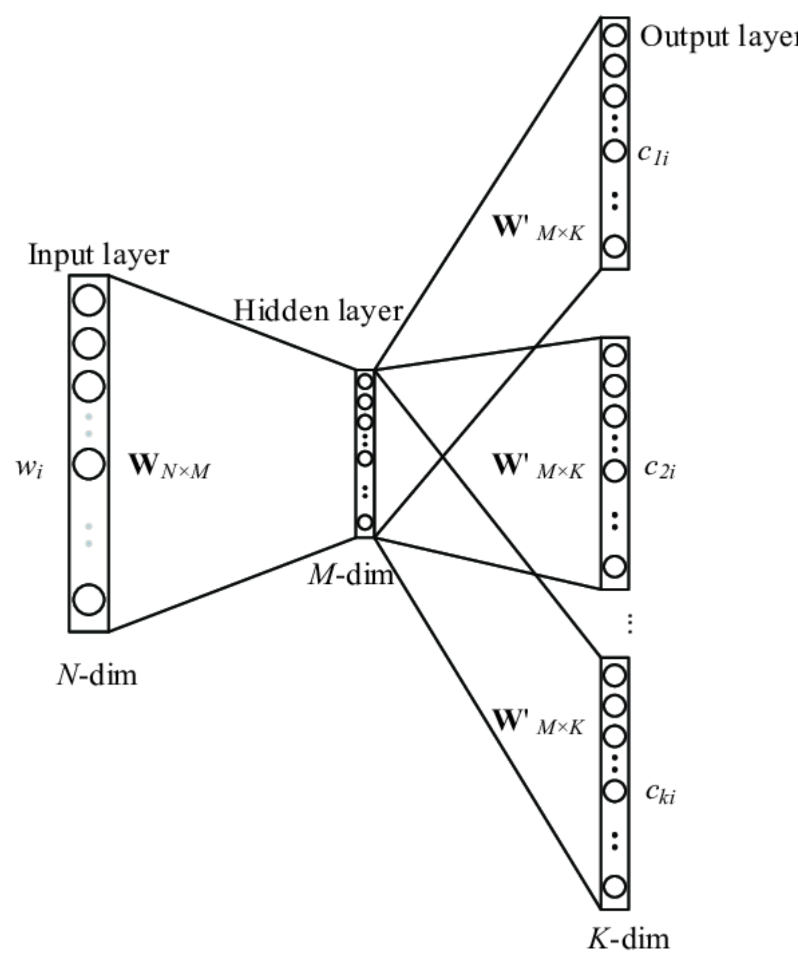
Language Models

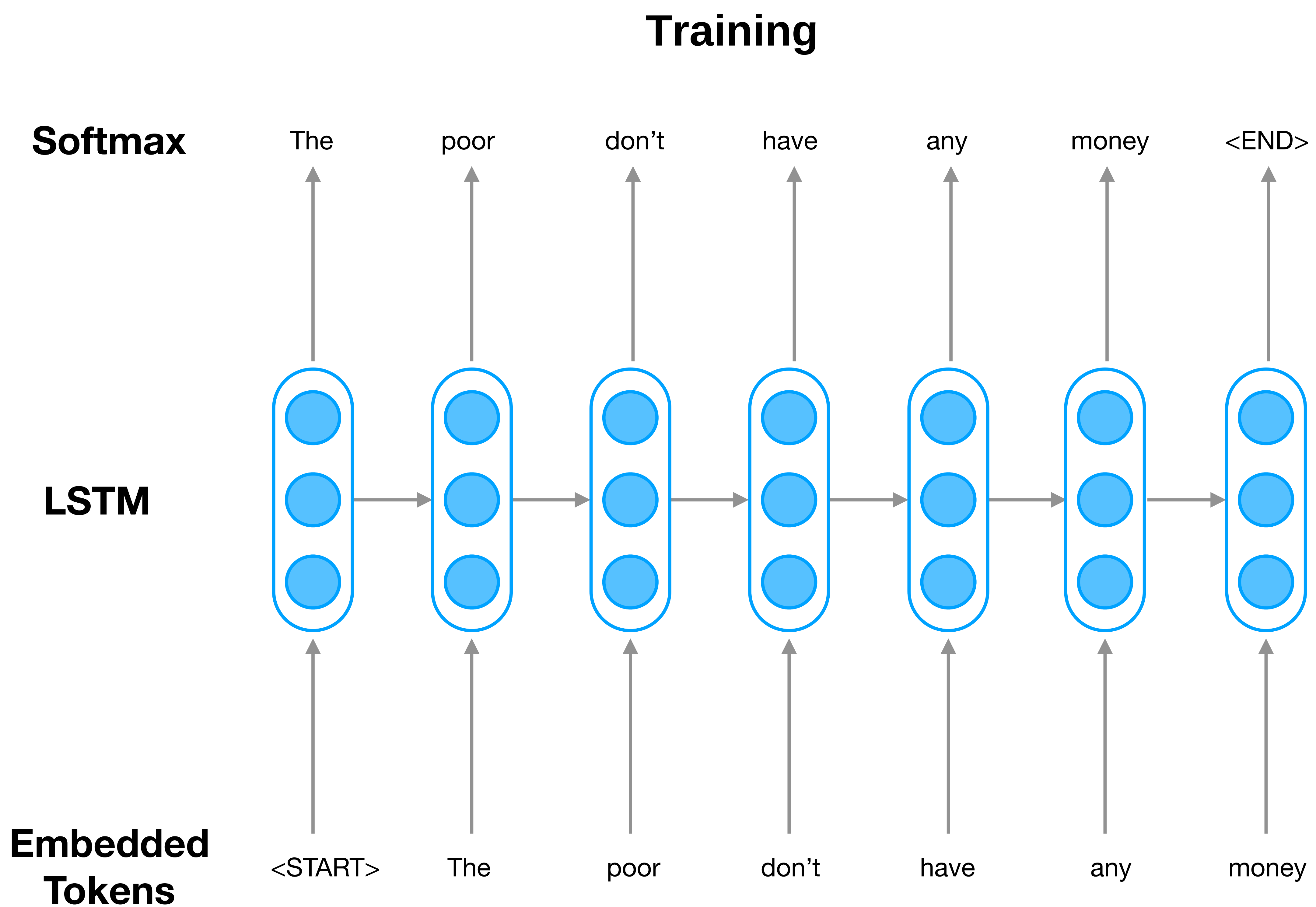
Word Embeddings

w2v, glove, etc

- Just key—value storage at inference
- Don’t change from relationships with other words in the current text

