Reliable text generation through graph search

CSE 373

Sean Welleck | 11.21.2022

Motivation

Modeling and generating language

- Language encapsulates ideas.
- Factual knowledge
  - *Molly Seidel won the* ☐ *medal in the 2020 Olympic marathon.*
- State of the art **language model**: ..... Today's lecture
  -

I am a highly intelligent question answering bot.

Q: Who was president of the United States in 1955?
A: Dwight D. Eisenhower was president of the United States in 1955.

Q: Molly Seidel won which medal in the 2020 Olympic marathon?
A: Molly Seidel won a bronze medal in the 2020 Olympic marathon.

Motivation

Modeling and generating language

- Language encapsulates ideas.
- Common sense
  - *I tipped the bottle. As a result,* [ ]
- State of the art GPT-3 language model:
  - **I will continue your sentence based on my common-sense understanding of the world:**

    I tipped the bottle. As a result, the drink spilled out.

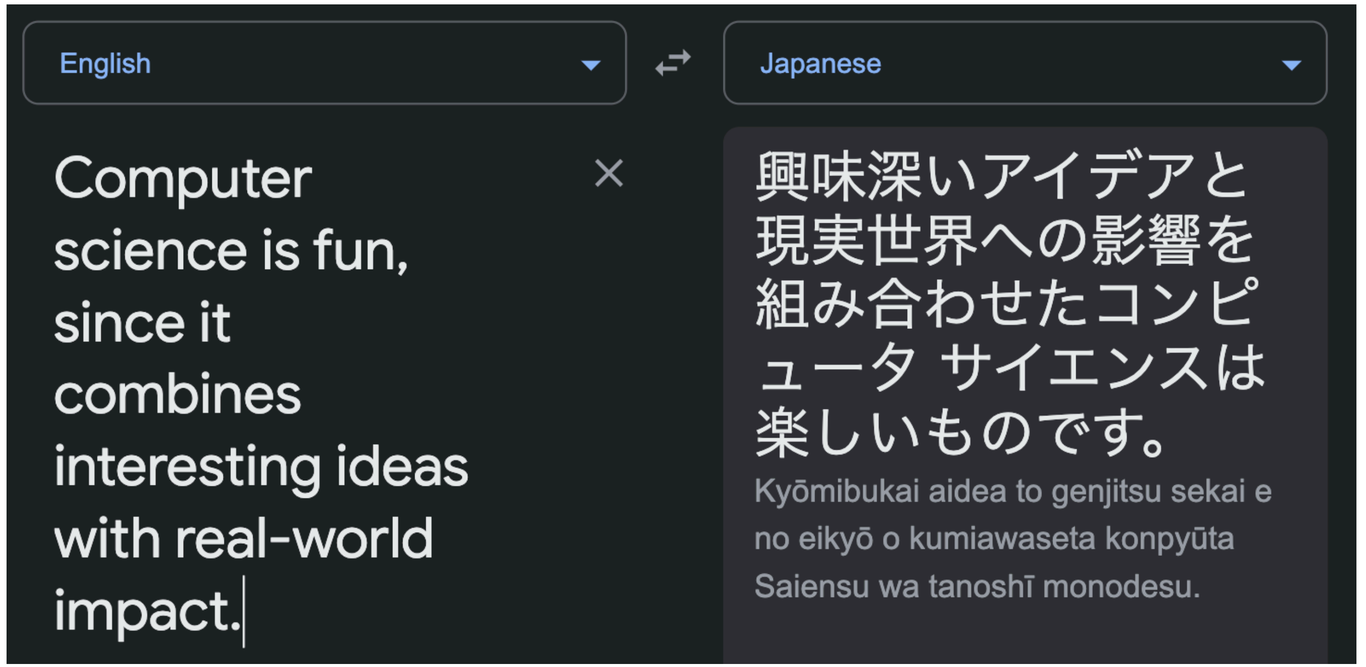
Motivation

Modeling and generating language

- **Generating** language is **useful**.
- Dialogue
  - **You: What have you been up to?**
    Friend: Watching old movies.
    You: Did you watch anything interesting?
    Friend: Yes, I watched The Omen and Troy.

