

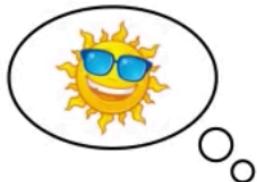
# Hidden Markov Models

Machine Learning

Fall 2018

Kasthuri Kannan



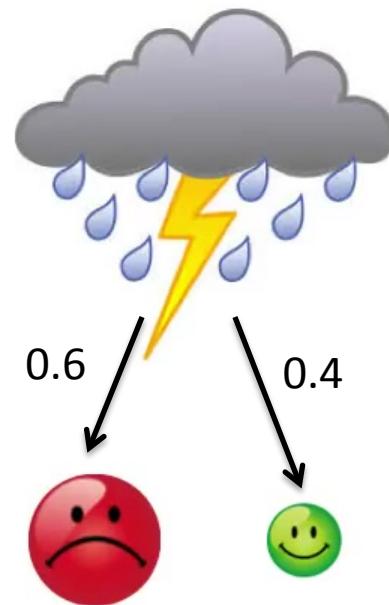
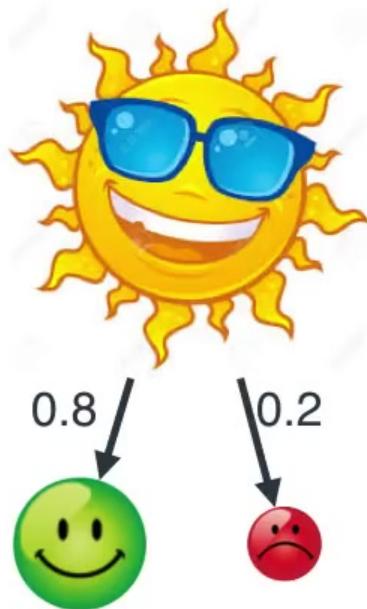


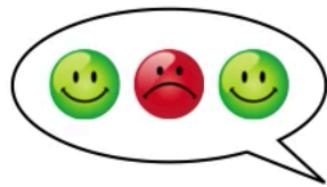
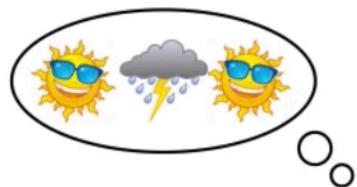


# Weather



# Weather





# Weather

Monday



H

Tuesday



G

Wednesday



H

Thursday



G

Friday



H

Saturday



G

# Weather

Monday



H



S

Tuesday



G



R

Wednesday



H



S

Thursday



G



R

Friday



H



S

Saturday

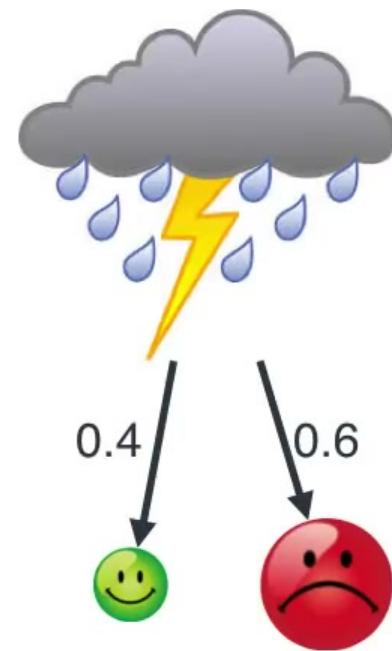
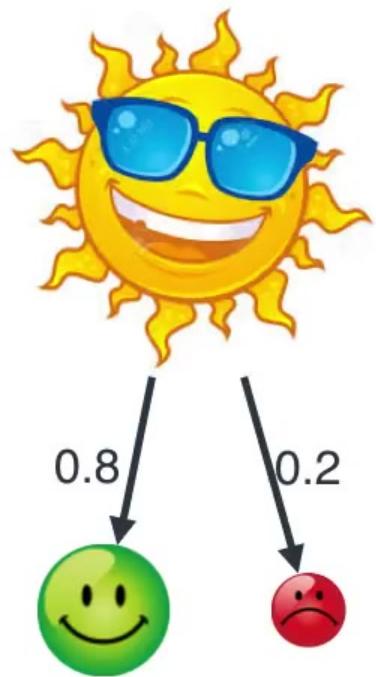


