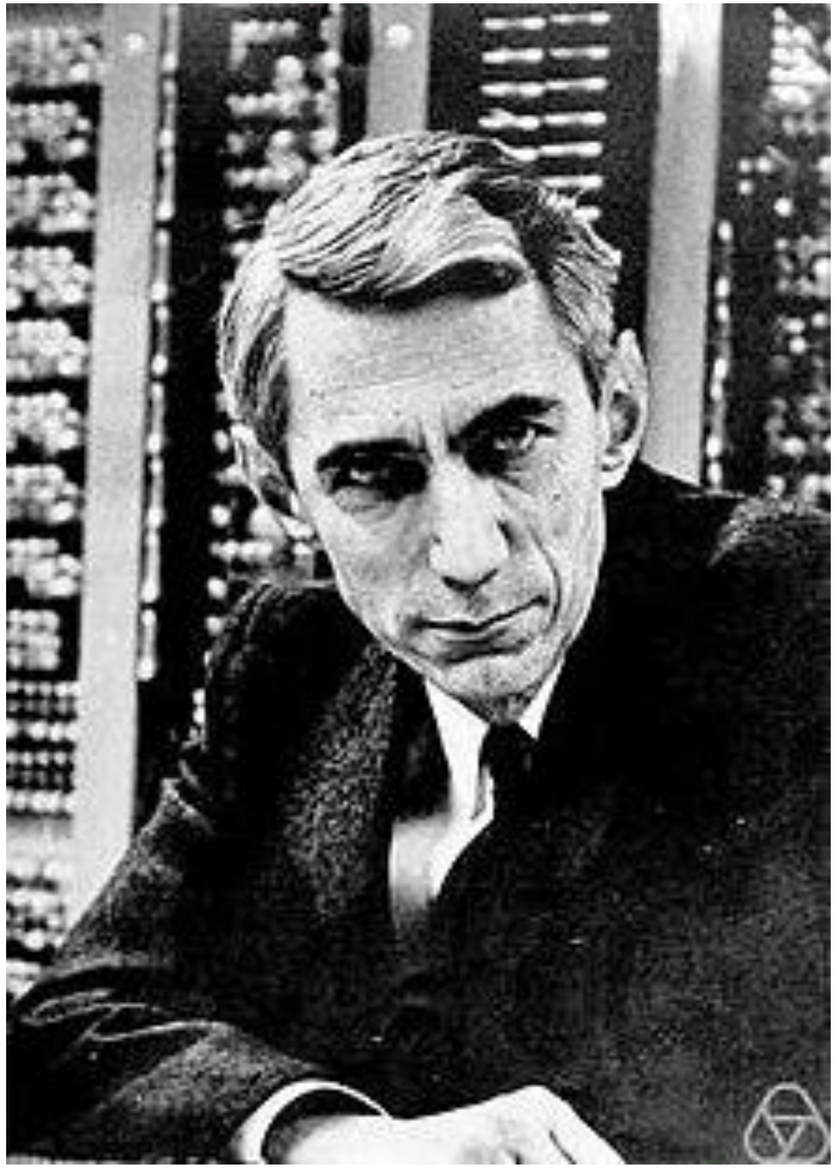
Shannon Revisited: Conditional Histograms and N-grams



Prediction and Entropy of Printed English

By C. E. SHANNON

(*Manuscript Received Sept. 15, 1950*)

A new method of estimating the entropy and redundancy of a language is described. This method exploits the knowledge of the language statistics possessed by those who speak the language, and depends on experimental results in prediction of the next letter when the preceding text is known. Results of experiments in prediction are given, and some properties of an ideal predictor are developed.

Conditional Histograms and N-grams

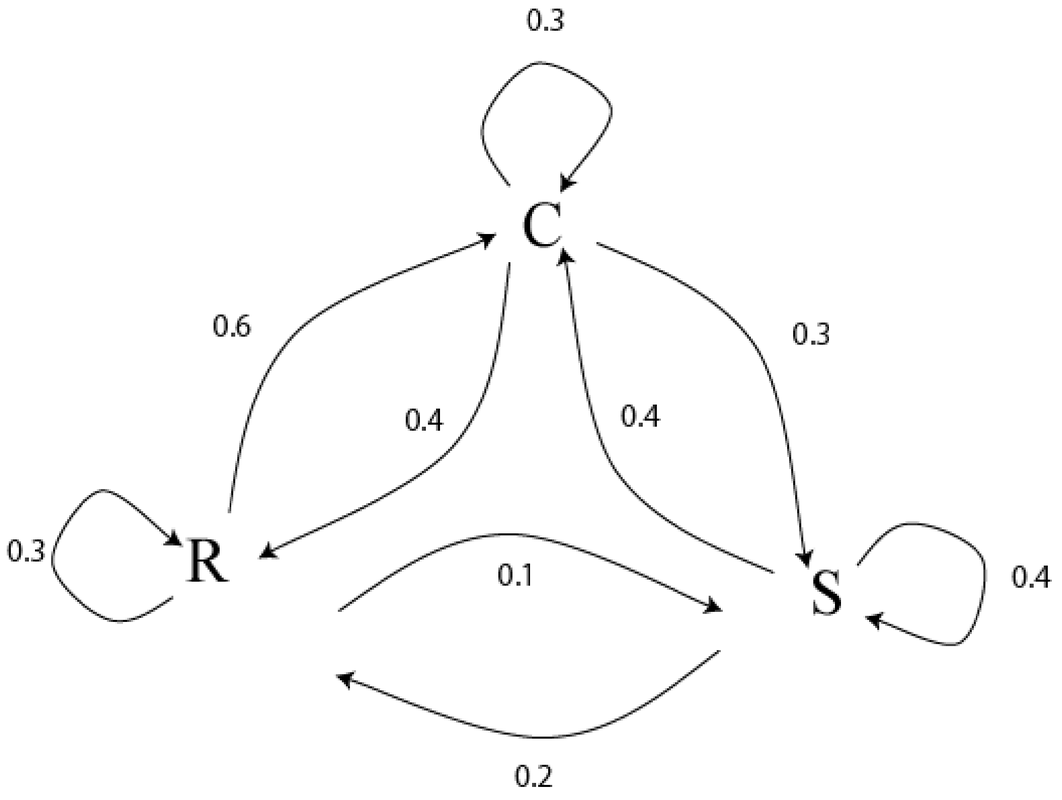
Let’s predict weather:

- Given today’s weather only, we want to know tomorrow’s
- Suppose weather can only be {Sunny, Cloudy, Raining}

The “Weather Channel” algorithm:

- Over a long period of time, record:
  - How often S followed by R
  - How often S followed by S
  - Etc.
- Compute percentages for each state:
  - P(R|S), P(S|S), etc.
- Predict the state with highest probability!
- It’s a Markov Chain

Markov Chain



$$\begin{pmatrix} 0.3 & 0.6 & 0.1 \\ 0.4 & 0.3 & 0.3 \\ 0.2 & 0.4 & 0.4 \end{pmatrix}$$

What if we know today and yestarday's weather?

Text Synthesis

[Shannon,'48] proposed a way to generate English-looking text using N-grams:

- Assume a generalized Markov model
- Use a large text to compute prob. distributions of each letter given N-1 previous letters
- Starting from a seed repeatedly sample this Markov chain to generate new letters
- Also works for whole words

WE NEED TO EAT CAKE

Mark V. Shaney (Bell Labs)

Results (using `alt.singles` corpus):

- *"As I've commented before, really relating to someone involves standing next to impossible."*
- *"One morning I shot an elephant in my arms and kissed him."*
- *"I spent an interesting evening recently with a grain of salt"*

Early one morning the sun was shining I was laying in bed

Wondering if she had changed at all if her hair was still red

Bob Dylan, *Tangled up in Blue*

slide from Steve Seitz's video

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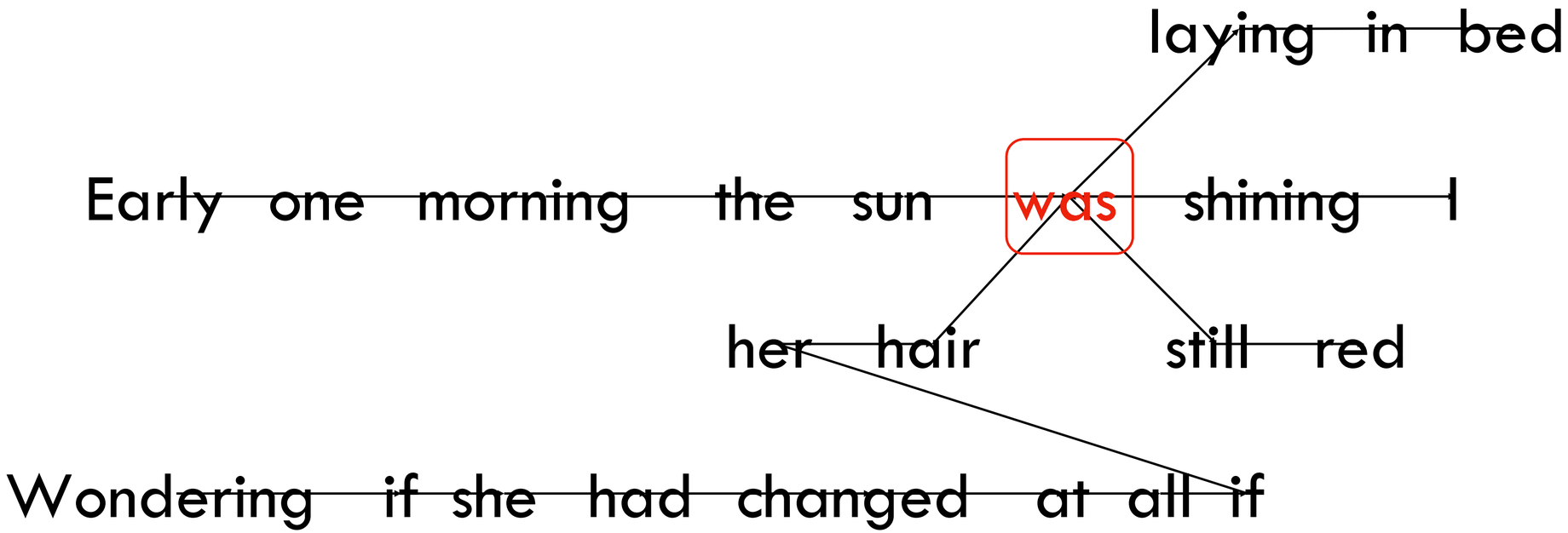

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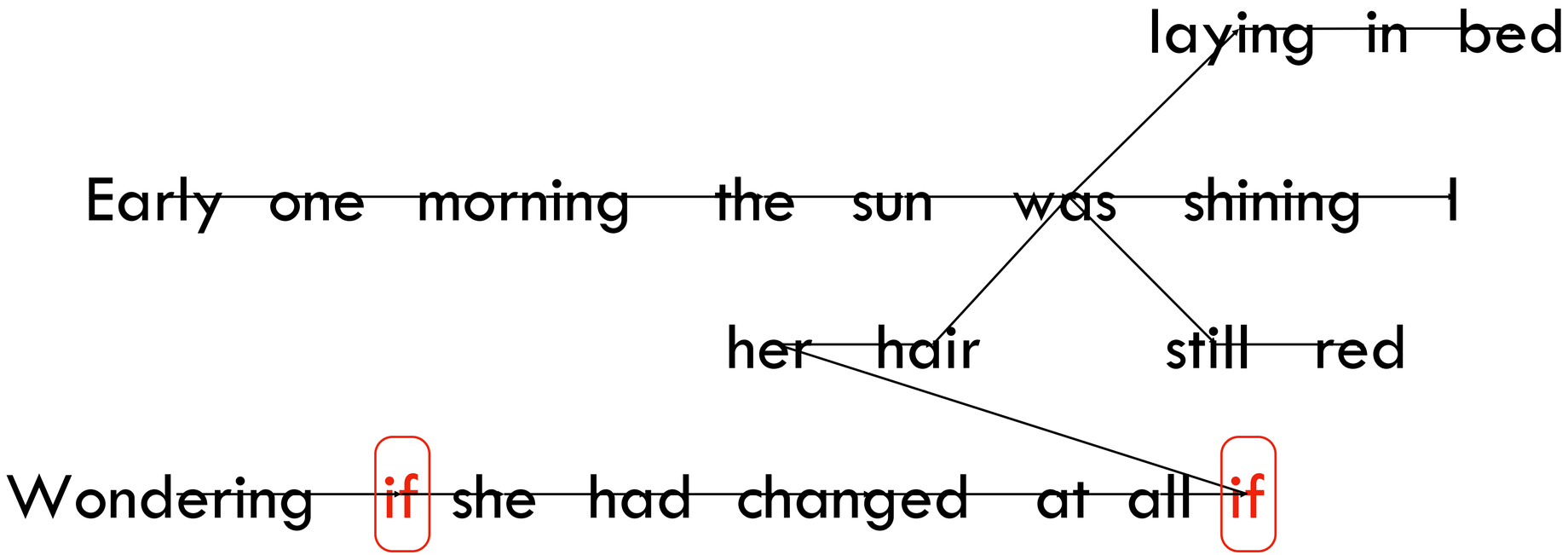

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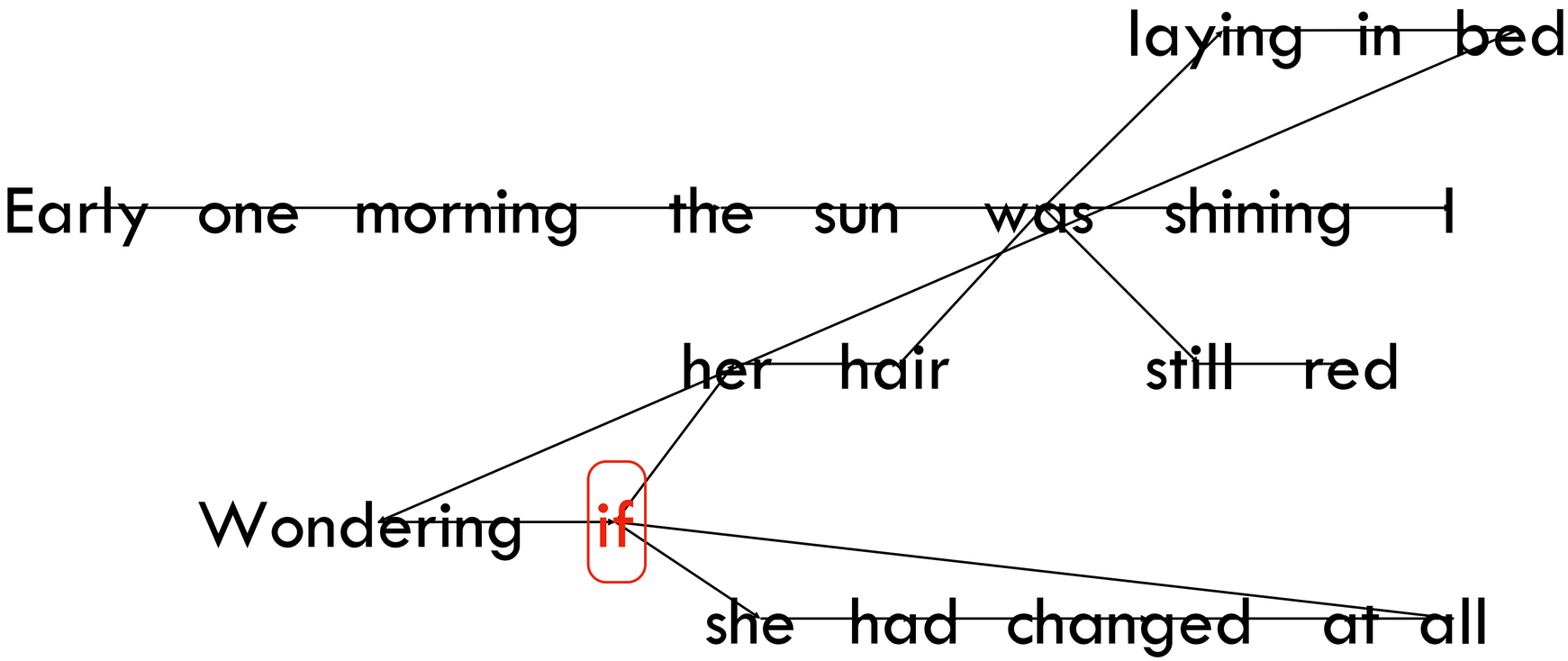

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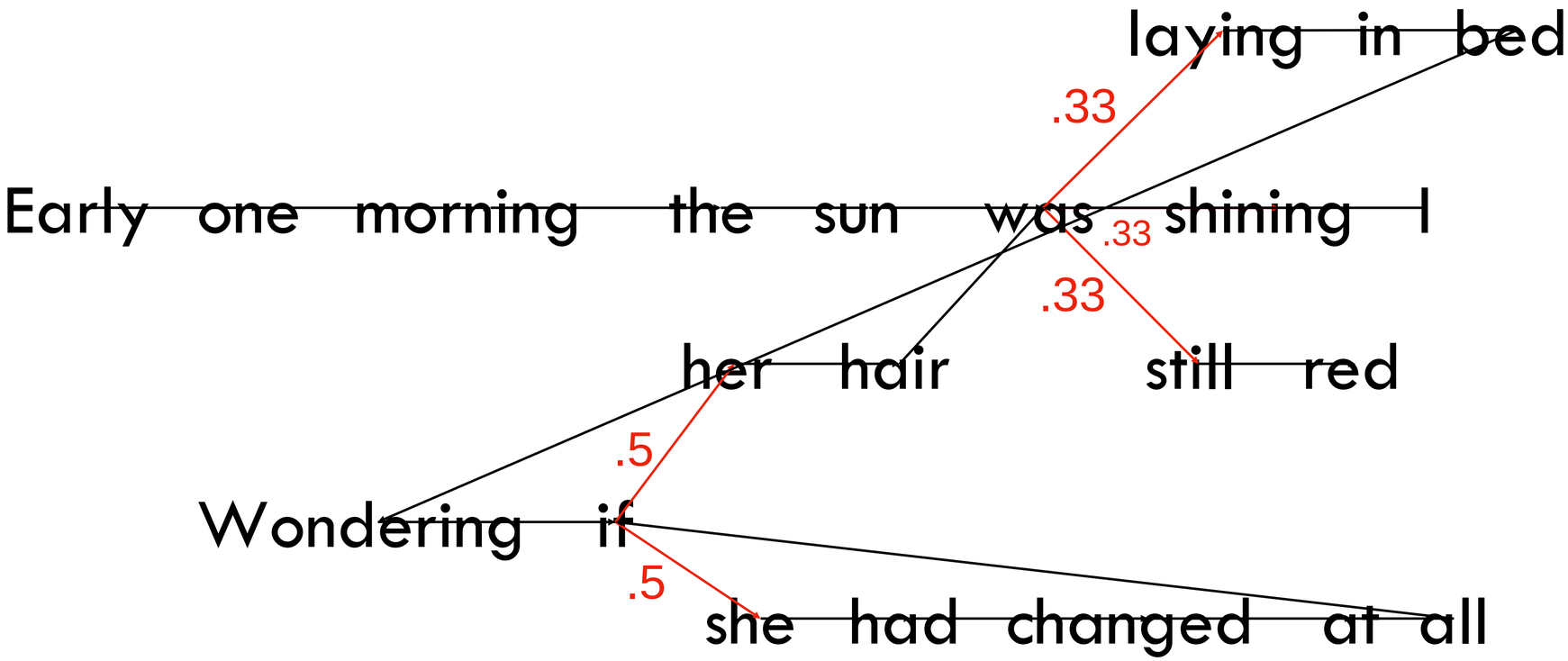

Language Model

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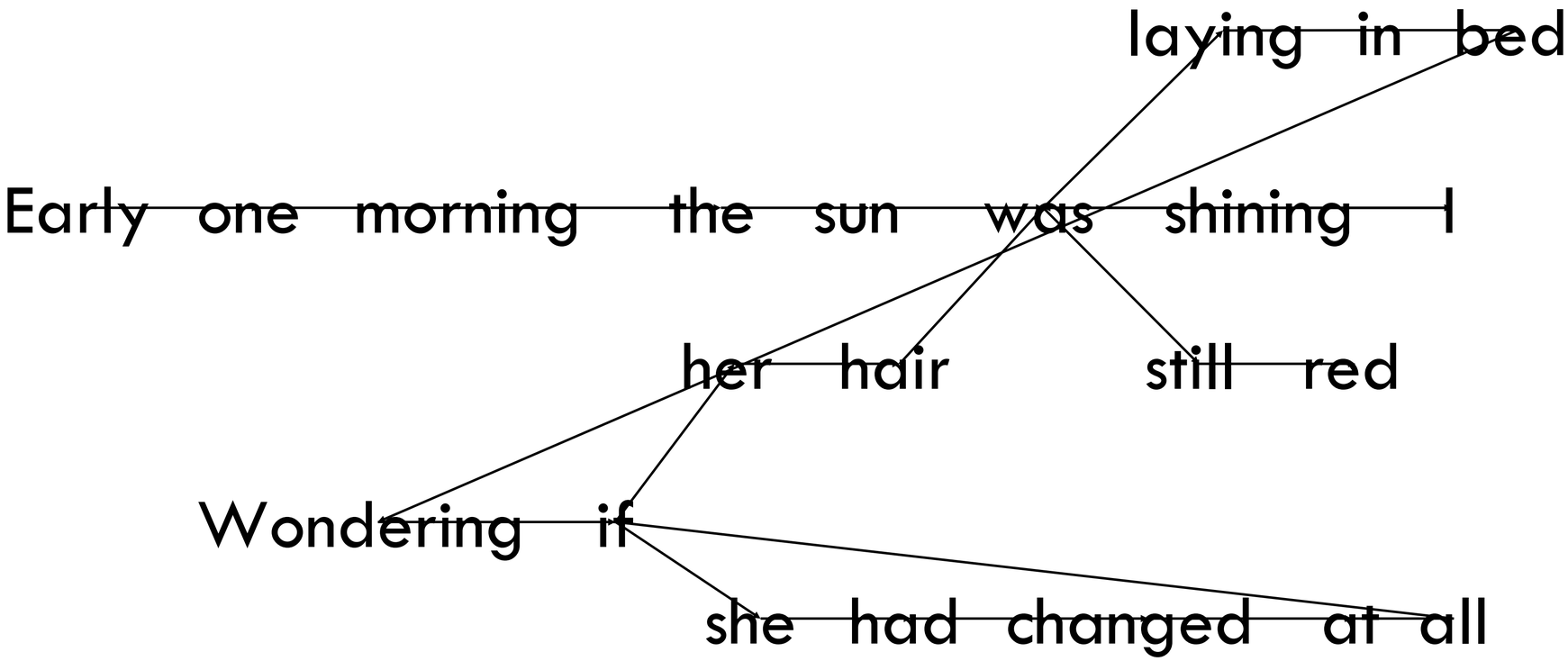

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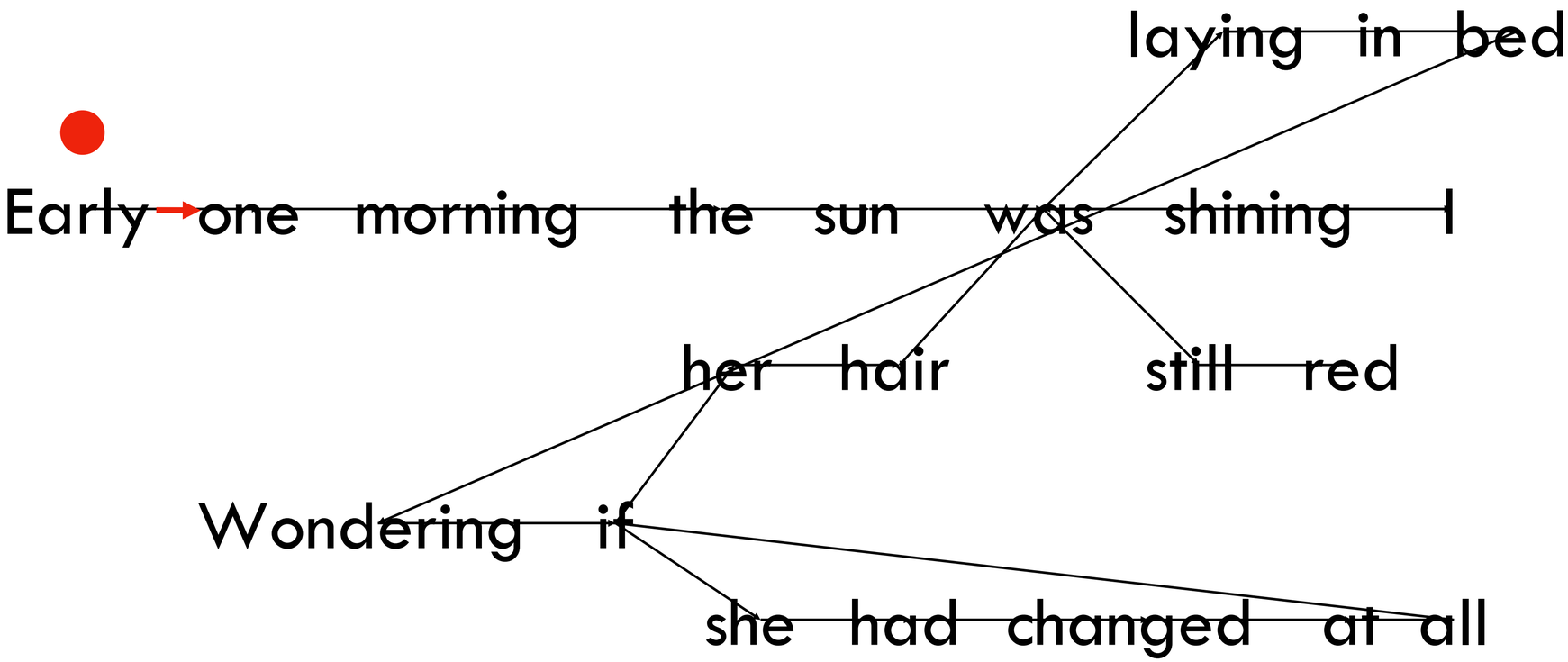
Early



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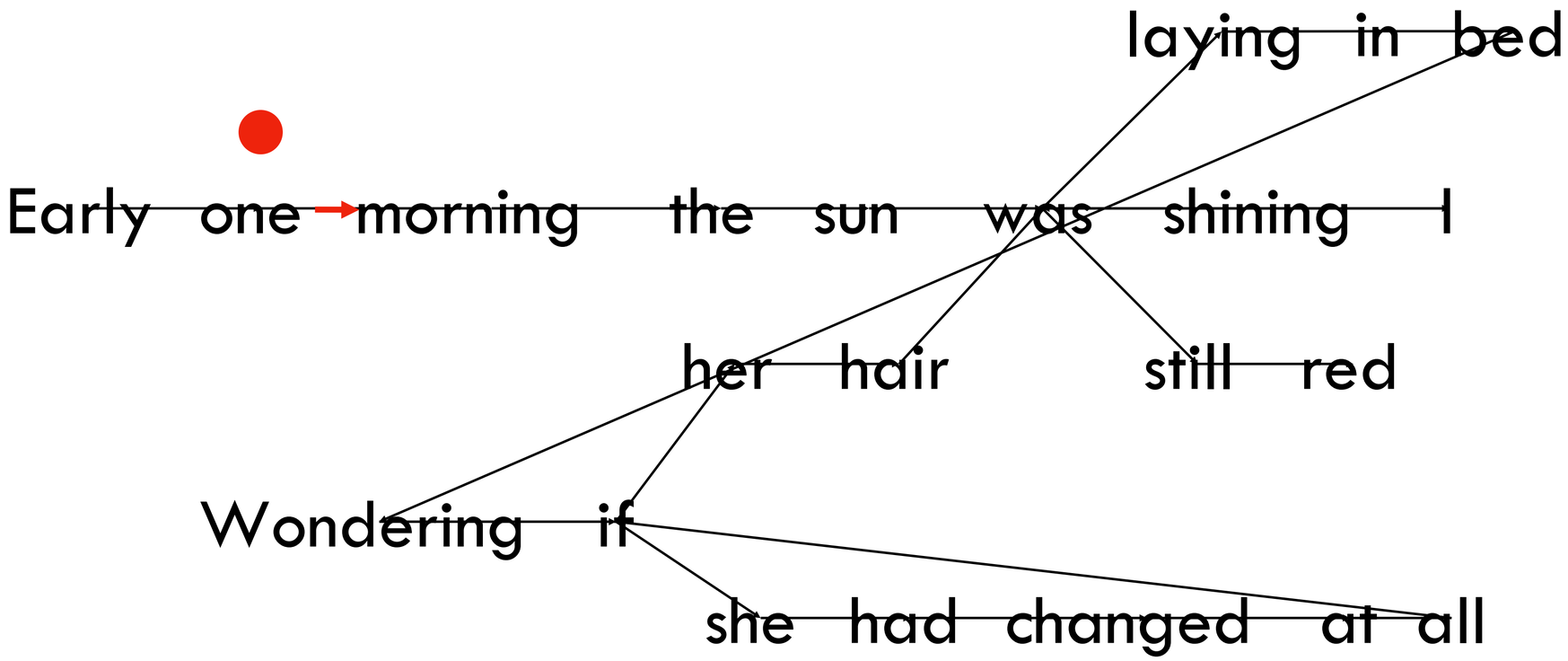
Early one



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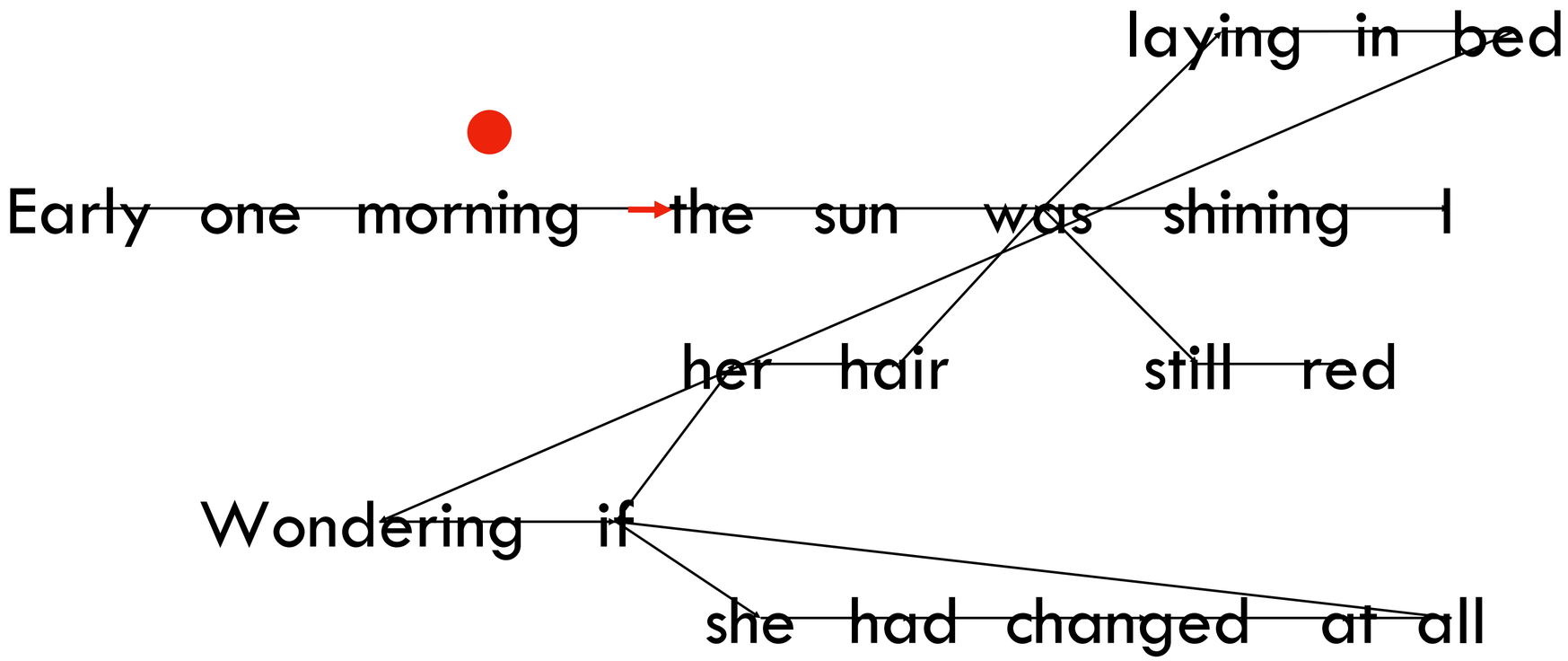
Early one morning



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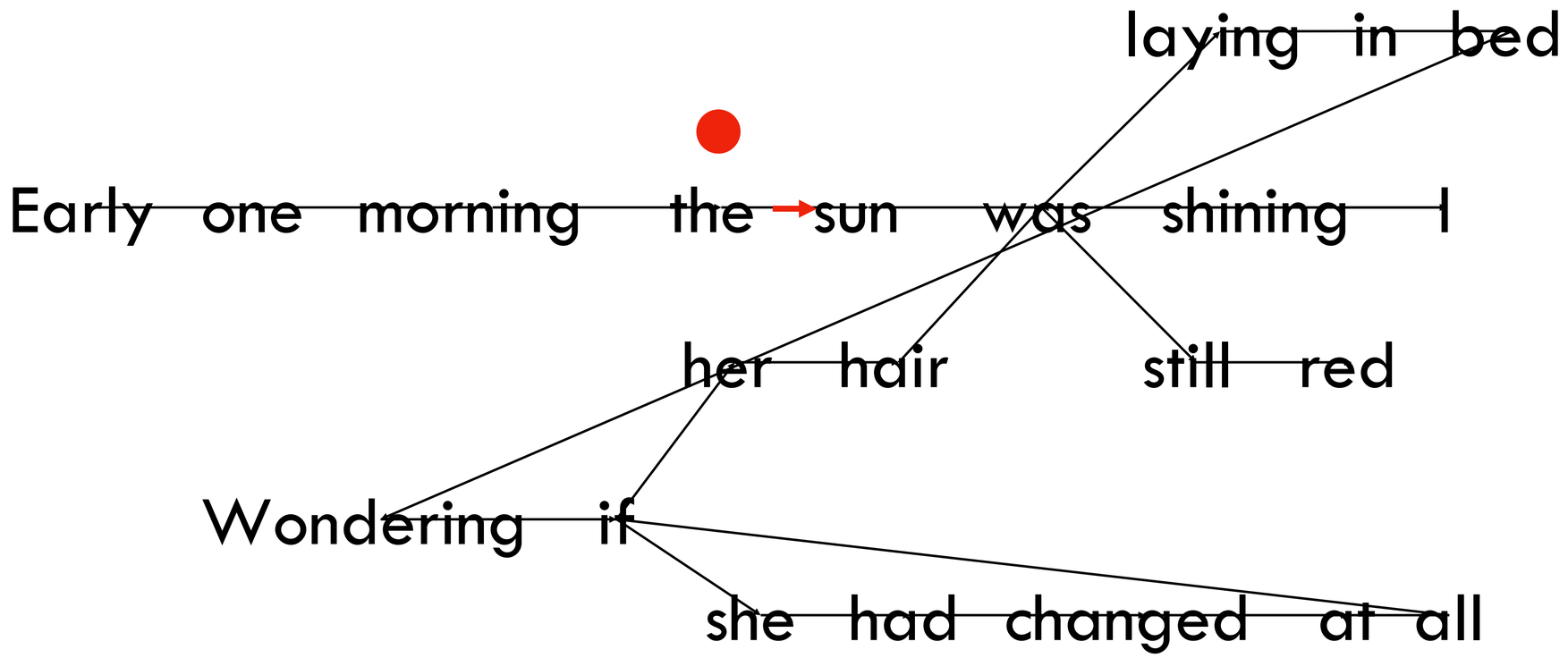

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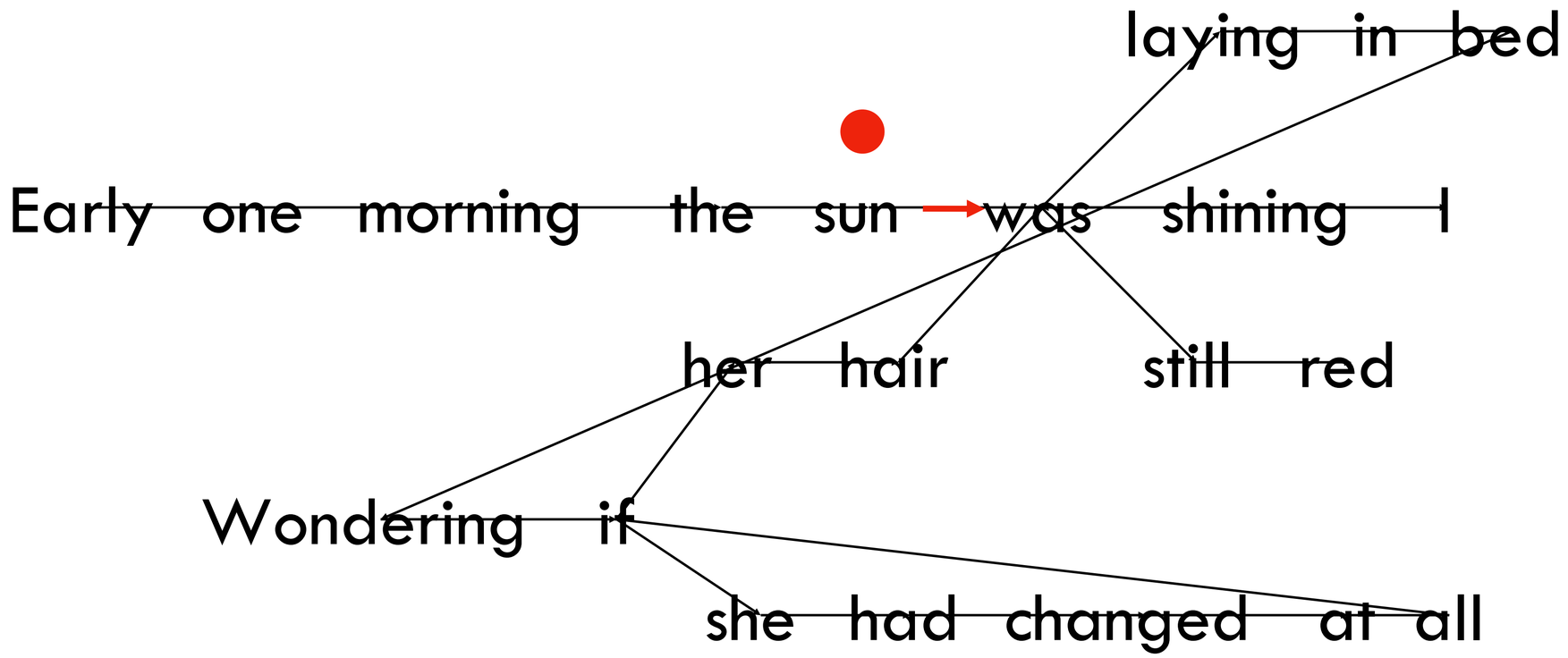
Early one morning the sun



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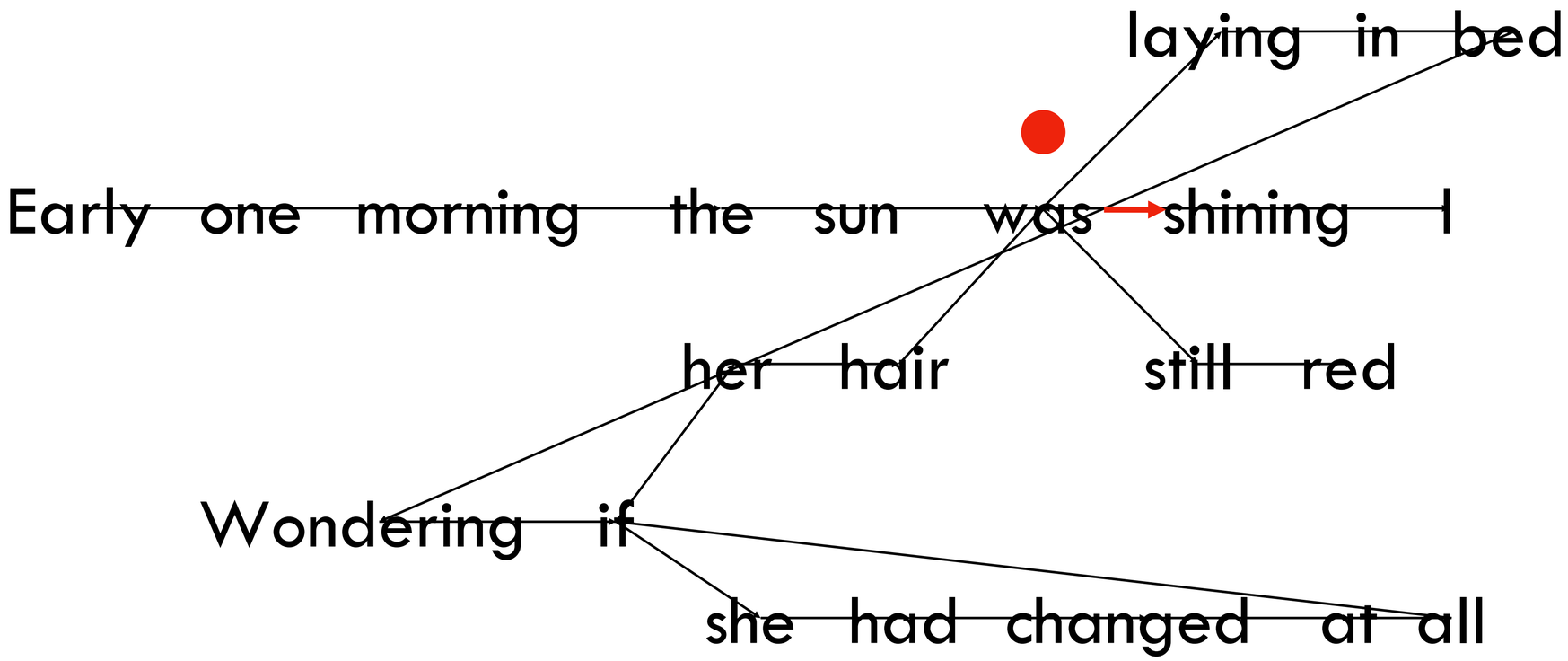

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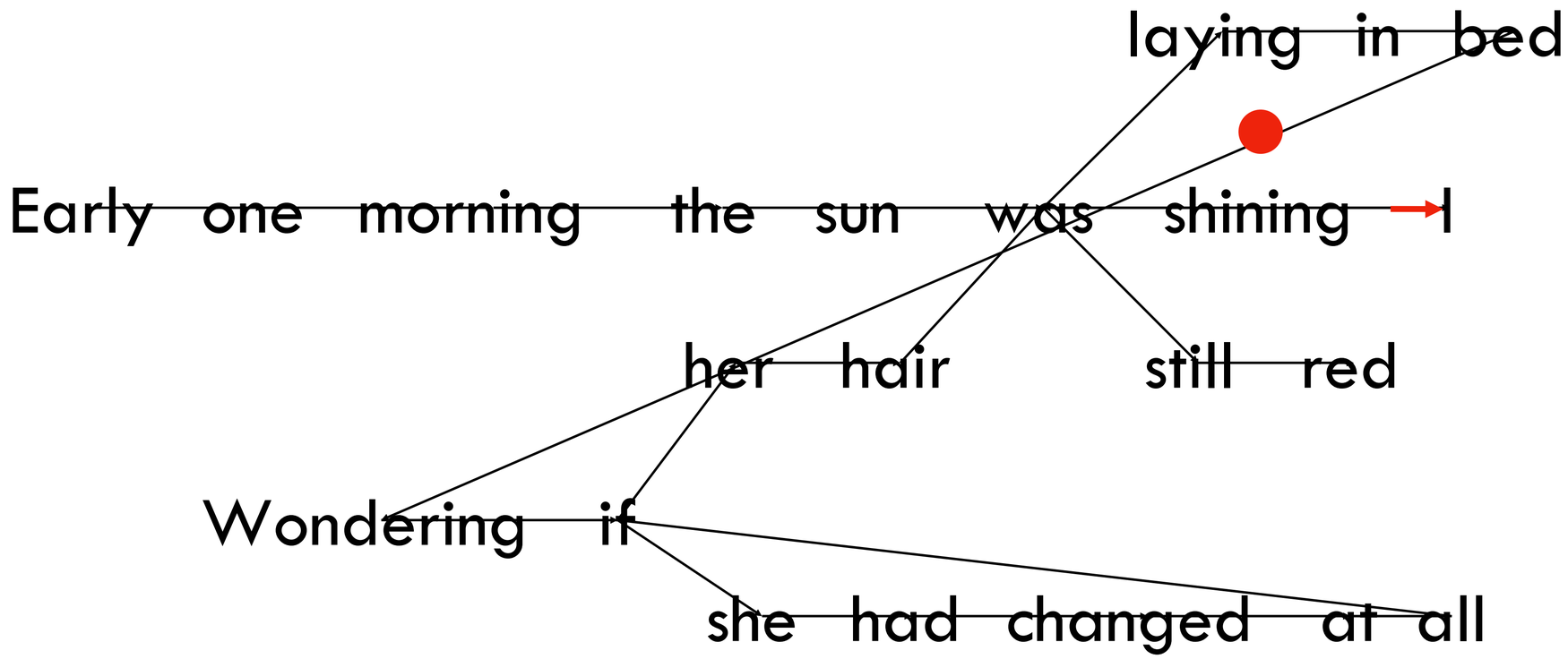

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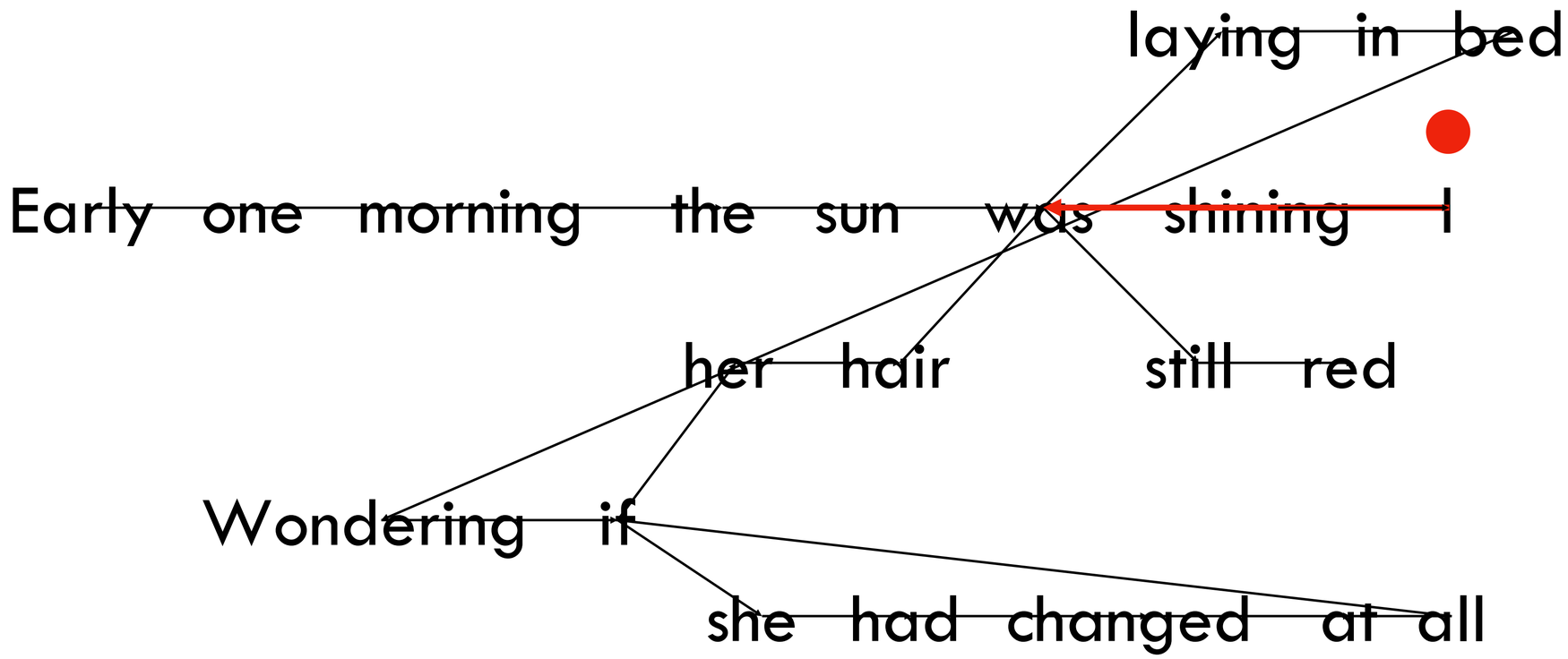

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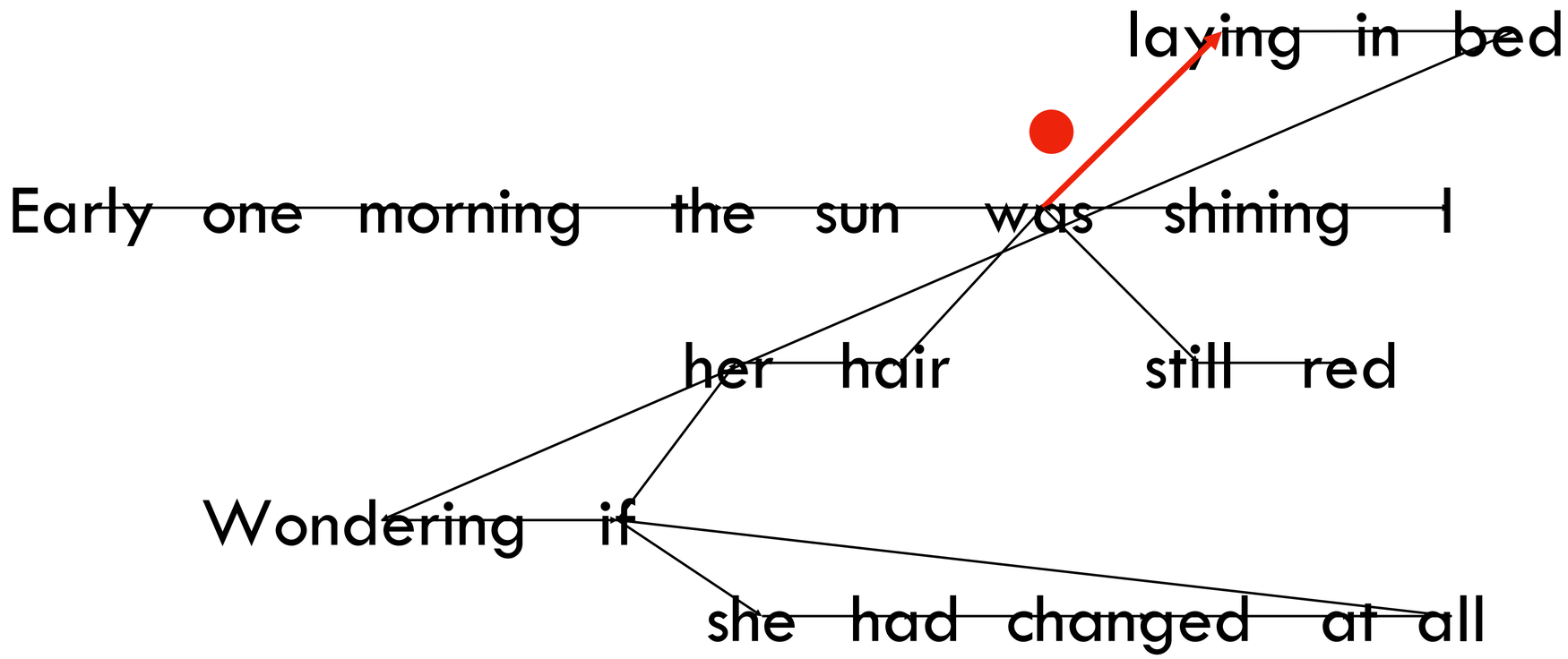

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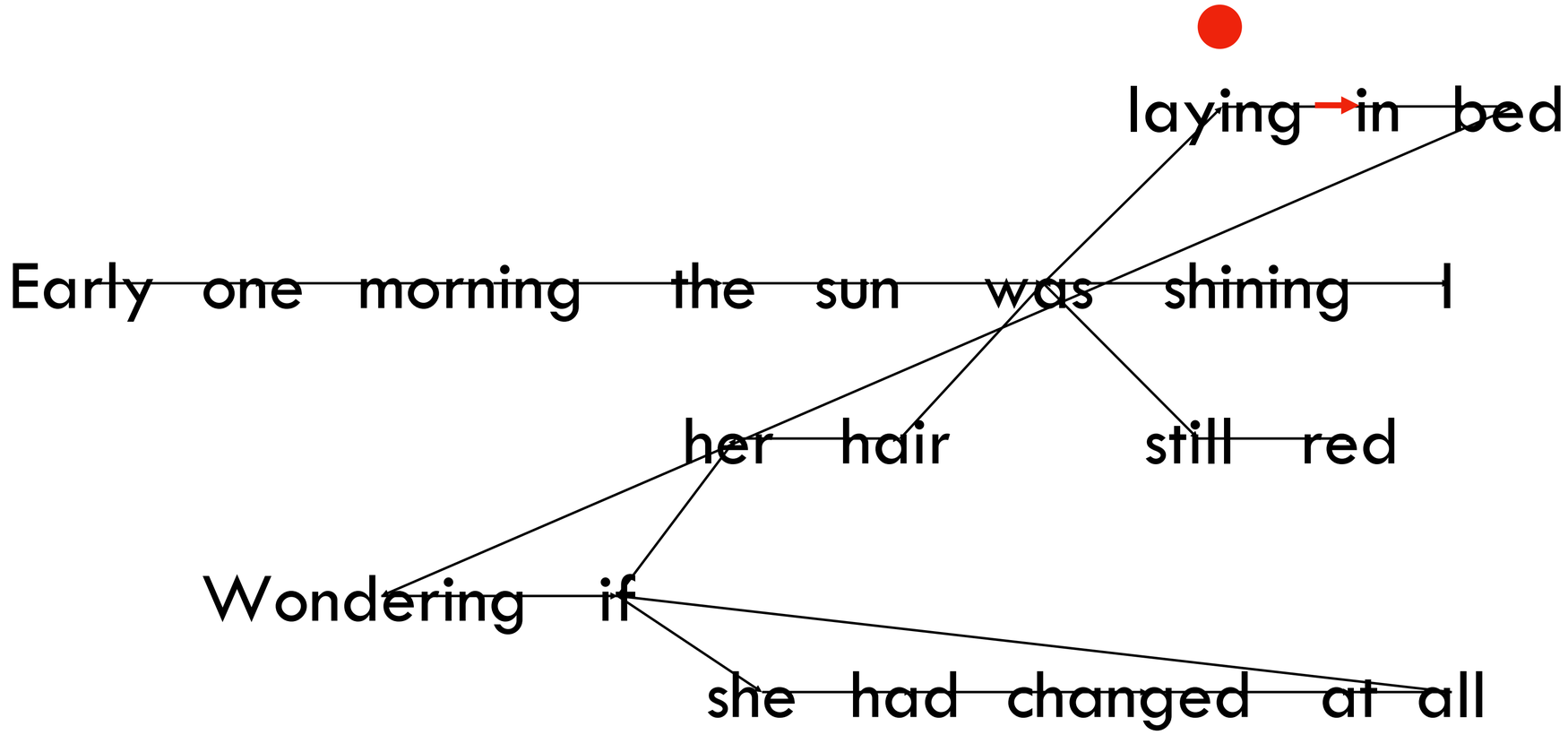
Early one morning the sun was shining I was laying



