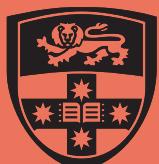


COMP 4446 / 5046

Lecture 4: Inference – Greedy and Search

Jonathan K. Kummerfeld

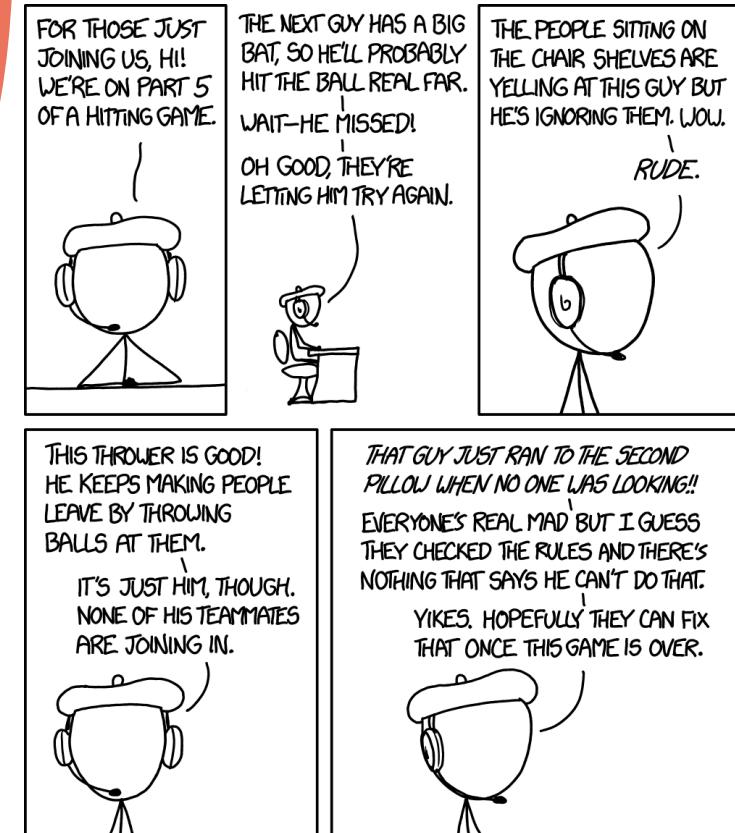
Semester 1, 2025



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Play-By-Play



[The thrower started hitting the bats too much, so the king of the game told him to leave and brought out another thrower from thrower jail.]

Source: <https://xkcd.com/1593/>



Exhaustive

Greedy

Beam search

Graph Search

Dynamic

~~Programming~~

Lab Preview



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Exhaustive



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Now, let's explore different inference methods

Data

Examples of the language phenomena we want our system to handle

Model

A function that maps (input, output) pairs to scores

Inference Method

A way to make a prediction for an example given a Model

Metric

A function that gives a score to the output produced by a Model given some Data

Learning Method

A way to update a Model given Data a Metric and an Inference Method

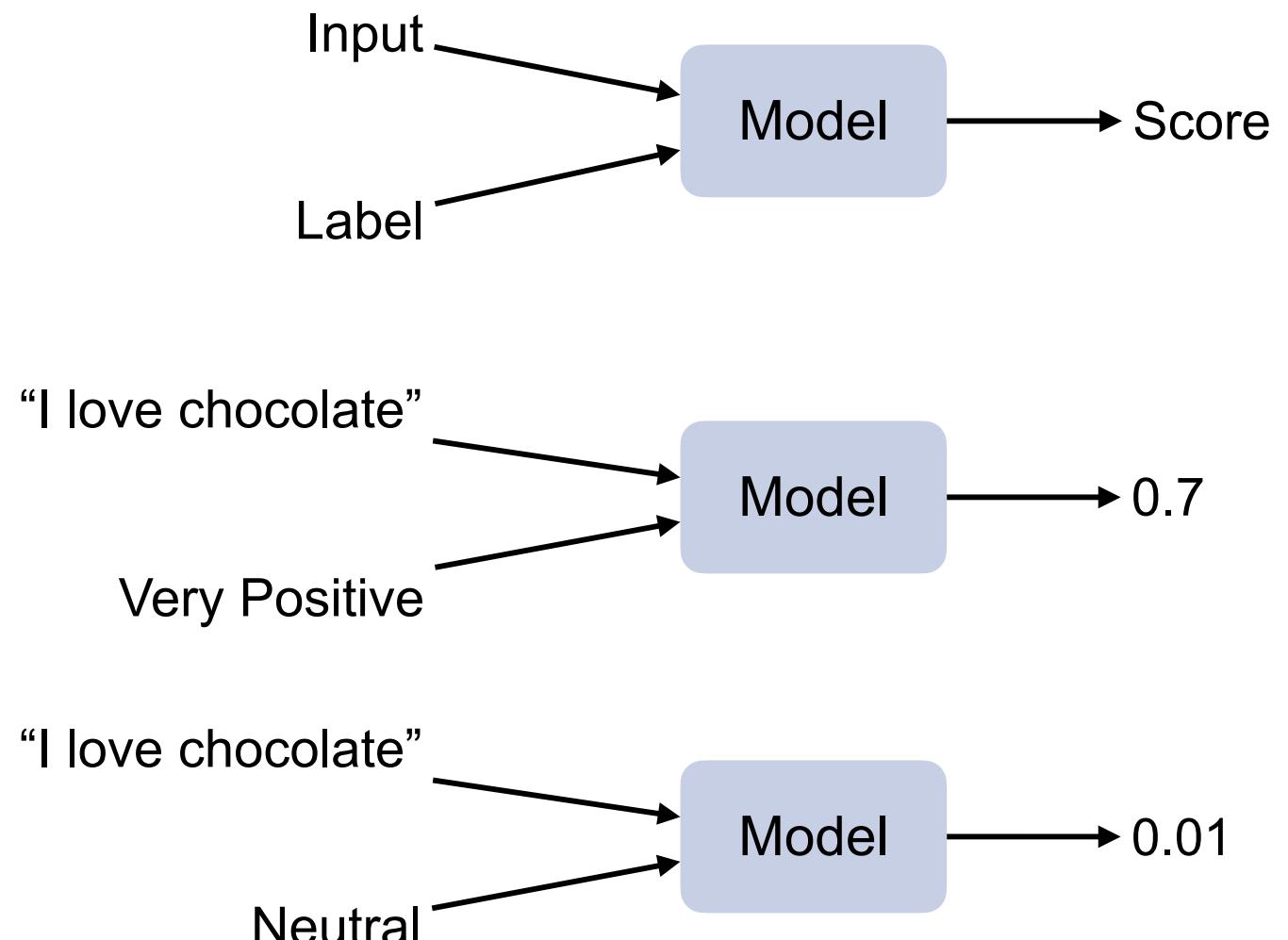


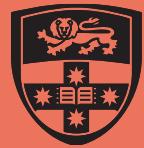
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We'll treat the model as a black box





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The model could score whole sequences

Input → Model → Score

Label

“Joe likes trucks”

BEIOS

B-PER, O, O

Model

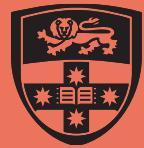
0.8

“Zach likes Joe”

