

NLP for Signed Languages: Challenges and Opportunities

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Berkeley
NLP



Berkeley AI
Research

Arguments for today's talk

1. The linguistic complexity of signed languages gives rise to unique NLP challenges

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2. Awareness of the language and the community helps us build practical NLP models

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Common misconceptions of signed languages

- Not just gestures for spoken language

“Name”



American Sign Language



British Sign Language

Common misconceptions of signed languages

- Not just gestures for spoken language
- Not just hand gestures

“Name”



American Sign Language



British Sign Language

Common misconceptions of signed languages

- Not just gestures for spoken language
- Not just hand gestures
- Not just 1 universal sign language

“Name”



American Sign Language



British Sign Language

Common misconceptions of signed languages

- Not just gestures for spoken language
- Not just hand gestures
- Not just 1 universal sign language
- Not slower than speaking

“Name”



American Sign Language



British Sign Language

Signed languages are crucial



- Only 30-40% of English speech can be lipread

Signed languages are crucial



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- Cochlear implants do not provide complete access to spoken language

Signed languages are crucial



- Only 30-40% of English speech can be lipread
- Cochlear implants do not provide complete access to spoken language
- Integral to Deaf culture

Why not just use subtitles / text?



- Convey tone, emotion

Why not just use subtitles / text?



- Convey tone, emotion
- Literacy levels vary among signers

Why not just use subtitles / text?



- Convey tone, emotion
- Literacy levels vary among signers
- Primary / most accessible language for many

Possible applications of AI



Translation

Possible applications of AI



Translation

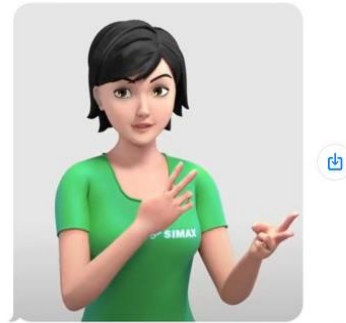


Education

Possible applications of AI



Translation



Chatbots

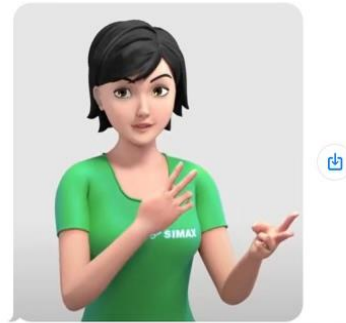


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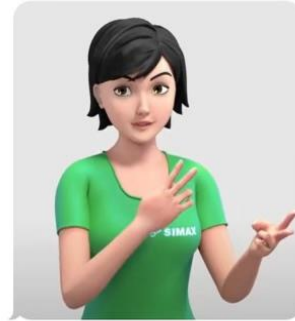


Smart assistants

Possible applications of AI



Translation



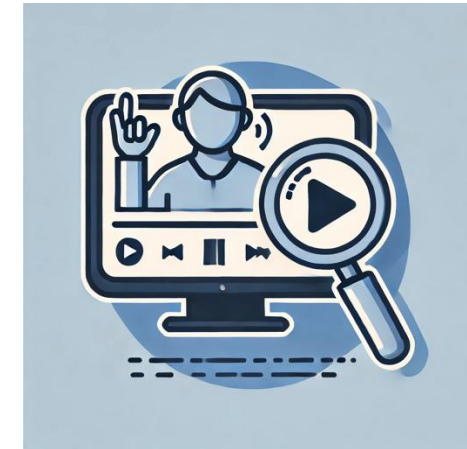
Chatbots



Smart assistants



Education



Information retrieval

Current progress in AI for signed languages

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- 101 papers between 2021-2023 (Desai et al., [2024](#))

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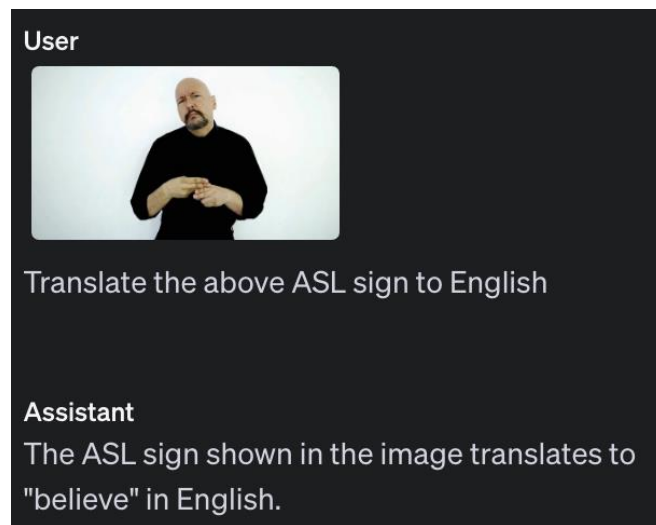
SignLLM
(Fang et al., 2024)

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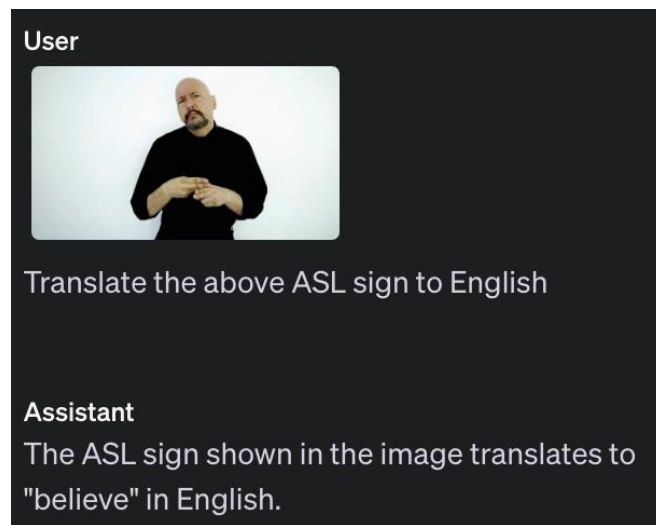
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SignLLM
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GPT-4o
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“Sign language gloves”

Challenge: data

- ~ 40 public datasets
 - Largest: ~1000 hours



BOBSL dataset
(Albanie et al., 2021)

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- Gap between training data and target users



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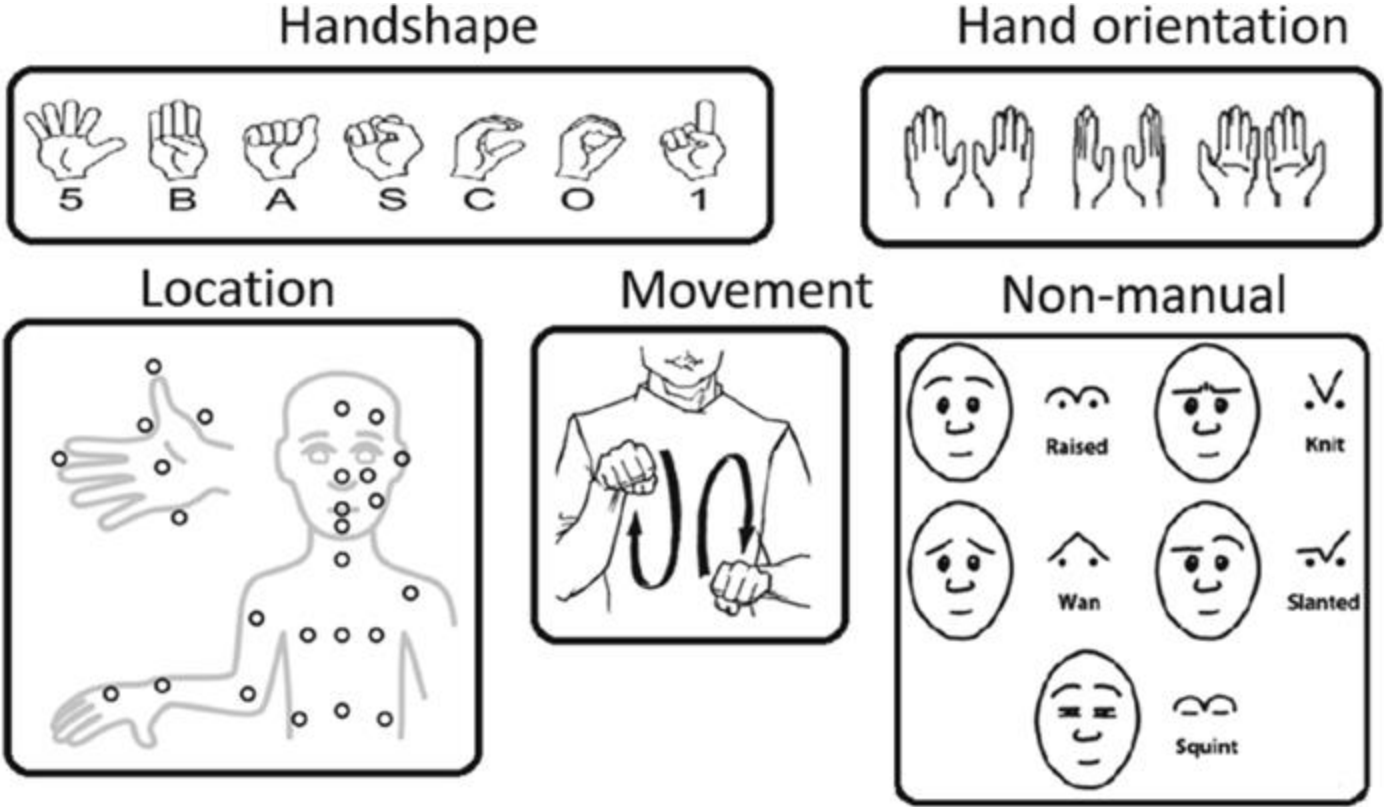
Challenge: data

- ~ 40 public datasets
 - Largest: ~1000 hours
- Gap between training data and target users
- Lack of experts
- Consent and privacy?



BOBSL dataset
(Albanie et al., 2021)

Challenge: simultaneous channels



5 phonological parameters of ASL

Challenge: spatial dependencies



you-GIVE-TO-me



you-GIVE-TO-him/her



s/he-GIVE-TO-you

Directional verbs in ASL

Challenge: Deaf-centric design

April 12, 2016

UW undergraduate team wins \$10,000 Lemelson-MIT Student Prize for gloves that translate sign language



Wearable-tech glove translates sign language into speech in real time

The device is inexpensive, flexible and highly durable, UCLA bioengineers say

Matthew Chin

June 29, 2020

Hand-ear co-ordination: Interactive glove translates sign language into speech

Infinity Glove, a Lebanon-based start-up, seeks to help translate sign-language into speech by using a high tech glove solution. Cody Combs / The National



Cody Combs

Feb 21, 2024



Listen In English



Listen in Ar

Powered by automated trans

Challenge: Deaf-centric design

Why Sign-Language Gloves Don't Help Deaf People

Wearable technologies that claim to translate ASL overlook the intricacies of the language, as well as the needs of signers.

By Michael Erard

Sign Language Translating Devices Are Cool. But Are They Useful?



Emily Matchar

Innovation Correspondent

February 26, 2019

News & Views | Published: 15 July 2020

WEARABLE TECHNOLOGY

Do deaf communities actually want sign language gloves?

[Joseph Hill](#) 



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ASL STEM Wiki



Dataset to support DHH students in STEM

ASL STEM Wiki

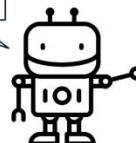


Automatic sign suggestion



User

Here are other ways people sign "relativistic electromagnetism"



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Tool to assist ASL interpreters, informed by linguistic properties and Deaf pedagogy

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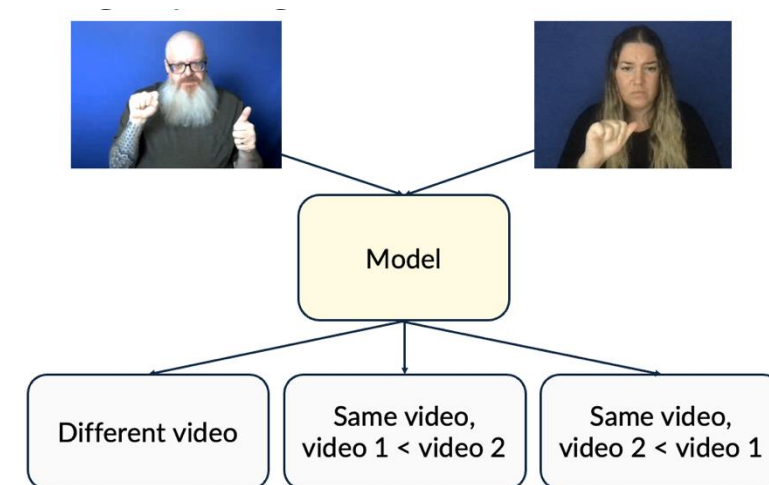
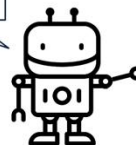


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Tool to assist ASL interpreters, informed by linguistic properties and Deaf pedagogy

Self-supervised sign language modeling for data efficiency

Barriers to STEM education for DHH students

- ASL -> primary and most accessible language for many deaf and hard-of-hearing (DHH) students in the US



“Relativistic electromagnetism”

Barriers to STEM education for DHH students

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- Deaf students score higher on science with direct instruction in ASL ([Kurz et al., 2015](#))



“Relativistic electromagnetism”

Barriers to STEM education for DHH students

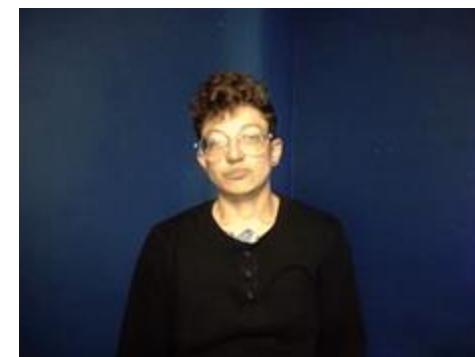
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- STEM resources in ASL are **scarce**
- Lack of **standardized ASL signs** for technical words



“Relativistic electromagnetism”

ASL STEM Wiki

- 254 Wikipedia articles
 - Science, technology, mathematics, medicine, geography



Wiki Home [Having trouble?](#)

Photosynthesis

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Article <https://en.wikipedia.org/wiki/Photosynthesis>

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0.0 Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that can later be released to fuel the organisms' activities.