G

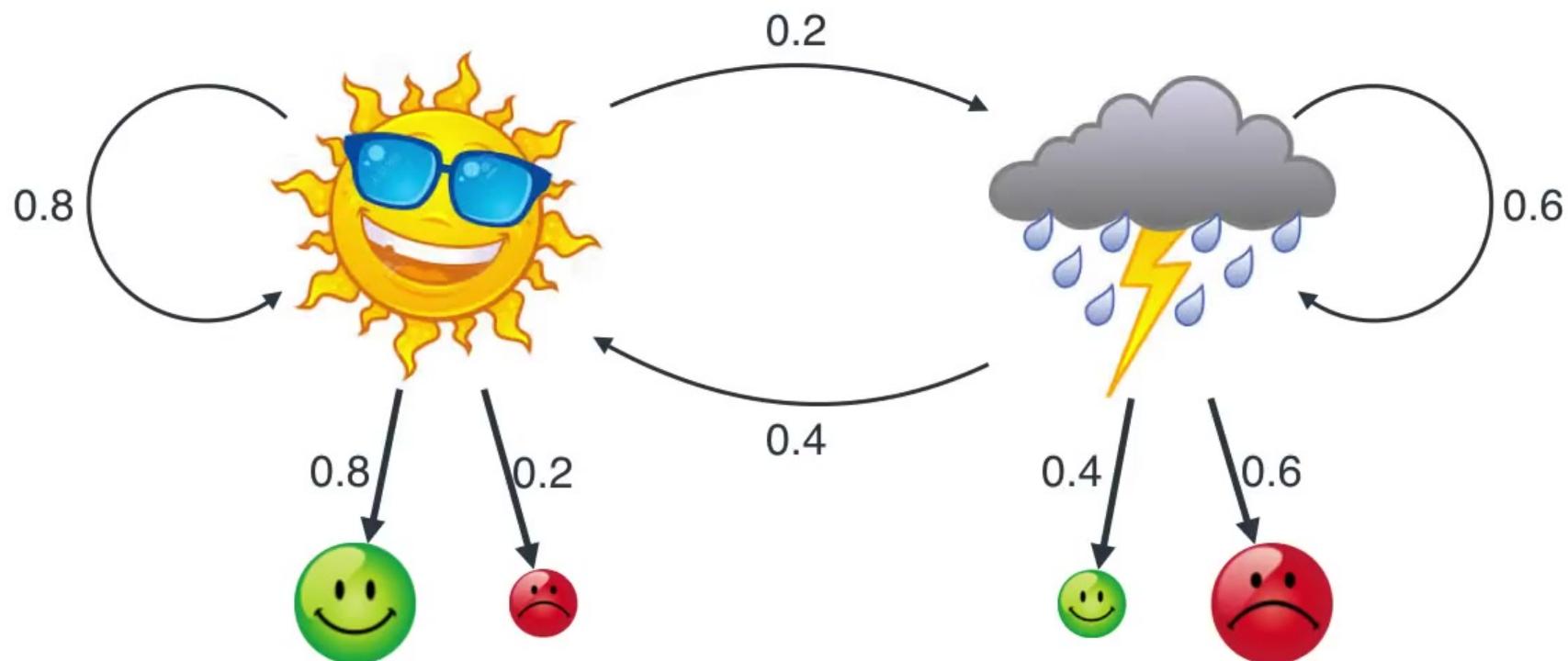


R

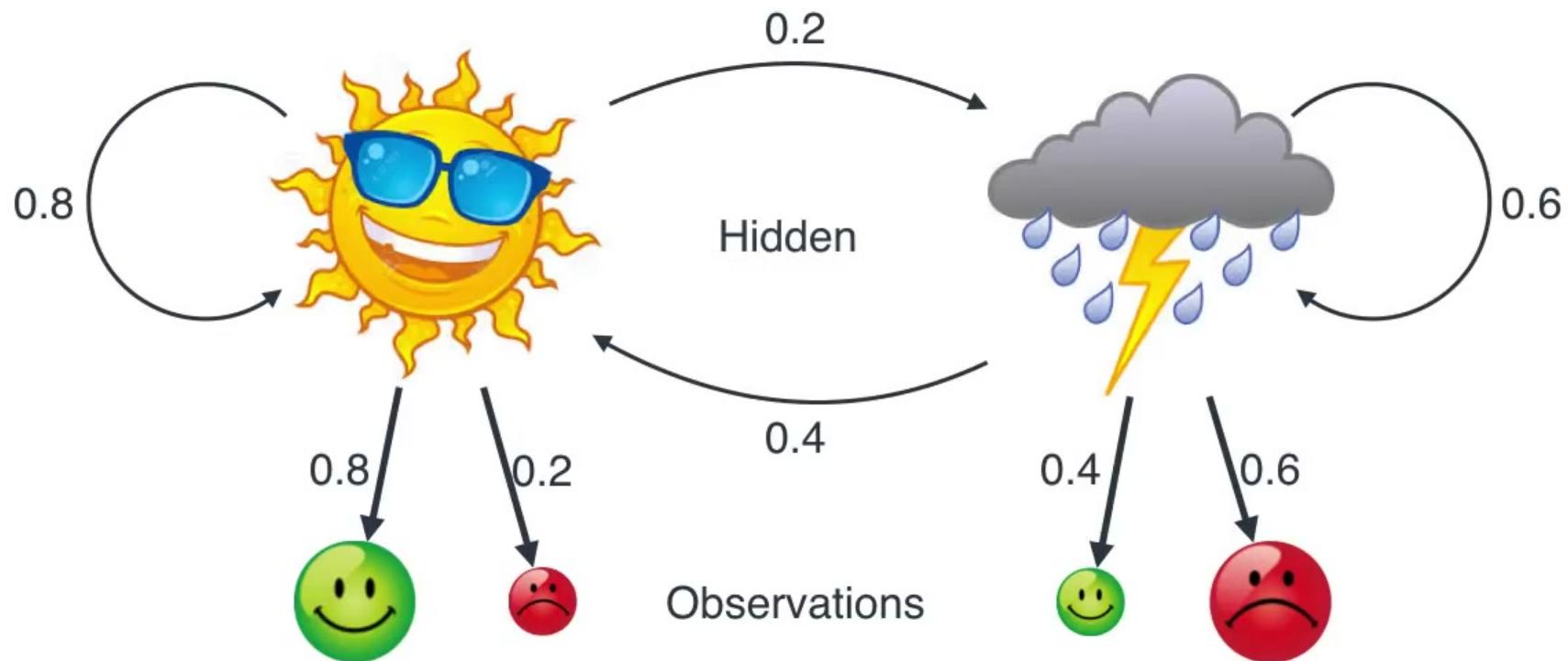
- Doesn't reflect the true scenario
  - Sunny days are likely to follow sunny days and vice versa
- Also doesn't consider probabilities



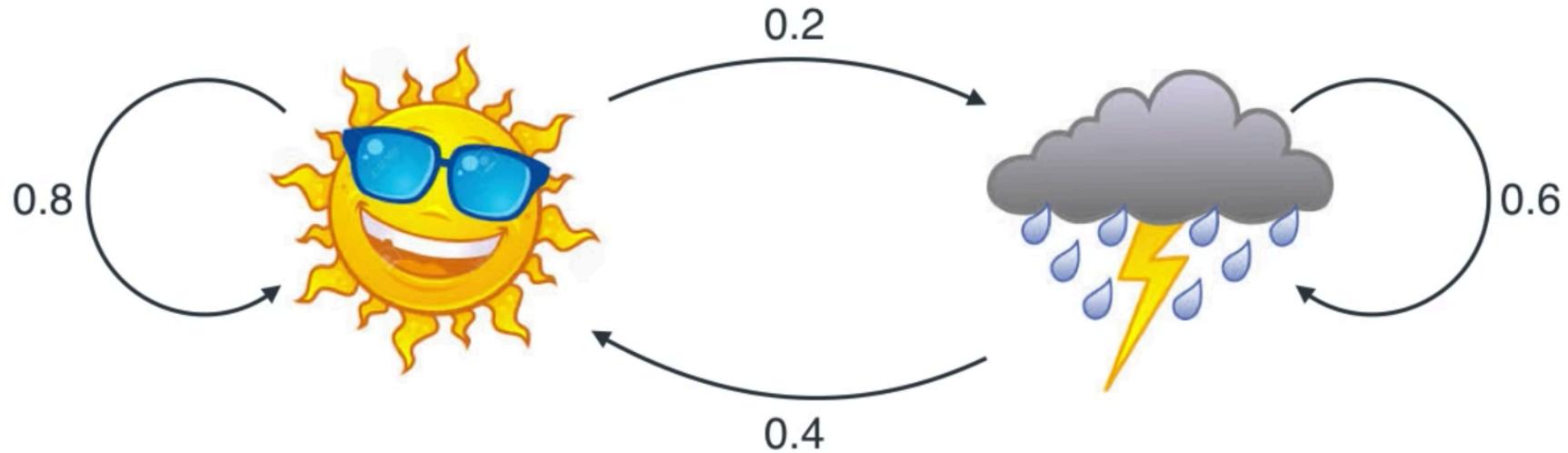
Hidden Markov Model



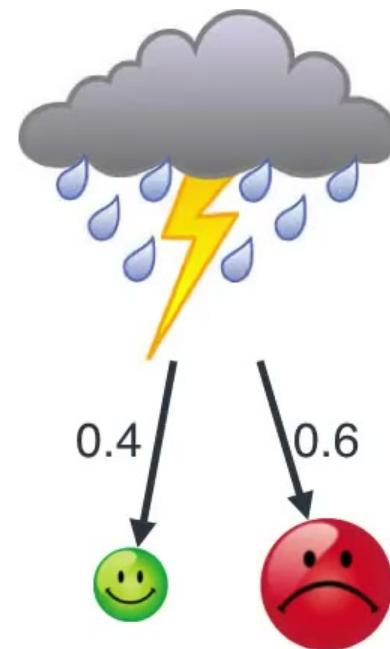
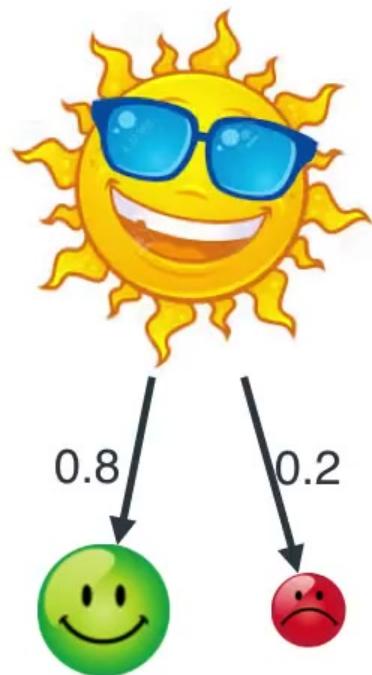
# Hidden Markov Model



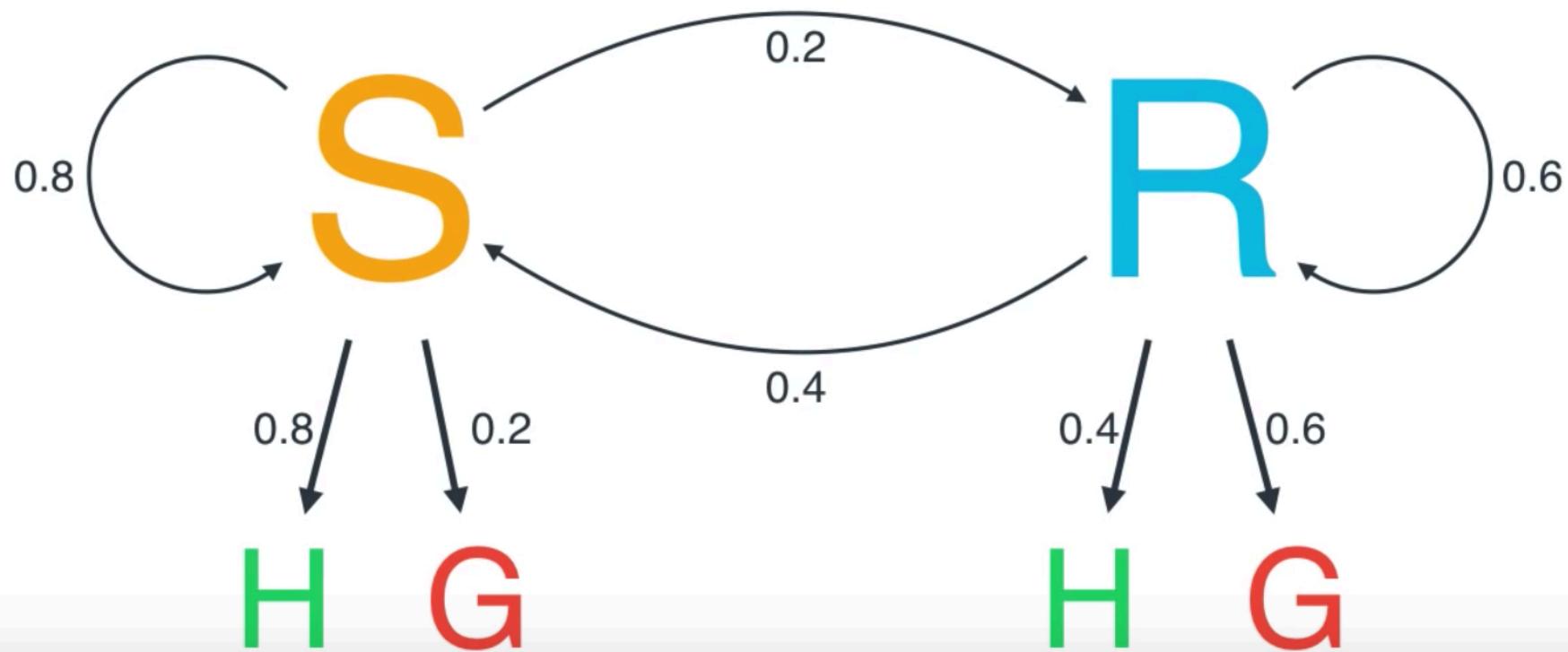
# Transition Probabilities



# Emission Probabilities



# Hidden Markov Model



# Questions

1. How did we find these probabilities?
2. What's the probability that a random day is Sunny or Rainy?
3. If Bob is Happy today, what's the probability that it's Sunny or Rainy?
4. If for three days Bob is Happy, Grumpy, Happy, what was the weather?

