Computer Aided Archaeology

11 - 14C Calibration 2

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Improving information gain using OxCal

Precision

- Combine
- Wiggle Matching

Derived information

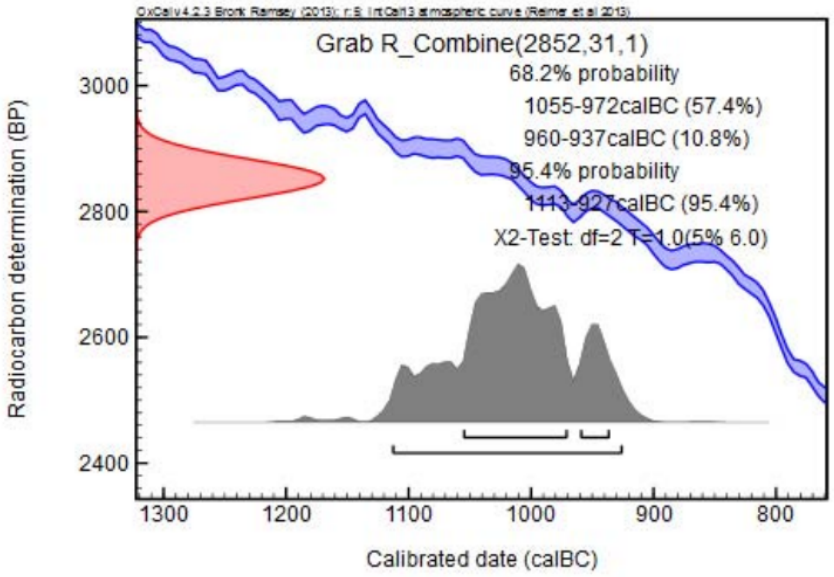
- Summed Probability
- Duration

Stratigraphical Modelling

- Sequential Calibration

Combine

- calculates the probability distribution for a specific event using multiple measurements
- goal: get a better estimation for the event by combining the dates
- is essentially similar to "measuring longer"



- has a strong assumption:
  - all dates actually refer to the same event
- can actually only be used if the samples have been taken from the same object
  - Measurements from several bones of the same individual
  - Measurements of several grains from one depot
- is sometimes also done, but it is questionable:
  - Measurements of bones and grains from the same grave
  - Problem: Bones accumulate the 14C signal over a longer periode and do not precisely reflect the time of death!

Combine

An experiment

two measurements of the same bone of an individual, died 1950 (14C) years ago

Simulation in R:

```
sample1 <- rnorm(1,1950, 25)
sample1
```

```
## [1] 1952.187
```

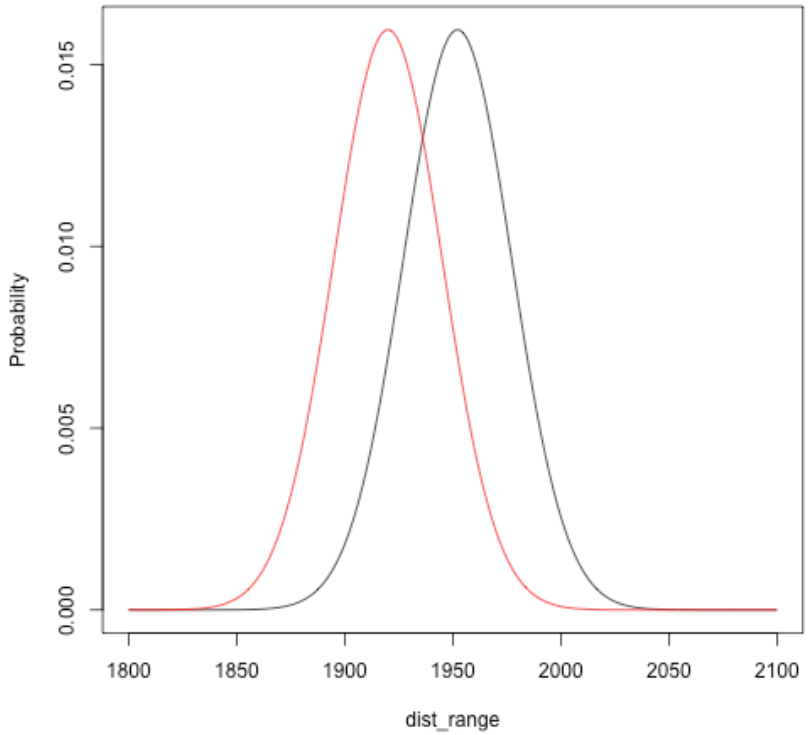
```
sample2 <- rnorm(1,1950, 25)
sample2
```

```
## [1] 1920.018
```