0.1 This chemical energy is stored in carbohydrate molecules, such as sugars, which are synthesized from carbon dioxide and water – hence the name photosynthesis, from the Greek phōs, "light", and sunthesis, "putting together".

0.2 In most cases, oxygen is also released as a waste product.

0.3 Most plants, most algae, and cyanobacteria perform photosynthesis; such organisms are called photoautotrophs.

0.4 Photosynthesis is largely responsible for producing and maintaining the oxygen content of the Earth's atmosphere, and supplies most of the energy necessary for life on Earth.

0.5 Although photosynthesis is performed differently by different species, the process always begins when energy from light is absorbed by proteins called reaction centres that contain green chlorophyll pigments.

0.6 In plants, these proteins are held inside organelles called chloroplasts, which are most abundant in leaf cells, while in bacteria they are embedded in the plasma membrane.

0.7 In these light-dependent reactions, some energy is used to strip electrons from suitable substances, such as water, producing oxygen gas.

0.8 The hydrogen freed by the splitting of water is used in the creation of two further compounds that serve as short-term stores of energy, enabling its transfer to drive other reactions: these compounds are reduced nicotinamide adenine dinucleotide phosphate (NADPH) and adenosine triphosphate (ATP), the "energy currency" of cells.

0.9 In plants, algae and cyanobacteria, long-term energy storage in the form of sugars is produced by a subsequent sequence of light-independent reactions called the Calvin cycle; some bacteria use different mechanisms, such as the reverse Krebs cycle, to achieve the same end.

0.10 Using the ATP and NADPH produced by the light-dependent reactions, the resulting compounds are then reduced and removed to form further carbohydrates, such as glucose.

0.11 The first photosynthetic organisms probably evolved early in the evolutionary history of life and most likely used reducing agents such as hydrogen or hydrogen sulfide, rather than water, as sources of electrons.

0.12 Cyanobacteria appeared later; the excess oxygen they produced contributed directly to the oxygenation of the Earth, which rendered the

00:01:350


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ASL STEM Wiki

- 254 Wikipedia articles
 - Science, technology, mathematics, medicine, geography
- 37 certified ASL interpreters



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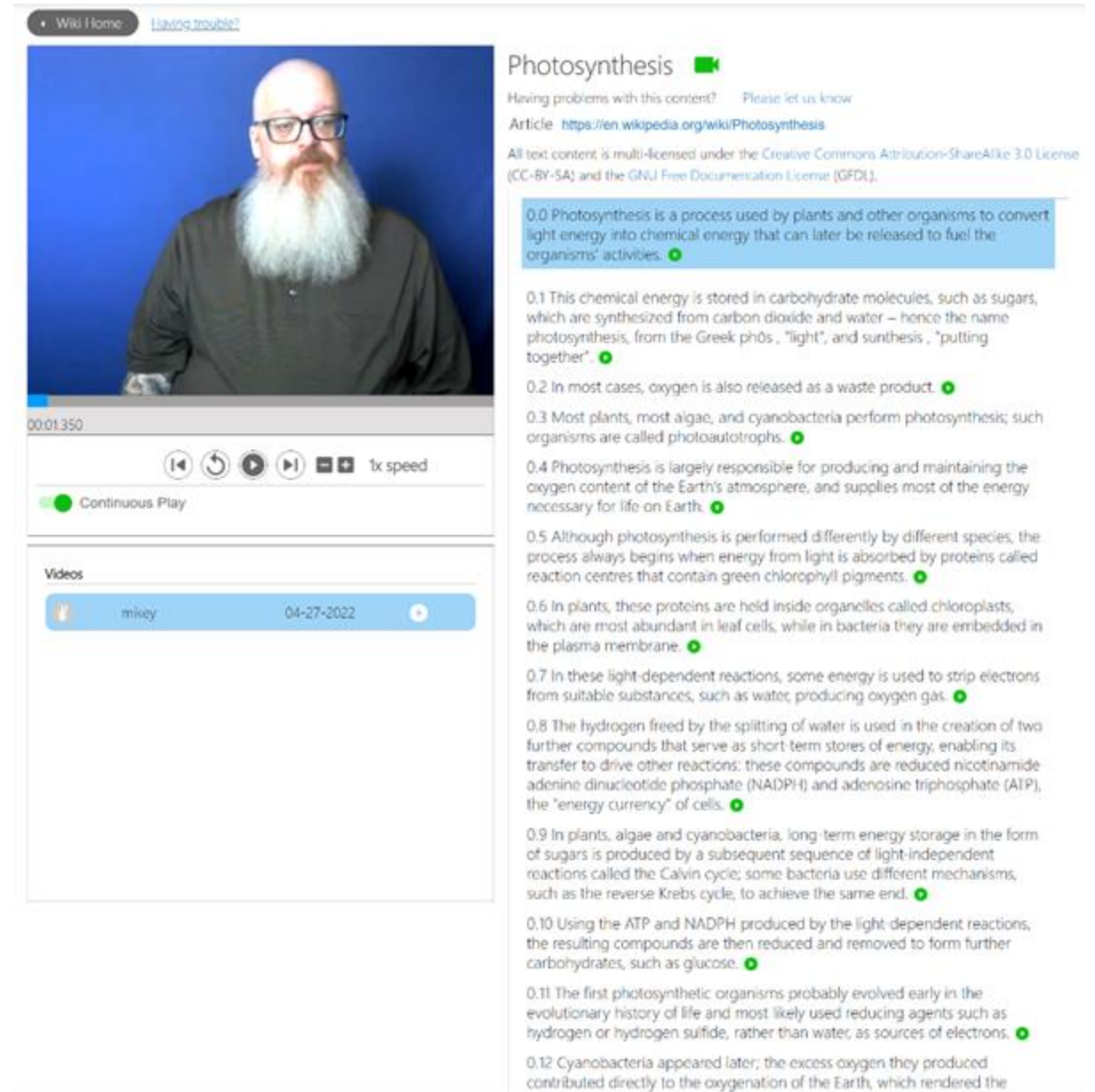
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- 300+ hours



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1. First dataset of continuous signing for STEM: **ASL STEM Wiki**

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2. Linguistic analysis & appropriate use cases

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4. New modeling technique: **contrastive learning** for signed language

Linguistic analysis – fingerspelling in ASL STEM Wiki

High rate of fingerspelling in ASL STEM Wiki



- **Fingerspelling:** spell out an English word using letter signs

“Relativistic electromagnetism”

High rate of fingerspelling in ASL STEM Wiki



- **Fingerspelling:** spell out an English word using letter signs
- ~6.4% of ASL ([Morford and MacFarlane, 2003](#))

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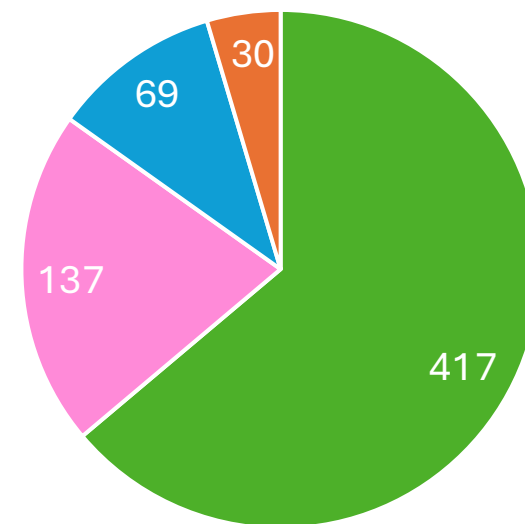
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High rate of fingerspelling in ASL STEM Wiki

- **63.9%** of fingerspelling is **STEM** words

Categories of fingerspelled words

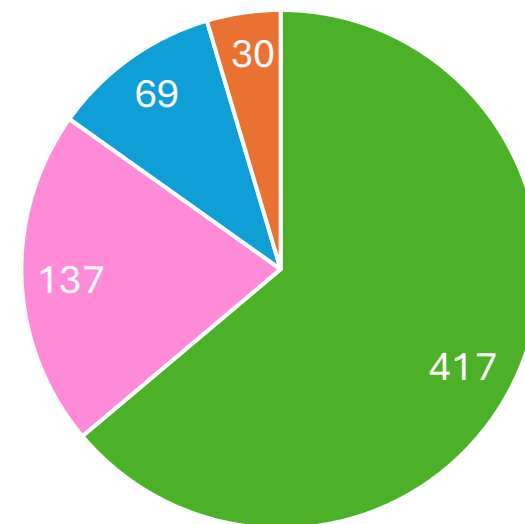


■ STEM ■ Proper noun ■ Loan word ■ Other

High rate of fingerspelling in ASL STEM Wiki

- **63.9%** of fingerspelling is **STEM** words
- Interpreters often resort to fingerspelling when a technical sign is not known

Categories of fingerspelled words



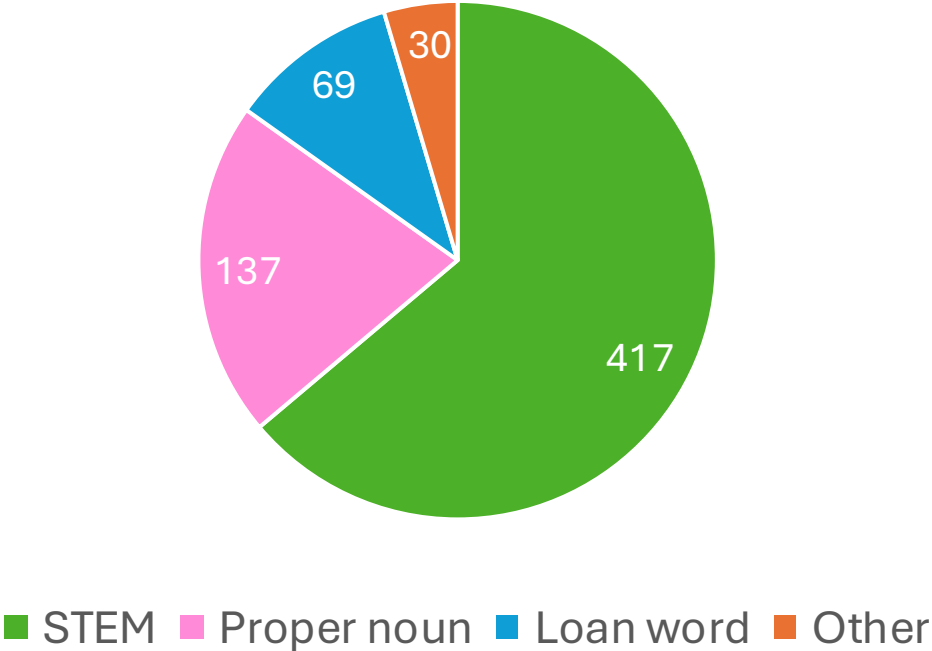
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High rate of fingerspelling in ASL STEM Wiki

- 63.0% of the words in the ASL STEM Wiki are fingerspelled.
- “[Deaf] students prefer that terms either be signed in ASL, or signed and fingerspelled, as opposed to just a term fingerspelled.”

