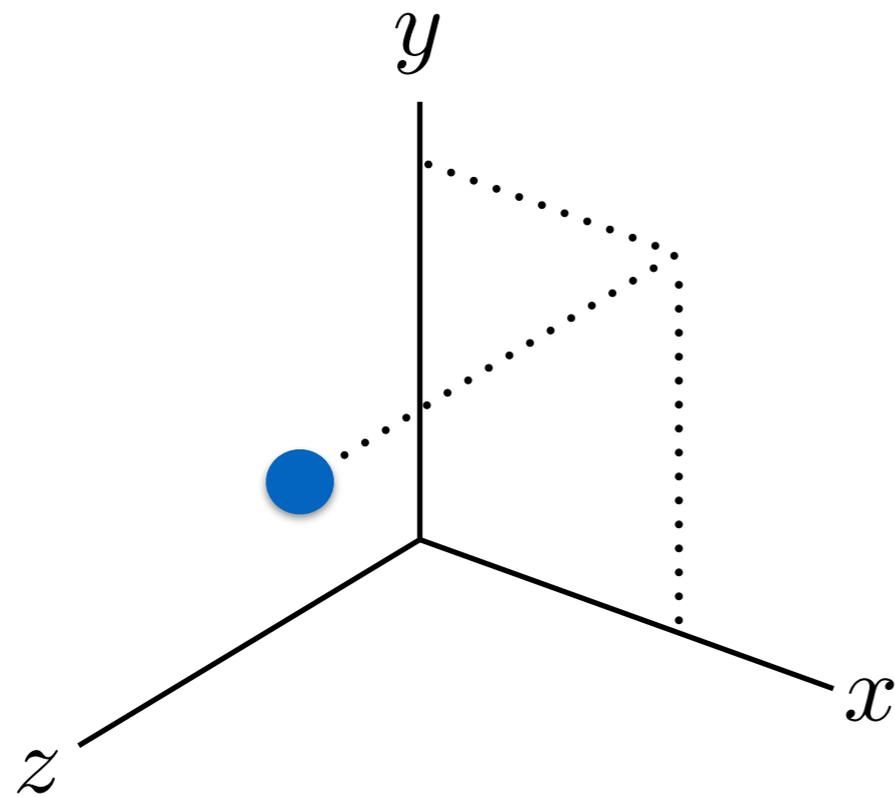
New column imposes *1* restriction on what the subspace may be

$$\begin{bmatrix} \cdot & x_2 \\ y_1 & y_2 \\ z_1 & \cdot \end{bmatrix}$$

New restriction may be redundant!

An example of the challenges

Missing data



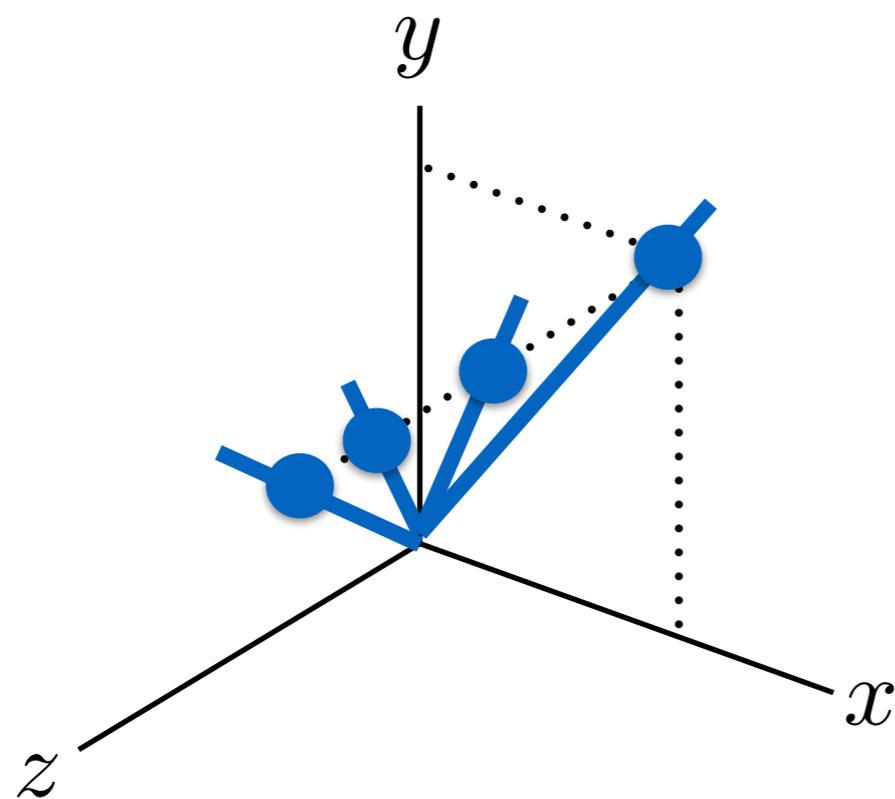
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An example of the challenges

Missing data



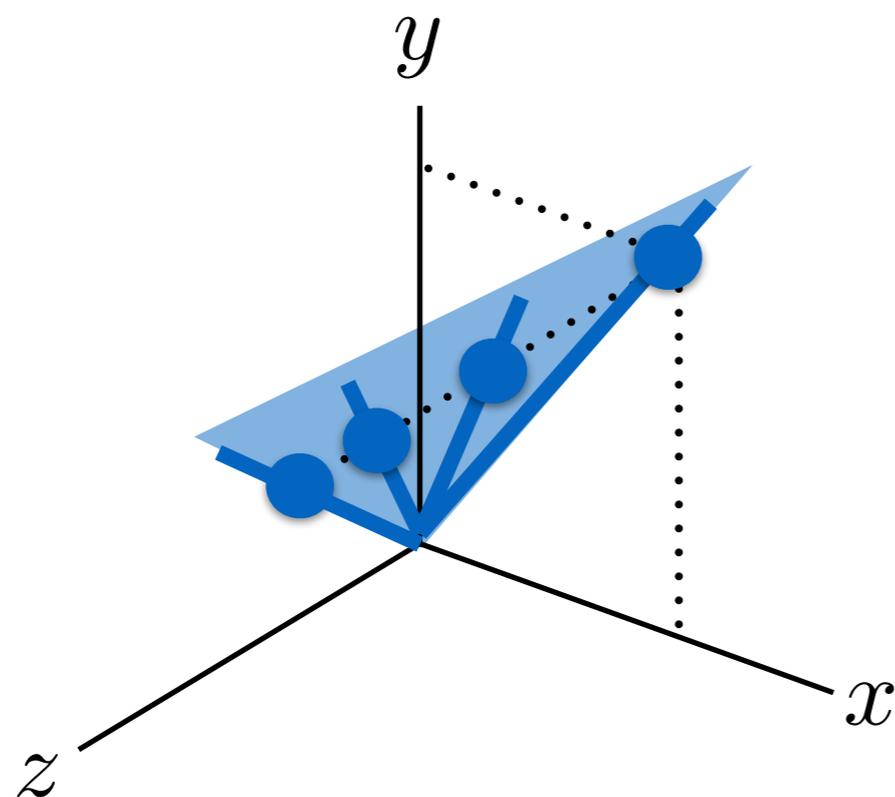
New column imposes *1* restriction on what the subspace may be

$$\begin{bmatrix} \cdot & x_2 \\ y_1 & y_2 \\ z_1 & \cdot \end{bmatrix}$$

New restriction may be redundant!

An example of the challenges

Missing data



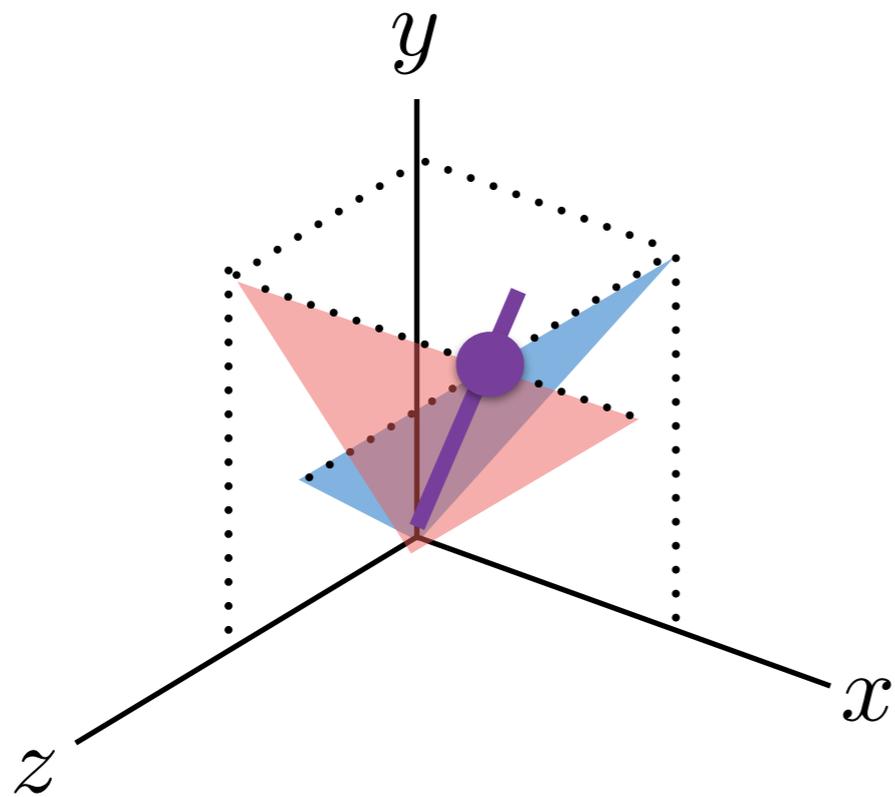
New column imposes *1* restriction on what the subspace may be

$$\begin{bmatrix} \cdot & x_2 \\ y_1 & y_2 \\ z_1 & \cdot \end{bmatrix}$$

New restriction may be redundant!

An example of the challenges

Missing data



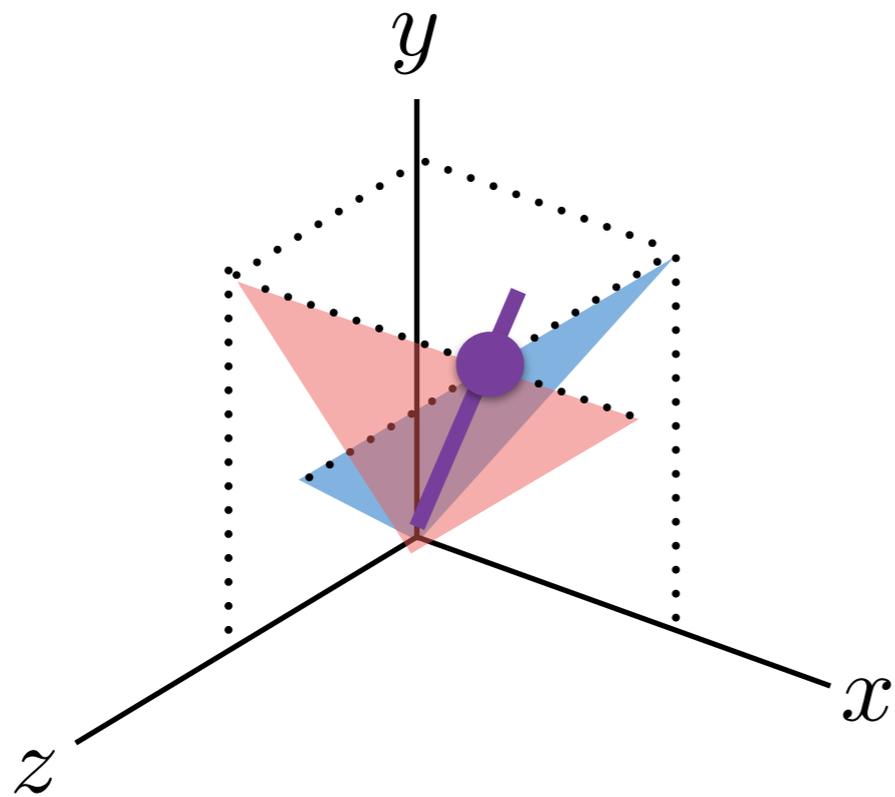
Each column imposes *1* restriction on what the subspace may be

$$\begin{bmatrix} \cdot & x_2 \\ y_1 & y_2 \\ z_1 & \cdot \end{bmatrix}$$

New restriction may be redundant!

An example of the challenges

Missing data



Each column imposes *1* restriction on what the subspace may be

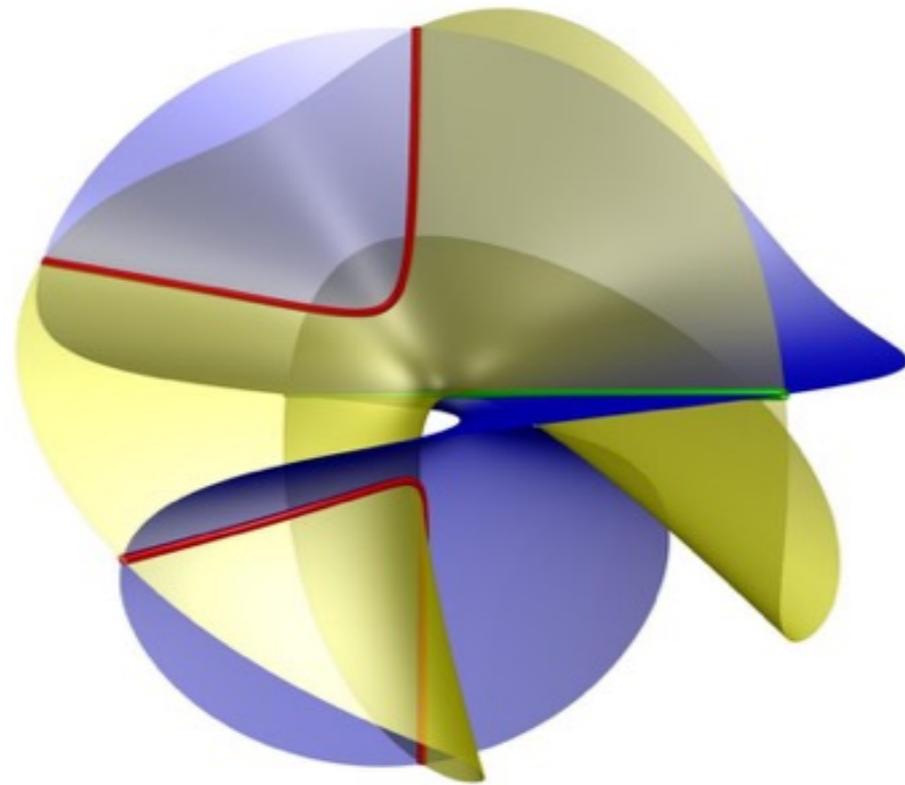
$$\begin{bmatrix} \cdot & x_2 \\ y_1 & y_2 \\ z_1 & \cdot \end{bmatrix}$$

New restriction may be redundant!

Depends on which entries we observe!

An example of the challenges

Missing data



Each column imposes *1* restriction on what the subspace may be

$$\begin{bmatrix} \cdot & x_2 \\ y_1 & y_2 \\ z_1 & \cdot \end{bmatrix}$$

$$f_1(\mathbf{U}_1|x_1) = 0$$

$$f_2(\mathbf{U}_2|x_2) = 0$$

New restriction may be redundant!

Depends on which entries we observe!

An example of the challenges

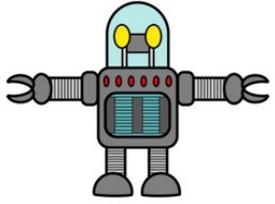
Missing data

Suppose \mathbf{X} contains $r + 1$ disjoint matrices $\{\mathbf{X}_\tau\}_{\tau=1}^{r+1}$ observed in the right entries. Then S^* is **the only** r -dimensional subspace that agrees with \mathbf{X} .

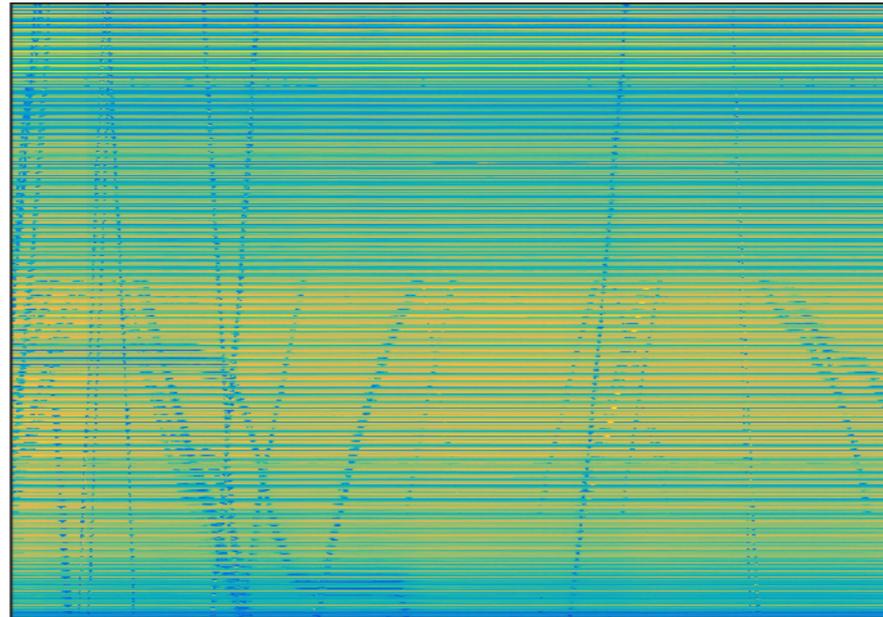
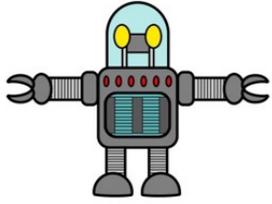
Determines Exactly:
Which entries you need to observe
to find a subspace

One of our main results

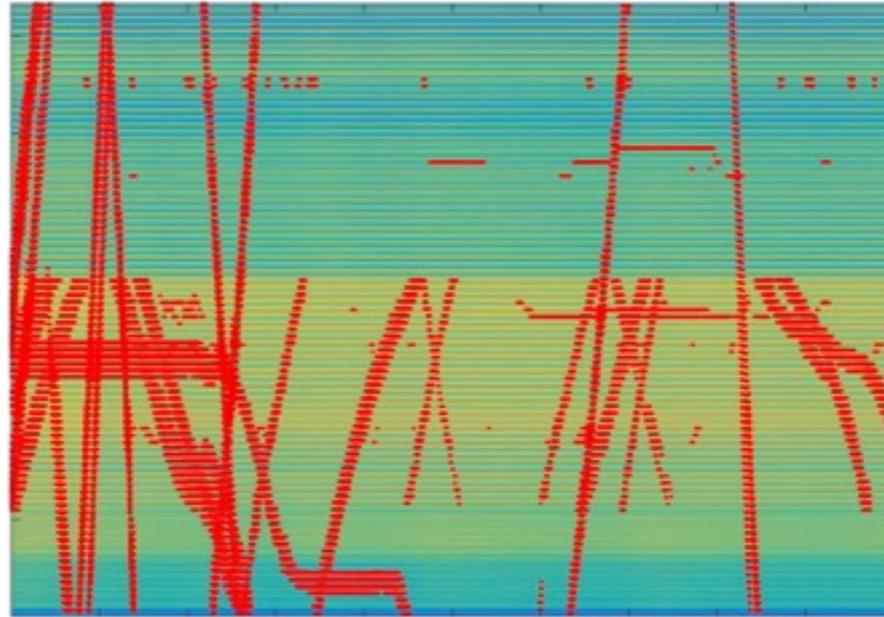
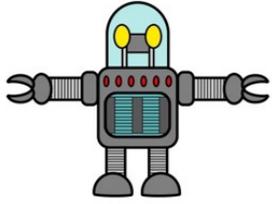
[10] Pimentel, Boston, Nowak, 2016



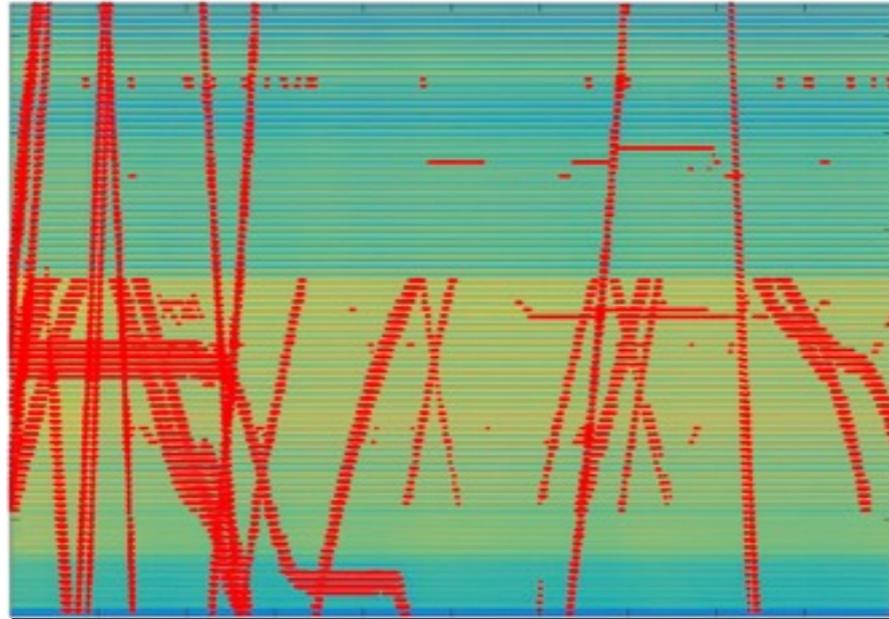
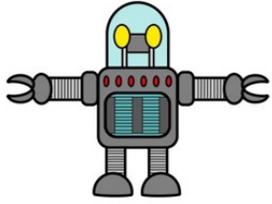
Background segmentation



