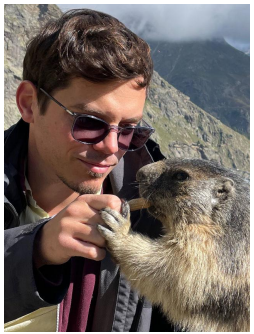
The Dual Form of Neural Networks Revisited

Connecting Test Time Predictions to Training Patterns via Spotlights of Attention

Kazuki Irie*

Róbert Csordás*



Jürgen Schmidhuber

* **Two first authors**

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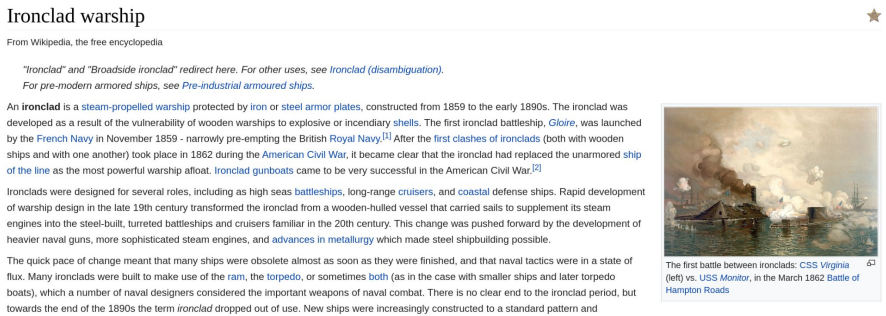
Motivating example

- Language model trained e.g. on Wikipedia articles
- Let it do predictions on a new article



Ironclad warship

From Wikipedia, the free encyclopedia

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Ironclads were designed for several roles, including as high seas battleships, long-range cruisers, and coastal defense ships. Rapid development of warship design in the late 19th century transformed the ironclad from a wooden-hulled vessel that carried sails to supplement its steam engines into the steel-built, turreted battleships and cruisers familiar in the 20th century. This change was pushed forward by the development of heavier naval guns, more sophisticated steam engines, and advances in metallurgy which made steel shipbuilding possible.

The quick pace of change meant that many ships were obsolete almost as soon as they were finished, and that naval tactics were in a state of flux. Many ironclads were built to make use of the ram, the torpedo, or sometimes both (as in the case with smaller ships and later torpedo boats), which a number of naval designers considered the important weapons of naval combat. There is no clear end to the ironclad period, but towards the end of the 1890s the term *ironclad* dropped out of use. New ships were increasingly constructed to a standard pattern and

The first battle between ironclads: CSS *Virginia* (left) vs. USS *Monitor*, in the March 1862 Battle of Hampton Roads

Or any other modalities you prefer…
(image generation…)

Can we tell which training sentences/articles are helping its predictions?

Duality: Linear Layer vs. Attention Layer

Following two systems are equivalent

Key/Value-Attention Layer

Store:

$$\boldsymbol{K} = (\boldsymbol{k}_1, ..., \boldsymbol{k}_T) \in \mathbb{R}^{d_{\text{in}} \times T}$$

$$\boldsymbol{V} = (\boldsymbol{v}_1, ..., \boldsymbol{v}_T) \in \mathbb{R}^{d_{\text{out}} \times T}$$

Compute: input $\boldsymbol{x} \in \mathbb{R}^{d_{\text{in}}}$

$$S_2(\boldsymbol{x}) = \text{Attention}(\boldsymbol{K}, \boldsymbol{V}, \boldsymbol{x})$$

NB: Unnormalised dot attention

$$\text{Attention}(\boldsymbol{K}, \boldsymbol{V}, \boldsymbol{q}) = \boldsymbol{V}\boldsymbol{K}^\intercal \boldsymbol{q}$$

vs. standard attention: $\boldsymbol{V}\,\text{softmax}(\boldsymbol{K}^\intercal \boldsymbol{q})$

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$$S_2(\boldsymbol{x}) = \text{Attention}(\boldsymbol{K}, \boldsymbol{V}, \boldsymbol{x})$$