Motivation

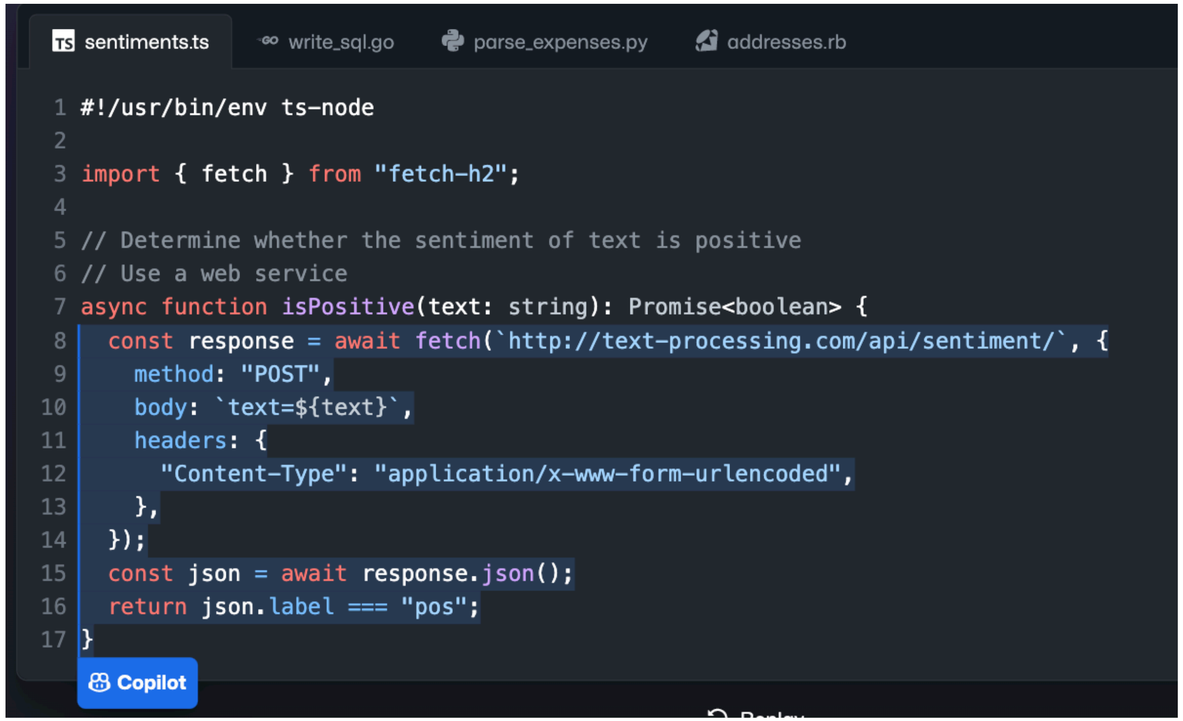
Modeling and generating language

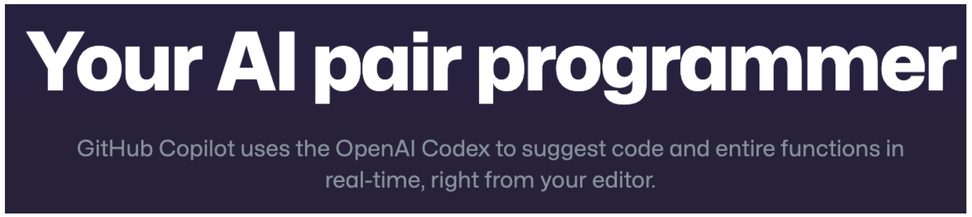
- **Generating** language is **useful**.
- Machine translation
  - 

Motivation

Modeling and generating langue

- **Generating** language is **useful**.
- Programming assistants





Today's lecture

A common *language modeling* recipe underlies all of these applications.

Open-Ended Generation

Build next-gen apps with OpenAI's powerful models.

OpenAI's API provides access to GPT-3, which performs a wide variety of natural language tasks, and Codex, which translates natural language to code.

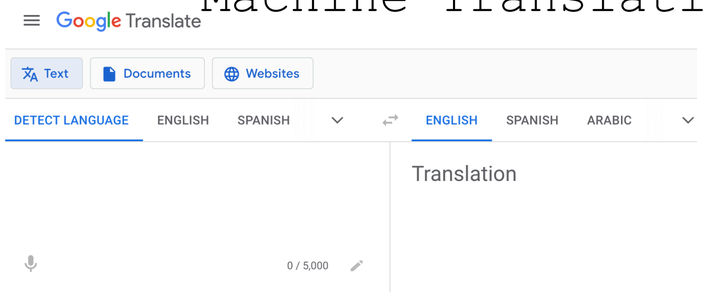
Long-form QA

How has technological growth increased so exponentially in the last 50 years?

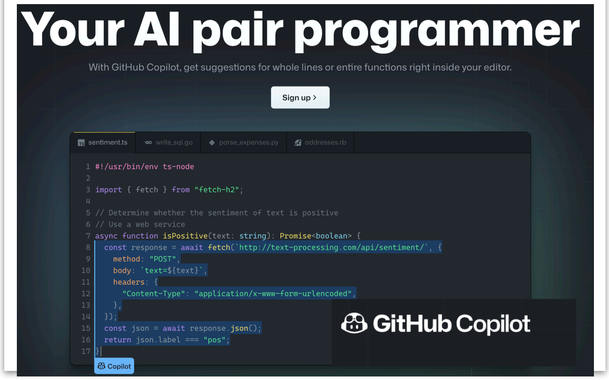
175B best-of-64

There are many explanations for the exponential growth in technology in the last century. One explanation is that the pace of technological progress speeds up exponentially over time because of a common force driving it forward[3]. Another explanation is that each new generation of technology stands on the shoulders of its predecessors, allowing for improvements that lead to the next generation of even better