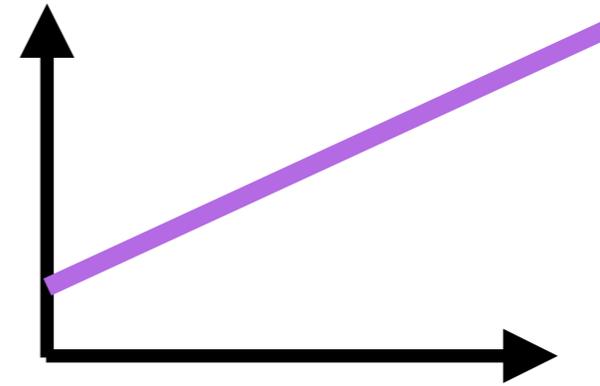
Background segmentation



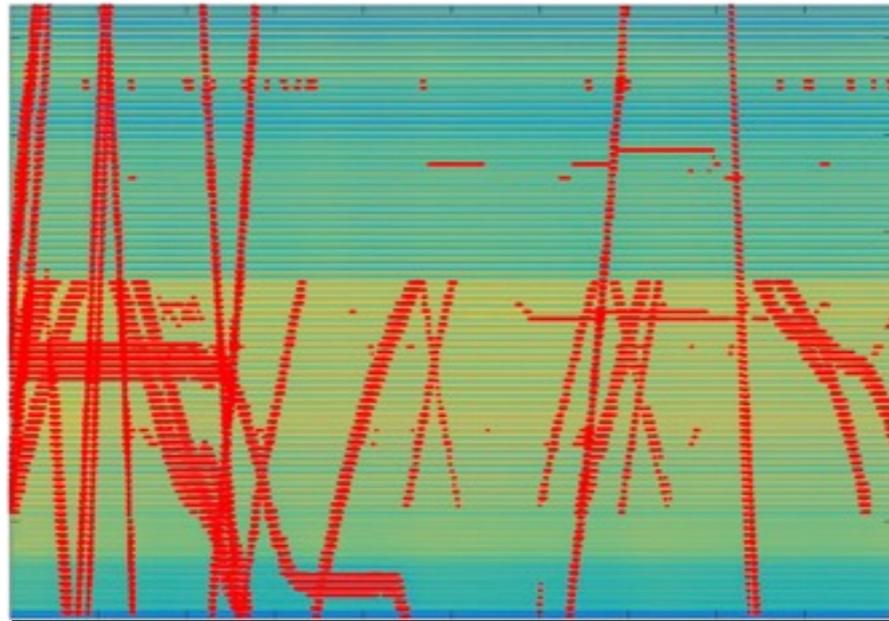
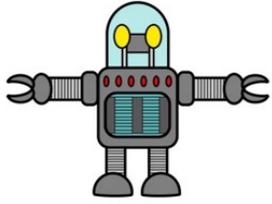
Background segmentation



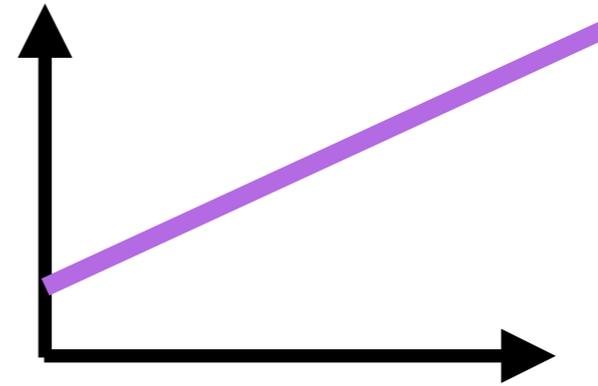
$$y = ax + b$$



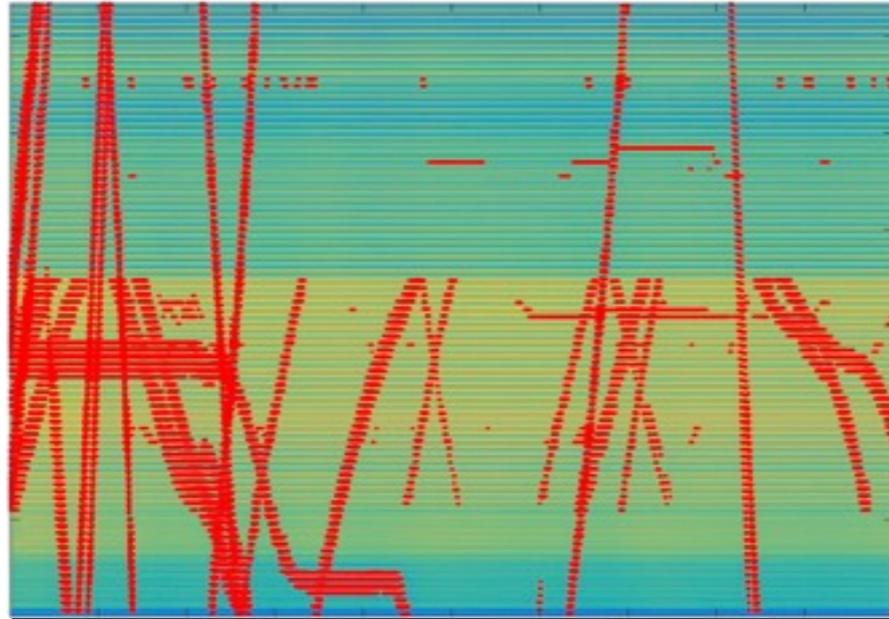
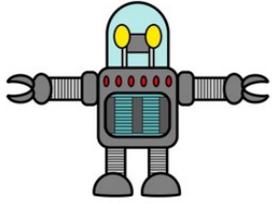
Background segmentation



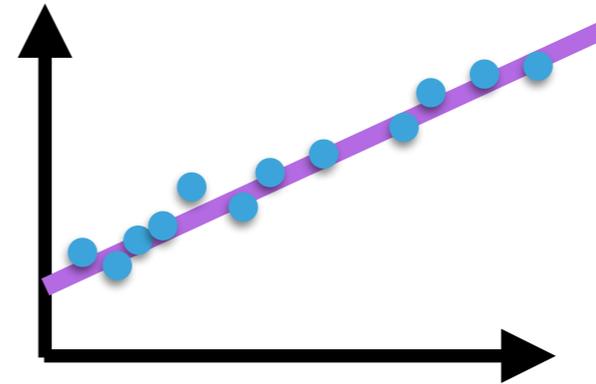
$$Y = AX + B$$
$$y = ax + b$$



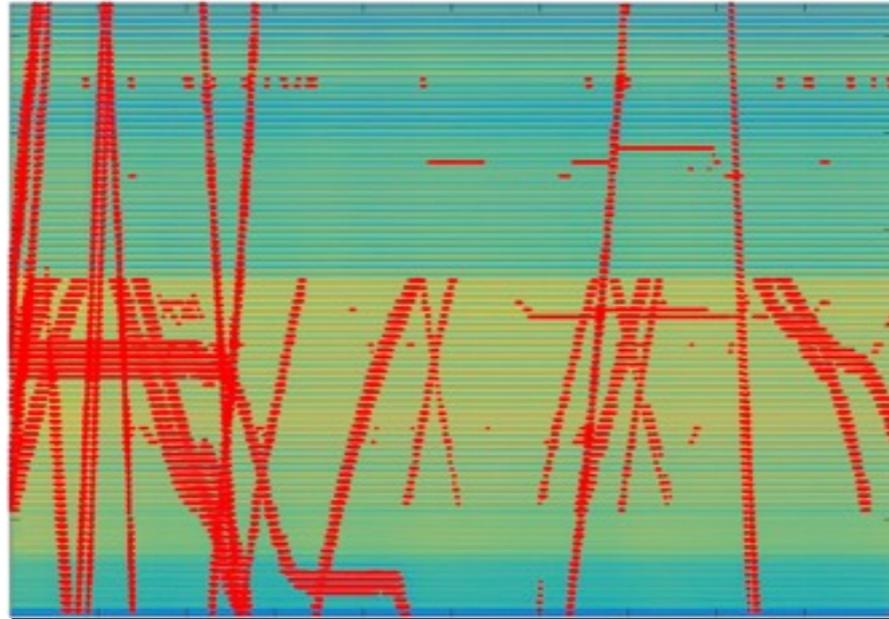
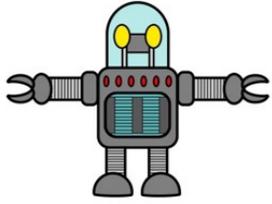
Background segmentation



$$Y = AX + B$$
$$y = ax + b$$

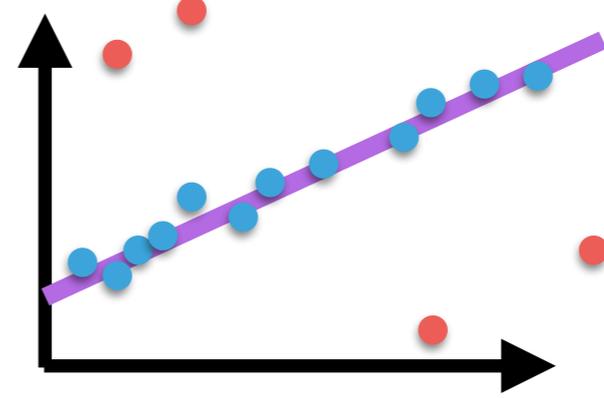


Background segmentation



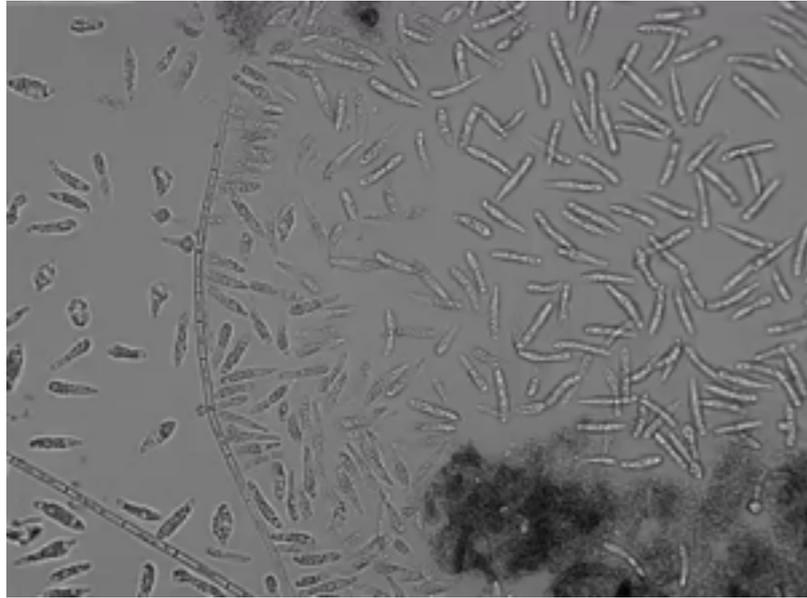
$$Y = AX + B$$

$$y = ax + b$$



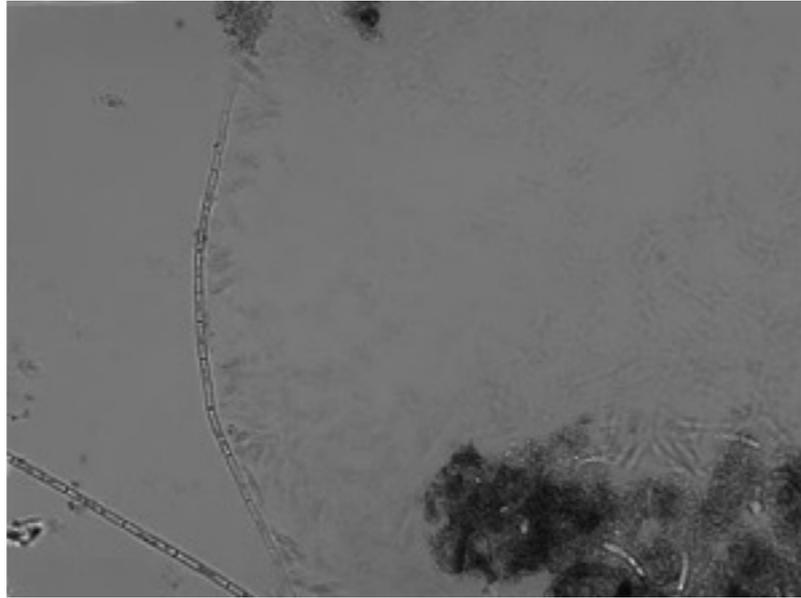
Background segmentation

Original Video



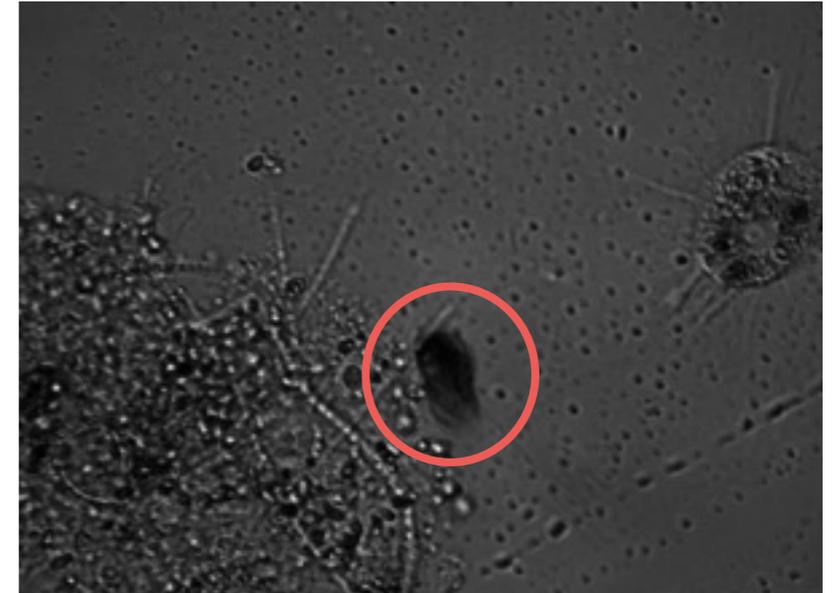
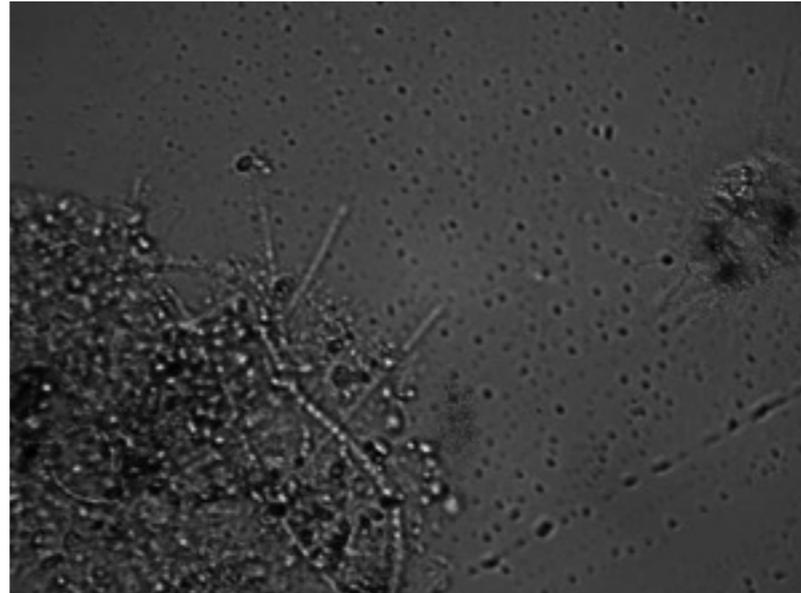
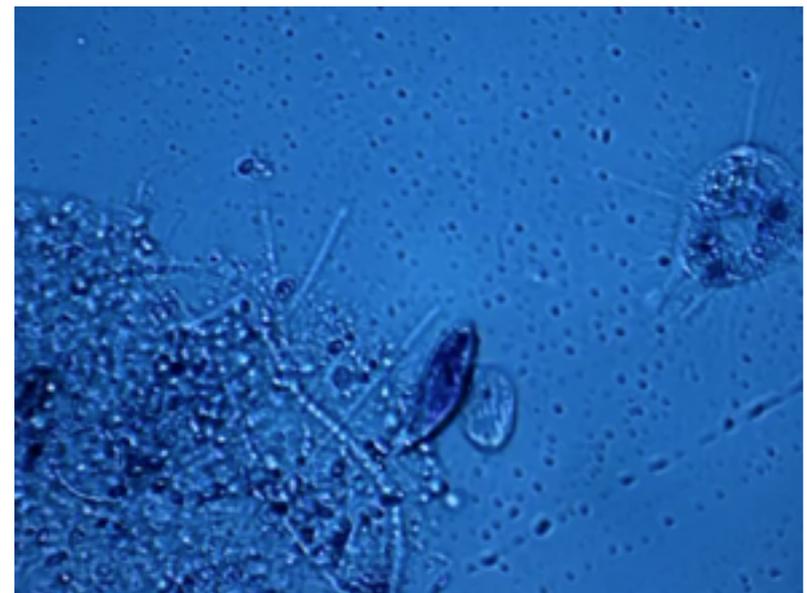
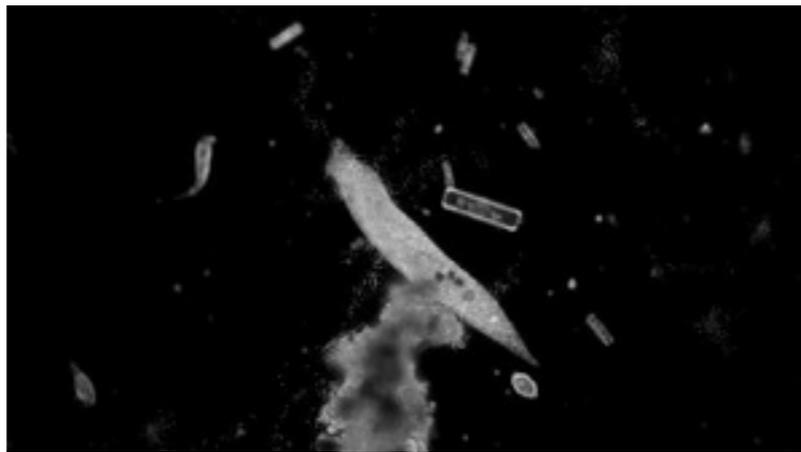
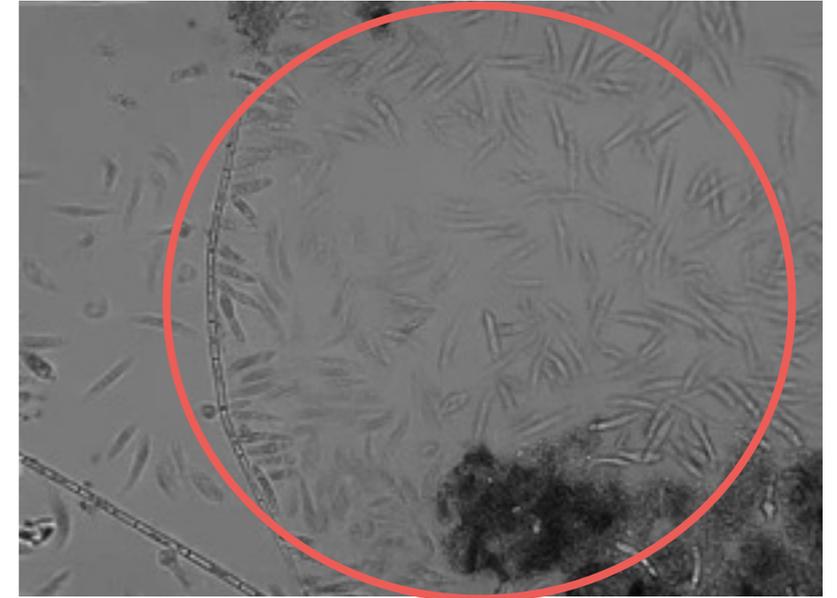
Our Work

[3] Pimentel et. al (2017)

