Introduction to Statistical Machine Translation

David Kauchak

CS457 – Fall 2011

Some slides adapted from

Philipp Koehn
CSAIL
Massachusetts Institute of Technology

Kevin Knight
USC/Information Sciences Institute
USC/Computer Science Department

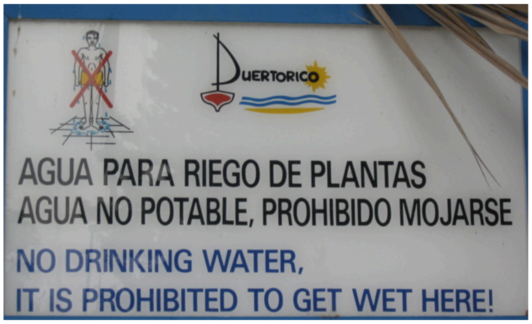
Admin

- How are the projects going?
- Remaining classes applications
  - 3 MT
    - General overview today
    - Dive into one specific implementation next time
    - MT lab
  - Other applications
    - Information extraction
    - Information retrieval
    - Question answering/summarization

Language translation

MT Systems

Where have you seen machine translation systems?


UERTORICO
AGUA PARA RIEGO DE PLANTAS
AGUA NO POTABLE, PROHIBIDO MOJARSE
NO DRINKING WATER,
IT IS PROHIBITED TO GET WET HERE!

Machine Translation

美国关岛国际机场及其办公室均接获一
名自称沙地阿拉伯富商拉登等发出的电
子邮件，威胁将会向机场等公众地方发
动生化袭击後，关岛经保持高度戒备。

➡

The U.S. island of Guam is maintaining a high state of alert after the Guam airport and its offices both received an e-mail from someone calling himself the Saudi Arabian Osama bin Laden and threatening a biological/chemical attack against public places such as the airport .

The classic acid test for natural language processing.

Requires capabilities in both interpretation and generation.

People around the world stubbornly refuse to write everything in English.

Machine Translation

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名自称沙地阿拉伯富商拉登等发出的电
子邮件，威胁将会向机场等公众地方发
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Machine translation is becoming very prevalent

Even PowerPoint has translation built into it!

The U.S. island of Guam is maintaining a high state of alert after the Guam airport and its offices both received an e-mail from someone calling himself the Saudi Arabian Osama bin Laden and threatening a biological/chemical attack against public places such as the airport .

United States Guam International Airport and the Office received one claiming to be a wealthy Saudi Arabia an email such as Osama bin Laden, threats to the airport after biochemical attacks in public places such as Guam remain on high alert.

Which is the human?

Beijing Youth Daily said that under the Ministry of Agriculture, the beef will be destroyed after tests.

The Beijing Youth Daily pointed out that the seized beef would be disposed of after being examined according to advice from the Ministry of Agriculture.

?

Which is the human?

Pakistan President Pervez Musharraf Wins Senate Confidence Vote

Pakistani President Musharraf Won the Trust Vote in Senate and Lower House

?

Which is the human?

There was not a single vote against him."

No members vote against him. "

?

Warren Weaver (1947)

```
ingcmpnqsnwf cv fpn owoktvcv

hu ihgzsnwfv rqcffnw cw owgcnwf

kowazoanv ...
```

Warren Weaver (1947)

```
 e    e  e        e
ingcmpnqsnwf cv fpn owoktvcv
        e         e        e
hu ihgzsnwfv rqcffnw cw owgcnwf
       e
kowazoanv ...
```

Warren Weaver (1947)

```
 e    e  e      the
ingcmpnqsnwf cv fpn owoktvcv
        e         e         e
hu ihgzsnwfv rqcffnw cw owgcnwf
       e
kowazoanv ...
```

Warren Weaver (1947)

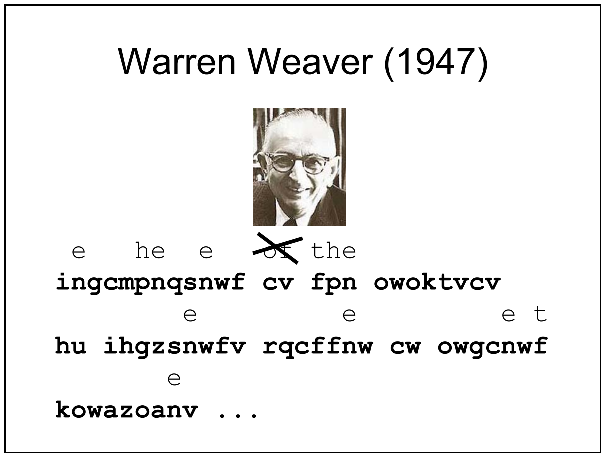
```
 e   he  e      the
ingcmpnqsnwf cv fpn owoktvcv
        e         e         e t
hu ihgzsnwfv rqcffnw cw owgcnwf
       e
kowazoanv ...
```

Warren Weaver (1947)

```
 e   he  e   of the
ingcmpnqsnwf cv fpn owoktvcv
        e         e         e t
hu ihgzsnwfv rqcffnw cw owgcnwf
       e
kowazoanv ...
```

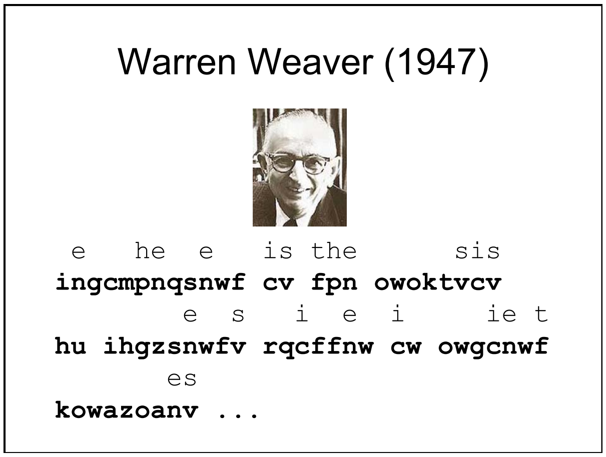
Warren Weaver (1947)

```
 e   he  e   of the      fof
ingcmpnqsnwf cv fpn owoktvcv
        e  f   o  e  o     oe t
hu ihgzsnwfv rqcffnw cw owgcnwf
       ef
kowazoanv ...
```



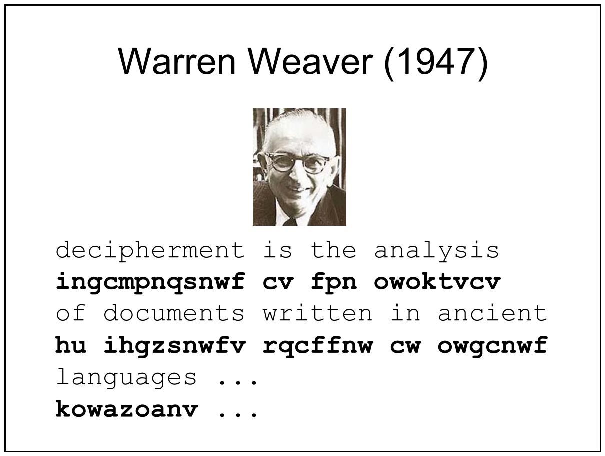
Warren Weaver (1947)

```
 e   he  e   ~~of~~ the
ingcmpnqsnwf cv fpn owoktvcv
        e         e         e t
hu ihgzsnwfv rqcffnw cw owgcnwf
       e
kowazoanv ...
```



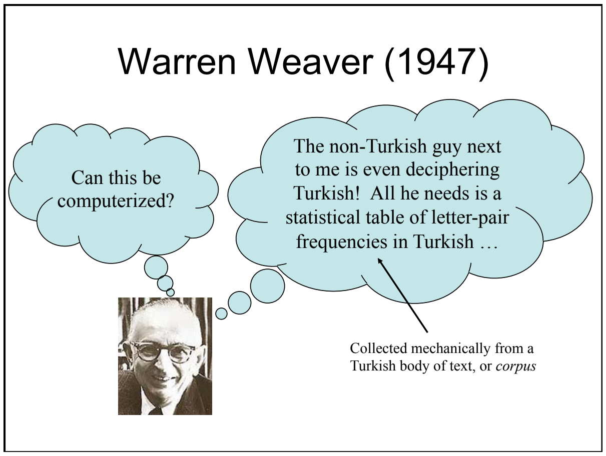
Warren Weaver (1947)

```
 e   he  e   is the      sis
ingcmpnqsnwf cv fpn owoktvcv
        e  s   i  e  i     ie t
hu ihgzsnwfv rqcffnw cw owgcnwf
       es
kowazoanv ...
```



Warren Weaver (1947)

```
decipherment is the analysis
ingcmpnqsnwf cv fpn owoktvcv
of documents written in ancient
hu ihgzsnwfv rqcffnw cw owgcnwf
languages ...
kowazoanv ...
```

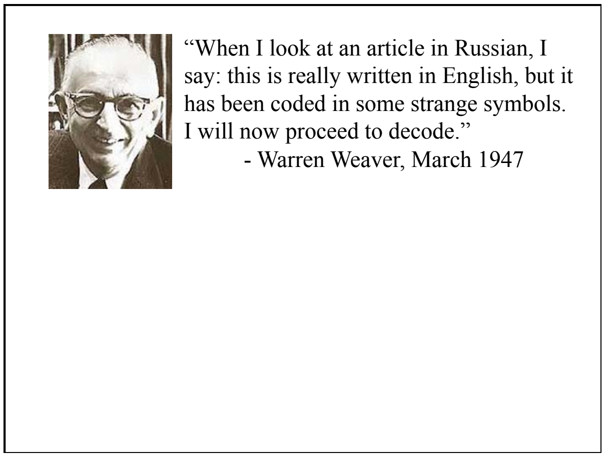


Warren Weaver (1947)

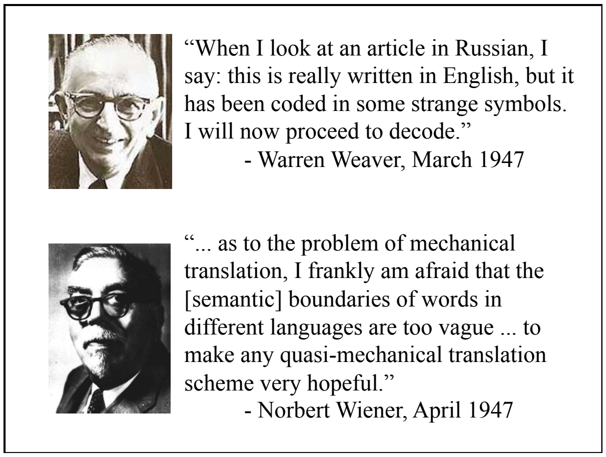
Can this be computerized?