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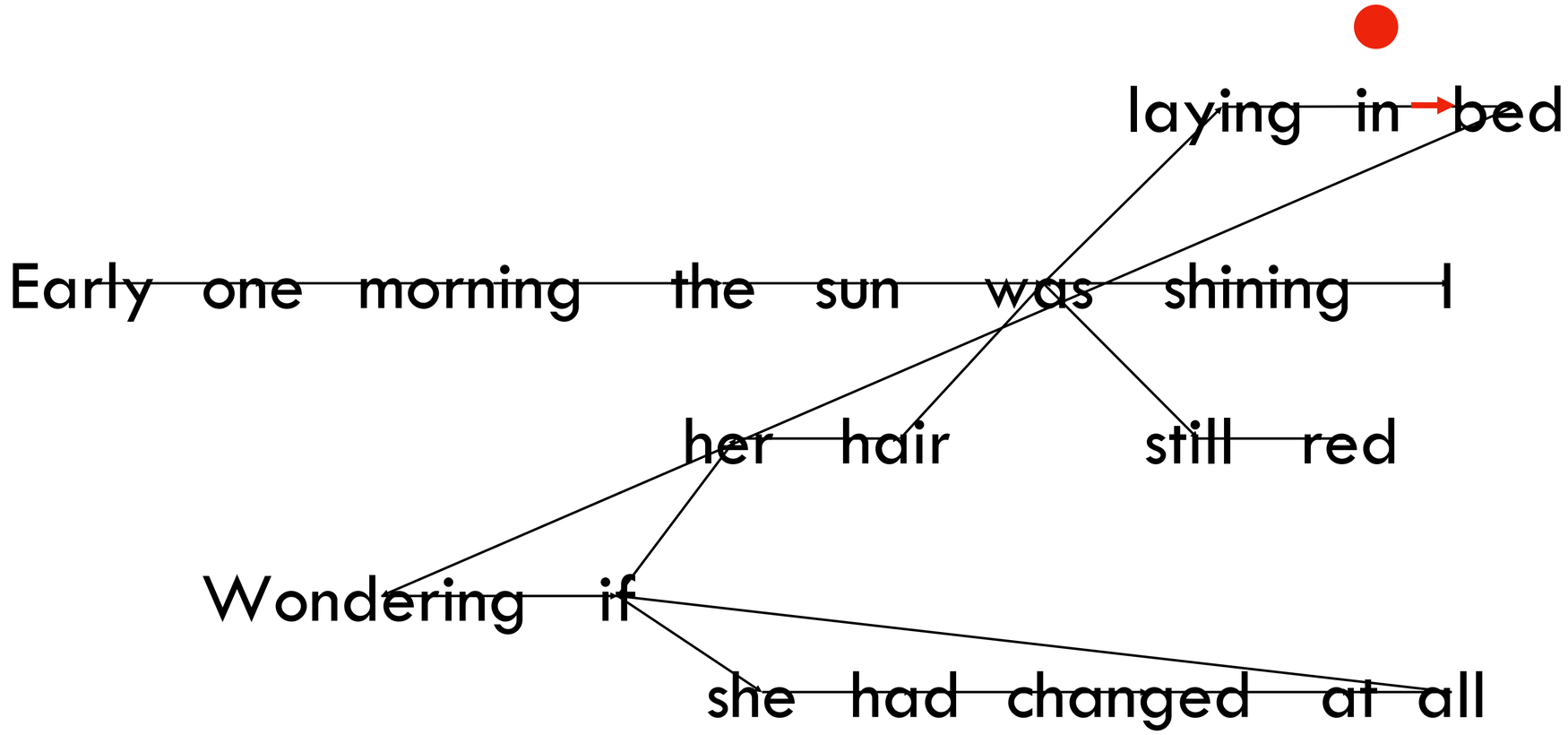

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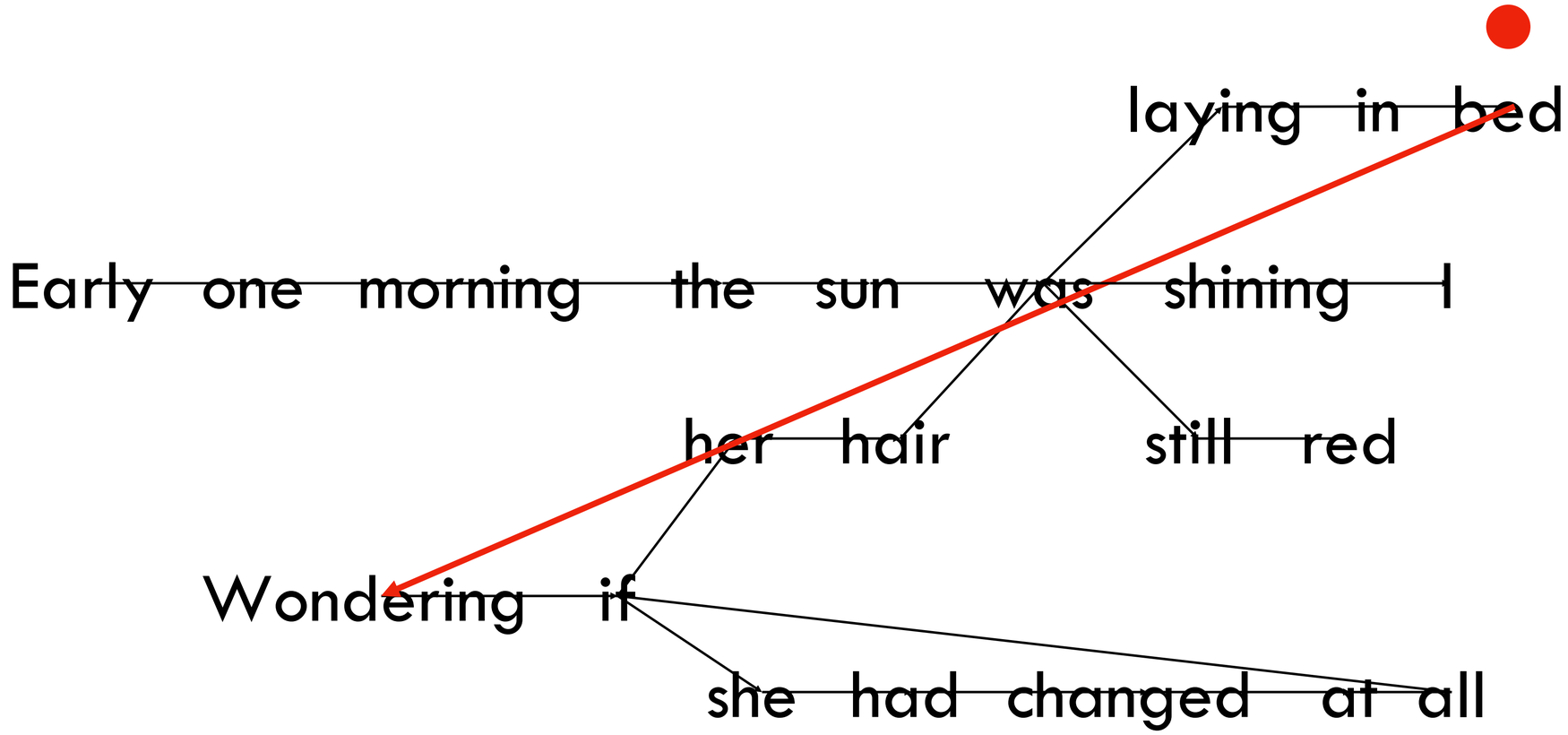

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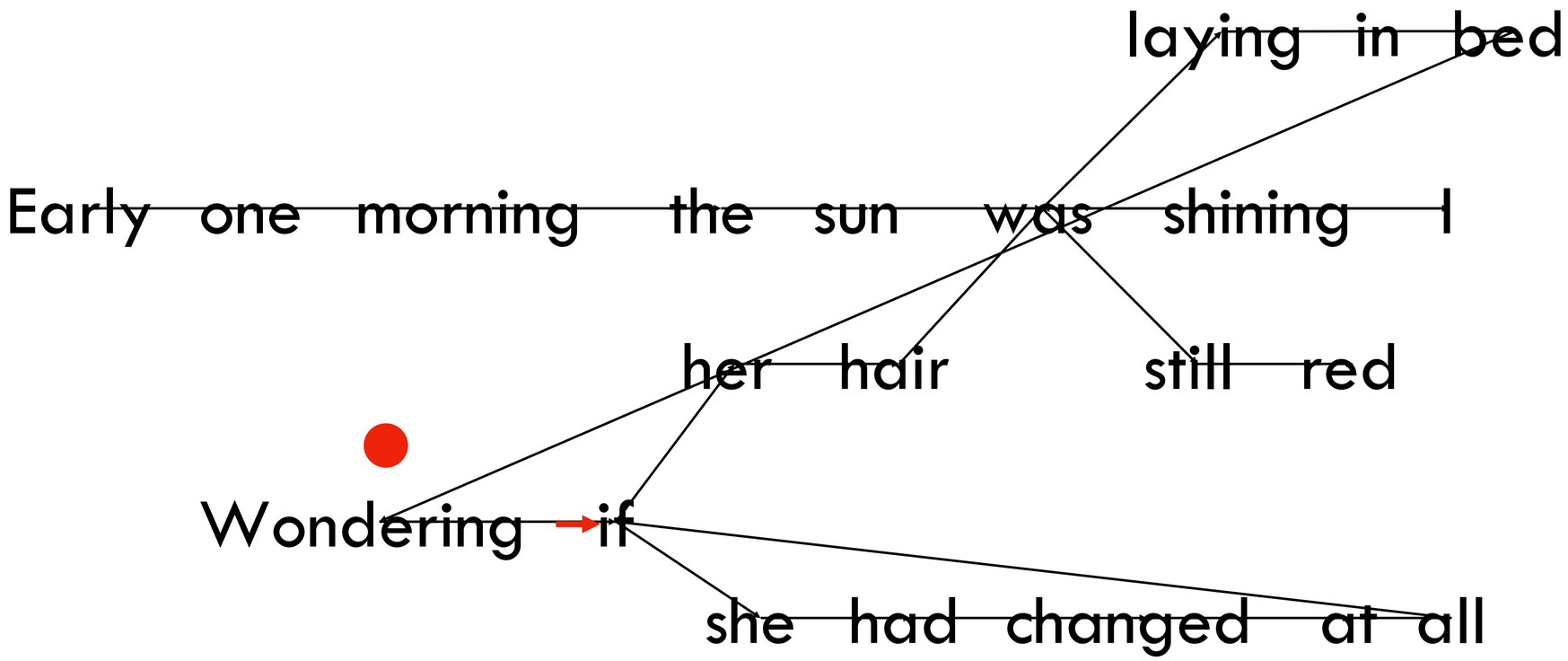
Wondering



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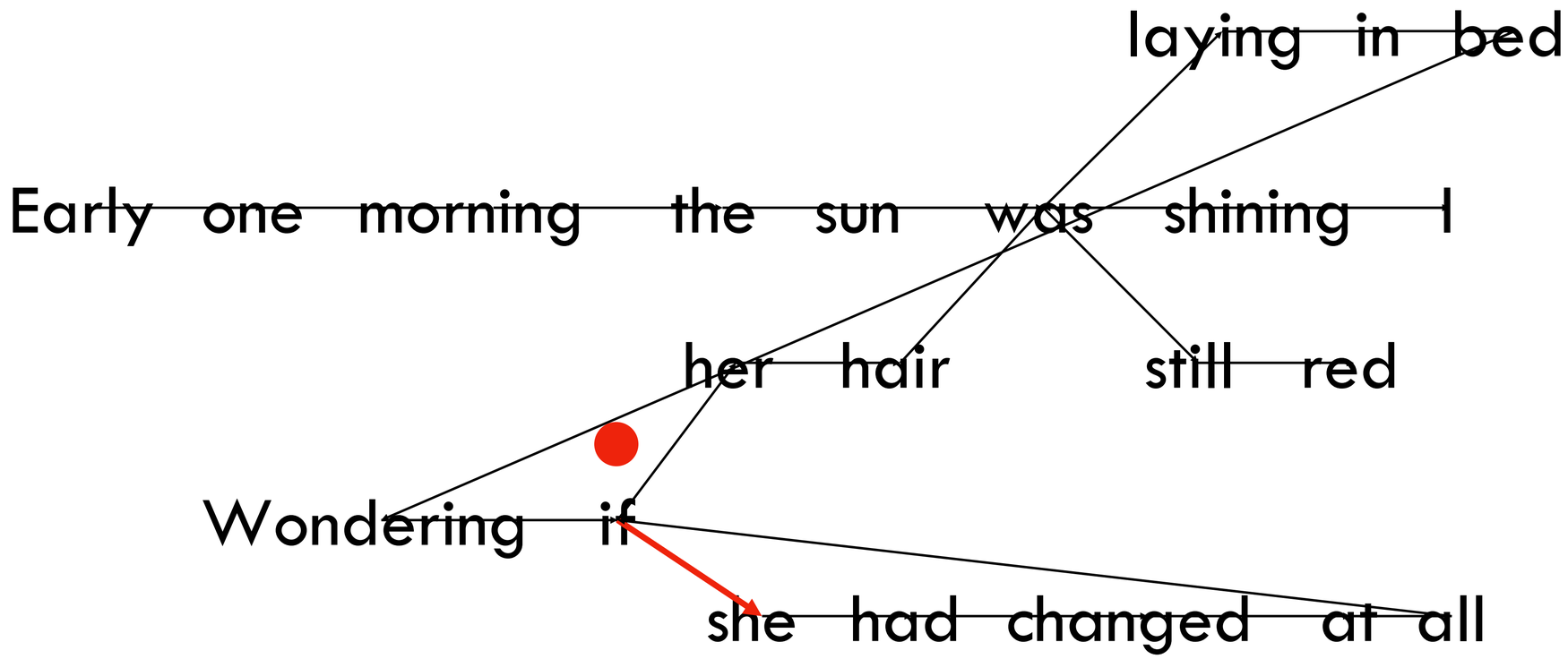

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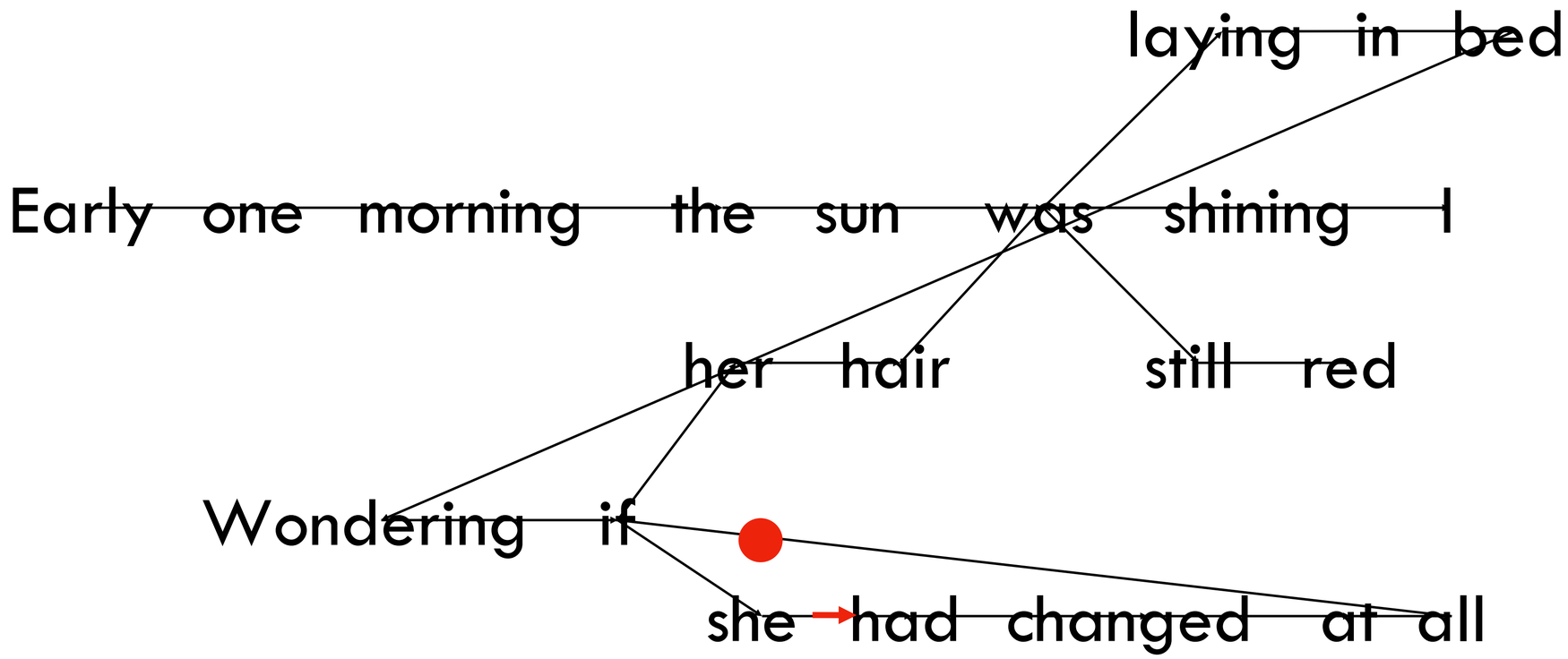

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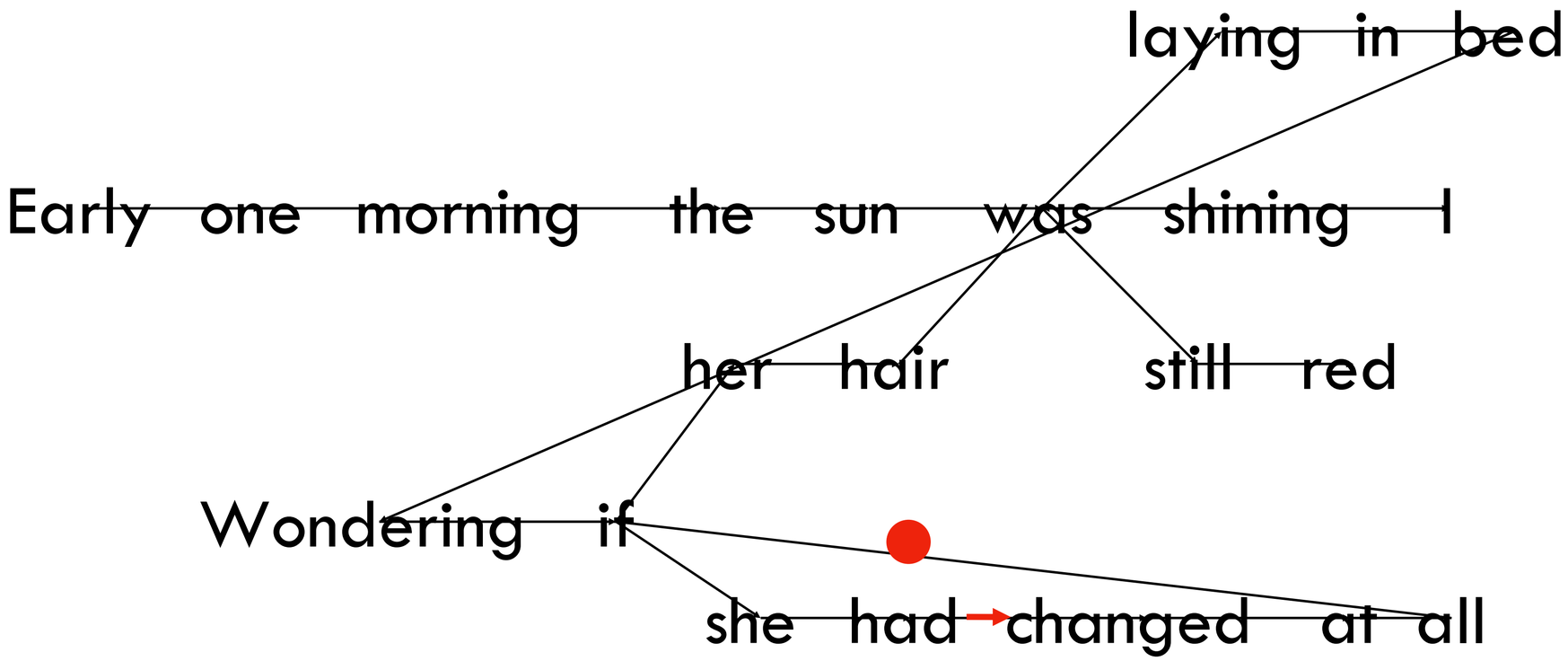

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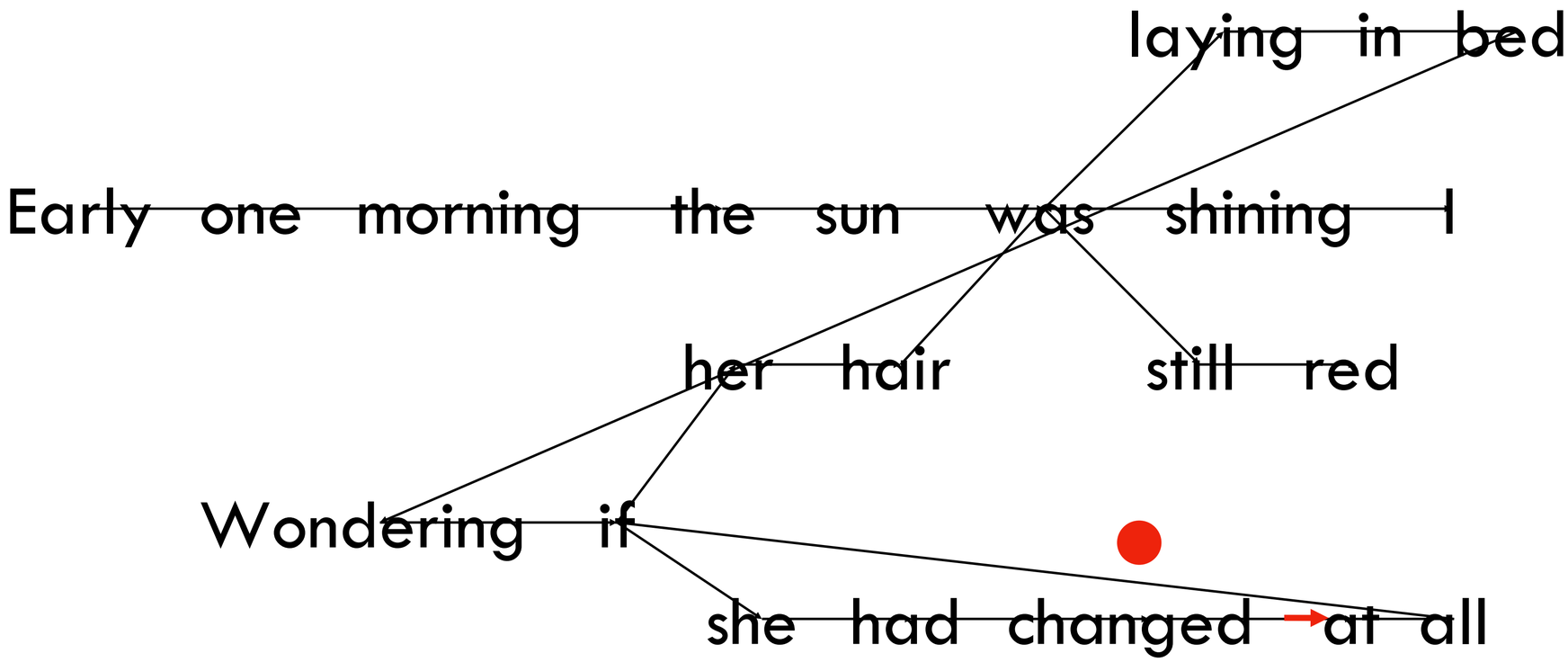
Wondering if she had changed



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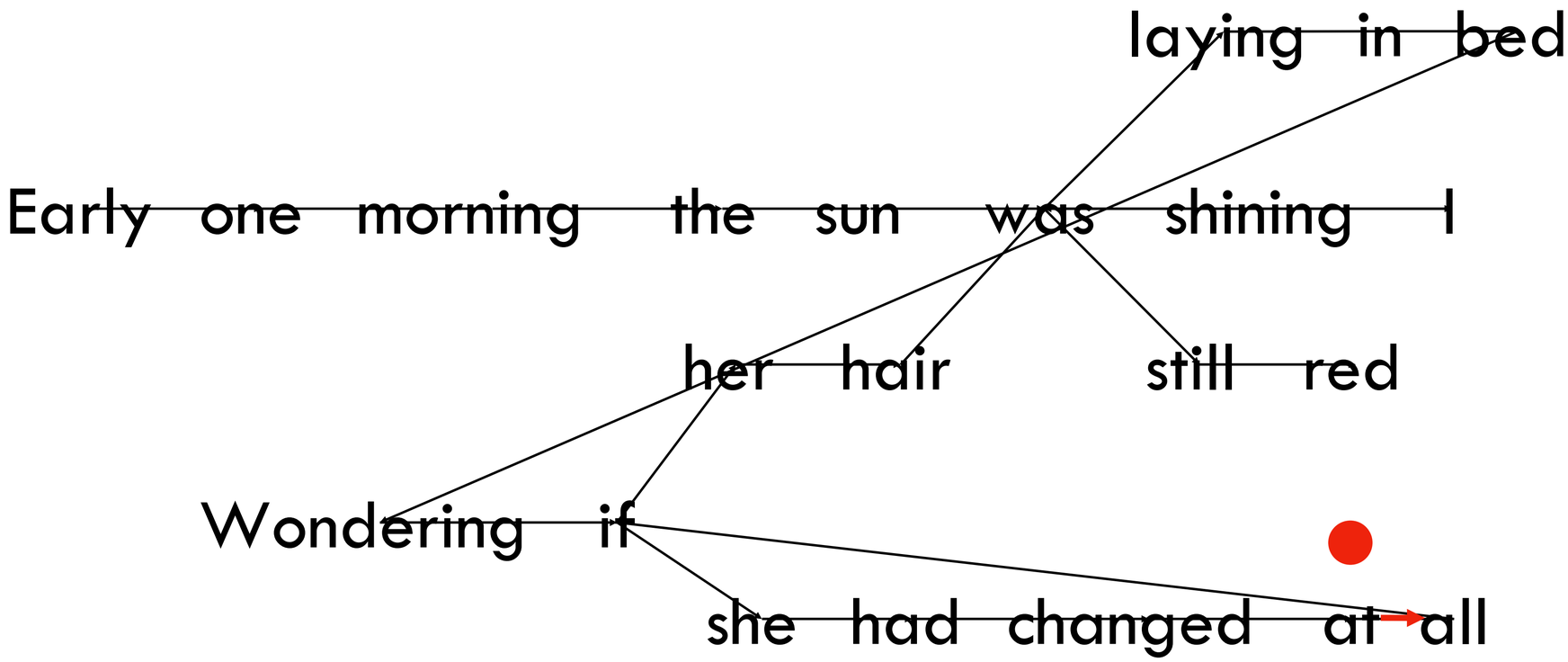

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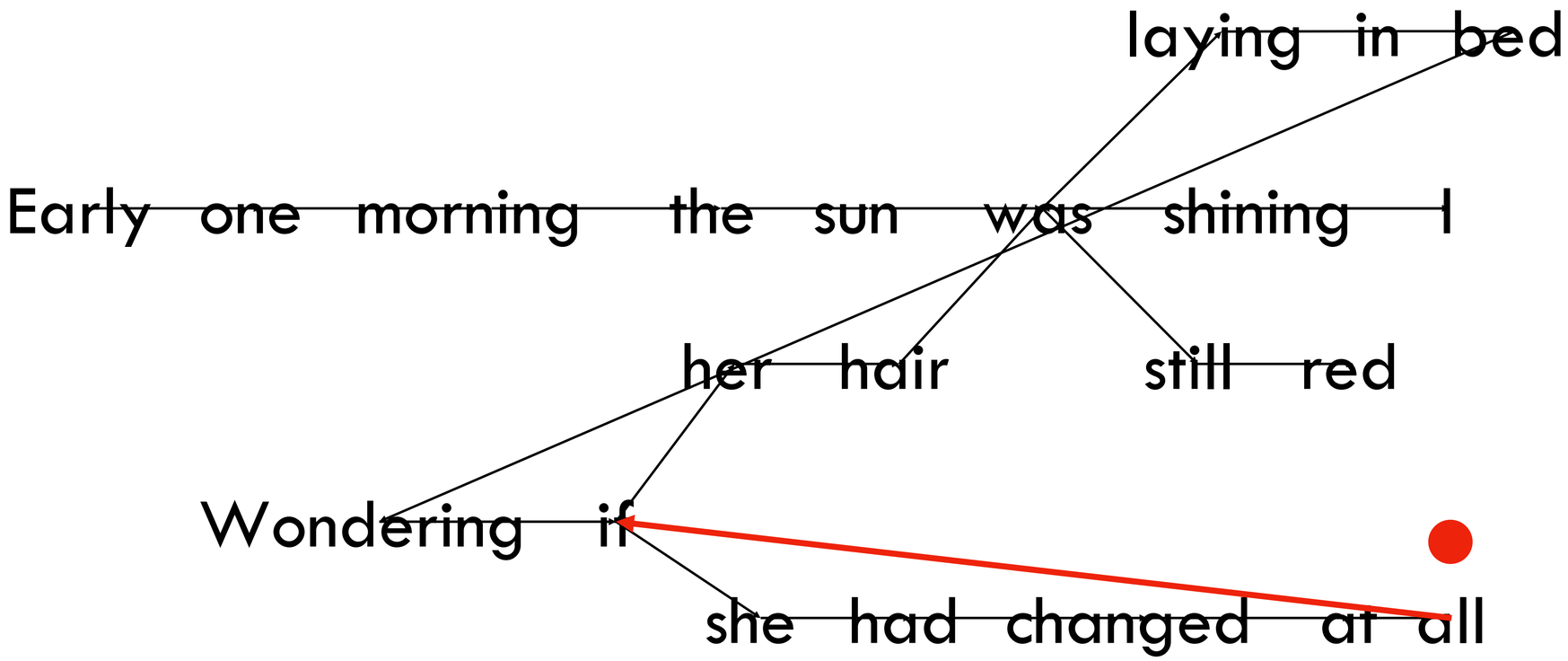

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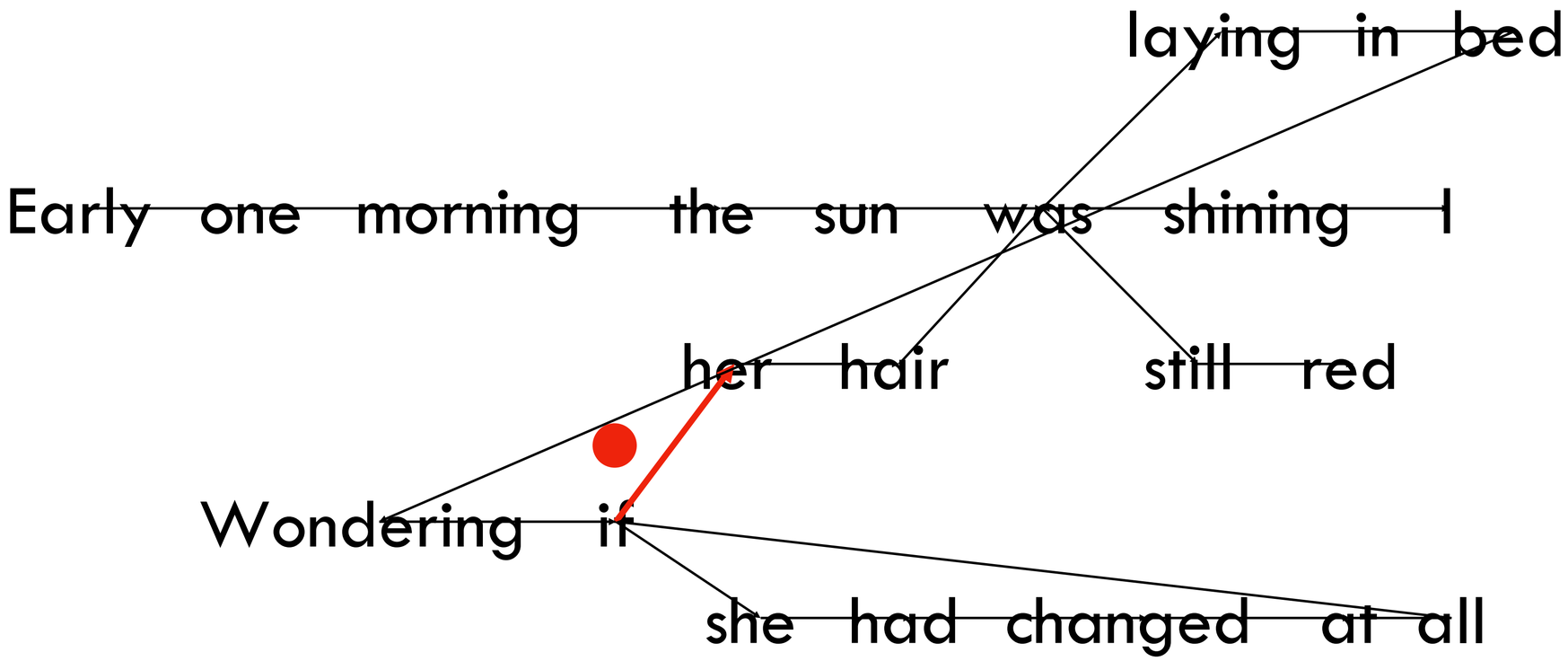

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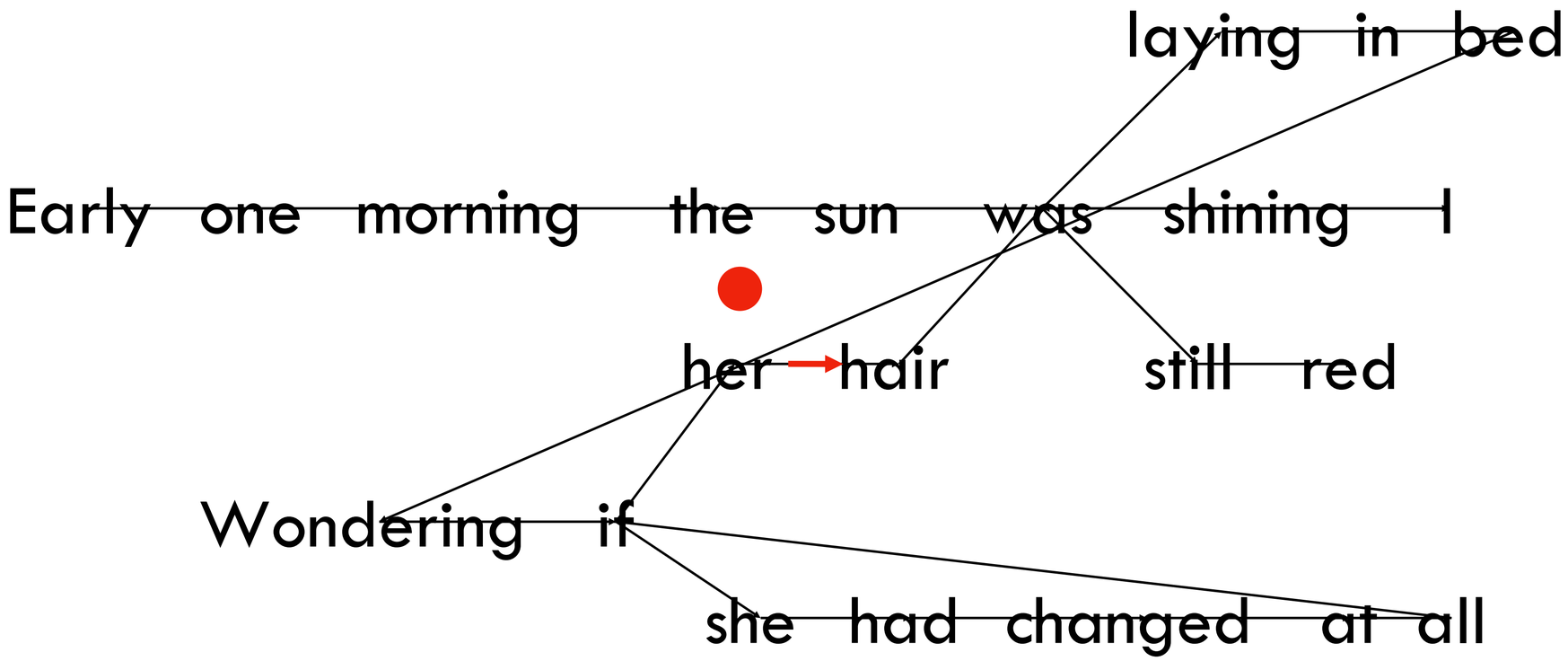

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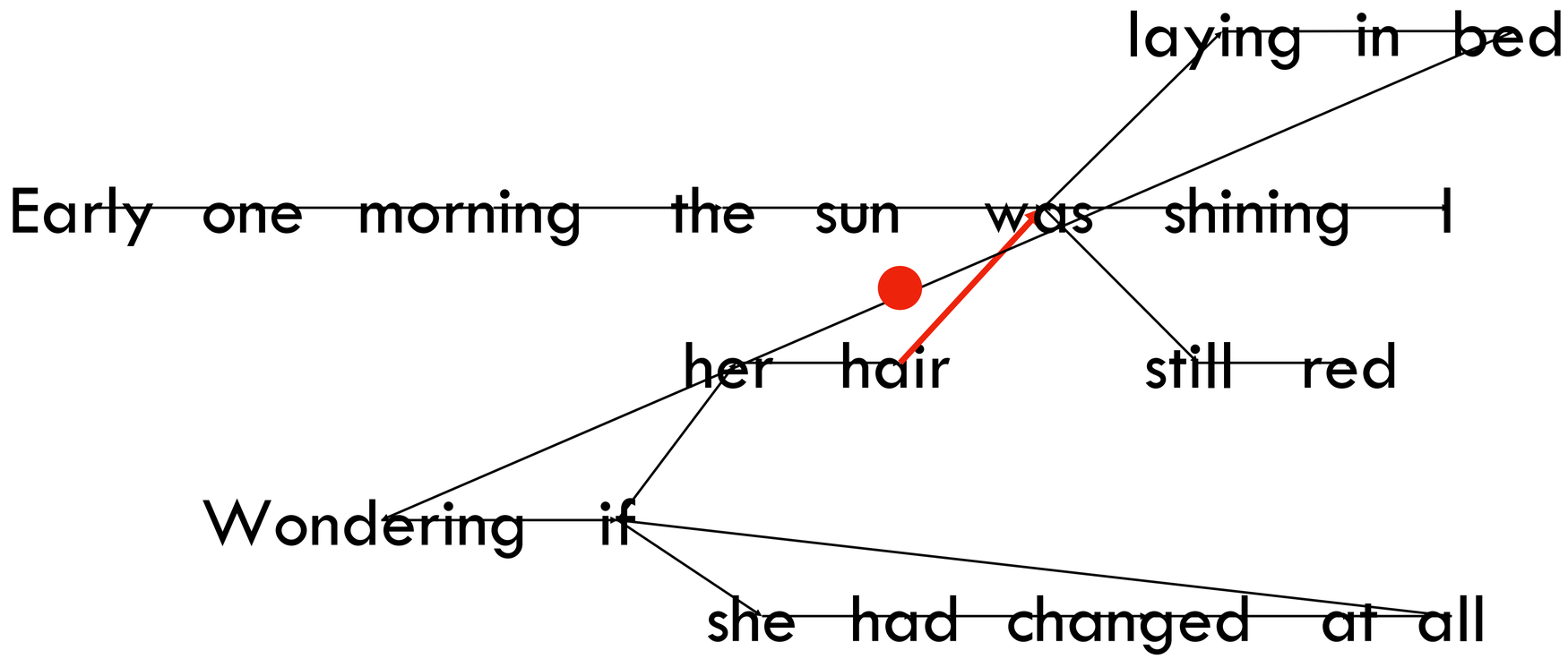

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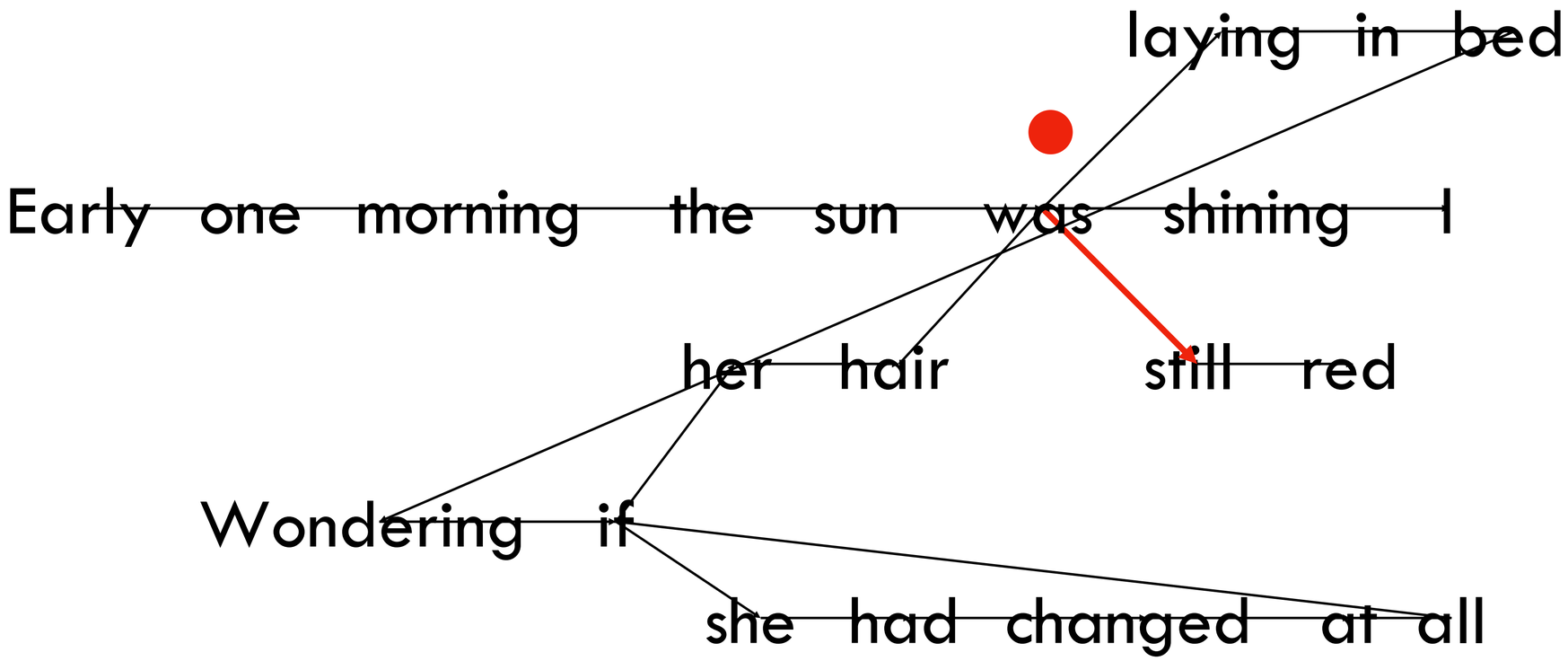

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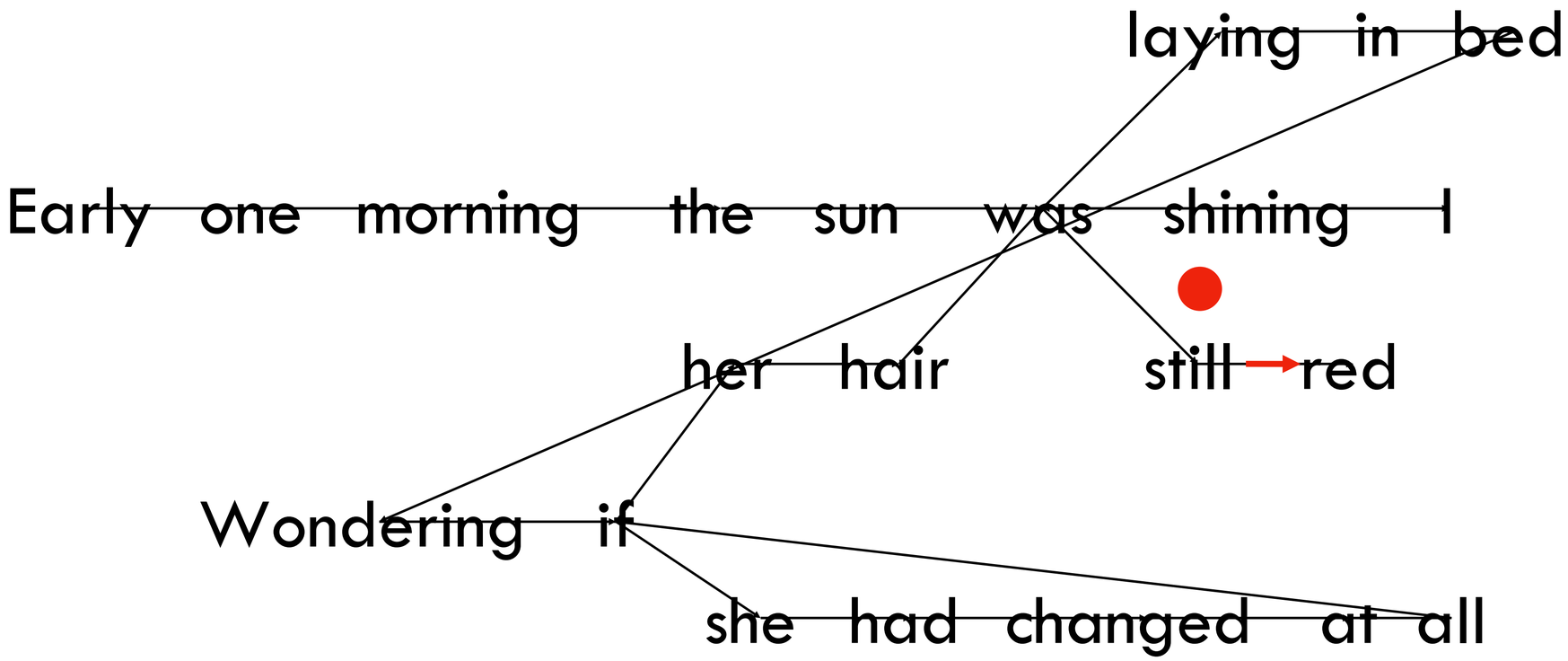

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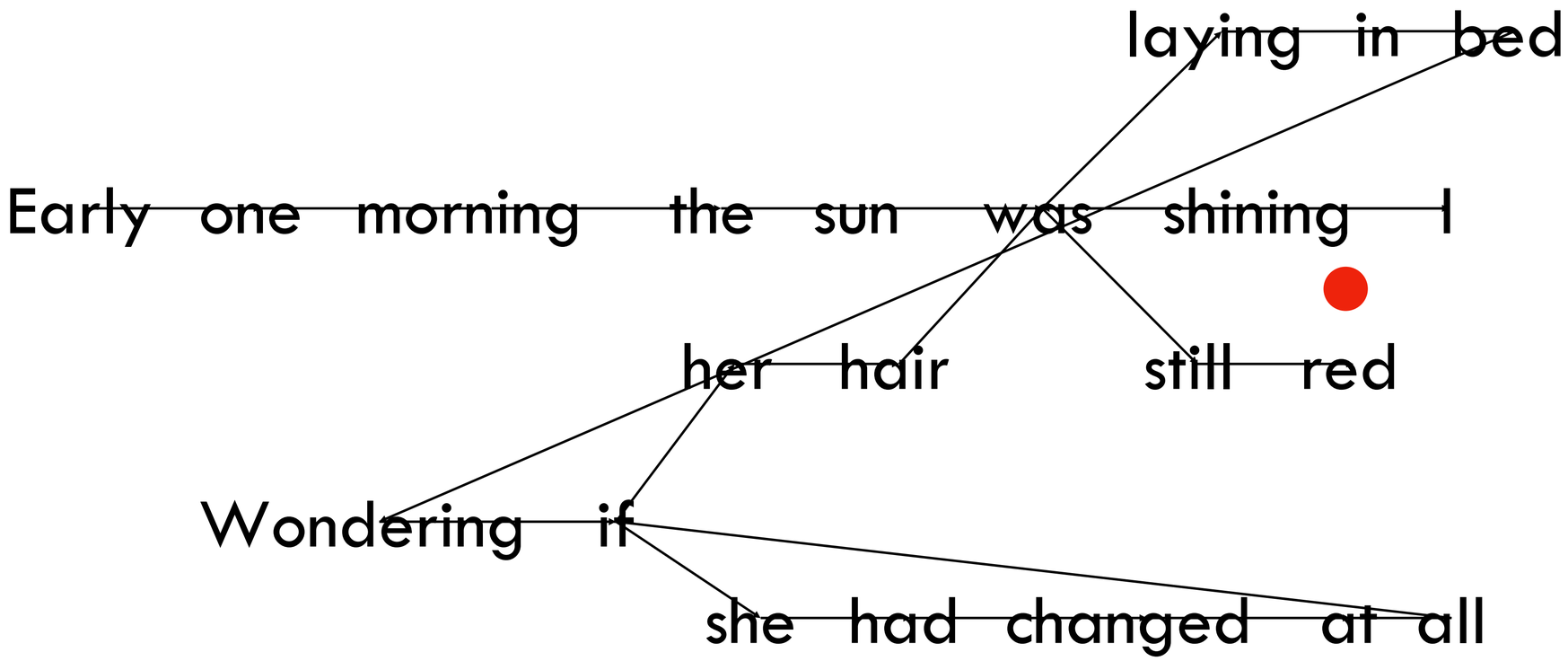

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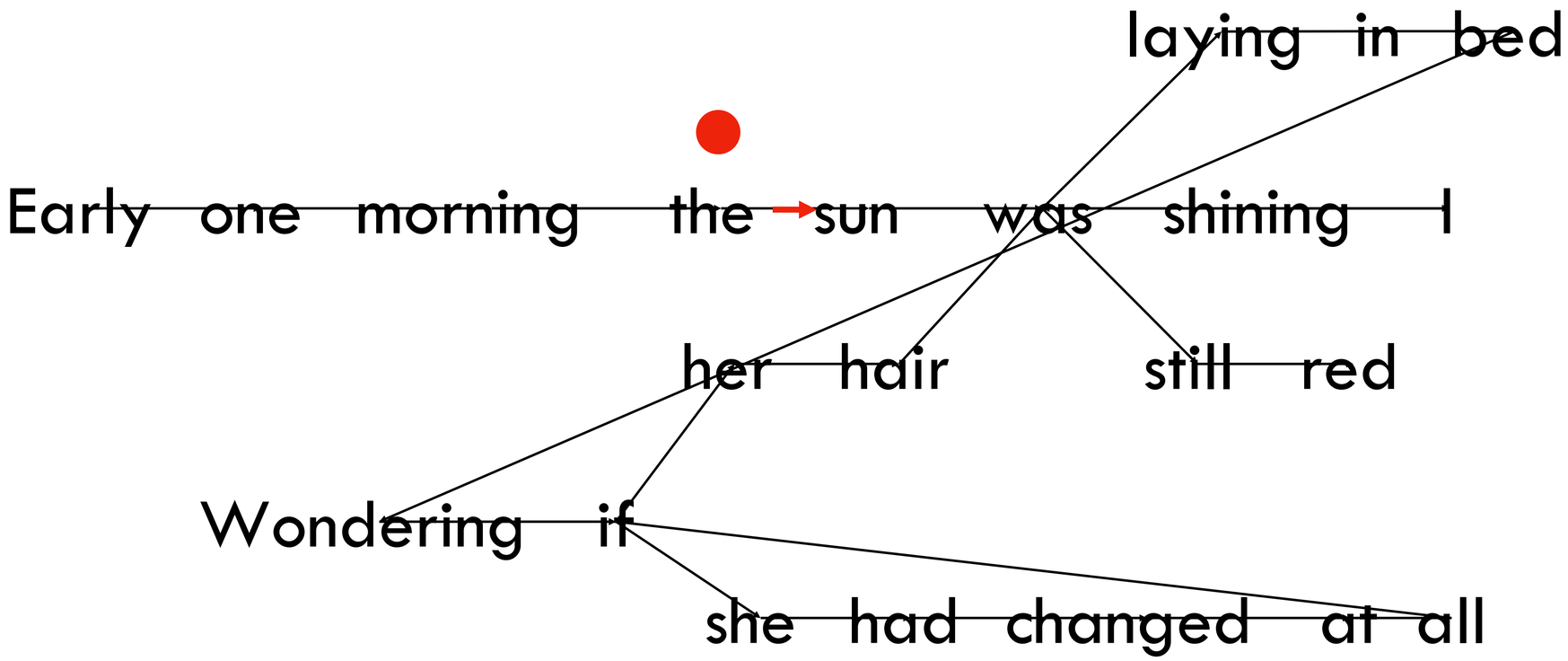

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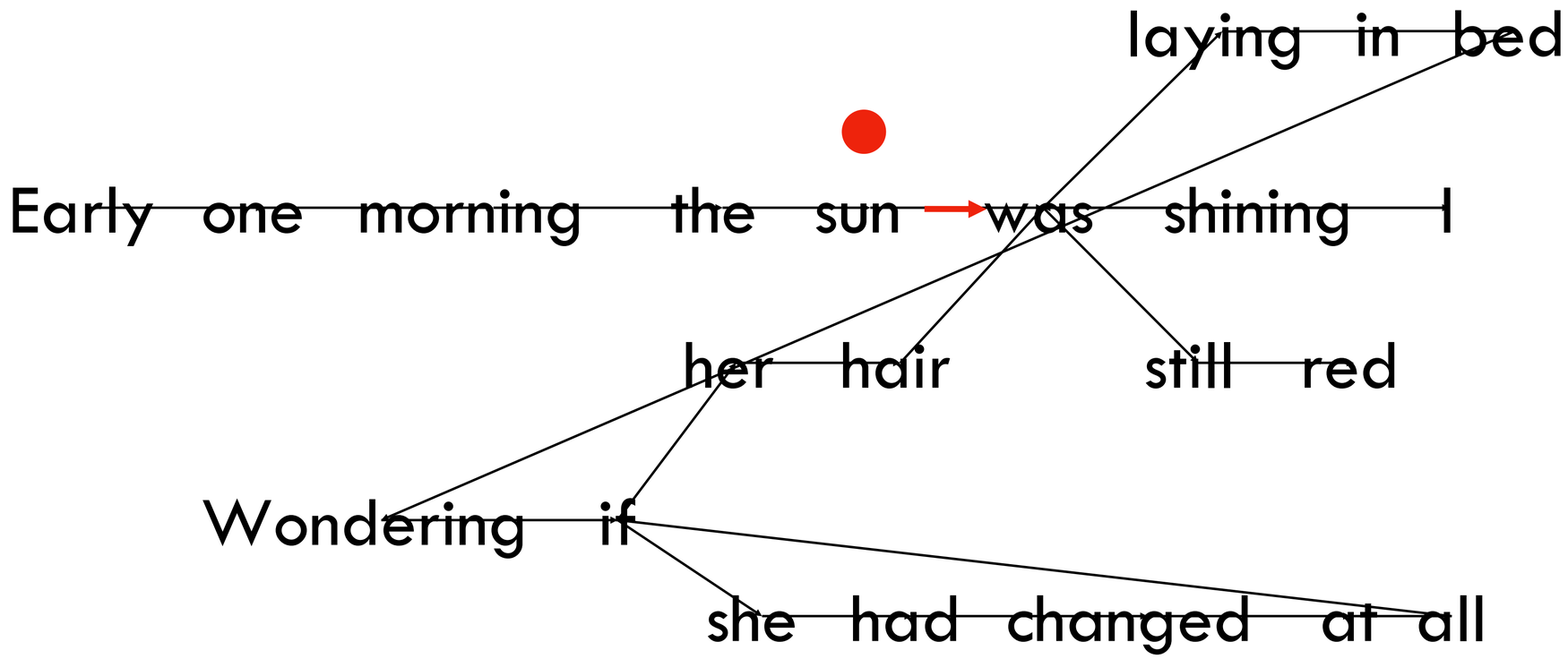

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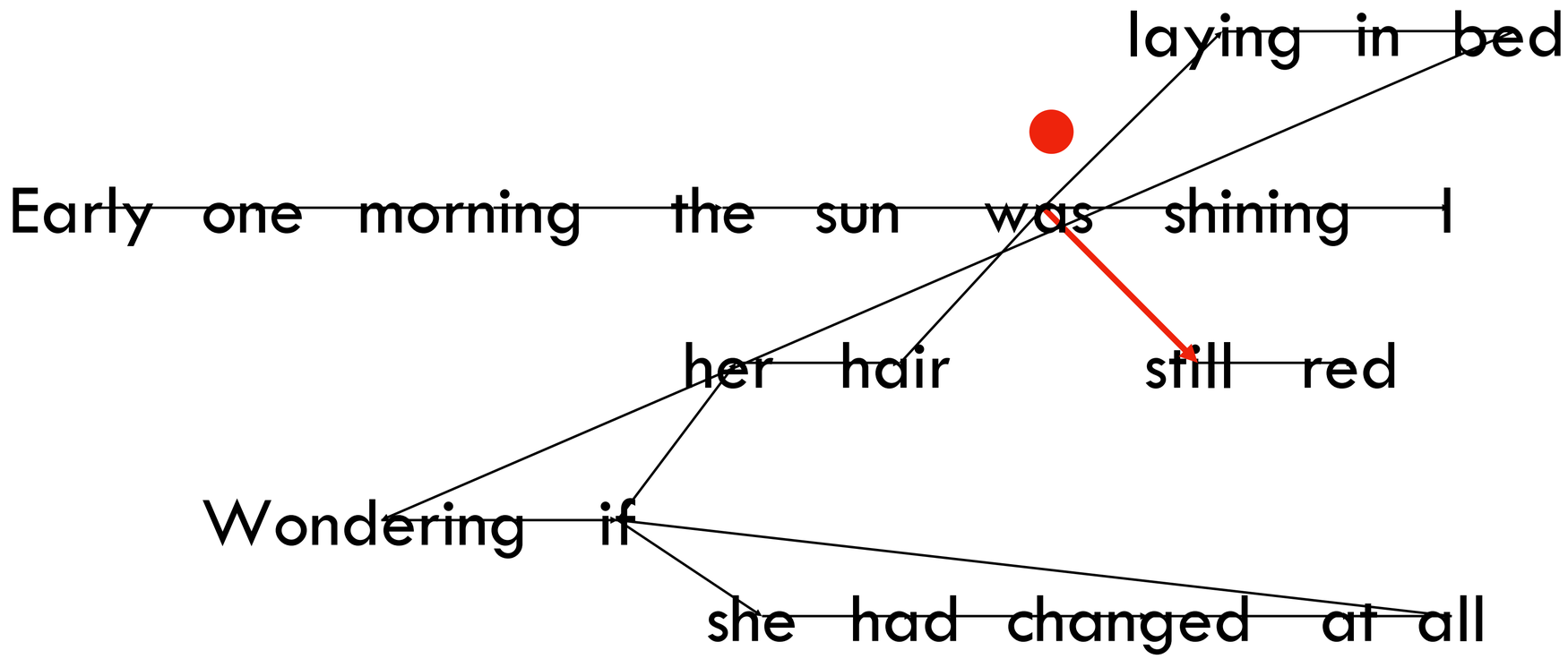

