Decoding Strategies

Greedy & Beam Search

Learning goals

- Get to know deterministic decoding strategies
- Learn how text is generated with greedy search and beam search
- Understand how beam search tries to fix the drawbacks of greedy search

GREEDY SEARCH (1)

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- **Core idea**: Greedy search selects the word with the highest probability at each timestep, iteratively building the output sequence
- **Exploration of search space**: It explores a single path through the output space, favoring the most probable word at each step without considering future consequences
- **Candidate Sequence**: Only keeps track of the most likely sequence at each step, discarding other possibilities
- **Decision Making**: It makes local decisions based solely on the highest probability at the current step without considering potential longer-term outcomes

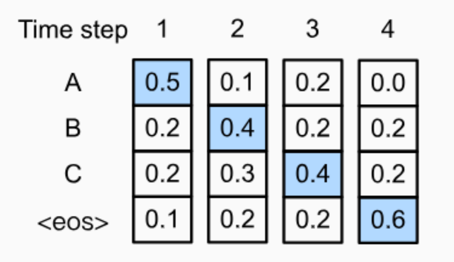
GREEDY SEARCH (2)

- The model accepts an input sequence of tokens $x_1, x_2, ..., x_N$, which we also call prompt
- The model then generates a token at each timestep t until T: $y_1, y_2, ..., y_T$
- In greedy search we choose the token with the highest conditional probability from the vocabulary V
- $y_t = argmax_{y \in V} P(y|y_1, y_2, ..., y_{t-1}, \mathbf{x})$
- With y_t being the chosen token at timestep t and $\mathbf{x} = (x_1, x_2, ..., x_N)$ being the initial prompt

GREEDY SEARCH: EXAMPLE

▸ d2l book

- Suppose our vocabulary only has four tokens: *A*, *B*, *C* and <eos>

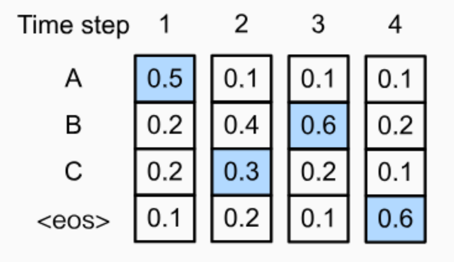


Time step	1	2	3	4
A	0.5	0.1	0.2	0.0
B	0.2	0.4	0.2	0.2
C	0.2	0.3	0.4	0.2
<eos>	0.1	0.2	0.2	0.6

- At each timestep greedy search chooses the token with the highest conditional probability
- The model thus predicts *A*, *B*, *C*, <eos>
- Its probability is $0.5 \cdot 0.4 \cdot 0.4 \cdot 0.6 = 0.048$

DRAWBACKS OF GREEDY SEARCH (1)

- Now we select token *C* at timestep 2 instead of *B*



Time step	1	2	3	4
A	**0.5**	0.1	0.1	0.1
B	0.2	0.4	**0.6**	0.2
C	0.2	**0.3**	0.2	0.1
<eos>	0.1	0.2	0.1	**0.6**

- At the timesteps 3 and 4 the conditional probabilities change since the context is no longer *A*, *B* but *A*, *C*
- The final token sequence is *A*, *C*, *B*, <eos>
- Its probability is $0.5 \cdot 0.3 \cdot 0.6 \cdot 0.6 = 0.054$
- Even though *C* at $t = 2$ has a lower probability, the final sequence has a higher probability

DRAWBACKS OF GREEDY SEARCH (2)

- **Suboptimal Global Solutions**: It makes decisions based only on the highest probability token at each step, often missing globally optimal solutions
- **Lack of Diversity**: It generates repetitive and predictable text, leading to bland outputs
- **Incoherence in Long Sequences**: It may produce incoherent text over longer sequences due to losing track of the overall context
- **Repetitiveness**: The lack of diversity leads to repetitive phrases, especially in longer texts
- **Overemphasis on Common Phrases**: It favors common words and phrases, resulting in overly generic outputs

