Inferring phylogenetic graphs of Natural Languages using Minimum Message Length

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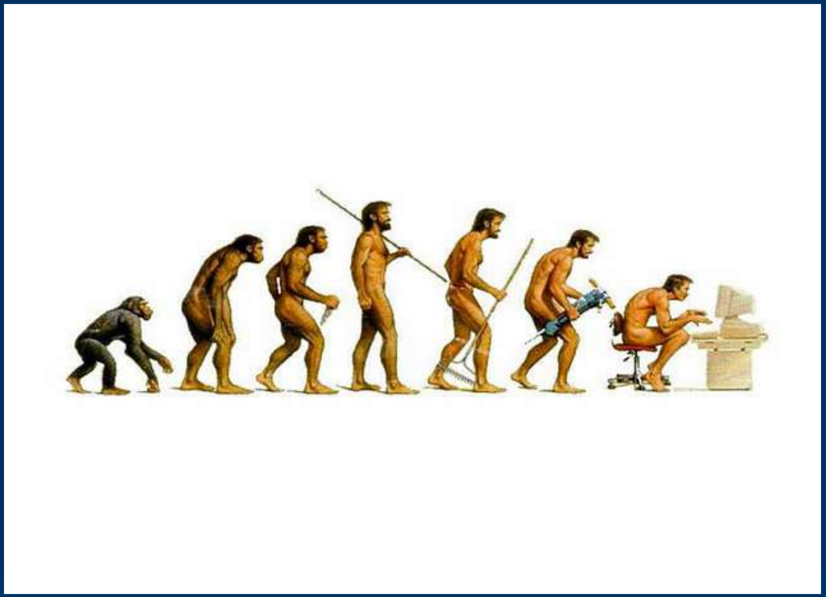
Motivation

- To study how languages have evolved (Phylogeny of languages).
  - e.g. Artificial languages,
  - European languages.
- To refine natural language compression method.

Evolution of languages

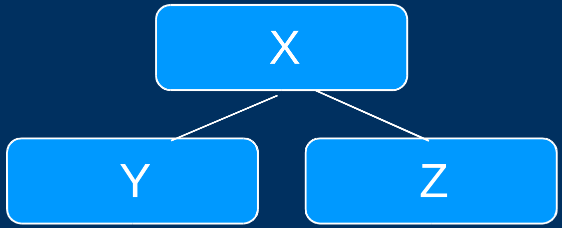
- What is phylogeny?
  - Phylogeny means Evolution



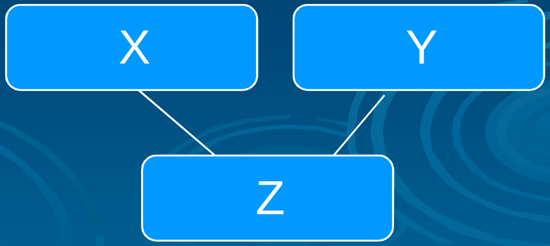
- What is a phylogenetic model?
  - A **phylogenetic tree/graph** is a tree/graph showing the evolutionary interrelationships among various species or other entities that are believed to have a common ancestor.

Difference between a phylogenetic tree and a phylogenetic graph

- Phylogenetic trees
  - Each child node has exactly one parent node.



- Phylogenetic graphs (new concept)
  - Each child node can descend from one or more parent node(s).



Evolution of languages

- 3 types of evolution
  - Evolution of phonology/pronunciation

Words	US	UK
schedule	skedule	shedule
leisure	leezhure	lezhure

  - Evolution of written script/spelling

English	Malay
Mobile	Mobil
Television	Televisyen

  - Evolution of grammatical structures

Minimum Message Length (MML)

- What is MML?
  - A measure of goodness of classification based on information theory (Wallace and Boulton, 1968; Wallace and Dowe, 1999a; Wallace, 2005).
- Data can be described using “models”
- MML methods favour the “best” description of data where
  - “best” = shortest overall two-part message length
- Two part message
  - Msglength = Msglength(model) + msglength(data|model)

Minimum Message Length (MML)

- Degree of similarity between languages can be measured by compressing them in terms of one another.
- Example :
  - Language A Language B
    - 3 possibilities –
      - Unrelated – shortest message length when compressed separately.
      - A descended from B – shortest message length when B compressed and then A compressed in terms of B.
      - B descended from A – shortest message length when A compressed and then B compressed in terms of A.