# How did we find the probabilities?

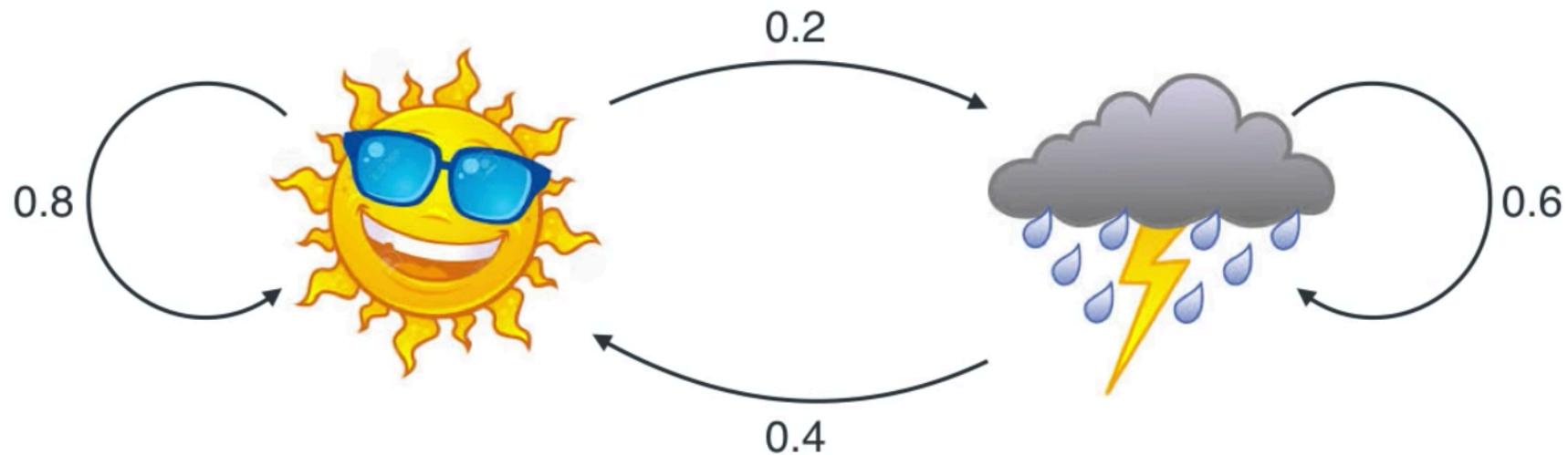


→      8      0.8

→      2      0.2

→      2      0.4

→      3      0.6



# How did we find the probabilities?



→ 8 0.8

→ 2 0.2

→ 2 0.4

→ 3 0.6

# Questions

1. ~~How did we find these probabilities?~~
2. **What's the probability that a random day is Sunny or Rainy?**
3. If Bob is Happy today, what's the probability that it's Sunny or Rainy?
4. If for three days Bob is Happy, Grumpy, Happy, what was the weather?



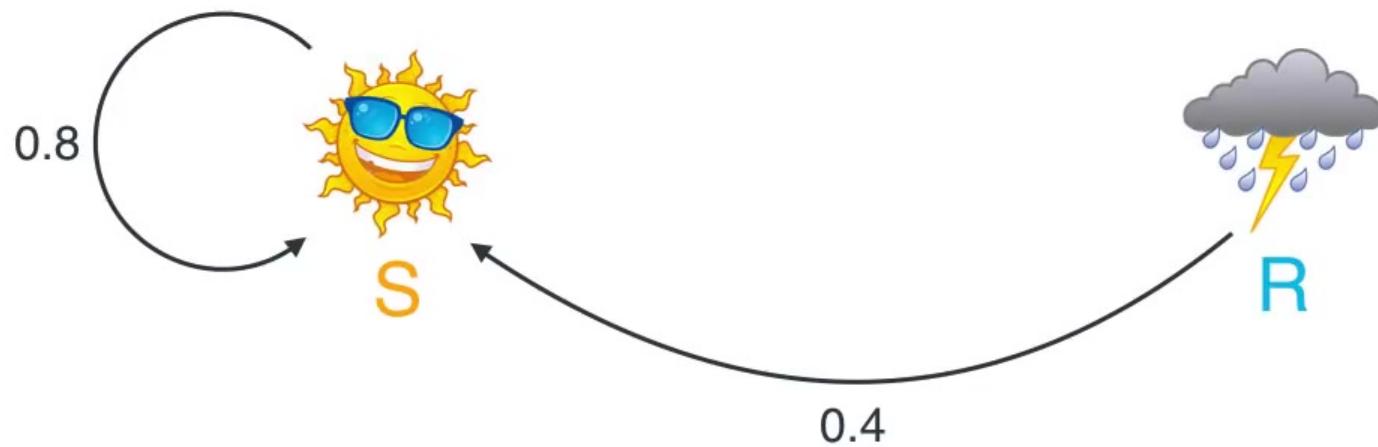
# How did we find the probabilities?



10

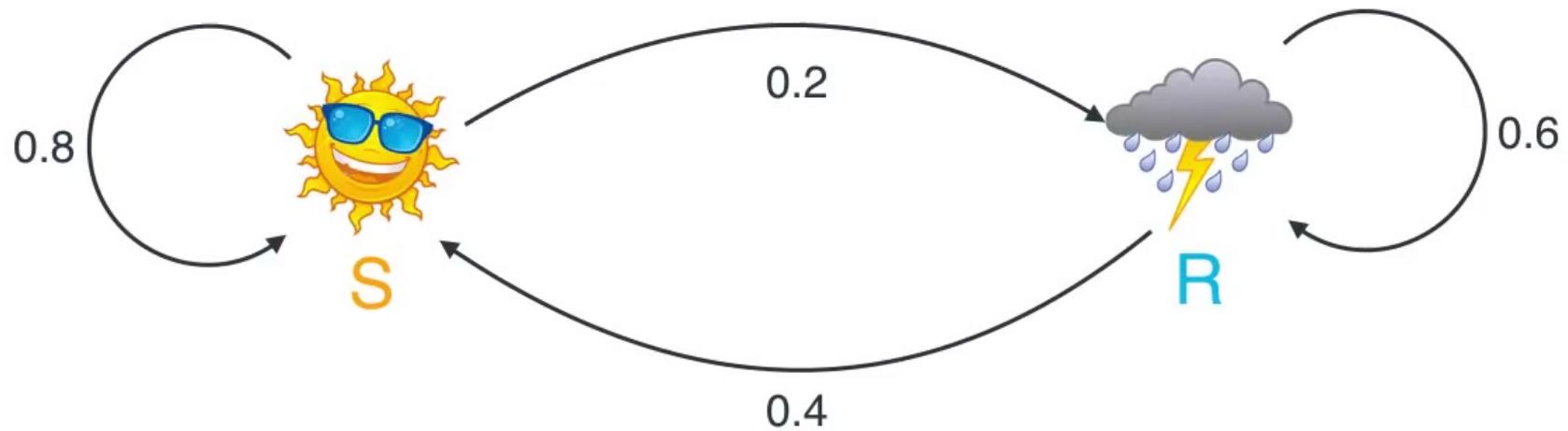
5

# Sunny or Rainy?



$$S = 0.8S + 0.4R$$

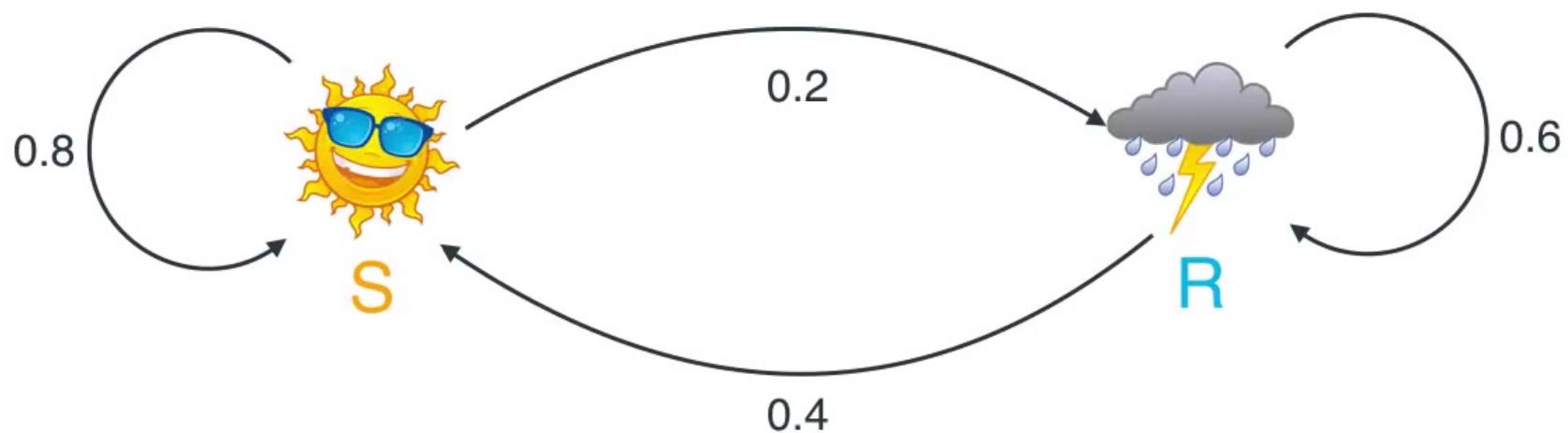
# Sunny or Rainy?



