Introduction

LING 571 — Deep Processing Techniques for NLP

Shane Steinert-Threlkeld

Roadmap

- **Motivation**
- Language and Intelligence
- Knowledge of Language
- Course Overview
- Intro to Syntax and Parsing

How are you feeling about the start of the quarter and a new academic year generally?

Total Results: 0

Motivation: Applications

- Applications of Speech and Language Processing
  - Call Routing
  - Information Retrieval
  - Question Answering
  - Machine Translation
  - Dialog Systems
  - Spell– and Grammar– Checking
  - Sentiment Analysis
  - Information Extraction
  - …

Building on Many Fields

- **Linguistics**: *Morphology, phonology, syntax, semantics…*
- **Psychology**: *Reasoning, mental representations*
- **Formal Logic**
- **Philosophy (of Language)**
- **Theory of Computation**: *Automata theory*
- **Artificial Intelligence**: *Search, Reasoning, Knowledge Representation, Machine Learning, Pattern Matching*
- **Probability**

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Operationalizing Intelligence: The Turing Test (1950)

- Two contestants: Human vs. Computer
  - Judge: human
  - Test: interact via text questions
  - Question: Can judge tell which contestant is human?

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- Two contestants: Human vs. Computer
  - **Judge**: human
  - **Test**: interact via text questions
  - **Question**: Can judge tell which contestant is human?
- *Crucially*:
  - Posits that passing requires language use and understanding

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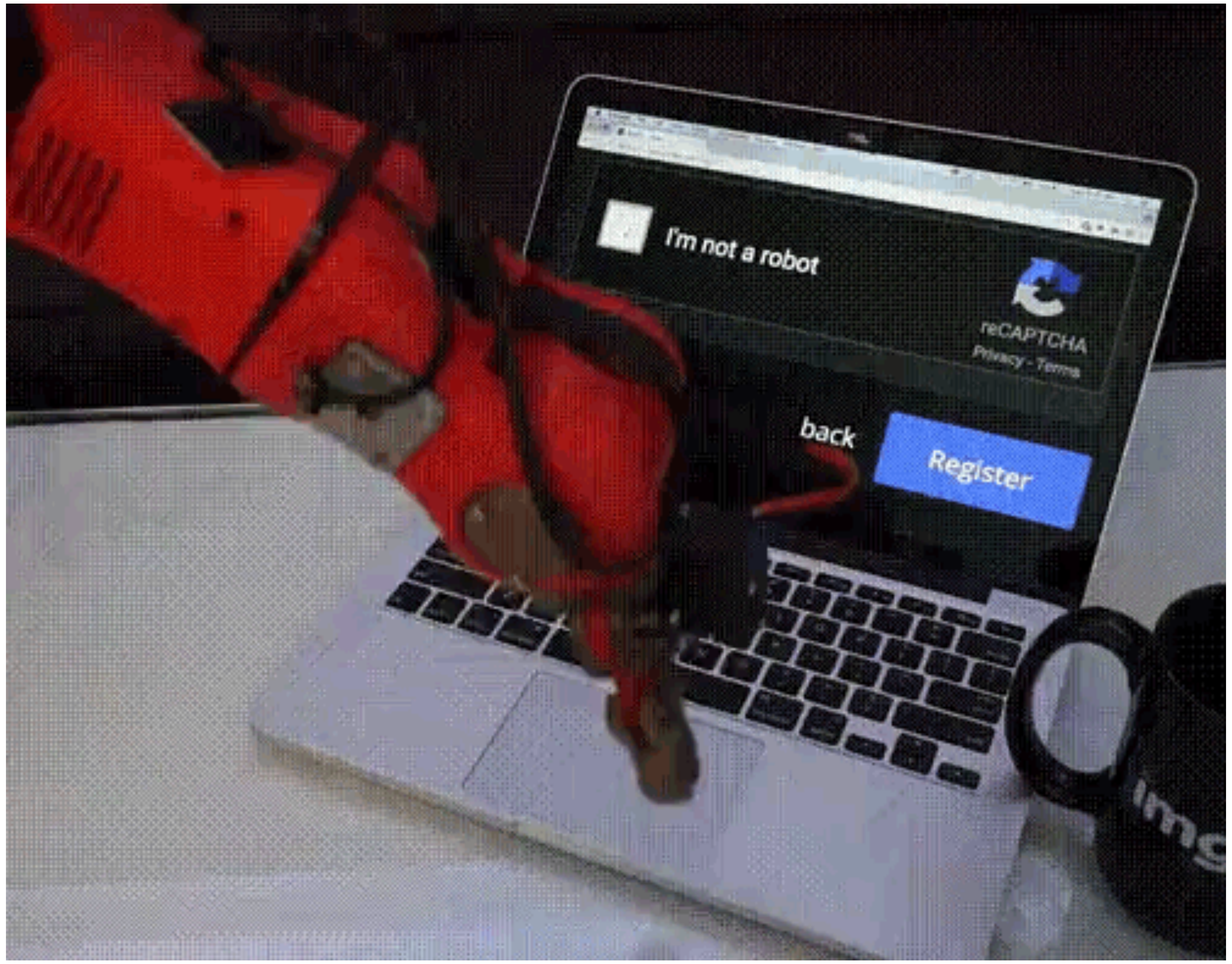
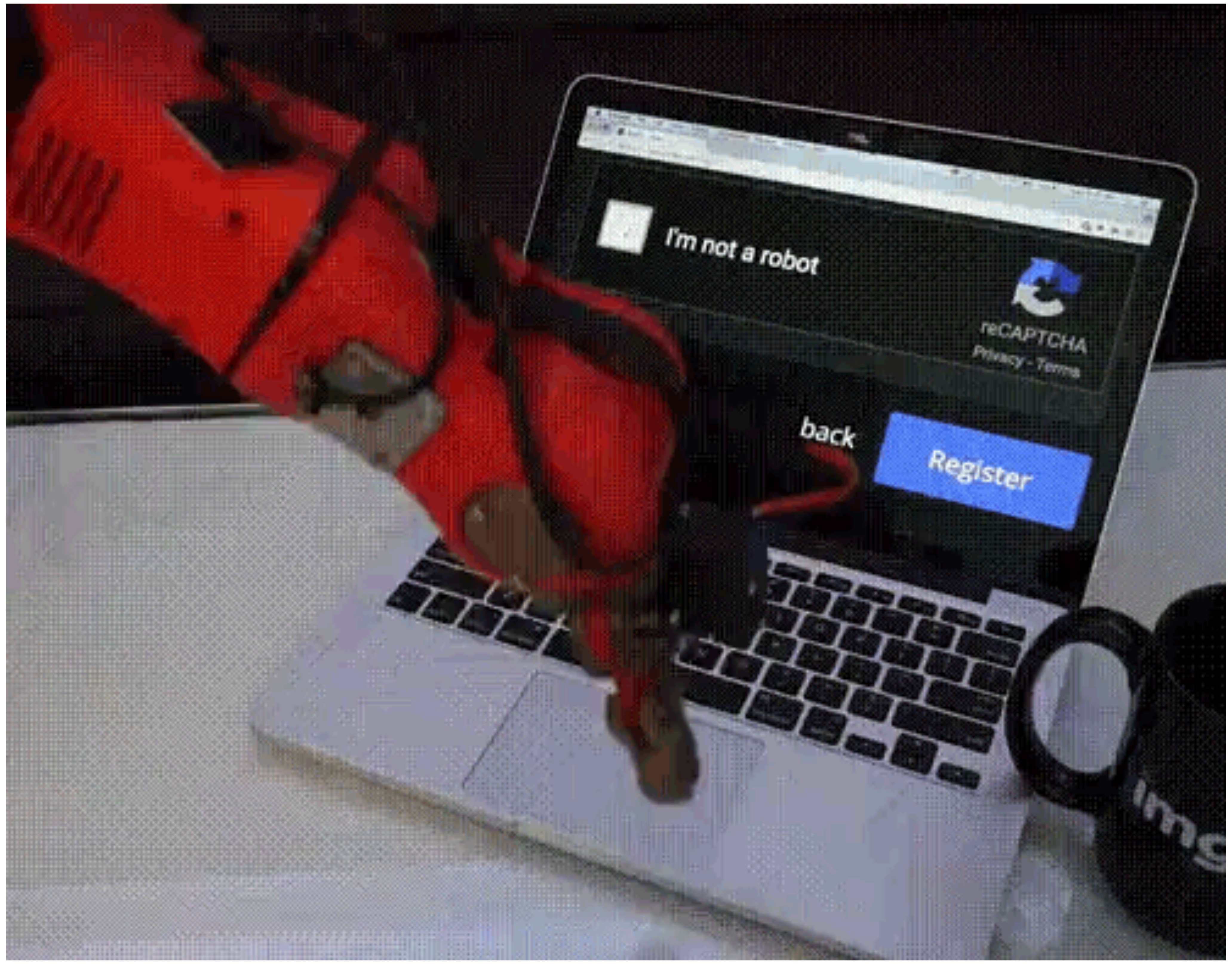
  - Long-term: Inspires "arms race"

CAPTCHA arms race



CAPTCHA arms race



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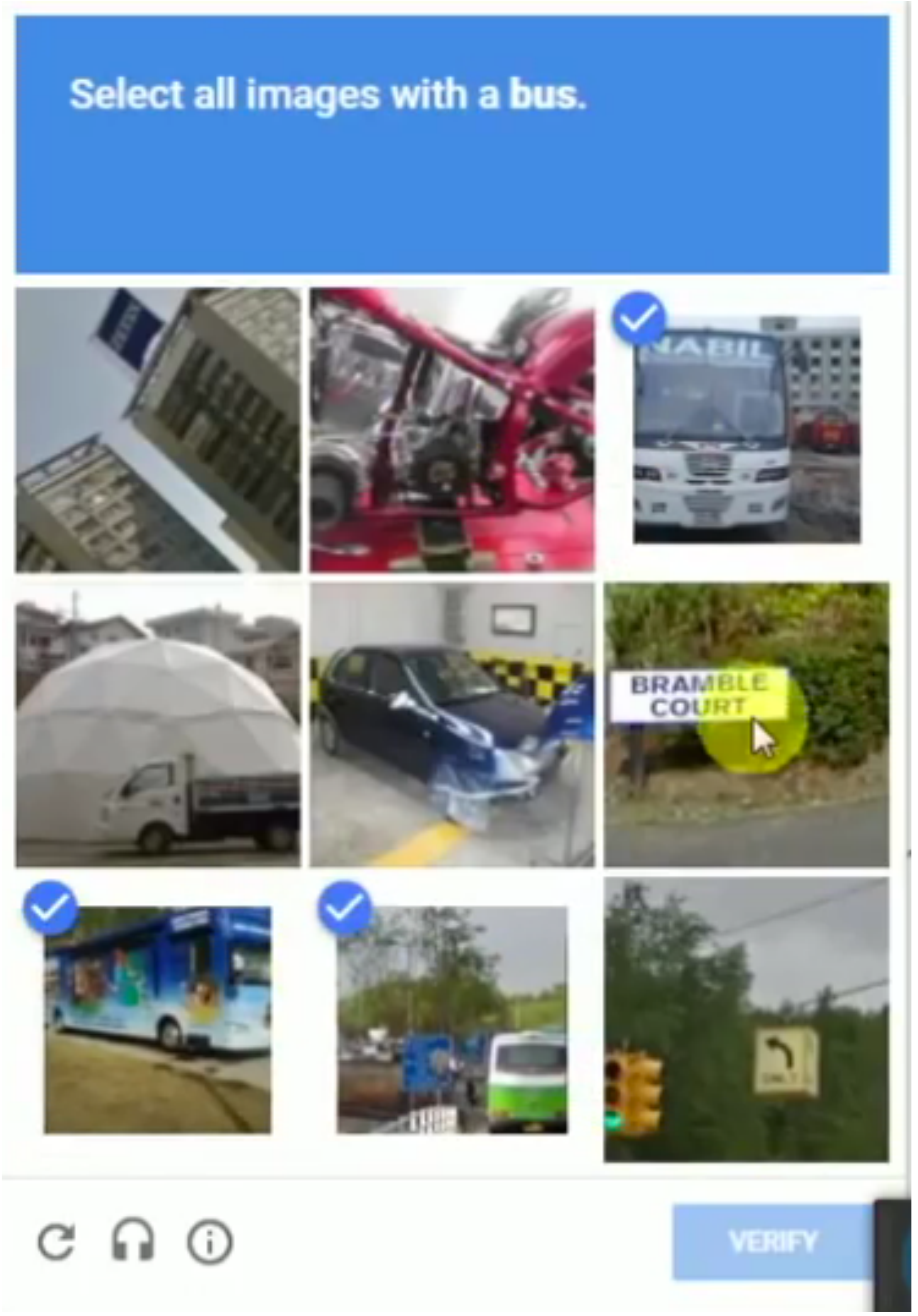