Development of American Sign Language Guidelines for K-12 Academic Assessments

Categories of fingerspelled words

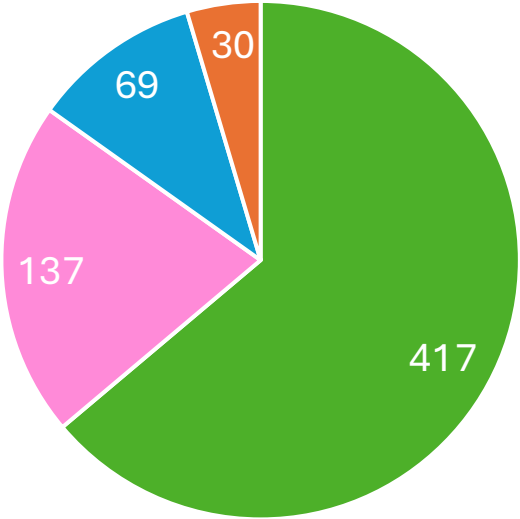


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Development of American Sign Language Guidelines for K-12 Academic Assessments

Categories of fingerspelled words



■ STEM ■ Proper noun ■ Loan word ■ Other

-> NLP tool to address the high rate of fingerspelling in STEM

Automatic sign suggestion: task setup

Automatic sign suggestion



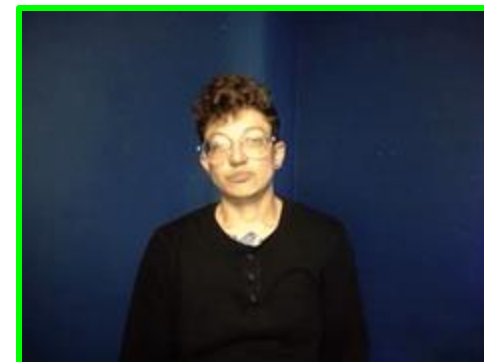
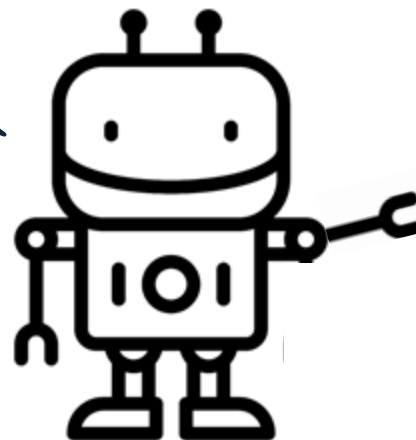
User

Automatic sign suggestion



User

Here are other ways
people sign
"relativistic
electromagnetism"

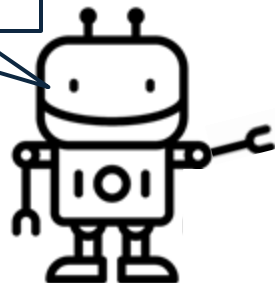


Automatic sign suggestion



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3 steps:

1. Fingerspelling detection
2. Fingerspelling alignment
3. Sign retrieval

Automatic sign suggestion

1. Fingerspelling detection
2. Fingerspelling alignment
3. Sign retrieval



Relativistic electromagnetism is a physical phenomenon due to Coulomb's law and Lorentz transformations.

1. Fingerspelling detection

Automatic sign suggestion

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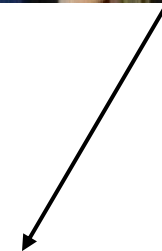
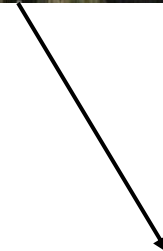


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2. Fingerspelling alignment

Automatic sign suggestion

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Relativistic electromagnetism is a physical phenomenon due to *Coulomb's* law and *Lorentz* transformations.

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Automatic sign suggestion

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Relativistic electromagnetism

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Relativistic electromagnetism



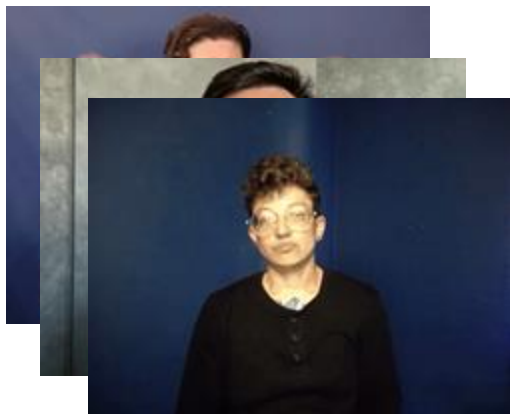
ASL database

3. Sign retrieval

Automatic sign suggestion

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Relativistic electromagnetism



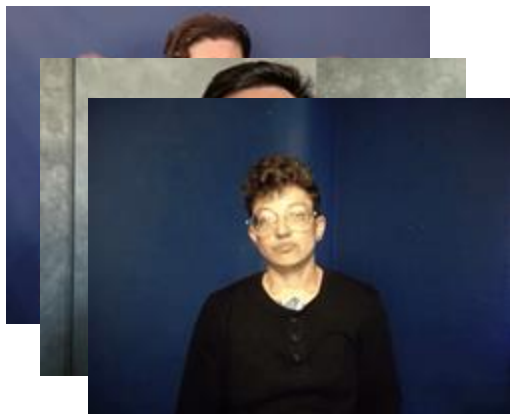
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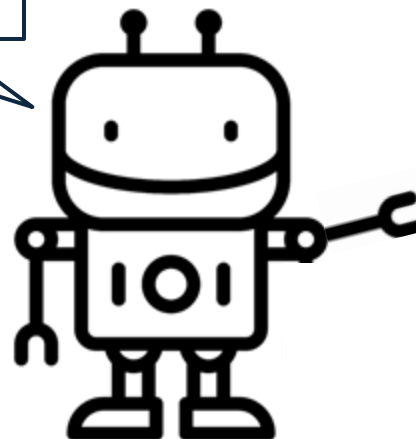
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Relativistic electromagnetism



Here are other ways people sign "relativistic electromagnetism"



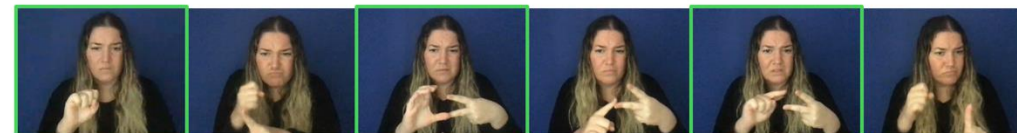
3. Sign retrieval

Self-supervised learning for fingerspelling detection

- Need fingerspelling labels

Automatic sign suggestion

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2. Fingerspelling alignment
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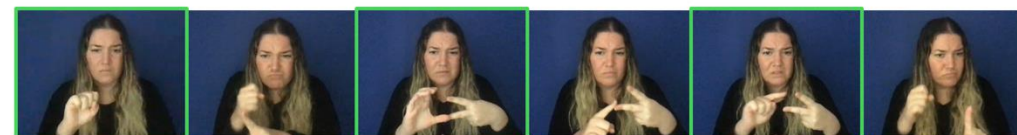
1. Fingerspelling detection

Self-supervised learning for fingerspelling detection

- Need fingerspelling labels
 - We annotated 507 videos

Automatic sign suggestion

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Self-supervised learning for fingerspelling detection

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 - 63,759 unannotated videos

Automatic sign suggestion

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Relativistic electromagnetism is a physical phenomenon due to Coulomb's law and Lorentz transformations.

1. Fingerspelling detection

Self-supervised learning

Temporal
contrastive
learning

Sentential
contrastive
learning

Self-supervised
learning

Self-supervised learning

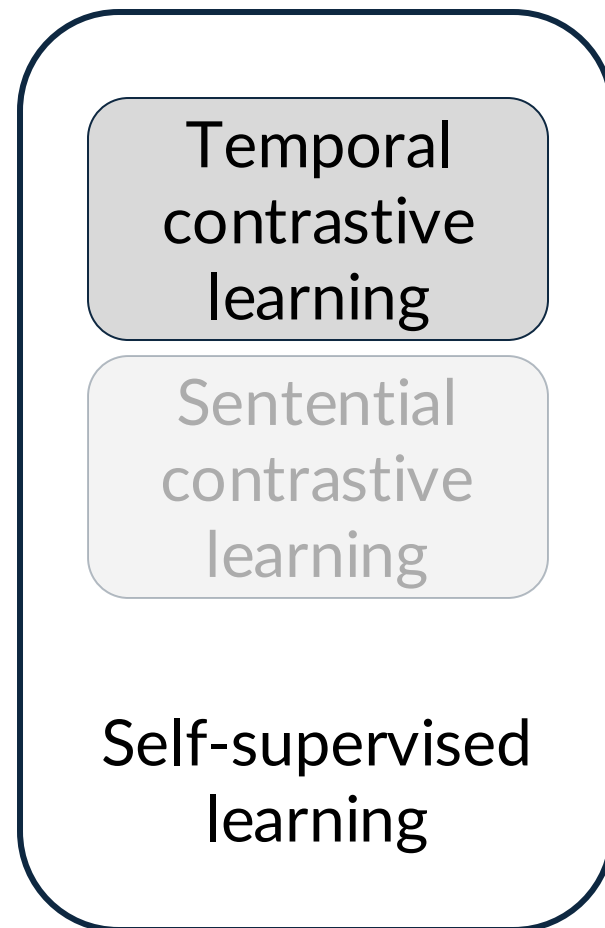
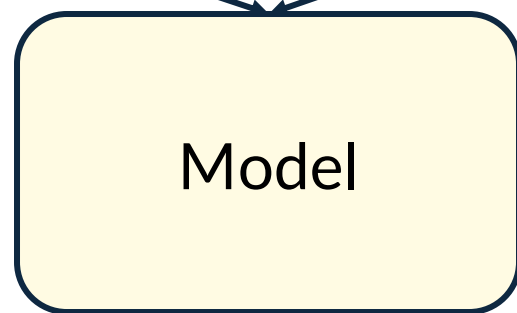


Temporal
contrastive
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Sentential
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Self-supervised
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Self-supervised learning



Self-supervised learning



Model

Different video

Same video,
video 1 < video 2

Same video,
video 2 < video 1

Temporal
contrastive
learning

Sentential
contrastive
learning

Self-supervised
learning

Self-supervised learning



Learn representations of the structure and timing of signs

Different video

Same video,
video 1 < video 2

Same video,
video 2 < video 1

Temporal
contrastive
learning

Sentential
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Self-supervised
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Self-supervised learning

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*Relativistic
electromagnetism is a
physical phenomenon
due to...*

*An observer at rest with
respect to a system of
static, free charges will...*

Temporal
contrastive
learning

Sentential
contrastive
learning

Self-supervised
learning

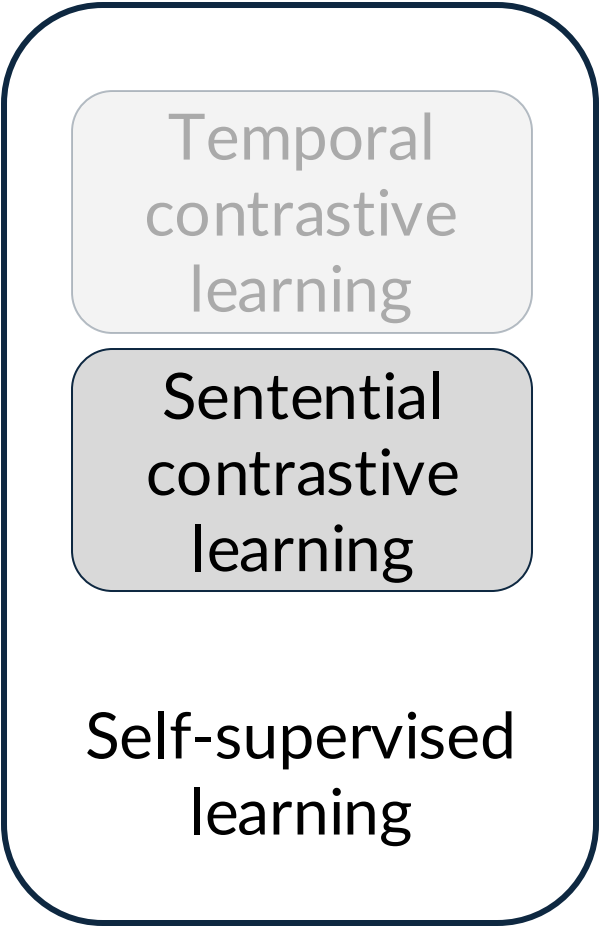
Self-supervised learning



*Relativistic
electromagnetism is a
physical phenomenon
due to...*

*An observer at rest with
respect to a system of
static, free charges will...*

Model



Self-supervised learning



*Relativistic
electromagnetism is a
physical phenomenon
due to...*

*An observer at rest with
respect to a system of
static, free charges will...*

Model

Video = sentence 1

Video = sentence 2

Temporal
contrastive
learning

Sentential
contrastive
learning

Self-supervised
learning

Self-supervised learning



*Relativistic
electromagnetism is a
physical phenomenon
due to...*

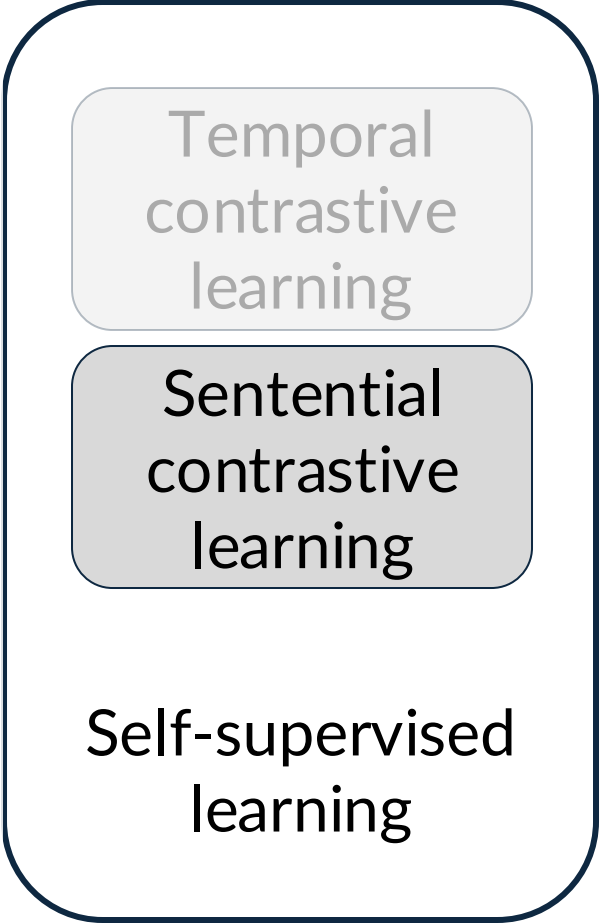
*An observer at rest with
respect to a system of
static, free charges will...*

Learn associations between ASL videos and English text

Model

Video = sentence 1

Video = sentence 2



Fingerspelling detection



Graph convolutional network



CANINE
(Clark et al., 2022)

Relativistic electromagnetism is a physical phenomenon due to...