$$S = 0.8S + 0.4R$$

$$R = 0.2S + 0.6R$$

# Sunny or Rainy?

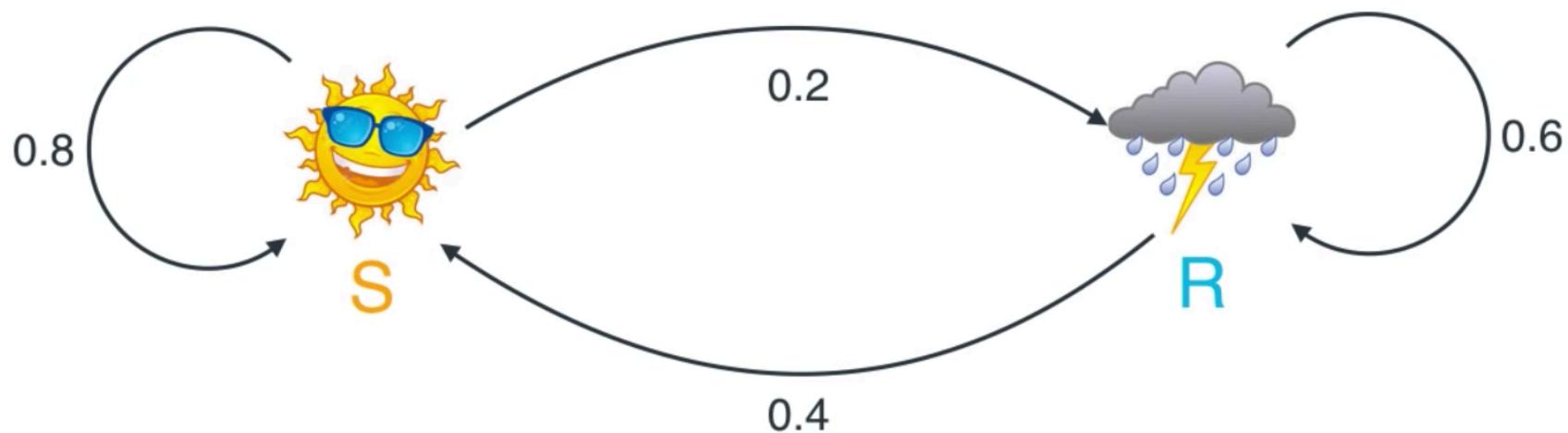


$$S = 0.8S + 0.4R$$

$$S + R = 1$$

$$R = 0.2S + 0.6R$$

# Sunny or Rainy?

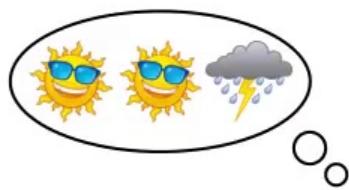


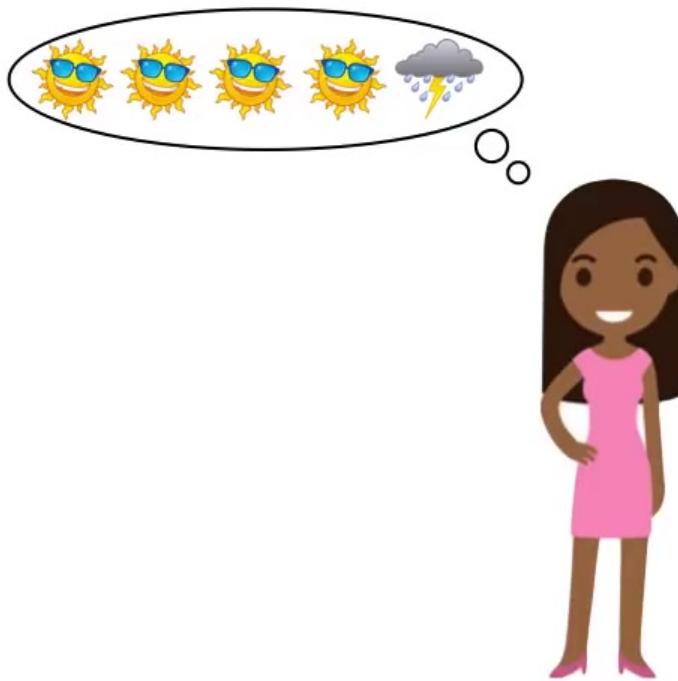
$$S = 0.8S + 0.4R$$

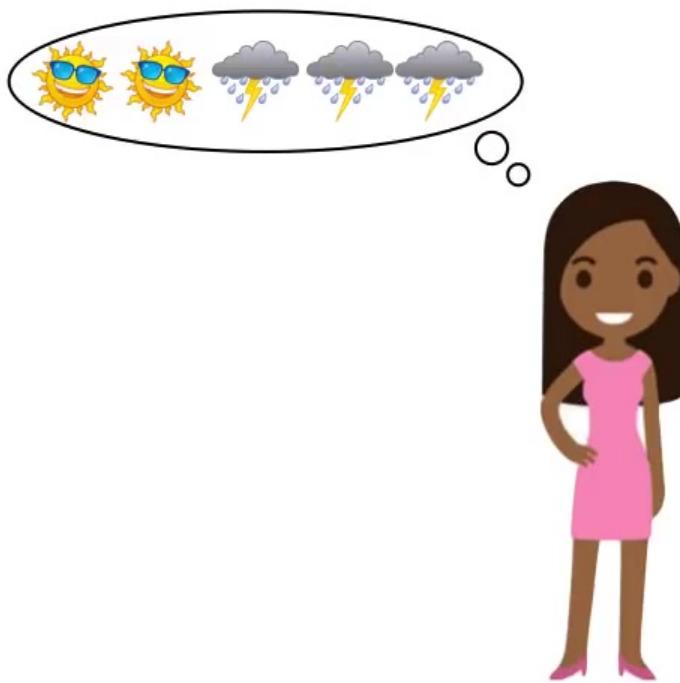
$$S + R = 1$$

$$R = 0.2S + 0.6R$$

$$\boxed{\begin{aligned} S &= 2/3 \\ R &= 1/3 \end{aligned}}$$







# Bayes Theorem



# Today, feeling happy

Wednesday



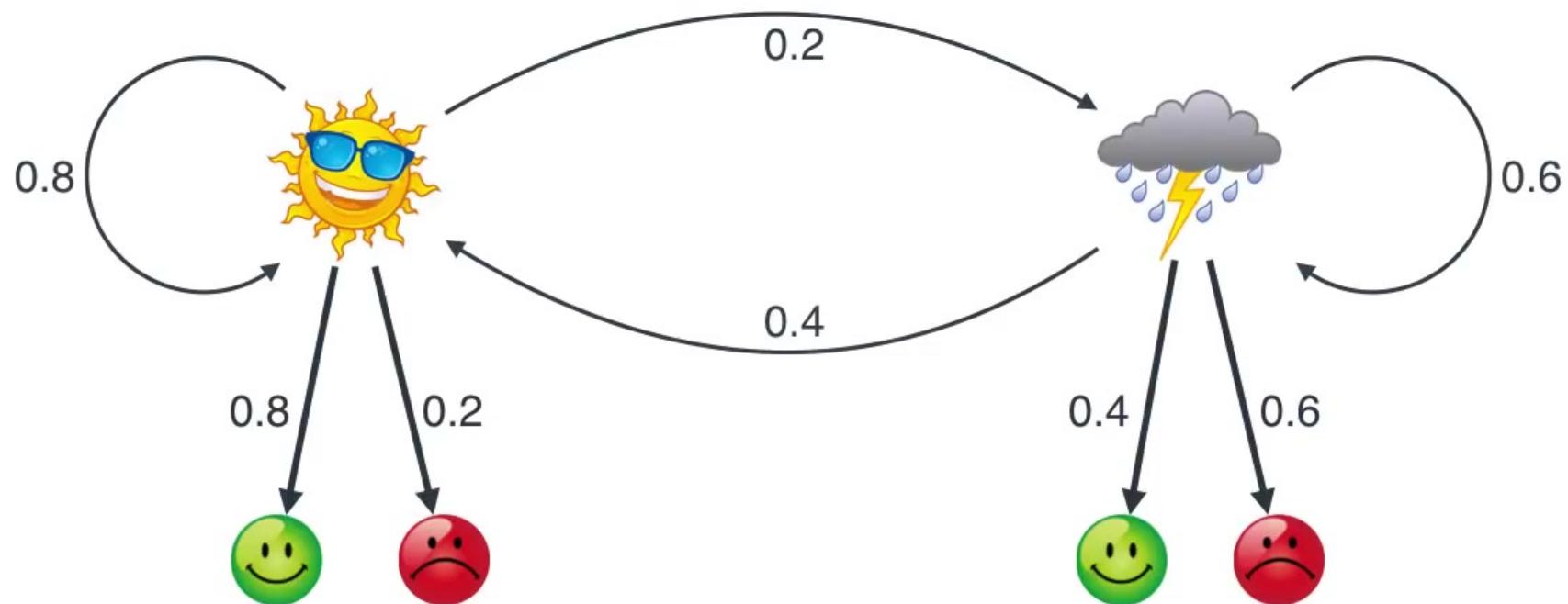
H



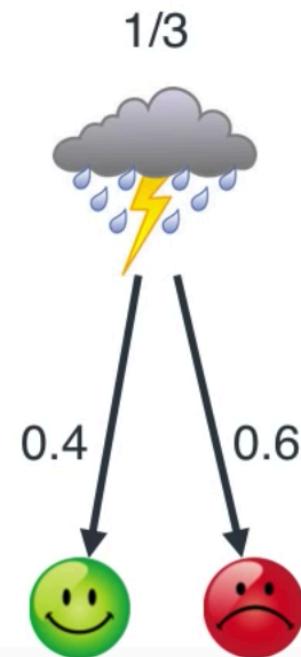
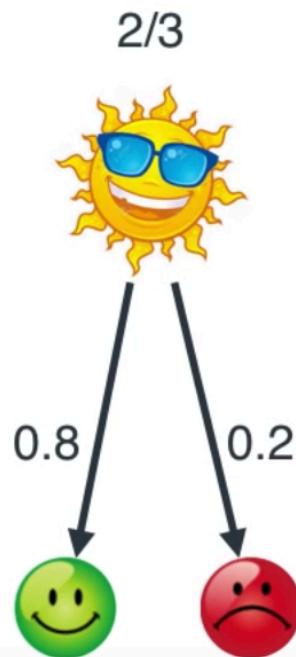
S

R

# Hidden Markov Model



# Bayes Theorem



2/3