Minimum Message Length (MML)

The best phylogenetic model is the tree/graph that achieves the shortest overall two-part message length.

Modelling mutation between words

- Root language
  - Equal frequencies for all characters.
    - Log(size of alphabet) * no. of chars.
  - Some characters occur more frequently than others.
    - e.g.: English “x” compared with “a”.
    - Multi-state (multinomial) distribution of characters.

Modelling mutation between words

- Child languages
  - Muti-state distribution
    - 4 states.
      - Insert
      - Delete
      - Copy
      - Change
  - Use string alignment techniques to find the best alignment between words.
  - Dynamic Programming Algorithm to find alignment between strings.
  - MML favors the alignment between words that produces the shortest overall message length.

Example:

r e c o m m a n d e r

| | | | | | | | | | |

r e c o m m e n d - -

Work to date

- Preliminary model
  - Only copy and change mutations
  - Words of the same length
  - artificial and some European languages.
- Expanded model
  - Copy, change, insert and delete mutations
  - Words of different length
  - artificial and some European languages.

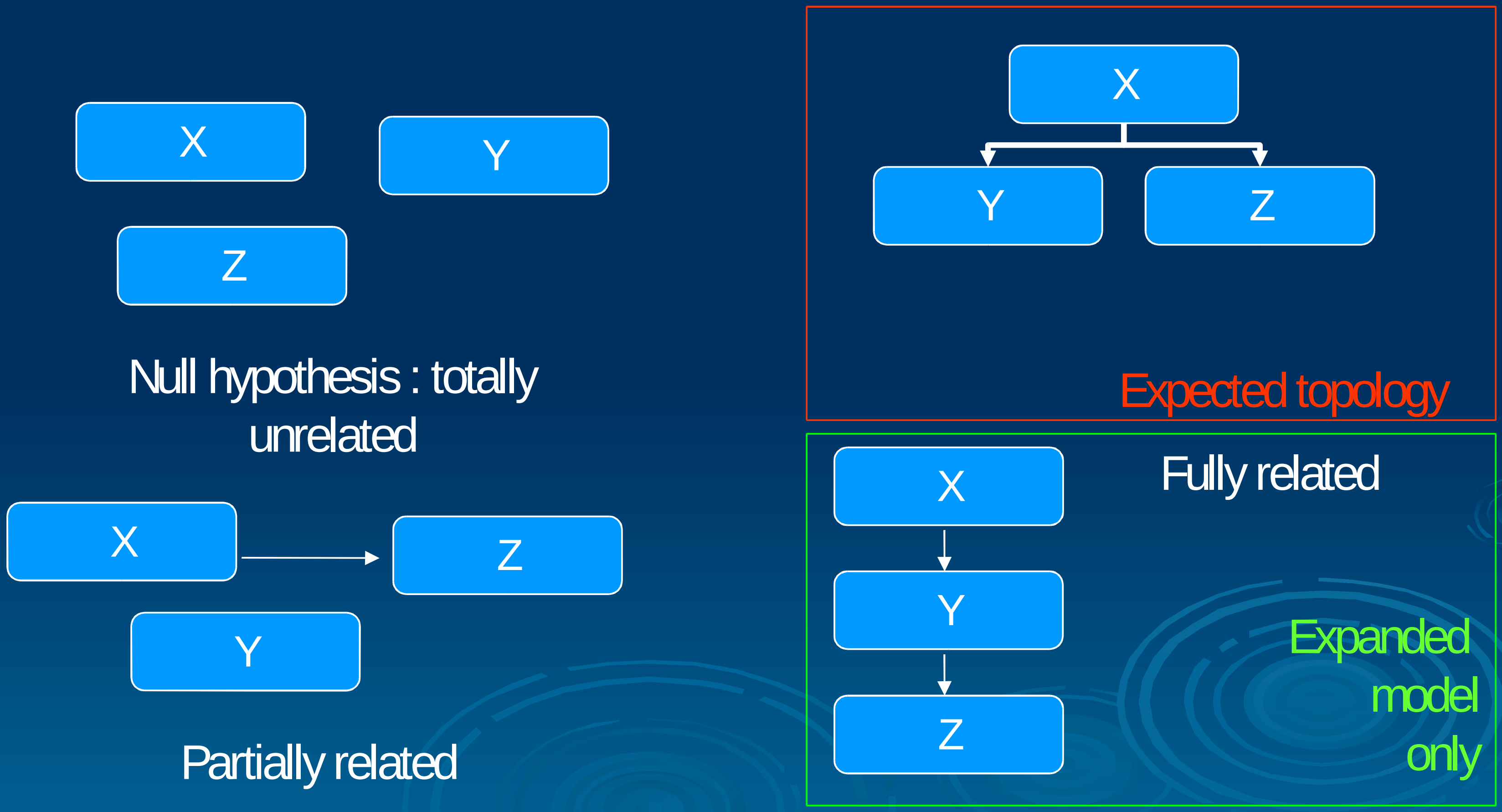
Results – Preliminary model

- Artificial languages
- A – random
- B – 5% mutation from A
- C – 5% mutation from B
- Full stop "." marks the end of string.

	A	B	C
1	asdfge.	assfge.	assfge.
2	zlsdrya.	zlcdrya.	zlchrya.
3	wet.	wet.	wbt.
4	vsert.	vsegt.	vsagt.
…	…....	…....	…....
50	…....	…....	…....

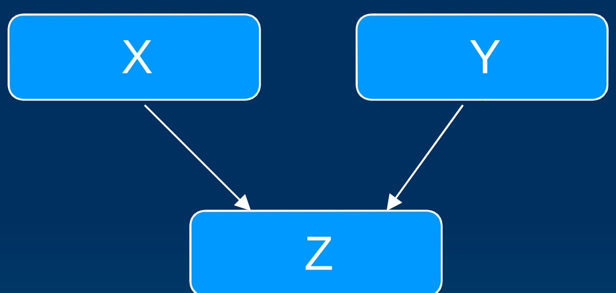
Results – Preliminary model

- Possible tree topologies for 3 languages :

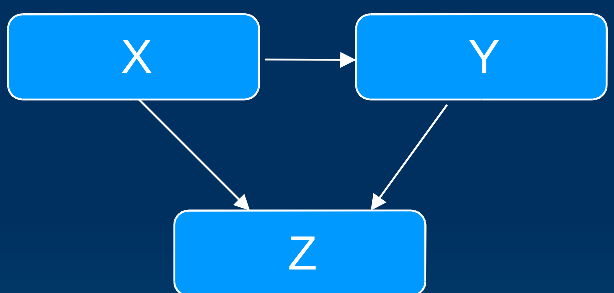


Results – Preliminary model

- Possible graph topologies for 3 languages:



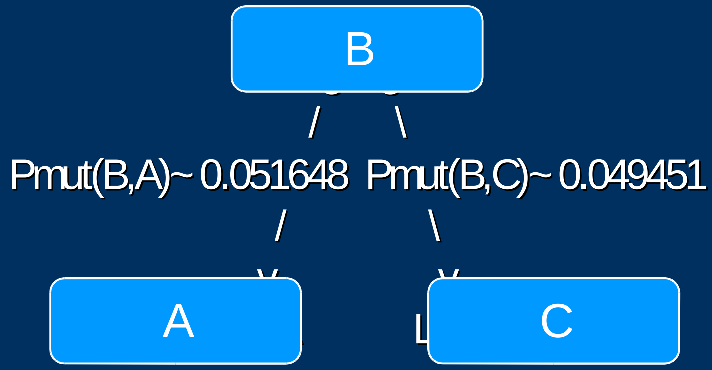
Non-related parents



Related parents

Results – Preliminary model

- Results :
  - Best tree =



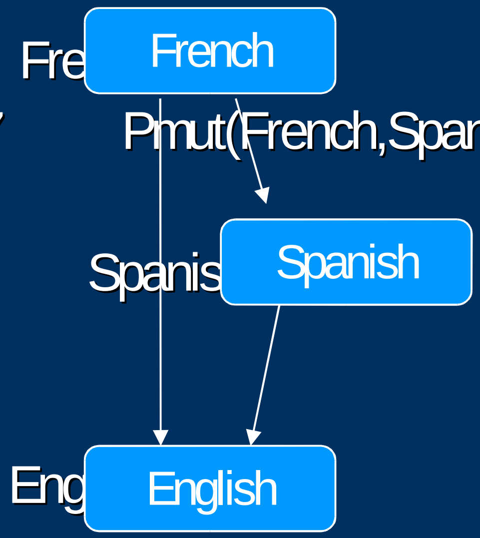
  - Overall Message Length = 2933.26 bits
    - Cost of topology = log(5)
    - Cost of fixing root language (B) = log(3)
    - Cost of root language = 2158.7186 bits
    - Branch 1
      - Cost of child language (Lang. A) binomial distribution = 392.069784 bits
    - Branch 2
      - Cost of child language (Lang. C) binomial distribution = 378.562159 bits