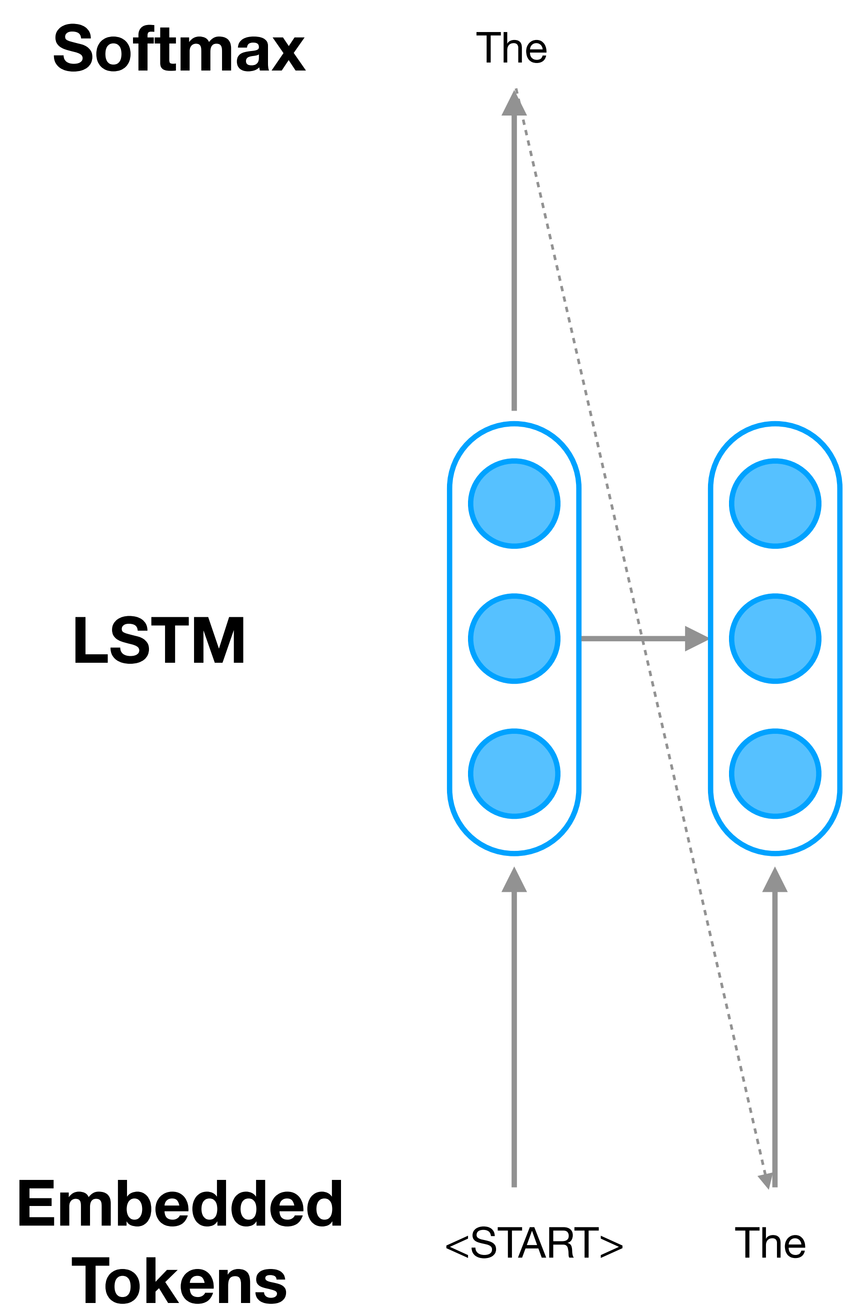


Language Model



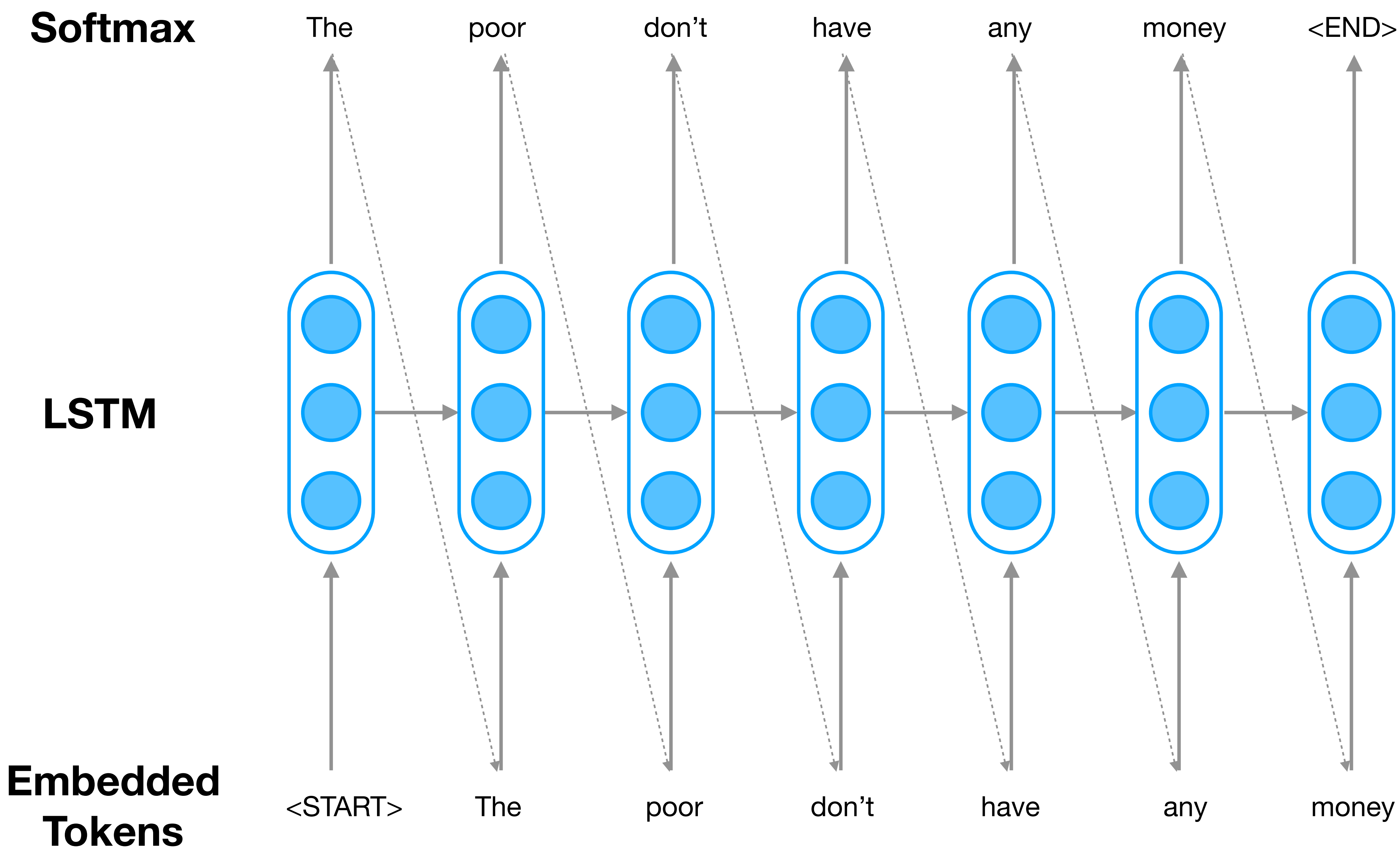
Language Model

Prediction

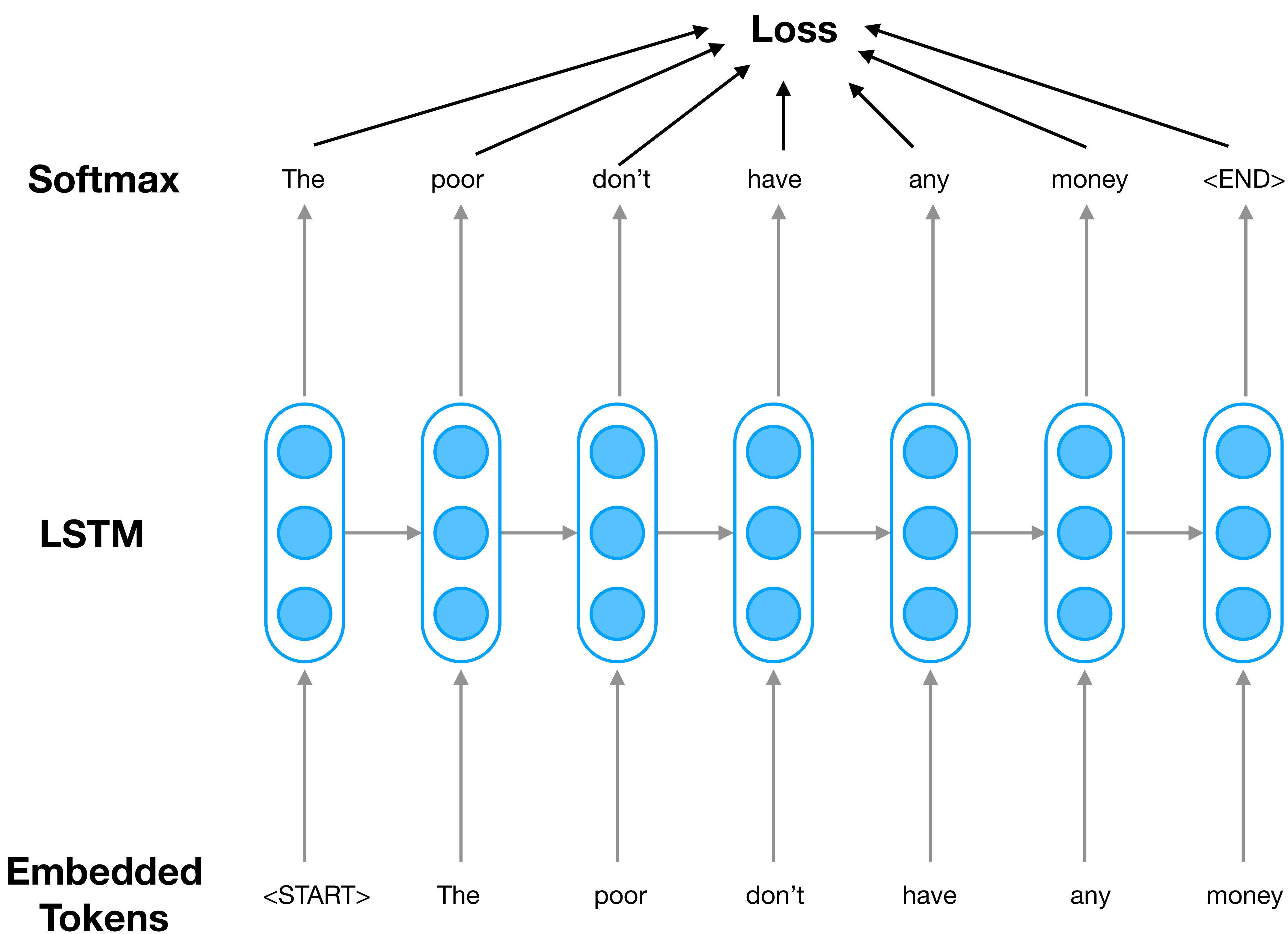