0.8



0.2

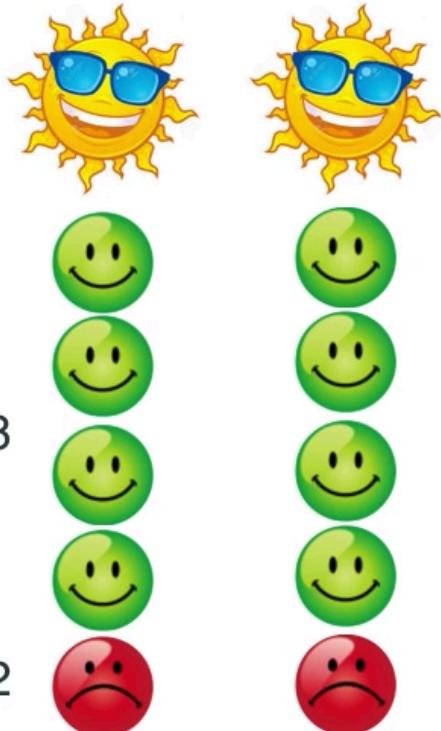


1/3

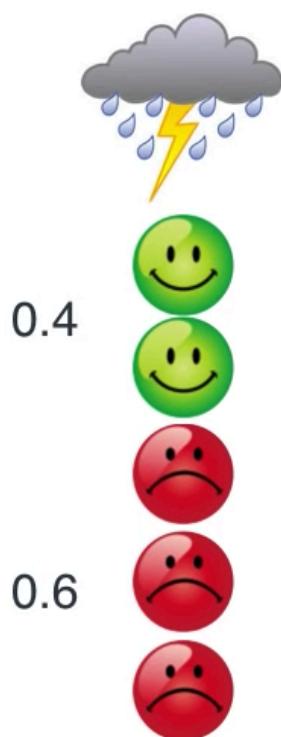


Bayes Theorem

2/3

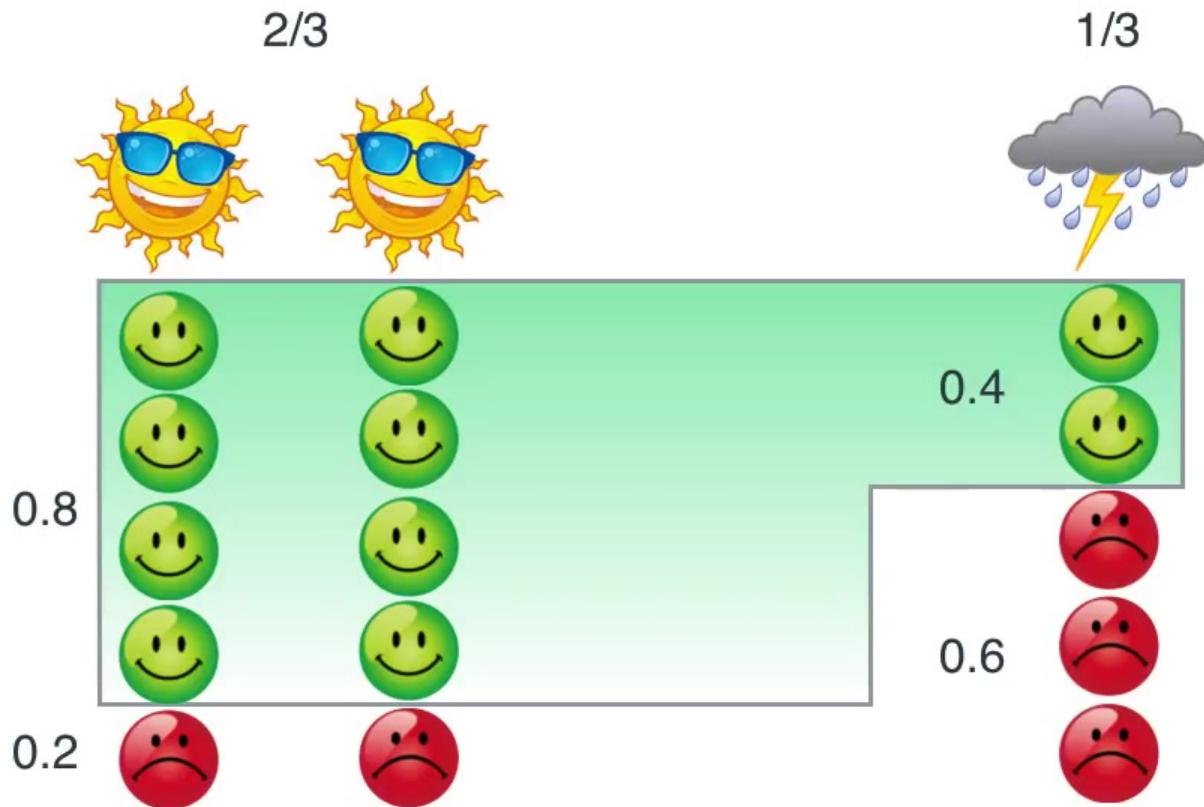


1/3

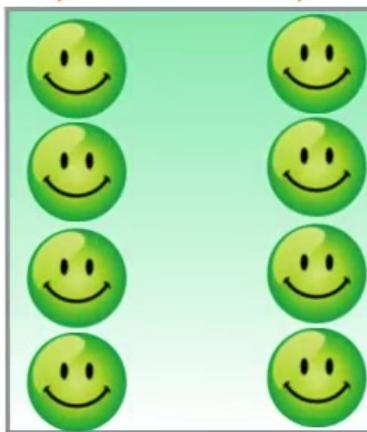


Bayes Theorem

## Bayes Theorem



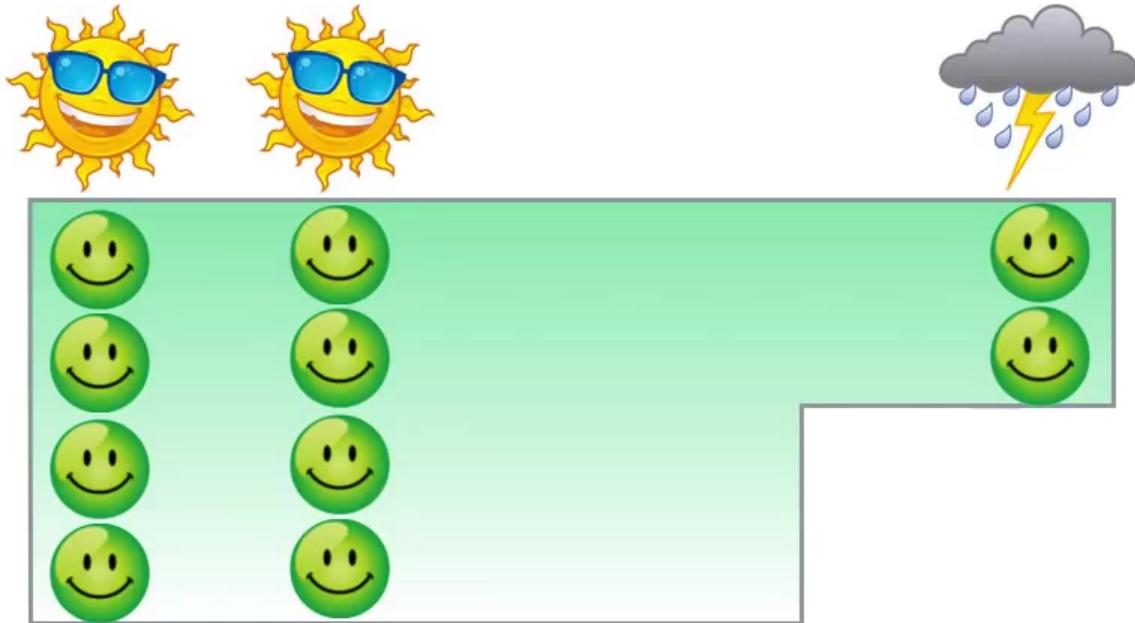
## Bayes Theorem



If

$P(\text{sun} | \text{smiley}) =$

## Bayes Theorem



If ☺

$$P(\text{☀️} \mid \text{☺}) = \frac{8}{10}$$

$$P(\text{🌧} \mid \text{☺}) = \frac{2}{10}$$

## Bayes Theorem



If

$$P(\text{Sun} \mid \text{Sad}) = \frac{2}{5}$$

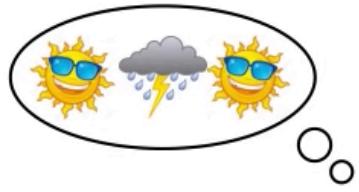
$$P(\text{Rain} \mid \text{Sad}) = \frac{3}{5}$$