B-PER, O, B-PER

Model

0.9

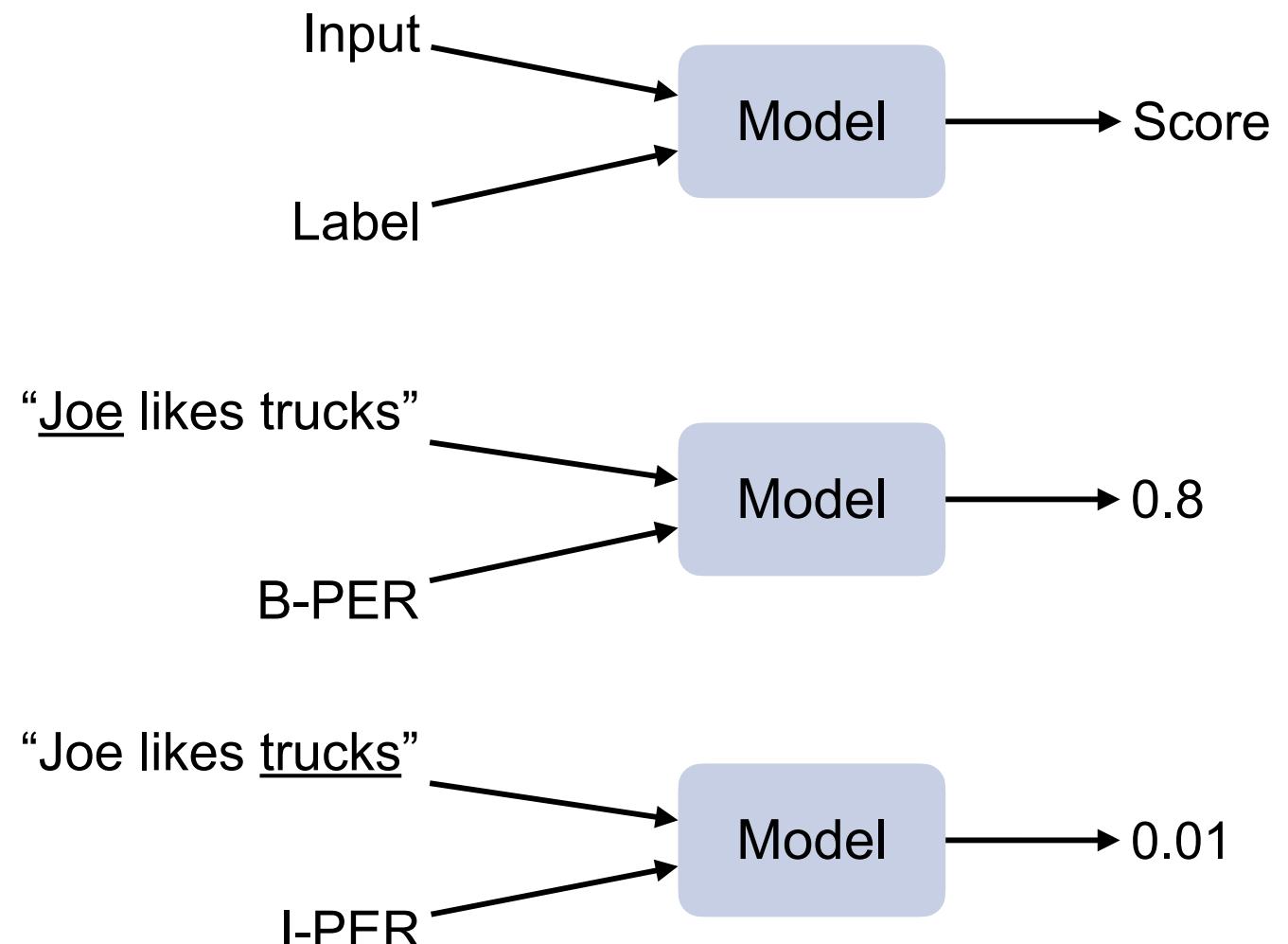


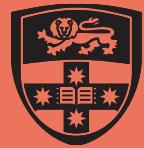
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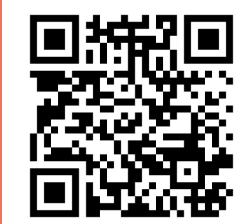
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The model could score whole sequences, or just one part



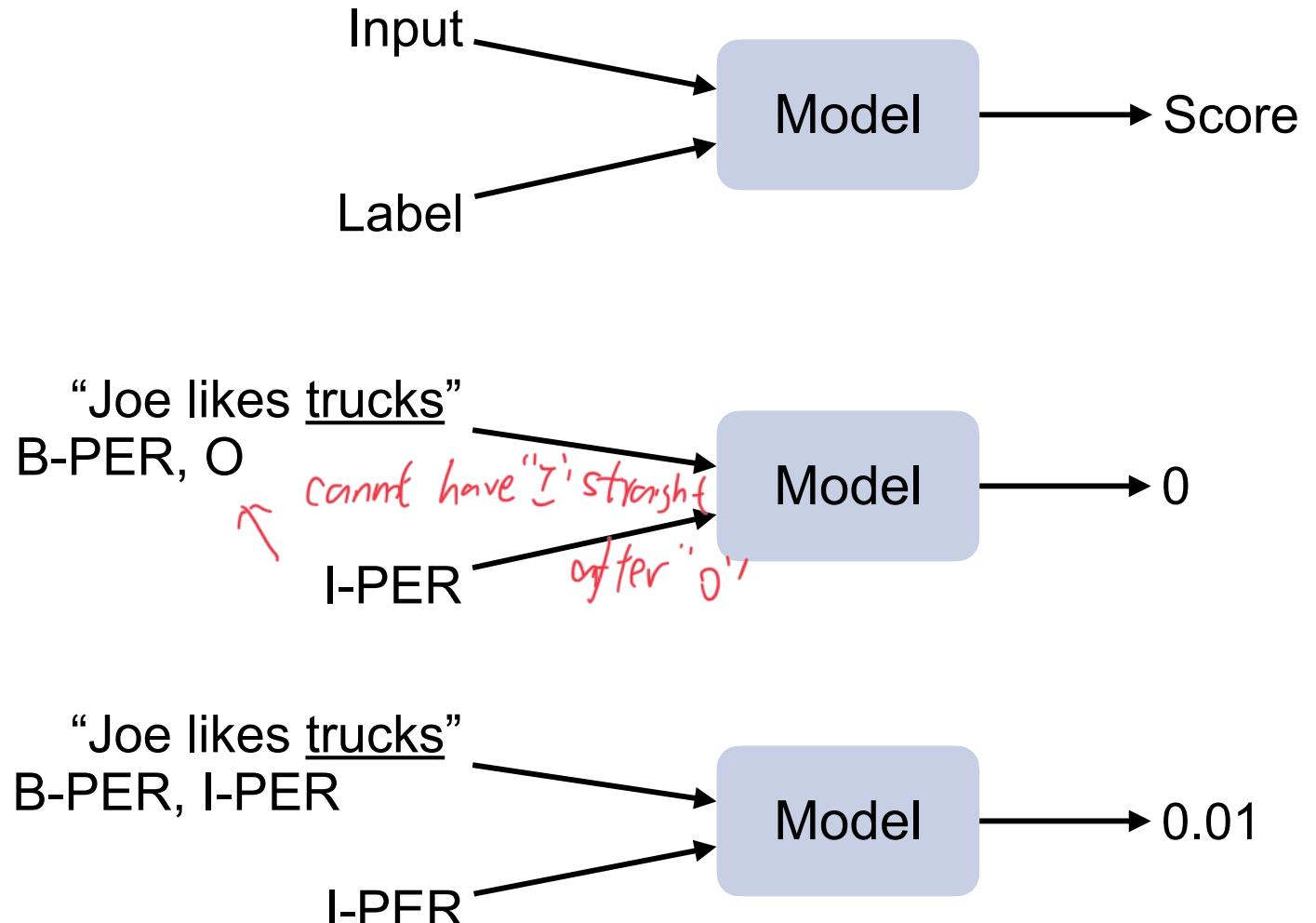


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The model could score whole sequences, or just one part, possibly with context





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We'll use several running examples in this section

Noun	Verb	Prep	Noun
Adj	Noun	Verb	Noun
Fruit	flies	like	bananas





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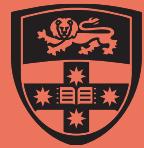
We'll use several running examples in this section

Ingredients:

4oz Chocolate, 70% cocoa
1cup Milk
Chocolate shavings

Steps:

1. Melt chocolate on stove
2. Slowly add milk
3. Heat until simmering
4. Take off heat and let cool completely (~20 min)
5. Return to stove and heat to desired temperature
6. Top with chocolate shavings



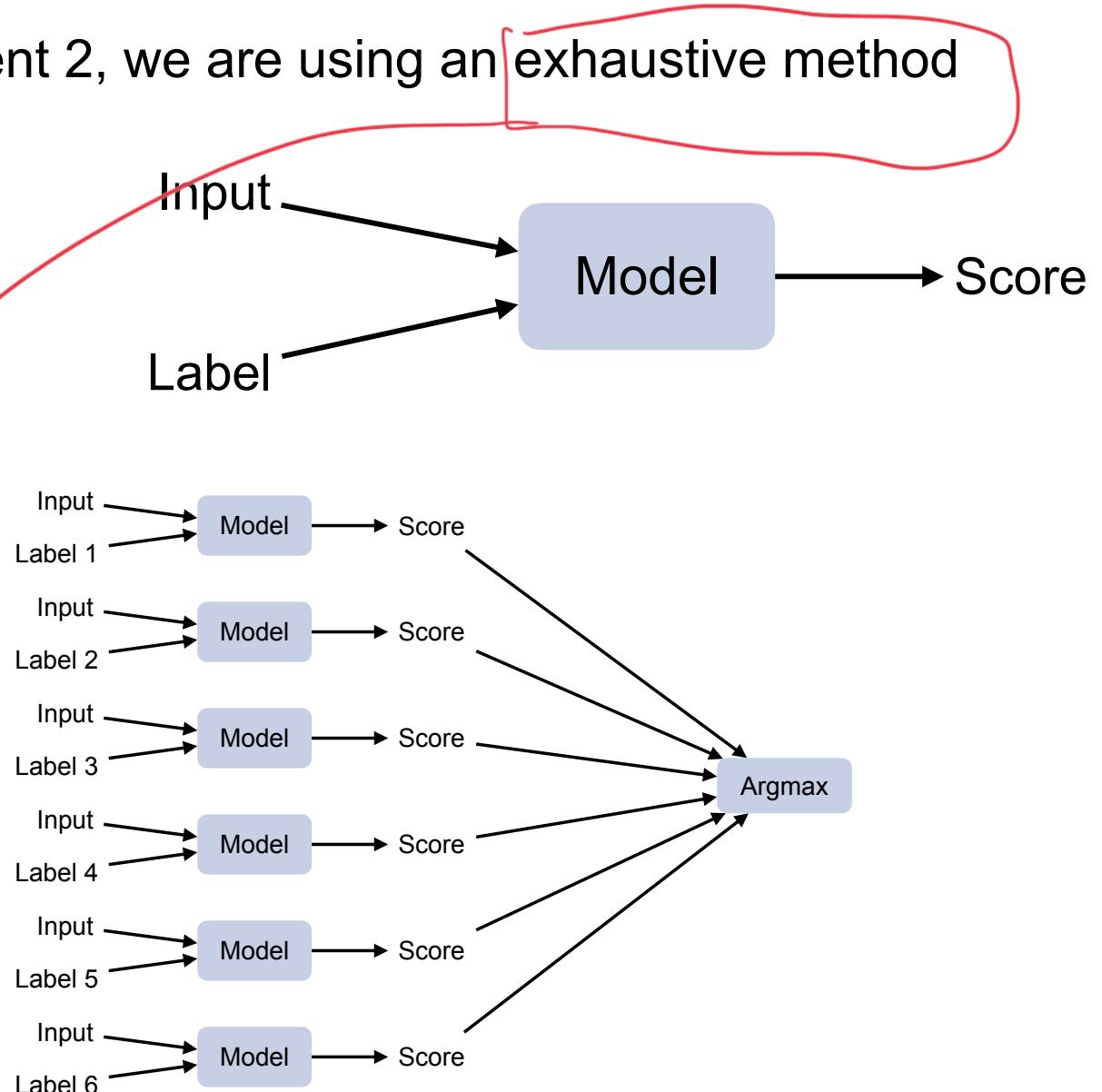
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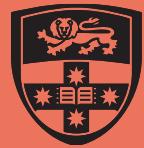