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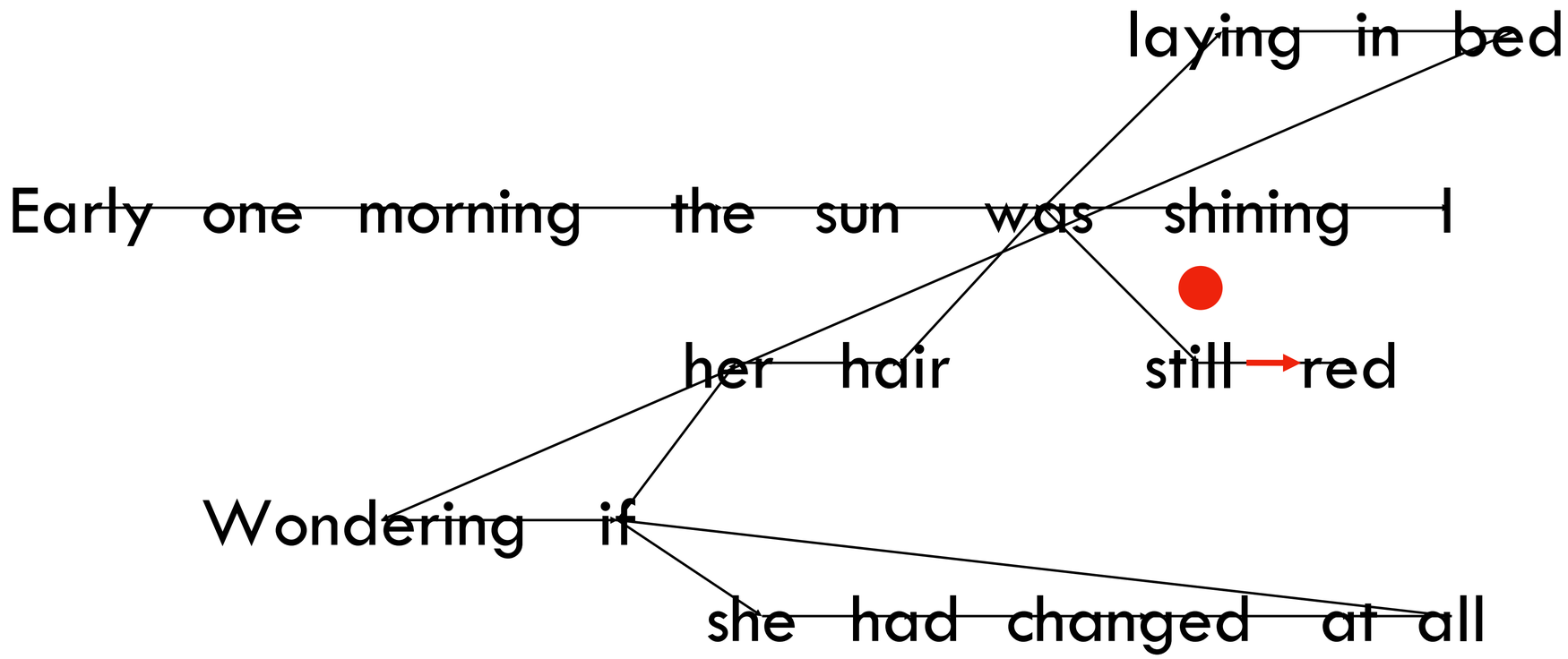

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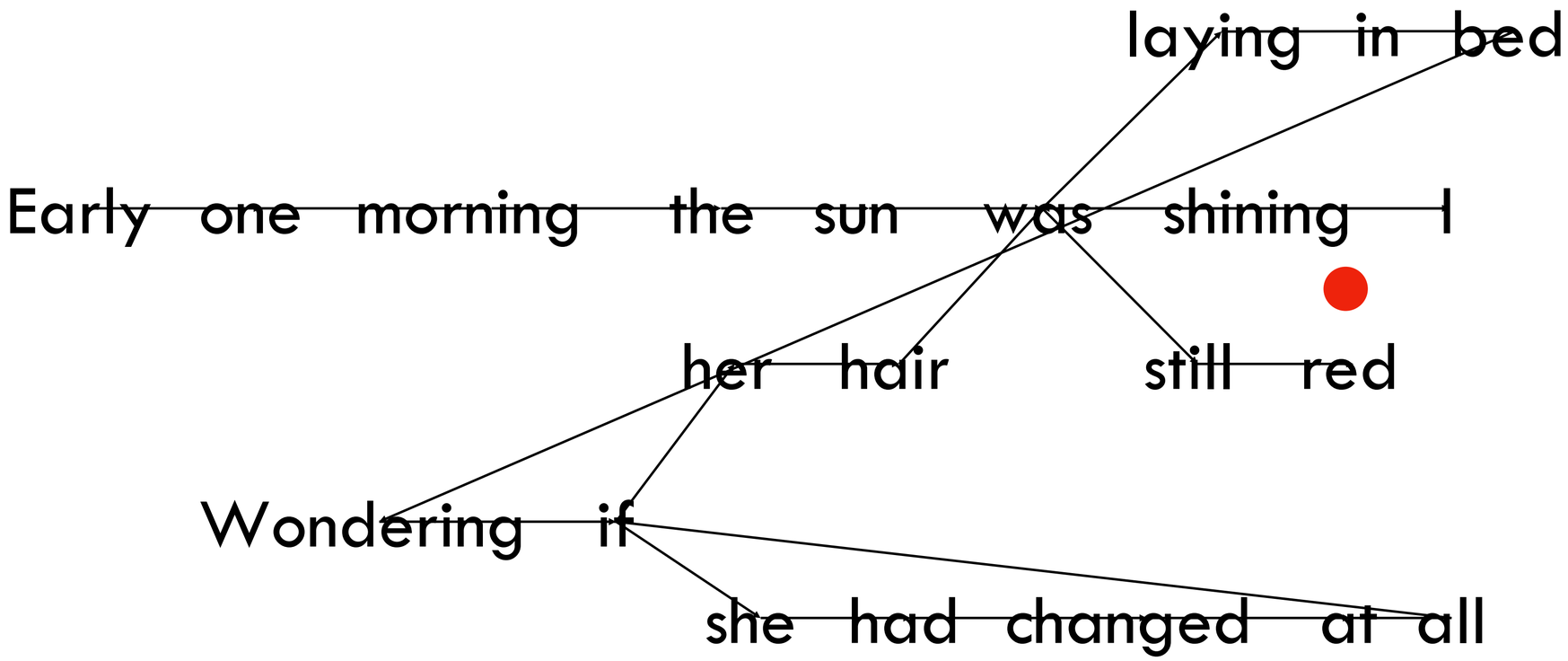

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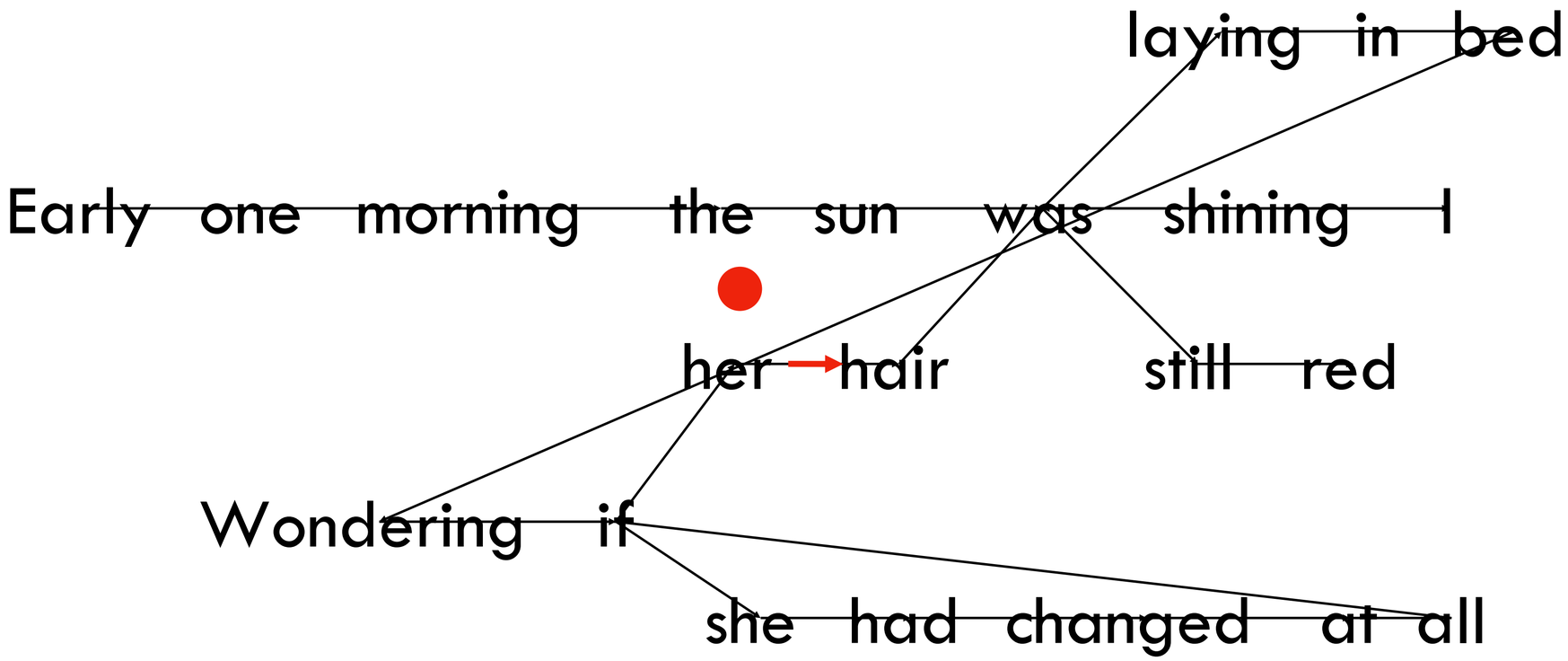

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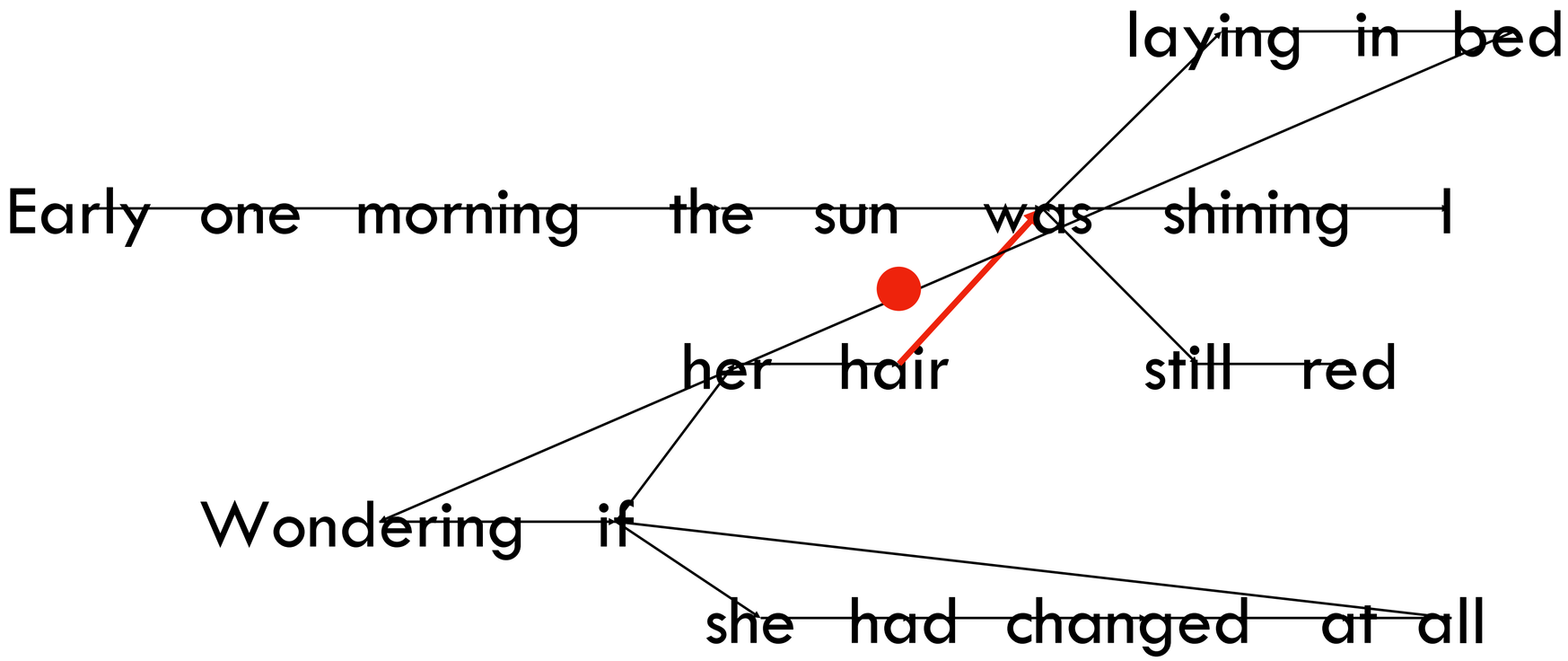

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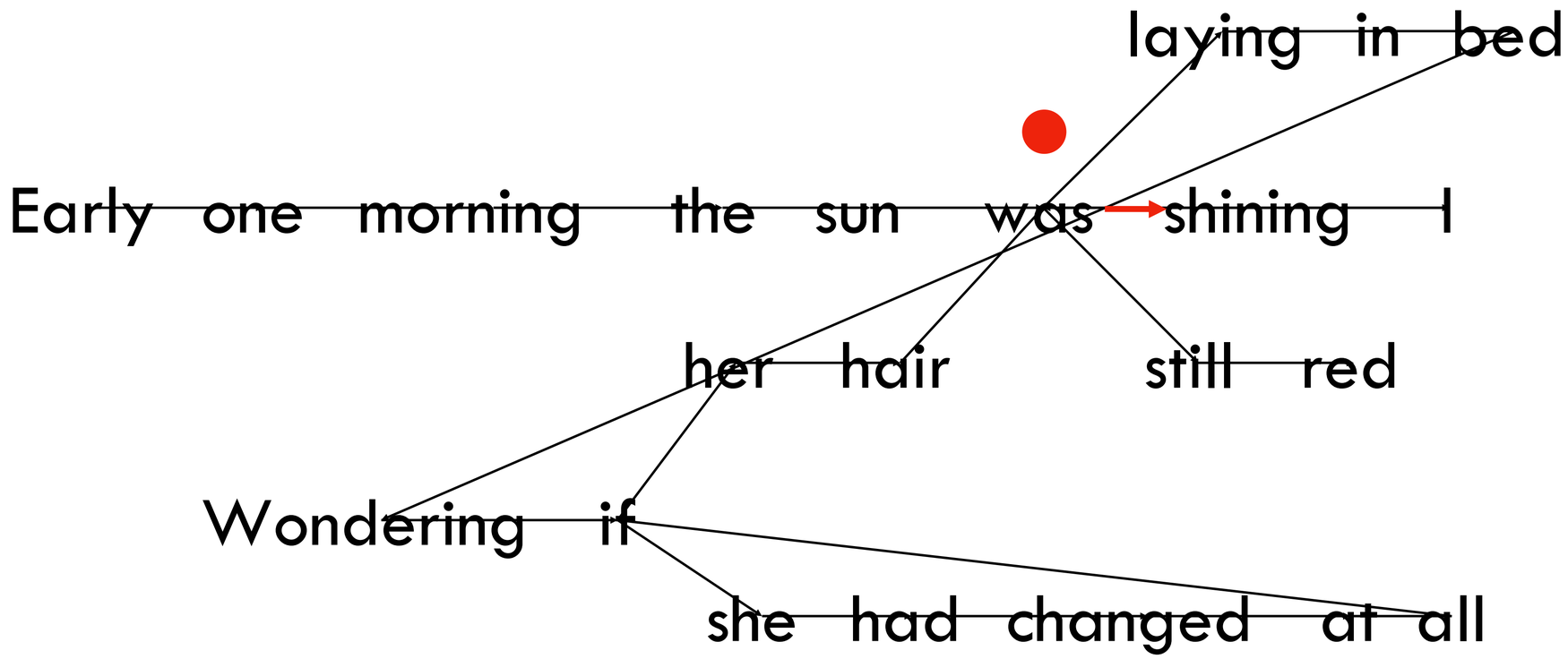

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the sun was still red

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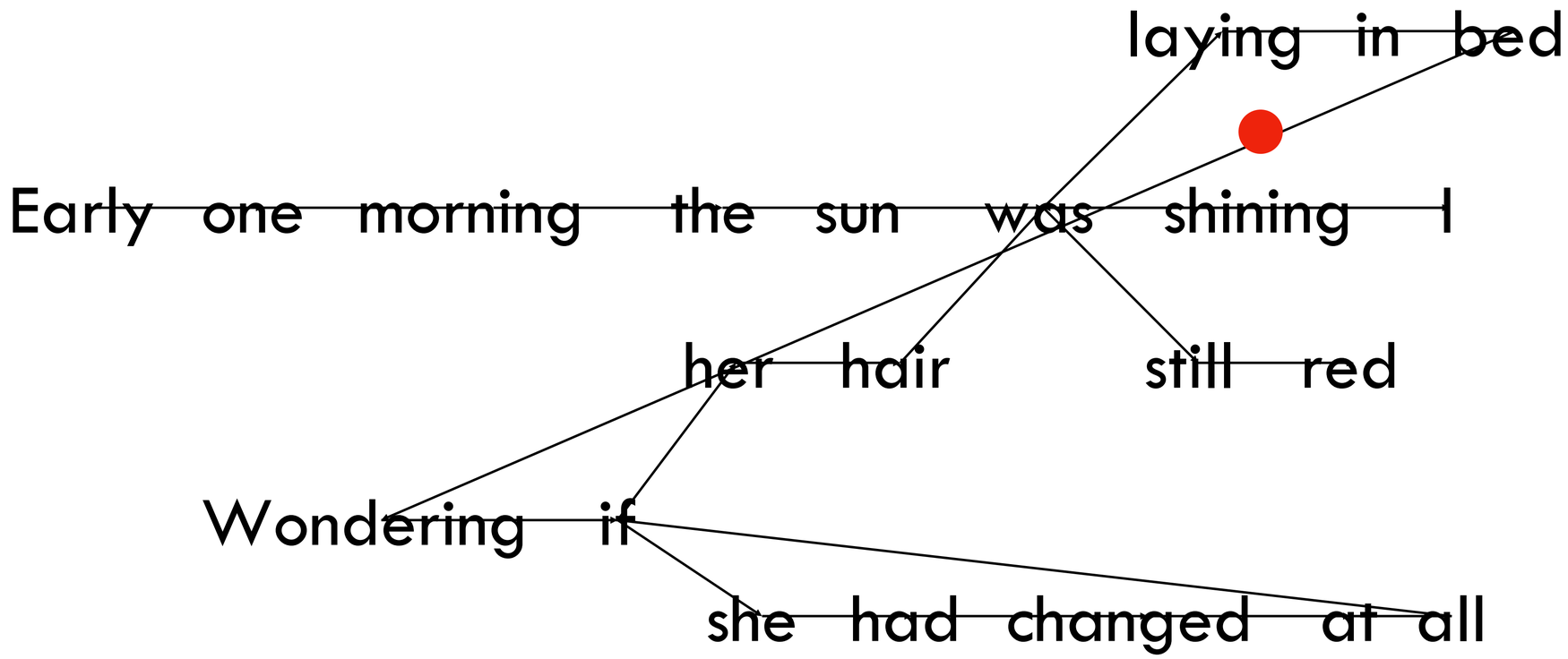

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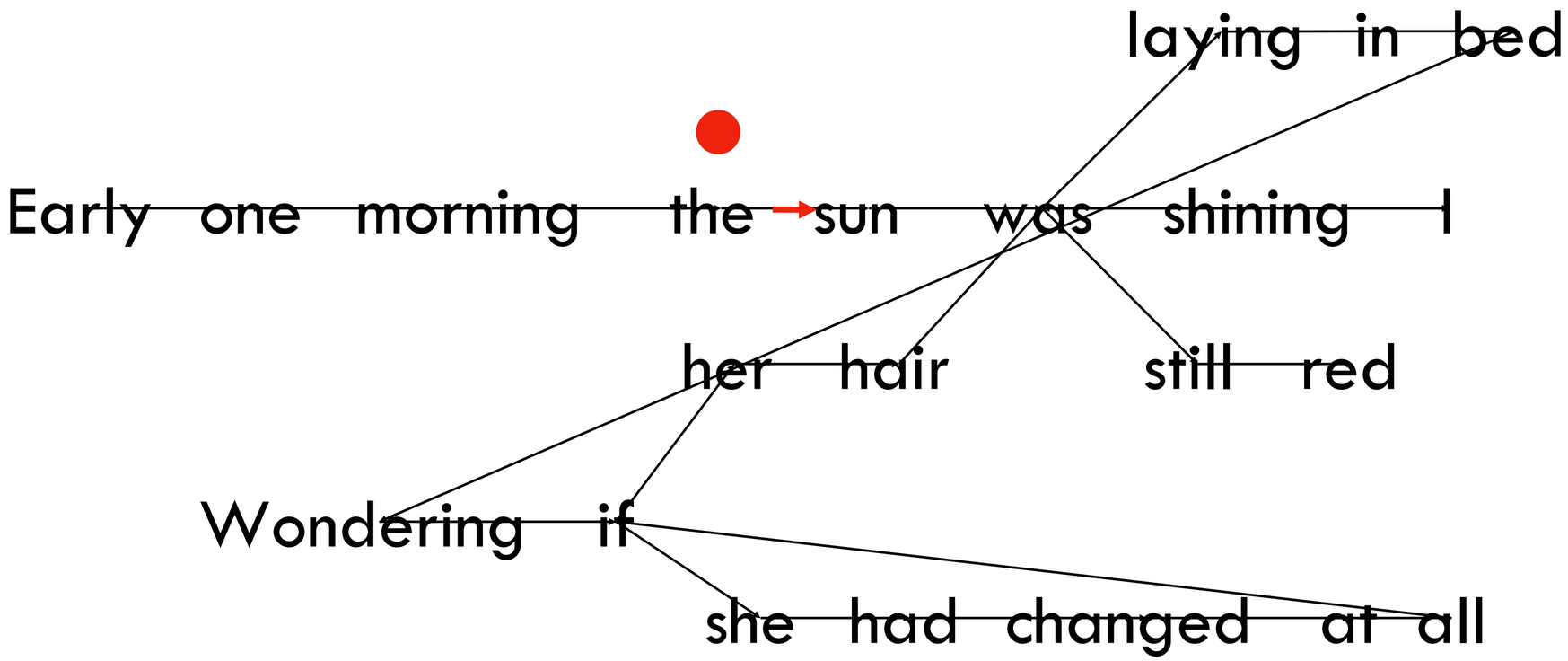

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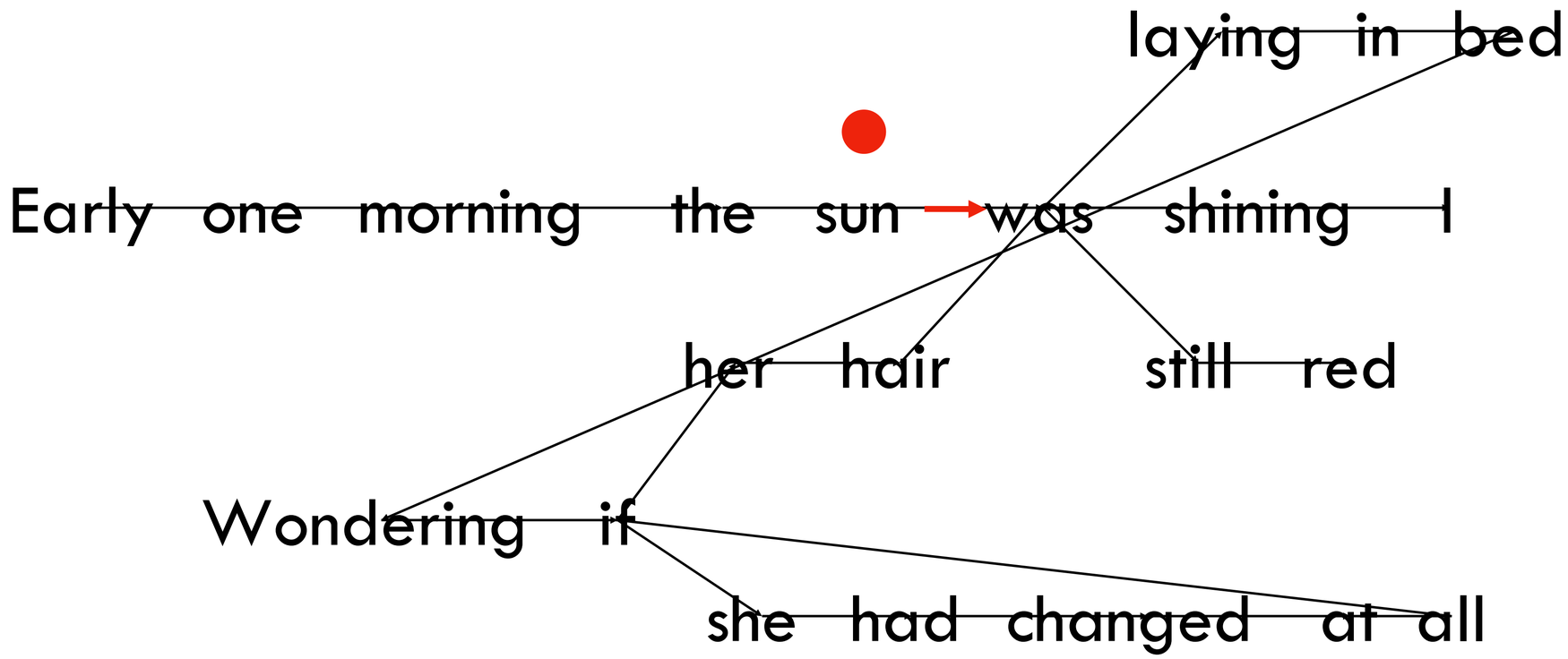

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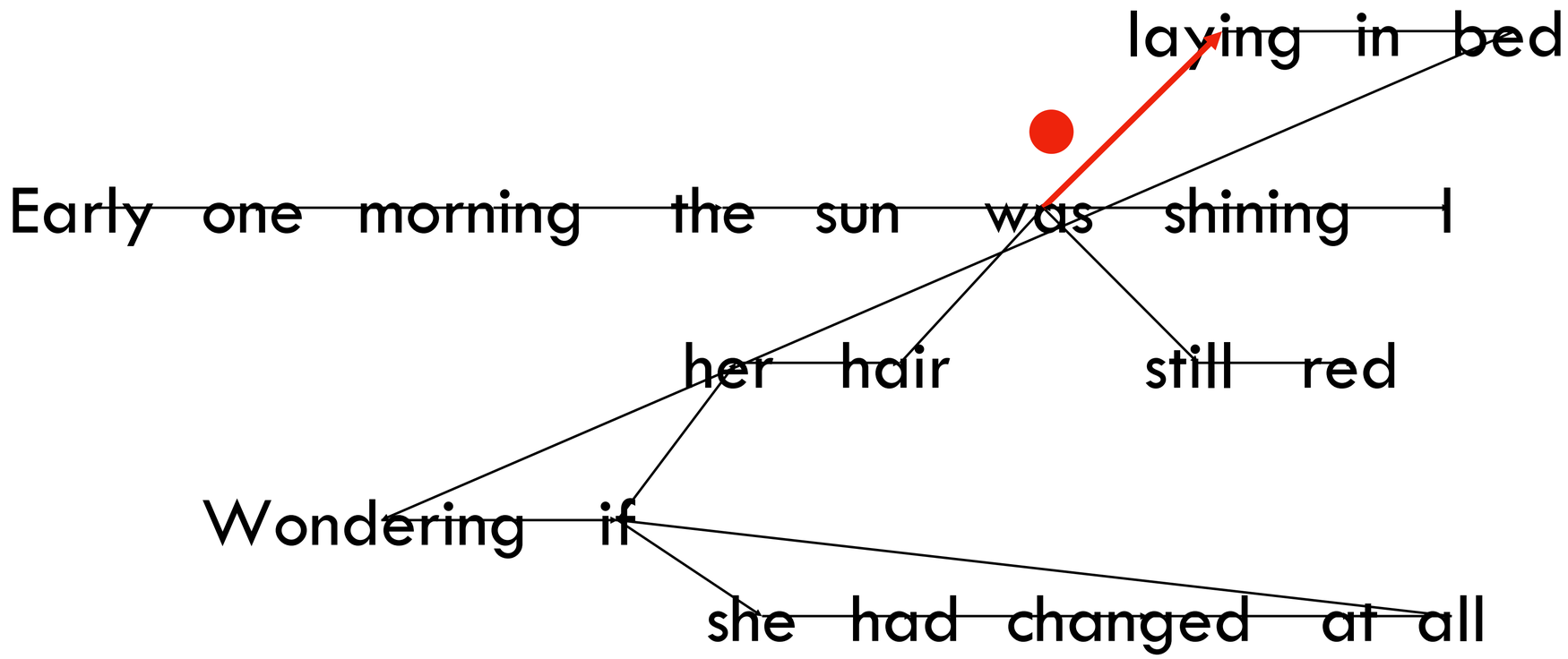

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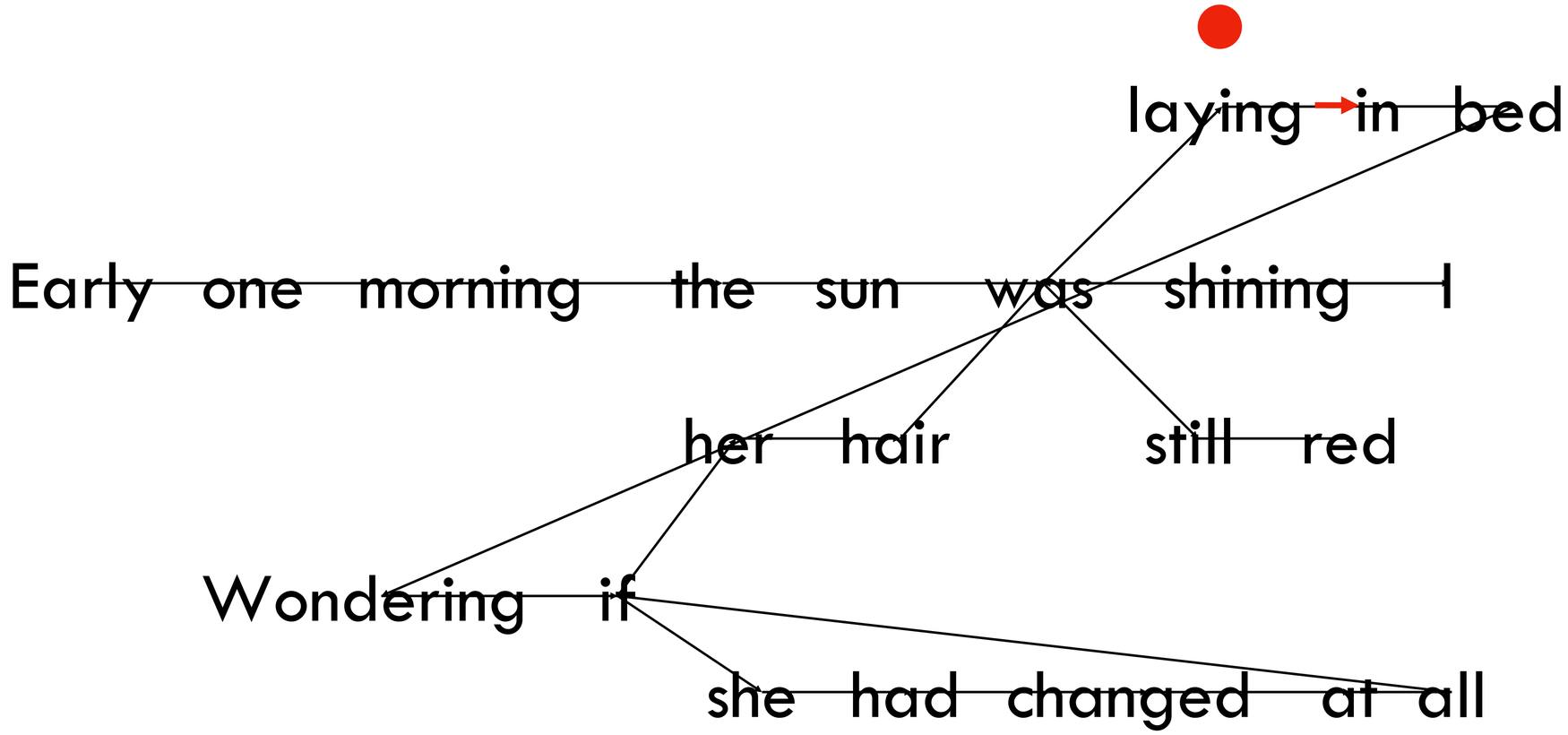
the sun was laying



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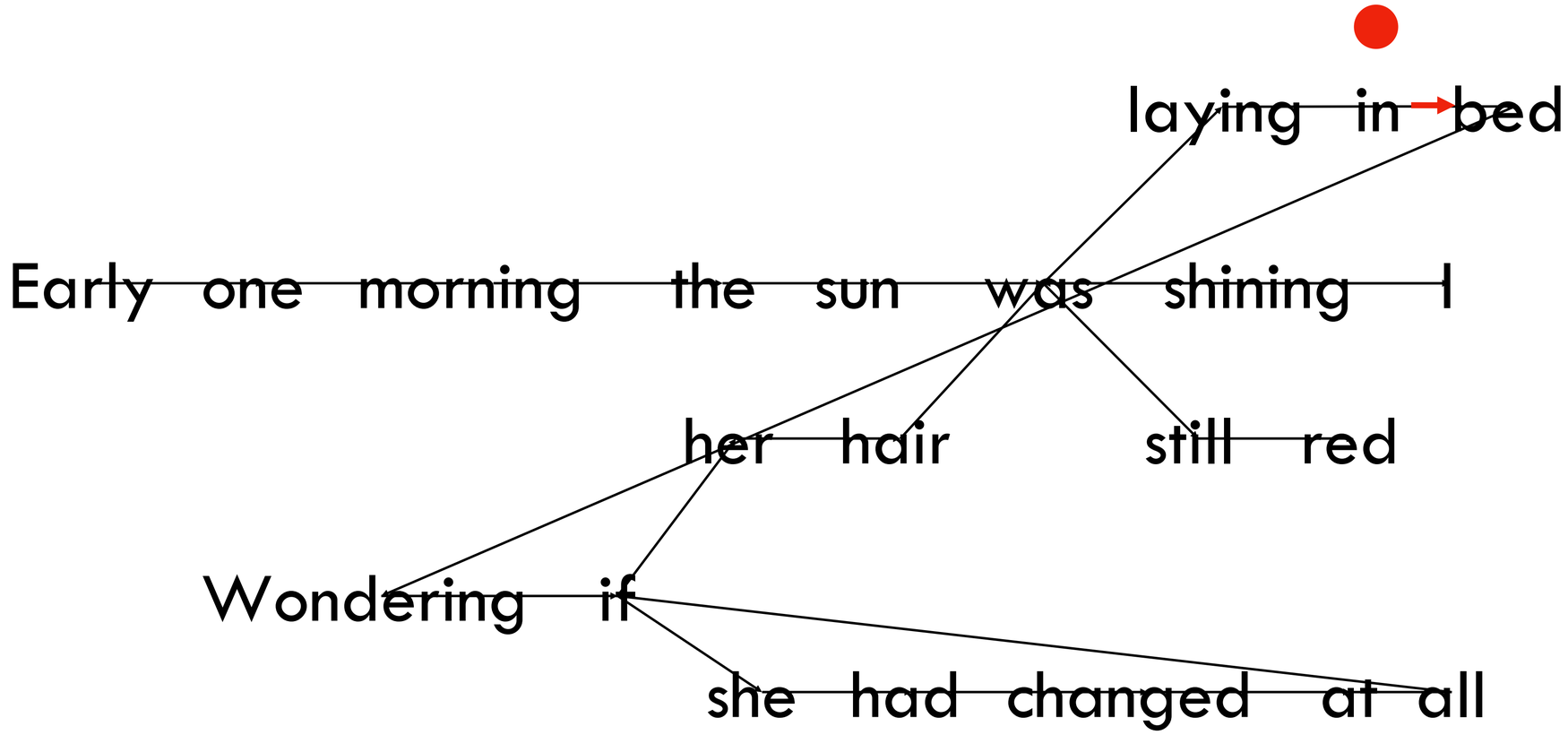
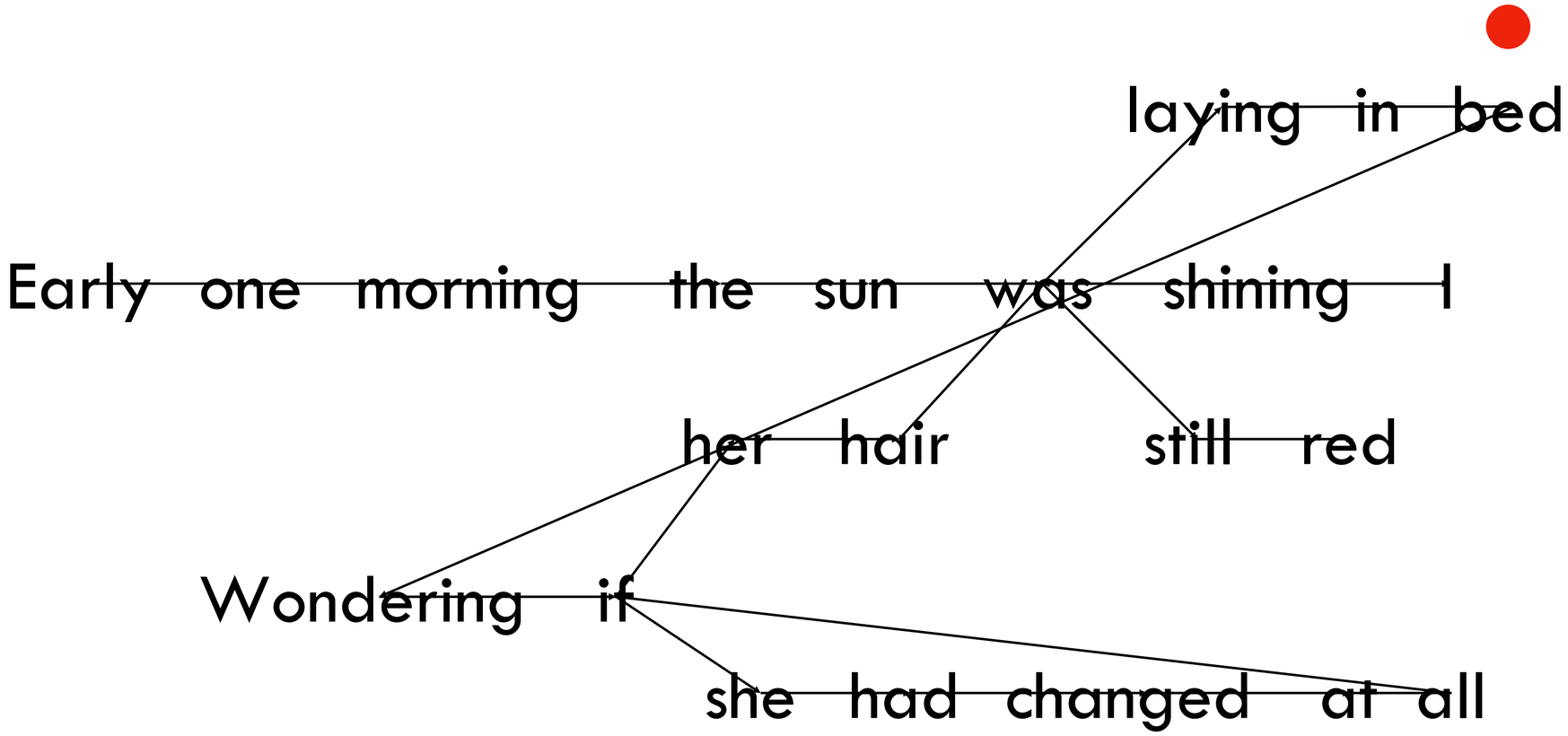
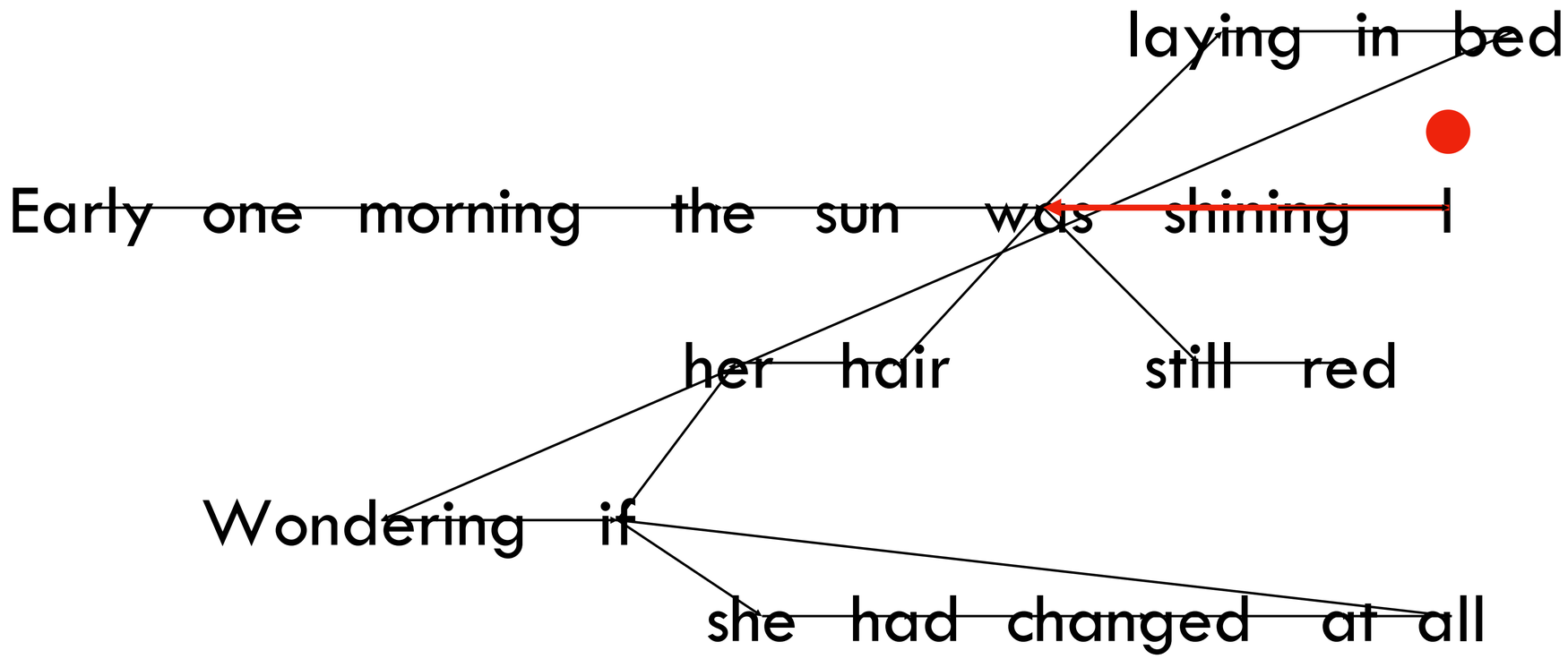


