Sequence Models for words and pixels

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Many slides from Steve Seitz's wonderful 5 min Lectures

CS194: Intro to Computer Vision & Comp. Photography
Alexei Efros, UC Berkeley, Fall 2024

Michel Gondry train video

http://www.youtube.com/watch?v=0S43IwBF0uM

“Amateur” by Lasse Gjertsen

http://www.youtube.com/watch?v=JzqumbhfxRo

Generative AI

Generative models trained on **lots of data** have revolutionized computer science and beyond!

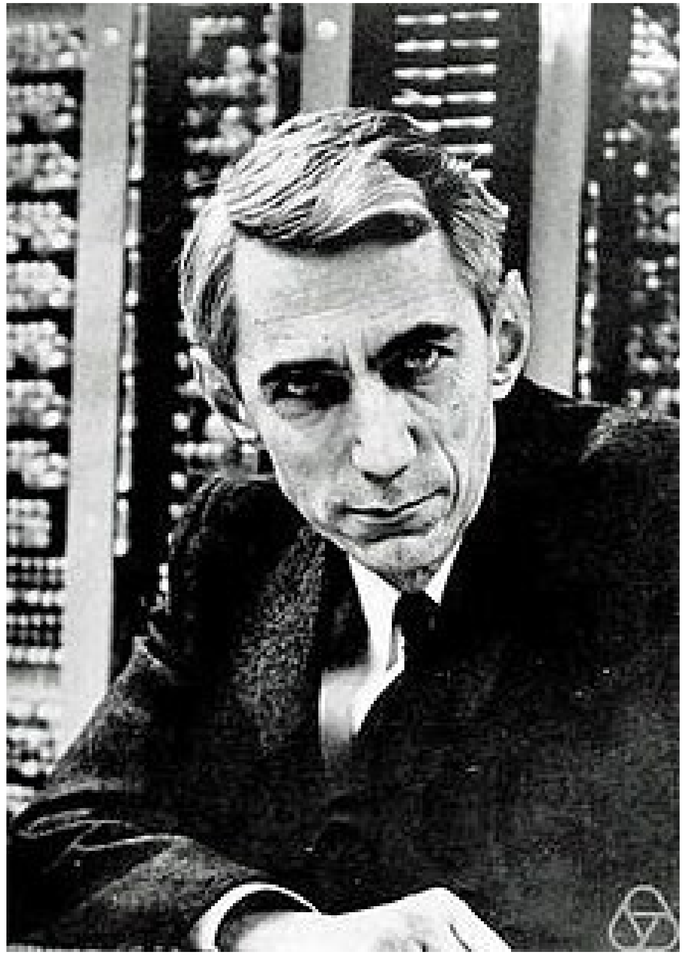
Text

Pixels

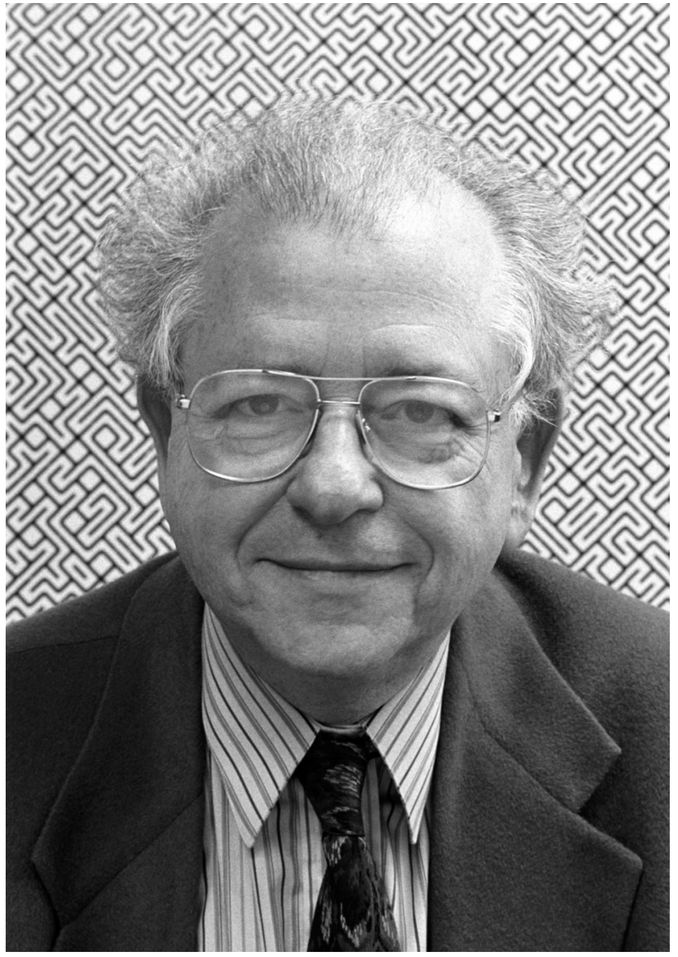
Audio

Ideas going back over a hundred years…

Andrey Markov
(1856-1922)



Claude Shannon
(1916-2001)



Bela Julesz
(1928-2003)

Weather Forecasting for Dummies™

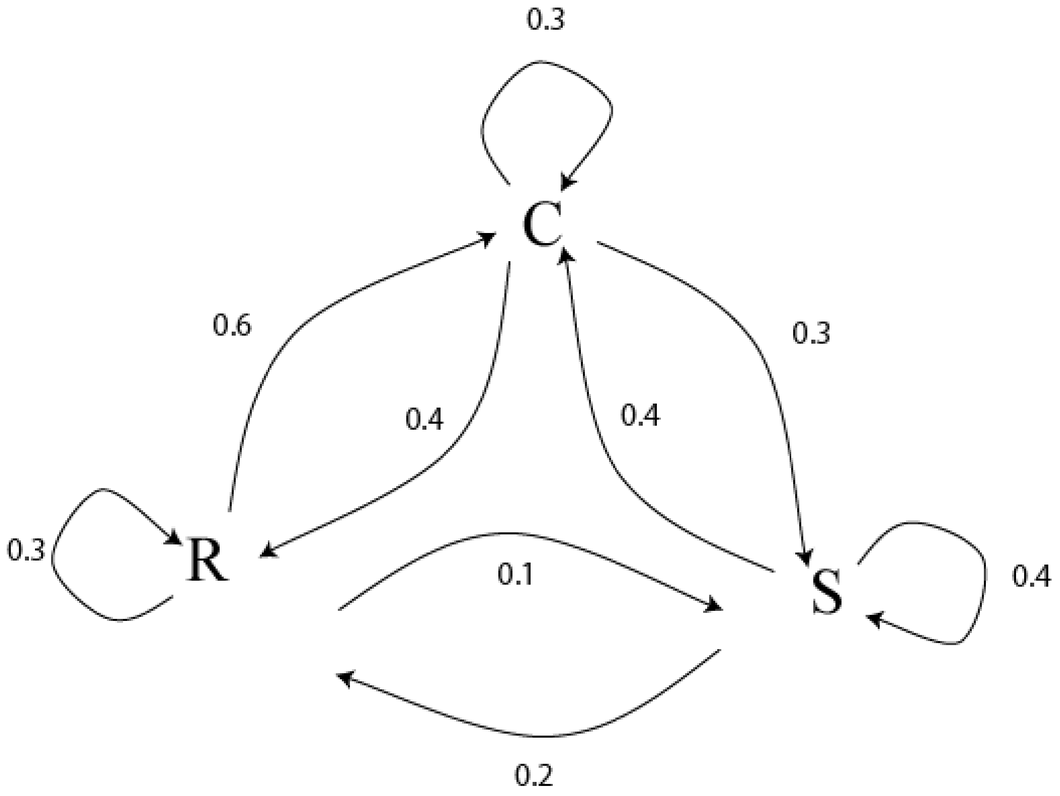
Let's predict weather:

- 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?

Now, let's apply this to text

[Markov, 1913] statistical analysis of text

[Shannon, 1948] proposed a way to generate English-looking text using N-grams:

- Assume a generalized Markov model of language
- 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
- E.g.:

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

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

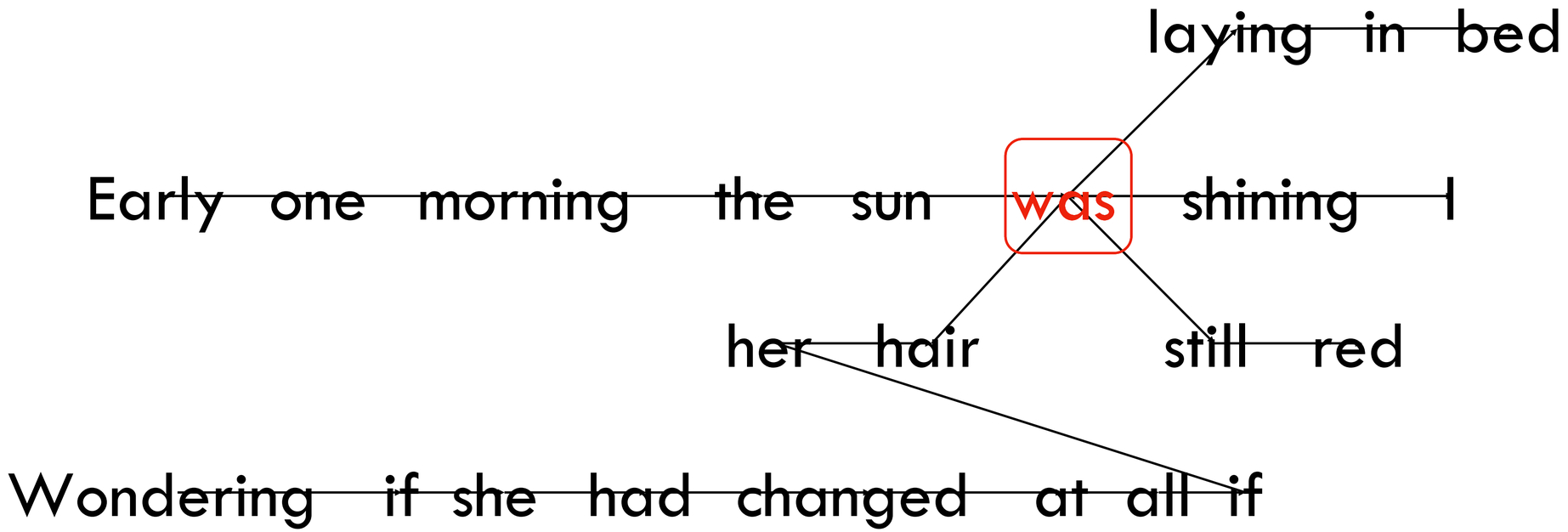
Wondering if she had changed at all if her hair was still red

slide from Steve Seitz's video

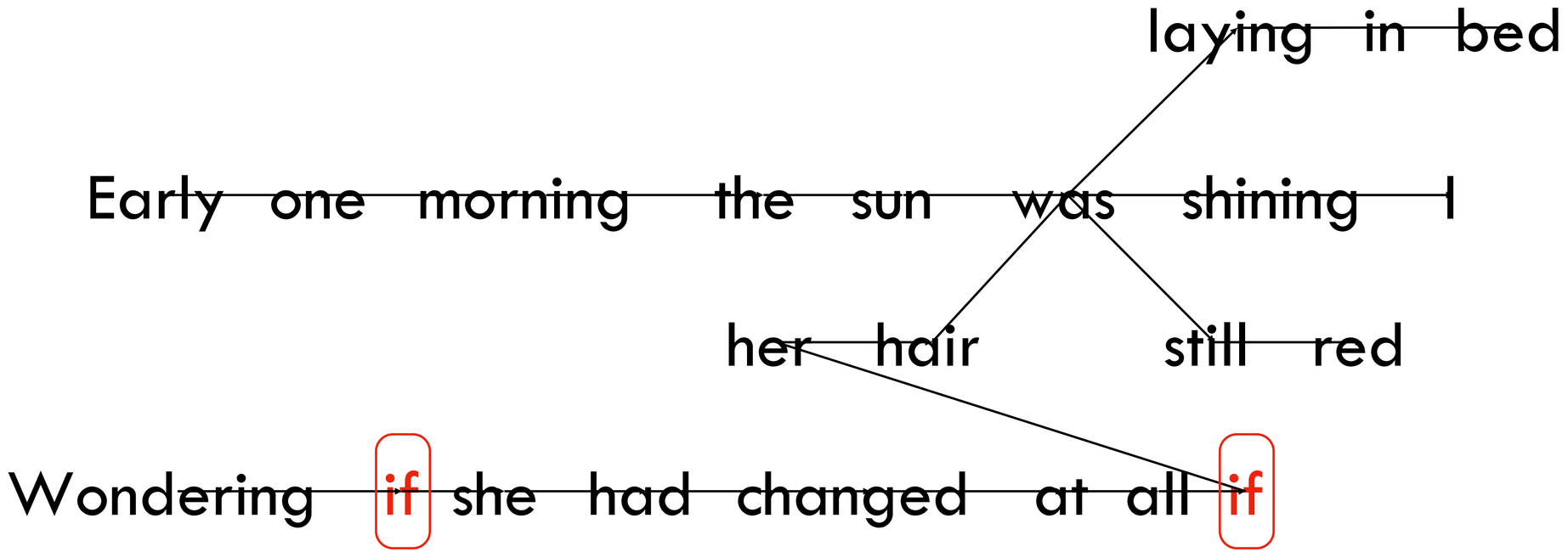
Early one morning the sun was shining I was laying in bed

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

slide from Steve Seitz's video



slide from Steve Seitz's video



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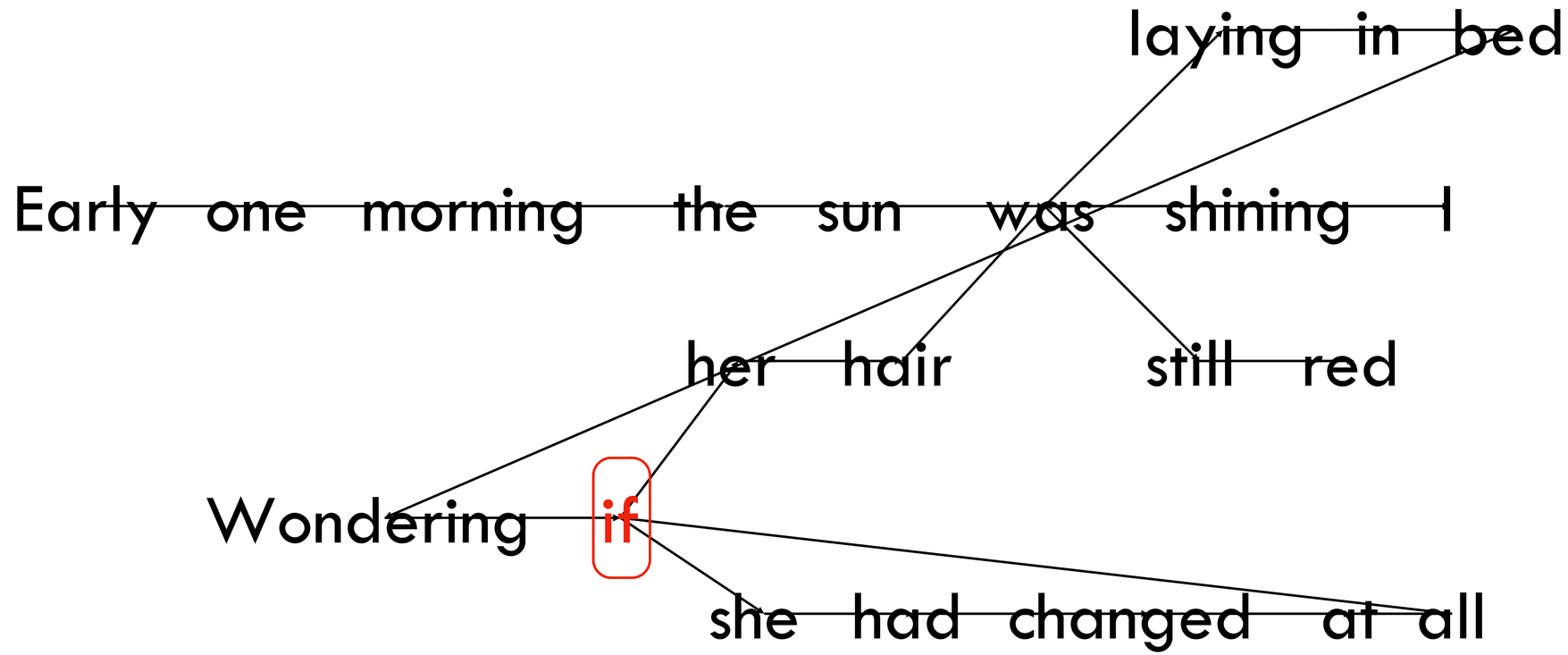
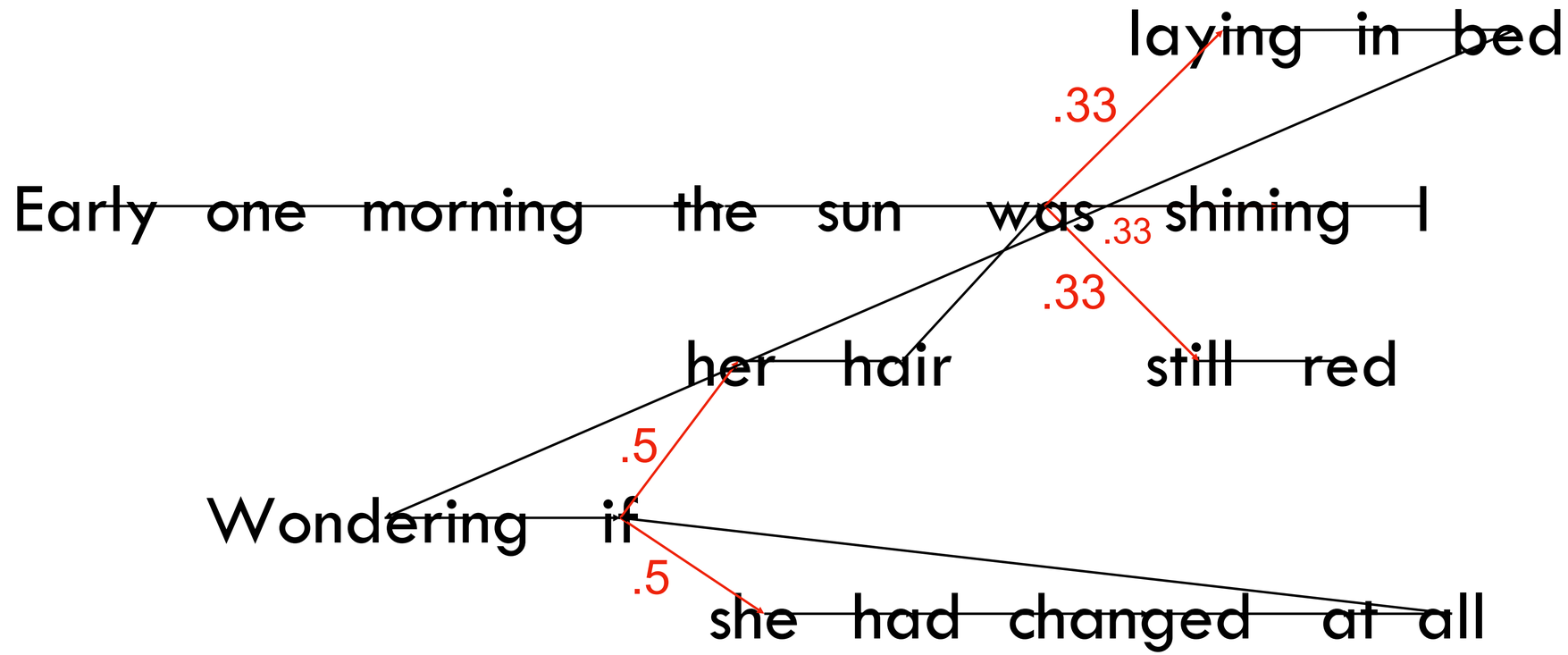


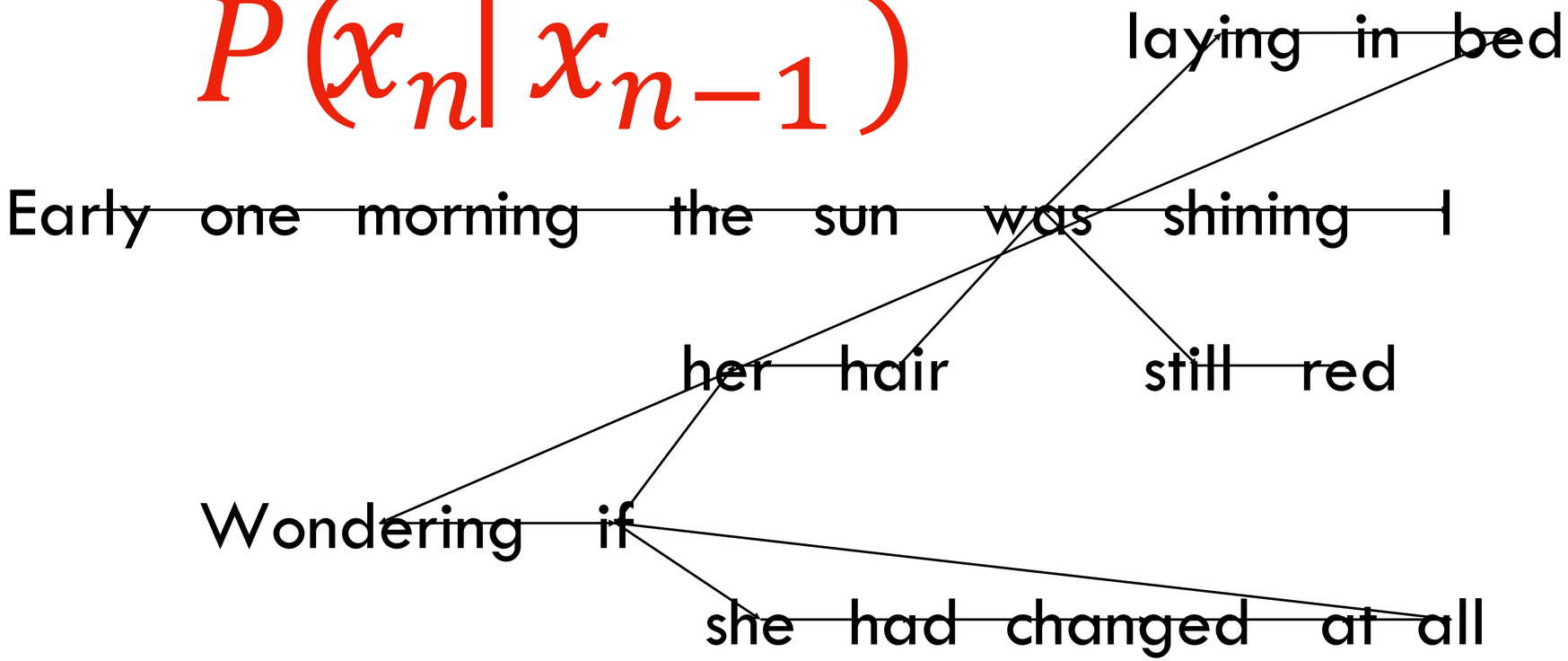
slide from Steve Seitz's video



Language Model

slide from Steve Seitz's video

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



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?

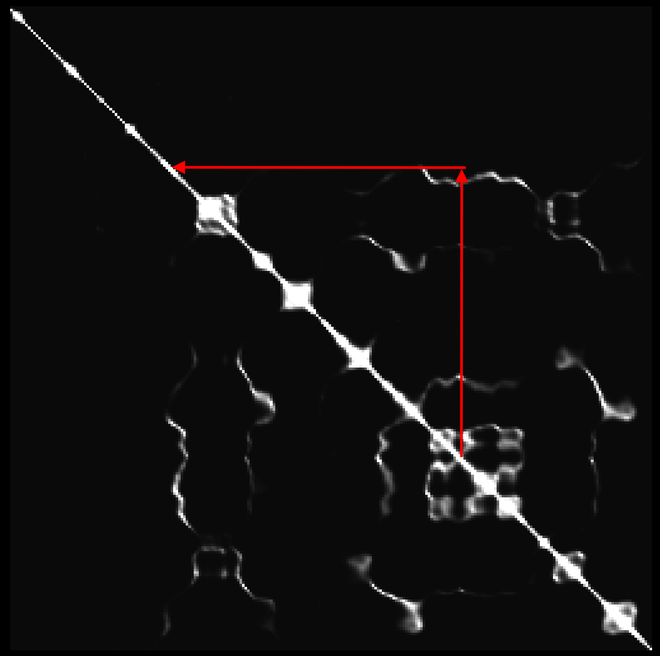
Finding good transitions

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

vs.

