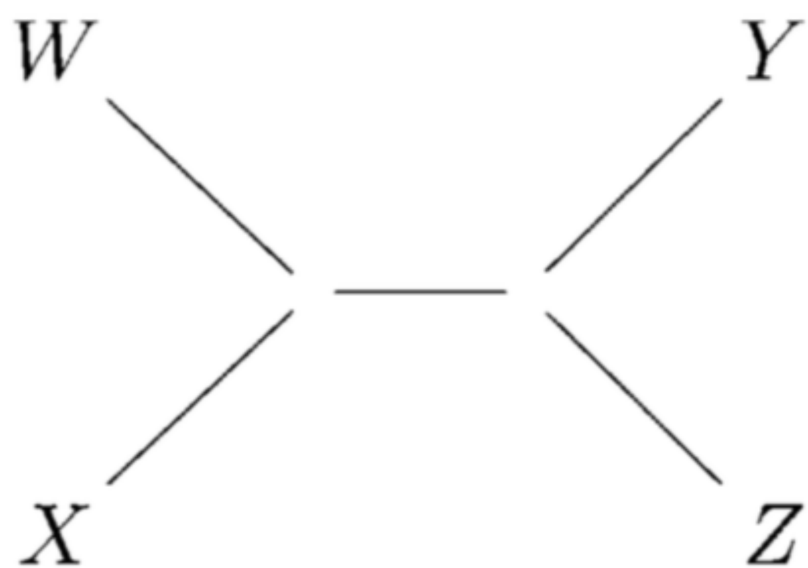
Lesson 5: D-statistics and Tests of Treeness

Monday July 16, 2018

9:00 – 11:30 am

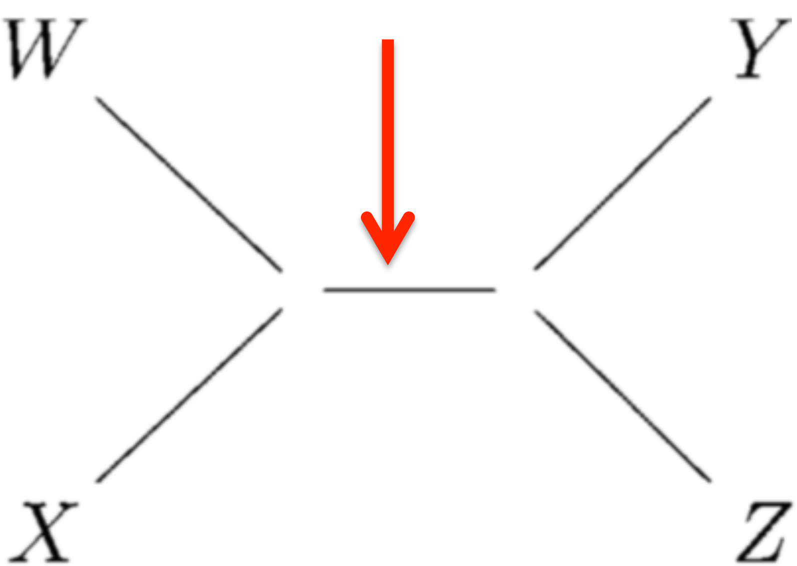
What are D-statistics?

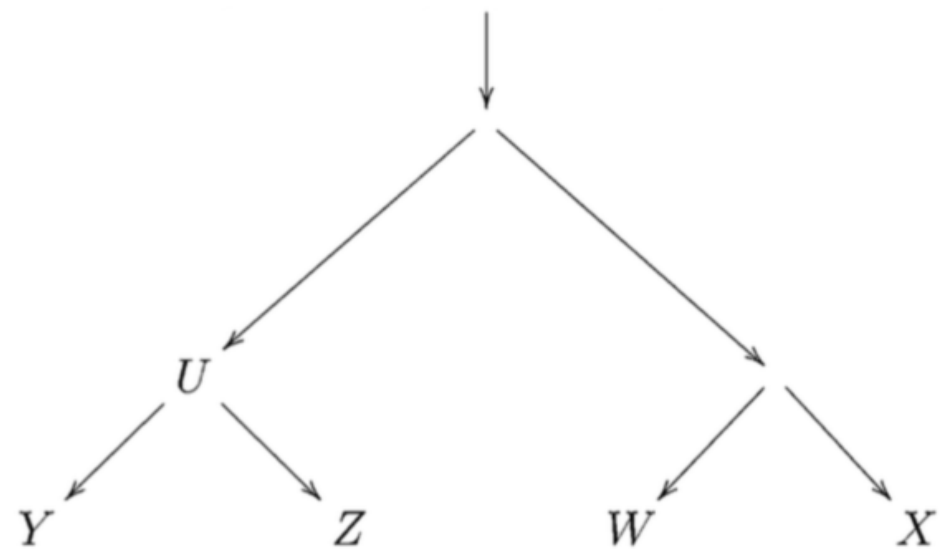
- Assumes unrooted phylogeny of four populations
- Four populations: W, X, Y, Z



What are D-statistics?

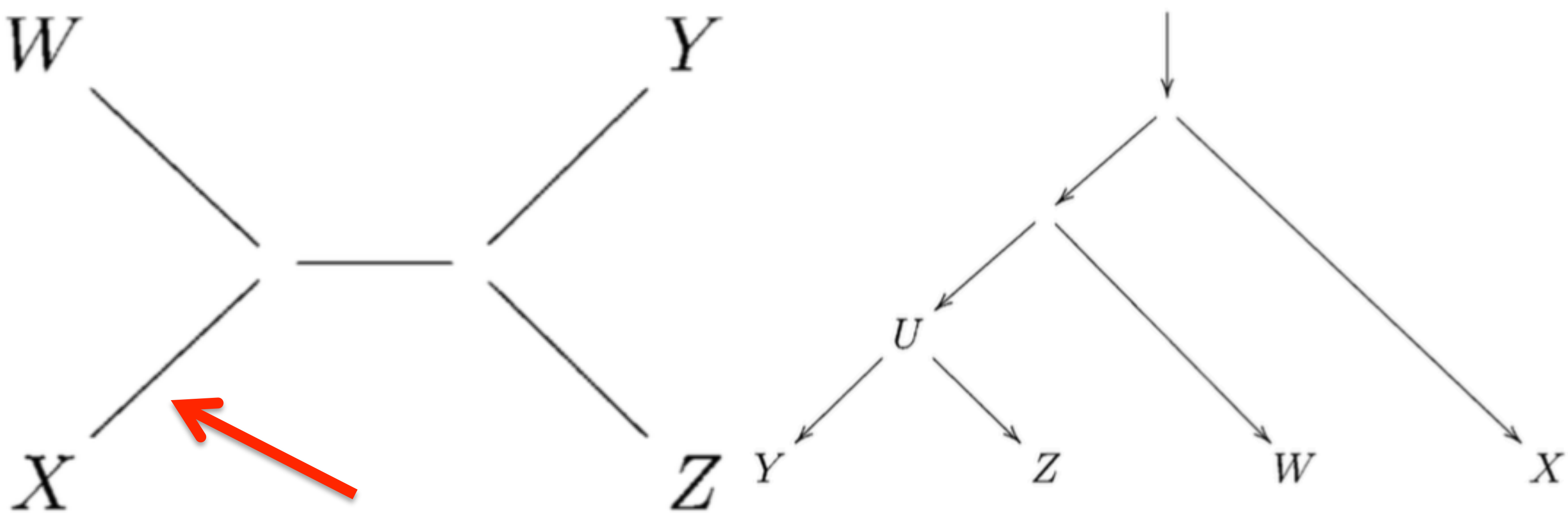
- Two ways to root this unrooted tree – first, in the middle, leading to two pairs of sister groups





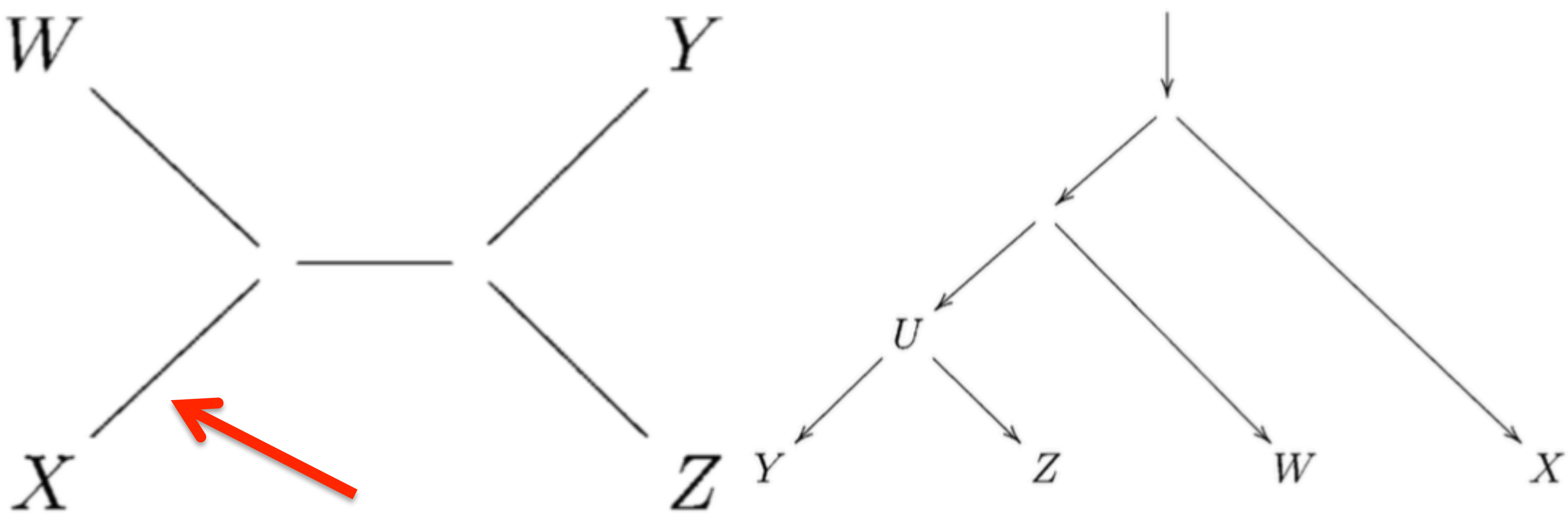
What are D-statistics?

- Second, with the root on one of the populations, leading to one pair of sister groups, and one popn closer to them, followed by one most distant.



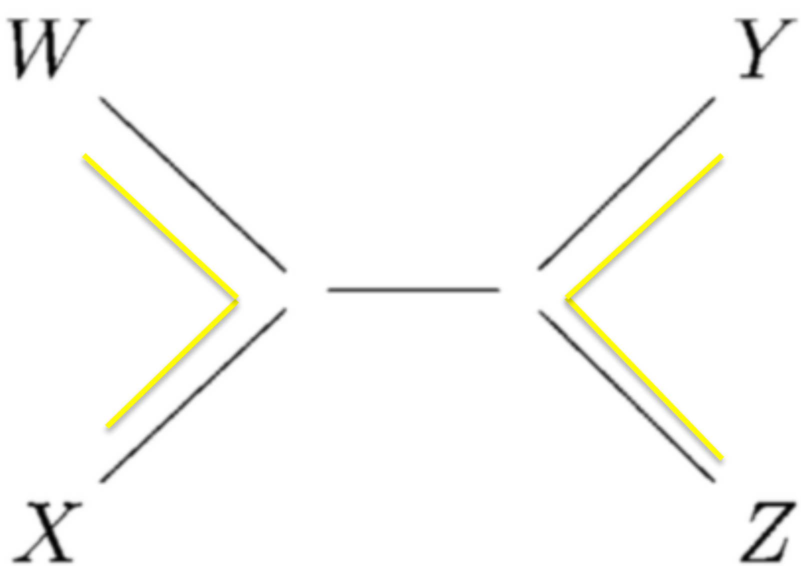
What are D-statistics?

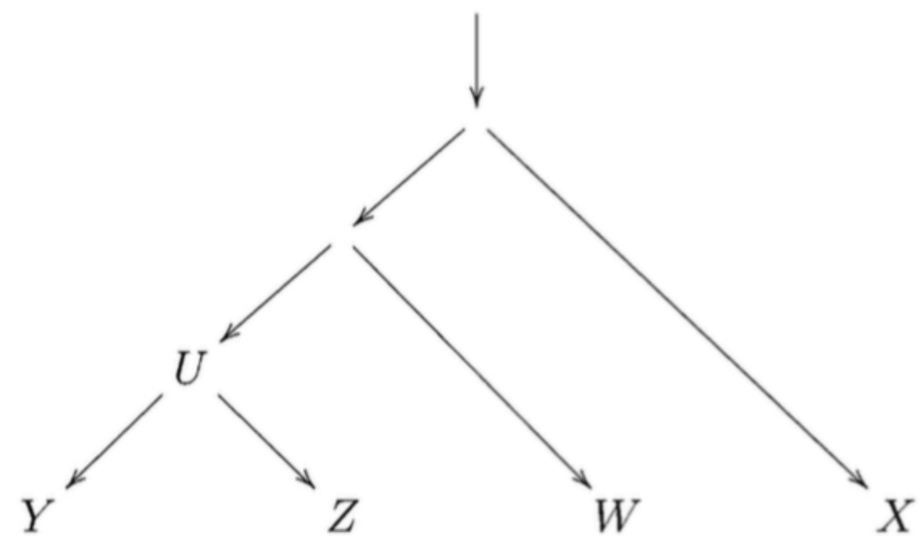
- We mostly use this case, using an African population (e.g., Mbuti) or the chimp as outgroup.