slide from Steve Seitz's video

the sun was laying in bed

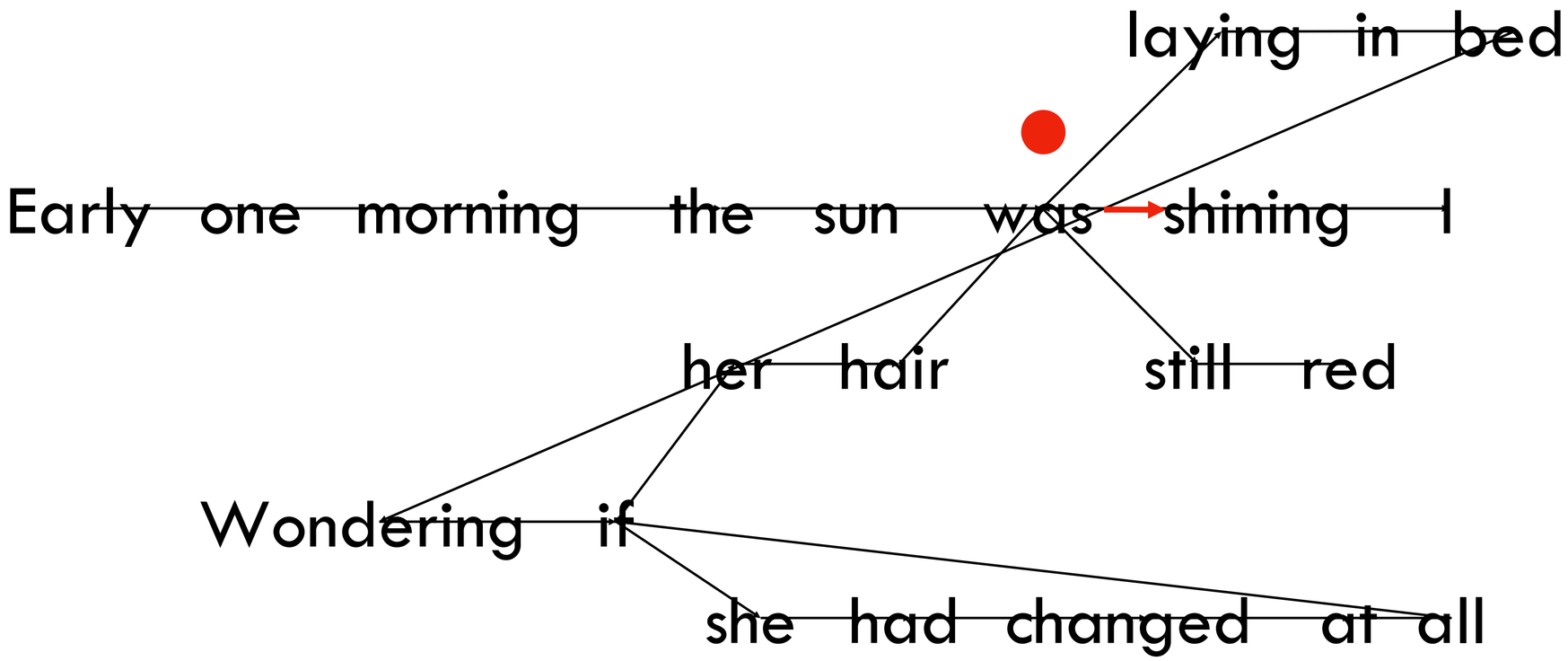


slide from Steve Seitz's video



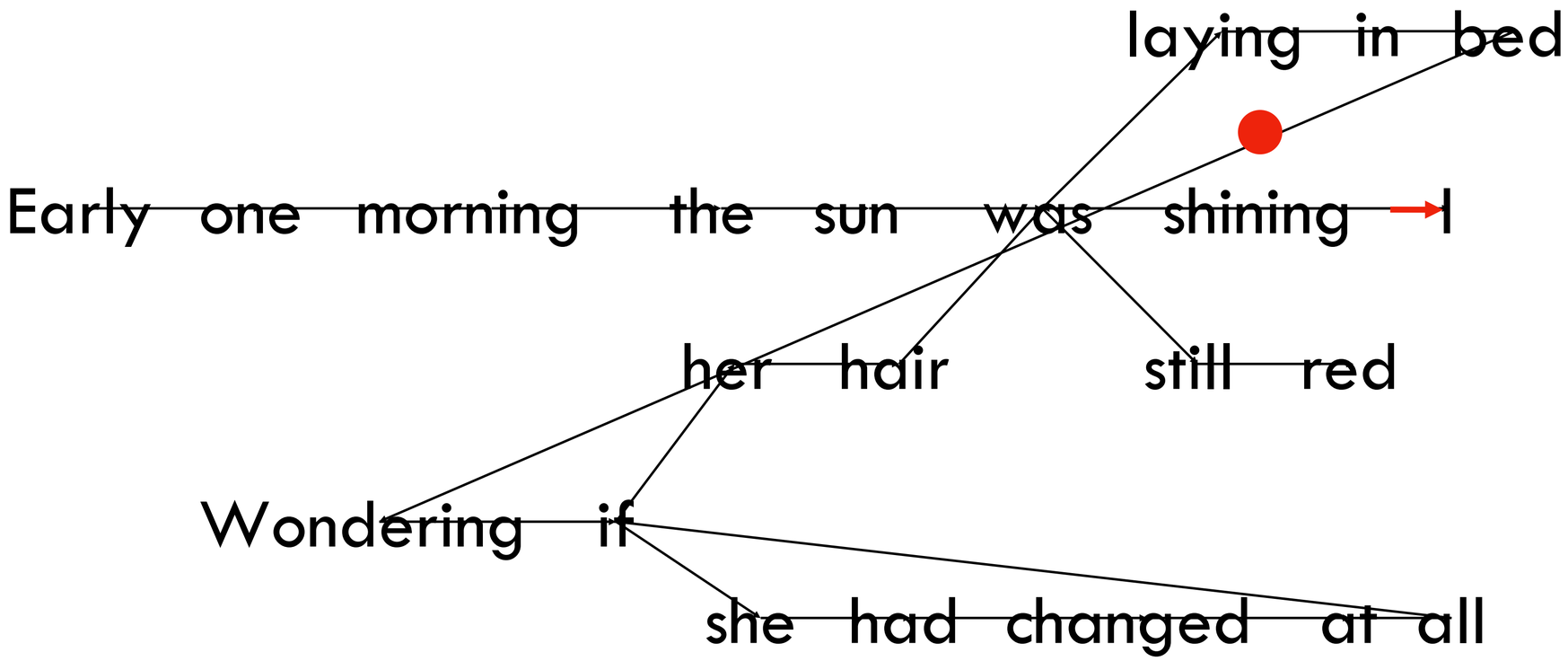
slide from Steve Seitz's video

I was



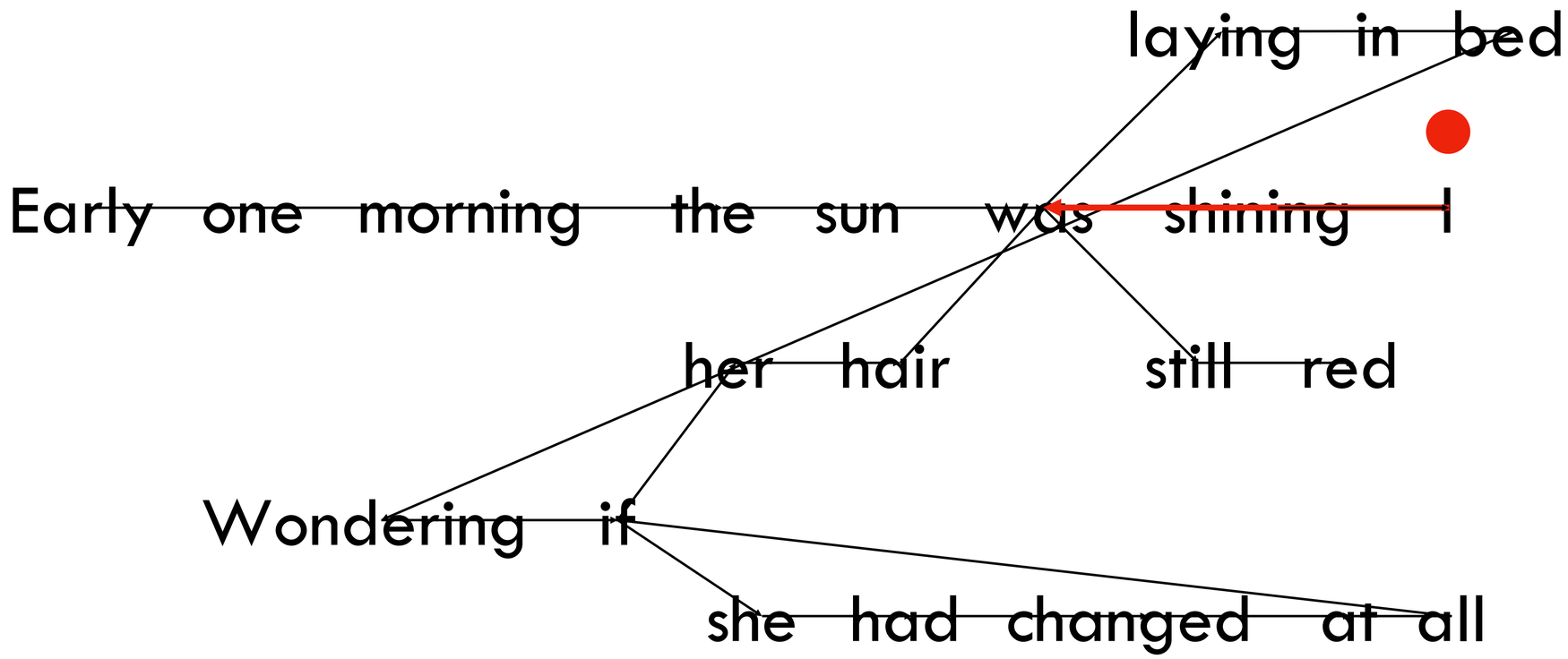
slide from Steve Seitz's video

I was shining



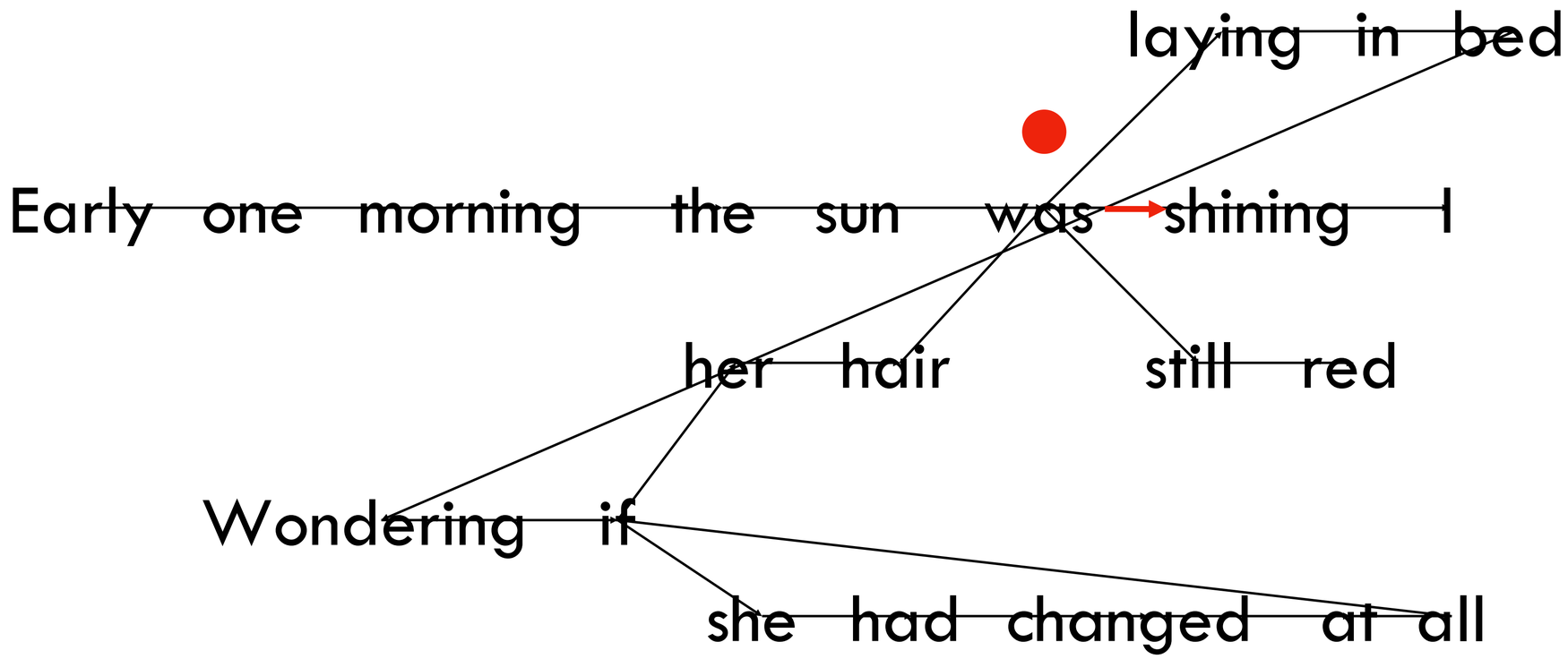
slide from Steve Seitz's video

I was shining I



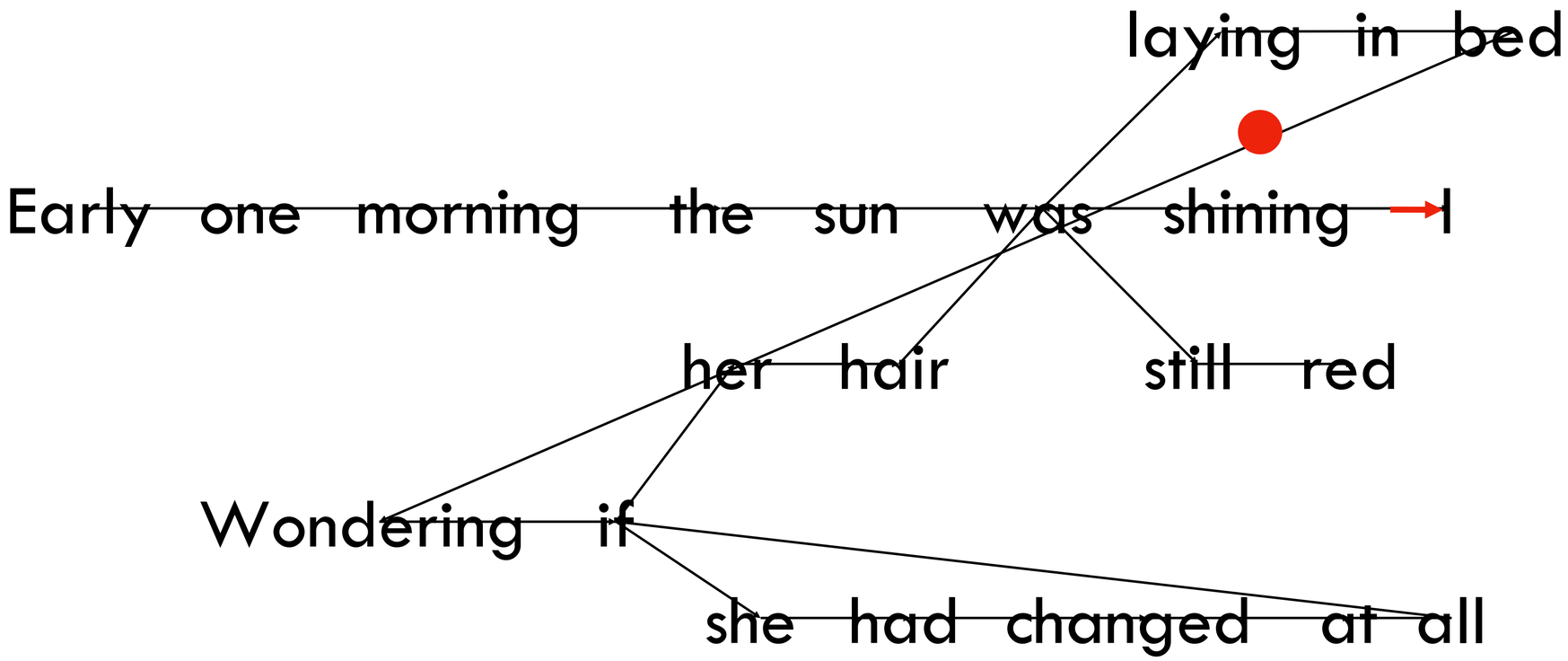
slide from Steve Seitz's video

I was shining I was



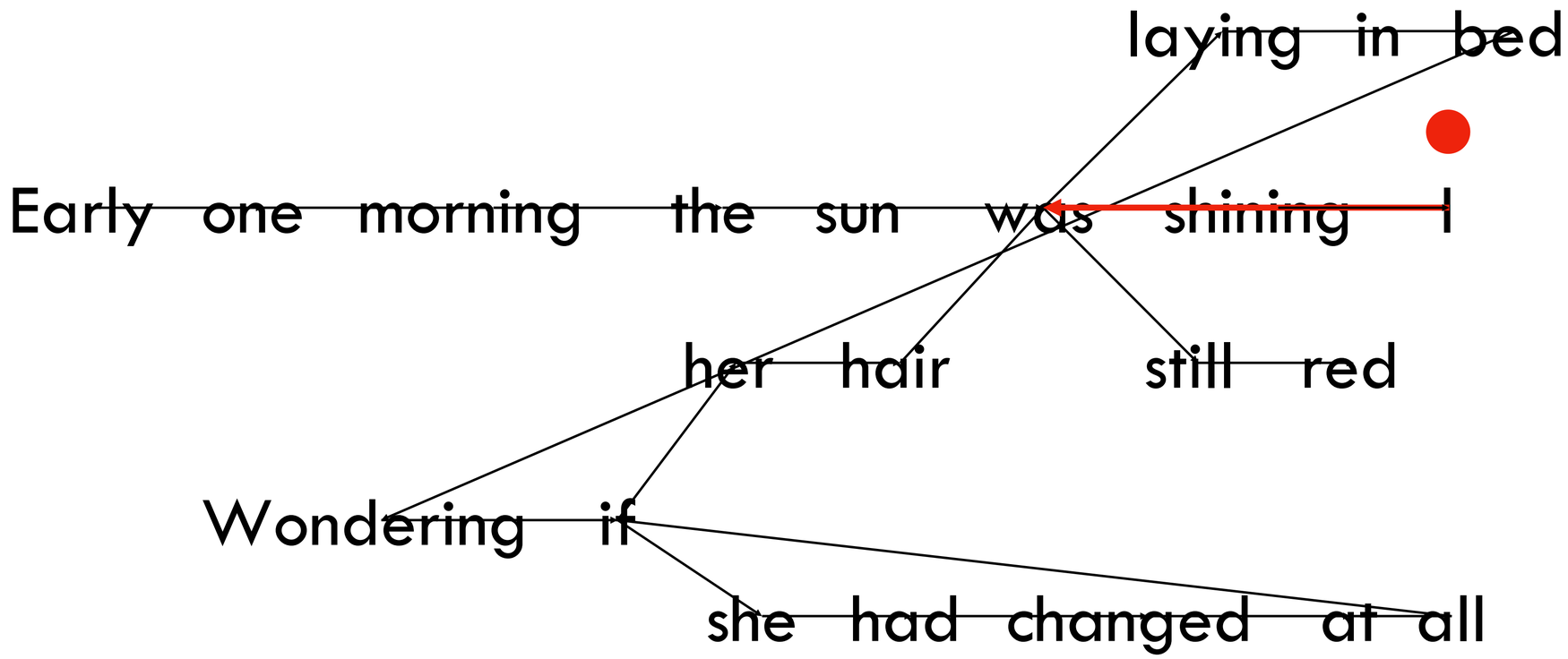
slide from Steve Seitz's video

I was shining I was shining



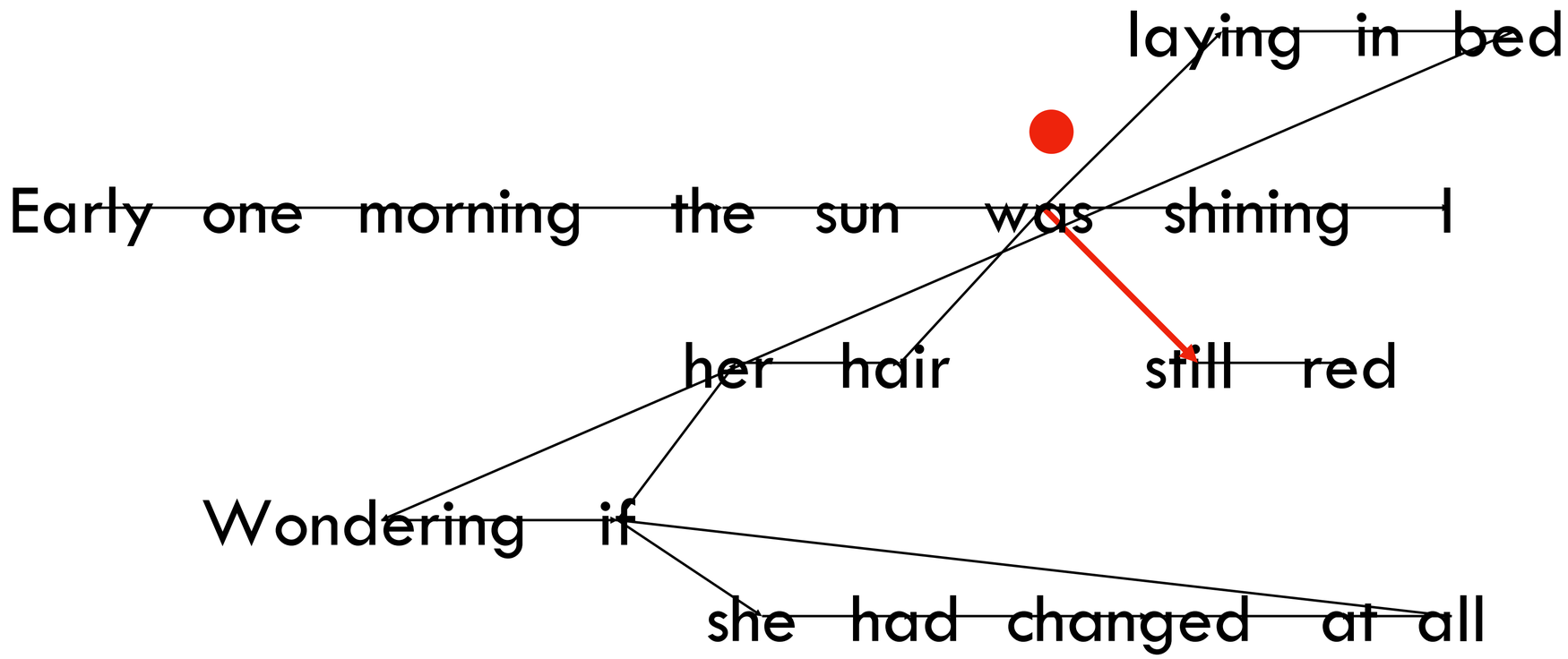
slide from Steve Seitz's video

I was shining I was shining I



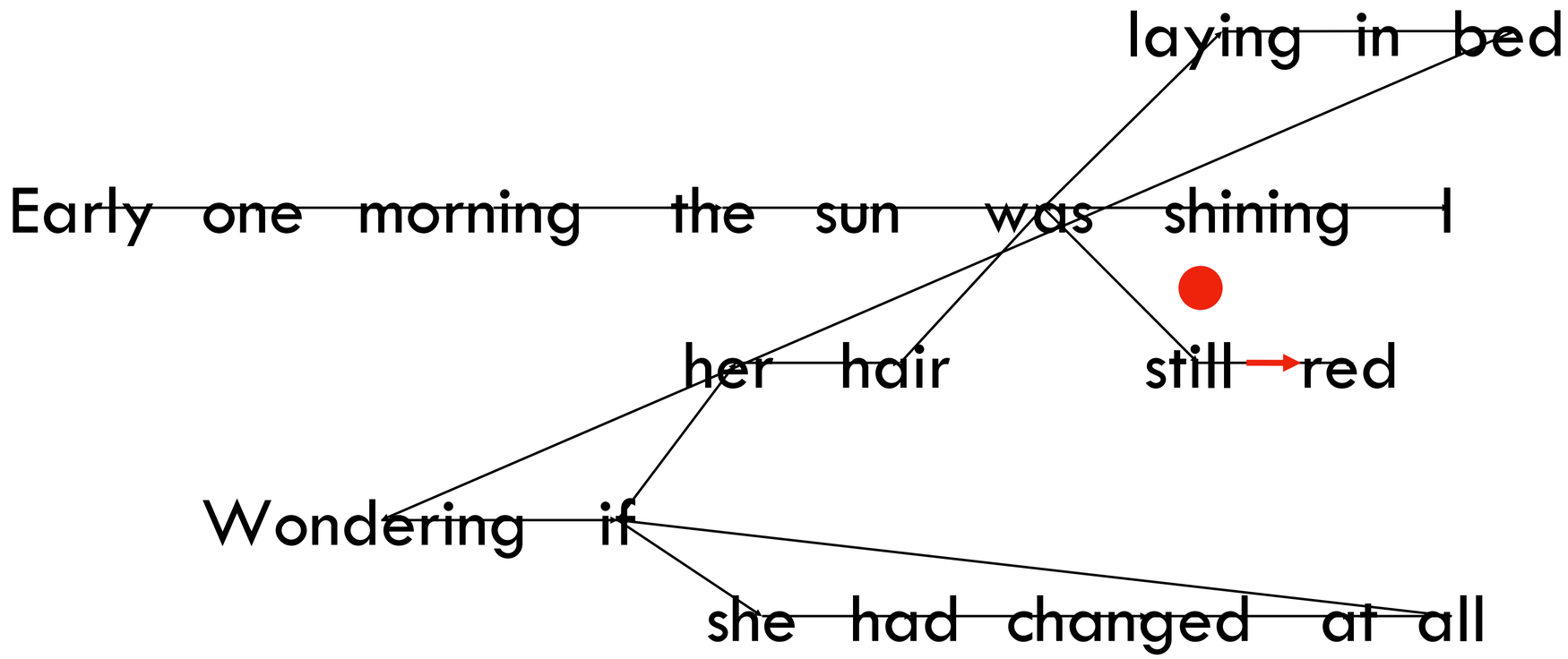
slide from Steve Seitz's video

I was shining I was shining I was



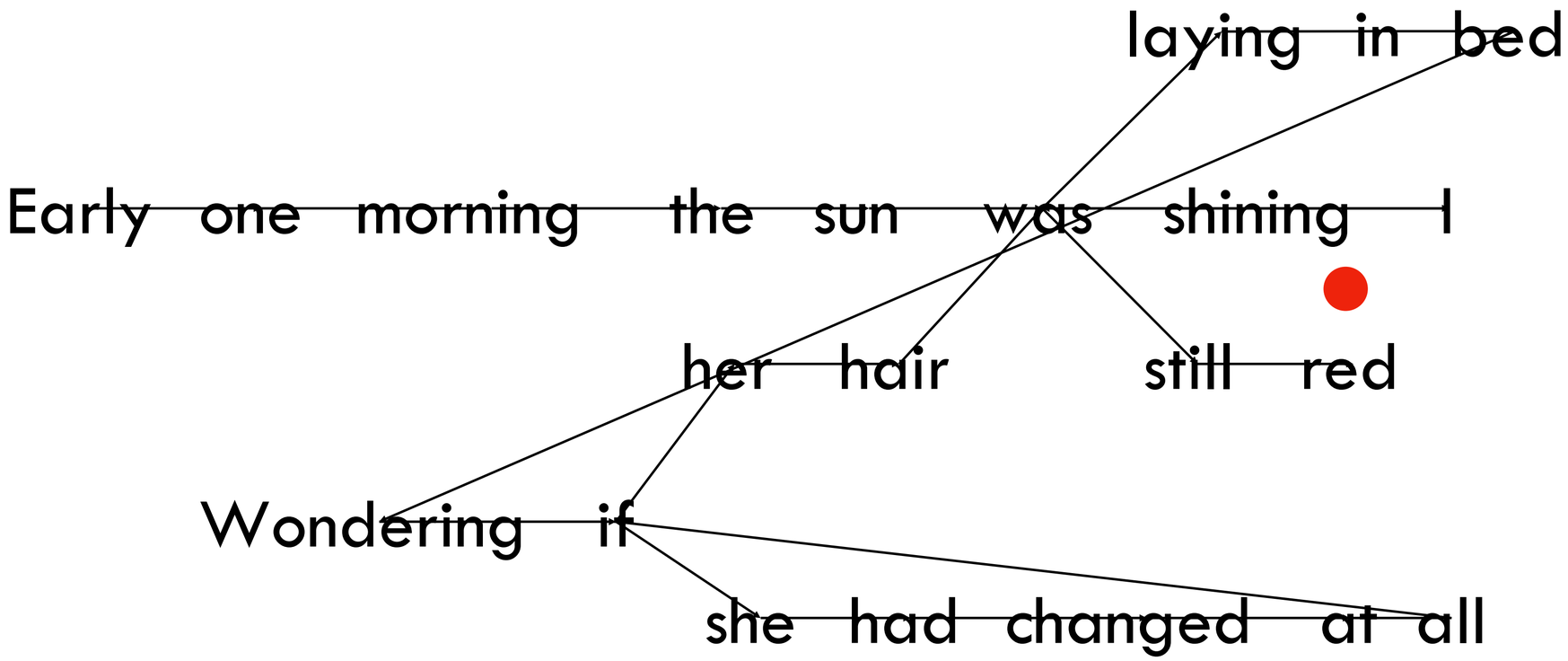
slide from Steve Seitz's video

I was shining I was shining I was still



slide from Steve Seitz's video

I was shining I was shining I was still red



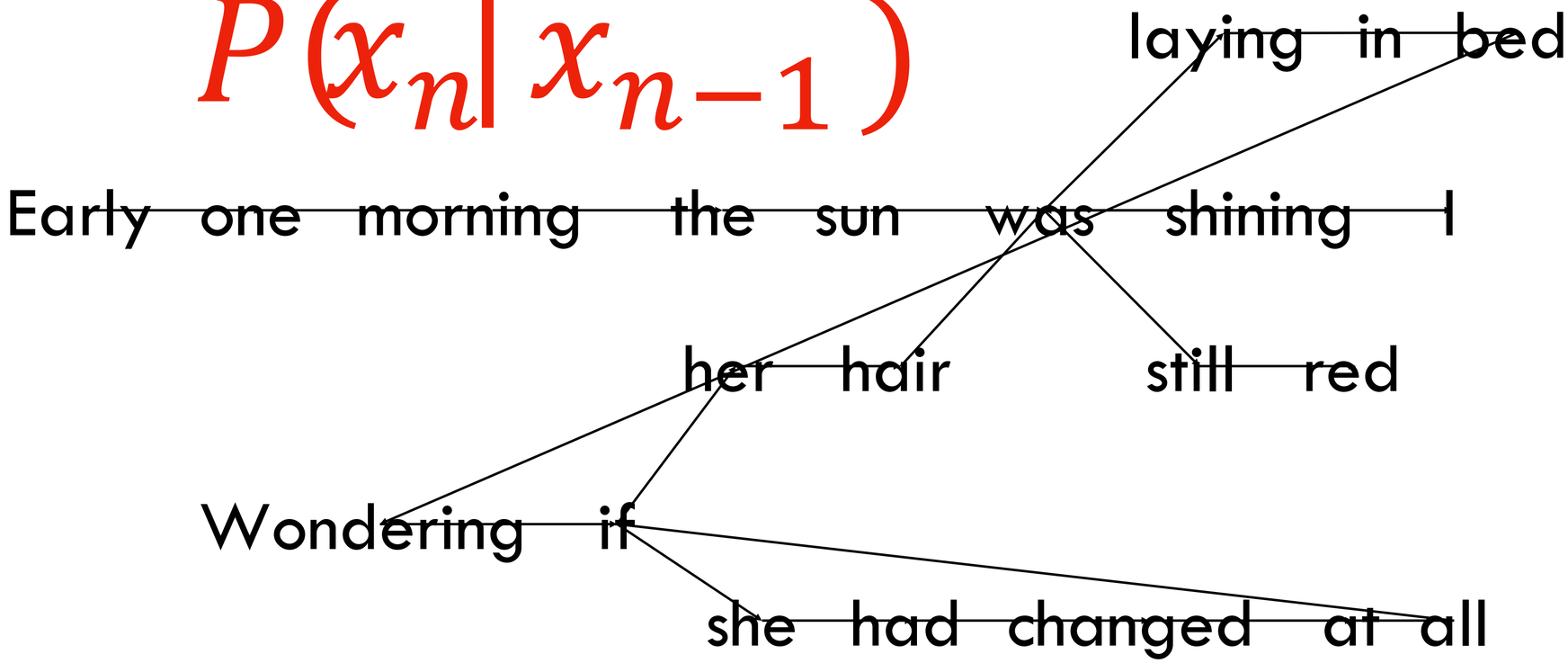
she was standing on the side of my mind …

side of my shoes heading out of my face …

one of my chair said our lives together …

slide from Steve Seitz's video

$$P(x_n | x_{n-1})$$



slide from Steve Seitz's video

Early one morning the sun was shining I was laying in bed

Wondering if she had changed at all if her hair was still red

Early one morning

trigrams

slide from Steve Seitz's video

Early one morning the sun was shining I was laying in bed

Wondering if she had changed at all if her hair was still red

Early one morning
one morning the

trigrams

slide from Steve Seitz's video

Early one morning the sun was shining I was laying in bed

Wondering if she had changed at all if her hair was still red

Early one morning
one morning the
morning the sun

trigrams

slide from Steve Seitz's video

Early one morning the sun was shining I was laying in bed

Wondering if she had changed at all if her hair was still red

Early one morning
one morning the
morning the sun
the sun was

trigrams

slide from Steve Seitz's video

Early one morning the sun was shining I was laying in bed

Wondering if she had changed at all if her hair was still red

Early one morning
one morning the
morning the sun
the sun was

trigrams

slide from Steve Seitz's video

Early one morning the sun was shining I was laying in bed

Wondering if she had changed at all if her hair was still red

Early one morning
one morning the
morning the sun
the sun was
sun was shining
was shining I
shining I was
I was laying
…

trigrams

slide from Steve Seitz's video

$$P(x_n | x_{n-1}, x_{n-2})$$

Early one → morning
one morning → the
morning the → sun
the sun → was
sun was → shining
was shining → I
shining I → was
I was → laying
…

Video Textures

Arno Schödl
Richard Szeliski
David Salesin
Irfan Essa

Microsoft Research, Georgia Tech

SIGGRAPH 2000

Still photos

Video clips

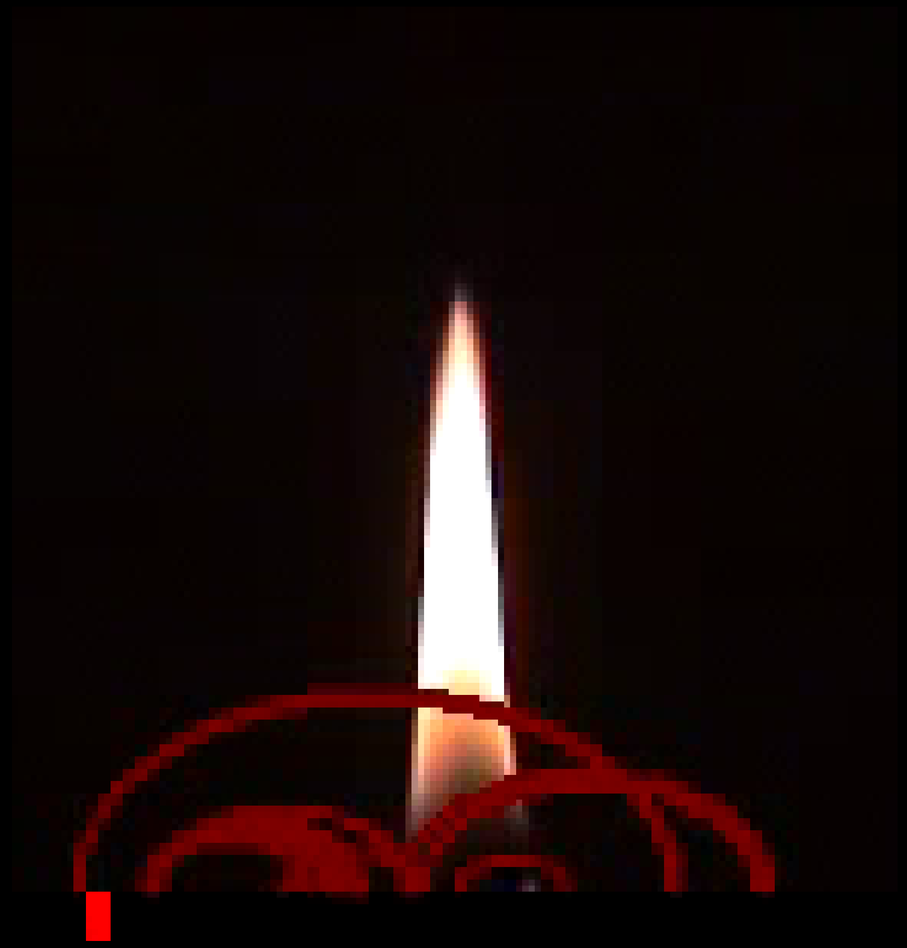
Video textures

Problem statement

video clip

video texture

Our approach

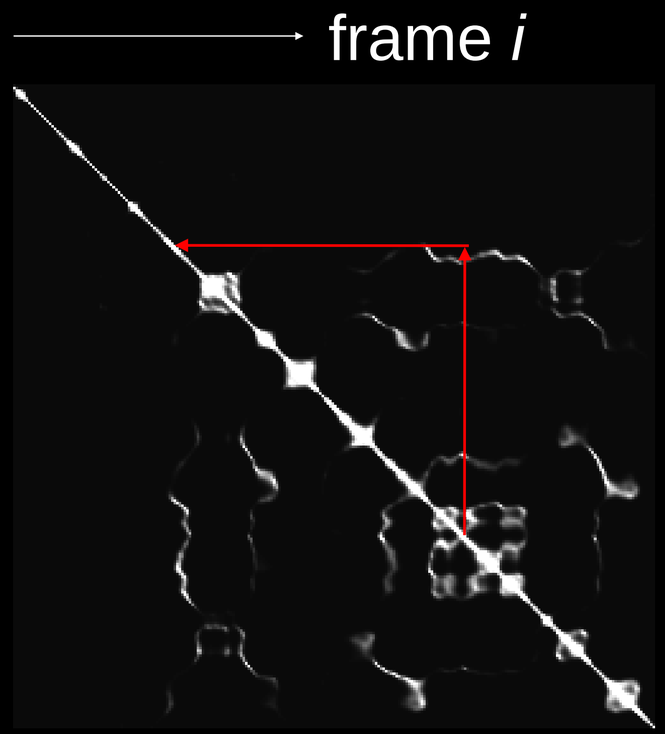


- How do we find good transitions?

Finding good transitions

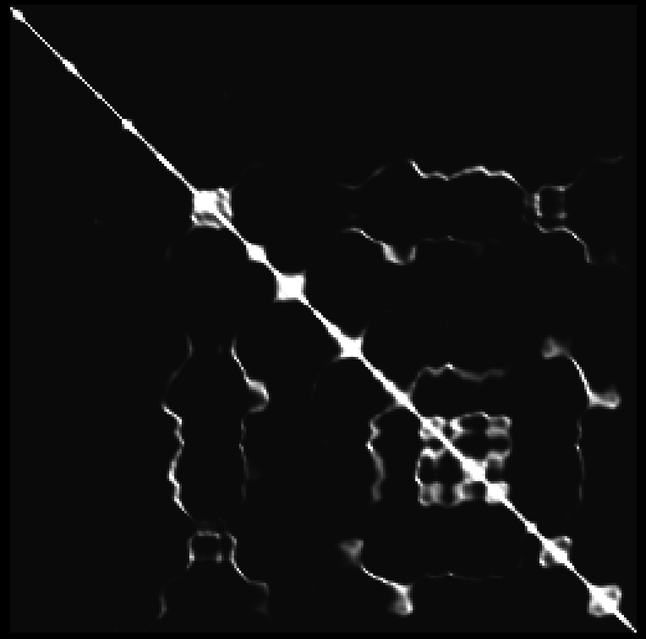
- Compute L_2 distance $D_{i,j}$ between all frames

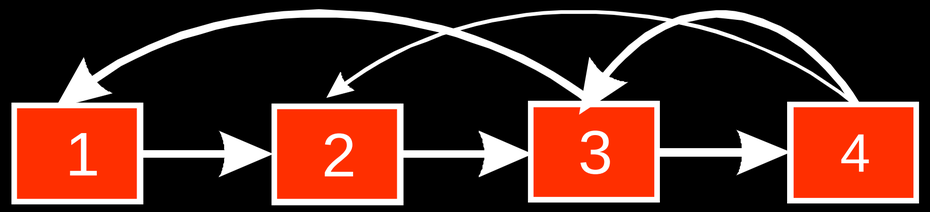
vs.



Similar frames make good transitions

Markov chain representation

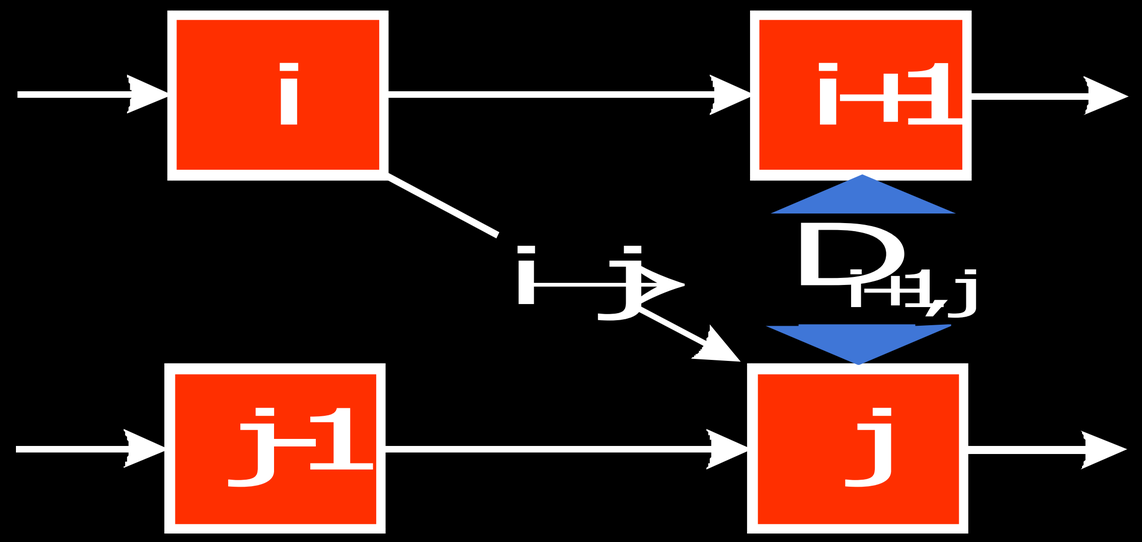




Similar frames make good transitions

Transition costs

- Transition from i to j if successor of i is similar to j
  - Cost function: $C_{i \to j} = D_{i+1,\, j}$
-



Transition probabilities

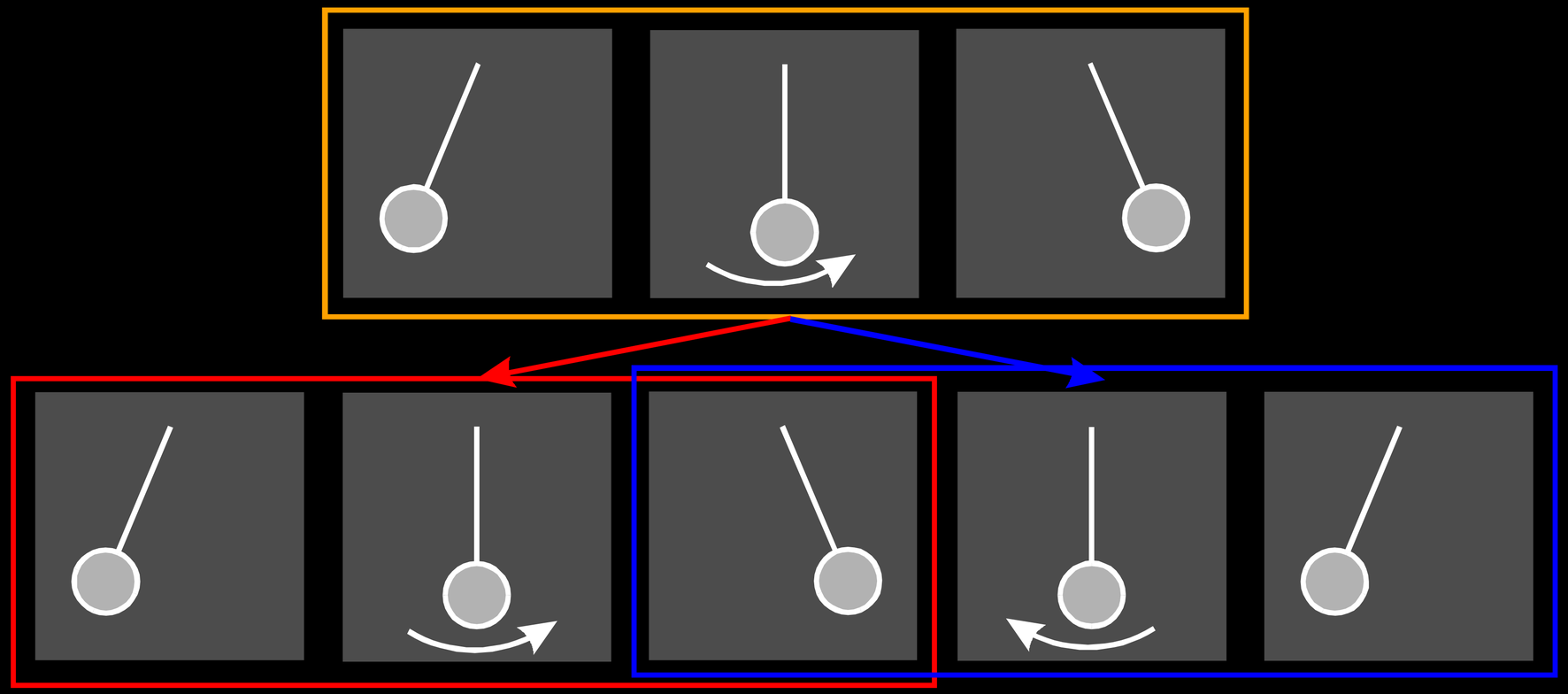
- Probability for transition $P_{i \to j}$ inversely related to cost:
  - $P_{i \to j} \sim \exp\left(- C_{i \to j} / \sigma^2 \right)$

high σ

low σ

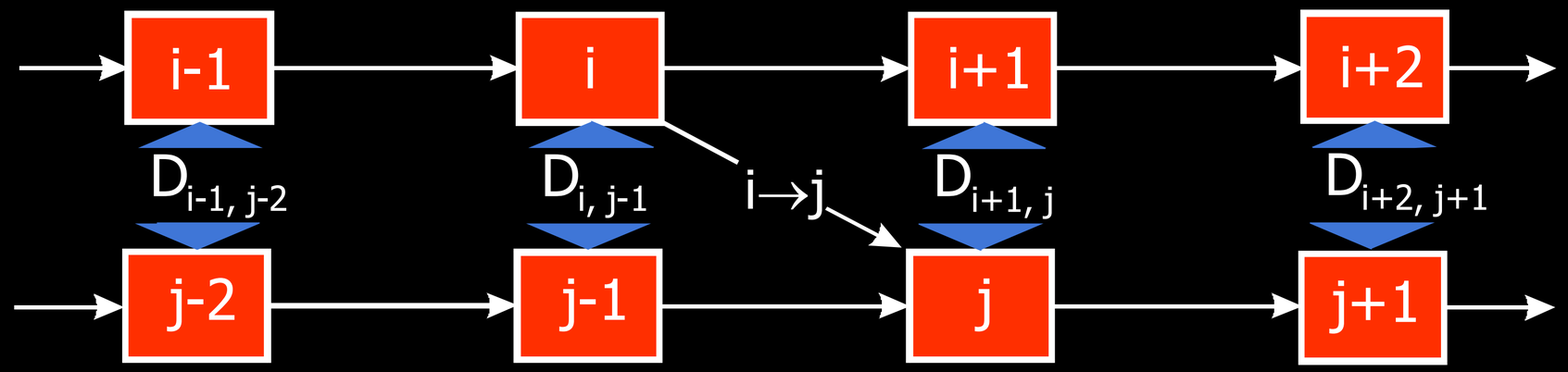
Preserving dynamics

Preserving dynamics



Preserving dynamics

- Cost for transition $i \rightarrow j$
  - $$C_{i \rightarrow j} = \sum_{k=-N}^{N-1} w_k D_{i+k+1,\, j+k}$$



Preserving dynamics – effect

- Cost for transition $i \rightarrow j$
  - $$C_{i \rightarrow j} = \sum_{k=-N}^{N-1} w_k D_{i+k+1,\, j+k}$$

Video portrait

- c.f. Harry Potter

Region-based analysis

- Divide video up into regions

- Generate a video texture for each region

User-controlled video textures

slow variable fast

User selects target frame range

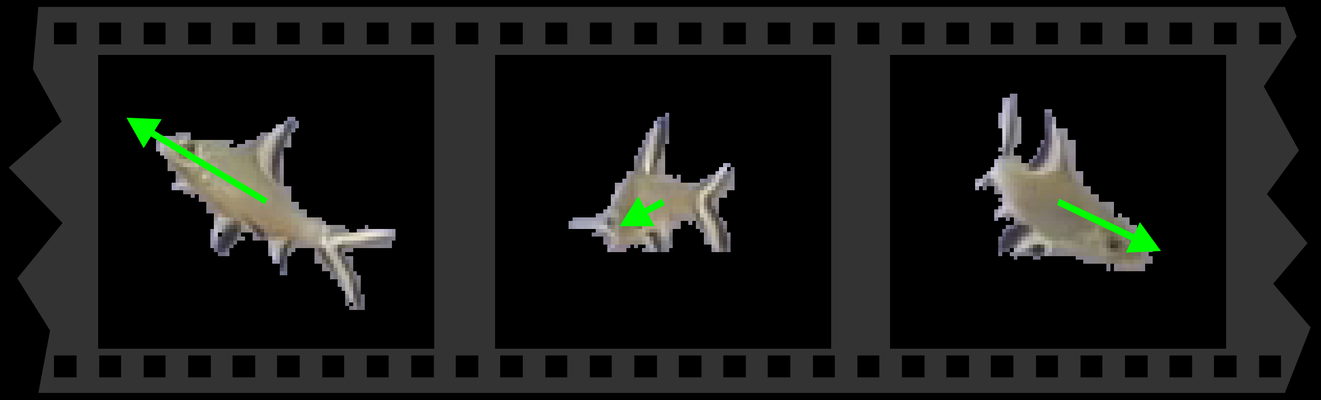
Video-based animation

- Like sprites computer games
- Extract sprites from real video
- Interactively control desired motion

©1985 Nintendo of America Inc.

Video sprite extraction

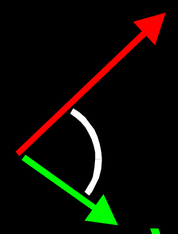
blue screen matting
and velocity estimation



Video sprite control

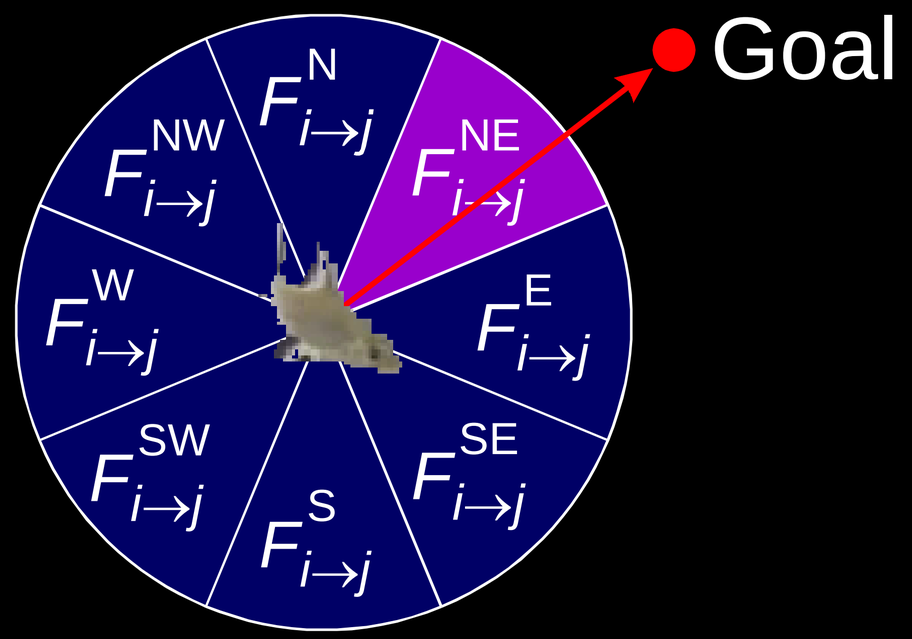
- Augmented transition cost:

$$C^{\text{Animation}}_{i\to j} = \alpha \underbrace{C_{i\to j}}_{\text{Similarity term}} + \beta \underbrace{\text{angle}}_{\text{Control term}}$$



Video sprite control

- Need future cost computation
- Precompute future costs for a few angles.
- Switch between precomputed angles according to user input
- [GIT-GVU-00-11]



Interactive fish

Summary / Discussion

- Some things are relatively easy

Discussion

- Some are hard

Texture

- Texture depicts spatially repeating patterns
- Many natural phenomena are textures

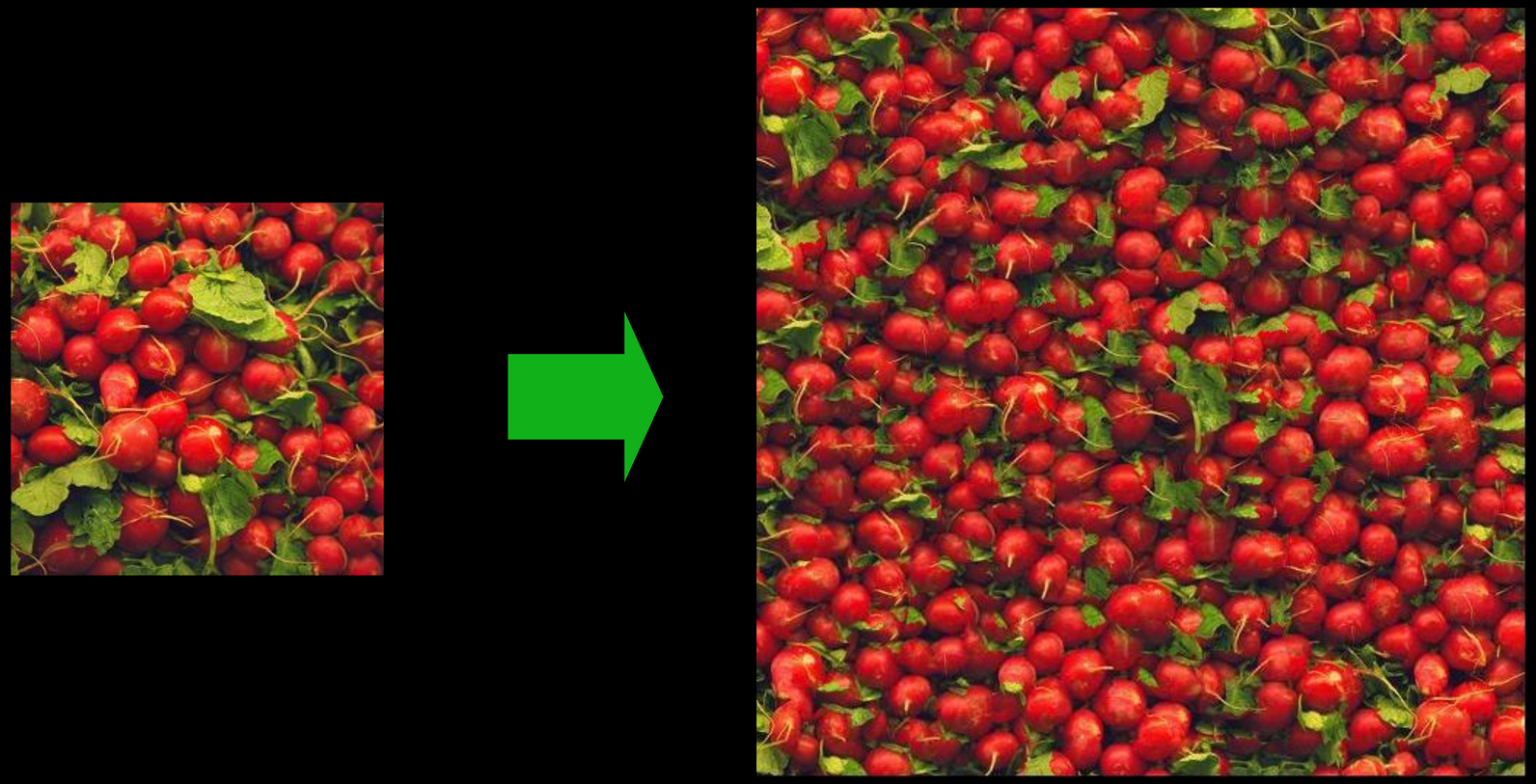
radishes

rocks

yogurt

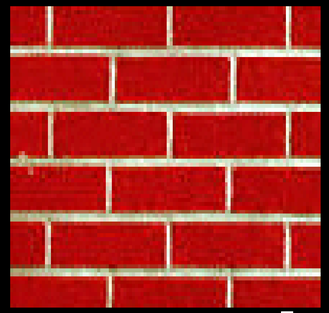
Texture Synthesis

- Goal of Texture Synthesis: create new samples of a given texture
- Many applications: virtual environments, hole-filling, texturing surfaces

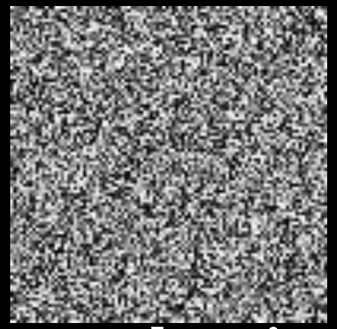


The Challenge

- Need to model the whole spectrum: from repeated to stochastic texture



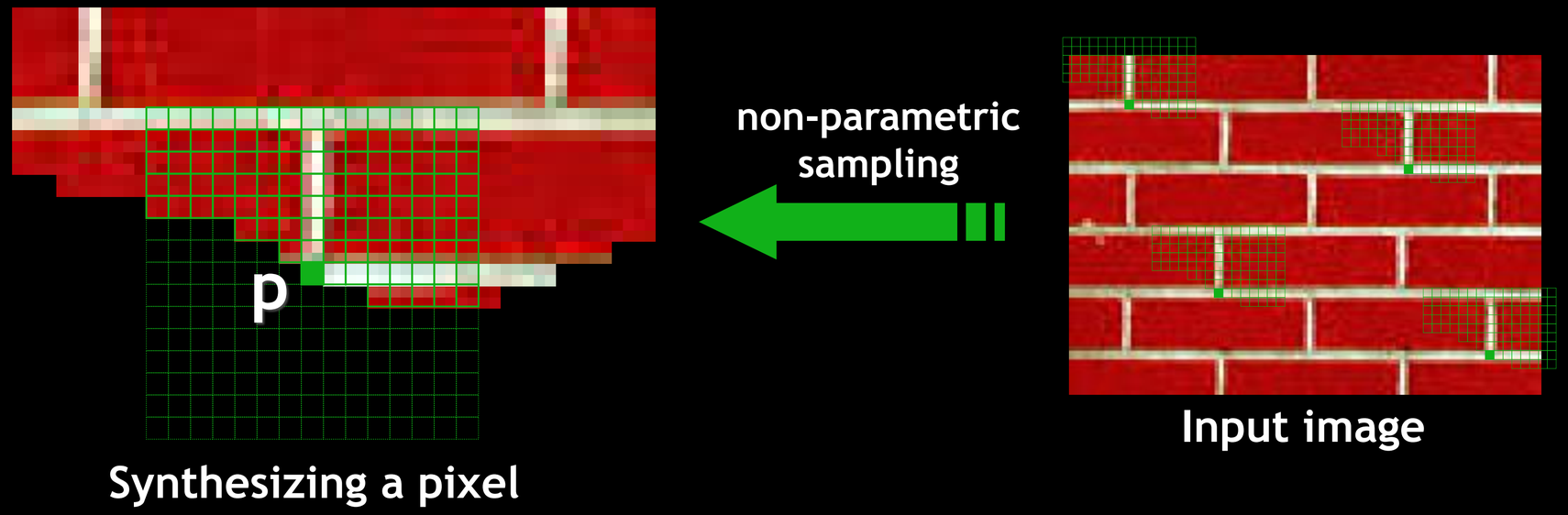
repeated



stochastic

Both?