Language Model

$$p(\mathbf{x}) = \prod_i p(x|x_{<i}) = p(x_0)p(x_1|x_0)p(x_2|x_0, x_1)\ldots$$



Language Model



Language Model

X	<START>	The	poor	
Y				don’t

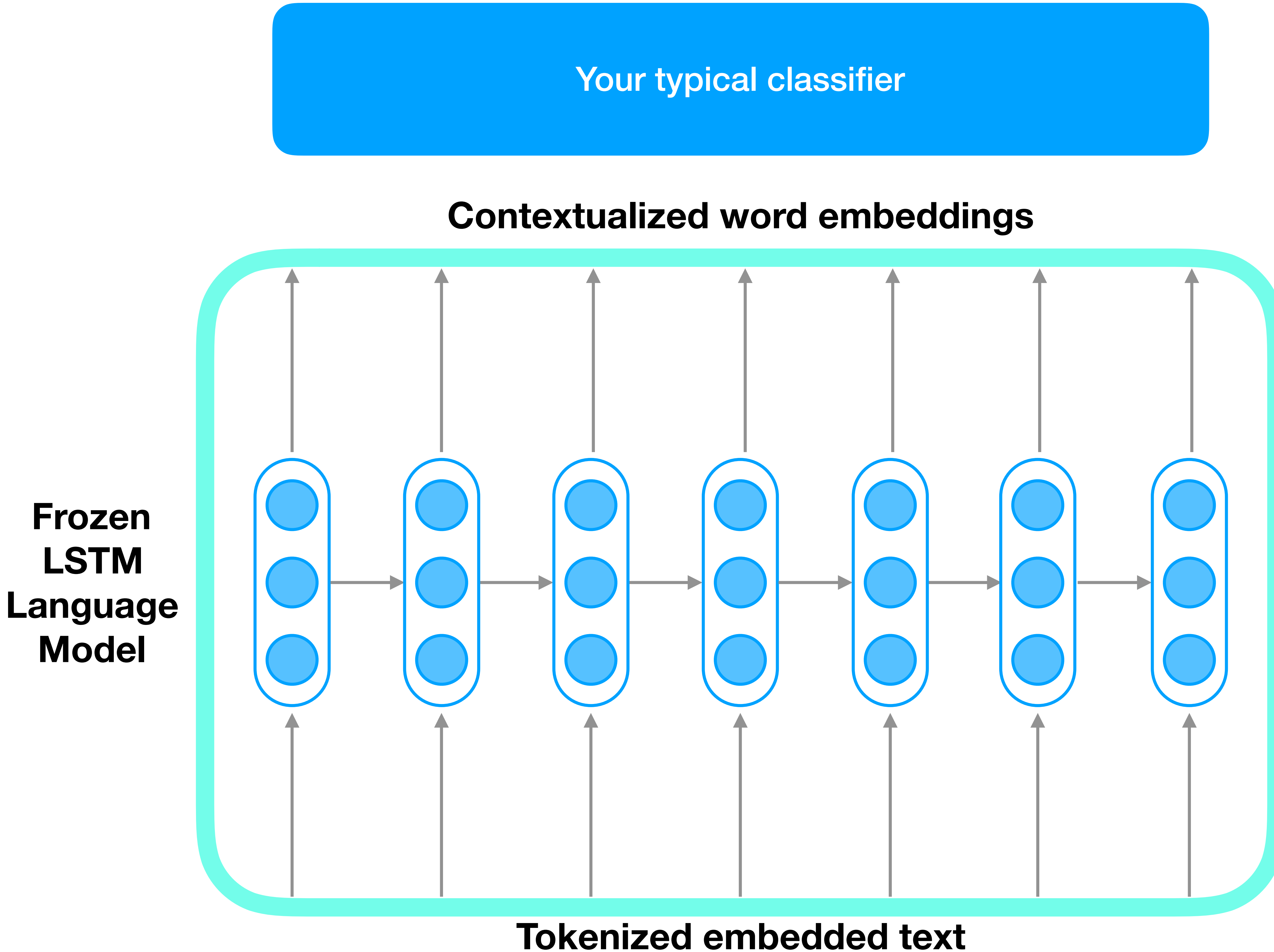
Language Model

X	<START>	The	poor	don’t	
Y					have

Language Model

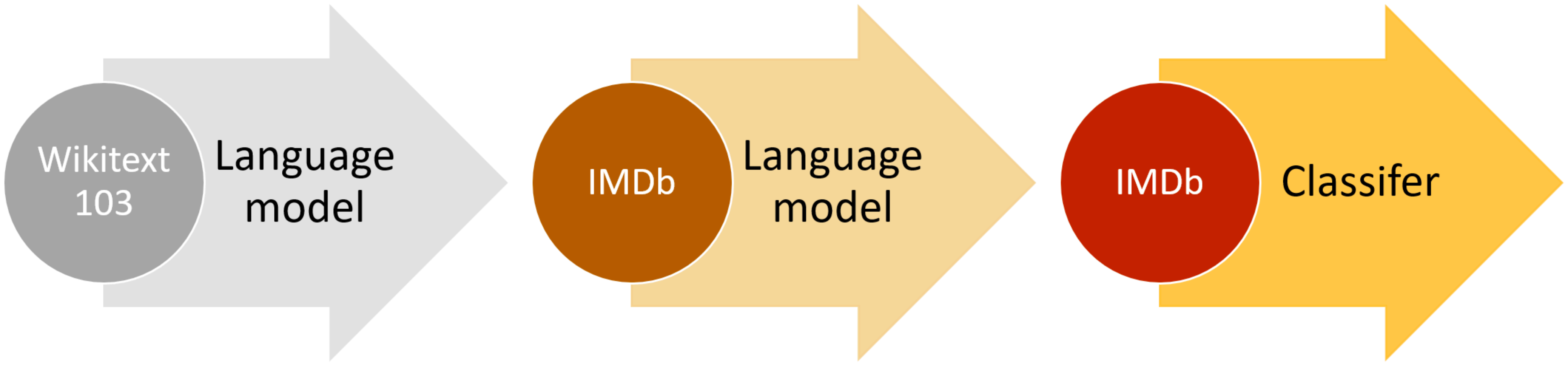
X	<START>	The	poor	don’t	have	
Y						any