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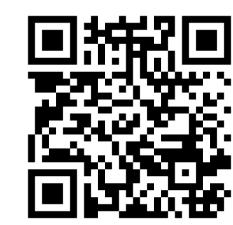
In assignment 2, we are using an exhaustive method

All possible
combination



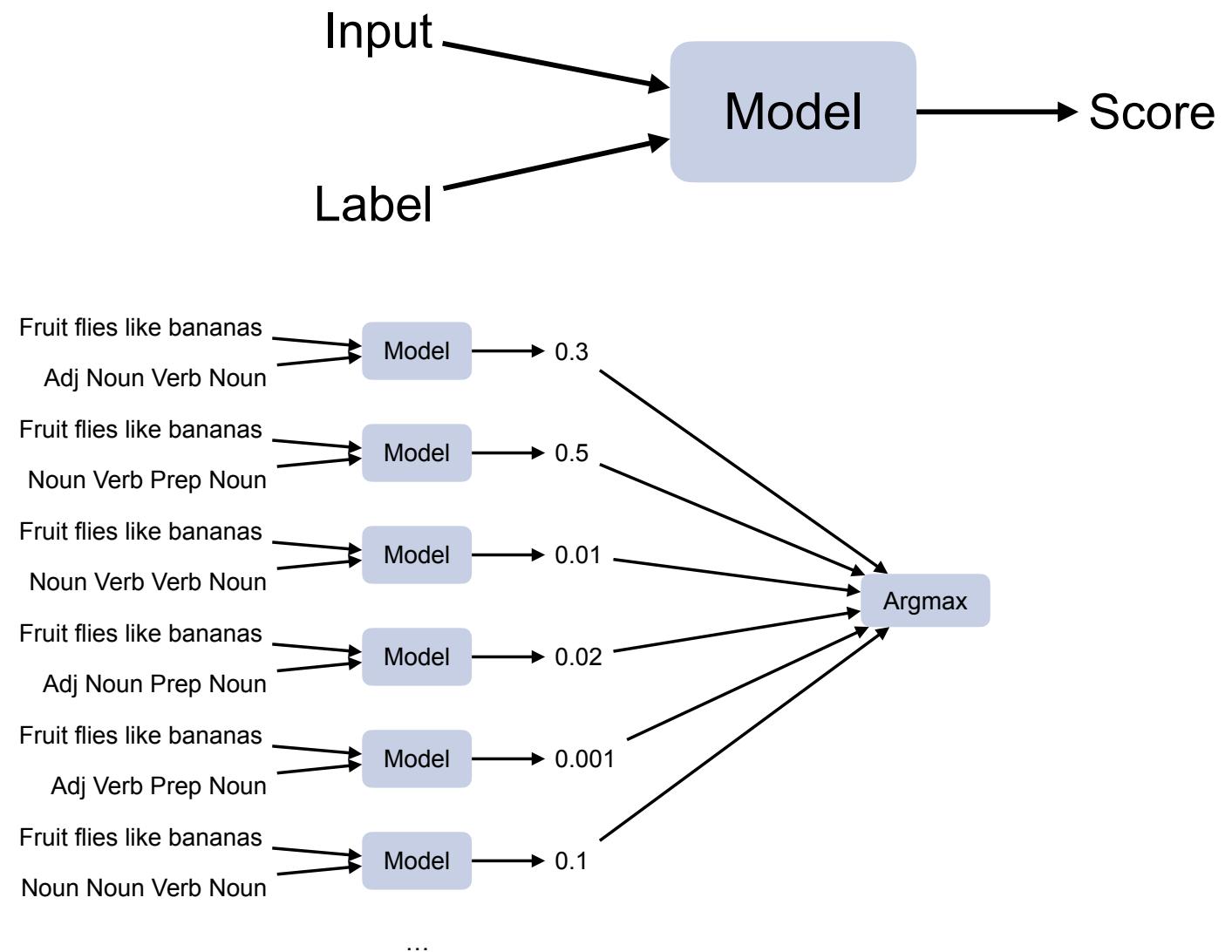


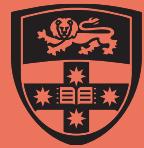
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In assignment 2, we are using an exhaustive method





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Exhaustive search is flexible, but not scalable

Benefit - The model can look at the entire structure

Fruit flies like bananas

Adj Noun Verb Noun

4 words

Model

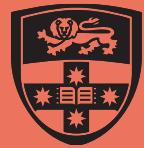
0.3

Problem - for many tasks, the search space is huge

17 tags in Universal Dependencies

Options = $|\text{tags}|^{\text{words}}$

For this example, $17^4 = 83,521$ options!

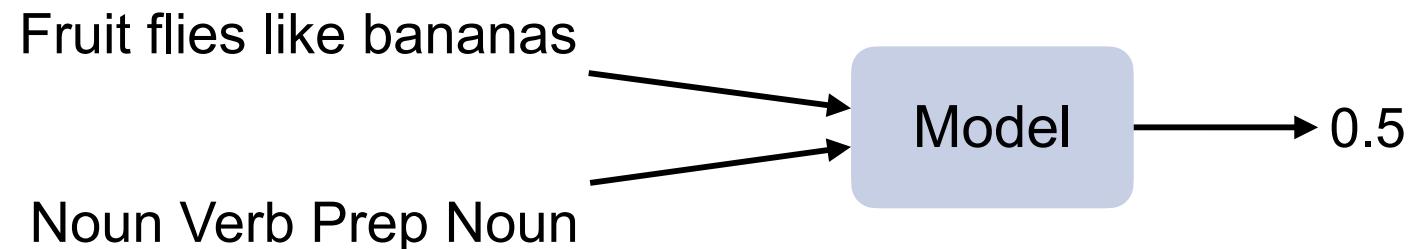
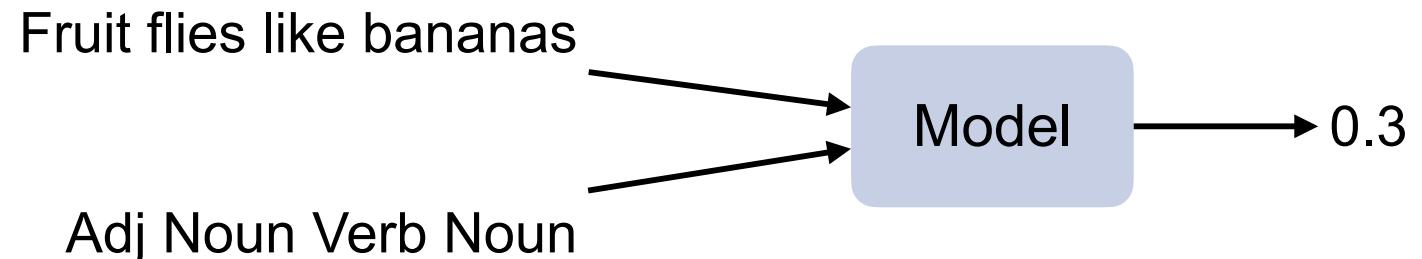


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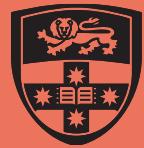