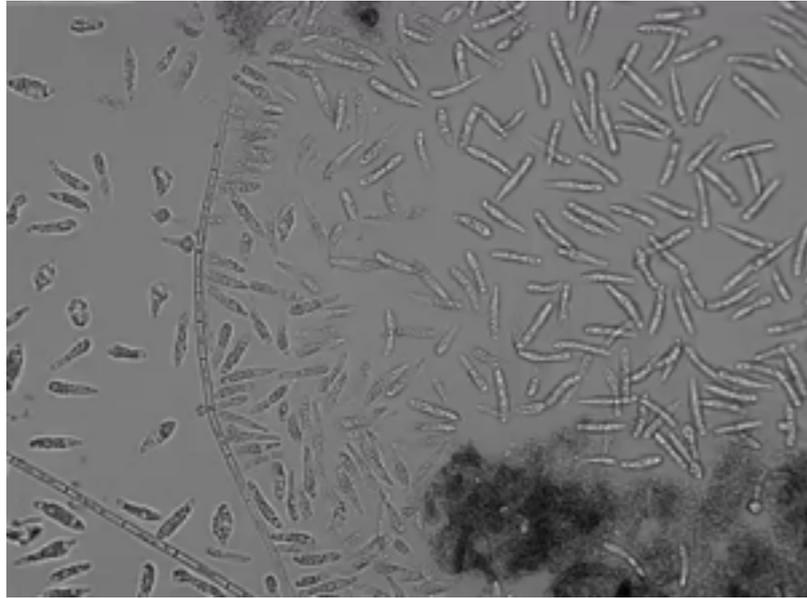


RPCA-ALM

RPCA-ALM (Lin et. al, 2011-2016)

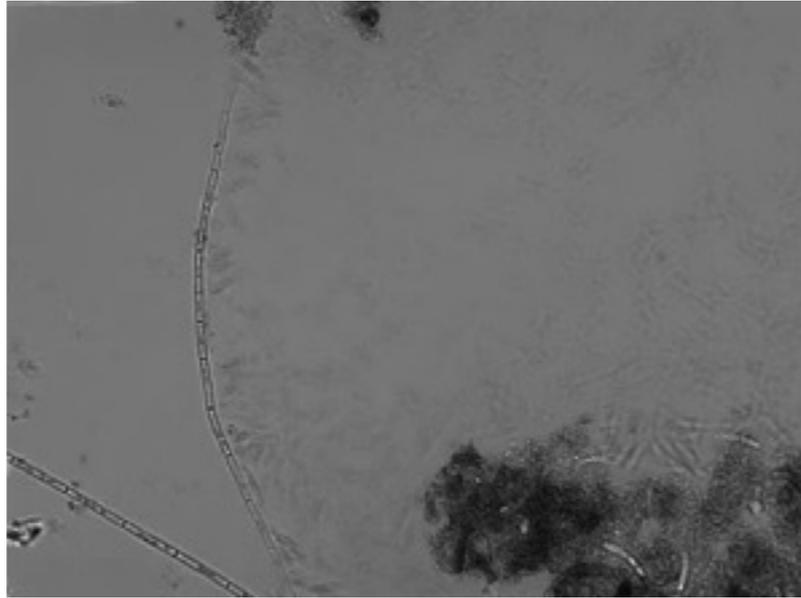


Original Video



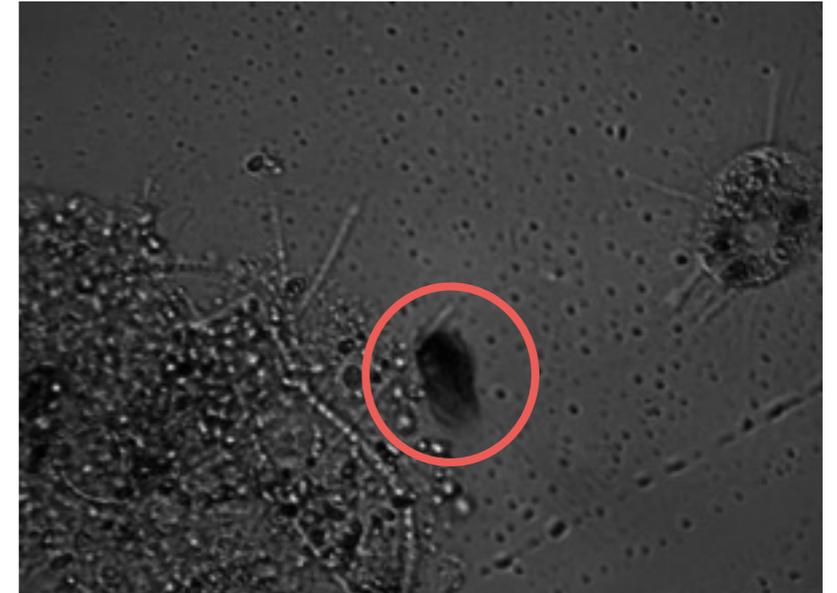
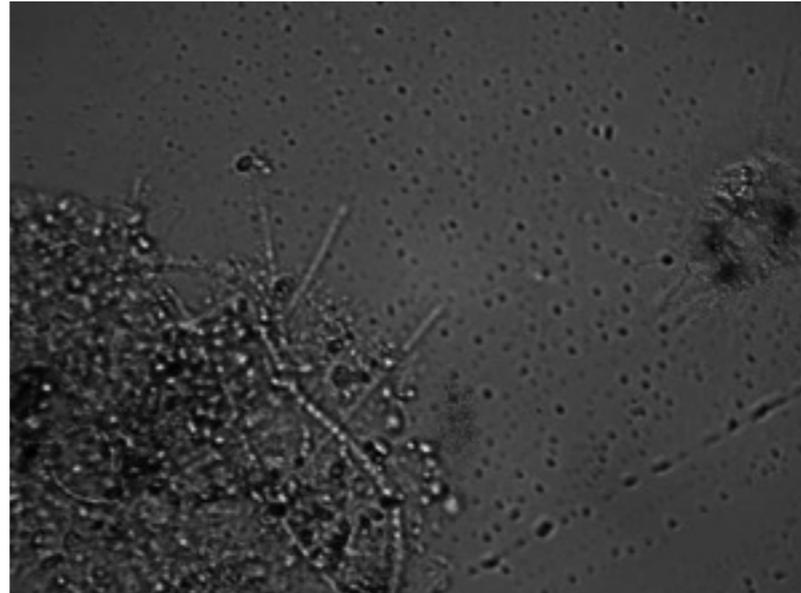
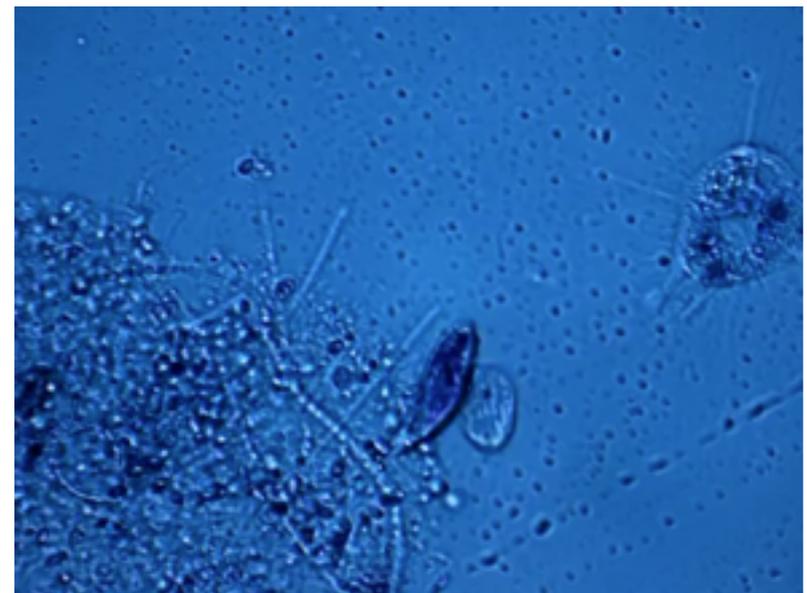
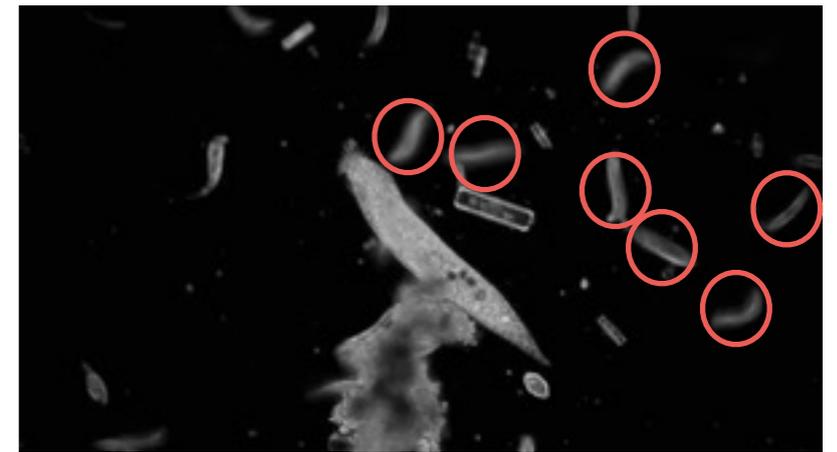
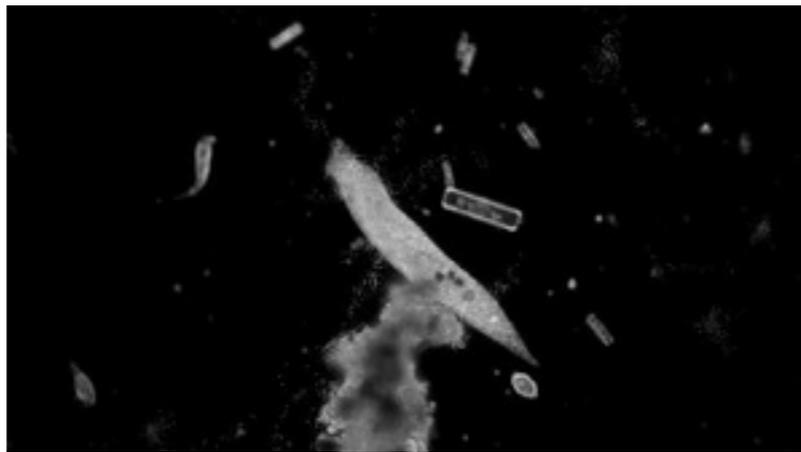
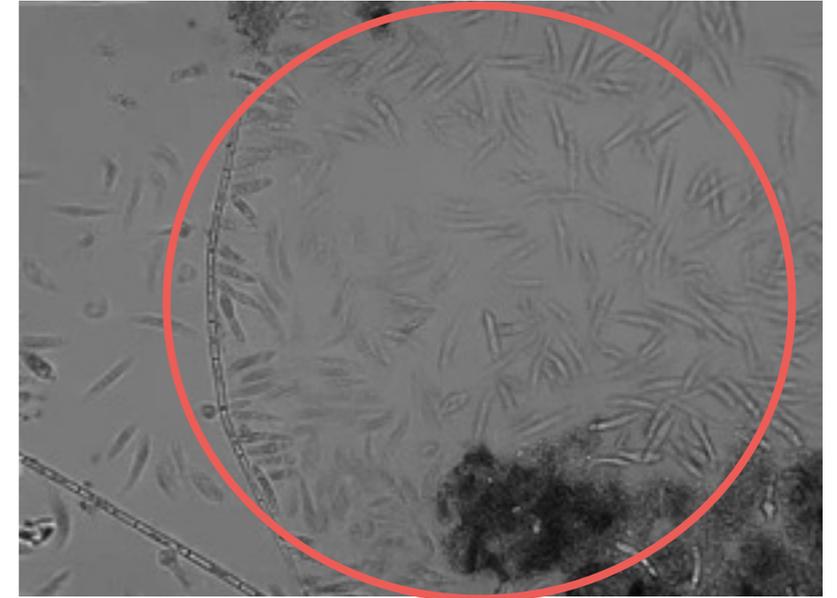
Our Work

[3] Pimentel et. al (2017)

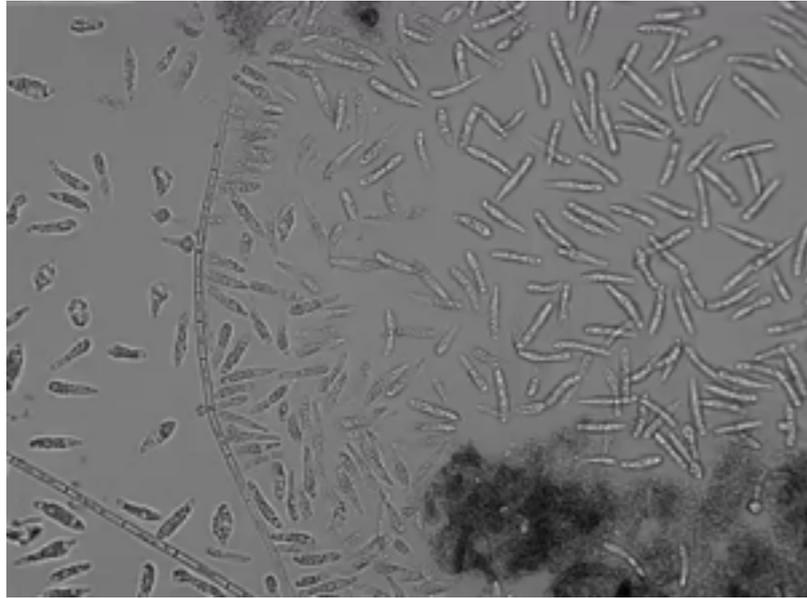


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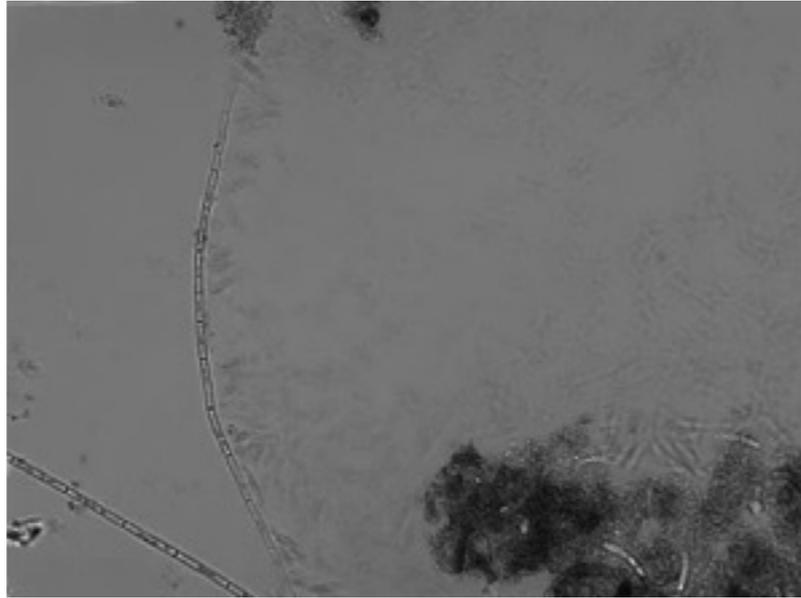


Original Video



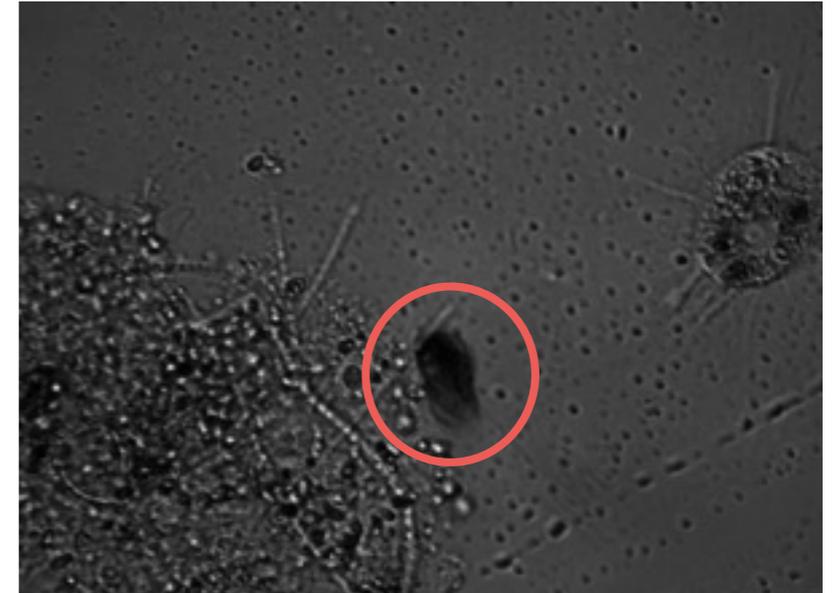
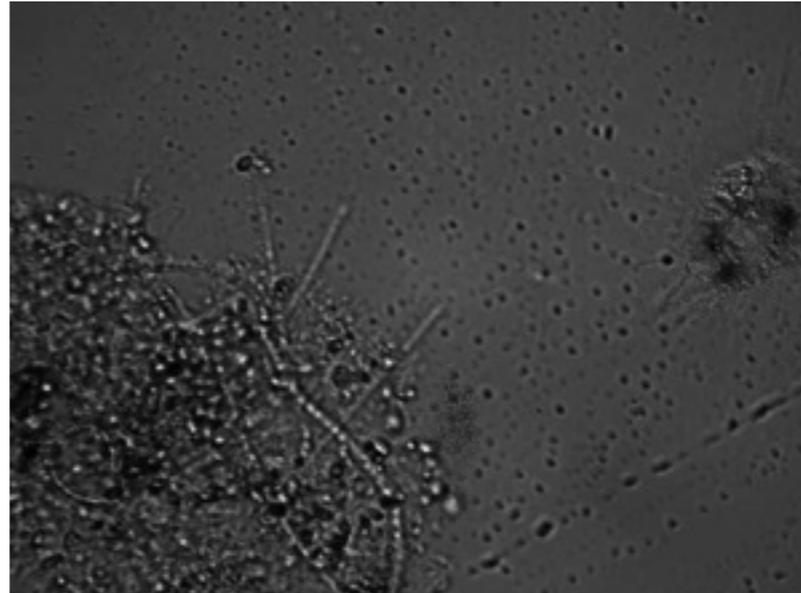
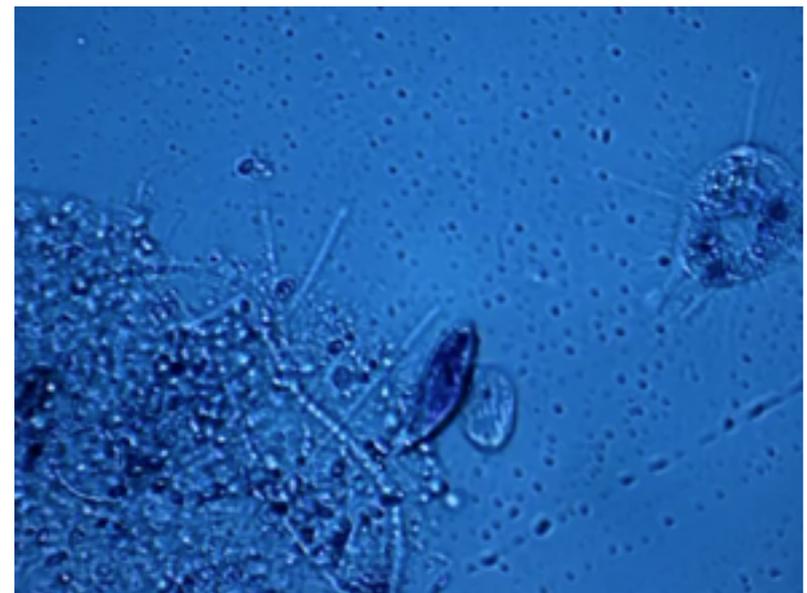
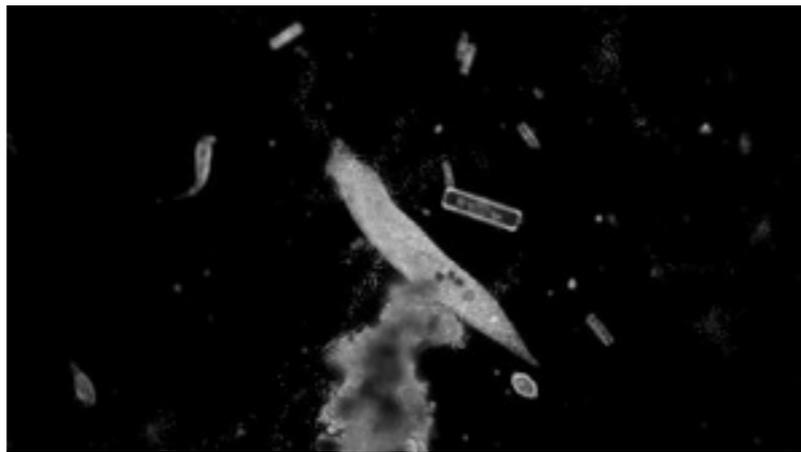
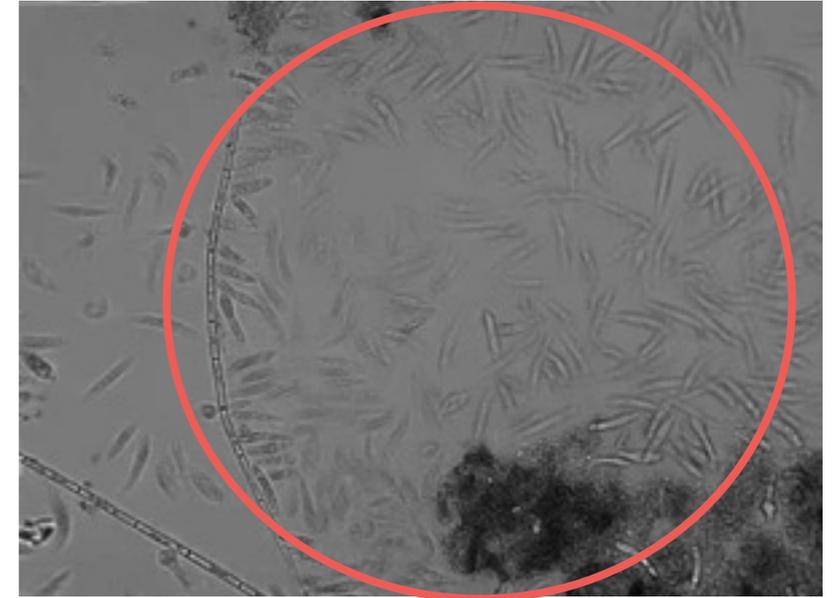
Our Work

