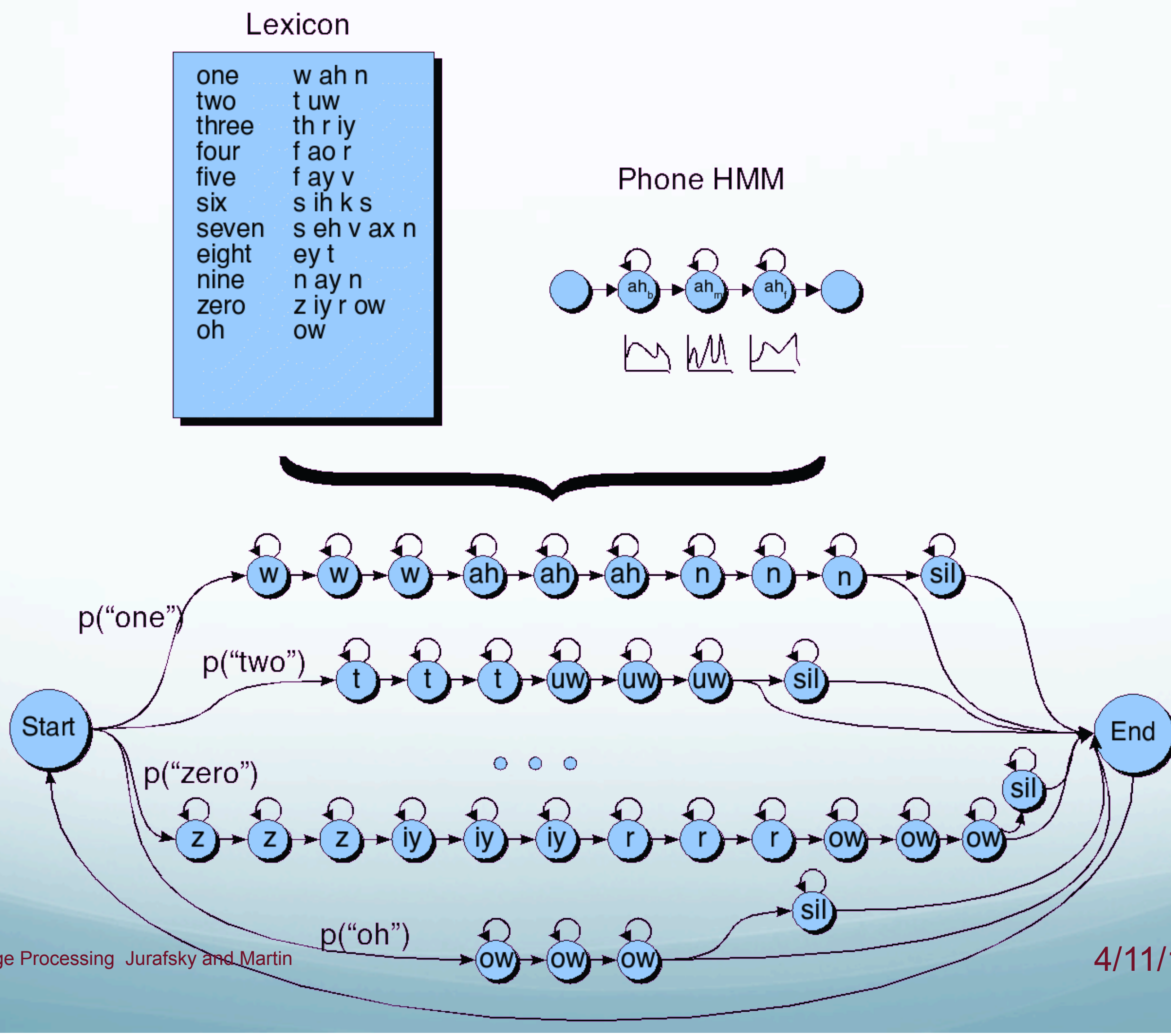
SDS: ASR, NLU, & VXML

Ling575
Spoken Dialog
April 16, 2015

Roadmap

- Dialog System components:
  - ASR: Noisy channel model
    - Representation
    - Decoding
  - NLU:
    - Call routing
    - Grammars for dialog systems
  - Basic interfaces: VoiceXML

HMM for the digit recognition task



Typical MFCC features

- Window size: 25ms
- Window shift: 10ms
- Pre-emphasis coefficient: 0.97
- MFCC:
  - 12 MFCC (mel frequency cepstral coefficients)
  - 1 energy feature
  - 12 delta MFCC features
  - 12 double-delta MFCC features
  - 1 delta energy feature
  - 1 double-delta energy feature
- Total 39-dimensional features

Why is MFCC so popular?

