Deep Neural Networks

Machine Learning and Pattern Recognition

(Largely based on slides from Luis Serrano & Fei-Fei Li & Andrej Karpathy & Justin Johnson & Serena Yeung)

Prof. Sandra Avila
Institute of Computing (IC/Unicamp)

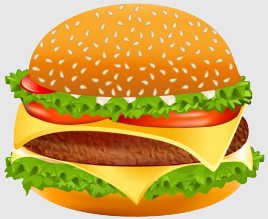
MC886/MO444, October 16, 2018

Perfect Roommate

Luis Serrano: https://youtu.be/UNmqTiOnRfg

Perfect Roommate

Pasta



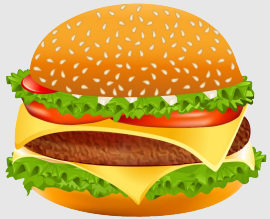
Burger

Salad

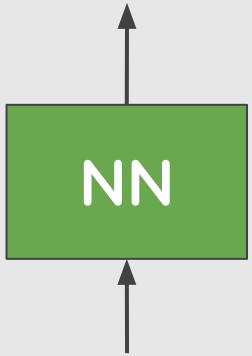
Weather

Weather

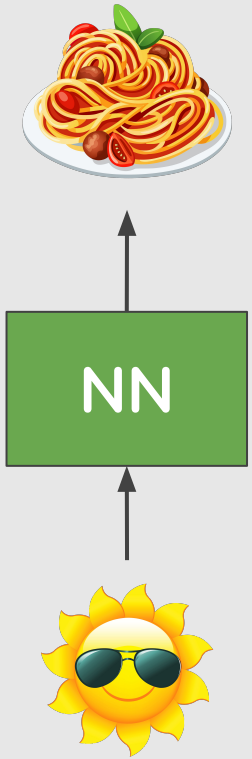
Weather



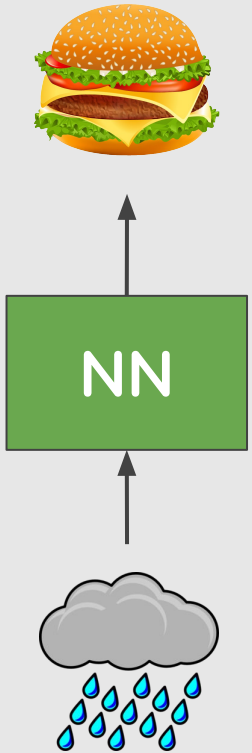
Neural Network



Neural Network

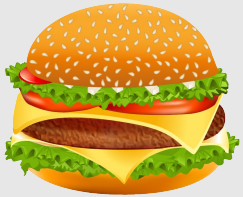


Neural Network



Neural Network

$$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$



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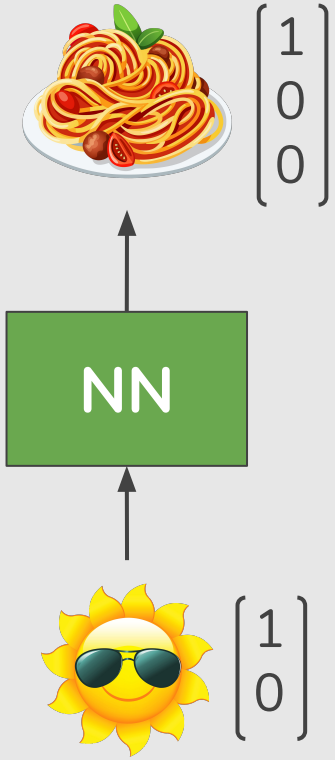
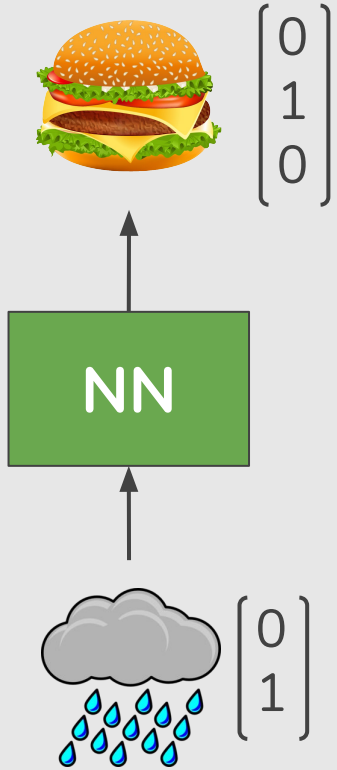
Neural Network



Neural Network



Neural Network

$$\begin{bmatrix} 1 \\ 0 \end{bmatrix}$$ 

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Neural Network

$$\begin{bmatrix} 1 \\ 0 \end{bmatrix}$$ 

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Neural Network

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Neural Network

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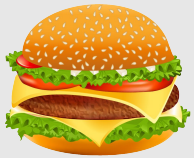
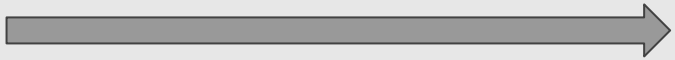
$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$  $= \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$ 

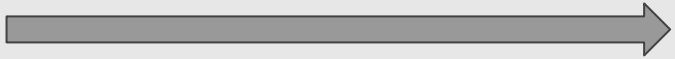
Neural Network

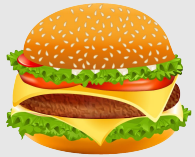
$\begin{bmatrix} 1 \\ 0 \end{bmatrix}$ 



$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$ 

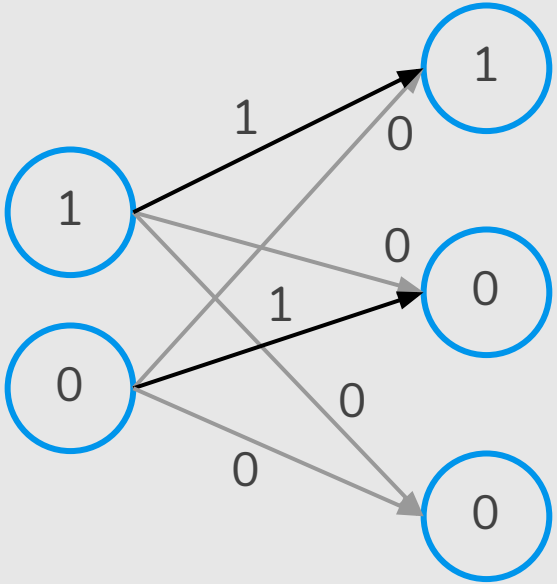
$\begin{bmatrix} 0 \\ 1 \end{bmatrix}$ 



$\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$ 

Neural Network

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$



$$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

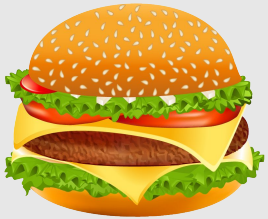
Perfect Roommate

Perfect Roommate

Pasta

Perfect Roommate

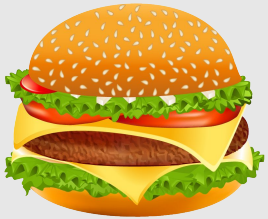
Pasta



Burger

Perfect Roommate

Pasta

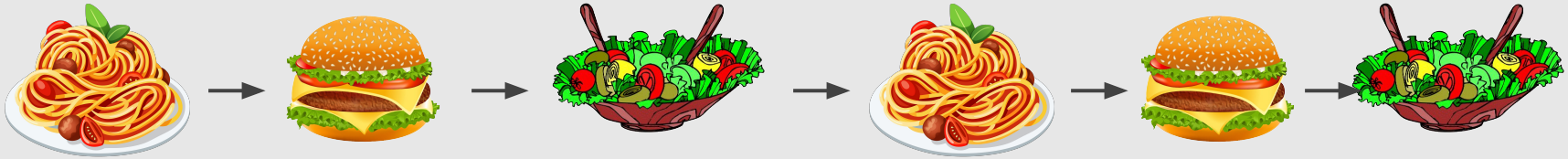


Burger

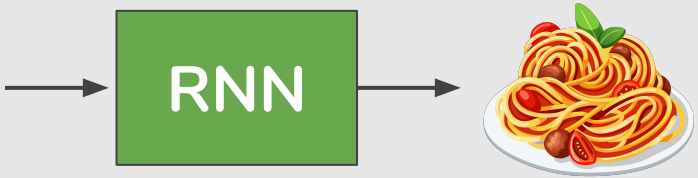
Salad

Cooking Schedule

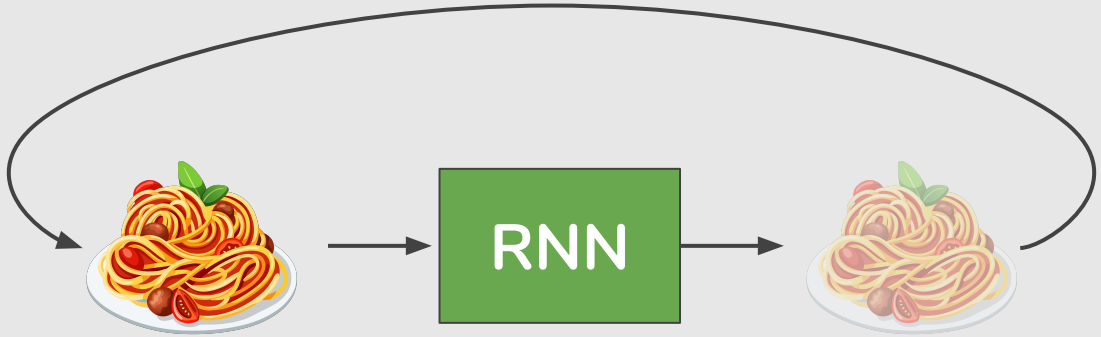
Monday Tuesday Wednesday Thursday Friday Saturday