What are D-statistics?

- D essentially measures the shared overlap in branch length between two pairs
- D(W, X; Y, Z) = E[(w-x)(y-z)]





Peter 2016

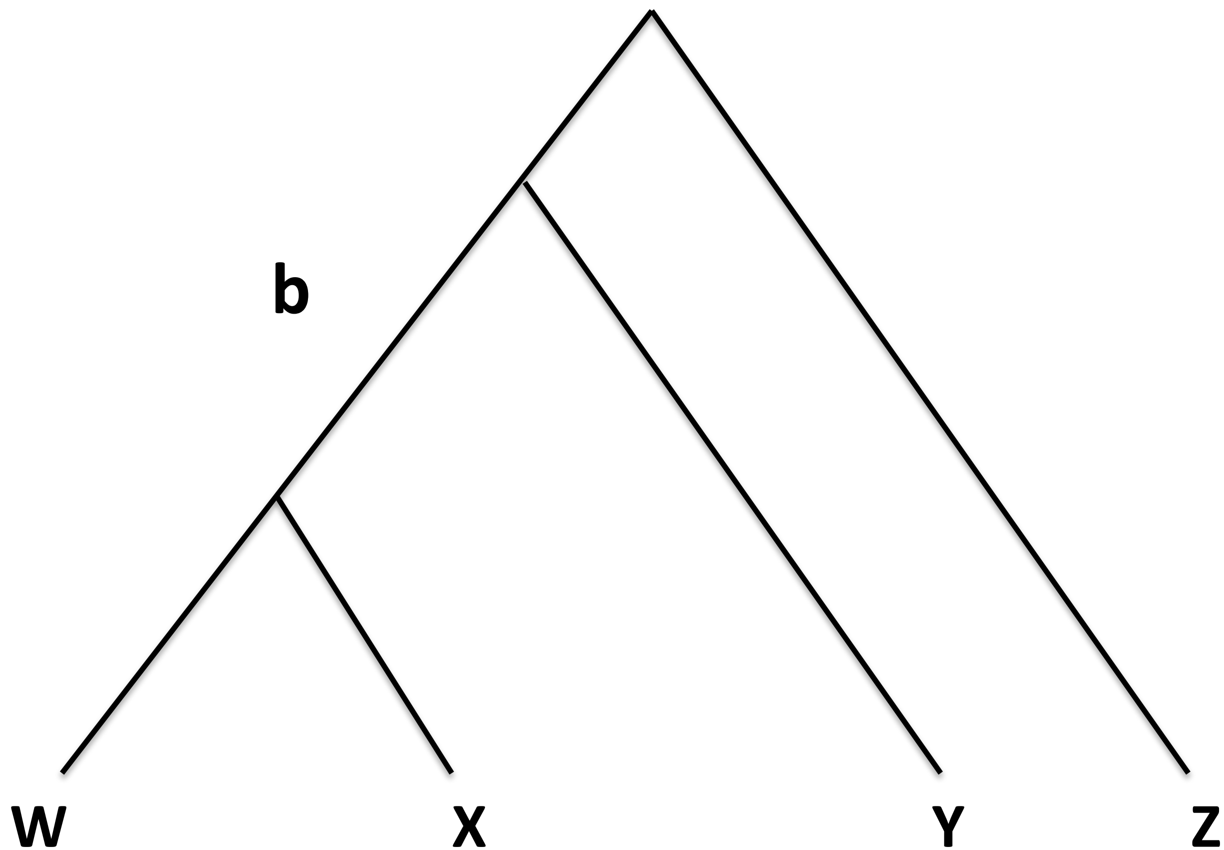
- “Since treeness implies that all subsets of taxa are also trees, the ingenious idea of Reich *et al.* (2009) was that rejection of treeness for subtrees of size three (for *F*3) and four (for *F*4) is sufficient to reject treeness for the entire tree. Furthermore, tests on these subsets also pinpoint the populations involved in the non-tree-like history.” (p. 7)
- Good because finding best-fitting tree is difficult problem.

Three unique D-statistics

- D1(W, X; Y, Z)
- D2(W, Y; X, Z)
- D3(X, Y; W, Z)
- One D can be written as the sum of the other two.

Three unique D-statistics

- D1(W, X; Y, Z) , D2(W, Y; X, Z), D3(X, Y; W, Z)



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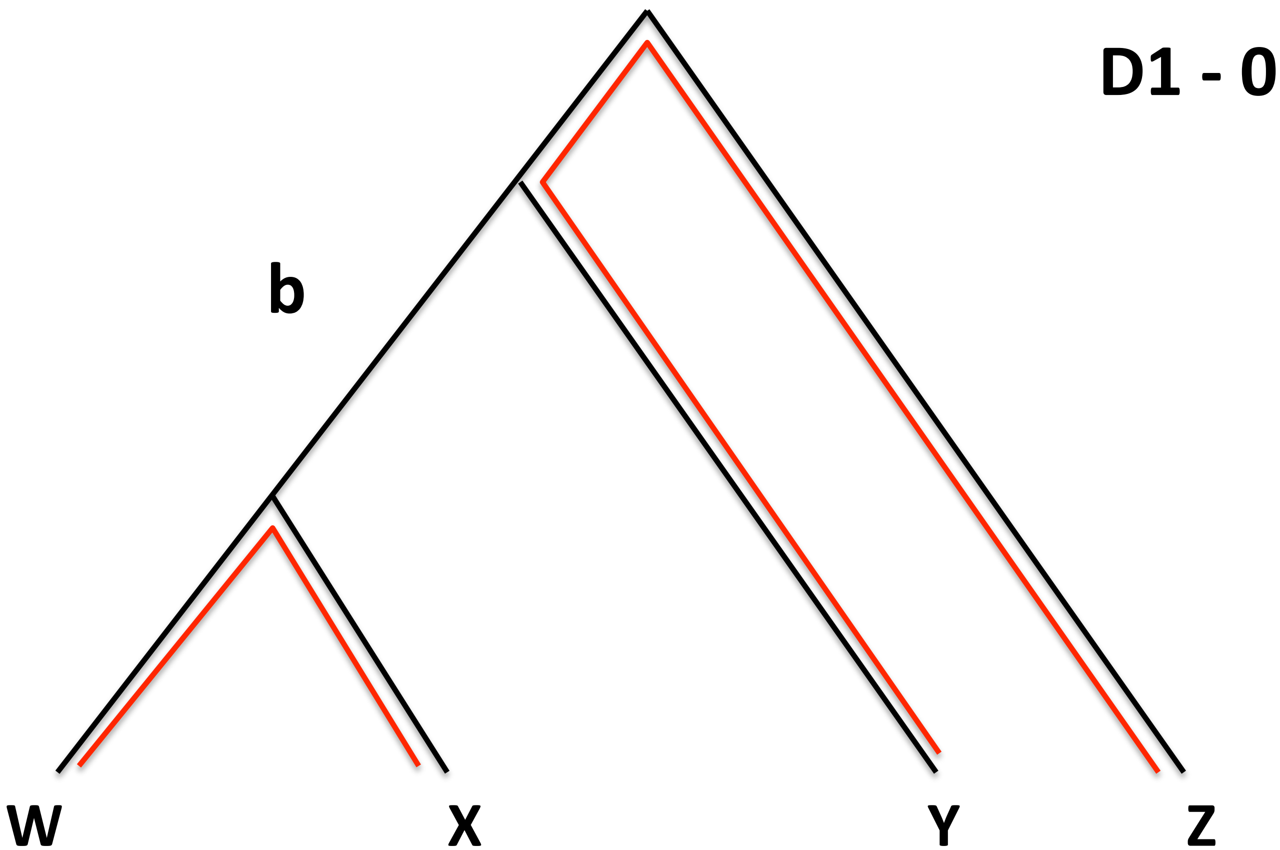

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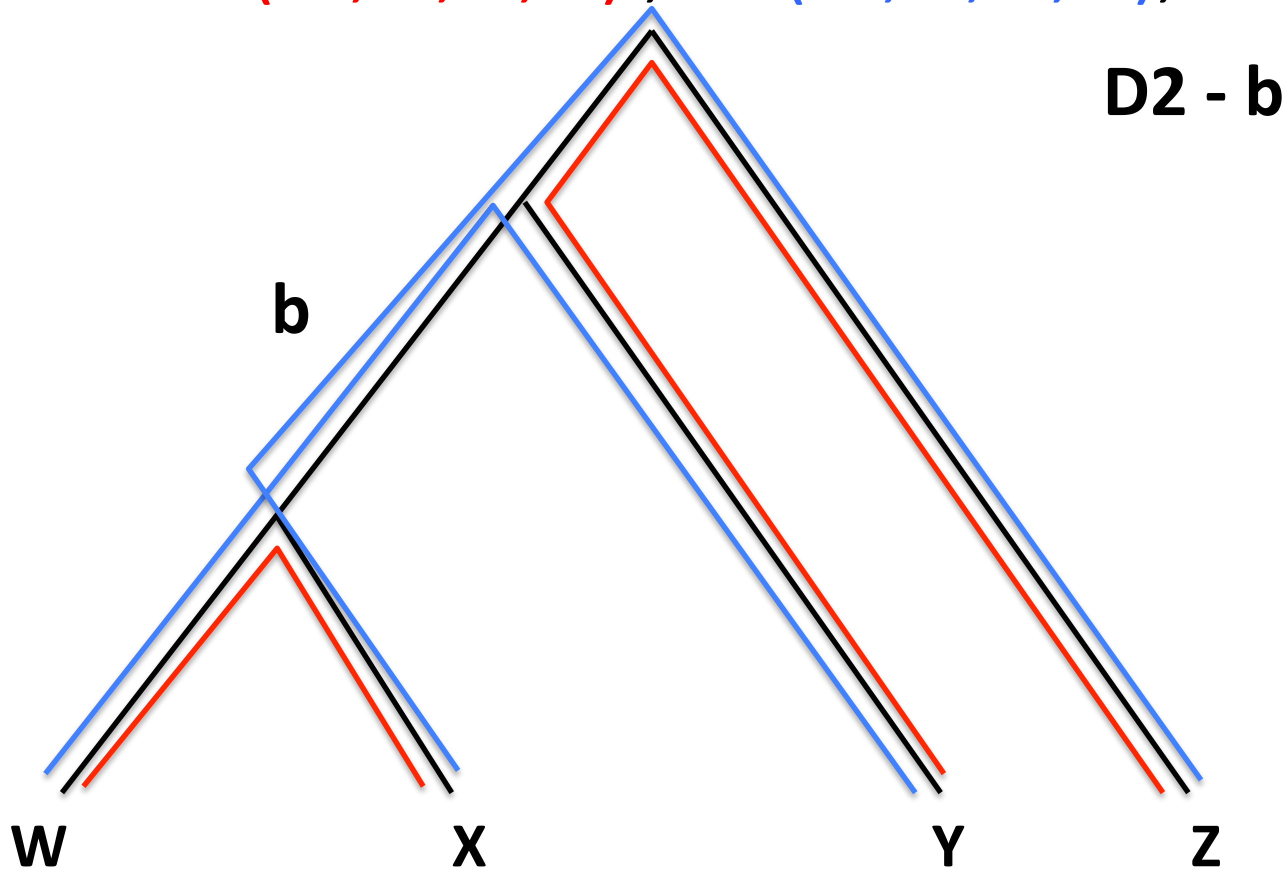

