Language-Independent Concept Spaces in Large Language Models

Under advice of Greg Anderson

Aidan M. Mokalla

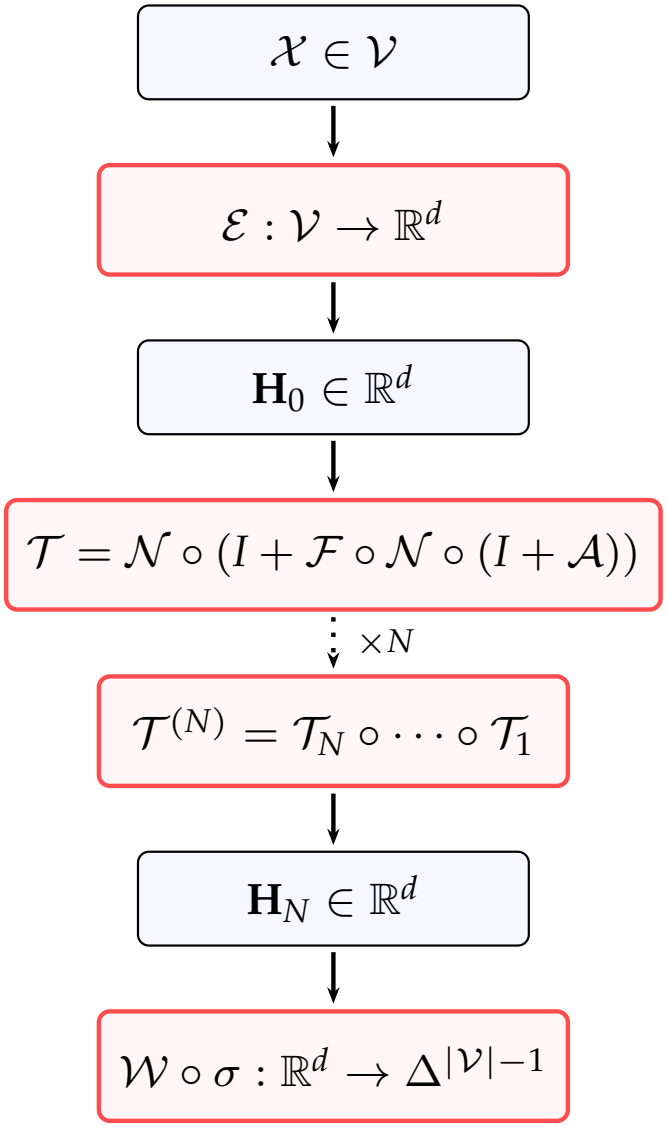
Reed College

AidanM@*reed.edu*

Oral Thesis Exam
May 7, 2025

Interpreting Large Language Models

Interpreting Large Language Models



Interpreting Large Language Models

1. Safety & Alignment[a]

[a] *"We check whether Sparse Autoencoders find features correlated with lying and deception in this out-of-distribution setting."* doi.org/10.48550/arXiv.2504.04072

Interpreting Large Language Models

1. Safety & Alignment
2. Bias & Fairness[a]

[a] *"we receive mixed signals as only some subsets of the data are useful in providing insights. To alleviate these two problems, we introduce a more rigorous evaluation dataset and a debiasing method based on Sparse Autoencoders to help reduce bias in models."*
doi.org/10.48550/arXiv.2410.13146

Interpreting Large Language Models

1. Safety & Alignment
2. Bias & Fairness
3. Compliance with Policies[a]

[a] *"These goals—the targeted removal of information from a model and the targeted suppression of information from a model's outputs—present various technical and substantive challenges."* doi.org/10.48550/arXiv.2412.06966

Interpreting Large Language Models

1. Safety & Alignment
2. Bias & Fairness
3. Policy & compliance
4. Improving Performance[a]

[a] *"We also find more abstract features—responding to things like bugs in computer code."* anthropic.com/research/mapping-mind-language-model