Efros & Leung Algorithm (ICCV 1999)

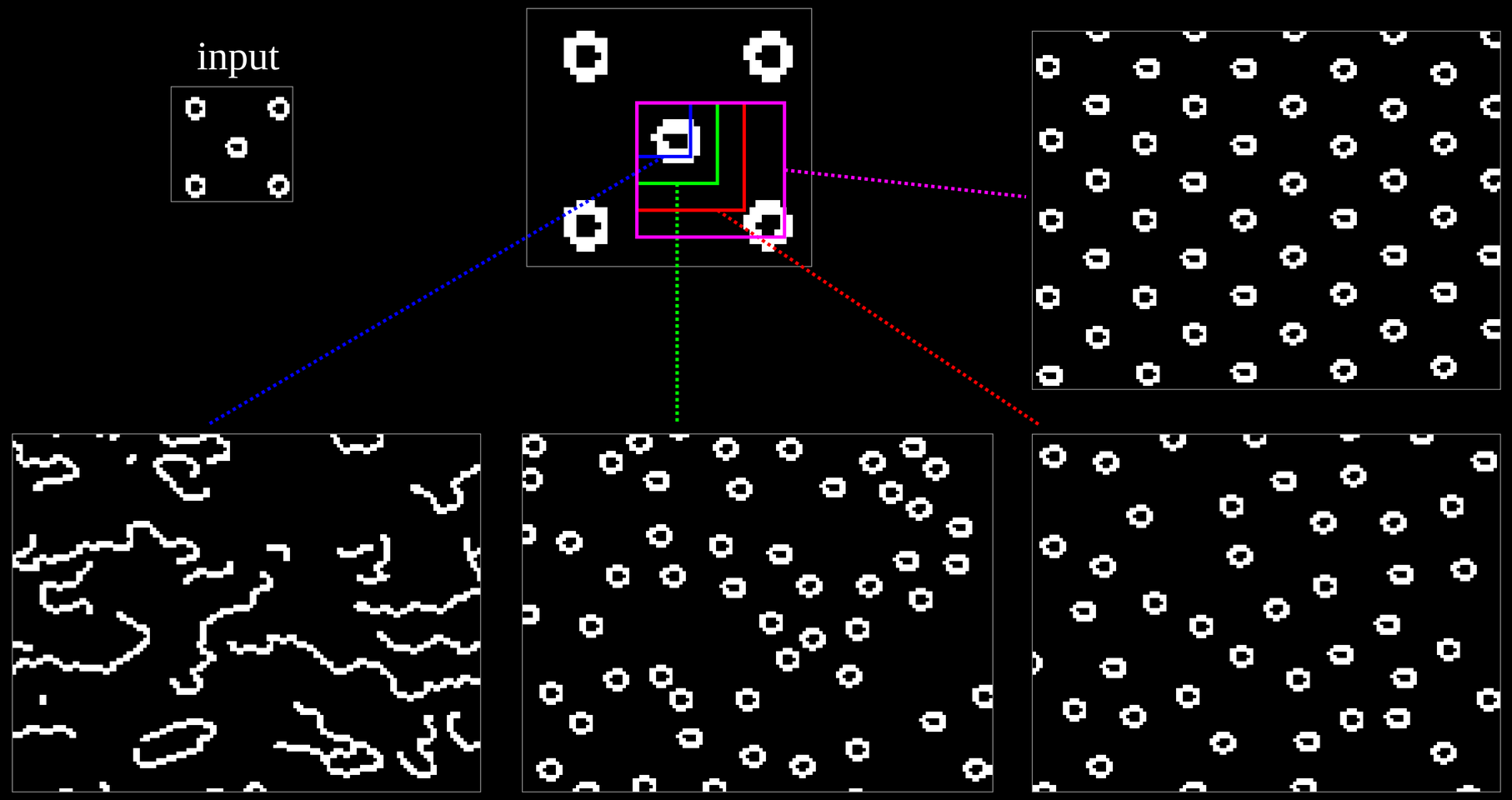


- Assuming Markov property, compute P(**p**|N(**p**))
  - Building explicit probability tables infeasible
  - Instead, we *search the input image* for all similar neighborhoods — that's our pdf for **p**
  - To sample from this pdf, just pick one match at random

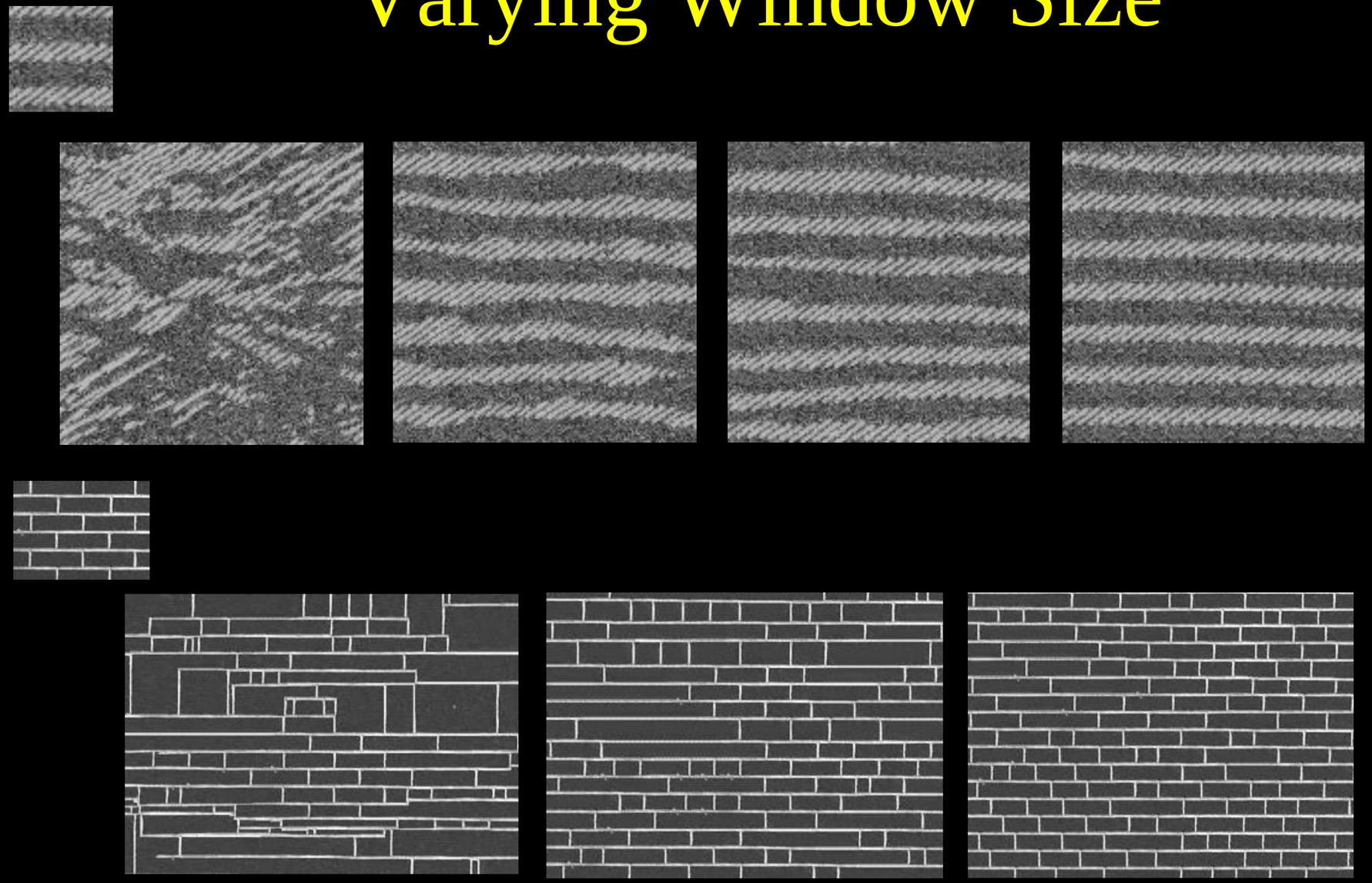
Some Details

- Growing is in “onion skin” order
  - Within each “layer”, pixels with most neighbors are synthesized first
  - If no close match can be found, the pixel is not synthesized until the end
- Using *Gaussian-weighted* SSD is very important
  - to make sure the new pixel agrees with its closest neighbors
  - Approximates reduction to a smaller neighborhood window if data is too sparse

Neighborhood Window



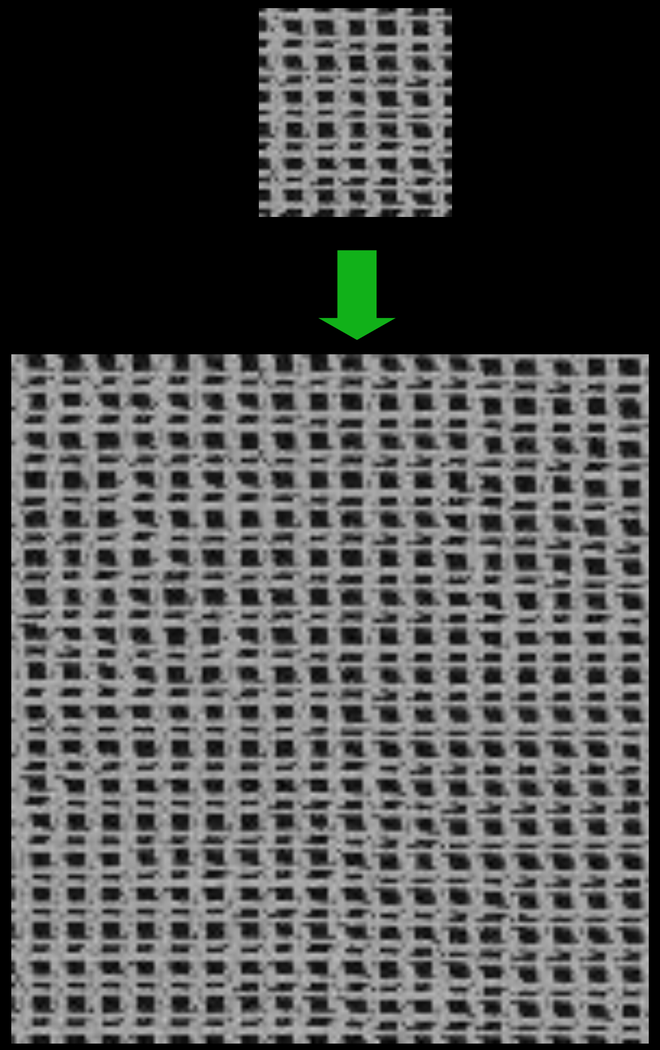
Varying Window Size



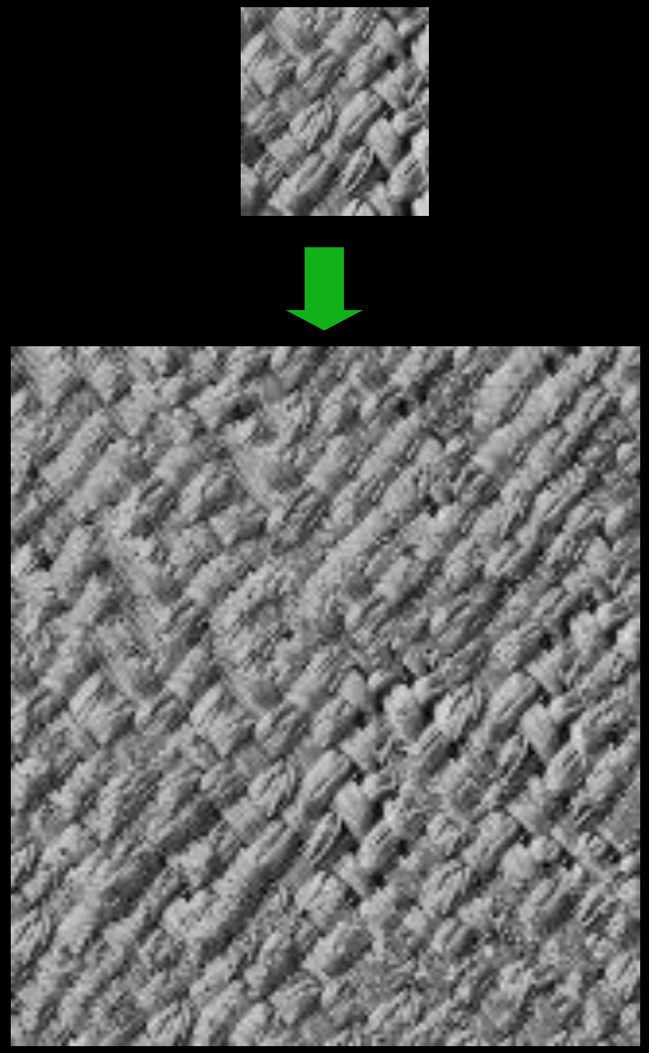
Increasing window size

Synthesis Results

french canvas

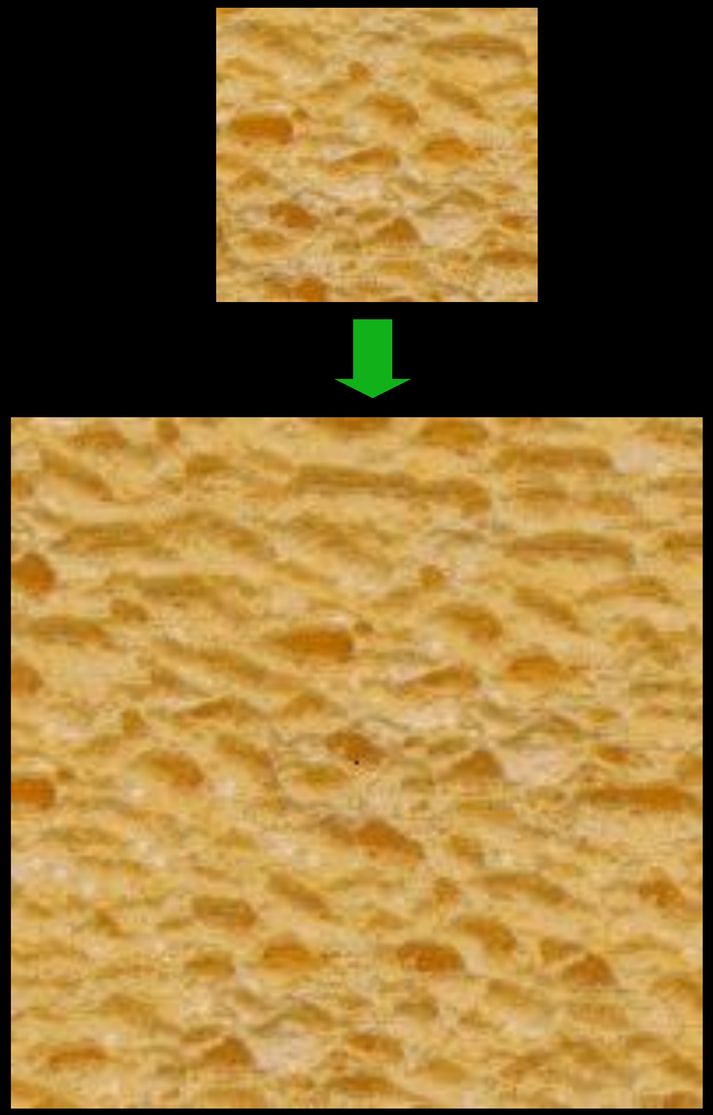


rafia weave

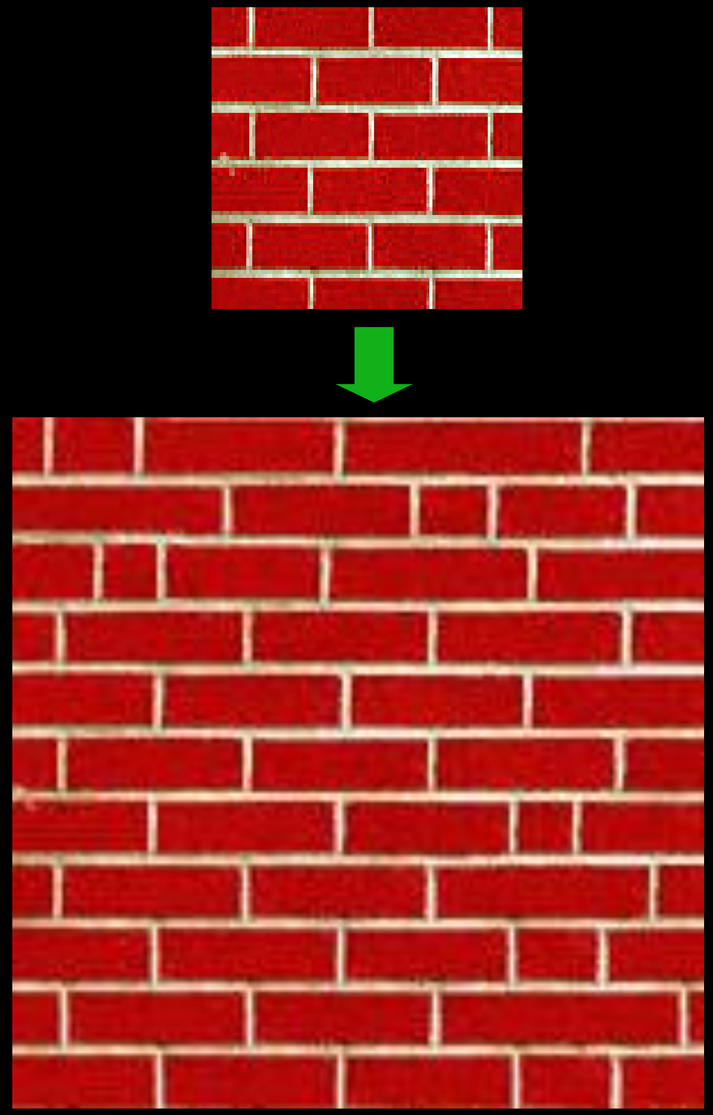


More Results

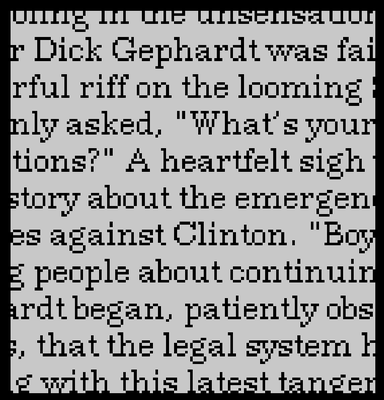
white bread

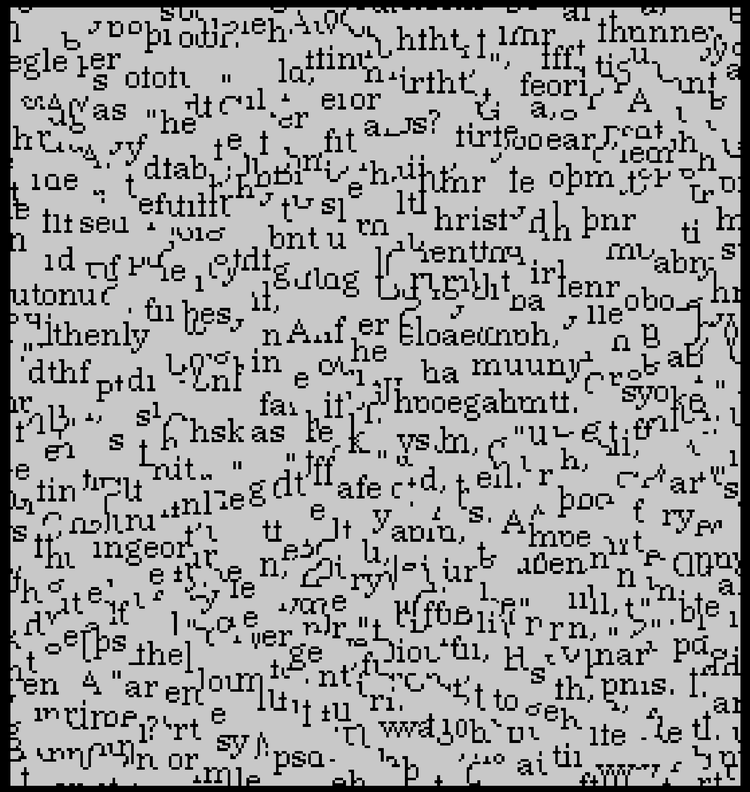


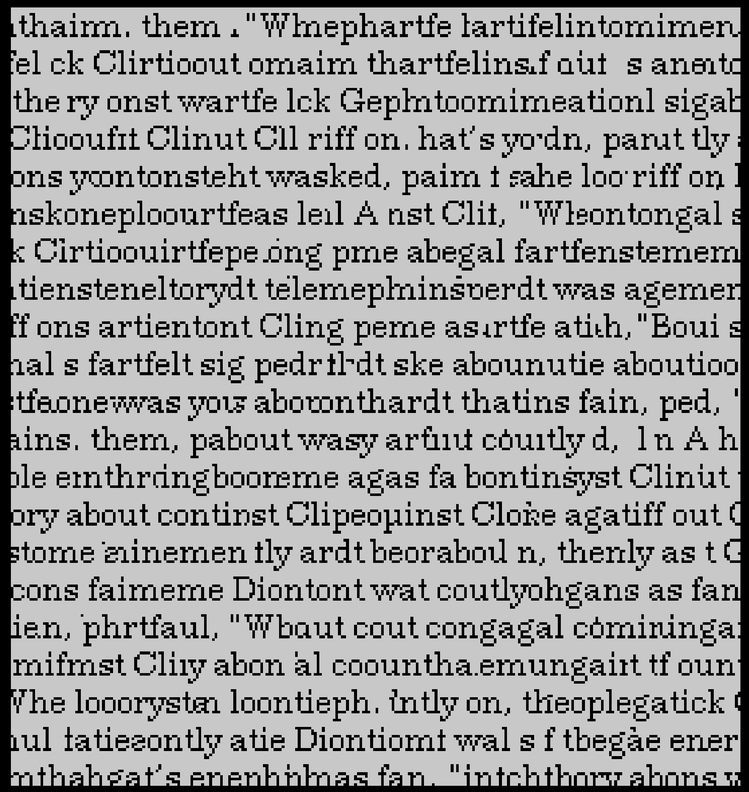
brick wall



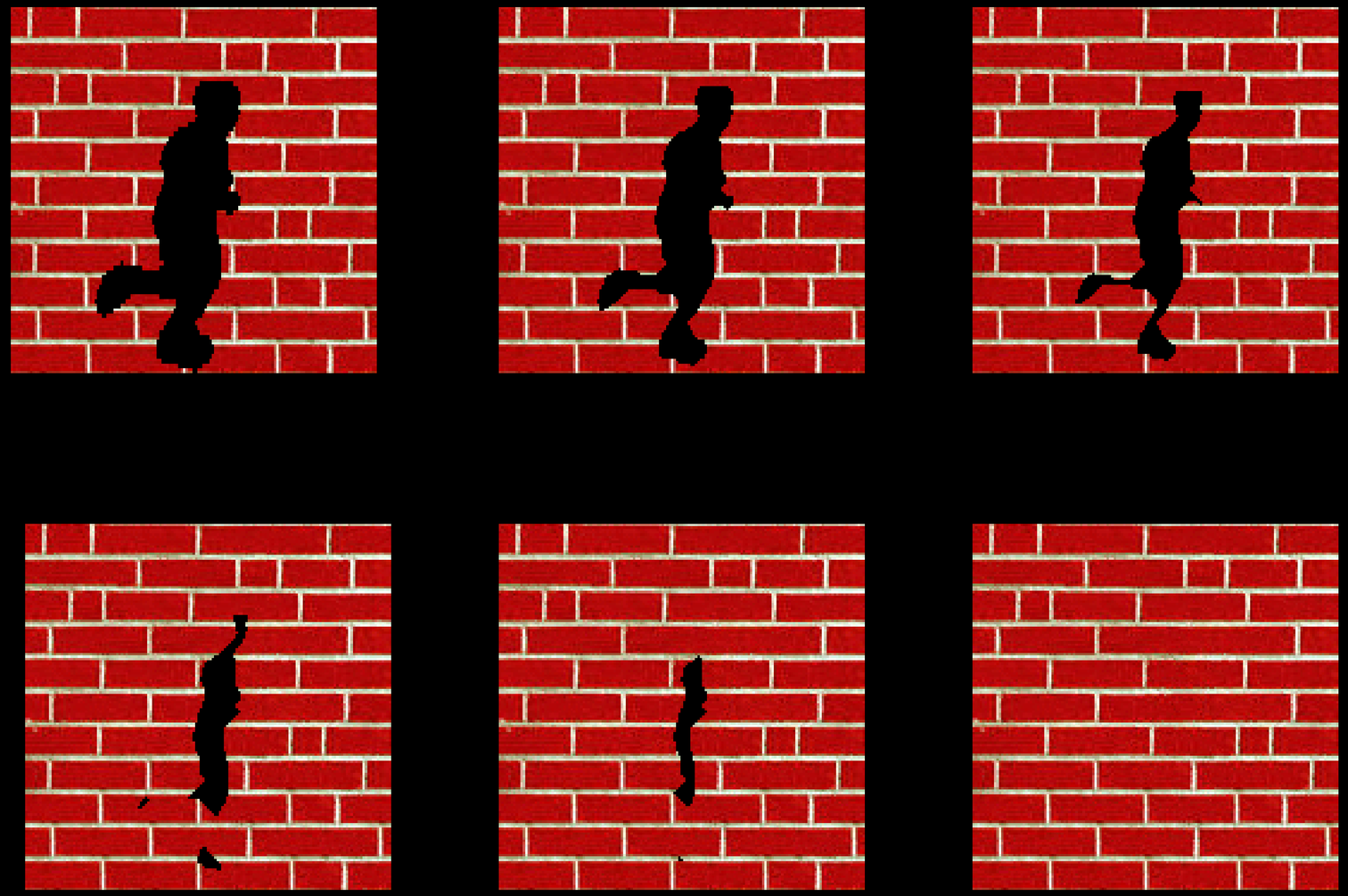
Homage to Shannon



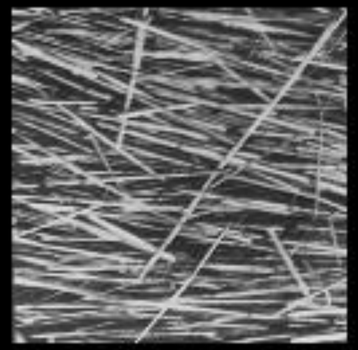




Hole Filling



Extrapolation



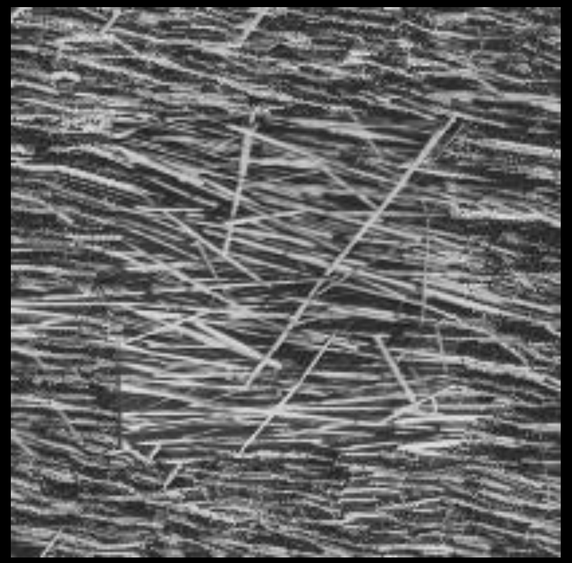


Image Analogies

Aaron Hertzmann[1,2]

Chuck Jacobs[2]

Nuria Oliver[2]

Brian Curless[3]

David Salesin[2,3]

[1]New York University

[2]Microsoft Research

[3]University of Washington

SIGGRAPH 2001

Image Analogies

A

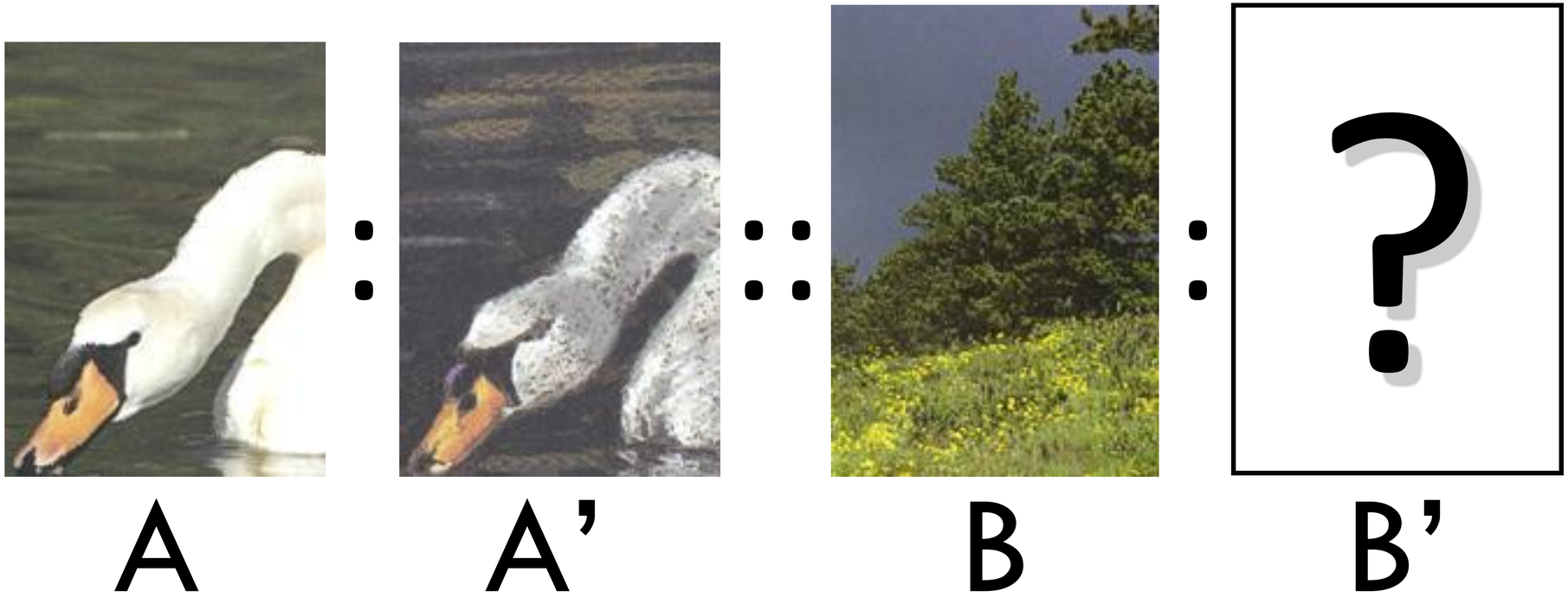
A’

B

B’

Image Analogies

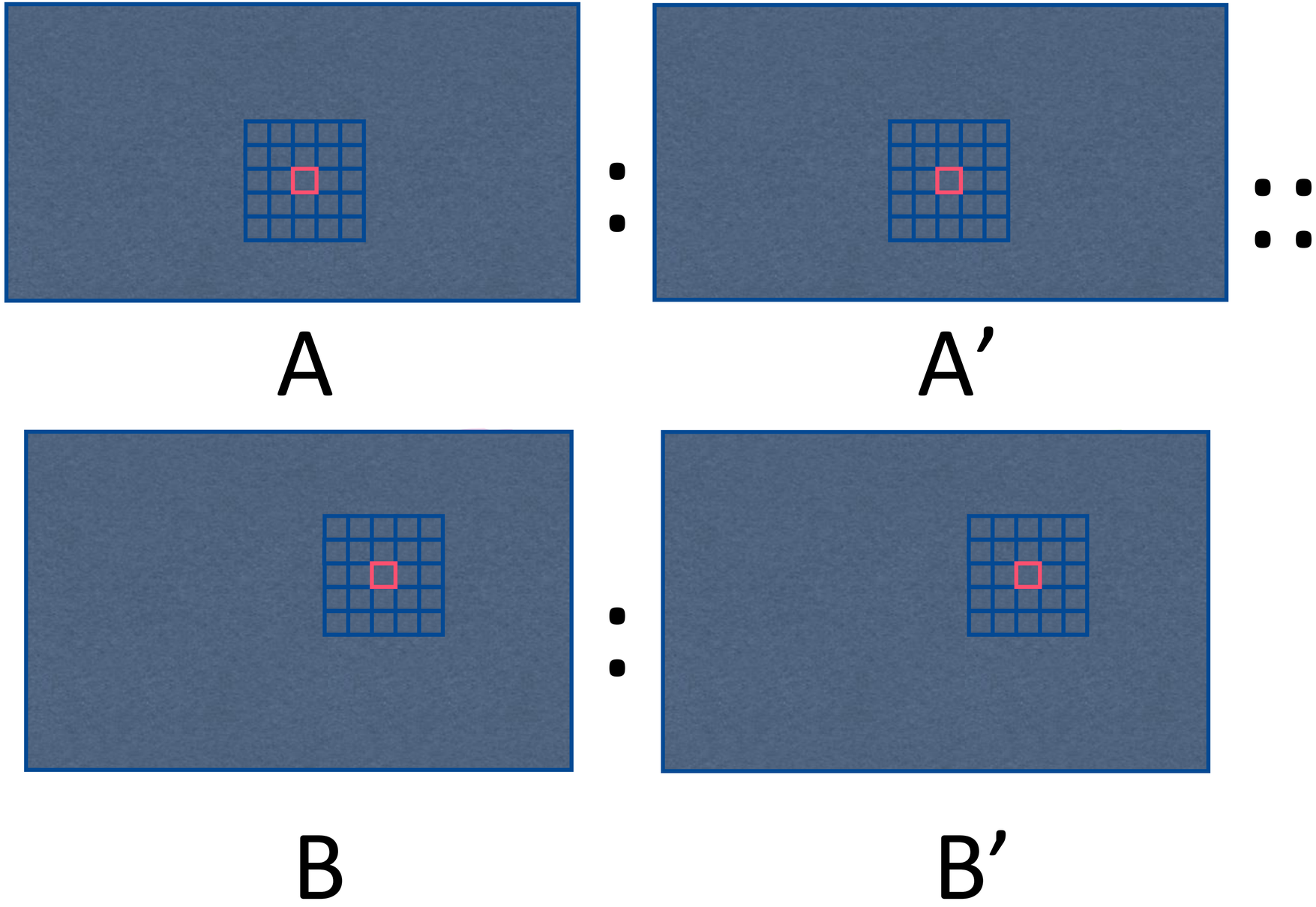
Goal: Process an image by example

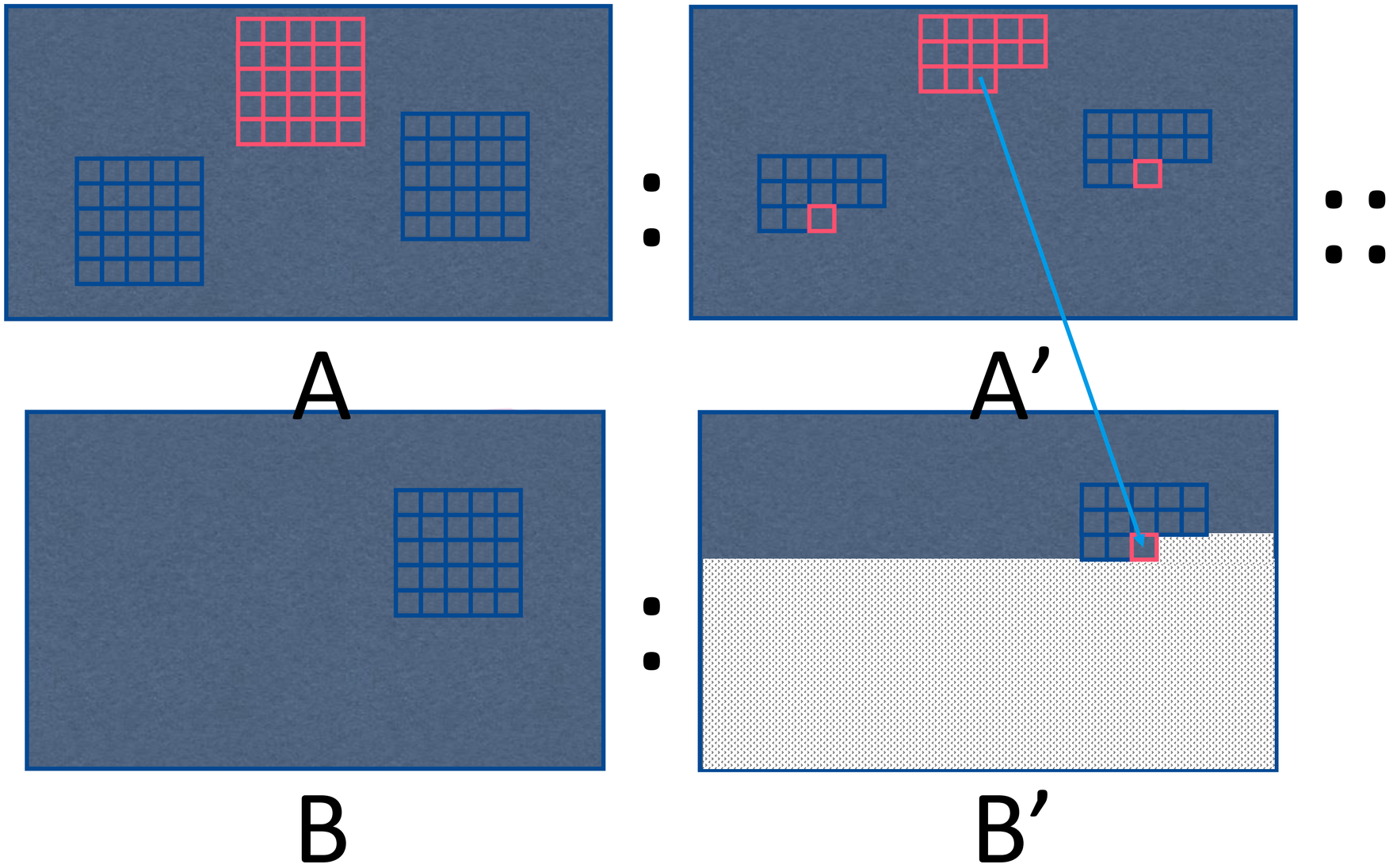


Hertzmann et al. SIGGRAPH 2001

Non-parametric sampling

A A’ B B’


A
A’
B
B’


A
A’
B
B’

Blur Filter

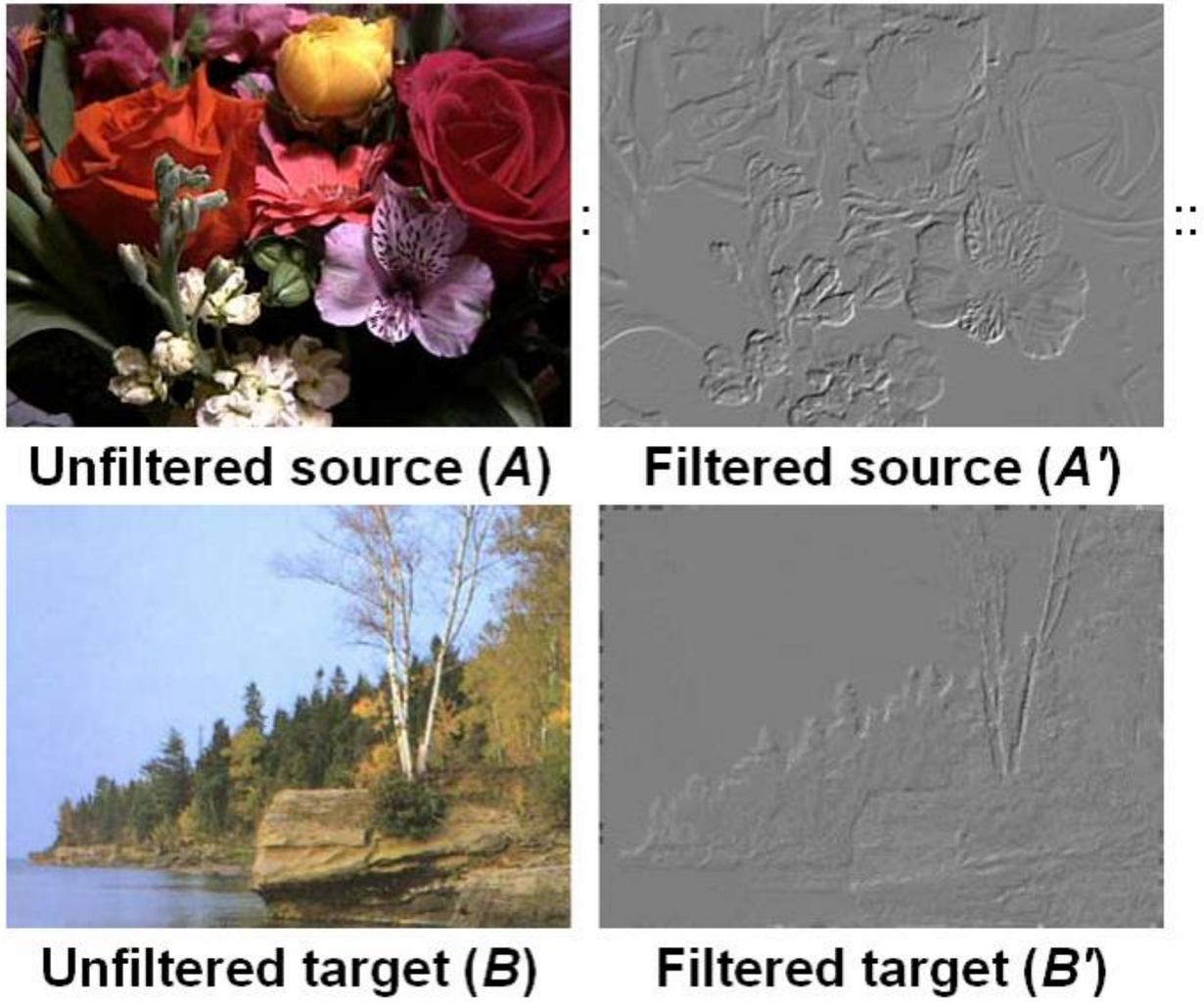
Unfiltered source (A)

Filtered source (A')

Unfiltered target (B)

Filtered target (B')

Edge Filter


:
::
Unfiltered source (A)
Filtered source (A')
Unfiltered target (B)
Filtered target (B')

Artistic Filters

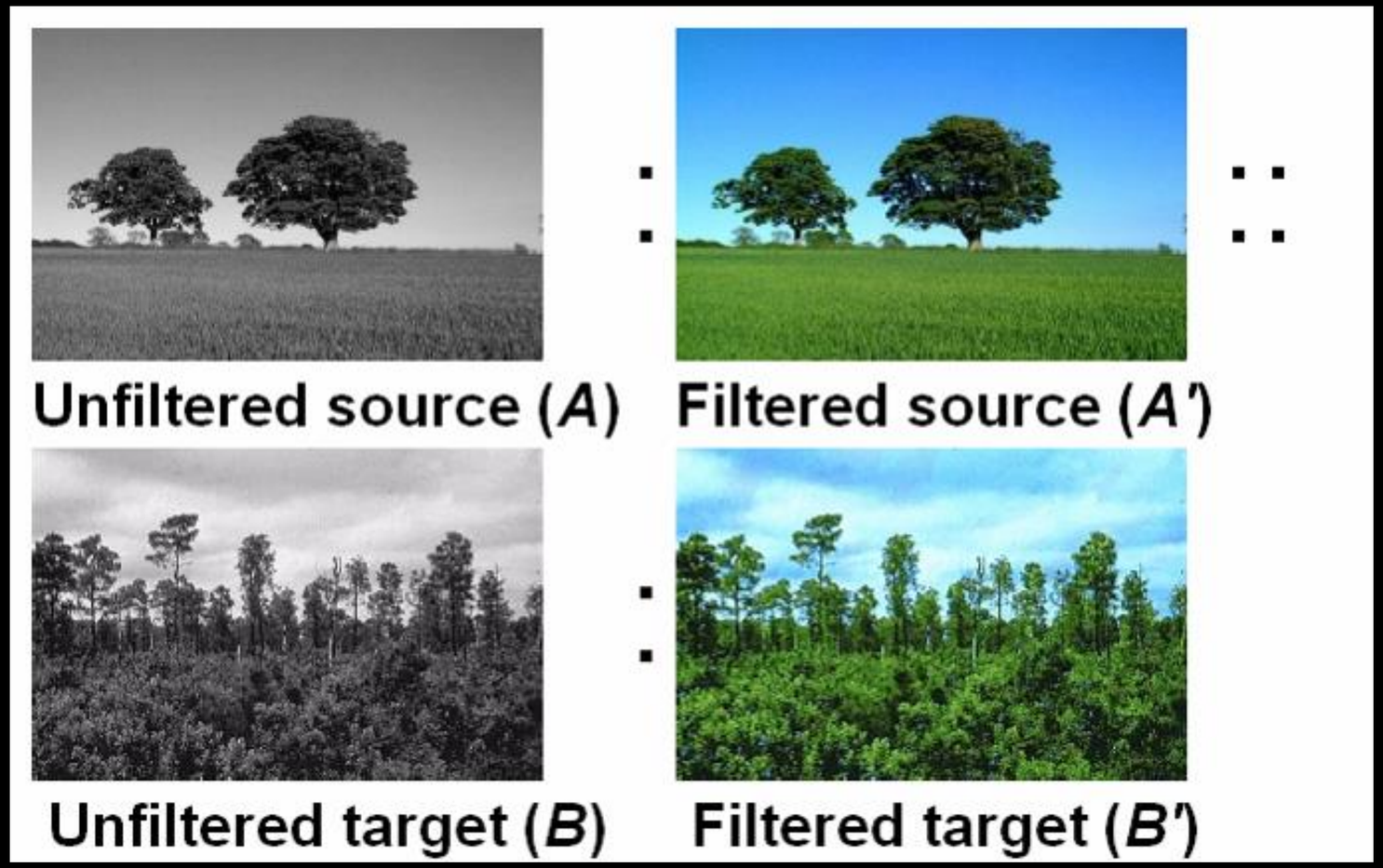
A

A’

B

B’

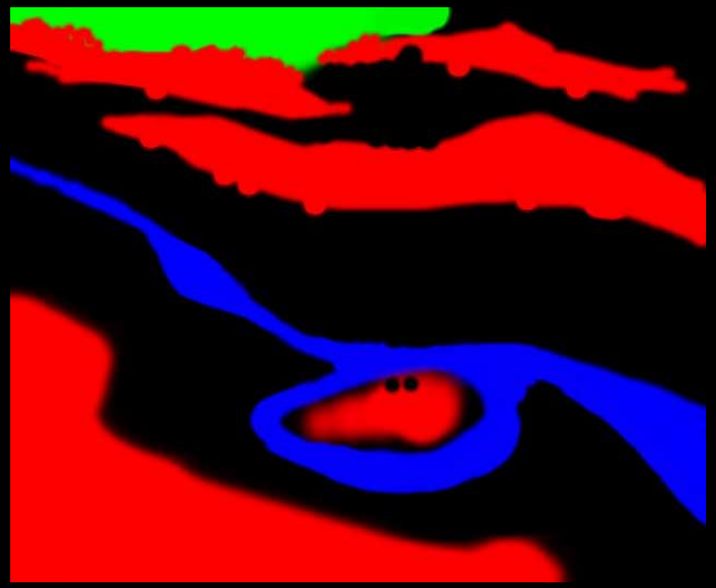
Colorization



Texture-by-numbers

A

A’



B

B’

Early one morning the sun was shining I was laying in bed

Wondering if she had changed at all if her hair was still red

slide from Steve Seitz's video

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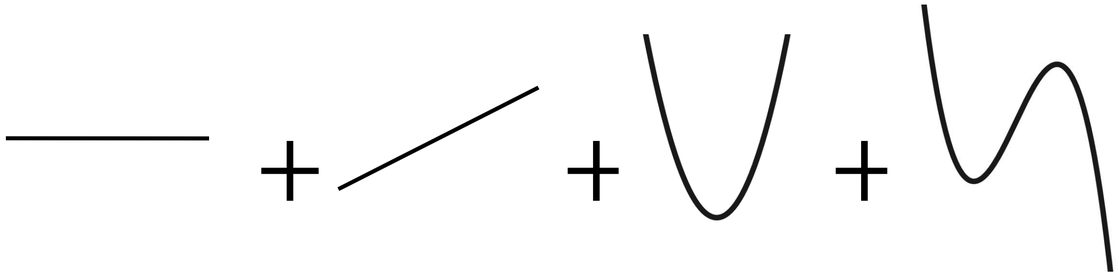
$$P(x_n | x_{n-1}, x_{n-2}, x_{n-3}, x_{n-4}, x_{n-5}, x_{n-6}, x_{n-7}, x_{n-8}, x_{n-9}, x_{n-10}, x_{n-11}, x_{n-12}, x_{n-13})$$

10^{70}combinations

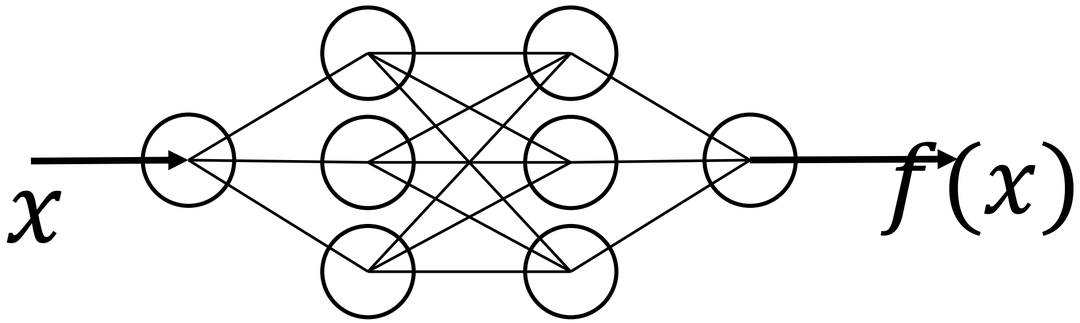
slide from Steve Seitz's video

Function Approximation

Fourier Series: $f(x) =$ $+ \ldots$

Taylor Series: $f(x) =$  $+ \ldots$

Neural Network:



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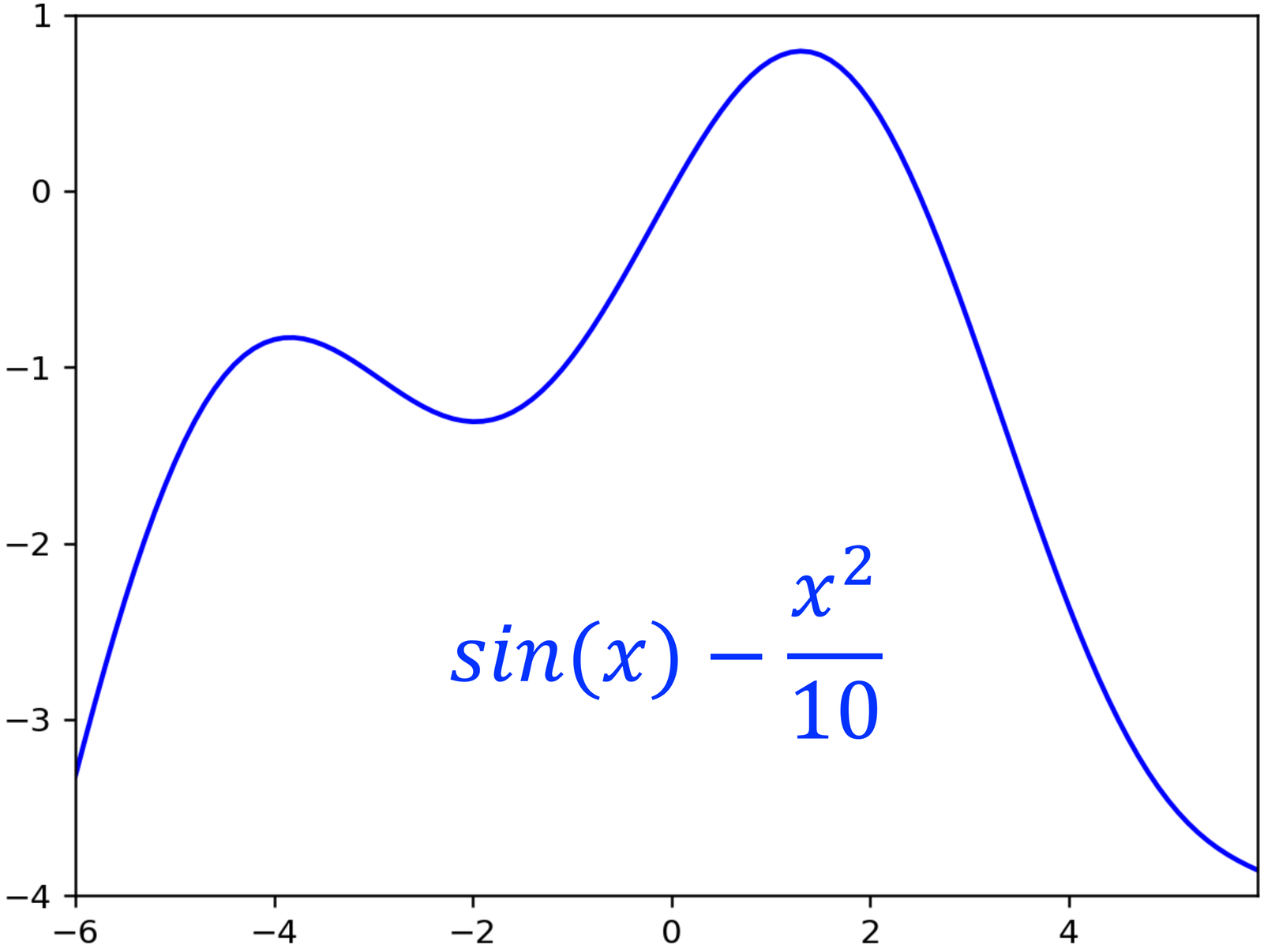
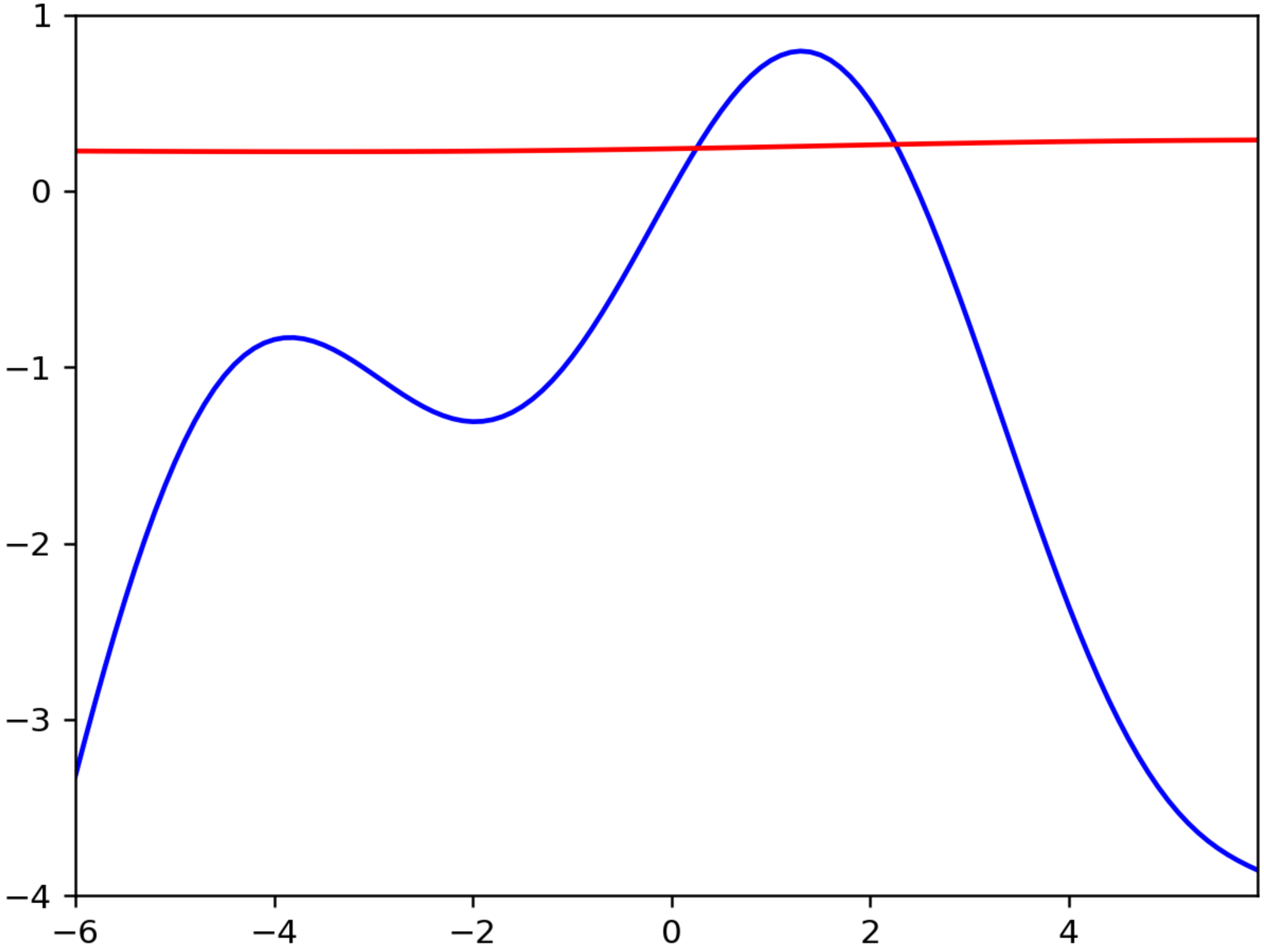
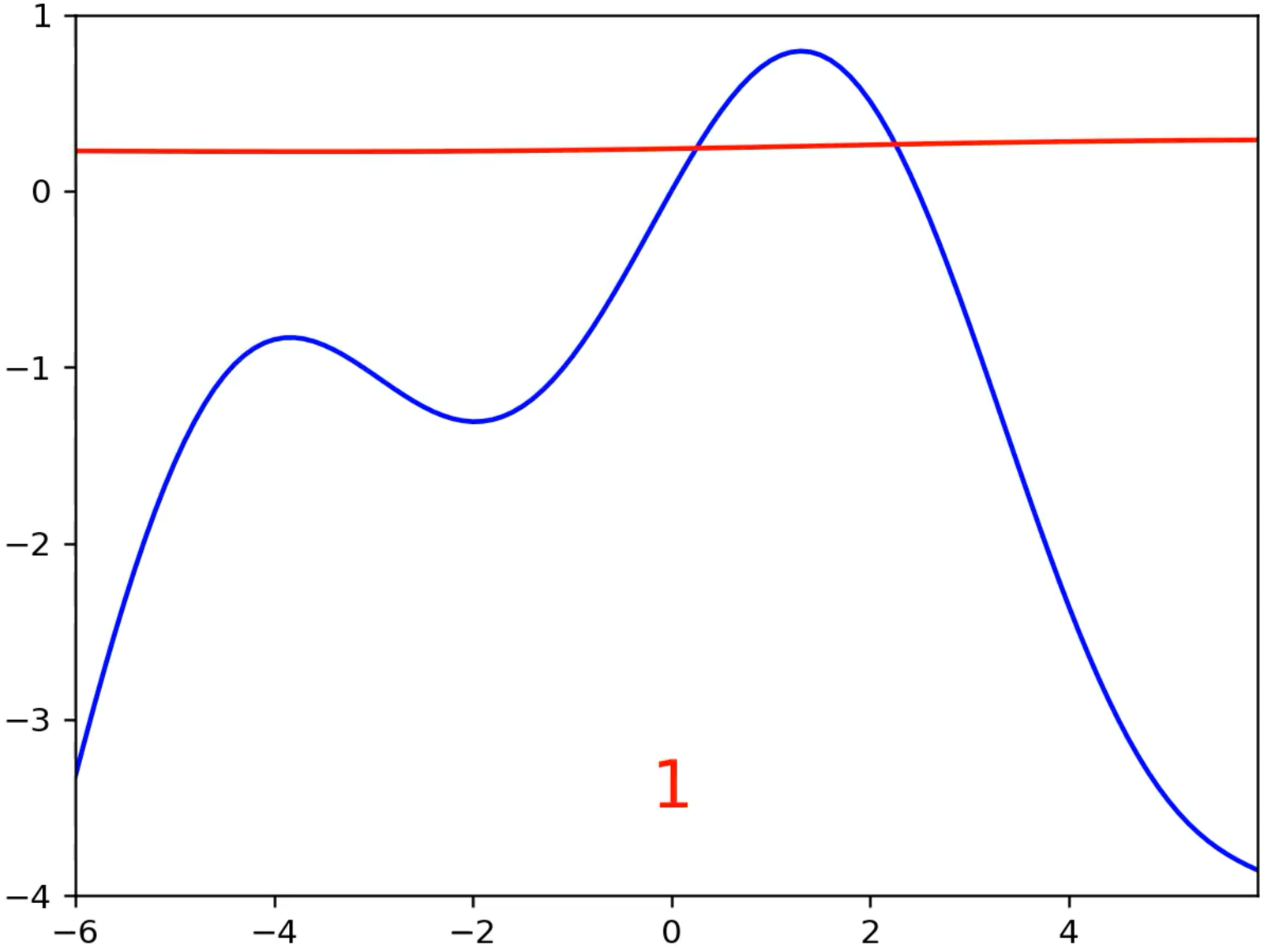


slide from Steve Seitz's video



slide from Steve Seitz's video



slide from Steve Seitz's video

$$P(x_n | x_{n-1}, x_{n-2}, x_{n-3}, x_{n-4}, x_{n-5}, x_{n-6}, x_{n-7}, \dots)$$

slide from Steve Seitz's video

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Wondering if she had changed at all if her hair was still red