Three unique D-statistics

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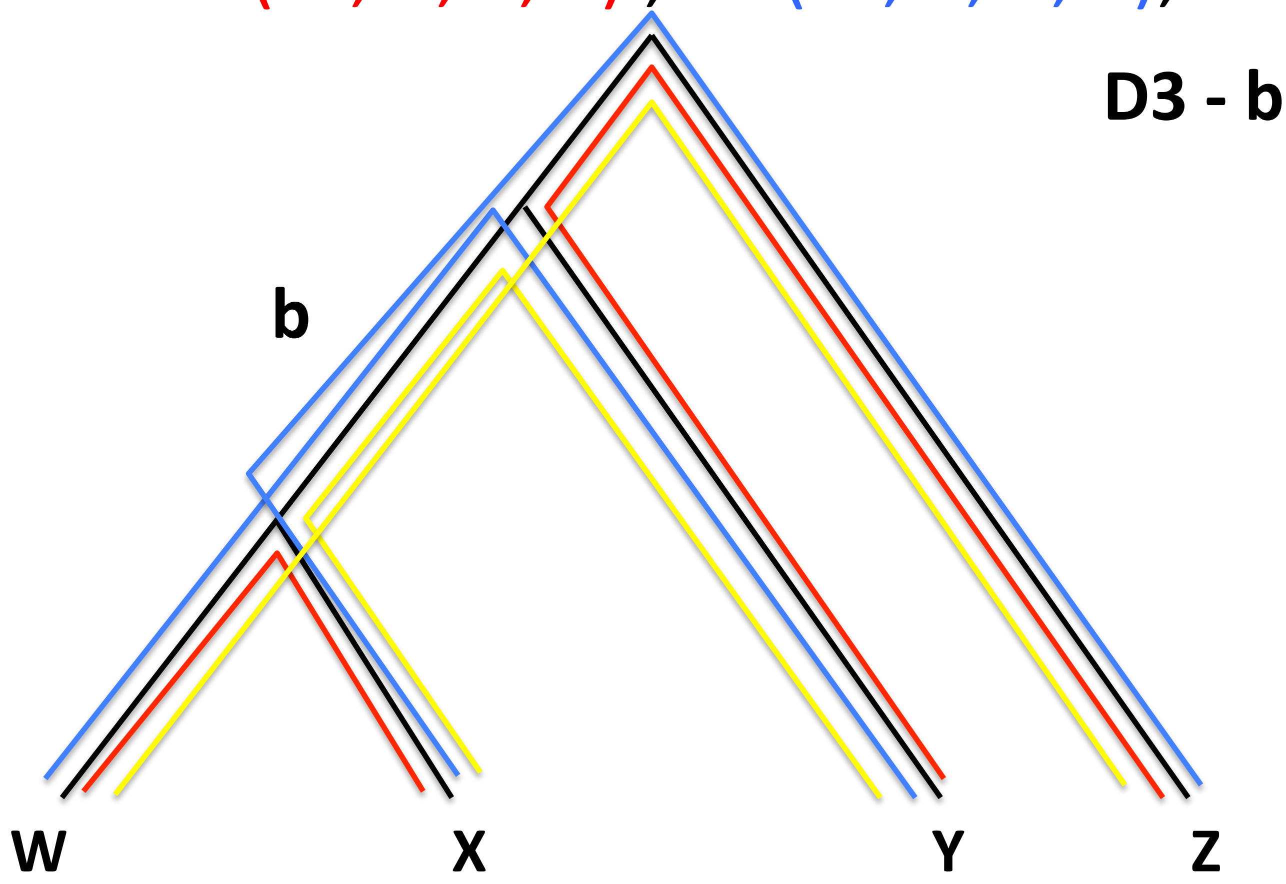

Three unique D-statistics

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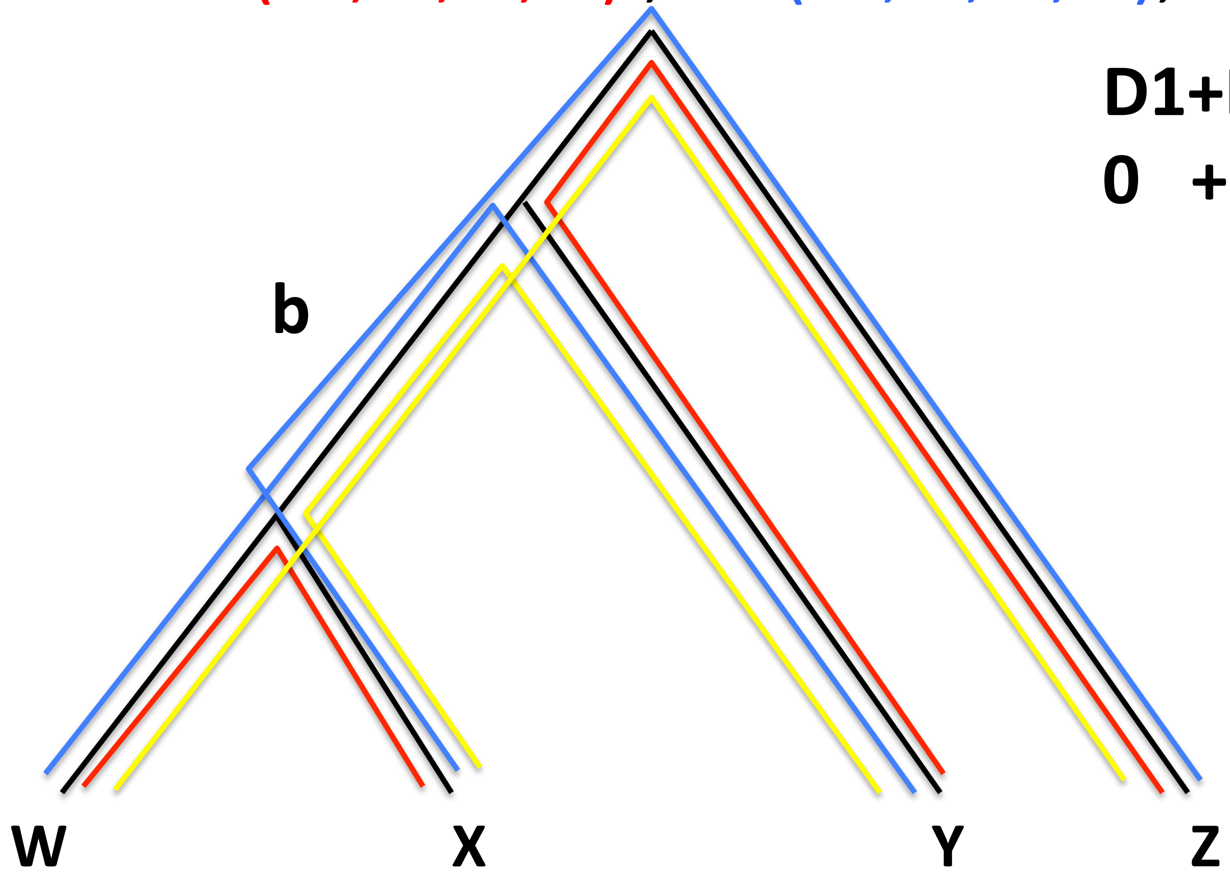


D1+D2=D3

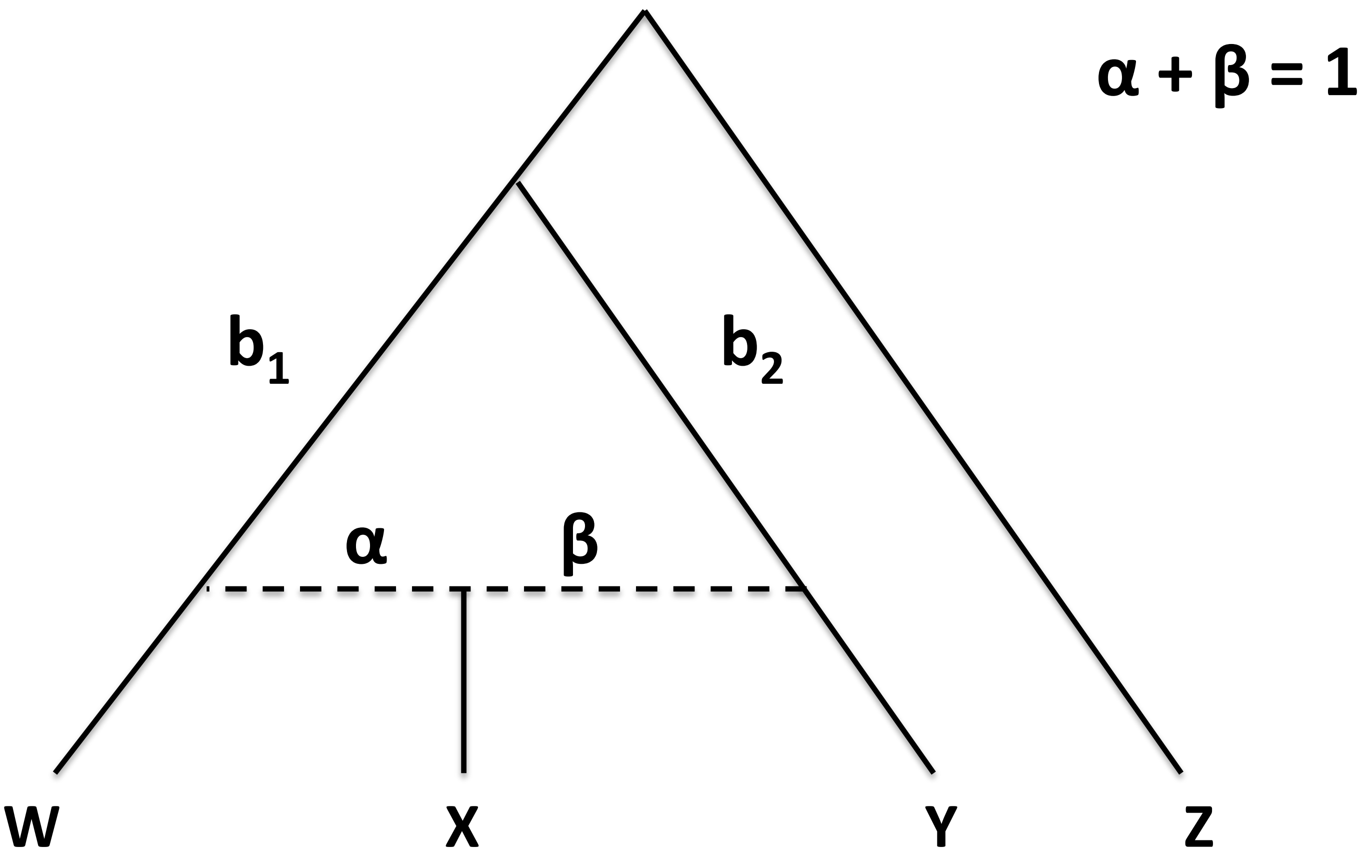
0 + b = b

Four point condition

- Considering all pairs, two sums are the same and no smaller than the third
- "any four taxa tree has at most one internal branch"
- Peter 2016 – "**Admixture, Population Structure and *F*-statistics**"

Three unique D-statistics

- D1(W, X; Y, Z) , D2(W, Y; X, Z), D3(X, Y; W, Z)



Three unique D-statistics

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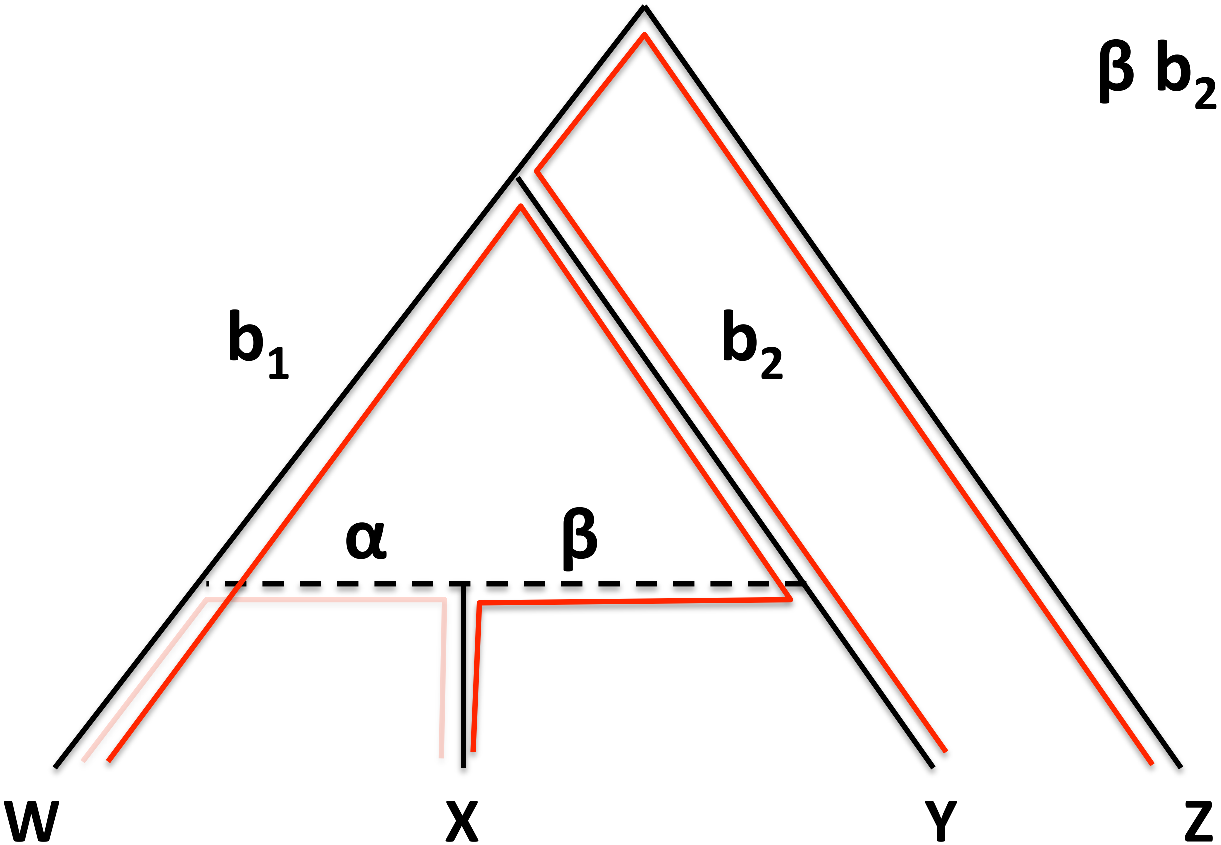