The non-Turkish guy next to me is even deciphering Turkish! All he needs is a statistical table of letter-pair frequencies in Turkish …

Collected mechanically from a Turkish body of text, or *corpus*



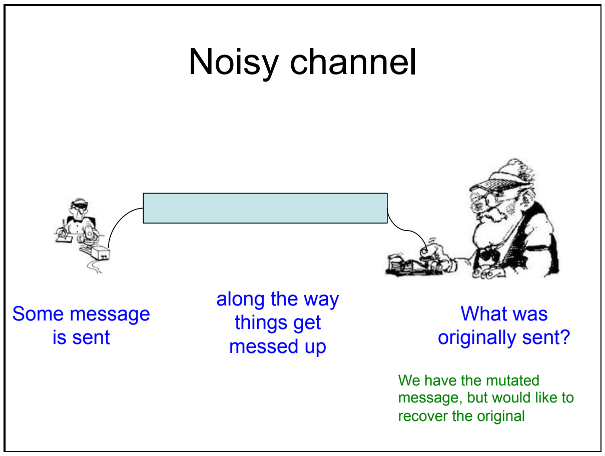
“When I look at an article in Russian, I say: this is really written in English, but it has been coded in some strange symbols. I will now proceed to decode.”
- Warren Weaver, March 1947



“When I look at an article in Russian, I say: this is really written in English, but it has been coded in some strange symbols. I will now proceed to decode.”
- Warren Weaver, March 1947

“... as to the problem of mechanical translation, I frankly am afraid that the [semantic] boundaries of words in different languages are too vague ... to make any quasi-mechanical translation scheme very hopeful.”
- Norbert Wiener, April 1947

Noisy channel



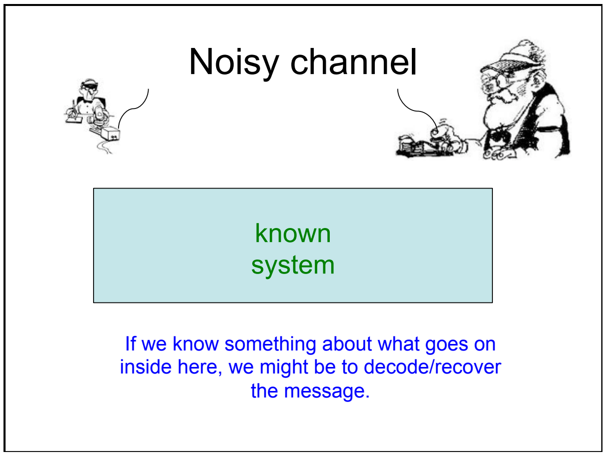
Some message is sent

along the way things get messed up

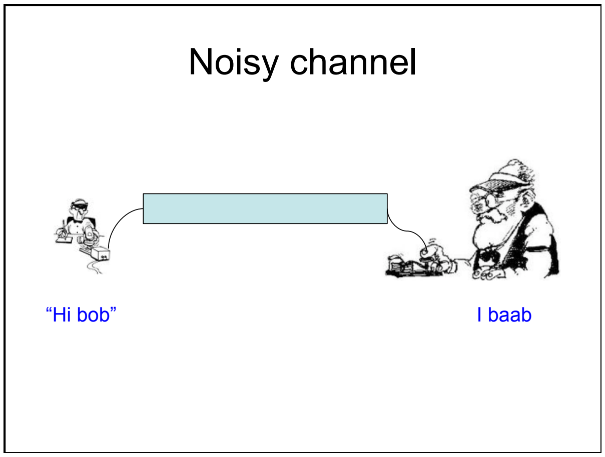
What was originally sent?

We have the mutated message, but would like to recover the original

Noisy channel



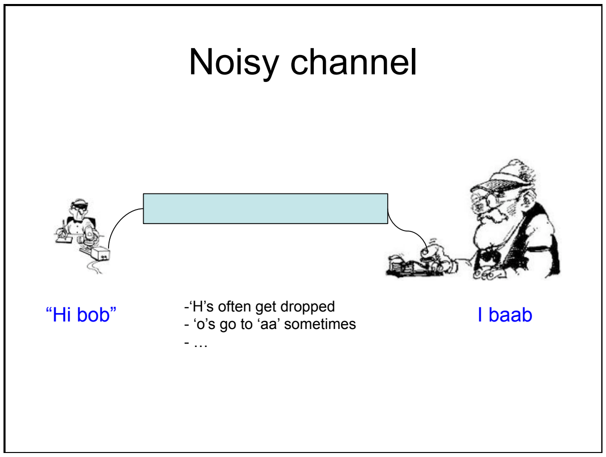
If we know something about what goes on inside here, we might be to decode/recover the message.



Noisy channel

"Hi bob"

I baab

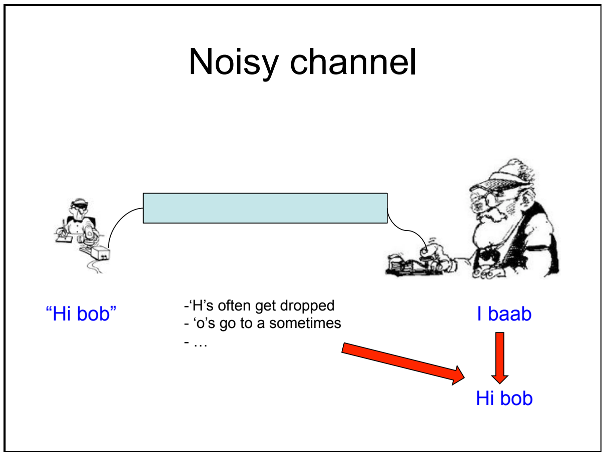


Noisy channel

"Hi bob"

-'H's often get dropped
- 'o's go to 'aa' sometimes
- …

I baab



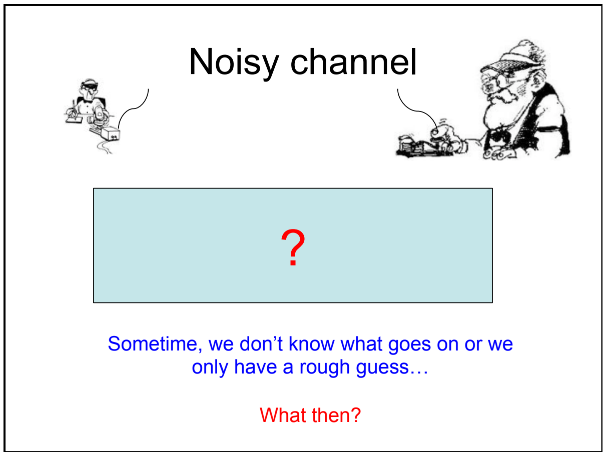
Noisy channel

"Hi bob"

-'H's often get dropped
- 'o's go to a sometimes
- …

I baab

Hi bob

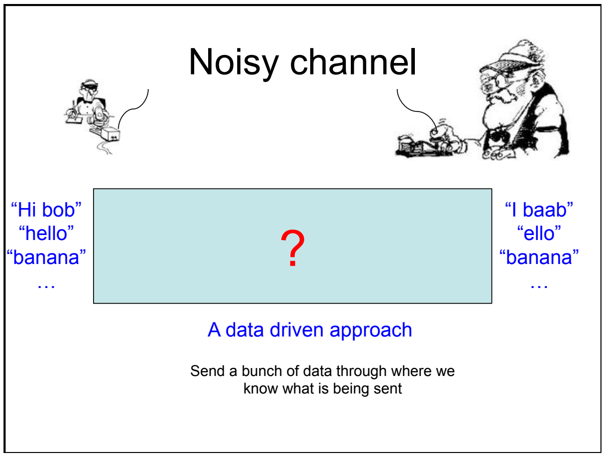


Noisy channel

?

Sometime, we don't know what goes on or we only have a rough guess…

What then?



Noisy channel

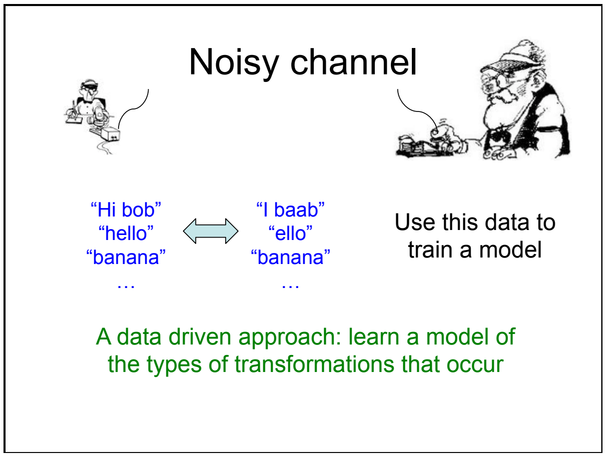
“Hi bob”
“hello”
“banana”
…

?

