HAAWAII
Highly Advanced Air Traffic Controller Workstation with Artificial Intelligence Integration

Machine learning and AI

Technical details on automatic speech recognition applied in ATC

First results in HAAWAII project

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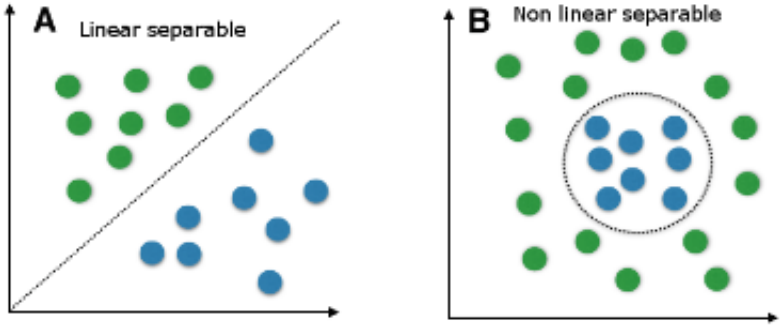
SESAR JOINT UNDERTAKING

co-funding Members

Introduction - ML & AI in current technologies

- Machine learning is only one part of AI
- HAAWAII relies on data-driven approach (although in an ideal case - a mix of large amount of data with expert knowledge)



- Our focus is ATC - understand the ATC communication (both channels)
  - General objective is to decrease a workload, decrease a probability of potential incidents due to miscommunication
  - Automatic speech recognition should be seen as a part of the solution

Content

(1) Importance of data
(2) What is automatic speech recognition (ASR)
(3) Development of ASRs
    (a) Rapid domain adaptation
    (b) learning w/o teacher - semi-supervised approach
    (c) Boosting on “unseen/rare words”, dynamic insertion
(4) Natural language understanding
(5) Performance on HAAWAII data

1. Importance of data

- Similar to any other machine learning approach - data is a key factor (in addition to expert knowledge) in building robust ASR
- The best commercial systems (e.g. GAFA) are trained on 100k's hours of speech
  - However, as these services are mostly free, end-users are "a part of services"
  - Their adaptation to target domain requires significant expert knowledge
- ASR can be developed using out-of-domain data (e.g. broadcast), but the robustness will not be high
  - Therefore, domain data is important to exploit
- Possibility to train with or w/o teacher
- Error-rates ~= 0 is practically impossible to reach (e.g. human error in verifying data)

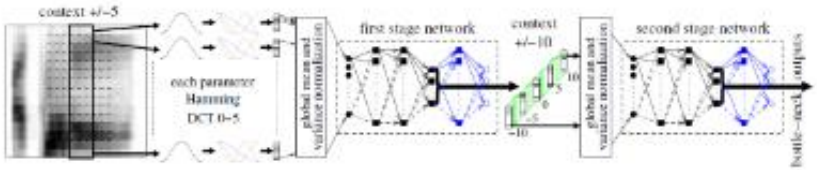
2. What is automatic speech recognition (ASR)

- Speech-to-text transformation, without extracting any meaning (called ASR)
- It also includes other parts:
  - Speaker diarization/segmentation
  - Paralinguistic pathological speech
  - Voice activity detection, or speech-non-speech detection?