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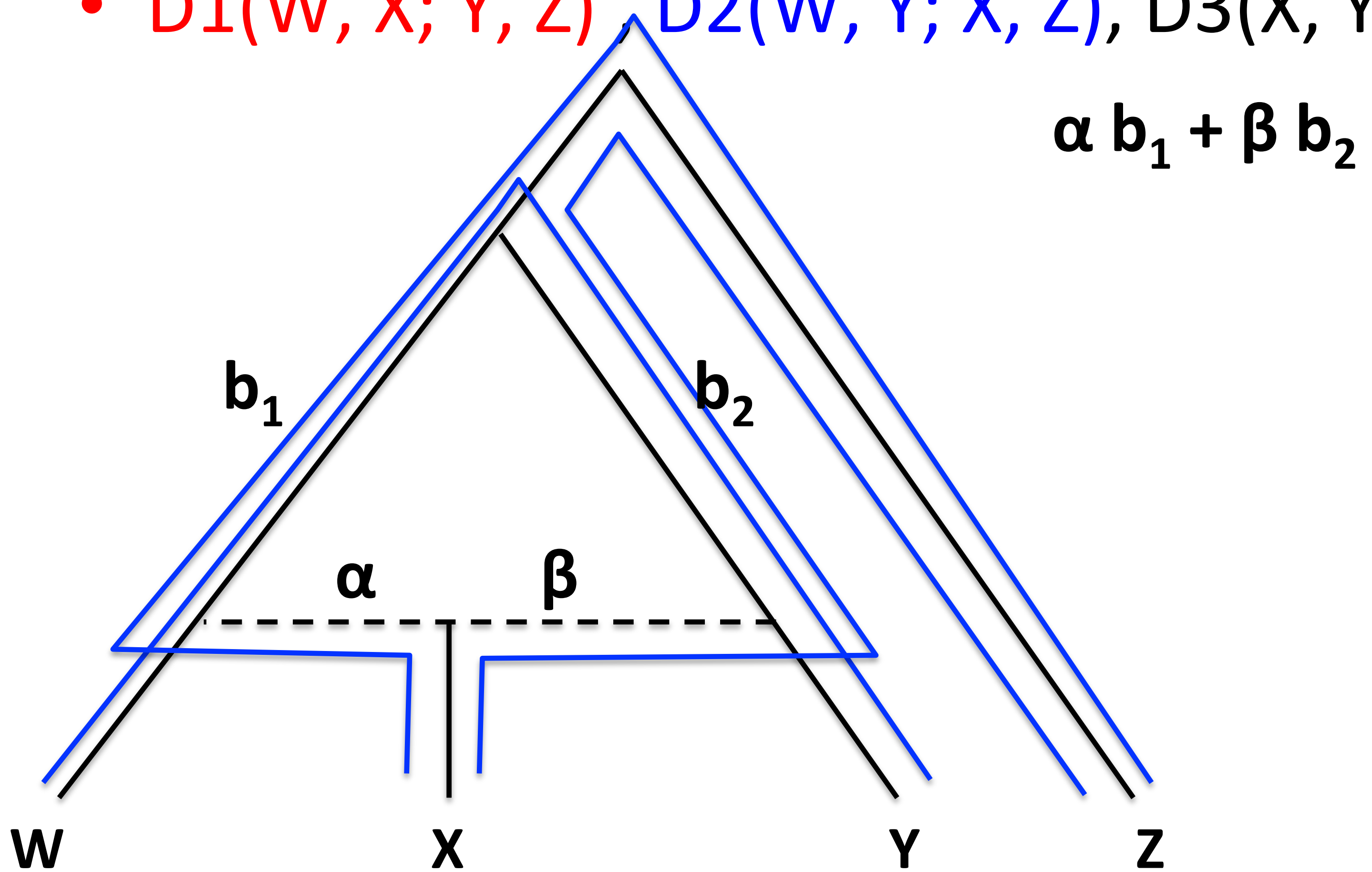

Three unique D-statistics

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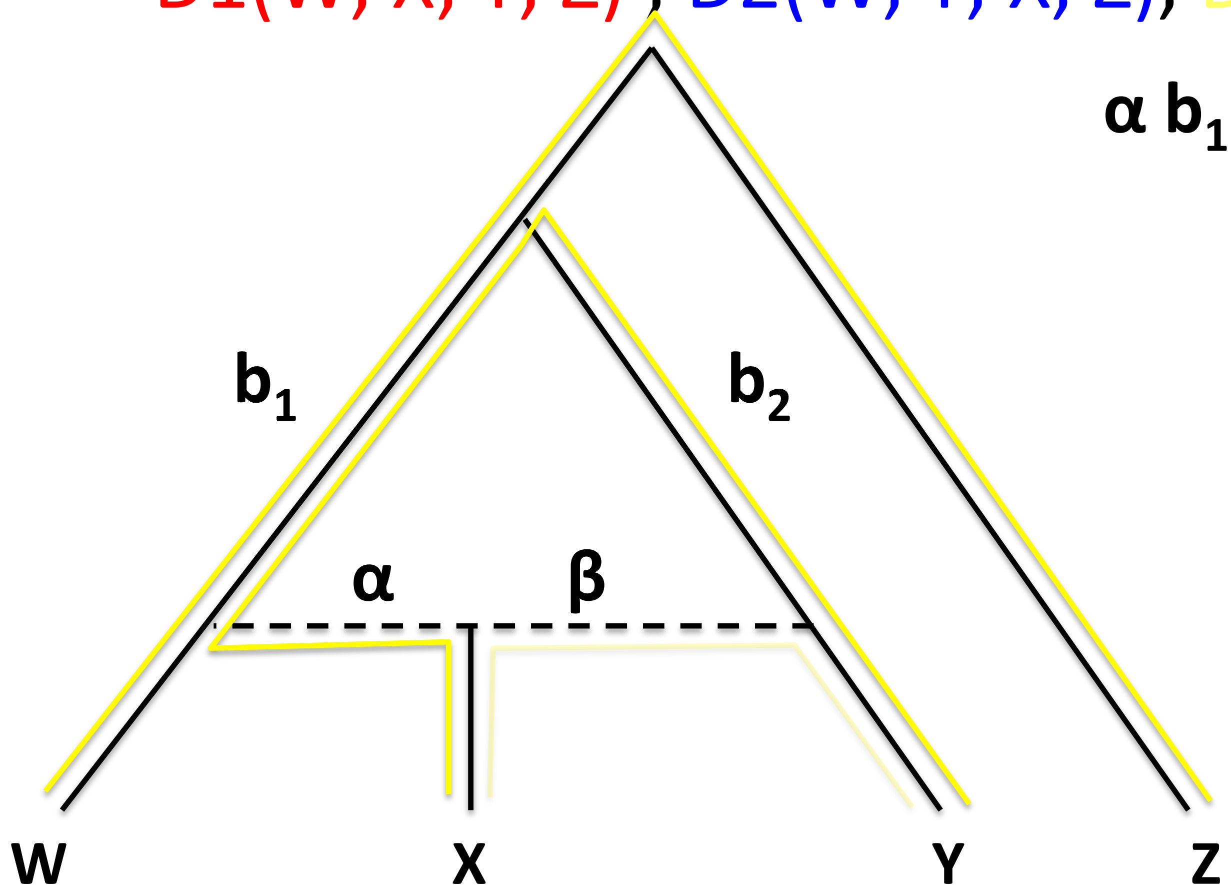
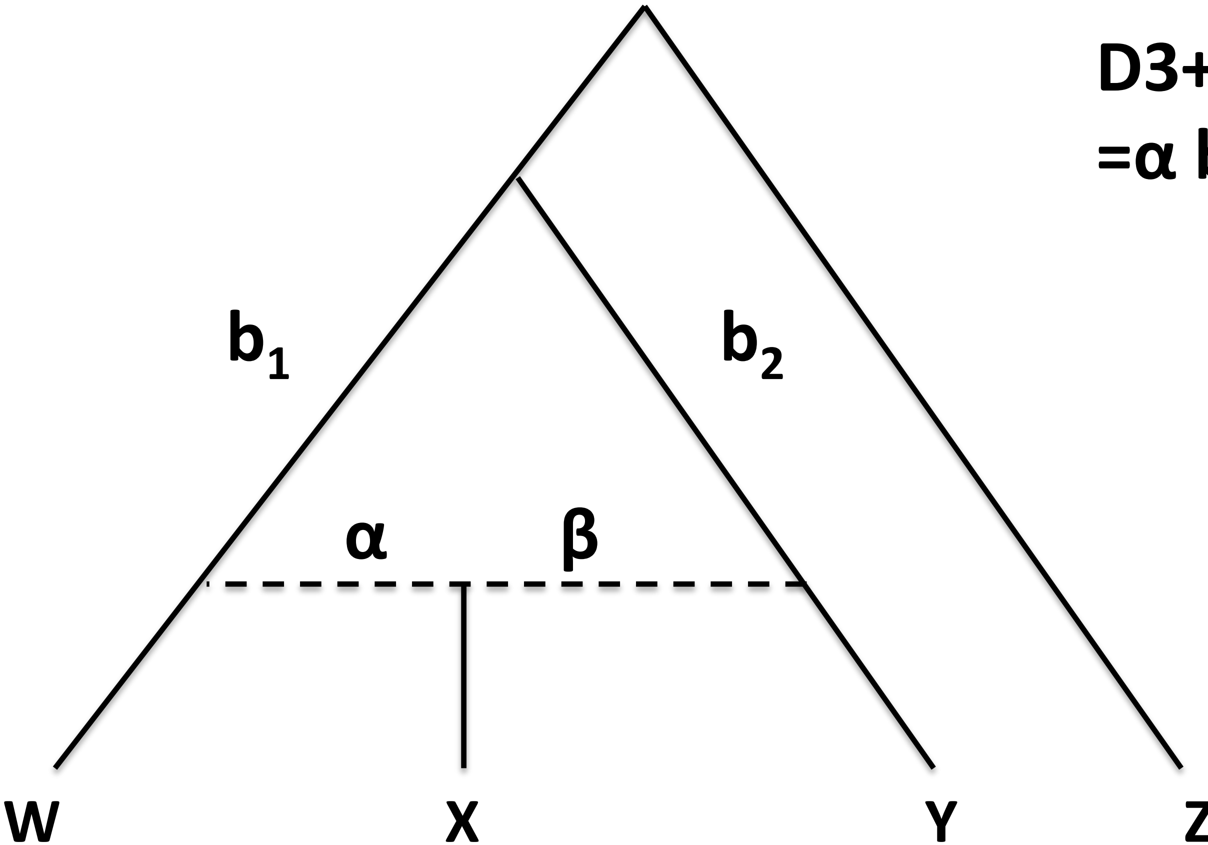


Three unique D-statistics

- D1(W, X; Y, Z) , D2(W, Y; X, Z), D3(X, Y; W, Z)

D3+D1=D2

$=\alpha\ b_1 + \beta\ b_2$



Practically speaking…

- D(W, X; Y, Z) explores the difference between BABA and ABBA, where BABA is where W and Y agree, and ABBA is where W and Z agree.
- D=(BABA-ABBA)/(BABA+ABBA)
- With multiple SNPs, sum numerator and denominator, taking ratio at the end.
- Taking two populations (e.g., W and X), we can assess whether they form a clade with respect to the other populations.

Expectations of D

- Assuming W and X form a clade with each other with respect to Y and Z, and assuming Z is an outgroup, we would expect that:
  - D(W, Y; X, Z)>0
  - D(X, Y; W, Z)>0
  - D(W, X; Y, Z)~0

Test of Treeness

Expectations of D

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Test of Treeness?

Haak et al. mainly relies on this, but we will explore differently

Expectations of D

- Assuming W and X form a clade with each other with respect to Y and Z, and assuming Z is an outgroup, we would expect that:
  - D(W, Y; X, Z)>0
  - D(X, Y; W, Z)>0
  - D(W, X; Y, Z)~0

Test of Admixture

Revisit in Lesson 8!

qpDstat

- Required command is:
  - qpDstat –p [parfilename] > [logfilename]

```
[mel_yang@comput14 mel_yang]$ cat masterlogfiles/Haaketal2015/data.eigen.D.Internal_all.par
genotypename:   /mnt/solexa/mel_yang/data/Haak2015PublicData/data.eigen.geno
snpname:        /mnt/solexa/mel_yang/data/Haak2015PublicData/data.eigen.snp
indivname:      /mnt/solexa/mel_yang/data/Haak2015PublicData/data.eigen.ind
popfilename:    /mnt/solexa/mel_yang/masterlogfiles/Haaketal2015/data.eigen.D.Internal_all.pop
printsd:        YES
```

```
[mel_yang@comput14 mel_yang]$ head masterlogfiles/Haaketal2015/data.eigen.D.Internal_all.pop
MA1 LBK_EN LateDorset Mbuti
MA1 LBK_EN HungaryGamba_IA Mbuti
MA1 LBK_EN SwedenSkoglund_NHG Mbuti
MA1 LBK_EN Alberstedt_LN Mbuti
MA1 LBK_EN Esperstedt_MN Mbuti
MA1 LBK_EN LBKT_EN Mbuti
MA1 LBK_EN Motala_HG Mbuti
MA1 LBK_EN Kostenki14 Mbuti
MA1 LBK_EN AG2 Mbuti
MA1 LBK_EN Unetice_EBA Mbuti
```

qpDstat

- Par file (printsd: YES)
- Pop file
- qpDstat –p [parfilename] > [logfilename]

```
result: Kostenki14  Loschbour  Ust_Ishim    Mbuti   -0.0004    0.006908   -0.064  15391  15405 328923
result: Kostenki14  Ust_Ishim  Loschbour    Mbuti    0.0741    0.006846   10.830  17872  15405 328923
result:  Loschbour Kostenki14  Ust_Ishim    Mbuti    0.0004    0.006908    0.064  15405  15391 328923
result:  Loschbour  Ust_Ishim Kostenki14    Mbuti    0.0746    0.007209   10.347  17872  15391 328923
result:  Ust_Ishim Kostenki14  Loschbour    Mbuti   -0.0741    0.006846  -10.830  15405  17872 328923
result:  Ust_Ishim  Loschbour Kostenki14    Mbuti   -0.0746    0.007209  -10.347  15391  17872 328923
result: Kostenki14  Loschbour  Ust_Ishim    Chimp   -0.0039    0.007776   -0.497  15485  15605 328923
result: Kostenki14  Ust_Ishim  Loschbour    Chimp    0.0832    0.007812   10.644  18435  15605 328923
result:  Loschbour Kostenki14  Ust_Ishim    Chimp    0.0039    0.007776    0.497  15605  15485 328923
result:  Loschbour  Ust_Ishim Kostenki14    Chimp    0.0870    0.007865   11.060  18435  15485 328923
```

Can we describe relationship between Kostenki14, Loschbour, and Ust’-Ishim?