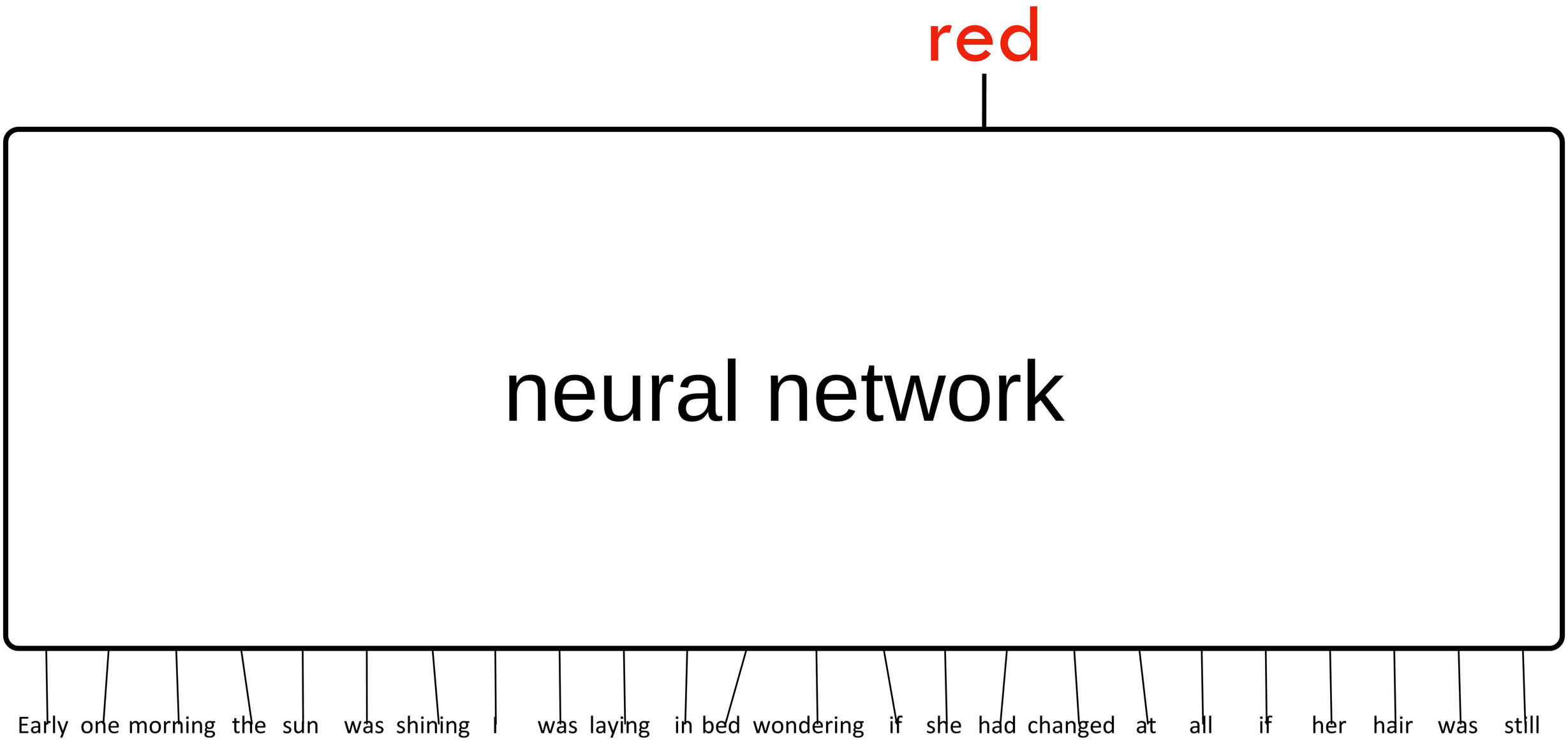
slide from Steve Seitz's video

red

Early one morning the sun was shining I was laying in bed

Wondering if she had changed at all if her hair was still

slide from Steve Seitz's video



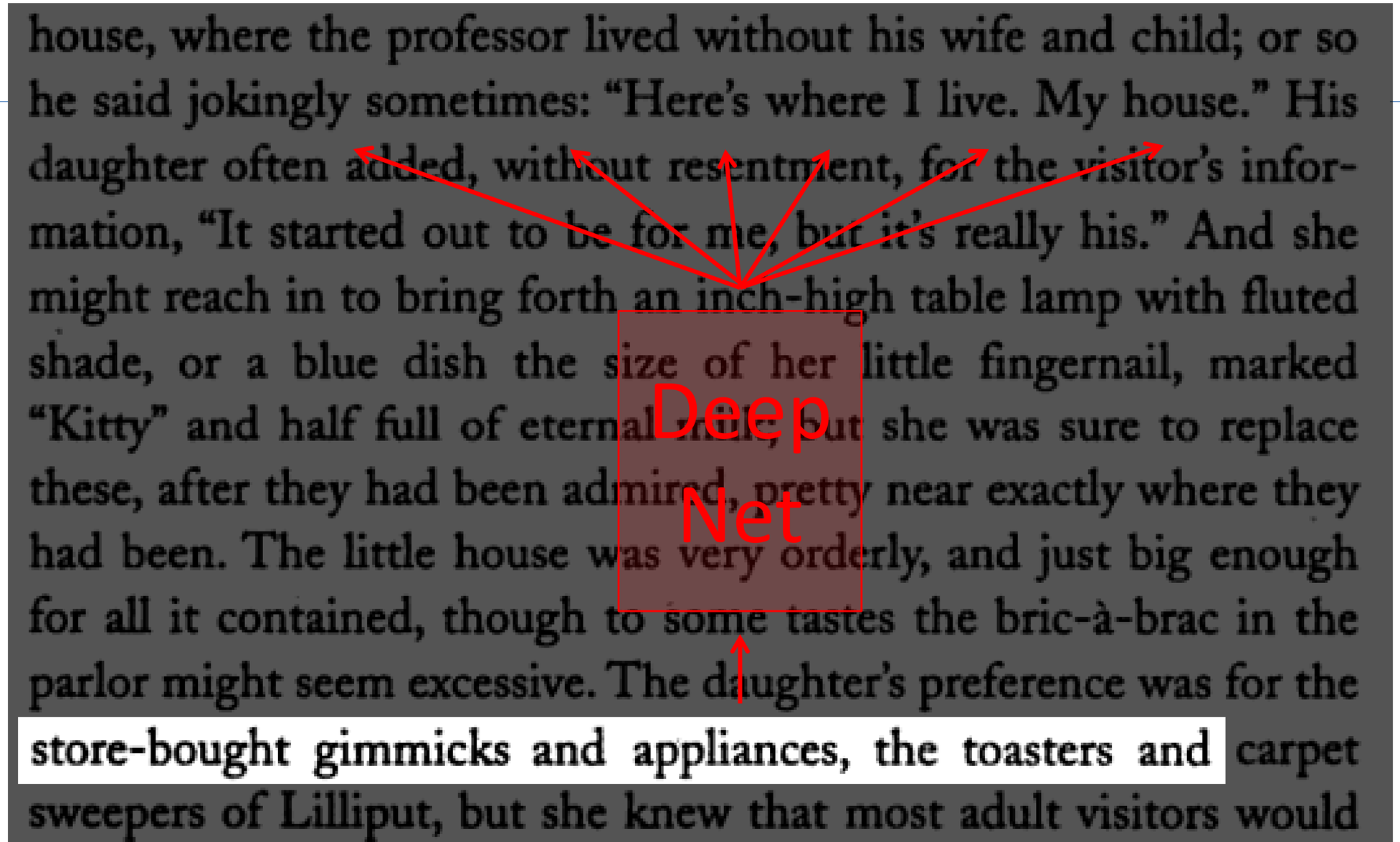
slide from Steve Seitz's video

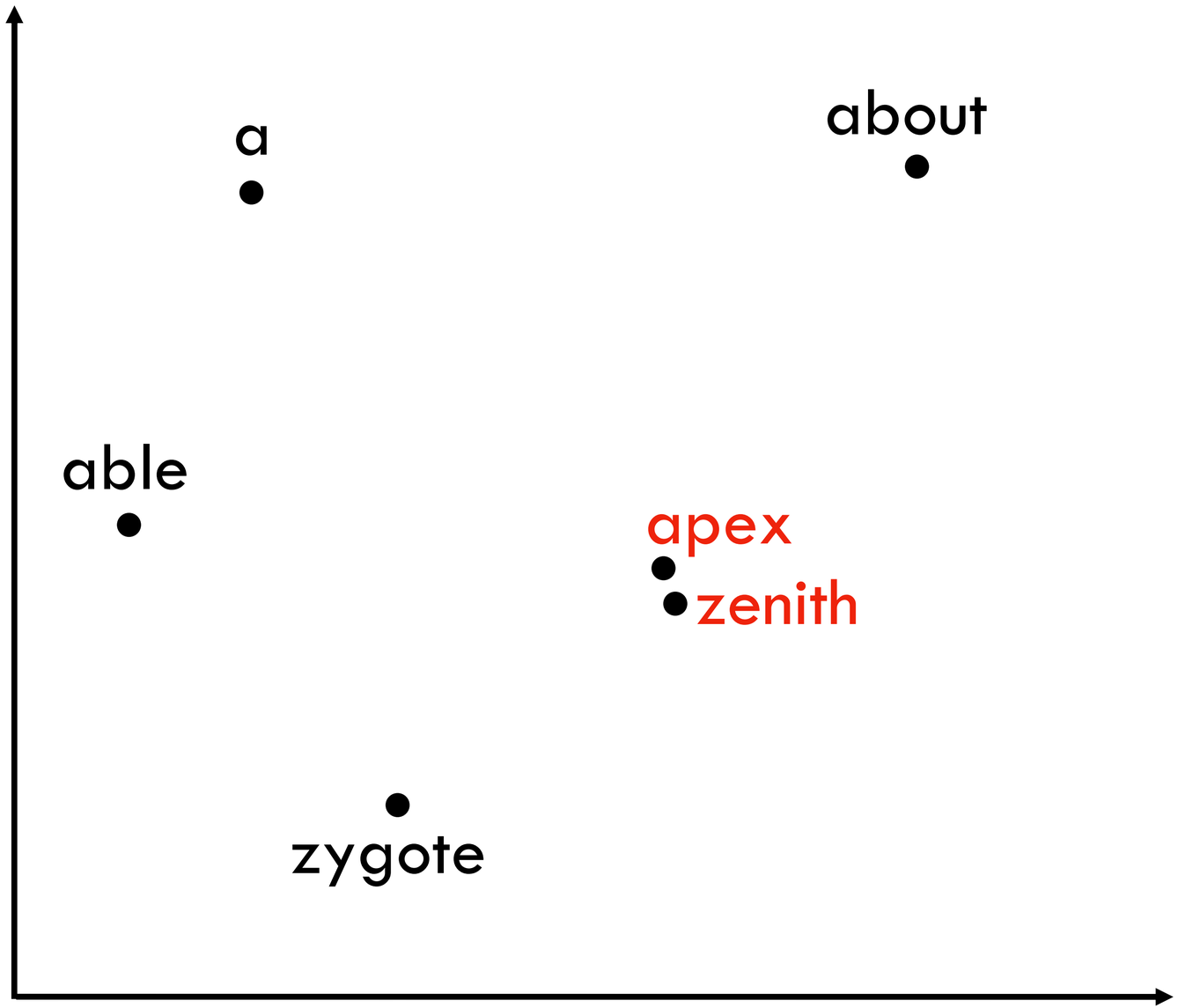
0	a
1	able
2	about
	⋮
39	apex
	⋮
56,356	zenith
	⋮
92,487	zygote

slide from Steve Seitz's video

word2vec

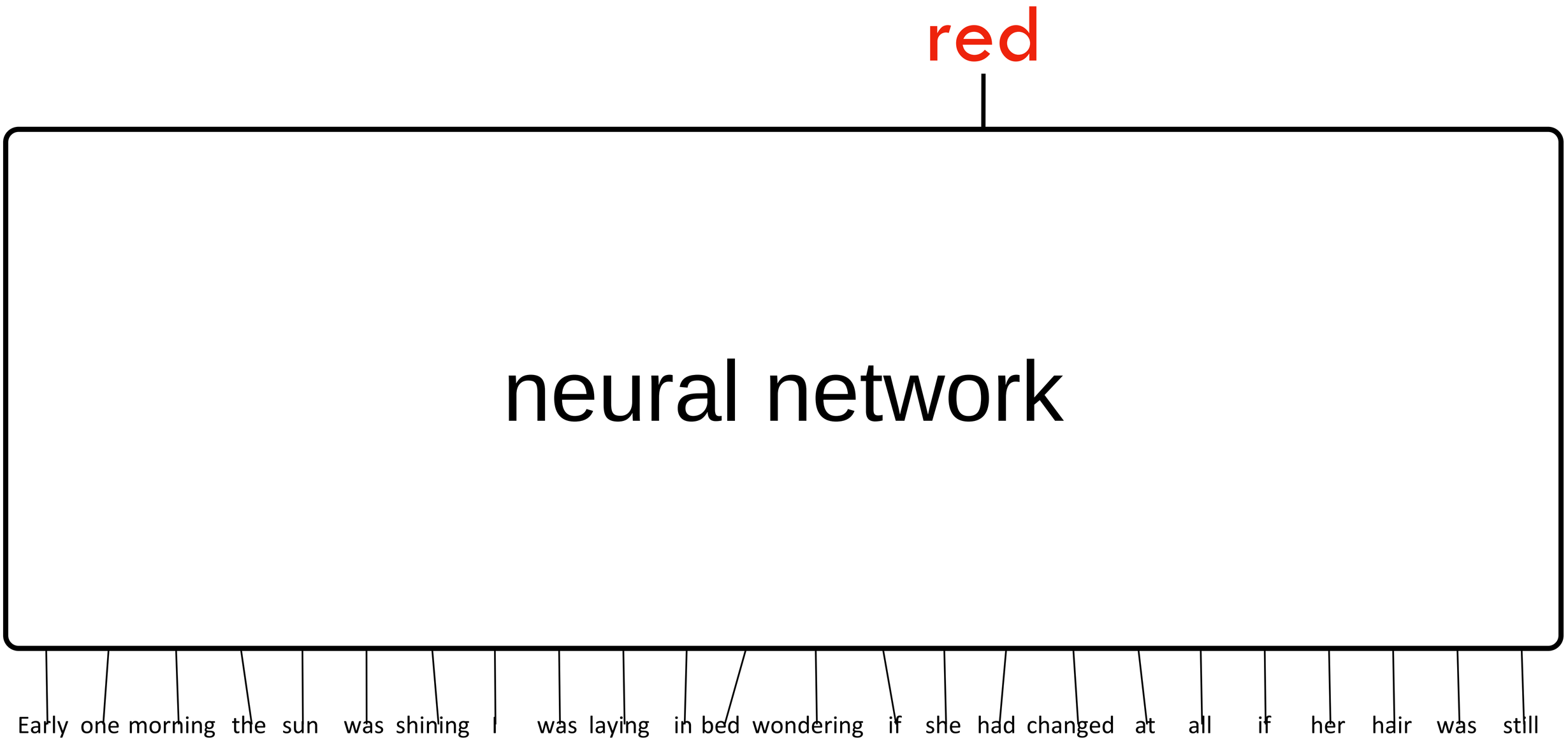
[Collobert & Weston 2008; Mikolov et al. 2013]



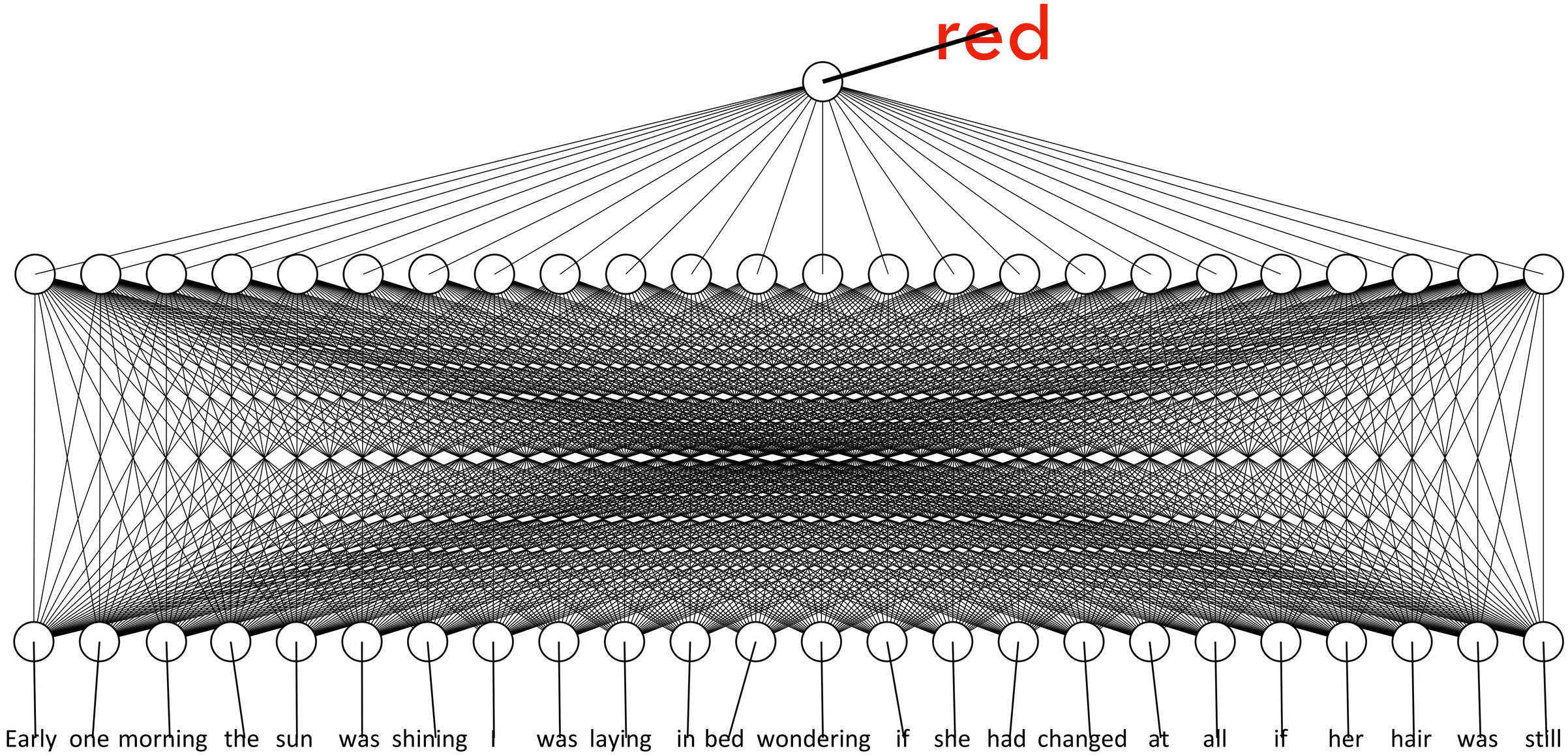


Word Embedding (e.g., word2Vec, GloVe)

slide from Steve Seitz's video



slide from Steve Seitz's video



slide from Steve Seitz's video

Early one morning the sun was shining I was laying in bed

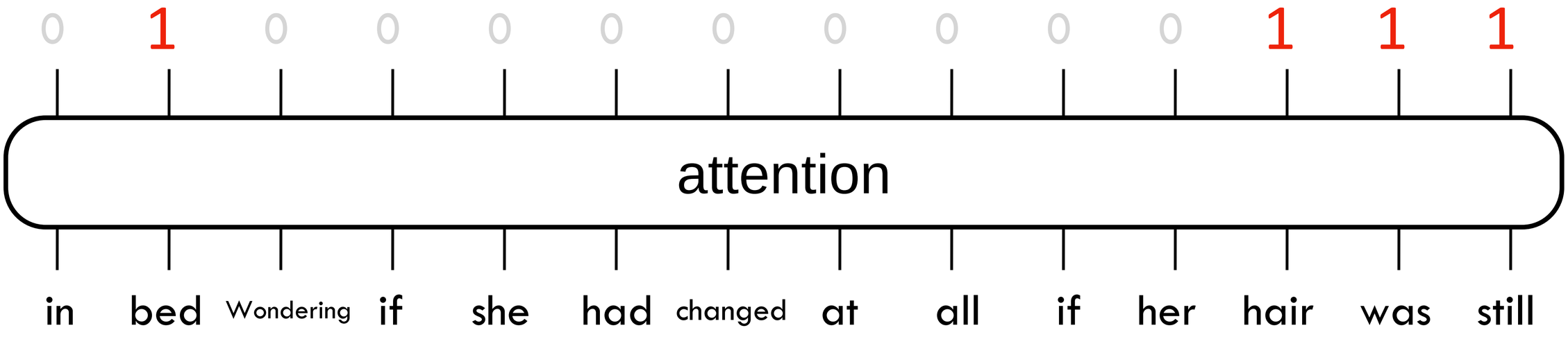
Wondering if she had changed at all if her hair was still ?

slide from Steve Seitz's video

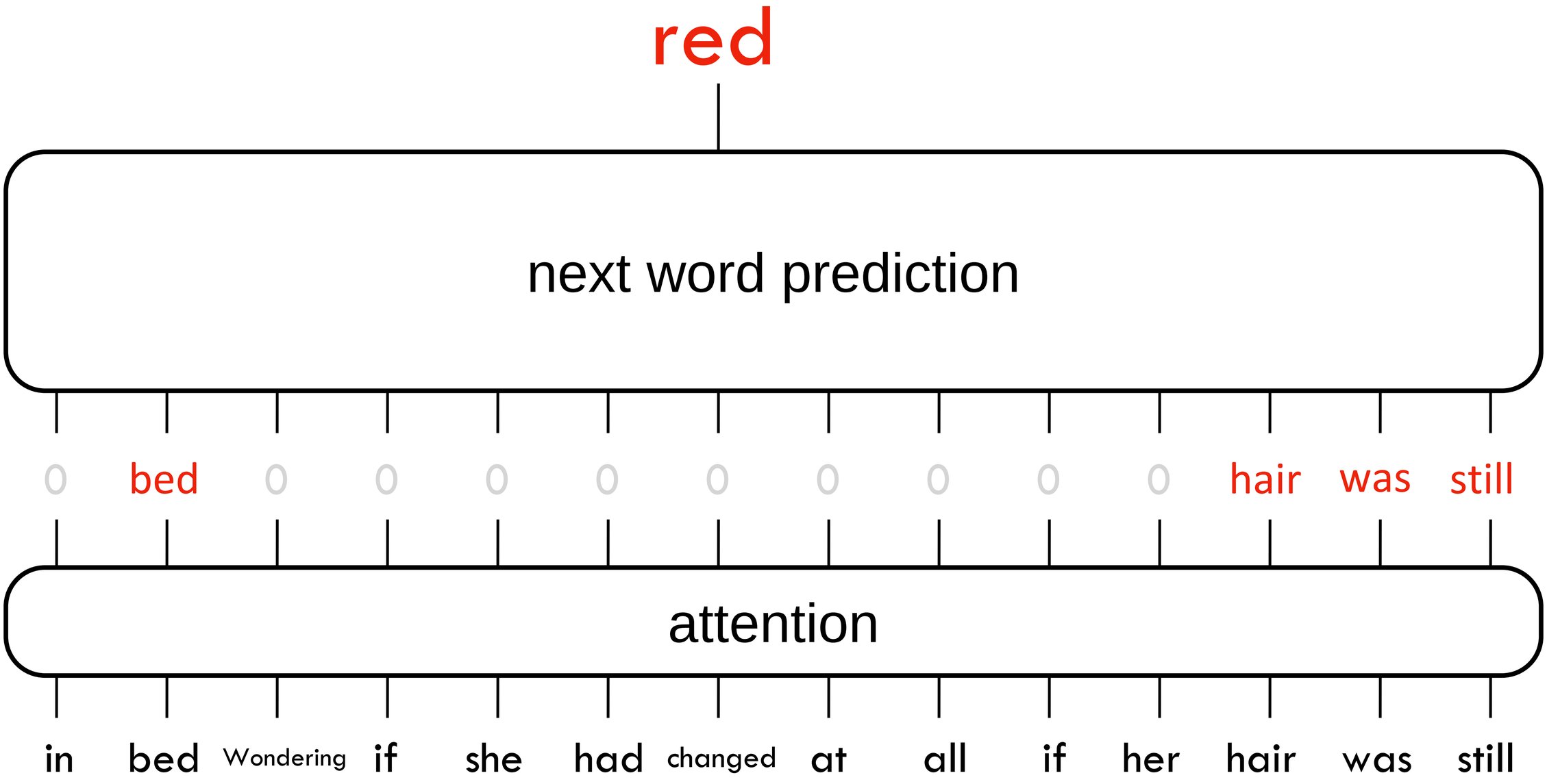
bed

hair was still red

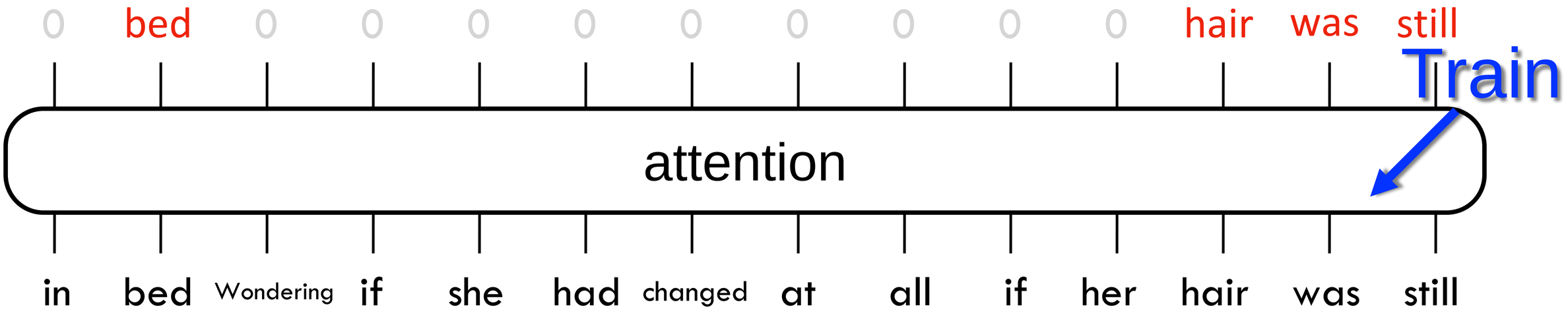
slide from Steve Seitz's video



slide from Steve Seitz's video



slide from Steve Seitz's video

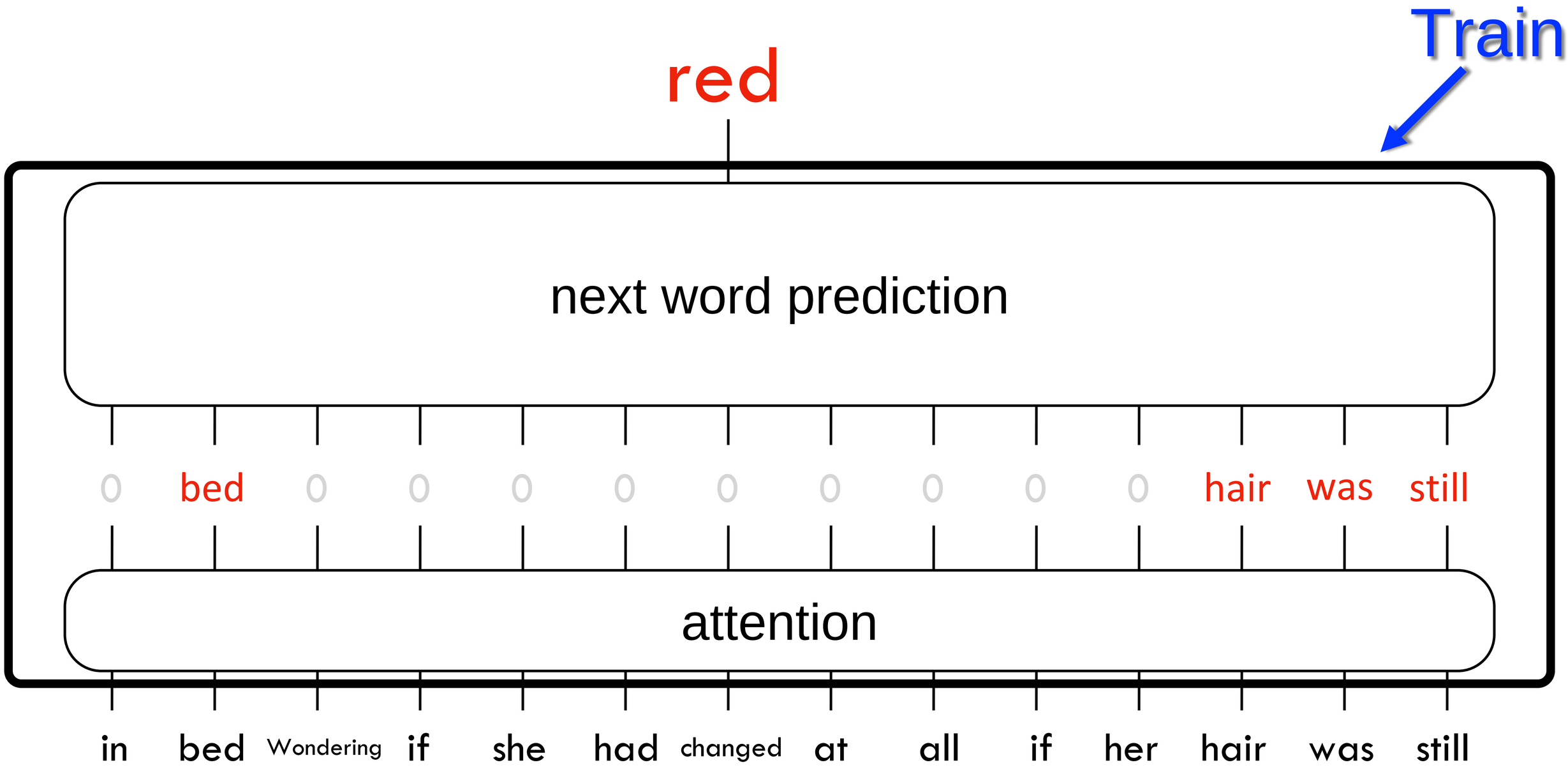


slide from Steve Seitz's video

Two roads diverted in a yellow wood
And sorry I could not travel both
And be one traveler, long I stood
And looked down as far as I could
To where it bent in the undergrowth;

Robert Frost, *Road Not Taken*

slide from Steve Seitz's video



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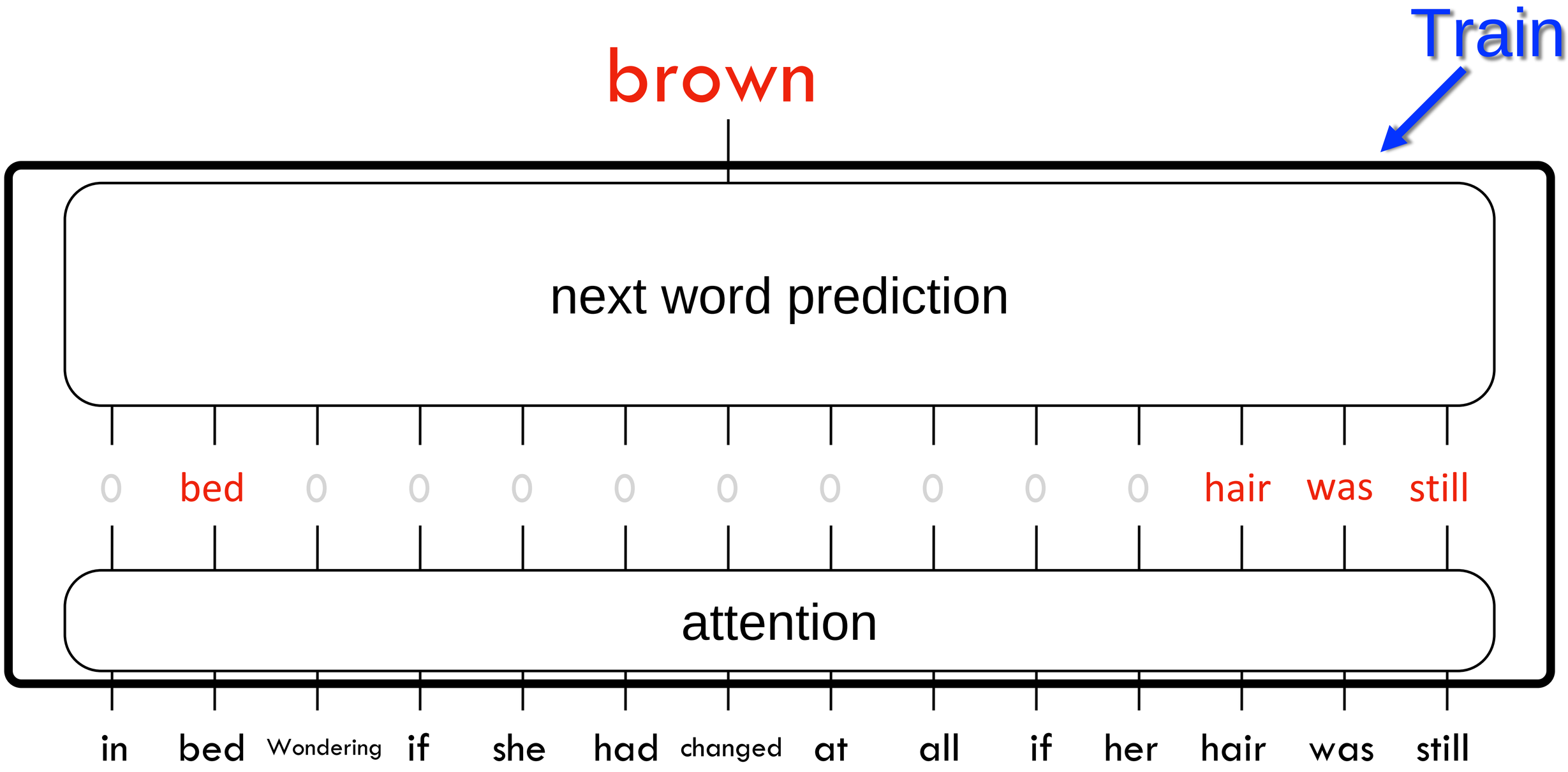
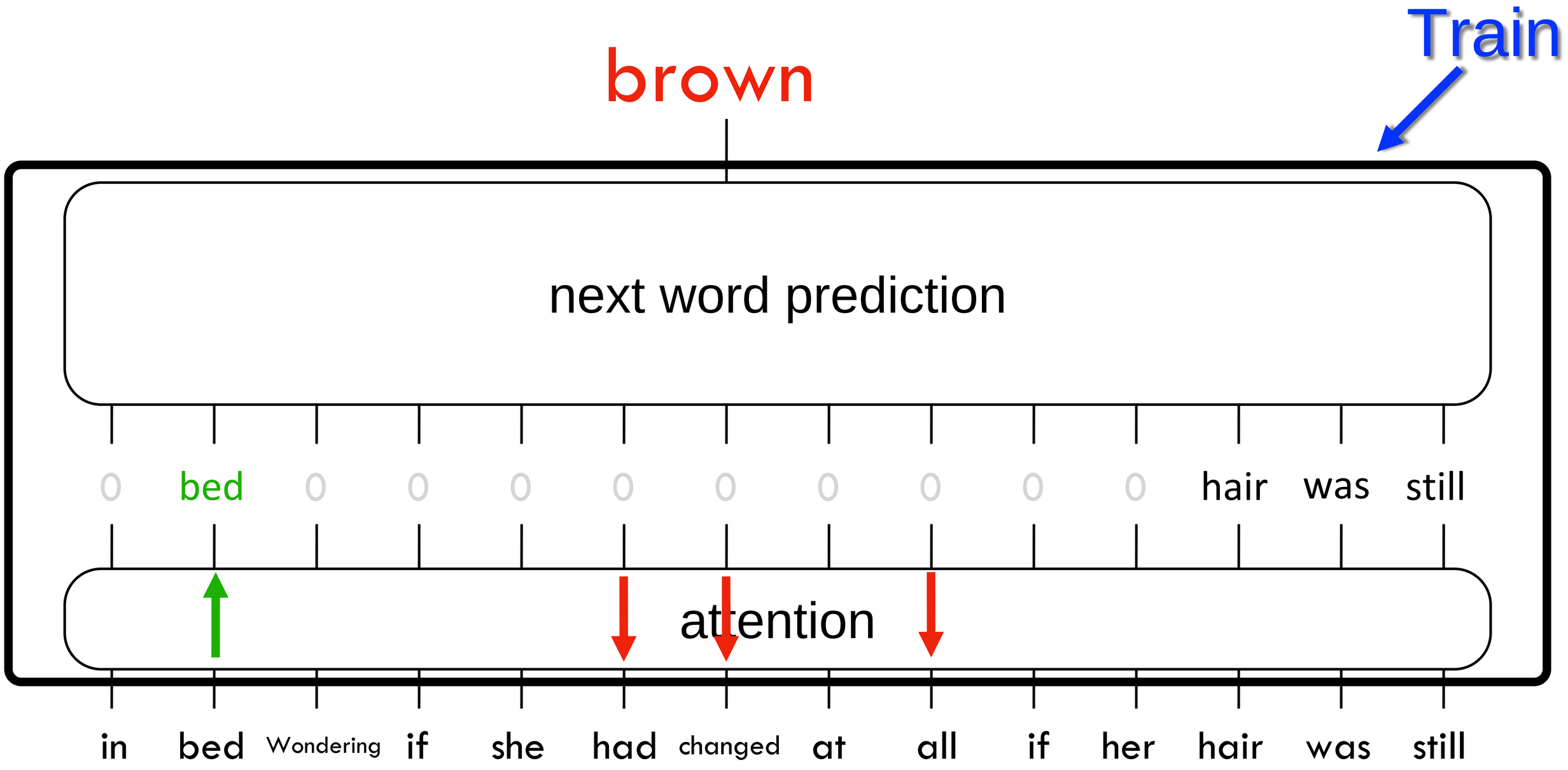


slide from Steve Seitz's video



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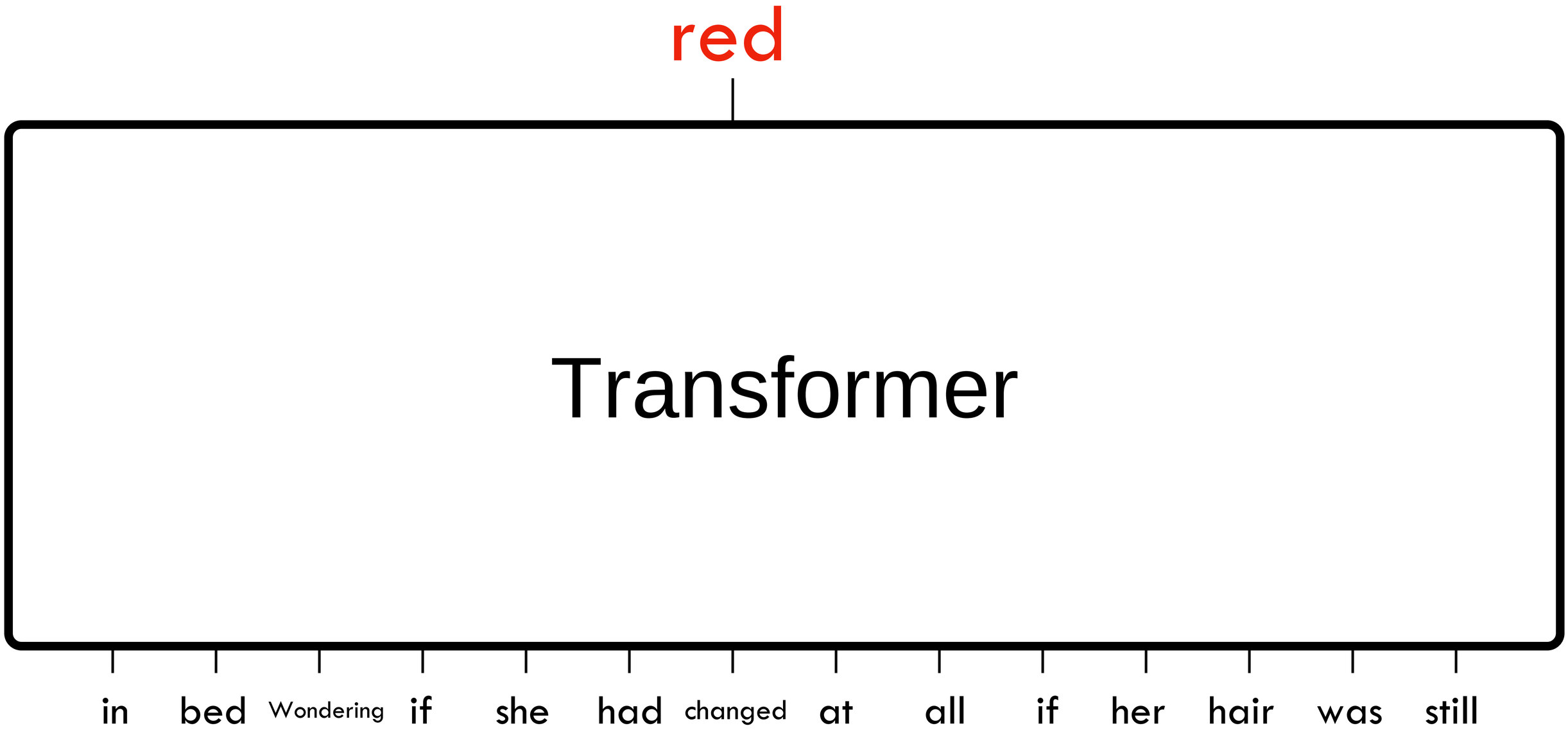
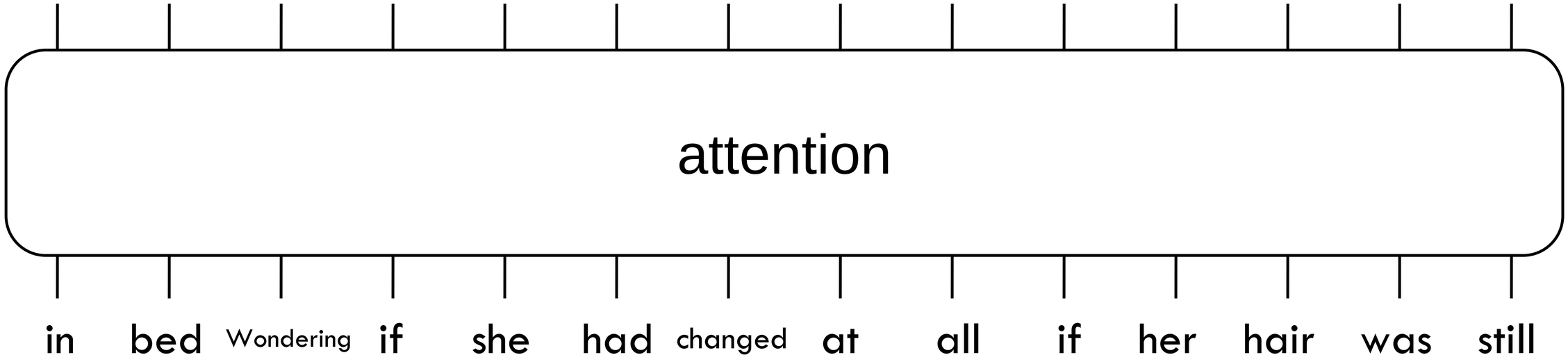
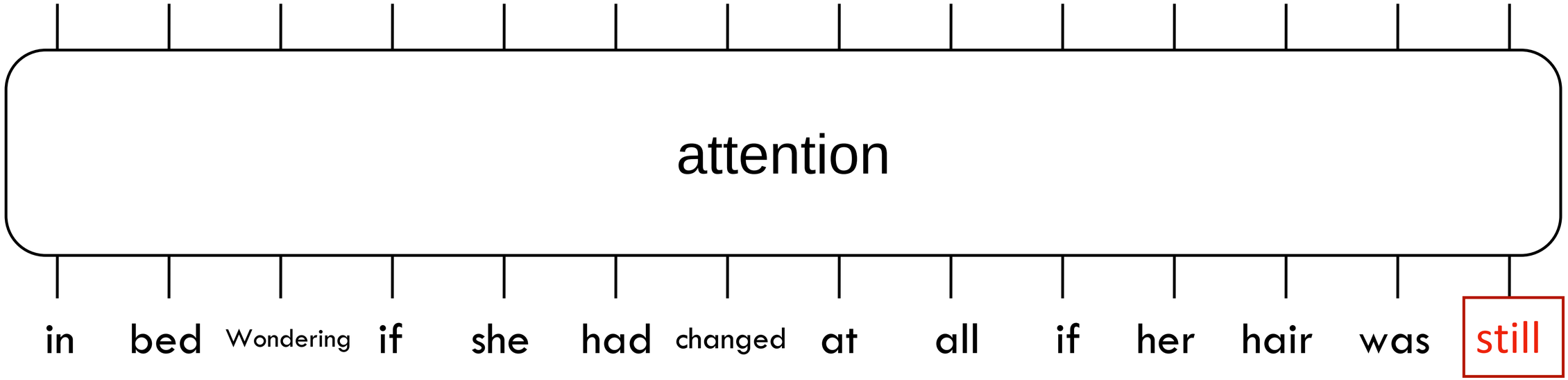


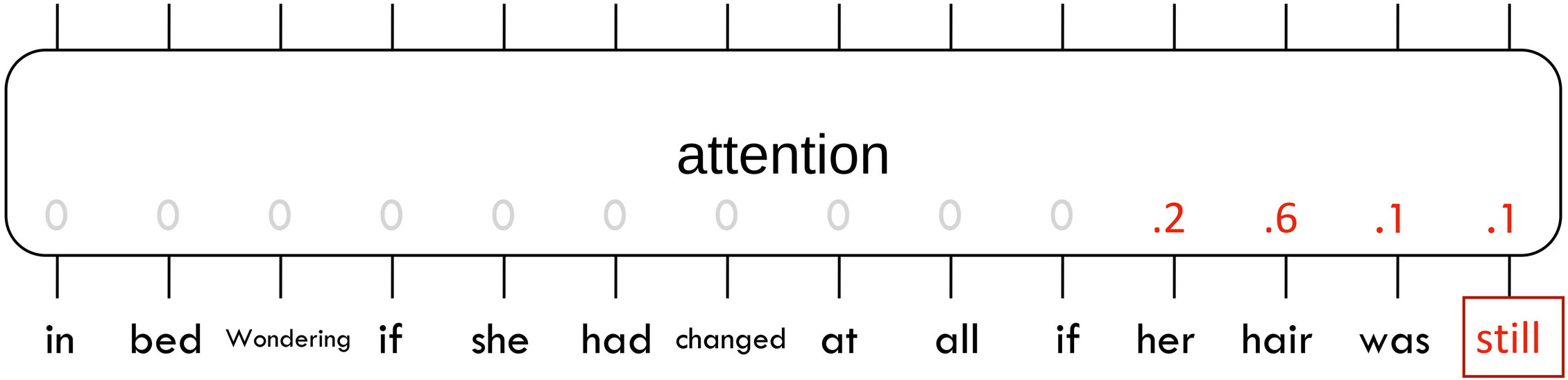
slide from Steve Seitz's video



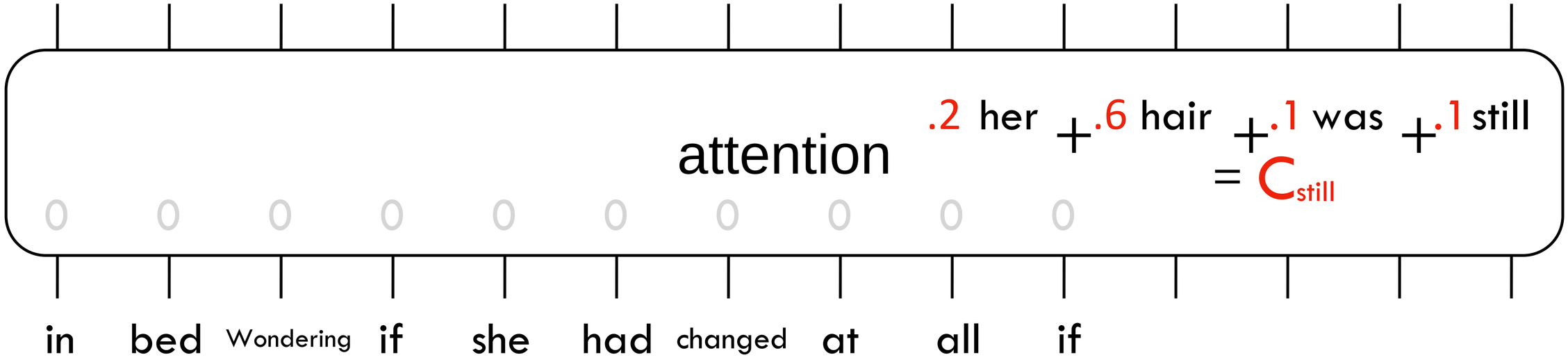
slide from Steve Seitz's video



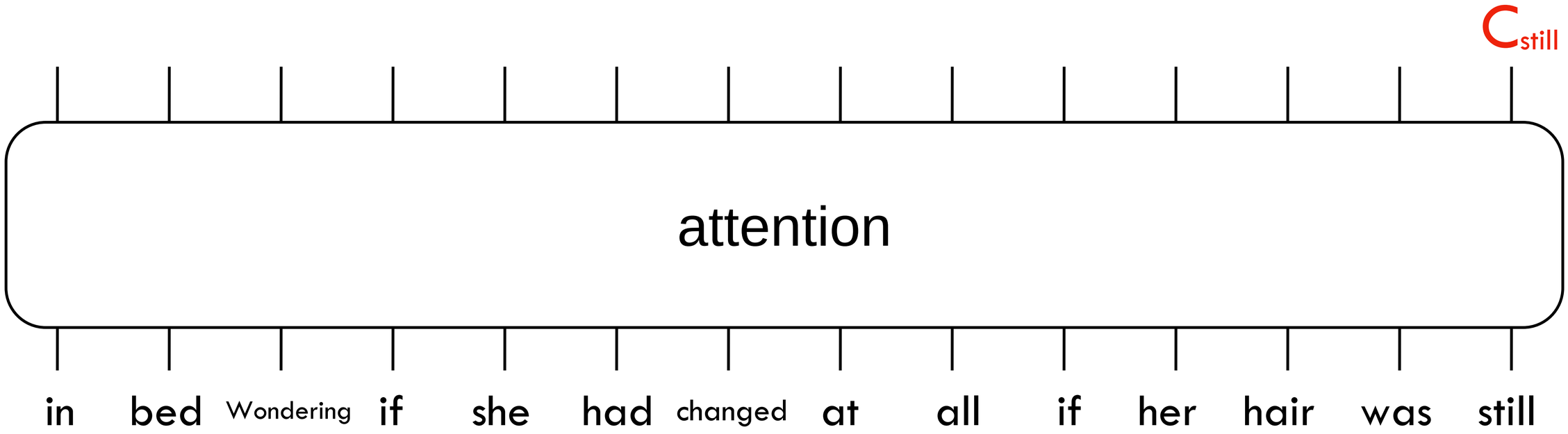
slide from Steve Seitz's video



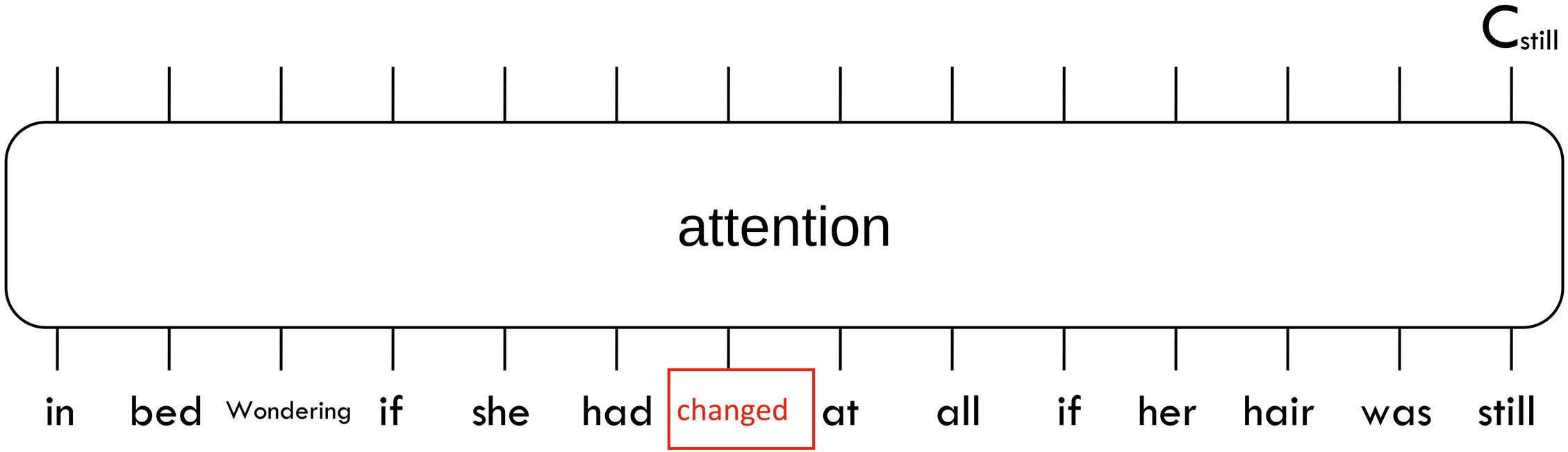
slide from Steve Seitz's video



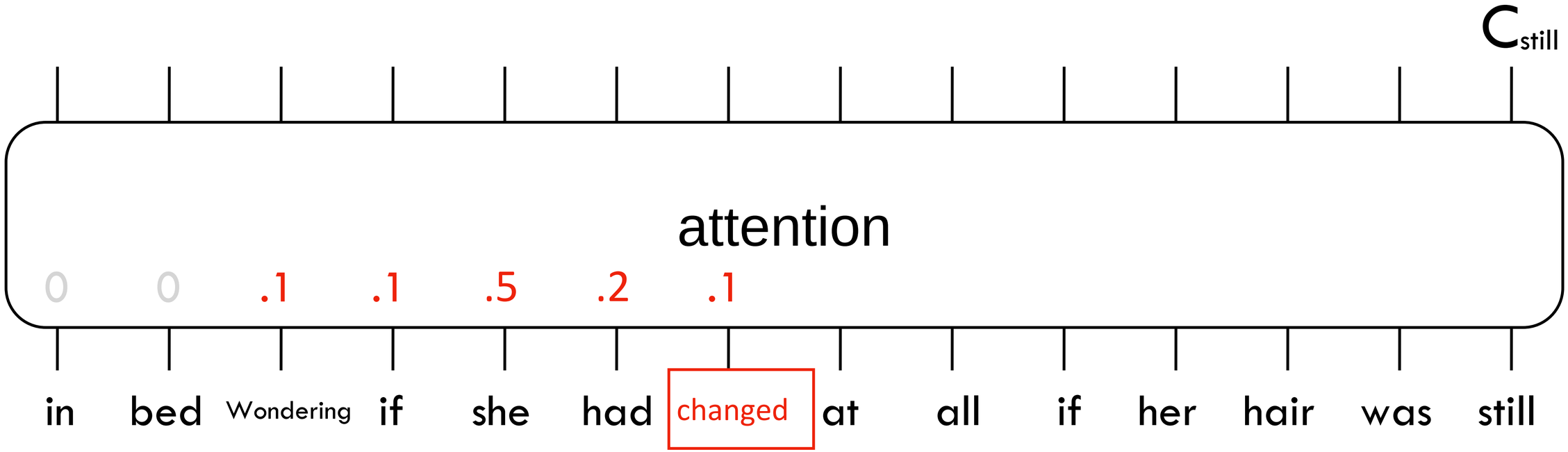
slide from Steve Seitz's video



slide from Steve Seitz's video



slide from Steve Seitz's video



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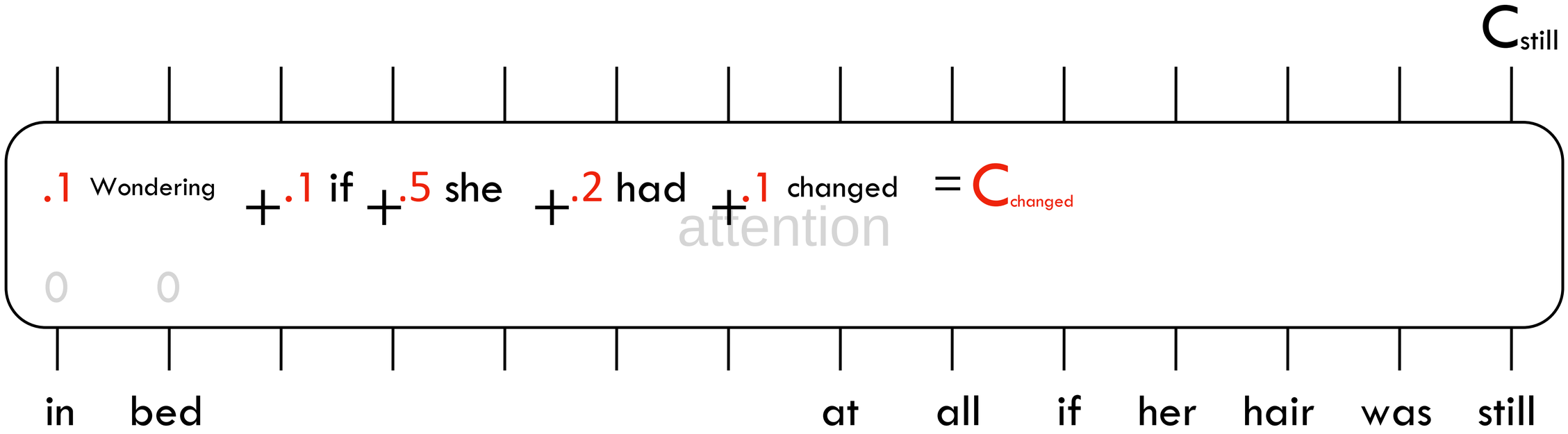
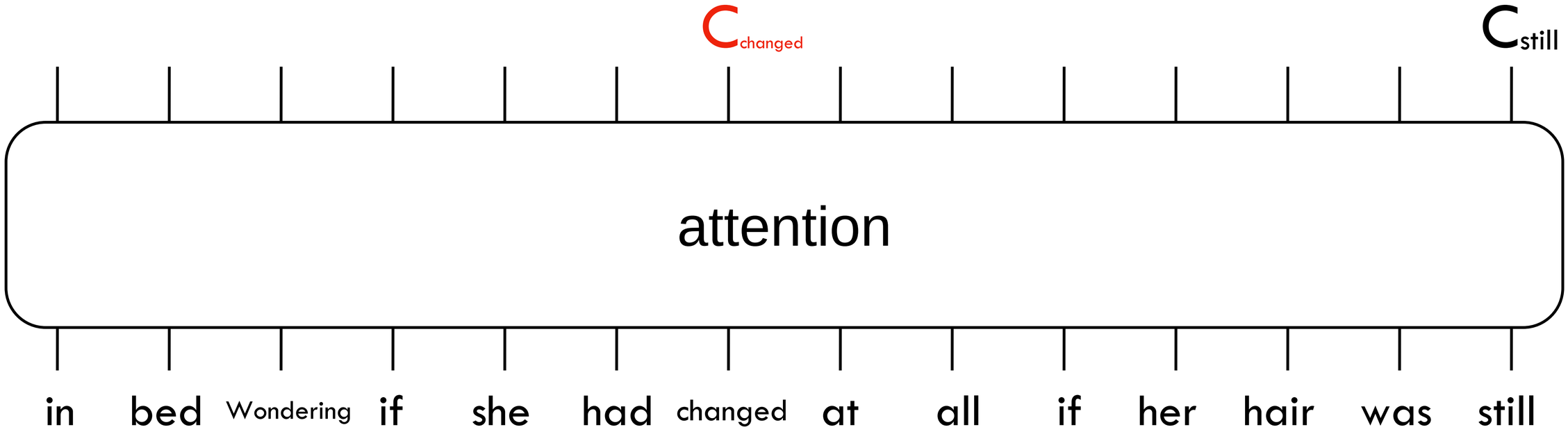


slide from Steve Seitz's video



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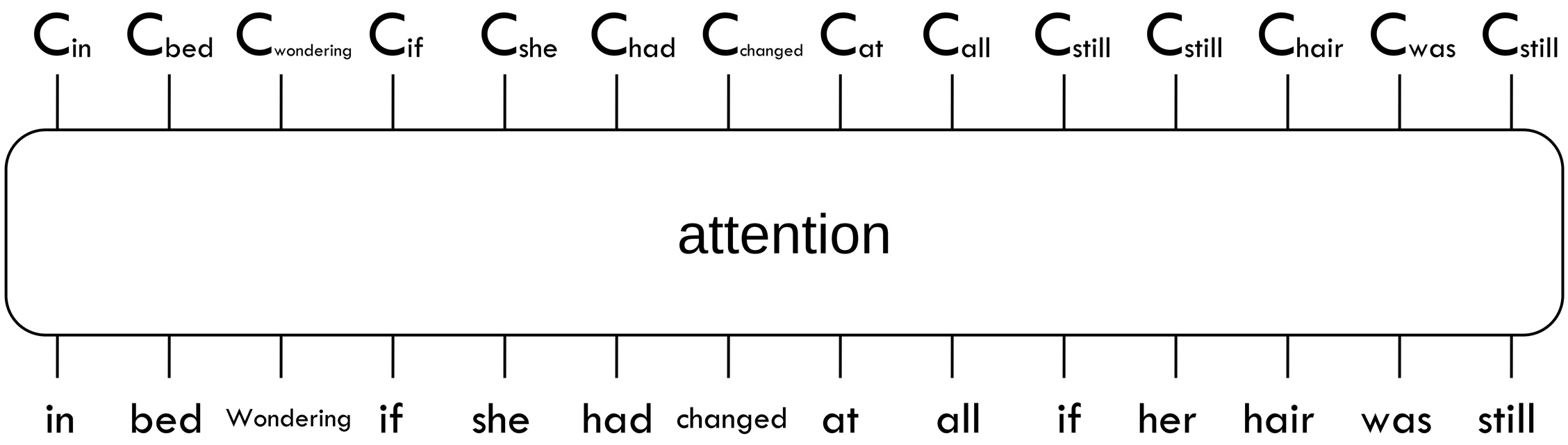