Temporal contrastive learning Sentential contrastive learning

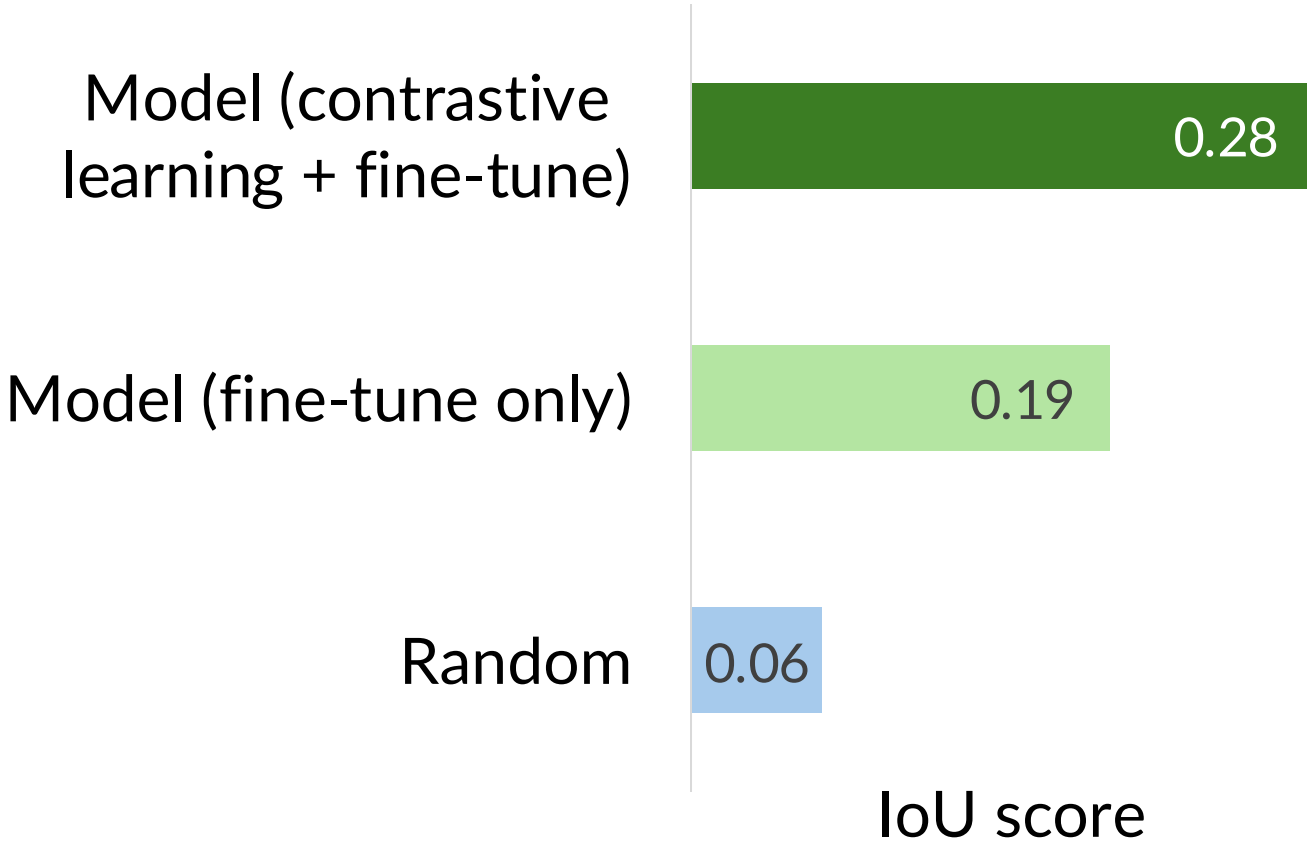
Self-supervised learning

Fingerspelling detection

Fine-tuning

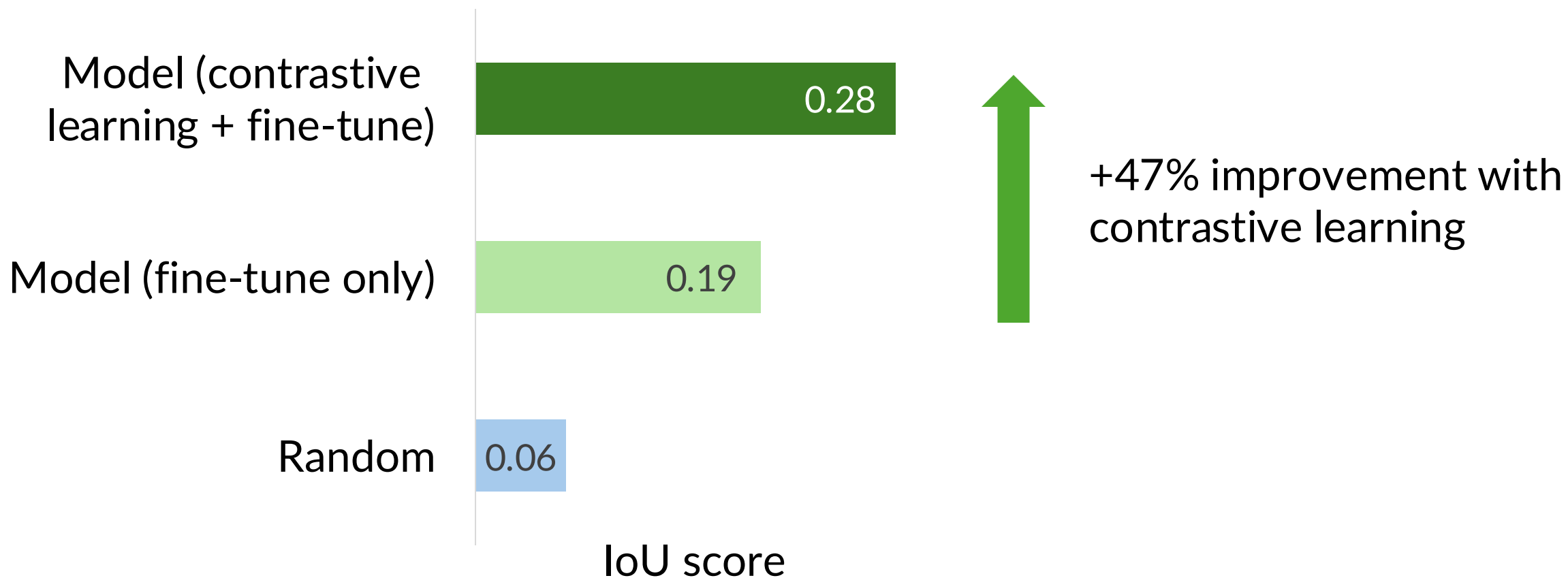
Does contrastive learning work?

Fingerspelling detection



Does contrastive learning work?

Fingerspelling detection



Summary

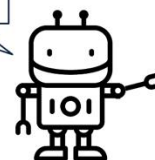


Automatic sign suggestion



User

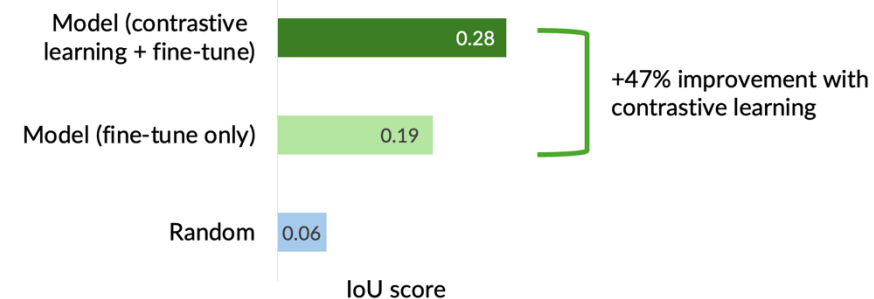
Here are other ways people sign "relativistic electromagnetism"



New dataset to support DHH students in STEM

New task to enhance ASL STEM interpretations

Fingerspelling detection

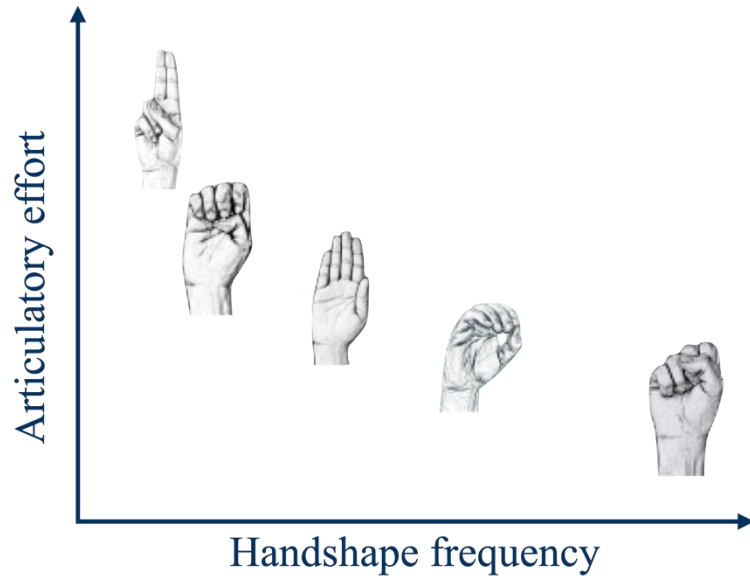


Contrastive learning for sign language modeling

Arguments for today's talk

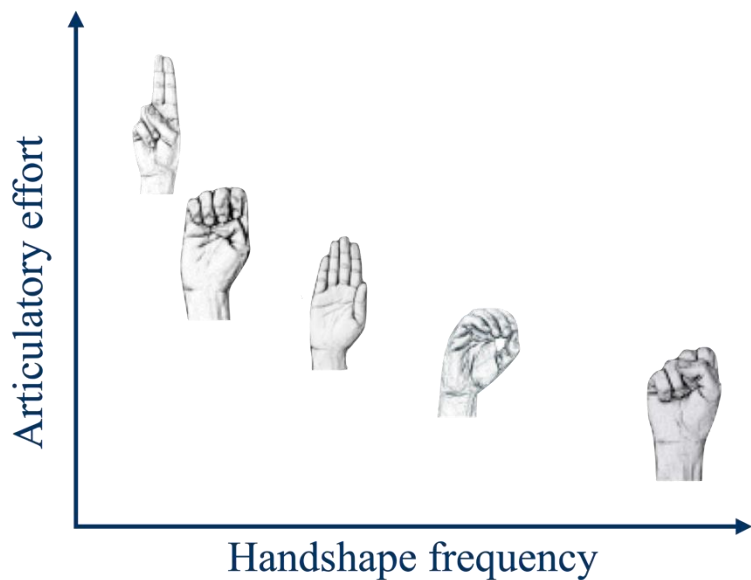
1. The linguistic complexity of signed languages gives rise to unique NLP challenges
2. Awareness of the language and the community helps us build practical NLP models
3. NLP can help answer open questions in sign linguistics