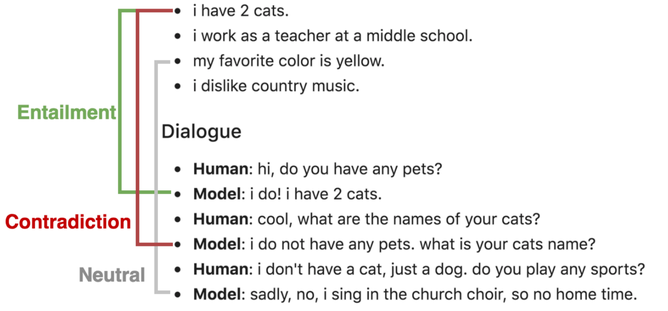
Machine Translation



Program Synthesis

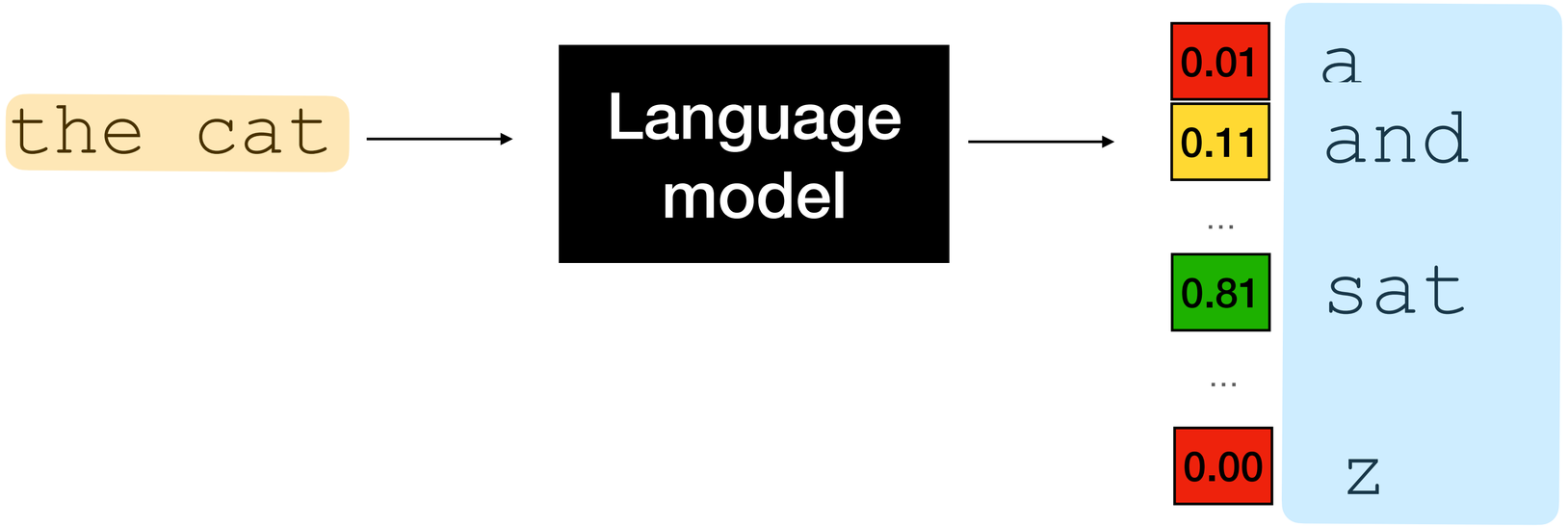


Dialogue



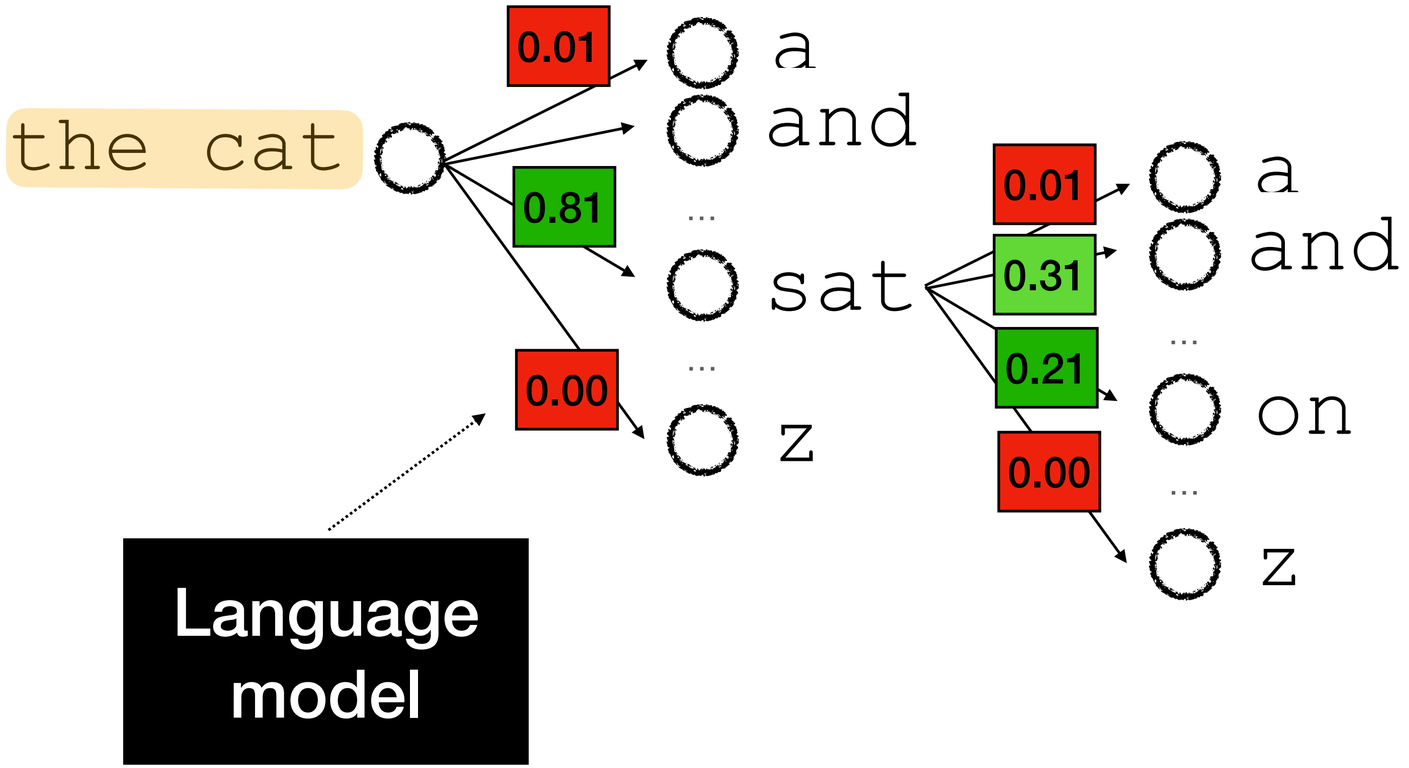
What is a language model?

- Given previous words, scores next-words



How do we generate text?

- Graph search!

