Speech recognition in Alzheimer's disease with personal assistive robots

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Introduction

- **Alzheimer's disease** (AD) is a progressive neuro-degenerative dementia characterized by **declines** in:
  - Cognitive ability (e.g., memory, visual-spatial reasoning),
  - Functional capacity (e.g., executive power), and
  - Social ability (e.g., linguistic abilities).

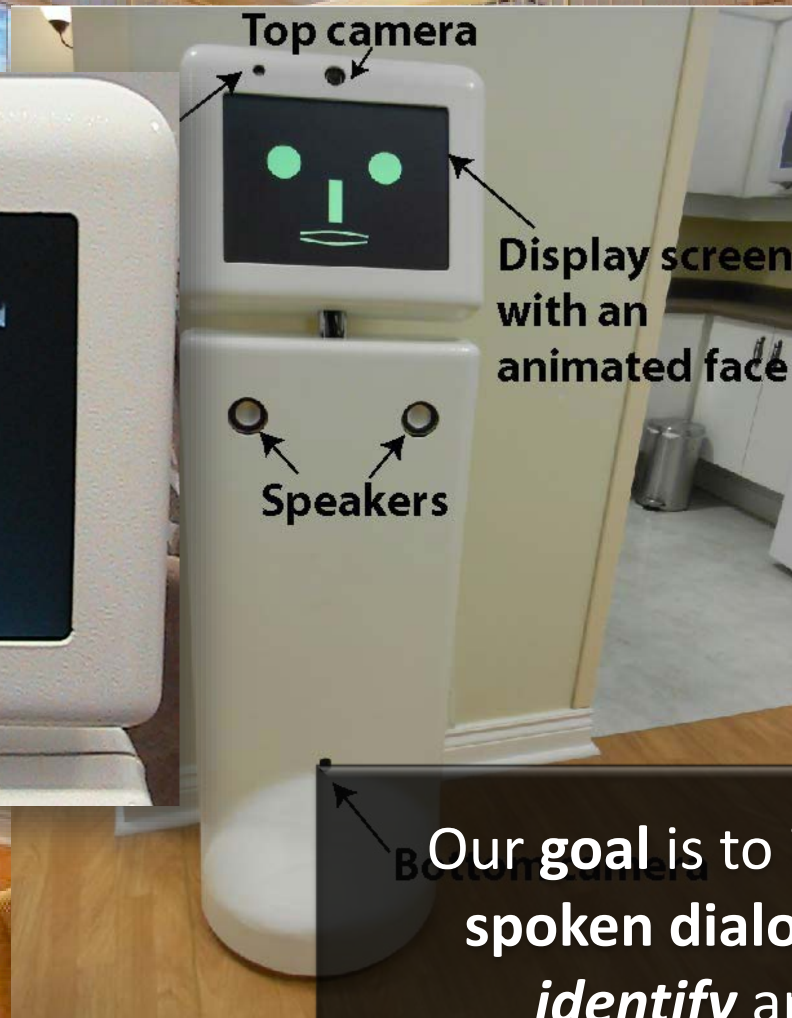
- **Caregivers** often assist individuals with AD, either at **home** or in **long-term care facilities**.
  - **>$100B** are spent annually in the U.S. on caregiving for AD.
  - As the population ages, the incidence of AD may **double** or **triple** in the next decade (Bharucha *et al.*, 2009).
  - **Demographic crisis!**

The HomeLab

- **‘COACH’** automates support of daily tasks often assisted by human caregivers.
  - E.g., hand-washing, tooth-brushing.
  - Based on partially-observable Markov decision processes (POMDPs) and **vision-only** input.

- *But what if the user does not want to spend their day in front of the sink?*

ED the robot



Our **goal** is to implement two-way **spoken dialogue** in ED that can ***identify*** and ***recover*** from communication breakdowns.

Language in AD and dementia

- Common features in dialogue in AD: *Repetition*, *incomplete words*, and *paraphrasing* (Guinn and Habash, 2012).
  - *Pauses*, *filler words*, *formulaic speech*, and *restarts* were **not**.
    - Surprisingly, this seems to contradict Davis and Maclagan (2009), and Snover *et al.* (2004).