Results – Preliminary model

- European Languages (with accents removed)
  - French
  - English
  - Spanish

	English	French	Spanish
1	baby.	bebe.	nene.
2	beach.	plage.	playa.
3	biscuits.	biscuits.	bizcocho.
4	cream.	creme.	crema.
…	…..	…..	…..
30	…..	…..	…..

Results – Preliminary model



P(from French)~ 0.834297

P(from Spanish not French) ~ 0.090559

P(from neither)~ 0.075145

Pmut(French,Spanish) ~ 0.245174

Cost of "parent" language (French) =1226.76 bits
Cost of language (Spanish) binomial distribution = 734.59 bits
Cost of child language (English) trinomial distribution = 537.70 bits
Total tree cost = log(5) + log(3) + log(2) + 1226.76 + 734.59 + 537.70
= 2503.95 bits

Results – Expanded model

- 16 sets of 4 languages
- Different length vocabularies
  - A – randomly generated
  - B – mutated from A
  - C – mutated from A
  - D – mutated from B
- Mutation probabilities
  - Copy – 0.65
  - Change – 0.20
  - Insert – 0.05
  - Delete – 0.10

Results – Expanded model

	Language A	Language B	Language C	Language D
1	awjmv.	afjmv.	wqmv.	afjnv.
2	bauke.	baxke.	auke.	bave.
3	doinet.	domnit	deoinet.	domnit.
4	eni.	eol.	enc.	eol.
5	foijgnw.	fiogw.	foijnw.	fidgw.
…...	……....	……....	……....	……....
…...	……....	……....	……....	……....
50	……....	……....	……....	……....

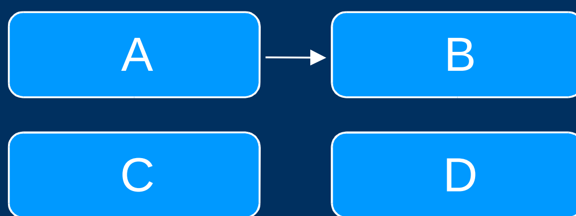
Examples of a set of 4 vocabularies used

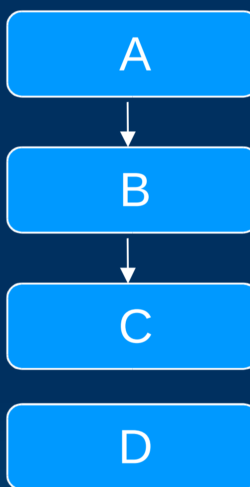
Results – Expanded model

- Possible tree structures for 4 languages:

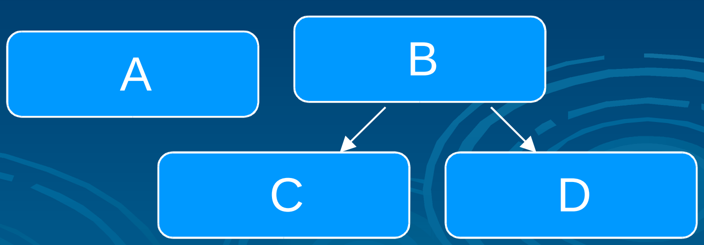
Null hypothesis :