NLP LM Transfer Learning

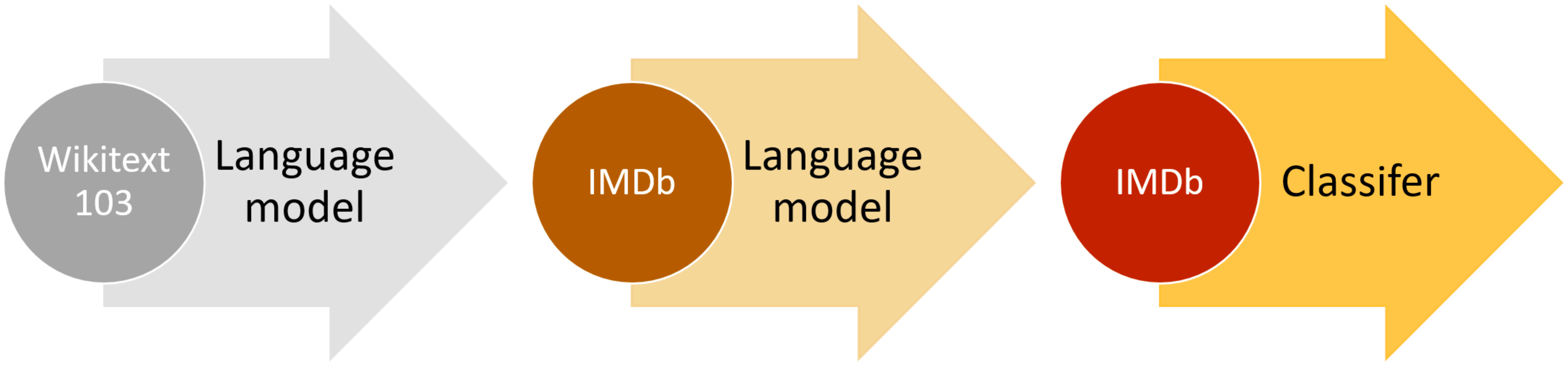


ULMFiT

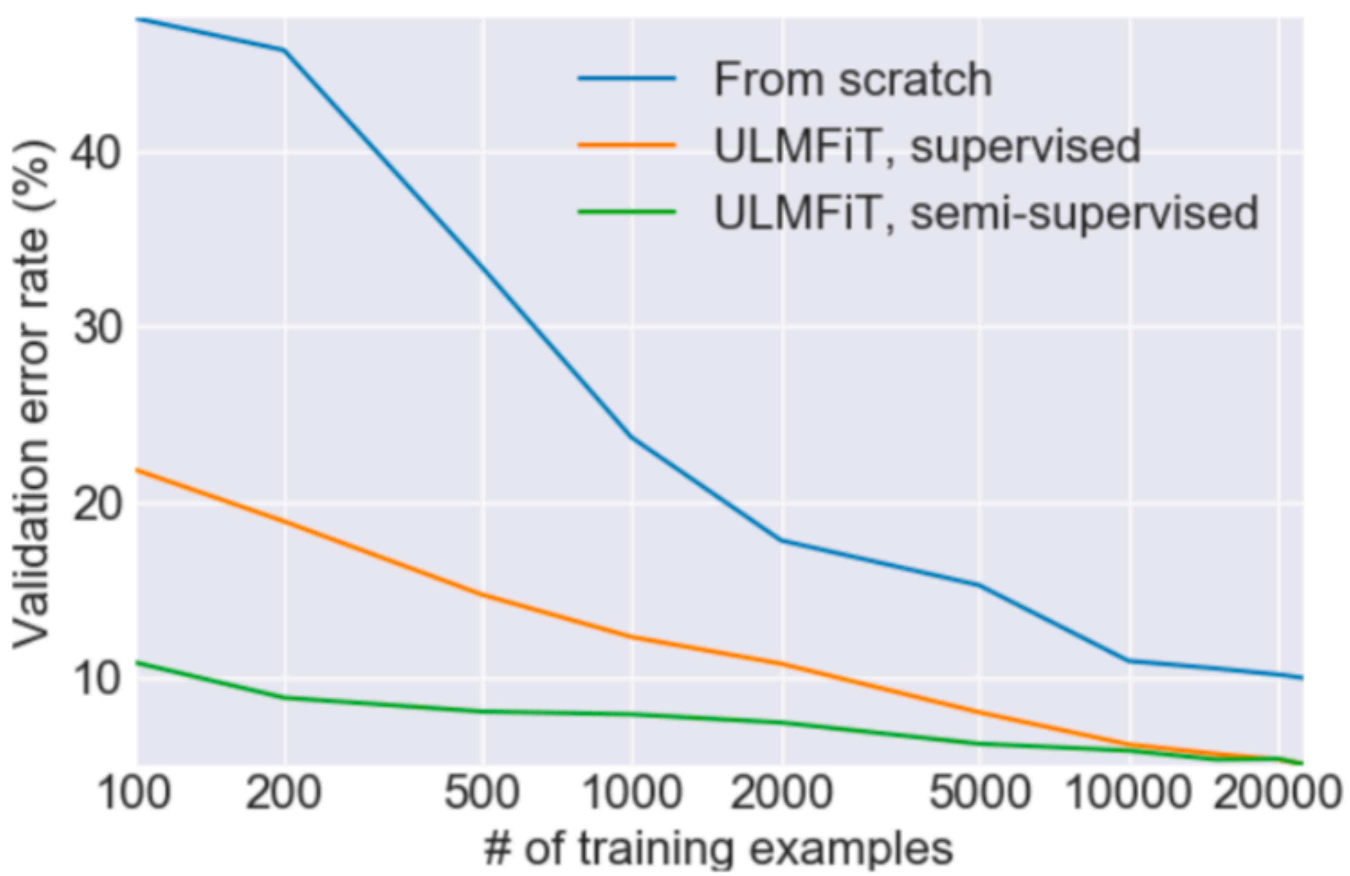
ULMFiT


Wikitext 103
Language model
IMDb
Language model
IMDb
Classifer

ULMFiT



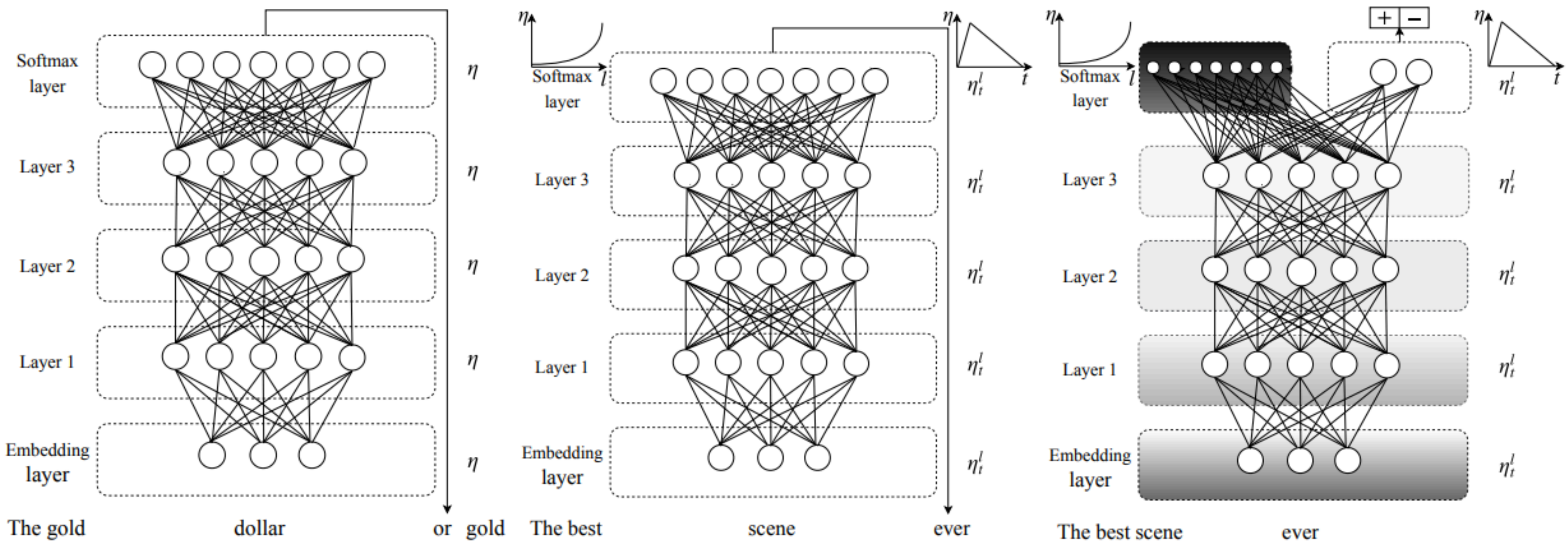
Wikitext 103
Language model
IMDb
Language model
IMDb
Classifer



From scratch
ULMFiT, supervised
ULMFiT, semi-supervised
Validation error rate (%)
40
30
20
10
100
200
500
1000
2000
5000
10000
20000
# of training examples

ULMFiT

$$\mathbf{h}_c = [\mathbf{h}_T, \mathtt{maxpool}(\mathbf{H}), \mathtt{meanpool}(\mathbf{H})]$$



(a) LM pre-training (b) LM fine-tuning (c) Classifier fine-tuning

Figure 1: ULMFiT consists of three stages: a) The LM is trained on a general-domain corpus to capture general features of the language in different layers. b) The full LM is fine-tuned on target task data using discriminative fine-tuning (‘*Discr*’) and slanted triangular learning rates (STLR) to learn task-specific features. c) The classifier is fine-tuned on the target task using gradual unfreezing, ‘*Discr*’, and STLR to preserve low-level representations and adapt high-level ones (shaded: unfreezing stages; black: frozen).