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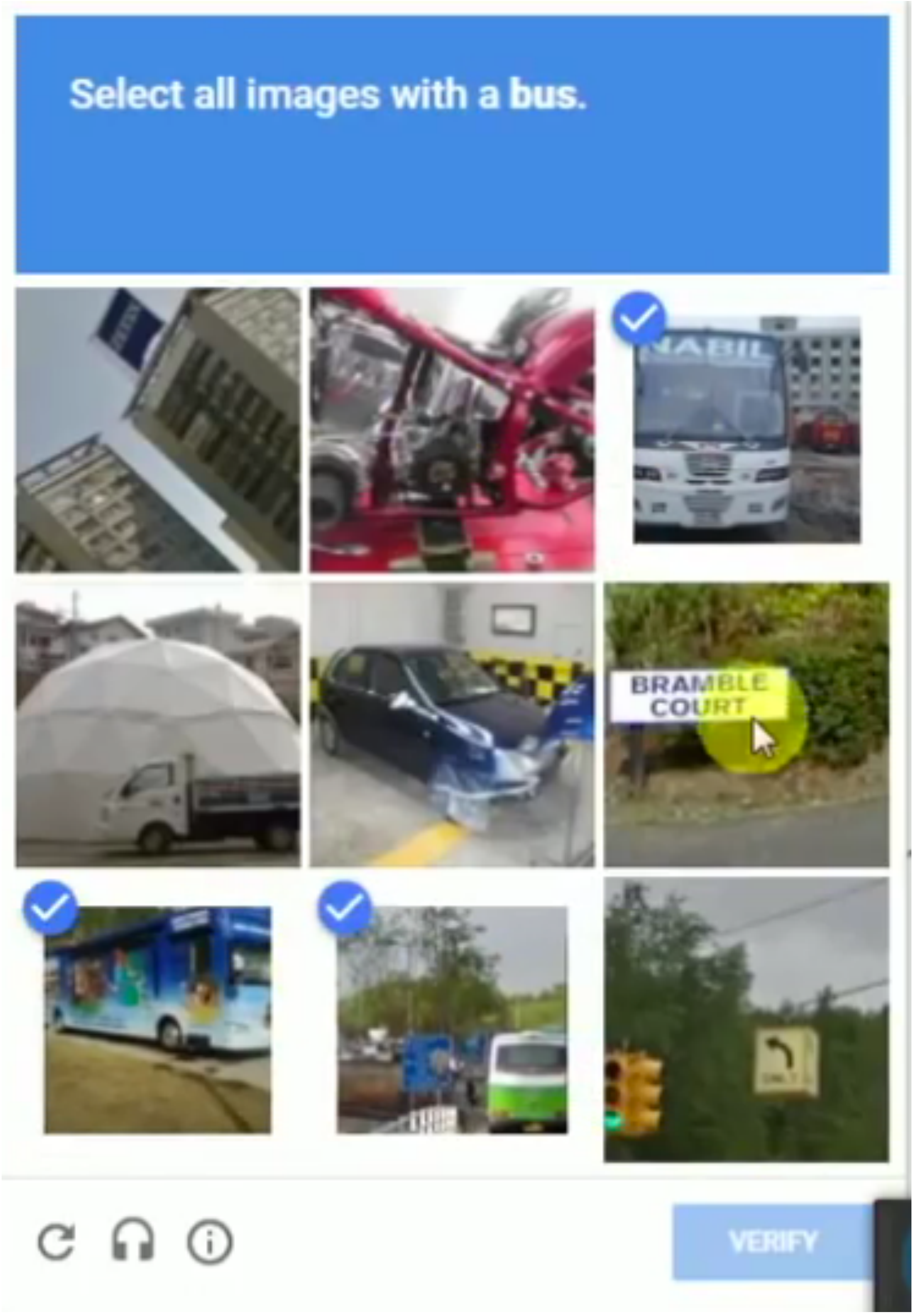

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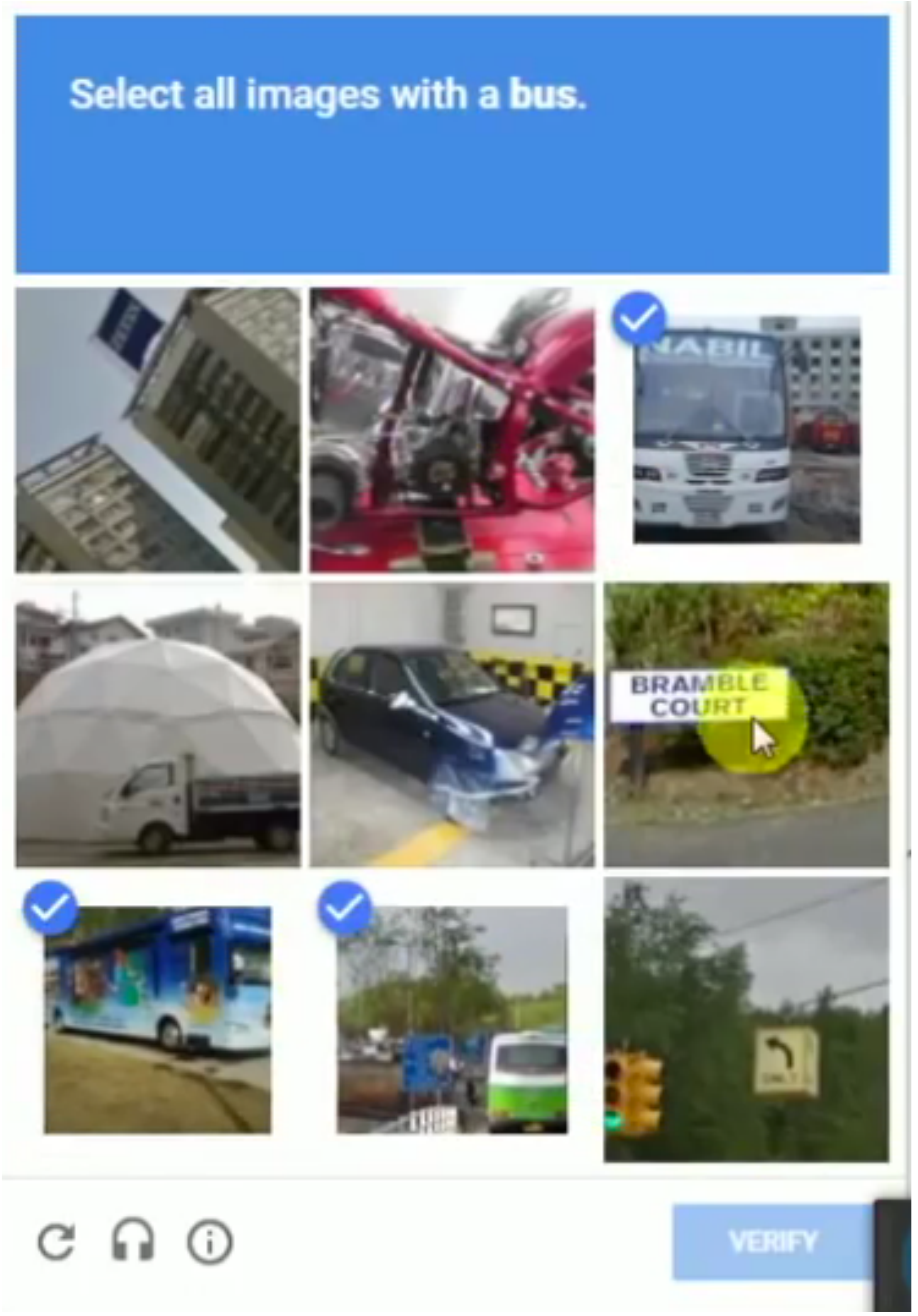

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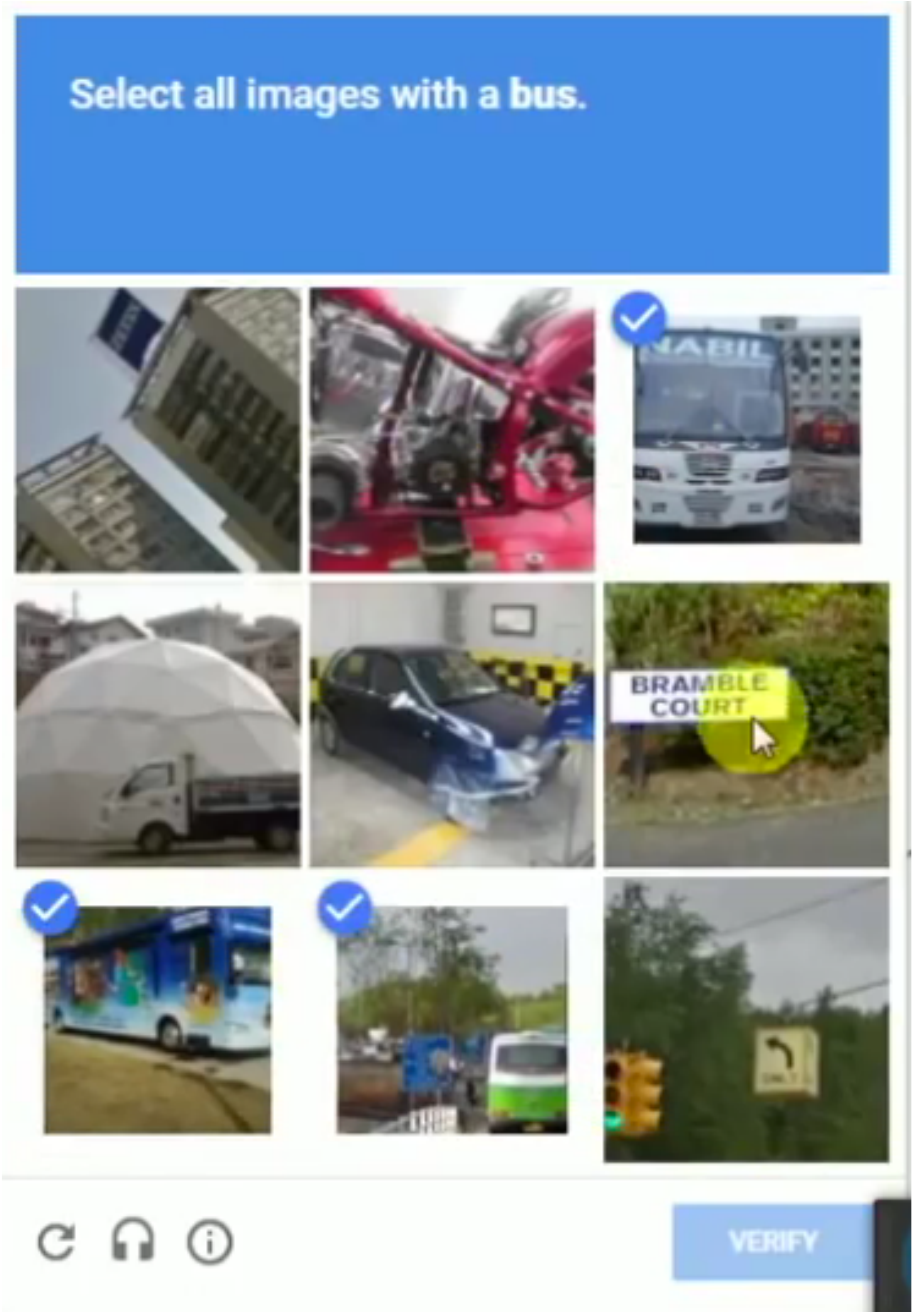