- Effects of AD on *syntax* remains controversial.
  - **Agrammatism** could be due to **memory deficits** (Reilly *et al.*, 2011).

- Pakhomov *et al.* (2010) found *pause-to-word* and *pronoun-to-noun ratios* were discriminative of frontotemporal lobar degeneration.

- Roark *et al.* (2011) found *pause frequency* and *duration* were indicative of mild cognitive impairment.

Data collection: tea for two

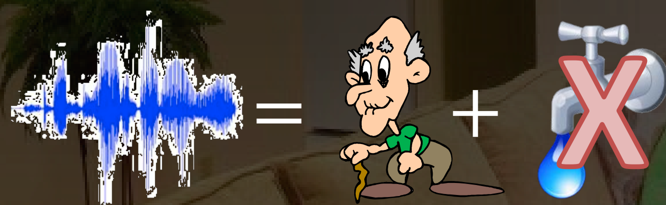
- Ten individuals (6 female) with AD recruited at Toronto Rehab.
  - Age: 77.8 years ($\sigma = 9.8$)
  - Education: 13.8 years ($\sigma = 2.7$)
  - MMSE: 20.8/30 ($\sigma = 5.5$)
- Three phases with different partners:
  - A **familiar** human-human dyad (during informed consent),
  - A human-robot dyad (during **tea-making**), and
  - An **unfamiliar** human-human dyad (during post-study interview).

Data collection: tea for two

- Our data are ***very* noisy**. Signal-to-noise: **–2.1 dB** to **7.63 dB**
  - **Clean** speech typically **40 dB** to **60 dB**.
  - Can we do **speech recognition** in this environment **accurately**?

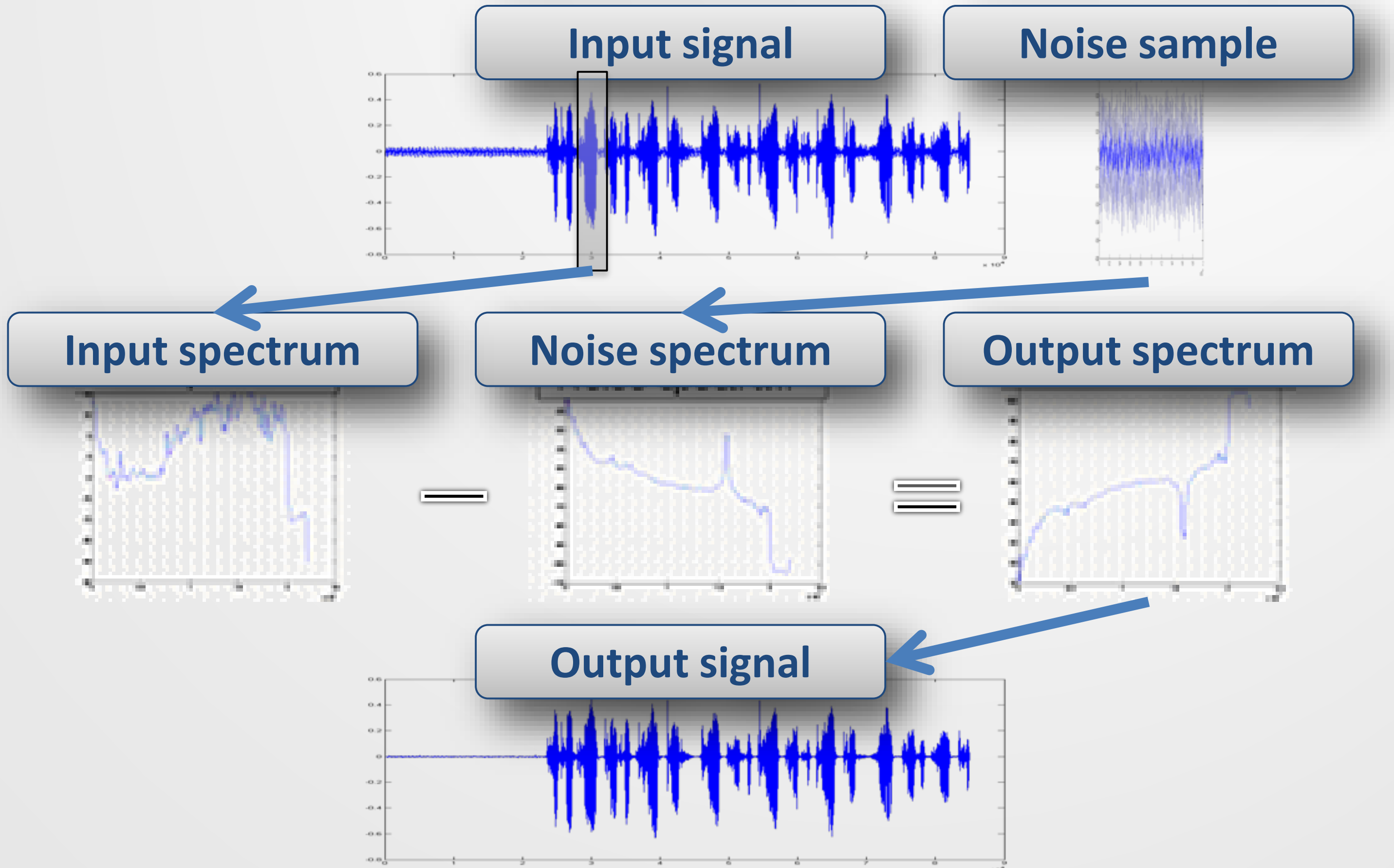
- We assume that our recordings can be decomposed as:

$$y(t) = x(t) + d(t)$$

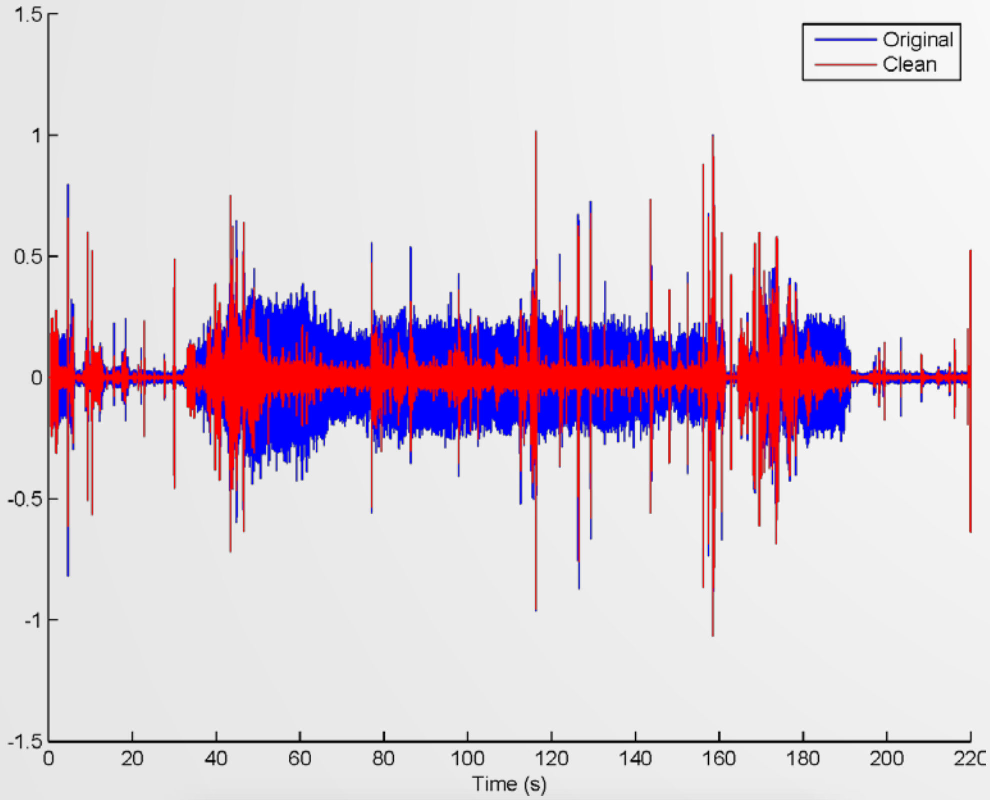


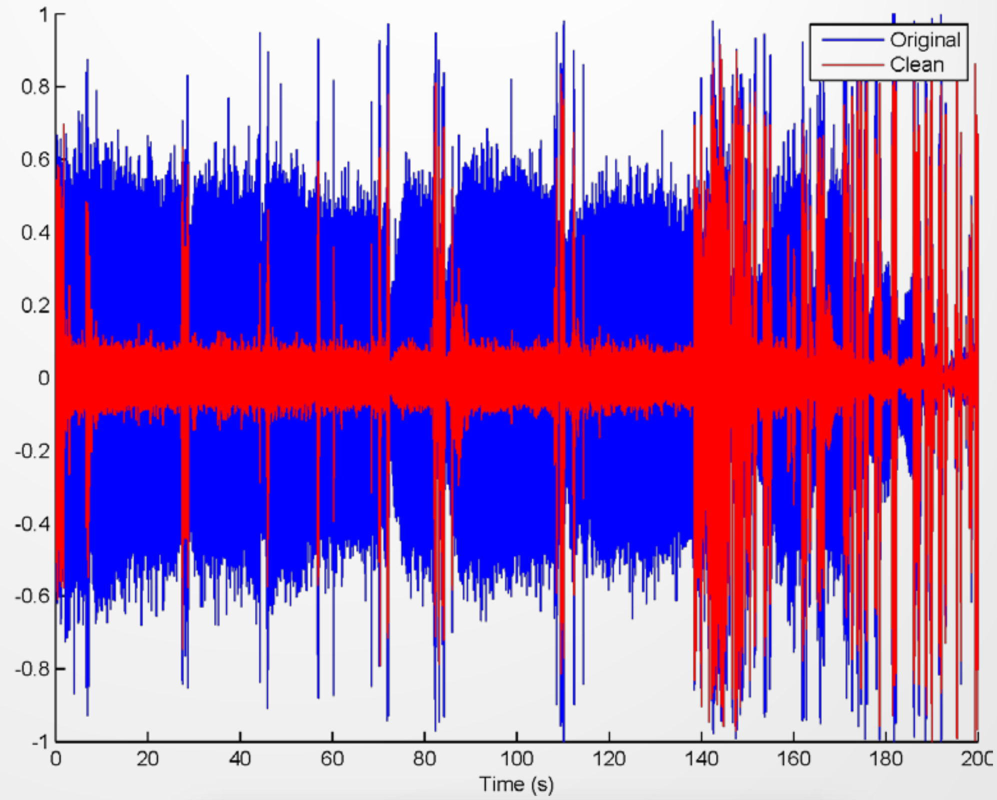
Noise reduction

- **Subtraction with log-spectral amplitude estimator (LSAE)**
  - Requires an annotated sample of the noise.



Noise reduction





Moderate

Severe

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Speech recognition

- Semi-continuous **hidden Markov model** with 42-dimensional MFCC input (incl. δ and $\delta\delta$), z-scaled.
- Two **trigram language models** derived from English Gigaword (**small**: top 5000 words, **large**: top 64,000 words).
- Five **speaker-independent acoustic models** derived from WSJ over 100 speakers with 1, 2, 4, 8, and 16 Gaussians/state.
- **Empirically** adjust other parameters (e.g., beam width).

