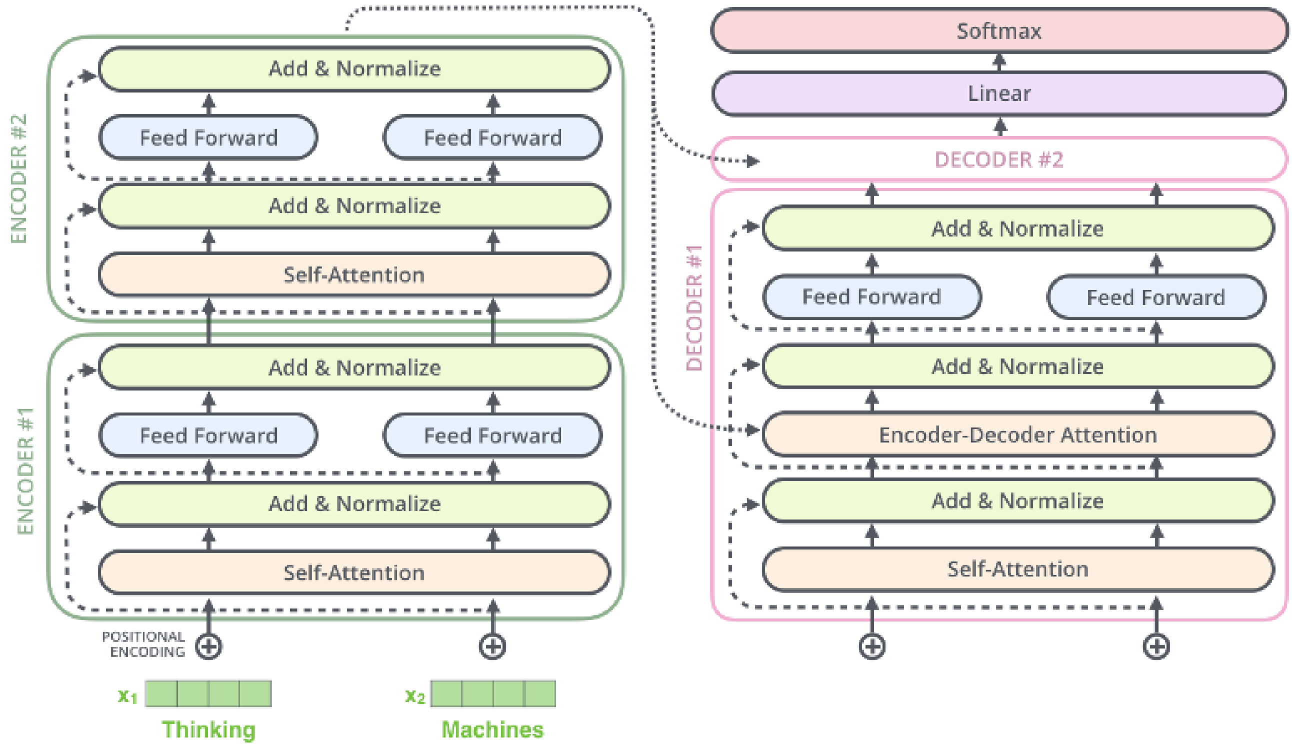

Softmax
Linear
DECODER #2
ENCODER #2
Add & Normalize
Feed Forward
Feed Forward
Add & Normalize
Self-Attention
ENCODER #1
Add & Normalize
Feed Forward
Feed Forward
Add & Normalize
Self-Attention
DECODER #1
Add & Normalize
Feed Forward
Feed Forward
Add & Normalize
Encoder-Decoder Attention
Add & Normalize
Self-Attention
POSITIONAL ENCODING
x1
x2
Thinking
Machines