Interpreting Large Language Models

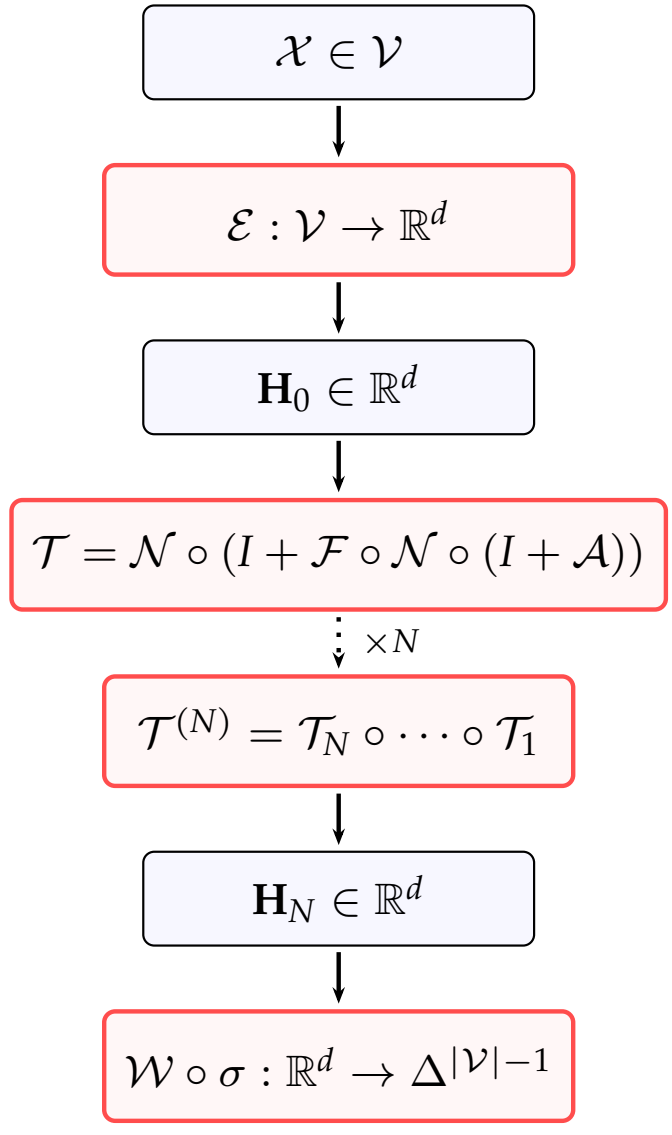
1. Safety & Alignment
2. Bias & Fairness
3. Policy & compliance
4. Improving Performance
5. Scientific Insight[a]

[a] *"We introduce a non-invasive decoder that reconstructs continuous language from cortical semantic representations recorded using functional magnetic resonance imaging (fMRI). Given novel brain recordings, this decoder generates intelligible word sequences that recover the meaning of perceived speech, imagined speech and even silent videos."* doi.org/10.1038/s41593-023-01304-9

Interpreting Large Language Models

Idea: *Concept Space*

$$\mathcal{C} \stackrel{\text{def}}{=} \text{span}\left[\bigcup_{\text{concepts}}\right]$$