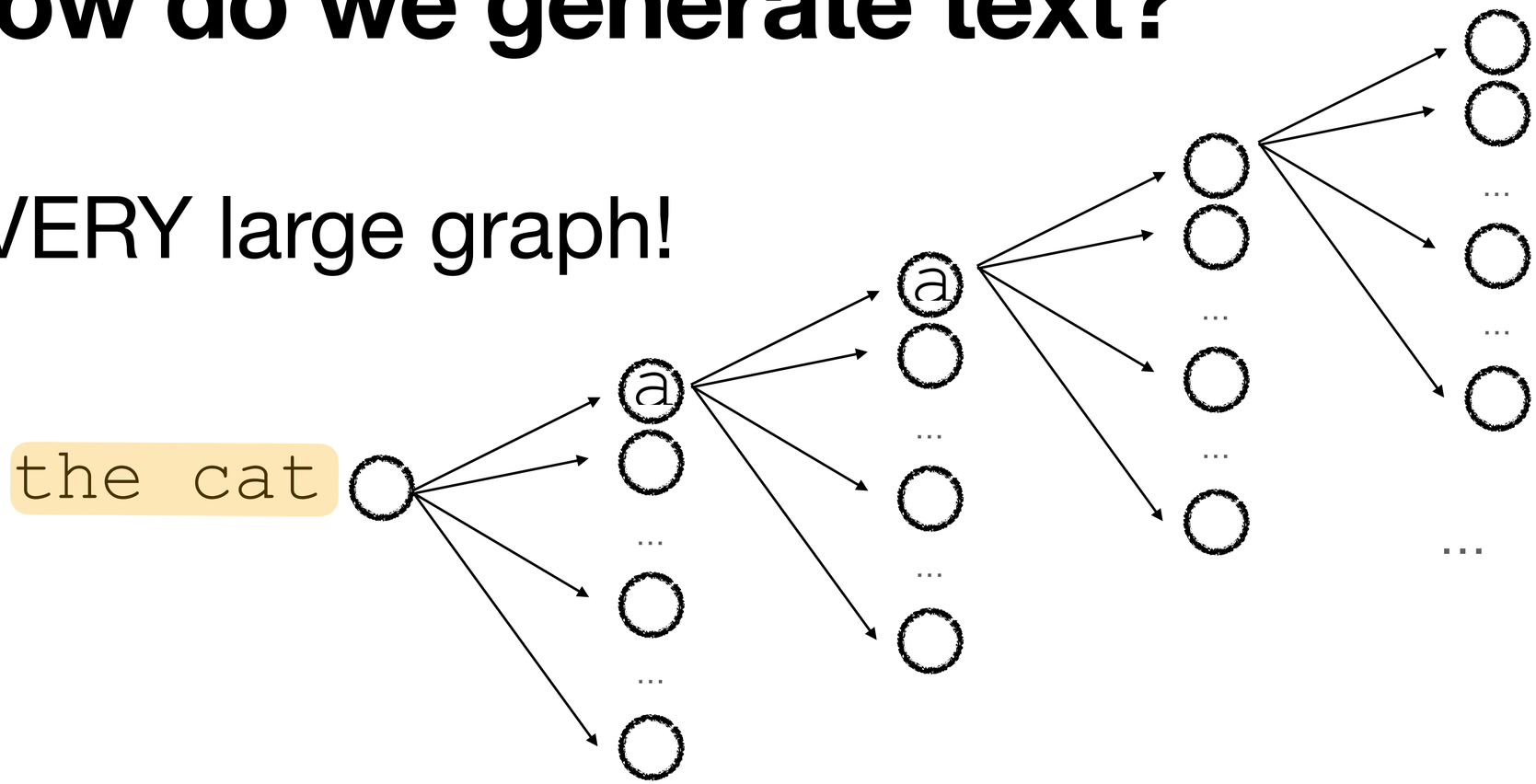


...

the cat sat
on the mat

How do we generate text?

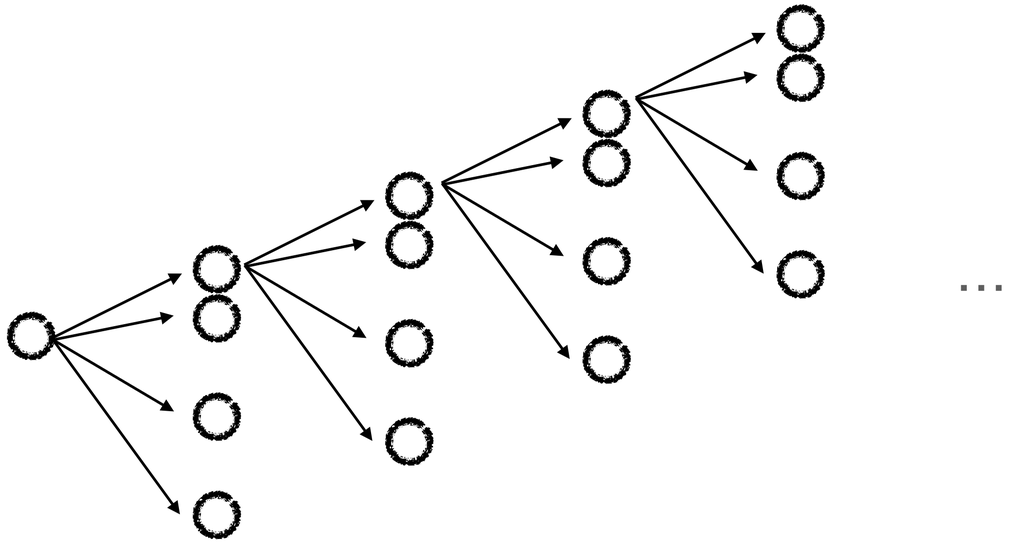
- VERY large graph!



$O(\text{num words}^{\text{sequence length}})$

What if we want the highest-scoring text?

興味深いアイデアと現実世界への影響を組み合わせたコンピュータ サイエンスは楽しいものです。



...

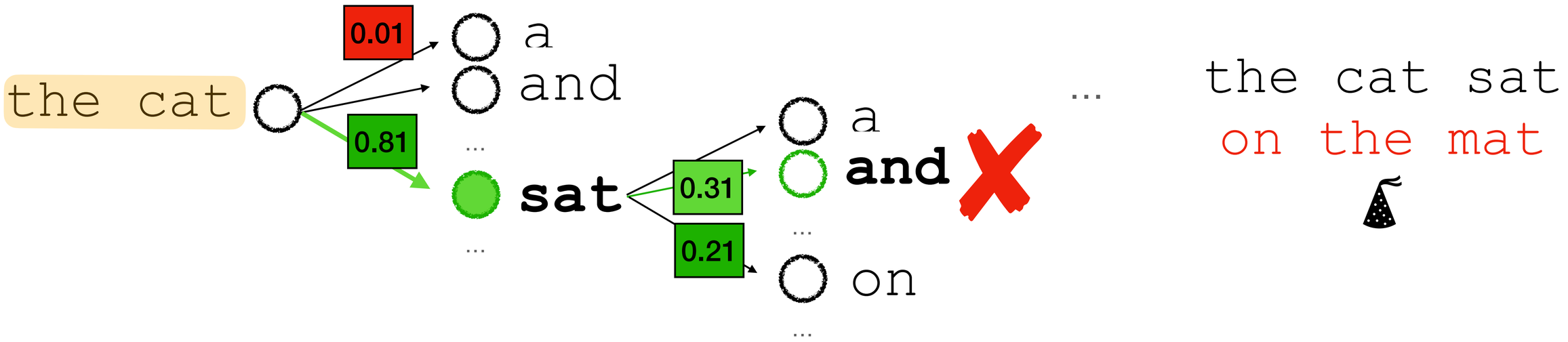
Computer science is fun, since it combines interesting ideas with real-world impact.