- Prior probabilities:  $2/3$  and  $1/3$  – no information
- Once we know the information (whether happy or grumpy) we can calculate the probabilities of being sunny or cloudy – posterior probabilities.

# Questions

1. ~~How did we find these probabilities?~~
2. ~~What's the probability that a random day is Sunny or Rainy?~~
3. ~~If Bob is Happy today, what's the probability that it's Sunny or Rainy?~~
4. **If for three days Bob is Happy, Grumpy, Happy, what was the weather?**



# If happy-grumpy, what's the weather?

Wednesday



H

Thursday

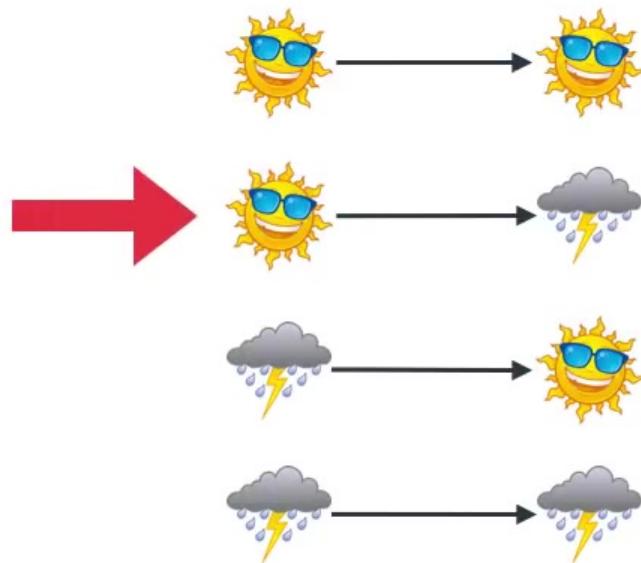


G

Wednesday      Thursday



Wednesday      Thursday



Wednesday



0.8



0.67

Thursday



Wednesday



0.8



0.67

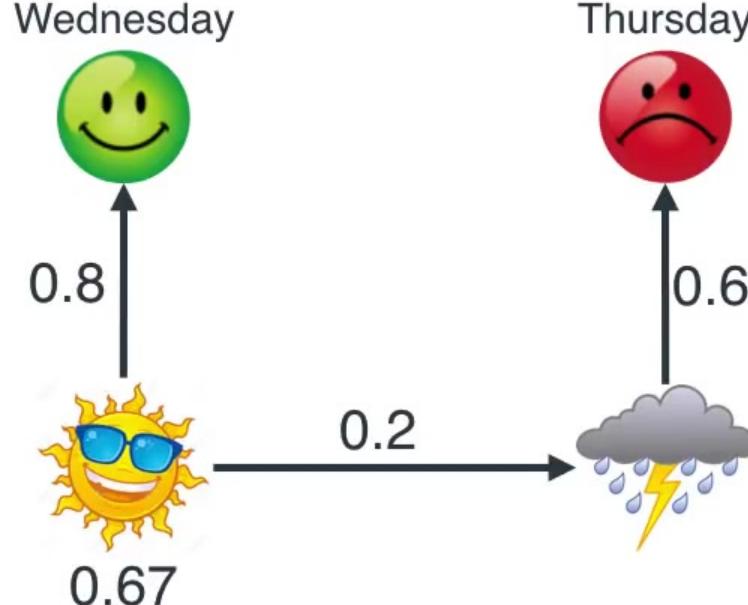
Thursday

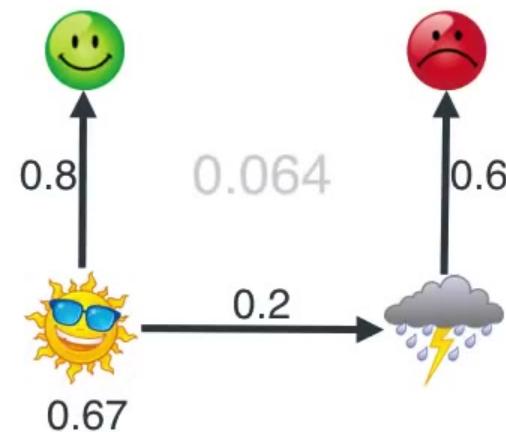
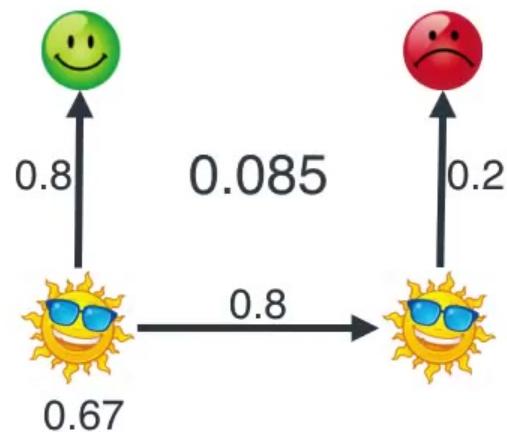


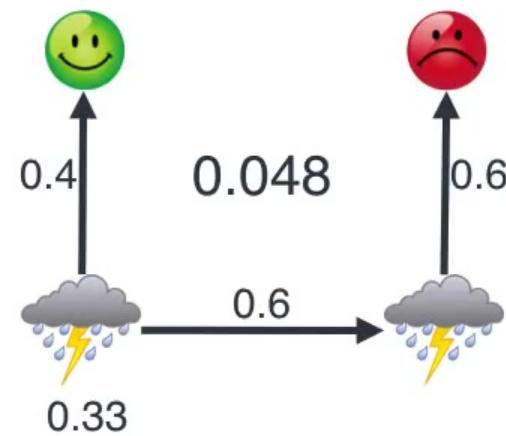
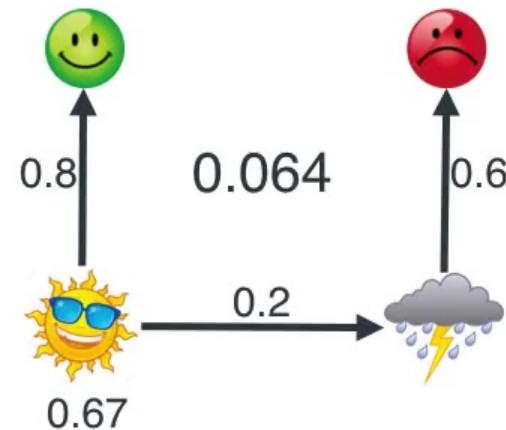
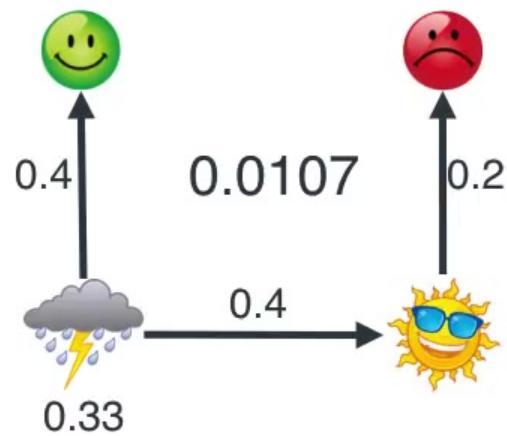
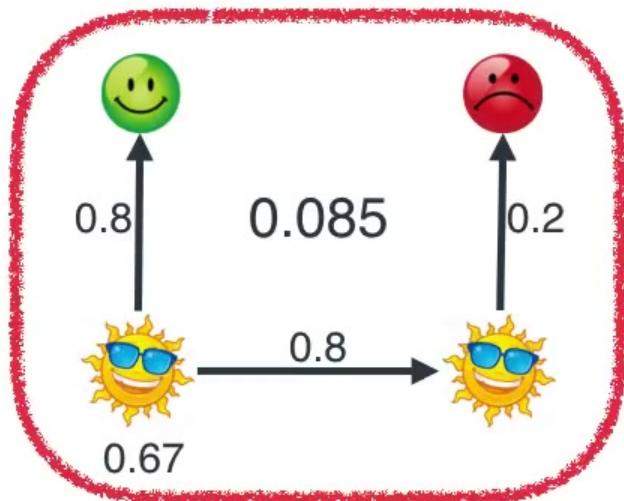
0.6