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Note: we are looking for the highest scoring output,
which might be wrong



choose higher score
but this is wrong

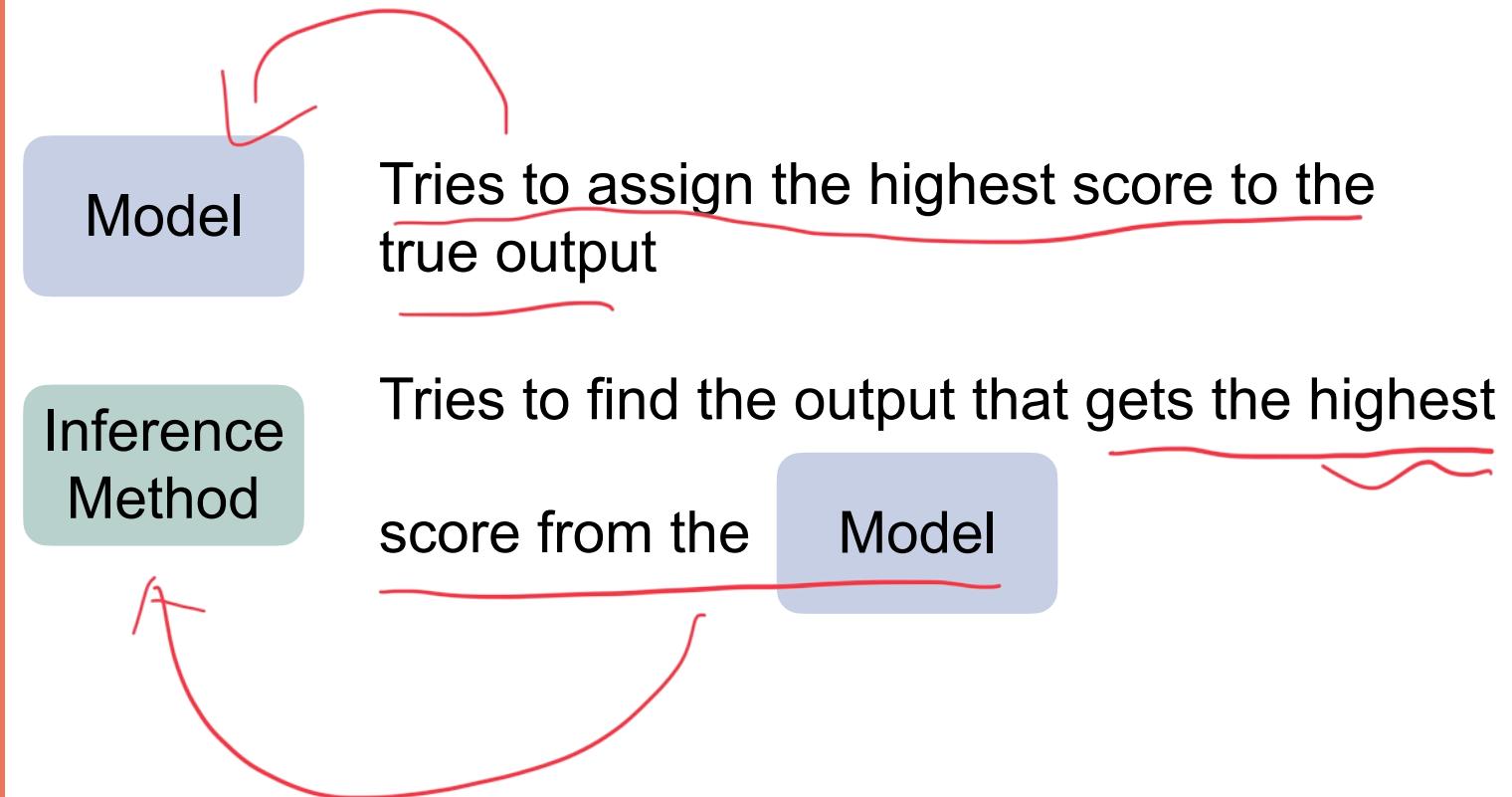


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This suggests another way of describing these two components of an NLP system





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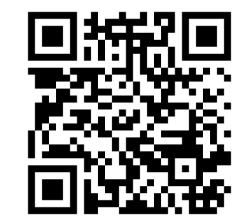


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Greedy



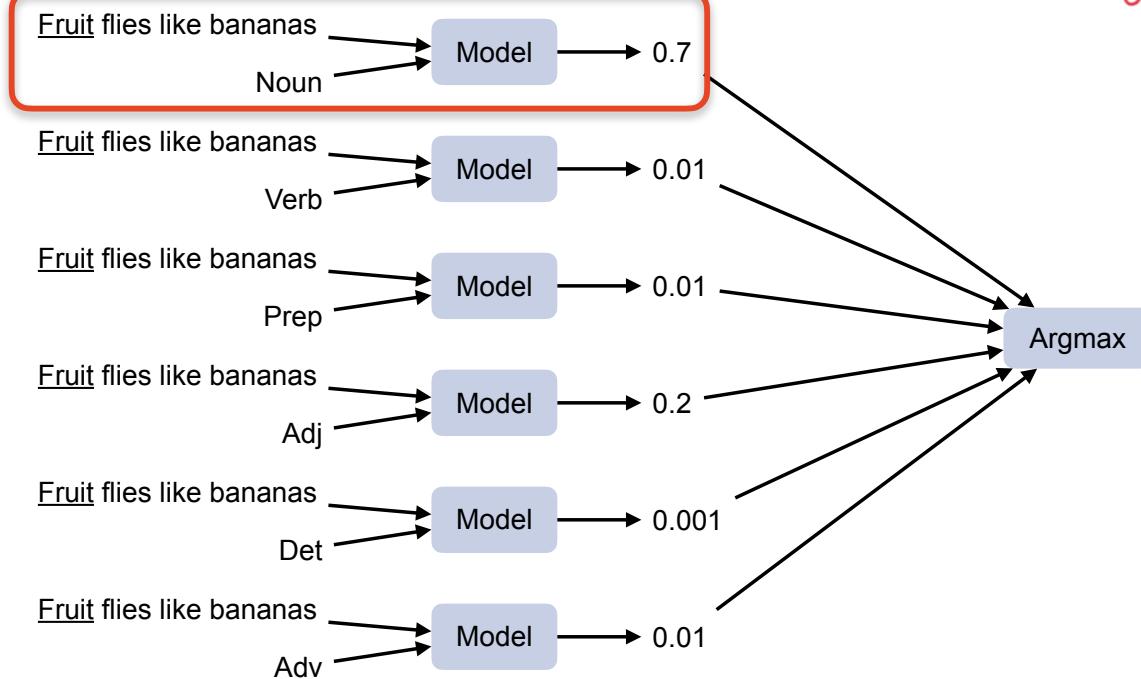
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Core greedy idea: Make choices one at a time

Fruit have highest score
0.7





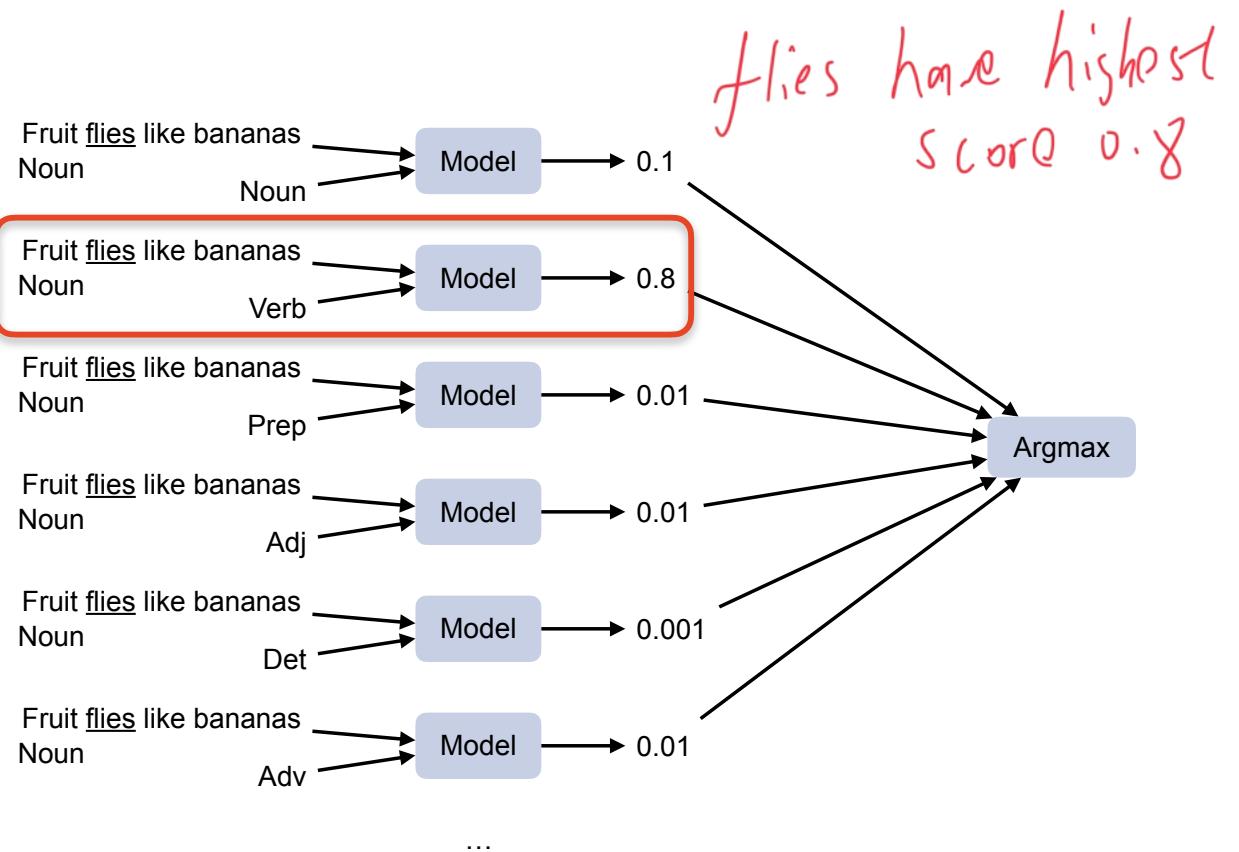
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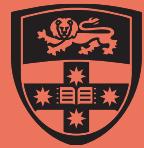