2. Cont.

Automatic Speech Recognizer

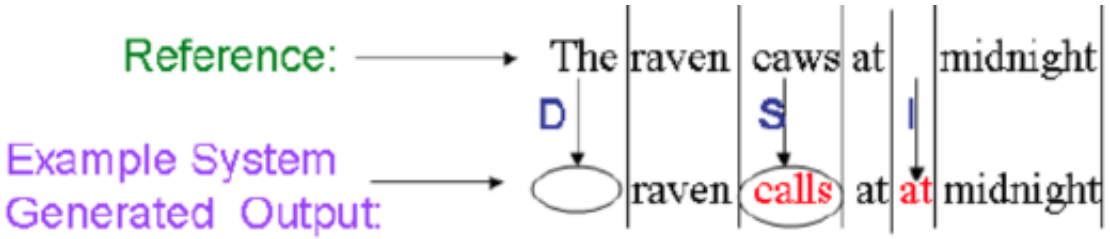

```
{ "response":
  { "task_id": "c2596dfc-057c-4615-83a2-c3586bccbc18",
    "task_type": "asr",
    "segments": [
      { "metadata":
        { "non_speech_ratio": "0",
          "type": "speech"
        },
        "nbests": [
          { "words": [
            ["text": "Do", "start": "0", "end": "1290", "confidence": "0.78"},
            ["text": "you have", "start": "1290", "end": "1630", "confidence": "0.92"],
            ["text": "a", "start": "1630", "end": "1700", "confidence": "1.00"],
            ["text": "suspect", "start": "1700", "end": "2610", "confidence": "1.00"],
            ["text": ".", "start": "2610", "end": "2620", "confidence": "1.00"]
            ],
            "confidence": "0.94",
            "transcription": "Do you have a suspect."
          }
        ]
      }
    ],
    "global_confidence": "0.94"
  }
}
```

2. Cont.

ASR evaluations:

$$\text{WER} = 100 \cdot \frac{S + D + I}{N}\% \qquad \text{Accuracy} = 100 - \text{WER}\%$$



$$\text{WER} = \frac{(1+1+1)}{5} = \frac{3}{5}$$

N - #words in reference transcripts, S, D, I - substitutions, deletions, insertions

Dynamic programming applied

But we need more: WER is not directly related to to higher level information extraction - we use also other metric

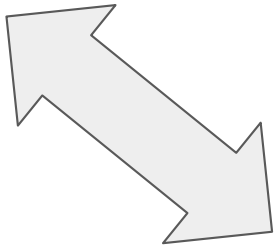
2. Cont.

```
Per utt details:
2020-08-01__14-57-06-59
speed bird six six golf alfa reduce speed two two zero knots or less
2020-08-01__14-57-10-46_P
one sixty knots to four dme kenya one hundred
2020-08-01__14-57-42-43
speed bird two five five nine contact the tower on one one eight decimal seven zero five good bye
2020-08-01__14-57-47-34_P
one one eight seven zero five good bye speed bird two five five nine
2020-08-01__14-58-25-45_P
descend flight level seven zero fly heading three six zero degrees > speed roger > bird six speed bird five one five
2020-08-01__14-58-32-73_P
director hello kenya one hundred descending level eight zero bravo seven eight eight information foxtrot direct biggin > <gbg>
2020-08-01__14-58-38-67
kenya one hundred heathrow > easy two hello hold at > it biggin it'll be > <gbg> a > serbia five minute > min no delay
2020-08-01__14-58-42-64_P
hold > london at biggin > <gbg> kenya > now one hundred
2020-08-01__14-59-22-99
speed bird five one five turn right heading zero nine zero degrees
2020-08-01__14-59-26-46_P
speed zero > bird nine zero degrees speed bird five one five

WER: 16.8 (ins 4, del 6, sub 12 / 131)
SER: 70.0

Insertions:
six     1
two     1
no      1
speed   1

Deletions:
on      1       1
it'll   1       1
at      1       2
biggin  1       3
one     2       12

Substitutions:
roger > bird    1       1
heathrow > easy 1       1
be > <gbg>      1       1
a > serbia      1       1
minute > min    1       1
biggin > <gbg>  2       3
at > it 1       2
hold > london   1       2
```