- Efficient to compute
- Incorporates a perceptual Mel frequency scale
- Separates the source and filter
- Fits well with HMM modelling

Decoding

- In principle:

$$\hat{W} = \underset{W \in \mathcal{L}}{\operatorname{argmax}} \overbrace{P(O|W)}^{\text{likelihood}} \; \overbrace{P(W)}^{\text{prior}}$$

- In practice:

$$\hat{W} = \underset{W \in \mathcal{L}}{\operatorname{argmax}} P(O|W)P(W)^{LMSF}$$

$$\hat{W} = \underset{W \in \mathcal{L}}{\operatorname{argmax}} P(O|W)P(W)^{LMSF}\, WIP^{N}$$

$$\hat{W} = \underset{W \in \mathcal{L}}{\operatorname{argmax}} \log P(O|W) + LMSF \times \log P(W) + N \times \log WIP$$

Why is ASR decoding hard?

[ay d ih s hh er d s ah m th ih ng ax b aw m uh v ih ng r ih s en l ih]

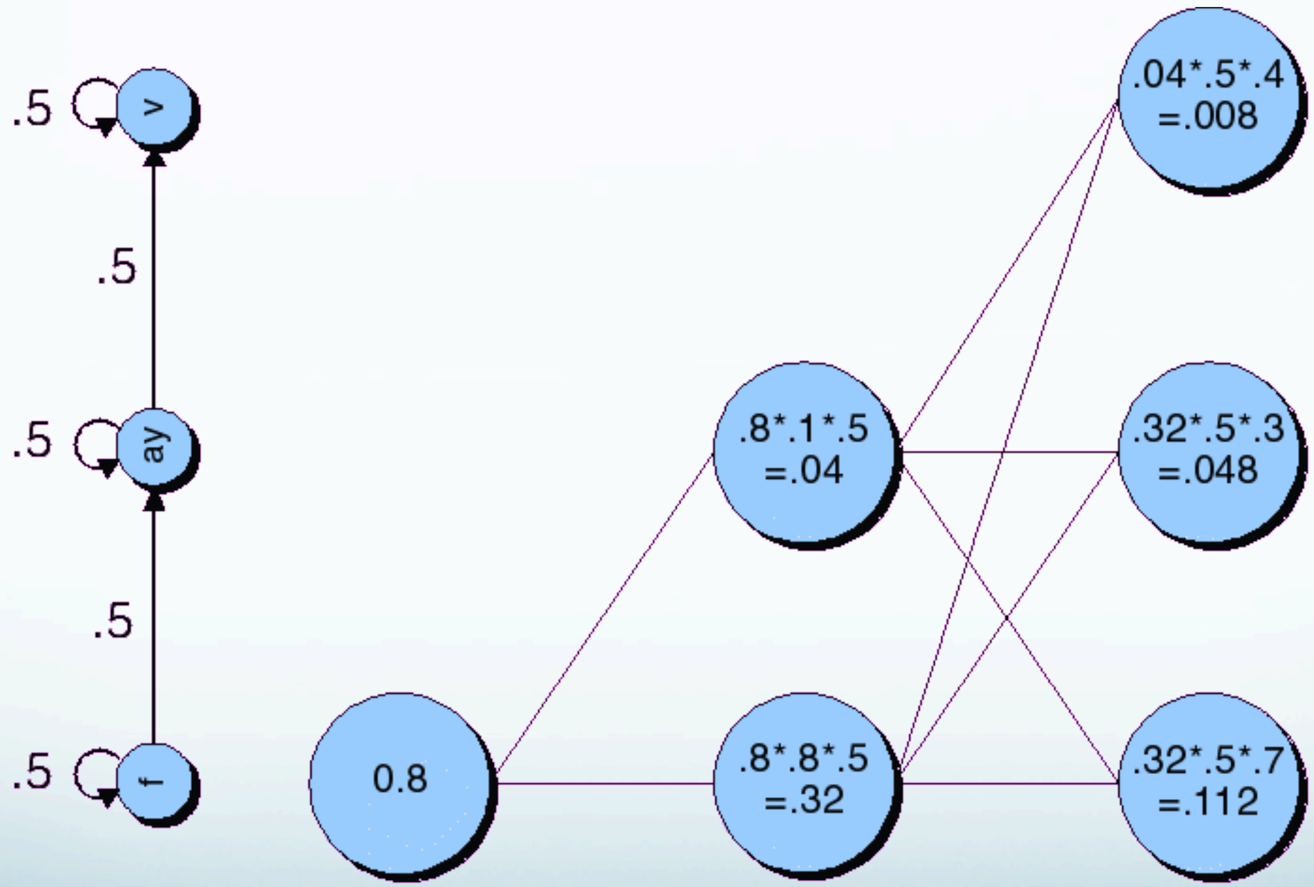
The Evaluation (forward) problem for speech

- The observation sequence O is a series of MFCC vectors
- The hidden states W are the phones and words
- For a given phone/word string W, our job is to evaluate P(O|W)
- Intuition: how likely is the input to have been generated by just that word string W

Evaluation for speech: Summing over all different paths!