Communicative efficiency in ASL handshapes

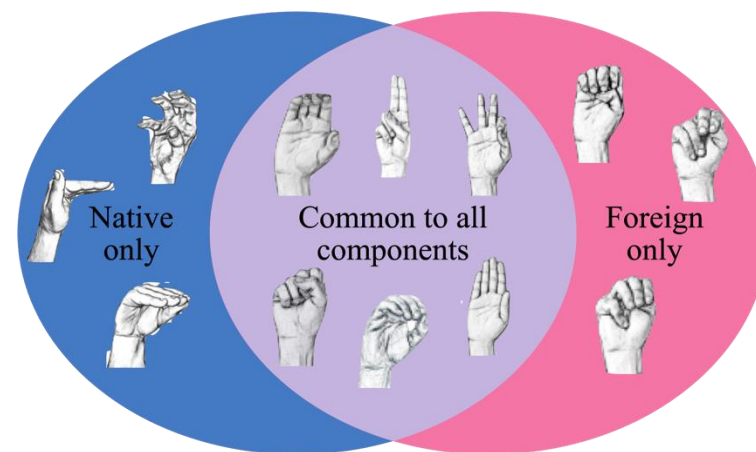


Compare ASL handshape frequency and signer effort

Communicative efficiency in ASL handshapes



Compare ASL handshape frequency and signer effort



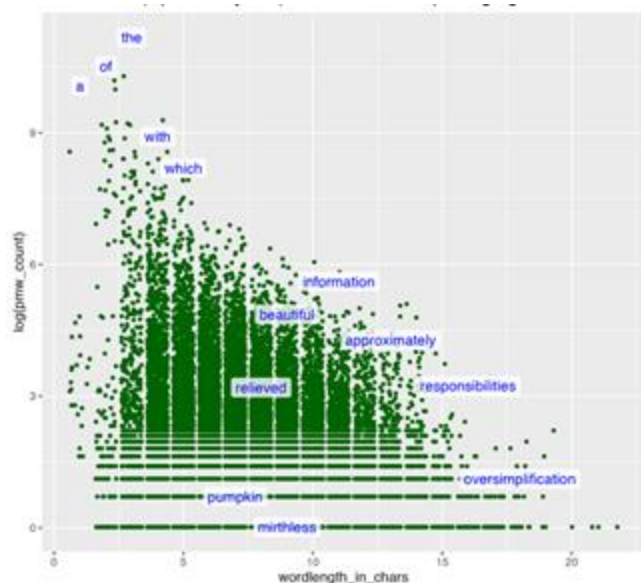
Compare efficiency pressures from native ASL signs vs. signs borrowed from English

Efficiency shapes human language

Efficiency: successful communication with **minimal effort** by sender + receiver

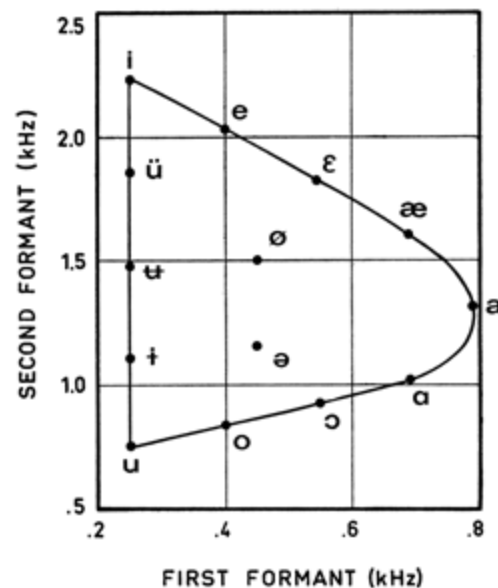
Efficiency shapes human language

Efficiency: successful communication with **minimal effort** by sender + receiver



Frequent/informative words are shorter

(Zipf, 1935; Piantadosi et al., 2011)



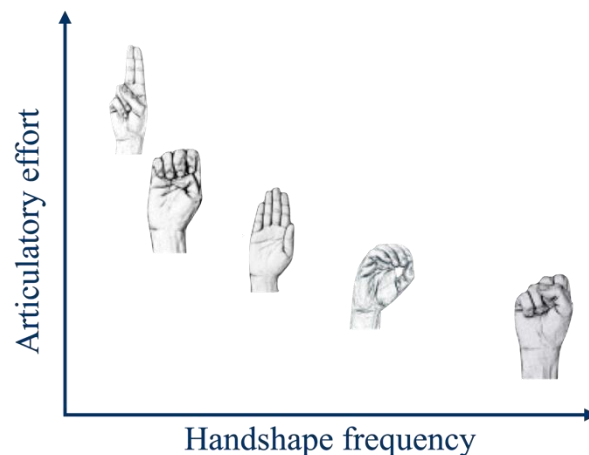
Vowel space maximizes perceptual contrast

(Liljencrants & Lindblom, 1972)

Efficiency shapes human language

Efficiency: successful communication with **minimal effort** by sender + receiver

What would communicative efficiency look like in the visual modality?



Language contact in ASL



Fingerspelling

Language contact in ASL



Fingerspelling



Loan signs

Language contact in ASL



Fingerspelling



Loan signs



Initialized signs

Language contact in ASL



Fingerspelling



Loan signs



Initialized signs

How do different language sources compare in communicative efficiency?

Research questions

RQ1. Do ASL handshapes reflect pressures for **communicative efficiency**?

Research questions

RQ1. Do ASL handshapes reflect pressures for **communicative efficiency**?

RQ2. If so, do we find communicative efficiency mostly in **native signs**, or also in signs **borrowed from English**?

Research questions

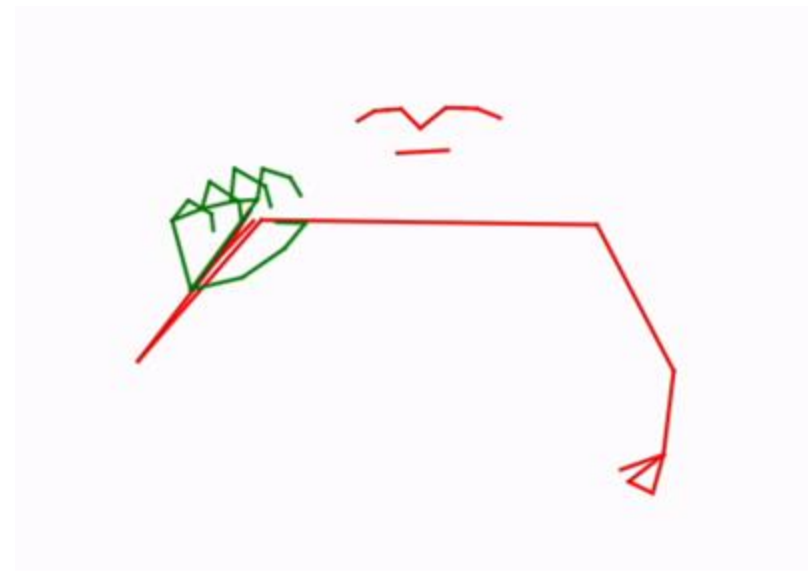
RQ1. Do ASL handshapes reflect pressures for **communicative efficiency**?

RQ2. If so, do we find communicative efficiency mostly in **native signs**, or also in signs **borrowed from English**?

→ Compare handshape frequency and sender / receiver effort

Data

ASL Fingerspelling Recognition Corpus

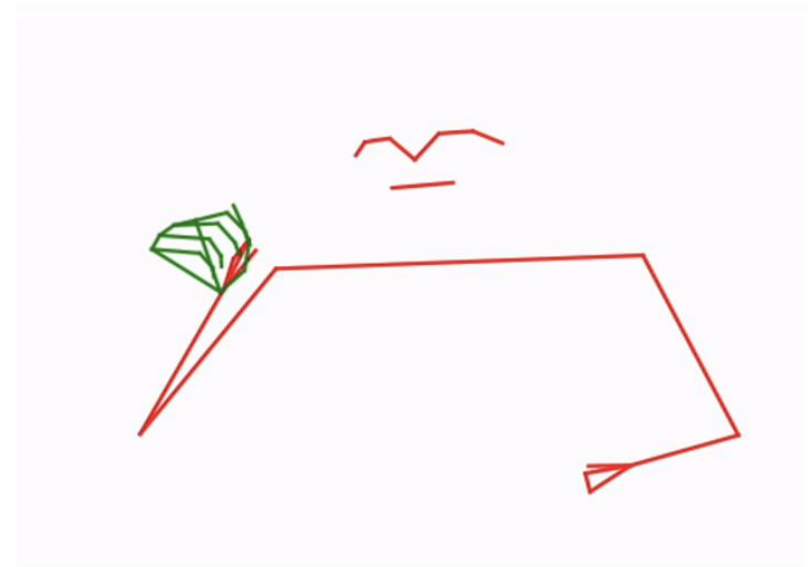


did you have a good
time

Data

ASL Fingerspelling Recognition Corpus

- 100k+ fingerspelled phrases, no character-level labels

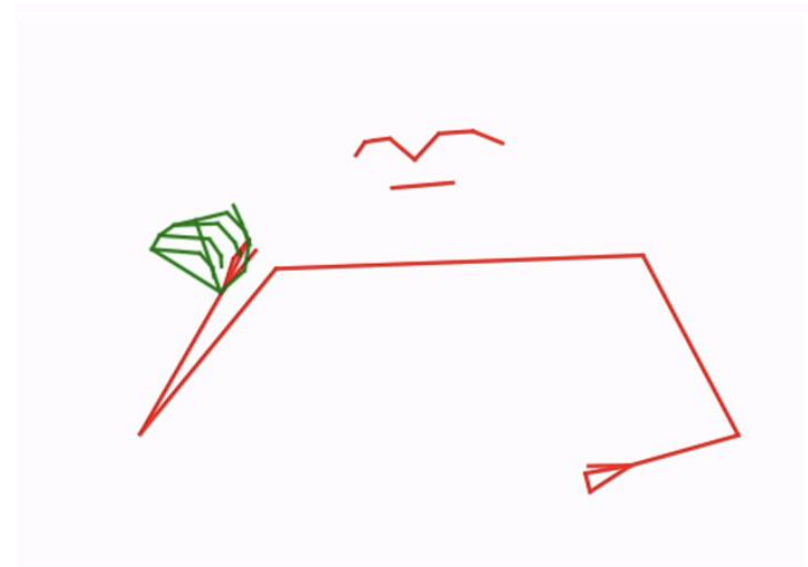


did you have a good
time

Data

ASL Fingerspelling Recognition Corpus

- 100k+ fingerspelled phrases, no character-level labels
- Heuristic algorithm + manual post-correction
 - 1062 letters extracted



did you have a good
time

Data

ASL-LEX (Caselli et al., 2017)



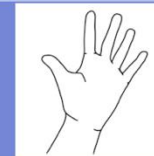
Alternate English Translations:

cheese, dairy, food

About the sign:

Entry ID	cheese
English Word Frequency	3.299
Frequency	5.63
Deaf Signer Iconicity	1.55
Initialized Sign	0
Fingerspelled Loan Sign	0
Compound	0
Number Of Morphemes	1

Handshape Image



Data

ASL-LEX (Caselli et al., 2017)

- Handshape categories

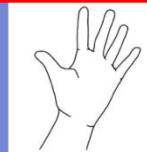


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Handshape Image



Data

ASL-LEX (Caselli et al., 2017)

- Handshape categories
- Sign frequency



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Handshape Image



Data

ASL-LEX (Caselli et al., 2017)

- Handshape categories
- Sign frequency
- Native / initialized / loan sign



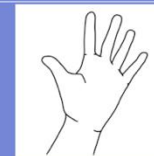
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Handshape Image



Effort metrics

Articulatory effort

Perceptual effort

Effort metrics

Articulatory effort

- Finger independence

Perceptual effort

Low finger independence
(Low **articulatory** effort)



High finger independence
(High **articulatory** effort)