3. Development of ASR

Kaldi toolkit

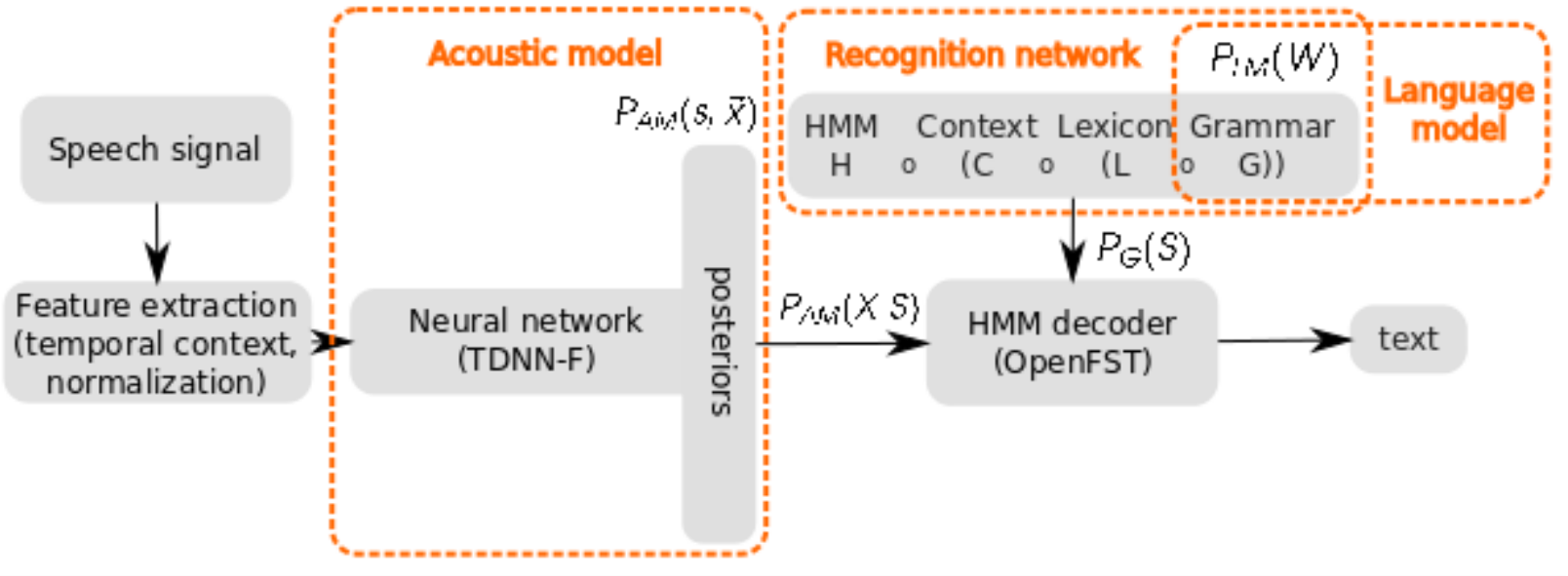
A toolkit for speech recognition research



(According to legend, Kaldi was the Ethiopian goatherd who discovered the coffee plant).

3. Cont.

Current KALDI - ASR state-of-the-art system



3. Cont. (rapid development of ASR)

Day	System for new language	WER%	Relative improvement
2	Baseline (Monolingual, TDNN-Factorized, LF-MMI)	~41	TBD
5	+ Lexicon augmentation	~35	TBD
7	+ Use of target data (30h)	~30%	TBD
8	+ Learning without teacher (600h) (*Single system*)	~25%	TBD
9	+ Customized LM	~20%	TBD
10	+ Boosting of specific words	~15%	TBD