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Core greedy idea: Make choices one at a time

2





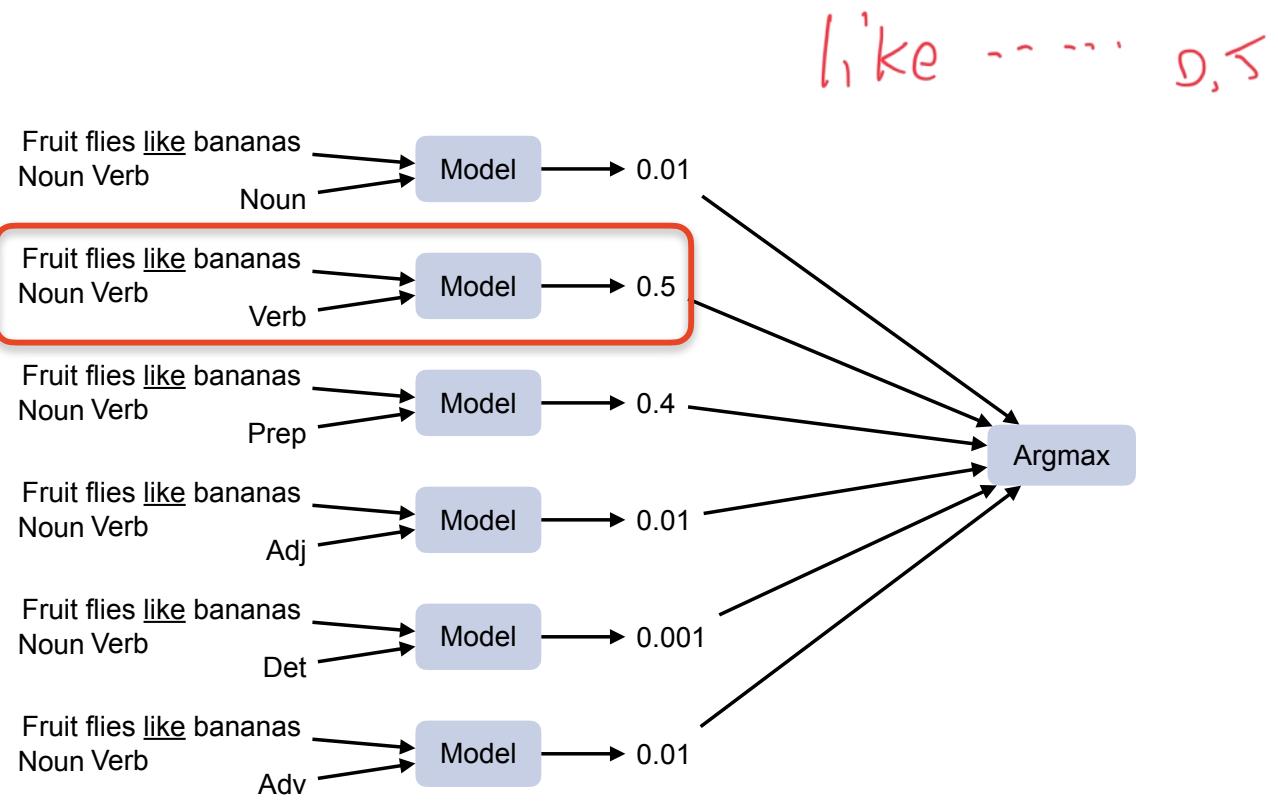
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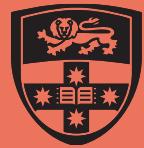


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Core greedy idea: Make choices one at a time

3





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The complexity problem is fixed!

17 tags in Universal Dependencies

Options considered in each step = $|tags|$

Step = $|words|$

$$\begin{aligned} \text{Complexity} &= |tags| * |words| \\ &= 17 * 4 \\ &= 68 \end{aligned}$$

EE KF/Case
Best, T12 2.2
greedy w/ complexity
Tik



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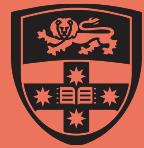


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But... the answer was different

Exhaustive:	Noun	Verb	Prep	Noun
Greedy:	Noun	Verb	Verb	Noun
	Fruit	flies	like	bananas

Note - both of these are wrong,
but one is the highest scoring
according to the model and the
other is not.



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A few notes on comparing exhaustive and greedy

Sometimes the answer can match. For example, if every part of the output is independent.

Greedy has less information about the output, but can still use a lot of context to make the decision



Exhaustive

Greedy

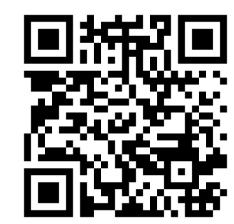
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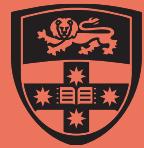


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First variant: **Top-1**

Method: At each step, choose the highest scoring option

This is what we just saw!



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First variant: **Top-1**

Method: At each step, choose the highest scoring option

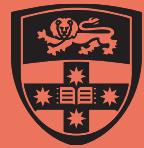
Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk

Steps:

1. Melt chocolate on stove
 2. Slowly add milk
 3. Heat until simmering
 4. Melt chocolate on stove *← make mistake*
 5. Add milk
 6. Heat
 7. Melt chocolate on stove
- ...



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②

Second variant: **Random sampling**

sample from a distribution

Method: At each step, choose using random sampling from the probability distribution

Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk



Melt chocolate on stove

Steps:



Take off heat and let cool completely (~20 min)

1. Melt chocolate on stove
2. Slowly add milk
3. Heat until simmering

0.3 - Melt chocolate on stove

0.29 - Take off heat and let cool completely (~20 min)

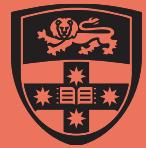
0.2 - Pour into mug

0.1 - Simmer for 5 minutes

...

0.3 means higher P

0.1 means lower P



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3

Third variant: **Top-K sampling**

Method: At each step, filter to the top K options, then choose using random sampling from the probability distribution

Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk

Steps:

1. Melt chocolate on stove
2. Slowly add milk
3. Heat until simmering

choose from top k
probabilities

- | | |
|------|---|
| 0.3 | - Melt chocolate on stove |
| 0.29 | - Take off heat and let cool completely (~20 min) |
| 0.2 | - Pour into mug |
| 0.1 | - Simmer for 5 minutes |
| ... | |

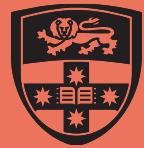
K = 3

↑

ignore belows

need reschedule

11/11



Exhaustive

Greedy

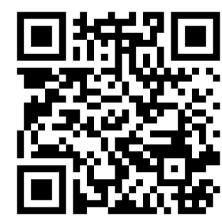
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Third variant: **Top-K** sampling

Method: At each step, filter to the top K options, then choose using random sampling from the probability distribution

Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk



Pour into mug

Steps:

1. Melt chocolate on stove
2. Slowly add milk
3. Heat until simmering



Take off heat and
let cool completely
(~20 min)

0.38 - Melt chocolate on stove

0.37 - Take off heat and let cool completely (~20 min)

0.25 - Pour into mug

0.1 - Simmer for 5 minutes

...

K = 3



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Fourth variant: Top-P sampling

4

Method: At each step, filter to the options that cover P% of the probability distribution, then choose using random sampling

Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk

ignore rest $(1 - P)\%$

Steps:

Choices

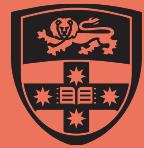
1. Melt chocolate on stove
2. Slowly add milk
3. Heat until simmering

- 0.3 - Melt chocolate on stove
- 0.29 - Take off heat and let cool completely (~20 min)
- 0.2 - Pour into mug
- 0.1 - Simmer for 5 minutes

P = 80%

Sum

then reschedule



Exhaustive

Greedy

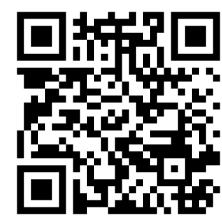
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Fourth variant: **Top-P** sampling

Method: At each step, filter to the options that cover P% of the probability distribution, then choose using random sampling

Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk



Pour into mug

Steps:

1. Melt chocolate on stove
2. Slowly add milk
3. Heat until simmering



Simmer for 5 minutes

0.34 - Melt chocolate on stove

0.33 - Take off heat and let cool completely (~20 min)

0.22 - Pour into mug

0.11 - Simmer for 5 minutes

P = 80%

...



