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 2023
Michel Gondry train video

http://www.youtube.com/watch?v=0S43lwBF0uM
“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!
Ideas going back over a hundred years…

Andrey Markov (1856-1922)
Claude Shannon (1916-2001)
Bela Julesz (1928-2003)
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
What if we know today and yesterday’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
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*
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 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 the sun was shining. I was laying in bed. Her hair was still red.

Wondering if she had changed at all if
Early one morning the sun was shining. I was laying in bed. Her hair still red. Wondering if she had changed at all.
Wondering if she had changed at all, her hair still red, the sun was shining. Early one morning, I was laying in bed. She had changed, I slide from Steve Seitz's video.
Wondering if she had changed at all, her hair still red, the sun was shining. Early one morning, she was laying in bed.
Wondering if she had changed at all, her hair still red, the sun was shining. Early one morning, I slide from Steve Seitz's video.
Early one morning the sun was shining. I was laying in bed. Her hair was still red. Wondering if she had changed at all.
Early one morning the sun was shining. I was laying in bed. Her hair was still red. Wondering if she had changed at all.
Early one morning

Wondering if she had changed at all

er hair was still red

the sun was shining

laying in bed

Early one morning
Early one morning the sun was shining. I was laying in bed, wondering if her hair was still red. I had changed at all.

slide from Steve Seitz's video
Wondering if she had changed at all her hair still red laying in bed Early one morning the sun was shining I Wondering if she had changed at all
Early one morning the sun was shining. I was laying in bed, wondering if her hair was still red. Wondering if she had changed at all.
Early one morning the sun was shining

Wondering if she had changed at all

Her hair still red

Laying in bed

slide from Steve Seitz's video
Early one morning the sun was shining. I was laying in bed. Wondering if her hair was still red, I wondered if she had changed at all.
Early one morning the sun was shining I was wondering if she had changed at all. Her hair was still red. I was laying in bed and wondering if she had changed at all.
Early one morning the sun was shining I was laying in bed. Wondering if her hair was still red, she had changed at all.
Early one morning the sun was shining I was laying in bed. Wondering if her hair still red, I 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, her hair still red.
Early one morning the sun was shining. I was laying in bed. Wondering if she had changed at all, her hair still red.
Early one morning the sun was shining I was laying in bed.
Wondering if she had changed at all.
Her hair still red.
Early one morning the sun was shining I was laying in bed
Wondering if she had changed at all

her hair still red

Wondering if she had changed at all

slide from Steve Seitz’s video
Early one morning the sun was shining I was laying in bed
Wondering if she had
Early one morning the sun was shining I was laying in bed
Wondering if she had changed
Early one morning the sun was shining I was laying in bed 
Wondering if she had changed at all 
her hair still red
Early one morning the sun was shining I was laying in bed
Wondering if she had changed at all
Early one morning the sun was shining I was laying in bed
Wondering if she had changed at all if
Early one morning the sun was shining I was laying in bed
Wondering if she had changed at all if her hair 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 still 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 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 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 red

slide from Steve Seitz's video
Wondering if she had changed at all, her hair was still red as the sun was shining. Early one morning I laid in bed, slide from Steve Seitz’s video.
Wondering if she had changed at all, her hair still red was shining. Early one morning the sun was laying in bed, shining on Steve Seitz’s video.
the sun was shining

Early one morning the sun was shining

Wondering if she had changed at all

her hair still red

laying in bed

slide from Steve Seitz’s video
Early one morning the sun was shining. I was laying in bed wondering if her hair was still red. She had changed at all.
Early one morning the sun was shining. I was laying in bed, wondering if she had changed at all. Her hair was still red.
Wondering if she had changed at all, her hair still red was shining. Early one morning, the sun was still red in bed. I slid from Steve Seitz’s video.
Wondering if she had changed at all, her hair still red was shining. Early one morning, the sun was still red laying in bed. Her hair was shining. A slide from Steve Seitz's video.
Wondering if she had changed at all, her hair was still red. Early one morning, the sun was shining. I was laying in bed. Her hair was still red. Wondering if she had changed at all, her hair was shining. Early one morning, the sun was shining. I was laying in bed. Her hair was still red. Wondering if she had changed at all, her hair was still red.
Wondering if she had changed at all, her hair was shining. The sun was still red, laying in bed. Early one morning, the sun was shining. Her hair was still red. Wondering if she had changed at all.
Wondering if she had changed at all, her hair was still red. Early one morning, the sun was shining. I lay in bed, slide from Steve Seitz's video.
Wondering if she had changed at all, her hair still red.