Sentiment analysis using a transformer

Model evaluation

Table of Contents

Restart

```julia
begin
    import Pkg
    Pkg.activate(mktempdir())
    Pkg.develop(url="https://github.com/rgreilly/Transformers")
    Pkg.add(["Revise", "PlutoUI", "Flux", "Plots", "DataFrames", "Printf",
        "BSON", "JSON", "Arrow", "StatsBase", "Unicode", "Random",
        "DataStructures", "ProgressMeter", "RemoteFiles"])

    using Revise
    using TransformersLite
    using PlutoUI
    using Flux
    using Flux: DataLoader
    using Plots
    using DataFrames
    using Printf
    using BSON, JSON
    using Arrow
    using StatsBase
    using Unicode
    using Random
    using DataStructures
    using ProgressMeter
    using RemoteFiles
end;
```

```
  Activating new project at `C:\Users\alexm\AppData\Local\Temp\jl_xnjEWG
`
     Cloning git-repo `https://github.com/rgreilly/Transformers`
Path `C:\Users\alexm\.julia\dev\TransformersLite` exists and looks like the
correct repo. Using existing path.
   Resolving package versions...
    Updating `C:\Users\alexm\AppData\Local\Temp\jl_xnjEWG\Project.toml`
  [6579f8b0] + TransformersLite v0.1.0 `C:\Users\alexm\.julia\dev\Transforme
rsLite`
    Updating `C:\Users\alexm\AppData\Local\Temp\jl_xnjEWG\Manifest.toml`
  [621f4979] + AbstractFFTs v1.5.0
⌅ [79e6a3ab] + Adapt v3.7.2
  [dce04be8] + ArgCheck v2.3.0
  [69666777] + Arrow v2.7.0
  [31f734f8] + ArrowTypes v2.3.0
  [a9b6321e] + Atomix v0.1.0
  [ab4f0b2a] + BFloat16s v0.4.2
  [fbb218c0] + BSON v0.3.7
  [198e06fe] + BangBang v0.3.39
  [9718e550] + Baselet v0.1.1
  [c3b6d118] + BitIntegers v0.3.1
⌅ [fa961155] + CEnum v0.4.2
⌅ [052768ef] + CUDA v4.4.1
  [1af6417a] + CUDA_Runtime_Discovery v0.2.2
  [082447d4] + ChainRules v1.58.1
  [d360d2e6] + ChainRulesCore v1.19.0
  [5ba52731] + CodecLz4 v0.4.1
  [6b39b394] + CodecZstd v0.8.1
  [bbf7d656] + CommonSubexpressions v0.3.0
  [34da2185] + Compat v4.10.1
  [a33af91c] + CompositionsBase v0.1.2
  [f0e56b4a] + ConcurrentUtilities v2.3.0
  [187b0558] + ConstructionBase v1.5.4
  [6add18c4] + ContextVariablesX v0.1.3
```

```
begin
    @RemoteFileSet FILES "Transformer utilities" begin
        reporting = @RemoteFile
    "https://github.com/rgreilly/Transformers/blob/main/examples/reporting.jl"
    dir="utilities" file="reporting.jl.json"
        utilities = @RemoteFile
    "https://github.com/rgreilly/Transformers/blob/main/examples/utilities.jl"
    dir="utilities" file="utilities.jl.json"
        training = @RemoteFile
        "https://github.com/rgreilly/Transformers/blob/main/examples/training.jl"
        dir="utilities" file="training.jl.json"
    end

    download(FILES) # Files downloaded in JSON format
end
```

convertJSON (generic function with 1 method)

```
function convertJSON(inFile, outFile)
    body = JSON.parsefile(inFile)["payload"]["blob"]["rawLines"]
    open(outFile, "w") do f
      for i in body
        println(f, i)
      end
    end
end
```

```
begin
    convertJSON("utilities/reporting.jl.json", "utilities/reporting.jl")
    convertJSON("utilities/utilities.jl.json", "utilities/utilities.jl")
    convertJSON("utilities/training.jl.json", "utilities/training.jl")

    include("utilities/reporting.jl")
    include("utilities/utilities.jl")
    include("utilities/training.jl")
end;
```

Multi-class classification: stars from 1 to 5

Load data

The original CSV data format has been converted to arrow format for faster loading.

```
begin
    path = "datasets/amazon_reviews_multi/en/1.0.0/"
    file_train = "train.arrow"
    file_test = "test.arrow"
    nlabels = 5
end;
```

Load training and test data into dataframes and about the size of both.

```
(205000, 5000)
```

```
begin
    filepath = joinpath(path, file_train)
    df = DataFrame(Arrow.Table(filepath))

    filepath = joinpath(path, file_test)
    df_test = DataFrame(Arrow.Table(filepath))

    (nrow(df), nrow(df_test))
end
```

Extract just the review text and the star rating

```
begin
    documents = df[:, "review_body"]
    labels = df[:, "stars"]

    println("training samples: ", size(documents), " ", size(labels))
end
```

```
training samples: (205000,) (205000,)
```

Do the same for the test data

```
begin
    documents_test = df_test[:, "review_body"]
    labels_test = df_test[:, "stars"];

    println("test samples: ", size(documents_test), " ", size(labels_test))
end
```

```
test samples: (5000,) (5000,)
```