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Fifth variant: **Contrastive** sampling

(S)

Method: At each step, adjust scores based on similarity with recent outputs, then choose the highest scoring option

Ingredients:

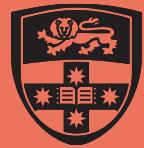
4oz Chocolate, 70% cocoa

1cup Milk

Steps:

1. Melt chocolate on stove
2. Slowly add milk
3. Heat until simmering

0.3 -	*	0.1	ocolate on stove
0.29	*	1.0	off heat and let cool completely (~20 min)
0.2 -	*	1.0	to mug
0.1 -	*	1.0	r for 5 minutes
...	...		



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Fifth variant: **Contrastive** sampling

Method: At each step, adjust scores based on similarity with recent outputs, then choose the highest scoring option

Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk

Steps:

1. Melt chocolate on stove
2. Slowly add milk
3. Heat until simmering

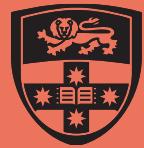
0.03 - Melt chocolate on stove

0.29 - Take off heat and let cool completely (~20 min)

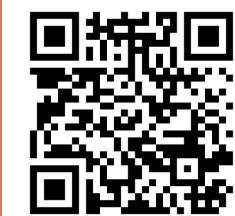
0.2 - Pour into mug

0.1 - Simmer for 5 minutes

...



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Fifth variant: **Contrastive** sampling

Method: At each step, adjust scores based on similarity with recent outputs, then choose the highest scoring option

Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk

Steps:

1. Melt chocolate on stove
2. Slowly add milk
3. Heat until simmering

This is starting to mix modelling with inference

since it says "which step" is not good and give corresponding penalty

0.04 - Melt chocolate on stove

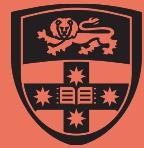
0.40 - Take off heat and let cool completely (~20 min)

0.27 - Pour into mug

0.14 - Simmer for 5 minutes

...

This can be combined with previous approaches



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Greedy variant comparison

Top-1	Argmax
Random	Sample - full distribution
Top-K	Sample - partial list, fixed length
Top-P	Sample - partial list, variable length
Contrastive	Adjust scores, then argmax

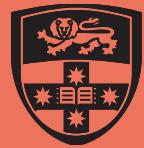


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Beam Search



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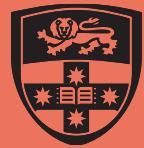
Core beam idea: Keep track of multiple options

Input at each step:

Fruit flies	Fruit <u>flies</u>	Fruit flies	Fruit flies
like bananas	like bananas	<u>like</u> bananas	like <u>bananas</u>
-	Noun	Noun Verb	Noun Verb Verb

Output so far [Greedy]:

Noun	Noun Verb	Noun Verb Prep	Noun Verb Prep Noun
------	-----------	----------------	---------------------



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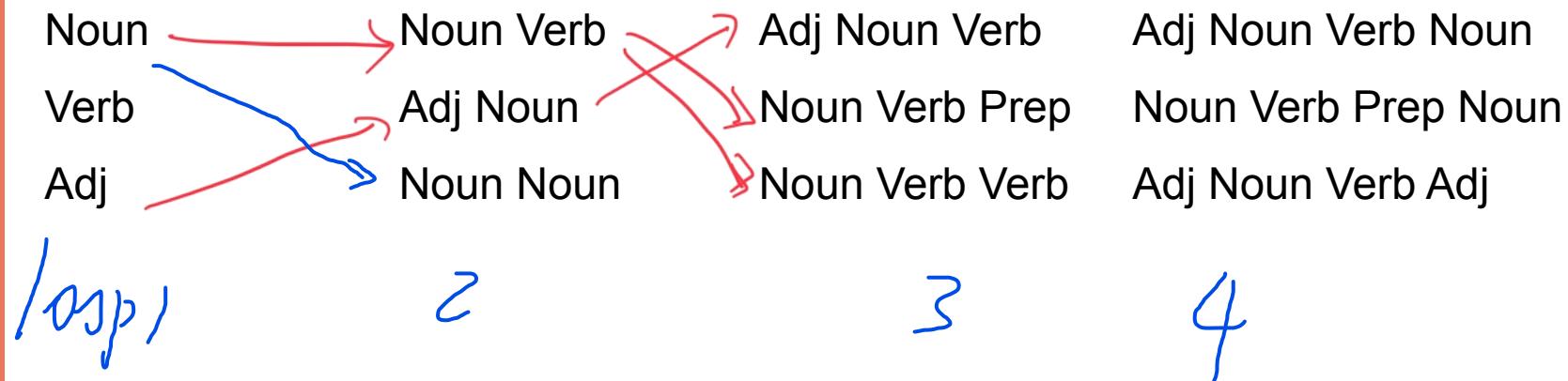
Core beam idea: Keep track of multiple options

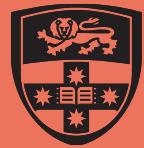
Input at each step:

Fruit flies	Fruit <u>flies</u>	Fruit flies	Fruit flies
like bananas	like bananas	<u>like</u> bananas	like <u>bananas</u>
-	Noun	Noun Verb	Adj Noun Verb
	Verb	Adj Noun	Noun Verb Prep
	Adj	Noun Noun	Noun Verb Verb

Output so far [Beam]:

3 best options





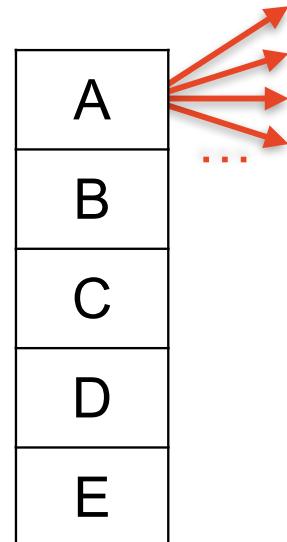
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Beam search
Graph Search
Dynamic
Programming
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Implement with a list of options at each step that you consider extending

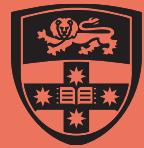
K best options
so far
(K = 5 here)



For A

New K best
options after
doing this step

A, q
A, p
A, g
A, u



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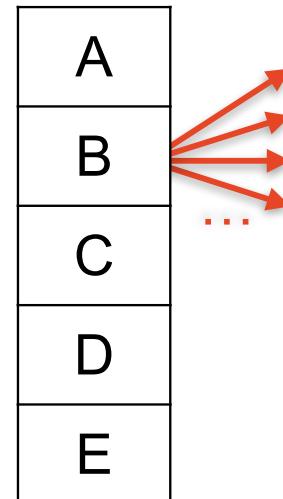


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Implement with a list of options at each step that you consider extending

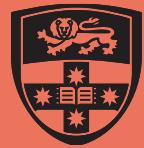
K best options
so far
(K = 5 here)

For B

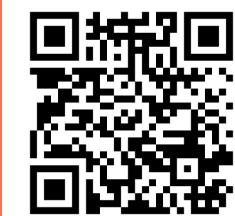


New K best
options after
doing this step

A, x
A, q
B, p
A, g
B, p



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Implement with a list of options at each step that you consider extending

K best options
so far
(K = 5 here)

A
B
C
D
E

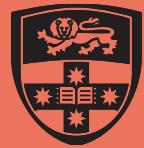
New K best
options after
doing this step

E, q
A, x
A, q
B, x
-

在 A B C D E
都完成，
只记录

Top 5

Depending on your scoring method, sometimes you can stop early - if you know that none of the remaining options will be better



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For variable length outputs, there are multiple possible beam definitions

Beams based on number of output lines: *Same hotline*

Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk

Chocolate shavings

Steps:

1. Melt chocolate on stove

Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk

Steps:

1. Melt chocolate on stove
2. Slowly add milk

Beams based on step number: *Same first step*

Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk

Chocolate shavings

Steps:

1. Melt chocolate on stove

Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk

Steps:

1. Melt chocolate on stove

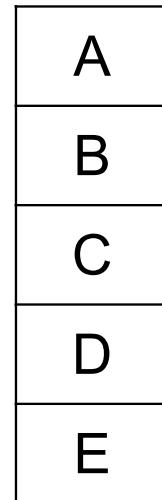


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Implementation note - how to select the top K?



Simple approach, $O(nk)$

For each option, go through the list to find where it goes. Once found, insert and update.