$$O(\texttt{num words}^{\texttt{sequence length}})$$

- Scoring all edges with the neural network & selecting maximum is infeasible

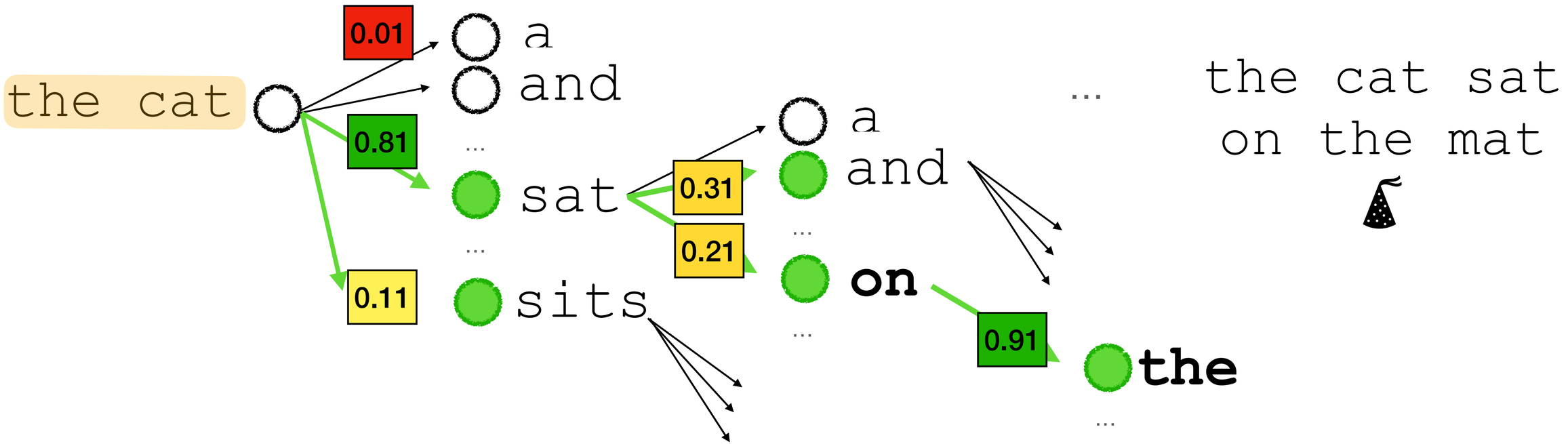
Greedy search

- Choose the highest scoring token at each step

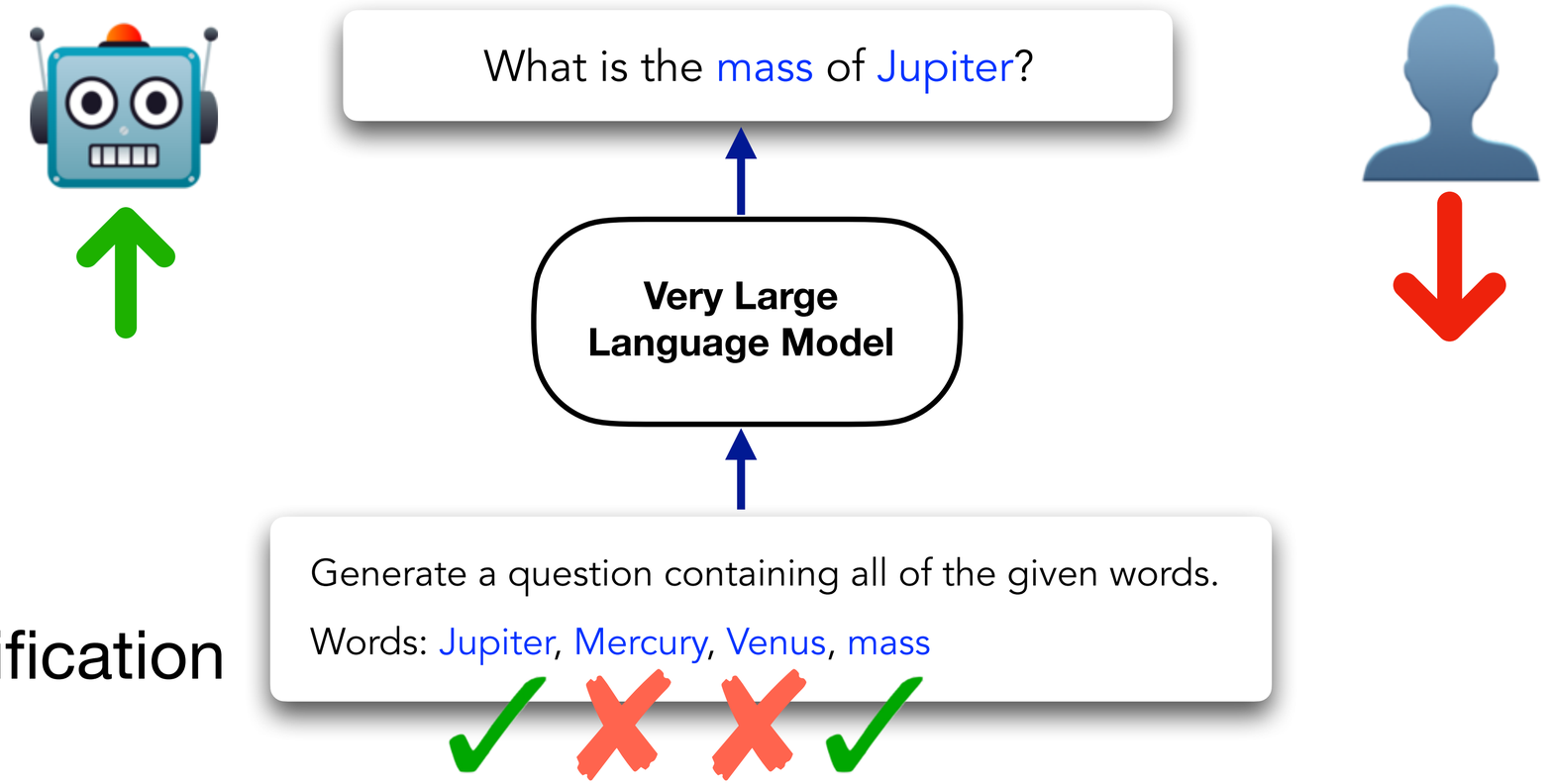


Beam search

- Expand a “beam” of paths at each step



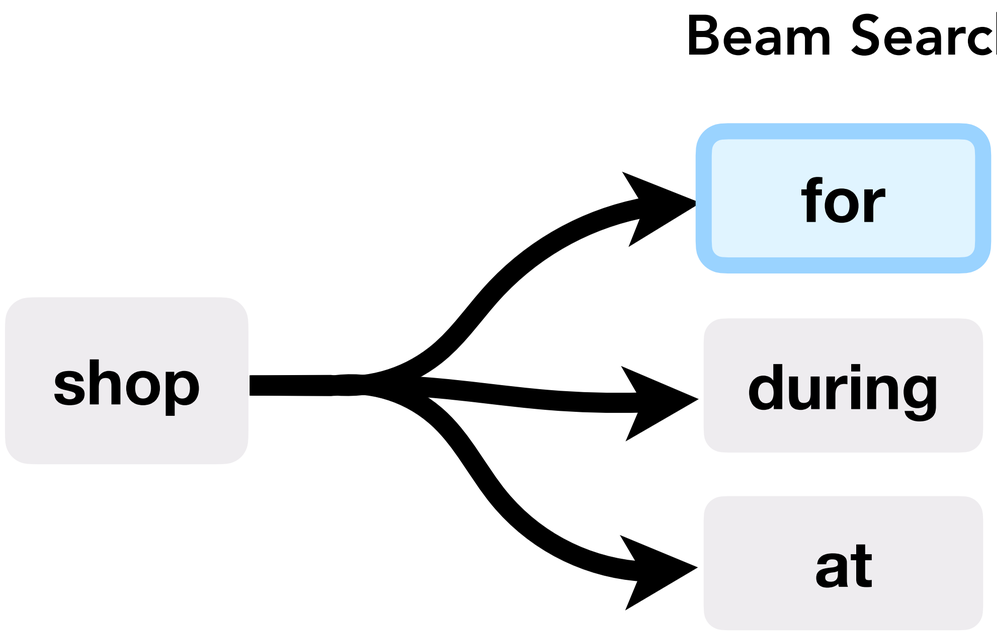
Constrained search



Specification

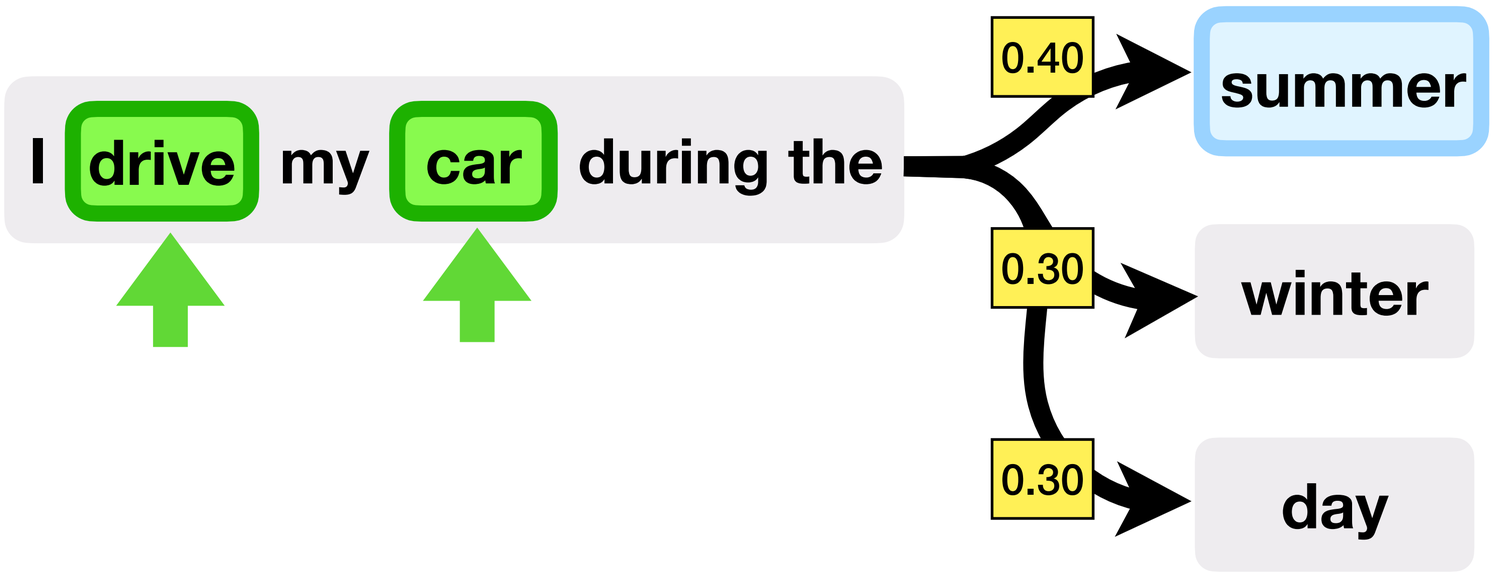
Beam search : no constraints!

Write a sentence with: car ∧ drive ∧ snow



Left-to-right search : myopic!

Write a sentence with: car ∧ drive ∧ snow

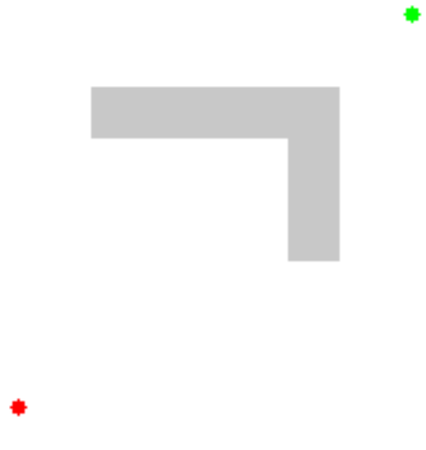


since it's hot outside.

to avoid the snow.

A* search

- A* Search: best-first search with future heuristics
  - $f(n) = \underbrace{s(n)} + \underbrace{h(n)}$
- $s(n)$: score to reach node n
- $h(n)$: estimated cost from n to goal.