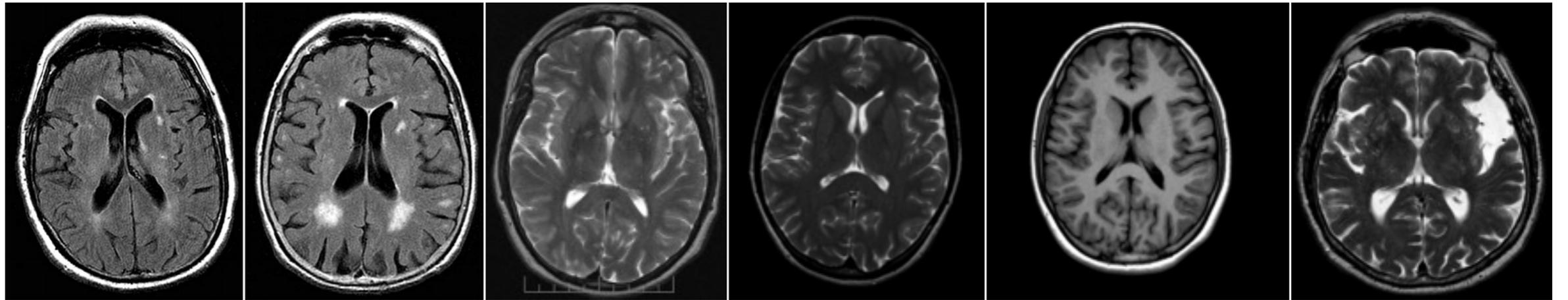
[3] Pimentel et. al (2017)



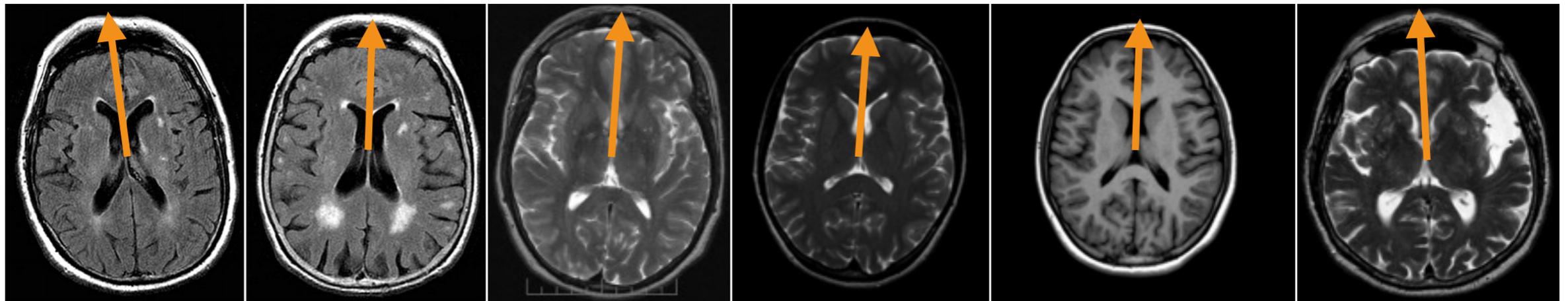
RPCA-ALM

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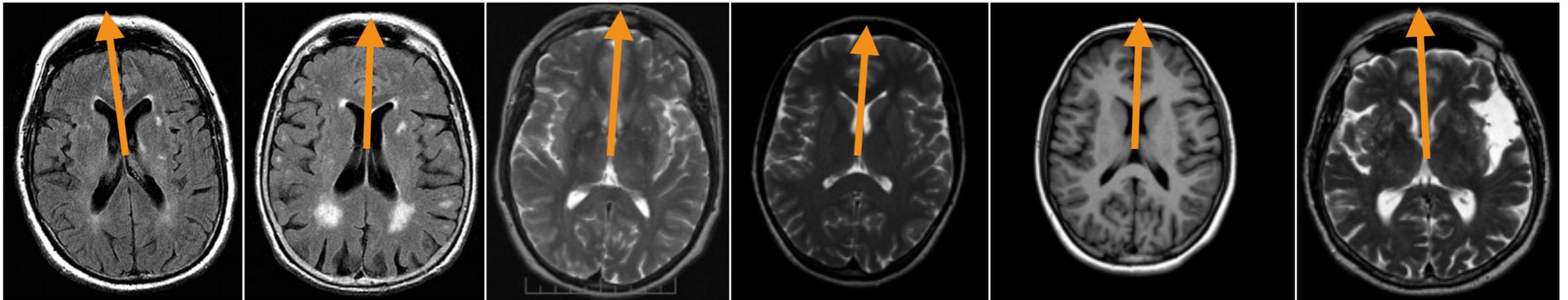


Which one has Alzheimer?



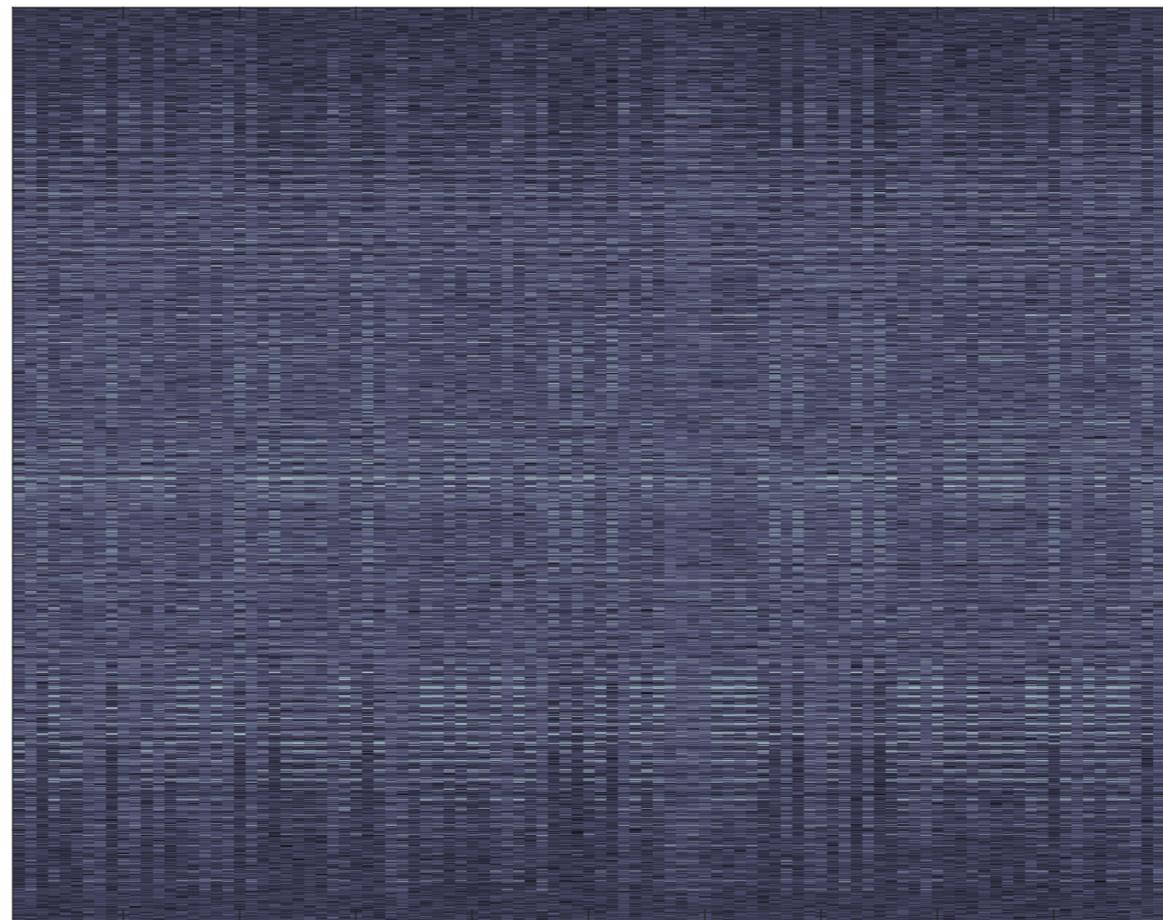
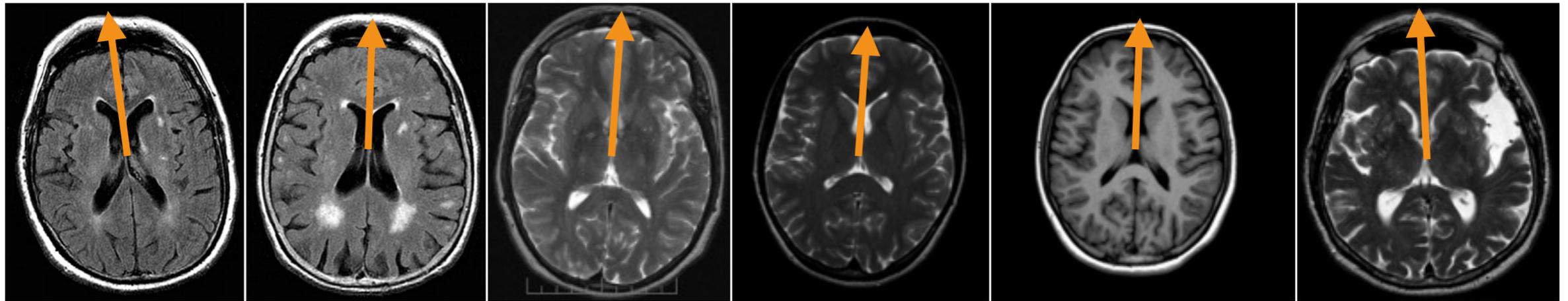
Which one has Alzheimer?

$$Y = UDV^T$$



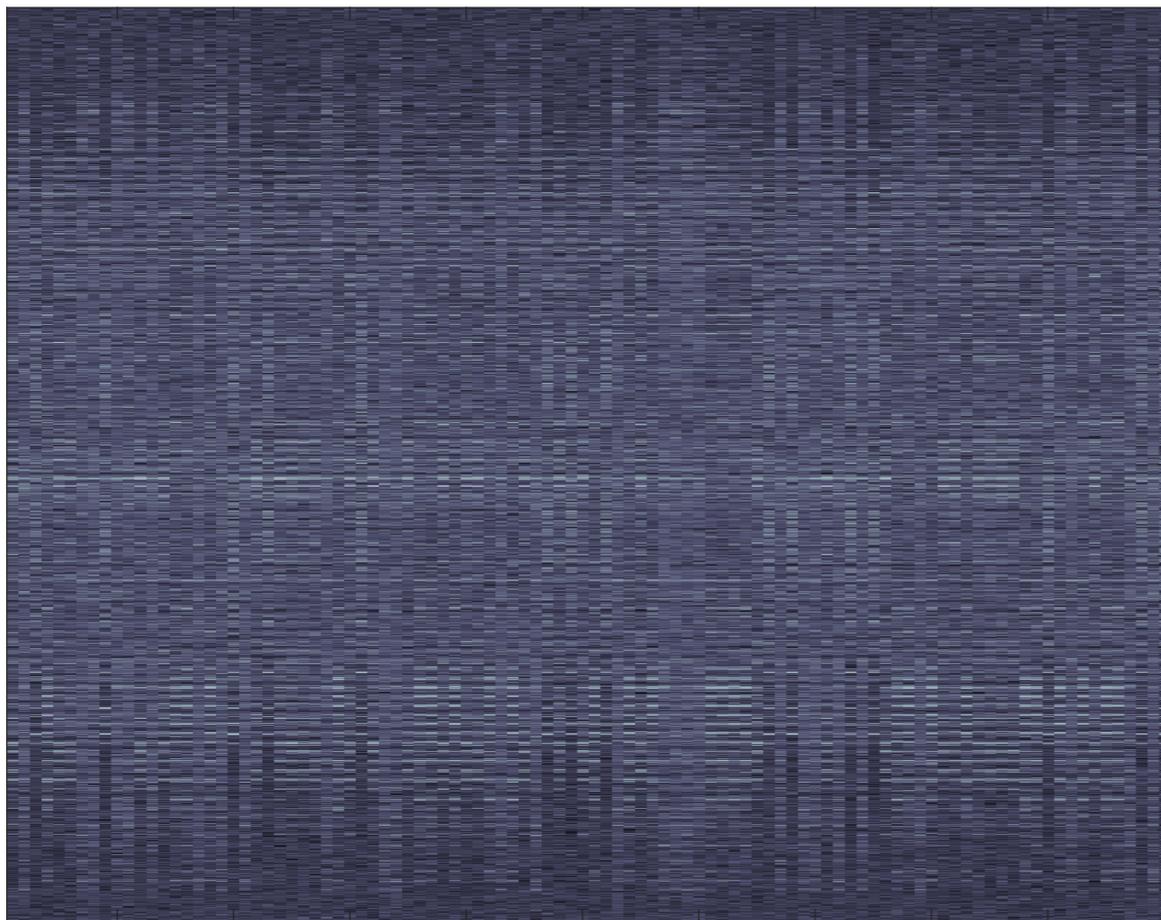
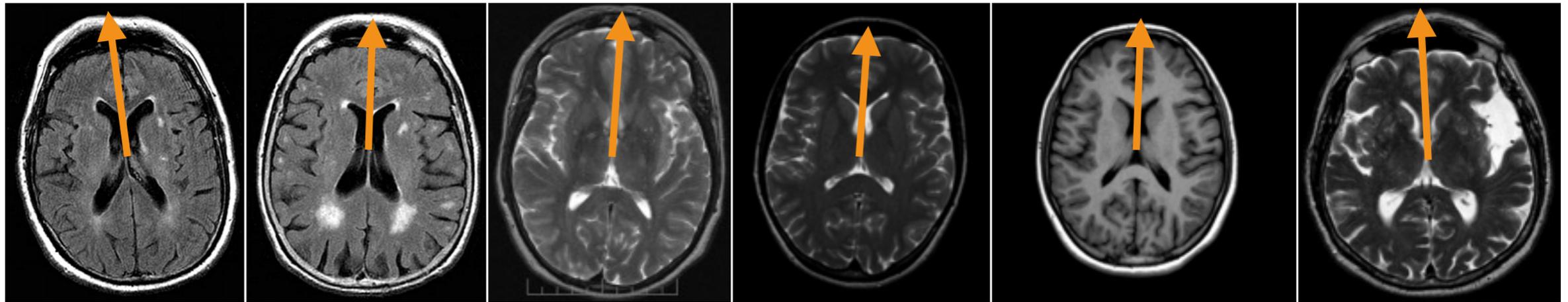
Which one has Alzheimer?

$$Y = UDV^T$$

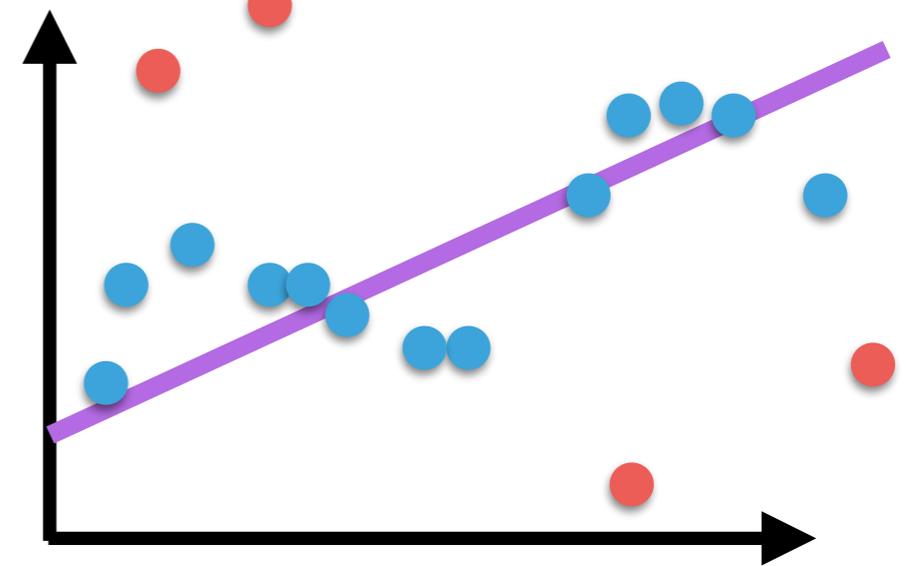


Which one has Alzheimer?

$$Y = UDV^T$$

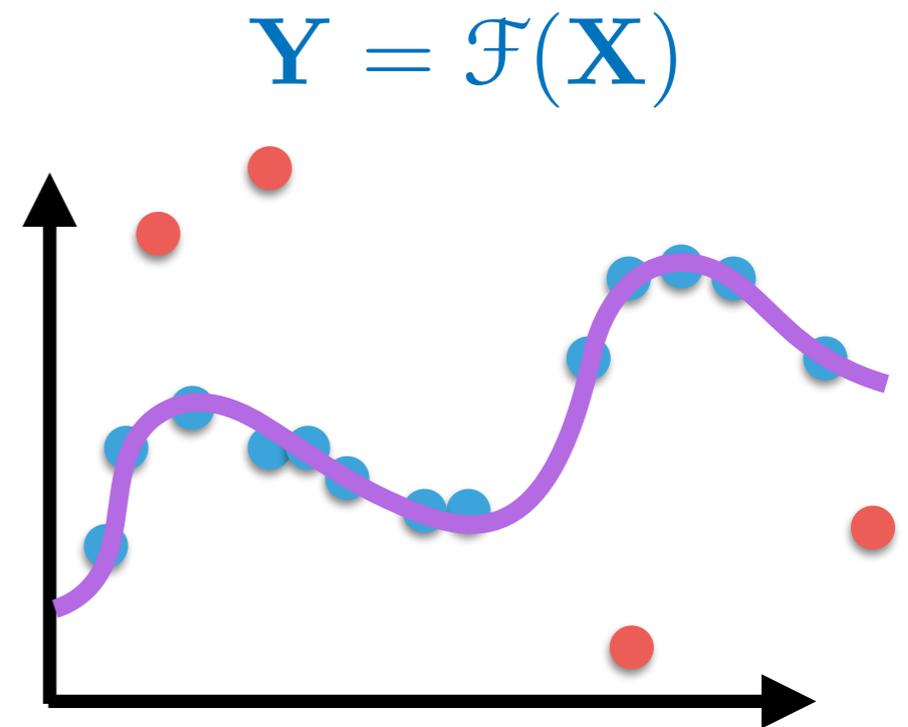
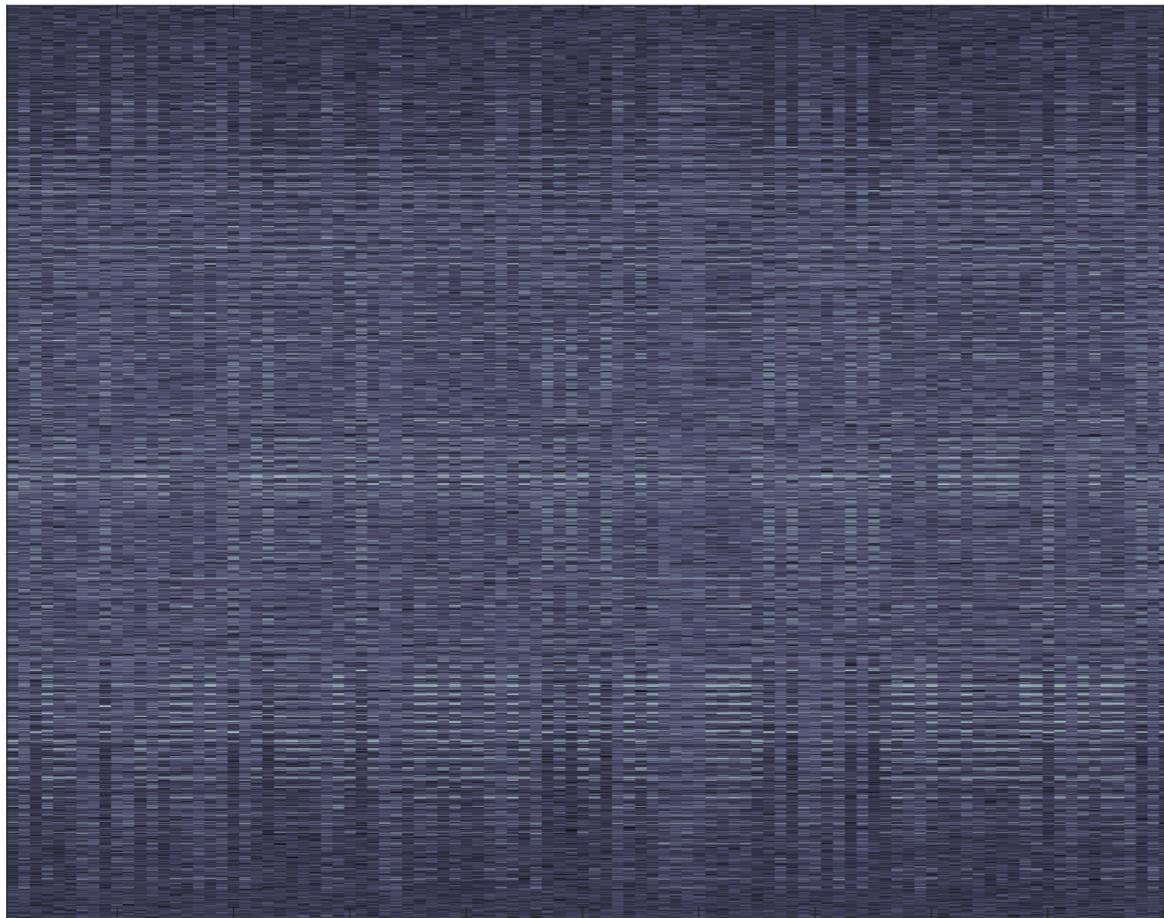
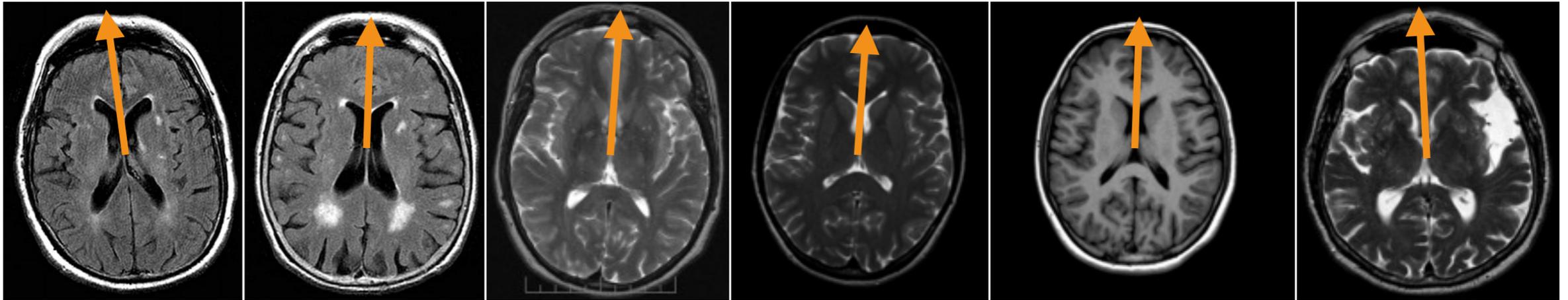