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

Wondering if she had changed at all.
the sun was shining in bed early one morning. her hair was still red. wondering if she had changed at all.
the sun was laying

Wondering if she had changed at all her hair still red

Early one morning the sun was shining

laying in bed
the sun was laying in bed

Early one morning the sun was shining. I Wondering if she had changed at all.

her hair still red
the sun was laying in bed

Early one morning the sun was shining I
her hair still red
Wondering if
she had changed at all
Wondering if she had changed at all, her hair still red, the sun was shining. Early one morning I was laying in bed, slide from Steve Seitz’s video.
I was wondering if she had changed at all.

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

Her hair was still red.

Wondering if she had changed at all.
I was shining

Wondering if she had changed at all

Early one morning the sun was shining

her hair still red

laying in bed

she had changed at all

slide from Steve Seitz’s video
I was shining I

Early one morning the sun was shining

Wondering if

she had changed at all

her hair still red

laying in bed
I was shining I was

Wondering if she had changed at all

Early one morning the sun was shining I

laying in bed

her hair still red

Wondering if she had changed at all

slide from Steve Seitz's video
Early one morning the sun was shining.

Wondering if she had changed at all.

Her hair was still red.
I was shining I was shining I

Wondering if she had changed at all

her hair still red

laying in bed

Early one morning the sun was shining

she had changed at all

slide from Steve Seitz's video
I was shining I was shining I was

Wondering if she had changed at all her hair still red

Early one morning the sun was shining I laying in bed

Wondering if she had changed at all
I was shining I was shining I was still.

Wondering if she had changed at all.

Her hair still red.

Early one morning the sun was shining.

Laying in bed.

She had changed at all.

slide from Steve Seitz’s video
I was shining I was shining I was still red

Wondering if she had changed at all

Early one morning the sun was shining I

her hair still red

laying in bed

Wondering if she had changed at all
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
Wondering if she had changed at all, her hair still red was shining, laying in bed. Early one morning the sun was shining. I wondered if she had changed at all.
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

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 the sun was shining I was laying in bed
Wondering if she had changed at all if her hair was still red

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

trigrams
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
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.

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

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

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

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:

$$C_{i \rightarrow j} = D_{i+1, j}$$
Transition probabilities

• Probability for transition $P_{i \rightarrow j}$ inversely related to cost:

  $P_{i \rightarrow j} \sim \exp \left( - \frac{C_{i \rightarrow j}}{\sigma^2} \right)$

high $\sigma$  low $\sigma$
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

User selects target frame range

slow variable fast
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:

\[ C_{i\rightarrow j} = \alpha C_{i\rightarrow j} + \beta \text{angle} \]

Animation

Similarity term

Control term

vector to mouse pointer

velocity vector
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
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
Homage to Shannon
Image Analogies

Aaron Hertzmann\textsuperscript{1,2}
Chuck Jacobs\textsuperscript{2}
Nuria Oliver\textsuperscript{2}
Brian Curless\textsuperscript{3}
David Salesin\textsuperscript{2,3}

\textsuperscript{1}New York University
\textsuperscript{2}Microsoft Research
\textsuperscript{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'
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

Unfiltered source (A)  Filtered source (A')

Unfiltered target (B)  Filtered target (B')
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

Task examples

Query

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

$10^{70}$ combinations
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 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 the sun was shining. I was laying in bed. Wondering if she had changed at all if her hair was still red.
Function Approximation

Fourier Series: $f(x) = \sin(\pi x) + \sin(2\pi x) + \sin(3\pi x) + \sin(4\pi x) + \ldots$

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

Neural Network: $f(x) = \begin{array}{c}
\vdots \\
n(\text{hidden layers}) \\
\vdots \\
\end{array}$
\[ \sin(x) - \frac{x^2}{10} \]
\( P(x_n|x_{n-1}, x_{n-2}, x_{n-3}, x_{n-4}, x_{n-5}, x_{n-6}, x_{n-7}, \ldots) \)
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 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 the sun was shining, I was laying in bed wondering if she had changed at all if her hair was still red.
56,356
zenith