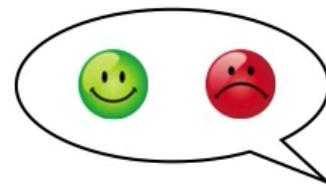
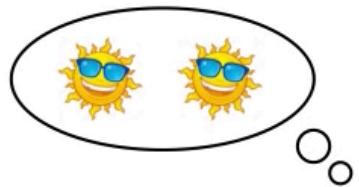


0.2









# Weather

Wednesday



H

Thursday



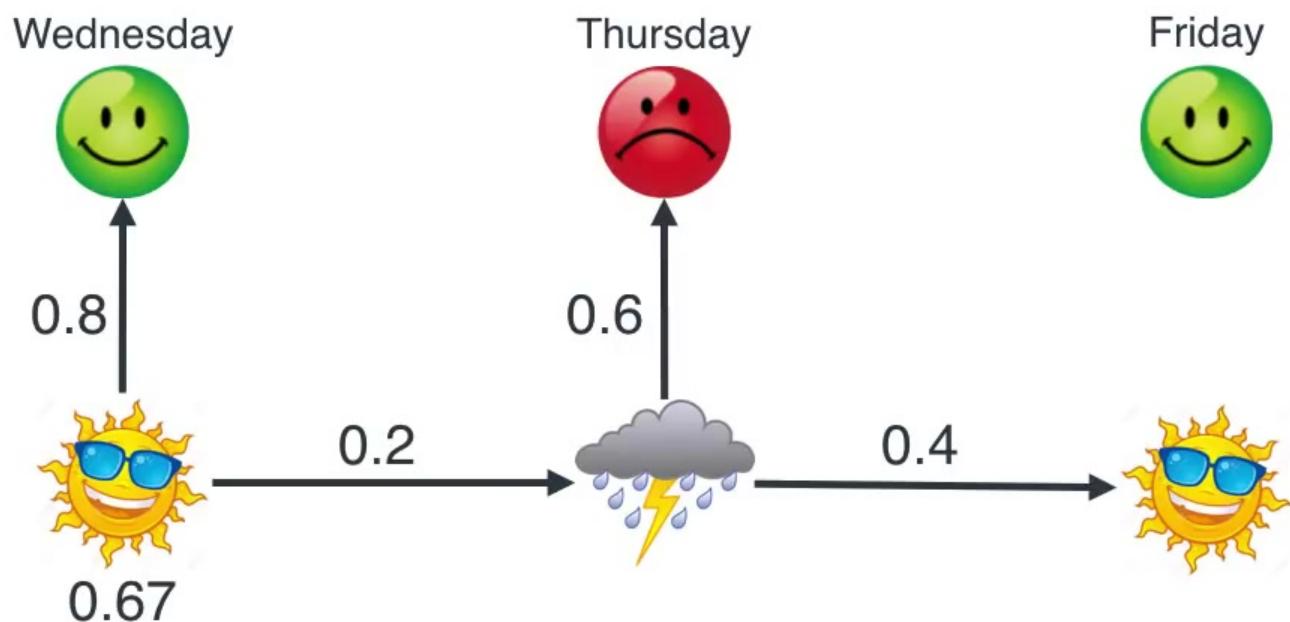
G

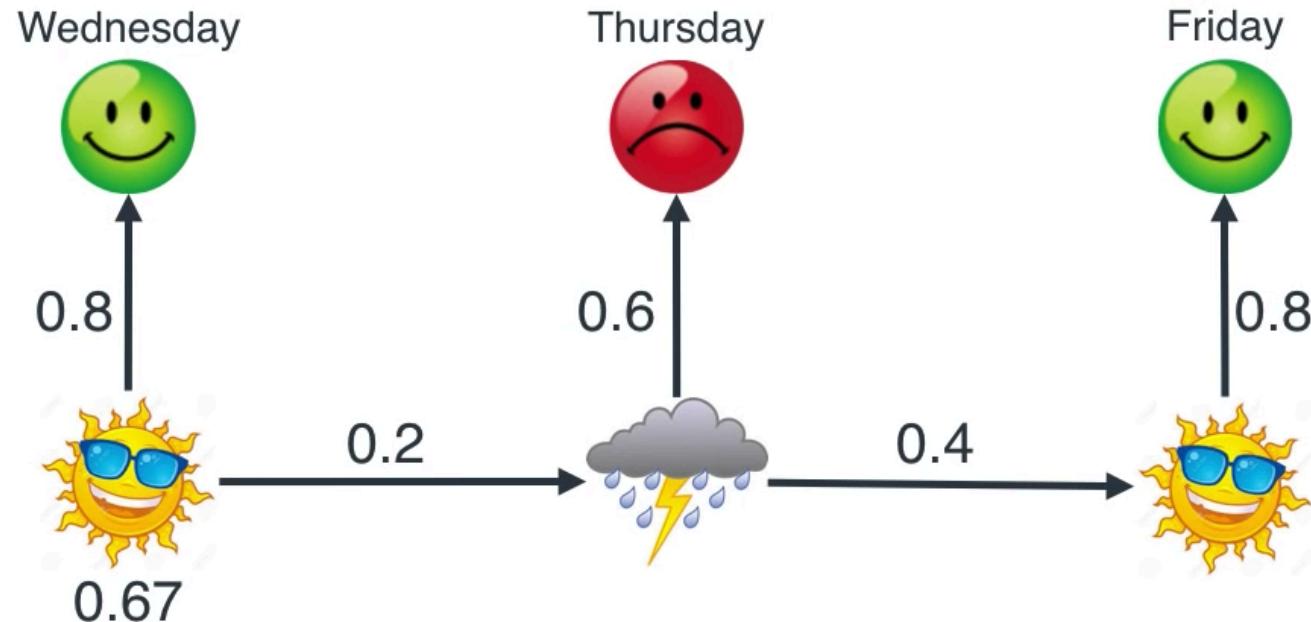
Friday



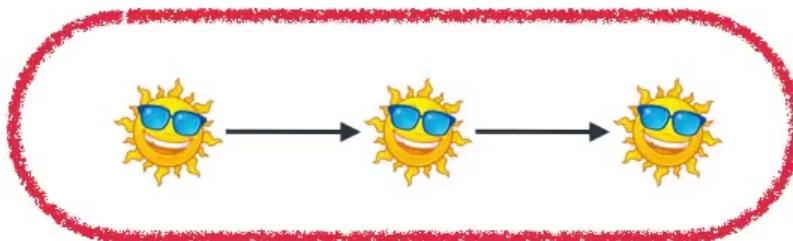
H

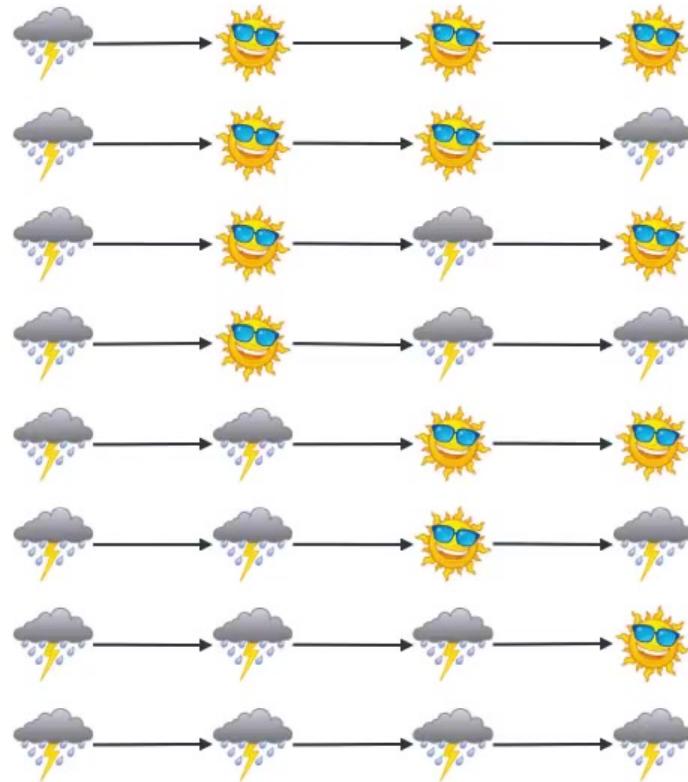
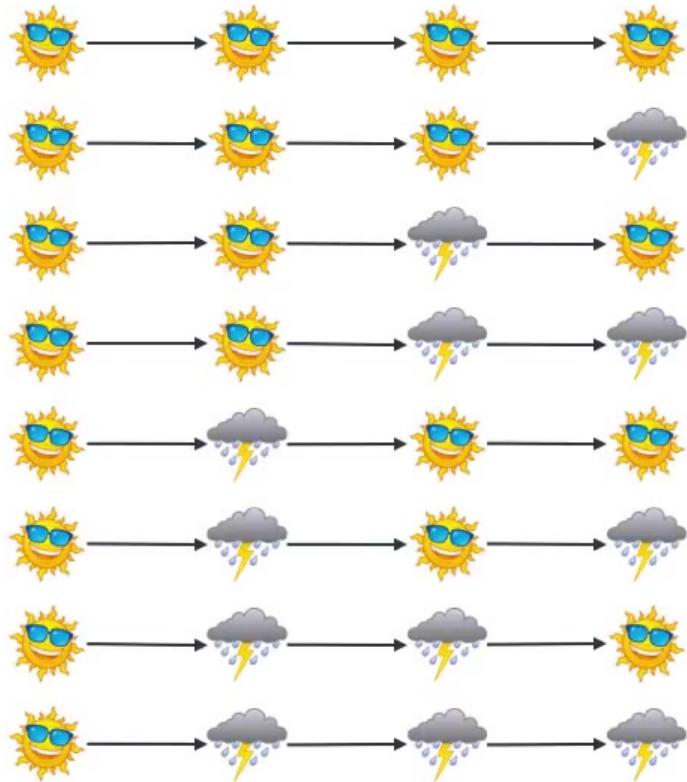