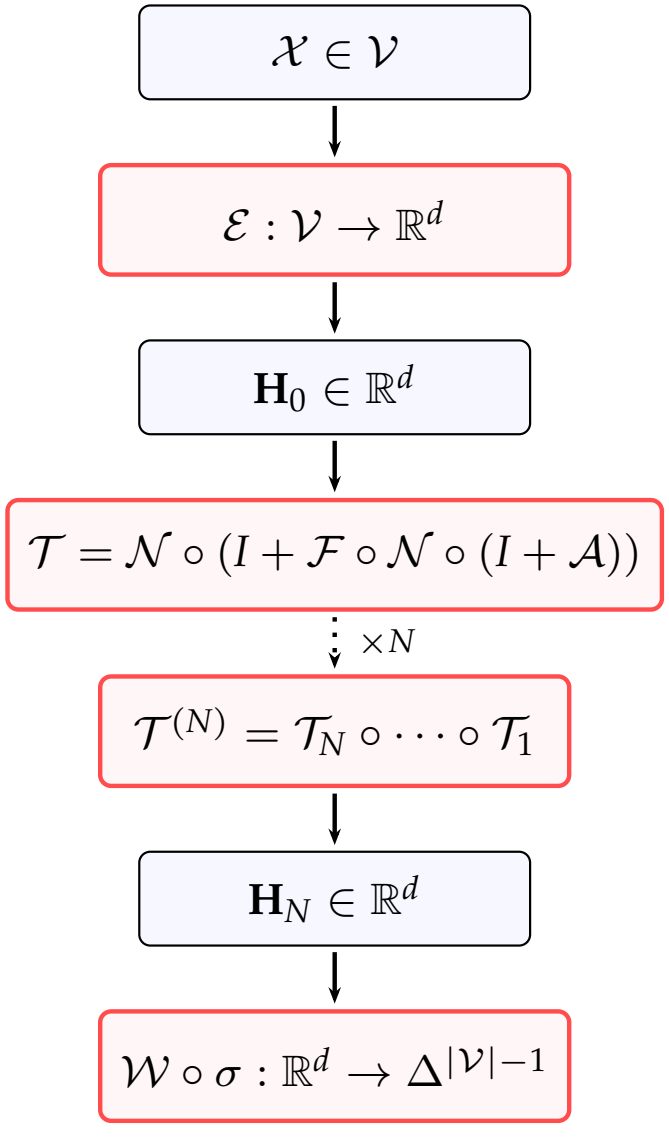
Interpreting Large Language Models

Idea: *Concept Space*

$$\mathcal{C} \overset{\text{def}}{=} \text{span}\left[\bigcup_{\text{concepts}}\right]$$

Where is $\mathcal{C}$?

1. $\mathbb{R}^d \overset{?}{\cong} \mathcal{C}$



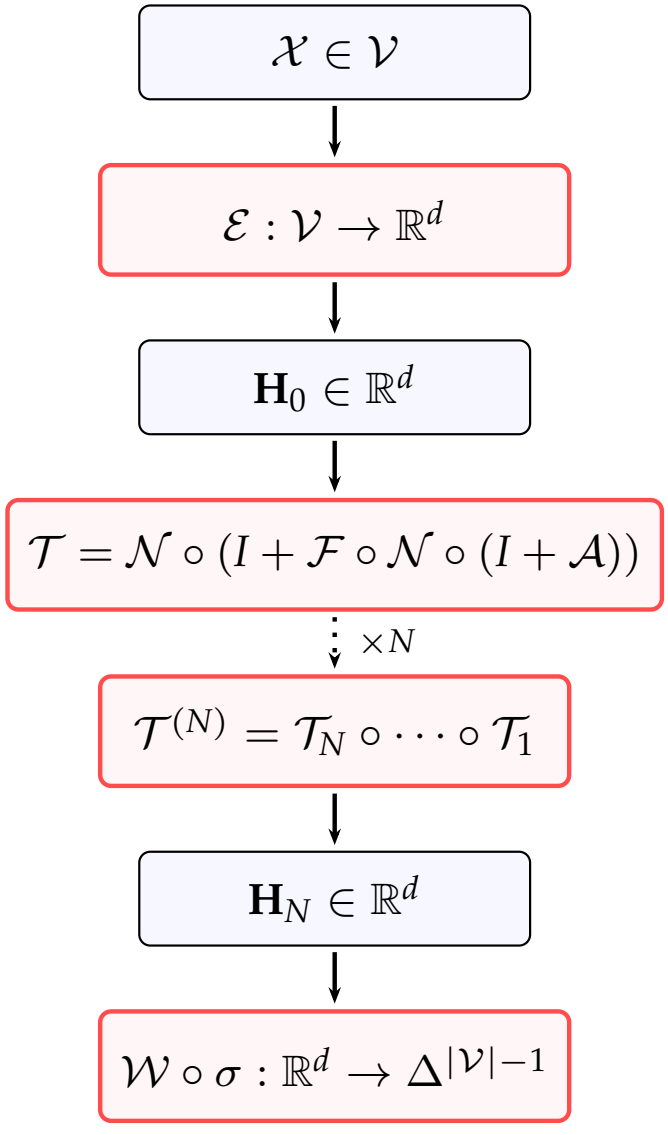
Interpreting Large Language Models

Idea: *Concept Space*

$$\mathcal{C} \stackrel{\text{def}}{=} \text{span}\left[\bigcup_{\text{concepts}}\right]$$

Where is $\mathcal{C}$?