BEAM SEARCH

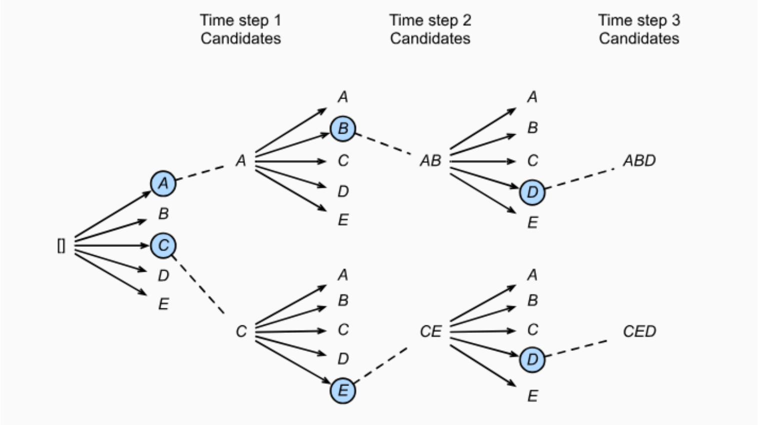
▸ Codelabs Academy

- **Core idea**: Beam search extends the exploration to multiple possible sequences instead of just the most probable one
- **Exploration of search space**: It explores multiple paths (or "beams") simultaneously, maintaining a set of promising candidate sequences
- **Candidate Sequence**: Keeps a fixed number of most probable sequences (determined by the beam width parameter *k*) at each step
- **Decision Making**: At each step, it considers multiple candidate sequences and selects the most probable ones based on their cumulative probabilities up to that point

BEAM SEARCH: EXAMPLE (1)

▸ d2l book

- Suppose $V = \{A, B, C, D, E\}$ and beam width $k = 2$



BEAM SEARCH: EXAMPLE (2)

- At each timestep beam search chooses the k tokens with the highest joint probability
- Suppose at $t = 1$ A and C have the highest conditional probabilities $P(y_1|\mathbf{x})$
- At $t = 2$ for all $y_2 \in V$ we compute:

$$P(A, y_2|\mathbf{x}) = P(A|\mathbf{x}) \cdot P(y_2|A, \mathbf{x})$$
$$P(C, y_2|\mathbf{x}) = P(C|\mathbf{x}) \cdot P(y_2|C, \mathbf{x})$$

- And we again pick the k sequences with the highest probabilities (AB and CE)
- At $t = 3$ again for all $y_3 \in V$ we compute:

$$P(A, B, y_2|\mathbf{x}) = P(A, B|\mathbf{x}) \cdot P(y_2|A, B, \mathbf{x})$$
$$P(C, E, y_2|\mathbf{x}) = P(C, E|\mathbf{x}) \cdot P(y_2|C, E, \mathbf{x})$$

- We repeat this process unitl the maximum length is reached or unitl the <EOS> token gets generated

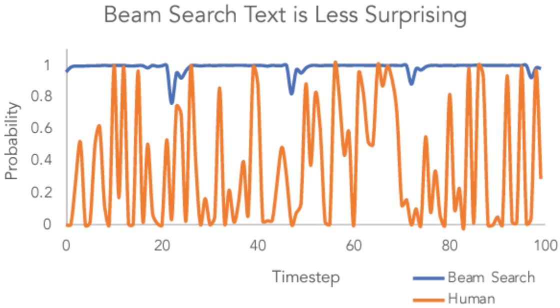
GREEDY SEARCH VERSUS BEAM SEARCH

Prompt: "Once upon a time"

- Greedy search: *", the United States was the world's leading producer of oil and natural gas. Today, we are the world's leading producer of coal. The United States is the world's largest producer of oil and natural gas"*
- Beam search (beam-width 2): *", I had a friend who was a big fan of the show. He was a huge fan of the show, and I was a huge fan of the show. We would talk about the show all the time"*

The generated stories are repetitive, also referred to as *degenerate*. These decoding strategies don't seem to work well for the task, where more creativity and diversity might be desirable.

BEAM SEARCH VS. HUMAN



- Humans typically use words that have a low probabililty
- Beam search though mostly outputs words which have a high probability

⇒ Incorporate some randomness (next chapter)