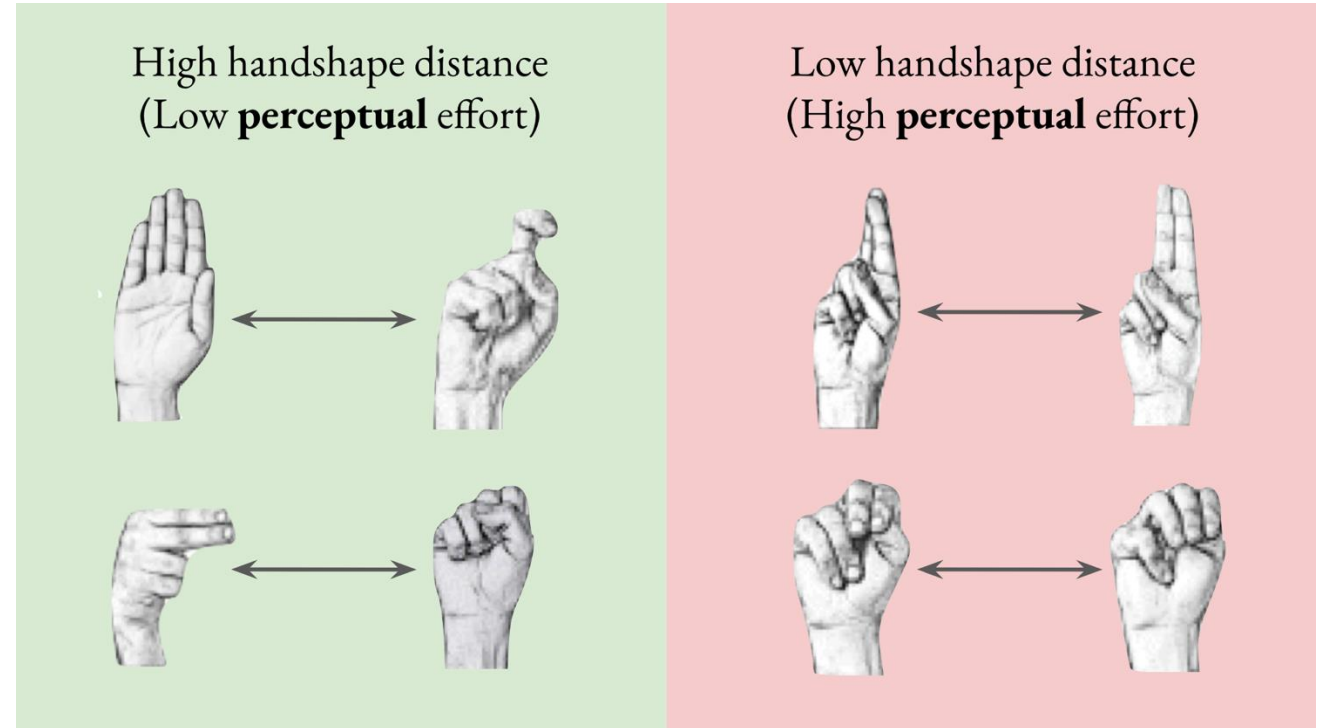
Effort metrics

Articulatory effort

- Finger independence

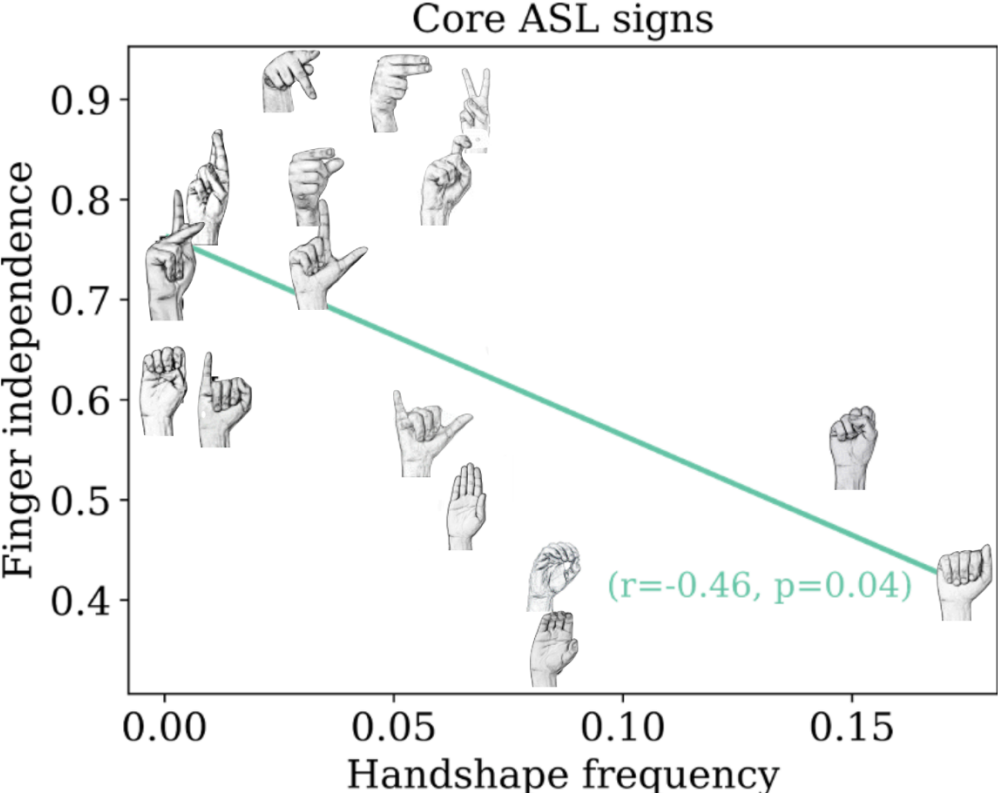
Perceptual effort

- Handshape distance



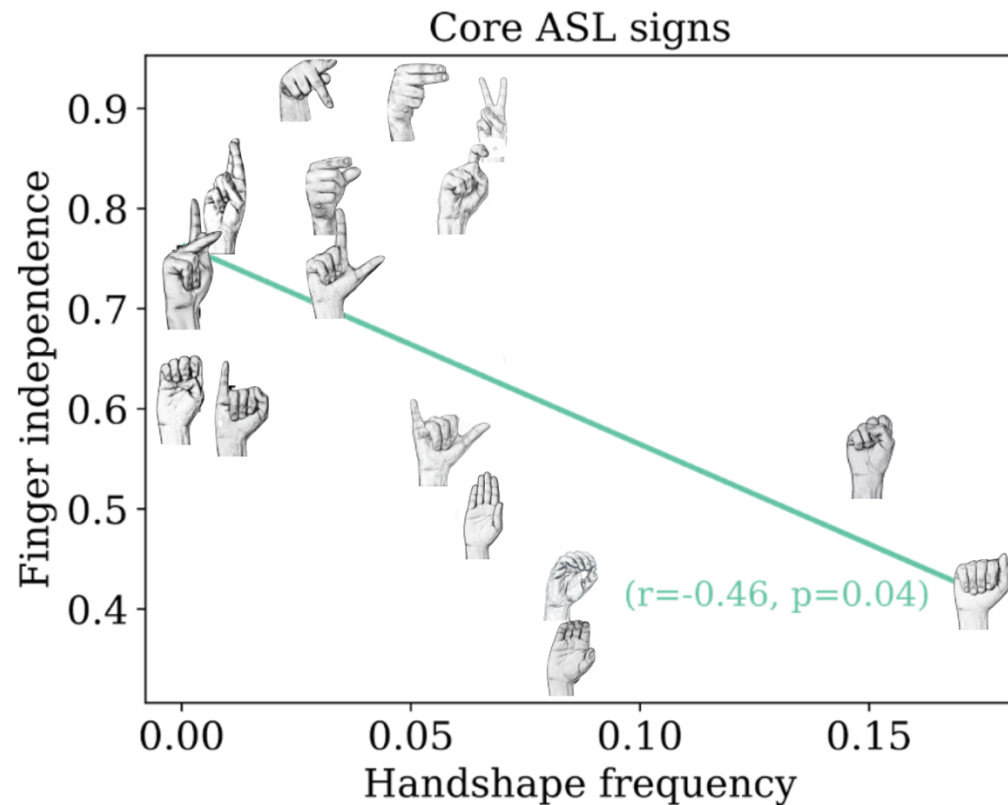
Results

Handshape frequency vs. articulatory effort: native ASL signs



Results

Handshape frequency vs. articulatory effort: native ASL signs

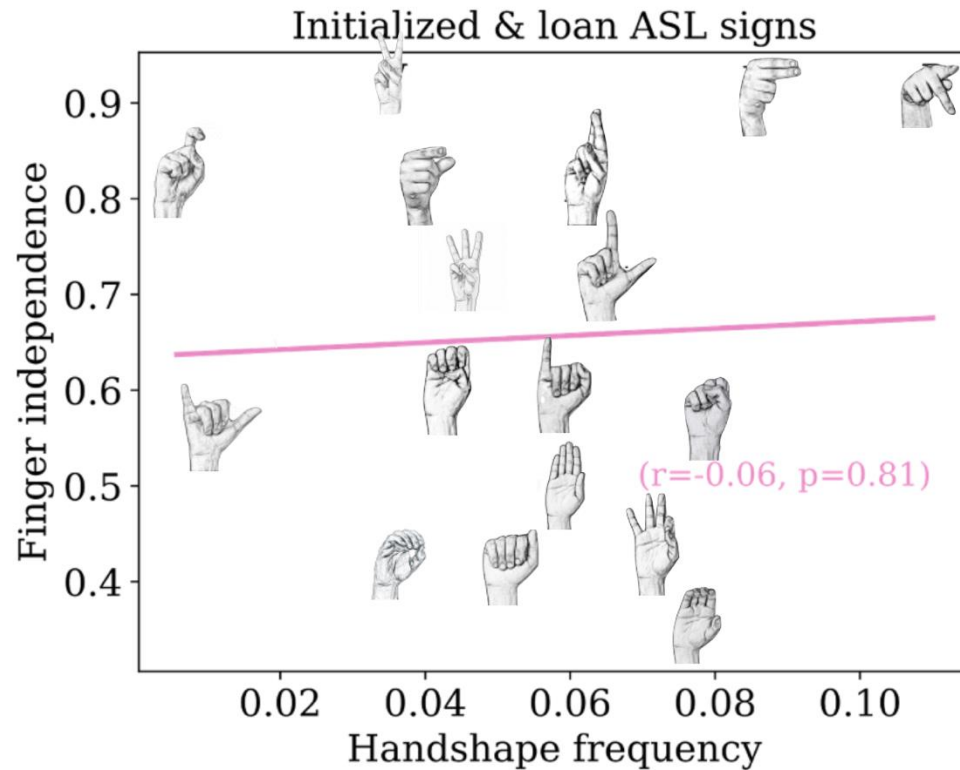


Pearson's $r=-0.46, p=0.04$
→strong correlation



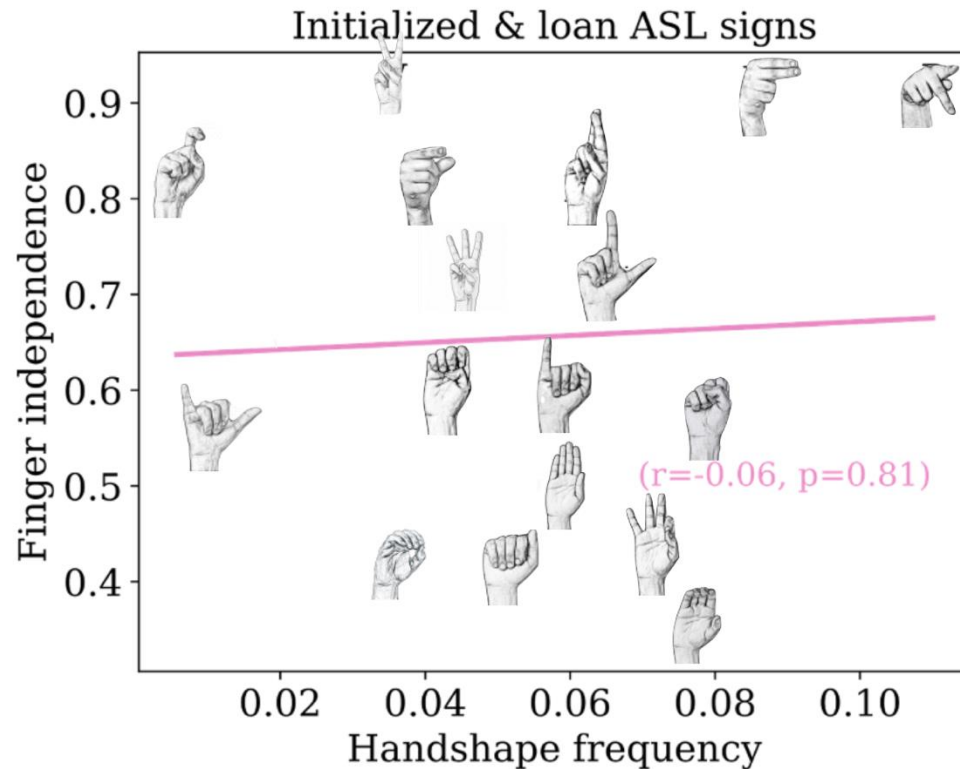
Results

Handshape frequency vs. articulatory effort: borrowed ASL signs
(initialized / fingerspelled loan signs)



Results

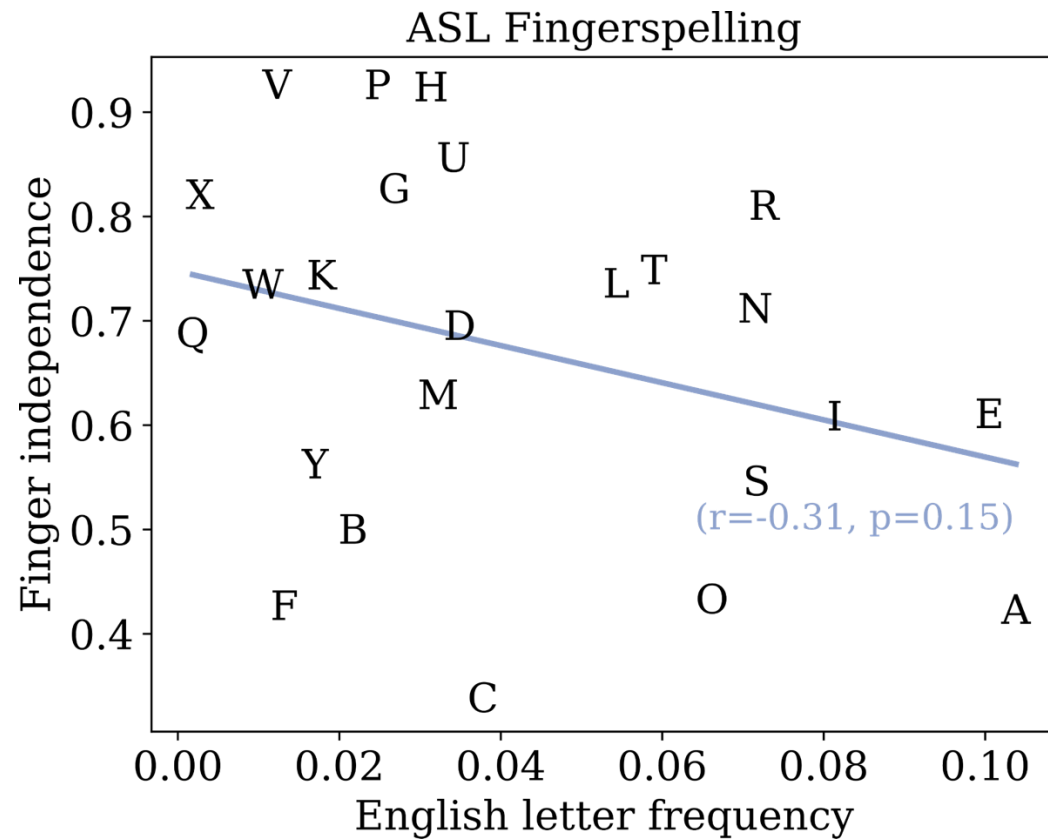
Handshape frequency vs. articulatory effort: borrowed ASL signs
(initialized / fingerspelled loan signs)