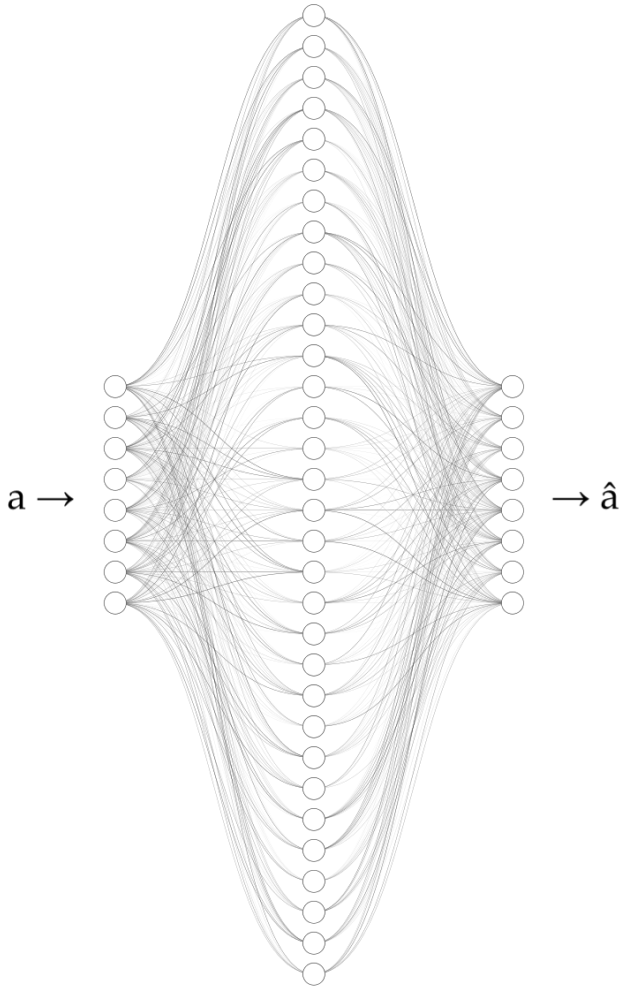
1. $\mathbb{R}^d \ncong \mathcal{C}$
2. $\mathbb{R}^{x>1(d)} \cong \mathcal{C}$



Approximating $\mathcal{C}$ with Sparse Coding

1. **Sparse Autoencoders** (SAEs)

SAE: $\mathbb{R}^d \rightarrow \mathbb{R}^{x>1^{(d)}} \rightarrow \mathbb{R}^d$

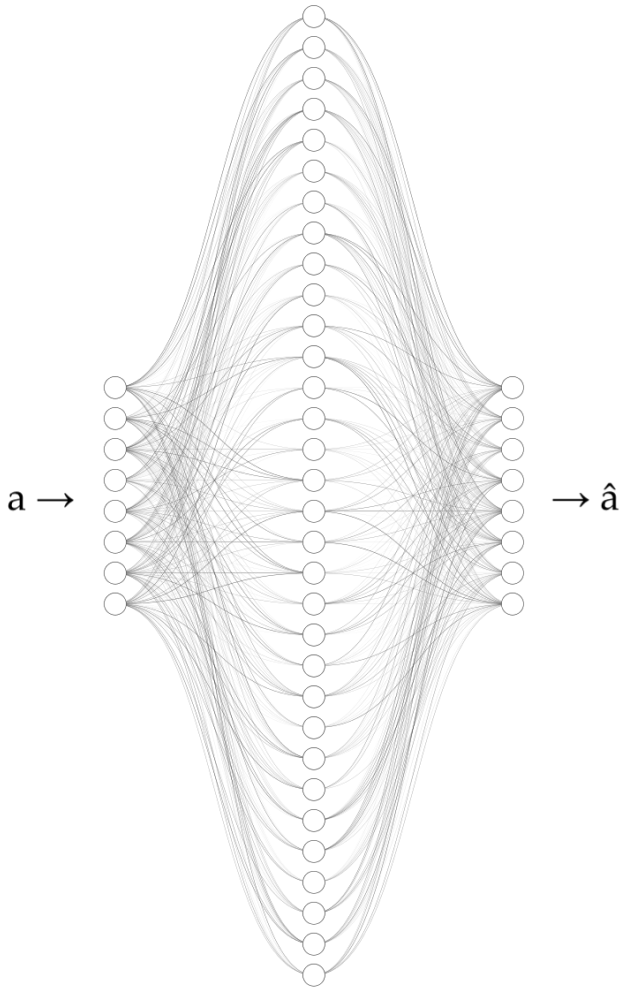


Approximating $\mathcal{C}$ with Sparse Coding

SAE: $\mathbb{R}^d \rightarrow \mathbb{R}^{x>1^{(d)}} \rightarrow \mathbb{R}^d$

1. **Sparse Autoencoders** (SAEs)