- f ay ay ay ay v v v v
- f f ay ay ay ay v v v
- f f f f ay ay ay ay v
- f f ay ay ay ay ay ay v
- f f ay ay ay ay ay ay ay ay v
- f f ay v v v v v v v

Viterbi trellis for "five"



Viterbi trellis for "five"

V	0	0	0.008	0.0072	0.00672	0.00403	0.00188	0.00161	0.000667	0.000493
AY	0	0.04	0.048	0.0448	0.0269	0.0125	0.00538	0.00167	0.000428	8.78e-05
F	0.8	0.32	0.112	0.0224	0.00448	0.000896	0.000179	4.48e-05	1.12e-05	2.8e-06
Time	1	2	3	4	5	6	7	8	9	10
B	*f* 0.8	*f* 0.8	*f* 0.7	*f* 0.4	*f* 0.4	*f* 0.4	*f* 0.4	*f* 0.5	*f* 0.5	*f* 0.5
	ay 0.1	*ay* 0.1	*ay* 0.3	*ay* 0.8	*ay* 0.8	*ay* 0.8	*ay* 0.8	*ay* 0.6	*ay* 0.5	*ay* 0.4
	v 0.6	*v* 0.6	*v* 0.4	*v* 0.3	*v* 0.3	*v* 0.3	*v* 0.3	*v* 0.6	*v* 0.8	*v* 0.9
	p 0.4	*p* 0.4	*p* 0.2	*p* 0.1	*p* 0.1	*p* 0.1	*p* 0.1	*p* 0.1	*p* 0.3	*p* 0.3
	iy 0.1	*iy* 0.1	*iy* 0.3	*iy* 0.6	*iy* 0.6	*iy* 0.6	*iy* 0.6	*iy* 0.5	*iy* 0.5	*iy* 0.4

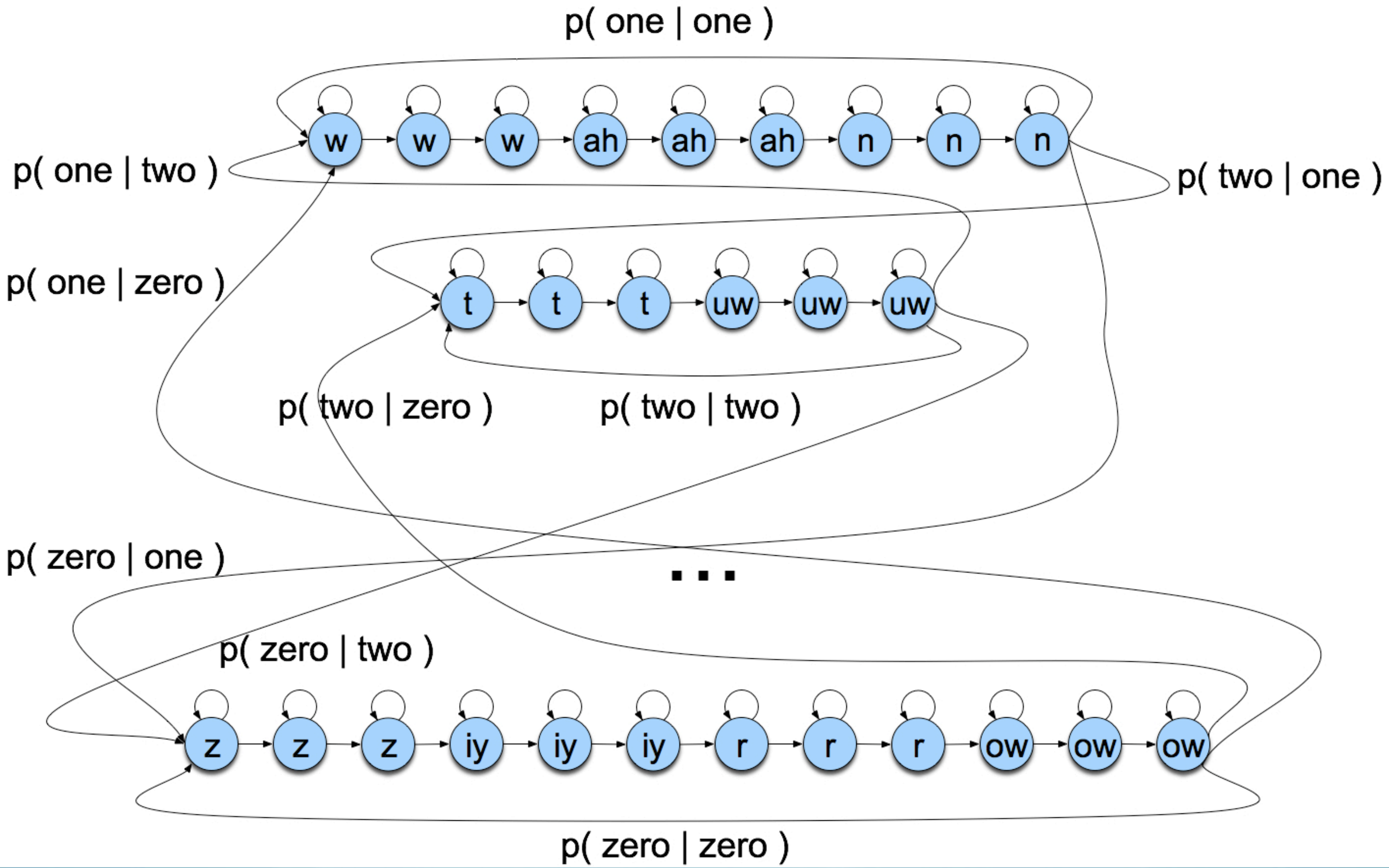
Language Model

- Idea: some utterances more probable

- Standard solution: “n-gram” model
  - Typically tri-gram: $P(w_i | w_{i-1}, w_{i-2})$
    - Collect training data from large side corpus
      - Smooth with bi- & uni-grams to handle sparseness
  - Product over words in utterance:

$$P(w_1^n) \approx \prod_{k=1}^{n} P(w_k \mid w_{k-1}, w_{k-2})$$

Search space with bigrams



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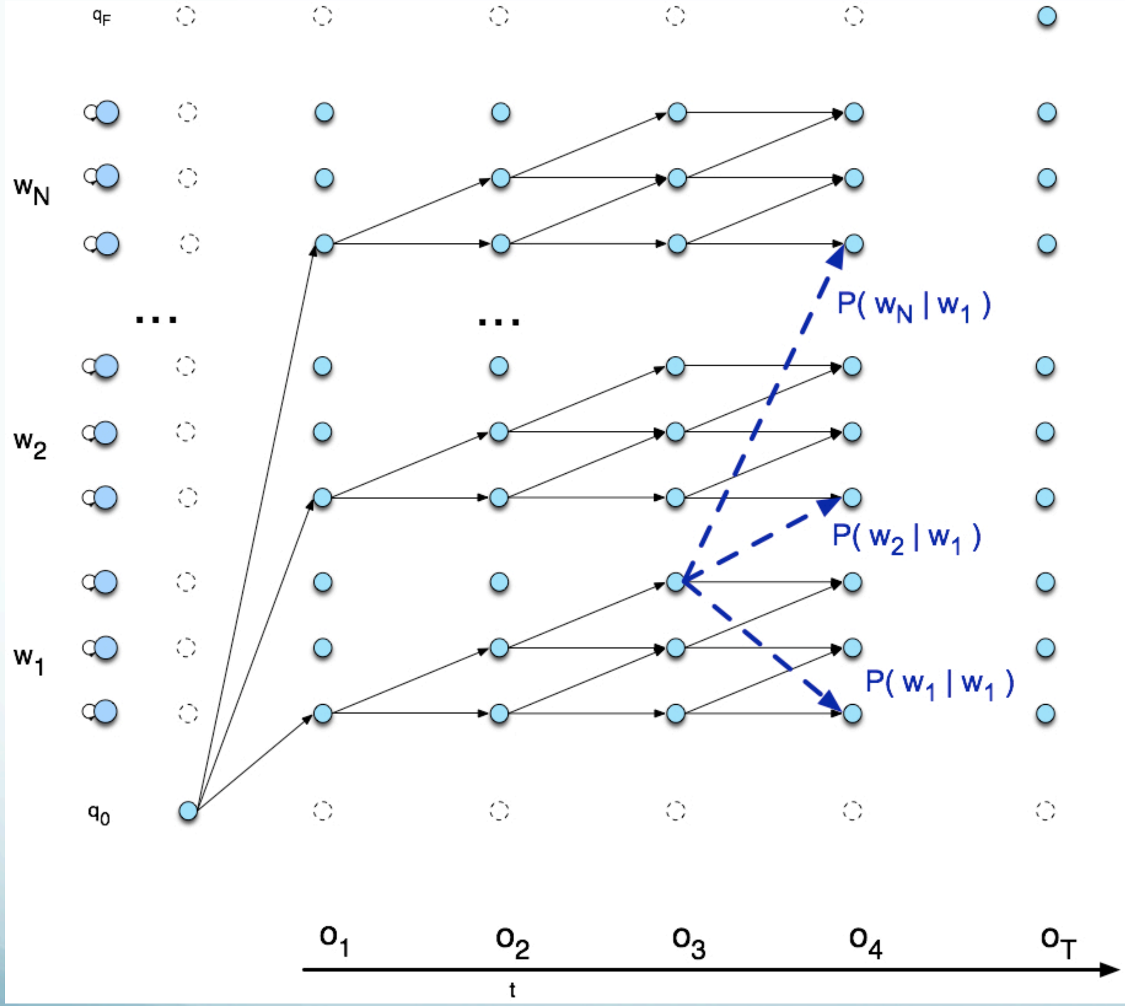
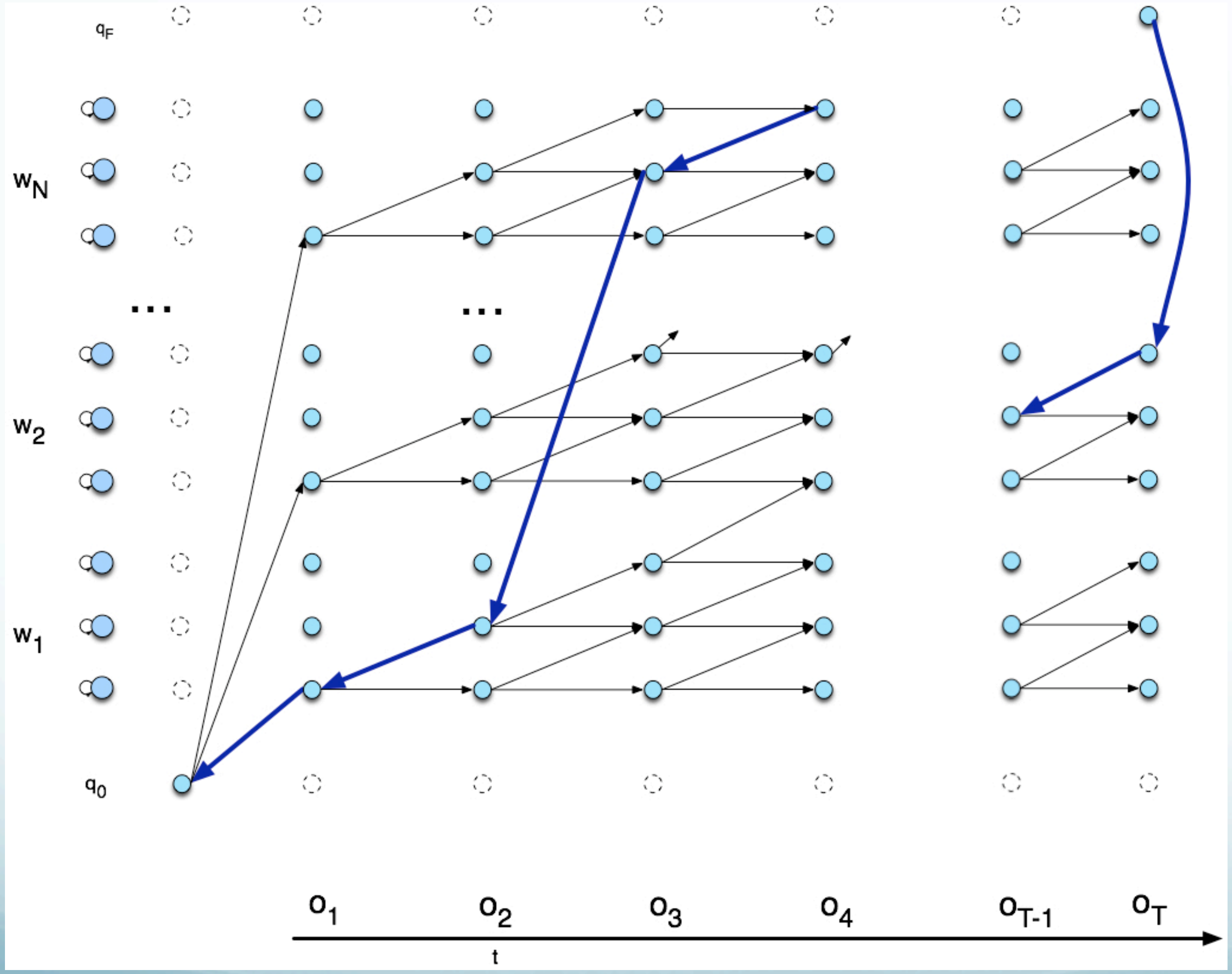
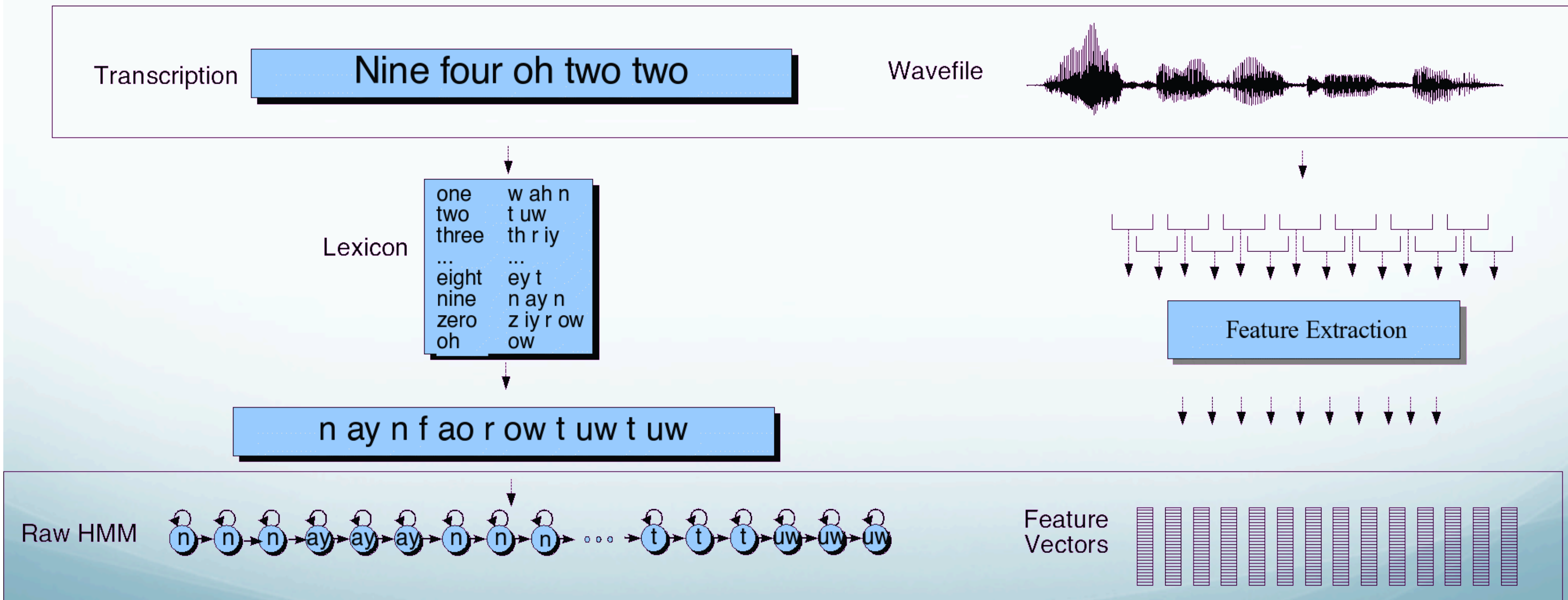