Linear Layer

$$\boldsymbol{W} = \sum_{t=1}^{T} \boldsymbol{v}_t \otimes \boldsymbol{k}_t$$

$$S_1(\boldsymbol{x}) = \boldsymbol{W}\boldsymbol{x}$$

NB: Unnormalised dot attention

$$\text{Attention}(\boldsymbol{K}, \boldsymbol{V}, \boldsymbol{q}) = \boldsymbol{V}\boldsymbol{K}^\intercal\boldsymbol{q}$$

vs. standard attention: $\boldsymbol{V}\text{softmax}(\boldsymbol{K}^\intercal\boldsymbol{q})$

Application to Linear Layers Trained by GD

Forward computation:

$$\boldsymbol{y} = \boldsymbol{W}\boldsymbol{x}$$

Backward computation (**gradient descent**) to **update W**:

outer product

$$\boldsymbol{W}_{t+1} = \boldsymbol{W}_t \underbrace{-\eta_t(\nabla_{\boldsymbol{y}}\mathcal{L})_t}_{\boldsymbol{e}_t} \otimes \boldsymbol{x}_t$$

for some error function $\mathcal{L}$ learning rate η_t at step $t \in \mathbb{N}$

Application to Linear Layers Trained by GD

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Trained weight matrix $\boldsymbol{W} = \boldsymbol{W}_0 + \sum_{t=1}^{T} \boldsymbol{e}_t \otimes \boldsymbol{x}_t$

We can directly apply the duality from the previous slide!

Duality (Corollary)

Linear layer trained by gradient descent

Store: $$\boldsymbol{W} = \boldsymbol{W}_0 + \sum_{t=1}^{T} \boldsymbol{e}_t \otimes \boldsymbol{x}_t$$

Compute: $$S_1(\boldsymbol{x}) = \boldsymbol{W}\boldsymbol{x}$$

Key/Value/Attention memory storing entire training experience

$$\boldsymbol{E} = (\boldsymbol{e}_1, ..., \boldsymbol{e}_T) \in \mathbb{R}^{d_{\text{out}} \times T}$$

$$\boldsymbol{X} = (\boldsymbol{x}_1, ..., \boldsymbol{x}_T) \in \mathbb{R}^{d_{\text{in}} \times T}$$

$$S_2(\boldsymbol{x}) = \boldsymbol{W}_0\boldsymbol{x} + \text{Attention}(\boldsymbol{X}, \boldsymbol{E}, \boldsymbol{x})$$

Matrix-version of Perceptron/Kernel Machine Duality (Aizerman et al. 1964)

Consequences/Remarks

Conceptual Remarks

- Nothing is forgotten (but it is still equivalent to a fixed storage linear layer)
- Good retrieval mechanism (capacity to selectively remember) is crucial for exploiting the memory (cf. softmax attention in Transformer)
- Etc…

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Practical Consequences

- With the dual form, we can visualise the attention from test examples (query) to training patterns (keys).

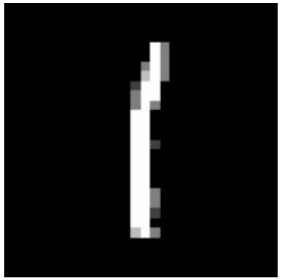
Continual Learning Experiments

- **Phase 1: Train on MNIST**
  → Test accuracy of 97% on MNIST

- **Phrase 2: Train on Fashion-MNIST**
  → Test accuracy of 85% on Fashion-MNIST, 45% on MNIST

But *nothing is forgotten*, right?

What happens exactly?