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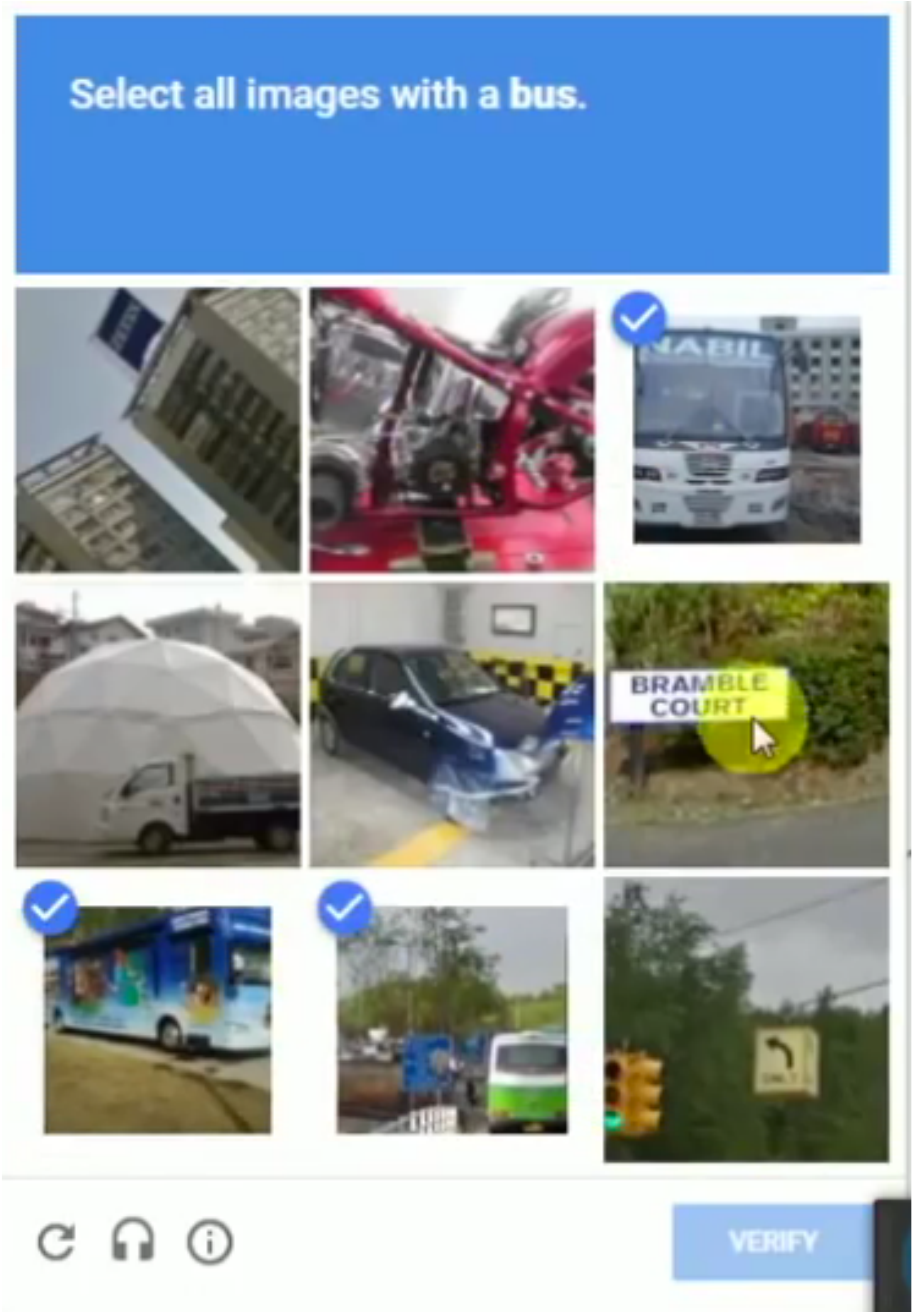

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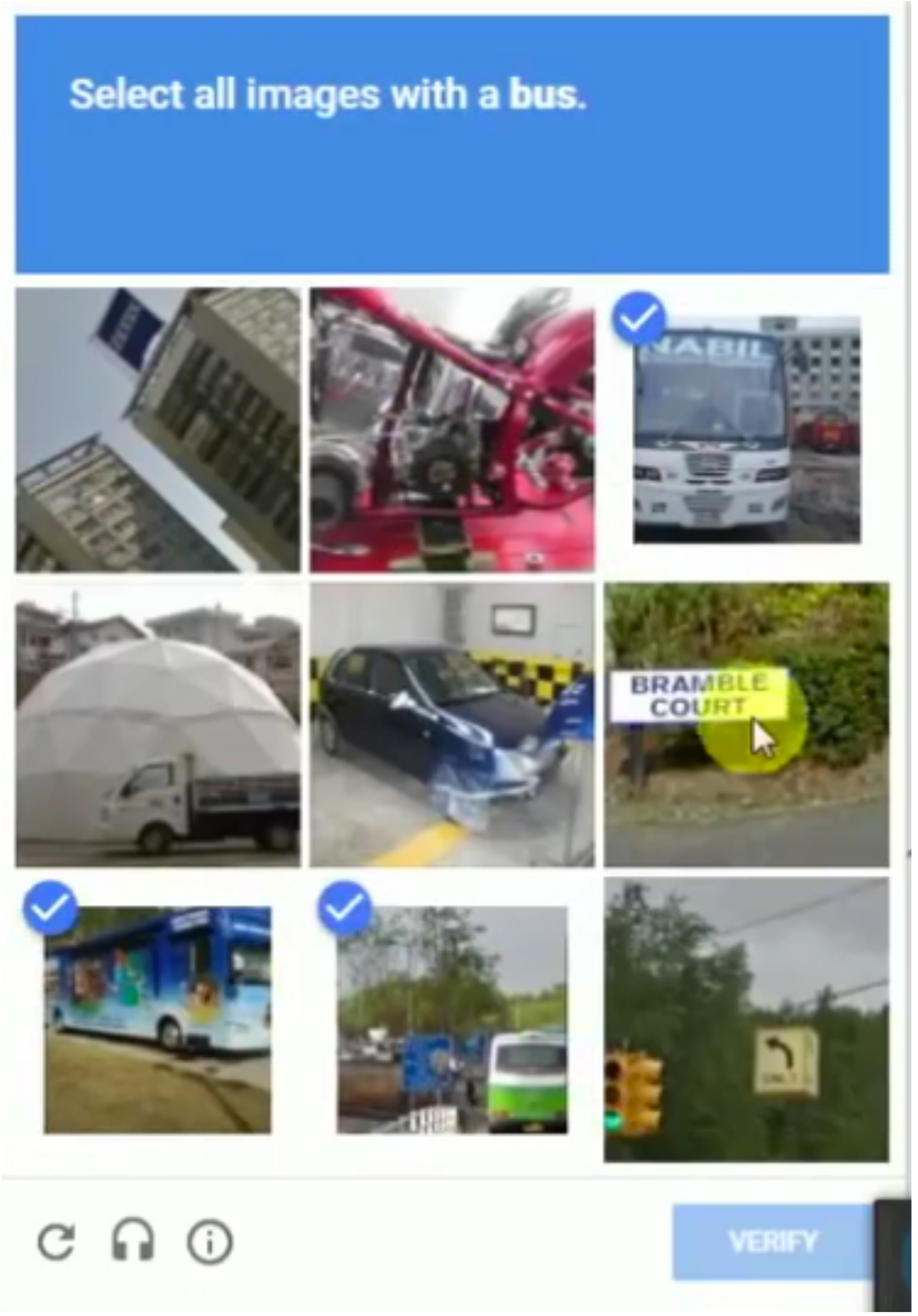

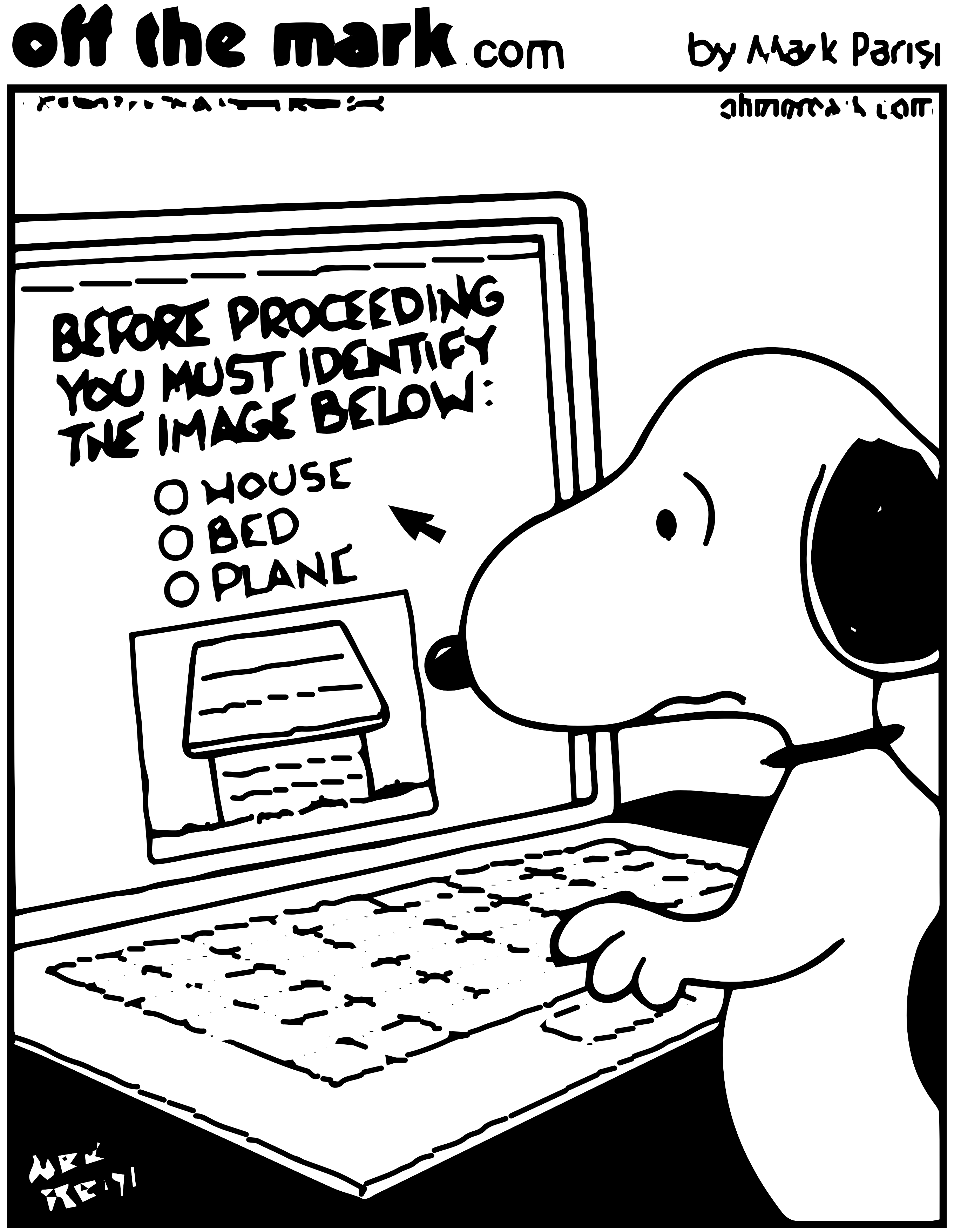

Turing Test Revisited

The Turing Test in the LLM era

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The ConceptARC Benchmark: Evaluating Understanding and Generalization in the ARC Domain

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Santa Fe Institute

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Santa Fe institute

Reviewed on OpenReview: https://openreview.net/forum?id=8ykyGbtt2q

Abstract

The abilities to form and abstract concepts are key to human intelligence, but such abilities remain lacking in state-of-the-art AI systems. There has been substantial research on conceptual abstraction in AI, particularly using idealized domains such as Raven's Progressive Matrices and Bongard problems, but even when AI systems succeed on such problems, the systems are rarely evaluated in depth to see if they have actually grasped the concepts they are meant to capture.

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  - bytes and lines → data processing
  - words → *what do we mean by "word"?*

Knowledge of Language

- What does HAL (of *2001, A Space Odyssey*) need to know to converse?