- Amount of improvement for various domains may not be the same

3. Cont.

Incremental learning without teacher - semi-supervised training

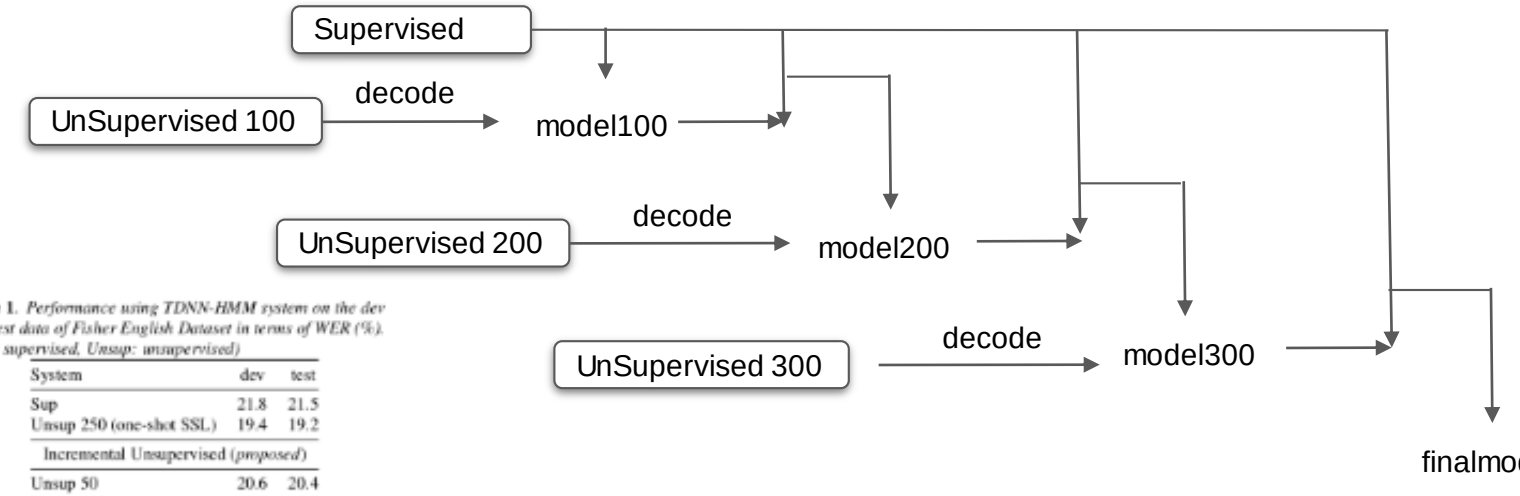
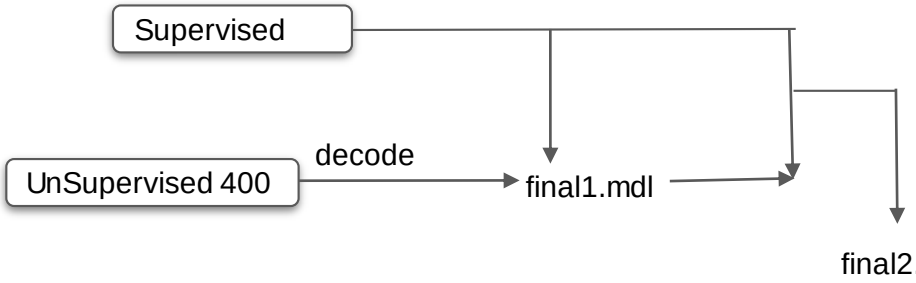
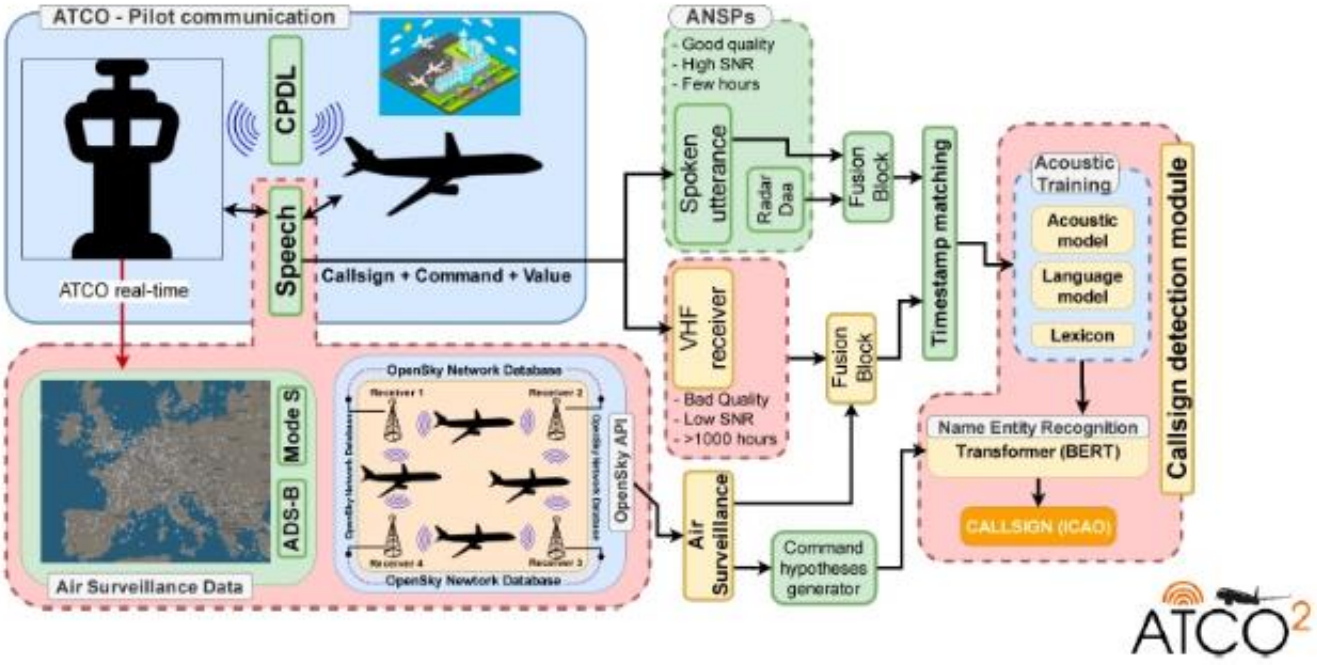