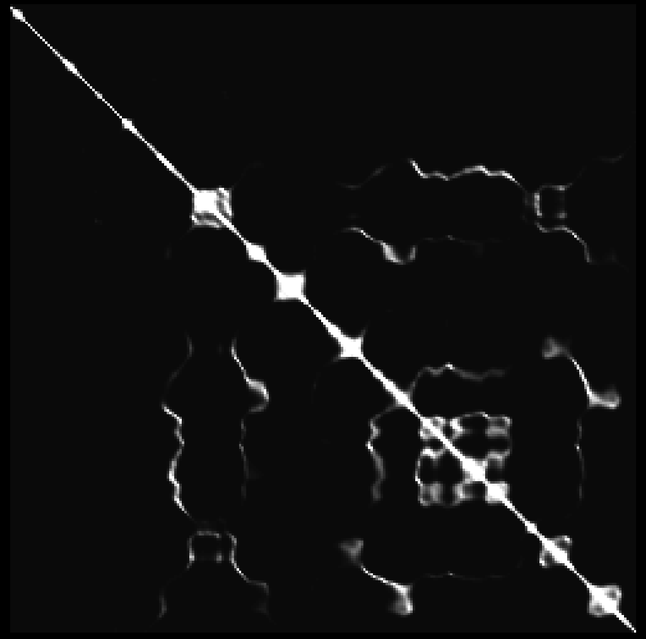
frame *i*

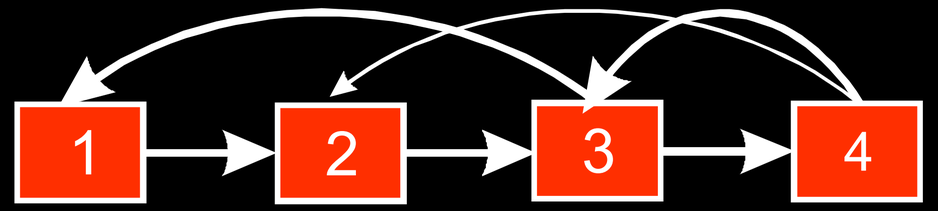
frame *j*



Similar frames make good transitions

Markov chain representation

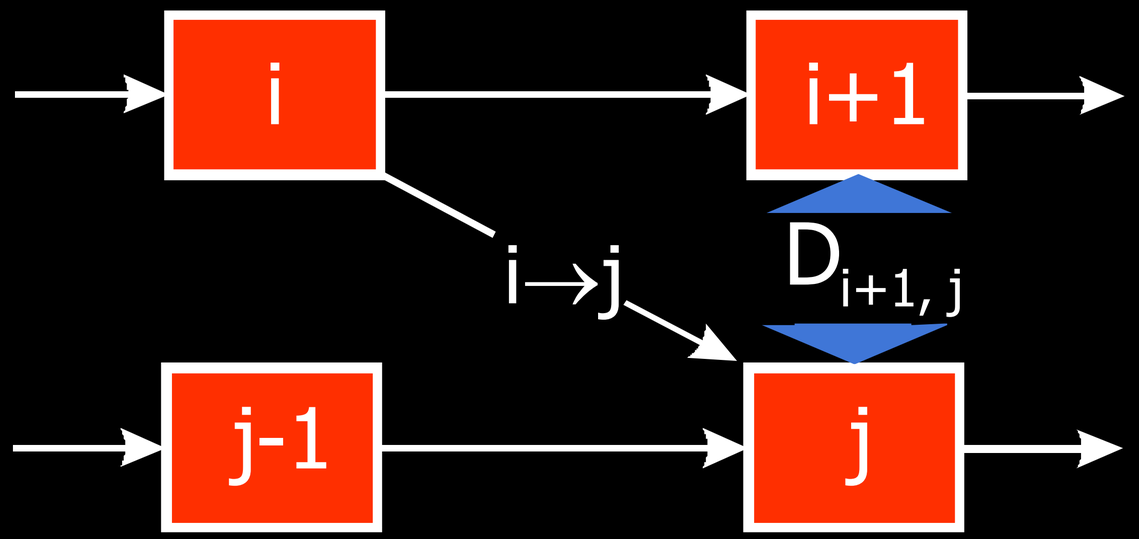




Similar frames make good transitions

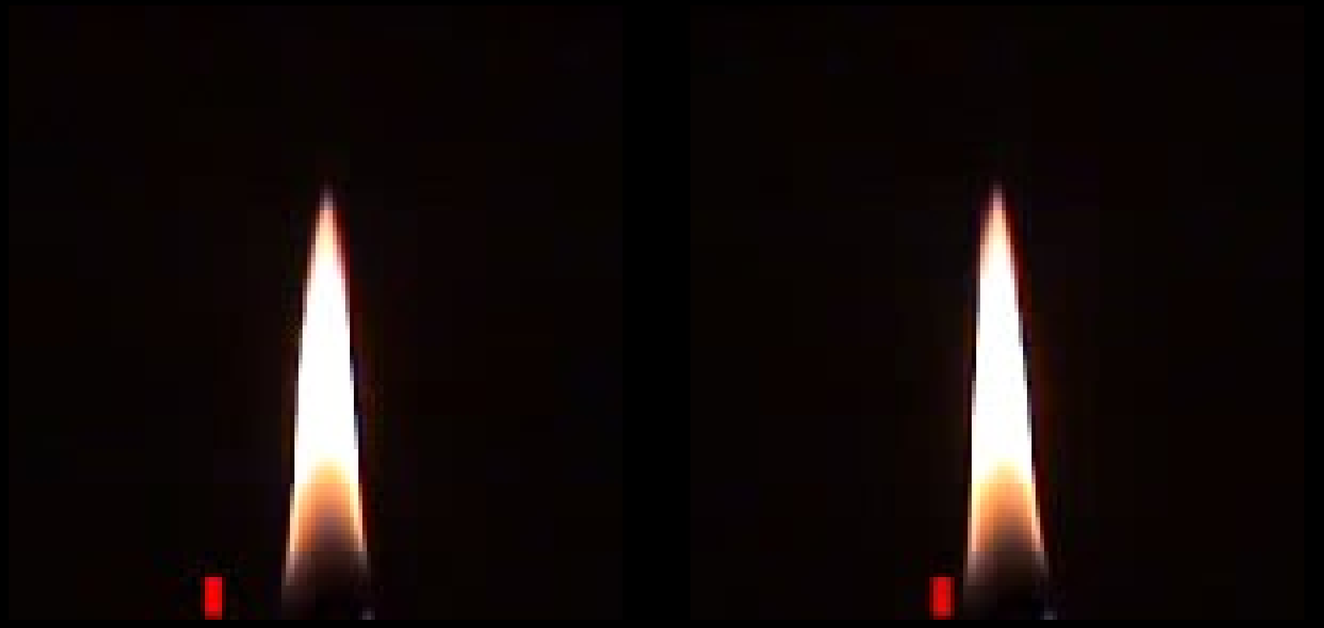
Transition costs

- 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

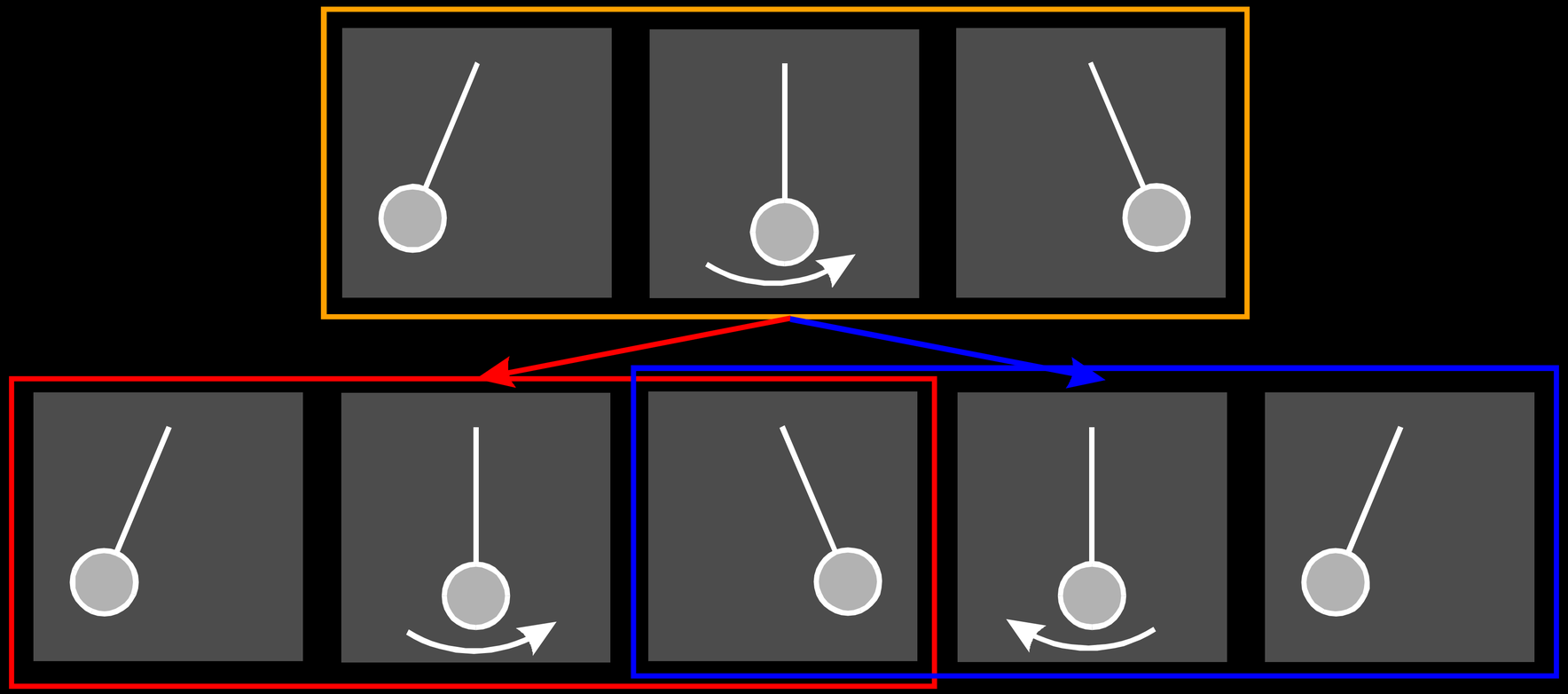
- Probability for transition $P_{i \to j}$ inversely related to cost:
  - $P_{i \to j} \sim \exp (- C_{i \to j} / \sigma^2)$



high σ low σ

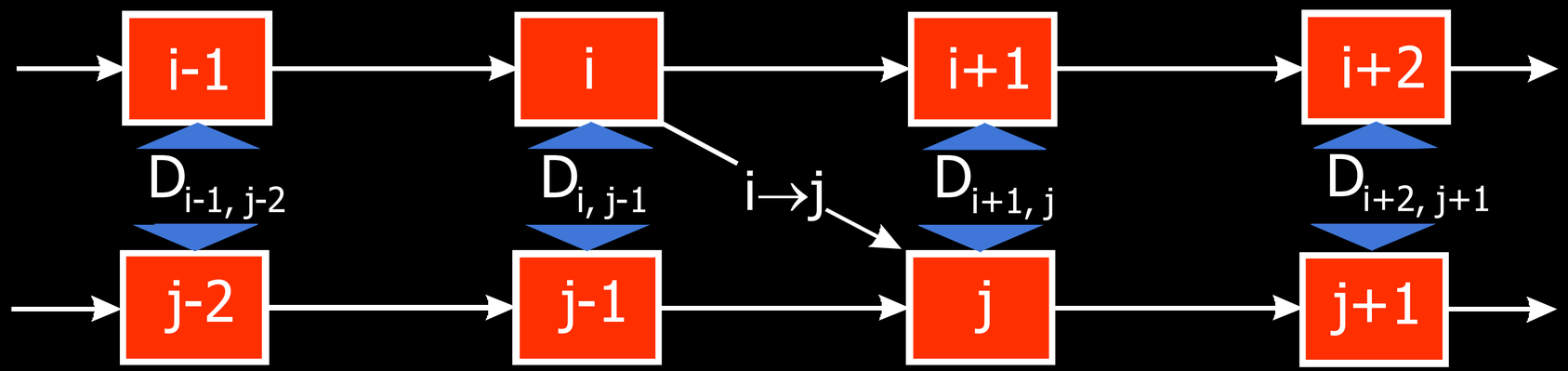
Preserving dynamics

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

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

Video sprite extraction

blue screen matting
and velocity estimation

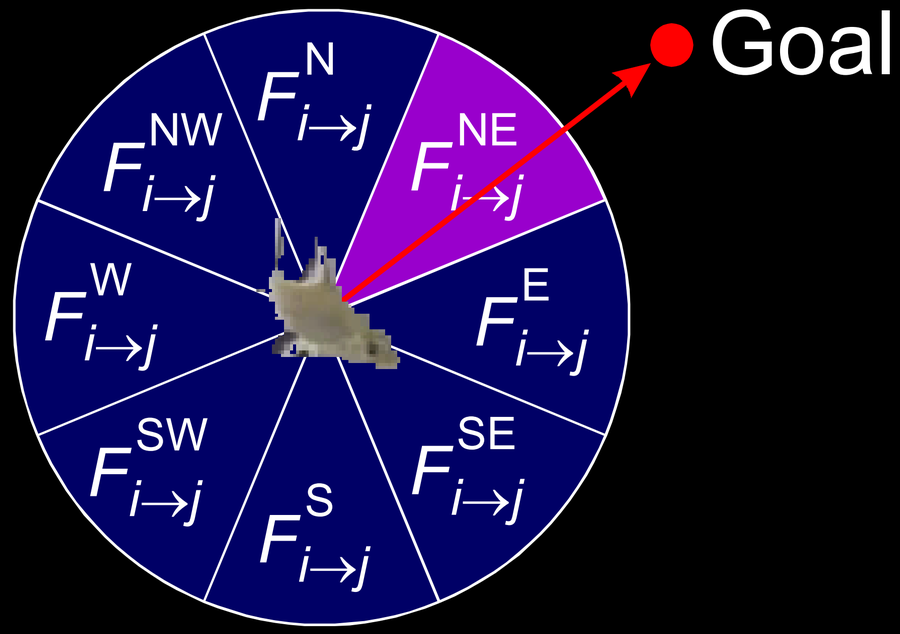
Video sprite control

- Augmented transition cost:

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

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

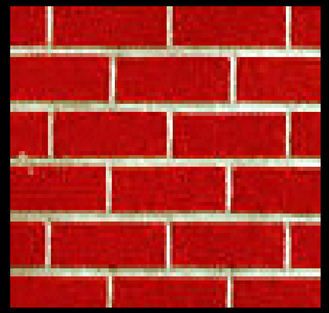
yogurt

Texture Synthesis

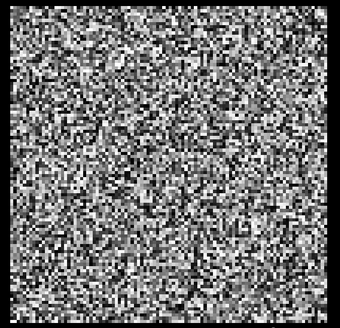
- Goal of Texture Synthesis: create new samples of a given texture
- Many applications: virtual environments, hole-filling, texturing surfaces

The Challenge

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



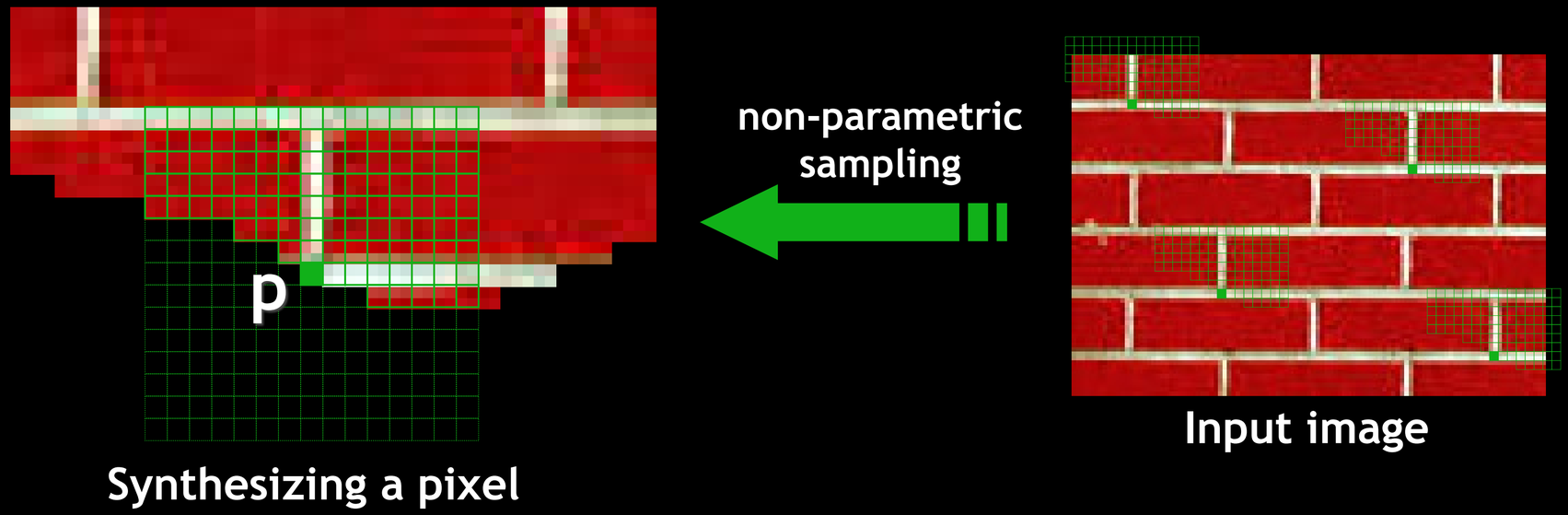
repeated



stochastic

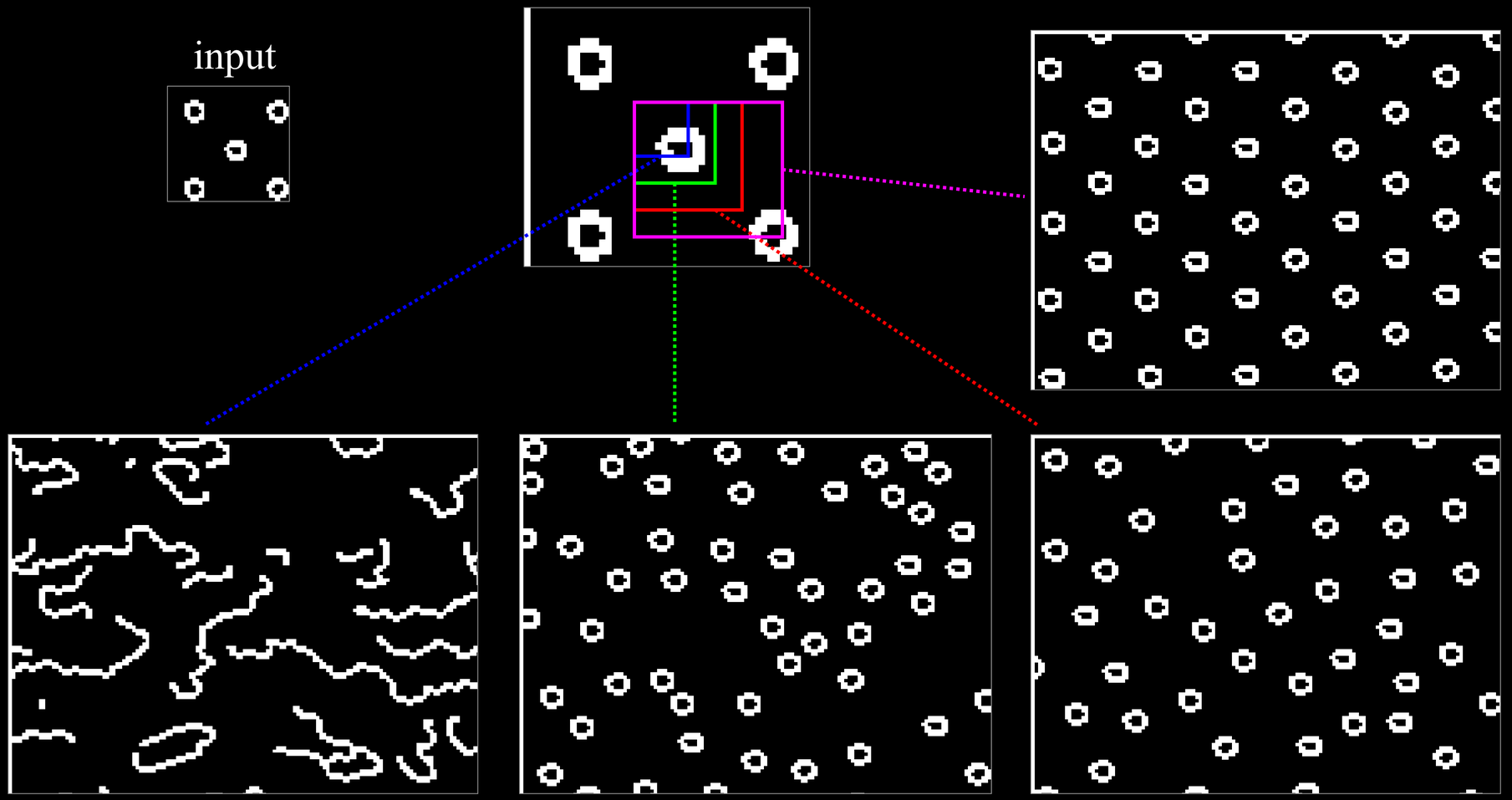
Both?

Efros & Leung Algorithm (ICCV 1999)

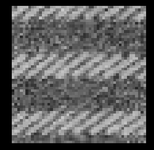


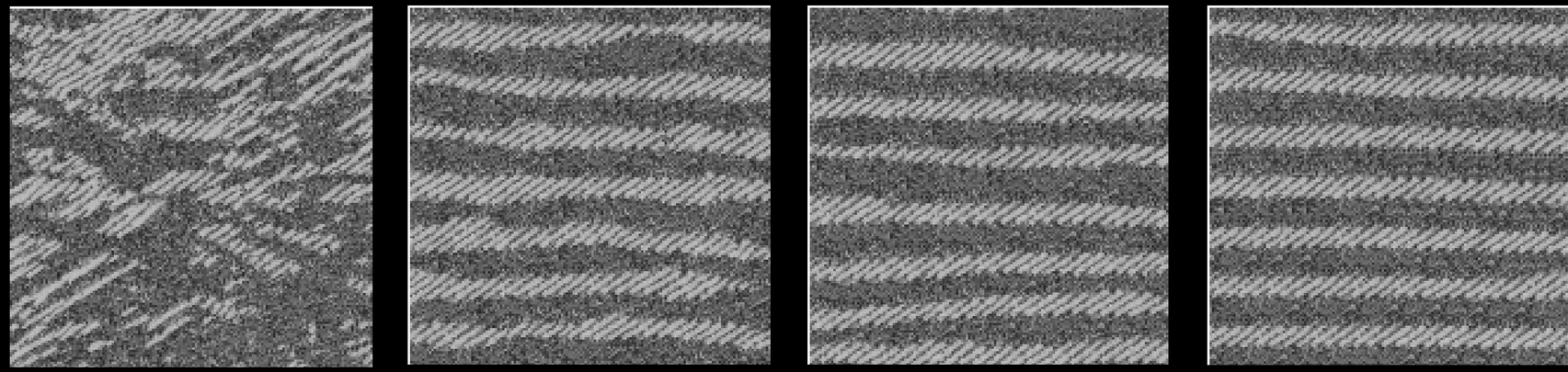
- Assuming Markov property, compute P(**p**|N(**p**))
  - Building explicit probability tables infeasible
  - Instead, we *search the input image* for all similar neighborhoods — that's our pdf for **p**
  - To sample from this pdf, just pick one match at random