Dave: *Open the pod bay doors, HAL.*
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- **Phonetics & Phonology** (Ling 450/550)
  - Sounds of a language, acoustics
  - Legal sound sequences in words

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- **Morphology** (Ling 570)
  - Recognize, produce variation in word forms
  - Singular vs. plural: `Door + sg → "door"` `Door + pl → "doors"`
  - Verb inflection: `be + 1st Person + sg + present → "am"`

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- **Part-of-speech Tagging** (Ling 570)
  - Identify word use in sentence
  - Bay (Noun) — Not verb, adjective

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- **Syntax**
  - (566: Analysis, 570: Chunking, 571: Parsing)
  - Order and group words in sentence
    - cf. *"*I'm I do, sorry that afraid Dave I can't*"

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> **Dave**: *Open the pod bay doors, HAL.*
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- **Semantics** (Word Meaning)
  - Individual (lexical) + Combined (Compositional)
  - `'Open' :` `AGENT` **cause** `THEME` **to become** *open*;
    - 'pod bay doors' → doors to the 'pod bay' → the bay which houses the pods.

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  - Politeness: "***I'm sorry***, ***I'm afraid I can't***…"

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    - Usually relies on surface forms (e.g. words)
  - Examples: HMM POS-tagging; FST morphology

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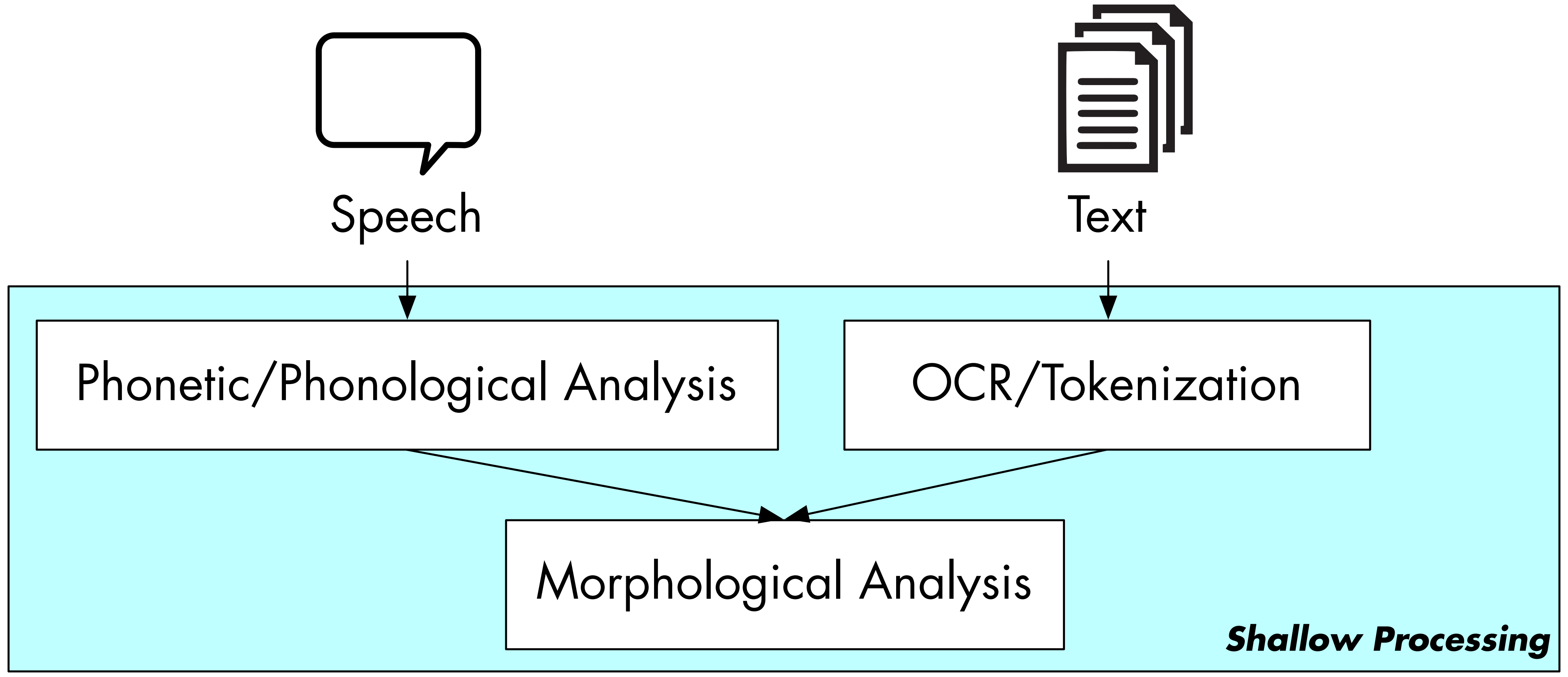
  - Examples: HMM POS-tagging; FST morphology
- Deep processing (LING 571)
  - Relies on ***more elaborate*** linguistic representations
    - Deep syntactic analysis (Parsing)
    - Rich language understanding (NLU)

Language Processing Pipeline



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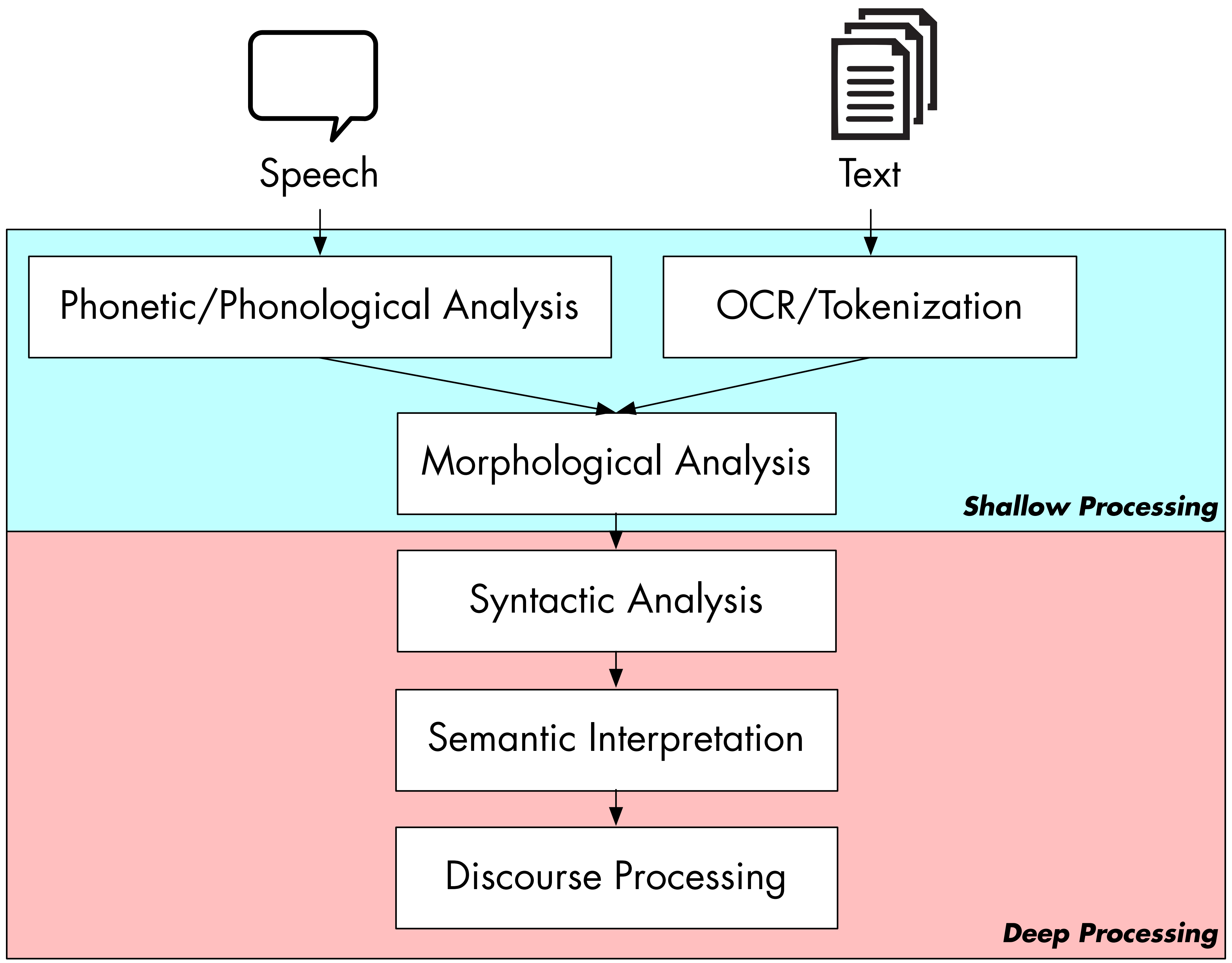

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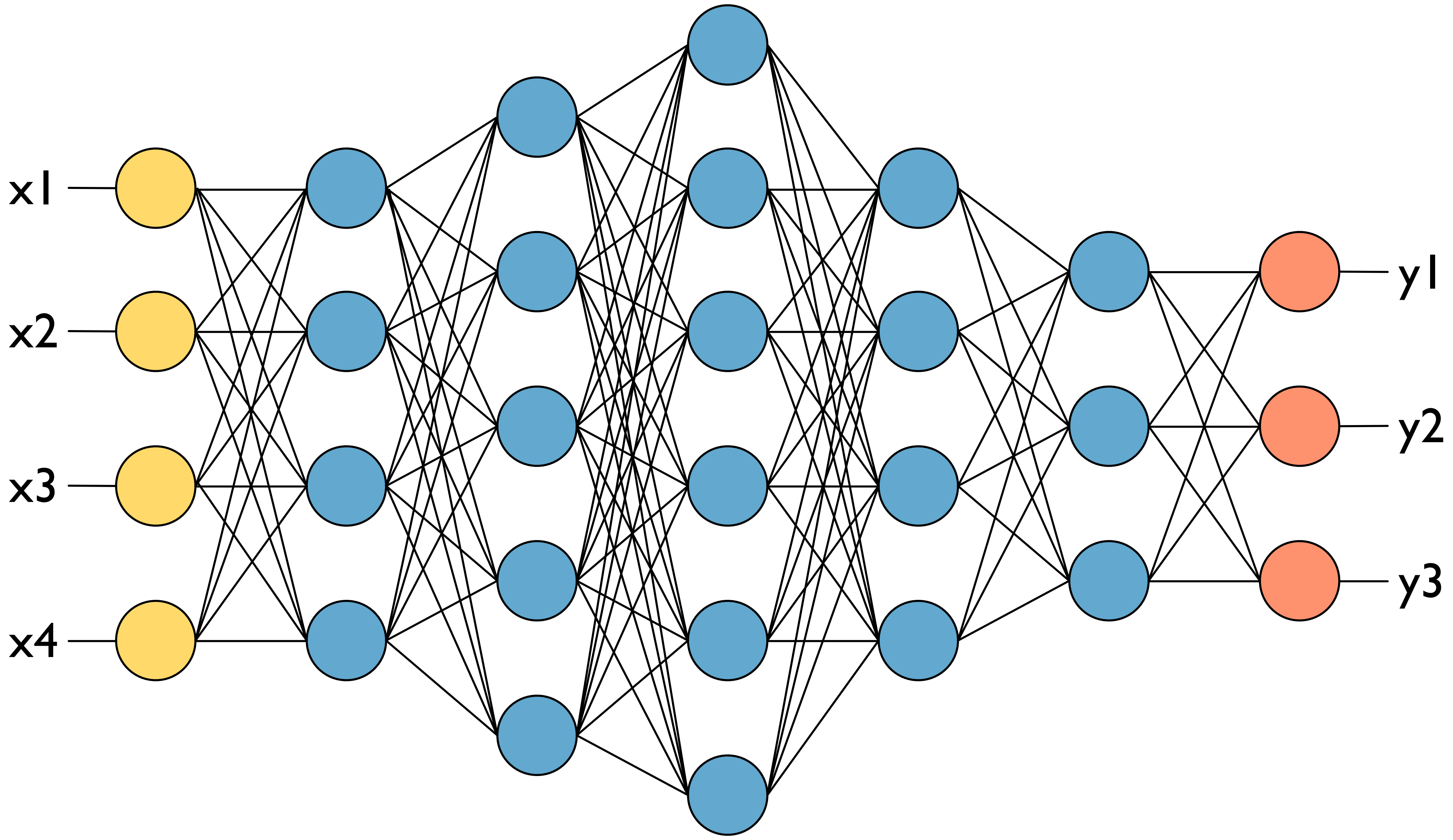