Major Players in Haak et al.

- Western European H-G (WHG)
- Eastern European H-G (EHG)*
- Scandinavian H-G (SHG)
- Early Neolithic (EN)*
- Middle Neolithic (MN)*
- Late Neolithic (LN)*
- Bronze Age (BA)*
- Present-day

With whom do these sets form a clade?

- To begin, we are going to assume each of these sets designated by Haak et al. (2015) in the 'ind' file form a clade. In a homework problem, you will test whether this is in fact true using D-statistics.
- EHG: Karelia, Samara
- SHG: Motala
- EN: LBK, LBKT, Starcevo, Els Trocs
- MN/CA: Yamnaya, Esperstedt, Baalberge, La Mina
- LN: Alberstedt, BenzigerodeHeimburg, Bell Beaker, Karsdorf, Corded Ware
- BA/IA: Halberstadt, Unetice

Are all these sets ‘European’?

- How do we address the above question?

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  - Need Panel: Kostenki14, Loschbour, Stuttgart, French, Sardinian, English
  - Need ‘non-European’: Han

Are all these sets ‘European’?

- How do we address the above question?
  - Need Panel: Kostenki14, Loschbour, Stuttgart, French, Sardinian, English
  - Need ‘non-European’: Han
  - D(X, Han; Panel, Mbuti)>0
  - D(Panel, Han; X, Mbuti)>0

D-statistic Tables

- Write script to pull out the sets we want: D(Panel, Han; Panel, Mbuti).

D-statistic Tables

- Write script to pull out the sets we want: D(Panel, Han; Panel, Mbuti).
- Some pseudocode (for homework!):
  - Start with complete log file (in the results/ folder).
  - Decide which results to retrieve information from.
  - Put them in array (numpy)
  - Write them to file, highlighting |Z|>3, in xlsx file (xlsxwriter)

D-statistic Tables

- Write script to pull out the sets we want: D(Panel, Han; Panel, Mbuti).
- Let's take a moment to write some pseudocode:
  - Start with complete log file (in the results/ folder).
  - Decide which results to retrieve information from.

result:	Kostenki14	Loschbour	Ust_Ishim	Mbuti	-0.0004	0.006908	-0.064	15391	15405	328923
result:	Kostenki14	Ust_Ishim	Loschbour	Mbuti	0.0741	0.006846	10.830	17872	15405	328923
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I have a function to make an array, inputting two lists, two set IDs, and indices they all belong too.

Python module: xlsxwriter

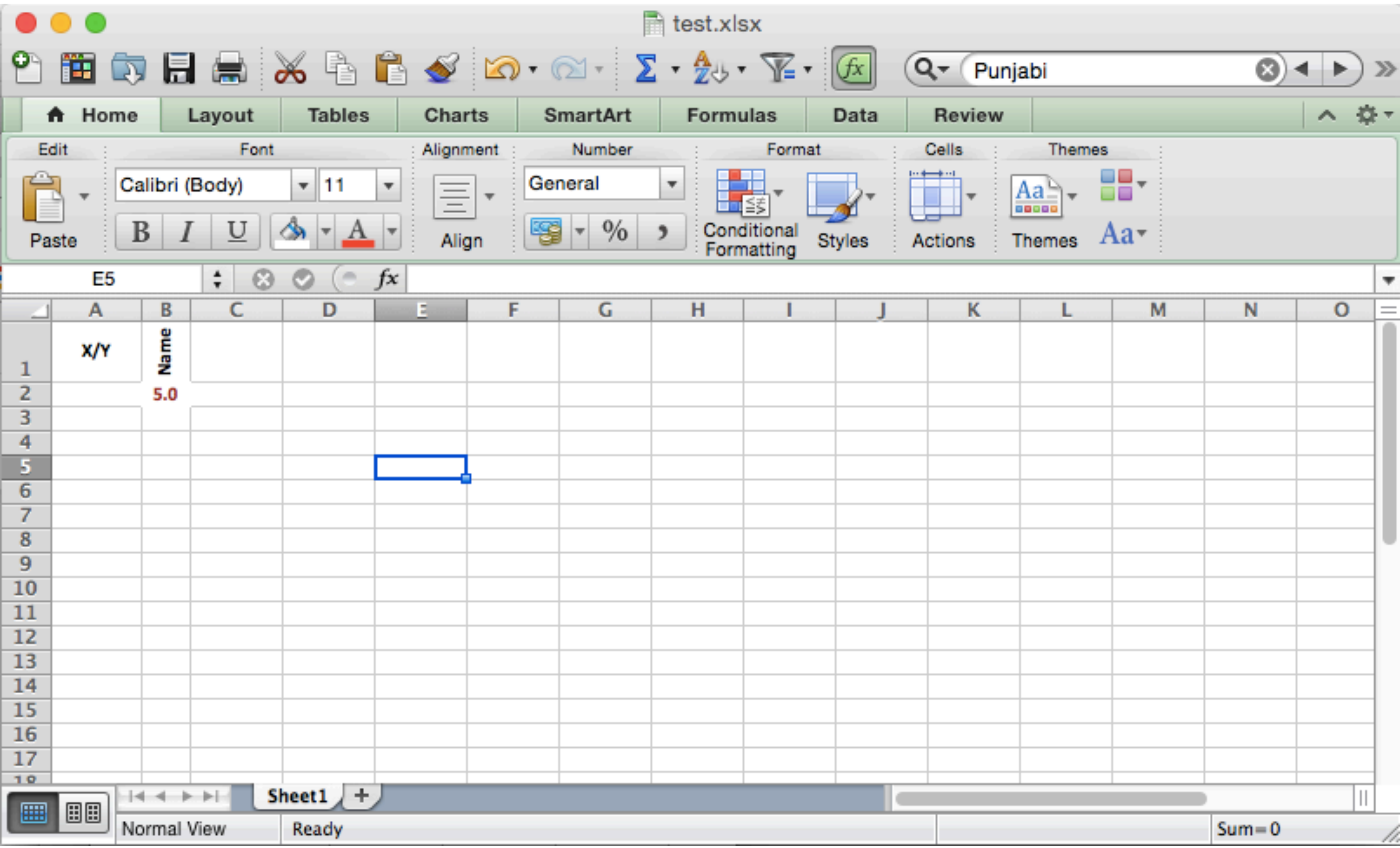
– http://xlsxwriter.readthedocs.io/

I have a second function taking array and applying xlsxwriter to turn it into a nicely formatted Excel table.

```python
import xlsxwriter as xls
newfile=xls.Workbook("/mnt/solexa/mel_yang/teaching/haak2015/test.xlsx")
worksheet=newfile.add_worksheet()

format1 = newfile.add_format({'center_across':True,'bold':True,'font_color':'#9C0006',
                             'bg_color':'white','num_format': '0.0'})
format2=newfile.add_format({'bold': True,'align':'center','valign':'vcenter','rotation':90})
format3 = newfile.add_format({'bold': True,'align':'center','valign':'vcenter'})
worksheet.set_column(1,1,4)
worksheet.set_column(0,0,8)
row,col=0,0
worksheet.write_string(0,0,"X/Y",format3)
worksheet.write_number(1,1,5,format1)
worksheet.write_string(0,1,"Name",format2)
newfile.close()
```

Python module: xlsxwriter



D-statistic Tables

- D(Panel, Han; Panel, Mbuti).

	D(X, Han; Y, Mbuti)						D(Y, Han; X, Mbuti)					
X/Y	Kostenki14	Loschbour	Stuttgart	French	Sardinian	English	Kostenki14	Loschbour	Stuttgart	French	Sardinian	English
Halberstadt_LBA	6.8	18.5	17.6	25.4	25.9	26.1	6.0	20.8	17.1	30.5	26.5	30.2
Unetice_EBA	10.0	27.2	26.3	38.7	37.8	39.4	6.6	28.9	23.6	39.9	34.3	39.4
Alberstedt_LN	7.6	16.7	19.1	27.9	28.4	27.3	6.1	18.6	17.5	30.1	26.8	28.8
BenzigerodeHeimburg_LN	9.7	22.3	20.4	31.7	30.3	31.7	8.2	25.2	18.8	35.4	30.8	35.0
Bell_Beaker_LN	9.5	25.6	27.7	36.7	36.7	37.0	6.7	27.9	24.0	37.8	33.5	37.7
Karsdorf_LN	3.5	9.5	9.3	15.5	14.5	15.6	2.5	10.3	7.6	16.6	13.2	16.5
Corded_Ware_LN	10.4	22.0	22.4	33.8	31.0	34.6	6.8	22.9	19.2	35.4	28.3	35.4
Yamnaya	10.2	22.6	21.2	35.0	30.3	36.0	6.1	22.9	17.0	34.0	24.8	34.6
Esperstedt_MN	8.8	16.7	24.9	27.8	32.1	26.5	7.3	19.5	23.9	31.7	32.9	29.7
Baalberge_MN	5.6	18.1	23.4	26.5	31.4	26.5	4.8	22.4	23.5	33.2	34.6	32.6
Spain_MN	9.6	26.1	31.1	35.3	41.2	33.4	8.5	29.1	29.8	40.4	42.3	37.2
LBKT_EN	1.7	5.2	10.9	10.5	13.1	9.9	3.2	9.3	13.4	17.8	18.8	16.3
LBK_EN	8.4	19.5	36.7	38.1	45.9	36.8	8.7	24.3	38.2	45.4	48.7	42.9
Starcevo_EN	5.6	10.0	19.4	20.8	25.4	19.7	6.7	13.4	20.1	27.1	29.5	26.0
Spain_EN	9.1	20.9	33.7	35.5	43.7	33.8	8.8	25.5	34.1	43.2	48.0	40.1
Motala_HG	15.6	42.7	22.4	37.5	32.9	38.3	10.3	43.4	17.5	34.9	26.8	34.3
Karelia_HG	9.9	20.5	11.9	24.3	19.6	24.6	4.4	18.2	6.2	18.7	11.6	19.6
Samara_HG	9.5	19.0	12.5	23.3	18.6	24.9	4.9	17.6	8.1	20.7	13.1	21.7

D-statistic Tables

- D(Panel, Han; Panel, Mbuti).

	D(X, Han; Y, Mbuti)						D(Y, Han; X, Mbuti)					
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Spain_MN	9.6	26.1	31.1	35.3	41.2	33.4	8.5	29.1	29.8	40.4	42.3	37.2
LBKT_EN	1.7	5.2	10.9	10.5	13.1	9.9	3.2	9.3	13.4	17.8	18.8	16.3
LBK_EN	8.4	19.5	36.7	38.1	45.9	36.8	8.7	24.3	38.2	45.4	48.7	42.9
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Samara_HG	9.5	19.0	12.5	23.3	18.6	24.9	4.9	17.6	8.1	20.7	13.1	21.7

331427 SNPs

29205 SNPs

56866 SNPs

With whom within Europe do these sets form a clade?

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- EHG: Karelia, Samara
- SHG: Motala
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- MN/CA: Yamnaya, Esperstedt, Baalberge, Spain_MN
- LN: Alberstedt, BenzigerodeHeimburg, Bell Beaker, Karsdorf, Corded Ware
- BA/IA: Halberstadt, Unetice

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- SHG: Motala
- EN: LBK, LBKT, Starcevo, Spain_EN
- MN/CA: Yamnaya, Esperstedt, Baalberge, Spain_MN
- LN: Alberstedt, BenzigerodeHeimburg, Bell Beaker, Karsdorf, Corded Ware
- BA/IA: Halberstadt, Unetice

Some questions to consider:

- Do we see cladal relationships (or connections) correlating with time?
- Do we observe cladal relationships (or connections) correlating with geography?

Establishing a panel!

- This is very important and may take some effort to get a representative one that is still easy to study.
- May need different panels depending on question you're addressing.
- Here, we will use all ancient Europeans, along with the French, Sardinian, and English.