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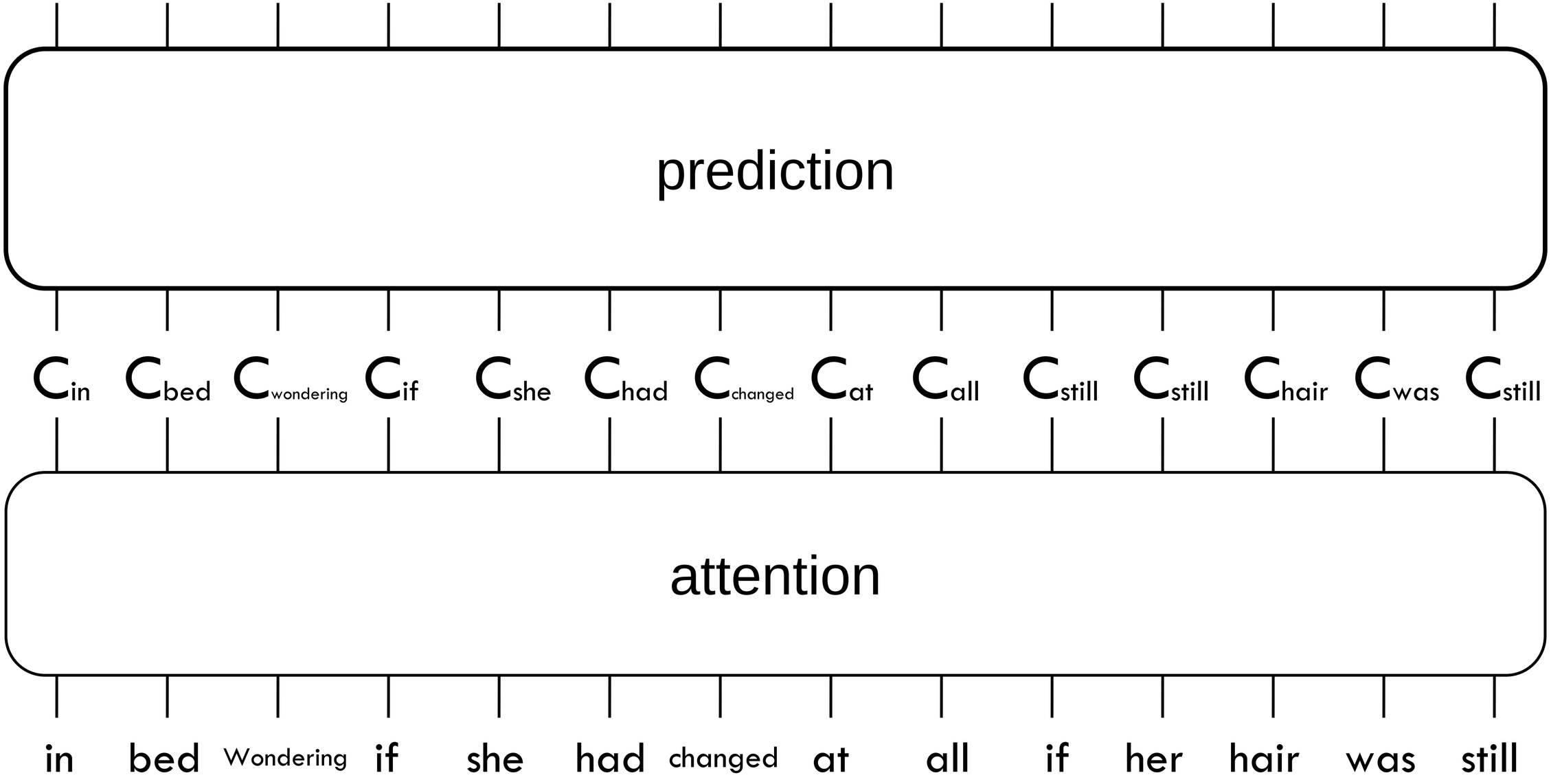

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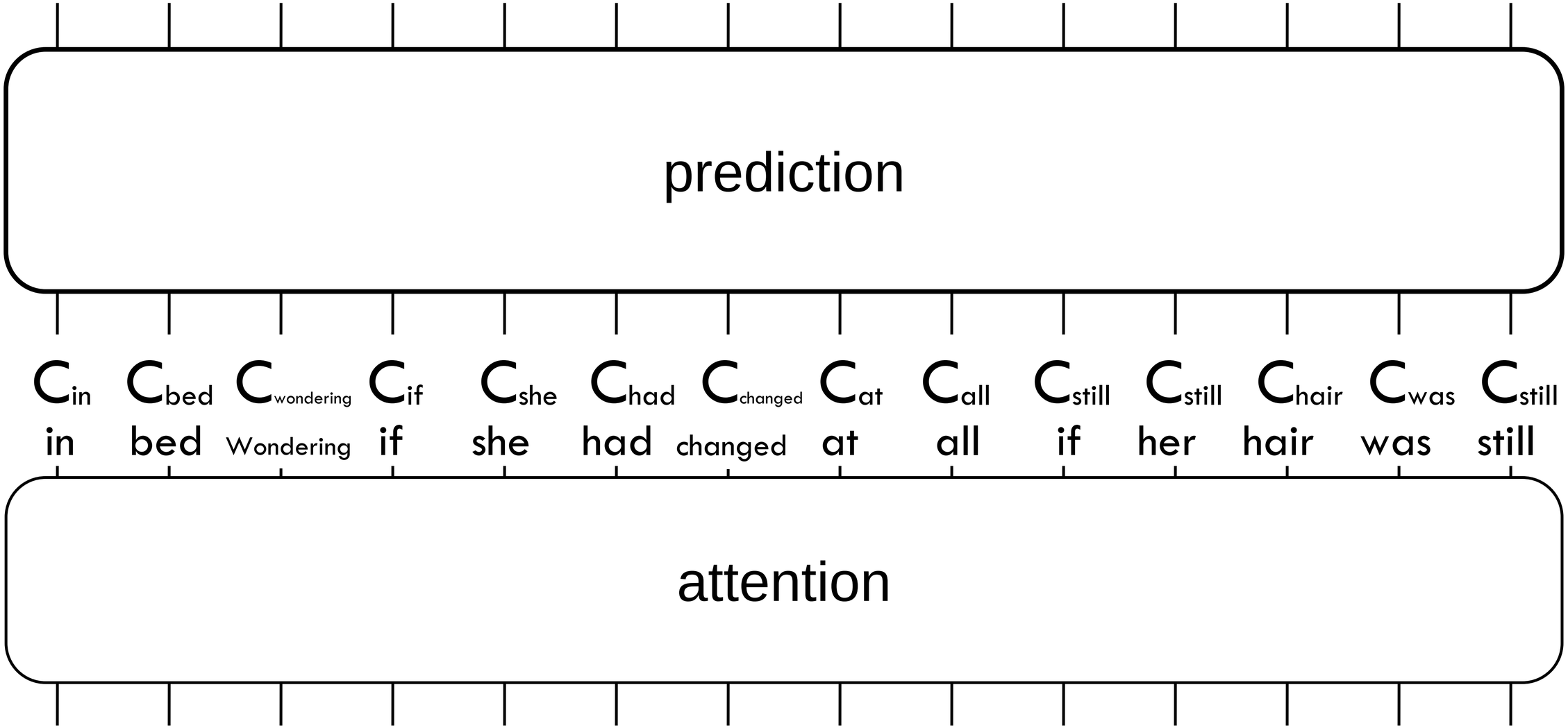

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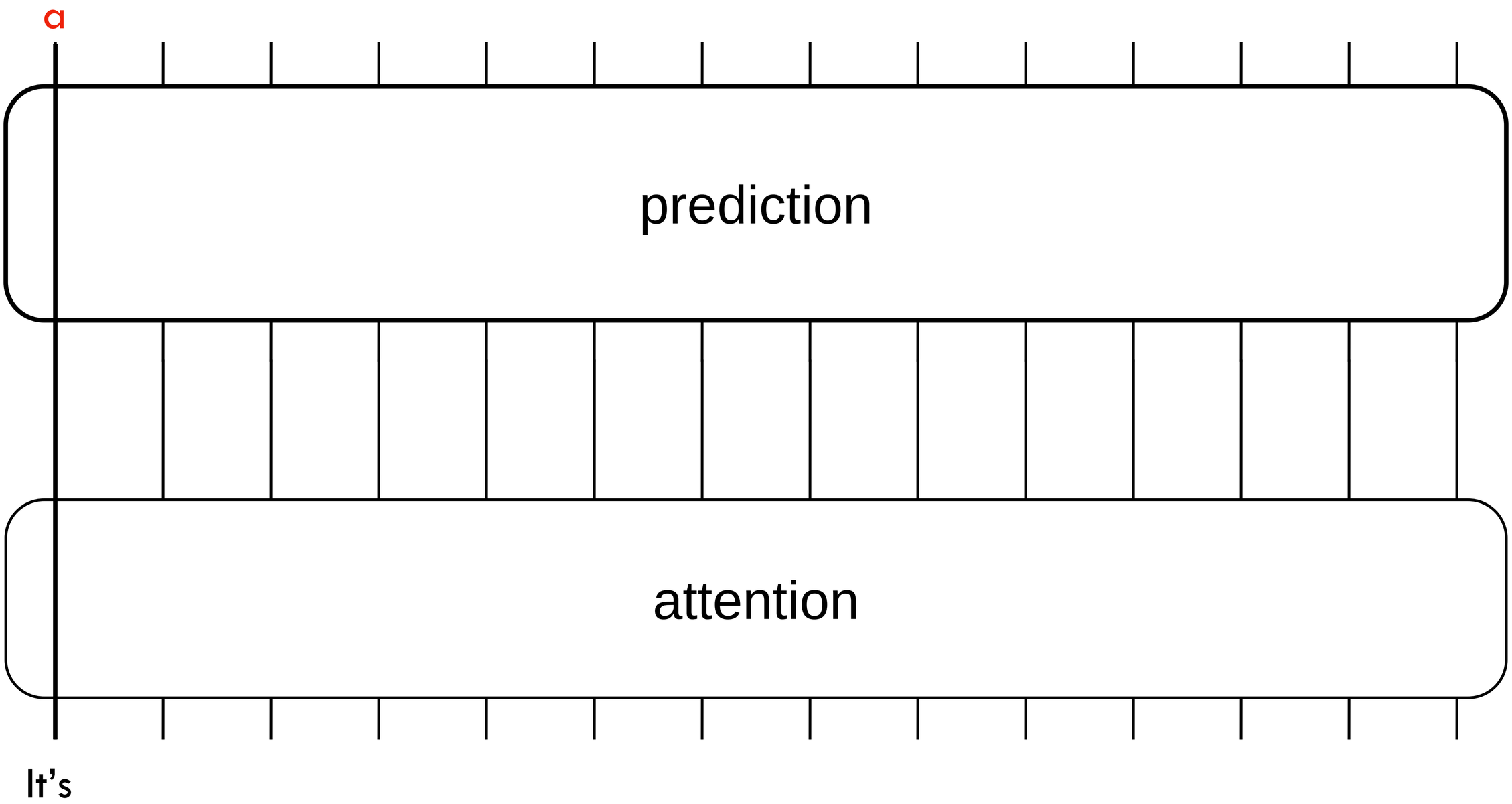
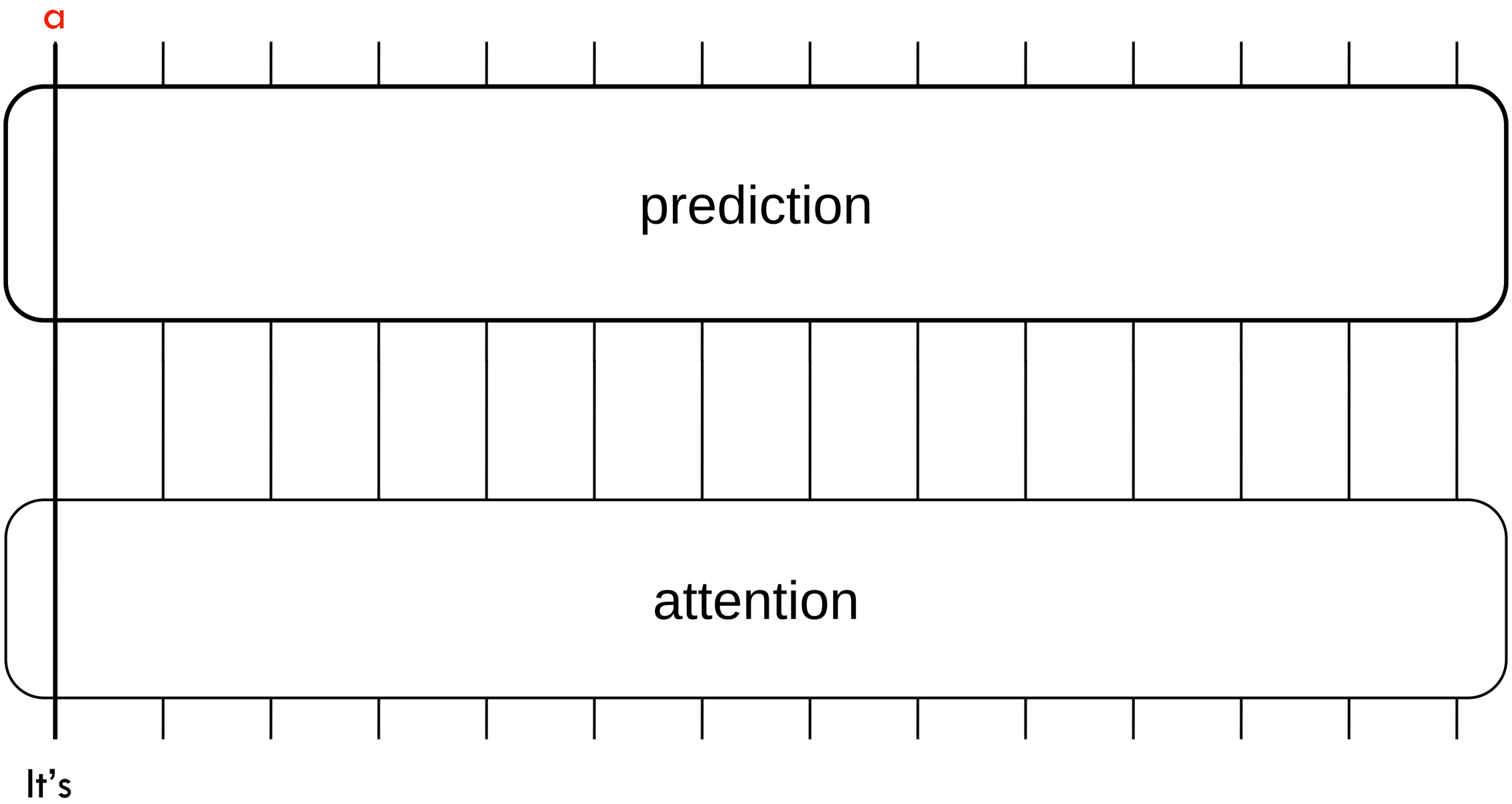


slide from Steve Seitz's video

a	the	looking	possible	getting
0.4	0.3	0.1	0.1	0.1

slide from Steve Seitz's video



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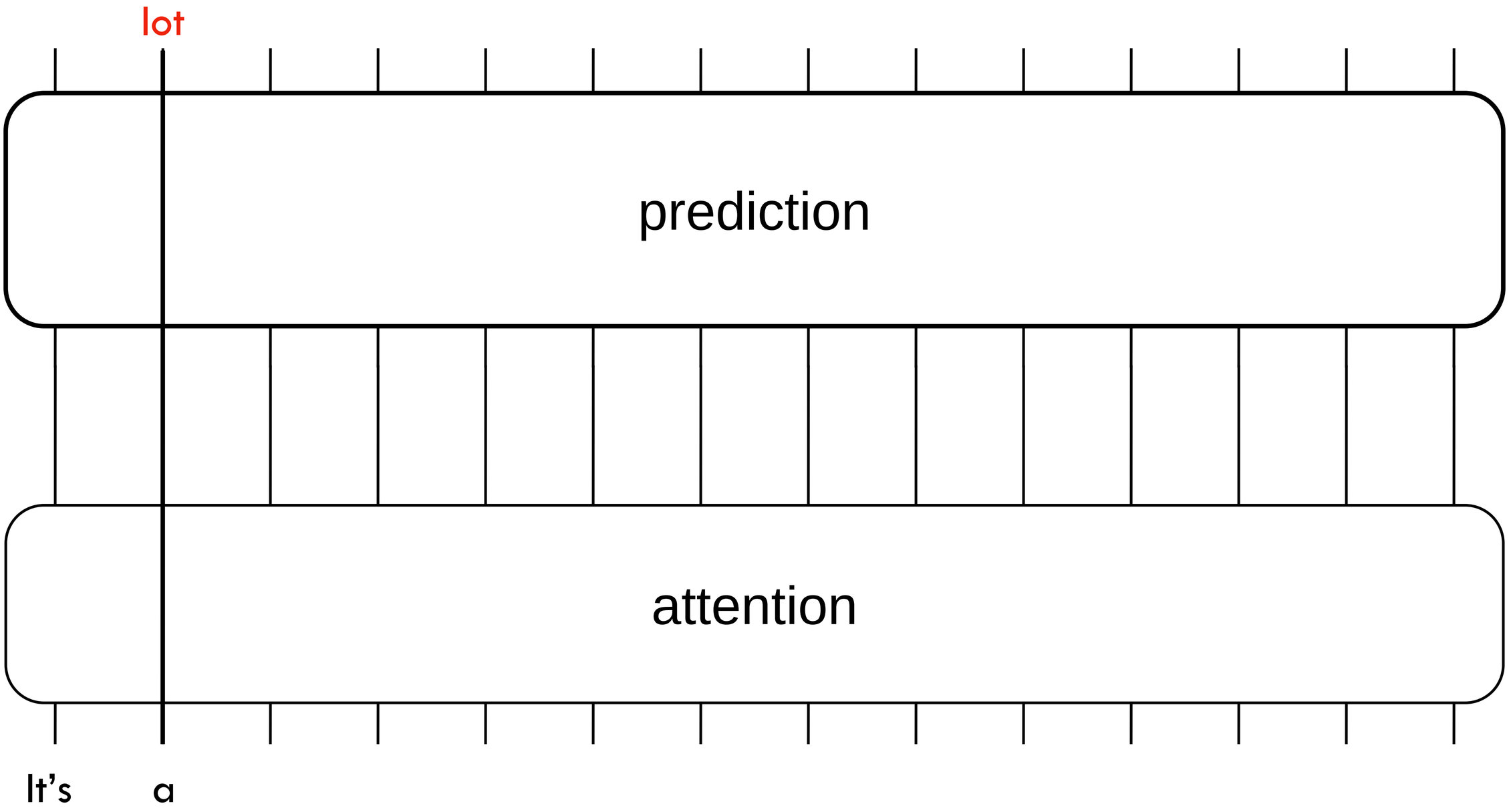

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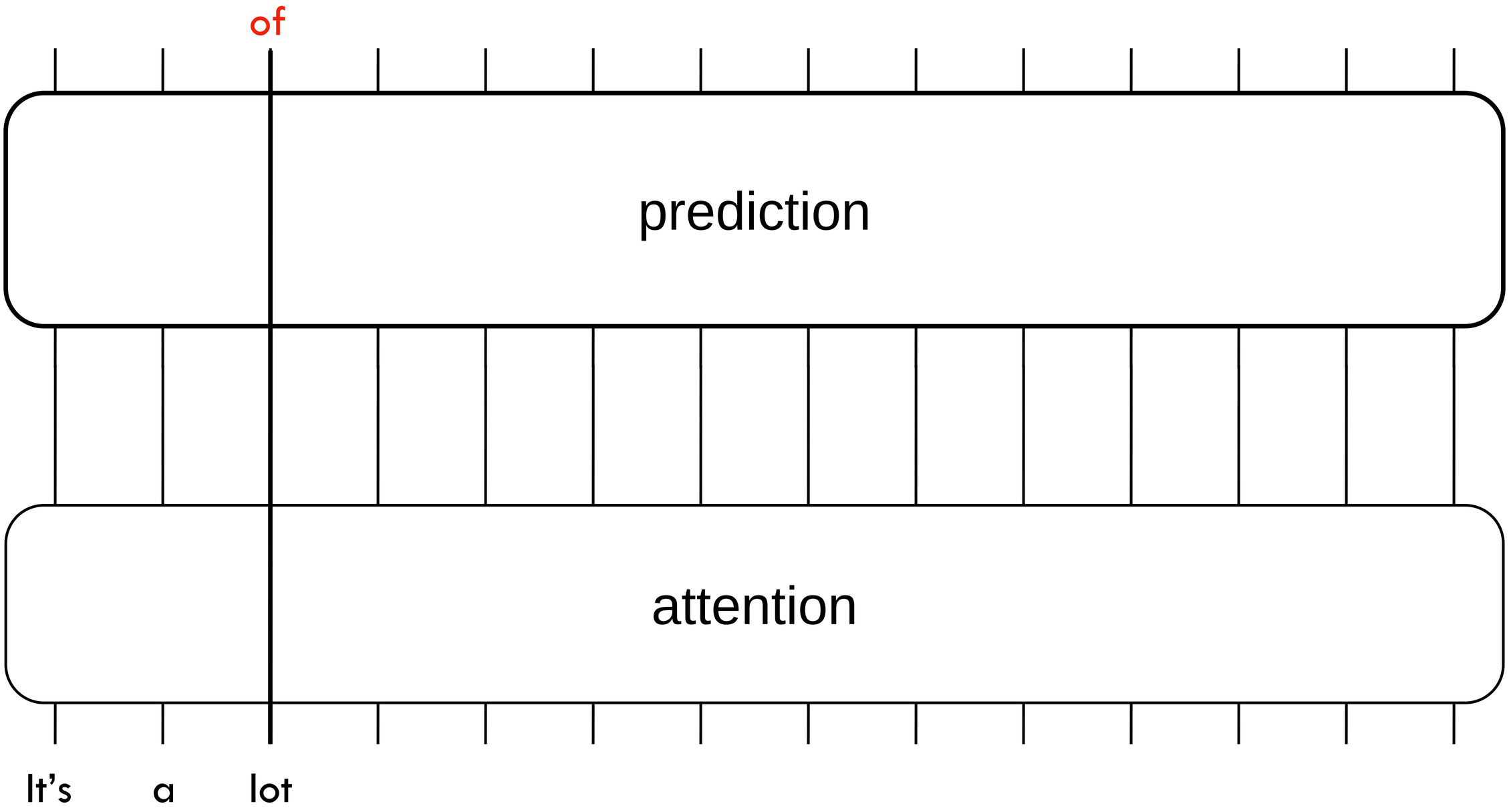

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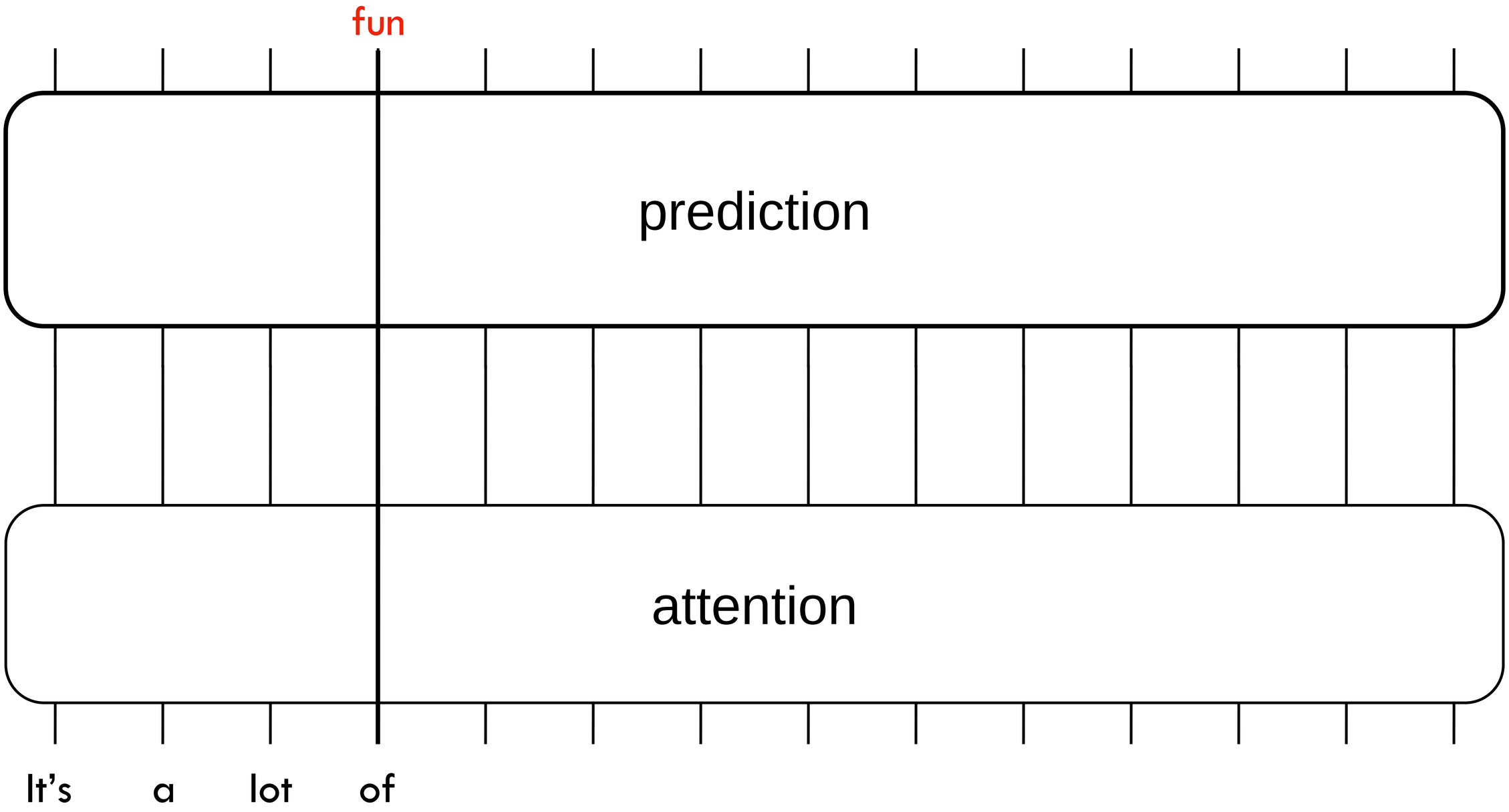

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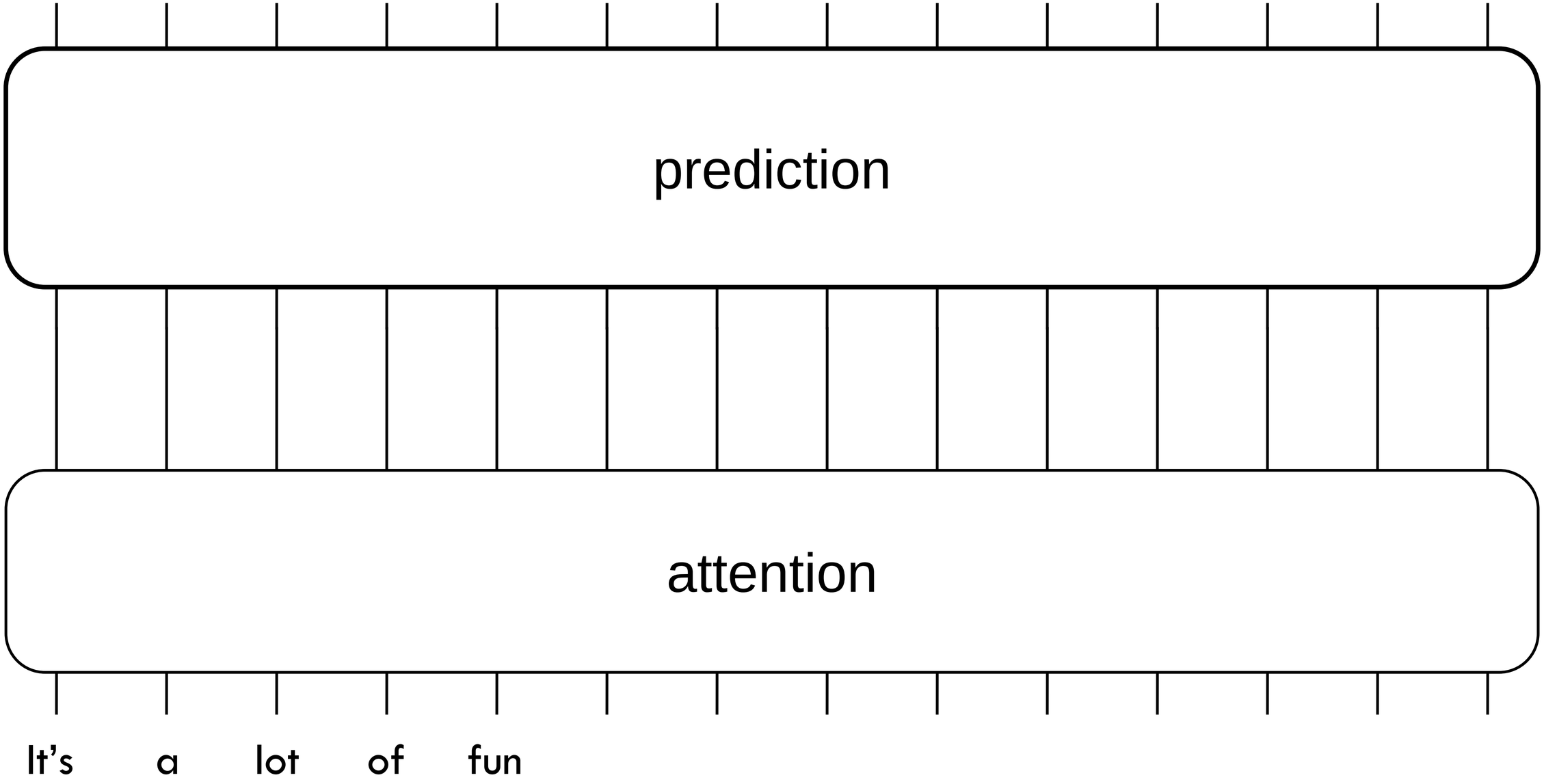

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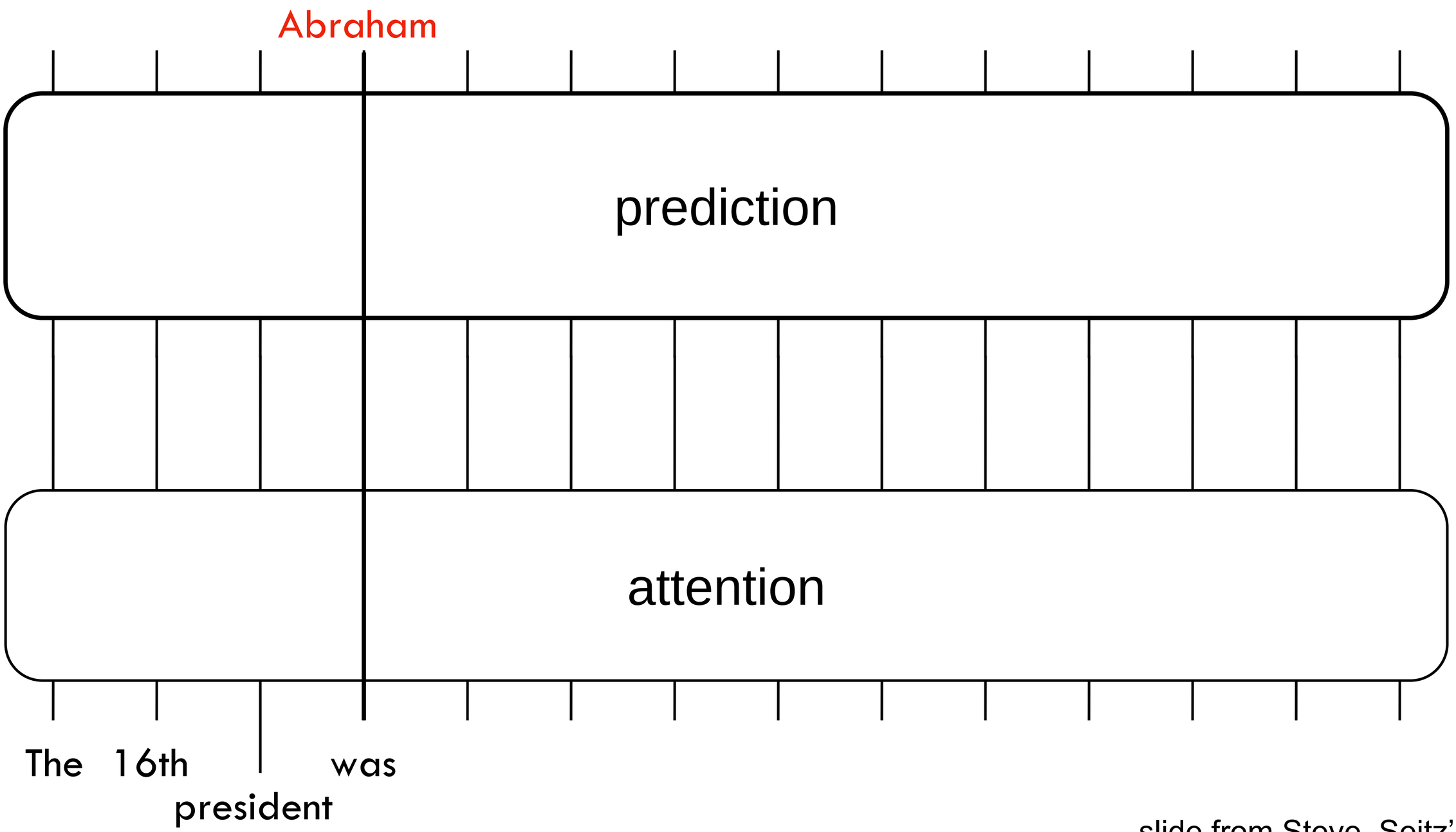


slide from Steve Seitz's video

The 16th President was ?

The capital of Zimbabwe is ?

Frank Zappa's middle name is ?

Napoleon was born on this date ?

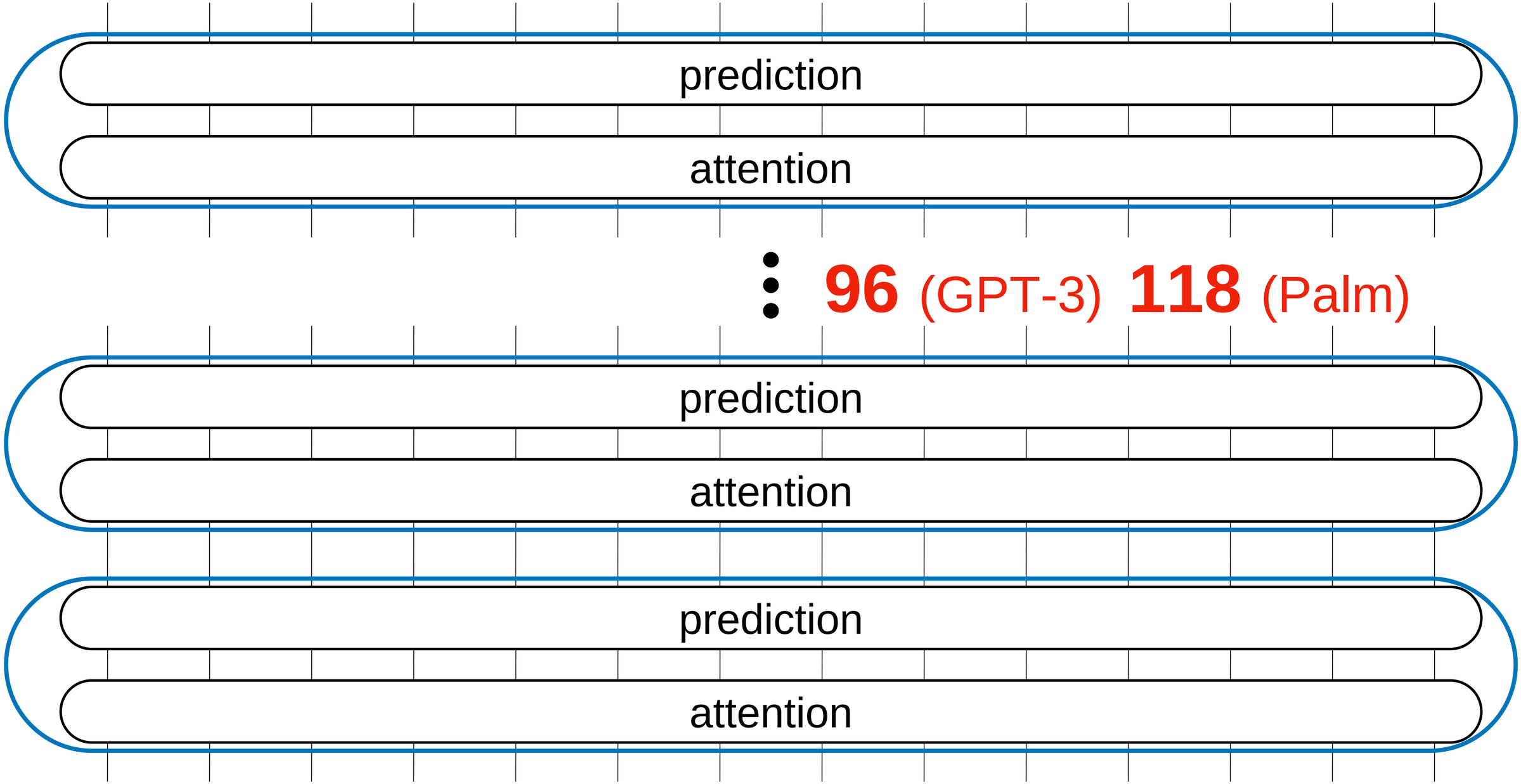
The prime factorization of 19456721434 is ?

Queen Victoria's maiden name was ?

US per-capita income in 1957 was ?

The lat long coordinates of Rome are ?

slide from Steve Seitz's video



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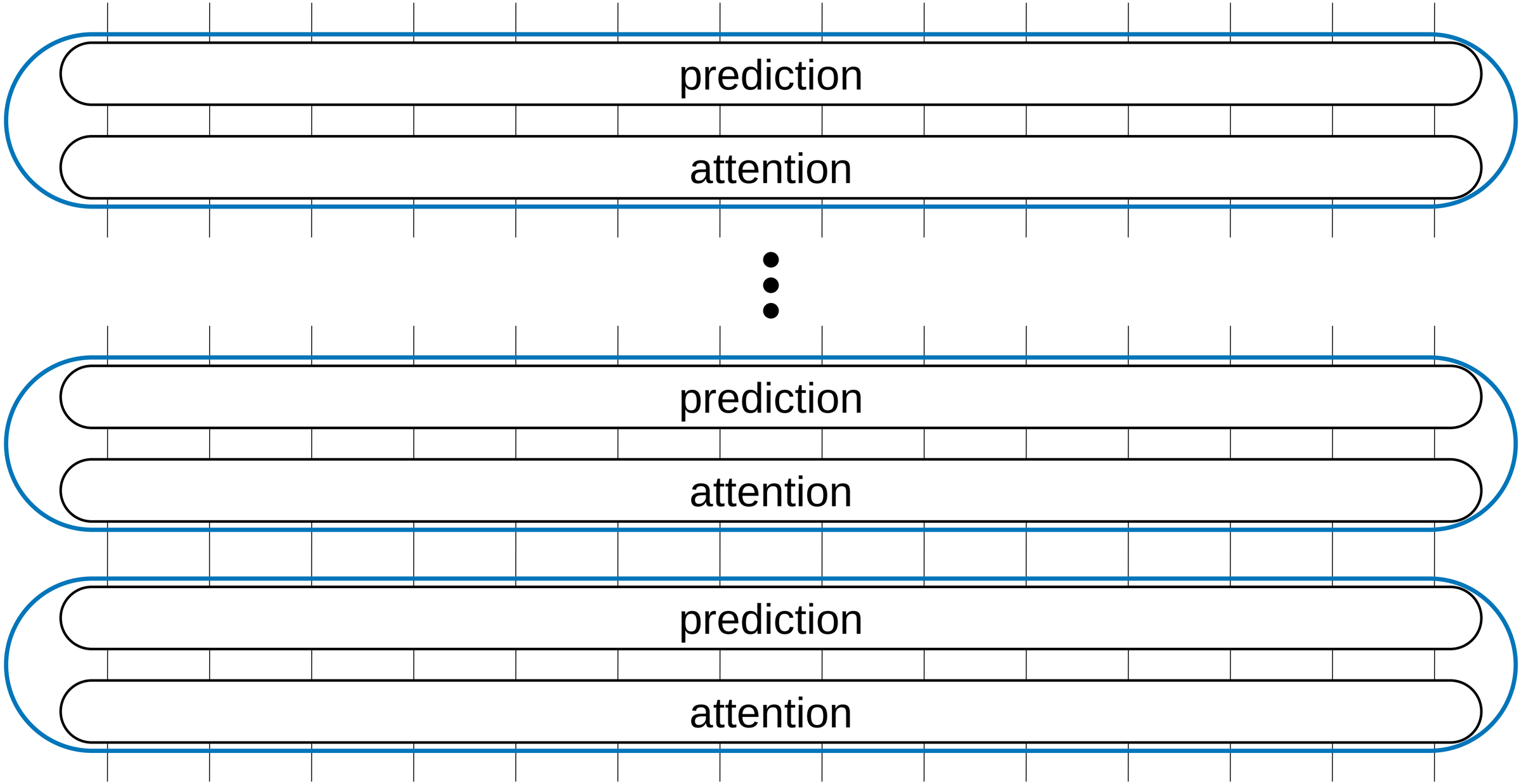

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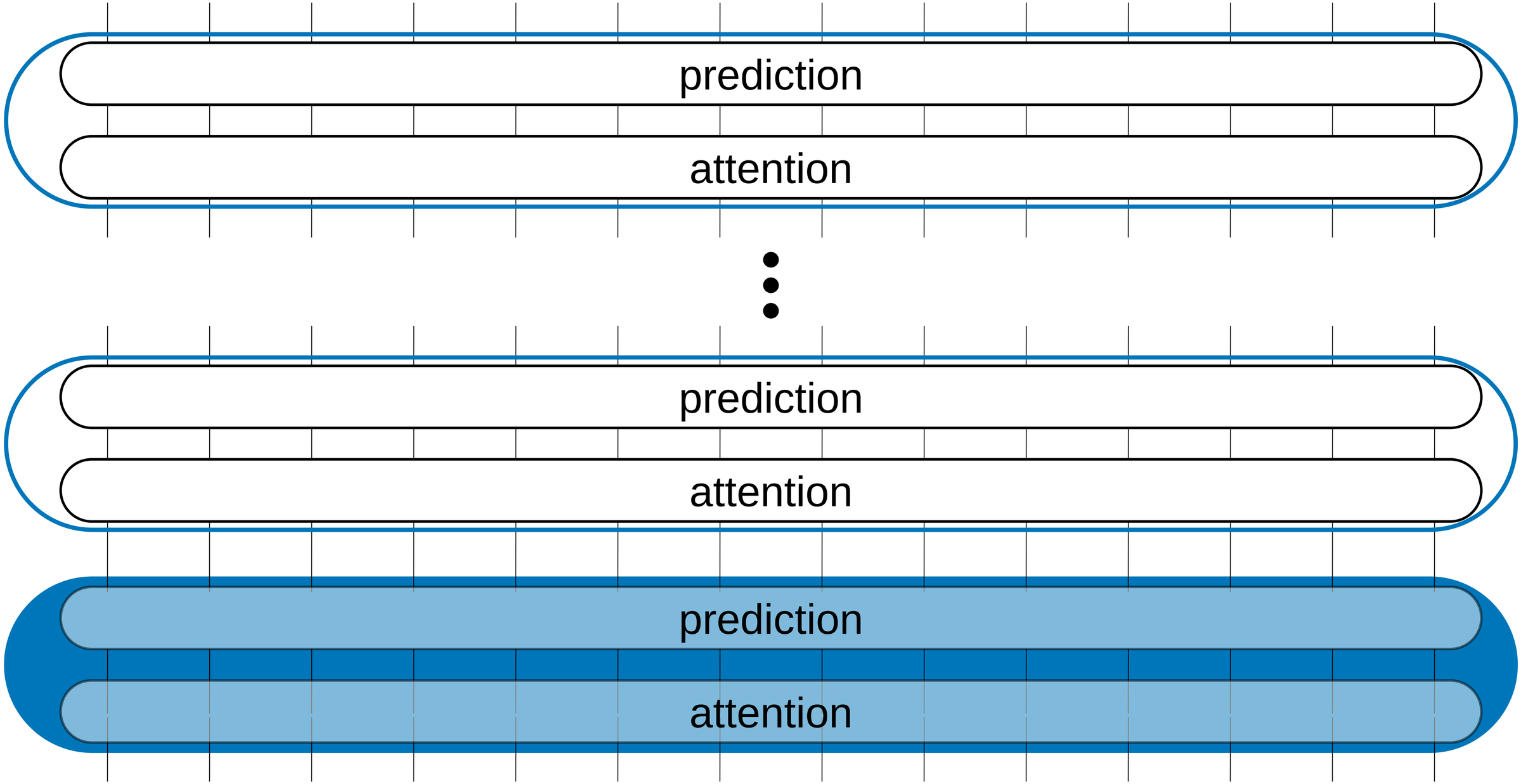

Syntax

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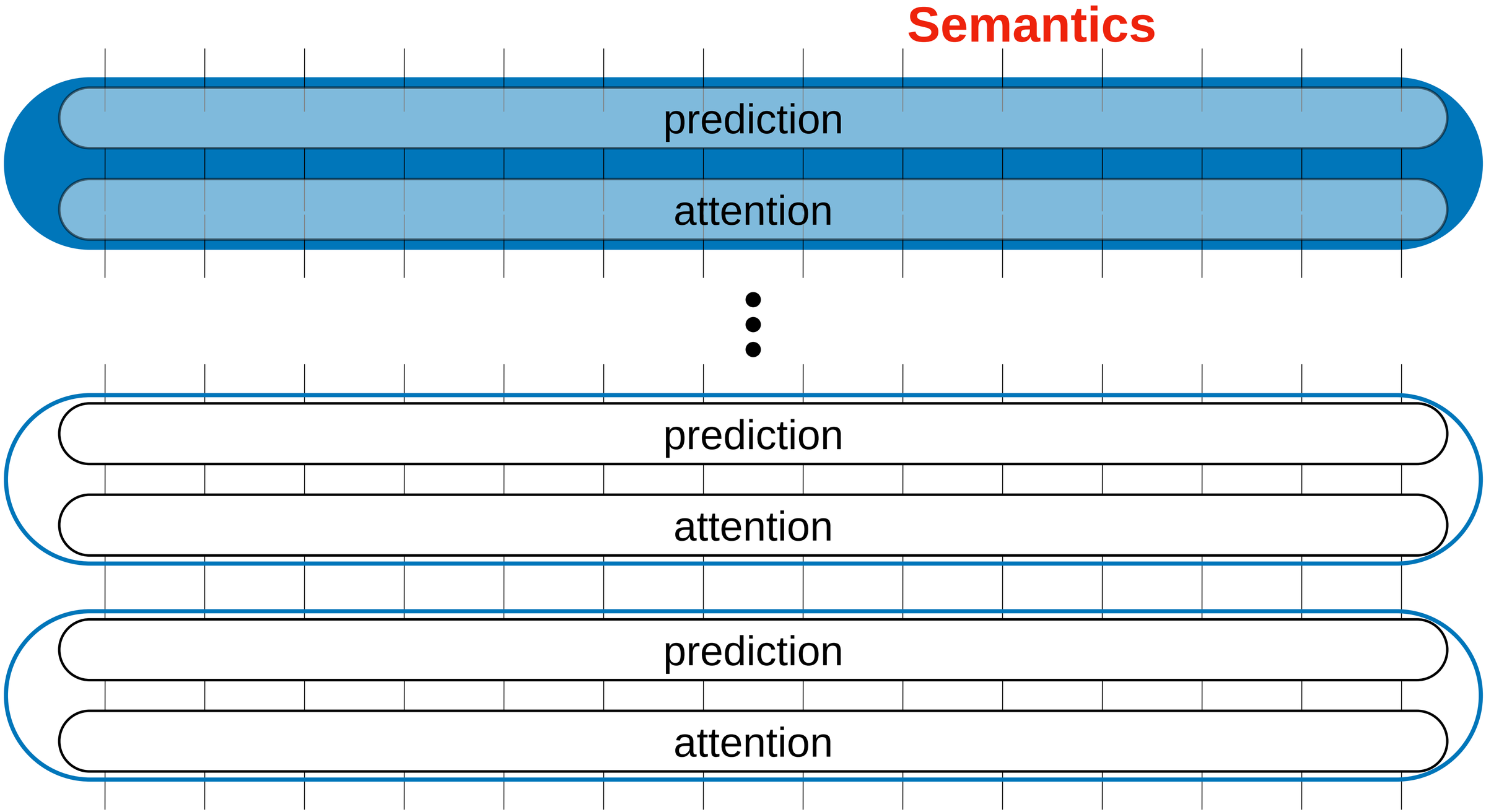

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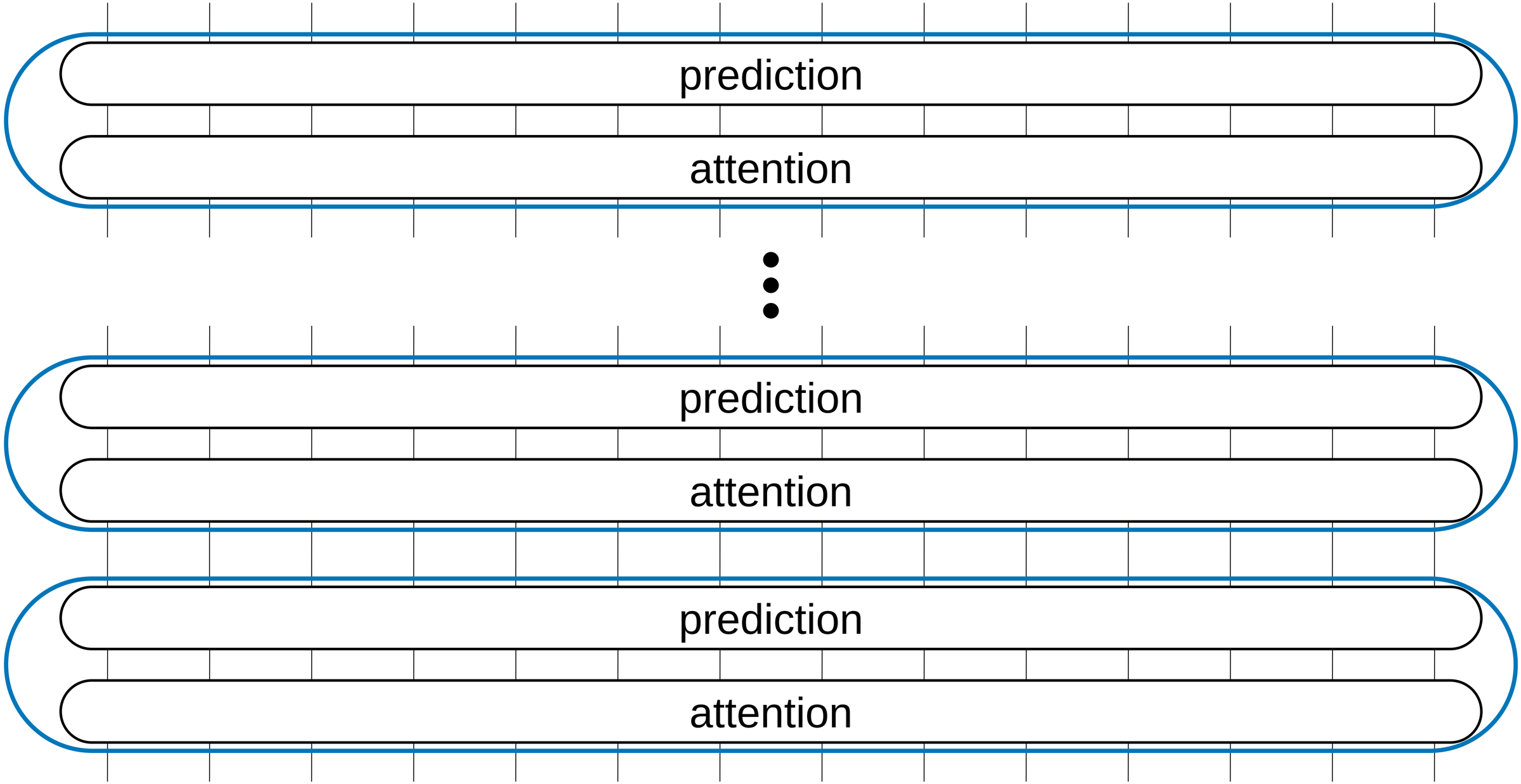


slide from Steve Seitz's video

How much data to train?