Table 1. *Performance using TDNN-HMM system on the dev and test data of Fisher English Dataset in terms of WER (%). (Sup: supervised, Unsup: unsupervised)*

System	dev	test
Sup	21.8	21.5
Unsup 250 (one-shot SSL)	19.4	19.2
Incremental Unsupervised (*proposed*)		
Unsup 50	20.6	20.4
Unsup 100	19.7	19.2
Unsup 150	**19.1**	**19.0**
Unsup 200	**18.8**	**18.5**
Unsup 250	**18.6**	**18.3**
Oracle 250	17.7	17.5

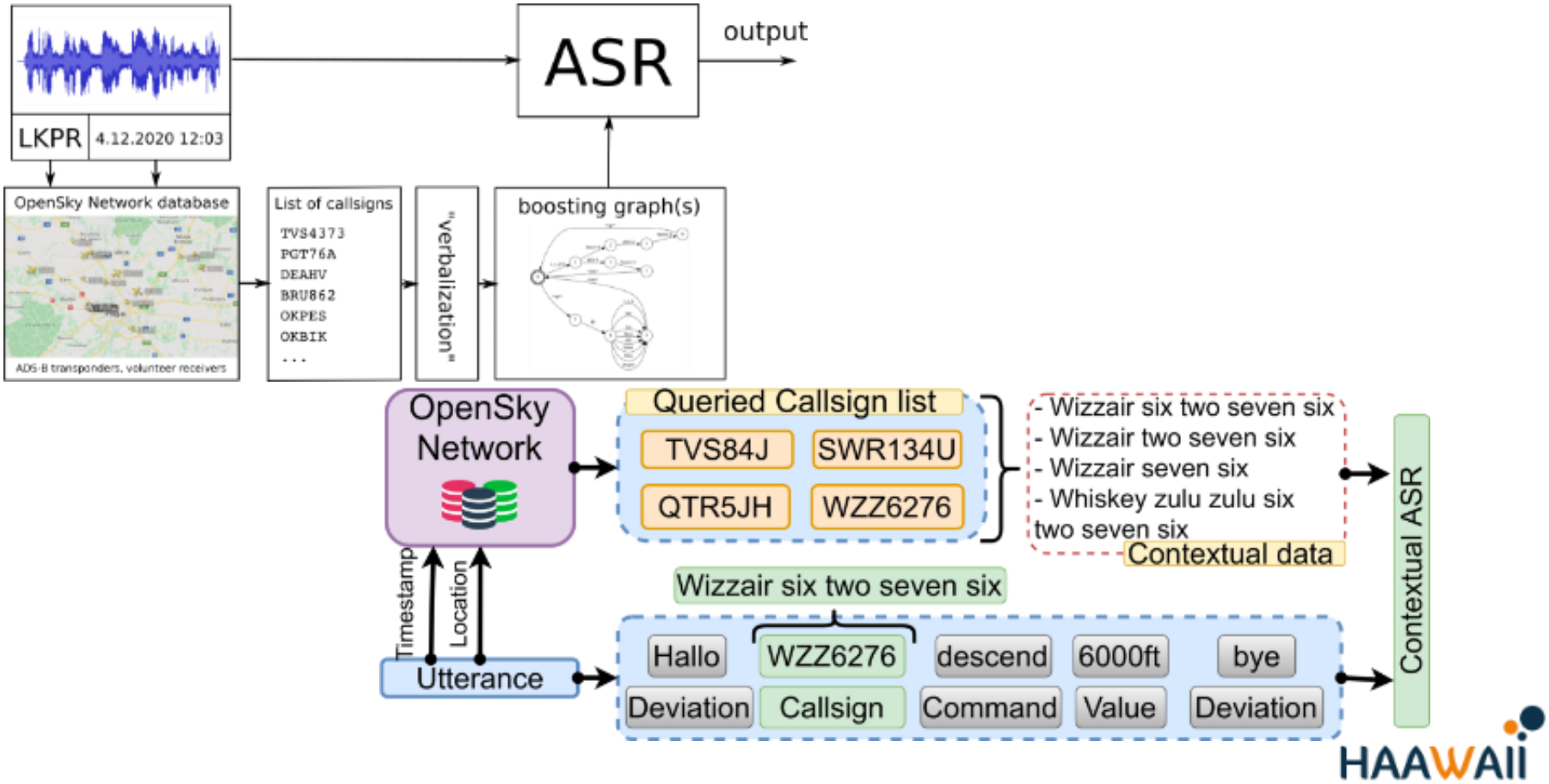


3. Cont. - current version of the ASR



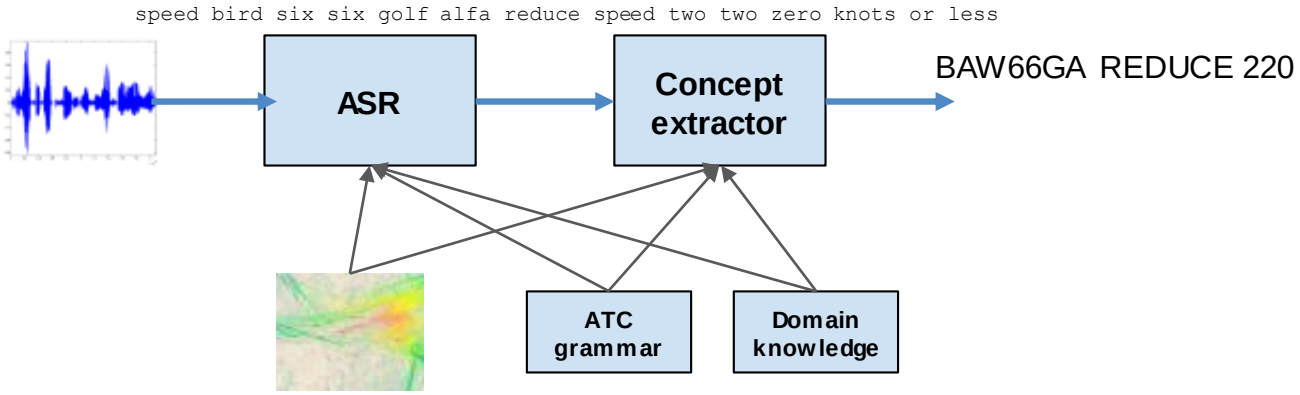
3. Cont.