D(P1, Karelia; P3, Mbuti)

P1/P3	French	Sardinian	English	HungaryGamba_IA	Halberstadt_LBA	HungaryGamba_BA	Unetice_EBA	Alberstedt_LN	BenzigerodeHeimburg_LN	Bell_Beaker_LN	Karsdorf_LN	Corded_Ware_LN	HungaryGamba_CA	Yamnaya	SwedenSkoglund_NHG	SwedenSkoglund_MN	Iceman	Esperstedt_MN	Baalberge_MN	Spain_MN	Stuttgart	LBKT_EN	LBK_EN	HungaryGamba_EN	Starcevo_EN	Spain_EN	Loschbour	SwedenSkoglund_MHG	LaBrana1	HungaryGamba_HG	Motala_HG	Karelia_HG	Samara_HG	MA1	Kostenki14	Ust_Ishim
French	nan	10.0	2.2	-0.5	-2.0	0.8	-3.4	-2.9	-3.5	-2.4	-1.9	-6.9	6.1	-11.5	-9.0	4.4	6.1	3.0	5.3	3.0	9.3	2.3	8.6	9.2	5.9	7.5	-4.7	-3.1	-5.5	-4.9	-18.0	nan	-16.8	-13.5	-4.1	-2.7
Sardinian	2.9	nan	0.9	-1.2	-3.0	0.5	-5.1	-3.6	-5.1	-3.3	-3.3	-9.6	8.0	-15.5	-10.9	6.1	8.3	5.2	7.1	5.9	12.3	3.5	12.5	12.6	8.0	11.9	-6.3	-4.1	-7.0	-6.9	-21.1	nan	-20.1	-16.4	-4.8	-3.3
English	4.2	9.7	nan	-0.1	-1.1	0.8	-2.6	-2.1	-2.8	-1.5	-1.5	-5.7	5.7	-10.1	-8.7	4.5	5.9	3.0	5.7	2.8	9.1	2.1	8.0	8.5	5.6	6.9	-3.4	-2.4	-4.9	-4.0	-16.6	nan	-15.1	-12.6	-3.6	-2.2
HungaryGamba_IA	-0.4	3.5	-1.2	nan	-1.8	-0.6	-5.2	-3.1	-3.0	-2.5	-2.3	-6.0	2.8	-7.7	-6.6	0.8	1.5	1.3	1.8	-1.4	4.2	0.7	2.6	4.2	1.6	1.4	-4.9	-1.3	-5.0	-4.4	-14.1	nan	-11.6	-9.1	-3.5	-1.6
Halberstadt_LBA	2.0	5.6	1.5	0.5	nan	0.8	-0.2	0.4	-0.9	0.2	0.0	-2.2	3.0	-5.9	-7.7	3.4	3.8	5.2	4.1	4.9	5.2	1.3	8.2	5.4	3.8	5.9	-2.2	-2.4	-3.2	-2.7	-10.8	nan	-11.8	-10.6	-2.8	-1.0
HungaryGamba_BA	3.0	8.2	1.4	0.7	-0.8	nan	-2.3	-1.8	-2.5	-0.9	-0.6	-4.4	7.4	-8.2	-6.6	5.3	6.0	3.4	6.2	3.0	8.6	2.6	9.0	8.7	4.7	7.2	-1.1	-1.7	-2.5	-1.2	-12.4	nan	-12.9	-11.2	-2.9	-1.7
Unetice_EBA	3.3	7.6	2.2	-0.6	0.7	1.1	nan	0.3	-0.6	0.3	-1.1	-2.0	4.6	-6.3	-7.3	3.5	5.2	5.0	5.4	4.5	7.2	1.9	8.8	7.6	5.5	7.7	-3.1	-2.3	-4.5	-3.3	-11.9	nan	-12.7	-11.0	-3.1	-1.5
Alberstedt_LN	2.5	6.8	1.8	-0.1	1.1	1.1	0.7	nan	0.3	1.4	-0.8	-0.4	4.0	-4.6	-6.8	4.0	5.7	5.6	5.5	5.6	6.3	2.7	9.2	7.0	5.1	8.7	-3.4	-1.8	-3.7	-3.2	-8.7	nan	-9.2	-8.9	-2.0	-1.6
BenzigerodeHeimburg_LN	2.2	6.1	1.0	0.5	0.0	0.0	-0.7	0.3	nan	1.1	-0.5	-1.7	4.6	-5.8	-7.2	3.6	4.6	4.5	4.8	3.5	5.6	1.0	7.8	6.5	3.4	6.6	-2.9	-2.7	-2.8	-3.2	-11.3	nan	-10.8	-9.6	-1.6	-1.8
Bell_Beaker_LN	2.9	8.4	1.9	0.8	0.2	1.3	-0.9	0.0	-0.1	nan	-0.4	-2.8	5.2	-7.4	-7.6	3.8	6.2	4.1	4.9	4.7	8.3	2.1	9.3	8.1	4.9	8.1	-2.3	-2.9	-4.0	-2.8	-13.3	nan	-14.1	-11.8	-2.9	-1.9
Karsdorf_LN	1.3	2.3	1.0	-0.9	0.0	0.9	-0.6	-0.9	-0.7	0.0	nan	0.0	1.7	-1.4	-2.0	2.2	0.8	1.2	0.1	0.5	2.1	-0.7	2.9	3.1	0.0	1.2	-2.8	0.4	-3.4	-2.3	-6.4	nan	-5.6	-2.4	-0.8	-0.6
Corded_Ware_LN	2.5	5.5	2.0	-0.1	1.0	1.2	0.9	1.5	0.5	1.3	0.9	nan	4.1	-3.4	-7.6	2.0	3.7	5.2	4.3	3.0	6.1	0.7	7.2	5.4	3.5	6.0	-4.6	-2.0	-4.4	-4.5	-11.8	nan	-10.7	-8.4	-2.1	-1.0
HungaryGamba_CA	2.2	9.1	0.7	-0.1	-2.2	3.3	-3.6	-2.0	-1.2	-1.0	-1.9	-6.2	nan	-10.8	-6.1	4.2	5.9	5.1	6.5	4.1	9.6	2.5	10.4	11.5	6.0	8.5	-2.7	-1.6	-4.2	-2.8	-13.0	nan	-13.0	-10.7	-1.4	-2.8
Yamnaya	-0.1	1.4	-0.5	0.1	-1.0	-0.5	-1.5	-0.8	-1.3	-1.2	0.4	-1.6	1.3	nan	-9.3	-0.5	1.2	-0.4	0.2	-1.8	2.6	-0.2	1.8	1.6	1.2	1.1	-6.5	-2.5	-6.2	-5.8	-13.2	nan	-10.1	-7.4	-3.1	-1.3
SwedenSkoglund_NHG	3.8	6.1	2.5	1.9	-1.5	2.5	-0.1	-1.0	-0.3	0.8	0.3	-3.1	4.8	-6.4	nan	6.7	4.7	2.6	3.8	2.3	5.4	1.7	5.1	6.0	2.5	4.1	8.3	1.9	4.3	6.0	4.5	nan	-5.7	-7.0	-0.3	-1.2
SwedenSkoglund_MN	3.0	10.2	1.6	-0.3	-0.7	2.8	-2.2	-0.9	-1.5	-1.0	-0.6	-5.8	5.6	-10.2	-3.8	nan	8.8	5.0	6.6	7.1	9.7	2.6	10.6	10.3	5.0	10.5	-1.1	-1.2	-2.6	-2.4	-11.2	nan	-13.8	-12.5	-3.8	-2.1
Iceman	3.4	11.5	1.7	-0.8	-1.4	2.1	-2.3	-0.6	-2.1	-0.4	-2.2	-5.7	6.8	-10.9	-7.3	7.6	nan	5.7	7.5	8.6	10.9	4.8	13.6	12.7	8.7	12.0	-4.0	-2.2	-4.6	-4.0	-15.3	nan	-14.7	-13.8	-2.7	-2.5
Esperstedt_MN	4.6	12.1	3.1	0.6	3.0	3.3	1.5	2.7	1.1	1.8	-0.7	-0.5	7.6	-7.9	-5.9	6.4	8.8	nan	8.7	11.7	11.4	2.8	17.7	12.5	7.2	14.3	-1.9	-1.7	-2.2	-2.2	-9.3	nan	-11.5	-11.1	0.0	-0.4
Baalberge_MN	3.4	10.7	2.2	0.2	0.5	2.8	-0.6	0.0	-0.8	-0.4	-2.0	-4.5	7.4	-10.0	-6.1	6.1	7.7	6.7	nan	8.0	9.6	3.5	12.1	11.8	6.3	11.0	-1.8	-1.1	-3.4	-0.6	-11.3	nan	-12.2	-10.8	-3.1	-1.8
Spain_MN	3.4	12.9	1.6	-1.0	1.1	1.4	-0.9	0.7	-1.2	0.3	-2.0	-4.9	7.4	-11.5	-8.4	8.0	10.5	10.6	9.5	nan	11.4	4.1	16.1	12.3	9.8	18.4	-1.0	-2.9	-1.7	-3.0	-13.1	nan	-17.0	-15.2	-2.1	-1.7
Stuttgart	2.8	11.7	1.4	-0.5	-2.1	2.0	-3.9	-2.4	-4.1	-1.6	-3.0	-6.5	8.3	-12.5	-9.0	6.4	8.0	6.0	7.1	5.7	nan	4.5	14.3	13.7	7.8	11.0	-6.3	-3.7	-7.3	-5.5	-16.8	nan	-16.4	-14.5	-2.8	-1.7
LBKT_EN	0.2	3.7	-0.2	-1.5	-1.6	0.3	-1.6	-0.1	-2.4	-0.6	-1.1	-3.9	2.2	-6.9	-5.3	1.8	4.4	0.5	3.6	2.0	4.4	nan	5.2	4.7	5.5	4.0	-4.6	-0.7	-4.2	-3.1	-8.2	nan	-6.2	-6.7	-1.2	-3.1
LBK_EN	2.8	13.7	0.6	-1.2	-0.4	2.3	-2.7	-0.6	-2.5	-1.1	-2.3	-6.6	9.7	-14.3	-10.6	7.1	11.1	10.6	9.2	10.1	14.9	4.8	nan	16.3	11.3	16.1	-8.1	-4.1	-7.7	-6.9	-19.5	nan	-19.6	-17.1	-4.2	-2.5
HungaryGamba_EN	2.8	12.8	0.5	-0.8	-2.8	1.6	-4.3	-2.3	-3.7	-2.4	-2.9	-8.5	9.6	-15.1	-9.6	6.8	10.0	6.4	9.3	6.5	13.6	4.4	15.6	nan	9.8	12.8	-6.5	-4.7	-7.1	-5.3	-19.4	nan	-18.9	-14.8	-3.8	-2.8
Starcevo_EN	2.5	8.9	1.2	-0.2	-0.5	0.9	-0.8	0.5	-2.3	-0.9	-2.9	-4.0	7.1	-7.9	-6.4	3.0	6.8	5.2	5.1	6.7	9.1	3.9	11.7	10.6	nan	9.6	-5.2	-1.6	-4.6	-3.5	-12.3	nan	-9.6	-8.1	-1.9	-0.8
Spain_EN	3.3	14.3	1.1	-1.4	-0.7	1.6	-1.9	0.5	-1.7	-0.4	-2.5	-5.6	8.5	-12.5	-9.5	8.2	10.8	9.5	9.3	13.7	13.2	4.5	17.3	14.9	9.5	nan	-5.5	-3.3	-5.4	-5.0	-16.9	nan	-18.5	-15.5	-2.9	-2.2
Loschbour	5.2	8.3	4.8	1.6	1.8	5.0	1.0	-0.5	0.9	2.9	-1.0	-3.3	6.7	-6.7	5.4	7.3	5.1	4.0	6.9	7.3	5.3	1.4	4.2	6.4	2.8	5.7	nan	2.5	18.2	15.0	5.6	nan	-8.2	-8.4	3.9	1.3
SwedenSkoglund_MHG	0.8	1.6	0.3	0.4	0.3	-0.1	0.4	-0.3	-0.1	-0.3	1.2	-1.3	2.3	-3.2	1.4	0.9	1.7	0.5	0.7	0.1	1.8	-0.2	1.5	1.0	1.2	1.0	1.6	nan	1.5	2.4	-1.9	nan	-2.2	-2.4	-1.2	-0.4
LaBrana1	1.8	4.7	0.8	-1.0	-0.4	2.0	-2.3	-1.7	-0.4	-0.7	-2.0	-4.4	3.6	-7.9	0.5	3.9	3.2	2.4	3.8	4.9	2.6	0.3	2.8	3.8	1.8	3.8	16.3	1.8	nan	8.2	-0.5	nan	-8.0	-7.4	3.1	1.1
HungaryGamba_HG	4.3	6.4	3.8	1.0	1.0	4.3	0.8	-0.3	0.4	2.1	-0.2	-2.9	5.0	-5.2	4.6	5.1	4.8	2.6	5.9	5.0	5.5	0.3	4.8	6.9	2.7	5.1	15.7	1.8	9.7	nan	4.3	nan	-6.1	-7.5	1.4	-0.3
Motala_HG	4.6	6.2	3.9	1.0	2.1	3.8	3.5	3.3	2.9	3.0	0.8	0.3	5.7	-2.6	8.6	5.9	4.3	6.2	5.8	6.5	6.0	0.8	6.5	5.6	2.9	6.2	13.1	3.2	8.6	10.6	nan	nan	-3.4	-5.2	1.7	0.6
Karelia_HG	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
Samara_HG	0.9	0.4	1.2	0.6	-0.3	0.4	0.8	1.1	0.8	-0.1	0.0	-0.2	0.6	0.7	-0.3	-0.5	0.1	0.3	0.4	-1.7	1.5	0.2	0.3	0.8	0.8	-0.9	0.0	0.1	0.4	1.7	-0.3	nan	nan	-0.3	0.1	0.7
MA1	-6.9	-6.4	-6.7	-3.4	-7.5	-6.0	-8.0	-6.2	-6.1	-8.6	-0.4	-7.5	-2.7	-7.5	-9.0	-5.0	-5.8	-6.7	-3.8	-9.1	-3.8	-2.3	-7.7	-4.3	-3.0	-7.4	-7.8	-3.3	-6.4	-7.0	-11.6	nan	-5.6	nan	0.4	2.4
Kostenki14	-12.5	-8.7	-12.4	-8.1	-10.5	-9.6	-14.5	-10.1	-10.7	-12.8	-6.0	-15.3	-3.2	-18.5	-13.4	-6.8	-5.3	-6.1	-6.3	-8.6	-3.8	-2.4	-7.8	-6.5	-1.9	-6.9	-7.4	-5.7	-7.0	-9.1	-20.0	nan	-16.6	-10.3	nan	1.2
Ust_Ishim	-23.8	-19.1	-23.7	-14.6	-17.0	-17.7	-24.6	-19.0	-21.5	-23.0	-11.0	-24.9	-11.7	-27.0	-22.8	-13.4	-13.2	-14.3	-12.7	-18.7	-11.8	-7.1	-16.7	-15.8	-8.2	-17.1	-18.3	-10.9	-17.4	-19.0	-31.9	nan	-24.0	-15.9	-6.8	nan