Scheduling

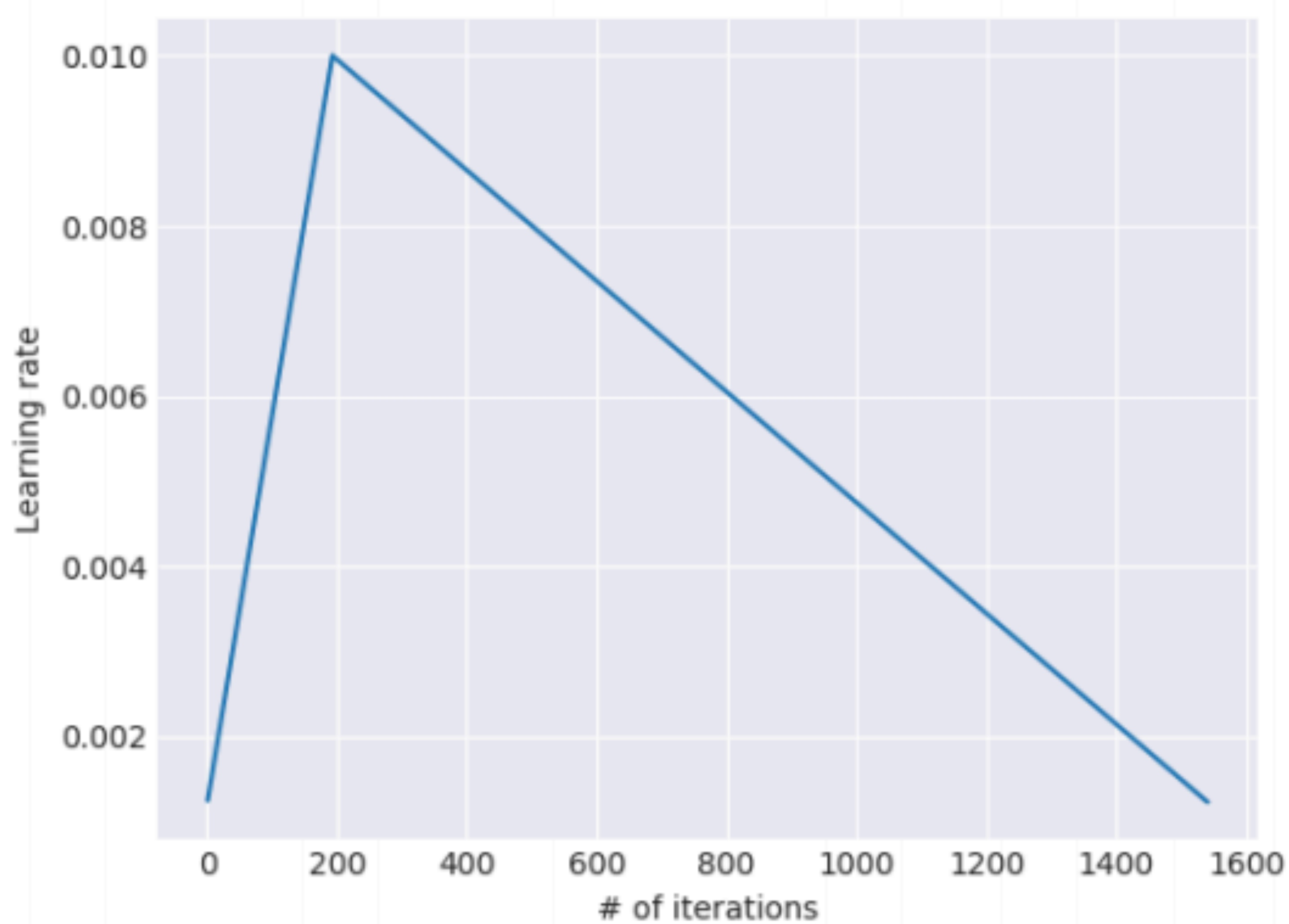
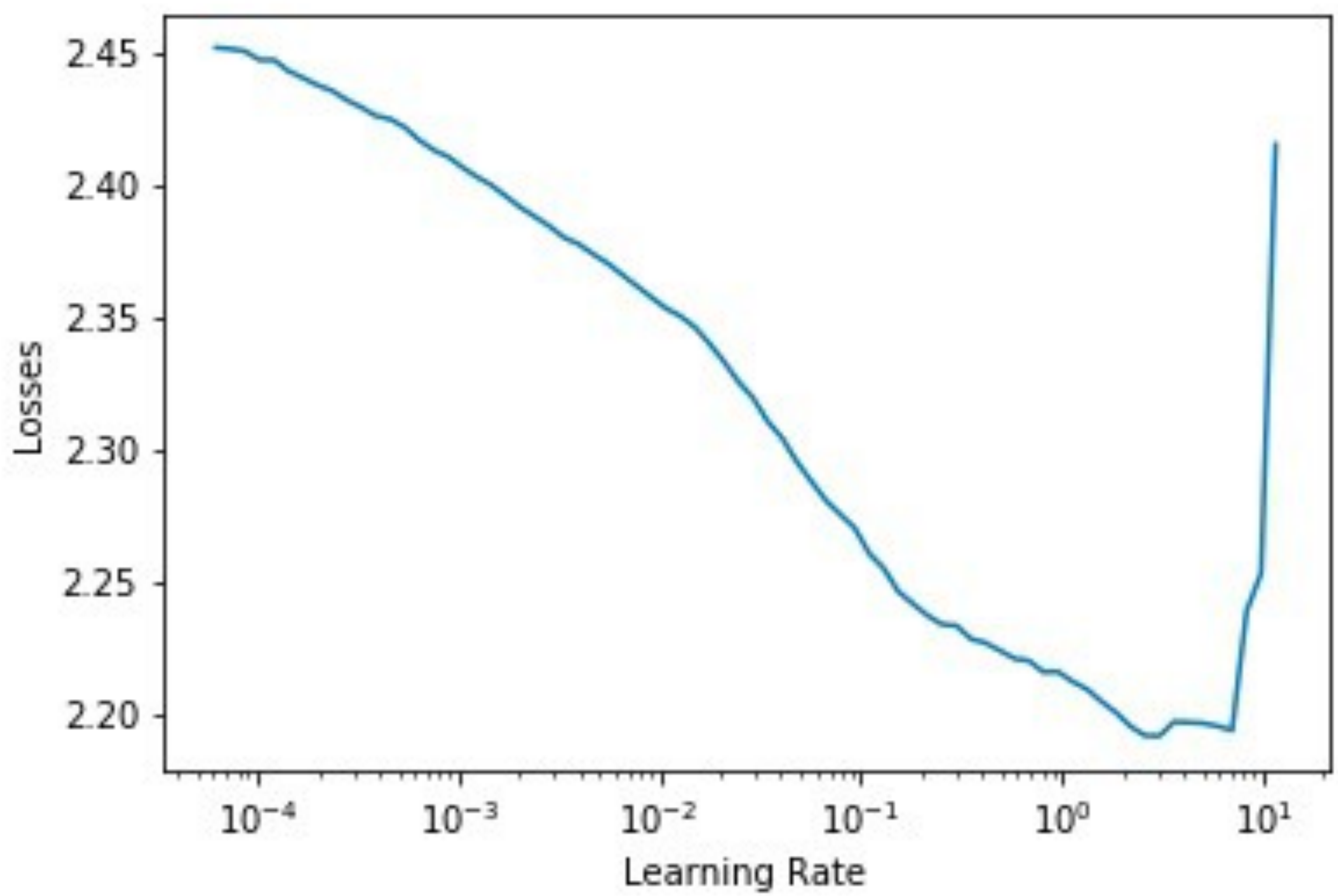


Figure 2: The slanted triangular learning rate schedule used for ULMFiT as a function of the number of training iterations.

LR Finder



2.45
2.40
2.35
2.30
2.25
2.20
Losses
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Learning Rate

ULMFiT

Gradual Unfreezing (Catastrophic Forgetting)

$\mathbf{h}_c = [\mathbf{h}_T, \texttt{maxpool}(\mathbf{H}), \texttt{meanpool}(\mathbf{H})]$