“I baab”
“ello”
“banana”
…

A data driven approach

Send a bunch of data through where we know what is being sent



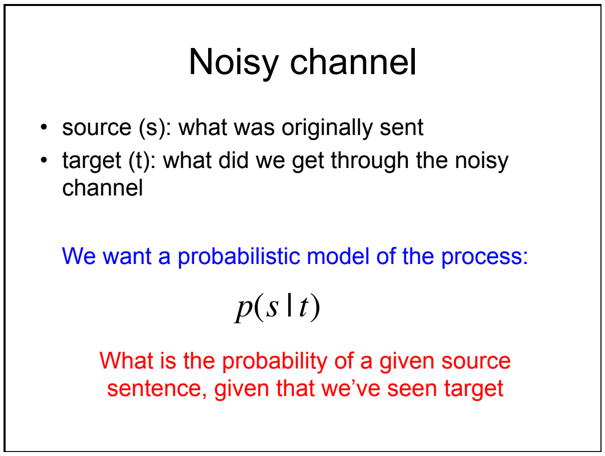
Noisy channel

“Hi bob”
“hello”
“banana”
…

“I baab”
“ello”
“banana”
…

Use this data to train a model

A data driven approach: learn a model of the types of transformations that occur



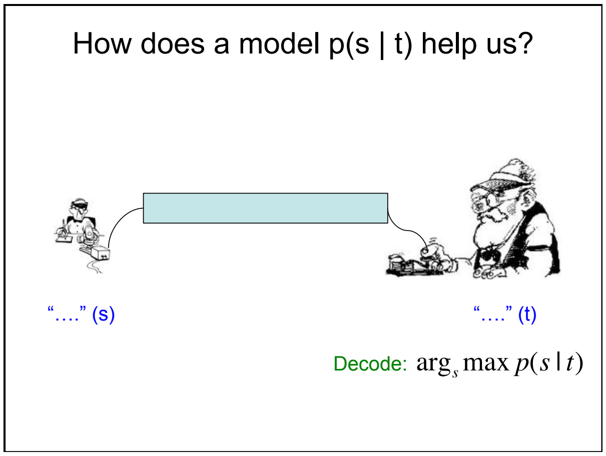
Noisy channel

- source (s): what was originally sent
- target (t): what did we get through the noisy channel

We want a probabilistic model of the process:

$$p(s \mid t)$$

What is the probability of a given source sentence, given that we’ve seen target



How does a model p(s | t) help us?

“….” (s)

“….” (t)

Decode: $\arg_s \max p(s \mid t)$

Noisy channel model

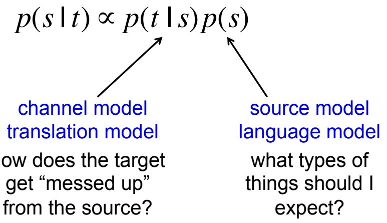
$$p(s \mid t) = \frac{p(t \mid s)\,p(s)}{p(t)}$$

Bayes' rule

$p(t)$	how likely is it to receive the target message
$p(s)$	What types of messages are likely to be sent? What do sent messages look like?
$p(t \mid s)$	What types of transformation happen? How likely are we to generate t from s?

Noisy channel model

model



$$p(s \mid t) \propto p(t \mid s)\,p(s)$$

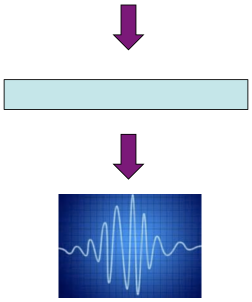
channel model
translation model

how does the target
get "messed up"
from the source?

source model
language model

what types of
things should I
expect?

Applications: Speech recognition



source

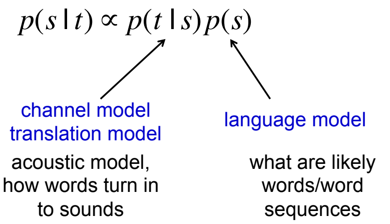
noise

given the target audio, what
were the original words?

target

Applications: Speech recognition

model



$$p(s \mid t) \propto p(t \mid s)\,p(s)$$

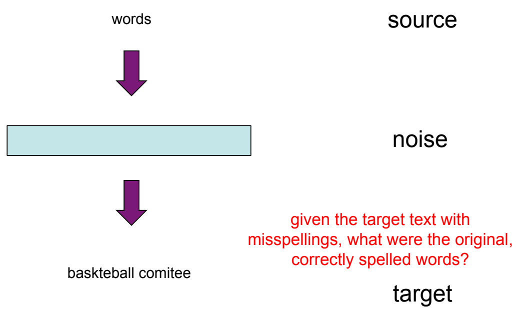
channel model
translation model

acoustic model,
how words turn in
to sounds

language model

what are likely
words/word
sequences

Applications: Spelling correction



words

source

noise

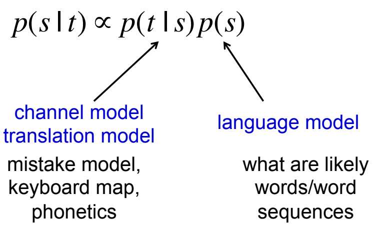
given the target text with misspellings, what were the original, correctly spelled words?

baskteball comitee

target

Applications: Spelling correction

model



$$p(s \mid t) \propto p(t \mid s)\,p(s)$$

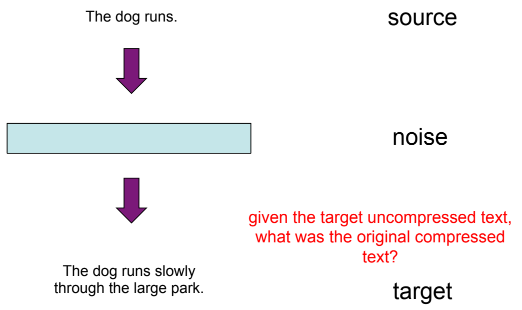
channel model
translation model

mistake model, keyboard map, phonetics

language model

what are likely words/word sequences

Applications: Sentence compression



The dog runs.

source

noise

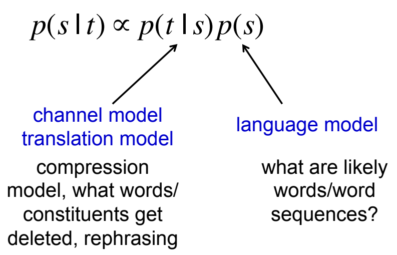
given the target uncompressed text, what was the original compressed text?

The dog runs slowly through the large park.

target

Applications: Sentence compression

model



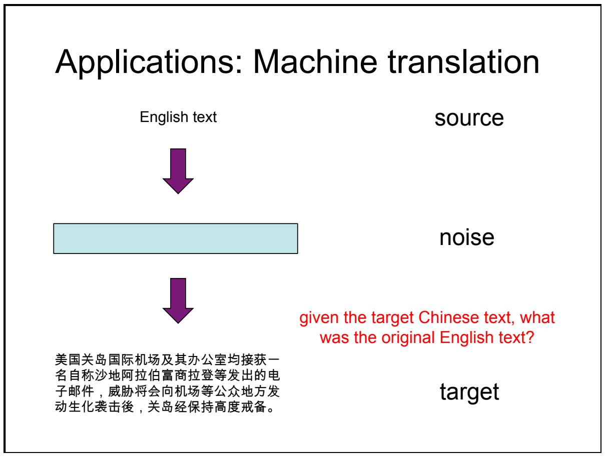
$$p(s \mid t) \propto p(t \mid s)\,p(s)$$

channel model
translation model

compression model, what words/ constituents get deleted, rephrasing

language model

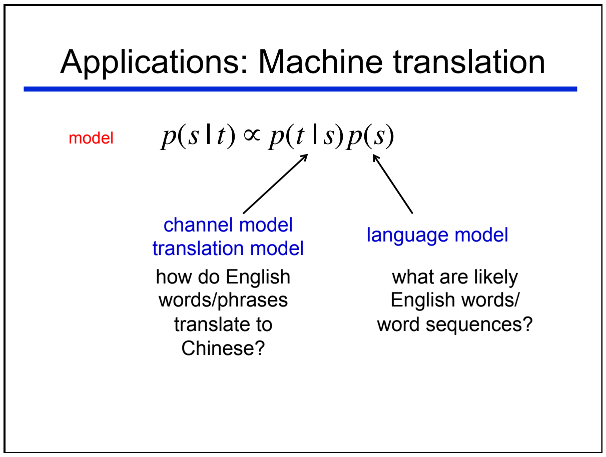
what are likely words/word sequences?



Applications: Machine translation

given the target Chinese text, what was the original English text?

美国关岛国际机场及其办公室均接获一名自称沙地阿拉伯富商拉登等发出的电子邮件，威胁将会向机场等公众地方发动生化袭击後，关岛经保持高度戒备。



Applications: Machine translation

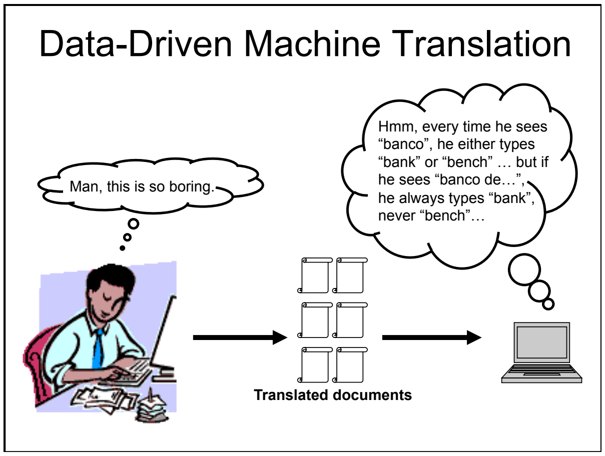
model $p(s \mid t) \propto p(t \mid s)\, p(s)$

channel model
translation model

how do English words/phrases translate to Chinese?

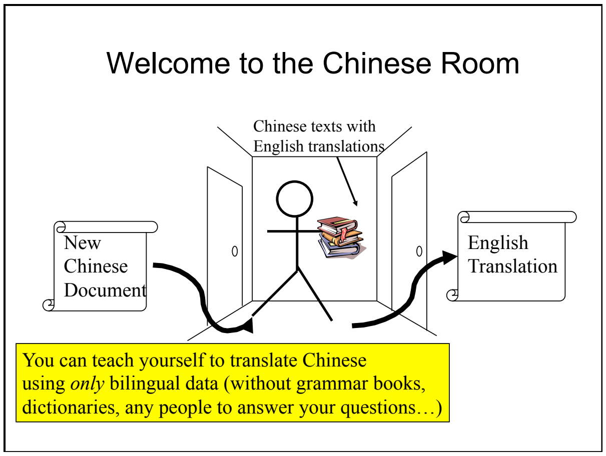
language model

what are likely English words/ word sequences?