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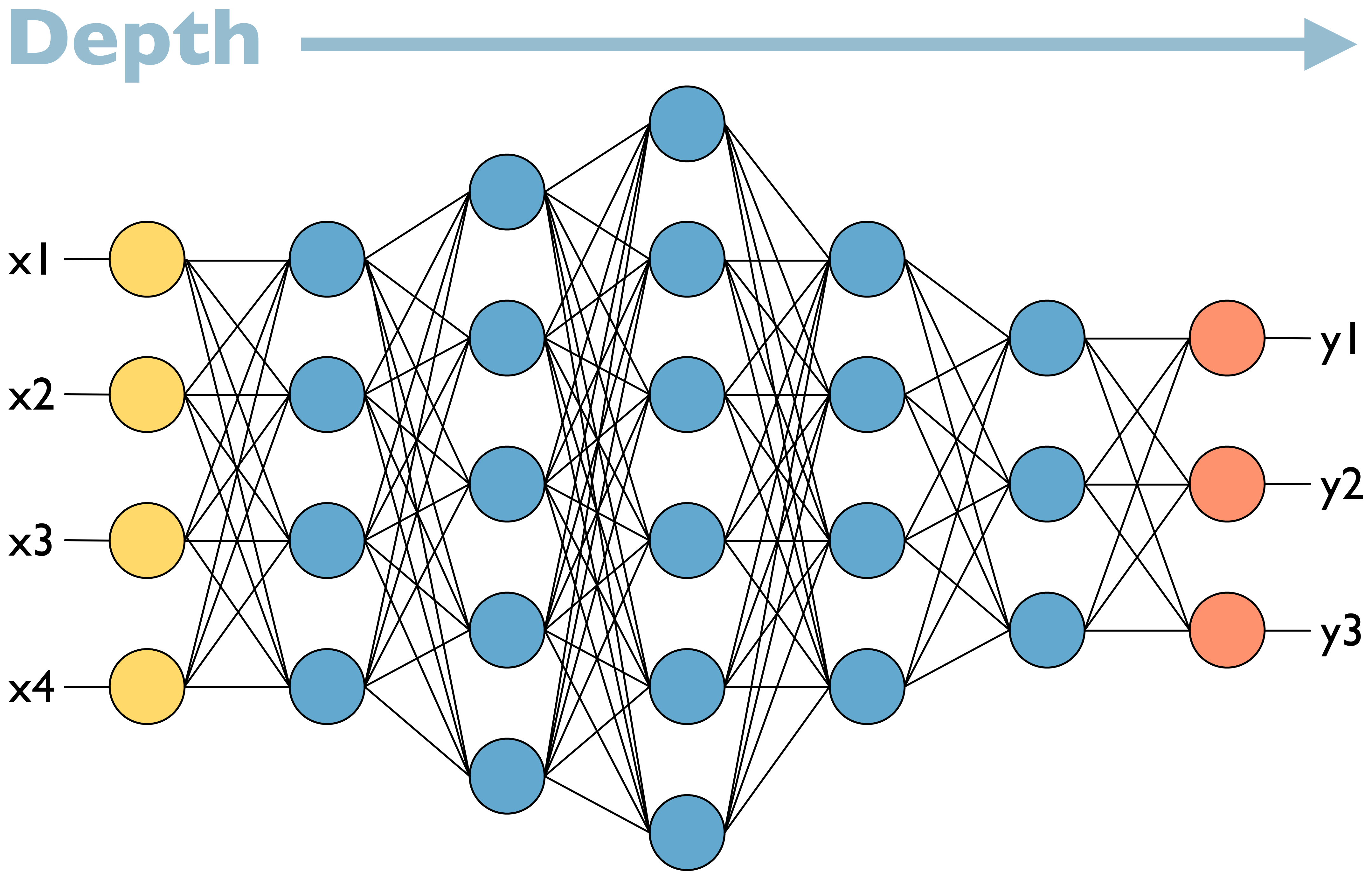

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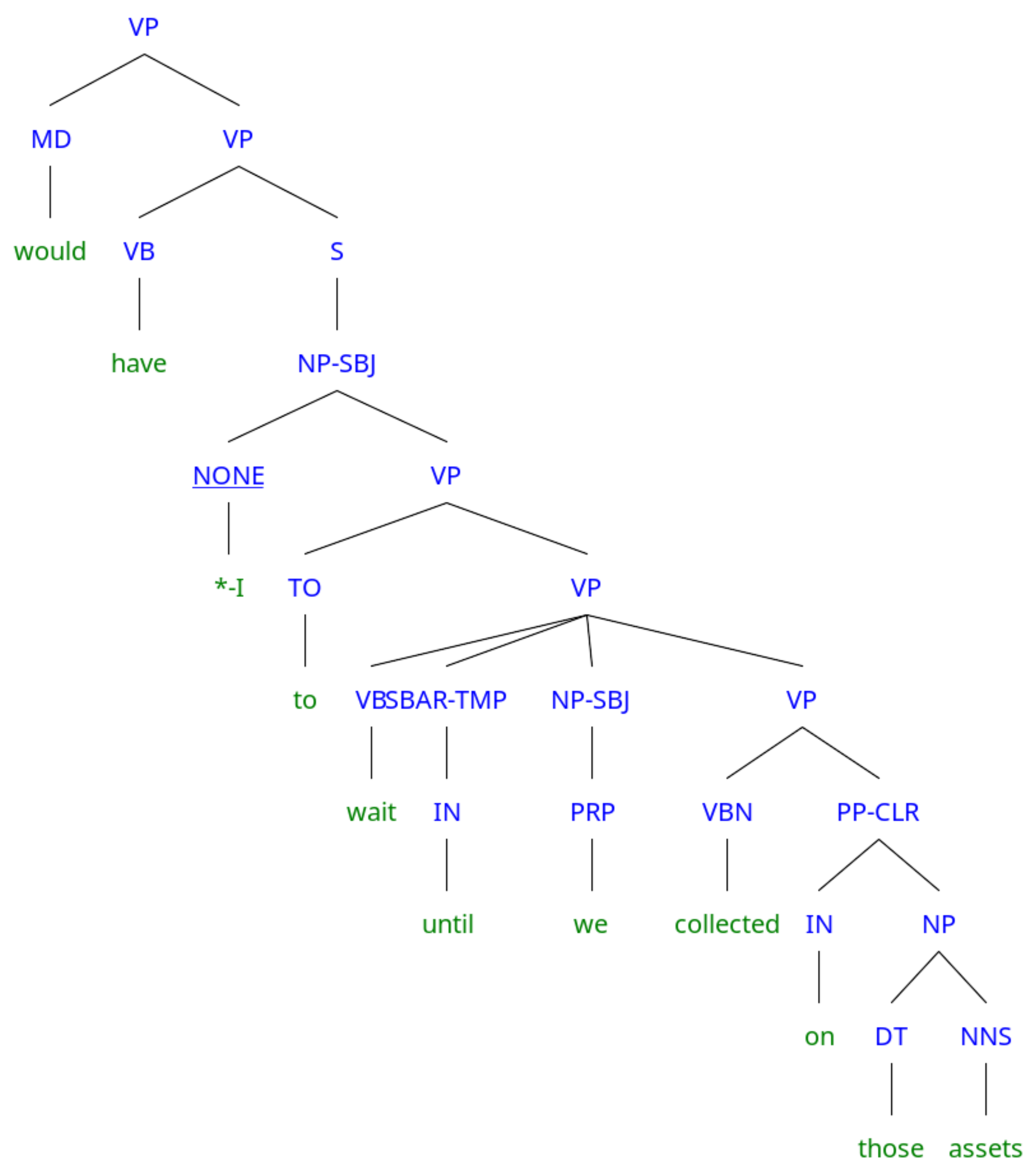

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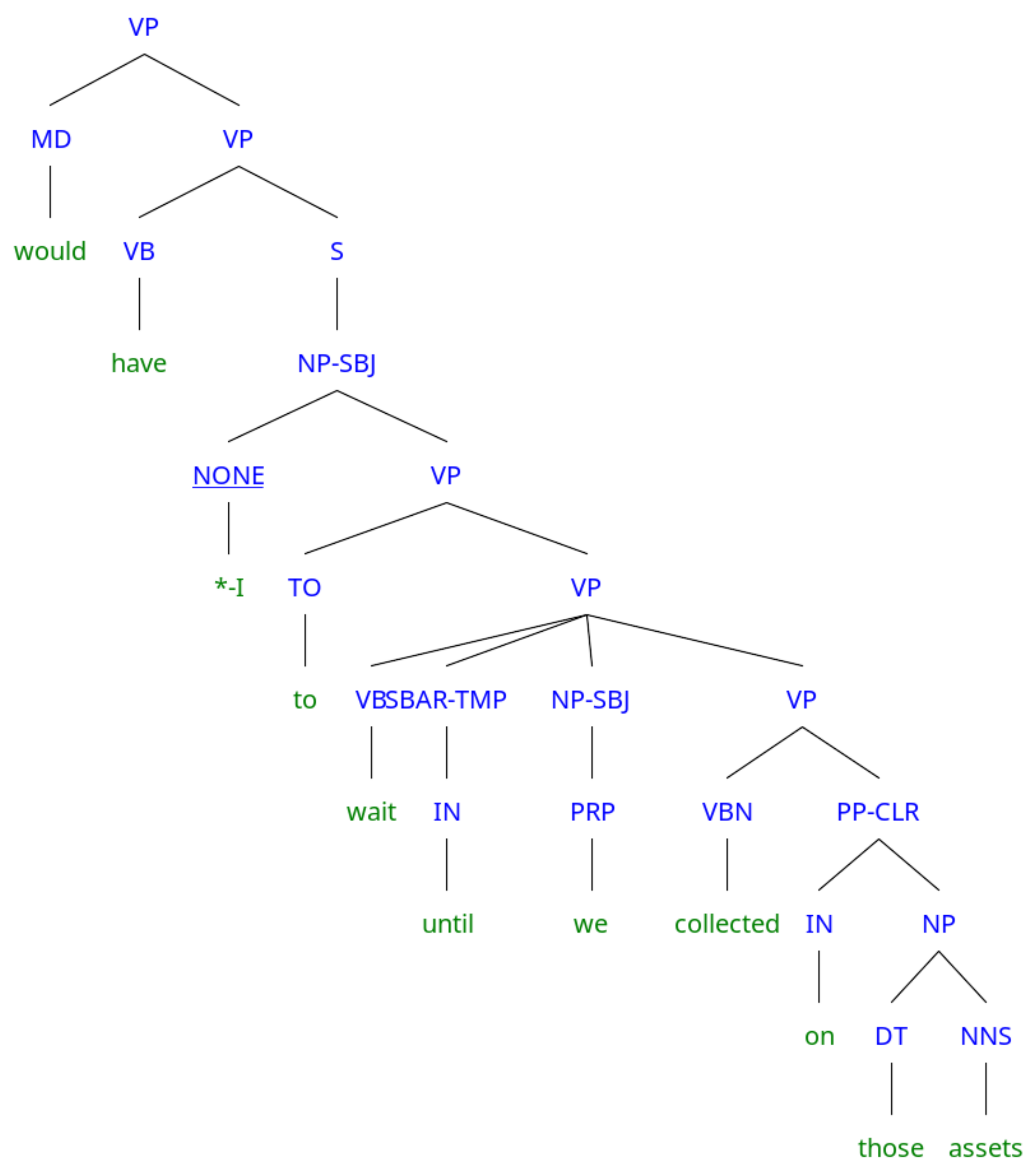