Viterbi backtrace



Training

- Trained using Baum-Welch algorithm



Summary: ASR Architecture

- Five easy pieces: ASR Noisy Channel architecture
  1) Feature Extraction:
     39 "MFCC" features
  2) Acoustic Model:
     Gaussians for computing p(o|q)
  3) Lexicon/Pronunciation Model
     - HMM: what phones can follow each other
  4) Language Model
     - N-grams for computing $p(w_i|w_{i-1})$
  5) Decoder
     - Viterbi algorithm: dynamic programming for combining all these to get word sequence from speech!

Evaluation

- How to evaluate the word string output by a speech recognizer?

Word Error Rate

- Word Error Rate =

100 (Insertions+Substitutions + Deletions)

Total Word in Correct Transcript

Aligment example:

REF: portable **** PHONE UPSTAIRS last night so

HYP: portable FORM OF STORES last night so

Eval I S S

WER = 100 (1+2+0)/6 = 50%

NIST sctk-1.3 scoring software: Computing WER with sclite

- http://www.nist.gov/speech/tools/
- Sclite aligns a hypothesized text (HYP) (from the recognizer) with a correct or reference text (REF) (human transcribed)

```
id: (2347-b-013)

Scores: (#C #S #D #I) 9 3 1 2

REF:  was an engineer SO I   i was always with **** **** MEN UM   and they

HYP:  was an engineer ** AND i was always with THEM THEY ALL THAT and they

Eval:                 D  S                     I    I    S   S
```

Better metrics than WER?

- WER has been useful
- But should we be more concerned with meaning ("semantic error rate")?
  - Good idea, but hard to agree on
  - Has been applied in dialogue systems, where desired semantic output is more clear

Accents: An experiment

- A word by itself

- The word in context

Challenges for the Future

- Doing more with more
  - More applications:
    - From Siri, in-car navigation, call-routing
    - To full voice search, voice-based personal assistants, ubiquitous computing
  - More speech types:
    - Accented speech
    - Speech in noise
    - Overlapping speech
    - Child speech
    - Speech pathology

NLU for Dialog Systems

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- What about spoken dialog systems?

NLU for SDS

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- Why not?

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- Why not?
  - Examples of travel air speech input (due to A. Black)
    - Eh, I wanna go, wanna go to Boston tomorrow
    - If its not too much trouble I'd be very grateful if one might be able to aid me in arranging my travel arrangements to Boston, Logan airport, at sometime tomorrow morning, thank you.
    - Boston, tomorrow

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  - Speech recognition:
    - Error-prone, perfect full analysis difficult to obtain

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    - I'd like my checking account balance, or
    - "ah I'm calling 'cuz ah a friend gave me this number and ah she told me ah with this number I can buy some cars or whatever but she didn't know how to explain it to me so I just called you you know to get that information."

Call Routing

- General approach:
  - Build classification model based on labeled training data, e.g. manually routed calls
    - Apply classifier to label new data

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    - (Dimensionality reduction by singular value decomposition)
  - Compute cosine similarity for new call & training examples

Meaning Representations for Spoken Dialog

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- Frame:
  - Domain-dependent information structure
  - Set of attribute-value pairs
  - Information relevant to answering questions in domain

Natural Language Understanding

- Most systems use frame-slot semantics
  Show me morning flights from Boston to SFO on Tuesday

  - SHOW:
  - FLIGHTS:
    - ORIGIN:
      - CITY: Boston
      - DATE:
        - DAY-OF-WEEK: Tuesday
      - TIME:
        - PART-OF-DAY: Morning
    - DEST:
      - CITY: San Francisco

Another NLU Example

- Sagae et 2009
- Utterance (speech): we are prepared to give you guys generators for electricity downtown
- ASR (NLU input): we up apparently give you guys generators for a letter city don town
- Frame (NLU output):
  - **<s>.mood declarative**
  - **<s>.sem.agent kirk**
  - **<s>.sem.event deliver**
  - **<s>.sem.modal.possibility can**
  - **<s>.sem.speechact.type offer**
  - **<s>.sem.theme power-generator**
  - **<s>.sem.type event**

