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# GENERALIZED DRIVEN DECODING FOR SPEECH RECOGNITION SYSTEM COMBINATION

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## The Driven Decoding Algorithm

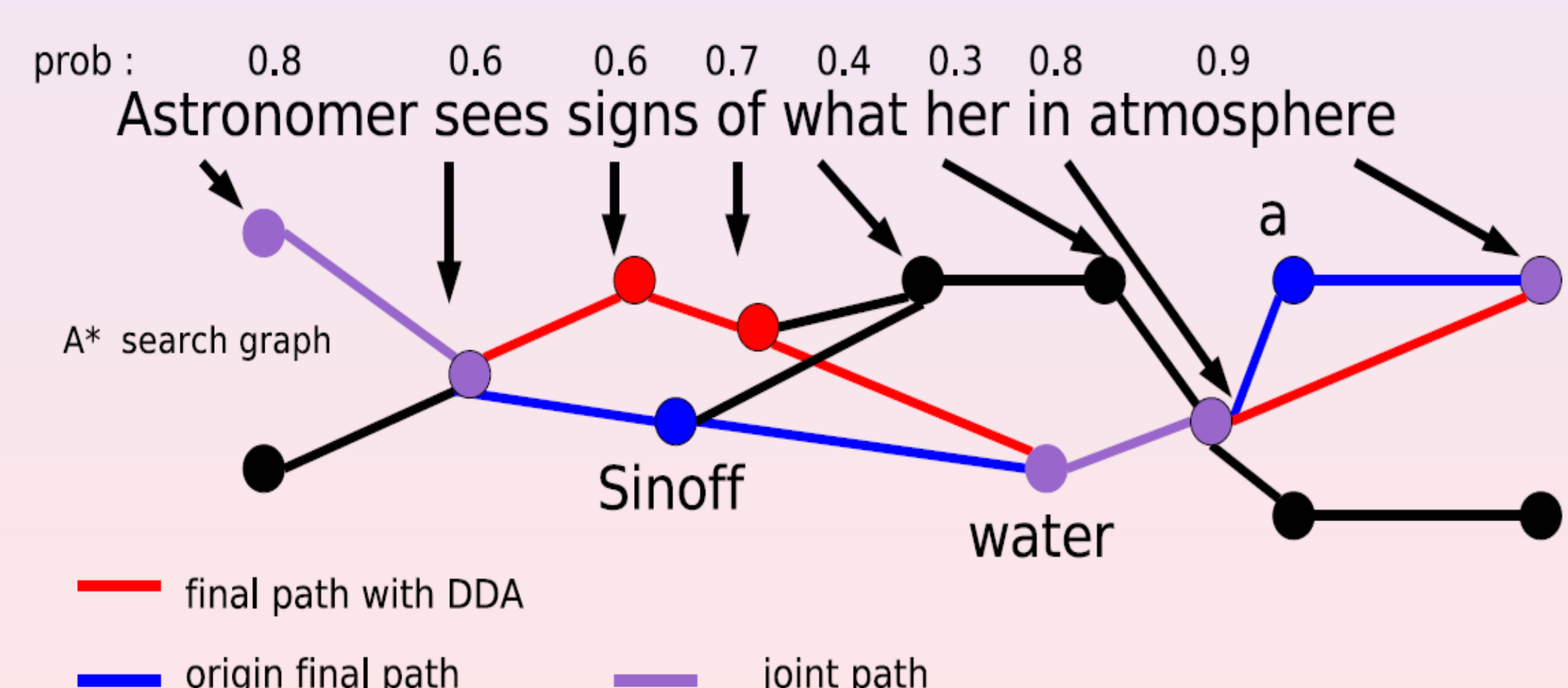
### Principle of driven decoding algorithm (DDA)

The DDA based combination :

- A first recognition pass using an auxiliary ASR system
  - Auxiliary system provides the one-best hypothesis  $h_{aux}$
  - The auxiliary transcript drives the main search algorithm
- DDA is an **integrated approach** for system combination

#### Trancripts drive A\* decoding :

- A\* search is synchronised to the transcript
- Linguistic probabilities are dynamically rescored
- Rescoring is based on posteriors



### Anatomy of the Speeral decoder

- Large vocabulary continuous speech recognition system
- HMM-based acoustic modeling
- Trigram language models
- Search : derived from a A\* search algorithm operating on a lattice of phonemes
- Exploration is supervised by the function  $F(h_n)$  evaluating the probability of  $h_n$  crossing the node  $n$ :

$$F(h_n) = g(h_n) + p(h_n) \quad (1)$$

### DDA step-2 : transcript to hypothesis matching score

- Linguistic probabilities are modified using the following rescoring rule:

$$L(w_i|w_{i-2}, w_{i-1}) = P(w_i|w_{i-2}, w_{i-1})^{1-\beta} \cdot \alpha(w_i)^\beta \quad (2)$$

$L(w_i|w_{i-2}, w_{i-1})$  is the resulting linguistic score,  $P(w_i|w_{i-2}, w_{i-1})$  the initial probability,  $\beta$  an empirical fudge factor and  $\alpha(w_i)$  is the confidence score of  $w_i$  given by :

$$\text{if } \theta(w_i) > 0 \text{ then } \alpha(w_i) = \phi(w_i) \cdot \frac{\theta(w_i)}{\gamma} \text{ and } \beta = 0.6 \\ \text{else } \beta = 0$$

$\gamma$  is the analysis window size reported by the edit distance ( $\gamma = 4$ ) and  $\phi(w_i)$  posteriors from word  $w_i$  of the auxiliary system.