All of it…

355 years

a month

The 16th President was

The capital of Zimbabwe is

Frank Zappa's middle name is

Napoleon was born on this date

The prime factorization of 19456721434 is

Queen Victoria's maiden name was

US per-capita income in 1957 was

The lat long coordinates of Rome are

slide from Steve Seitz's video

The 16th President was Abraham Lincoln

The capital of Zimbabwe is Harare

Frank Zappa's middle name is Vincent

Napoleon was born on this date 1769

The prime factorization of 19456721434 is $2 \times 3 \times 3 \times 17$

Queen Victoria's maiden name was Alexandrina Victoria

US per-capita income in 1957 was $2,974

The lat long coordinates of Rome are 41.894722, 12.48

slide from Steve Seitz's video

a haiku about a turtle and a stop sign

slide from Steve Seitz's video

a haiku about a turtle and a stop sign

Turtle at the stop sign
waiting for the perfect moment
to cross the busy road

slide from Steve Seitz's video

translate “tangled up in blue” to 5 languages

slide from Steve Seitz’s video

translate “tangled up in blue” to 5 languages

1. Spanish: Enredado en azul
2. French: Emmêlé dans le bleu
3. Italian: Intrecciato nel blu
4. German: Verwickelt in blau
5. Japanese: 青い糸に絡まって

slide from Steve Seitz’s video

the number after the number after 37 is 74

I'm heading north. I turn right. Then I turn left.
I'm now heading south

slide from Steve Seitz's video

the recipe for chocolate guacamole pancakes

Ingredients:
1 ripe avocado, mashed
1/4 cup cocoa powder
1/4 cup all-purpose flour
1 teaspoon baking powder
1/4 teaspoon salt
1/2 cup milk
1 egg
1 tablespoon vegetable oil
1/4 cup chocolate chips

Directions:
1. In a medium bowl, combine the avocado, cocoa powder, flour, baking powder, and salt.
2. In a separate bowl, whisk together the milk, egg, and vegetable oil.
3. Add the wet ingredients to the dry ingredients and mix until well combined.
4. Fold in the chocolate chips.
5. Heat a large skillet over medium heat.
6. Scoop 1/4 cup batter onto the skillet for each pancake.
7. Cook for 2-3 minutes per side, or until the pancakes are golden brown.
8. Serve with your favorite toppings.

slide from Steve Seitz's video

For more details: https://jalammar.github.io/illustrated-transformer/
https://jalammar.github.io/illustrated-gpt2/

slide from Steve Seitz's video

a pattern of characters that looks like a star

```
. o .
o o o
. o .
```

slide from Steve Seitz's video

a pattern of characters that looks like a vertical line

```
. O .
. O .
. O .
. O .
. O .
```

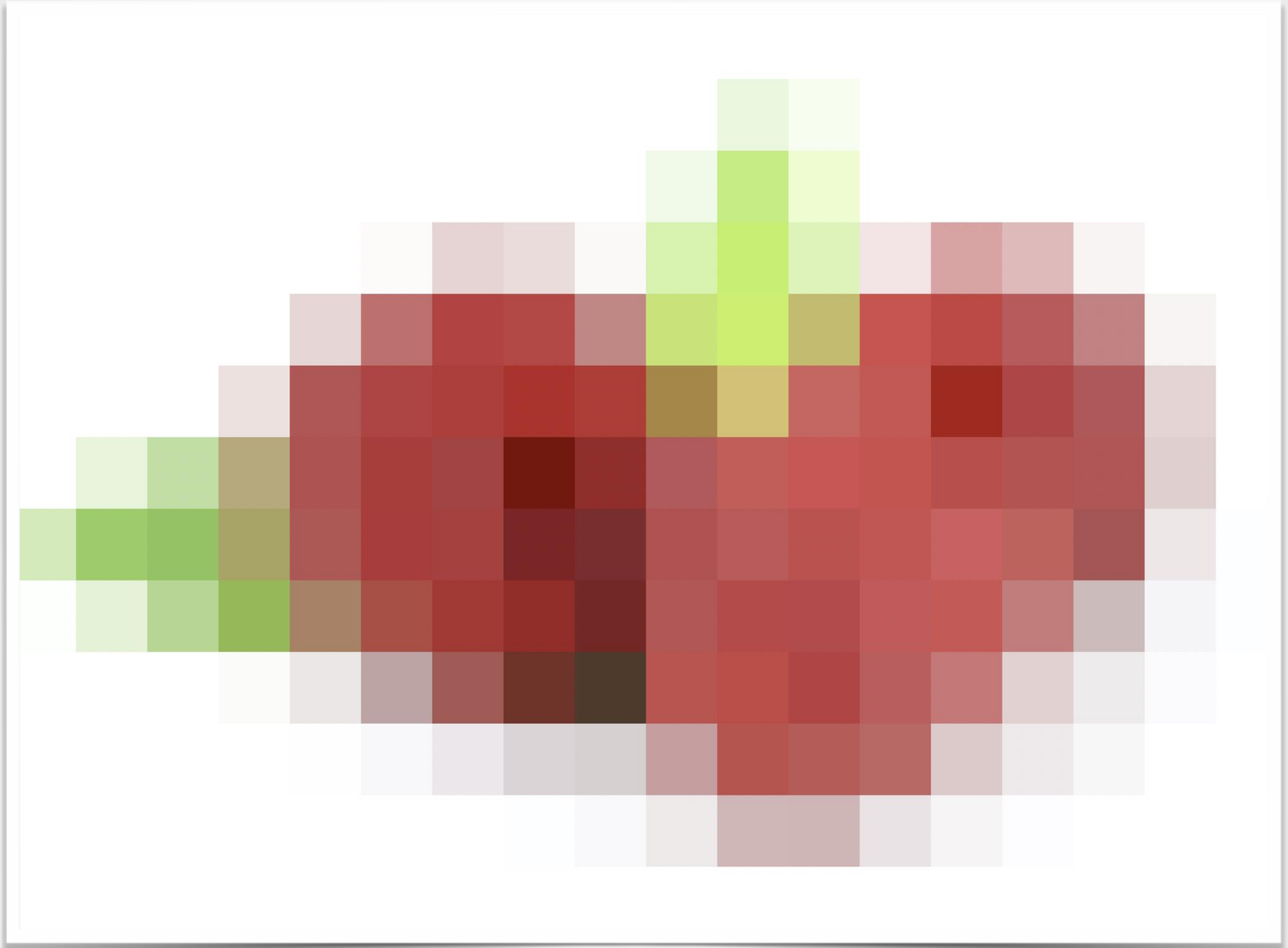
slide from Steve Seitz's video

a pattern of characters that looks like a triangle

```
. ○ .
. ○ ○ .
. ○ ○ ○ .
. ○ ○ ○ ○ .
. ○ ○ ○ ○ ○ .
```

slide from Steve Seitz's video

slide from Steve Seitz’s video



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white	white	white	white	white	white	white	white	white	green	white	white	white	white	white
white	white	white	white	white	white	white	white	green	green	green	white	red	red	white
white	white	white	white	red	red	red	red	green	green	brown	red	red	red	red
white	white	white	red	red	red	red	red	brown	green	red	red	red	red	red
white	green	brown	red	red	red	red	red	red	red	red	red	red	red	red
green	green	brown	red	red	red	red	red	red	red	red	red	red	red	red
white	green	green	brown	red	red	red	red	red	red	red	red	red	red	white
white	white	white	white	red	red	red	black	red	red	red	red	red	white	white
white	white	white	white	white	white	white	white	red	red	red	red	white	white	white
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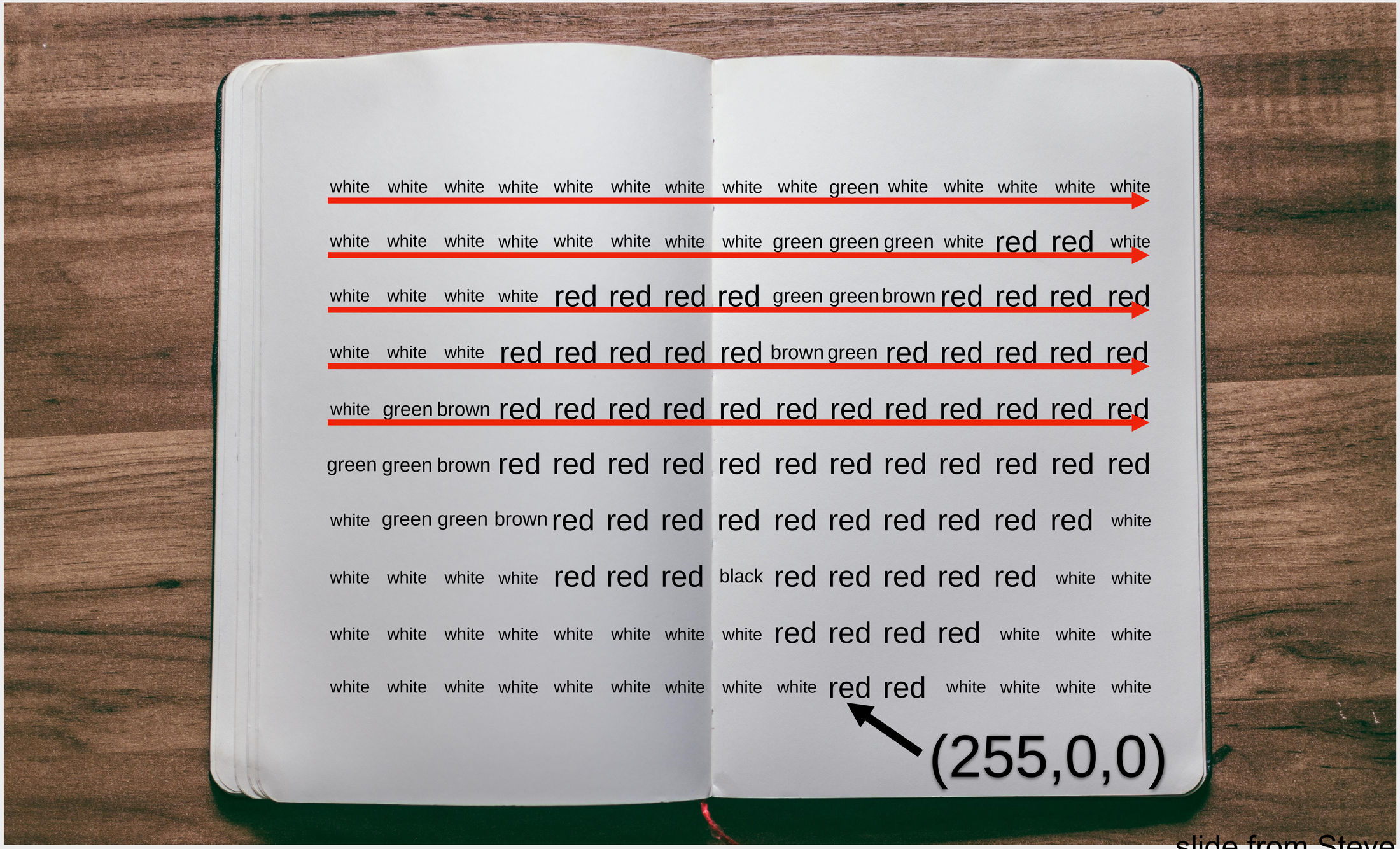
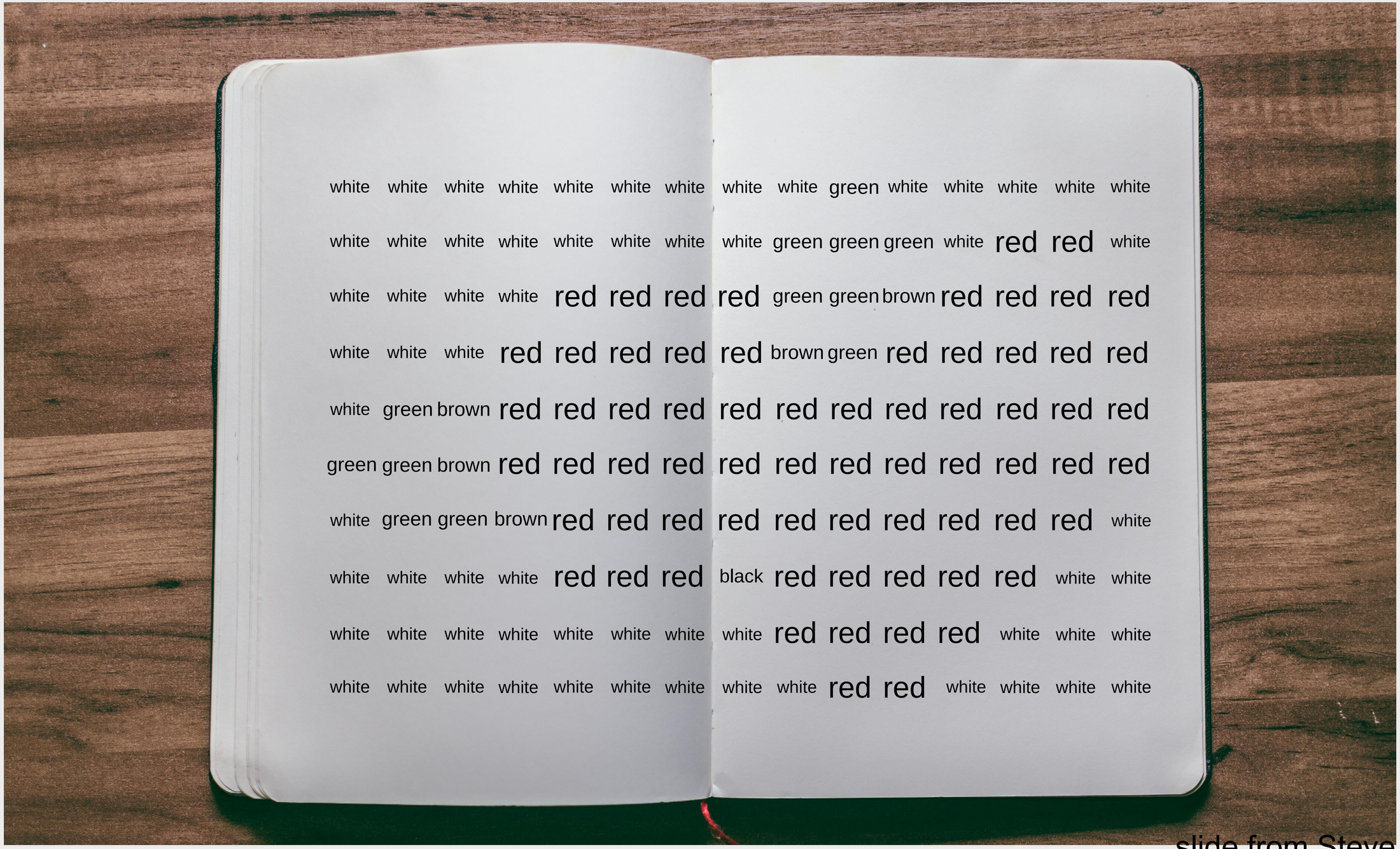
slide from Steve Seitz's video



slide from Steve Seitz's video



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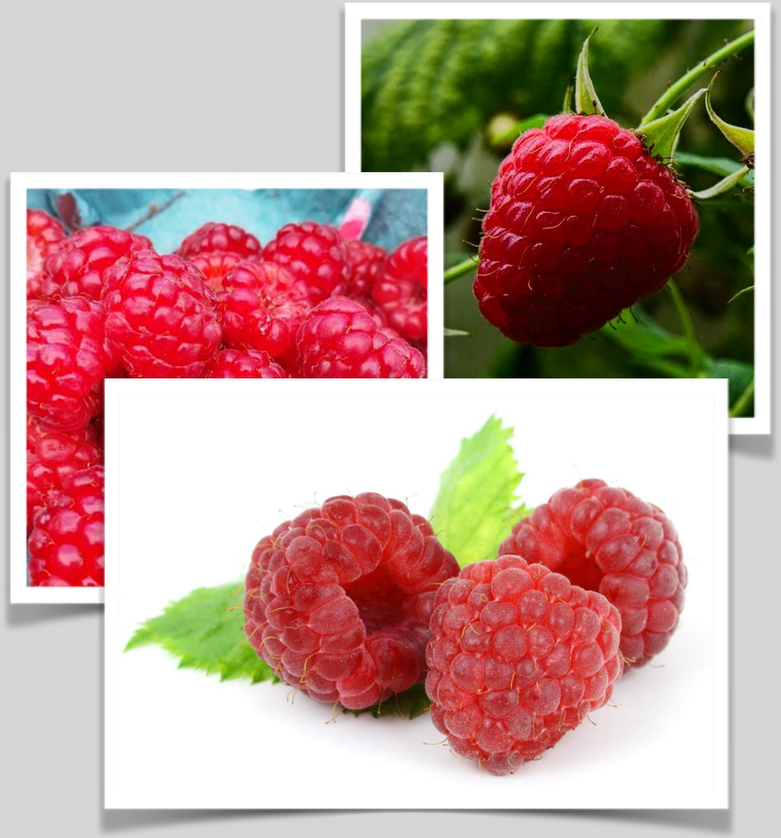


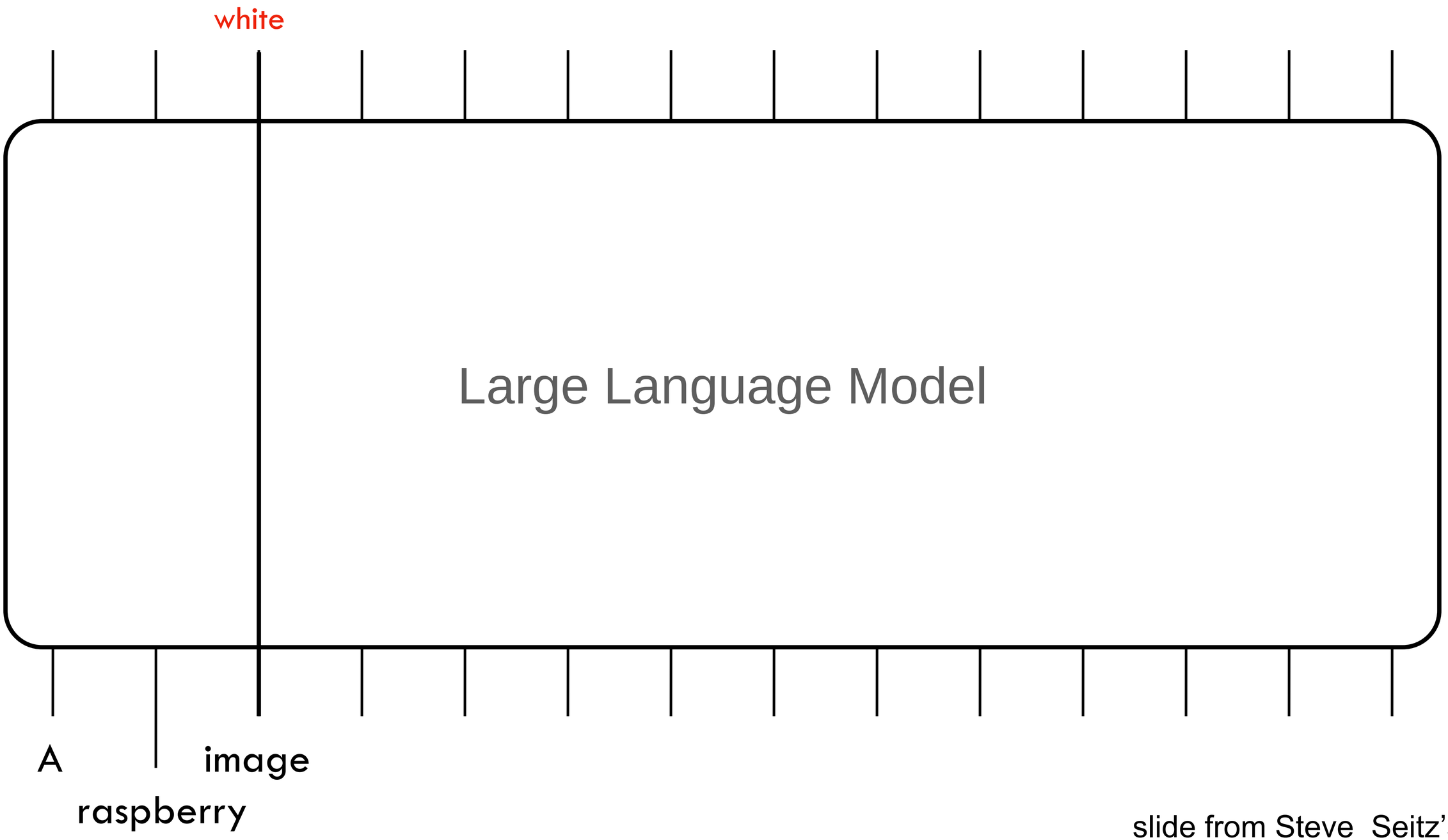
raspberries

pancakes

sunsets

1 Billion

slide from Steve Seitz's video



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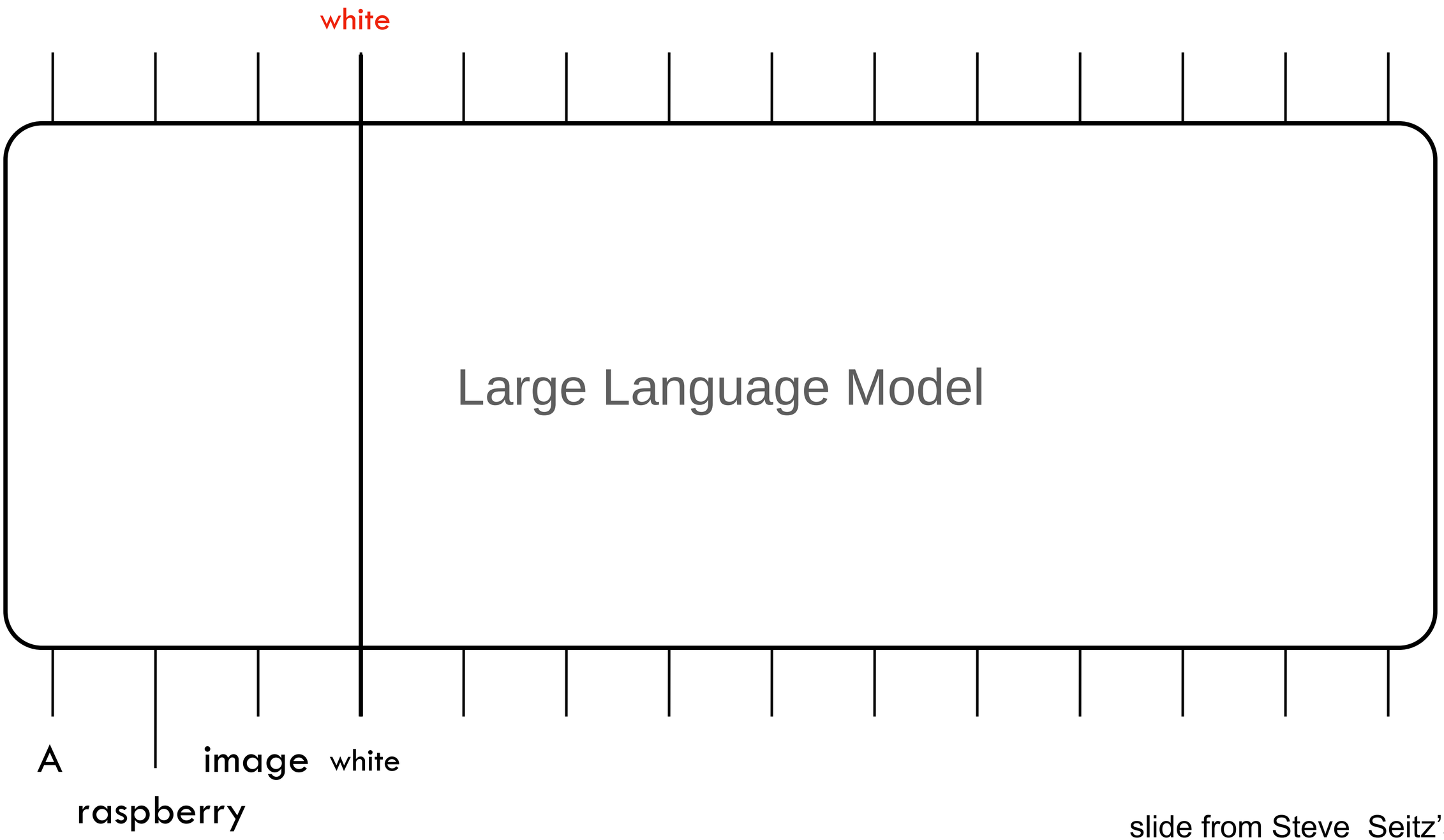

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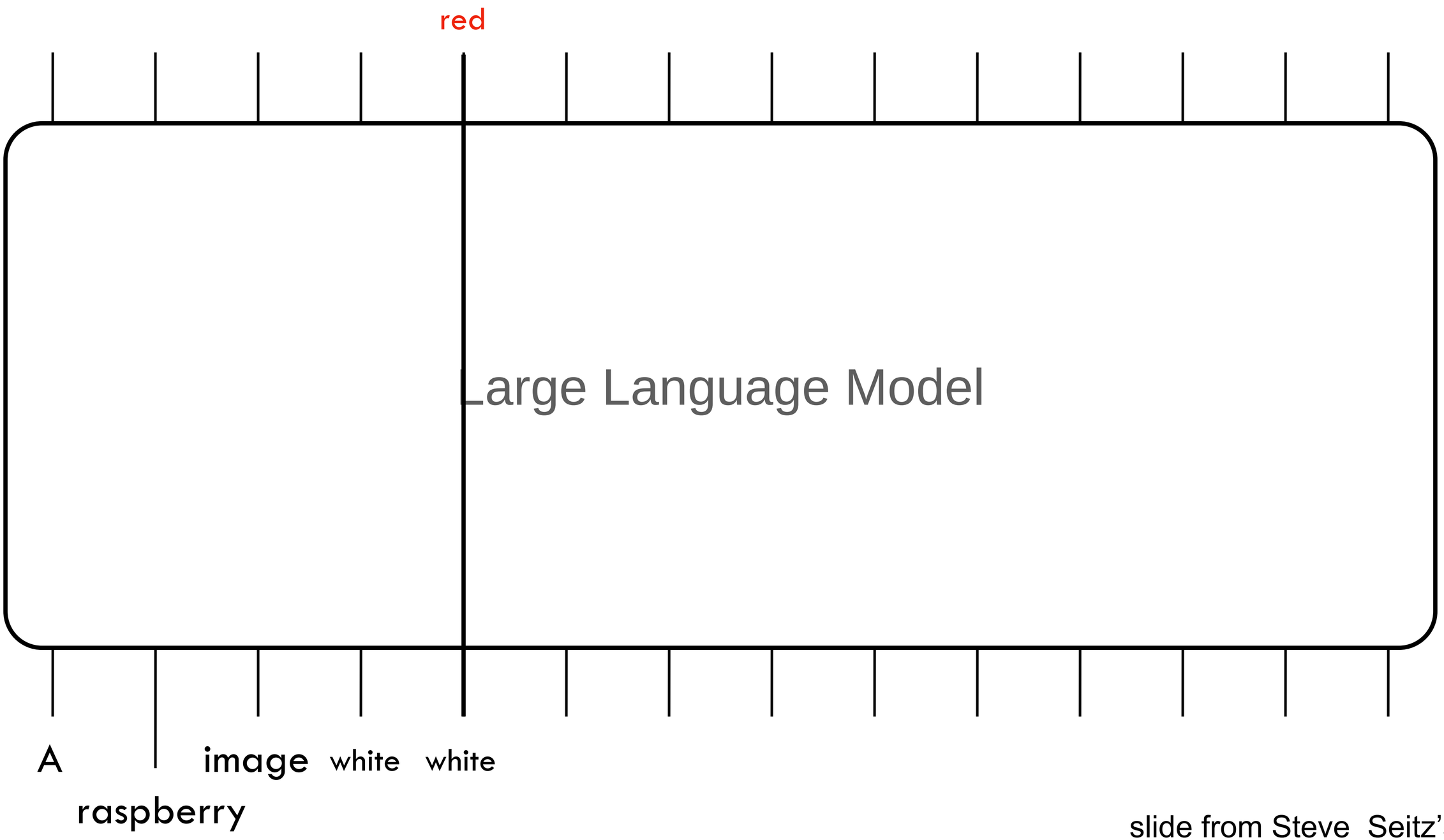

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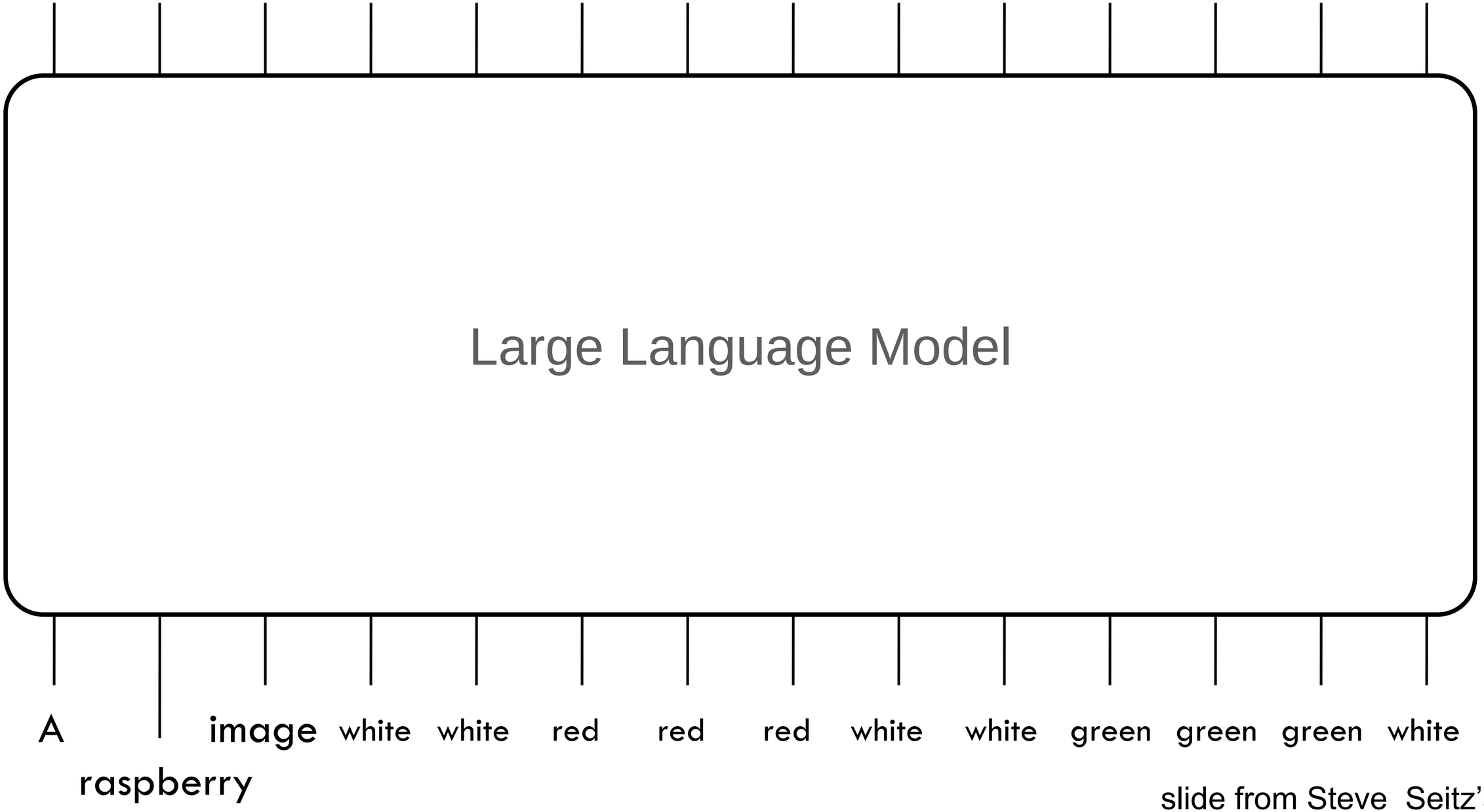
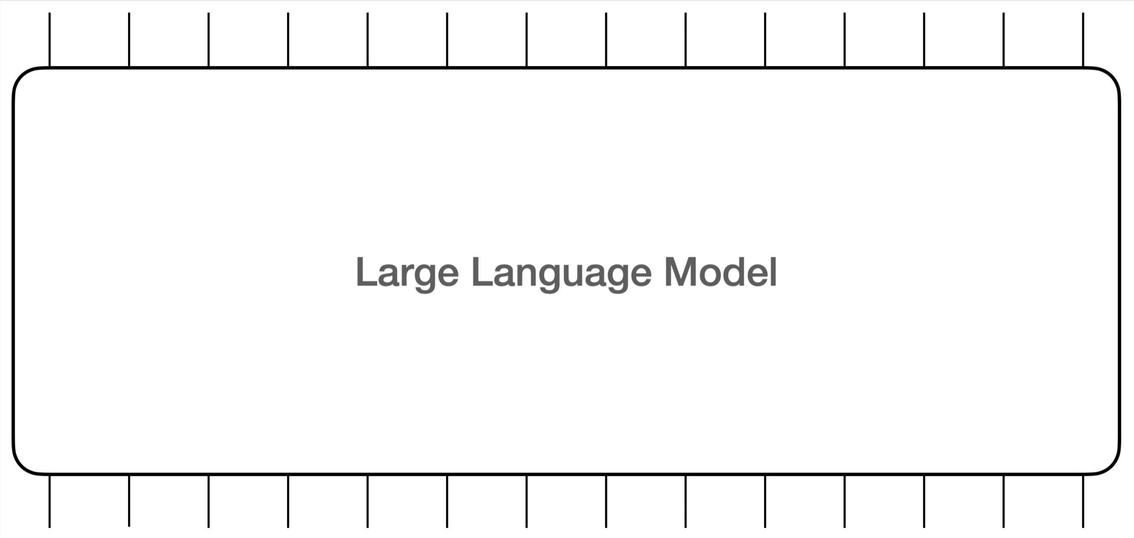


slide from Steve Seitz's video

1,000,000s of pixels



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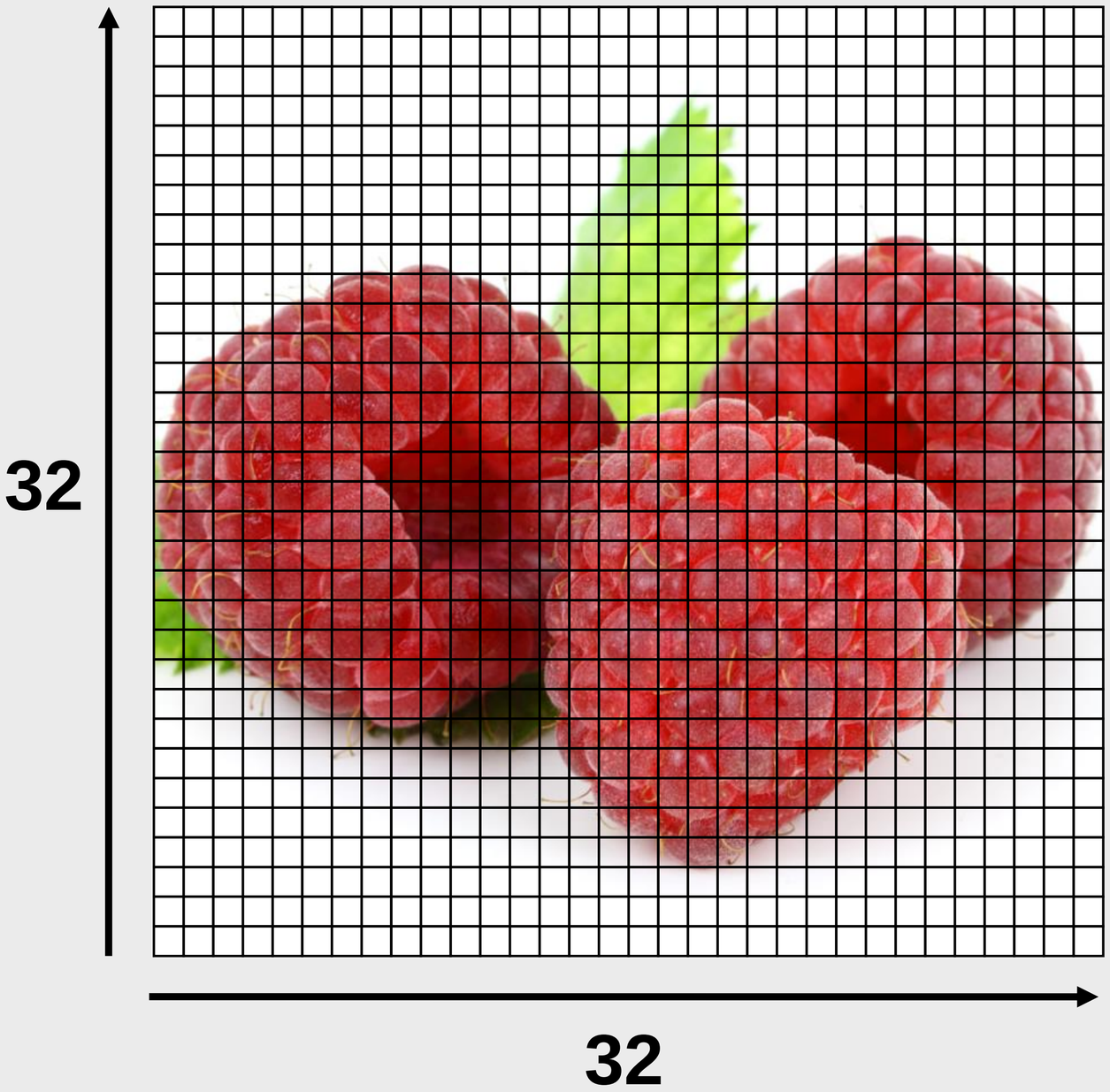
slide from Steve Seitz's video



slide from Steve Seitz's video

Torralba et al, 80 Million Tiny Images (2006)

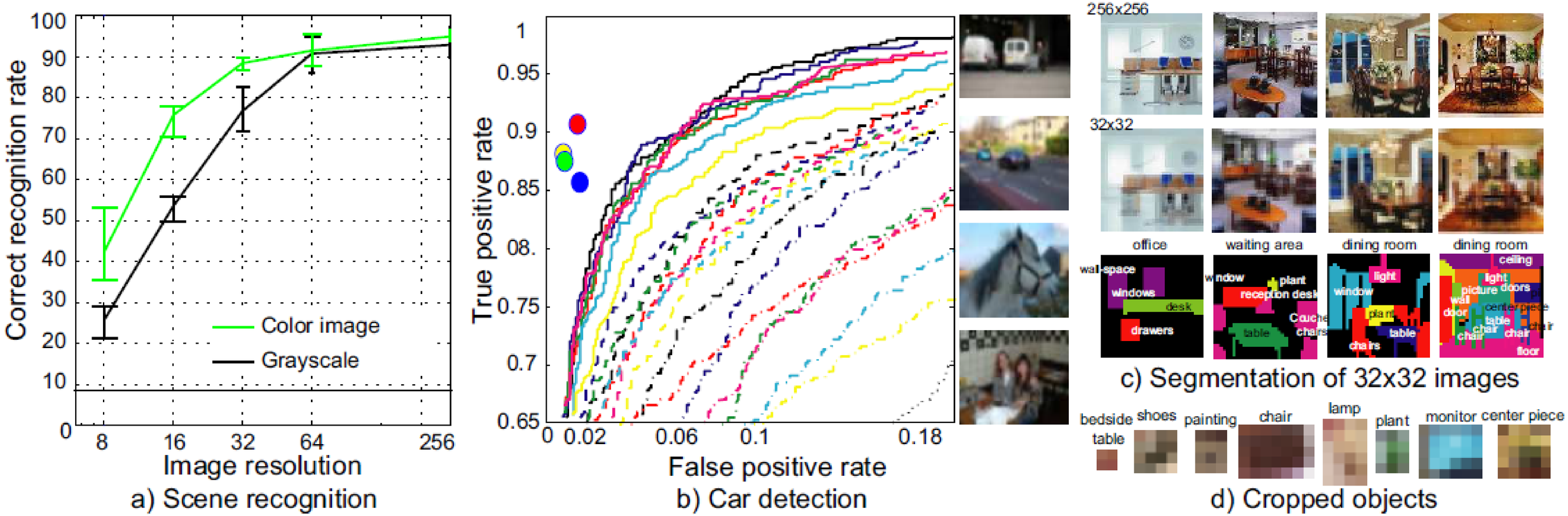
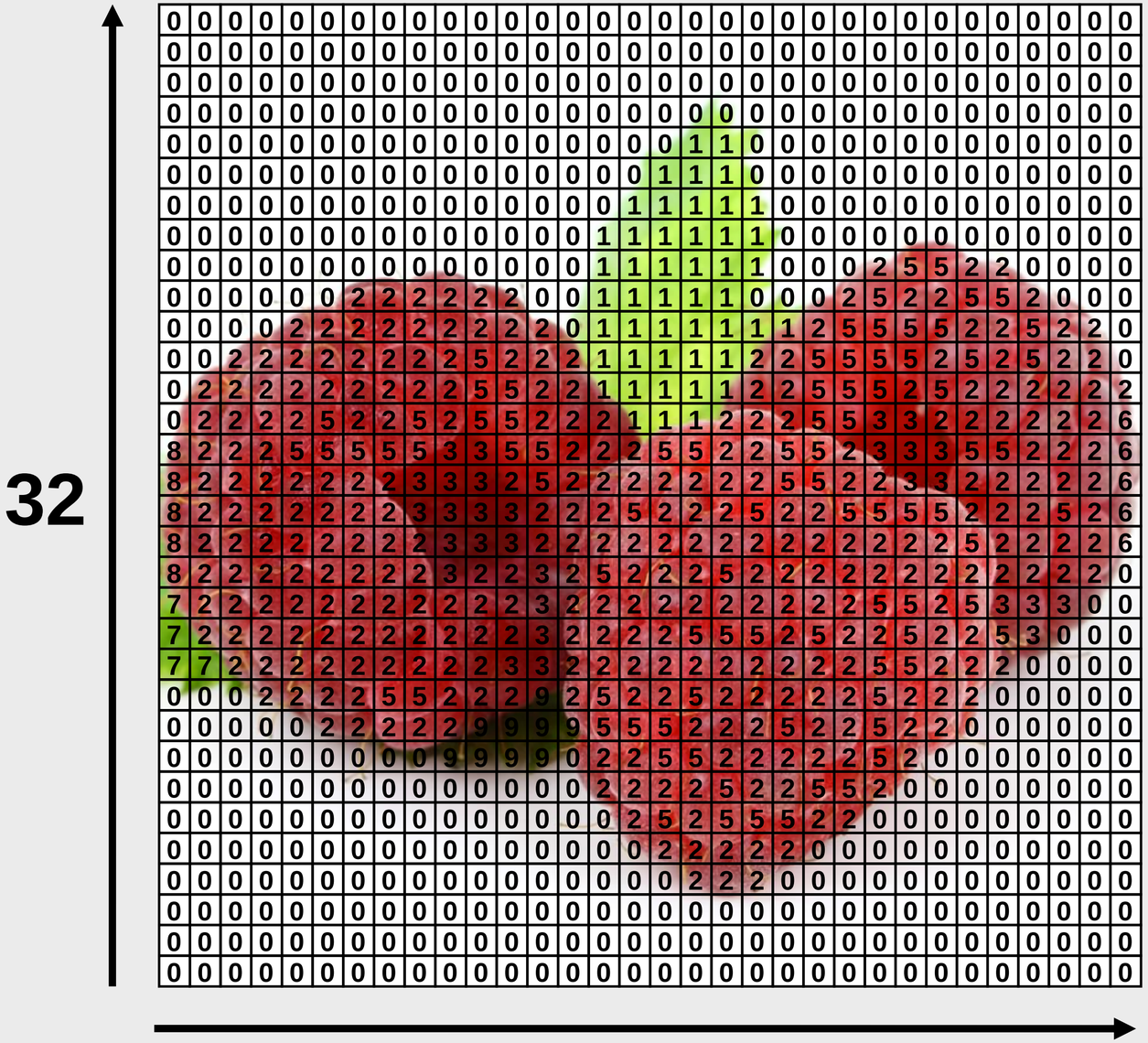
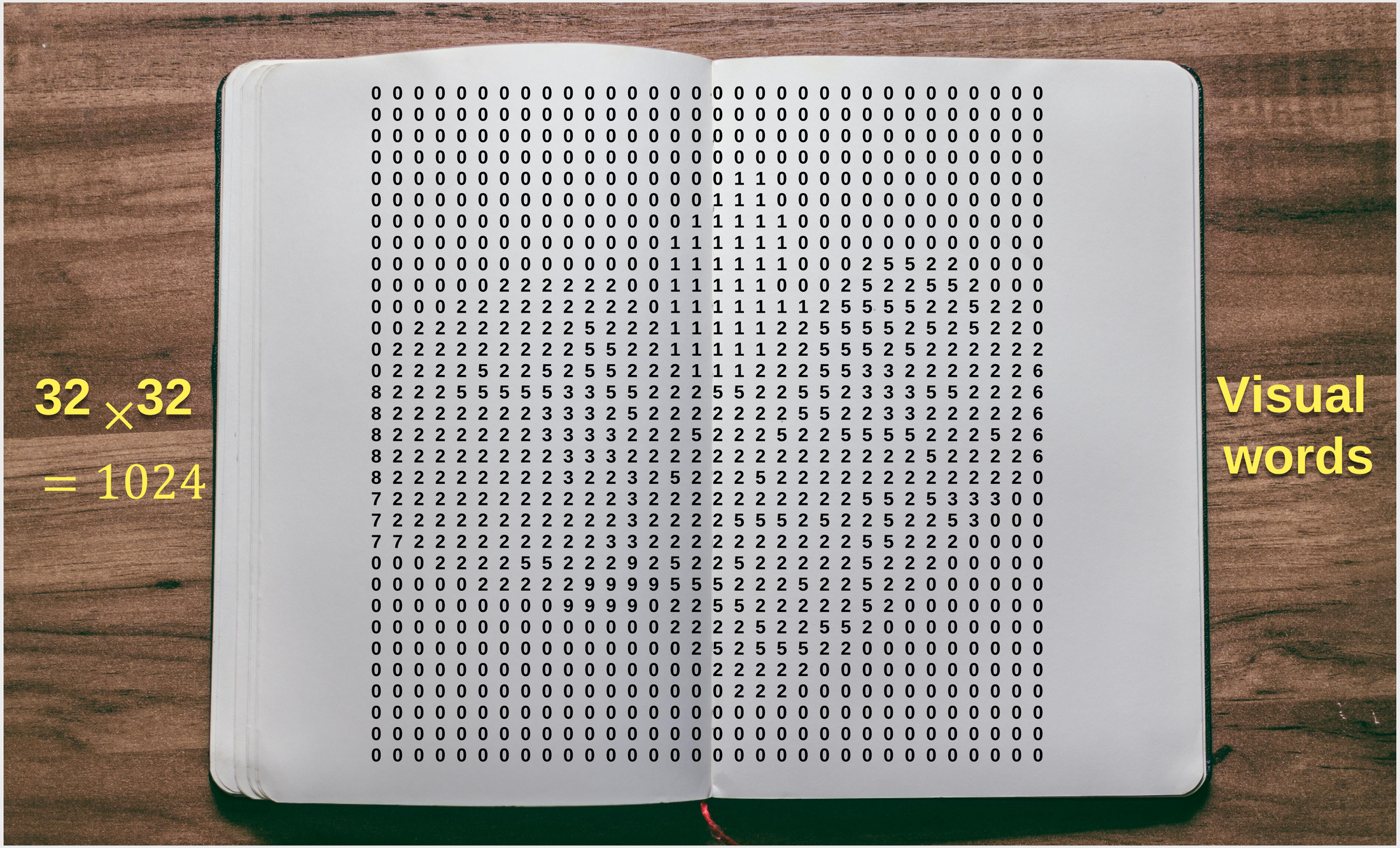


Fig. 1. a) Human performance on scene recognition as a function of resolution. The green and black curves show the performance on color and gray-scale images respectively. For color 32×32 images the performance only drops by 7% relative to full resolution, despite having 1/64th of the pixels. b) Car detection task on the PASCAL 2006 test dataset. The colored dots show the performance of four human subjects classifying tiny versions of the test data. The ROC curves of the best vision algorithms (running on full resolution images) are shown for comparison. All lie below the performance of humans on the tiny images, which rely on none of the high-resolution cues exploited by the computer vision algorithms. c) Humans can correctly recognize and segment objects at very low resolutions, even when the objects in isolation can not be recognized (d).



slide from Steve Seitz's video



slide from Steve Seitz's video

squirrel reaching for a nut

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 1 1 6 6 4 4 4 9 9 9 9 9 9
1 1 1 1 1 7 7 1 1 1 1 1 1 1 1 1

slide from Steve Seitz's video

squirrel reaching for a nut

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 1 1 6 6 4 4 4 9 9 9 9 9 9
1 1 1 1 1 7 7 1 1 1 1 1 1 1 1 1

slide from Steve Seitz's video

squirrel reaching for a nut

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 1 1 6 6 4 4 4 9 9 9 9 9 9
1 1 1 1 1 7 7 1 1 1 1 1 1 1 1 1 $\boxed{}$

slide from Steve Seitz's video

squirrel reaching for a nut

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 1 1 6 6 4 4 4 9 9 9 9 9 9
1 1 1 1 1 7 7 1 1 1 1 1 1 1 1 1 **1**

slide from Steve Seitz's video

squirrel reaching for a nut

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 1 1 6 6 4 4 4 9 9 9 9 9 9
1 1 1 1 1 7 7 1 1 1 1 1 1 1 1 1 **6**

slide from Steve Seitz's video

squirrel reaching for a nut

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 1 1 6 6 4 4 4 9 9 9 9 9 9
1 1 1 1 1 7 7 1 1 1 1 1 1 1 1 1 **6**

slide from Steve Seitz's video

squirrel reaching for a nut

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 1 1 6 6 4 4 4 9 9 9 9 9 9
1 1 1 1 1 7 7 1 1 1 1 1 1 1 1 1 **6**

slide from Steve Seitz's video

squirrel reaching for a nut

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 1 1 6 6 4 4 4 9 9 9 9 9 9
1 1 1 1 1 7 7 1 1 1 1 1 1 1 1 1 6

slide from Steve Seitz's video

squirrel reaching for a nut

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slide from Steve Seitz's video

squirrel reaching for a nut

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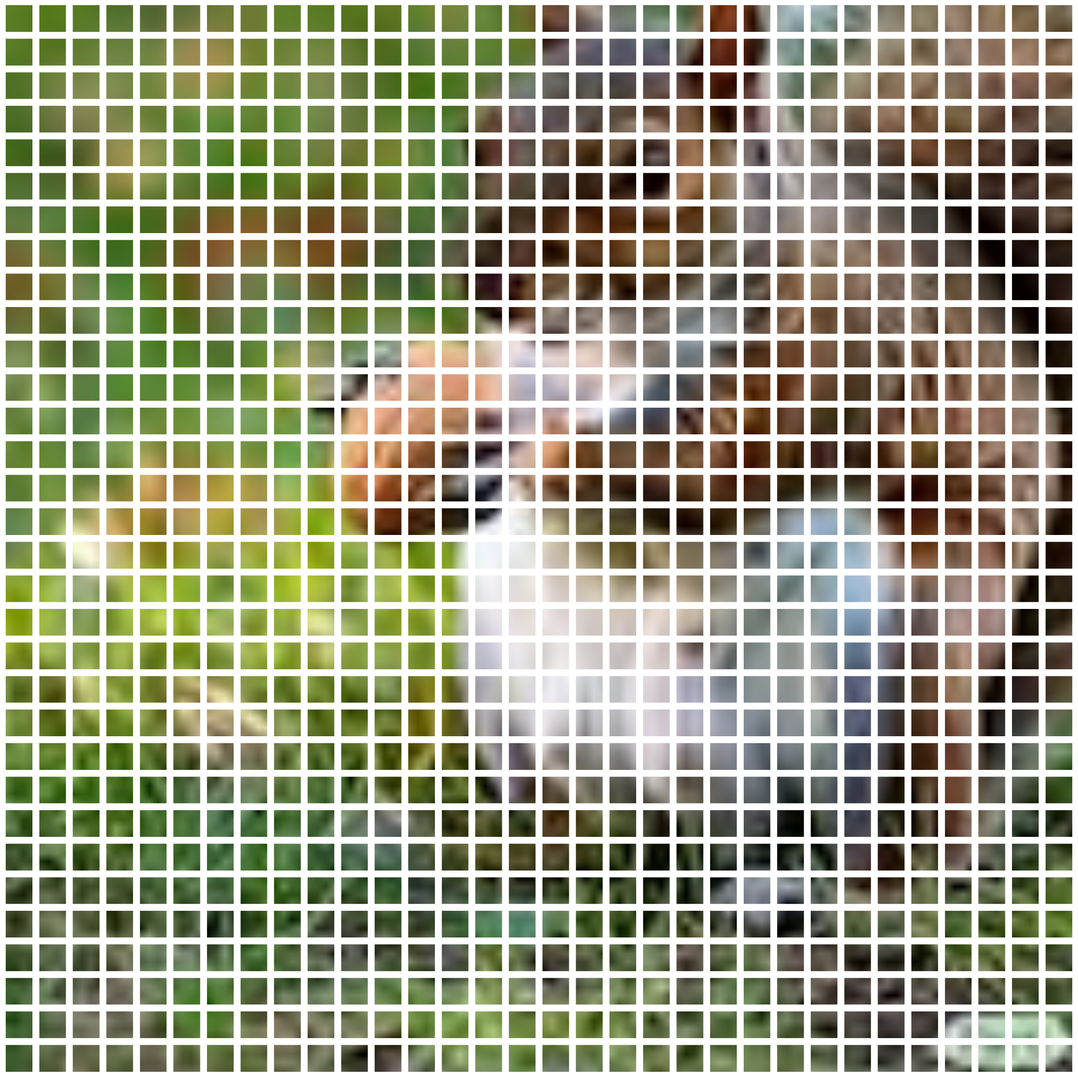
slide from Steve Seitz's video



squirrel reaching for a nut

slide from Steve Seitz's video

squirrel reaching for a nut

slide from Steve Seitz's video

squirrel reaching for a nut

Up-sampled 4x

slide from Steve Seitz's video

squirrel reaching for a nut

Parti, https://parti.research.google/

squirrel reaching for a nut underwater

slide from Steve Seitz's video

fossil of a squirrel reaching for a nut

slide from Steve Seitz's video

squirrel made of toothpicks wearing sunglasses reaching for a nut

slide from Steve Seitz's video

DLSR photograph of a whimsical fantasy house shaped like a squirrel with windows and a door, in the forest

slide from Steve Seitz's video

Squirrel reaching for a nut. by Leonardo da Vinci

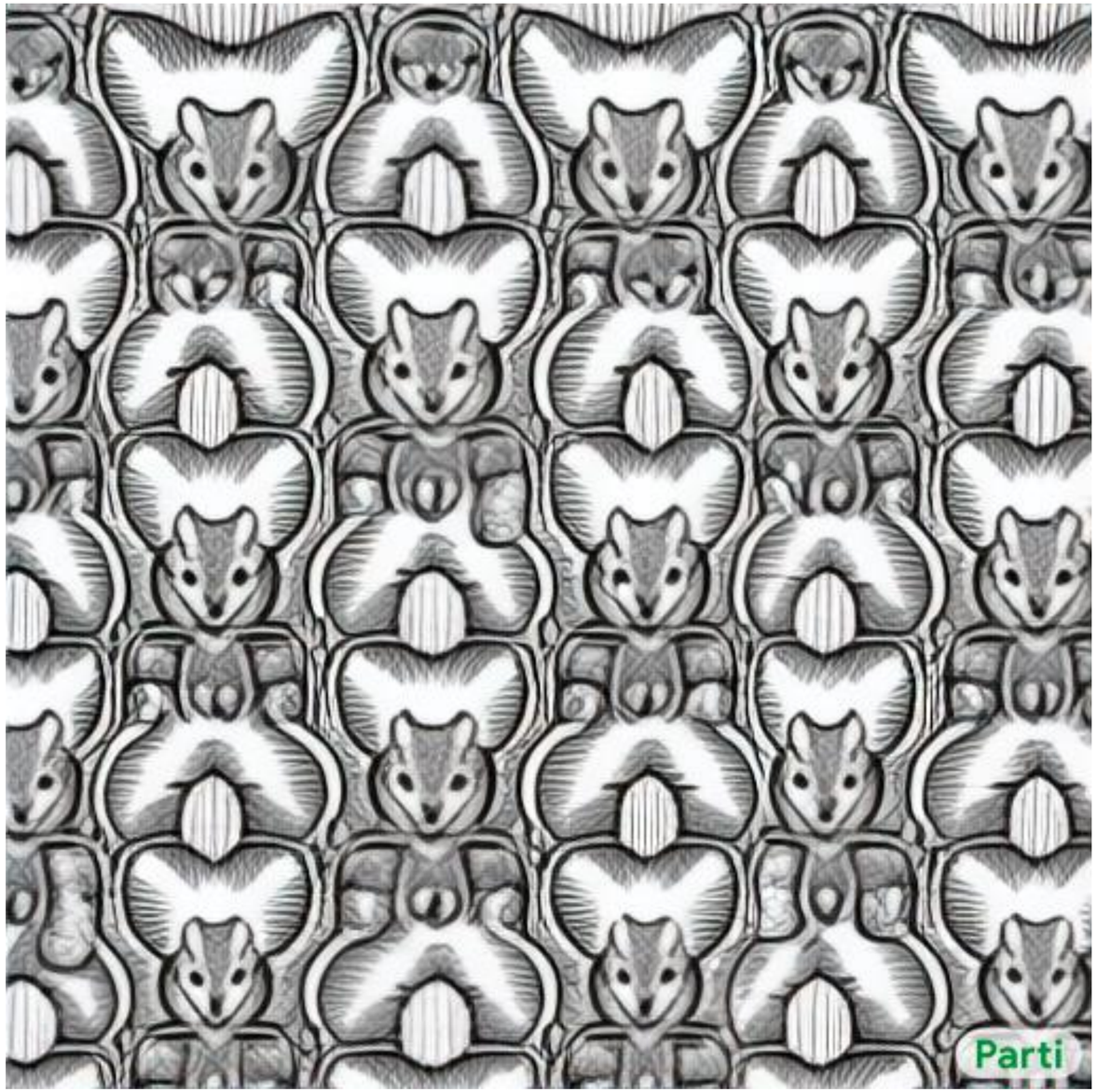
slide from Steve Seitz's video

Squirrel reaching for a nut. Van Gogh painting

slide from Steve Seitz's video

Intricately carved cathedral door of a squirrel reaching for a nut

slide from Steve Seitz's video



Squirrel reaching for a nut. Woodcut tessellation pattern by M.C. Escher

slide from Steve Seitz's video

Squirrel reaching for a nut. Latte art

slide from Steve Seitz's video