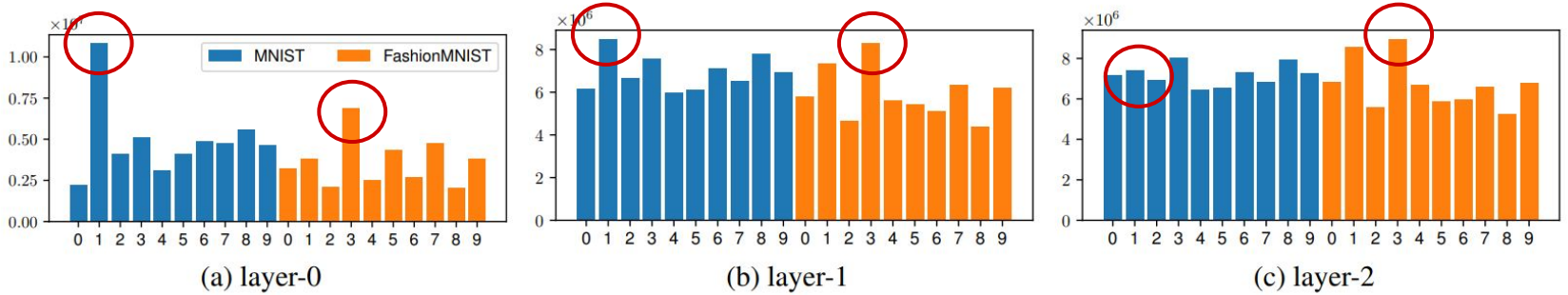


(d) MNIST, 1

(b) F-MNIST, 3 (dress)

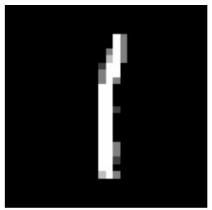
MNIST then F-MNIST: Attention Interference…

Example MNIST class-1 image misclassified as class 3



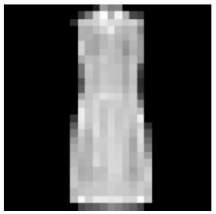
x-axis: classes (separately for MNIST and F-MNIST)

y-axis: sum of attention scores per class



(d) MNIST, 1

MNIST class 1



(e) F-MNIST, 3 (dress)

(b) F-MNIST, 3 (dress)

F-MNIST class 3

Language Modelling

(warship)

Test

Ironclad warship

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Language Modelling

(warship)

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Train

Portuguese ironclad *Vasco da Gama*

From Wikipedia, the free encyclopedia

Vasco da Gama was an ironclad of the Portuguese Navy built in the 1870s by the Thames Iron Works in London. Ordered to strengthen the defenses of the Portuguese capital of Lisbon, *Vasco da Gama* was launched in 1876 and completed in 1878. She served as the flagship of the Portuguese fleet for the majority of her long and peaceful career. She was rebuilt and heavily modernized between 1901 and 1903. Her crew was involved in revolts in 1913 and 1914; during the latter event, they bombarded Lisbon and killed around one hundred people. Long-since obsolete by the 1930s, *Vasco da Gama* was finally sold for scrapping in 1935.

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1 Design
1.1 Modifications
2 Service history
3 Notes
4 References

(warship)

Vasco da Gama at the opening of the Kaiser Wilhelm Canal in 1895

History
Portugal

Design [edit]

Vasco de Gama was the only capital ship to be built for the Portuguese Navy; ordered from a British shipyard, she was intended to defend the

Train

SMS *Markgraf*

From Wikipedia, the free encyclopedia

SMS *Markgraf*[4] was the third battleship of the four-ship *König* class. She served in the Imperial German Navy during World War I. The battleship was laid down in November 1911 and launched on 4 June 1913. She was formally commissioned into the Imperial Navy on 1 October 1914, just over two months after the outbreak of war in Europe. *Markgraf* was armed with ten 30.5-centimeter (12.0 in) guns in five twin turrets and could steam at a top speed of 21 knots (39 km/h; 24 mph). *Markgraf* was named in honor of the royal family of Baden. The name Markgraf is a rank of German nobility and is equivalent to the English Margrave, or Marquess.

Along with her three sister ships, *König*, *Grosser Kurfürst*, and *Kronprinz*, *Markgraf* took part in most of the fleet actions during the war, including the Battle of Jutland on 31 May and 1 June 1916. At Jutland, *Markgraf* was the third ship in the German line and heavily engaged by the opposing British Grand Fleet; she sustained five large-caliber hits and her crew suffered 23 casualties. *Markgraf* also participated in Operation Albion, the conquest of the Gulf of Riga, in late 1917. The ship was damaged by a mine while en route to Germany following the successful conclusion of the operation.

After Germany's defeat in the war and the signing of the Armistice in November 1918, *Markgraf* and most of the capital ships of the High Seas Fleet were interned by the Royal Navy in Scapa Flow. The ships were disarmed and reduced to skeleton crews while the Allied powers negotiated the final version of the Treaty of Versailles. On 21 June 1919, days before the treaty was signed, the commander of the interned fleet, Rear Admiral Ludwig von Reuter, ordered the fleet to be scuttled to ensure that the British would not be able to seize the ships. Unlike most of the scuttled ships, *Markgraf* was never raised for scrapping; the wreck is still sitting on the bottom of the bay.