$$Y = AX + B$$

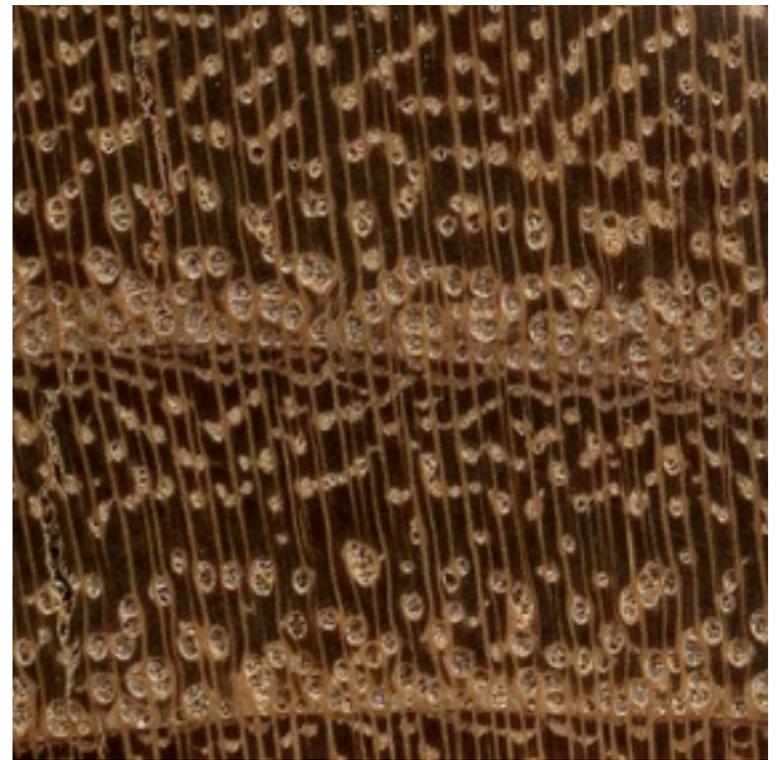
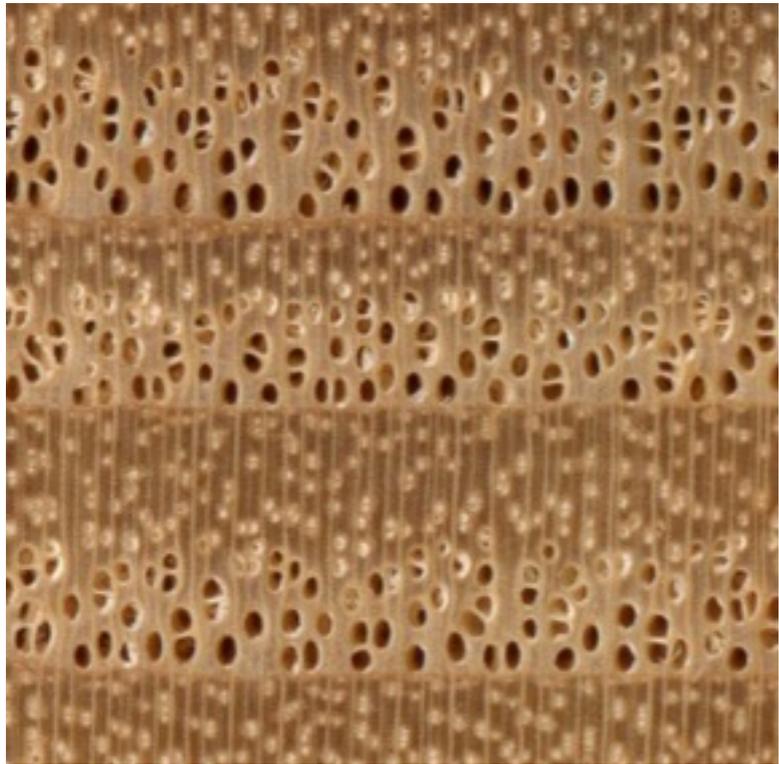


Which one has Alzheimer?

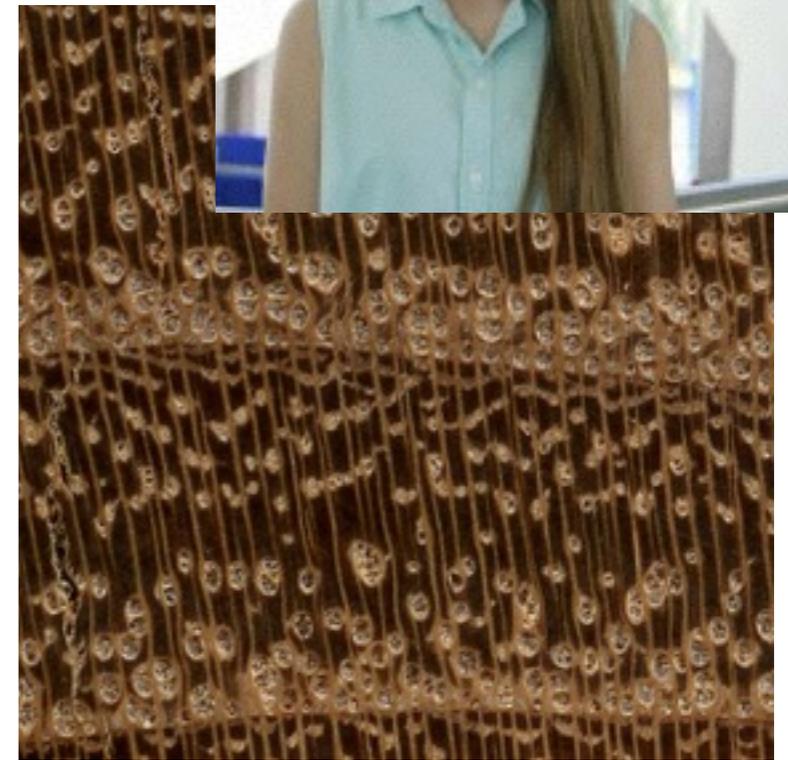
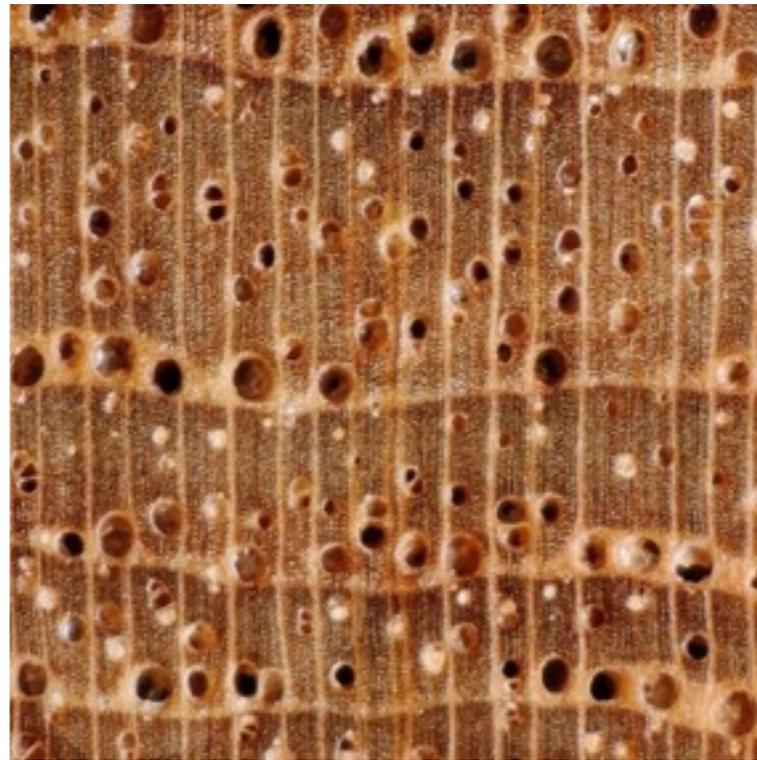
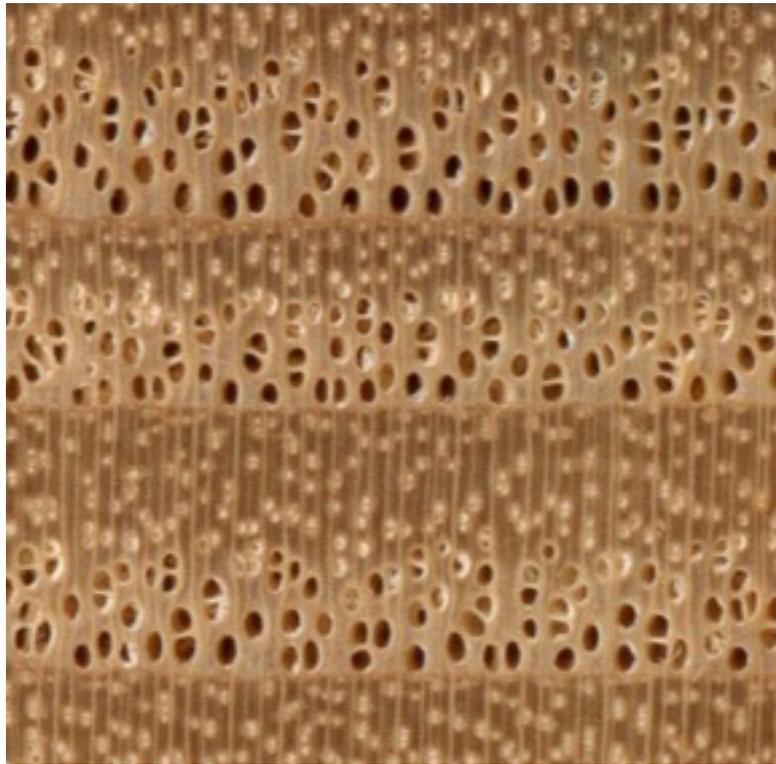
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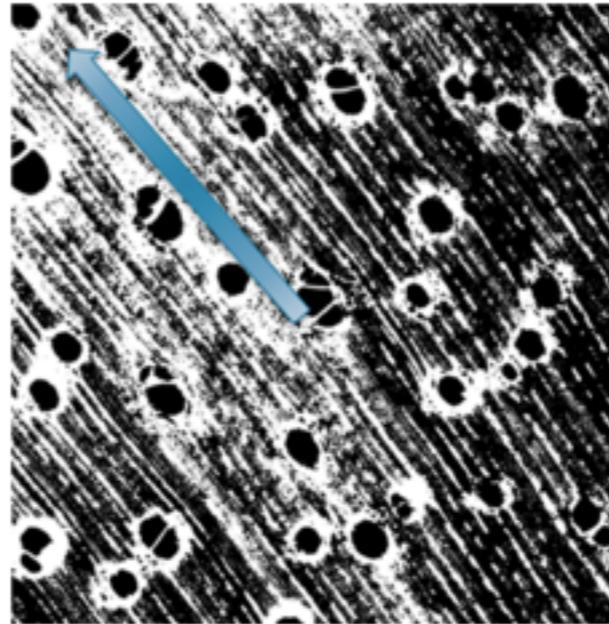
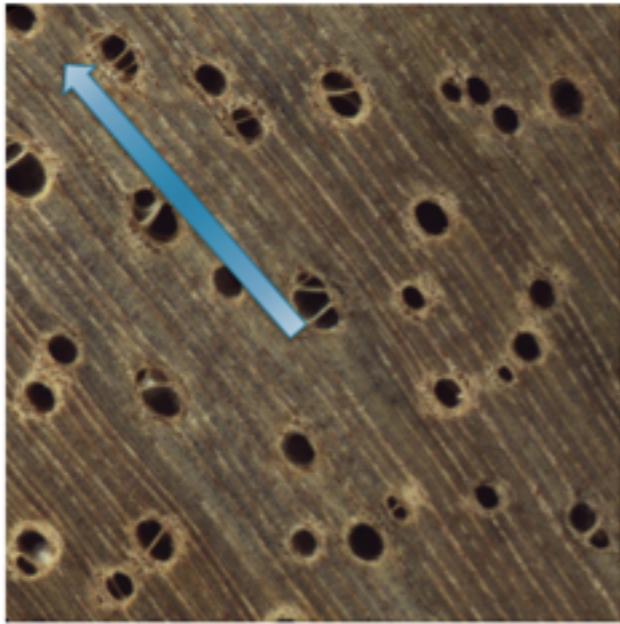
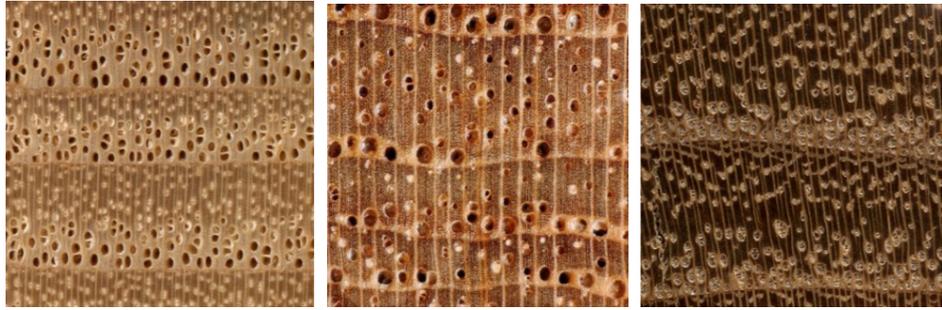
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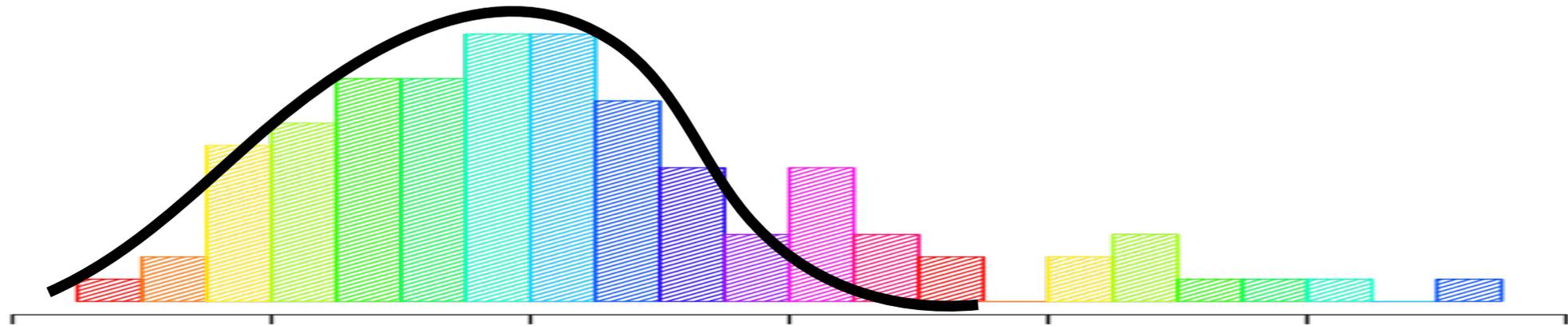
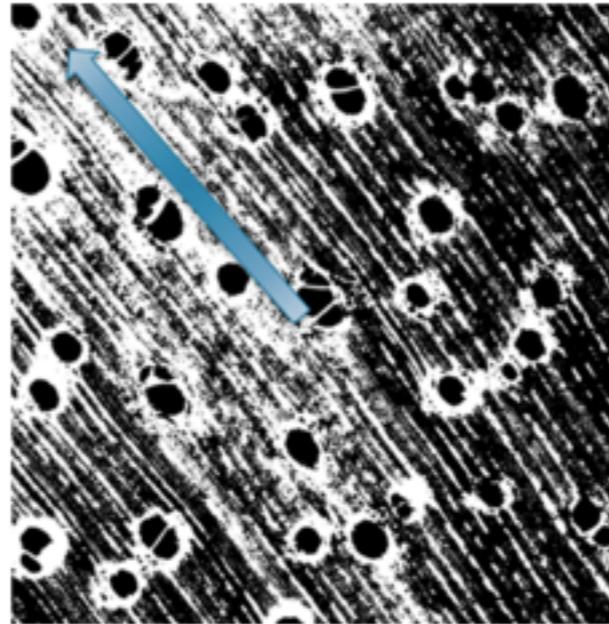
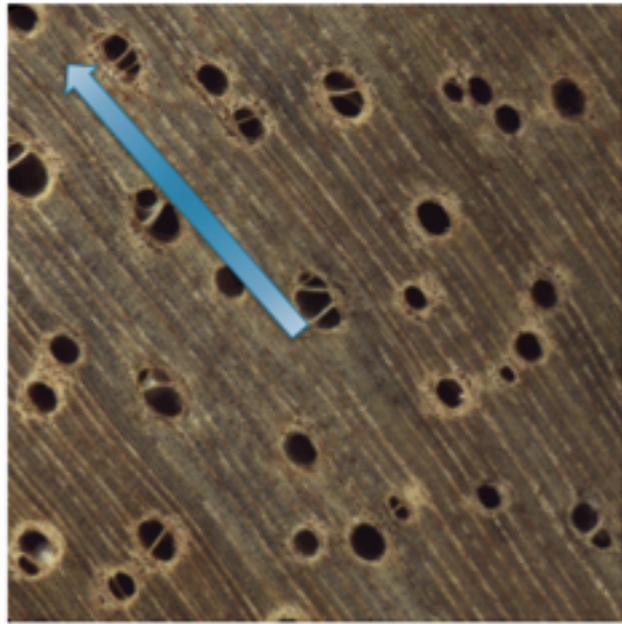
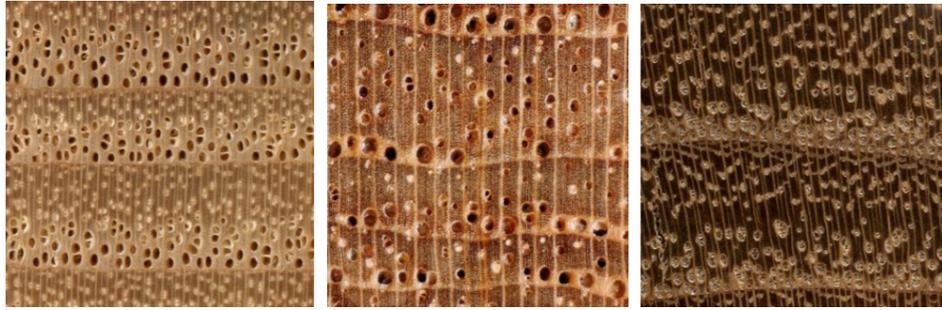
Which is an endangered species?