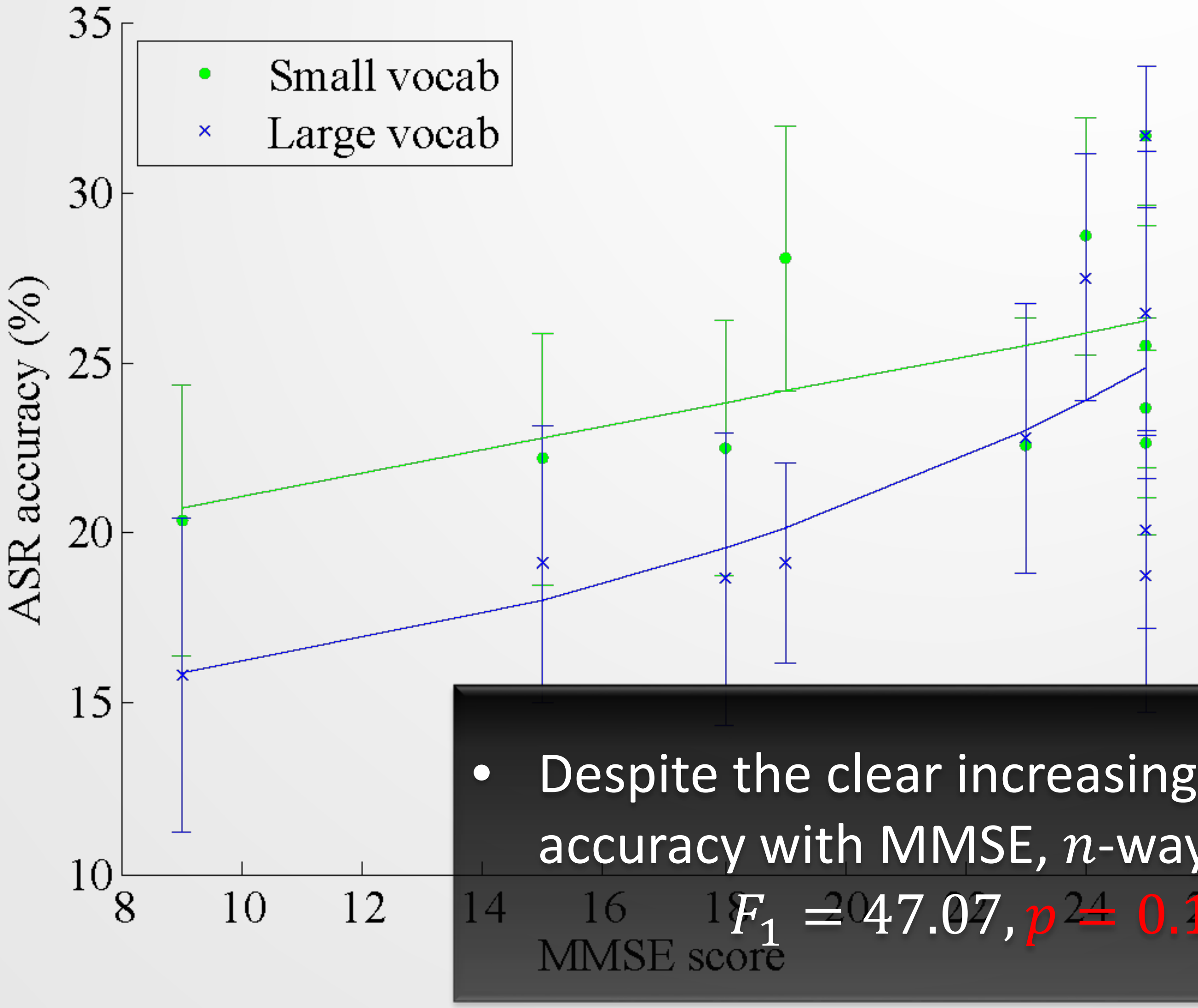
Results

Vocab.	Scenario	Noise reduction	AD (%)	Caregiver (%)
Small	Interview	None	$25.1\ (\sigma = 9.9)$	$28.8\ (\sigma = 6.0)$
		LSAE	$40.9\ (\sigma = 5.6)$	$40.2\ (\sigma = 5.3)$
	In task	None	$13.7\ (\sigma = 3.7)$	-
		LSAE	[illegible]	-
Large	Interview	None	[illegible]	[illegible] $= 10.0)$
		LSAE	$38.2\ (\sigma = 6.3)$	$35.1\ (\sigma = 11.2)$
	In task	None	$5.8\ (\sigma = 3.7)$	-
		LSAE	$14.3\ (\sigma = 12.8)$	-

$t(58) = 3.9,$
$p < 0.005$

$t(39) = 8.7,$
$p < 0.0001$

Accuracy and MMSE



- Despite the clear increasing trend in accuracy with MMSE, n-way ANOVA: $F_1 = 47.07, p = 0.164$

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Communication strategies

- To be useful, **ED** needs to mimic some **verbal techniques** employed by caregivers.