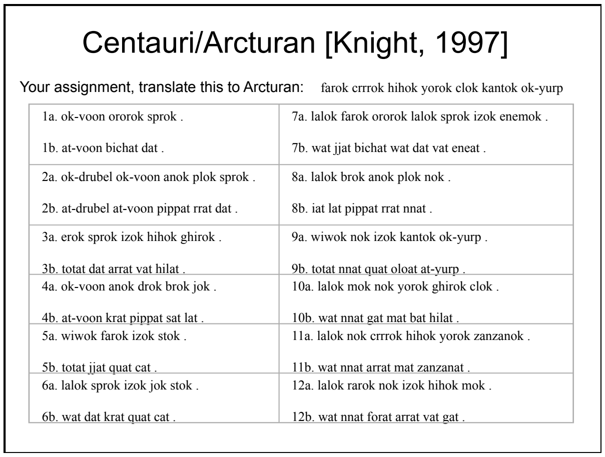
Data-Driven Machine Translation

Man, this is so boring.
Hmm, every time he sees “banco”, he either types “bank” or “bench” … but if he sees “banco de…”, he always types “bank”, never “bench”…
Translated documents



Welcome to the Chinese Room

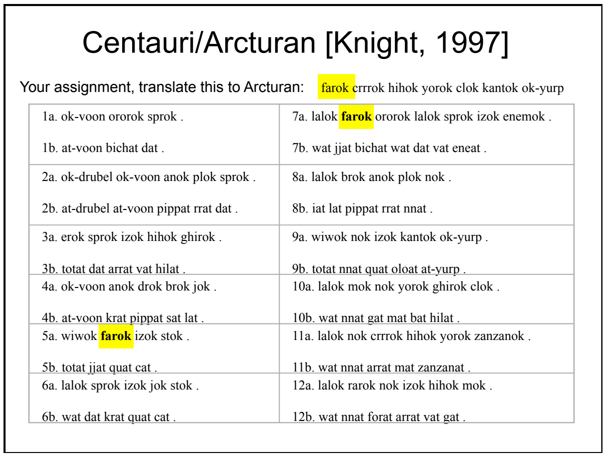
You can teach yourself to translate Chinese using *only* bilingual data (without grammar books, dictionaries, any people to answer your questions…)



Centauri/Arcturan [Knight, 1997]

Your assignment, translate this to Arcturan: farok crrrok hihok yorok clok kantok ok-yurp

1a. ok-voon ororok sprok . 1b. at-voon bichat dat .	7a. lalok farok ororok lalok sprok izok enemok . 7b. wat jjat bichat wat dat vat eneat .
2a. ok-drubel ok-voon anok plok sprok . 2b. at-drubel at-voon pippat rrat dat .	8a. lalok brok anok plok nok . 8b. iat lat pippat rrat nnat .
3a. erok sprok izok hihok ghirok . 3b. totat dat arrat vat hilat .	9a. wiwok nok izok kantok ok-yurp . 9b. totat nnat quat oloat at-yurp .
4a. ok-voon anok drok brok jok . 4b. at-voon krat pippat sat lat .	10a. lalok mok nok yorok ghirok clok . 10b. wat nnat gat mat bat hilat .
5a. wiwok farok izok stok . 5b. totat jjat quat cat .	11a. lalok nok crrrok hihok yorok zanzanok . 11b. wat nnat arrat mat zanzanat .
6a. lalok sprok izok jok stok . 6b. wat dat krat quat cat .	12a. lalok rarok nok izok hihok mok . 12b. wat nnat forat arrat vat gat .



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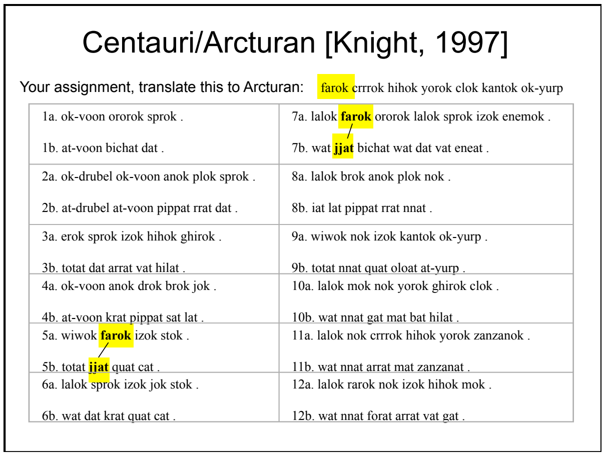
6a. lalok sprok izok jok stok . 6b. wat dat krat quat cat .	12a. lalok rarok nok izok hihok mok . 12b. wat nnat forat arrat vat gat .



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4a. ok-voon anok drok brok jok . 4b. at-voon krat pippat sat lat .	10a. lalok mok nok yorok ghirok clok . 10b. wat nnat gat mat bat hilat .
5a. wiwok **farok** izok stok . 5b. totat **jjat** quat cat .	11a. lalok nok crrrok hihok yorok zanzanok . 11b. wat nnat arrat mat zanzanat .
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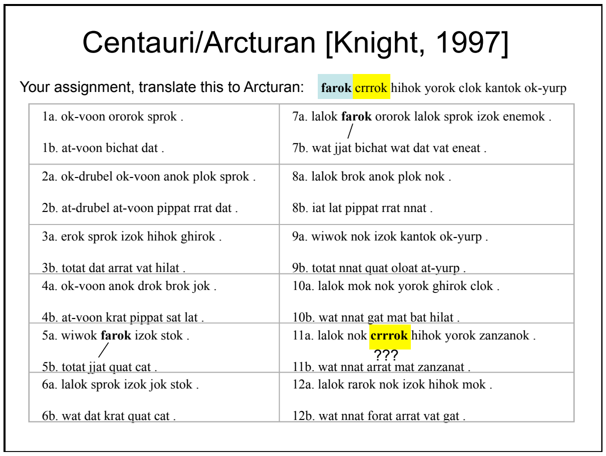

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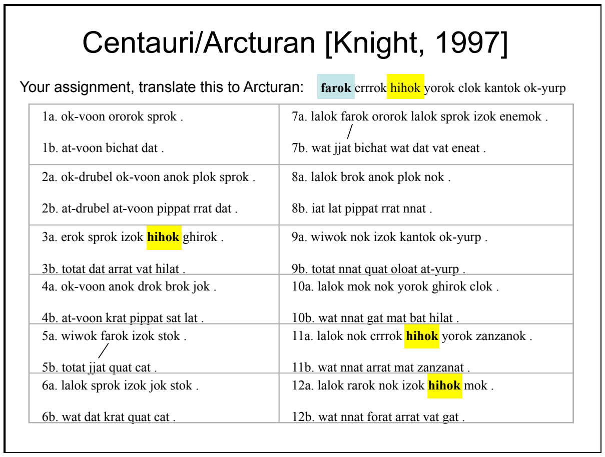
5a. wiwok **farok** izok stok . 5b. totat jjat quat cat .	11a. lalok nok **crrrok** hihok yorok zanzanok . ??? 11b. wat nnat arrat mat zanzanat .
6a. lalok sprok izok jok stok . 6b. wat dat krat quat cat .	12a. lalok rarok nok izok hihok mok . 12b. wat nnat forat arrat vat gat .



Centauri/Arcturan [Knight, 1997]

Your assignment, translate this to Arcturan: **farok** crrrok hihok yorok clok kantok ok-yurp

1a. ok-voon ororok sprok . 1b. at-voon bichat dat .	7a. lalok farok ororok lalok sprok izok enemok . 7b. wat jjat bichat wat dat vat eneat .
2a. ok-drubel ok-voon anok plok sprok . 2b. at-drubel at-voon pippat rrat dat .	8a. lalok brok anok plok nok . 8b. iat lat pippat rrat nnat .
3a. erok sprok izok **hihok** ghirok . 3b. totat dat arrat vat hilat .	9a. wiwok nok izok kantok ok-yurp . 9b. totat nnat quat oloat at-yurp .
4a. ok-voon anok drok brok jok . 4b. at-voon krat pippat sat lat .	10a. lalok mok nok yorok ghirok clok . 10b. wat nnat gat mat bat hilat .
5a. wiwok farok izok stok . 5b. totat jjat quat cat .	11a. lalok nok crrrok **hihok** yorok zanzanok . 11b. wat nnat arrat mat zanzanat .
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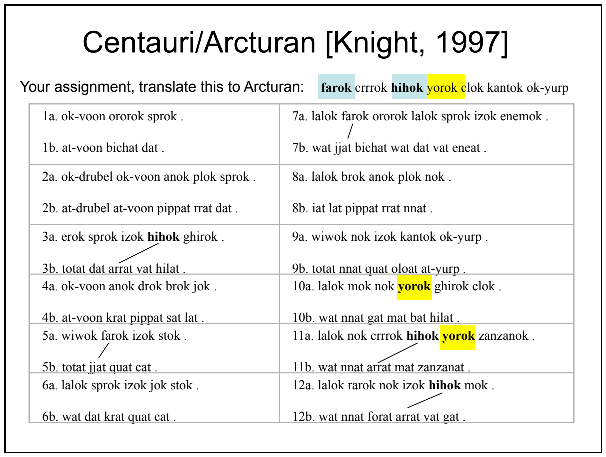

Centauri/Arcturan [Knight, 1997]

Your assignment, translate this to Arcturan: **farok** crrrok **hihok** yorok clok kantok ok-yurp