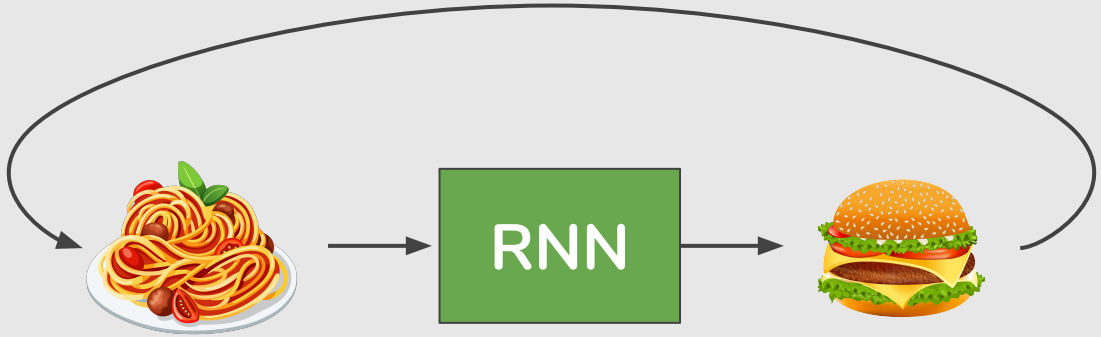
Recurrent Neural Network



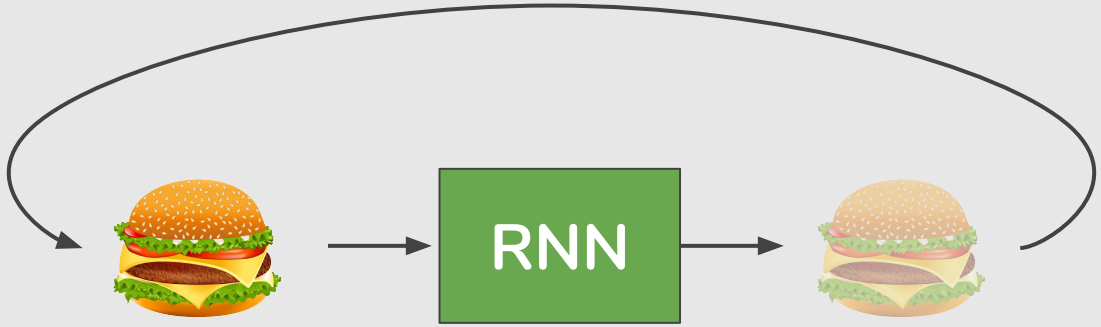
Recurrent Neural Network



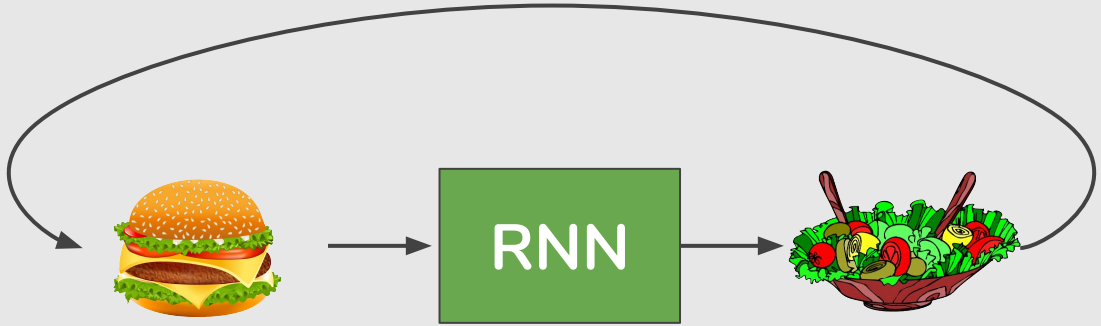
Recurrent Neural Network



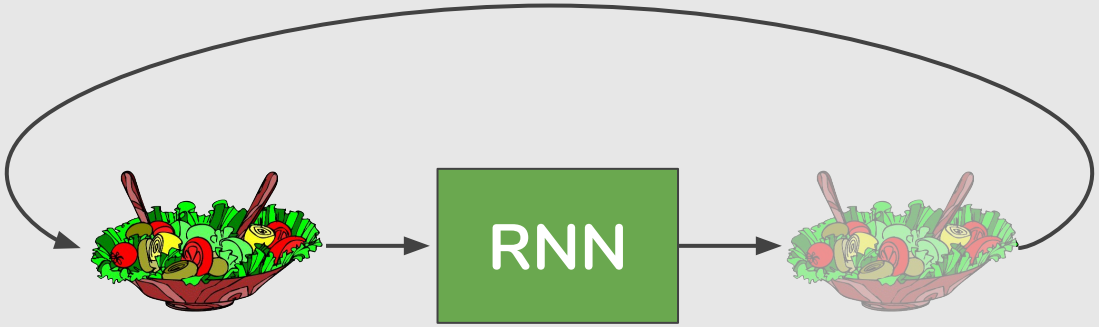
Recurrent Neural Network



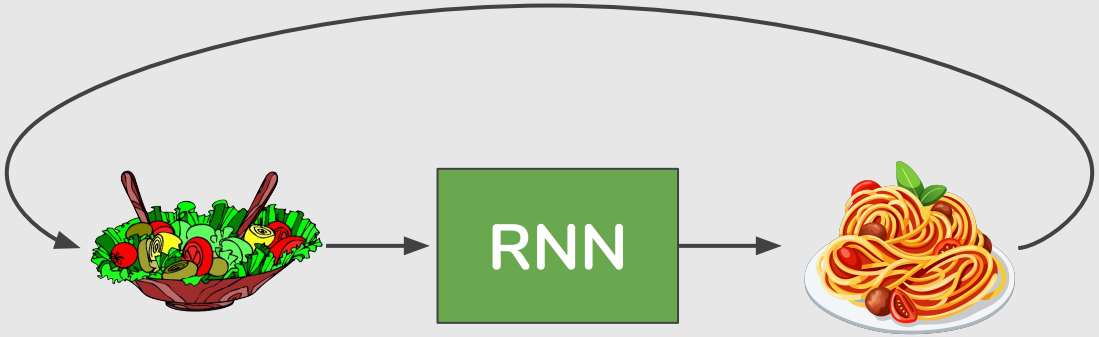
Recurrent Neural Network



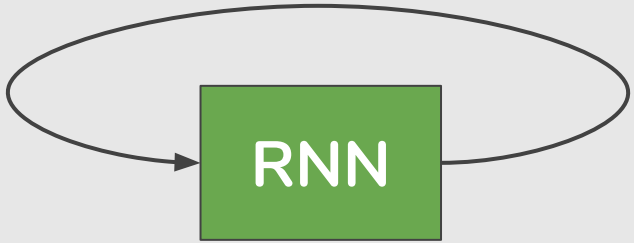
Recurrent Neural Network



Recurrent Neural Network

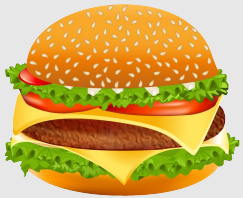


Recurrent Neural Network



Recurrent Neural Network

$$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$



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Recurrent Neural Network

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Recurrent Neural Network

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Recurrent Neural Network

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$$\begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$  $= \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$ 

Recurrent Neural Network

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$$= \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$ 