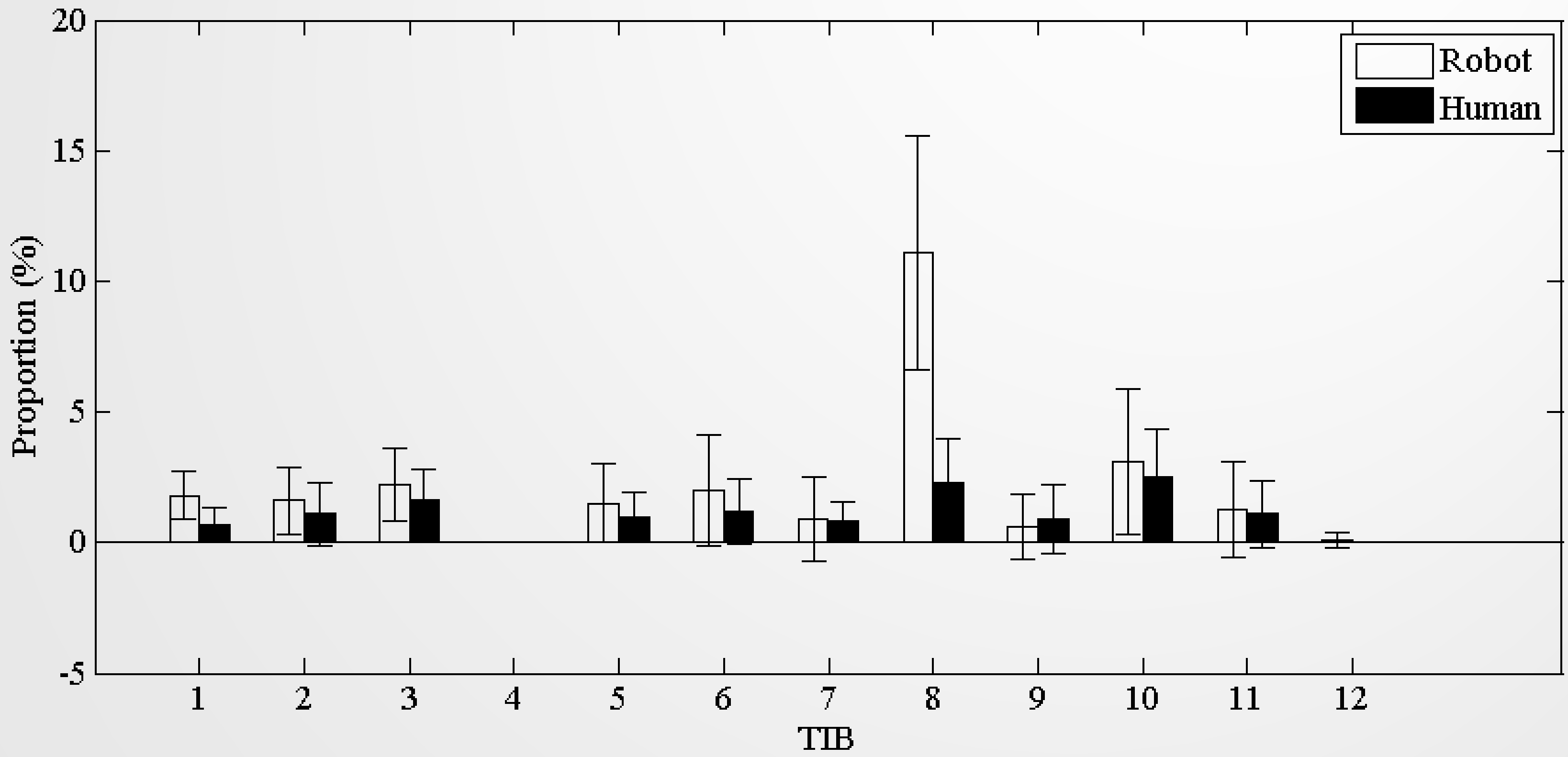
- Caregivers are commonly trained to use **communication strategies** (Small et al., 2003) , such as:
  - Using a **relatively slow** rate of speech,
  - **Repeating** misunderstood prompts **verbatim**,
  - Posing **closed-ended** questions (e.g., yes/no questions),
  - **Simplifying** the **syntactic complexity** of sentences,
  - Giving one question or **one direction at a time**, and
  - Using pronouns minimally.