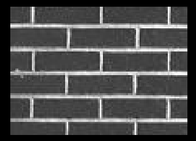
Neighborhood Window

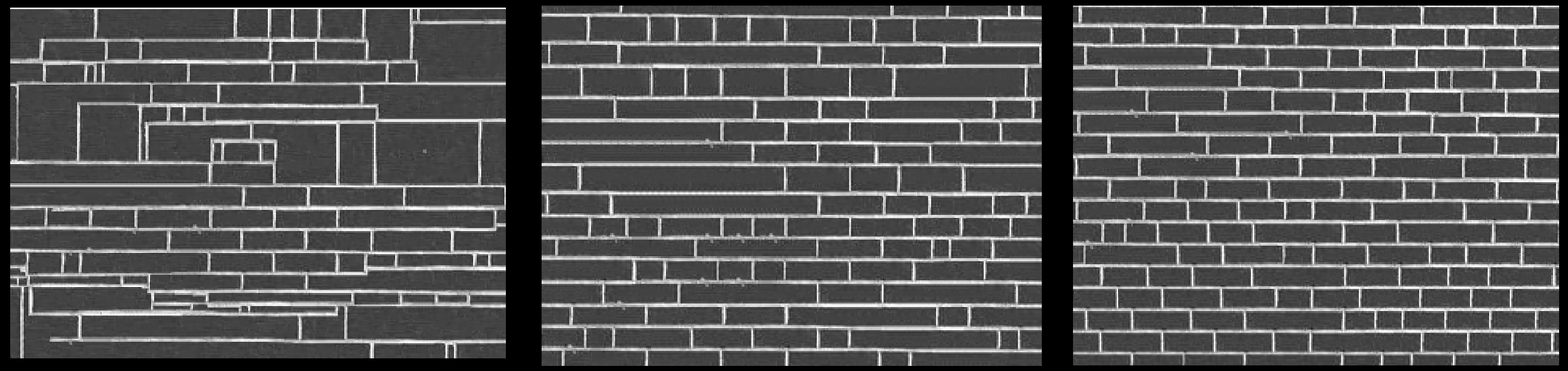


Varying Window Size





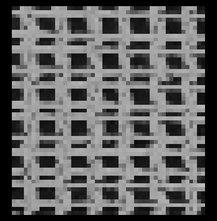


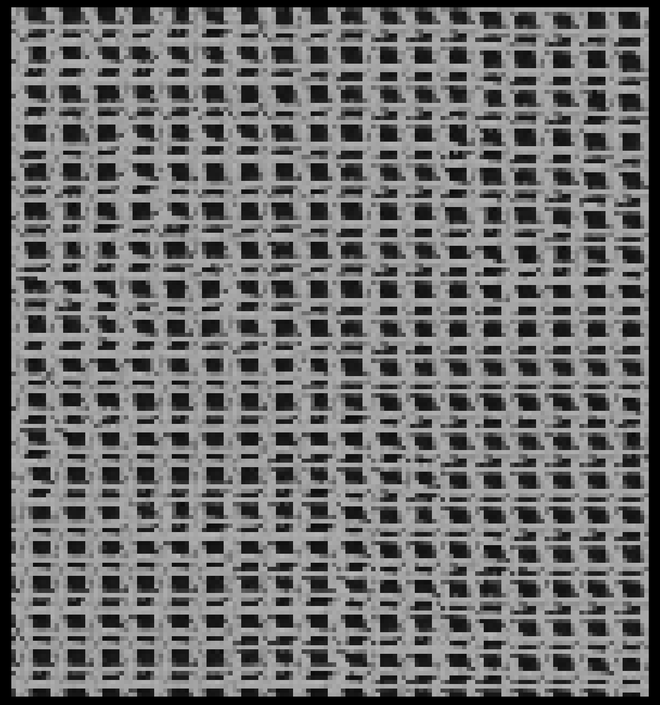


Increasing window size

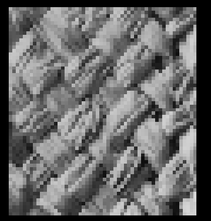
Synthesis Results

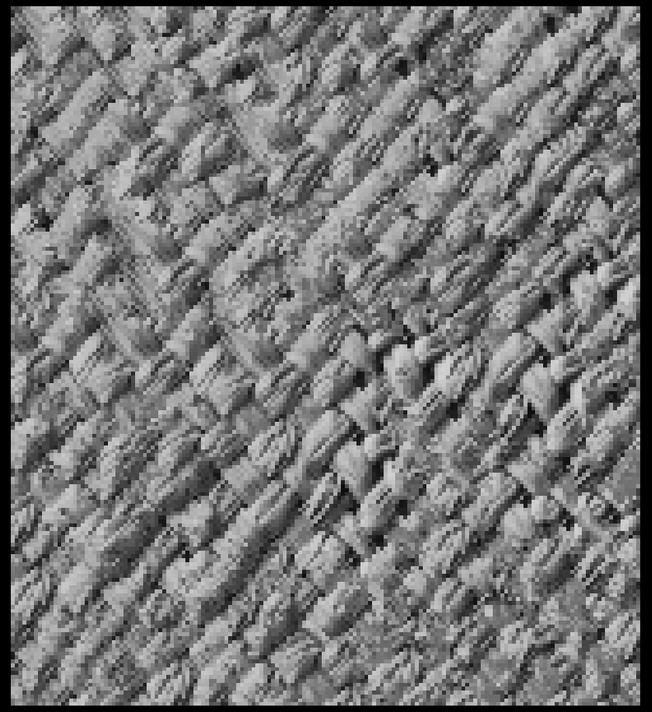
french canvas





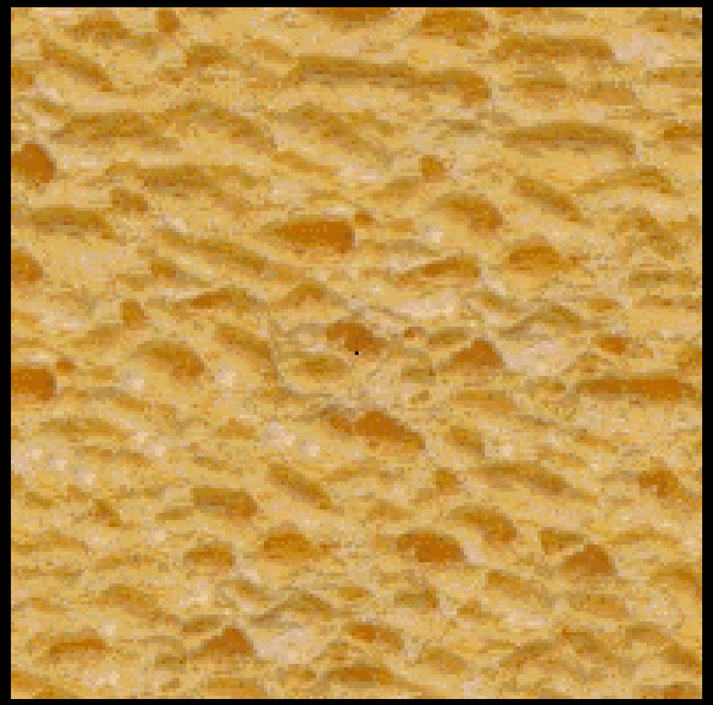
rafia weave



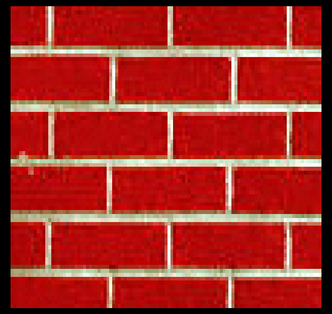


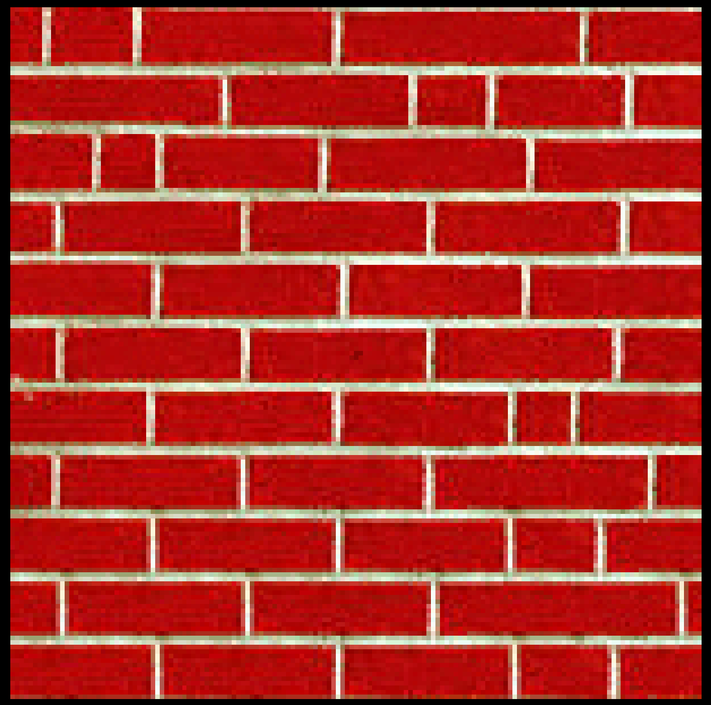
More Results

white bread

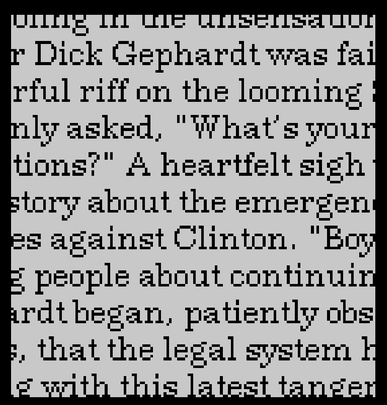


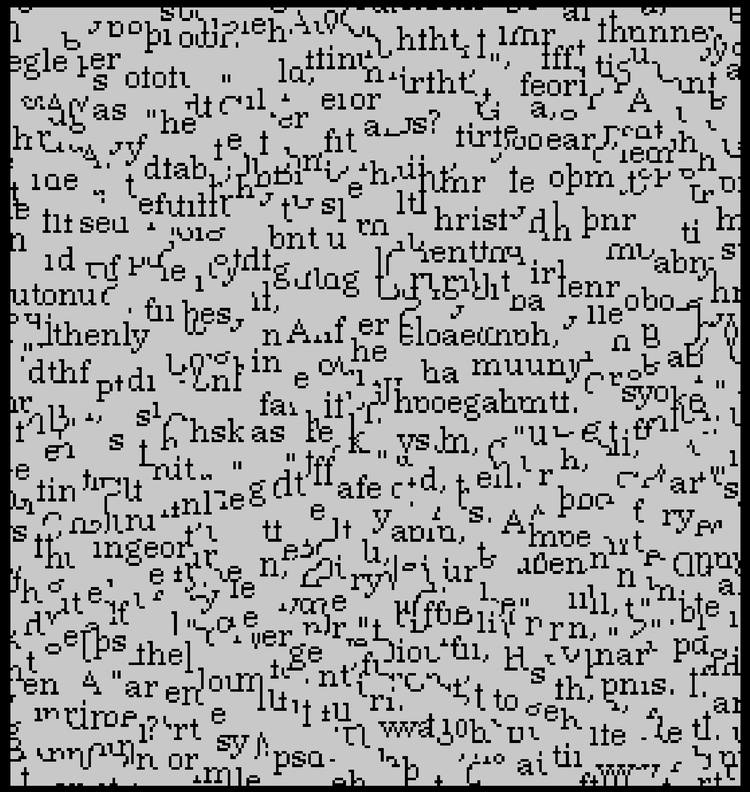
brick wall

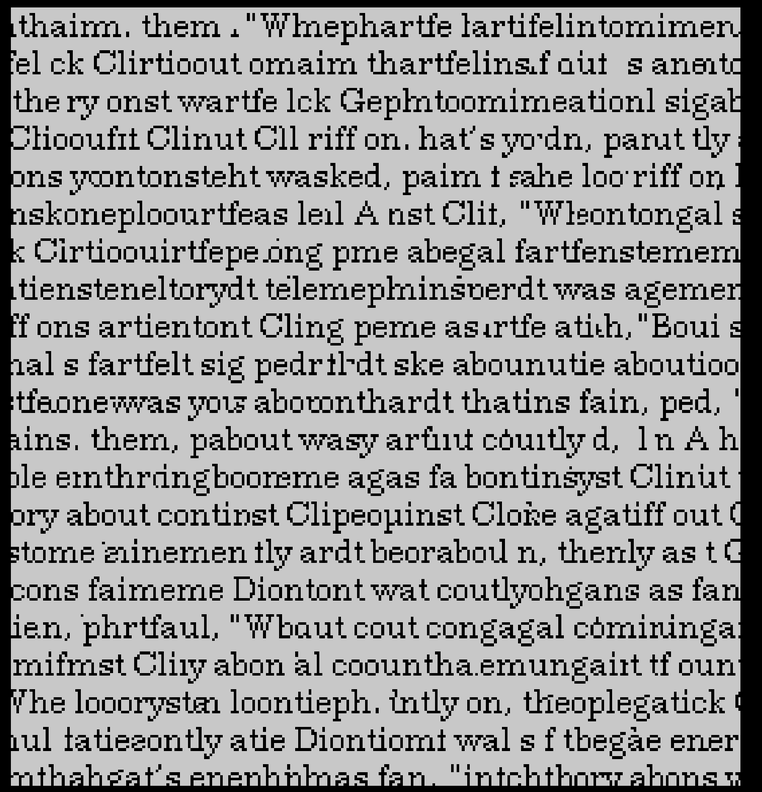




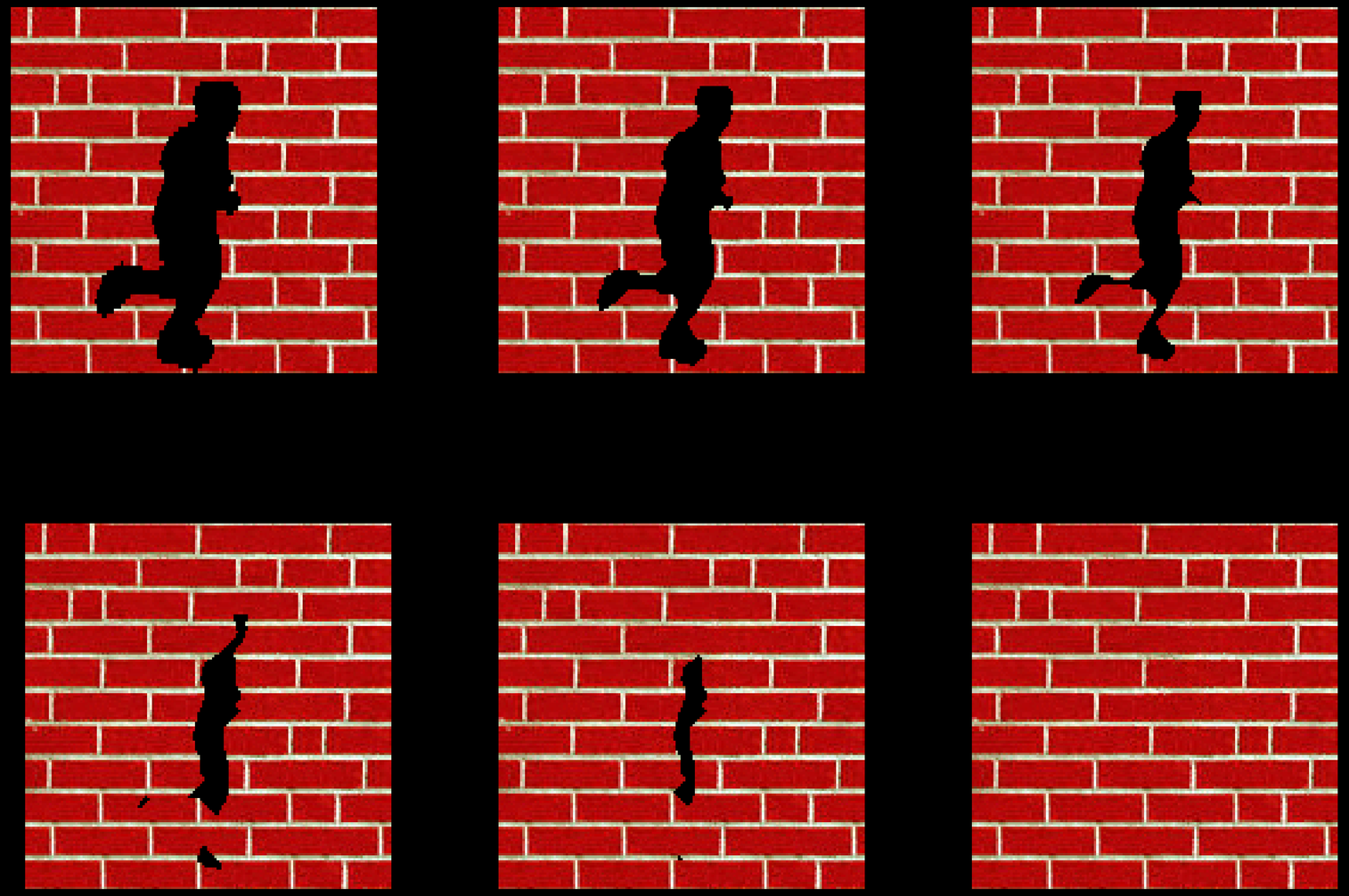
Homage to Shannon



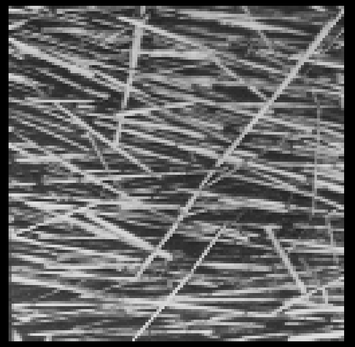




Hole Filling



Extrapolation



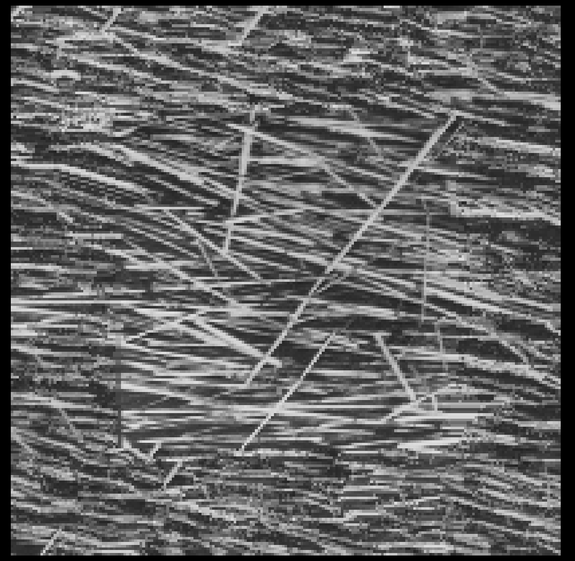


Image Analogies

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’

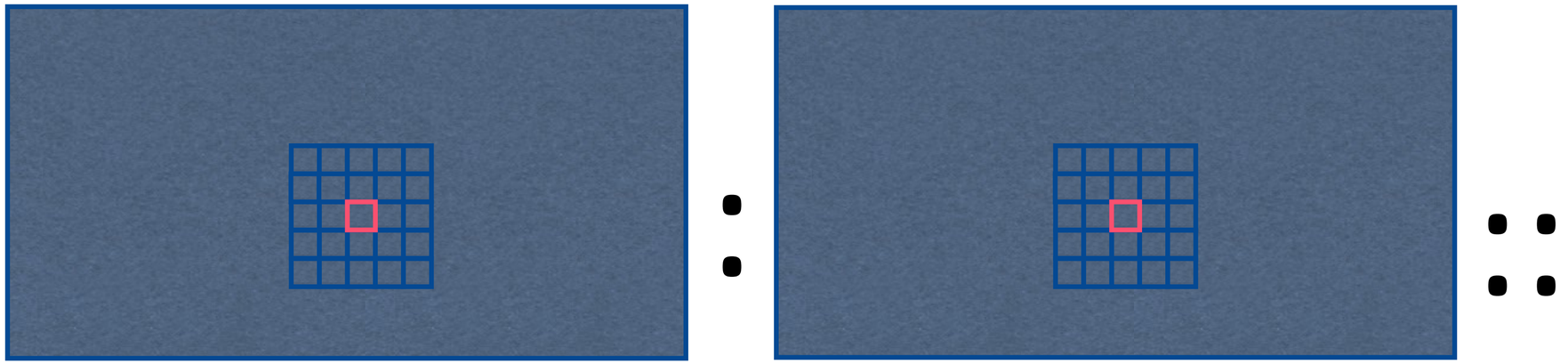
Image Analogies

Goal: Process an image by example

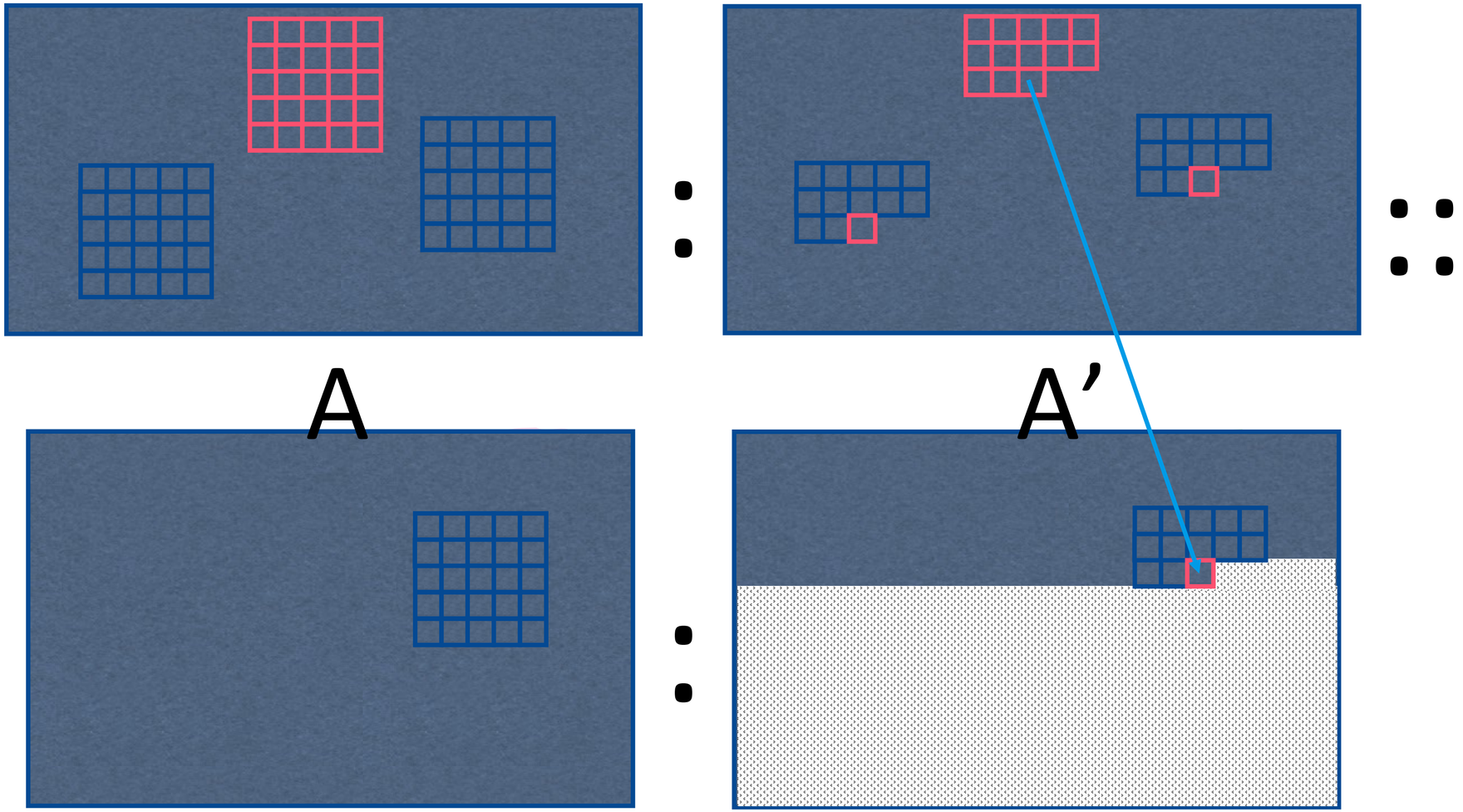
A A’ B B’

Hertzmann et al. SIGGRAPH 2001

Non-parametric sampling



A : A’ :: B : B’


A
A’
B
B’

Blur Filter

Unfiltered source (A)

Filtered source (A')

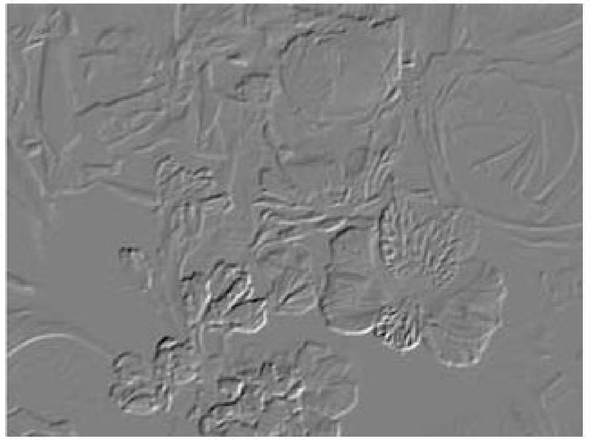
Unfiltered target (B)

Filtered target (B')

Edge Filter

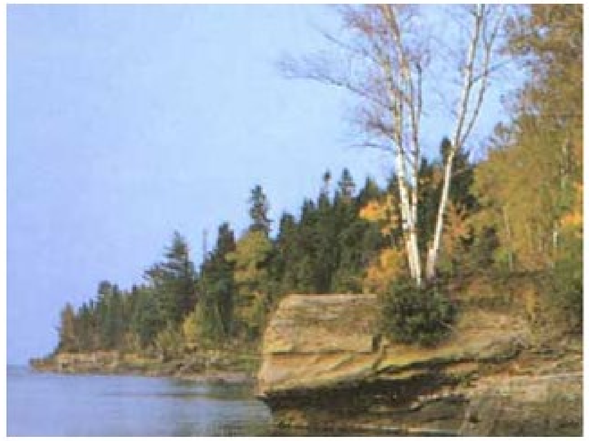
Unfiltered source (*A*)

:

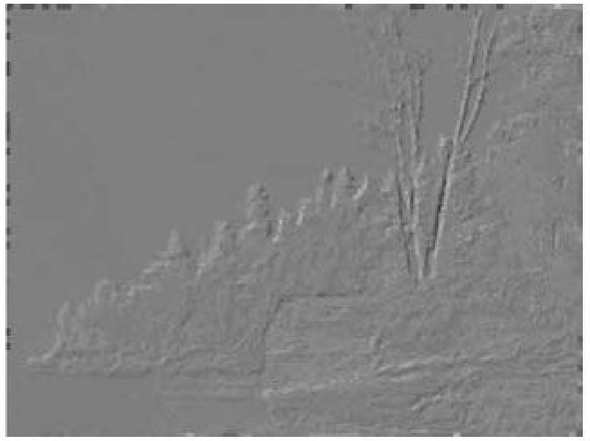


Filtered source (*A'*)

::



Unfiltered target (*B*)



Filtered target (*B'*)

Artistic Filters

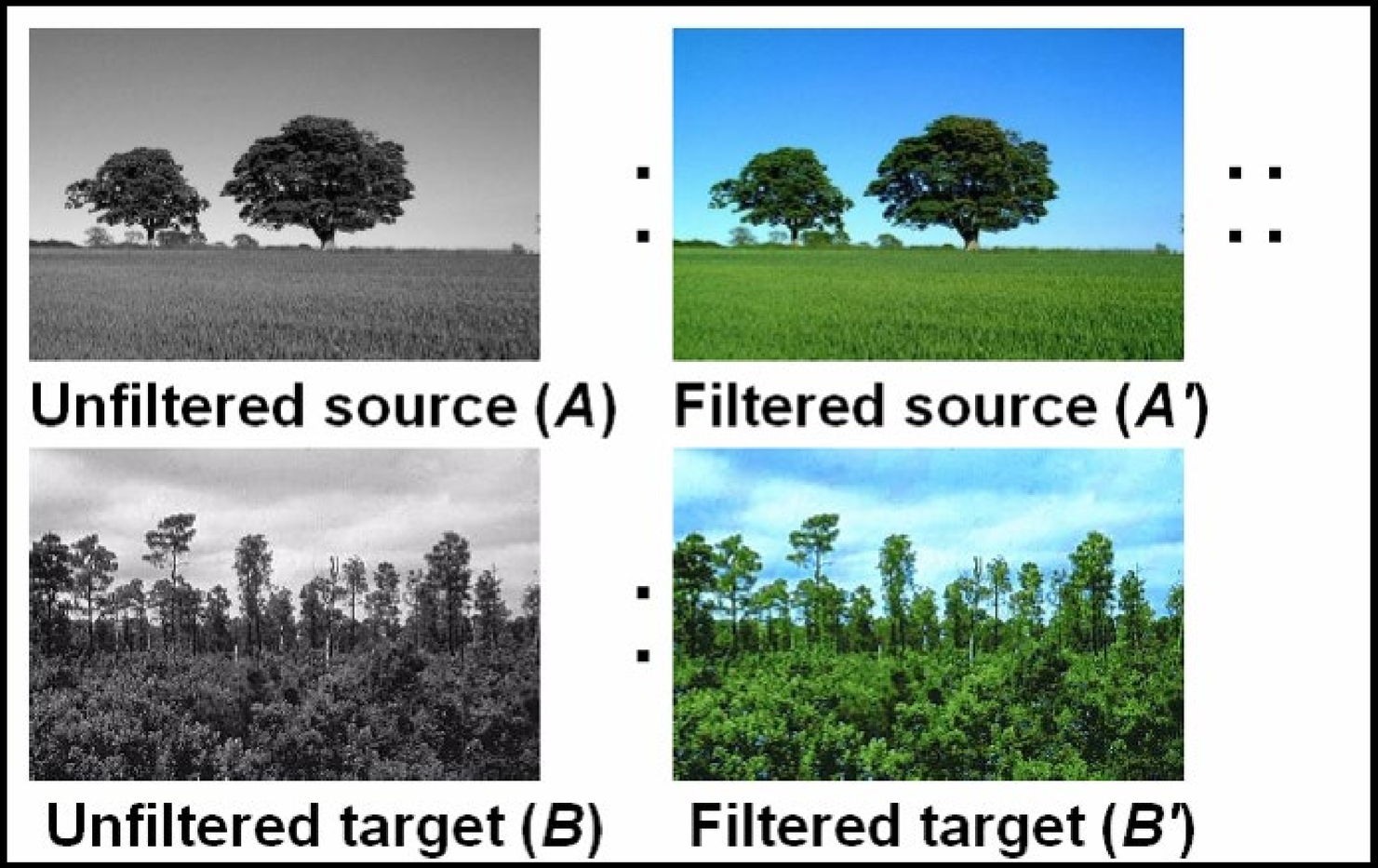
A

A’

B

B’

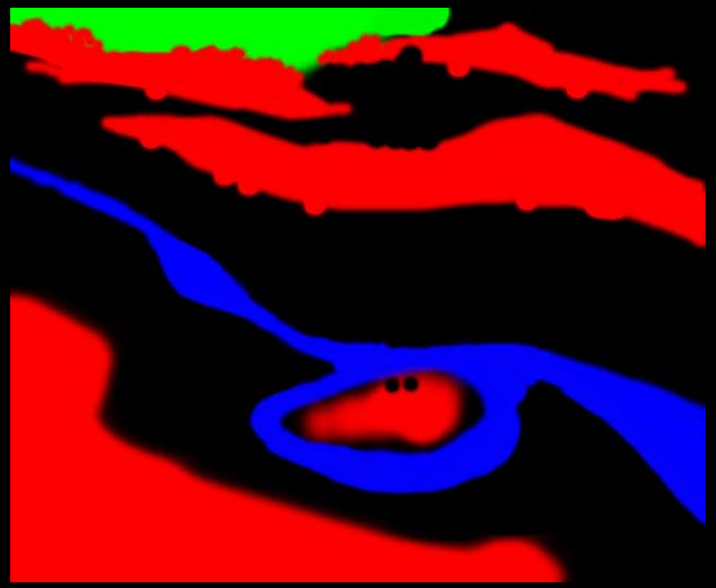
Colorization



Texture-by-numbers

A

A’



B

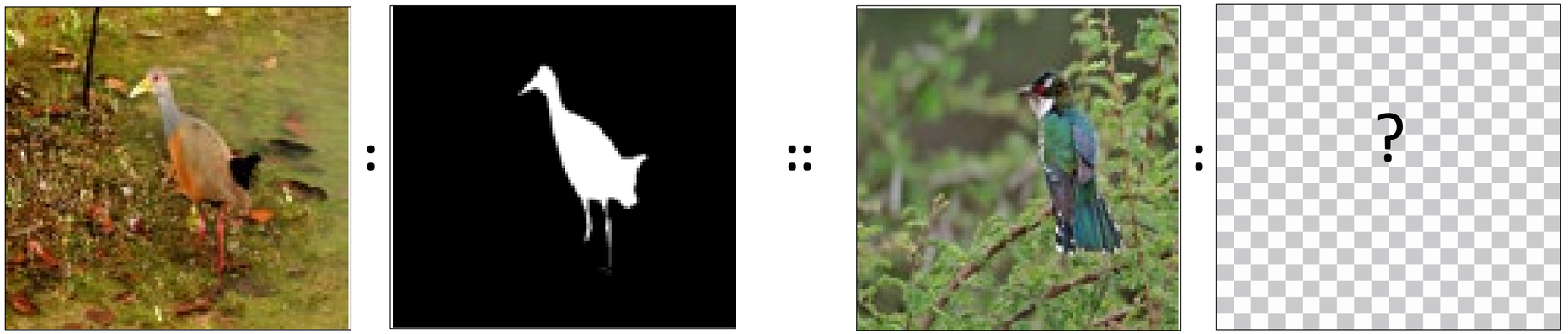
B’

Visual Prompting via Image Inpainting

Amir Bar*, Yossi Gandelsman*,

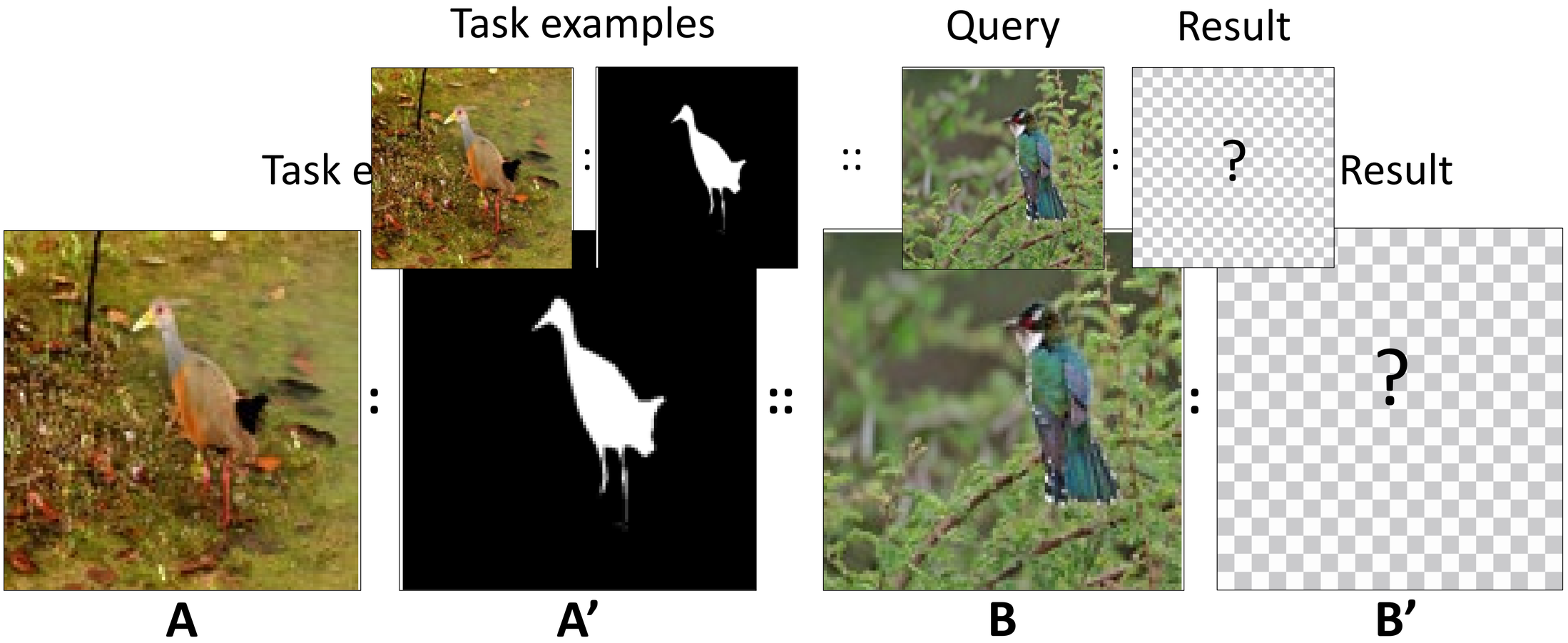
Trevor Darrell, Amir Globerson, Alexei A Efros