Pearson's $r=-0.06, p=0.81$
→no correlation

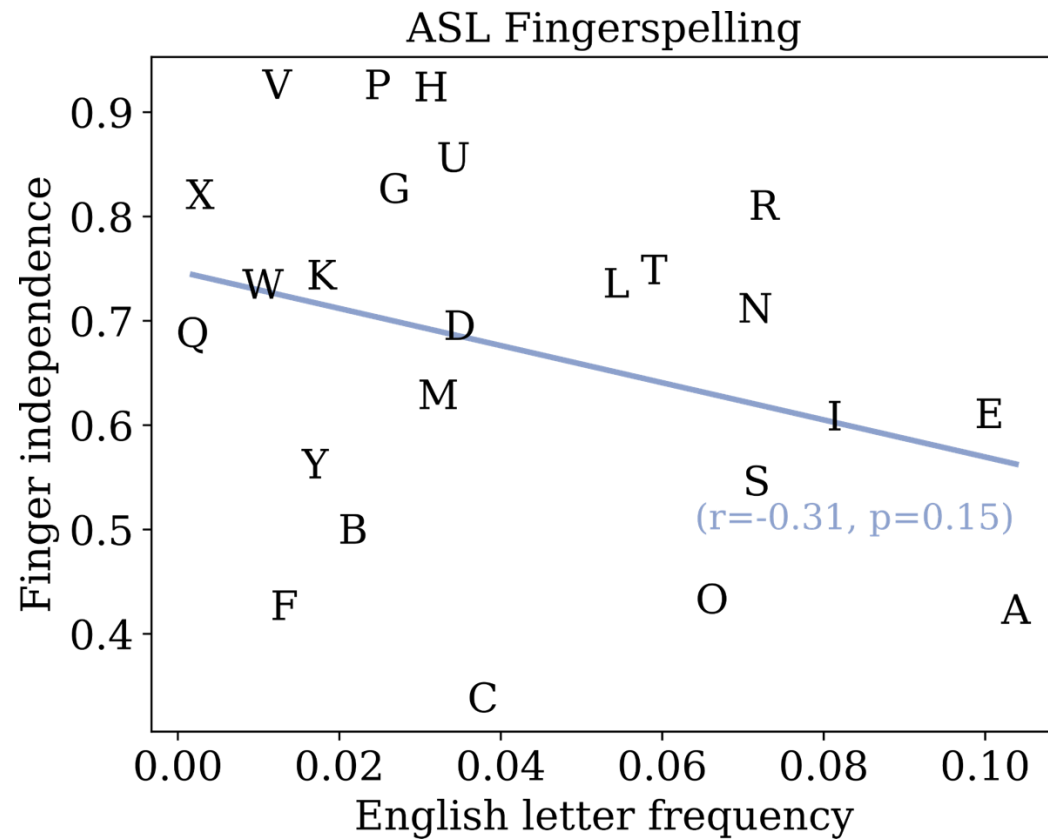
Results

English letter frequency vs. articulatory effort (fingerspelling)



Results

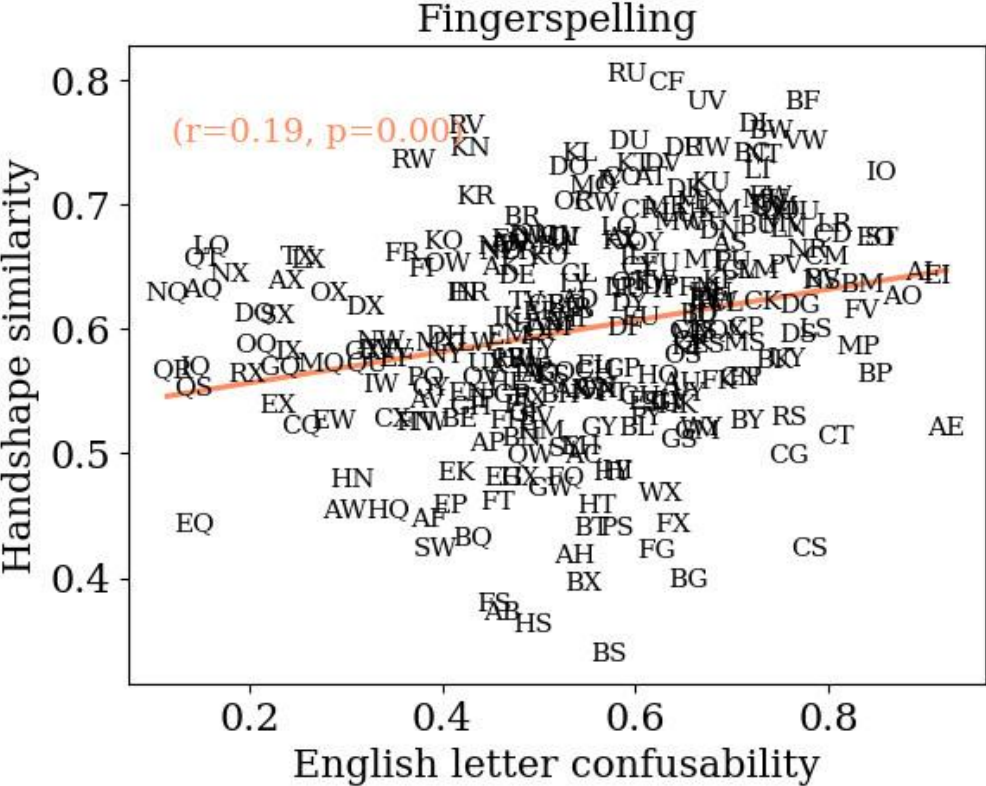
English letter frequency vs. articulatory effort (fingerspelling)



Pearson's $r=-0.31, p=0.15$
→no correlation

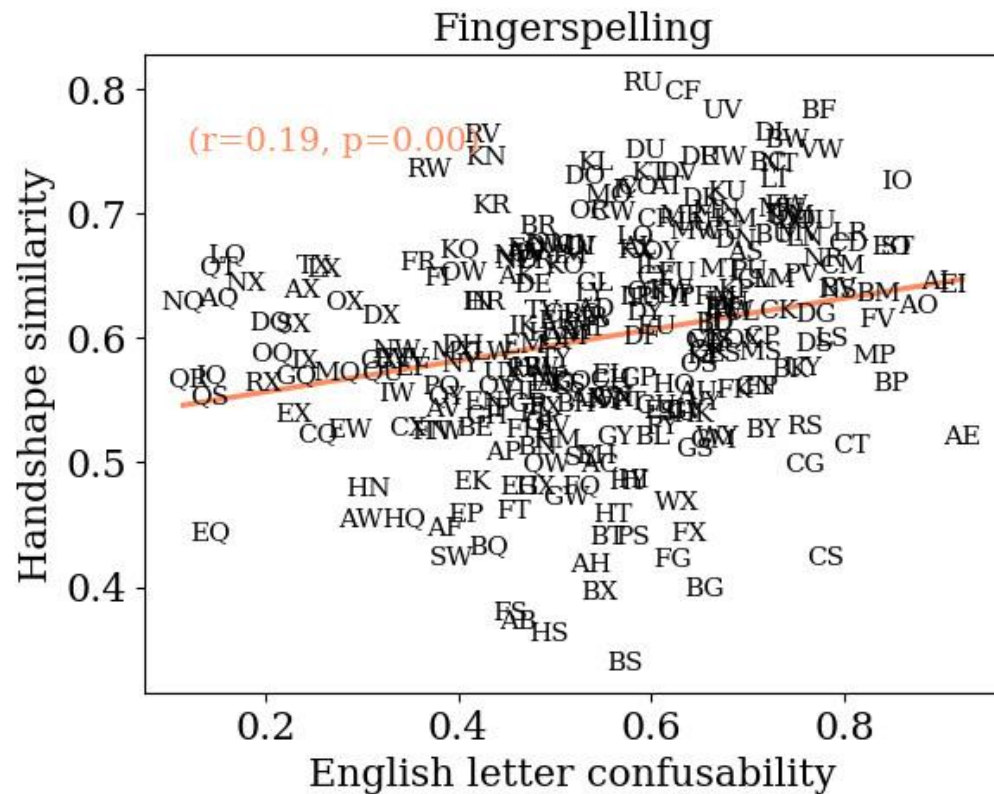
Results

English letter confusability vs. perceptual effort (fingerspelling)



Results

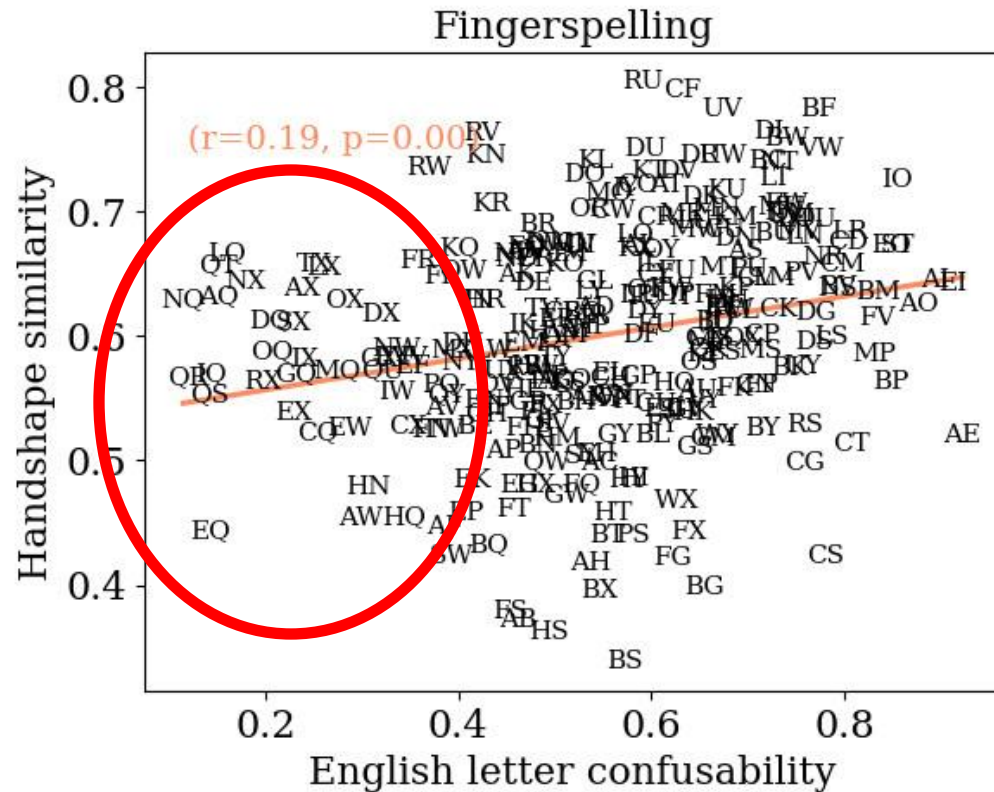
English letter confusability vs. perceptual effort (fingerspelling)



Pearson's $r=0.19, p=0.00$
→ weak correlation?