A* search

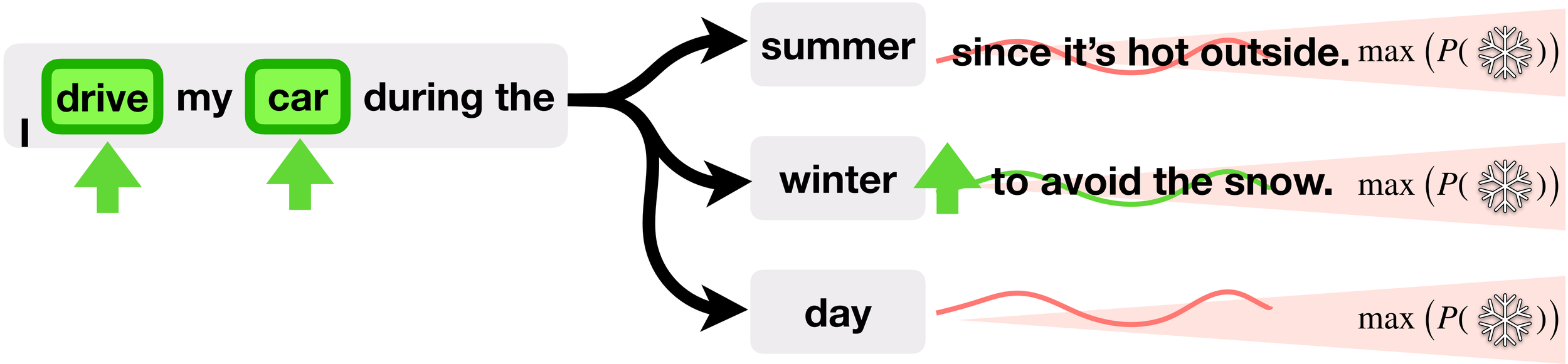
- Initialize priority queue of nodes Q_f
- Until goal reached:
  - Expand best node from Q_f
  - Score and add the node's neighbors to Q_f

$Q_f : O(\texttt{num words}^{\texttt{sequence length}})$ storage

Use a beam instead : "A*esque" search

NeuroLogic A*-Esque Decoding [Lu et al 2022]

Write a sentence with: car ∧ drive ∧ snow



Constraints: {sponge, pour, pool, side, clean}
Example output: Pour water on a sponge and use it to clean the side of the pool.

$(\textbf{sponge} \vee \textbf{sponges}) \wedge (\textbf{pour} \vee \textbf{pours} \vee \textbf{pouring} \vee \textbf{poured}) \wedge (\textbf{pool} \vee \textbf{pools}) \wedge (\textbf{side} \vee \textbf{sides}) \wedge (\textbf{clean} \vee \textbf{clean} \vee \textbf{cleans} \vee \textbf{cleaning})$

C

beam search

The woman, whose name has not been released, was taken to a local hospital, where she was listed in stable condition, according to the sheriff's office.

completely irrelevant

NeuroLogic

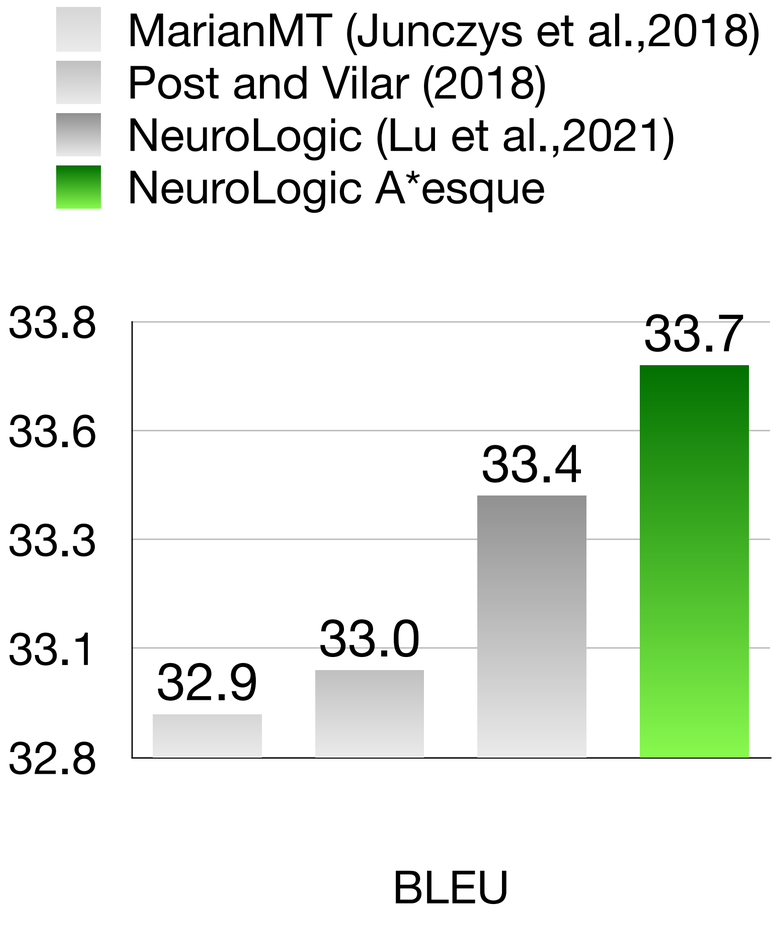
The man cleans a sponge in a pouring pool at the side of the road.

slightly awkward

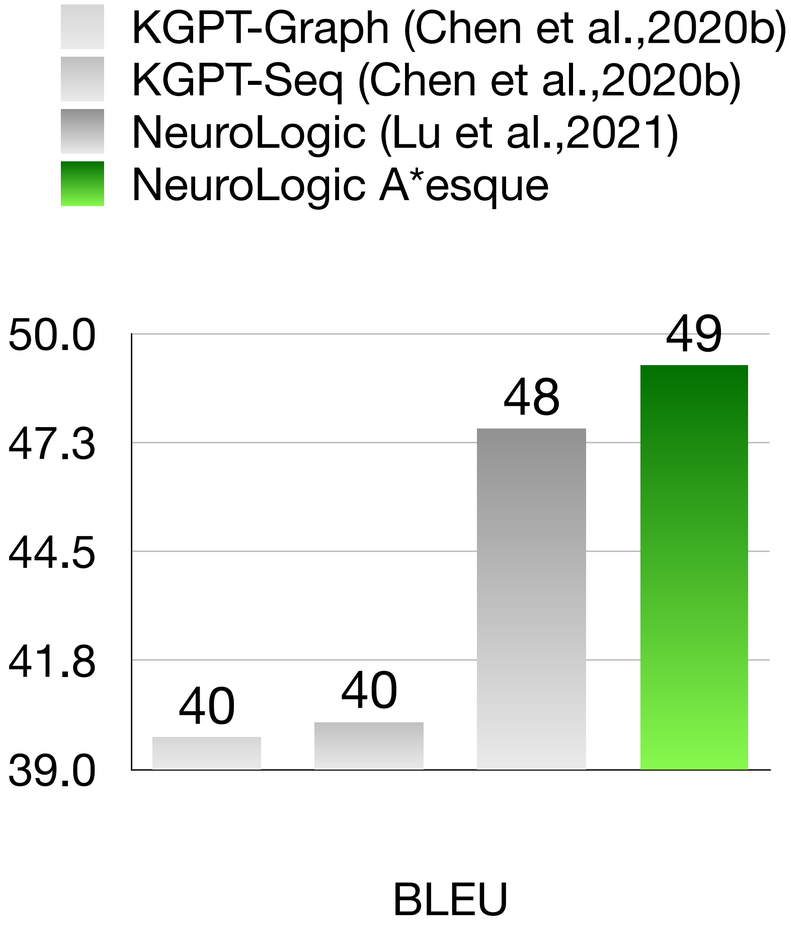
A* NeuroLogic

The boy cleaned the side of the pool with a sponge, and poured water over it .