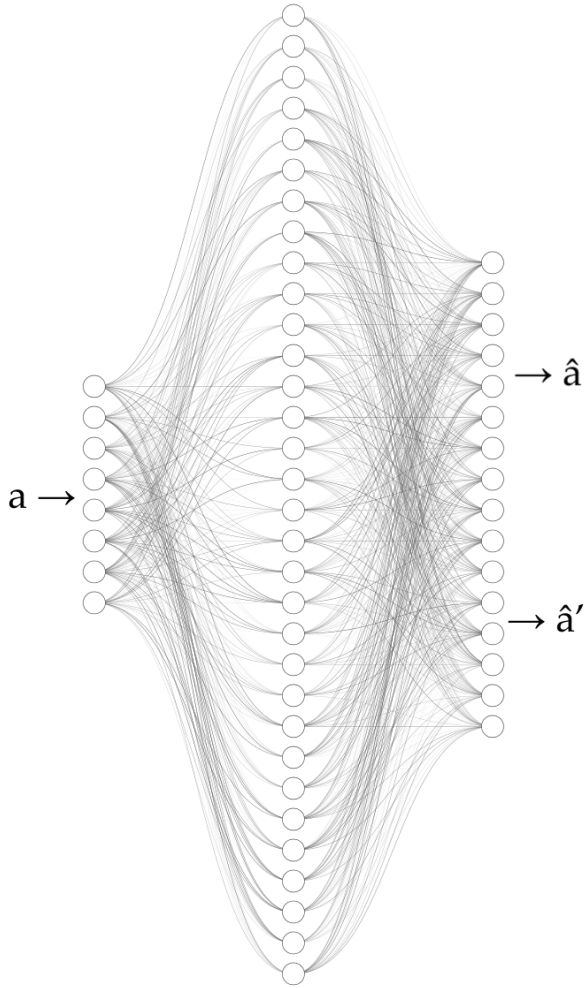
$$\mathcal{L}(\text{SAE}) = ||\text{a} - \hat{\text{a}}||_2^2 + \lambda \text{sparsity}(\text{SAE}, \text{a})$$



Approximating $\mathcal{C}$ with Sparse Coding

USAE: $\mathbb{R}^d \to \mathbb{R}^{x>1^{(d)}} \to \mathbb{R}^{2d}$

1. **Sparse Autoencoders**
2. **Universal Sparse Autoencoders** (USAEs)



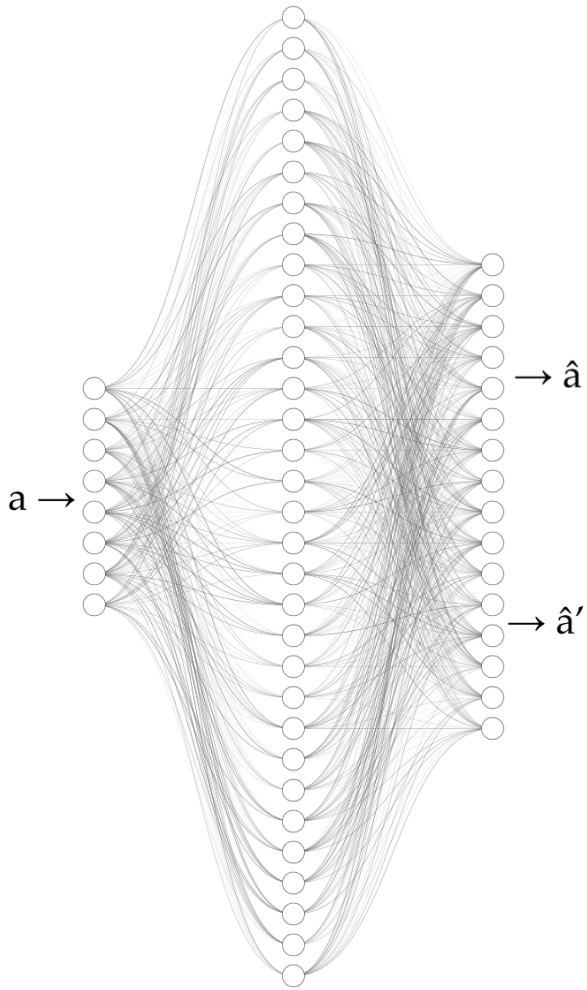
Approximating $\mathcal{C}$ with Sparse Coding