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  - Classification or sequence labeling approaches
    - HMM-based, MaxEnt-based

Grammars

- Formal specification of strings in a language
- A 4-tuple:
  - A set of terminal symbols: Σ
  - A set of non-terminal symbols: N
  - A set of productions P: of the form A -> α
  - A designated start symbol S
- In regular grammars:
  - A is a non-terminal and α is of the form {N}Σ*
- In context-free grammars:
  - A is a non-terminal and α in (Σ U N)*

Simple Air Travel Grammar

- LIST -> show me | I want | can I see|…
- DEPARTTIME -> (after|around|before) HOUR| morning | afternoon | evening
- HOUR -> one|two|three…|twelve (am|pm)
- FLIGHTS -> (a) flight|flights
- ORIGIN -> from CITY
- DESTINATION -> to CITY
- CITY -> Boston | San Francisco | Denver | Washington

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- Simple, but…
  - VERY limited, assumes direct correspondence

Semantic Grammars

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- Frames can be nested
- Widely used: Phoenix NLU (CU, CMU), vxml grammars

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    - Build rules manually, then train probabilities w/data
  - Domain- and application-specific
    - Hard to port

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- Many alternative classifier models
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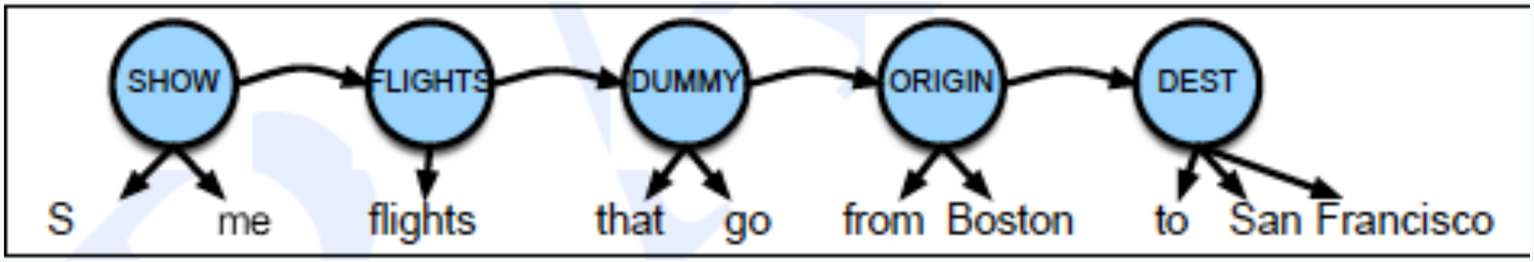
- C*= argmax P(C|W)
-     = argmax P(W|C)P(C)/P(W)
-     = argmax P(W|C)P(C)
- Assume limited M-concept history, N-gram words
  - = $$\prod_{i=2}^{N} P(w_i \mid w_{i-1} \ldots w_{i-N+1}, c_i) \prod_{i=2}^{N} P(c_i \mid c_{i-1} \ldots c_{i-M+1})$$

Probabilistic Slot Filling

- Example HMM



VoiceXML

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    - Structures voice interaction
    - Can incorporate Javascript/PHP/etc for functionality

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  - Support for sub-dialog call-outs

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- TTS:
  - <ssml> markup language
  - Allows choice of: language, voice, pronunciation
  - Allows tuning of: timing, breaks

Simple VoiceXML Example

- Minimal form:

```
<form>
  <field name="transporttype">
     <prompt>
        Please choose airline, hotel, or rental car.
     </prompt>
     <grammar type="application/x=nuance-gsl">
       [airline hotel "rental car"]
     </grammar>
  </field>
  <block>
    <prompt>
     You have chosen <value expr="transporttype">.
    </prompt>
  </block>
</form>
```

Basic VXML Document

- Main body: <form></form>
  - Sequence of fields: <field></field>

Basic VXML Document

- Main body: <form></form>
  - Sequence of fields: <field></field>
    - Correspond to variable storing user input
      - <field name=“transporttype”>

Basic VXML Document

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  - Sequence of fields: <field></field>
    - Correspond to variable storing user input
      - <field name="transporttype">
    - Prompt for user input
      - <prompt> Please choose airline, hotel, or rental car.</prompt>
        - Can include URL for recorded prompt, backs off

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      - <prompt> Please choose airline, hotel, or rental car.</prompt>
        - Can include URL for recorded prompt, backs off
    - Specify grammar to recognize/interpret user input
      - <grammar>[airline hotel "rental car"]</grammar>

Other Field Elements

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- Action to be performed on input:
  - <filled>
    - <prompt>You have chosen <value exp="transporttype">.
    - </prompt></filled>

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- Goto allows jump to:
  - Other form: <goto next="weather.xml">
  - Other position in form: <goto next="#departdate">
- Conditionals:
  - <if cond="varname=='air'">....</if>
- Guards:
  - Default: Skip field if slot value already entered