NeurIPS 2022



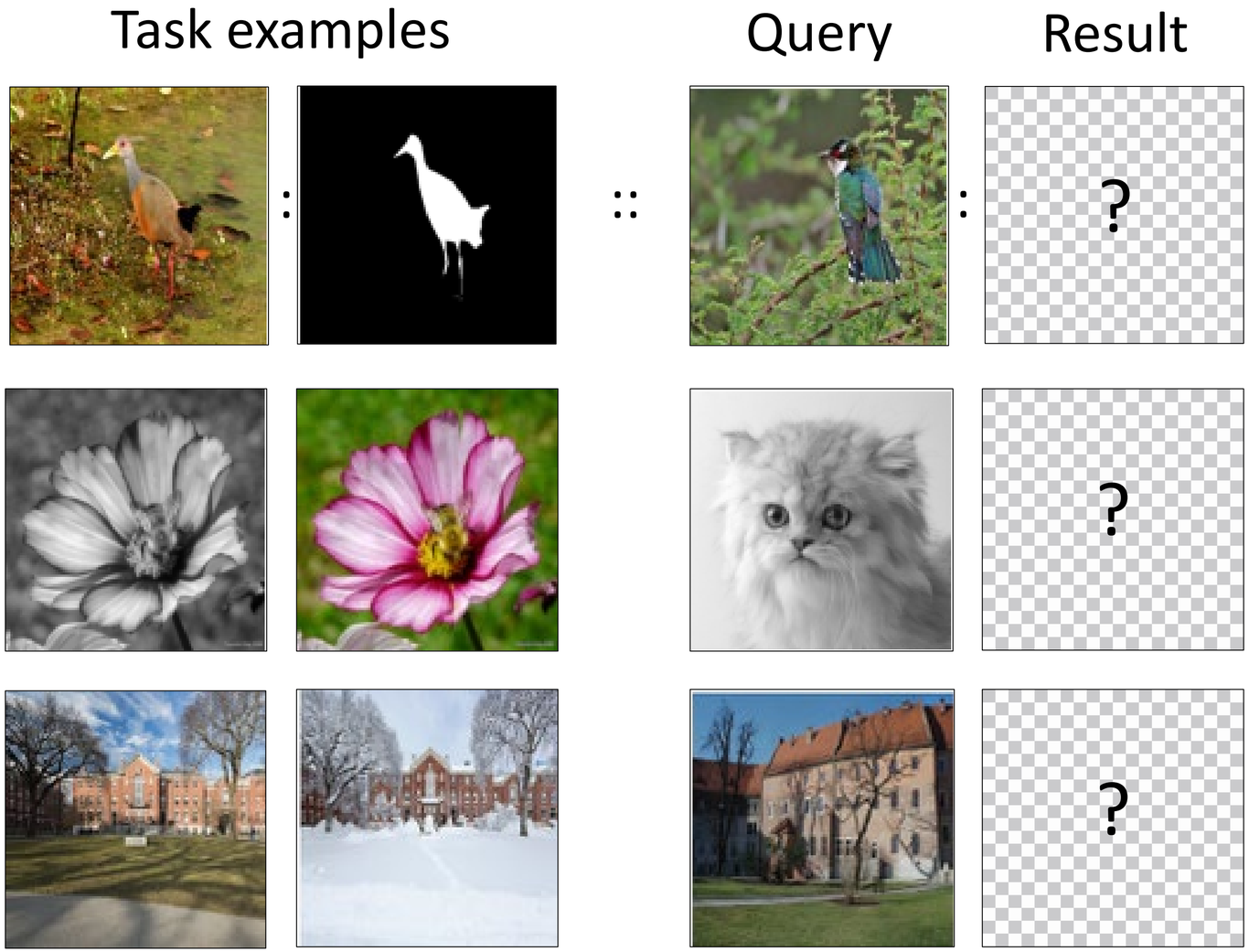
* Equal contribution

Visual Prompting

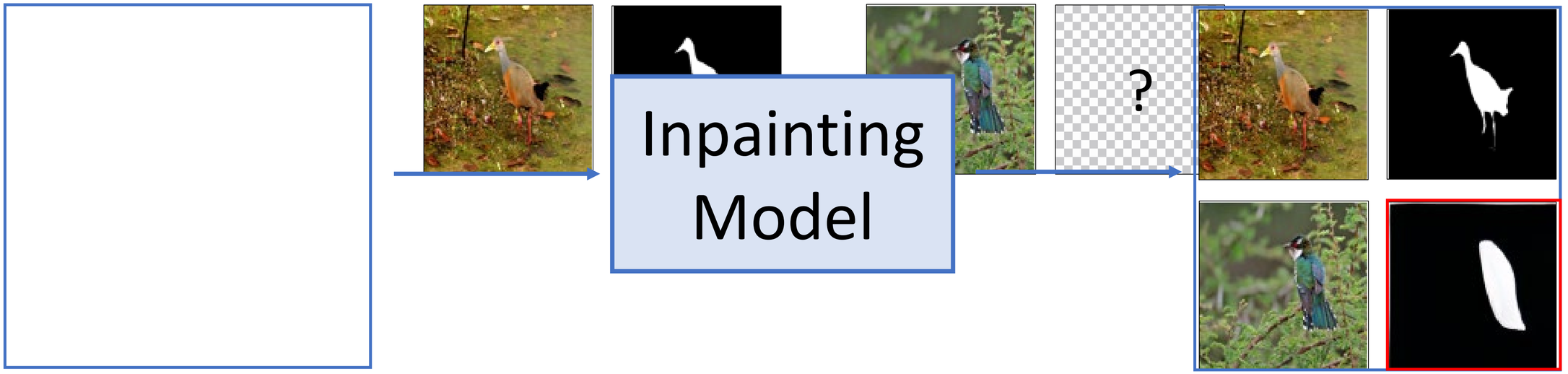


Hertzmann, Aaron, et al. "Image analogies." SIGGRAPH 2001.

Visual Prompting



Inpainting models to the rescue!

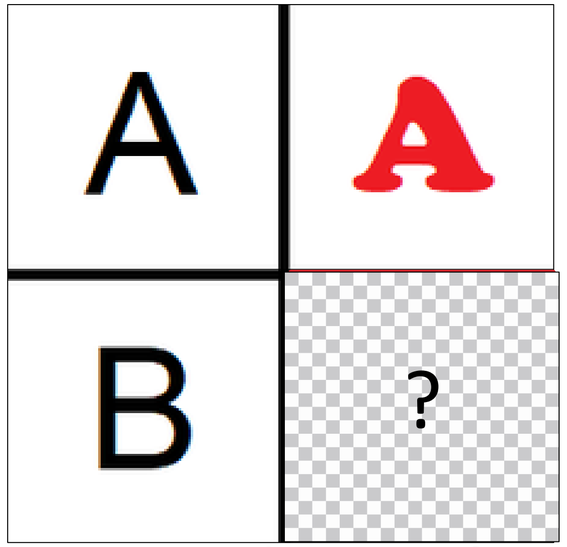


Visual prompt image

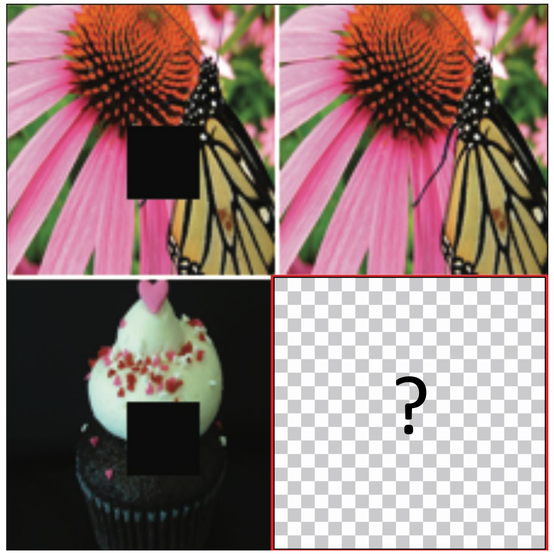
Wide range of tasks

Colorization

Segmentation

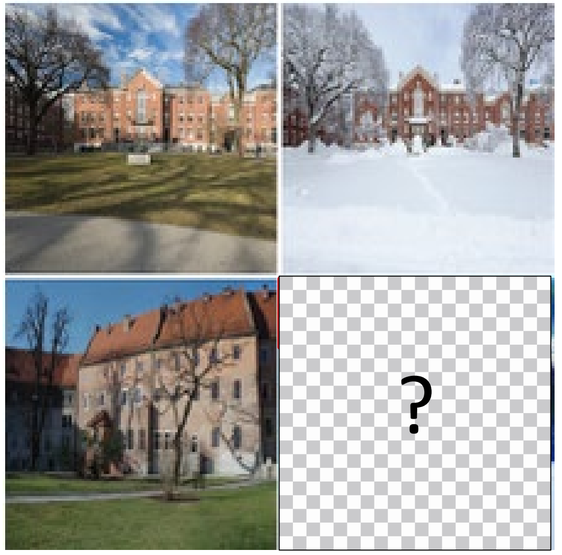


Font Style Transfer



Inpainting

Edge Detection



Style Transfer

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

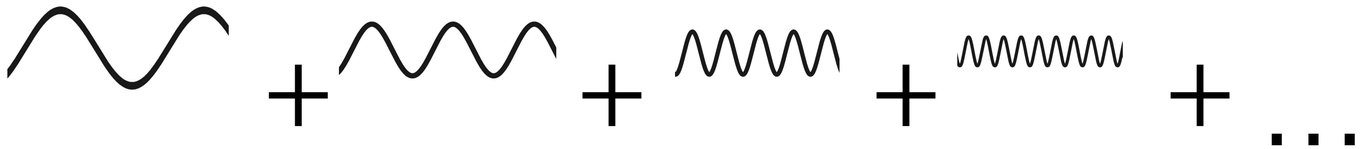
slide from Steve Seitz's video

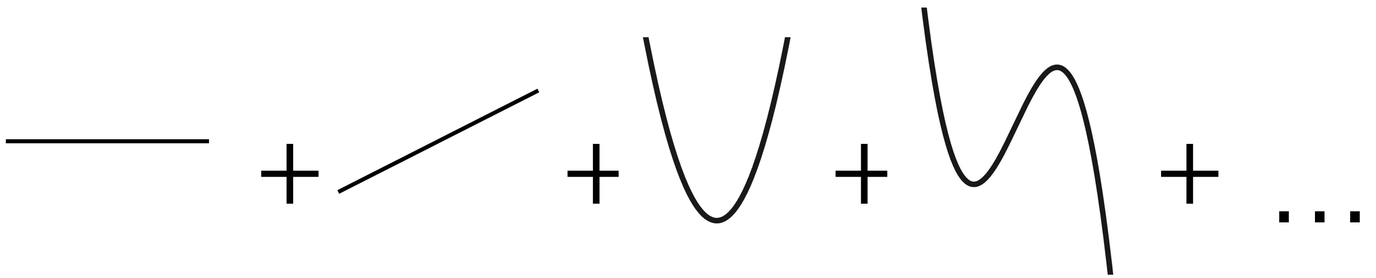
$$P(x_n | x_{n-1}, x_{n-2}, x_{n-3}, x_{n-4}, x_{n-5}, x_{n-6}, x_{n-7}, x_{n-8}, x_{n-9}, x_{n-10}, x_{n-11}, x_{n-12}, x_{n-13})$$

10^{70} combinations

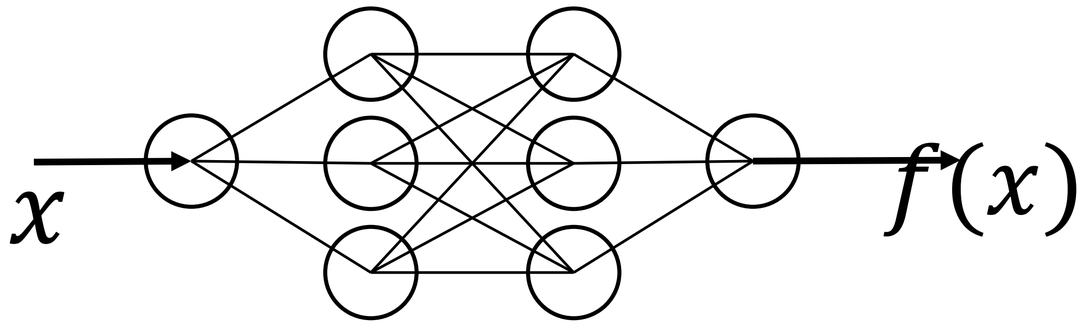
slide from Steve Seitz's video

Function Approximation

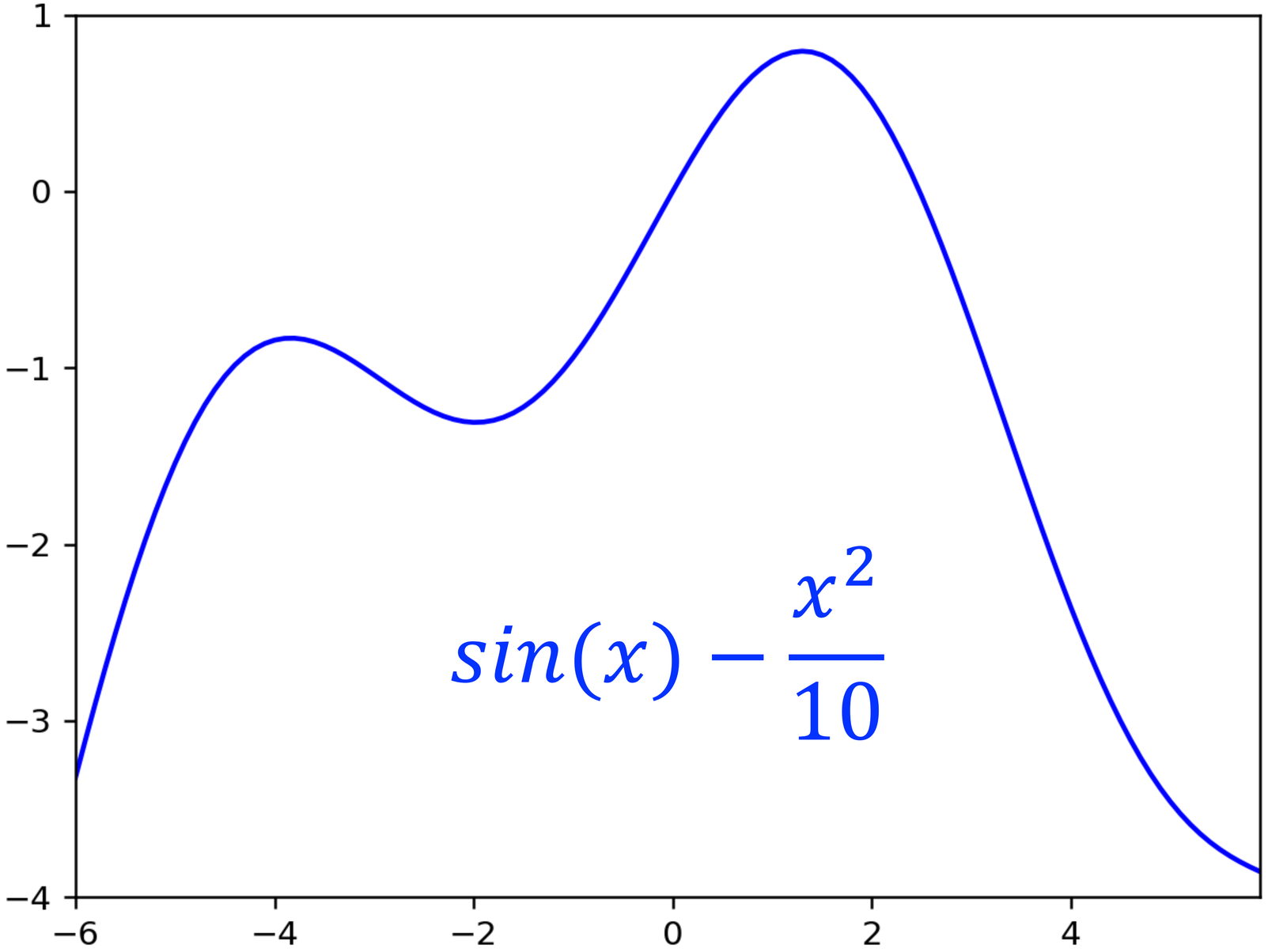
Fourier Series: $f(x) =$  $+ \ldots$

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

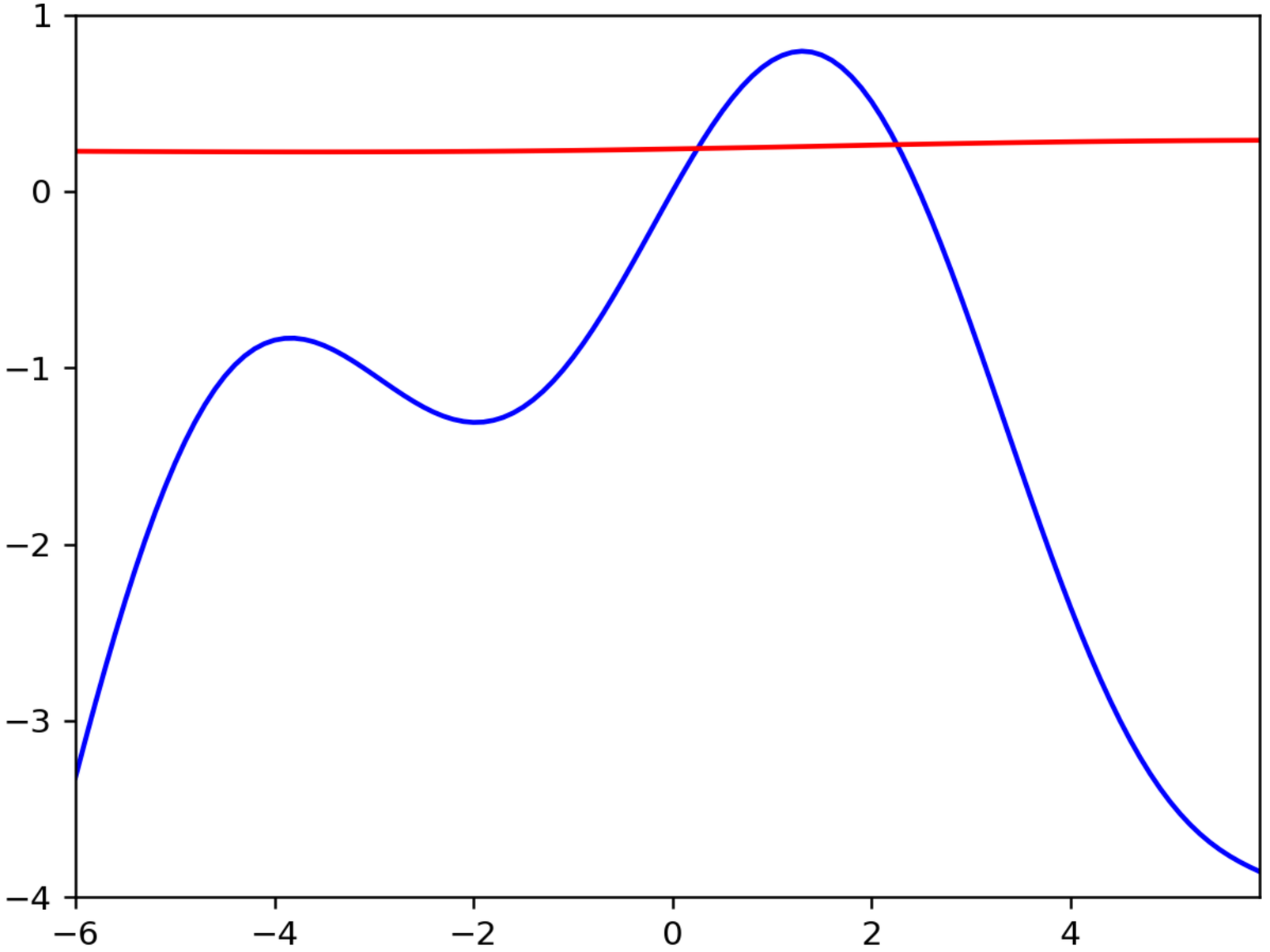
Neural Network:



slide from Steve Seitz's video



slide from Steve Seitz's video



slide from Steve Seitz's video

e 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

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

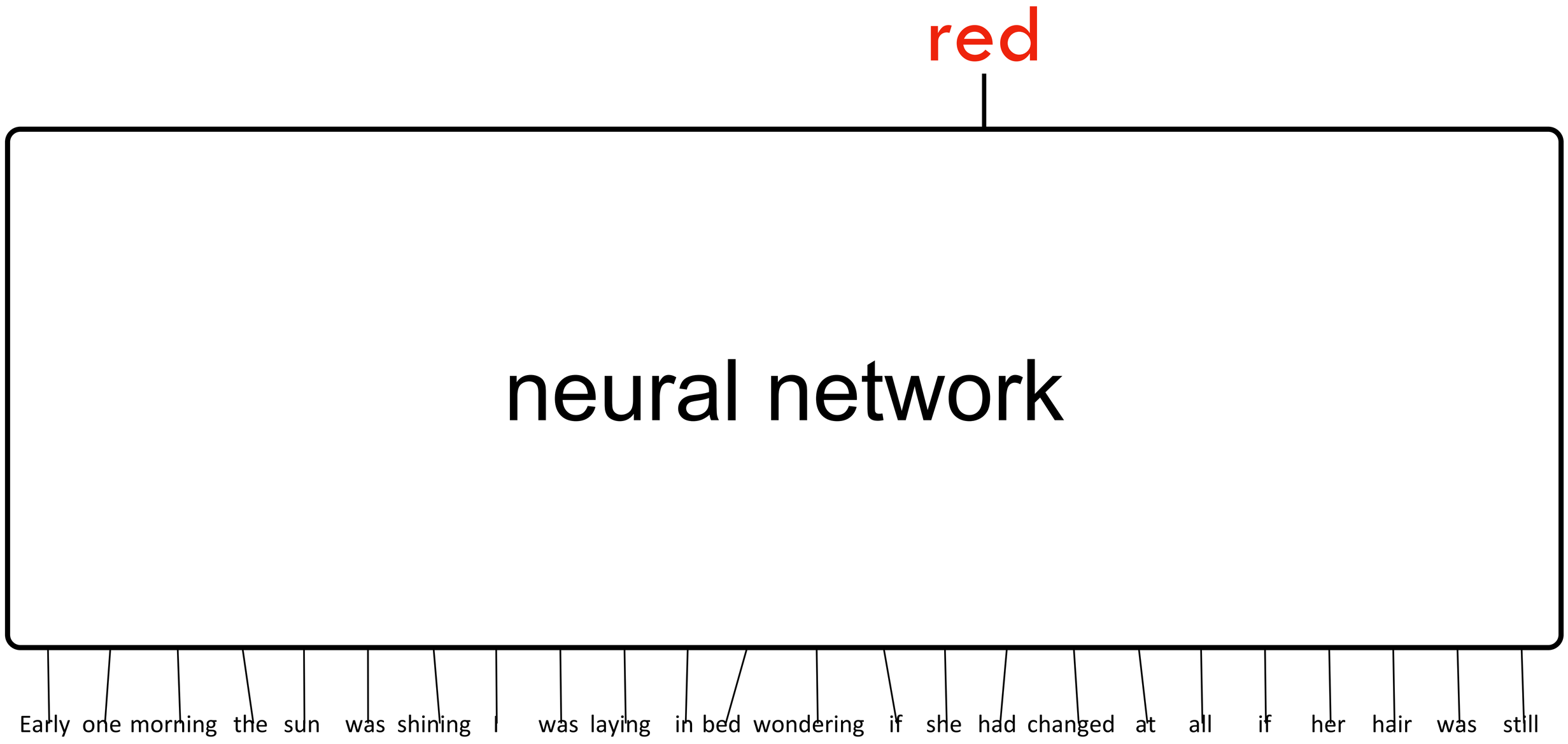
slide from Steve Seitz's video

red

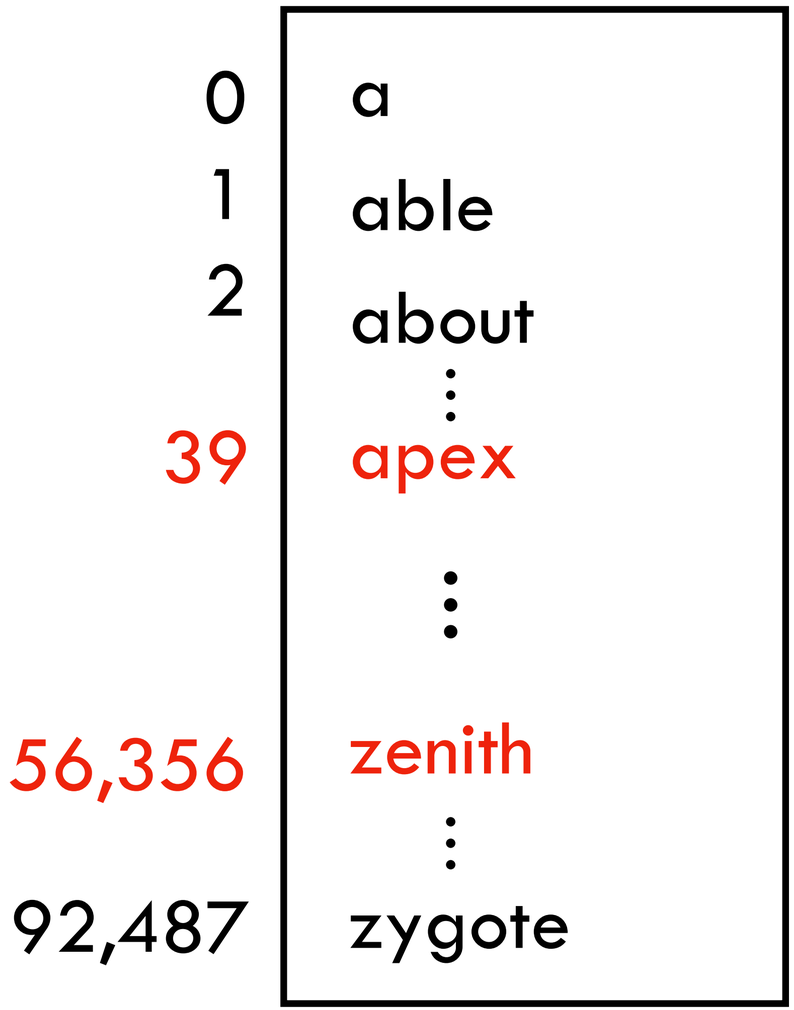
Early one morning the sun was shining I was laying in bed