### DDA step 1 : on-demand synchronization

- Speeral speech recognition system generates hypotheses as the phoneme-lattice is explored
- A\* is an asynchronous decoder :
  - Hypotheses are extended or left according to  $F()$
  - Leave a path leads to backtracking
- DDA synchronizes the current hypothesis and the auxiliary transcript
- Synchronization by fast DTW algorithm

## Confusion network driven decoding

Principle :

- As with the single best output, the combination method operates at the search level
- The current word utterance is dynamically mapped to the confusion network.
- The alignment step allows to extract the best projection of the hypothesis in the network
- The rescoring problem is similar to the one-best driven decoding case
- Performance are very close to the one obtained with the more simple one-best driven decoding

	F. Inter	F. Info	RFI
LIUM	18.5	18.9	25.6
DDA-LIUM-P1	17.8	18.1	22.4
DDA-LIUM-P2	17.2	17.8	21.5
DDA-WCN-LIUM-P1	17.7	18.1	22.3
DDA-WCN-LIUM-P2	17.2	17.8	21.5

Table: Word error rates for confusion network driven decoding (DDA-WCN), according to the decoding pass. Results are compared to the ones of the best single system (LIUM) and to the best one-best DDA system (DDA-LIUM)

## Multi system combination

### Two-Level ROVER-DDA combination

- Relies on a first merging step where all auxiliary transcripts are merged
- We use ROVER for merging LIUM and IRISA system outputs
- The word confidence scores of the output are computed by averaging the confidence scores of words in each single system output
- The resulting transcript is then used as an auxiliary hypothesis

### Integrated DDA-based combination

- All auxiliary systems outputs are submitted
- For each of them, a matching score is computed according to independent transcript-to-hypothesis synchronization
- all linguistic scores are merged by the log-linear combination extended to  $n$  systems:

$$L(w_i|w_{i-2}, w_{i-1}) = P(w_i|w_{i-2}, w_{i-1})^{1-\beta} \cdot \frac{1}{N} \sum_{k=0}^N \alpha_k(w_i)^{\beta_k} \quad (3)$$

where  $\beta$  is the averaged  $\beta_k$  as defined in equation 2,  $\alpha_k$  are the posteriors provided by the system  $k$  and  $N$  the number of auxiliary systems.

### Results

	F. Inter	F. Info	RFI
LIUM	18.5	18.9	25.6
ROVER-3	17.1	18.2	22.5
2-Level DDA-ROVER	16.8	17.3	21.3
DDA-3	16.7	17.0	20.6
DDA-3+ROVER	16.0	16.4	20.7

Table: Word error rates of multiple-system combination according to the combination schemes : the baseline ROVER combination of the 3 single systems (ROVER-3), the 2-level method (2-Level DDA-ROVER), the full DDA-integration (DDA-3) of auxiliary systems, and the ROVER combination of all systems including DDA-3 (DDA-3+ROVER). This last one obtains the best results with a WER decrease of about 15.7% relative with respect to the best single system (LIUM).

	F. Inter	F. Info	RFI
Best single system(LIUM)	18.5	18.9	25.6
DDA-3	16.7	17.0	20.6
ORACLE-3	10.3	10.5	14.5
DDA-3+ROVER	16.0	16.4	20.7
ORACLE DDA+ROVER	9.8	10.0	13.6

Table: Analysis of DDA by comparison to ROVER and Oracle measures.

## Experimental framework

### The LIA system

- System involved in the ESTER evaluation campaign :
  - Speeral decoder
  - Alize-based segmenter
  - 65K lexicon; 20M trigrams estimated on about 200M of words
  - 2 decoding pass (MLLR adaptation)
  - 8xRT on a standard desktop computer

### The LIUM system

- Based on the CMU Sphinx 3.3 decoder (beam search algorithm)
- 4-gram word-lattice rescoring process
- Context-dependent acoustic models trained on Ester materials
- SAT-based adaptation
- The entire process runs under 12xRT

### The IRISA system

- Based on word-synchronous beam-search algorithm
- HMM acoustic modeling and n-gram linguistic models with a vocabulary of 64k words
- The system operates in four steps
  - (1) Context-independent acoustic models with a trigram LM
  - (2) The graph is rescored with a 4gram LM and context-dependent models
  - (3) MLLR speaker adaptation
  - (4) Consensus decoding is applied to the 1000-best sentence hypotheses

### Baseline results

	F. Inter	F. Info	RFI
LIA	21.1	22.2	24.6
LIUM	18.5	18.9	25.6
IRISA	21.4	21.8	25.6
DDA-IRISA-P1	19.6	19.3	23.5
DDA-IRISA-P2	18.7	18.7	22.2
DDA-LIUM-P1	17.8	18.1	22.4
DDA-LIUM-P2	17.2	17.8	21.5

Table: Word error rates for DDA combination of Speeral with an LIUM system (DDA-LIUM) and IRISA system (DDA-IRISA) with (P1 and without (P2) unsupervised speaker adaptation. Experiments performed of 3 hours of French broadcast news from the ESTER corpus.

- ASR systems are assessed on 3 hours of radio broadcast from ESTER corpus
- The Driven Driven Algorithm (DDA) is used here during the second pass

## Driven decoding analysis and Conclusion

- Linguistic rescoring allows to guide the search toward alternative paths
- DDA may not be considered as an on-line vote method
- DDA is an integrated approach allowing a new exploration of the search graph
- DDA outperforms the ROVER approach
- ROVER combination of DDA-3 and all single systems outperforms the pure DDA approach
- WCN-driven decoding improves the primary system but performance are very close to the one obtained with the more simple one-best driven decoding
- By using DDA-based cross-site system combination and a final ROVER pass, we obtained a global absolute gain of about 3.3% WER (15.7% relative gain).