Heap approach, $O(n \log k)$

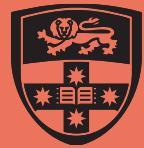
Use a min-heap. Update it with each new item.
pop best score

Quickselect approach, $O(n)$

Record all options. Use quickselect to find the Kth best. Make one pass through the list to get the other $K-1$.

Usually k is small enough that any of these are fine and the computation of different options dominates anyway

Similar to constant



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Sometimes beam search does not capture useful variation

Ingredients:

4oz Chocolate, 70% cocoa

different

Ingredients:

4oz Chocolate, 75% cocoa



Ingredients:

4oz Cocoa Powder

Ingredients:

3.5oz Chocolate, 75% cocoa

Ingredients:

3.5oz Chocolate, 76% cocoa

4 Scores similar to
each other

large beam
width 未解决

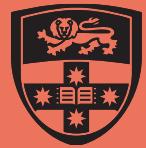


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Graph Search



Exhaustive

Greedy

Beam search

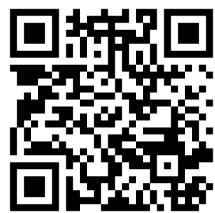
Graph Search

Dynamic

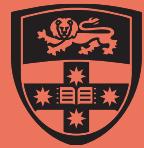
Programming

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We can also treat the problem as a search task and use graph theory



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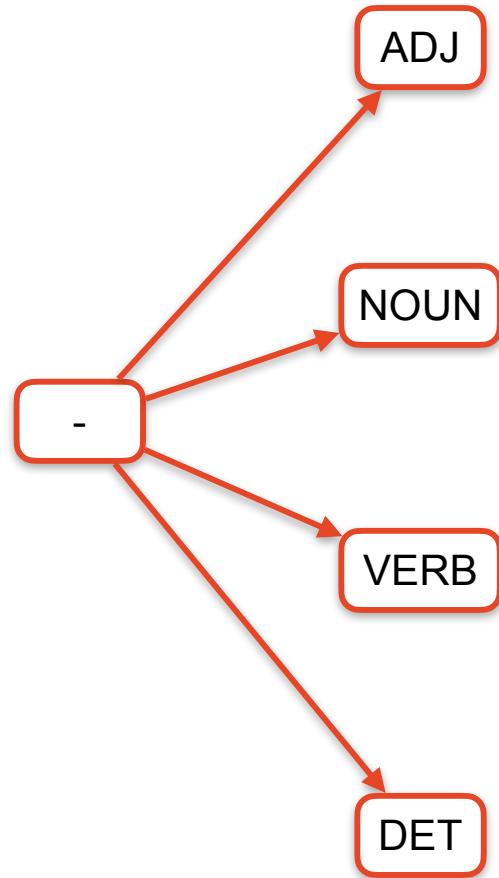


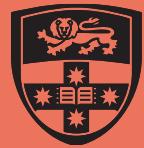
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We can also treat the problem as a search task and use graph theory



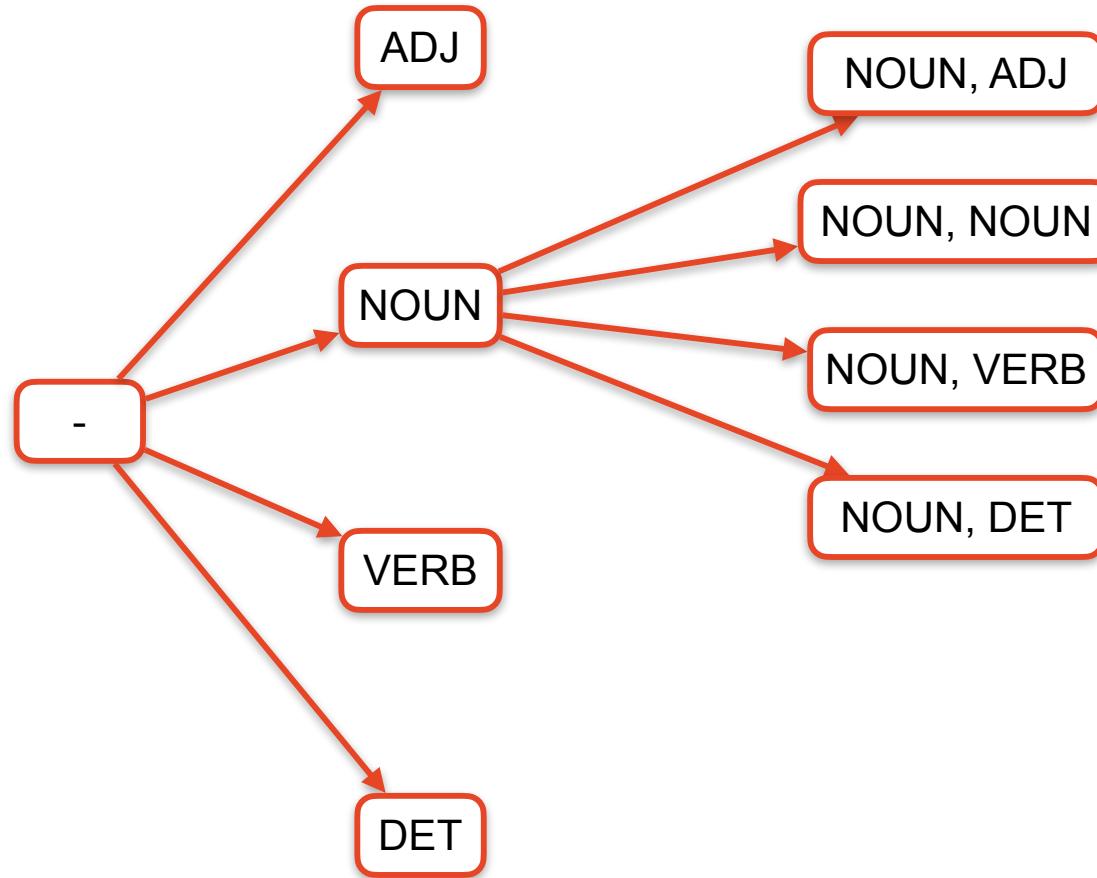


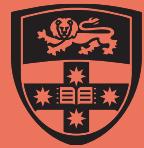
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We can also treat the problem as a search task and use graph theory



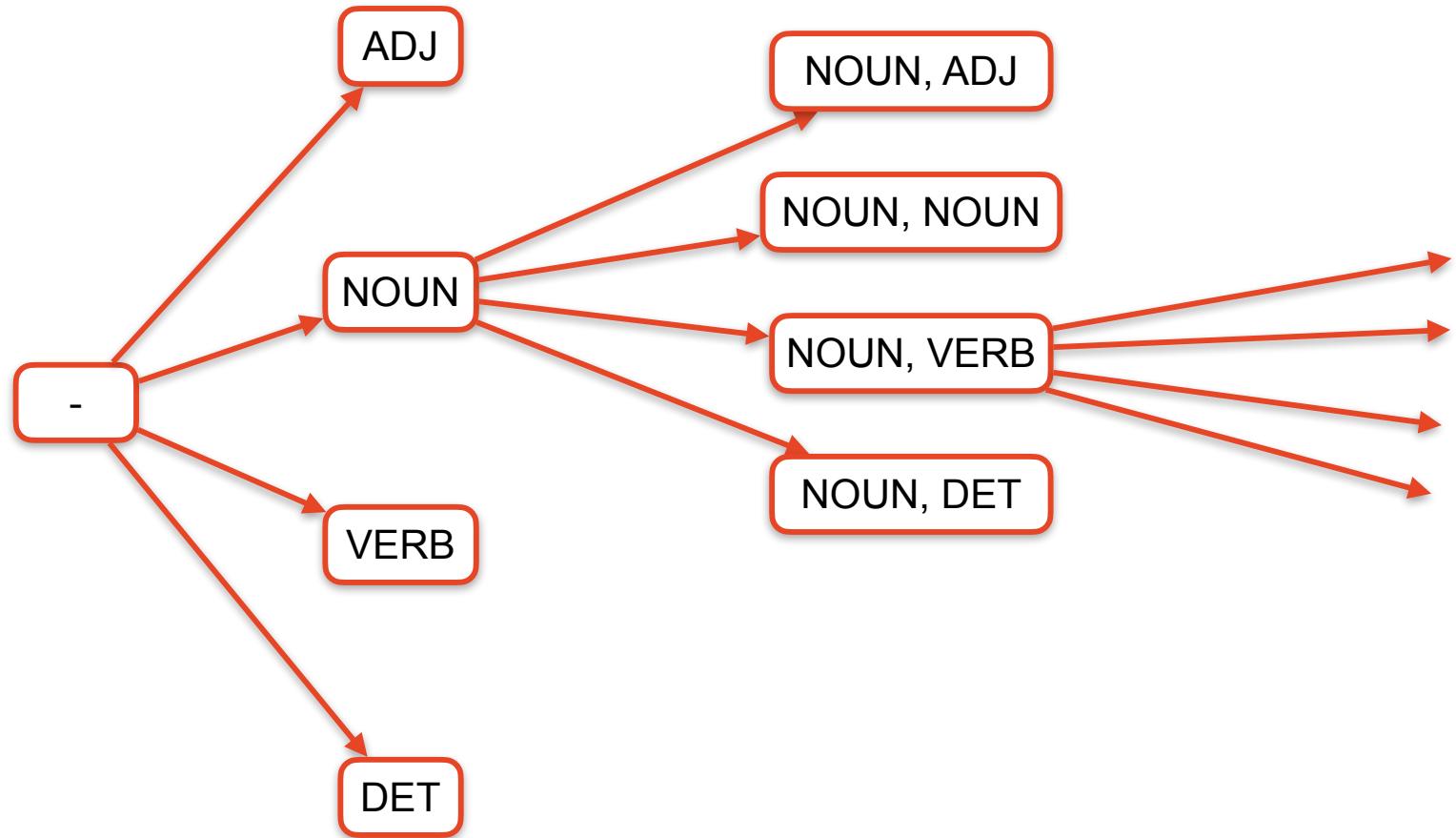


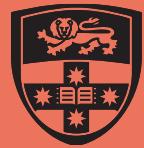
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We can also treat the problem as a search task and use graph theory