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

slide from Steve Seitz's video



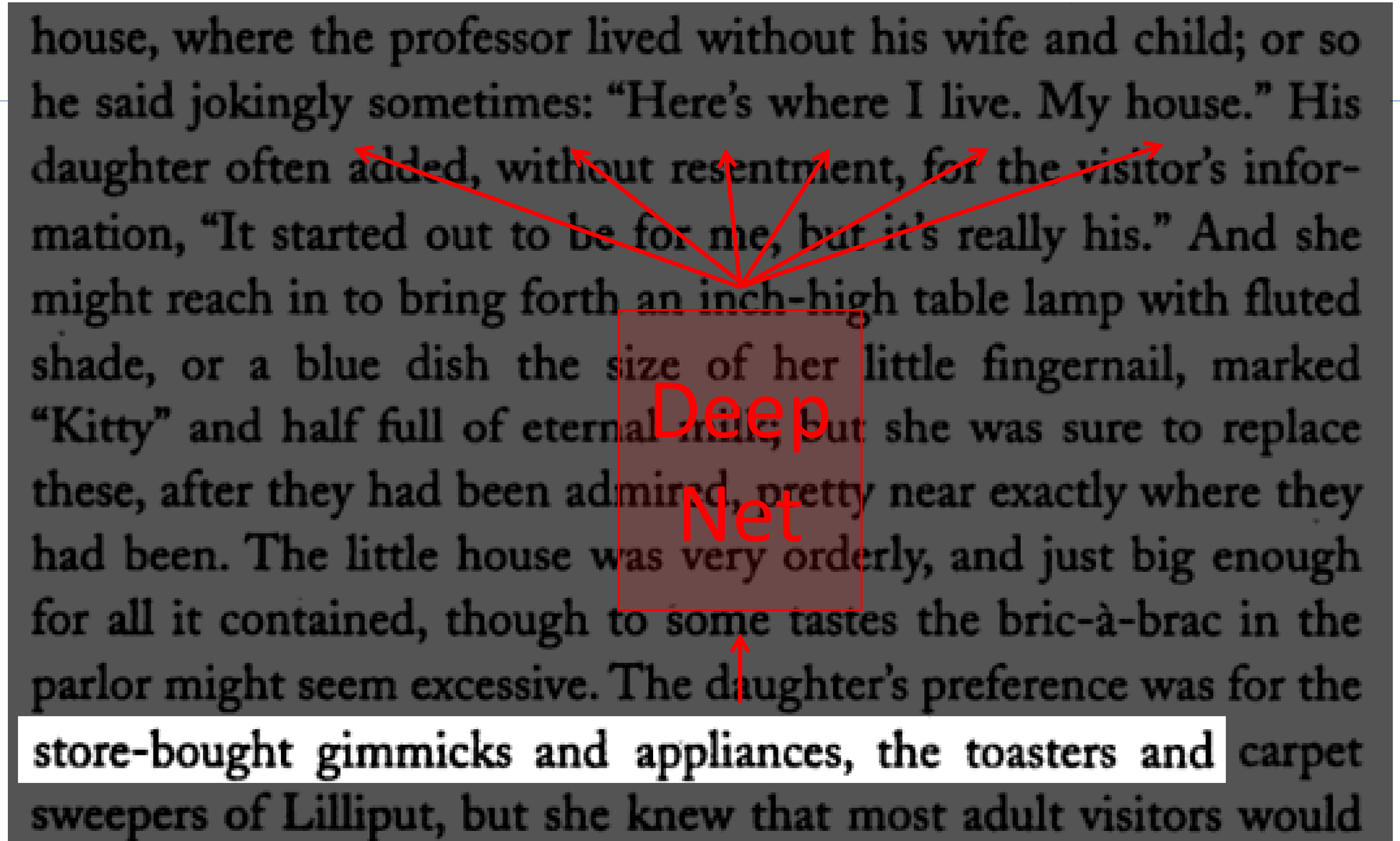
slide from Steve Seitz's video

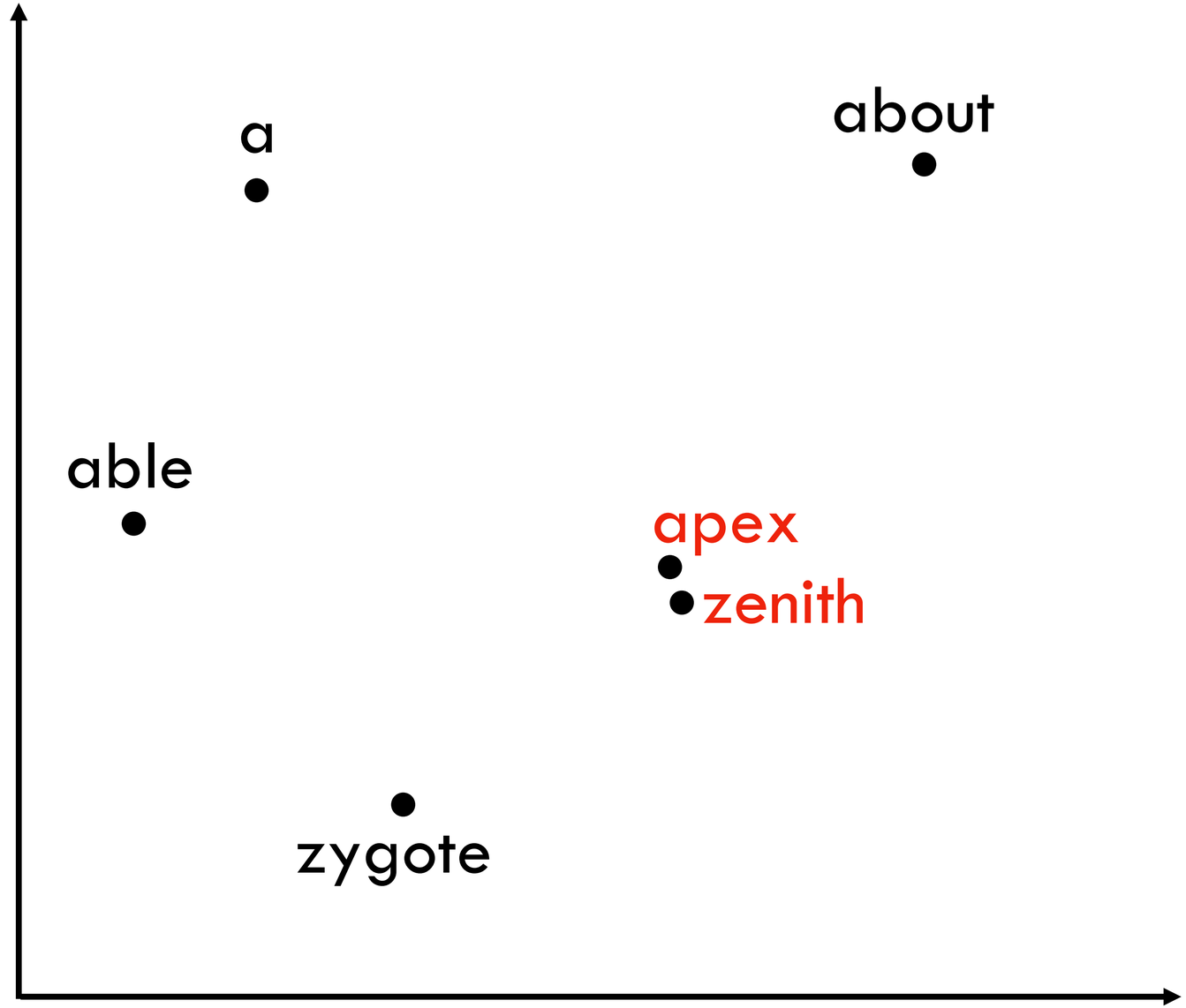


slide from Steve Seitz's video

word2vec

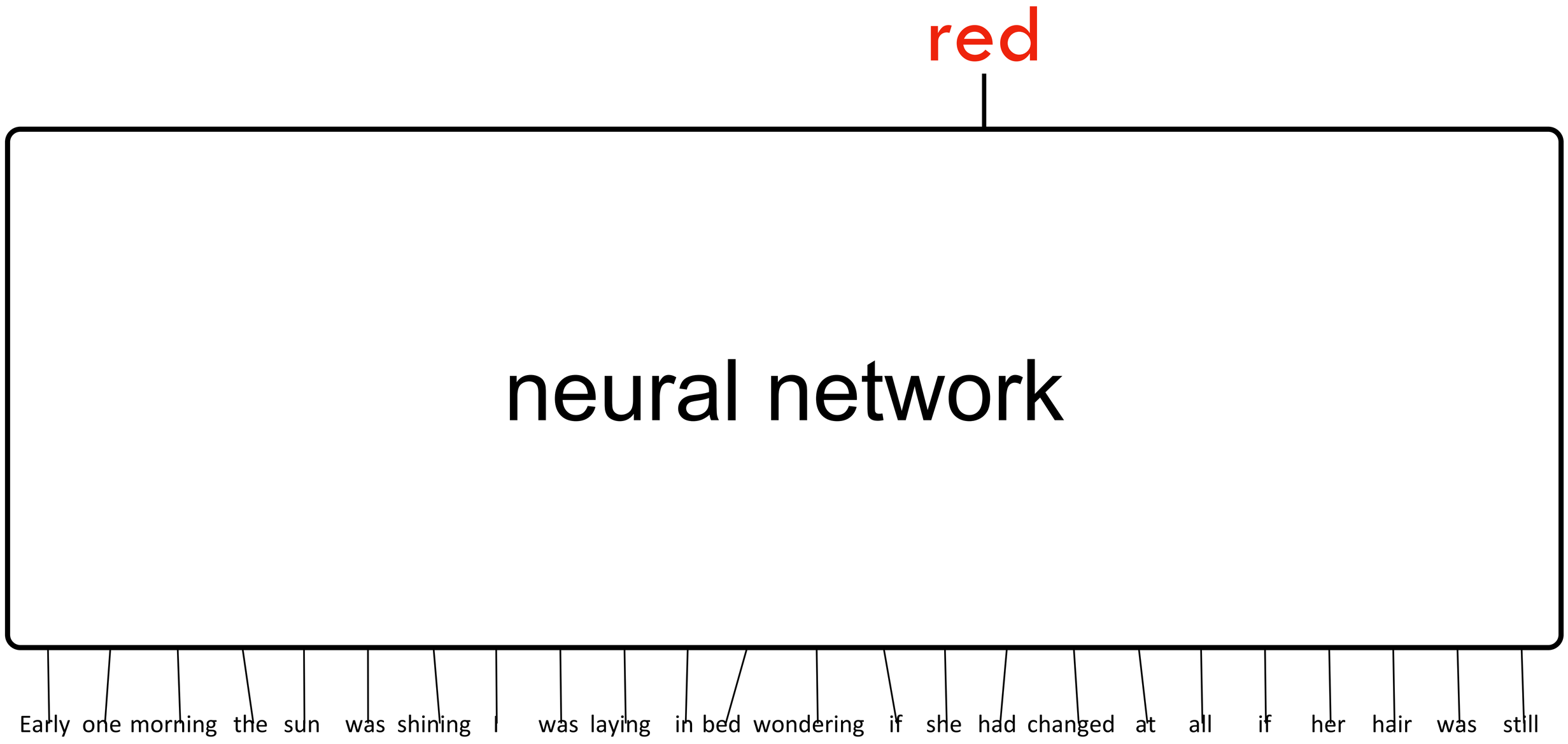
[Collobert & Weston 2008; Mikolov et al. 2013]



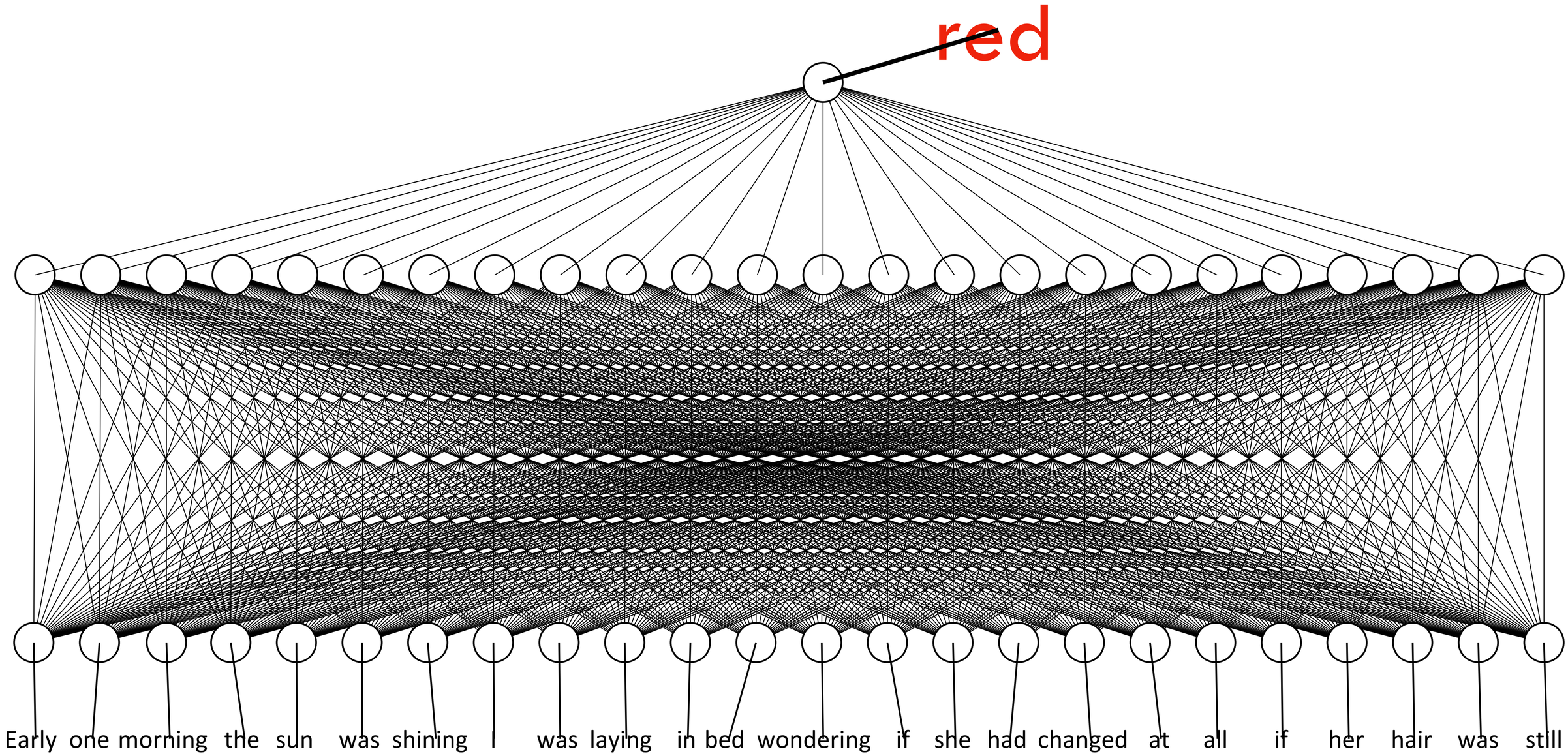


Word Embedding (e.g., word2Vec, GloVe)

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

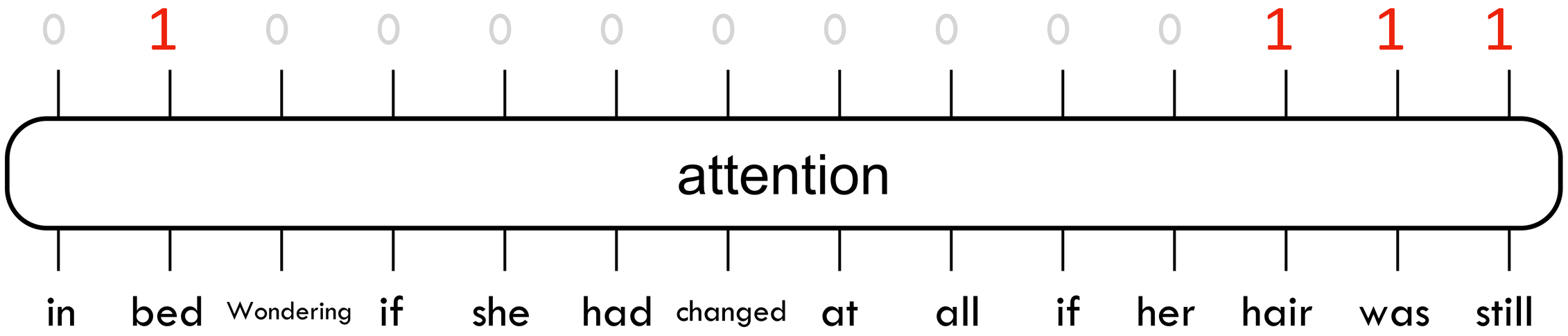
Wondering if she had changed at all if her hair was still ?

slide from Steve Seitz's video

bed

hair was still red

slide from Steve Seitz's video



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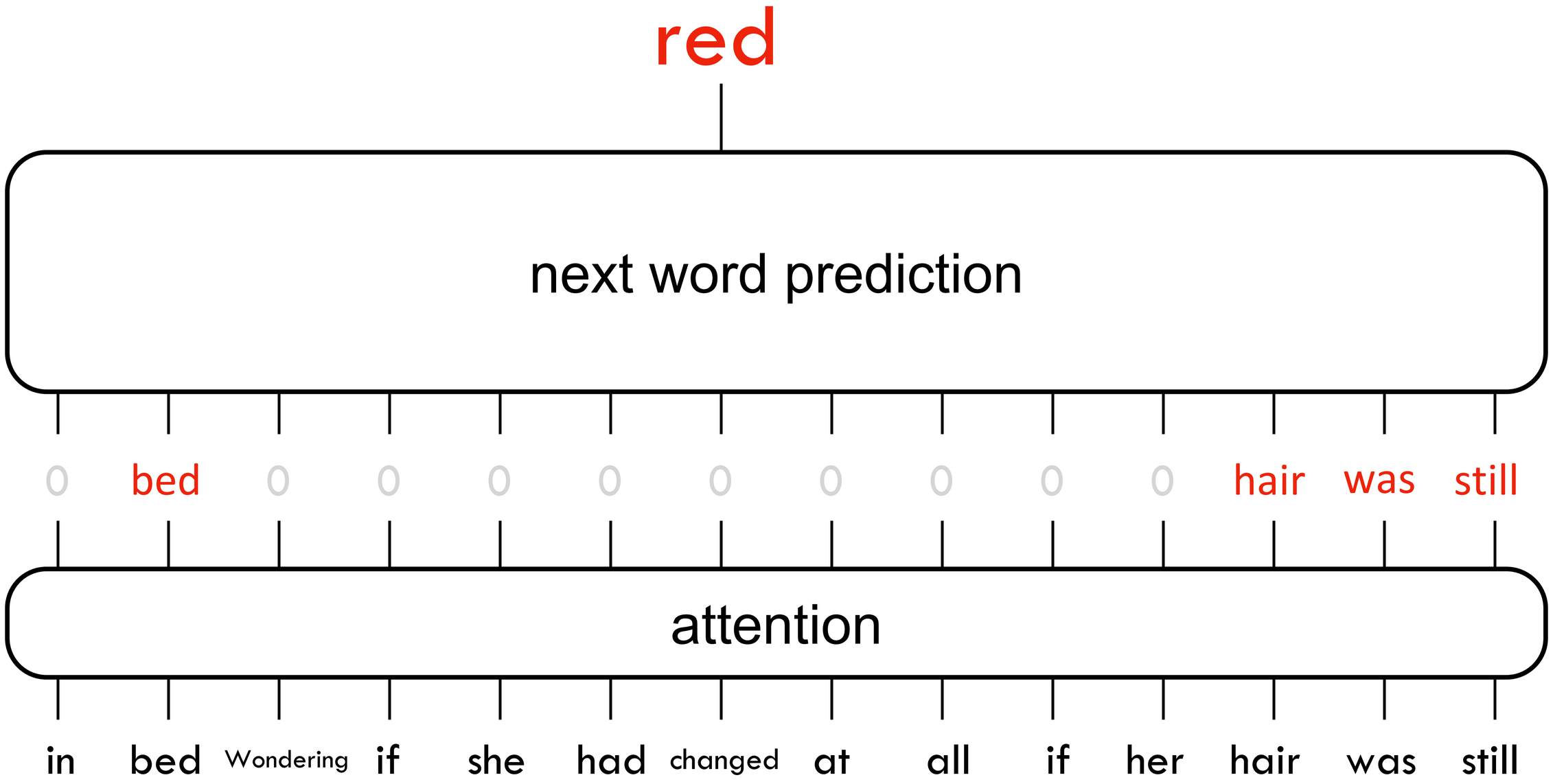
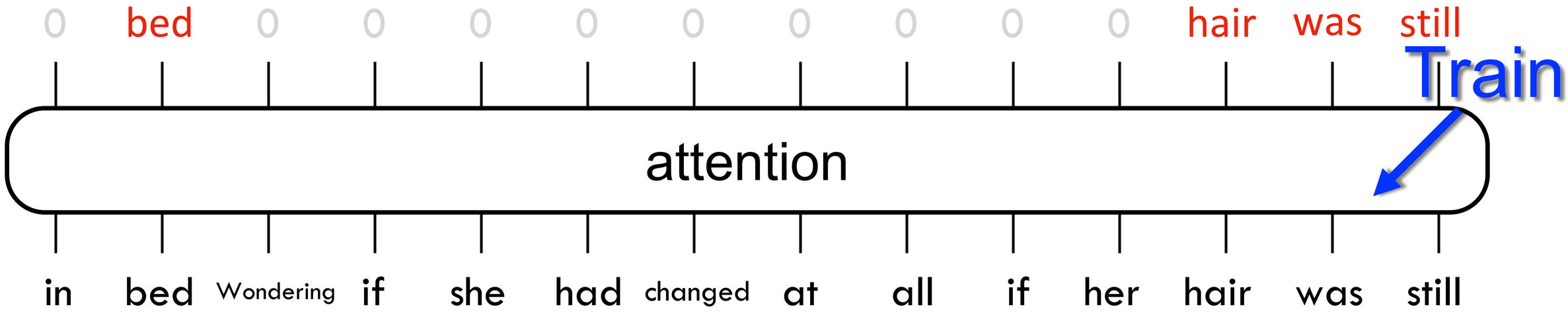


slide from Steve Seitz's video

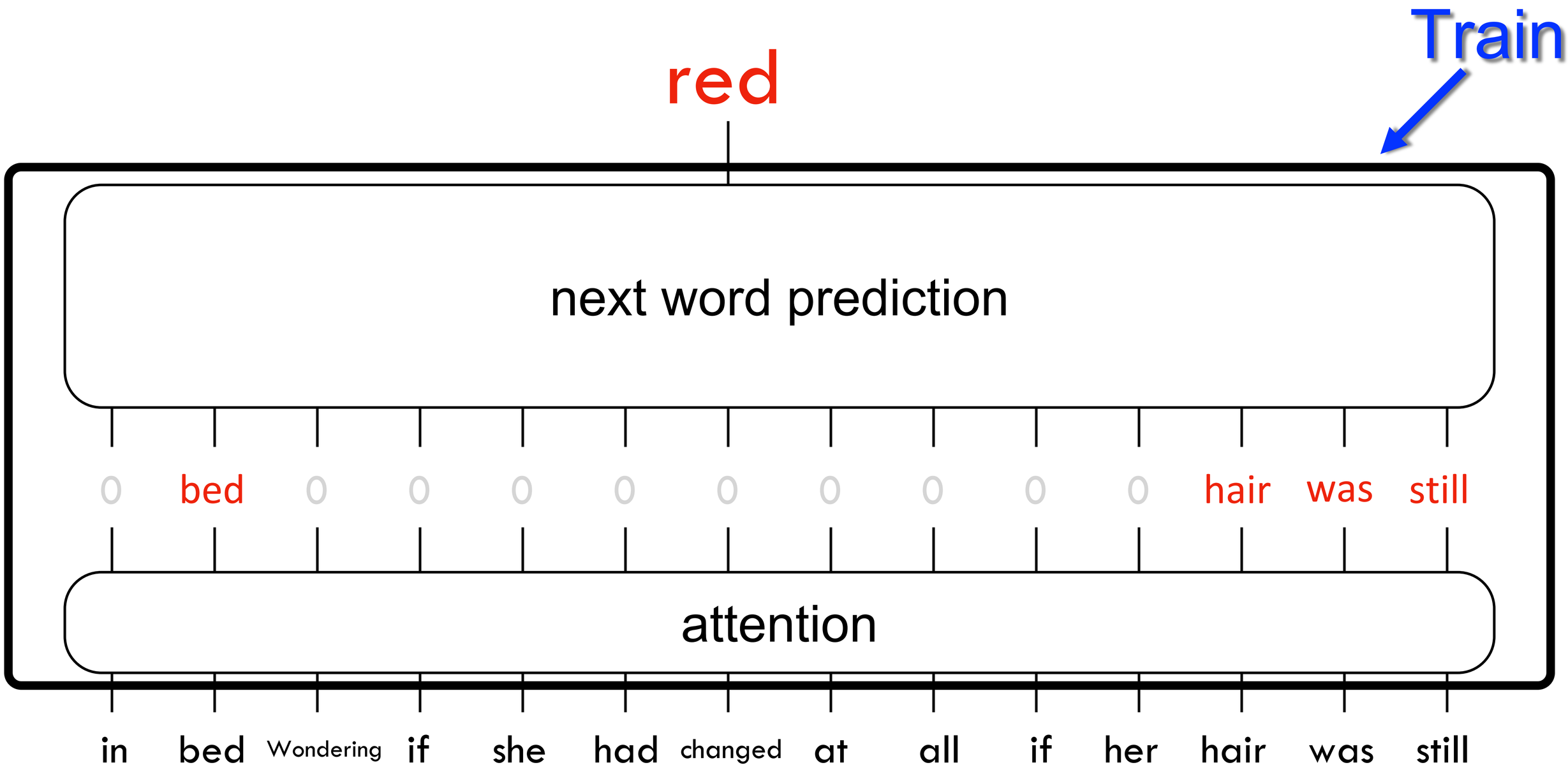


slide from Steve Seitz's video

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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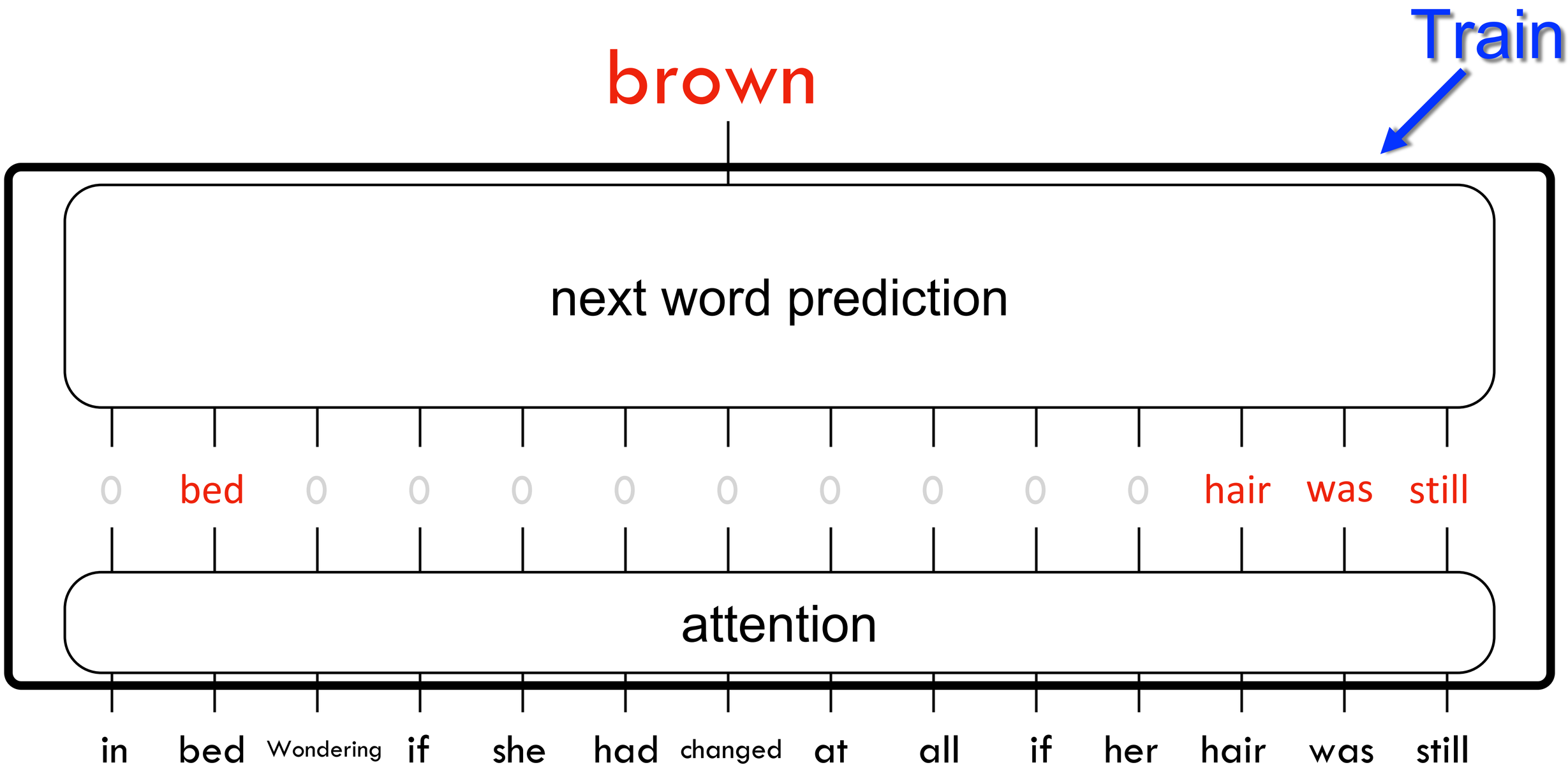

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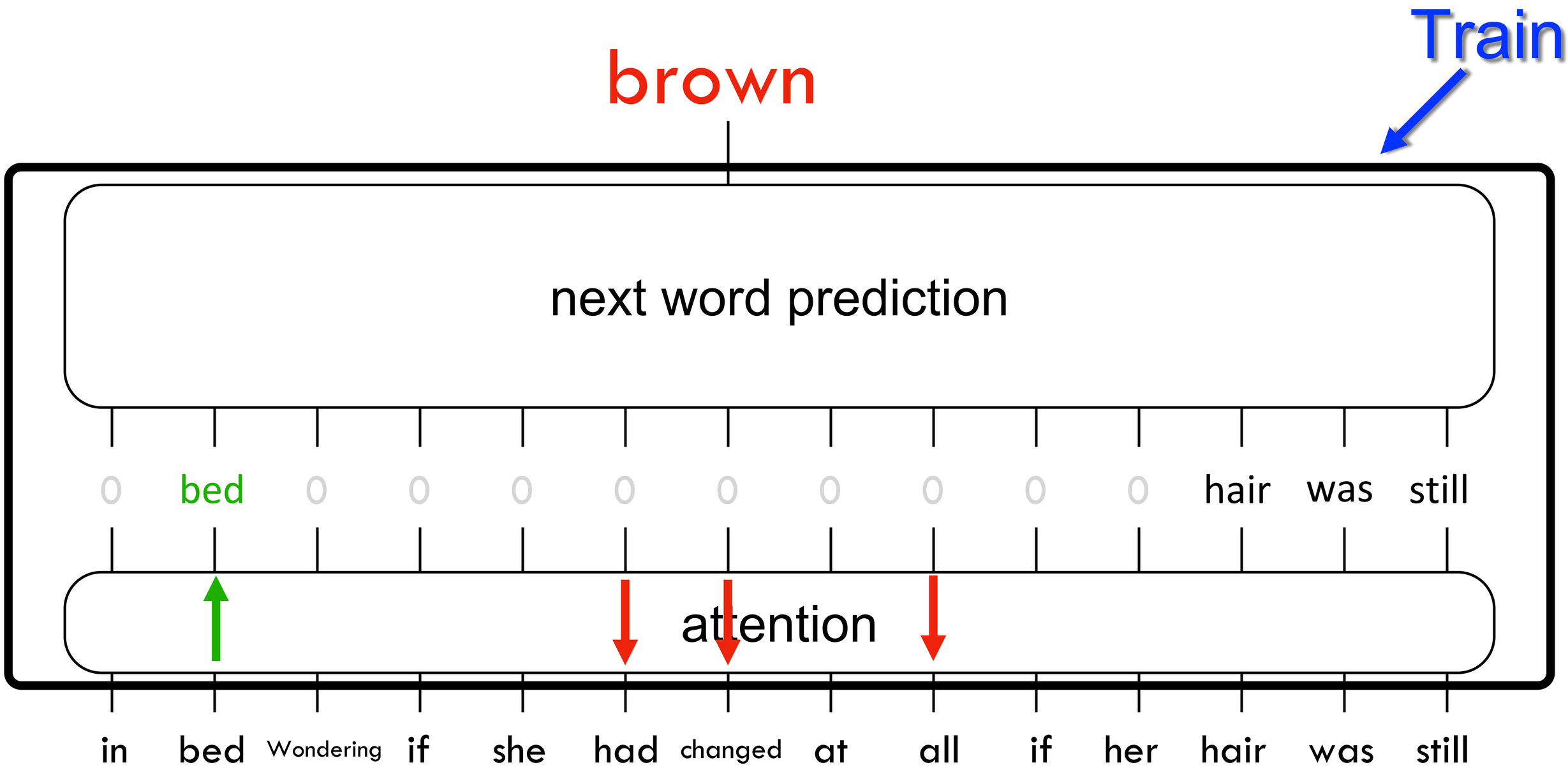