Load the already trained and saved model. Note that models and associated details are stored in the `outputs` directory under a sub-directory name generated from the time it was saved in the format: `yyyymmdd_hhmm`.

```julia
begin
        directory = "../outputs/20231219_1608/" #CHANGE HERE
    saved_objects = BSON.load(joinpath(directory, "model.bson"))
    tokenizer = saved_objects[:tokenizer]
    @show tokenizer
    indexer = saved_objects[:indexer]
    @show indexer
    model = saved_objects[:model]
    display(model)
end;
```

```
tokenizer = identity
indexer = IndexTokenizer{String}(length(vocabulary)=6654, unksym=[UNK])
TransformerClassifier(
  Embed((32, 6654)),                    # 212_928 parameters
  PositionEncoding(32),
  Dropout(0.1),
  TransformerEncoderBlock(
    MultiheadAttention(num_heads=4, head_size=8, 32=>32)(
      denseQ = Dense(32 => 32),         # 1_056 parameters
      denseK = Dense(32 => 32),         # 1_056 parameters
      denseV = Dense(32 => 32),         # 1_056 parameters
      denseO = Dense(32 => 32),         # 1_056 parameters
    ),
    Dropout(0.1),
    LayerNorm(32),                      # 64 parameters
    Dense(32 => 128, relu),             # 4_224 parameters
    Dense(128 => 32),                   # 4_128 parameters
    Dropout(0.1),
    LayerNorm(32),                      # 64 parameters
  ),
  Dense(32 => 1),                       # 33 parameters
  FlattenLayer(),
  Dense(50 => 5),                       # 255 parameters
)         # Total: 21 trainable arrays, 225_920 parameters,
          # plus 1 non-trainable, 32_000 parameters, summarysize 1009.188 KiB.
```

Tokenise

Tokenise the training and test data

```
begin
    max_length = size(model.classifier.weight, 2)
    @time tokens = map(d->preprocess(d, tokenizer, max_length=max_length),
    documents) #takes about 30 seconds for all documents
    @time indices = indexer(tokens) #takes about 12 seconds for all documents

    y_train = copy(labels)
    idxs = Base.OneTo(length(labels))
    X_train, y_train = indices[:, idxs], y_train[idxs];
    y_train = Flux.onehotbatch(y_train, 1:5) # multi-class
    train_data, val_data = split_validation(X_train, y_train;
        rng=MersenneTwister(2718))

    println("train samples:      ", size(train_data[1]), " ", size(train_data[2]))
    println("validation samples: ", size(val_data[1]), " ", size(val_data[2]))
end
```

```
  4.125783 seconds (28.48 M allocations: 1.786 GiB, 16.44% gc time)
 12.979427 seconds (4 allocations: 79.765 MiB)
train samples:      (50, 184500) (5, 184500)
validation samples: (50, 20500) (5, 20500)
```

```
begin
    y_test = copy(labels_test)
    y_test = Flux.onehotbatch(y_test, 1:5);

    @time tokens_test = map(d->preprocess(d, tokenizer, max_length=max_length),
    documents_test)
    @time indices_test = indexer(tokens_test)

    X_test = indices_test

    println("test indices: ", size(indices_test))
    println("test samples: ", size(X_test), " ", size(y_test))
end
```

```
  0.100063 seconds (718.85 k allocations: 46.182 MiB, 26.17% compilation ti
me)
  0.307723 seconds (19 allocations: 1.946 MiB, 1.12% compilation time)
test indices: (50, 5000)
test samples: (50, 5000) (5, 5000)
```

Create the training and validation data loaders

```
321-element DataLoader(::Tuple{Matrix{Int64}, OneHotArrays.OneHotMatrix{UInt32, Vector{UI
  with first element:
  (50×64 Matrix{Int64}, 5×64 OneHotMatrix(::Vector{UInt32}) with eltype Bool,)
```

```
begin
    train_data_loader = DataLoader(train_data; batchsize=64, shuffle=false);
    val_data_loader  = DataLoader(val_data; batchsize=64, shuffle=false);
end
```

Evaluate

```
accuracy (generic function with 1 method)
```

```
begin
    loss(x, y) = Flux.logitcrossentropy(model(x), y)
    loss(x::Tuple) = loss(x[1], x[2])
    accuracy(ŷ, y) = mean(Flux.onecold(ŷ) .== Flux.onecold(y))
end
```

```
0.5520271002710027
```

```
@time batched_metric(model, accuracy, train_data_loader)
```

```
39.119026 seconds (6.73 M allocations: 56.692 GiB, 8.86% gc time, 10.61% compilation time)
```