How to identify breakdowns?

- **Trouble Indicating Behaviors (TIB)** (Watson, 1999).
  - Difficulties can be phonological, morpho/syntactic, semantic (e.g., lexical access), discourse (e.g., misunderstanding topic).
  - 7 seniors with AD use TIBs significantly more ($p < 0.005$) than matched controls (Watson, 1999).

- >33% of moderate AD dyads display related '**trouble-source repair**' (Orange, Lubinsky, Higginbotham, 1996).
  - **Most common trouble**: discourse (e.g., inattention, working memory)
  - **Most common repair**: *wh*-questions and hypotheses (e.g., "*Do you mean …?*").

How to identify breakdowns?



- People with AD were much ($t(18) = -5.8, p < 0.0001$) more likely to exhibit **TIB 8 (lack of uptake)** with the robot …

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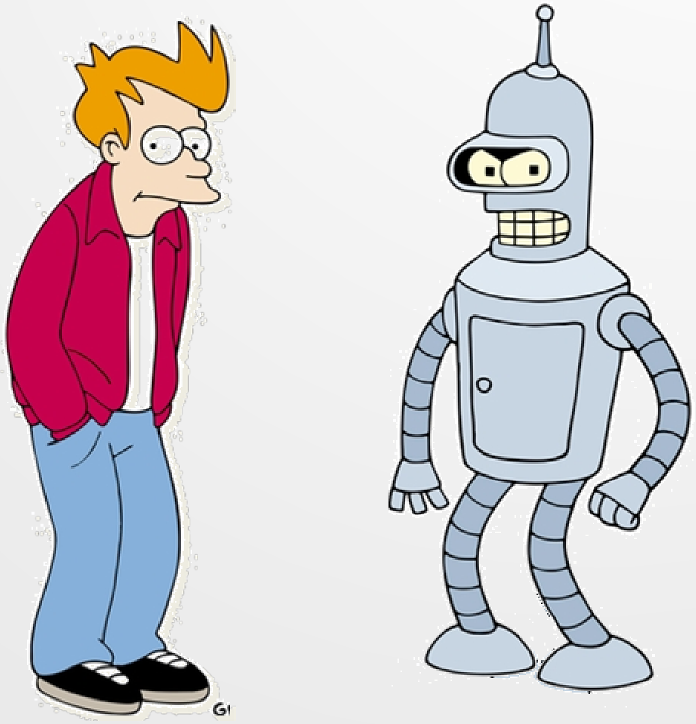
How to identify breakdowns?

- … people with AD were much more likely ($t(18) = -4.78$, $p < 0.0001$) to have **successful** interactions with a **robot** (18.1%) than with a non-familiar **human** (6.7%).



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Ongoing work

- We can achieve up to **40% word accuracy** in AD using standard acoustic/language models and **noise reduction**.
  - **Accuracy depends on MMSE**, but not significantly.
  - We are currently **improving ASR** by adapting **vocabularies**, **acoustic** and **language models.**

- Older adults with AD are very likely to **ignore** the robot, but when they *don't* they have **more fluid dialogues** than with unfamiliar humans.

- Automatically **identify TIBs** from > 200 acoustic and lexical/syntactic features with an accuracy of [redacted]%.

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