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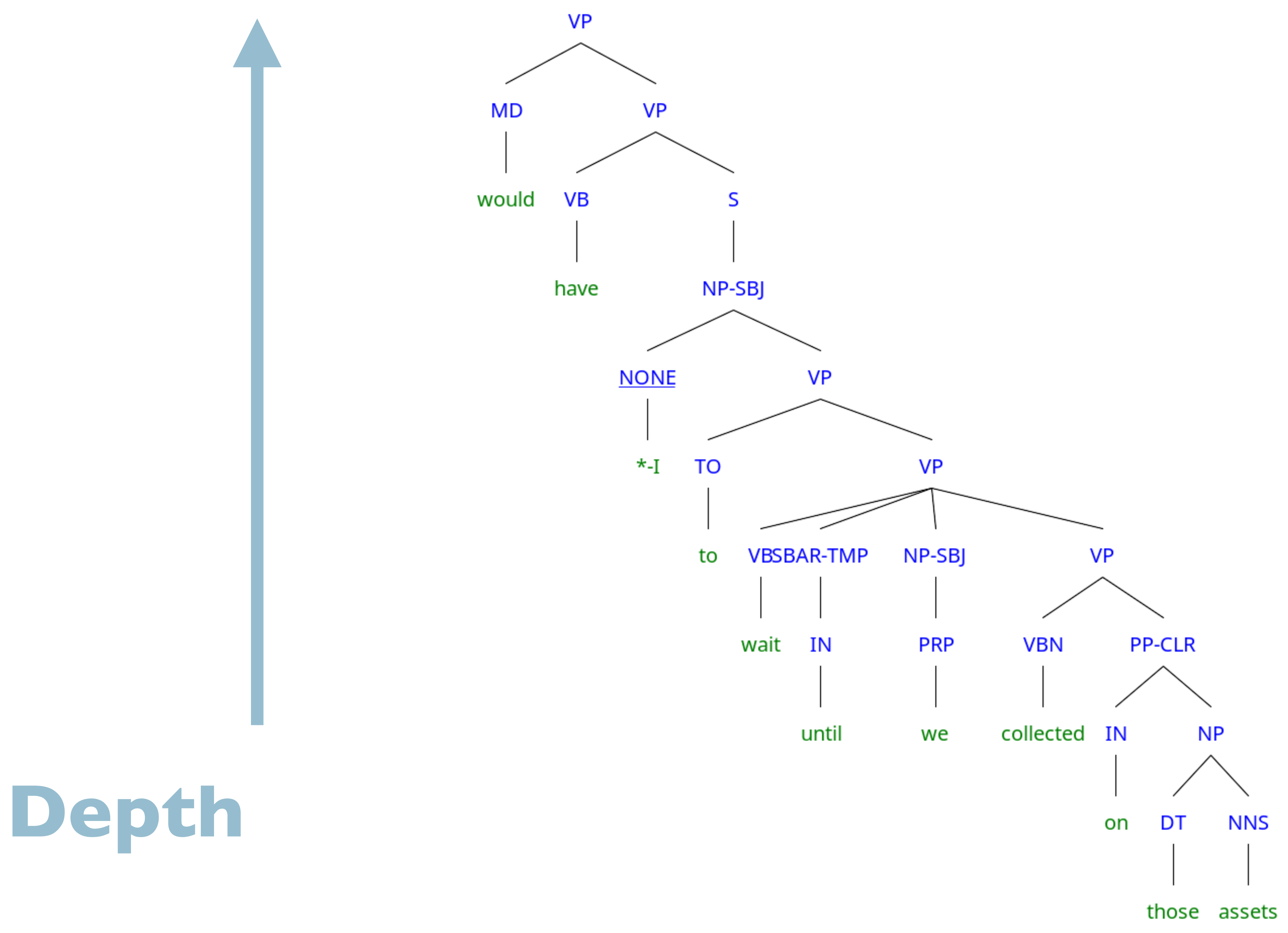

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- In both paradigms, graph depth aids, but $\not\Rightarrow$ abstraction

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- **Evaluation**
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- **Multilinguality**
  - Can we apply the same approach to other languages?
  - How much must it be modified to do so?

Ambiguity: POS

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- “I made her duck.”

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- "I made her duck."
- Could mean…
  - I caused her to duck down.
  - I made the (carved) duck she has.
  - I cooked duck for her.
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POSS

PRON

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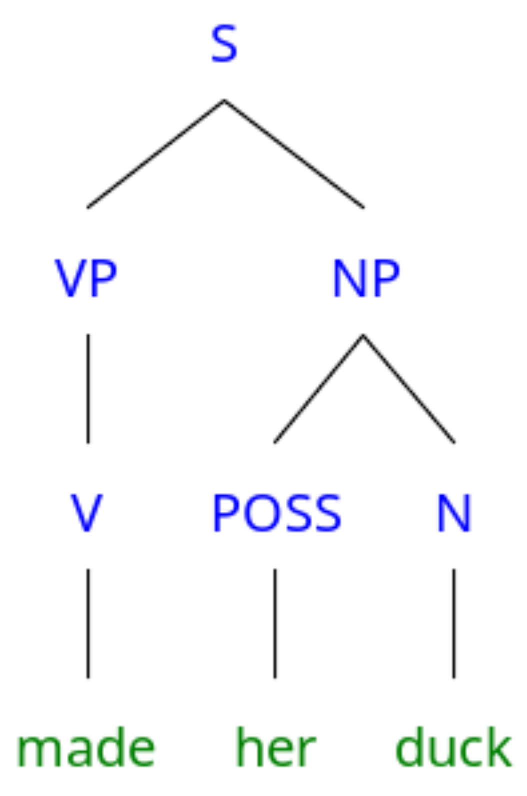

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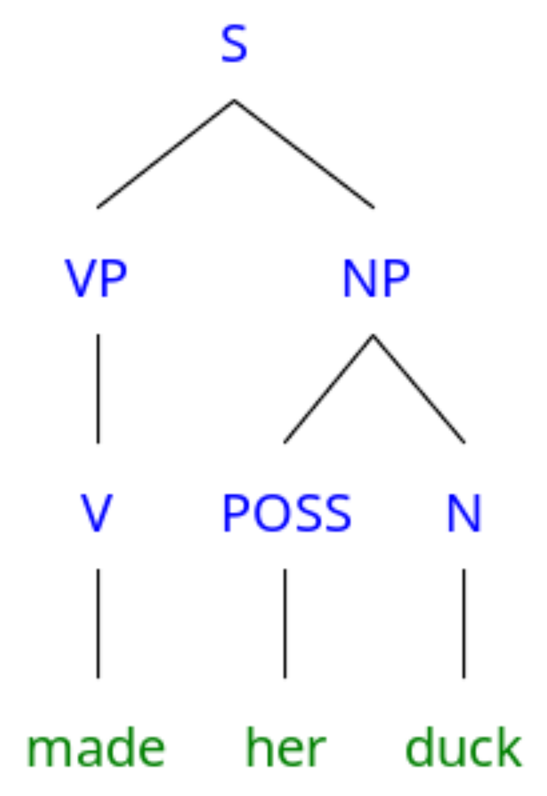

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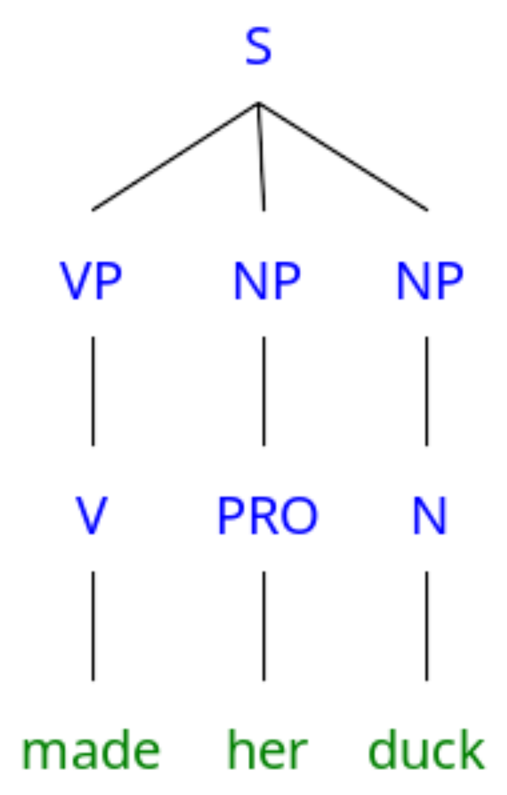

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I magically turned her into a duck	***made*** = [AG] **transformed** [TH] ***duck*** = **animal**

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Ambiguity

- Pervasive in language
- Not a bug, a feature! (Piantadosi et al 2012)
- *"I believe we should all pay our tax bill with a smile. I tried—but they wanted cash."*
- What would language be like without ambiguity?

Ambiguity

- Challenging for computational systems

Ambiguity

- Challenging for computational systems
- Issue we will return to again and again in class.

Course Information

Course Information

- Website is main source of information: https://www.shane.st/teaching/571/aut23/
  - slides, office hours, resources, etc
- Canvas: lecture recordings, homework submission / grading
  - Communication!!! Please use the discussion board for questions about the course and its content.
  - Other students have same questions, can help each other.
  - May get prompter reply. The teaching staff will not respond outside of normal business hours, and may take up to 24 hours.

Course Information

- Grading, policies, etc: see link under “Policies” on course page
  - Shared policies for 570, 571, 572, 574
- Office hours:
  - Shane: MW 230-330 (GUG 415K + Zoom; see website)
  - Saiya: TBA
- Homeworks:
  - 9, released on Wednesday, due the following Wednesday
  - With a pause during Thanksgiving week
  - [NB: also no class the Wednesday before Thanksgiving]

Course Content

- Syntax
  - (Probabilistic) Context-Free Grammars
    - Parsing algorithms (CKY, Earley)
  - Dependency Parsing
- Semantics
  - Logical / event semantics, lambda calculus
  - Distributional semantics, lexical semantics
  - Semantic Role Labeling
- Pragmatics / Discourse
  - Reference, Co-reference, structure / discourse parsing

What are you most looking forward to in 571 this quarter?

Total Results: 0

Syntax Crash Course

LING 571 — Deep Processing Techniques for NLP
Shane Steinert-Threlkeld

Roadmap

- Sentence Structure
  - More than a bag of words
- Representation
  - Context-free Grammars
    - Formal Definition

Applications

- Shallow techniques useful, but limited
- Deeper analysis supports:
  - Grammar checking — and teaching
  - Question-answering
  - Information extraction
  - Dialogue understanding
  - …

Grammar and NLP

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  - Explicit rules
  - “Don’t split infinitives!” etc.

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  - Explicit rules
  - “Don’t split infinitives!” etc.
- “Grammar” in linguistics **IS**:
  - How to capture structural knowledge of language as a native speaker would have
  - Largely implicit
  - Learned early, naturally

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  - Meaning:
    - *Dog bites man.* **vs.** *Man bites dog.*
  - Acceptability:
    - *Colorless green ideas sleep furiously.*
    - ** Colorless sleep ideas furiously green.*
    - ** Dog man bites*

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  - …
- Single unit: type determined by “head”
  - e.g. **N** heads NP

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    - Components expected by verbs
- Hierarchical

Representation: Context-free Grammars

- CFGs: 4-tuple
  - A set of **terminal** symbols: Σ
    - [think: words]
  - A set of **nonterminal** symbols: N
    - [think: phrase categories]
  - A set of **productions** P:
    - of the form $A \rightarrow \alpha$
    - Where A is a non-terminal and $\alpha \in \{\Sigma \cup N\}^*$
  - A **start** symbol $S \in N$

Representation: Context-free Grammars

- Altogether a grammar defines a language *L*
  - $L = \{w \in \Sigma^* \mid S \Rightarrow^* w\}$
    - The language *L* is the set of all words in which:
    - $S \Rightarrow^* w$: *w* can be *derived* starting from *S* by some sequence of productions

CFG Components

- **Terminals**:
  - Only appear as leaves of parse tree (hence the name)
  - Right-hand side of productions (RHS)
  - Words/morphemes of the language
    - *cat, dog, is, the, bark, chase…*