1a. ok-voon ororok sprok . 1b. at-voon bichat dat .	7a. lalok farok ororok lalok sprok izok enemok . 7b. wat jjat bichat wat dat vat eneat .
2a. ok-drubel ok-voon anok plok sprok . 2b. at-drubel at-voon pippat rrat dat .	8a. lalok brok anok plok nok . 8b. iat lat pippat rrat nnat .
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4a. ok-voon anok drok brok jok . 4b. at-voon krat pippat sat lat .	10a. lalok mok nok **yorok** ghirok clok . 10b. wat nnat gat mat bat hilat .
5a. wiwok farok izok stok . 5b. totat jjat quat cat .	11a. lalok nok crrrok **hihok** **yorok** zanzanok . 11b. wat nnat arrat mat zanzanat .
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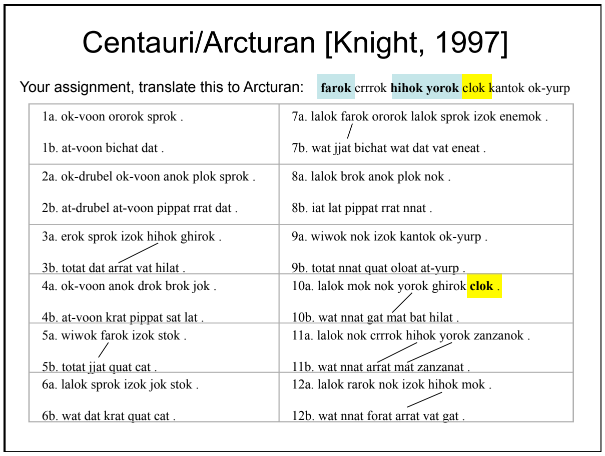

Centauri/Arcturan [Knight, 1997]

Your assignment, translate this to Arcturan: **farok** crrrok **hihok yorok** clok kantok ok-yurp

1a. ok-voon ororok sprok . 1b. at-voon bichat dat .	7a. lalok farok ororok lalok sprok izok enemok . 7b. wat jjat bichat wat dat vat eneat .
2a. ok-drubel ok-voon anok plok sprok . 2b. at-drubel at-voon pippat rrat dat .	8a. lalok brok anok plok nok . 8b. iat lat pippat rrat nnat .
3a. erok sprok izok hihok ghirok . 3b. totat dat arrat vat hilat .	9a. wiwok nok izok kantok ok-yurp . 9b. totat nnat quat oloat at-yurp .
4a. ok-voon anok drok brok jok . 4b. at-voon krat pippat sat lat .	10a. lalok mok nok yorok ghirok **clok** . 10b. wat nnat gat mat bat hilat .
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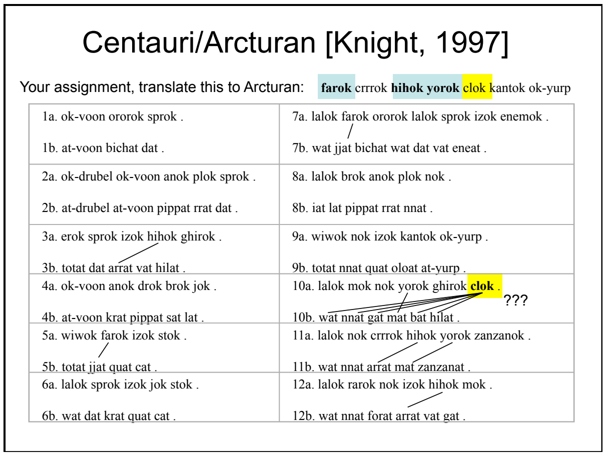

Centauri/Arcturan [Knight, 1997]

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1a. ok-voon ororok sprok . 1b. at-voon bichat dat .	7a. lalok farok ororok lalok sprok izok enemok . 7b. wat jjat bichat wat dat vat eneat .
2a. ok-drubel ok-voon anok plok sprok . 2b. at-drubel at-voon pippat rrat dat .	8a. lalok brok anok plok nok . 8b. iat lat pippat rrat nnat .
3a. erok sprok izok hihok ghirok . 3b. totat dat arrat vat hilat .	9a. wiwok nok izok kantok ok-yurp . 9b. totat nnat quat oloat at-yurp .
4a. ok-voon anok drok brok jok . 4b. at-voon krat pippat sat lat .	10a. lalok mok nok yorok ghirok **clok** . ??? 10b. wat nnat gat mat bat hilat .
5a. wiwok farok izok stok . 5b. totat jjat quat cat .	11a. lalok nok crrrok hihok yorok zanzanok . 11b. wat nnat arrat mat zanzanat .
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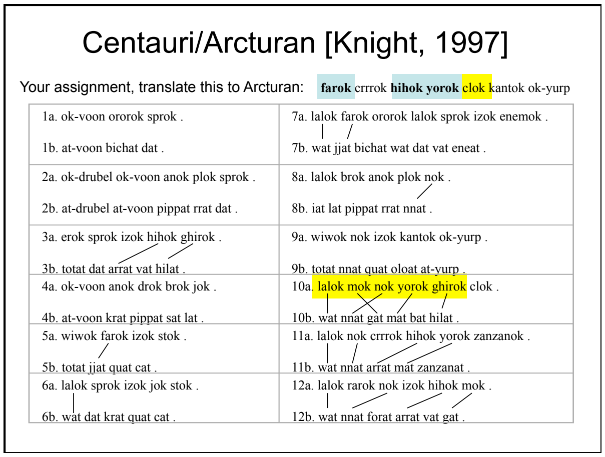

Centauri/Arcturan [Knight, 1997]

Your assignment, translate this to Arcturan: **farok** crrrok **hihok yorok clok** kantok ok-yurp

1a. ok-voon ororok sprok . 1b. at-voon bichat dat .	7a. lalok farok ororok lalok sprok izok enemok . 7b. wat jjat bichat wat dat vat eneat .
2a. ok-drubel ok-voon anok plok sprok . 2b. at-drubel at-voon pippat rrat dat .	8a. lalok brok anok plok nok . 8b. iat lat pippat rrat nnat .
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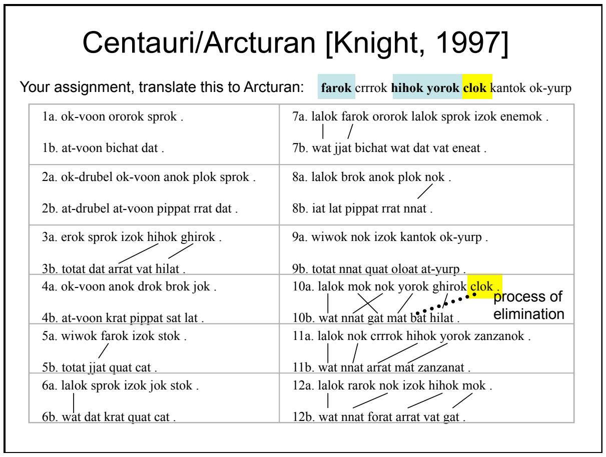

Centauri/Arcturan [Knight, 1997]

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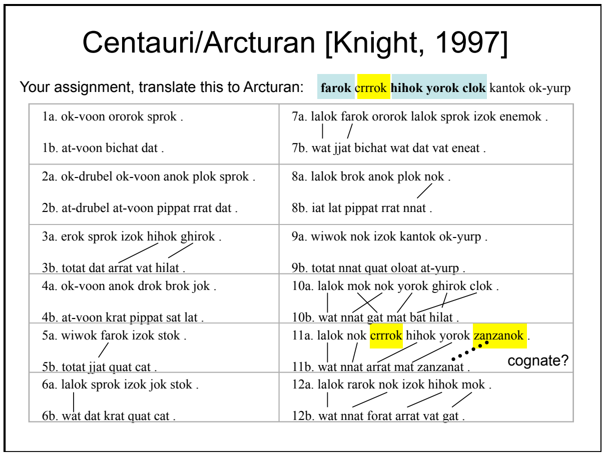
process of elimination



Centauri/Arcturan [Knight, 1997]

Your assignment, translate this to Arcturan: **farok** crrrok **hihok yorok clok** kantok ok-yurp

1a. ok-voon ororok sprok . 1b. at-voon bichat dat .	7a. lalok farok ororok lalok sprok izok enemok . 7b. wat jjat bichat wat dat vat eneat .
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3a. erok sprok izok hihok ghirok . 3b. totat dat arrat vat hilat .	9a. wiwok nok izok kantok ok-yurp . 9b. totat nnat quat oloat at-yurp .
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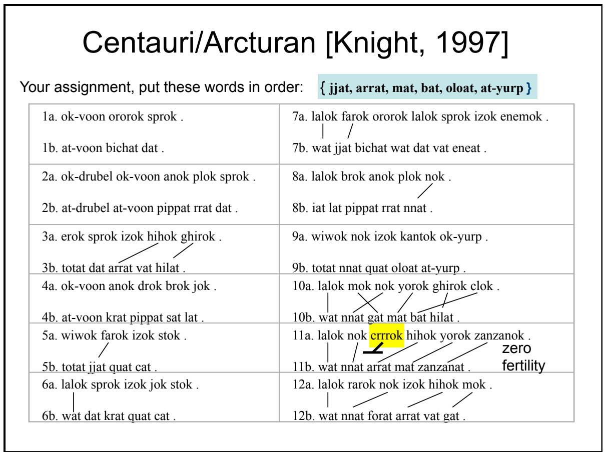
cognate?