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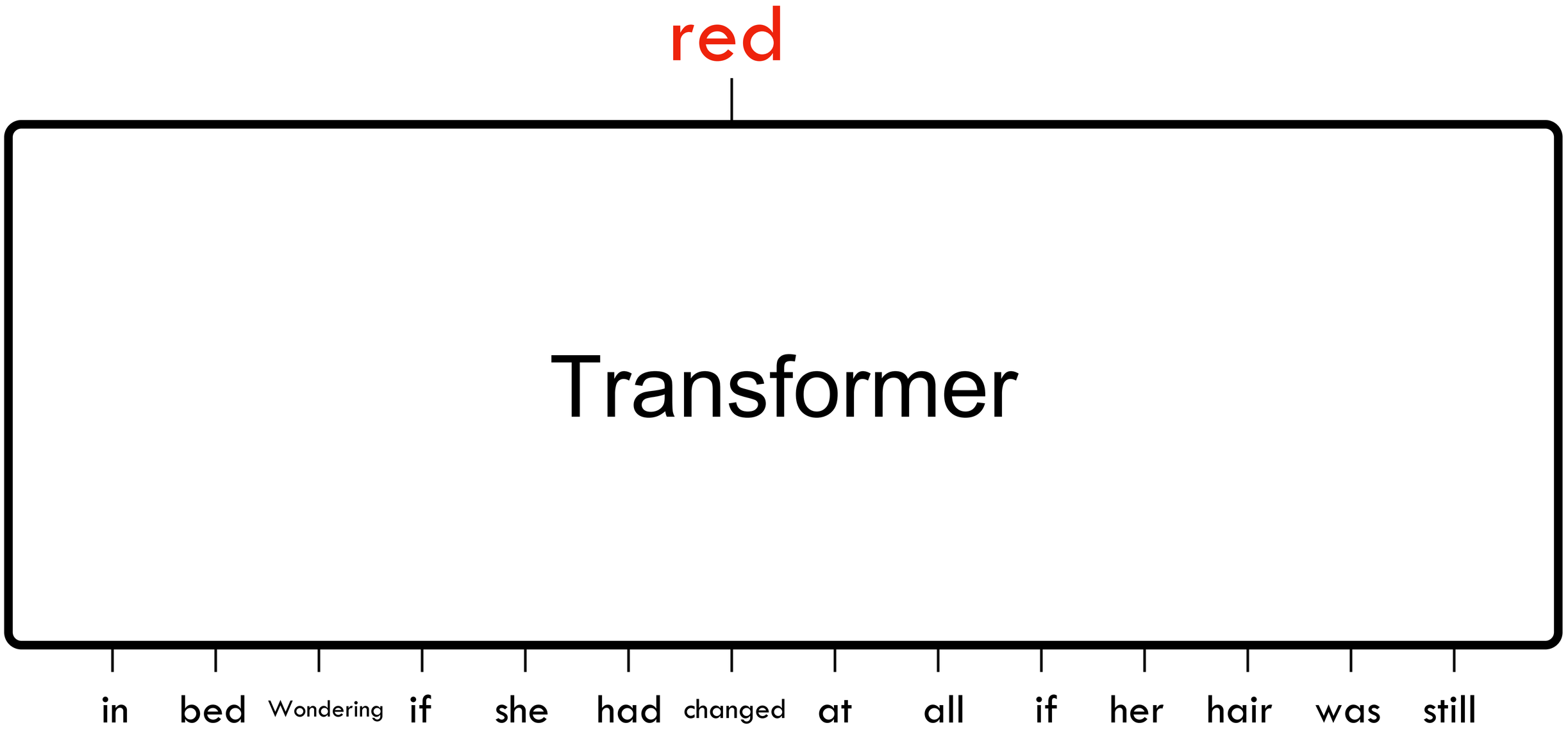

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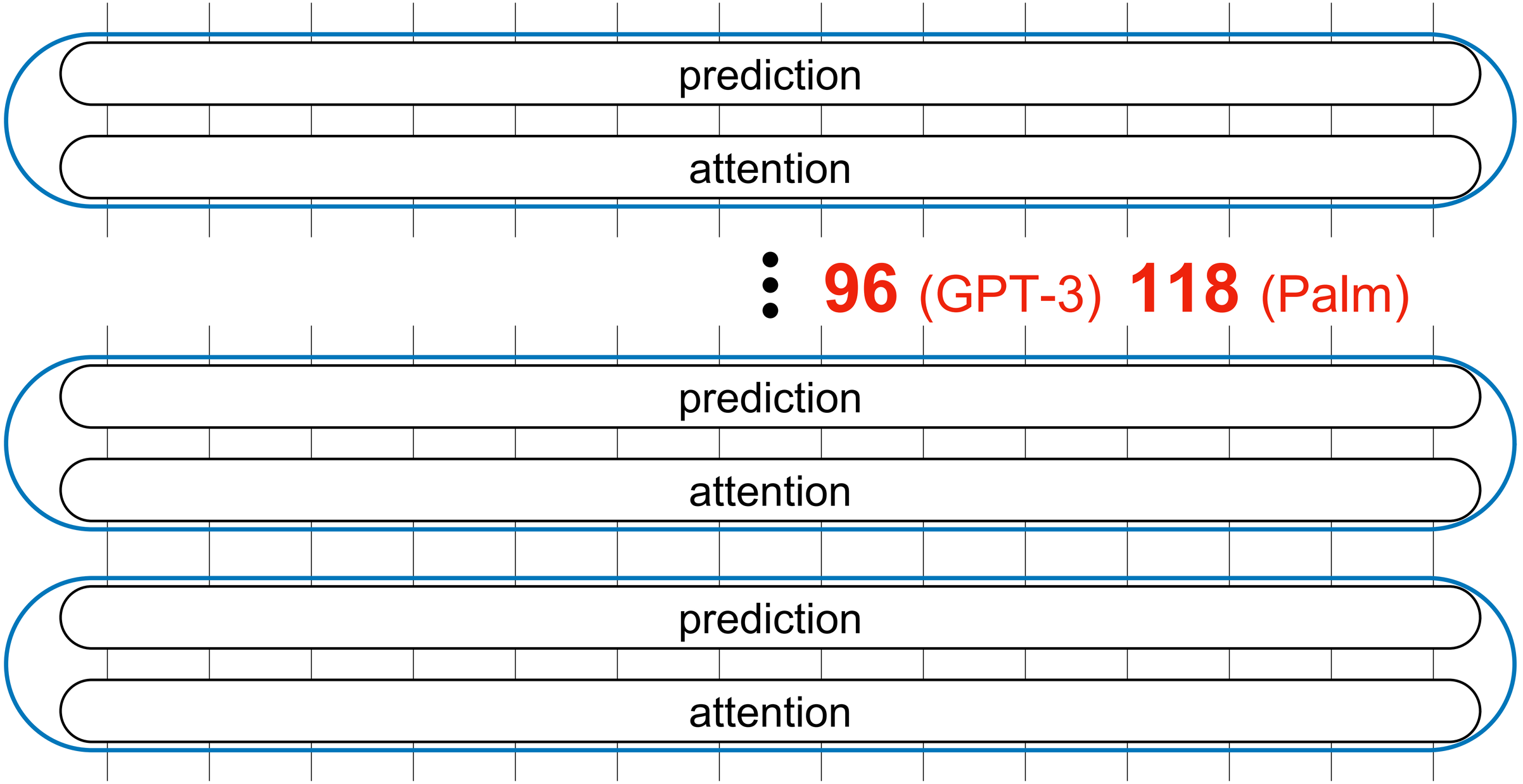

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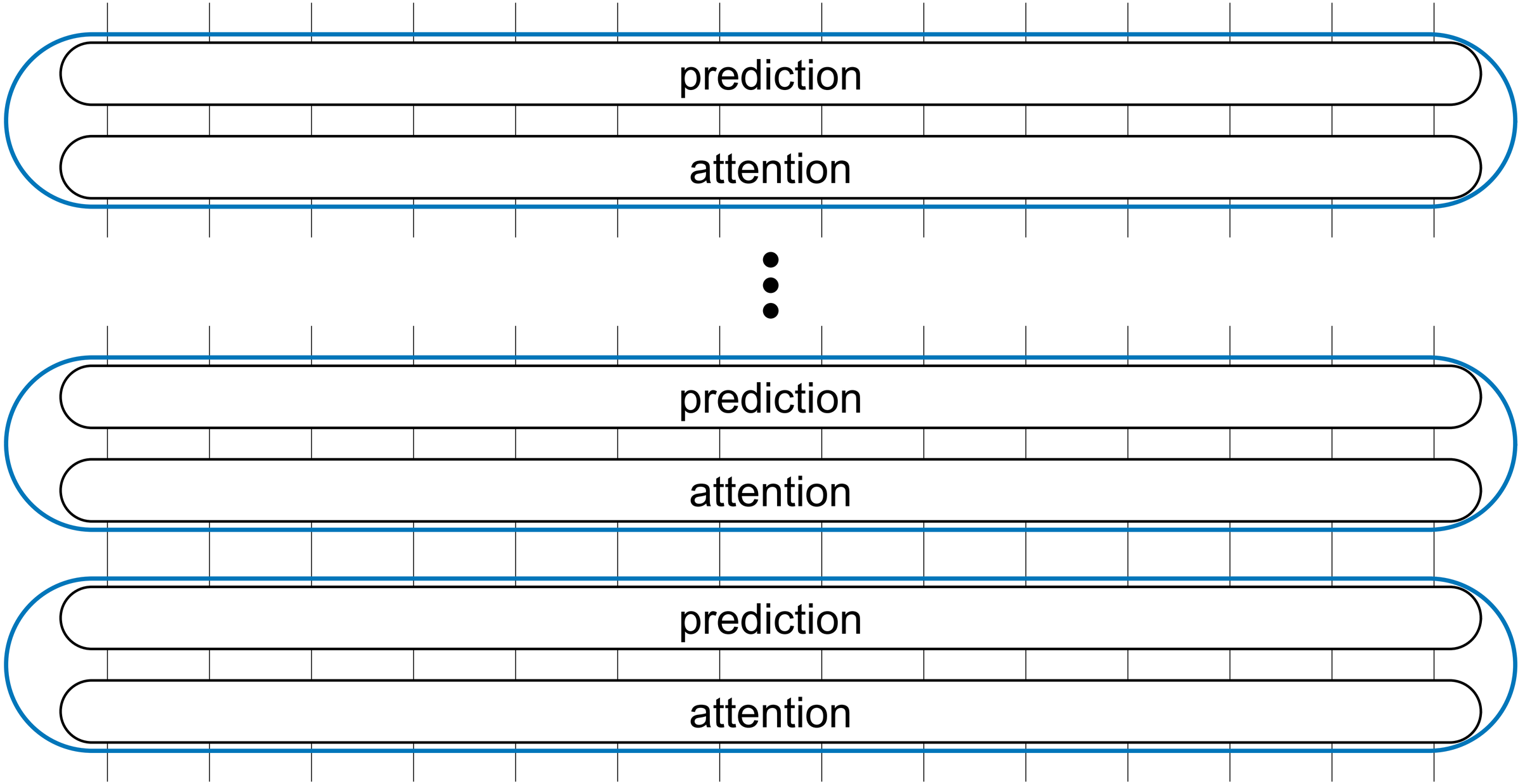

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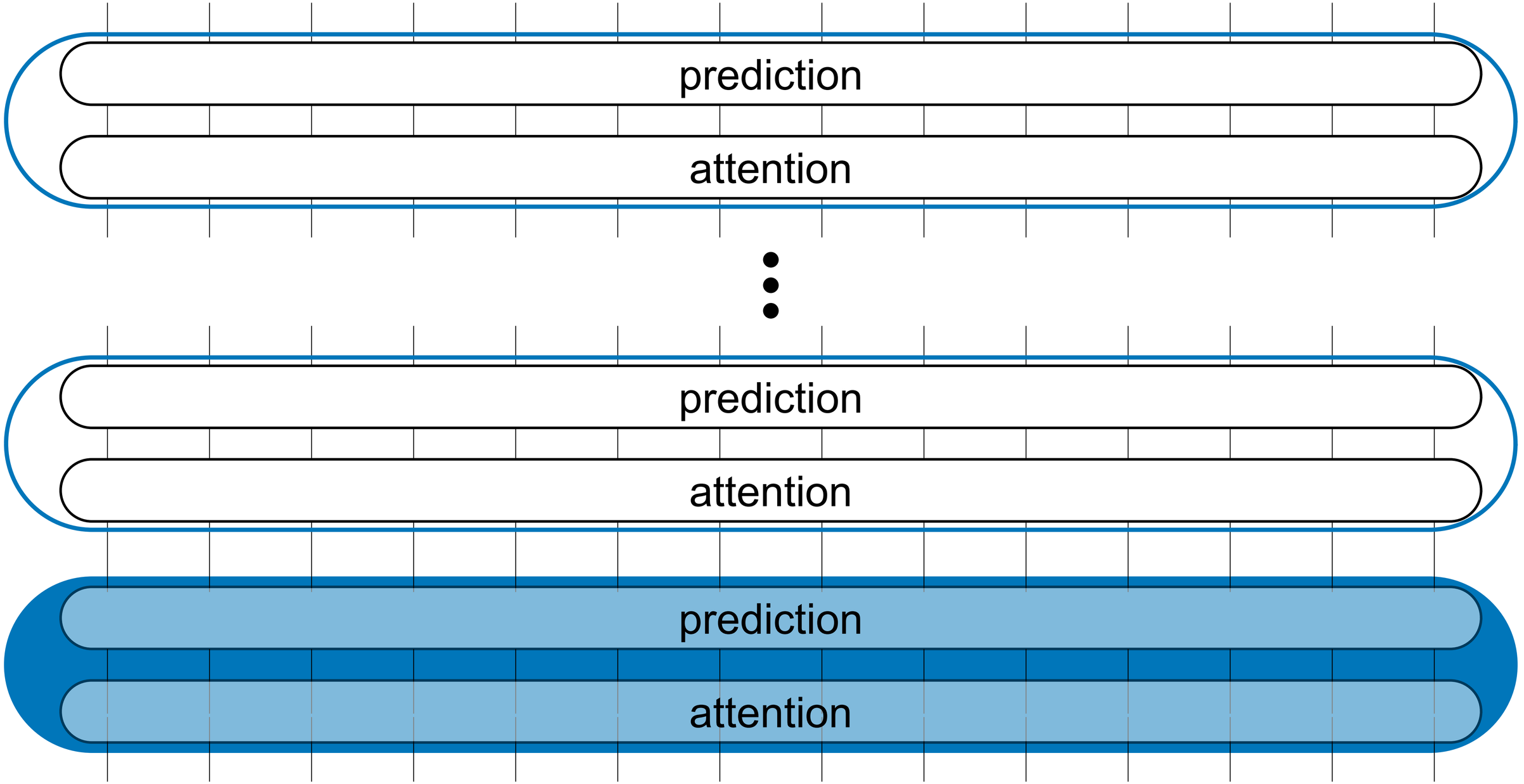

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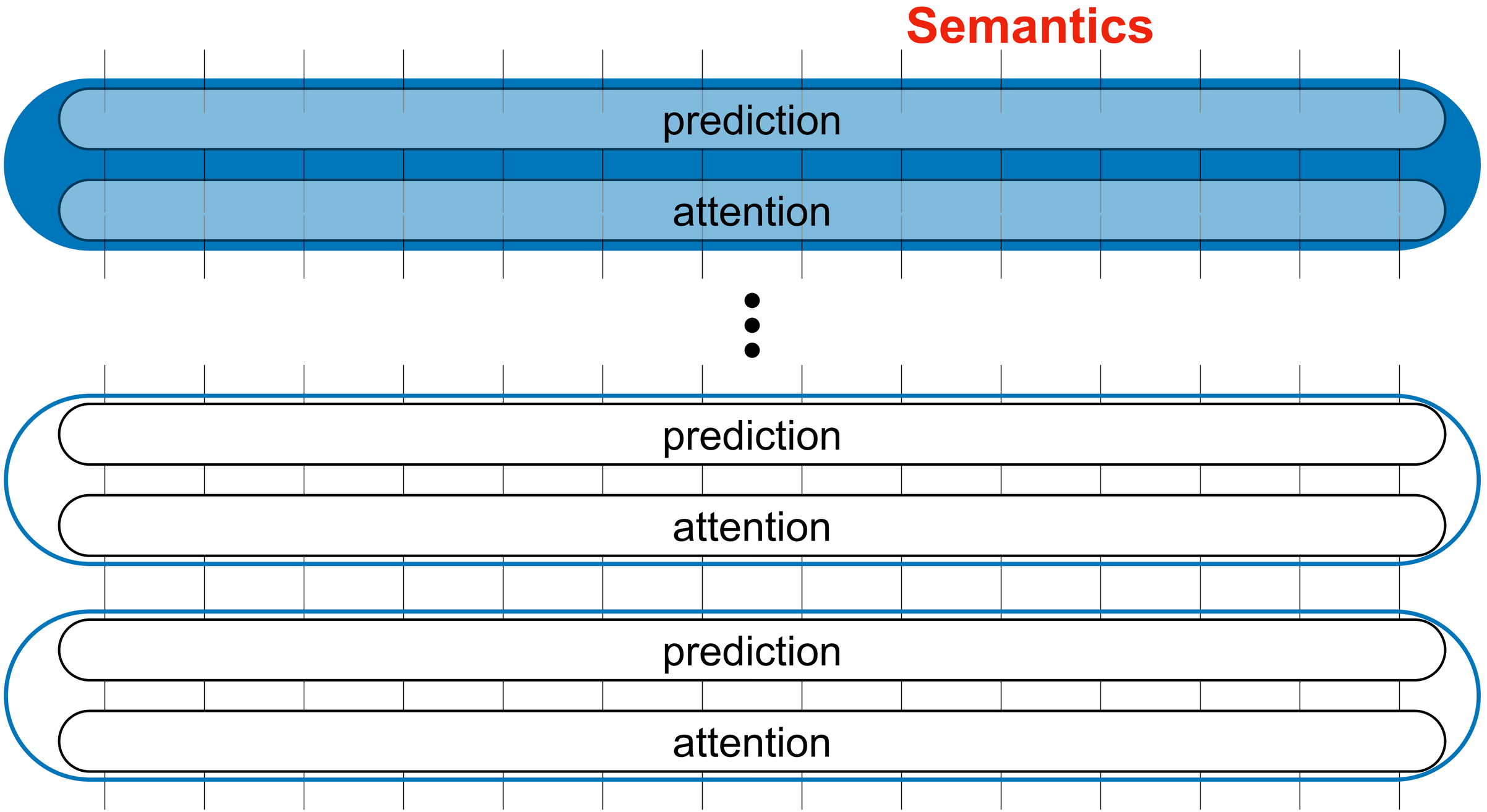

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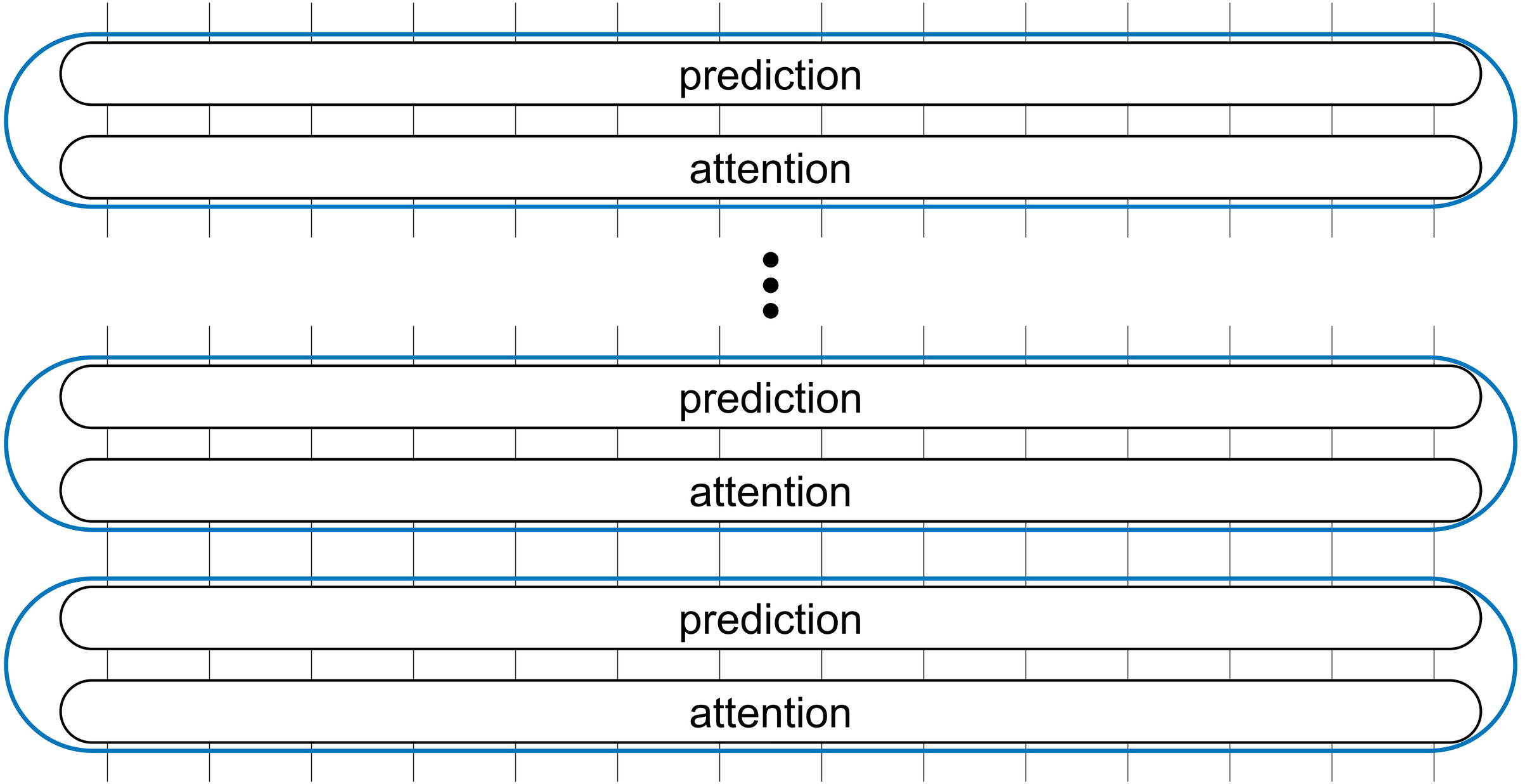


slide from Steve Seitz's video

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 2×3×3×17

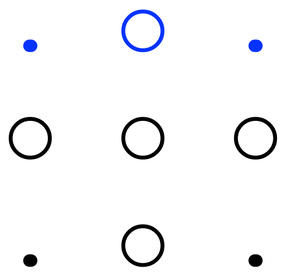
Queen Victoria's maiden name was Alexandrina Victoria