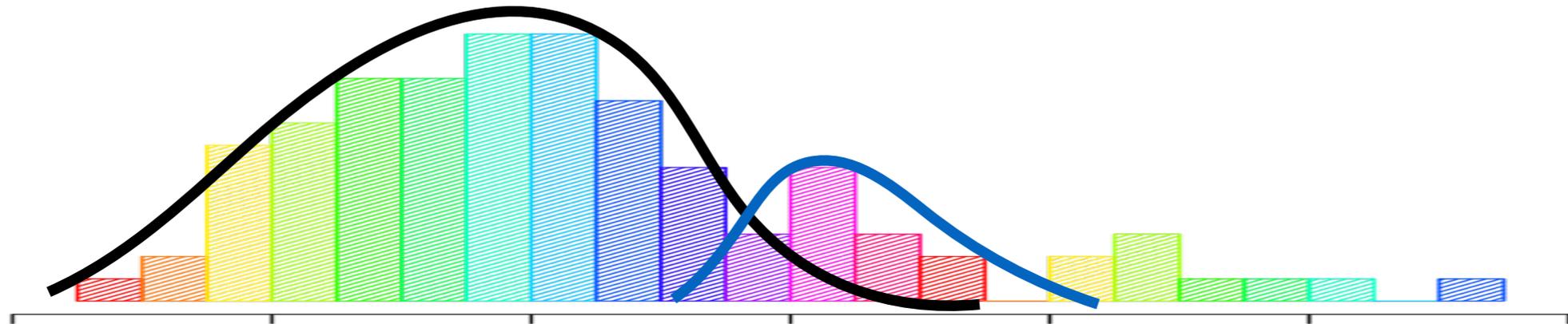
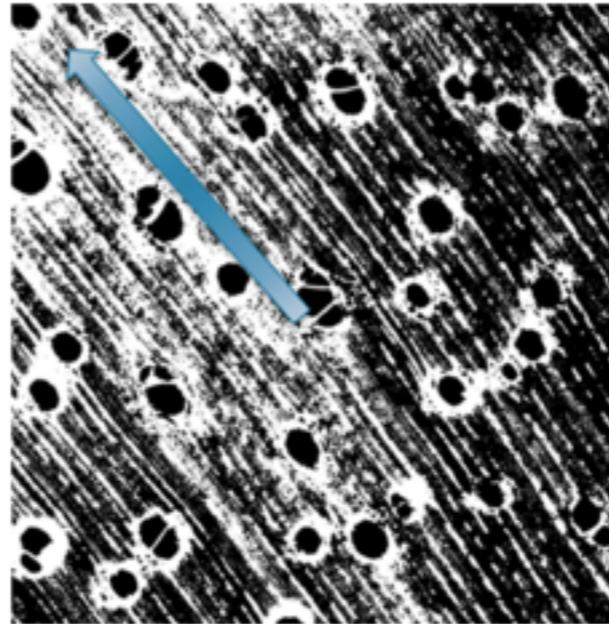
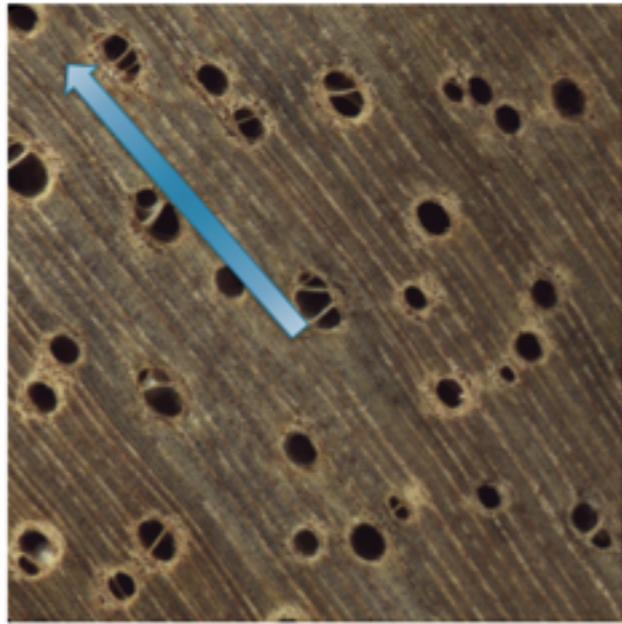
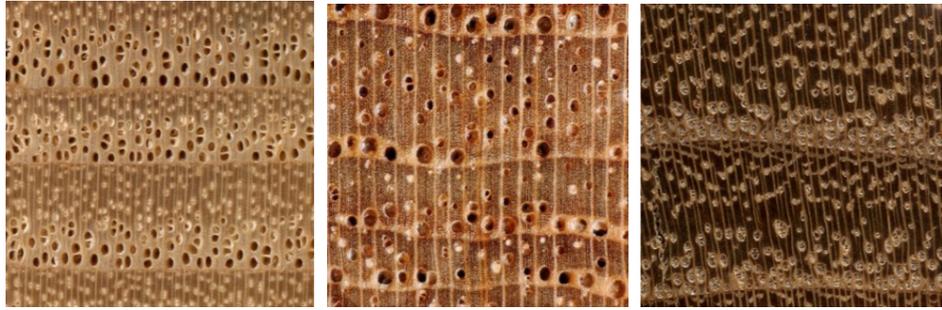
Which is an endangered species?



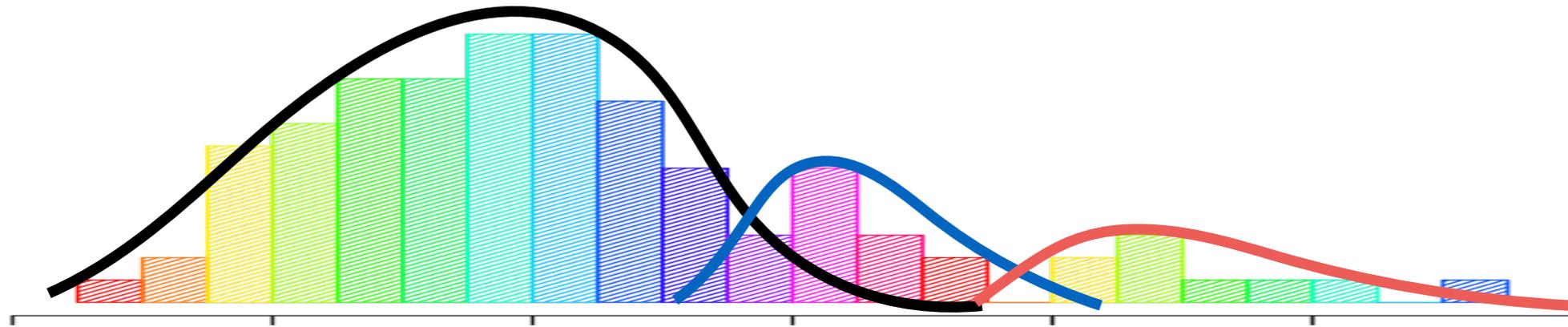
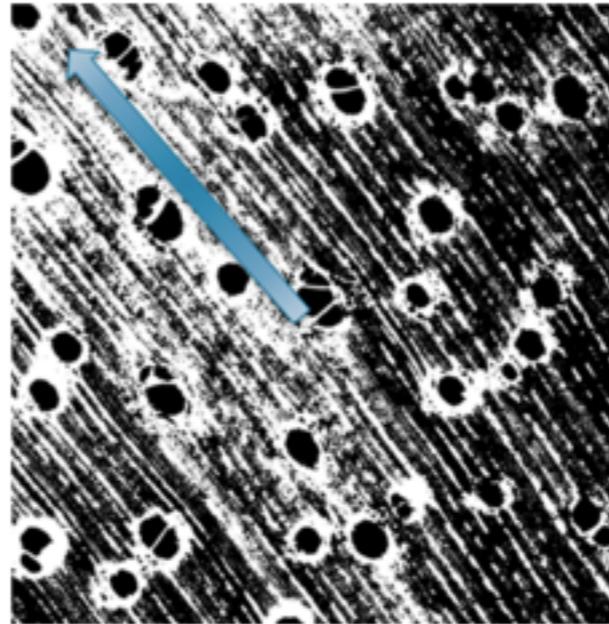
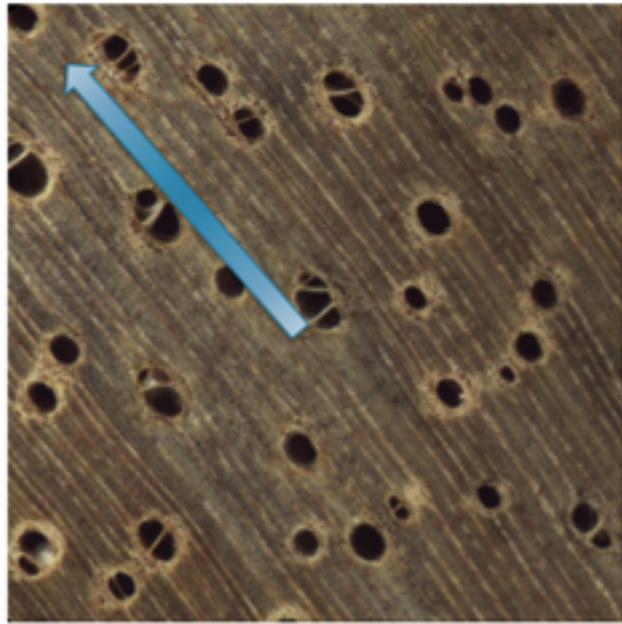
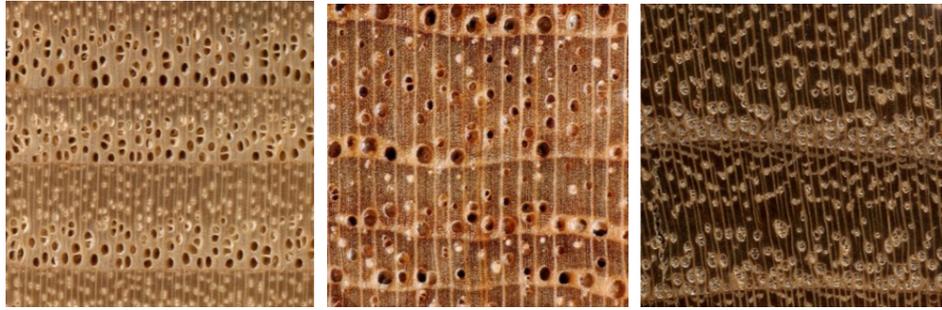
Which is an endangered species?



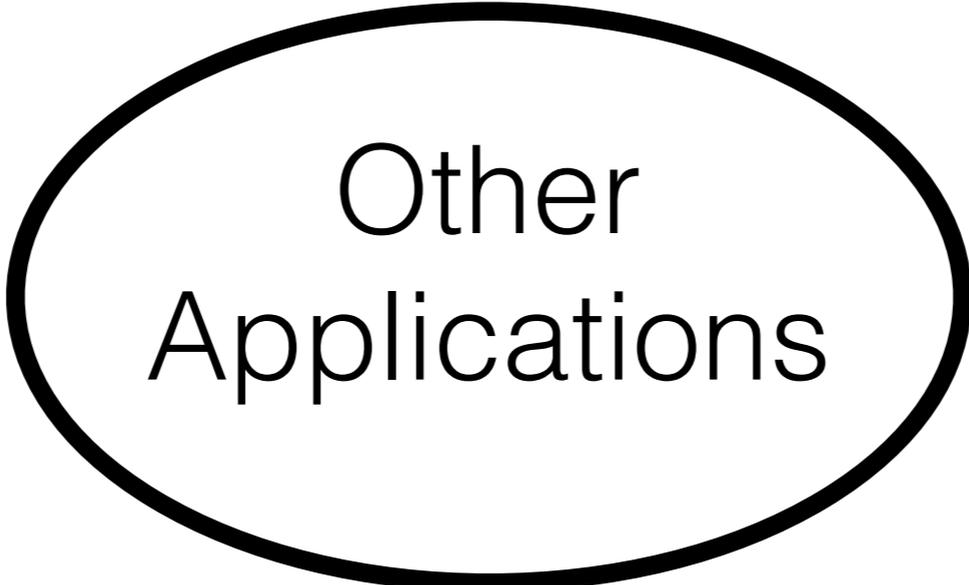
Which is an endangered species?



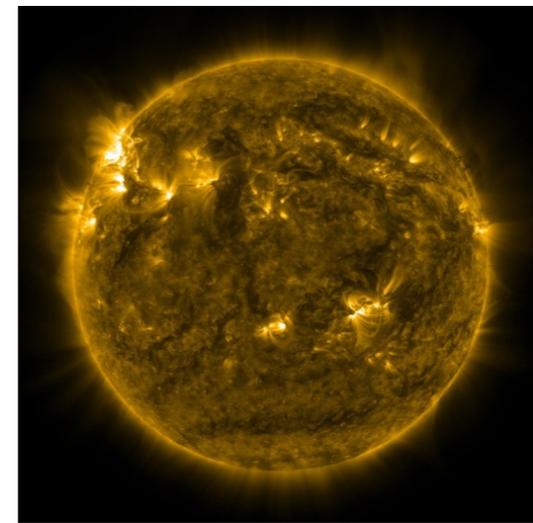
Which is an endangered species?



Which is an endangered species?

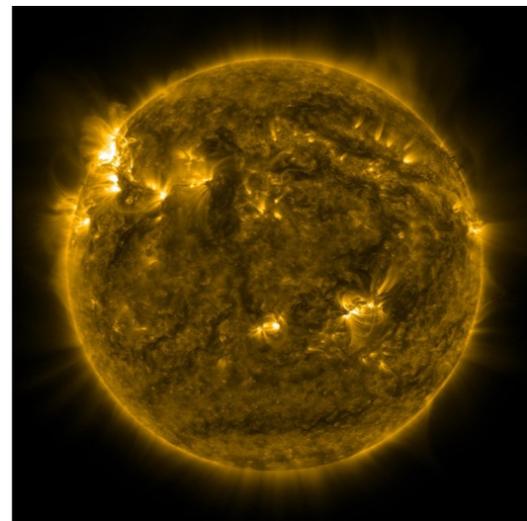


Other
Applications

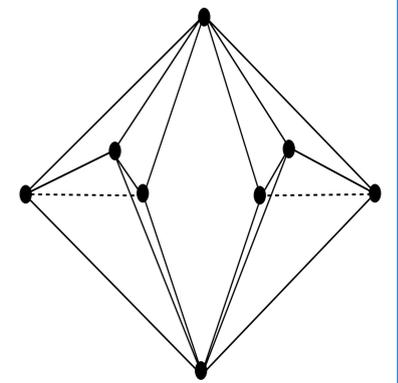


Astrophysics
Applications

Other
Applications

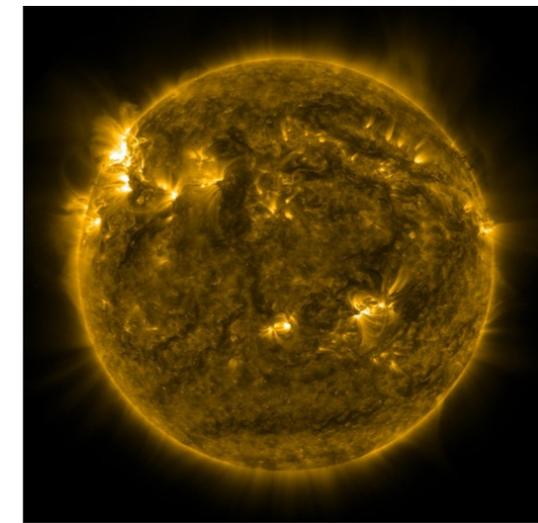


Astrophysics
Applications

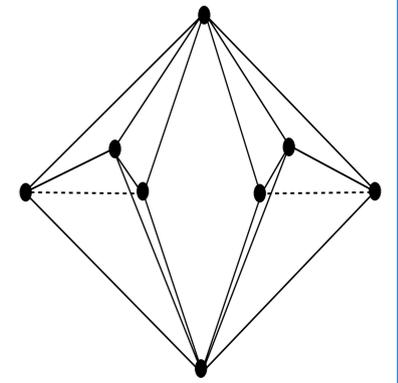


Rigidity
Theory

Other
Applications



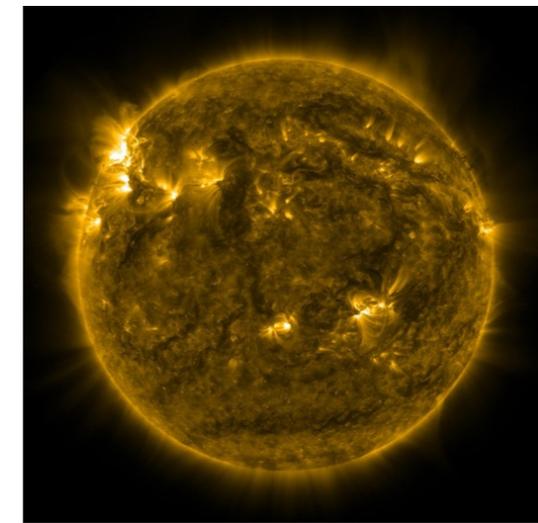
Astrophysics
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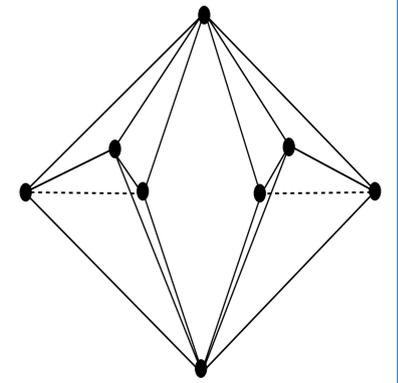
Rigidity
Theory