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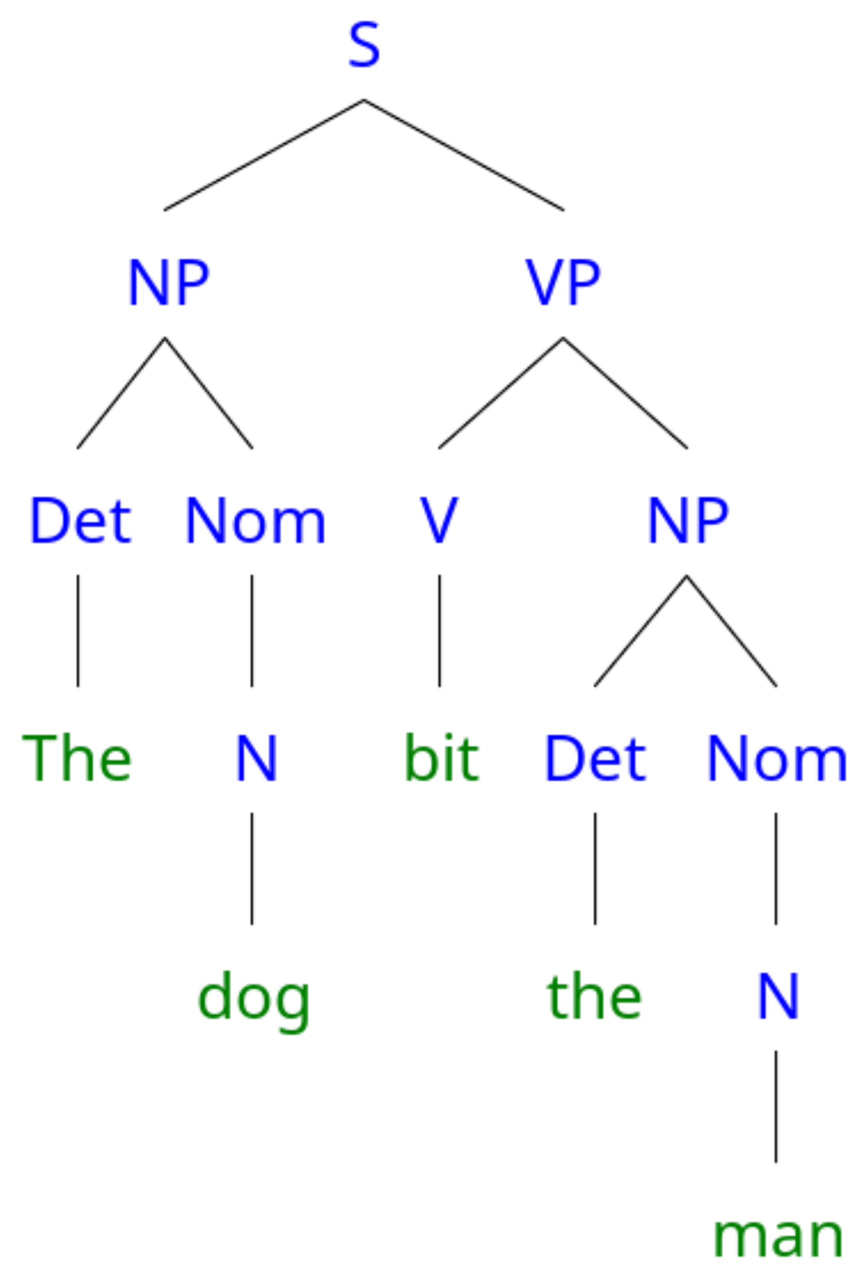
  - Only appear as leaves of parse tree (hence the name)
  - Right-hand side of productions (RHS)
  - Words/morphemes of the language
    - *cat, dog, is, the, bark, chase…*
- **Non-terminals**
  - Do not appear as leaves of parse tree
  - Appear on left or right side of productions
  - Represent constituent phrases of language
    - NP, VP, S[entence], etc…

Representation: Context-free Grammars

- Partial example:
  - Σ: *the, cat, dog, bit, bites, man*
  - *N*: NP, VP, Nom, Det, V, N, Adj
  - P:
    - S→NP VP;
    - NP→Det Nom;
    - Nom→N Nom | N;
    - VP→V NP;
    - N→*cat*; N→*dog*; N→*man*;
    - Det→*the*;
    - V→*bit*; V→*bites*
  - S: S



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- Acceptance
  - Legal string in language?
    - Formally: rigid
    - Practically: degrees of acceptability

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Parsing Goals

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    - Formally: rigid
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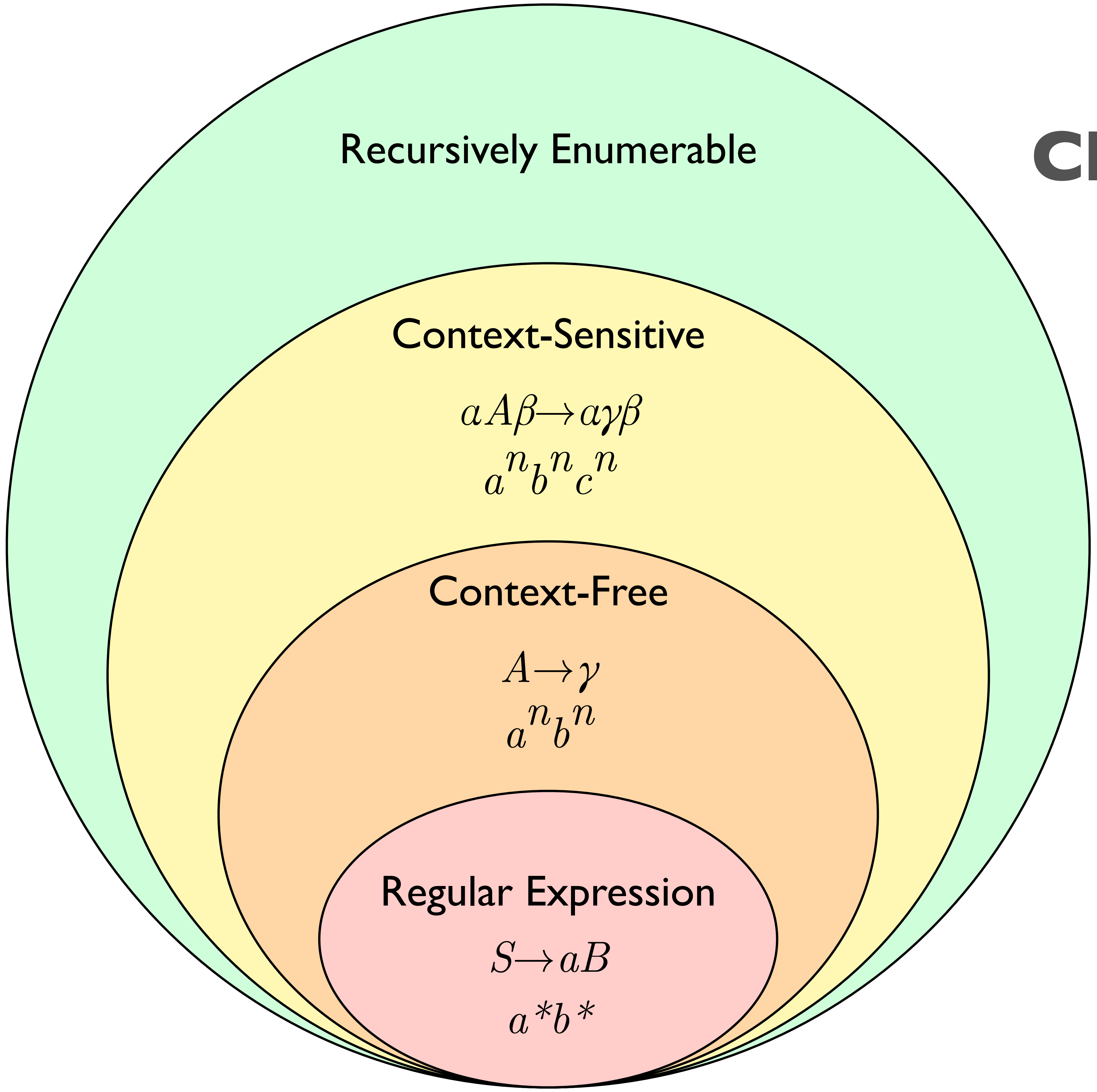
- Analysis
  - What structure produced the string
    - Produce one (or all) parses for the string
- Will develop techniques to produce analyses of sentences
  - Rigidly accept (with analysis) or reject
  - Produce varying degrees of acceptability

Sentence-level Knowledge: Syntax

- Different models of language that specify the ***expressive power*** of a formal language



Chomsky Hierarchy

S, A, B: non-terminals
a, b: terminals
α, β, γ: sequence of terminals + non-terminals
[γ: never empty]

Representing Sentence Structure

- Why not just Finite State Models (Regular Expressions)?
  - Cannot describe some grammatical phenomena
  - Inadequate expressiveness to capture generalization

Representing Sentence Structure: Center Embedding

- **Regular Language**: $A \rightarrow w; A \rightarrow w^*B$
- **Context-Free**: $A \rightarrow \alpha A \beta$ (e.g.)
  - Allows recursion:

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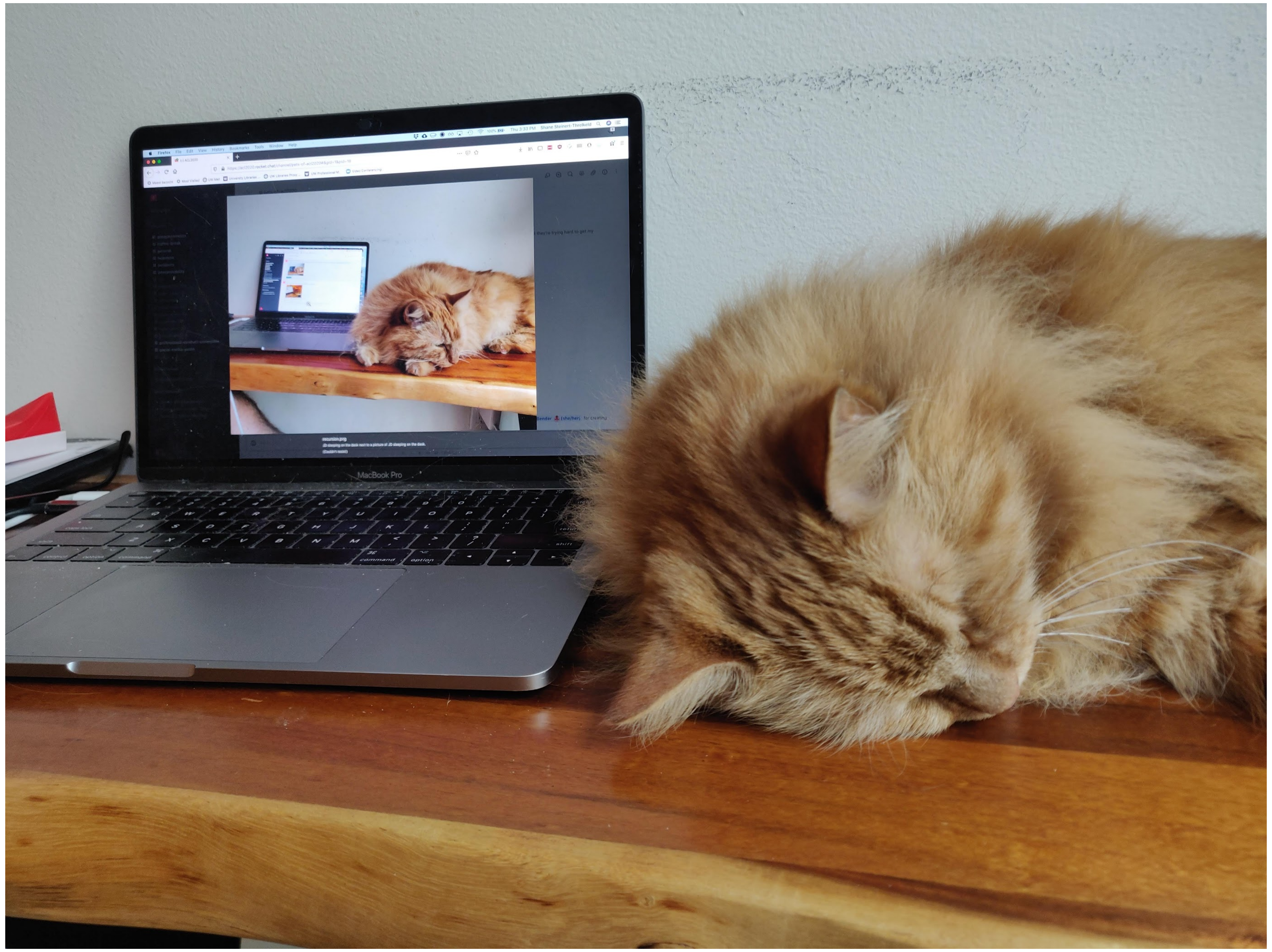
    - The luggage that the passengers checked arrived
    - The luggage that the passengers **whom the storm delayed** checked arrived