Recognition drawing of a *König*-class battleship

History
German Empire
Builder AG Weser, Bremen
Laid down November 1911
Launched 4 June 1913
Commissioned 1 October 1914
Fate Scuttled 21 June 1919 in Gutter

(warship)

Train

Italian cruiser *Aretusa*

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Aretusa was a torpedo cruiser of the *Partenope* class built for the Italian *Regia Marina* (Royal Navy) in the 1880s. Laid down in June 1889 at the Cantiere navale fratelli Orlando shipyard, she was launched in March 1891 and was commissioned in September 1892. Her main armament were her six torpedo tubes, which were supported by a battery of ten small-caliber guns. *Aretusa* spent most of her career in the main Italian fleet, where she was primarily occupied with training exercises. At the start of the Italo-Turkish War in September 1911, she was assigned to the Red Sea Squadron in Italian Eritrea. She bombarded Ottoman positions in the Arabian Peninsula and took part in a blockade of the coast. Worn out by the end of the war in October 1912, *Aretusa* was sold for scrap that December and broken up.

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Aretusa in 1895

History
Italy
Name *Aretusa*
Namesake Arethusa

(warship)

Language Modelling

(warship)

Test

Train

(warship)

Train

(warship)

Train

(singer)

(warship)

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Aretusa in 1895

History	
Italy	
Name	*Aretusa*
Namesake	Arethusa

Nina Simone

From Wikipedia, the free encyclopedia

Eunice Kathleen Waymon (February 21, 1933 – April 21, 2003), known professionally as **Nina Simone**, was an American singer, songwriter, pianist, and civil rights activist. Her music spanned styles including classical, folk, gospel, blues, jazz, R&B, and pop.

The sixth of eight children born to a poor family in Tryon, North Carolina, Simone initially aspired to be a concert pianist.[1] With the help of a few supporters in her hometown, she enrolled in the Juilliard School of Music in New York City.[2] She then applied for a scholarship to study at the Curtis Institute of Music in Philadelphia, where she was denied admission despite a well received audition,[3] which she attributed to racism. In 2003, just days before her death, the Institute awarded her an honorary degree.[4]

To make a living, Simone started playing piano at a nightclub in Atlantic City. She changed her name to "Nina Simone" to disguise herself from family members, having chosen to play "the devil's music"[5] or so-called "cocktail piano". She was told in the nightclub that she would have to sing to her own accompaniment, which effectively launched her career as a jazz vocalist.[3] She went on to record more than 40 albums between 1958 and 1974, making her debut with *Little Girl Blue*. She had a hit single in the United States in 1958 with "I Loves You, Porgy".[3] Her musical style fused gospel and pop with classical music, in particular Johann Sebastian Bach,[6] and accompanied expressive, jazz-like singing in her contralto voice.[7][8]

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1.2 1954–1958: Early success
1.3 1959–1964: Burgeoning popularity
1.4 1964–1974: Civil Rights era
1.5 1974–1993: Later life
1.6 1993–2003: Final years, illness and death
2 Activism

Simone in 1965

Nina Simone	
Background information	
Birth name	Eunice Kathleen Waymon
Born	February 21, 1933 Tryon, North Carolina, U.S.
Died	April 21, 2003 (aged 70) Carry-le-Rouet, France
Genres	classical - folk - gospel - blues

Language Modelling

(warship)

(warship)

(warship)

(singer)

Query (*Ironclad warship*)	... Her **principal** role was for combat in the English Channel and other European ...
Top-1 (*Portuguese ironclad*) Top-2 (*SMS Markgraf*) Top-3 (*Italian cruiser Aretusa*)	Her sailing rig also was removed . Her **main** battery guns were replaced with new ... ... between the two funnels . Her **secondary** armament consisted of fourteen 15 cm ... single mounts . Her **primary** offensive weapon was her five 450 mm.
Negative (*Nina Simone*)	... written especially for the singer . Her **first** hit song in America was her rendition ...

Thank you for your attention.

 https://github.com/robertcsordas/linear_layer_as_attention

Hope to see you at the poster!