D(P1, P2; Karelia, Mbuti)

P1/P2	French	Sardinian	English	HungaryGamba_IA	Halberstadt_LBA	HungaryGamba_BA	Unetice_EBA	Alberstedt_LN	BenzigerodeHeimburg_LN	Bell_Beaker_LN	Karsdorf_LN	Corded_Ware_LN	HungaryGamba_CA	Yamnaya	SwedenSkoglund_NHG	SwedenSkoglund_MN	Iceman	Esperstedt_MN	Baalberge_MN	Spain_MN	Stuttgart	LBKT_EN	LBK_EN	HungaryGamba_EN	Starcevo_EN	Spain_EN	Loschbour	SwedenSkoglund_MHG	LaBrana1	HungaryGamba_HG	Motala_HG	Karelia_HG	Samara_HG	MA1	Kostenki14	Ust_Ishim
French	nan	15.5	-3.7	-0.2	-3.7	-1.9	-9.1	-4.9	-5.9	-6.6	-2.9	-11.0	4.5	-15.9	-12.7	2.0	3.6	-0.7	2.6	-0.2	7.2	2.1	9.5	9.0	3.6	5.4	-9.2	-3.9	-7.3	-8.4	-27.9	nan	-17.1	-7.9	6.4	18.0
Sardinian	-15.5	nan	-15.5	-4.1	-7.8	-7.1	-16.6	-9.2	-11.5	-13.7	-5.1	-17.0	0.3	-21.3	-16.5	-2.2	-0.9	-5.0	-1.8	-7.5	2.1	0.3	-0.5	1.1	0.4	-2.0	-13.5	-5.6	-11.5	-12.1	-32.9	nan	-19.9	-11.2	2.6	13.7
English	3.7	15.5	nan	0.9	-2.4	-0.4	-6.2	-3.6	-4.1	-4.2	-2.3	-9.0	5.3	-12.5	-11.3	3.2	4.6	0.4	4.0	1.6	8.4	2.2	10.4	10.3	4.4	6.8	-7.7	-2.7	-5.8	-7.3	-25.2	nan	-15.8	-6.9	7.3	18.6
HungaryGamba_IA	0.2	4.1	-0.9	nan	-2.2	-1.2	-3.8	-2.8	-3.3	-3.0	-1.5	-5.2	2.8	-6.5	-8.1	1.1	2.3	0.7	1.6	-0.3	4.7	2.1	3.5	4.5	1.8	2.7	-6.1	-1.6	-4.1	-5.5	-13.8	nan	-12.5	-6.4	4.5	12.5
Halberstadt_LBA	3.7	7.8	2.4	2.2	nan	1.6	-0.8	-0.8	-0.8	0.0	0.0	-3.0	5.3	-4.3	-6.4	4.0	5.2	2.0	3.3	3.3	7.5	2.7	7.4	7.6	4.2	5.9	-4.0	-2.7	-2.8	-3.7	-12.5	nan	-11.0	-3.5	7.2	16.7
HungaryGamba_BA	1.9	7.1	0.4	1.2	-1.6	nan	-3.3	-2.7	-2.4	-2.2	-1.5	-5.6	4.4	-7.4	-8.9	2.6	4.1	0.2	3.3	1.4	6.8	2.4	6.6	6.7	3.5	4.9	-6.0	-1.6	-4.4	-5.4	-16.0	nan	-13.1	-5.6	6.1	15.7
Unetice_EBA	9.1	16.6	6.2	3.8	0.8	3.3	nan	-0.3	0.1	1.3	-0.6	-3.2	8.1	-5.8	-7.5	5.5	7.6	3.6	6.1	6.1	11.2	3.2	13.6	13.1	6.1	10.5	-4.0	-2.7	-2.4	-3.9	-18.2	nan	-13.3	-3.8	9.5	20.9
Alberstedt_LN	4.9	9.2	3.6	2.8	0.8	2.7	0.3	nan	0.0	1.2	0.0	-1.8	6.0	-3.3	-5.7	4.8	6.2	3.0	5.5	4.2	8.4	2.6	8.5	8.8	4.5	7.2	-3.0	-1.4	-1.9	-2.9	-10.9	nan	-9.9	-2.9	7.8	16.9
BenzigerodeHeimburg_LN	5.9	11.5	4.1	3.3	0.8	2.4	-0.1	0.0	nan	1.2	0.1	-2.2	5.9	-4.2	-7.0	4.9	6.5	3.2	5.6	4.5	9.3	3.3	10.3	10.3	5.4	8.2	-3.8	-2.6	-2.5	-3.6	-14.2	nan	-11.2	-4.1	8.2	18.2
Bell_Beaker_LN	6.6	13.7	4.2	3.0	0.0	2.2	-1.3	-1.2	-1.2	nan	-0.5	-4.4	6.3	-6.8	-8.5	4.7	6.6	2.6	5.4	4.8	9.6	2.6	11.8	11.5	5.9	9.1	-5.0	-2.7	-3.4	-4.6	-18.2	nan	-13.3	-4.4	8.6	19.7
Karsdorf_LN	2.9	5.1	2.3	1.5	0.0	1.5	0.6	0.0	-0.1	0.5	nan	-0.9	3.4	-1.5	-2.3	2.7	3.0	2.0	2.1	2.4	5.0	0.4	4.7	5.5	2.8	3.7	-1.6	-0.9	-1.2	-2.0	-5.9	nan	-5.4	-2.0	5.3	9.9
Corded_Ware_LN	11.0	17.0	9.0	5.2	3.0	5.6	3.2	1.8	2.2	4.4	0.9	nan	10.0	-1.8	-5.0	7.2	9.2	5.4	8.5	8.2	13.0	4.3	15.2	15.6	7.4	12.3	-1.6	-0.9	-0.4	-1.9	-13.2	nan	-10.3	-1.8	11.4	21.7
HungaryGamba_CA	-4.5	-0.3	-5.3	-2.8	-5.3	-4.4	-8.1	-6.0	-5.9	-6.3	-3.4	-10.0	nan	-10.8	-11.1	-1.6	-0.8	-2.6	-1.0	-3.7	0.9	0.1	-0.6	0.3	-1.0	-0.9	-9.4	-3.9	-7.7	-7.7	-18.3	nan	-13.6	-8.0	1.9	9.3
Yamnaya	15.9	21.3	12.5	6.5	4.3	7.4	5.8	3.3	4.2	6.8	1.5	1.8	10.8	nan	-4.0	8.6	11.0	6.5	9.3	10.2	14.5	6.1	18.3	17.9	8.4	14.3	-0.6	0.1	0.8	-1.3	-12.7	nan	-10.6	-1.0	13.1	23.7
SwedenSkoglund_NHG	12.7	16.5	11.3	8.1	6.4	8.9	7.5	5.7	7.0	8.5	2.3	5.0	11.1	4.0	nan	10.6	11.9	8.1	9.9	10.6	14.3	6.9	15.8	15.2	8.8	13.5	2.8	0.5	3.9	1.5	-4.8	nan	-5.2	1.9	13.1	22.6
SwedenSkoglund_MN	-2.0	2.2	-3.2	-1.1	-4.0	-2.6	-5.5	-4.8	-4.9	-4.7	-2.7	-7.2	1.6	-8.6	-10.6	nan	1.4	-1.6	0.4	-1.6	3.0	0.7	2.0	2.4	1.8	1.0	-8.0	-2.1	-6.7	-7.2	-16.8	nan	-13.4	-7.5	3.2	11.7
Iceman	-3.6	0.9	-4.6	-2.3	-5.2	-4.1	-7.6	-6.2	-6.5	-6.6	-3.0	-9.2	0.8	-11.0	-11.9	-1.4	nan	-3.0	-0.2	-3.2	2.1	0.3	0.7	1.4	1.4	-0.2	-9.2	-3.9	-7.9	-8.7	-19.0	nan	-14.9	-8.5	2.6	11.1
Esperstedt_MN	0.7	5.0	-0.4	-0.7	-2.0	-0.2	-3.6	-3.0	-3.2	-2.6	-2.0	-5.4	2.6	-6.5	-8.1	1.6	3.0	nan	1.6	0.4	5.4	2.2	4.4	5.0	2.0	3.5	-5.9	-2.3	-4.7	-4.9	-14.1	nan	-11.8	-4.9	5.9	13.8
Baalberge_MN	-2.6	1.8	-4.0	-1.6	-3.3	-3.3	-6.1	-5.5	-5.6	-5.4	-2.1	-8.5	1.0	-9.3	-9.9	-0.4	0.2	-1.6	nan	-2.1	2.6	-0.2	1.5	1.7	1.0	0.8	-8.4	-1.8	-7.4	-6.1	-16.5	nan	-12.7	-7.5	2.7	10.3
Spain_MN	0.2	7.5	-1.6	0.3	-3.3	-1.4	-6.1	-4.2	-4.5	-4.8	-2.4	-8.2	3.7	-10.2	-10.6	1.6	3.2	-0.4	2.1	nan	6.2	2.2	6.6	6.7	3.3	4.5	-7.9	-3.0	-6.6	-7.5	-20.7	nan	-14.6	-6.9	5.8	16.1
Stuttgart	-7.2	-2.1	-8.4	-4.7	-7.5	-6.8	-11.2	-8.4	-9.3	-9.6	-5.0	-13.0	-0.9	-14.5	-14.3	-3.0	-2.1	-5.4	-2.6	-6.2	nan	0.1	-2.2	-1.3	-0.9	-3.0	-11.7	-5.3	-10.1	-10.8	-22.9	nan	-17.2	-10.8	0.9	10.0
LBKT_EN	-2.1	-0.3	-2.2	-2.1	-2.7	-2.4	-3.2	-2.6	-3.3	-2.6	-0.4	-4.3	-0.1	-6.1	-6.9	-0.7	-0.3	-2.2	0.2	-2.2	-0.1	nan	0.0	0.0	1.7	-0.8	-5.7	-0.6	-4.5	-3.3	-8.2	nan	-6.1	-4.7	1.1	4.1
LBK_EN	-9.5	0.5	-10.4	-3.5	-7.4	-6.6	-13.6	-8.5	-10.3	-11.8	-4.7	-15.2	0.6	-18.3	-15.8	-2.0	-0.7	-4.4	-1.5	-6.6	2.2	0.0	nan	1.3	0.8	-1.4	-12.4	-5.5	-10.7	-11.0	-29.1	nan	-19.0	-10.7	2.8	13.4
HungaryGamba_EN	-9.0	-1.1	-10.3	-4.5	-7.6	-6.7	-13.1	-8.8	-10.3	-11.5	-5.5	-15.6	-0.3	-17.9	-15.2	-2.4	-1.4	-5.0	-1.7	-6.7	1.3	0.0	-1.3	nan	-0.1	-2.4	-12.7	-5.5	-10.9	-11.8	-27.9	nan	-19.0	-11.2	2.1	11.9
Starcevo_EN	-3.6	-0.4	-4.4	-1.8	-4.2	-3.5	-6.1	-4.5	-5.4	-5.9	-2.8	-7.4	1.0	-8.4	-8.8	-1.8	-1.4	-2.0	-1.0	-3.3	0.9	-1.7	-0.8	0.1	nan	-0.8	-7.9	-2.8	-6.6	-6.2	-13.9	nan	-10.8	-5.3	0.0	7.2
Spain_EN	-5.4	2.0	-6.8	-2.7	-5.9	-4.9	-10.5	-7.2	-8.2	-9.1	-3.7	-12.3	0.9	-14.3	-13.5	-1.0	0.2	-3.5	-0.8	-4.5	3.0	0.8	1.4	2.4	0.8	nan	-11.2	-4.3	-9.3	-9.9	-24.4	nan	-17.1	-9.6	3.3	13.5
Loschbour	9.2	13.5	7.7	6.1	4.0	6.0	4.0	3.0	3.8	5.0	1.6	1.6	9.4	0.6	-2.8	8.0	9.2	5.9	8.4	7.9	11.7	5.7	12.4	12.7	7.9	11.2	nan	0.9	1.4	-0.1	-8.3	nan	-7.9	-0.7	11.6	20.4
SwedenSkoglund_MHG	3.9	5.6	2.7	1.6	2.7	1.6	2.7	1.4	2.6	2.7	0.9	0.9	3.9	-0.1	-0.5	2.1	3.9	2.3	1.8	3.0	5.3	0.6	5.5	5.5	2.8	4.3	-0.9	nan	-0.4	0.7	-4.8	nan	-2.2	1.0	4.3	11.1
LaBrana1	7.3	11.5	5.8	4.1	2.8	4.4	2.4	1.9	2.5	3.4	1.2	0.4	7.7	-0.8	-3.9	6.7	7.9	4.7	7.4	6.6	10.1	4.5	10.7	10.9	6.6	9.3	-1.4	0.4	nan	-1.1	-9.4	nan	-8.5	-1.5	10.1	19.3
HungaryGamba_HG	8.4	12.1	7.3	5.5	3.7	5.4	3.9	2.9	3.6	4.6	2.0	1.9	7.7	1.3	-1.5	7.2	8.7	4.9	6.1	7.5	10.8	3.3	11.0	11.8	6.2	9.9	0.1	-0.7	1.1	nan	-6.9	nan	-7.7	-0.7	10.6	18.3
Motala_HG	27.9	32.9	25.2	13.8	12.5	16.0	18.2	10.9	14.2	18.2	5.9	13.2	18.3	12.7	4.8	16.8	19.0	14.1	16.5	20.7	22.9	8.2	29.1	27.9	13.9	24.4	8.3	4.8	9.4	6.9	nan	nan	-3.1	5.4	20.2	31.0
Karelia_HG	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
Samara_HG	17.1	19.9	15.8	12.5	11.0	13.1	13.3	9.9	11.2	13.3	5.4	10.3	13.6	10.6	5.2	13.4	14.9	11.8	12.7	14.6	17.2	6.1	19.0	19.0	10.8	17.1	7.9	2.2	8.5	7.7	3.1	nan	nan	5.4	15.8	24.7
MA1	7.9	11.2	6.9	6.4	3.5	5.6	3.8	2.9	4.1	4.4	2.0	1.8	8.0	1.0	-1.9	7.5	8.5	4.9	7.5	6.9	10.8	4.7	10.7	11.2	5.3	9.6	0.7	-1.0	1.5	0.7	-5.4	nan	-5.4	nan	10.9	18.4
Kostenki14	-6.4	-2.6	-7.3	-4.5	-7.2	-6.1	-9.5	-7.8	-8.2	-8.6	-5.3	-11.4	-1.9	-13.1	-13.1	-3.2	-2.6	-5.9	-2.7	-5.8	-0.9	-1.1	-2.8	-2.1	0.0	-3.3	-11.6	-4.3	-10.1	-10.6	-20.2	nan	-15.8	-10.9	nan	8.6
Ust_Ishim	-18.0	-13.7	-18.6	-12.5	-16.7	-15.7	-20.9	-16.9	-18.2	-19.7	-9.9	-21.7	-9.3	-23.7	-22.6	-11.7	-11.1	-13.8	-10.3	-16.1	-10.0	-4.1	-13.4	-11.9	-7.2	-13.5	-20.4	-11.1	-19.3	-18.3	-31.0	nan	-24.7	-18.4	-8.6	nan