Other
Applications

Drug Discovery

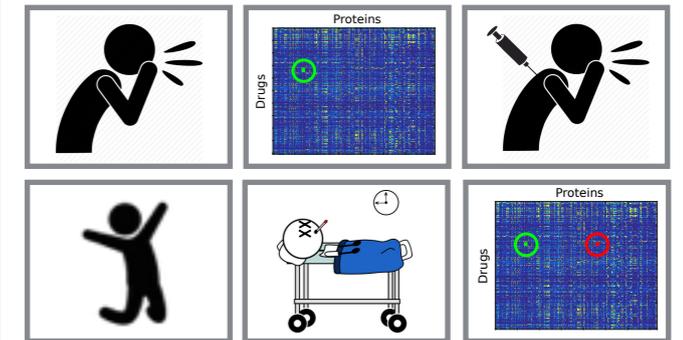


Astrophysics
Applications

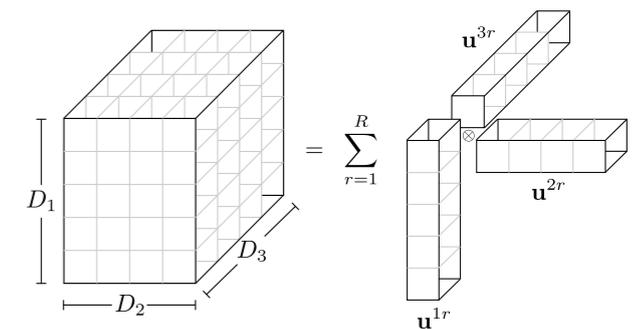


Rigidity
Theory

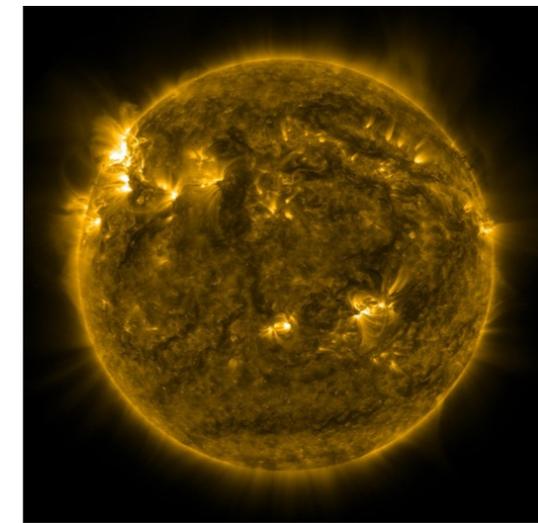
Other Applications



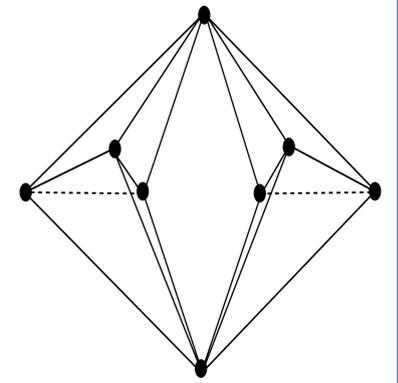
Drug Discovery



Tensor
Decompositions

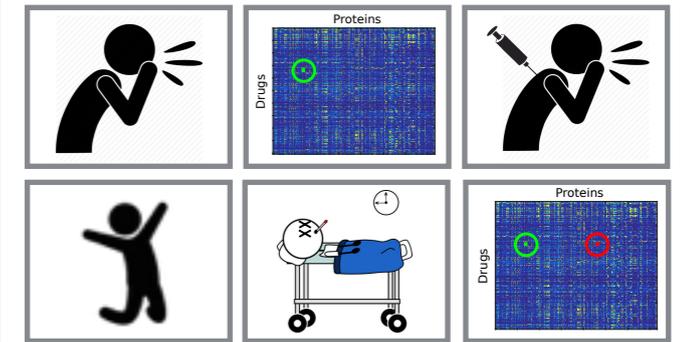


Astrophysics
Applications

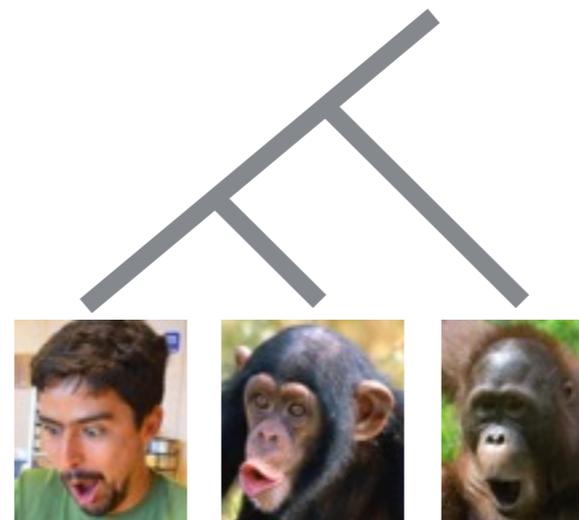


Rigidity
Theory

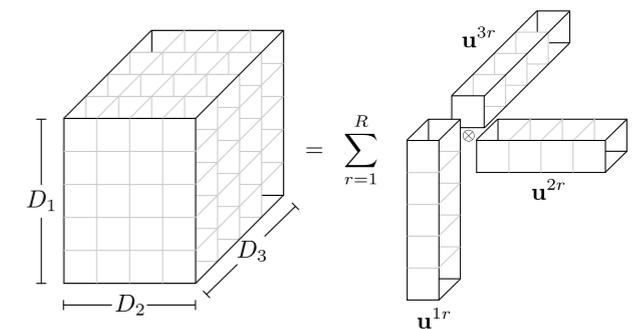
Other Applications



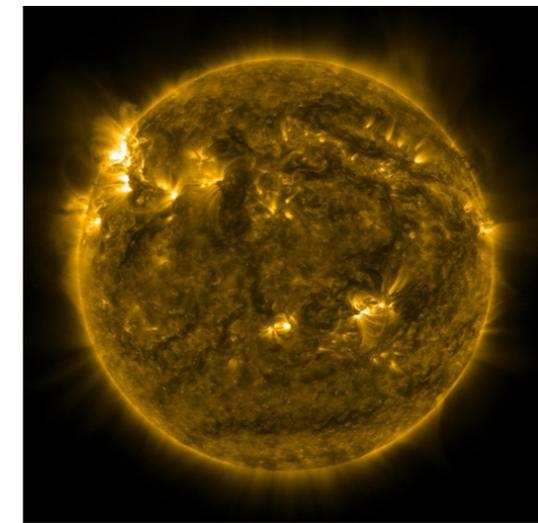
Drug Discovery



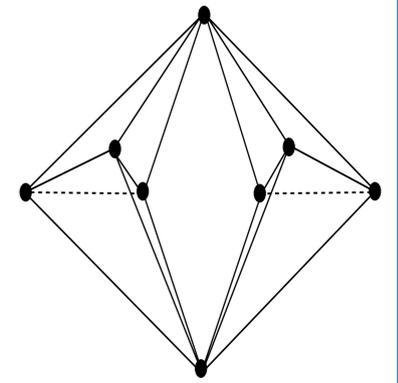
Phylogenetics



Tensor
Decompositions

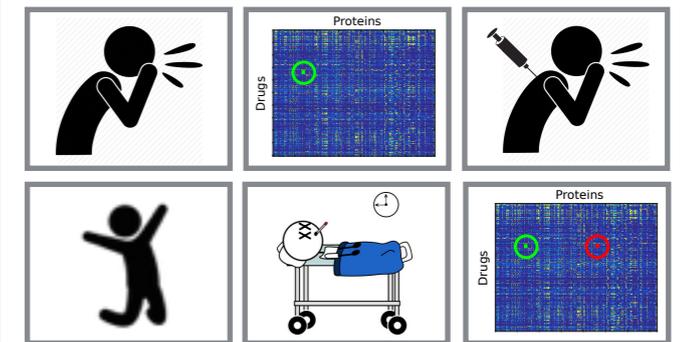


Astrophysics
Applications

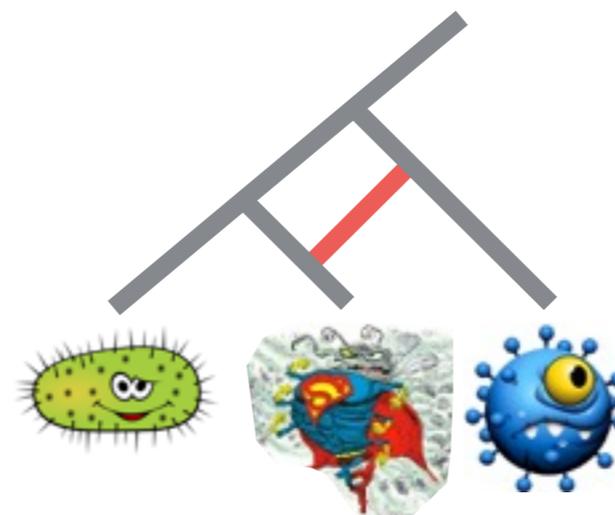


Rigidity
Theory

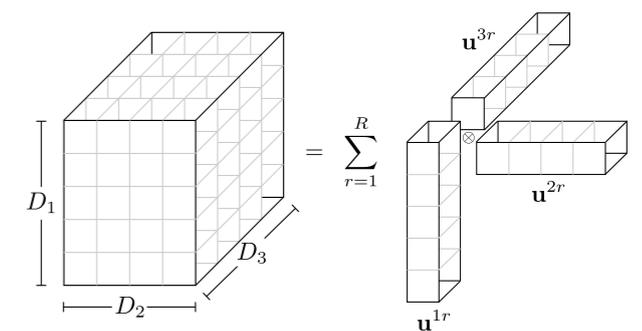
Other Applications



Drug Discovery

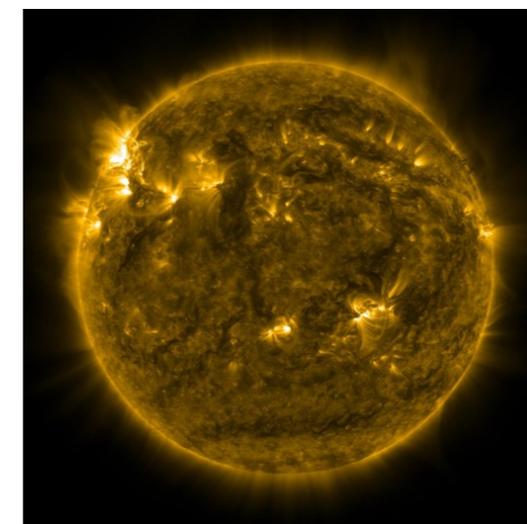


Phylogenetics

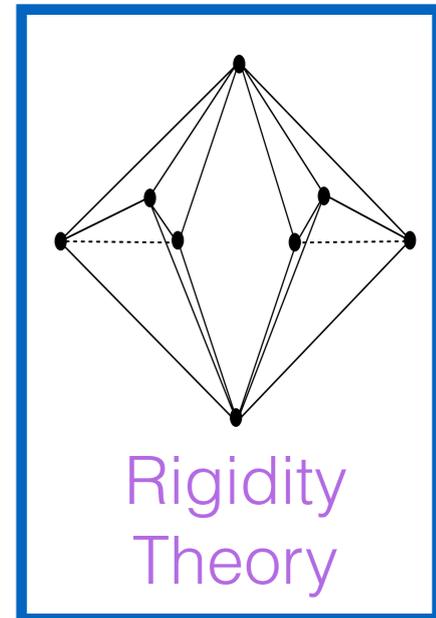


Tensor
Decompositions

Other Applications

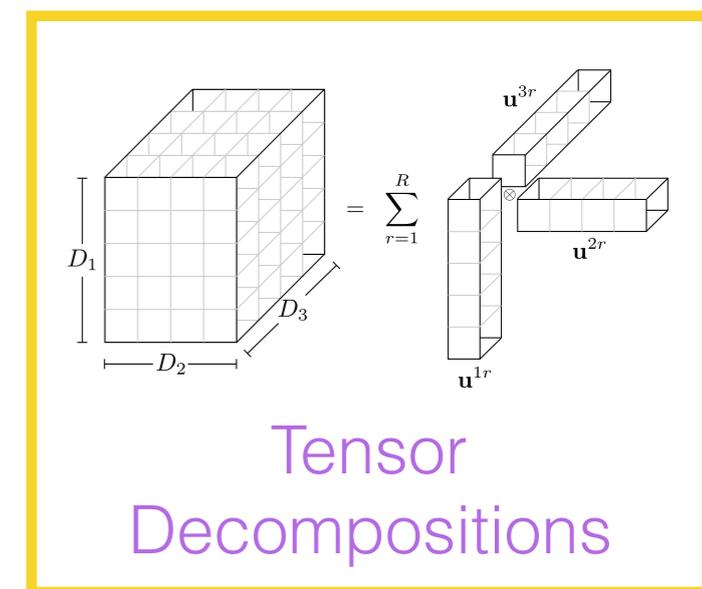
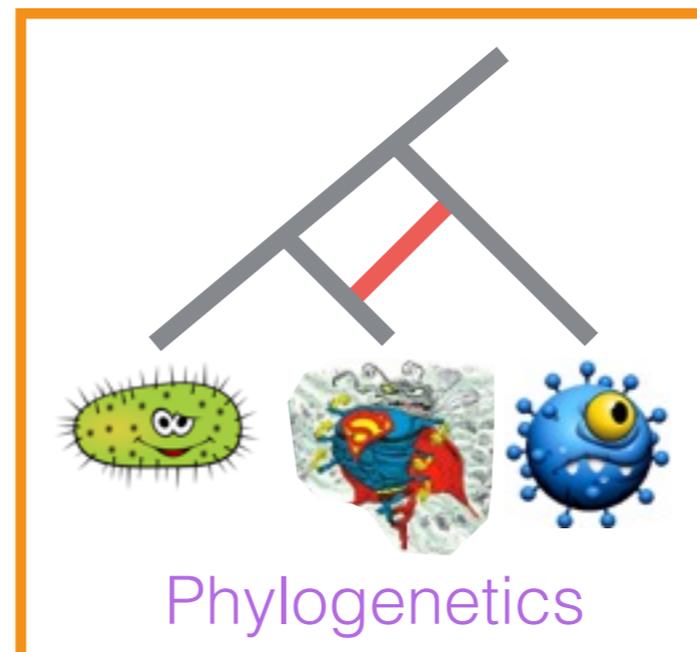
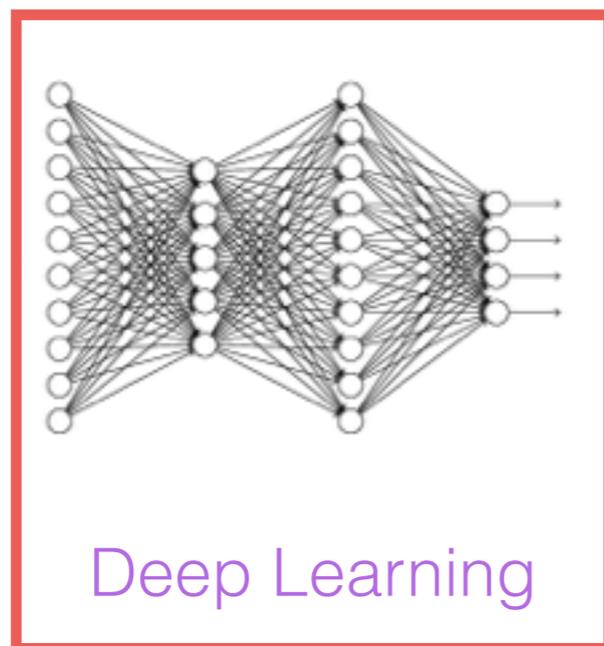


Astrophysics Applications

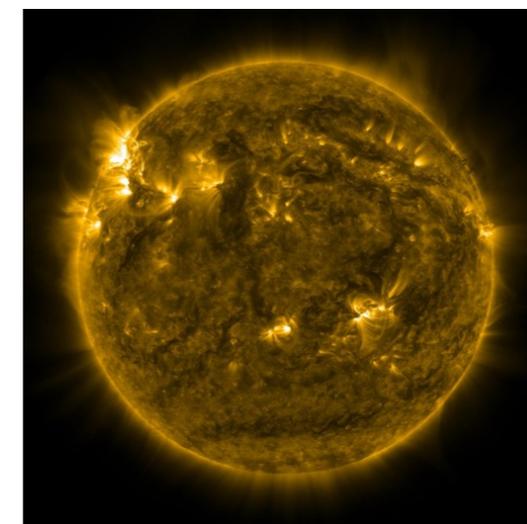


Rigidity Theory

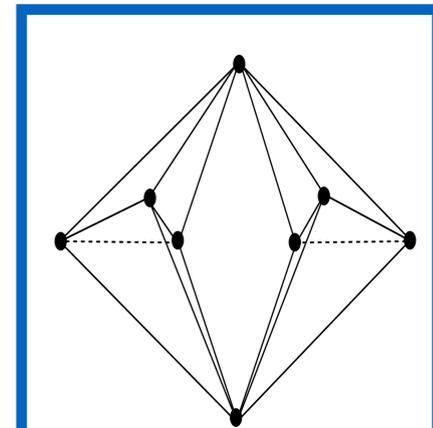
Drug Discovery



Other Applications

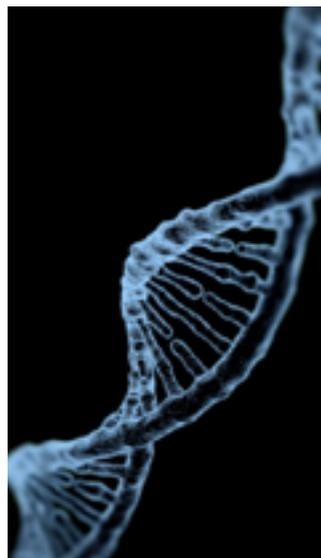


Astrophysics Applications

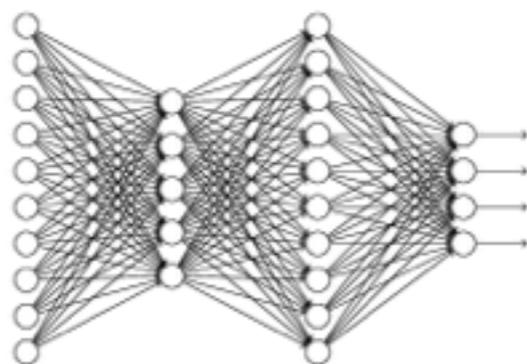


Rigidity Theory

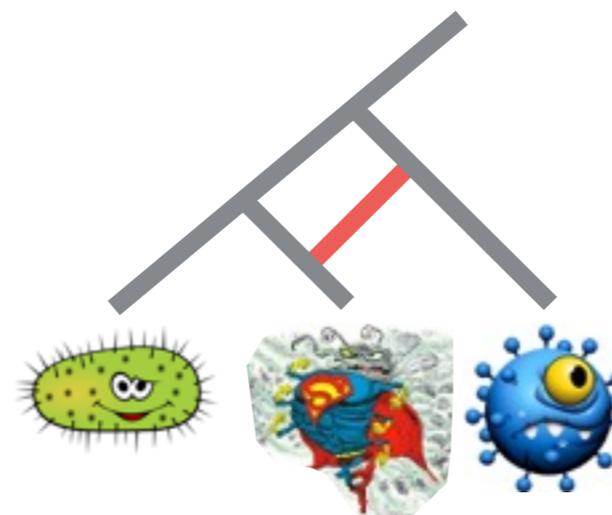
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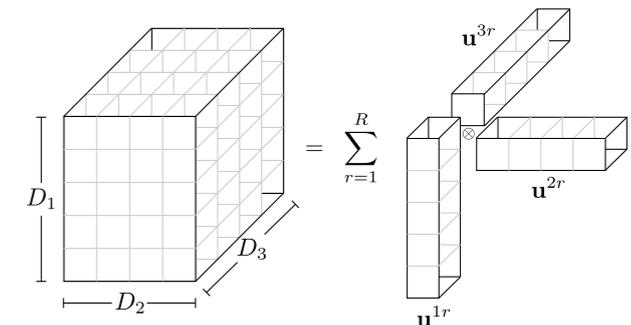
Genomics