Results

English letter confusability vs. perceptual effort (fingerspelling)

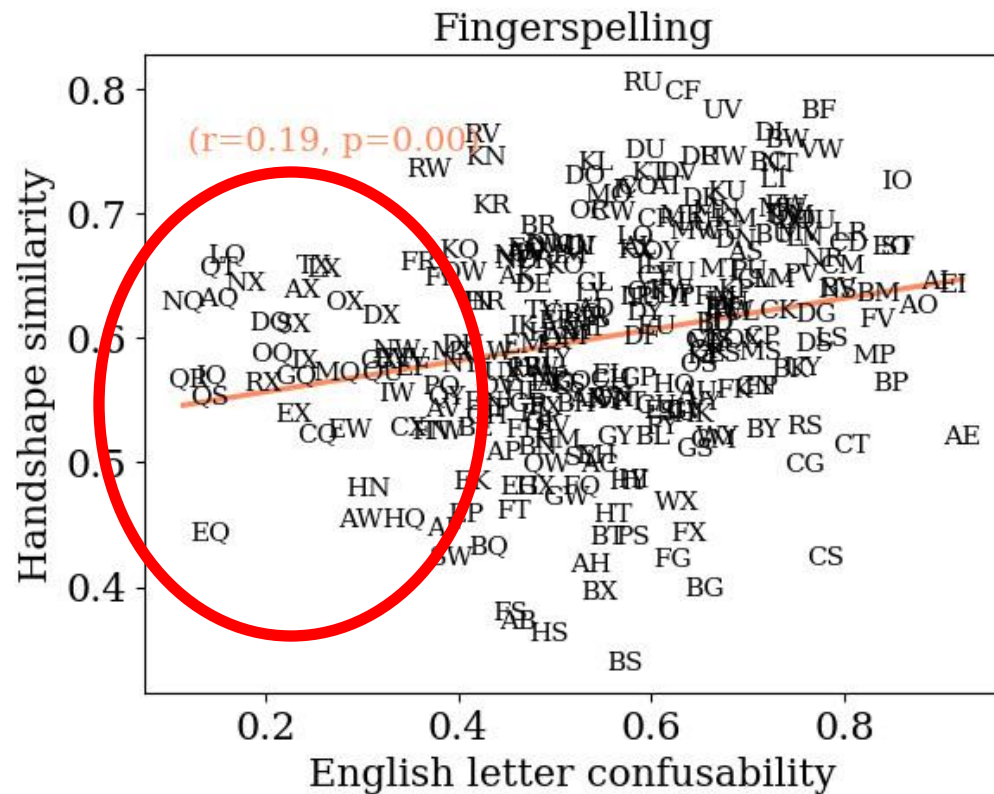


Pearson's $r=0.19, p=0.00$
→ weak correlation?

Confusability and letter frequency
are highly correlated

Results

English letter confusability vs. perceptual effort (fingerspelling)



Pearson's $r=0.19, p=0.00$

→no correlation once we
partial letter frequency out!

Confusability and letter frequency
are highly correlated

What we learned

RQ1. Do ASL handshapes reflect pressures for **communicative efficiency**?

Yes!

RQ2. If so, do we find communicative efficiency mostly in **native signs**, or also in signs **borrowed from English**? **Only in native signs!**

What we learned

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Why?

What we learned

RQ2. If so, do we find communicative efficiency mostly in **native signs**, or also in signs **borrowed from English**? **Only in native signs!**

Why?

- ASL fingerspelling is invented by hearing educators (Padden and Gunsauls, 2003)

What we learned

RQ2. If so, do we find communicative efficiency mostly in **native signs**, or also in signs **borrowed from English**? **Only in native signs!**

Why?

- ASL fingerspelling is invented by hearing educators (Padden and Gunsauls, 2003)
- Frequent words undergo faster language change (Bybee, 2015; Caselli et al., 2022)

What we learned

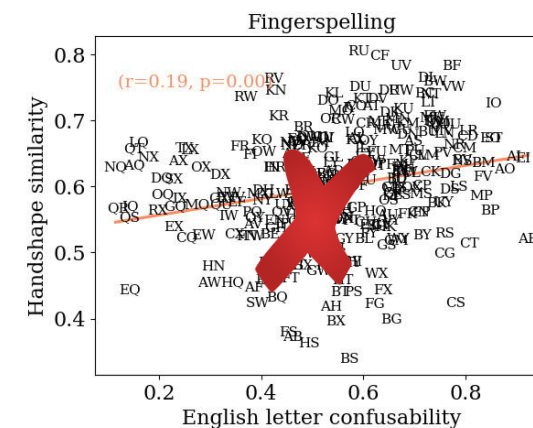
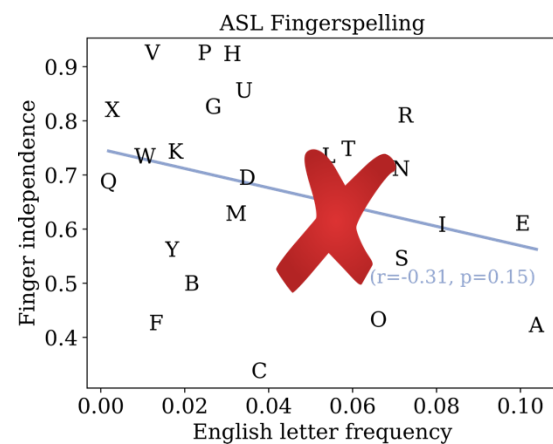
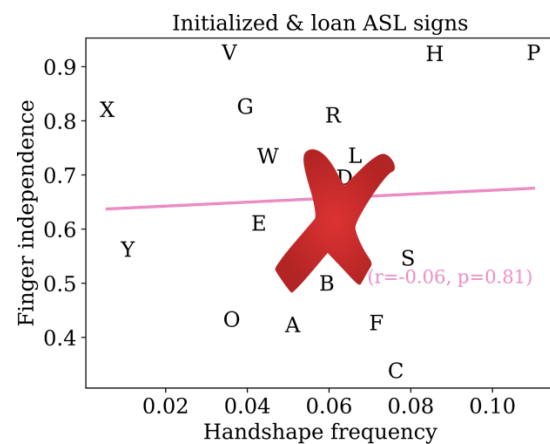
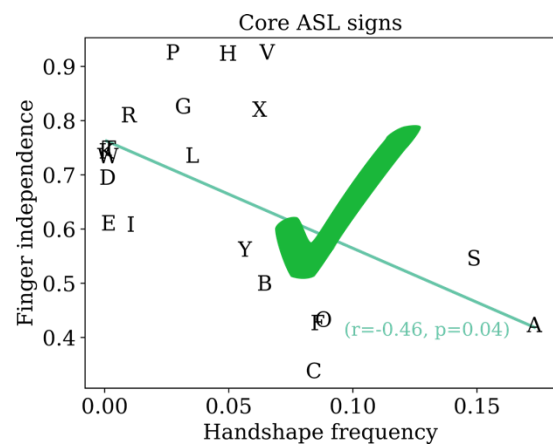
RQ2. If so, do we find communicative efficiency mostly in **native signs**, or also in signs **borrowed from English**? **Only in native signs!**

Why?

- ASL fingerspelling is invented by hearing educators (Padden and Gunsauls, 2003)
- Frequent words undergo faster language change (Bybee, 2015; Caselli et al., 2022)
- Foreign components obey fewer phonological rules (Brentari and Padden, 2001)

Summary

- Compare the frequency and effort of ASL handshapes
- Automatic metrics to quantify production/recognition effort
- We observe communicative efficiency in only handshapes of native signs, not signs borrowed from English



Takeaways from this talk

1. The linguistic complexity of signed languages gives rise to unique NLP challenges
2. Awareness of the language and the community helps us build practical NLP tools
3. NLP can help answer open questions in sign linguistics

Takeaways from this talk

1. The linguistic complexity of signed languages gives rise to unique NLP challenges – **testbed for general multimodal intelligence!**
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Takeaways from this talk

1. The linguistic complexity of signed languages gives rise to unique NLP challenges – **testbed for general multimodal intelligence!**
2. Awareness of the language and the community helps us build practical NLP tools – **accessibility + language revitalization!**
3. NLP can help answer open questions in sign linguistics

Takeaways from this talk

1. The linguistic complexity of signed languages gives rise to unique NLP challenges – testbed for general multimodal intelligence!
2. Awareness of the language and the community helps us build practical NLP tools – accessibility + language revitalization!
3. NLP can help answer open questions in sign linguistics – legitimize signed languages + advance science!

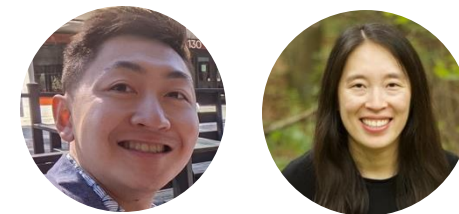
Future directions

Ongoing work (sneak peek)



Do sign recognition models rely on meaningful phonological features?

Ongoing work (sneak peek)



Do sign recognition models rely on meaningful phonological features?

- Minimal pairs contrasting in phonology



Handshape contrast



Location contrast

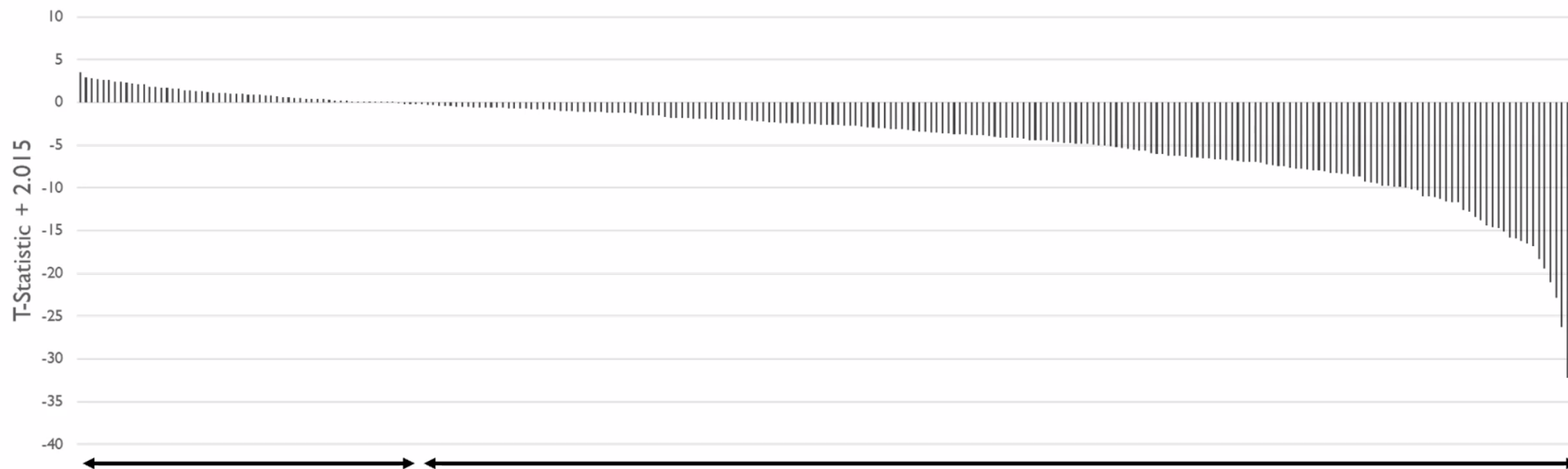


Movement contrast

Ongoing work (sneak peek)



- Model embeddings can distinguish most minimal pairs



200 of 254 minimal pairs (78.7%) induce significantly higher distances in embeddings across 5 pairs of signers ($p < 0.05$)

Ongoing work (sneak peek)



- Model embeddings can distinguish most minimal pairs
- No correlation between model perception and human expert perception

Ongoing work (sneak peek)



- Model embeddings can distinguish most minimal pairs
- No correlation between model perception and human expert perception – why?

Ongoing work (sneak peek)



- Model embeddings can distinguish most minimal pairs
- No correlation between model perception and human expert perception – why?

Contributions: evaluation, interpretability, data-efficient training

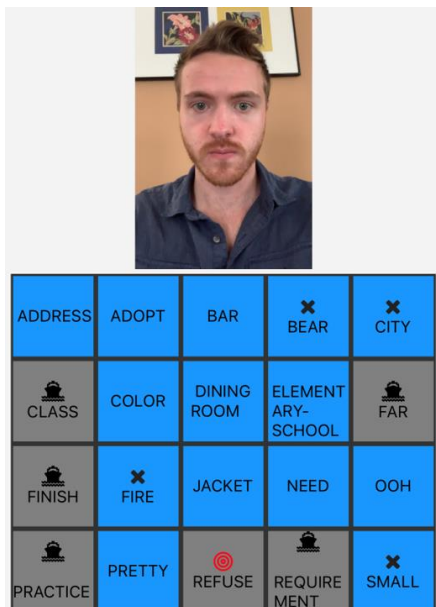
Future challenges

- Efficient data collection
- Better multimodal architectures
- Spatial reasoning

the world if we had sign foundation models:



Data collection

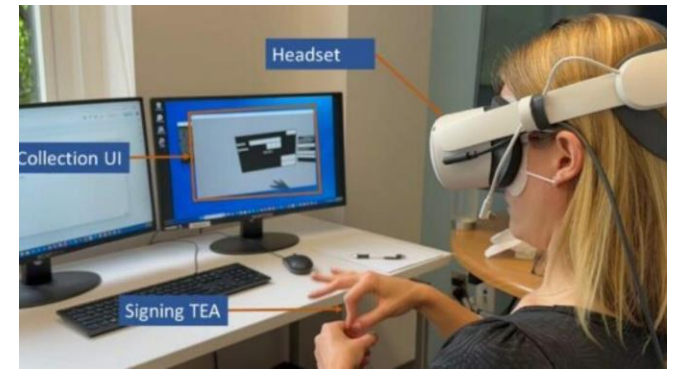


ASL Sea Battle
(Bragg et al., 2021)

- HCI interfaces for data collection
- AI tools to assist data annotation
- AI video anonymization
- Data augmentation

Education

- What environment to learn signed language digitally?
- Adaptive AI for personalized learning
- Educational content delivery, real-time classroom support



ASL Champ
(Gallaudet, 2024)

Signed language generation



Here Comes Mavo!
(Gallaudet, 2025)

- What does a good signing avatar look like?
- Translation between signed languages
- Storytelling

The end!