With whom within Europe do these sets form a clade?

- To begin, we are going to assume each of these sets designated by Haak et al. (2015) in the 'ind' file form a clade.
- EHG: Karelia, Samara
- SHG: Motala
- EN: **<u>LBK,</u>** LBKT, **<u>Starcevo, Spain_EN</u>**
- MN/CA: **<u>Yamnaya, Esperstedt, Baalberge, Spain_MN</u>**
- LN: **<u>Alberstedt, BenzigerodeHeimburg, Bell Beaker,</u>** Karsdorf, **<u>Corded Ware</u>**
- BA/IA: **<u>Halberstadt, Unetice</u>**

Divide up the rest, provide Excel tables: Can you find other cladal relationships?

Conclusions (Fill in!)

Comparing to Haak et al. (2015)

MN: More Baalberge (but also Esperstedt) have more connections to WHG than EN

LN: Alberstedt: Corded Ware, Esperstedt, Motala Benzigerode and Bell beaker: addtl Loschbour

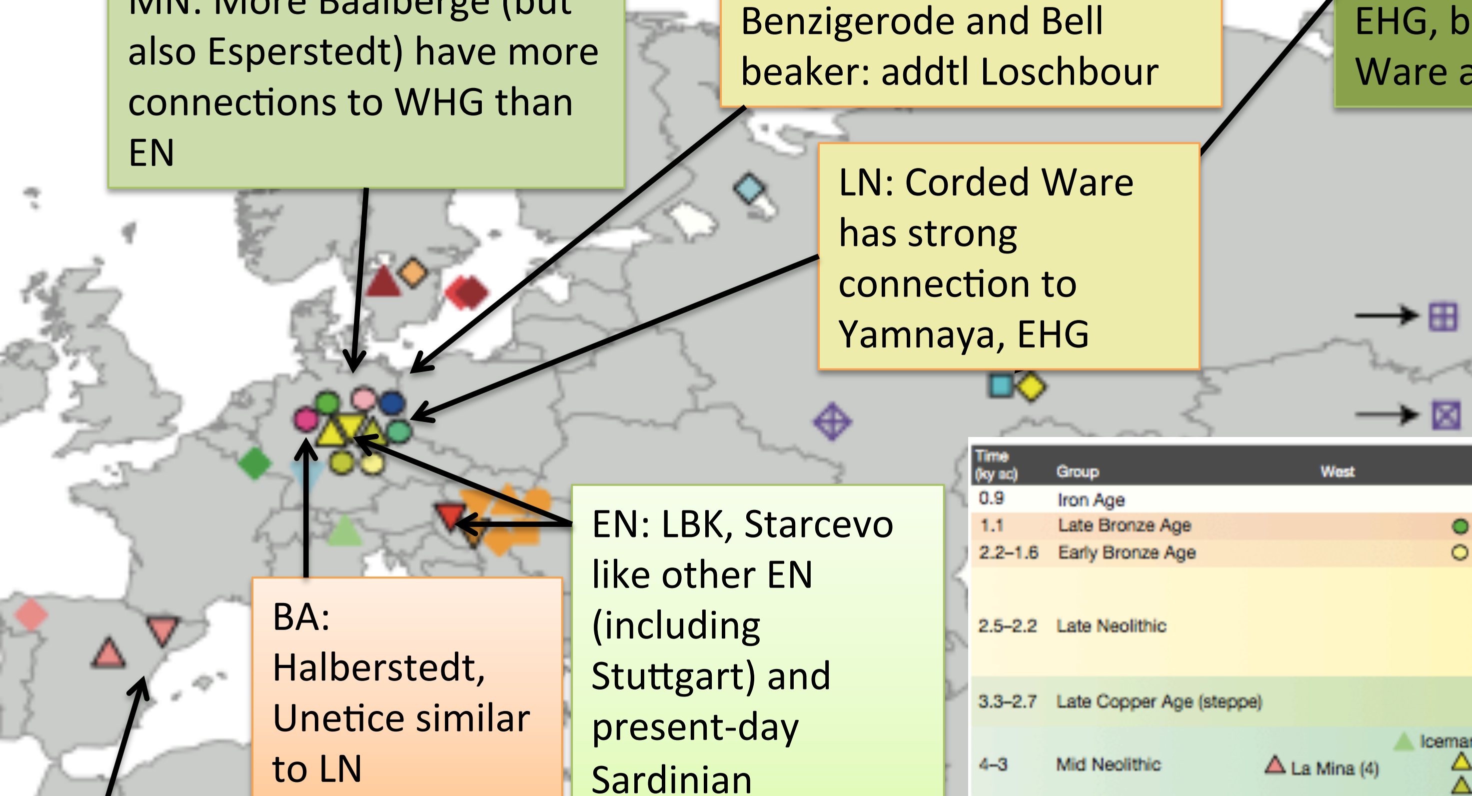
CA: Yamnaya has strong connections to Mal'ta1 and EHG, but also to Corded Ware and others in LN

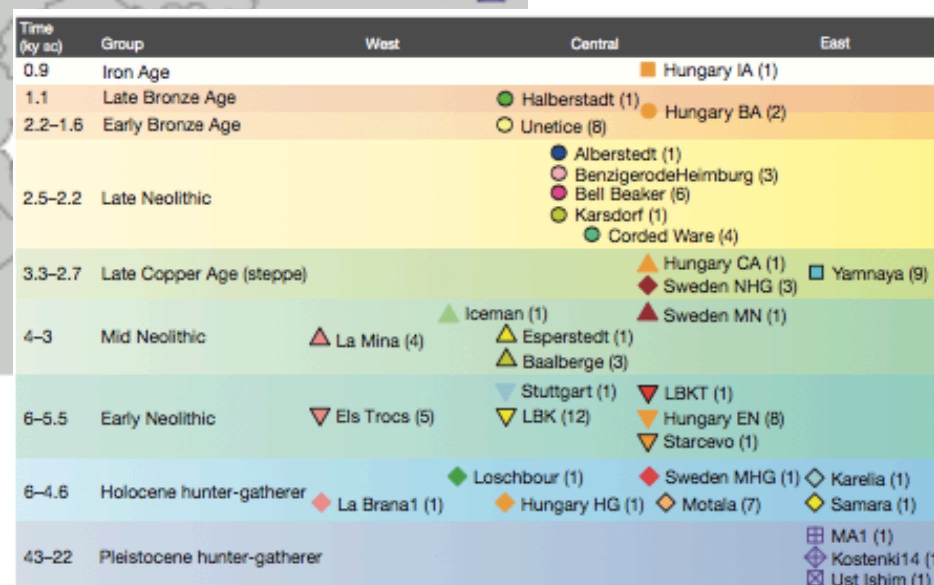
LN: Corded Ware has strong connection to Yamnaya, EHG

EN: LBK, Starcevo like other EN (including Stuttgart) and present-day Sardinian

BA: Halberstedt, Unetice similar to LN

Spain EN and MN very similar patterns to EN and MN in Germany





Time (ky BC)	Group	West	Central	East
0.9	Iron Age		Hungary IA (1)	
1.1	Late Bronze Age		Halberstadt (1); Hungary BA (2)	
2.2–1.6	Early Bronze Age		Unetice (8)	
2.5–2.2	Late Neolithic		Alberstedt (1); BenzigerodeHeimburg (3); Bell Beaker (6); Karsdorf (1); Corded Ware (4)	
3.3–2.7	Late Copper Age (steppe)		Hungary CA (1); Sweden NHG (3)	Yamnaya (9)
4–3	Mid Neolithic	La Mina (4)	Iceman (1); Esperstedt (1); Baalberge (3); Sweden MN (1)	
6–5.5	Early Neolithic	Els Trocs (5)	Stuttgart (1); LBK (12); LBKT (1); Hungary EN (8); Starcevo (1)	
6–4.6	Holocene hunter-gatherer	La Brana1 (1)	Loschbour (1); Hungary HG (1); Sweden MHG (1); Motala (7)	Karelia (1); Samara (1)
43–22	Pleistocene hunter-gatherer			MA1 (1); Kostenki14 (1); Ust Ishim (1)

What about admixture?

1. Our lesson shows strong connections, but not all clade-like relationships.
2. Does admixture play a role?
3. Continue studying D-statistics and testing for admixture with Hassan in Lesson 8 (Monday).
   - Think about, if assume clade, the symmetric case.
   - Not a sharp division in D-stats, lots of back and forth

qpDstat

- Required command is:
  - qpDstat –p [parfilename] > [logfilename]

```
[mel_yang@comput14 mel_yang]$ cat masterlogfiles/Haaketal2015/data.eigen.D.Internal_all.par
genotypename:   /mnt/solexa/mel_yang/data/Haak2015PublicData/data.eigen.geno
snpname:        /mnt/solexa/mel_yang/data/Haak2015PublicData/data.eigen.snp
indivname:      /mnt/solexa/mel_yang/data/Haak2015PublicData/data.eigen.ind
popfilename:    /mnt/solexa/mel_yang/masterlogfiles/Haaketal2015/data.eigen.D.Internal_all.pop
printsd:        YES
```

```
[mel_yang@comput14 mel_yang]$ head masterlogfiles/Haaketal2015/data.eigen.D.Internal_all.pop
MA1 LBK_EN LateDorset Mbuti
MA1 LBK_EN HungaryGamba_IA Mbuti
MA1 LBK_EN SwedenSkoglund_NHG Mbuti
MA1 LBK_EN Alberstedt_LN Mbuti
MA1 LBK_EN Esperstedt_MN Mbuti
MA1 LBK_EN LBKT_EN Mbuti
MA1 LBK_EN Motala_HG Mbuti
MA1 LBK_EN Kostenki14 Mbuti
MA1 LBK_EN AG2 Mbuti
MA1 LBK_EN Unetice_EBA Mbuti
```

Questions?