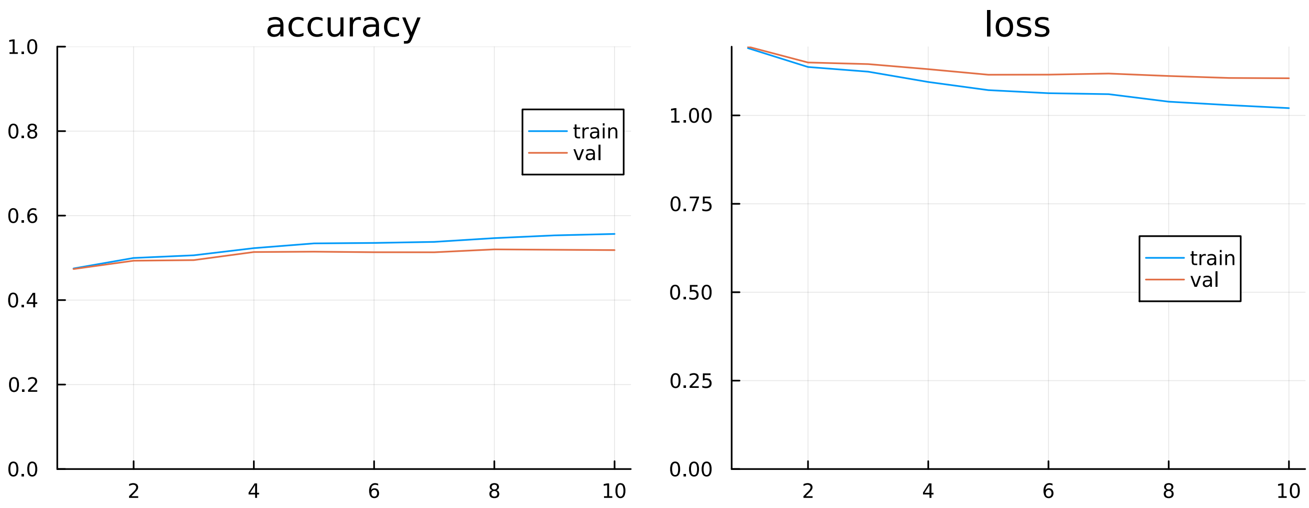
```
0.5595121951219513
```

```
@time batched_metric(model, accuracy, val_data_loader)
```

```
3.695079 seconds (100.34 k allocations: 6.257 GiB, 9.76% gc time)
```

```
history =
  Dict("train_loss" ⇒ [1.19026, 1.13687, 1.12365, 1.0945, 1.07144, 1.06278, 1.06003, 1.03
```

```
history = open(joinpath(directory, "history.json"), "r") do f
    JSON.parse(read(f, String))
end
```




```
begin
    epochs = 1:length(history["train_acc"])
    p1 = plot(epochs, history["train_acc"], label="train")
    plot!(p1, epochs, history["val_acc"], label="val")
    plot!(p1, ylims=[0, 1], title="accuracy", legend=(0.9, 0.8))

    p2 = plot(epochs, history["train_loss"], label="train")
    plot!(p2, epochs, history["val_loss"], label="val")
    plot!(p2, title="loss", ylims=[0, Inf], legend=(0.8, 0.5))

    p3 = plot(p1, p2, layout=grid(1, 2), size=(800, 300))
    savefig(p3, joinpath(directory, "history.png"))
    p3
end
```