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

The lat long coordinates of Rome are 41.894722, 12.48

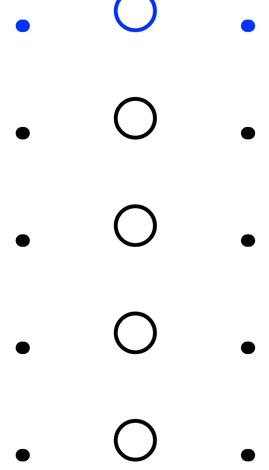
slide from Steve Seitz's video

a pattern of characters that looks like a star



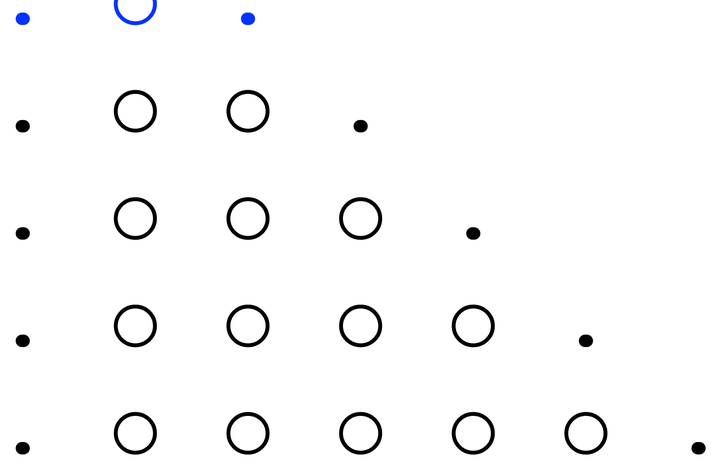
slide from Steve Seitz's video

a pattern of characters that looks like a vertical line



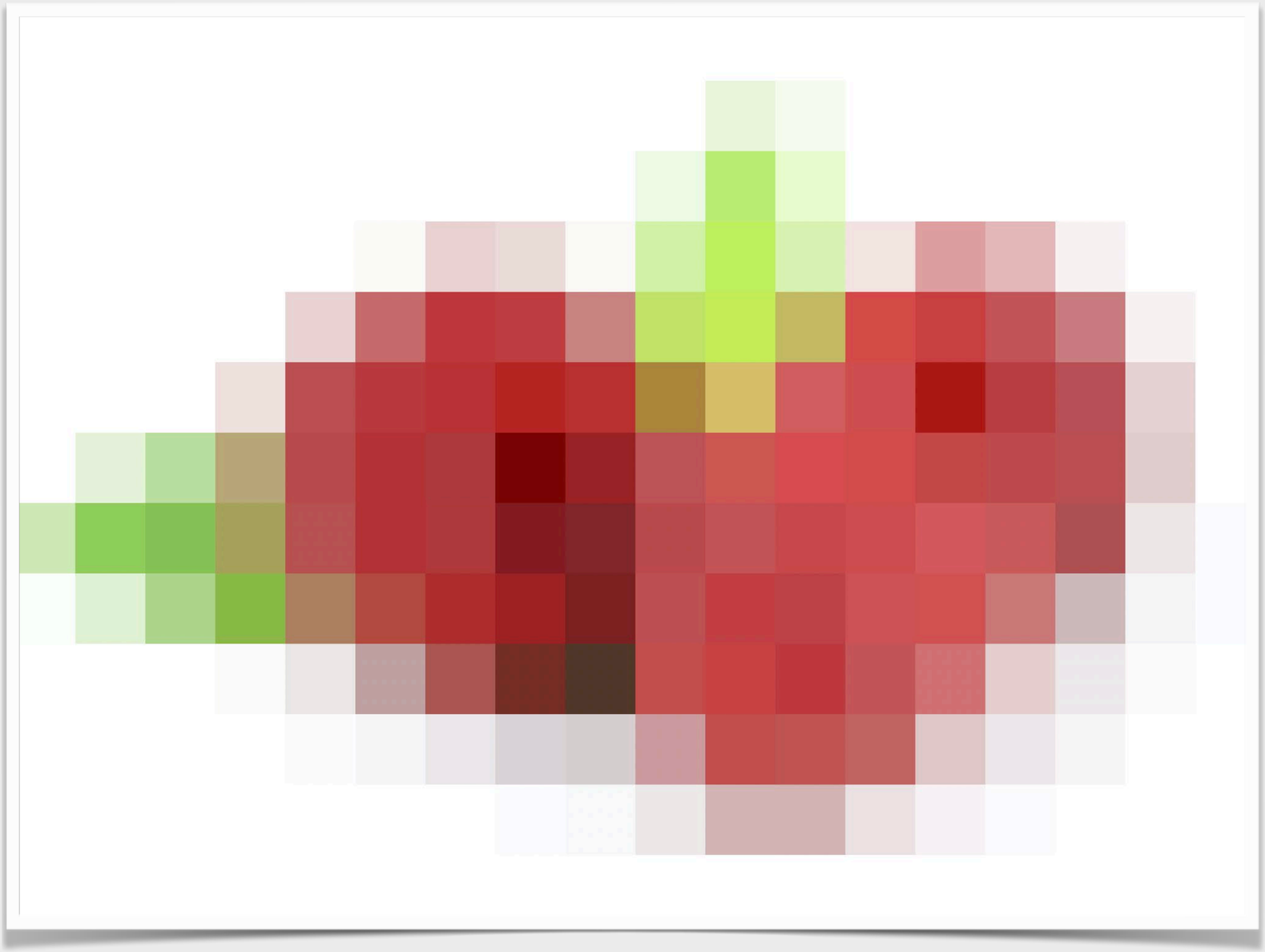
slide from Steve Seitz's video

a pattern of characters that looks like a triangle

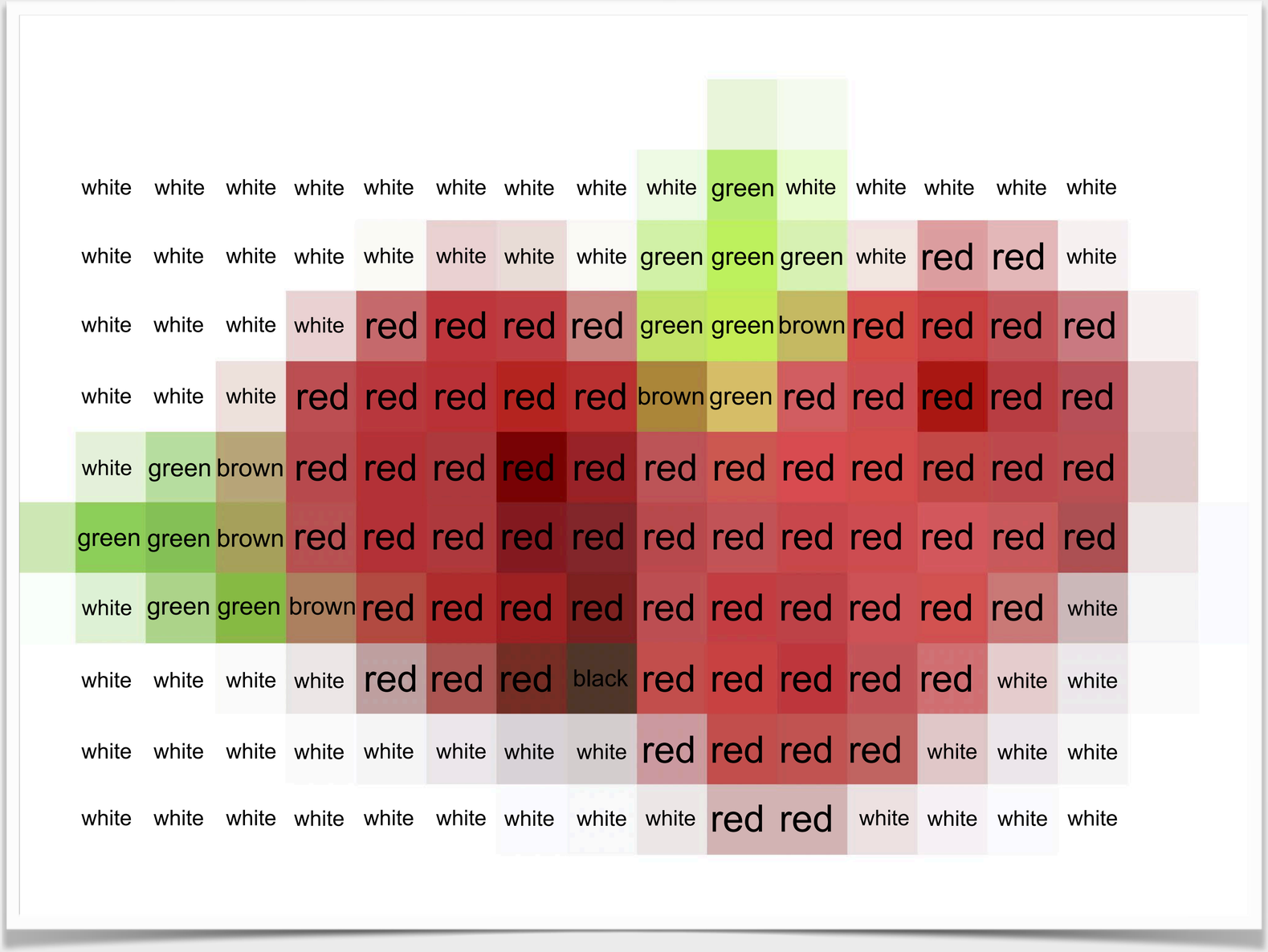


slide from Steve Seitz's video

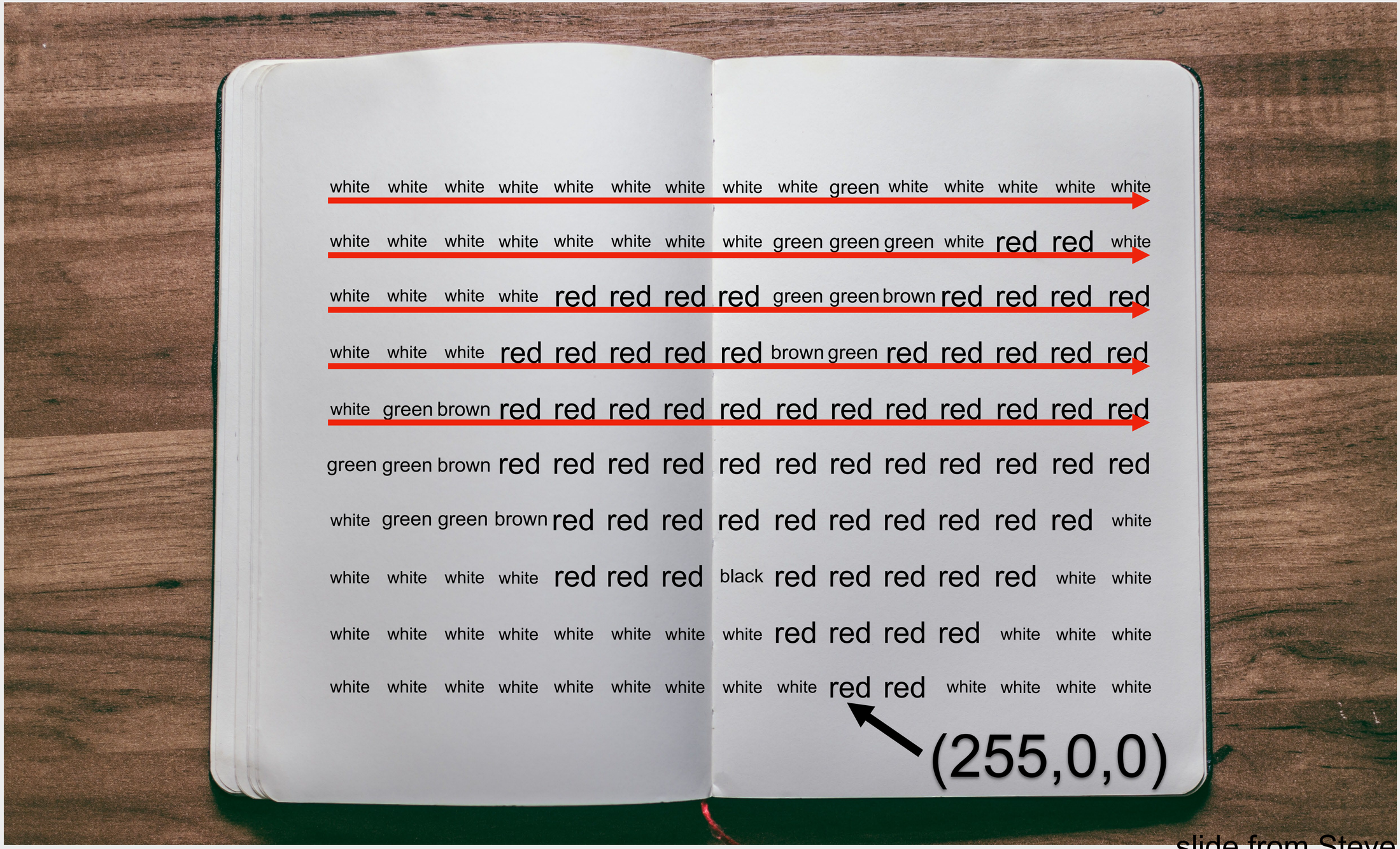
slide from Steve Seitz’s video



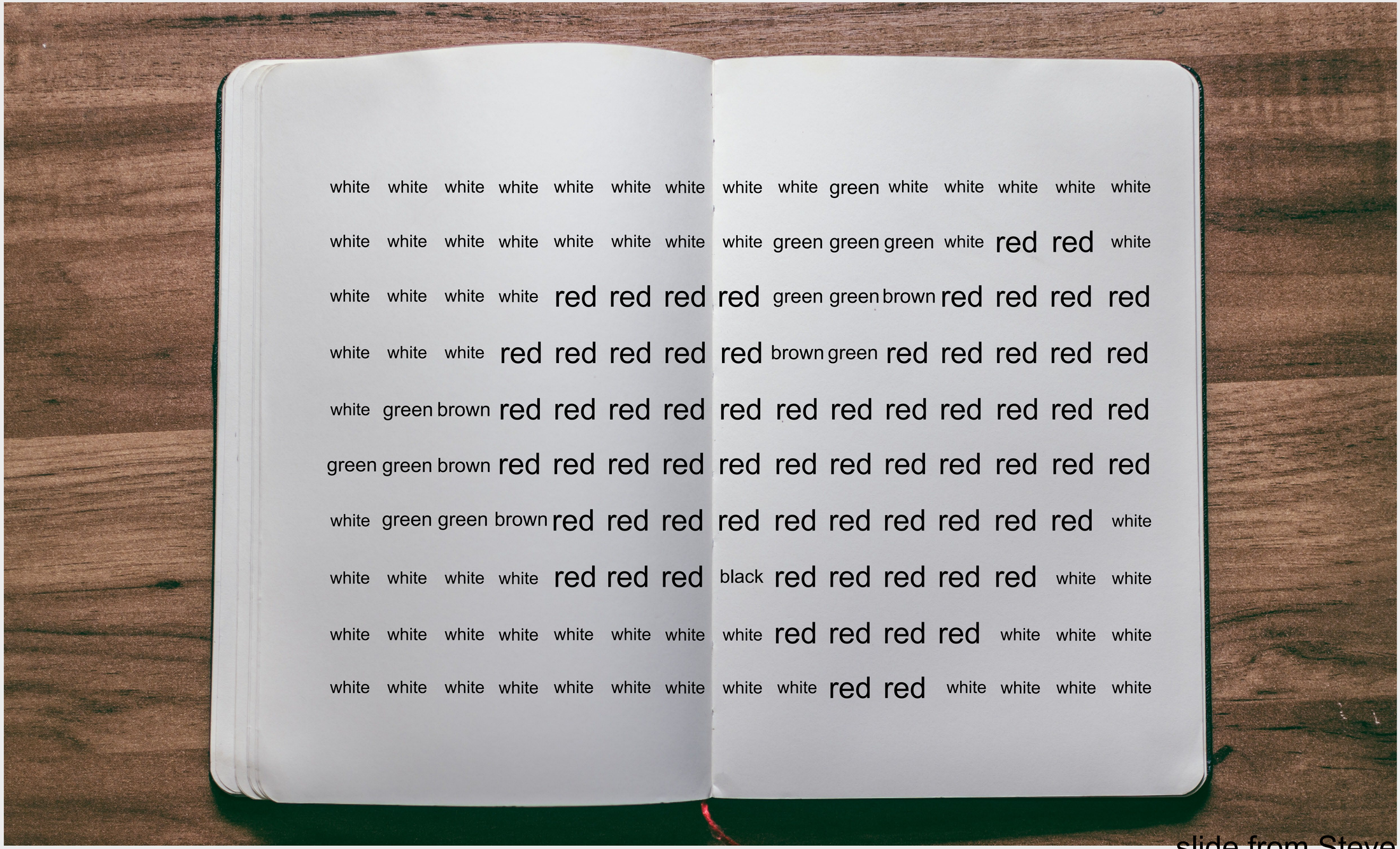
slide from Steve Seitz's video



slide from Steve Seitz's video



slide from Steve Seitz's video



slide from Steve Seitz's video

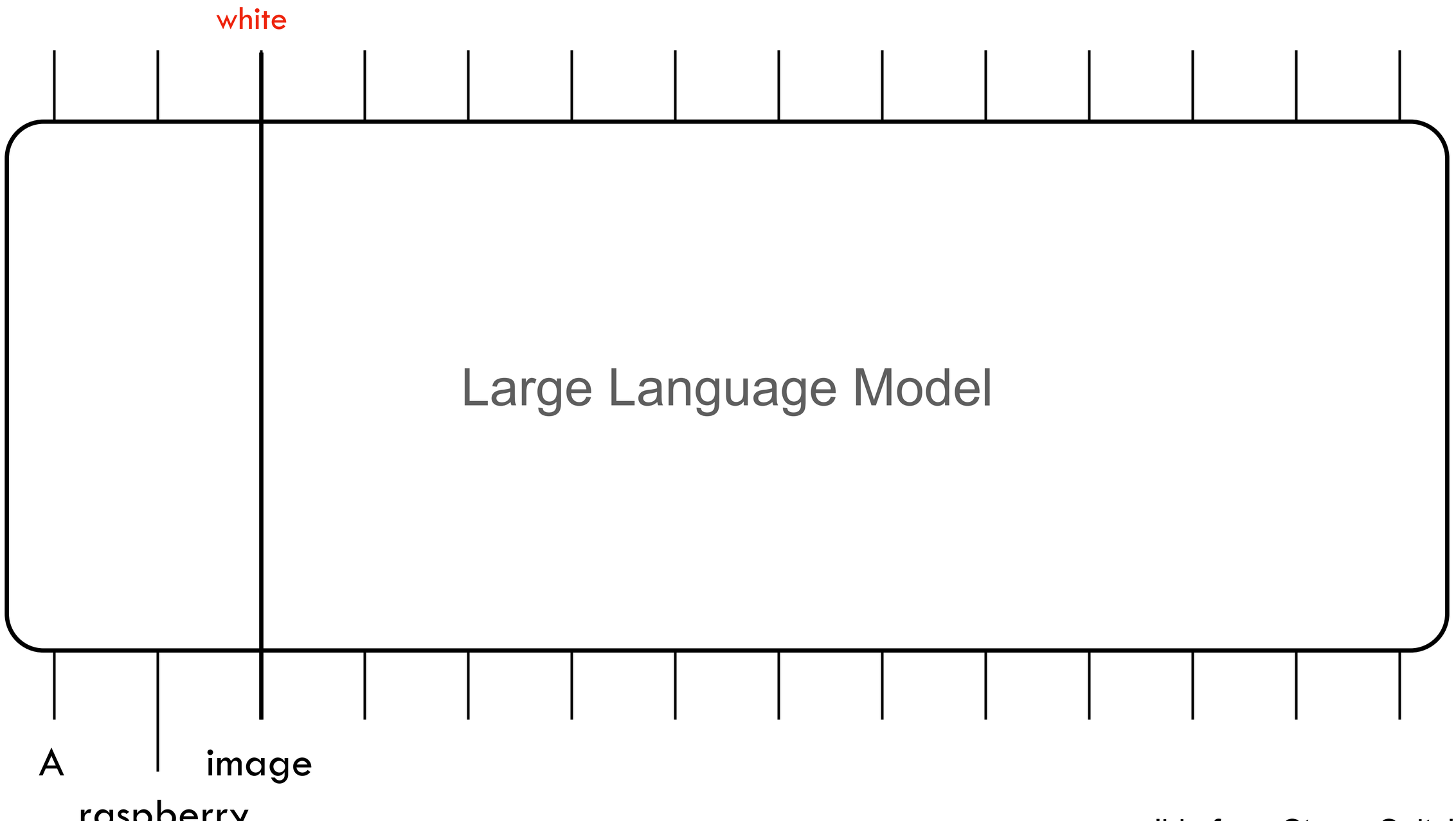
raspberries

pancakes

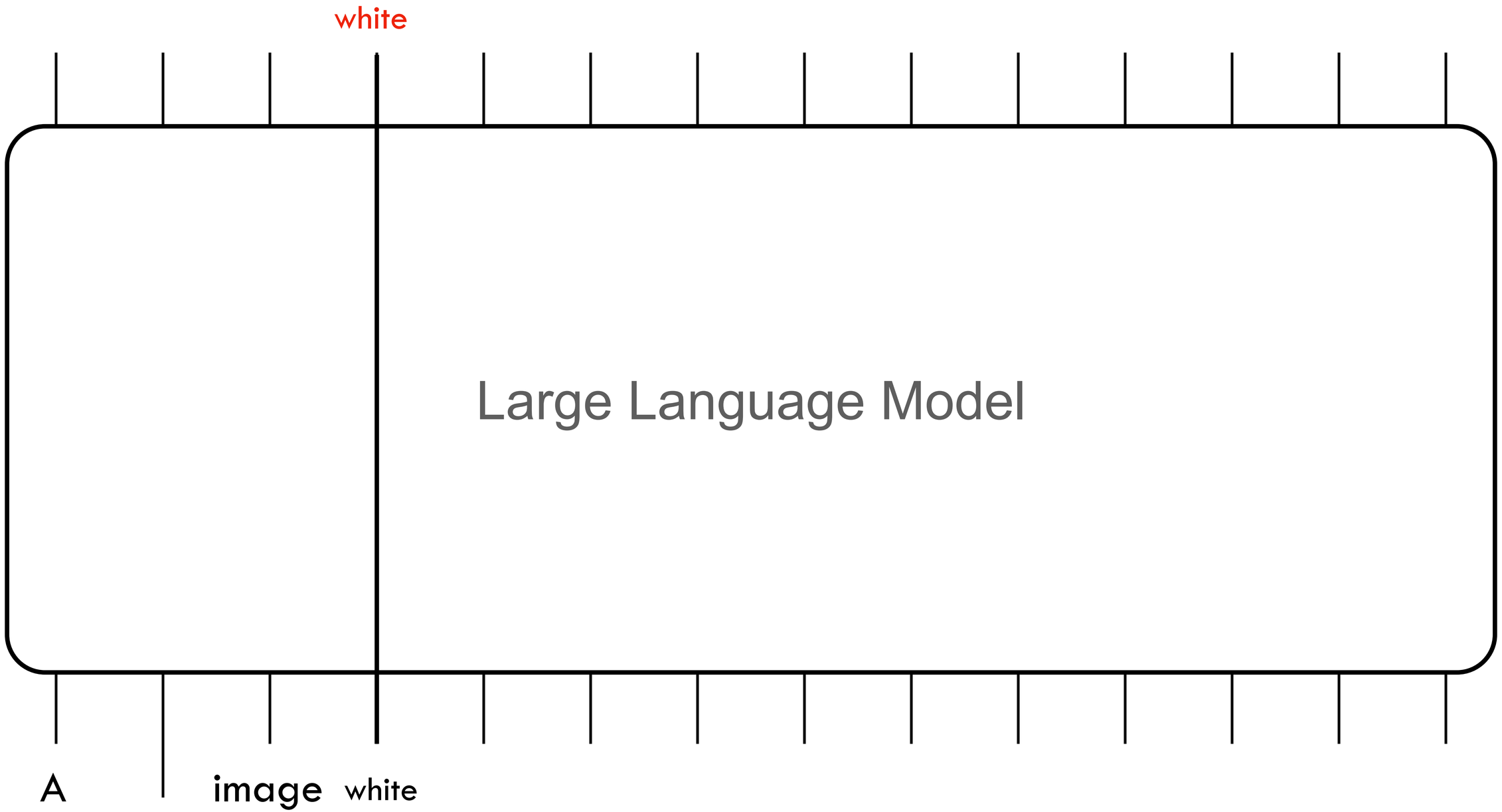
sunsets

1 Billion

slide from Steve Seitz's video



slide from Steve Seitz's video



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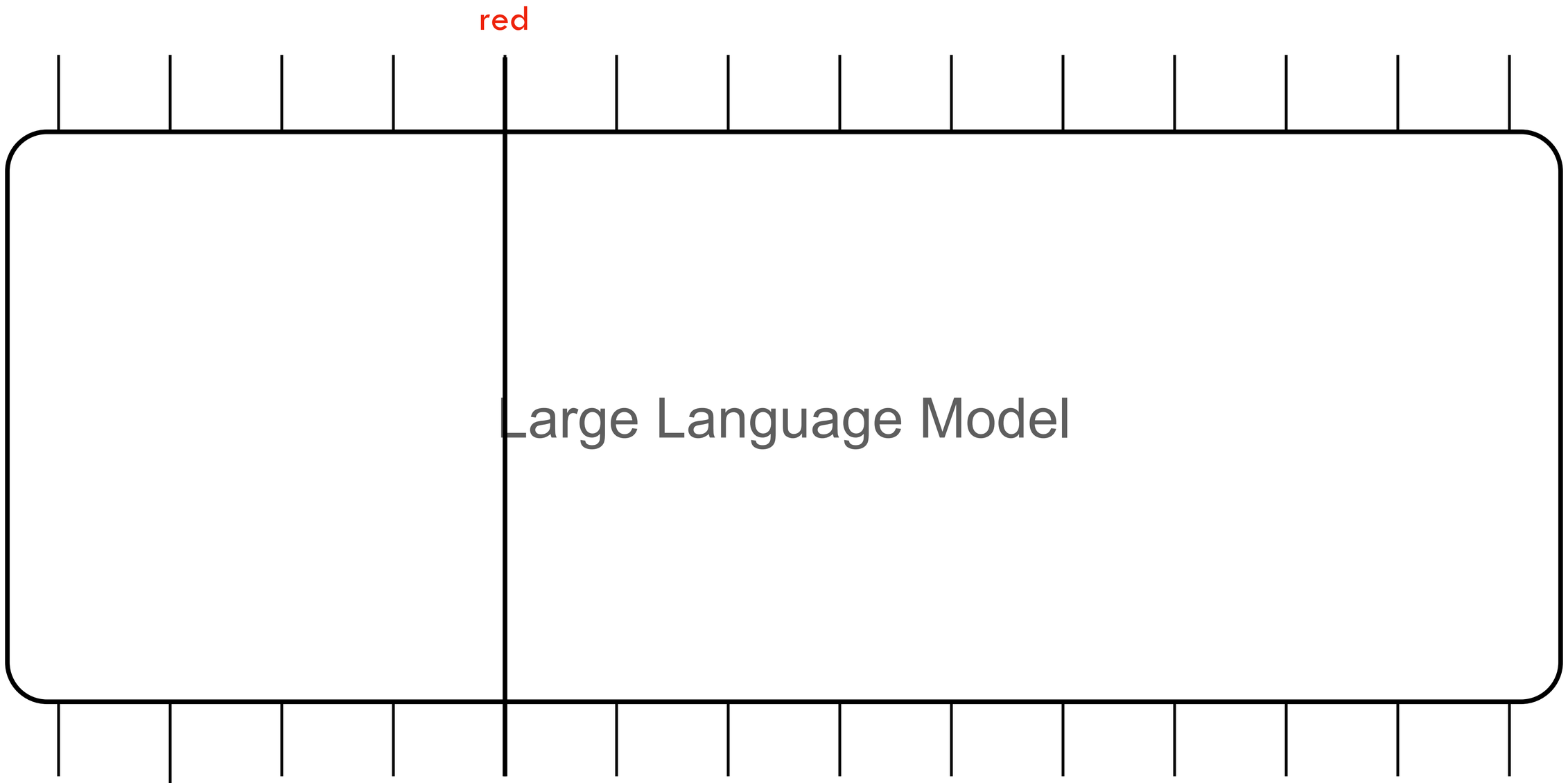

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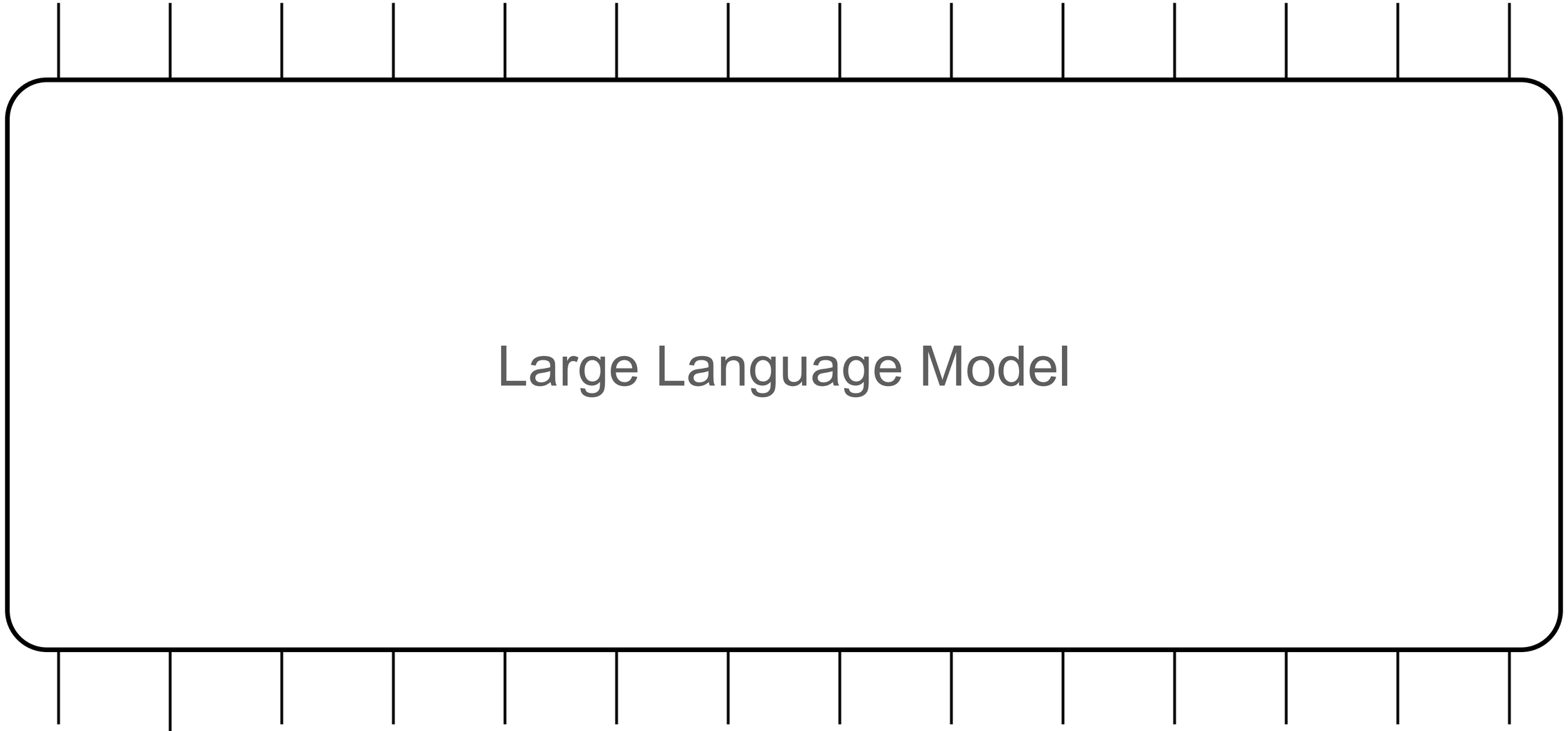
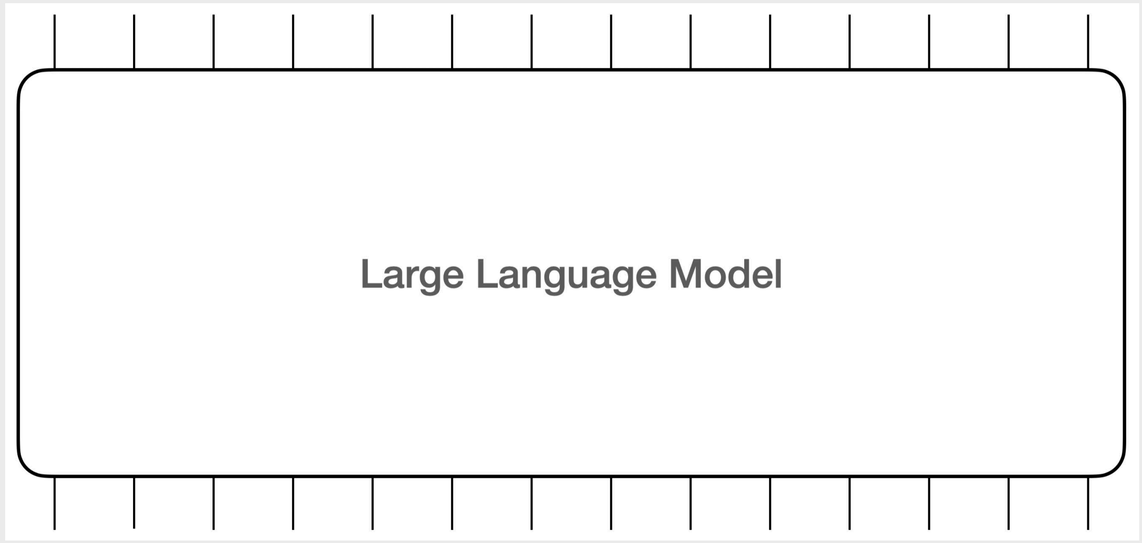