Centauri/Arcturan [Knight, 1997]

Your assignment, put these words in order: **{ jjat, arrat, mat, bat, oloat, at-yurp }**

1a. ok-voon ororok sprok . 1b. at-voon bichat dat .	7a. lalok farok ororok lalok sprok izok enemok . 7b. wat jjat bichat wat dat vat eneat .
2a. ok-drubel ok-voon anok plok sprok . 2b. at-drubel at-voon pippat rrat dat .	8a. lalok brok anok plok nok . 8b. iat lat pippat rrat nnat .
3a. erok sprok izok hihok ghirok . 3b. totat dat arrat vat hilat .	9a. wiwok nok izok kantok ok-yurp . 9b. totat nnat quat oloat at-yurp .
4a. ok-voon anok drok brok jok . 4b. at-voon krat pippat sat lat .	10a. lalok mok nok yorok ghirok clok . 10b. wat nnat gat mat bat hilat .
5a. wiwok farok izok stok . 5b. totat jjat quat cat .	11a. lalok nok crrrok hihok yorok zanzanok . 11b. wat nnat arrat mat zanzanat .
6a. lalok sprok izok jok stok . 6b. wat dat krat quat cat .	12a. lalok rarok nok izok hihok mok . 12b. wat nnat forat arrat vat gat .

zero fertility

It’s Really Spanish/English

Clients do not sell pharmaceuticals in Europe => Clientes no venden medicinas en Europa

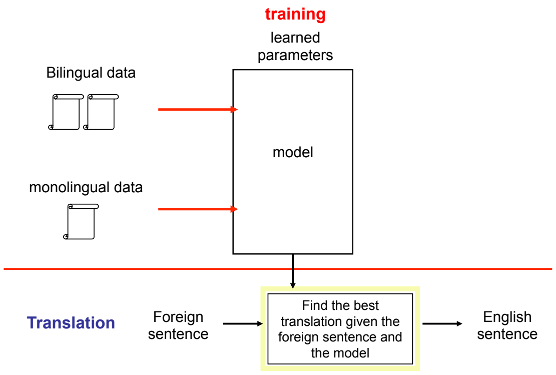
1a. Garcia and associates . 1b. Garcia y asociados .	7a. the clients and the associates are enemies . 7b. los clients y los asociados son enemigos .
2a. Carlos Garcia has three associates . 2b. Carlos Garcia tiene tres asociados .	8a. the company has three groups . 8b. la empresa tiene tres grupos .
3a. his associates are not strong . 3b. sus asociados no son fuertes .	9a. its groups are in Europe . 9b. sus grupos estan en Europa .
4a. Garcia has a company also . 4b. Garcia tambien tiene una empresa .	10a. the modern groups sell strong pharmaceuticals . 10b. los grupos modernos venden medicinas fuertes .
5a. its clients are angry . 5b. sus clientes estan enfadados .	11a. the groups do not sell zenzanine . 11b. los grupos no venden zanzanina .
6a. the associates are also angry . 6b. los asociados tambien estan enfadados .	12a. the small groups are not modern . 12b. los grupos pequenos no son modernos .

УБЕДИТЕЛЬНАЯ ПРОСЬБА
полотенца из номера не выносить
not to take the towels out of the room
EARNEST REQUEST

Data available

- Many languages
  - Europarl corpus has all European languages
    - http://www.statmt.org/europarl/
    - From a few hundred thousand sentences to a few million
  - French/English from French parliamentary proceedings
  - Lots of Chinese/English and Arabic/English from government projects/interests
    - Chinese-English: 440 million words (15-20 million sentence pairs)
    - Arabic-English: 790 million words (30-40 million sentence pairs)
  - Smaller corpora in many, many other languages
- Lots of monolingual data available in many languages
- Even less data with multiple translations available
- Available in limited domains
  - most data is either news or government proceedings
  - some other domains recently, like blogs

Statistical MT Overview


training

learned parameters

Bilingual data

monolingual data

model

Translation

Foreign sentence

Find the best translation given the foreign sentence and the model

English sentence

Statistical MT

- We will model the translation process probabilistically
- Given a foreign sentence to translate, for any possible English sentence, we want to know the probability that sentence is a translation of the foreign sentence
- If we can find the most probable English sentence, we're done

p(english sentence | foreign sentence)

Noisy channel model

model $p(e \mid f) \propto p(f \mid e)\, p(e)$

translation model

how do foreign sentences get translated to English sentences?

language model

what do English sentences look like?

Translation model

- The models define probabilities over inputs

$$p(f \mid e)$$

Morgen fliege ich nach Kanada zur Konferenz

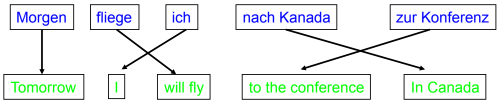
Tomorrow I will fly to the conference in Canada

What is the probability that the English sentence is a translation of the foreign sentence?

Translation model

- The models define probabilities over inputs

$$p(f \mid e)$$



- What is the probability of a foreign word being translated as a particular English word?
- What is the probability of a foreign foreign phrase being translated as a particular English phrase?
- What is the probability of a word/phrase changing ordering?
- What is the probability of a foreign word/phrase disappearing?
- What is the probability of a English word/phrase appearing?

Translation model

- The models define probabilities over inputs

$$p(f \mid e)$$

p(Morgen fliege ich nach Kanada zur Konferenz |
Tomorrow I will fly to the conference in Canada) = 0.1

p(Morgen fliege ich nach Kanada zur Konferenz |
I like peanut butter and jelly) = 0.0001

Language model

- The models define probabilities over inputs

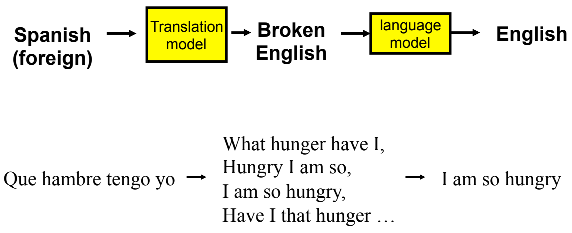
$$p(e)$$

Tomorrow I will fly to the conference in Canada

What is a probability distribution?

- A probability distribution defines the probability over a space of possible inputs
- For the language model, what is the space of possible inputs?
  - A language model describes the probability over ALL possible combinations of English words
- For the translation model, what is the space of possible inputs?
  - ALL possible combinations of foreign words with ALL possible combinations of English words

One way to think about it…



Spanish (foreign) → Translation model → **Broken English** → language model → **English**

Que hambre tengo yo → What hunger have I, Hungry I am so, I am so hungry, Have I that hunger … → I am so hungry

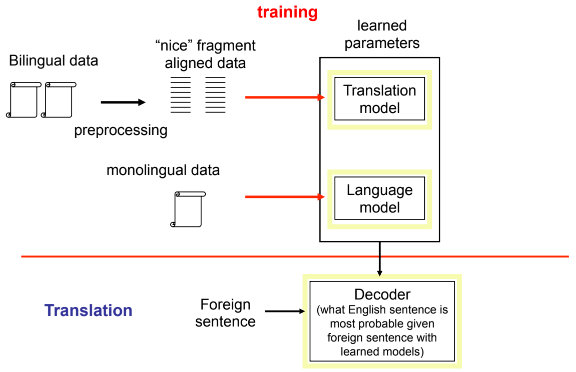
Translation

$$p(e \mid f) \propto p(f \mid e)p(e)$$

- Let's assume we have a translation model and a language model
- Given a foreign sentence, what question do we want to ask to translate that sentence into English?

$$\arg_e \max p(e \mid f) \propto p(f \mid e)p(e)$$

Statistical MT Overview



Problems for Statistical MT

- Preprocessing
  - How do we get aligned bilingual text?
  - Tokenization
  - Segmentation (document, sentence, word)
- Language modeling
  - Given an English string e, assigns P(e) by formula
- Translation modeling
  - Given a pair of strings <f,e>, assigns P(f | e) by formula
- Decoding
  - Given a language model, a translation model, and a new sentence f … find translation e maximizing P(e) * P(f | e)
- Parameter optimization
  - Given a model with multiple feature functions, how are they related? What are the optimal paraeters?
- Evaluation
  - How well is a system doing? How can we compare two systems?

Problems for Statistical MT

- Preprocessing
- Language modeling
- Translation modeling
- Decoding
- Parameter optimization
- Evaluation

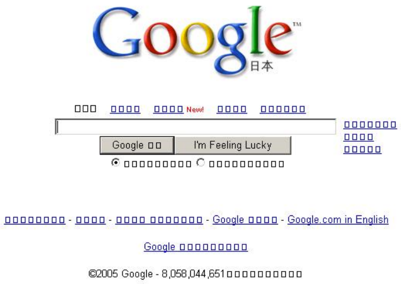
Data

We want pairs of aligned sentences/text fragments. How do we get them?

From No Data to Sentence Pairs

- Easy way 1: Linguistic Data Consortium (LDC)
- Easy way 2: pay $$$
  - Suppose one billion words of parallel data were sufficient
  - At 20 cents/word, that's $200 million
- Hard way: Find it, and then earn it!
  - De-formatting
  - Remove strange characters
  - Character code conversion
  - **Document alignment**
  - **Sentence alignment**
  - **Tokenization (also called Segmentation)**

If you don't get the characters right…



□□□ □□□□ □□□□ New! □□□□ □□□□□□

Google □□ | I'm Feeling Lucky

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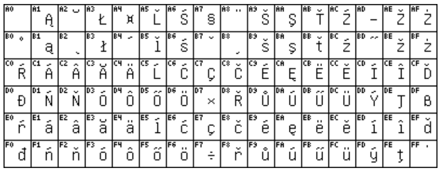
©2005 Google - 8,058,044,651□□□□□□□□□□

http://en.wikipedia.org/wiki/ISO/IEC_8859

ISO-8859-2 (Latin2)



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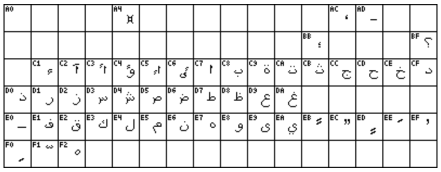
B0 °	B1 ą	B2 ˛	B3 ł	B4 ´	B5 ľ	B6 ś	B7 ˇ	B8 ¸	B9 š	BA ş	BB ť	BC ź	BD ˝	BE ž	BF ż
C0 Ŕ	C1 Á	C2 Â	C3 Ă	C4 Ä	C5 Ĺ	C6 Ć	C7 Ç	C8 Č	C9 É	CA Ę	CB Ë	CC Ě	CD Í	CE Î	CF Ď
D0 Đ	D1 Ń	D2 Ň	D3 Ó	D4 Ô	D5 Ő	D6 Ö	D7 ×	D8 Ř	D9 Ů	DA Ú	DB Ű	DC Ü	DD Ý	DE Ţ	DF ß
E0 ŕ	E1 á	E2 â	E3 ă	E4 ä	E5 ĺ	E6 ć	E7 ç	E8 č	E9 é	EA ę	EB ë	EC ě	ED í	EE î	EF ď
F0 đ	F1 ń	F2 ň	F3 ó	F4 ô	F5 ő	F6 ö	F7 ÷	F8 ř	F9 ů	FA ú	FB ű	FC ü	FD ý	FE ţ	FF ˙