Recurrent Neural Network

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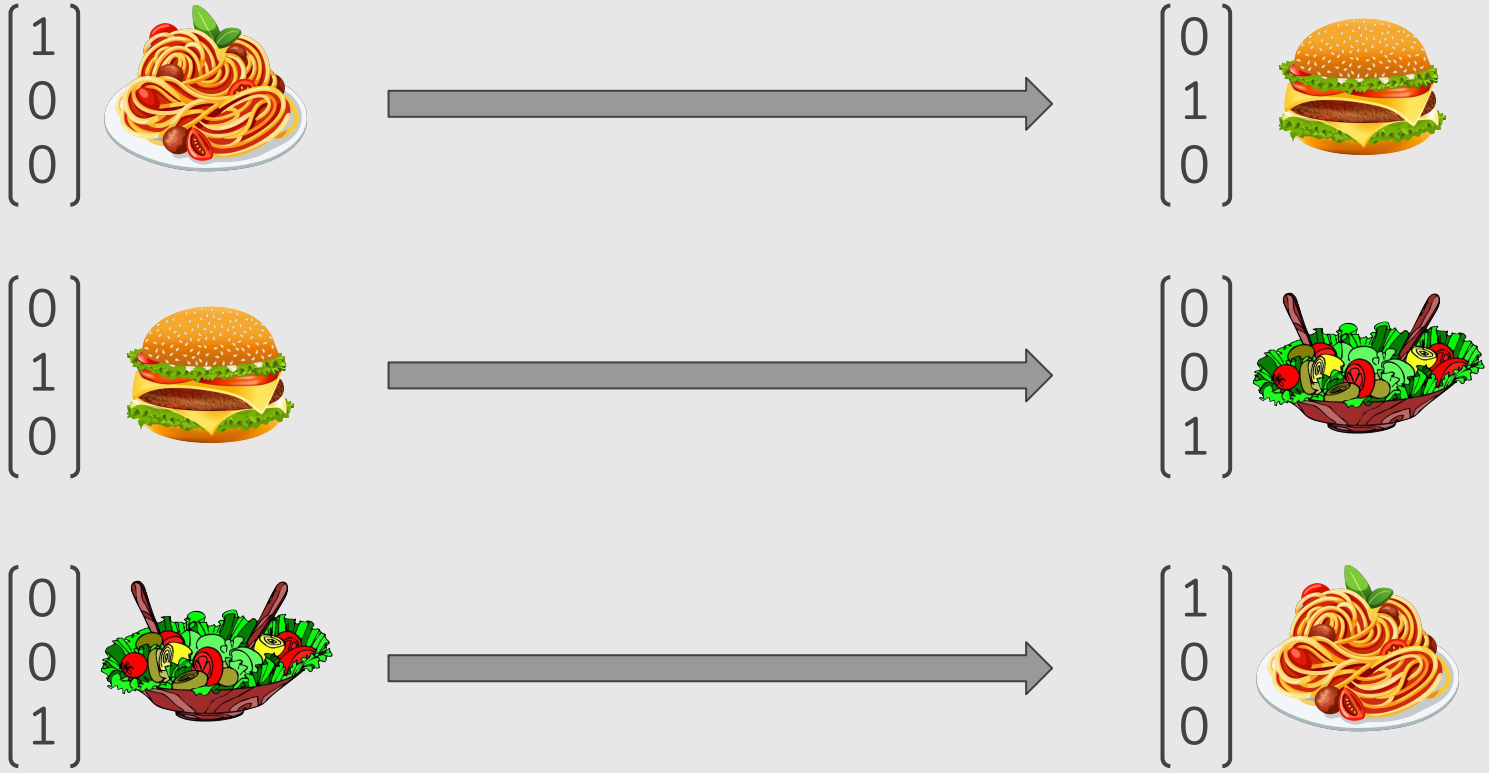
$$\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$ 

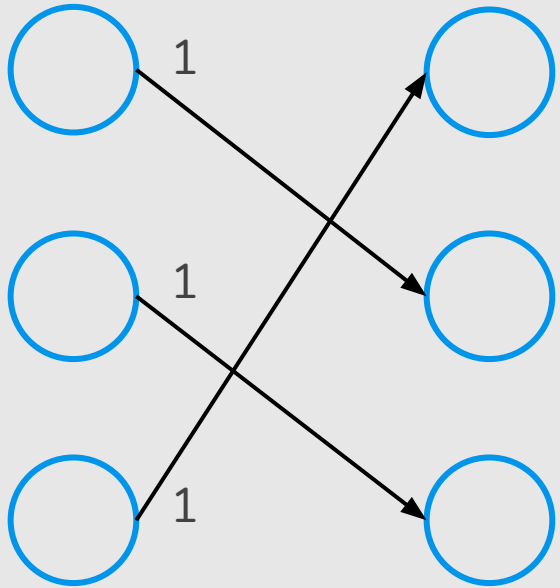
$$\begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$  $= \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$ 

Recurrent Neural Network



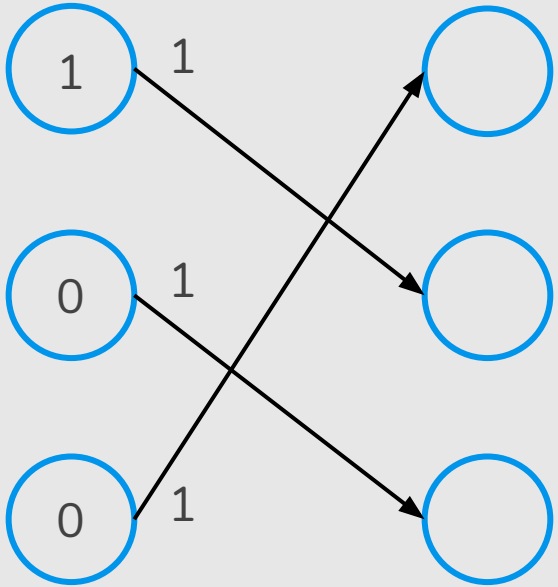
Simple (Recurrent) Neural Network

$$\begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$



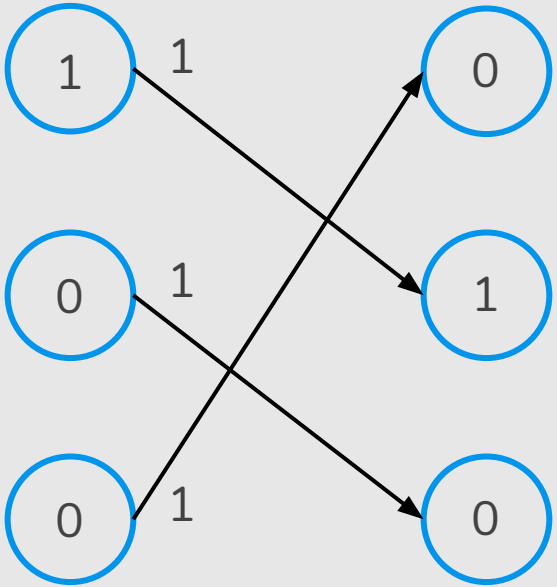
Simple (Recurrent) Neural Network

$$\begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$



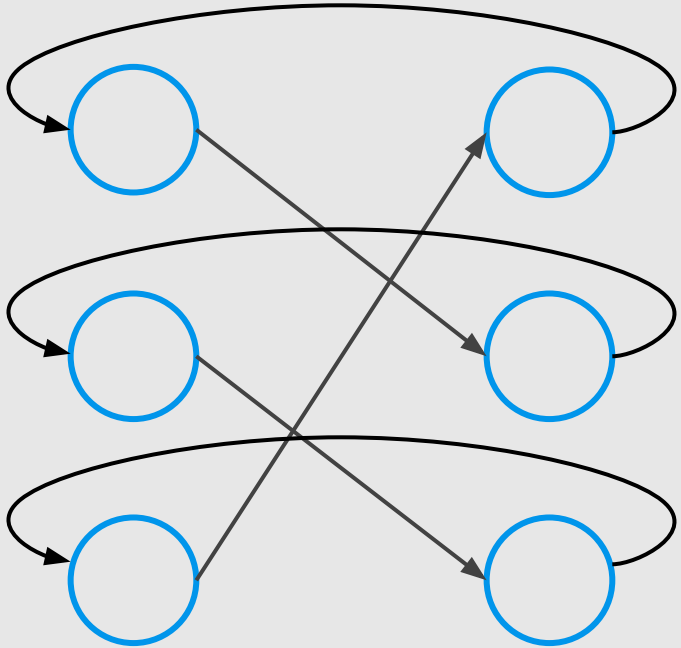
Simple (Recurrent) Neural Network

$$\begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$



$$\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

Simple (Recurrent) Neural Network



Weather

Weather

Sunny
Same as yesterday

Rain
Next dish

Cooking Schedule

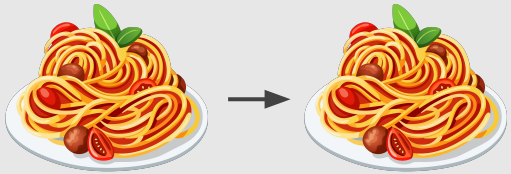
Monday Tuesday Wednesday Thursday Friday Saturday