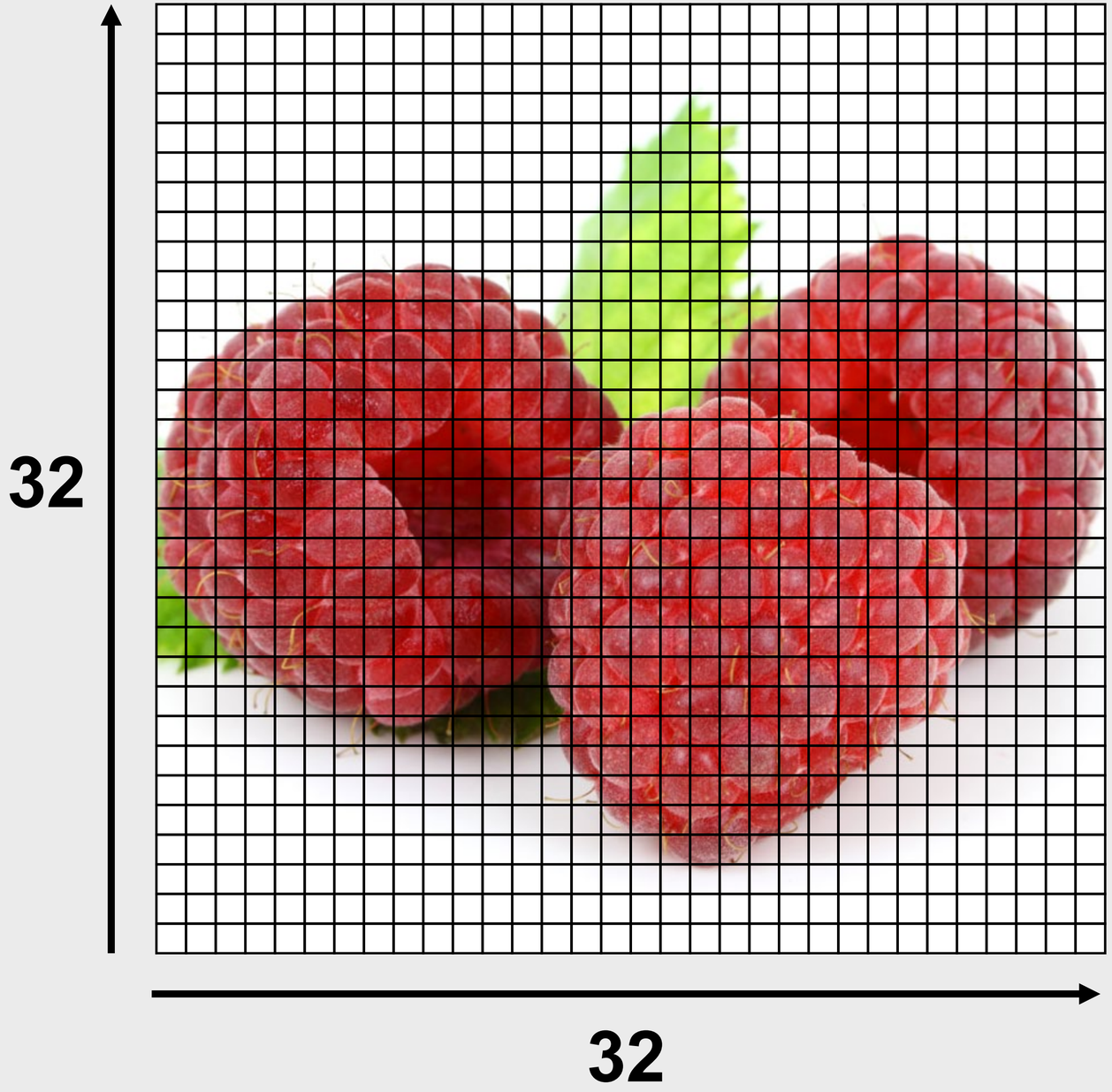
slide from Steve Seitz's video

1,000,000s of pixels



1,000s of words

slide from Steve Seitz's video



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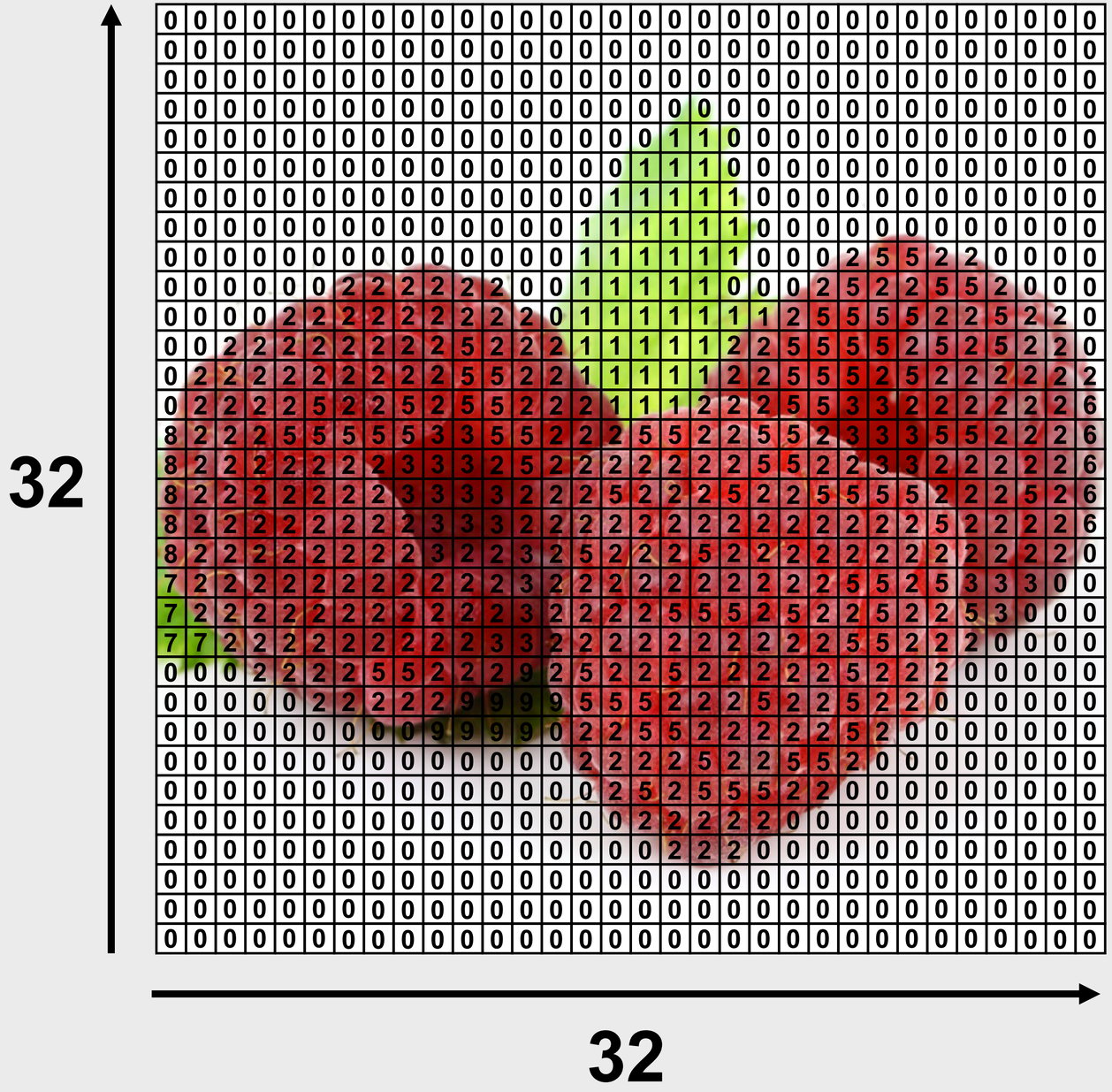

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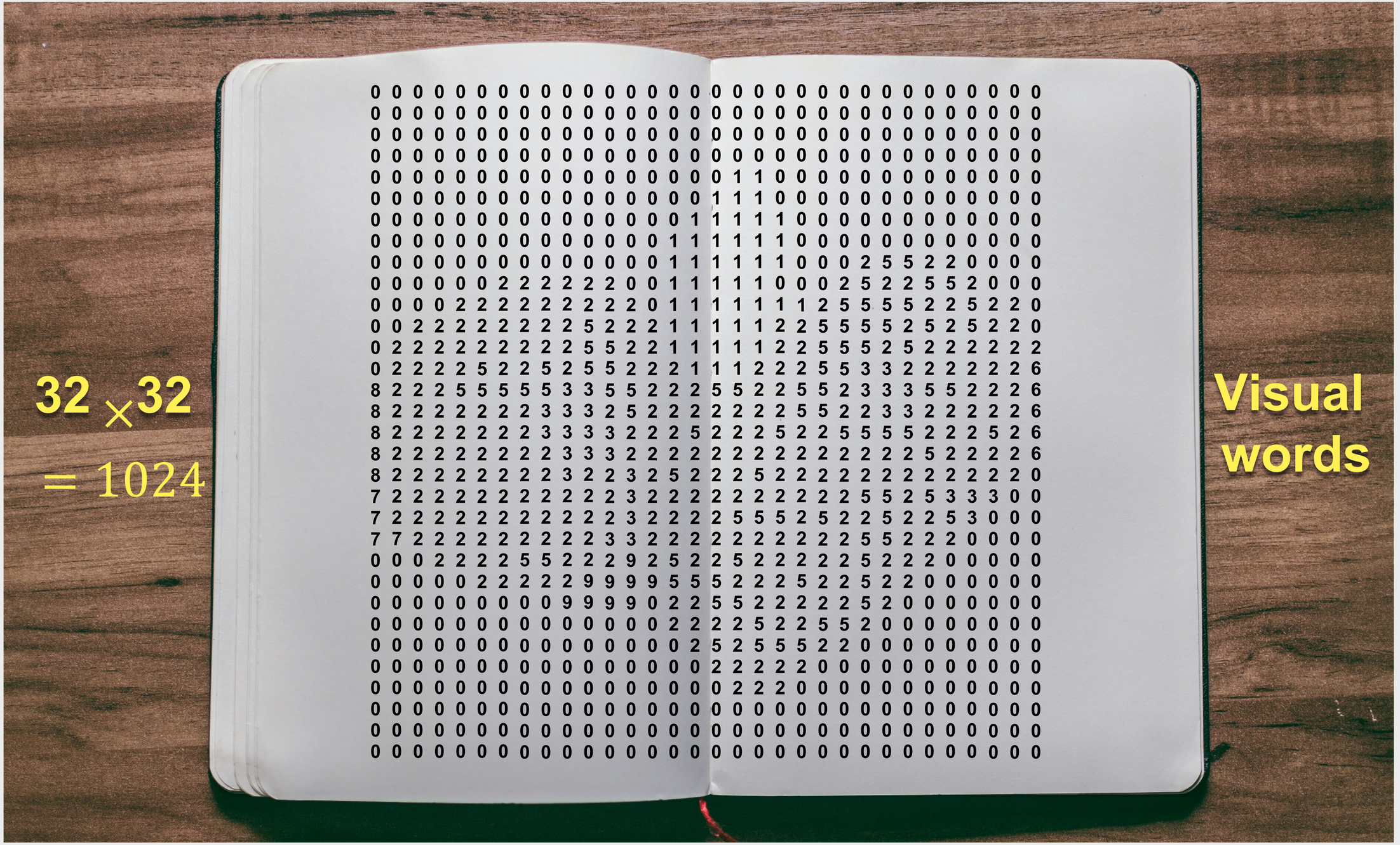


slide from Steve Seitz's video

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 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 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 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 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 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**

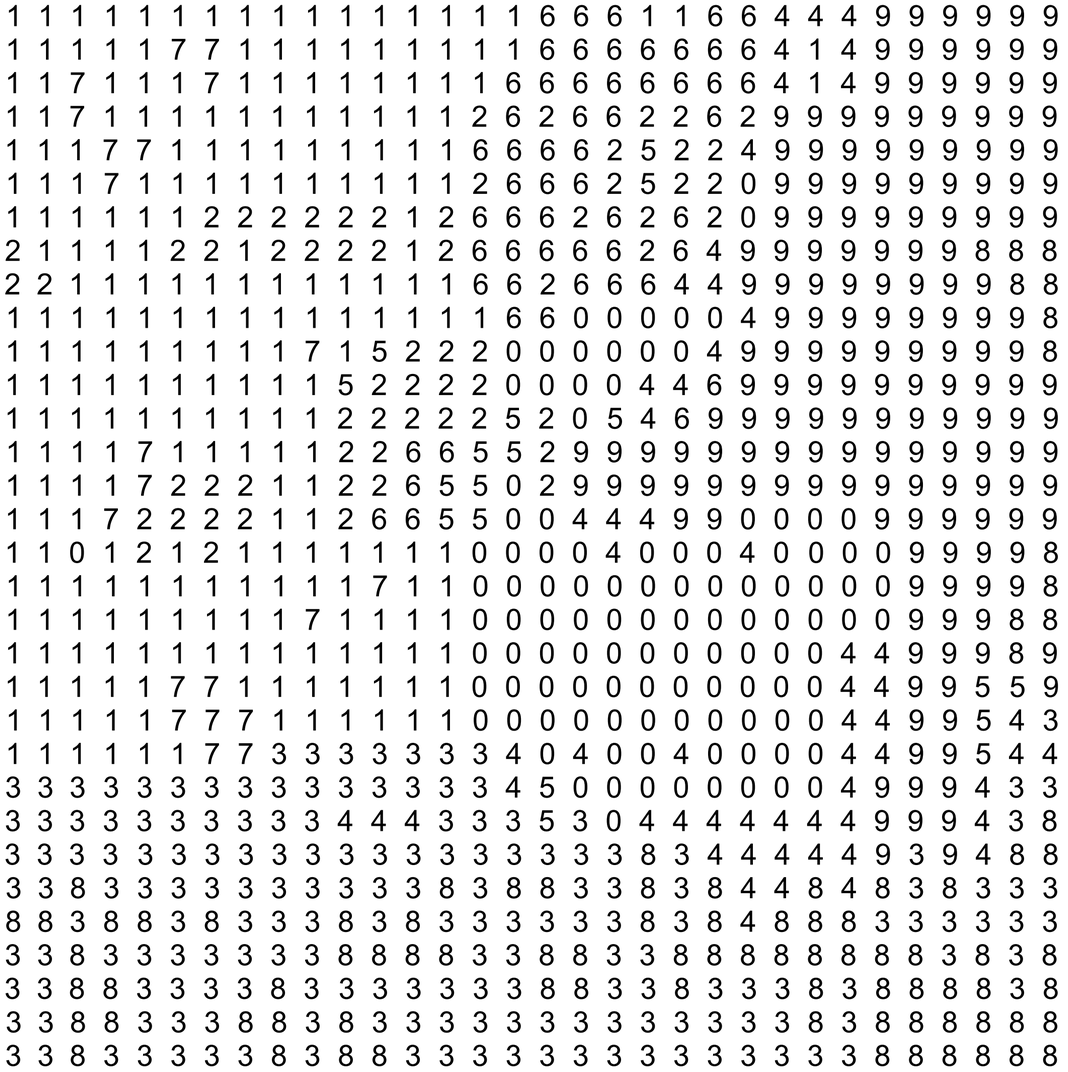
slide from Steve Seitz's video

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



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 6 6 6 6 6 6 4 1 4 9 9 9 9 9 9
1 1 7 1 1 1 7 1 1 1 1 1 1 1 1 6 6 6 6 6 6 6 6 4 1 4 9 9 9 9 9 9
1 1 7 1 1 1 1 1 1 1 1 1 1 1 2 6 2 6 6 2 2 6 2 9 9 9 9 9 9 9 9 9
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1 1 1 7 1 1 1 1 1 1 1 1 1 1 2 6 6 6 2 5 2 2 0 9 9 9 9 9 9 9 9 9
1 1 1 1 1 1 2 2 2 2 2 2 1 2 6 6 6 2 6 2 6 2 0 9 9 9 9 9 9 9 9 9
2 1 1 1 1 2 2 1 2 2 2 2 1 2 6 6 6 6 6 2 6 4 9 9 9 9 9 9 9 8 8 8
2 2 1 1 1 1 1 1 1 1 1 1 1 1 6 6 2 6 6 6 4 4 9 9 9 9 9 9 9 9 8 8
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 6 6 0 0 0 0 0 4 9 9 9 9 9 9 9 9 8
1 1 1 1 1 1 1 1 1 1 7 1 5 2 2 2 0 0 0 0 0 0 4 9 9 9 9 9 9 9 9 8
1 1 1 1 1 1 1 1 1 1 5 2 2 2 2 0 0 0 0 4 4 6 9 9 9 9 9 9 9 9 9 9
1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 5 2 0 5 4 6 9 9 9 9 9 9 9 9 9 9 9
1 1 1 1 7 1 1 1 1 1 2 2 6 6 5 5 2 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
1 1 1 1 7 2 2 2 1 1 2 2 6 5 5 0 2 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
1 1 1 7 2 2 2 2 1 1 2 6 6 5 5 0 0 4 4 4 9 9 0 0 0 0 9 9 9 9 9 9
1 1 0 1 2 1 2 1 1 1 1 1 1 1 0 0 0 0 4 0 0 0 4 0 0 0 0 9 9 9 9 8
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1 1 1 1 1 7 7 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 4 4 9 9 5 5 9
1 1 1 1 1 7 7 7 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 4 4 9 9 5 4 3
1 1 1 1 1 1 7 7 3 3 3 3 3 3 3 4 0 4 0 0 4 0 0 0 0 4 4 9 9 5 4 4
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 4 5 0 0 0 0 0 0 0 0 4 9 9 9 4 3 3
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3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 8 3 4 4 4 4 4 9 3 9 4 8 8
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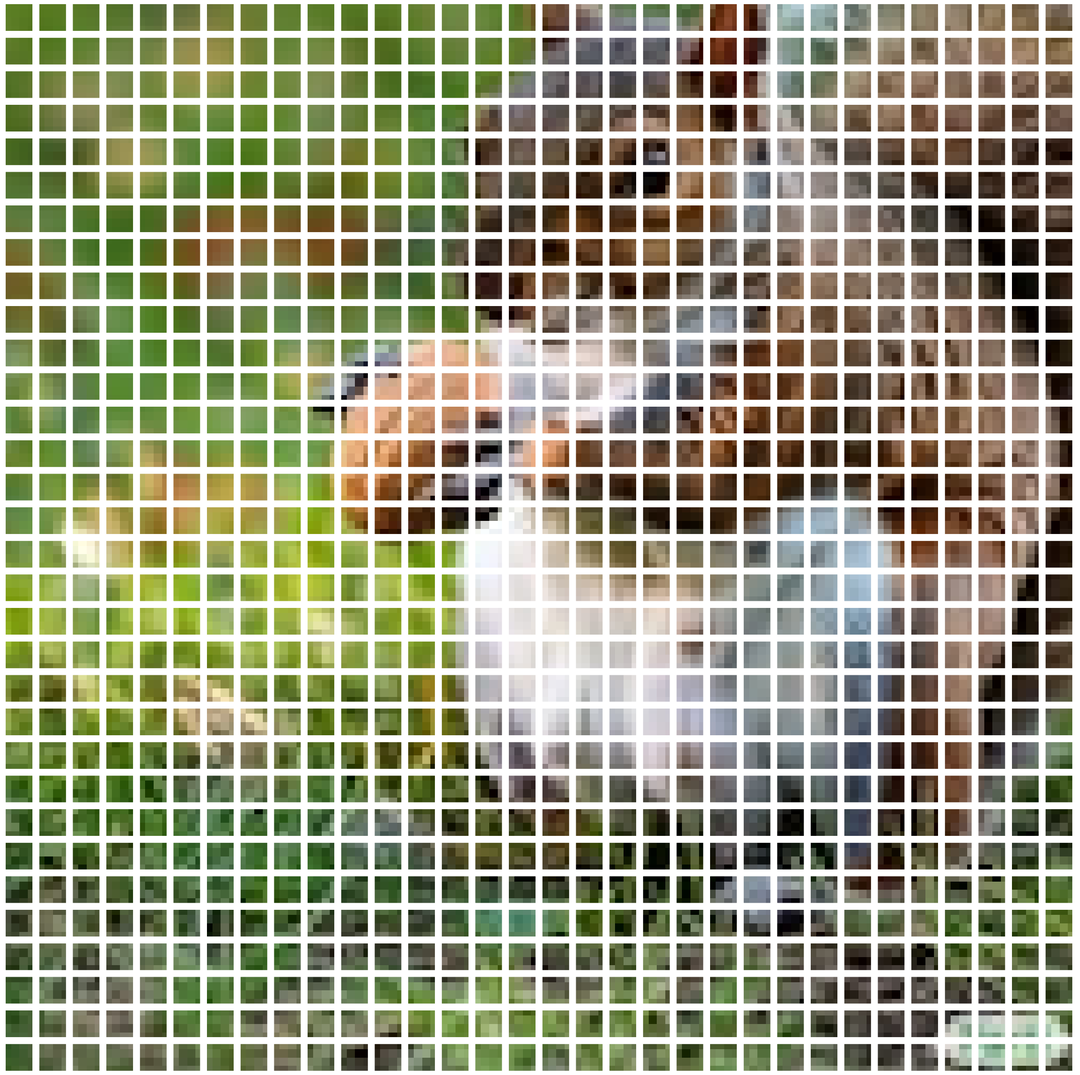
slide from Steve Seitz's video



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

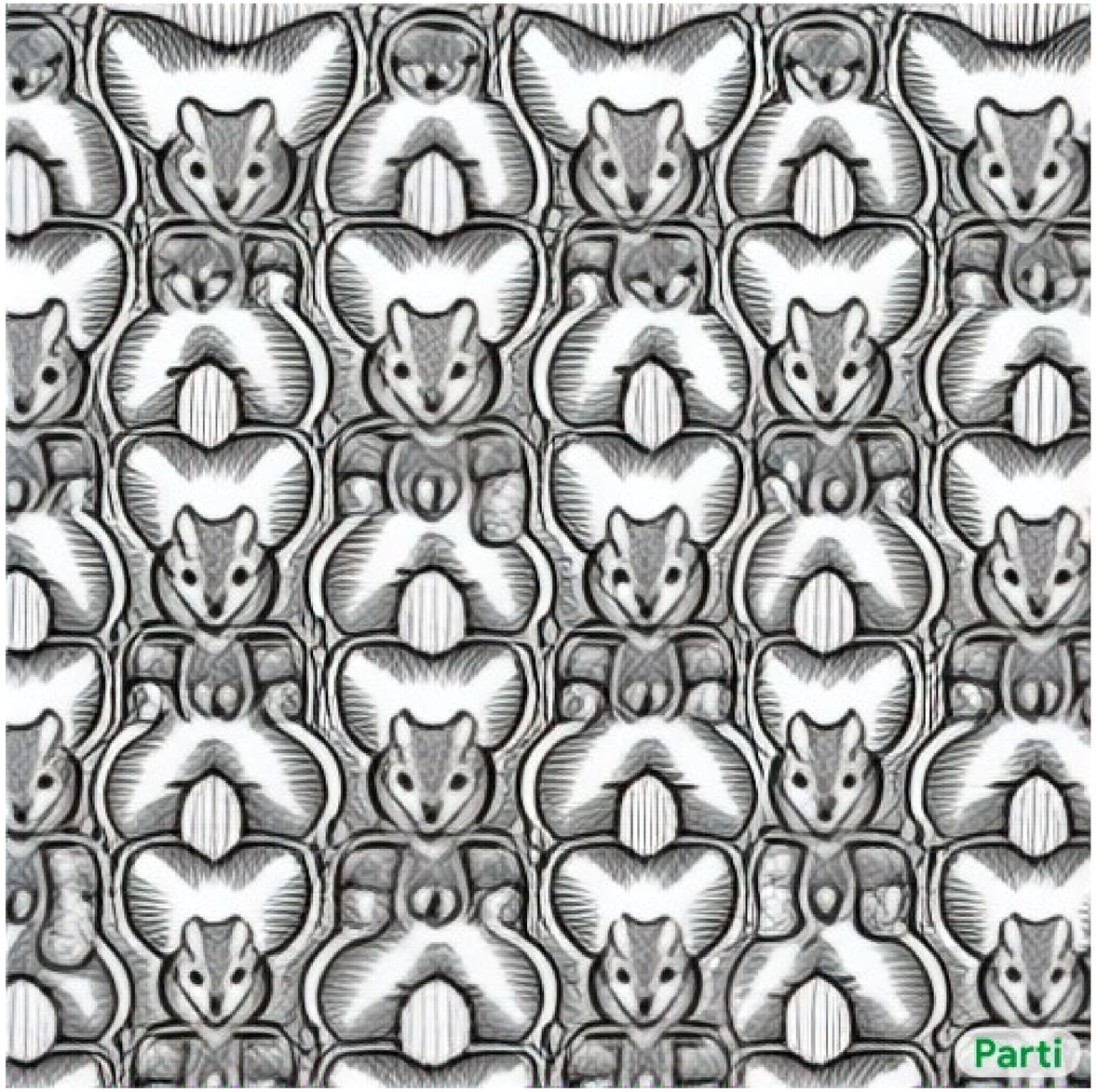
slide from Steve Seitz's video

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

Algorithm vs. Data

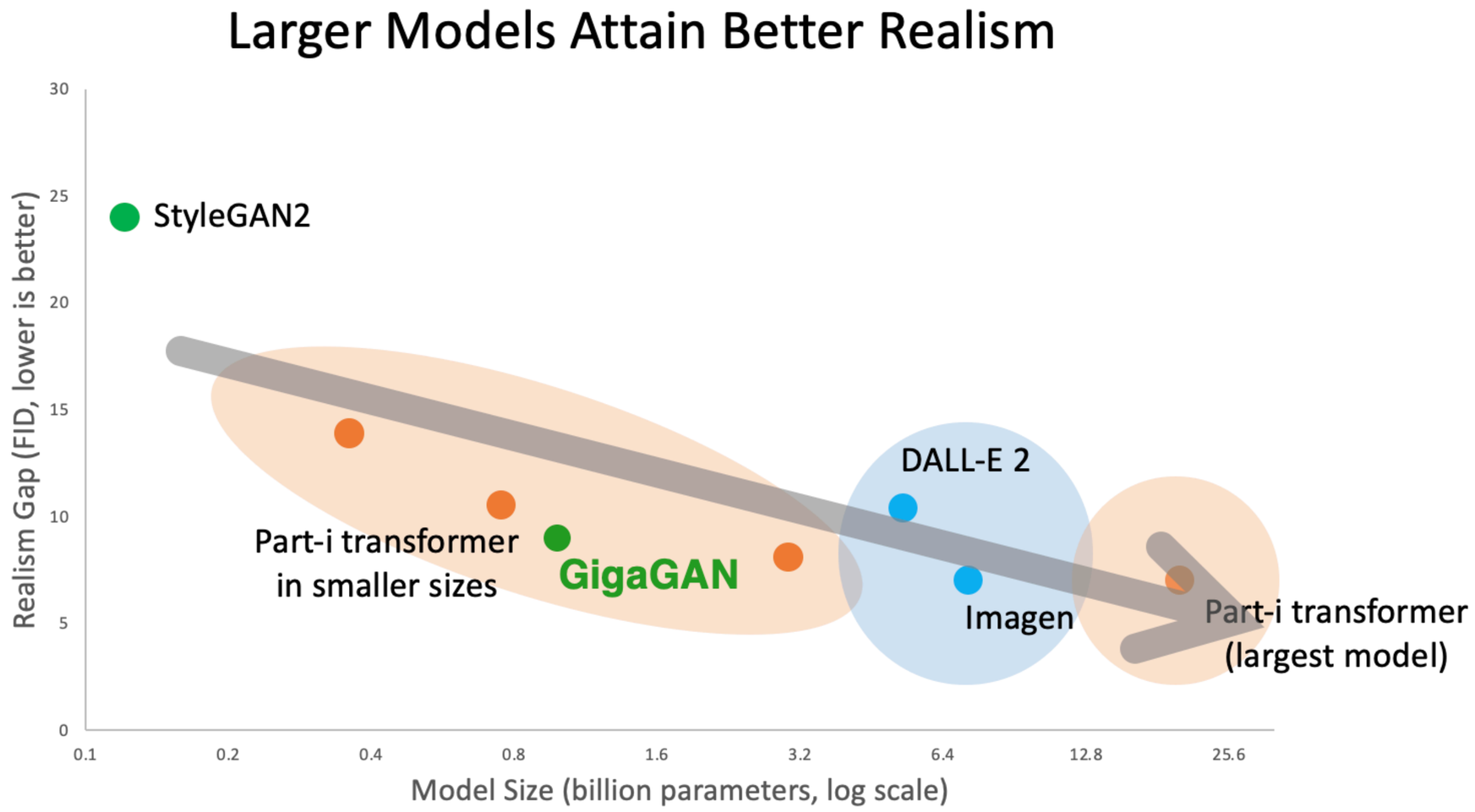
Diffusion-based

Auto-regressive

GAN-based

Prompt*: “squirrel reaching for a nut”*

data capacity vs. image quality



Graph by Taesung Park

Generative Magic

Prompt: “*a green creature made of leaves and vines bursting out of the ground ready to attack; detailed, best on artstation, raymond swanland, magic the gathering, epic, stunning, masterpiece*”

“influences” from the training data

generated image

Wang et al, Evaluating Data Attribution for Text-to-Image Models, ICCV 2023

to paraphrase Arthur C. Clarke:

Interpolation in sufficiently high-dimensional space is indistinguishable from magic