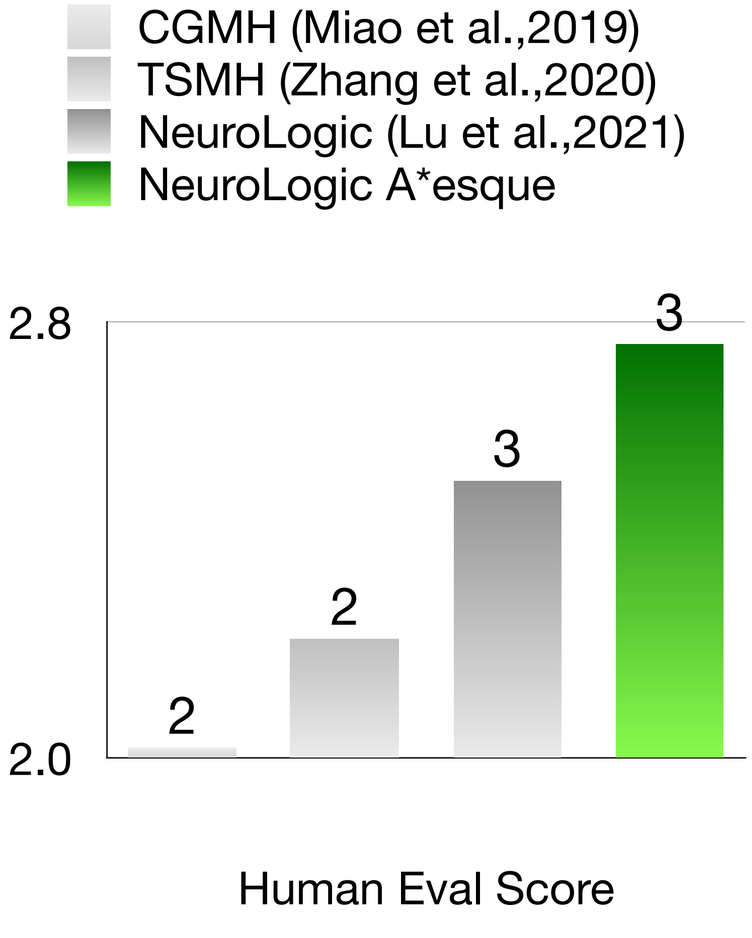
Constrained MT
(Dinu et al., 2019)



Few-Shot E2ENLG
(Chen et al., 2020)



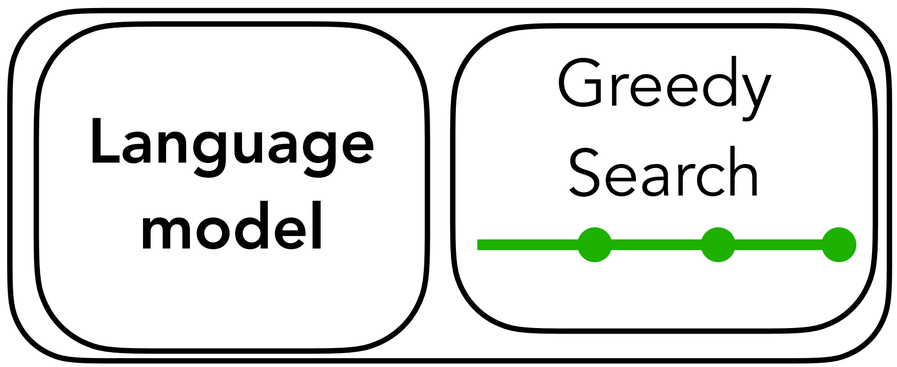
Question Generation
(Zhang et al., 2020)



Theorem

Let x be an even integer.

Then $x + 5$ is odd.



Proof by Contradiction: Aiming for a contradiction, suppose $x + 5$ is even.

Then there exists $r \in \mathbb{Z}$ such that $x + 5 = 2r$.

But from Odd Integer Plus Odd Integer is Odd, $2r + 1$ is odd.

The result follows by Proof by Contradiction.

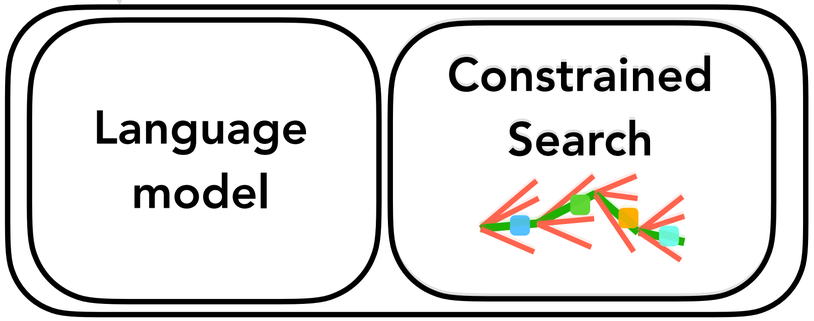
Fake theorem

Invalid reasoning

Theorem

Let x be an even integer.

Then $x + 5$ is odd.



Even Integer

Odd Integer

Integer

Proof by Contradiction

Proof by Contradiction: Aiming for a contradiction, suppose $x + 5$ is even.

Then there exists an integer k such that $x + 5 = 2k$.

This contradicts the premise that x is even.

Hence, by Proof by Contradiction, $x + 5$ is odd.

- **Stepwise Stochastic Beam Search**
  [Welleck et al 2022]

  - Beam-search over arbitrary-length segments with a constraint scoring function.

Recap

- Text generation is graph search!
  - Searching for a path in a directed graph of tokens
  - Edges: scored by a neural language model
- **New search algorithms** : higher quality, constraint satisfaction, etc.

Thanks for your attention!