USAE: $\mathbb{R}^d \rightarrow \mathbb{R}^{x>1(d)} \rightarrow \mathbb{R}^{2d}$

1. **Sparse Autoencoders**

2. **Universal Sparse Autoencoders** (USAEs)

$$\mathcal{L}(\text{USAE}) = ||a - \hat{a}||_2^2 + \lambda \text{sparsity}(\text{USAE}, a) + \lambda' ||a' - \hat{a}'||_2^2$$



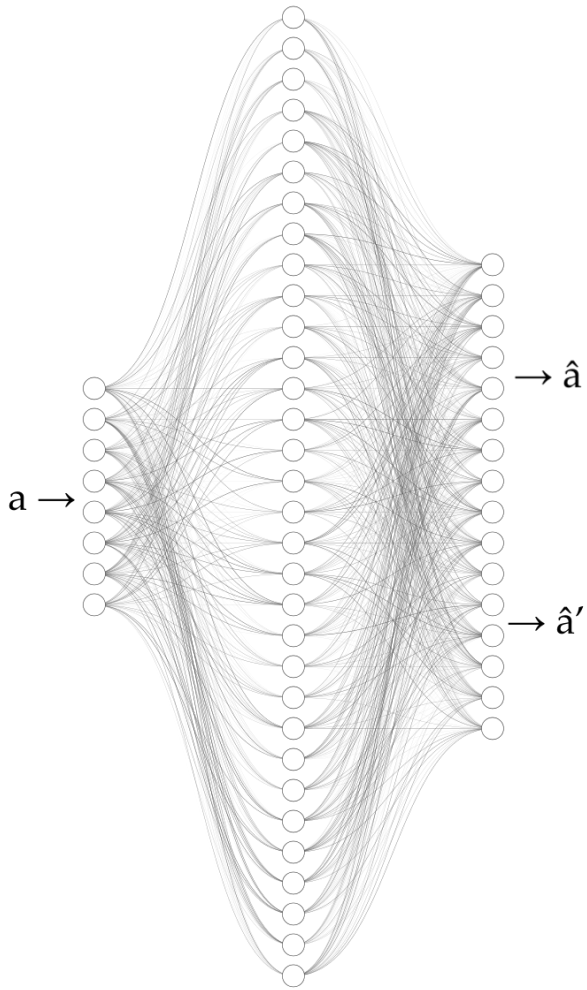
Approximating $\mathcal{C}$ with Sparse Coding

USAE: $\mathbb{R}^d \rightarrow \mathbb{R}^{x>1^{(d)}} \rightarrow \mathbb{R}^{2d}$

1. $\mathcal{L}(\text{SAE}) = ||\text{a} - \hat{\text{a}}||_2^2 + \lambda \text{sparsity}(\text{SAE}, \text{a})$

2. $\mathcal{L}(\text{USAE}) = ||\text{a} - \hat{\text{a}}||_2^2 + \lambda \text{sparsity}(\text{USAE}, \text{a}) + \lambda' ||\text{a}' - \hat{\text{a}}'||_2^2$