ISO-8859-6 (Arabic)



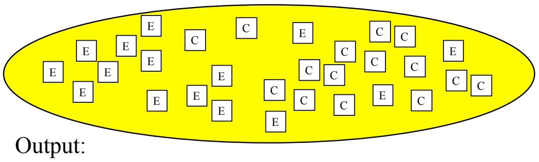
A0				A4 ¤								AC ،	AD -		
											BB ؛				BF ؟
	C1 ء	C2 آ	C3 أ	C4 ؤ	C5 إ	C6 ئ	C7 ا	C8 ب	C9 ة	CA ت	CB ث	CC ج	CD ح	CE خ	CF د
D0 ذ	D1 ر	D2 ز	D3 س	D4 ش	D5 ص	D6 ض	D7 ط	D8 ظ	D9 ع	DA غ					
E0 ـ	E1 ف	E2 ق	E3 ك	E4 ل	E5 م	E6 ن	E7 ه	E8 و	E9 ى	EA ي	EB ً	EC ٌ	ED ٍ	EE َ	EF ُ
F0 ِ	F1 ّ	F2 ْ													

Chinese?

- **GB Code**
- **GBK Code**
- **Big 5 Code**
- **CNS-11643-1992**
- …

Document Alignment

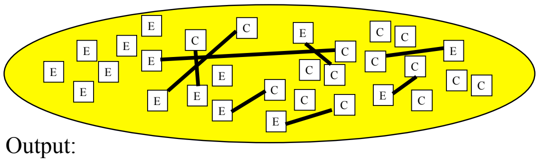
- Input:
  - Big bag of files obtained from somewhere, believed to contain pairs of files that are translations of each other.



- Output:
  - List of pairs of files that are actually translations.

Document Alignment

- Input:
  - Big bag of files obtained from somewhere, believed to contain pairs of files that are translations of each other.



- Output:
  - List of pairs of files that are actually translations.

Sentence Alignment

The old man is happy. He has fished many times. His wife talks to him. The fish are jumping. The sharks await.

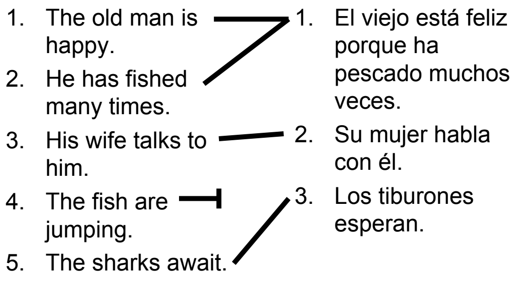
El viejo está feliz porque ha pescado muchos veces. Su mujer habla con él. Los tiburones esperan.

Sentence Alignment

1. The old man is happy.
2. He has fished many times.
3. His wife talks to him.
4. The fish are jumping.
5. The sharks await.

1. El viejo está feliz porque ha pescado muchos veces.
2. Su mujer habla con él.
3. Los tiburones esperan.

Sentence Alignment



1. The old man is happy.
2. He has fished many times.
3. His wife talks to him.
4. The fish are jumping.
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1. El viejo está feliz porque ha pescado muchos veces.
2. Su mujer habla con él.
3. Los tiburones esperan.

Sentence Alignment

1. The old man is happy. He has fished many times.	—	1. El viejo está feliz porque ha pescado muchos veces.
2. His wife talks to him.	—	2. Su mujer habla con él.
3. The sharks await.	—	3. Los tiburones esperan.

Note that unaligned sentences are thrown out, and sentences are merged in n-to-m alignments (n, m > 0).

Tokenization (or Segmentation)

- English
  - – Input (some byte stream):

```
"There," said Bob.
```

  - – Output (7 “tokens” or “words”):

```
" There , " said Bob .
```

- Chinese
  - – Input (byte stream): 美国关岛国际机场及其办公室均接获一名自称沙地阿拉伯富商拉登等发出的电子邮件。
  - – Output: 美国 关岛国 际机 场 及其 办公 室 均接获 一名 自称 沙地 阿拉 伯富 商拉登 等发 出 的 电子邮件。

Problems for Statistical MT

- Preprocessing
- Language modeling
- Translation modeling
- Decoding
- Parameter optimization
- Evaluation

Language Modeling

- Most common: n-gram language models
- More data the better (Google n-grams)
- Domain is important

DON'T
DROPPINGS!
Who owns this PET?
You must teachs your dog manners.
Then we are dog lovers each other.
thank you.

Problems for Statistical MT

- Preprocessing
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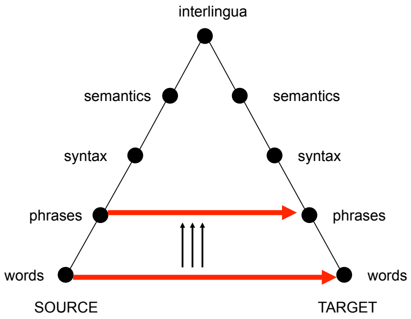
MT Pyramid



Translation Model

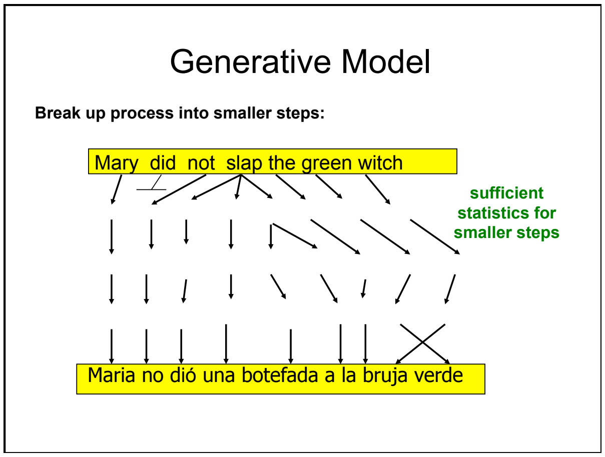
Learn How to Translate from Data

Direct Estimation:

Mary did not slap the green witch

not enough data for this
(most input sentences unseen)

Maria no dió una botefada a la bruja verde



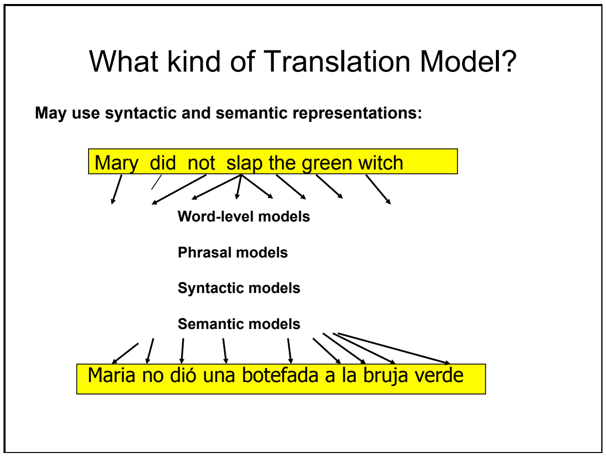
Generative Model

Break up process into smaller steps:

Mary did not slap the green witch

sufficient statistics for smaller steps

Maria no dió una botefada a la bruja verde



What kind of Translation Model?

May use syntactic and semantic representations:

Mary did not slap the green witch

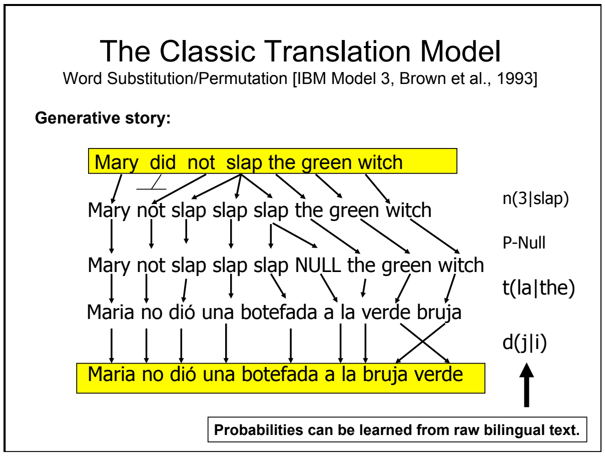
Word-level models

Phrasal models

Syntactic models

Semantic models

Maria no dió una botefada a la bruja verde



The Classic Translation Model

Word Substitution/Permutation [IBM Model 3, Brown et al., 1993]

Generative story:

Mary did not slap the green witch

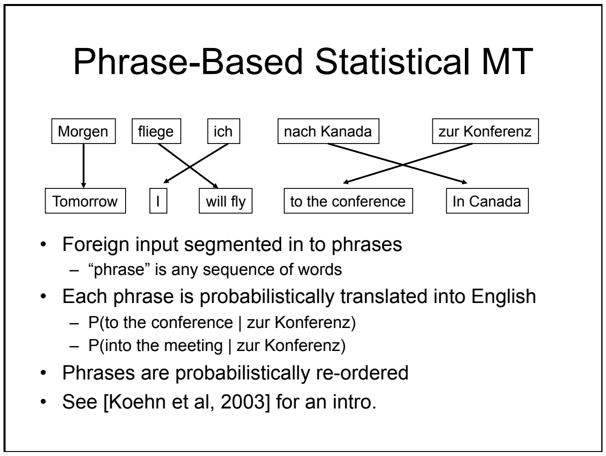
Mary not slap slap slap the green witch — n(3|slap)

Mary not slap slap slap NULL the green witch — P-Null

Maria no dió una botefada a la verde bruja — t(la|the)

Maria no dió una botefada a la bruja verde — d(j|i)

Probabilities can be learned from raw bilingual text.