Test data

```
0.5242
```

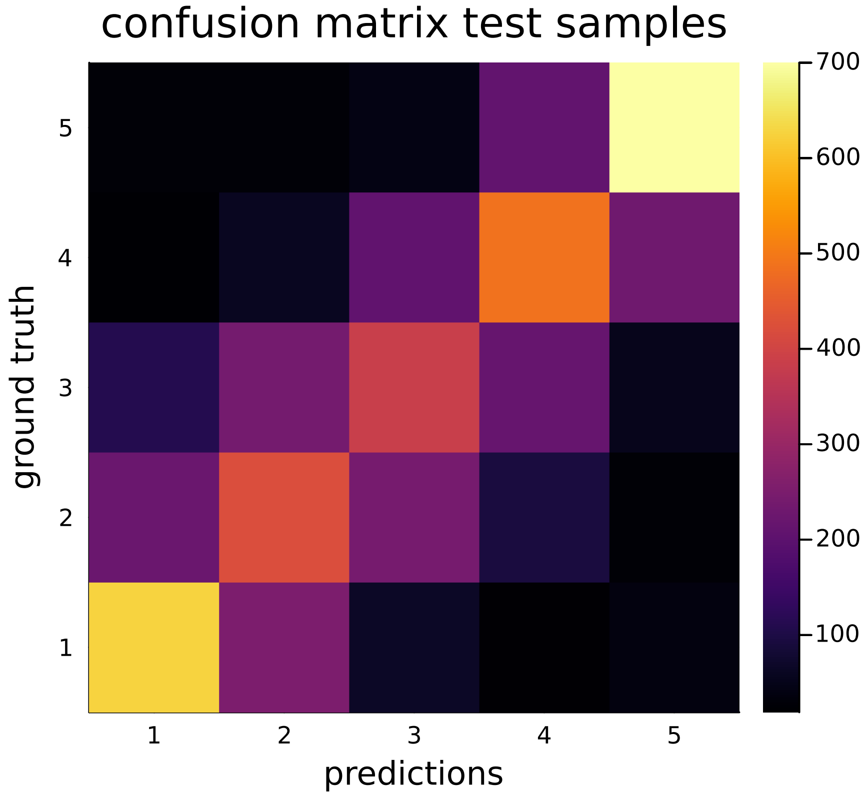
```
begin
    logits = model(X_test)
    accuracy(logits, y_test)
end
```

```
[1, 1, 1, 2, 2, 1, 4, 1, 2, 1, 3, 1, 1, 2, 1, 1, 2, 1, 2, 2,    more ,3, 5, 1, 5, 2, 3, 5, 5
```

```
begin
    probs = softmax(logits, dims=1)
    y_pred = Flux.onecold(probs);
end
```

```
cm = 5×5 Matrix{Int64}:
 627  252   64   21   36
 221  421  242   92   24
 110  239  385  215   51
  19   57  206  488  230
  25   26   41  208  700
```

```
cm = confusion_matrix(vec(y_pred), Flux.onecold(y_test), 1:nlabels)
```




```
begin
    p4 = heatmap(1:5, 1:5, cm, xlabel="predictions", ylabel="ground truth", xlims=
    (0.5, nlabels+0.5), aspectratio=1,
        title="confusion matrix test samples", xticks=(1:5)) #, ["negative", "mix",
    "positive"]))
    savefig(p4, joinpath(directory, "confusion_matrix.png"))
    p4
end
```

```
classification_report(cm, 1:nlabels)
```

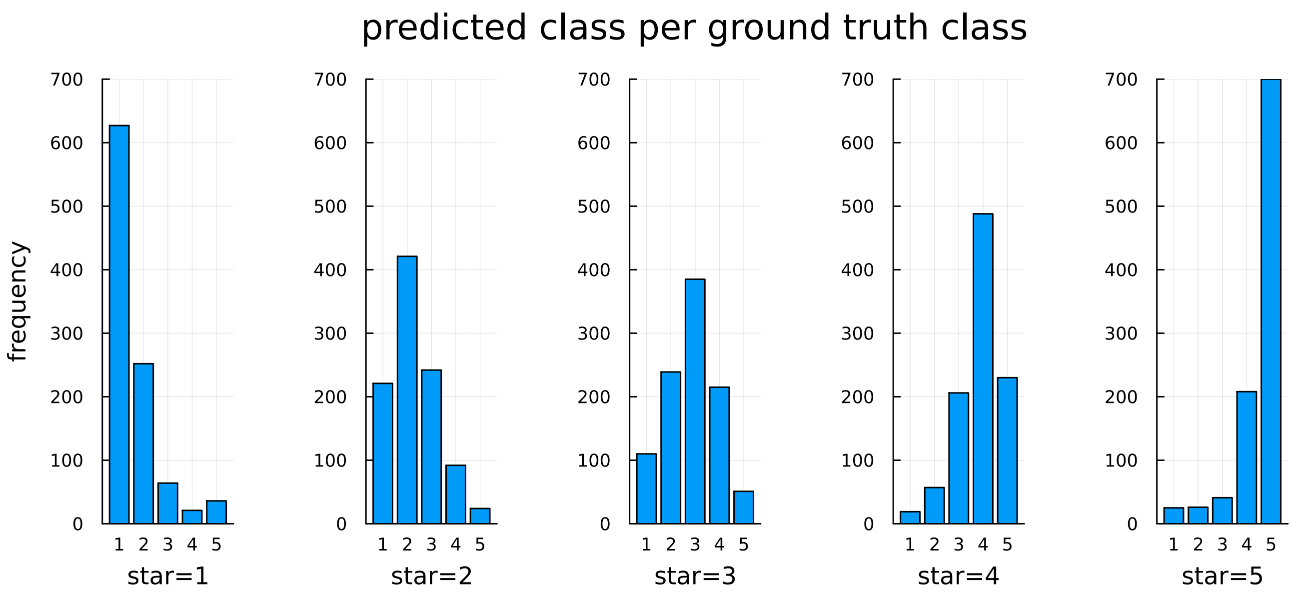
```
                precision    recall  f1-score   support
           1         0.63      0.63      0.63      1000
           2         0.42      0.42      0.42      1000
           3         0.41      0.39      0.40      1000
           4         0.48      0.49      0.48      1000
           5         0.67      0.70      0.69      1000

weighted avg         0.52      0.52      0.52      5000
```