Cooking Schedule

Monday Tuesday Wednesday Thursday Friday Saturday

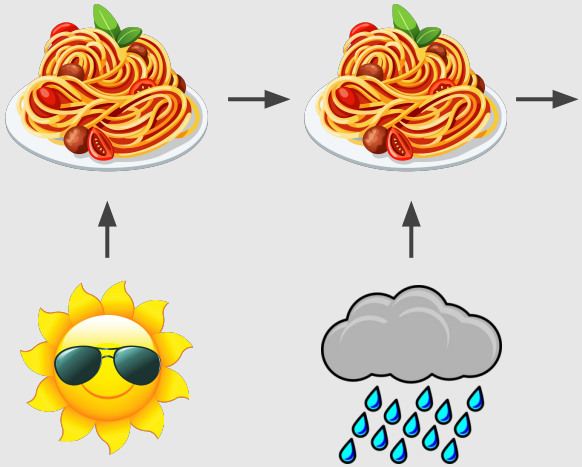
Cooking Schedule

Monday Tuesday Wednesday Thursday Friday Saturday



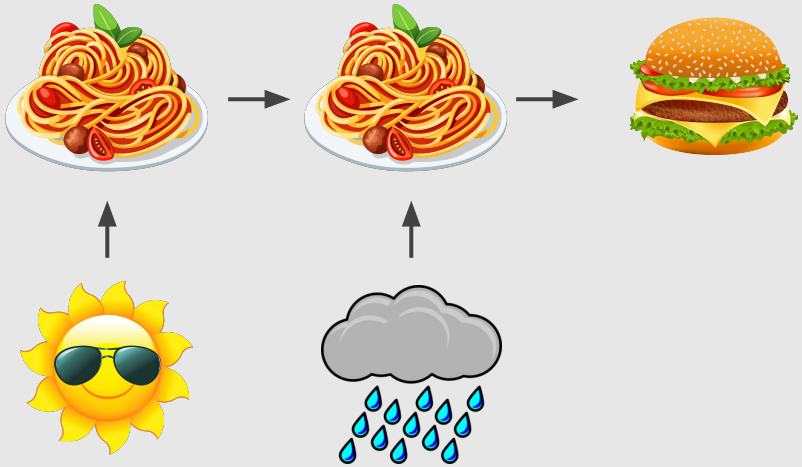
Cooking Schedule

Monday Tuesday Wednesday Thursday Friday Saturday



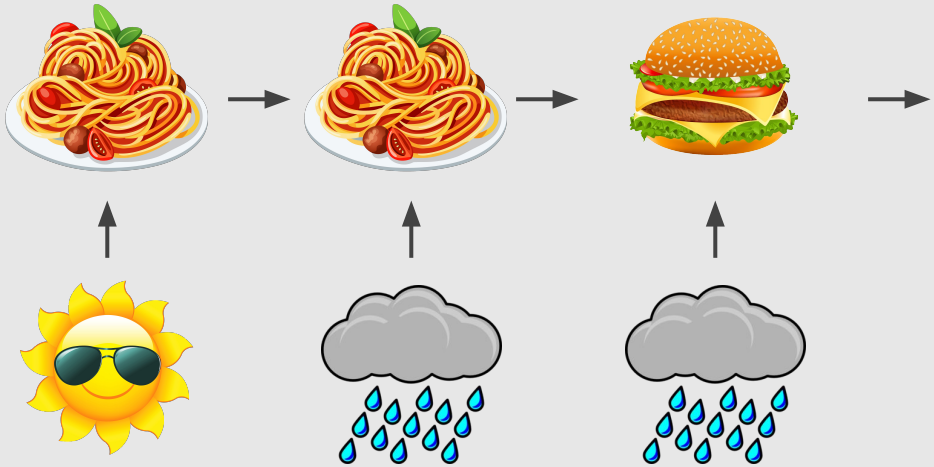
Cooking Schedule

Monday Tuesday Wednesday Thursday Friday Saturday



Cooking Schedule

Monday Tuesday Wednesday Thursday Friday Saturday



Cooking Schedule

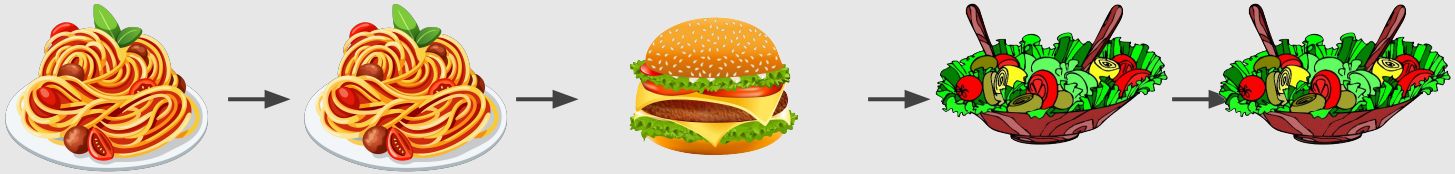
Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					
					

Cooking Schedule

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					
					

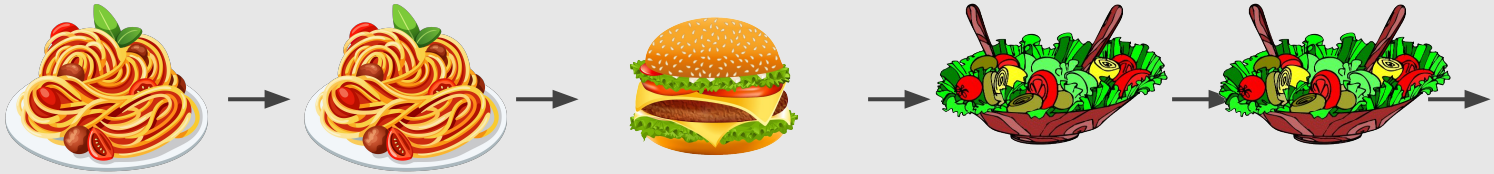
Cooking Schedule

Monday Tuesday Wednesday Thursday Friday Saturday



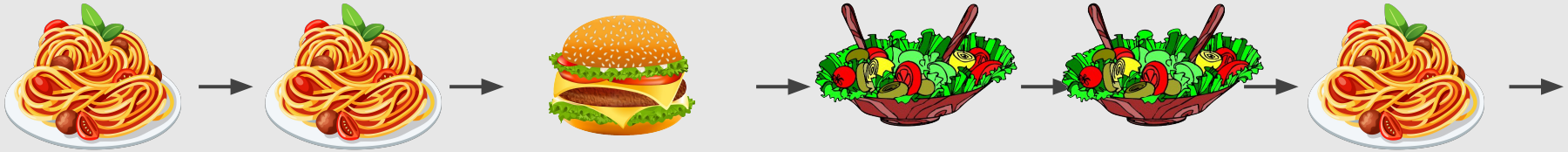
Cooking Schedule

Monday Tuesday Wednesday Thursday Friday Saturday

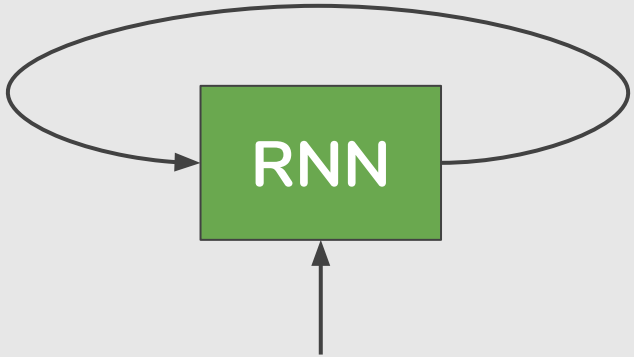


Cooking Schedule

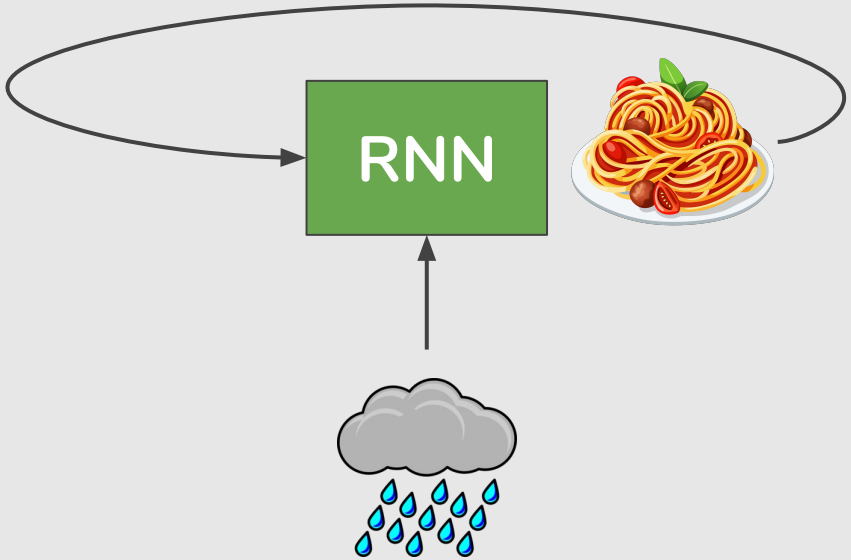
Monday Tuesday Wednesday Thursday Friday Saturday