Boosting of important words: callsign boosting



4. Natural language understanding

- Recognition is only a part of understanding
- ASR → NLU pipeline:
  - How to assess ASR impacting NLU
  - Impact of ASR errors on NLU
- NLU i ATC: concept extraction

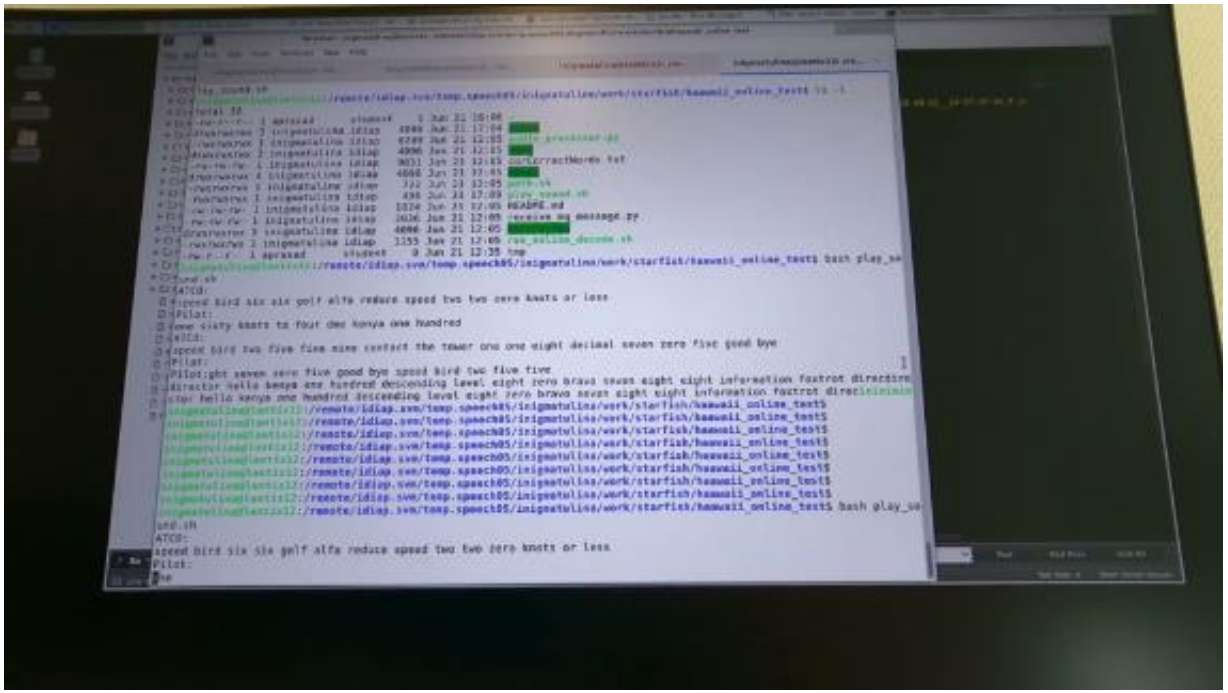


5. Performance on HAAWAII

ASR system	Results [WER]	Command accuracy
Preliminary results (beg. Of the project)	~30%	??
Pilot	11%	??
ATCO	8%	??

5. Cont.

Video: real-time ASR engine applied on HAAWAII data



Cnclusions

Special session: ASR in ATC

- Special session on the use of automatic speech recognition in ATM will be organised
- INTERSPECH 2021 conference, 30/8 - 3/9/2021 in Brno, Czech Republic
  - Hybrid organisation mode
- https://www.interspeech2021.org
- Interspeech is the major international conference focusing on speech processing R&D
  - Around 2'000+ participants, around 10+ tracks with talks and posters
- https://www.interspeech2021.org/call-for-special-sessions-and-challenges

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Thanks

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