totally unrelated

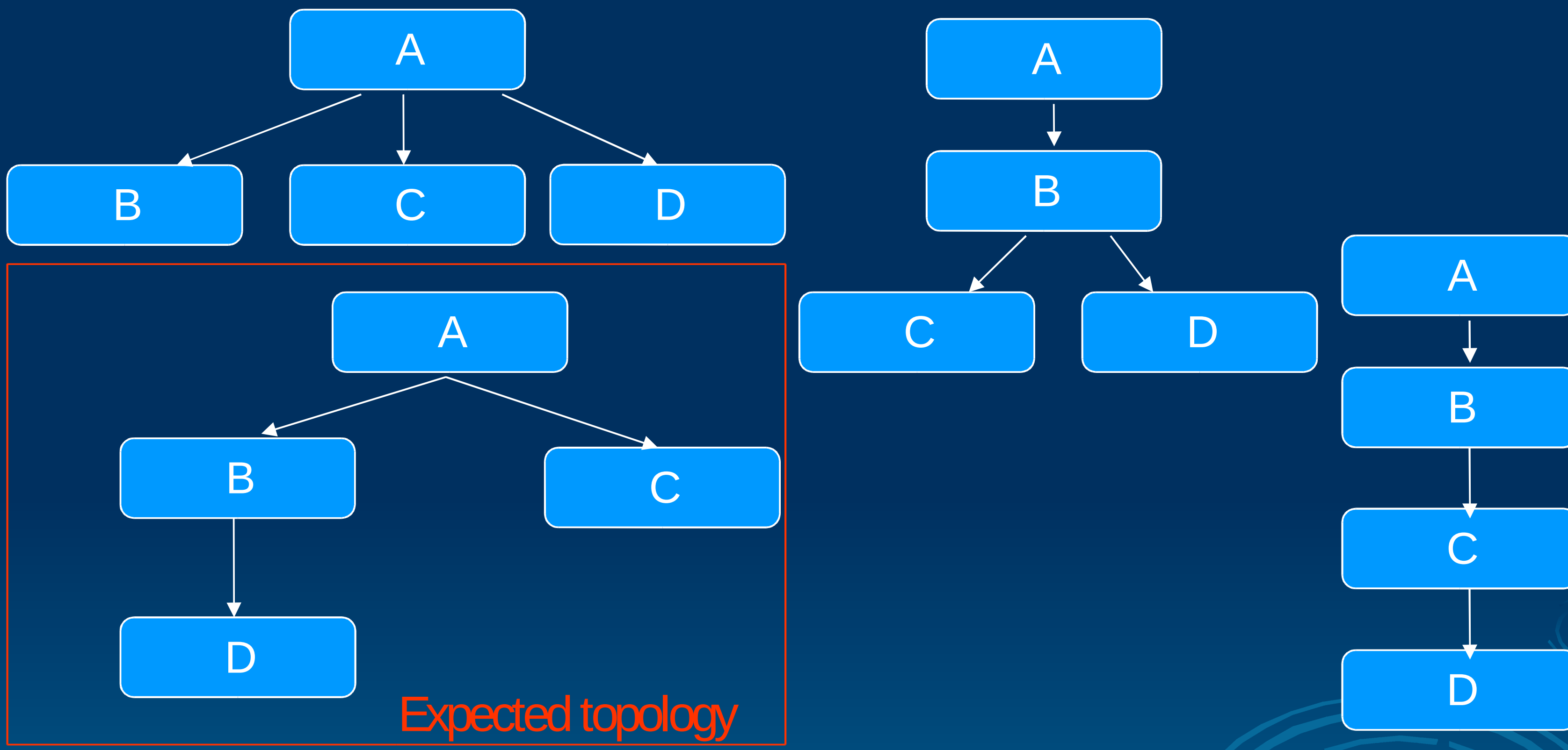




Partially related



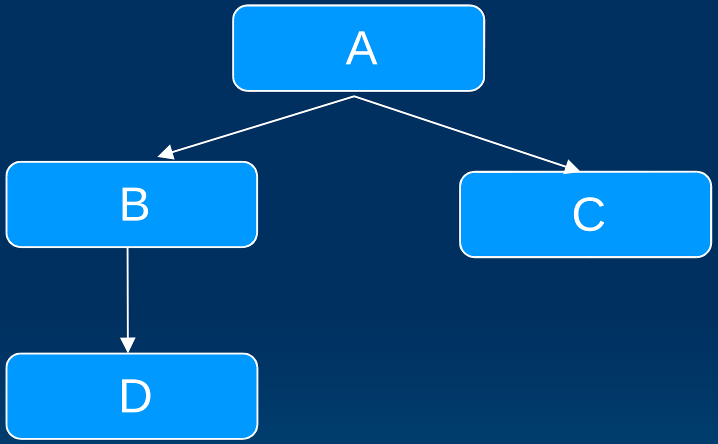
Results – Expanded model



Fully related

Results – Expanded model

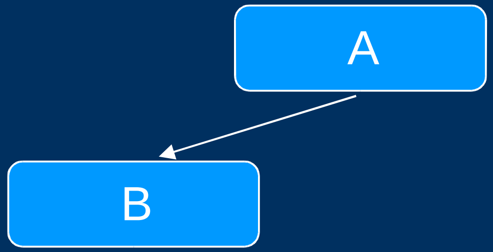
- Correct tree structure 100% of the time.
- Sample of inferred tree and cost :