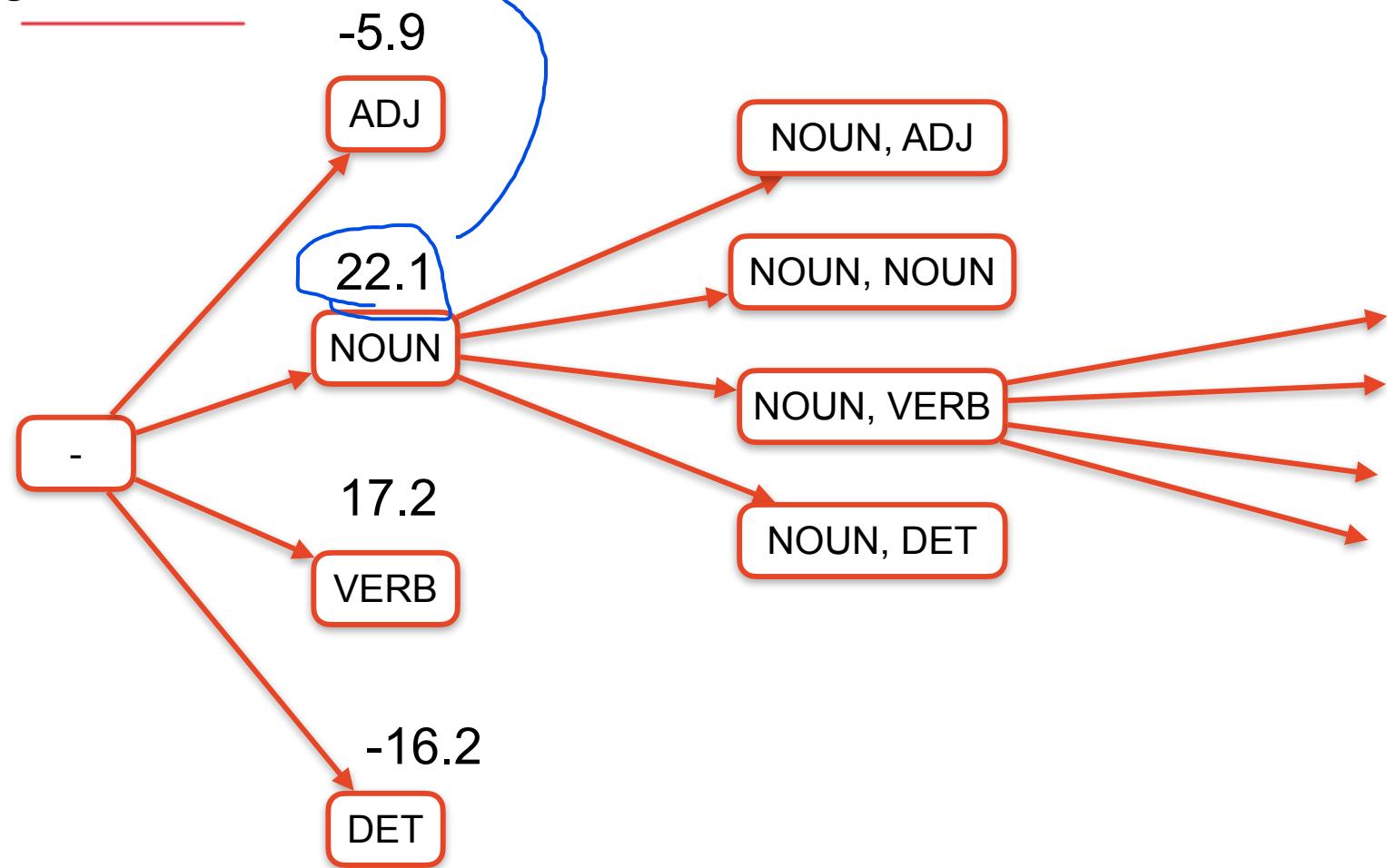
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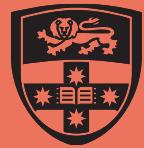


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greedy search visualization

Core idea: Estimate final score and use that to guide generation





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Core idea: Estimate final score and use that to guide generation

Ingredients:

4oz Chocolate, 70% cocoa

1cup Milk

Chocolate shavings

Steps:

1. Melt chocolate on stove

2. Slowly add milk

3. Heat until simmering

4. Take off heat and let cool

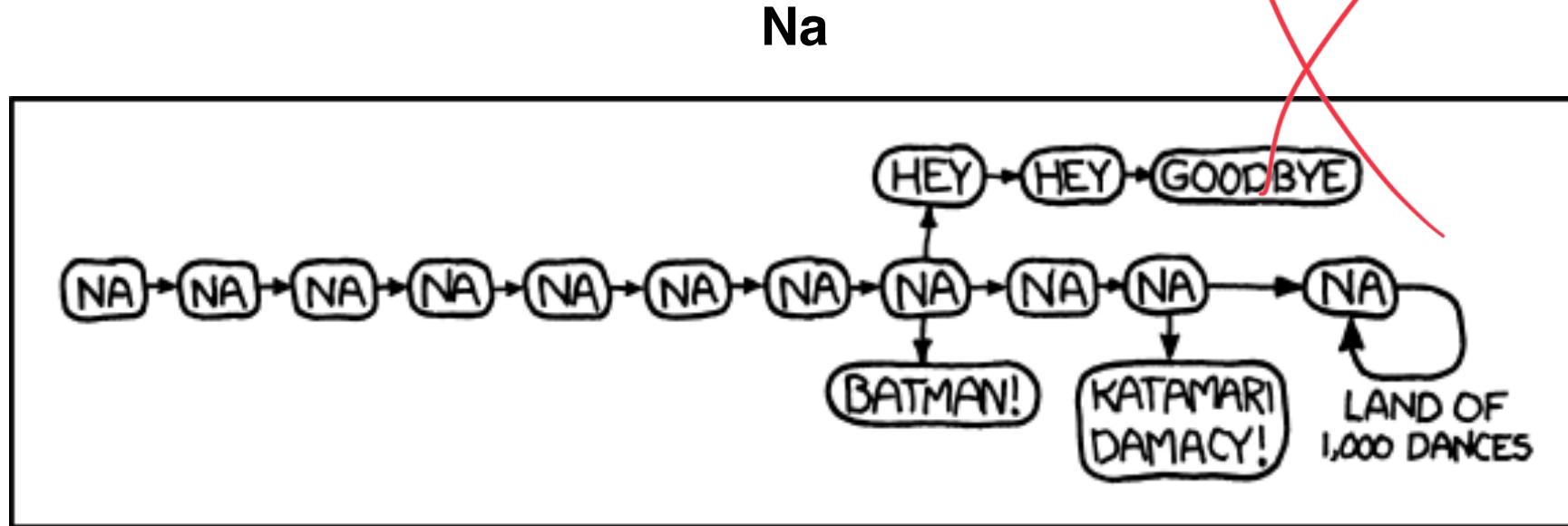
Note - if you learned about A* search, this sounds similar, but there we are finding the shortest path, here we want the largest score.

Score of generation so far

Estimate of score to finish

3 minute Break - stretch and visit Menti

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[I hear that there are actual lyrics later on in Land of 1,000 Dances, but other than the occasional "I said," I've never listened long enough to hear any of them.]

Source: <https://xkcd.com/851/>



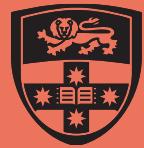
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Lecture 4, 2025

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Lab Preview



Implement an RNN in PyTorch

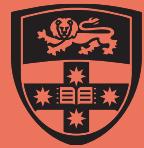
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Pre-work: Reading and example RNN code

Workshop: Implementing the RNN from lecture 3



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Muddy Card

Open shortly, closes at 7:05pm

[https://saipll.shinyapps.io/
student-interface/](https://saipll.shinyapps.io/student-interface/)



If you do not wish to participate in the study, use
the Ed form instead

Go to Ed → Lessons → Muddy Cards Lecture 4