Deep Learning

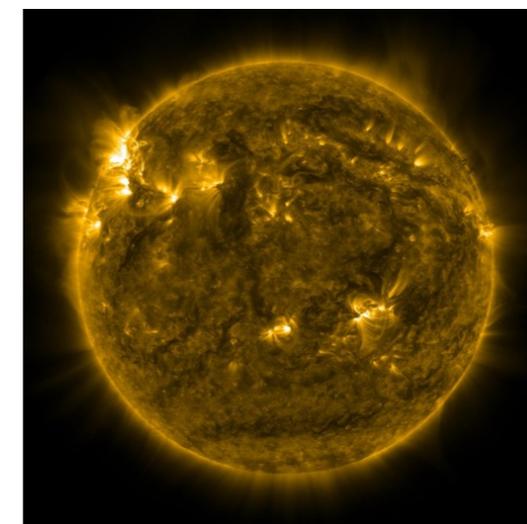


Phylogenetics

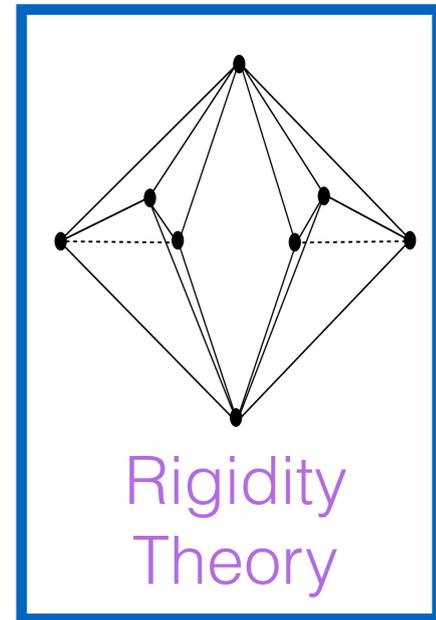


Tensor Decompositions

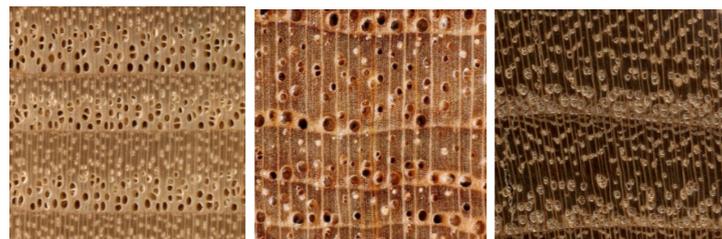
Other Applications



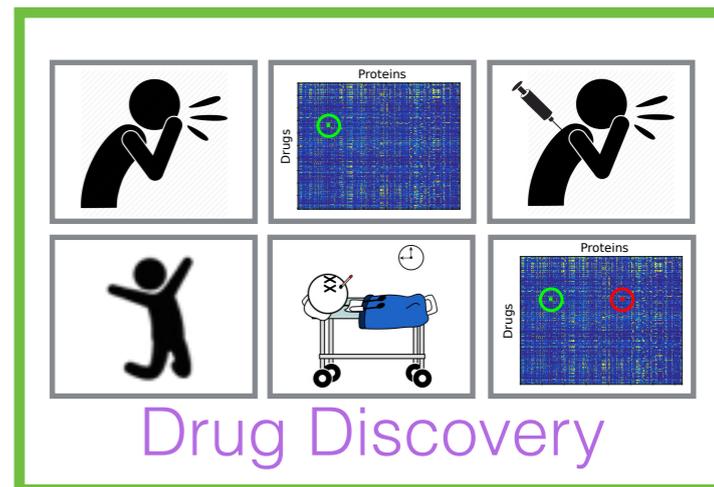
Astrophysics Applications



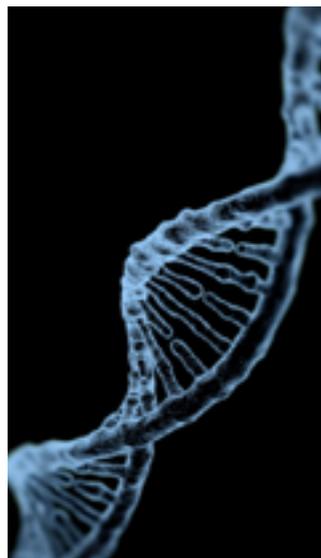
Rigidity Theory



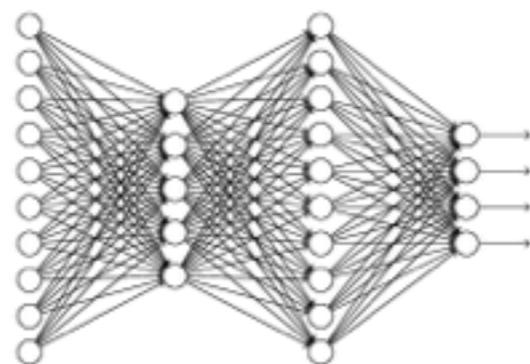
Wood Classification



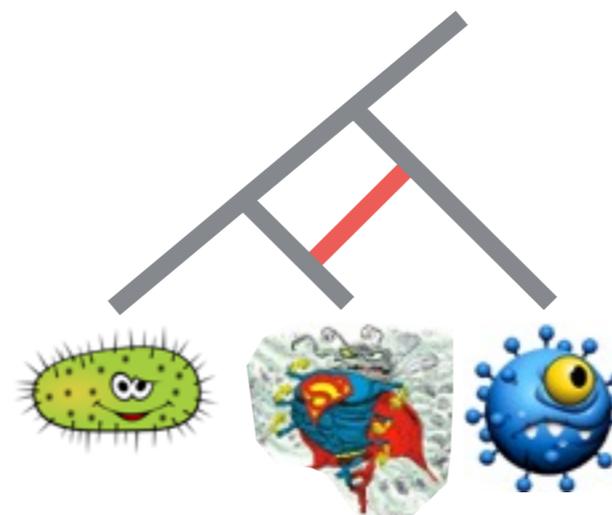
Drug Discovery



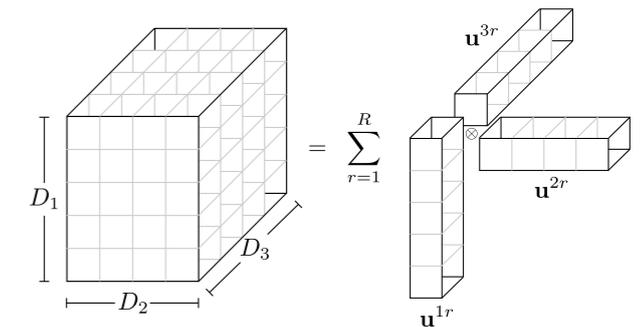
Genomics



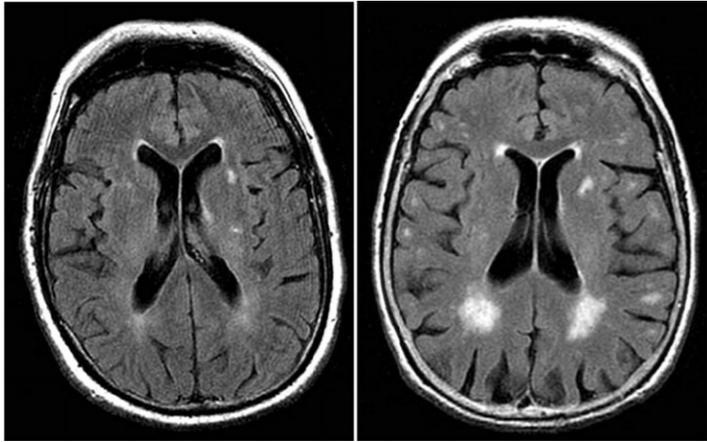
Deep Learning



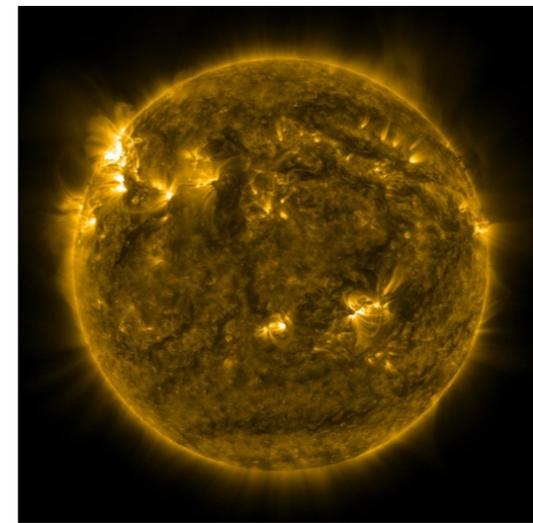
Phylogenetics



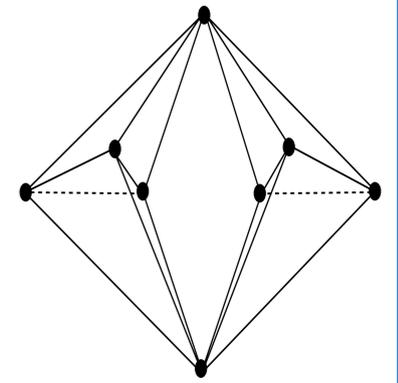
Tensor Decompositions



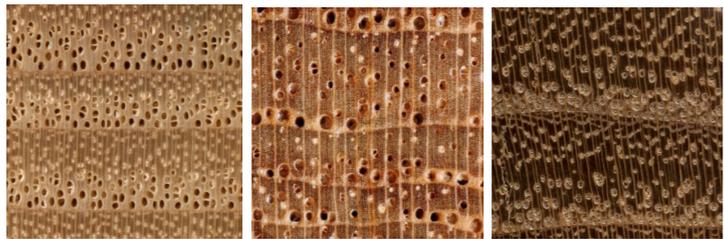
Biomedical Applications



Astrophysics Applications

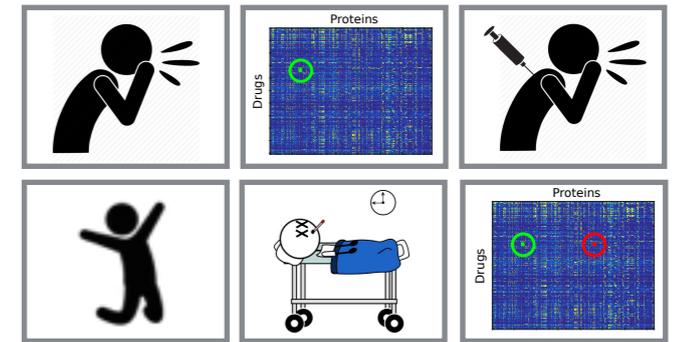


Rigidity Theory

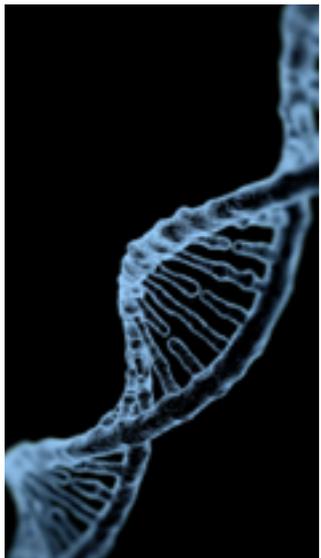


Wood Classification

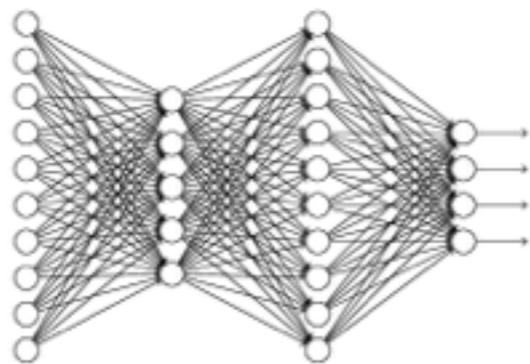
Other Applications



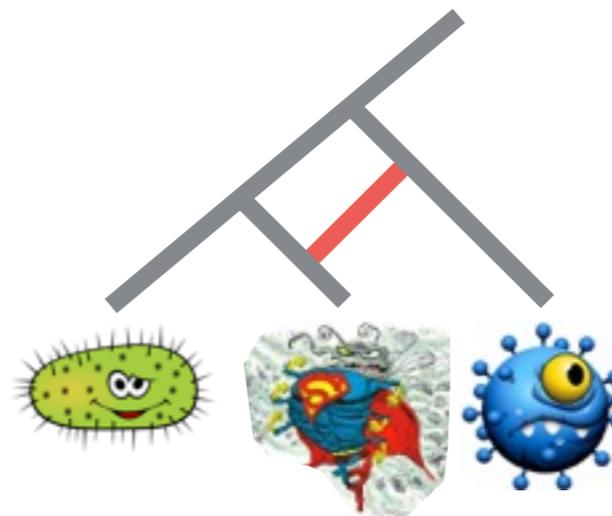
Drug Discovery



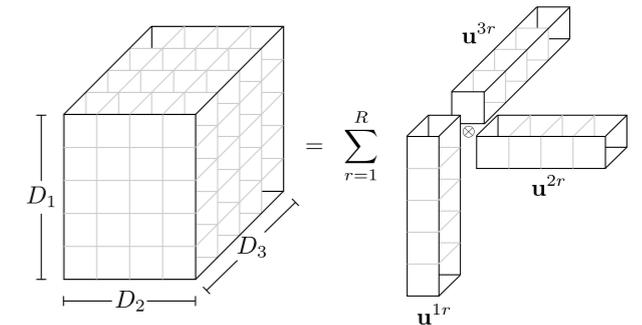
Genomics



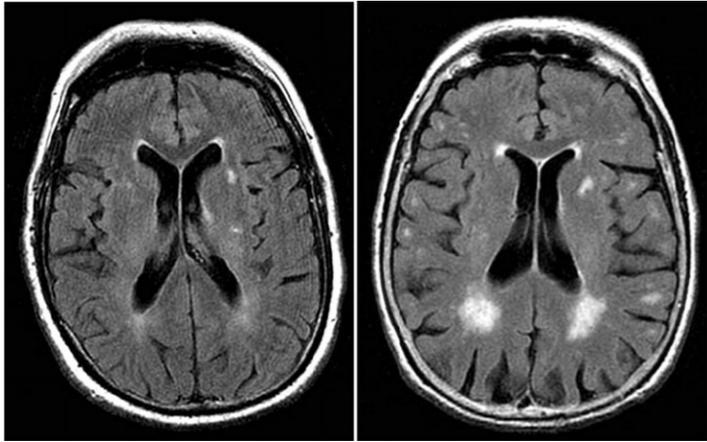
Deep Learning



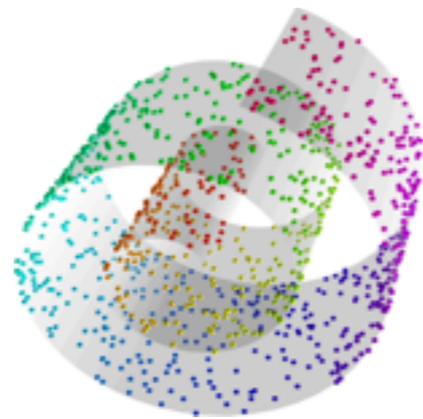
Phylogenetics



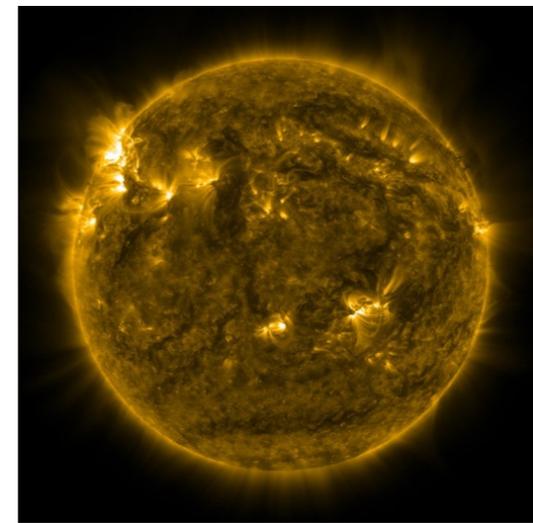
Tensor Decompositions



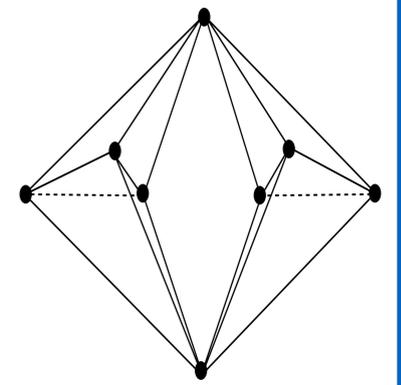
Biomedical Applications



Manifold Learning

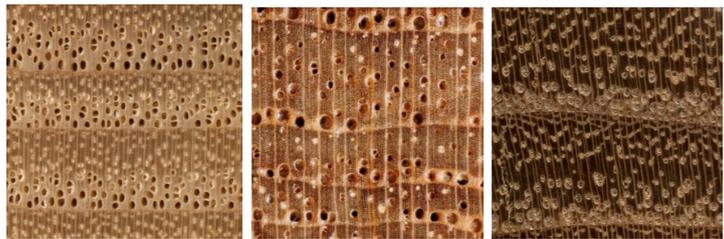


Astrophysics Applications

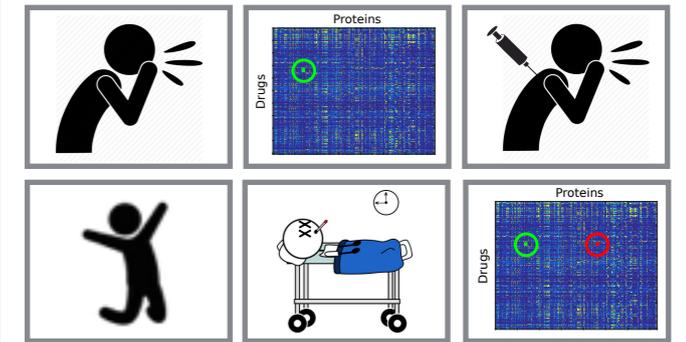


Rigidity Theory

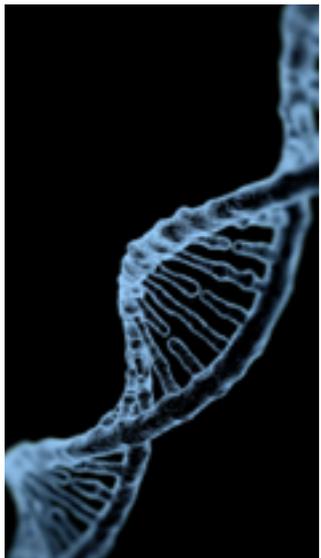
Other Applications



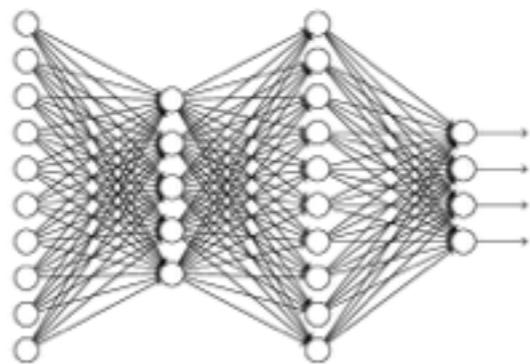
Wood Classification



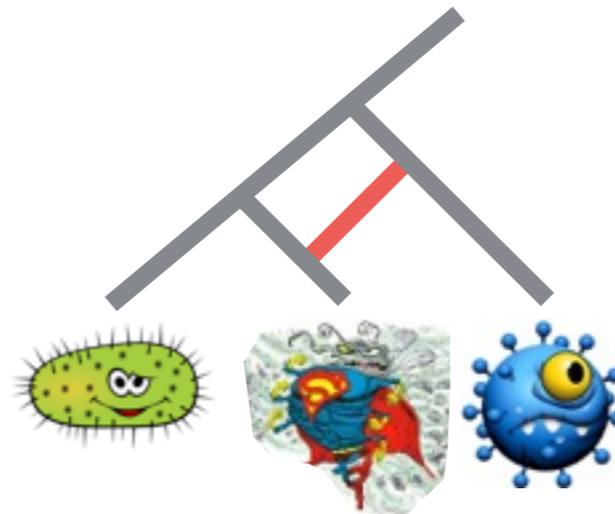
Drug Discovery



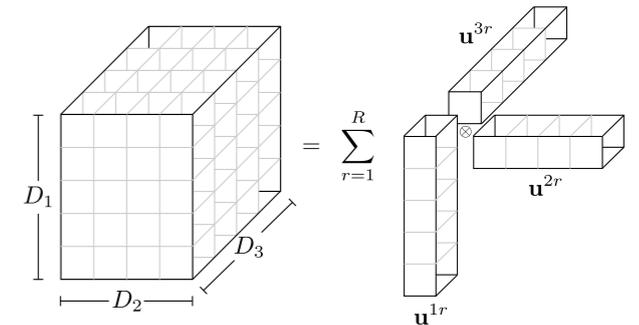
Genomics



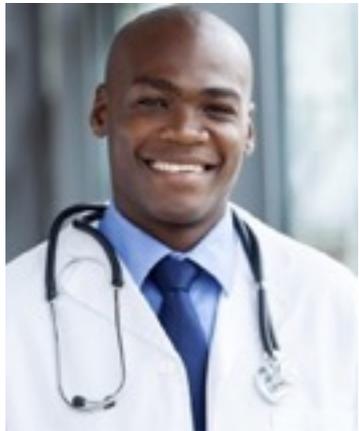
Deep Learning



Phylogenetics



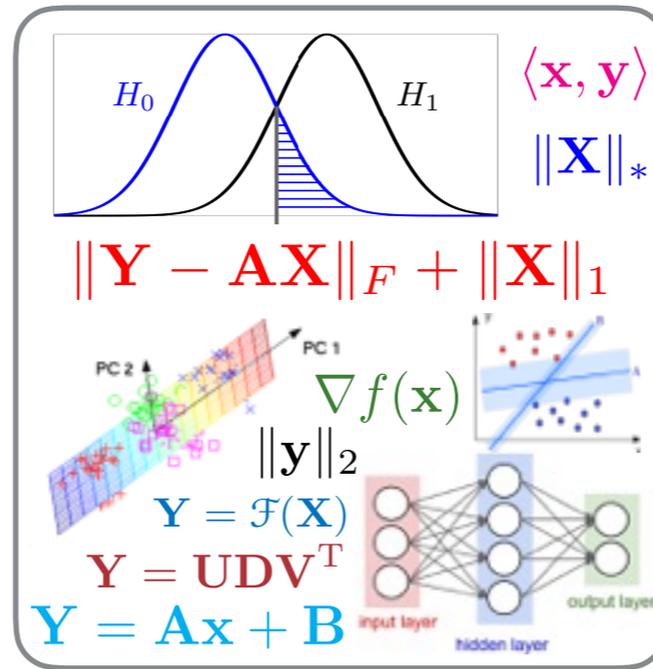
Tensor Decompositions



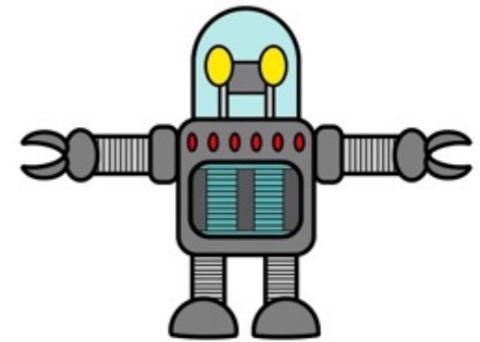
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Statistics
Probability
Vector Spaces
Optimization
Analysis
Algebra
Math



Parallelization
Storage
Speed
Algorithms
Hardware
Networks
Data Acquisition
Parameter Tuning
Training
Coding





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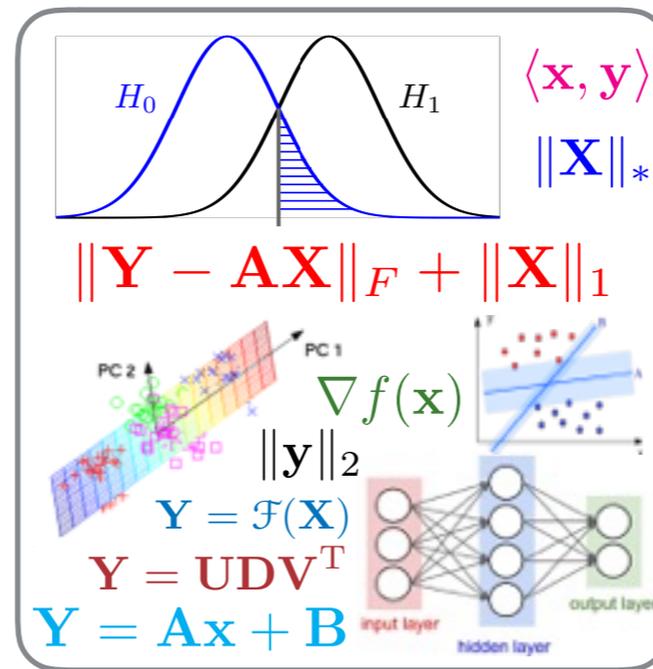


Thank you!

pimentel@gsu.edu



Statistics
Probability
Vector Spaces
Optimization
Analysis
Algebra
Math



Parallelization
Storage
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Hardware
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