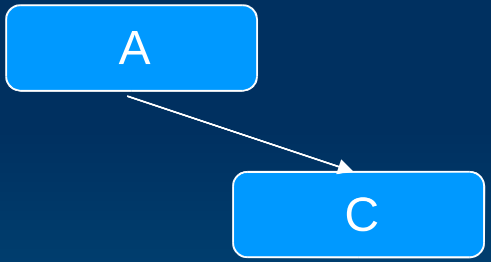
- Language A : size = 383 chars, cost = 1821.121913 bits

Results – Expanded model

- Pr(Delete) = 0.076250
- Pr(Insert) = 0.038750
- Pr(Mismatch) = 0.186250
- Pr(Match) = 0.698750
- 4 state Multinomial cost = 930.108894 bits



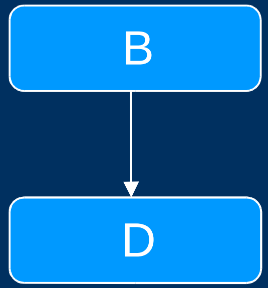
- Pr(Delete) = 0.071250
- Pr(Insert) = 0.038750
- Pr(Mismatch) = 0.183750
- Pr(Match) = 0.706250
- 4 state Multinomial cost = 916.979371 bits



- *Note that all multinomial cost includes and extra cost of log(26) to state the new character for mismatch and insert *

Results – Expanded model

- Pr(Delete) = 0.066580
- Pr(Insert) = 0.035248
- Pr(Mismatch) = 0.189295
- Pr(Match) = 0.708877
- 4 state Multinomial cost = 873.869382 bits



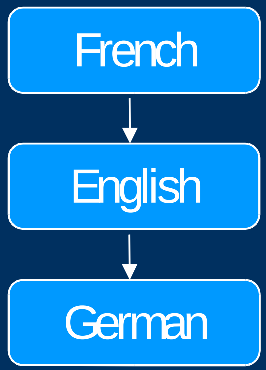
- Cost of fixing topology = log(7) = 2.81 bits
- Total tree cost = 930.11 + 916.98 + 873.87 +
  1821.11 + log(7) + log(4) + log(3) + log(2)
  = 4549.46 bits

Results – Expanded model

- European Languages
  - French
  - English
  - German

	English	French	German
1	even.	meme.	sogar.
2	eyes.	oeil.	auge.
3	false.	faux.	falsch.
4	fear.	peur.	angst.
…	…...	…...	…...
601	…...	…...	…...

Results – Expanded model



Total cost of this tree = 56807.155 bits

Cost of fixing topology = log(4) = 2 bits

Cost of fixing root language (French) = log(3) = 1.585 bits

- Cost of French = no. of chars * log(27) = 21054.64 bits

Results – Expanded model

- Cost of fixing parent/child language (English) = log(2) = 1 bit
- Cost of multistate distribution (French -> English) = 15567.98 bits
- MML inferred probabilities:
  - Pr(Delete) = 0.164322
  - Pr(Insert) = 0.071429
  - Pr(Mismatch) = 0.357143
  - Pr(Match) = 0.407106

- Cost of multistate distribution (English -> German) = 20179.95 bits
- MML inferred probabilities:
  - Pr(Delete) = 0.069480
  - Pr(Insert) = 0.189866
  - Pr(Mismatch) = 0.442394
  - Pr(Match) = 0.298260

- Note that an extra cost of log(26) is needed for each mismatch and log(27) for each insert to state the new character.

Conclusion

- MML methods have managed to
  - infer the correct phylogenetic tree/graphs for artificial languages.
  - infer phylogenetic trees/graphs for languages by encoding them in terms of one another.
- We can not (or can we?) conclude that one language really descends from another language. We can only conclude that they are related.

Future work :

- Compression – grammar and vocabulary.
- Compression – phonemes of languages.
- Endangered languages – Indigenous languages.
- Refine coding scheme.
  - Some characters occur more frequently than others.
    E.g.: English - “x” compared with “a”.
  - Some characters are more likely to mutate from one language to another language.

Questions?

Some further reading on MML

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