3. USAEs are more interpretable than SAEs.



Approximating $\mathcal{C}$ with Sparse Coding

3. USAEs are more interpretable than SAEs.

   [i] Concept Convergence

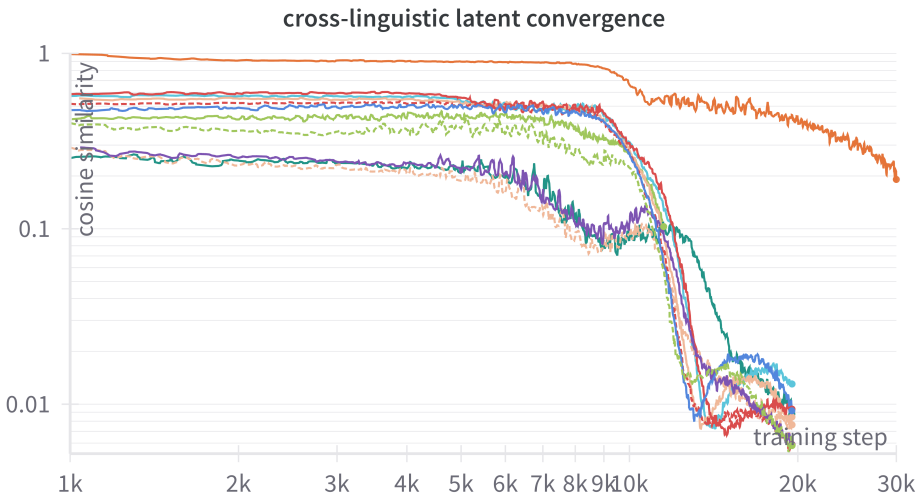
   [ii] Reconstruction Accuracy

   [iii] Sparsity

Approximating $\mathcal{C}$ with Sparse Coding

3. USAEs are more interpretable than SAEs.

[i] Concept convergence



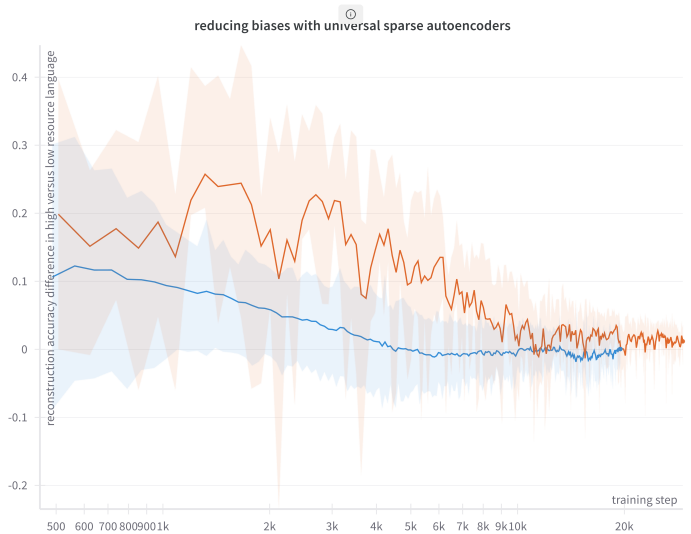
[ii] Reconstruction Accuracy

[iii] Sparsity

Approximating $\mathcal{C}$ with Sparse Coding

3. USAEs are more interpretable than SAEs.

   [i] Concept convergence
   [ii] Reconstruction Accuracy

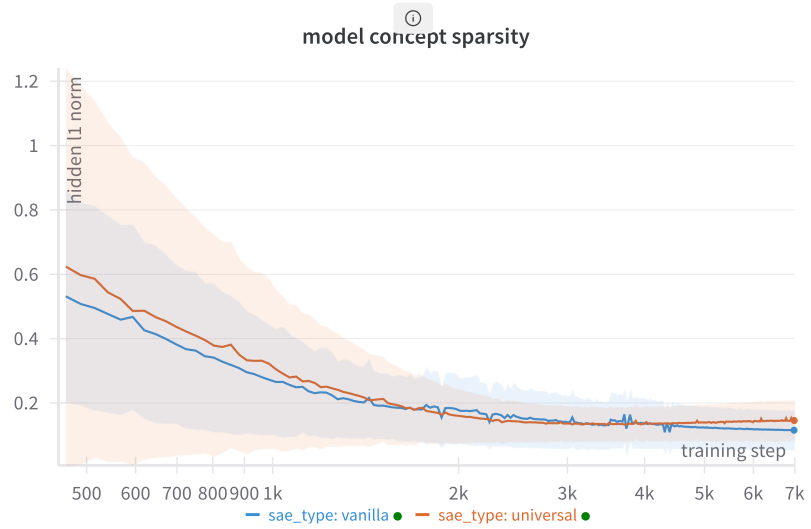


[iii] Sparsity

Approximating $\mathcal{C}$ with Sparse Coding

3. USAEs are more interpretable than SAEs.

   [i] Concept convergence
   [ii] Reconstruction Accuracy
   [iii] Sparsity



Fin