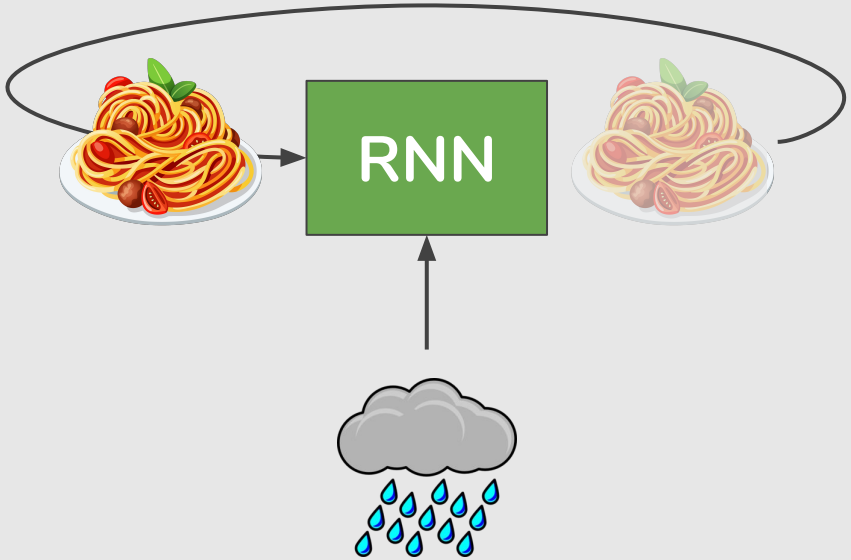
Recurrent Neural Network



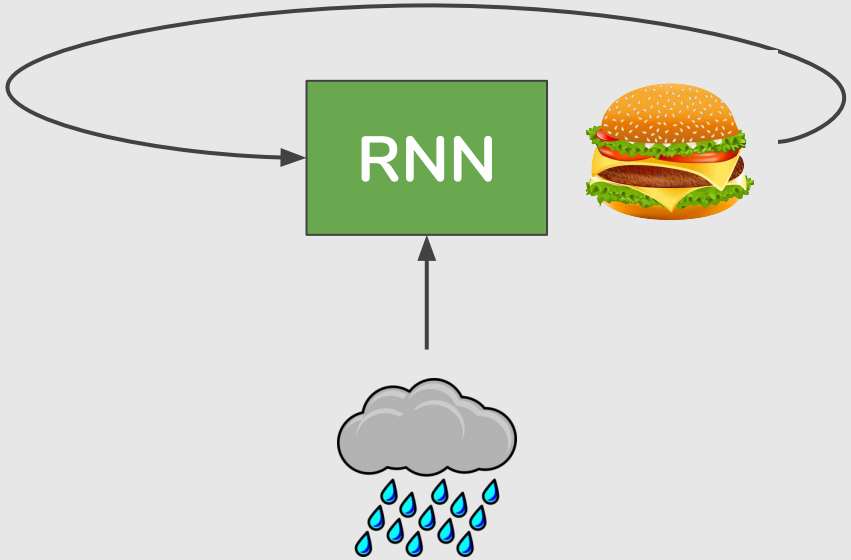
Recurrent Neural Network



Recurrent Neural Network

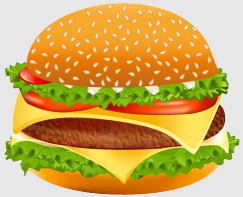


Recurrent Neural Network



Recurrent Neural Network

$$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$



$$\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

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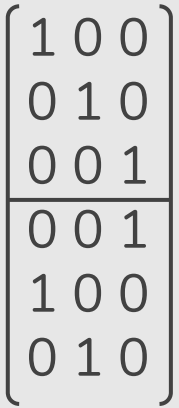
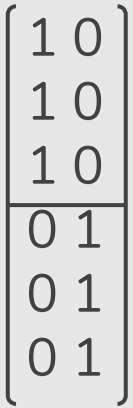
Recurrent Neural Network



Food



Weather

Recurrent Neural Network (Food)

$$\begin{bmatrix}1\\0\\0\end{bmatrix}$$

$$\begin{bmatrix}0\\1\\0\end{bmatrix}$$

$$\begin{bmatrix}0\\0\\1\end{bmatrix}$$

$$\left[\begin{array}{ccc}1&0&0\\0&1&0\\0&0&1\end{array}\right]$$

$$\left[\begin{array}{ccc}0&0&1\\1&0&0\\0&1&0\end{array}\right]$$

Food

Recurrent Neural Network (Food)

$$\begin{bmatrix}1\\0\\0\end{bmatrix}$$ 

$$\begin{bmatrix}0\\1\\0\end{bmatrix}$$ 

$$\begin{bmatrix}0\\0\\1\end{bmatrix}$$ 

$$\left[\begin{array}{ccc}1&0&0\\0&1&0\\0&0&1\\\hline 0&0&1\\1&0&0\\0&1&0\end{array}\right]$$

Food

$$\begin{bmatrix}1\\0\\0\end{bmatrix}$$  =

Recurrent Neural Network (Food)

$$\begin{bmatrix}1\\0\\0\end{bmatrix}$$ 

$$\begin{bmatrix}0\\1\\0\end{bmatrix}$$ 

$$\begin{bmatrix}0\\0\\1\end{bmatrix}$$ 

$$\left[\begin{array}{ccc}1&0&0\\0&1&0\\0&0&1\\\hline 0&0&1\\1&0&0\\0&1&0\end{array}\right]$$

Food

$$\begin{bmatrix}1\\0\\0\end{bmatrix}$$ 

$$=$$

$$\left[\begin{array}{c}1\\0\\0\\\hline 0\\1\\0\end{array}\right]$$

same

next day

Recurrent Neural Network (Food)

$$\begin{bmatrix}1\\0\\0\end{bmatrix}$$ 

$$\begin{bmatrix}0\\1\\0\end{bmatrix}$$ 

$$\begin{bmatrix}0\\0\\1\end{bmatrix}$$ 

$$\left[\begin{array}{ccc}1&0&0\\0&1&0\\0&0&1\\\hline 0&0&1\\1&0&0\\0&1&0\end{array}\right]$$

Food

$$\begin{bmatrix}0\\1\\0\end{bmatrix}$$ 

$$=$$

$$\left[\begin{array}{c}0\\1\\0\\\hline 0\\0\\1\end{array}\right]$$

same

next day

Recurrent Neural Network (Weather)

$\begin{bmatrix} 1 \\ 0 \end{bmatrix}$ 

$\begin{bmatrix} 0 \\ 1 \end{bmatrix}$ 

$$\left[\begin{array}{cc} 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ \hline 0 & 1 \\ 0 & 1 \\ 0 & 1 \end{array}\right]$$

Weather

Recurrent Neural Network (Weather)

$$\begin{bmatrix} 1 \\ 0 \end{bmatrix}$$ 

$$\begin{bmatrix} 0 \\ 1 \end{bmatrix}$$ 

$$\left[\begin{array}{cc} 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ \hline 0 & 1 \\ 0 & 1 \\ 0 & 1 \end{array}\right] \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$  =

Weather

Recurrent Neural Network (Weather)

$$\begin{bmatrix}1\\0\end{bmatrix}$$ 

$$\begin{bmatrix}0\\1\end{bmatrix}$$ 

$$\left[\begin{array}{c|c}\begin{matrix}1&0\\1&0\\1&0\end{matrix} & \begin{matrix}0&1\\0&1\\0&1\end{matrix}\end{array}\right] \begin{bmatrix}1\\0\end{bmatrix}$$ 