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  - No speech timeout
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  - Speech, but nothing valid recognized
- <help>:
  - General system help prompt

Complex Interaction

- Preamble, grammar:

```
<noinput>    I'm sorry, I didn't hear you.  <reprompt/>  </noinput>

<nomatch> I'm sorry, I didn't understand that.  <reprompt/> </nomatch>

<form>
   <grammar type="application/x=nuance-gsl">
    <![ CDATA[
    Flight (   ?[
                 (i [wanna (want to)] [fly go])
                 (i'd like to [fly go])
                 ([(i wanna)(i'd like a)] flight)
            ]
            [
              ( [from leaving departing] City:x) {<origin $x>}
              ( [(?going to)(arriving in)] City:x) {<destination $x>}
              ( [from leaving departing] City:x
                [(?going to)(arriving in)] City:y) {<origin $x> <destination $y>}
            ]
            ?please
     )
     City [ [(san francisco) (s f o)] {return( "san francisco, california")}
            [(denver) (d e n)] {return( "denver, colorado")}
            [(seattle) (s t x)] {return( "seattle, washington")}
     ]
     ]]> </grammar>

  <initial name="init">
     <prompt> Welcome to the consultant. What are your travel plans?  </prompt>
  </initial>
```

Mixed Initiative

- With guard defaults

```
  <field name="origin">
     <prompt> Which city do you want to leave from?  </prompt>
     <filled>
        <prompt> OK, from <value expr="origin"> </prompt>
     </filled>
  </field>
  <field name="destination">
     <prompt> And which city do you want to go to?  </prompt>
     <filled>
        <prompt> OK, to <value expr="destination"> </prompt>
     </filled>
  </field>
  <block>
     <prompt> OK, I have you are departing from  <value expr="origin">
              to  <value expr="destination">.  </prompt>
    send the info to book a flight...
  </block>
</form>
```

Complex Interaction

- Preamble, external grammar:

```
<?xml version="1.0"?>
<vxml version = "2.0">

<form id="F1">

  <field name="F_1">
      <grammar src="NameGram.xml"
type="application/grammar-xml" />
      <prompt>
      Please tell me your full name so I can verify you
      </prompt>
  </field>

  <filled mode="all" namelist="F_1">
      <prompt>
        Your name is <value expr="F_1"/>
        <break strength="medium"/>
      </prompt>
    </filled>
</form>
</vxml>
```

Multi-slot Grammar

```
<?xml version= "1.0"?>
 <grammar xml:lang="en-US" root = "TOPLEVEL">
  <rule id="TOPLEVEL" scope="public">
   <item>

  <!-- FIRST NAME RETURN -->

    <item repeat="0-1">
     <ruleref uri="#FIRSTNAME"/>
     <tag>out.firstNameSlot=rules.FIRSTNAME.firstNameSubslot;</tag>
    </item>
  <!-- MIDDLE NAME RETURN -->

    <item repeat="0-1">
     <ruleref uri="#MIDDLENAME"/>
     <tag>out.middleNameSlot=rules.MIDDLENAME.middleNameSubslot;</tag>
    </item>
  <!-- LAST NAME RETURN -->

     <ruleref uri="#LASTNAME"/>
     <tag>out.lastNameSlot=rules.LASTNAME.lastNameSubslot;</tag>
    </item>

 <!-- TOP LEVEL RETURN-->
   <tag> out.F_1= out.firstNameSlot + out.middleNameSlot + out.lastNameSlot; </tag>
  </rule>
```

Multi-slot Grammar II

```
<rule id="FIRSTNAME" scope="public">
  <one-of>
    <item> matt<tag>out.firstNameSubslot="matthew";</tag></item>
    <item> dee <tag> out.firstNameSubslot="dee ";</tag></item>
    <item> jon <tag> out.firstNameSubslot="jon ";</tag></item>
    <item> george <tag>out.firstNameSubslot="george ";</tag></item>
    <item> billy <tag> out.firstNameSubslot="billy ";</tag></item>
  </one-of>
  </rule>

  <rule id="MIDDLENAME" scope="public">
  <one-of>
    <item> bon <tag>out.middleNameSubslot="bon ";</tag></item>
    <item> double ya <tag> out.middleNameSubslot="w ";</tag></item>
    <item> dee <tag> out.middleNameSubslot="dee ";</tag></item>
  </one-of>
  </rule>

  <rule id="LASTNAME" scope="public">
  <one-of>
    <item> henry <tag> out.lastNameSubslot="henry "; </tag></item>
    <item> ramone <tag> out.lastNameSubslot="dee ";  </tag></item>
    <item> jovi <tag> out.lastNameSubslot="jovi ";  </tag></item>
    <item> bush <tag> out.lastNameSubslot=""bush ";  </tag></item>
    <item> williams <tag> out.lastNameSubslot="williams "; </tag></item>
  </one-of>
  </rule>

</grammar>
```

Augmenting VoiceXML

- Don't write XML directly
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  - Use php or other system to generate VoiceXML
    - Used in ‘Let’s Go Dude’ bus info system
- Pass input to other web services
  - i.e. to RESTful services
- Access web-based audio for prompts