Phrase-Based Statistical MT

Morgen | fliege | ich | nach Kanada | zur Konferenz

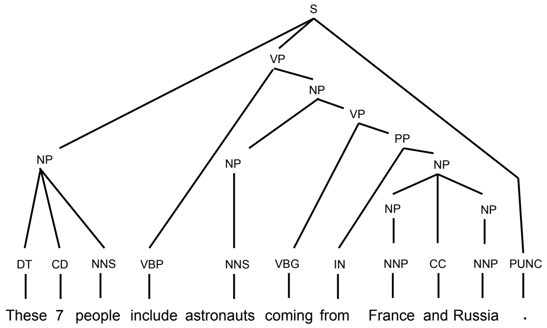
Tomorrow | I | will fly | to the conference | In Canada

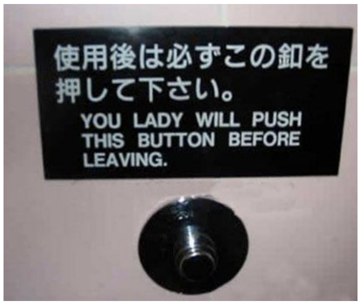
- Foreign input segmented in to phrases
  - “phrase” is any sequence of words
- Each phrase is probabilistically translated into English
  - P(to the conference | zur Konferenz)
  - P(into the meeting | zur Konferenz)
- Phrases are probabilistically re-ordered
- See [Koehn et al, 2003] for an intro.

Advantages of Phrase-Based

- Many-to-many mappings can handle non-compositional phrases
- Easy to understand
- Local context is very useful for disambiguating
  - “Interest rate” → …
  - “Interest in” → …
- The more data, the longer the learned phrases
  - Sometimes whole sentences

Syntax


S
VP
NP
VP
PP
NP
NP
NP
NP
NP
DT CD NNS VBP NNS VBG IN NNP CC NNP PUNC
These 7 people include astronauts coming from France and Russia .


使用後は必ずこの釦を押して下さい。
YOU LADY WILL PUSH THIS BUTTON BEFORE LEAVING.

Problems for Statistical MT

- Preprocessing
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- Decoding
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Decoding

- Of all conceivable English word strings, find the one maximizing P(e) x P(f | e)
- Decoding is an NP-complete problem (for many translation models
  - (Knight, 1999)
- Several decoding strategies are often available

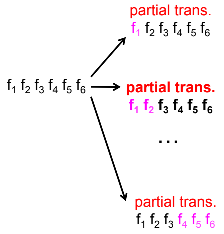
Search

$\arg_e \max p(f \mid e) p(e)$

$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$

Search

$\arg_e \max p(f \mid e) p(e)$



$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$

partial trans.
$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$

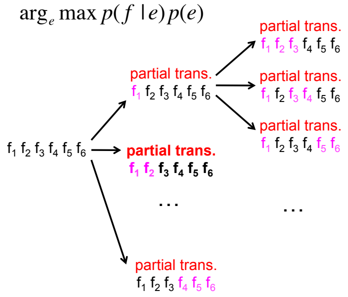
partial trans.
$\mathbf{f_1\ f_2\ f_3\ f_4\ f_5\ f_6}$

…

partial trans.
$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$

Search

$\arg_e \max p(f \mid e) p(e)$



$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$

partial trans.
$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$

partial trans.
$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$

partial trans.
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partial trans.
$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$

partial trans.
$\mathbf{f_1\ f_2\ f_3\ f_4\ f_5\ f_6}$

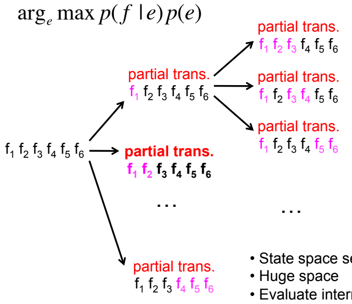
…

…

partial trans.
$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$

Search

$\arg_e \max p(f \mid e) p(e)$


$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$
partial trans.
$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$
partial trans.
$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$
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partial trans.
$\mathbf{f_1\ f_2\ f_3\ f_4\ f_5\ f_6}$
…
…
partial trans.
$f_1\ f_2\ f_3\ f_4\ f_5\ f_6$

- State space search problem
- Huge space
- Evaluate intermediate hypotheses using model and prune partial hypotheses

Problems for Statistical MT

- Preprocessing
- Language modeling
- Translation modeling
- Decoding
- Parameter optimization
- Evaluation

Basic Model, Revisited

$\underset{e}{\text{argmax}}\ P(e \mid f) =$

$\underset{e}{\text{argmax}}\ P(e) \times P(f \mid e) / P(f) =$

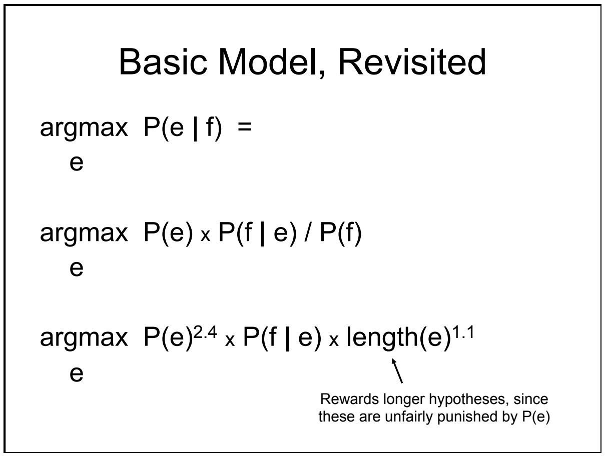
$\underset{e}{\text{argmax}}\ P(e) \times P(f \mid e)$

Basic Model, Revisited

$\underset{e}{\text{argmax}}\ P(e \mid f) =$

$\underset{e}{\text{argmax}}\ P(e) \times P(f \mid e) / P(f) =$

$\underset{e}{\text{argmax}}\ P(e)^{2.4} \times P(f \mid e)$ … works better!



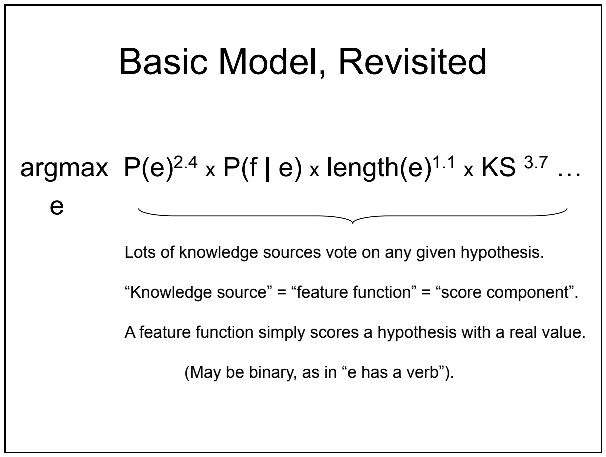
Basic Model, Revisited

$$\underset{e}{\text{argmax}}\ P(e \mid f) =$$

$$\underset{e}{\text{argmax}}\ P(e) \times P(f \mid e) / P(f)$$

$$\underset{e}{\text{argmax}}\ P(e)^{2.4} \times P(f \mid e) \times \text{length}(e)^{1.1}$$

Rewards longer hypotheses, since these are unfairly punished by P(e)



Basic Model, Revisited

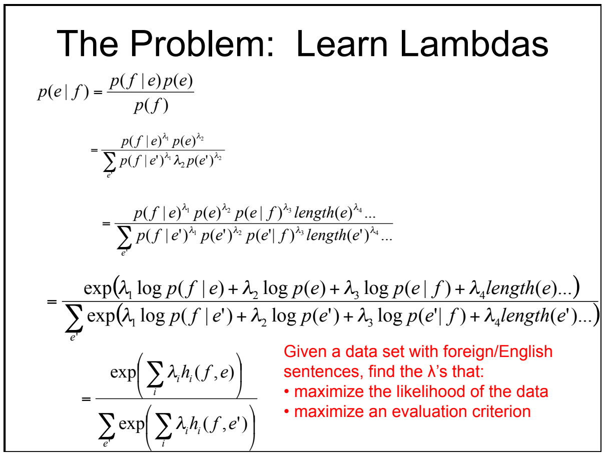
$$\underset{e}{\text{argmax}}\ \underbrace{P(e)^{2.4} \times P(f \mid e) \times \text{length}(e)^{1.1} \times KS^{3.7} \ldots}$$

Lots of knowledge sources vote on any given hypothesis.

“Knowledge source” = “feature function” = “score component”.

A feature function simply scores a hypothesis with a real value.

(May be binary, as in “e has a verb”).



The Problem: Learn Lambdas

$$p(e \mid f) = \frac{p(f \mid e)\, p(e)}{p(f)}$$

$$= \frac{p(f \mid e)^{\lambda_1}\, p(e)^{\lambda_2}}{\sum_{e'} p(f \mid e')^{\lambda_1}\, \lambda_2 p(e')^{\lambda_2}}$$

$$= \frac{p(f \mid e)^{\lambda_1}\, p(e)^{\lambda_2}\, p(e \mid f)^{\lambda_3}\, length(e)^{\lambda_4} \ldots}{\sum_{e'} p(f \mid e')^{\lambda_1}\, p(e')^{\lambda_2}\, p(e' \mid f)^{\lambda_3}\, length(e')^{\lambda_4} \ldots}$$

$$= \frac{\exp\left(\lambda_1 \log p(f \mid e) + \lambda_2 \log p(e) + \lambda_3 \log p(e \mid f) + \lambda_4 length(e) \ldots\right)}{\sum_{e'} \exp\left(\lambda_1 \log p(f \mid e') + \lambda_2 \log p(e') + \lambda_3 \log p(e' \mid f) + \lambda_4 length(e') \ldots\right)}$$

$$= \frac{\exp\left(\sum_i \lambda_i h_i(f, e)\right)}{\sum_{e'} \exp\left(\sum_i \lambda_i h_i(f, e')\right)}$$

Given a data set with foreign/English sentences, find the λ’s that:

- maximize the likelihood of the data
- maximize an evaluation criterion