Weather

$$=$$

$$\left[\begin{array}{c|c}\begin{matrix}1\\1\\1\end{matrix} & \begin{matrix}0\\0\\0\end{matrix}\end{array}\right]$$ 

same

next day

Recurrent Neural Network (Weather)

$$\begin{bmatrix}1\\0\end{bmatrix}$$ 

$$\begin{bmatrix}0\\1\end{bmatrix}$$ 

$$\left[\begin{array}{cc}1&0\\1&0\\1&0\\\hline 0&1\\0&1\\0&1\end{array}\right]$$

Weather

$$\begin{bmatrix}0\\1\end{bmatrix}$$ 

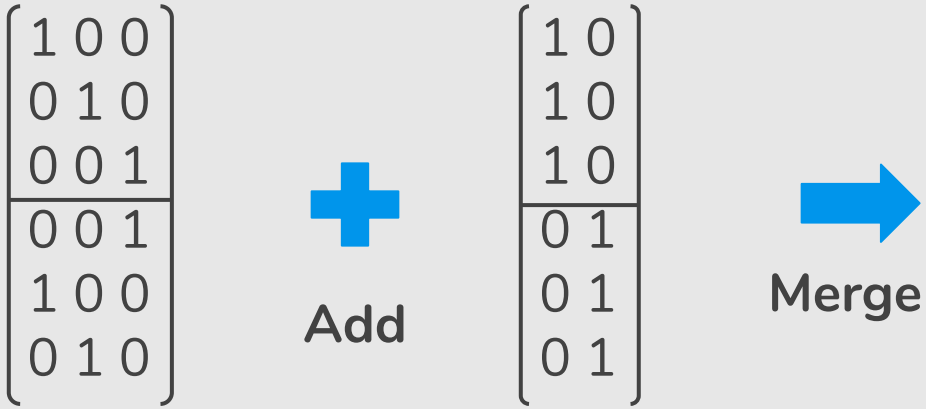
$$=$$

$$\left[\begin{array}{c}0\\0\\0\\\hline 1\\1\\1\end{array}\right]$$

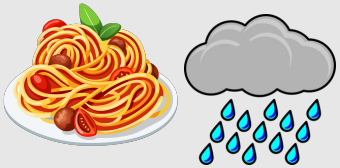
same

next day

Recurrent Neural Network



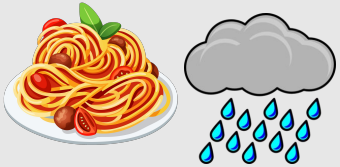
Recurrent Neural Network



(Add)

Recurrent Neural Network

(Add)



$$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

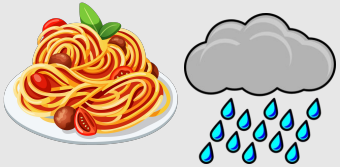
same

$$\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

next day

Recurrent Neural Network

(Add)



$$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$  same

$$\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$  next day

$$+$$

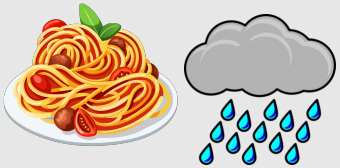
Add

$$\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$  same

$$\begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$  next day

Recurrent Neural Network

(Add)



$$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$  same

$$\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$  next day

$$+$$

Add

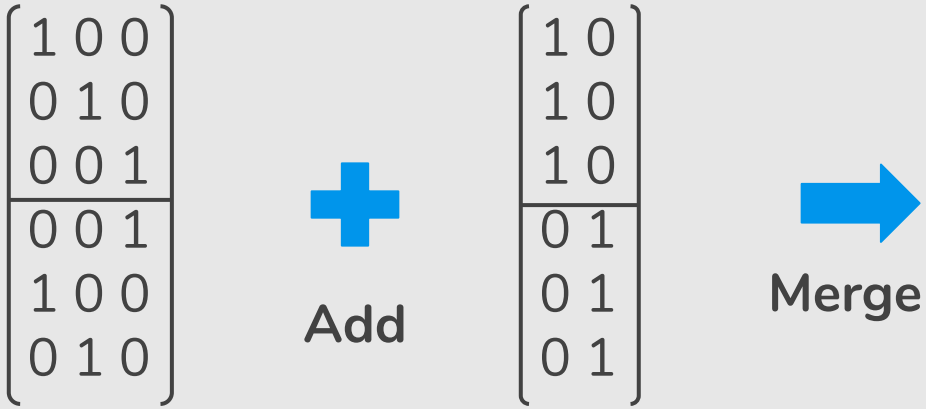
$$\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$  same

$$\begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$  next day

$$=$$

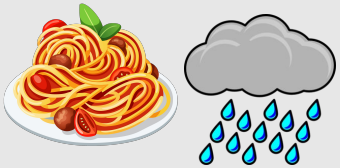
$$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}$$

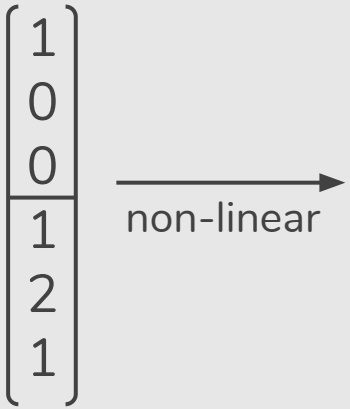
Recurrent Neural Network



Recurrent Neural Network

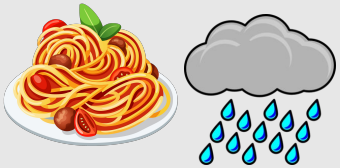
(Merge)

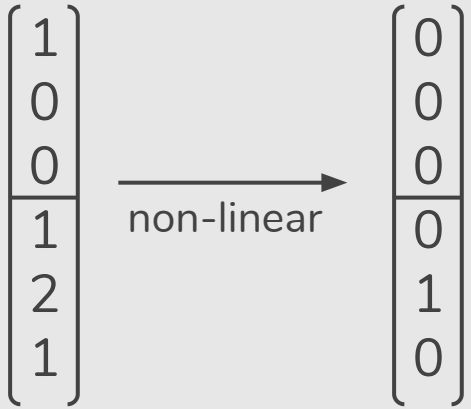




Recurrent Neural Network

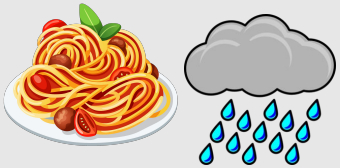
(Merge)

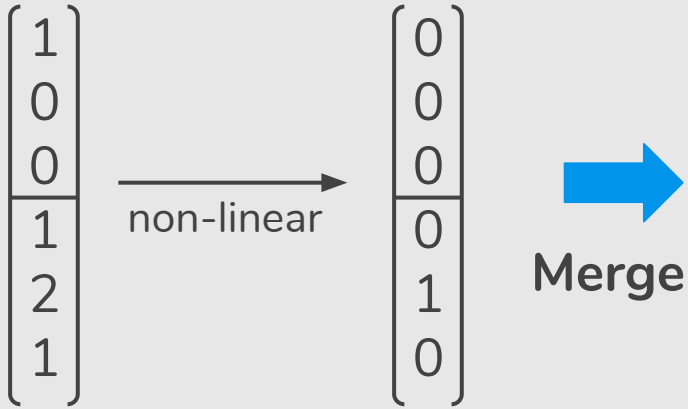




Recurrent Neural Network

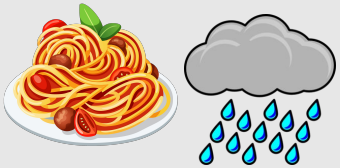
(Merge)





Recurrent Neural Network

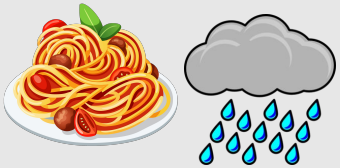
(Merge)



$$\begin{bmatrix} 1 \\ 0 \\ 0 \\ \hline 1 \\ 2 \\ 1 \end{bmatrix} \xrightarrow{\text{non-linear}} \begin{bmatrix} 0 \\ 0 \\ 0 \\ \hline 0 \\ 1 \\ 0 \end{bmatrix} \xrightarrow{\text{Merge}} \begin{bmatrix} 0+0 \\ 0+1 \\ 0+0 \end{bmatrix} =$$

Recurrent Neural Network

(Merge)