Recursion in Grammar



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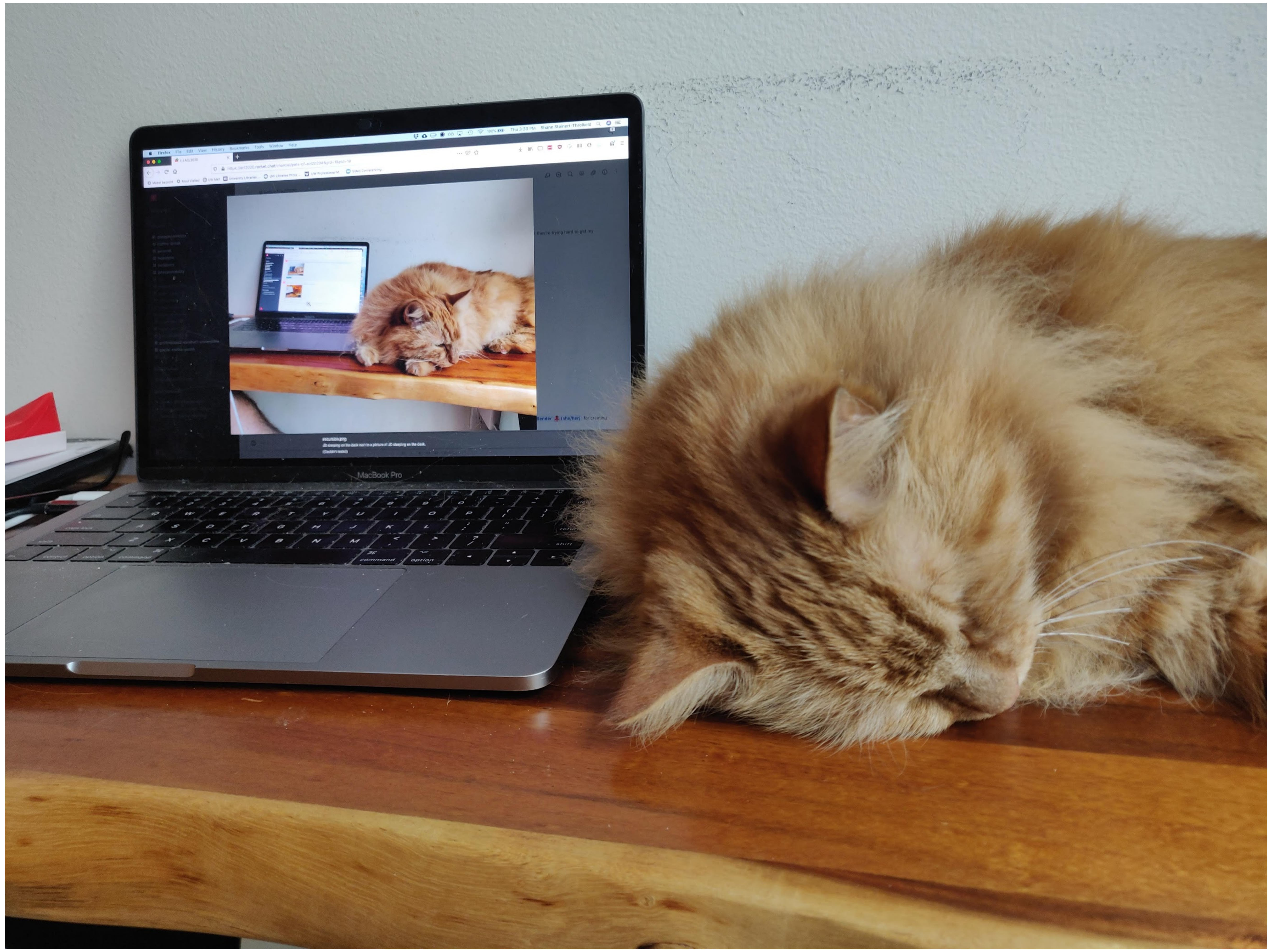
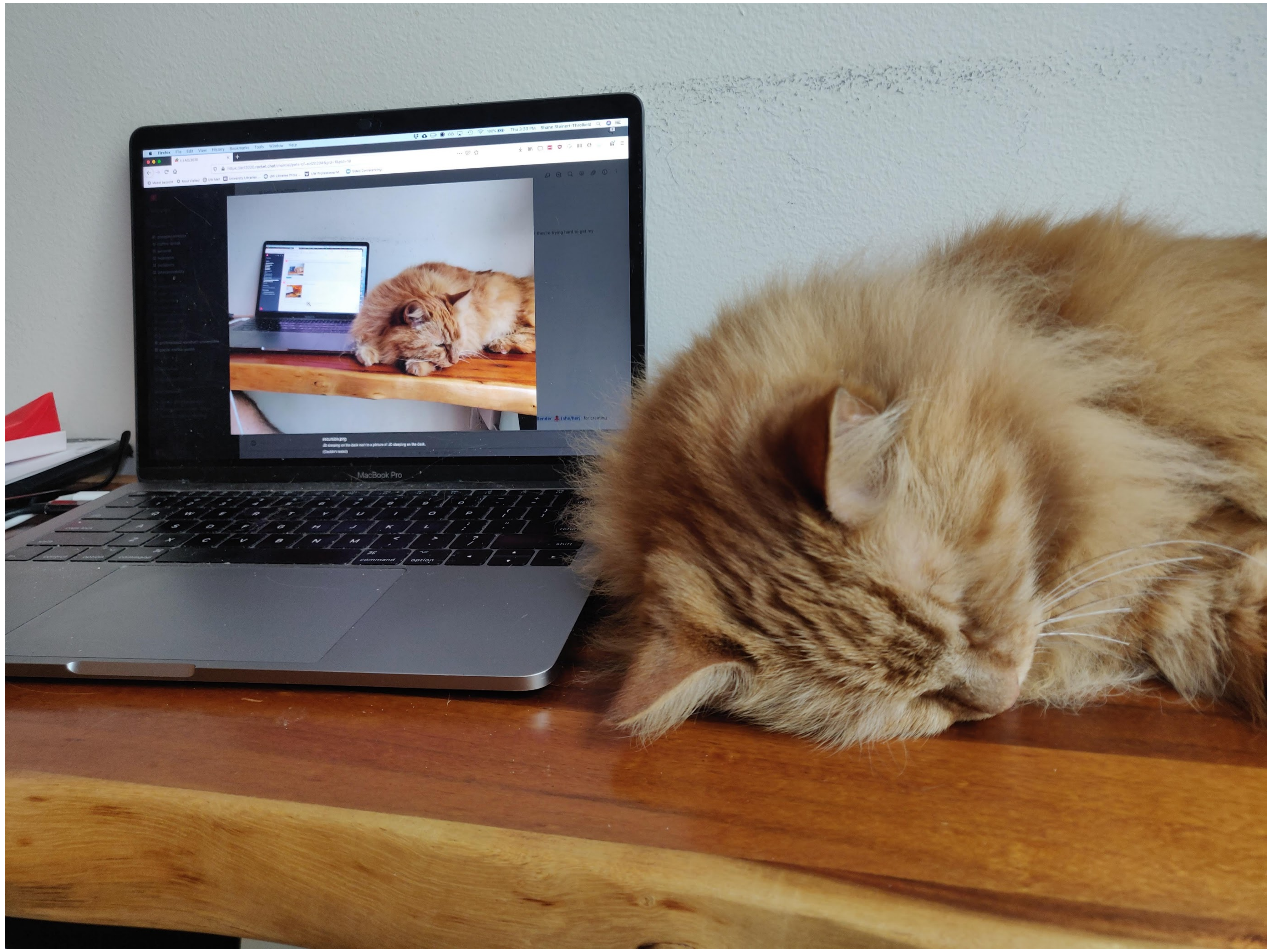


This is JD lying on the desk next to a picture of JD lying on the desk next to a picture of JD lying on the desk.

Recursion in Grammar



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Exercise: write a toy grammar for producing this sentence! Is context-free-ness required?

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  - Many articles have attempted to demonstrate we do
  - …many have failed.

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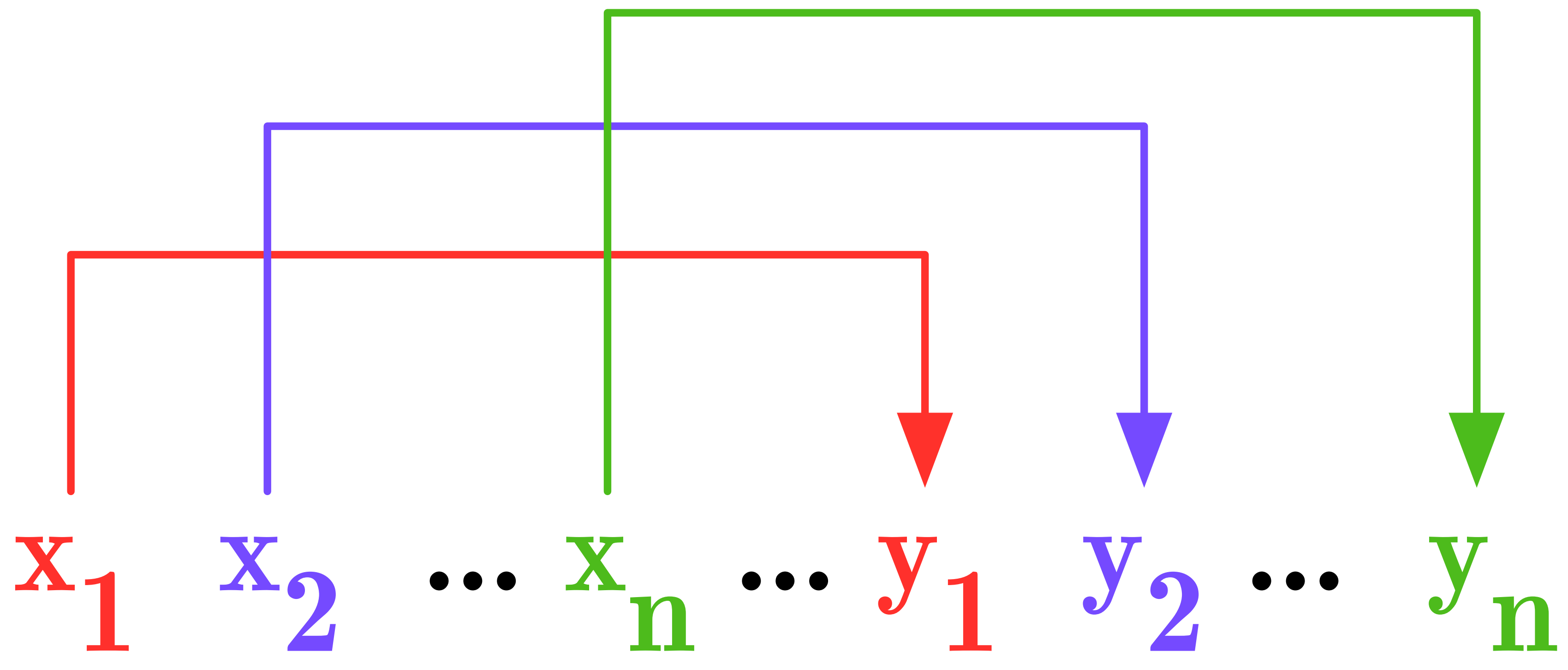
- …but do we need context-sensitivity?
  - Many articles have attempted to demonstrate we do
  - …many have failed.
- Solid proof for Swiss German: ***Cross-Serial Dependencies*** (Shieber, 1985)
  - $a^i b^j c^i d^j$



Context-Sensitive Example

- Verbs and their arguments must be ordered ***cross-serially***
  - Arguments and verbs must match

…mer em Hans s huus hälfed aastriiche.
…we Hans (DAT) the house.ACC help paint
"We helped hans paint the house."

…mer d'chind em Hans s huus haend wele laa hälfed aastriiche.
…we the children Hans (DAT) the house.ACC have wanted.to let help paint
"We wanted to let the children help Hans paint the house."

What questions do you have?