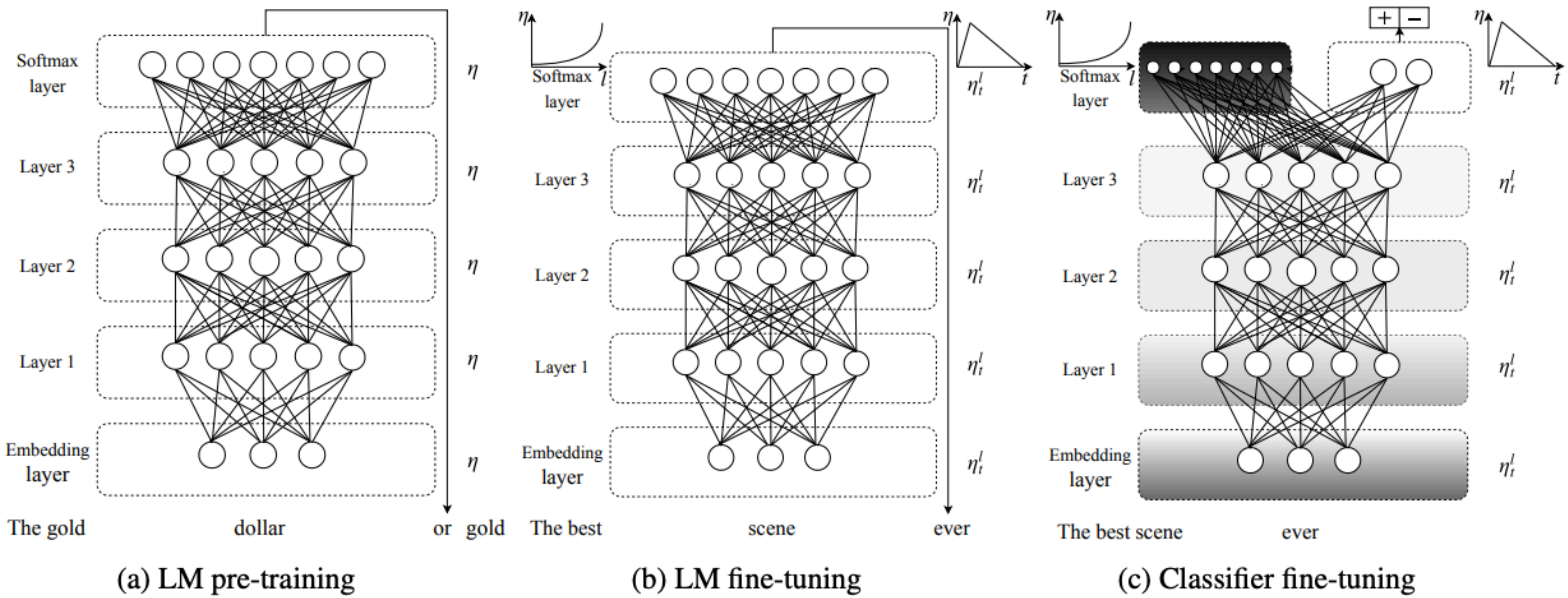


Figure 1: ULMFiT consists of three stages: a) The LM is trained on a general-domain corpus to capture general features of the language in different layers. b) The full LM is fine-tuned on target task data using discriminative fine-tuning (‘*Discr*’) and slanted triangular learning rates (STLR) to learn task-specific features. c) The classifier is fine-tuned on the target task using gradual unfreezing, ‘*Discr*’, and STLR to preserve low-level representations and adapt high-level ones (shaded: unfreezing stages; black: frozen).

ULMFiT

Classifier

$$\mathbf{h}_c = [\mathbf{h}_T, \mathtt{maxpool}(\mathbf{H}), \mathtt{meanpool}(\mathbf{H})]$$

```
(1): PoolingLinearClassifier(
    (layers): Sequential(
      (0): BatchNorm1d(900, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
      (1): Dropout(p=0.4)
      (2): Linear(in_features=900, out_features=50, bias=True)
      (3): ReLU(inplace)
      (4): BatchNorm1d(50, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
      (5): Dropout(p=0.1)
      (6): Linear(in_features=50, out_features=2, bias=True)
    )
)
```

AWD-LSTM

ENCODER DROPOUT										
	before dropout					**after dropout**				
	token	d1	d2	...		**token**	d1	d2	...	
	I	0.399	0.75379	0.62616		I	0	0	0	
	love	0.88533	0.29449	0.15856		love	0.88533	0.29449	0.15856	
	cats	0.48927	0.04071	0.21427		cats	0.48927	0.04071	0.21427	
	dogs	0.72918	0.86882	0.77136		dogs	0.72918	0.86882	0.77136	

AWD-LSTM

ENCODER DROPOUT

	before dropout				**after dropout**		
token	d1	d2	...	**token**	d1	d2	...
I	0.399	0.75379	0.62616	I	0	0	0
love	0.88533	0.29449	0.15856	love	0.88533	0.29449	0.15856
cats	0.48927	0.04071	0.21427	cats	0.48927	0.04071	0.21427
dogs	0.72918	0.86882	0.77136	dogs	0.72918	0.86882	0.77136

INPUT DROPOUT

batch: [I love cats, I love dogs]

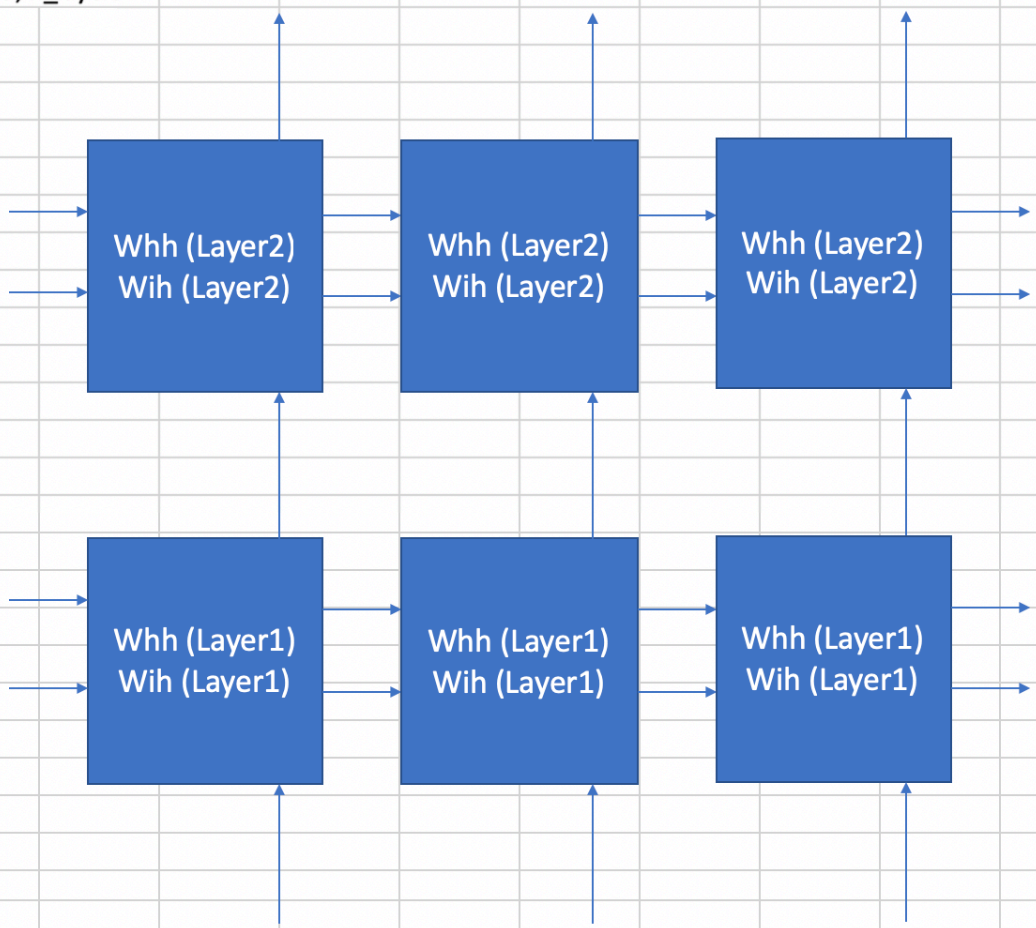
	before dropout				**after dropout**		
I	0	0	0	I	0	0	0
love	0.88533	0.29449	0.15856	love	0	0.29449	0.15856
cats	0.48927	0.04071	0.21427	cats	0	0.04071	0.21427

	before dropout				**after dropout**		
I	0	0	0	I	0	0	0
love	0.88533	0.29449	0.15856	love	0.88533	0.29449	0
dogs	0.72918	0.86882	0.77136	dogs	0.72918	0.86882	0