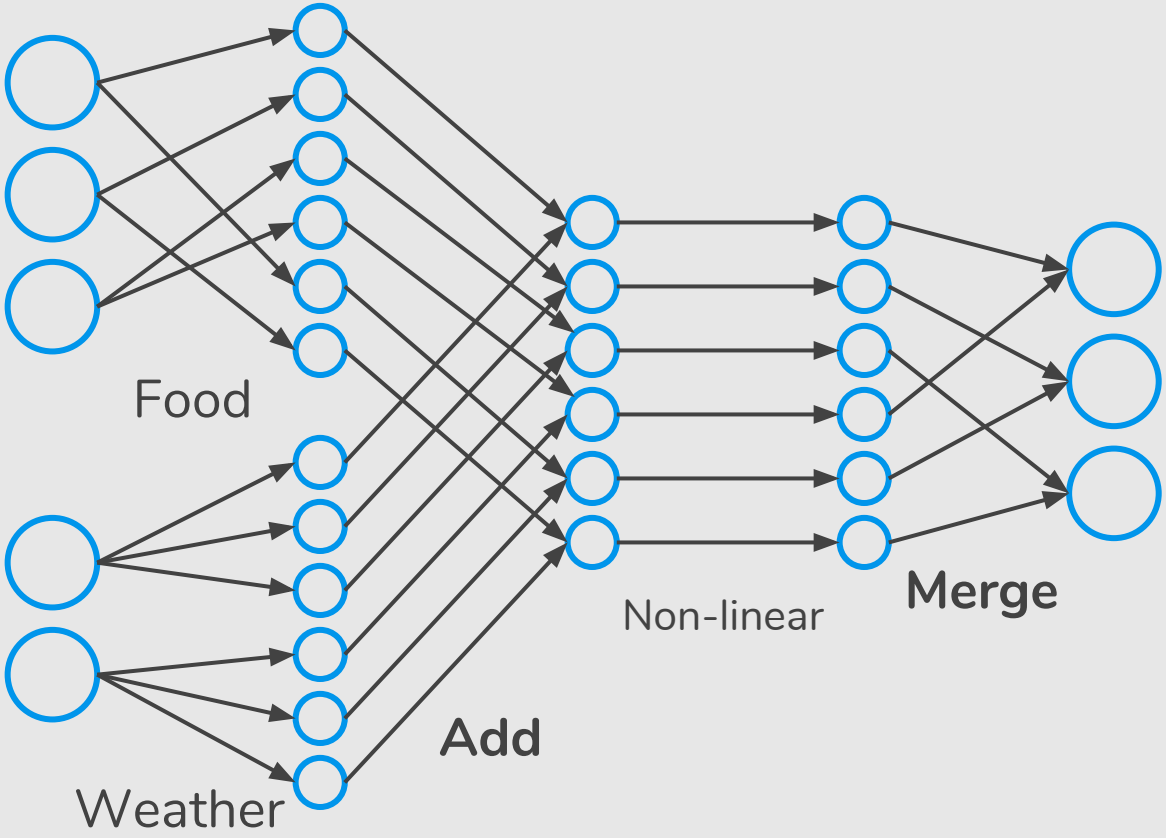


$$\begin{bmatrix} 1 \\ 0 \\ 0 \\ \hline 1 \\ 2 \\ 1 \end{bmatrix} \xrightarrow{\text{non-linear}} \begin{bmatrix} 0 \\ 0 \\ 0 \\ \hline 0 \\ 1 \\ 0 \end{bmatrix}$$

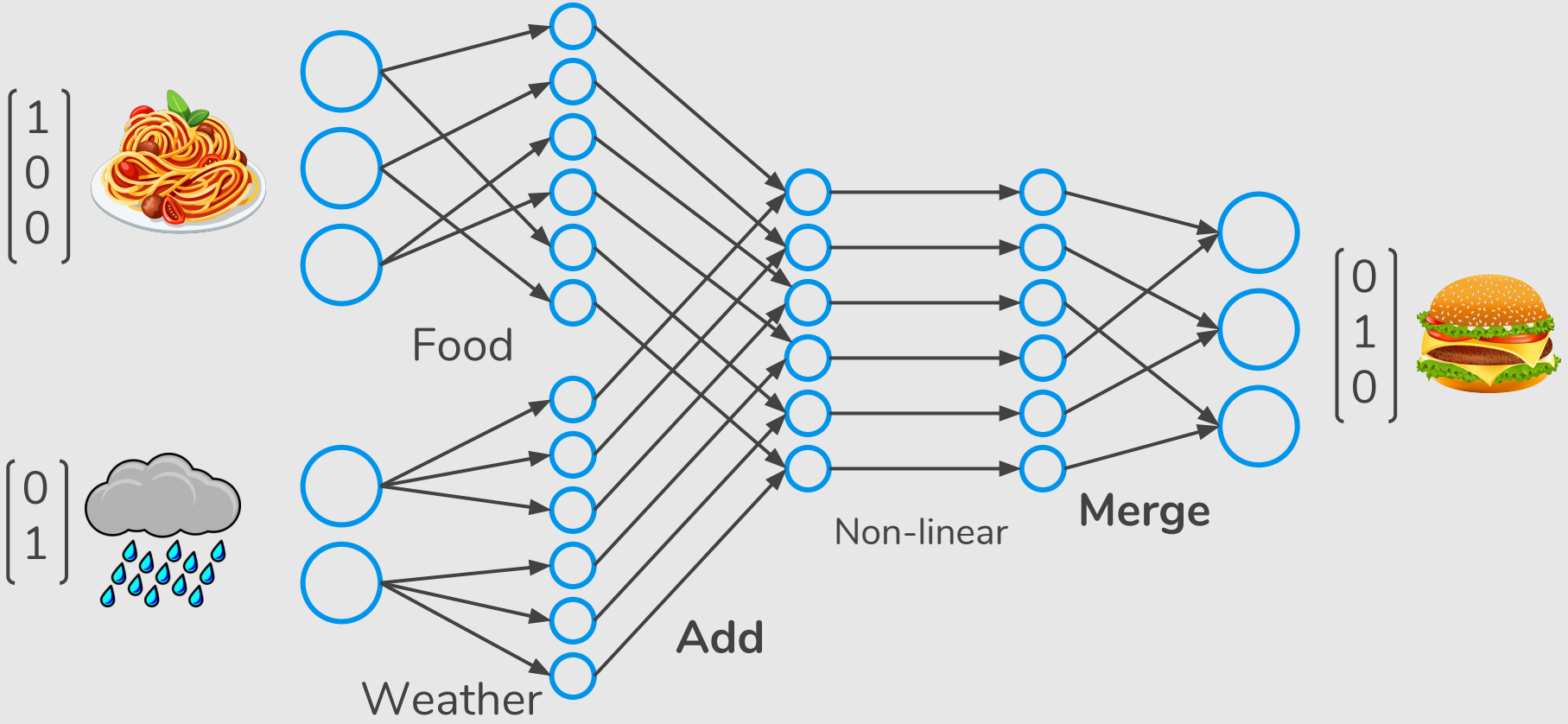
Merge

$$\begin{bmatrix} 0+0 \\ 0+1 \\ 0+0 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