92,487
zygote

slide from Steve Seitz's video
word2vec
[Collobert & Weston 2008; Mikolov et al. 2013]

house, where the professor lived without his wife and child; or so he said jokingly sometimes: “Here’s where I live. My house.” His daughter often added, without resentment, for the visitor’s information, “It started out to be for me, but it’s really his.” And she might reach in to bring forth an inch-high table lamp with fluted shade, or a blue dish the size of her little fingernail, marked “Kitty” and half full of eternal wick, but she was sure to replace these, after they had been admired, pretty near exactly where they had been. The little house was very orderly, and just big enough for all it contained, though to some tastes the bric-à-brac in the parlor might seem excessive. The daughter’s preference was for the store-bought gimmicks and appliances, the toasters and carpet sweepers of Lilliput, but she knew that most adult visitors would
Word Embedding (e.g., word2Vec, GloVe)
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.

neural network

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
bed

hair was still red
Wondering if she had changed at all if her hair was still in bed.
Wondering if she had changed at all if her hair was still
Wondering if she had changed at all if her hair was still in bed.
Two roads diverged 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*
Wondering if she had changed at all if her hair was still.
Wondering if she had changed at all if her hair was still.
Wondering
if she had changed at all if her hair was still

next word prediction

brown

Train
Wondering if she had changed at all if her hair was still red from Steve Seitz's video.

Transformer
Wondering if she had changed at all if her hair was still in bed. Attention slide from Steve Seitz’s video.
Wondering if she had changed at all if her hair was still in bed.
Wondering if she had changed at all if her hair was still in bed.
Wondering if she had changed at all if hair was still = C

slide from Steve Seitz's video
attention

in bed Wondering if she had changed at all if her hair was still
Wondering if she had changed at all if her hair was still in bed. Attention slide from Steve Seitz's video:
Wondering if she had at all if her hair was still changed.5 .1 .2 .1 still changed slide from Steve Seitz's video
Wondering if her hair was still changed. 

\( C \text{_{still}} \text{= C}_{\text{changed}} \) 

\( 0.1 \text{Wondering} + 0.1 \text{if} + 0.5 \text{she} + 0.2 \text{had} + 0.1 \text{changed} = C_{\text{changed}} \) 

slide from Steve Seitz's video
Wondering if she had changed at all if her hair was still in bed slide from Steve Seitz's video
Wondering if she had changed at all if her hair was still.
Wondering if she had changed at all if her hair was still.
Wondering if she had changed at all if her still hair was still in bed...
Attention prediction

Attention
looking possible getting
It's a slide from Steve Seitz's video.
It's a lot of attention prediction from Steve Seitz's video.
It's a lot of attention prediction from Steve Seitz's video.
It's a lot of fun for Steve Seitz's video.
It's a lot of fun.
The 16th president was Abraham.
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?
prediction

attention

96 (GPT-3) 118 (Palm)

prediction

attention

prediction

attention
prediction

attention

...
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
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
a haiku about a turtle and a stop sign
a haiku about a turtle and a stop sign

Turtle at the stop sign
waiting for the perfect moment
to cross the busy road
translate “tangled up in blue” to 5 languages
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
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
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.
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
.
○
○ ○ ○
.
○ ○
a pattern of characters that looks like a vertical line

. ○ .
. ○ .
. ○ .
. ○ .
. ○ .
a pattern of characters that looks like a triangle

.  o  .
.  o  o  .
.  o  o  o  .
.  o  o  o  o  .
.  o  o  o  o  o  .

slide from Steve Seitz’s video
slide from Steve Seitz's video
raspberries  pancakes  sunsets

1 Billion

slide from Steve Seitz's video
Large Language Model
A white raspberry image

Large Language Model

slide from Steve Seitz's video
Large Language Model
Large Language Model

slide from Steve Seitz’s video
1,000,000s of pixels

1,000s of words

slide from Steve Seitz's video
32 × 32 = 1024

Visual words
squirrel reaching for a nut
squirrel reaching for a nut
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

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

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
squirrel reaching for a nut
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