AWD-LSTM

WEIGHT DROPOUT

n_hid=5, n_layers=2



before dropout

Whh (Layer1)				
0.30546	0.94294	0.66715	0.5655	0.31191
0.06246	0.36674	0.35672	0.53357	0.04652
0.84278	0.17049	0.92283	0.97827	0.67913
0.94699	0.02277	0.79537	0.09479	0.16284
0.34098	0.09256	0.69661	0.22605	0.57153
0.09455	0.78172	0.48226	0.82222	0.25151
0.92516	0.50419	0.82879	0.67049	0.84304
0.11741	0.09362	0.69367	0.5633	0.34755
0.98025	0.73131	0.21491	0.86319	0.31456
0.0289	0.90899	0.30697	0.75105	0.62107
0.96808	0.4712	0.77992	0.83567	0.09754
0.15539	0.94866	0.51977	0.51167	0.08723
0.10944	0.88881	0.74007	0.96823	0.03516
0.62014	0.4363	0.02097	0.61126	0.30466
0.10465	0.02462	0.2334	0.25372	0.54579
0.14384	0.962	0.70157	0.39285	0.41064
0.42081	0.64236	0.06941	0.41805	0.78772
0.45229	0.9871	0.49831	0.17108	0.48868
0.42142	0.66105	0.53273	0.30901	0.45095
0.33421	0.77472	0.33966	0.42693	0.4567

after dropout

Whh (Layer1)				
0.30546	0	0.66715	0.5655	0
0	0.36674	0.35672	0.53357	0.04652
0.84278	0.17049	0.92283	0.97827	0.67913
0.94699	0.02277	0.79537	0.09479	0.16284
0.34098	0.09256	0.69661	0.22605	0.57153
0	0.78172	0.48226	0.82222	0.25151
0	0.50419	0	0.67049	0.84304
0	0.09362	0.69367	0.5633	0
0.98025	0.73131	0	0	0.31456
0	0	0.30697	0.75105	0.62107
0	0	0.77992	0.83567	0.09754
0.15539	0	0.51977	0.51167	0.08723
0.10944	0.88881	0.74007	0.96823	0.03516
0.62014	0.4363	0.02097	0.61126	0.30466
0.10465	0.02462	0.2334	0	0.54579
0	0.962	0.70157	0	0.41064
0	0	0.06941	0.41805	0.78772
0.45229	0.9871	0.49831	0	0.48868
0.42142	0.66105	0.53273	0.30901	0.45095
0	0.77472	0.33966	0.42693	0.4567

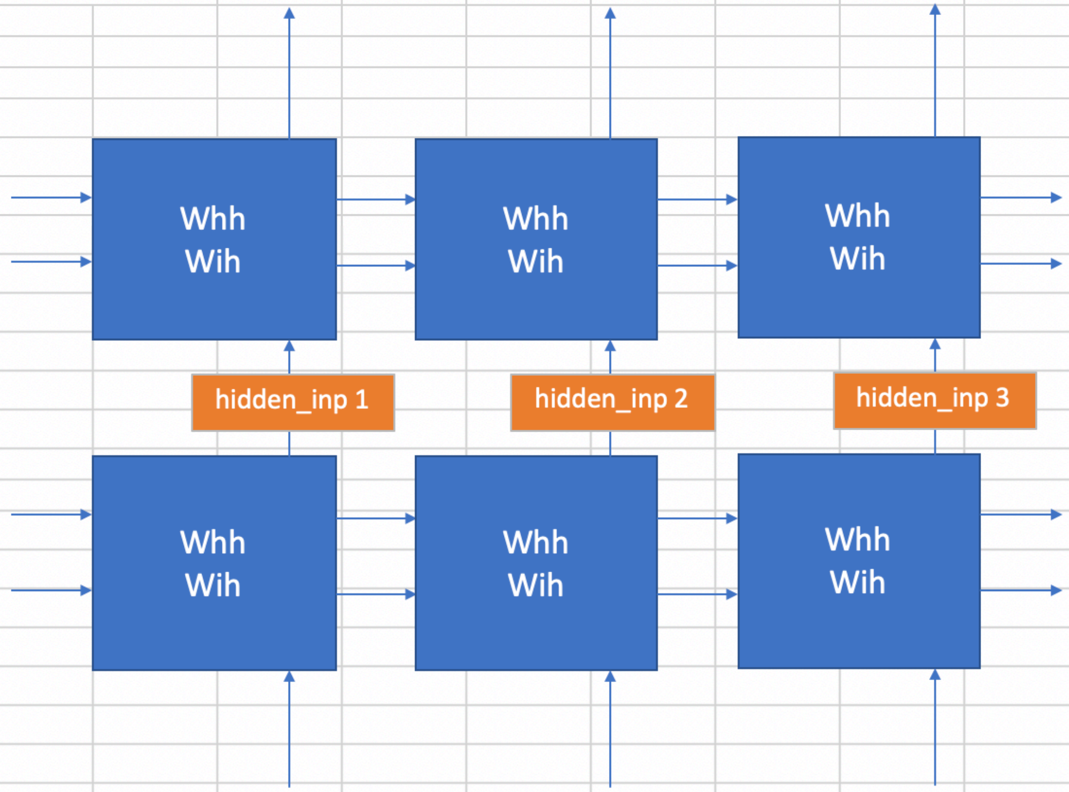
I	I
0	0
0	0
0	0

love	love
0	0.88533
0.29449	0.29449
0.15856	0

cats	dogs
0	0.72918
0.04071	0.86882
0.21427	0

AWD-LSTM

HIDDEN DROPOUT



before dropout

I	0.11587	0.89354	0.18537	0.13159	0.04328	0.36997	0.68241	0.21505	0.07696	0.1405
love	0.51854	0.94156	0.80541	0.49411	0.44335	0.31453	0.20678	0.95815	0.70224	0.2766
cats	0.41255	0.70882	0.76667	0.93813	0.89034	0.1676	0.92944	0.32216	0.11675	0.99425

after dropout

hidden_inp 1	I	0.11587	0	0.18537	0.13159	0	0.36997	0.68241	0	0	0.1405
hidden_inp 2	love	0.51854	0	0.80541	0.49411	0	0.31453	0.20678	0	0	0.2766
hidden_inp 3	cats	0.41255	0	0.76667	0.93813	0	0.1676	0.92944	0	0	0.99425

before dropout

I	0.90644	0.01673	0.38366	0.86887	0.26845	0.332	0.93804	0.34769	0.83711	0.66387
love	0.82539	0.09143	0.32444	0.35099	0.64491	0.79199	0.24797	0.56466	0.46948	0.33358
dogs	0.38805	0.56548	0.1424	0.31113	0.11645	0.36759	0.73068	0.05727	0.7315	0.01498

after dropout

hidden_inp 1	I	0	0	0.38366	0.86887	0	0.332	0	0.34769	0.83711	0.66387
hidden_inp 2	love	0	0	0.32444	0.35099	0	0.79199	0	0.56466	0.46948	0.33358
hidden_inp 3	dogs	0	0	0.1424	0.31113	0	0.36759	0	0.05727	0.7315	0.01498