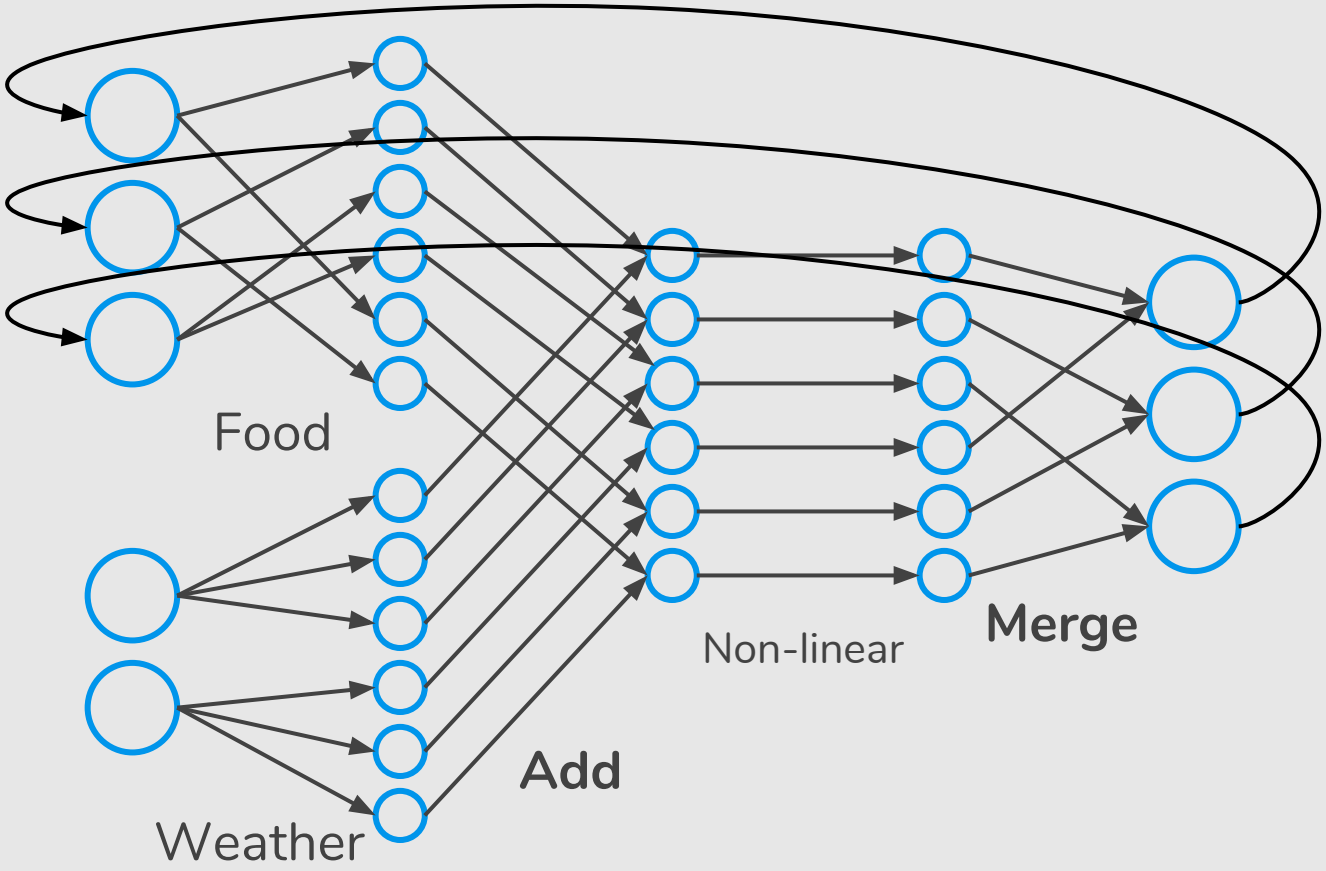
Recurrent Neural Network



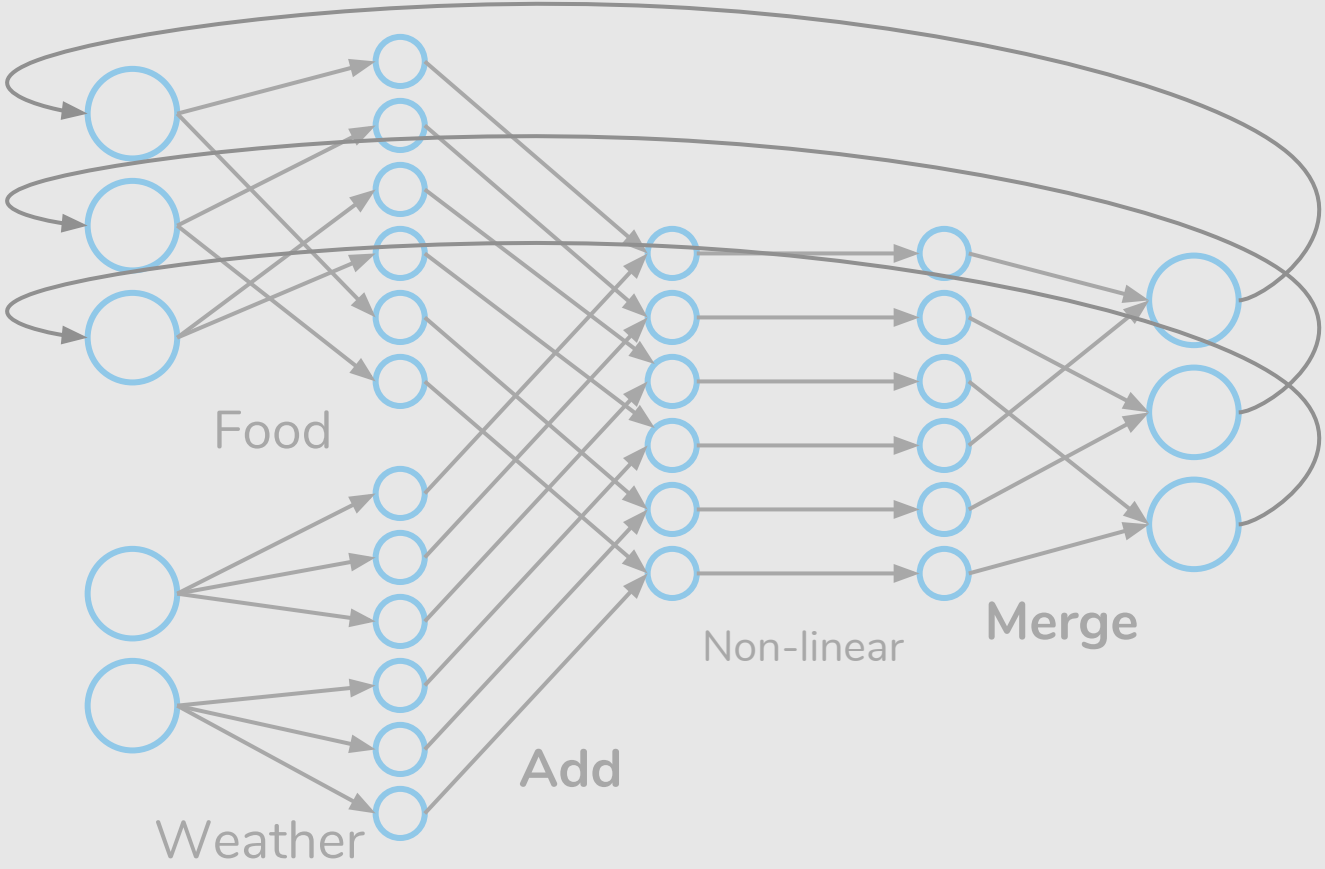
Recurrent Neural Network



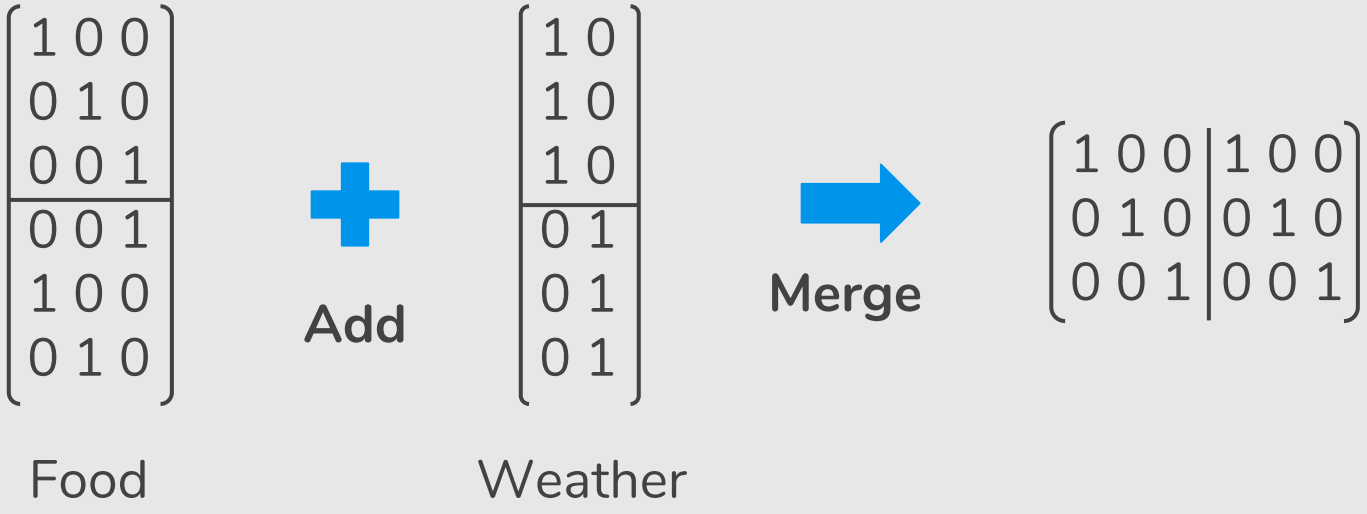
Recurrent Neural Network



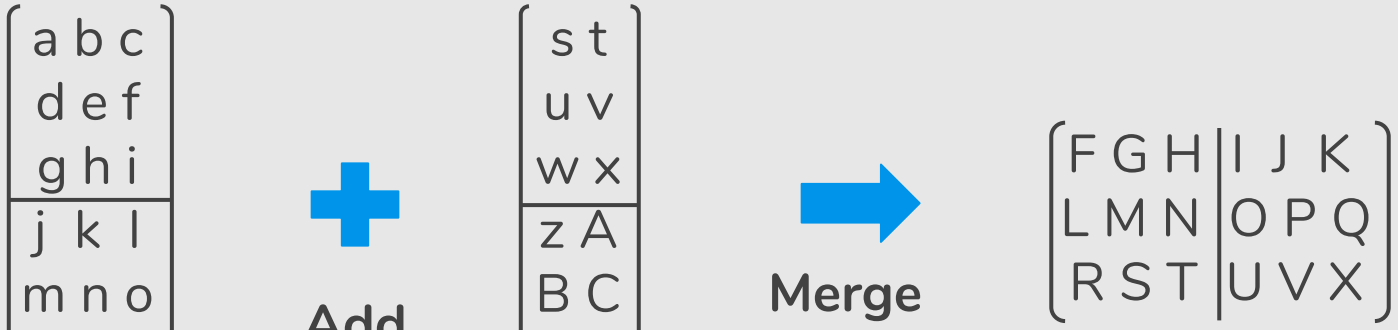
How to train the RNN?



RNN


1 0 0
0 1 0
0 0 1
0 0 1
1 0 0
0 1 0
Food
Add
1 0
1 0
1 0
0 1
0 1
0 1
Weather
Merge
1 0 0 | 1 0 0
0 1 0 | 0 1 0
0 0 1 | 0 0 1

Start with Random Weights



Food

Weather

References

Machine Learning Books

- Deep Learning, http://www.deeplearningbook.org/contents/rnn.html

Machine Learning Courses

- https://www.coursera.org/learn/neural-networks
- “The 3 popular courses on Deep Learning”: https://medium.com/towards-data-science/the-3-popular-courses-for-deeplearning-ai-ac37d4433bd