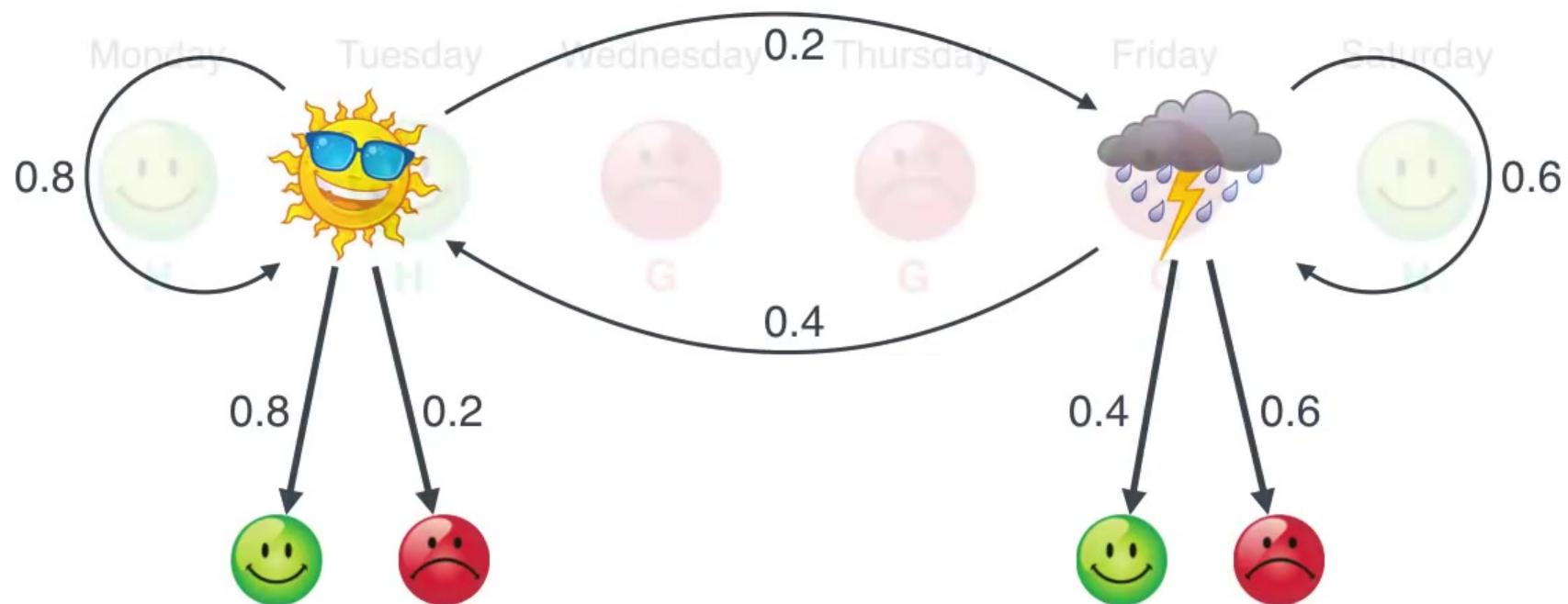


0.02048





# Hidden Markov Model



# Weather

Monday



H

Tuesday



H

Wednesday



G

Thursday



G

Friday



G

Saturday



H



S



R



S



R



S



R

Monday



Tuesday



Wednesday



Thursday



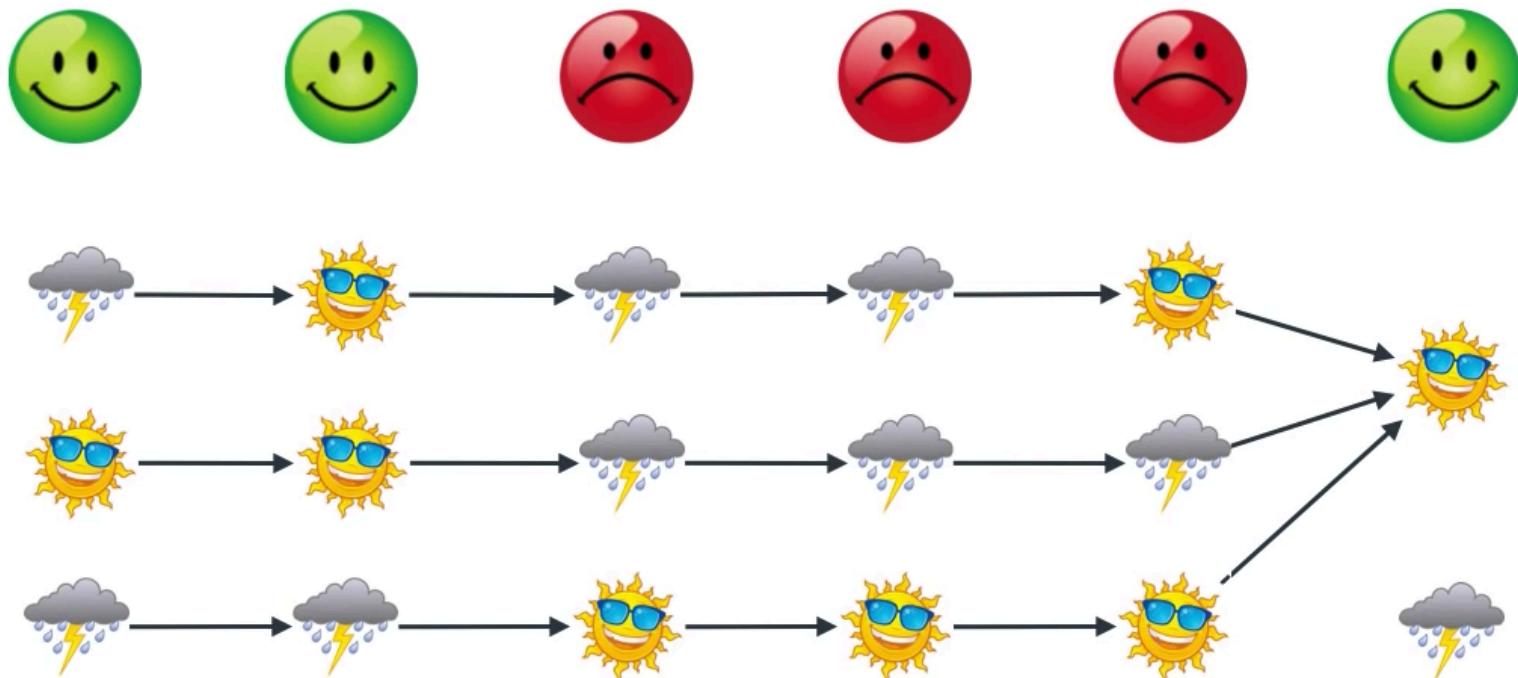
Friday



Saturday



Monday      Tuesday      Wednesday      Thursday      Friday      Saturday



Monday



Tuesday



Wednesday



Thursday



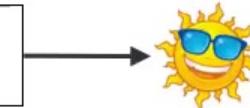
Friday



Saturday



Best path up to here



Best path up to here



Monday



Tuesday



Wednesday



Thursday



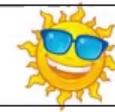
Friday



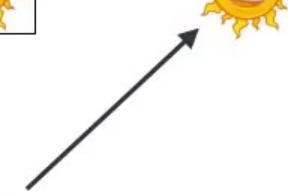
Saturday



Best path up to here

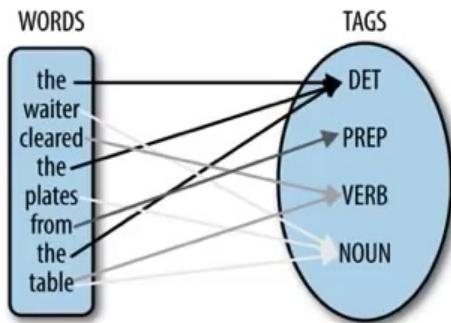


Best path u



<https://www.youtube.com/watch?v=6JVqutwtzmo&t=178s>

# Applications



Part of Speech Tagging



Robot Localization



Genetics



Speech Recognition

References: <https://www.youtube.com/watch?v=kqSzLo9fenk>