Examples

```
begin
    println("star  y  ŷ   prob")
    for star in nlabels:-1:1
        pos_max = argmax(probs[star, :])
        @printf("   %1d  %d  %d  %.4f\n %s\n\n",
                star, labels_test[pos_max], y_pred[pos_max], probs[star, pos_max],
    documents_test[pos_max]
                )
    end
end
```

```
star  y  ŷ   prob
   5  5  5  0.9818
 Best USB cable I ever owned. Fit and finish are top notch. Highly recommende
d.

   4  4  4  0.9047
 I like the case, it works well. I wish it came in purple. The only complaint
I have is that it doesn't charge well on the cordless charger.

   3  3  3  0.6972
 Works ok kinda cheap

   2  4  2  0.6562
 The cover and shams look as pictured. Very soft and comfortable. Its very del
icate, I tore a hole by the zipper very easily. I did not return cover because
it was super cheap.

   1  1  1  0.9905
 I didn't even want to give this 1 star! This is a piece of JUNK! Terrible mad
e! I am having. Such a HARD TIME RETURNING THIS PRODUCT! Don't WASTE YOUR MONE
Y. It looks like these toys were made for a doll house. Wrongly advertised!
```

Probabilities




```
begin
    canvases1 = []
    label_names = 1:5
    for gt_star in 1:5
        idxs = labels_test .== gt_star
        value_counts = [sum((y_pred[idxs]) .== l) for l in 1:nlabels]
        p = bar(value_counts, xlabel="star=$gt_star",legend=:none, xticks=
    (1:nlabels, 1:5))#["neg", "mix", "pos"]))
        push!(canvases1, p)
    end
    plot!(canvases1[1], ylabel="frequency")
    p5 =plot(canvases1..., layout=(1, 5), link=:y, size=(900, 400),
    plot_title="predicted class per ground truth class",
        margin=5Plots.mm)
    savefig(p5, joinpath(directory, "prediction_star.png"))
    p5
end
```

Single sample

```julia
begin
    idx = 4600

    d = documents_test[idx]
    println(labels_test[idx])
    println(d)
    println("")

    tokens2 = preprocess(d, tokenizer, max_length=50)
    println(join(tokens2, "|"))
    println("")

    x = indexer(tokens2)
    x = vcat(x, ones(Int, 50 - length(x)))
    println(join(x, "|"))
end
```

```
5
I used for a party and was great !

used|for|party|and|was|great

89|7|764|4|14|29|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1
```

```
5×1 Matrix{Float32}:
 0.0014079323
 0.00606461
 0.028641572
 0.2757954
 0.6880905
```

```julia
softmax(model(x))
```

Conclusion

Quick disclaimer, I was unable to run the training data after changing it as the training was taking over double the time it took to run it initially. Later on it wouldn't even get past the model creation stage without any changes that couls possibly break it. The Train_multi.jl/pdf is the same as the file that was used to generate the output for this evaluation

The reason why I was able to slightly improve the model's performance was because I added some transformerEncoderBlocks, one of which made use of Attention heads to improve the models capacity to capture complex patterns and to focus on different elements of the input. I also added some dense layers. I added dropout layers to prevent overfitting.

Apart from this I experimented with different values for the Dropout Rate to prevent overfitting aswell as the size of the embedding to find a sweet spot.

```
md"""
# Conclusion

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I also added some dense layers.
I added dropout layers to prevent overfitting.

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"""
```