Combine

An experiment

The Measurements will look like this

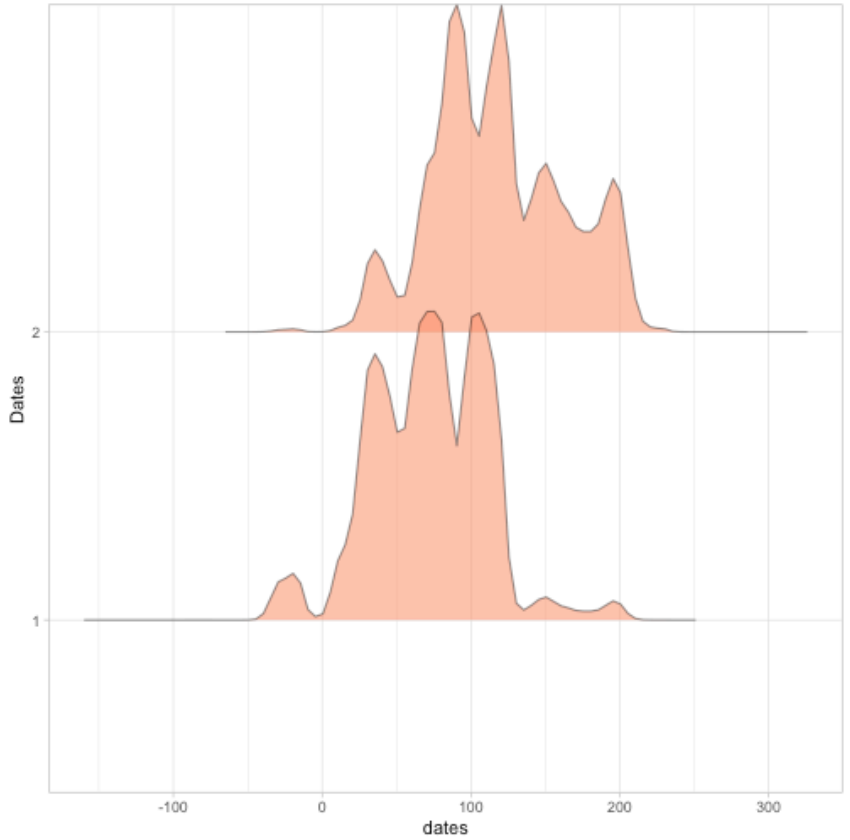


Combine

An experiment

Calibration individually

```
## NULL
```



Combine

An experiment

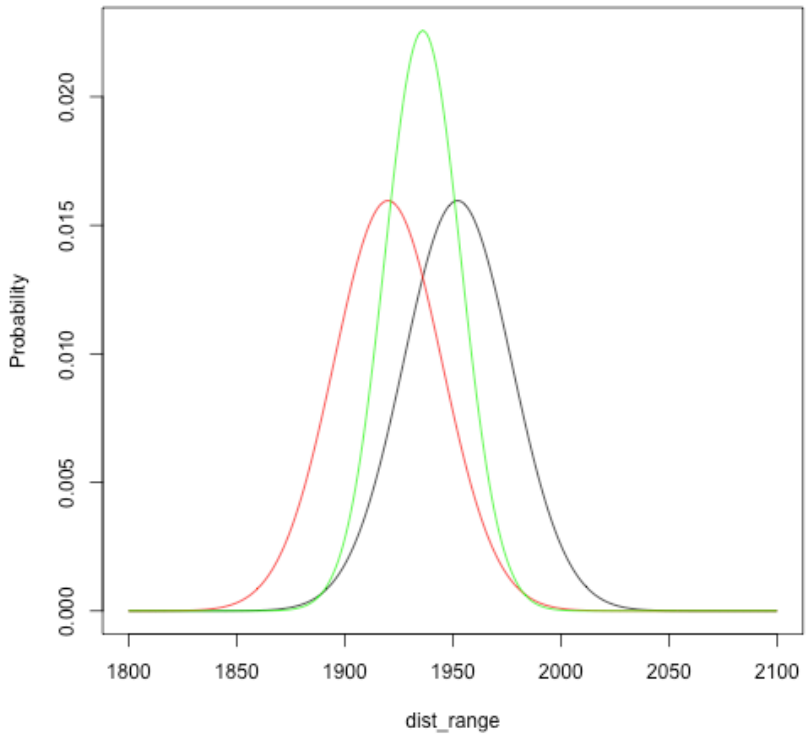
Now we combine the measurements:

$$p_{comb} = p_1 * p_2$$

Or more general:

$$p_{comb} = \prod_i p_i$$

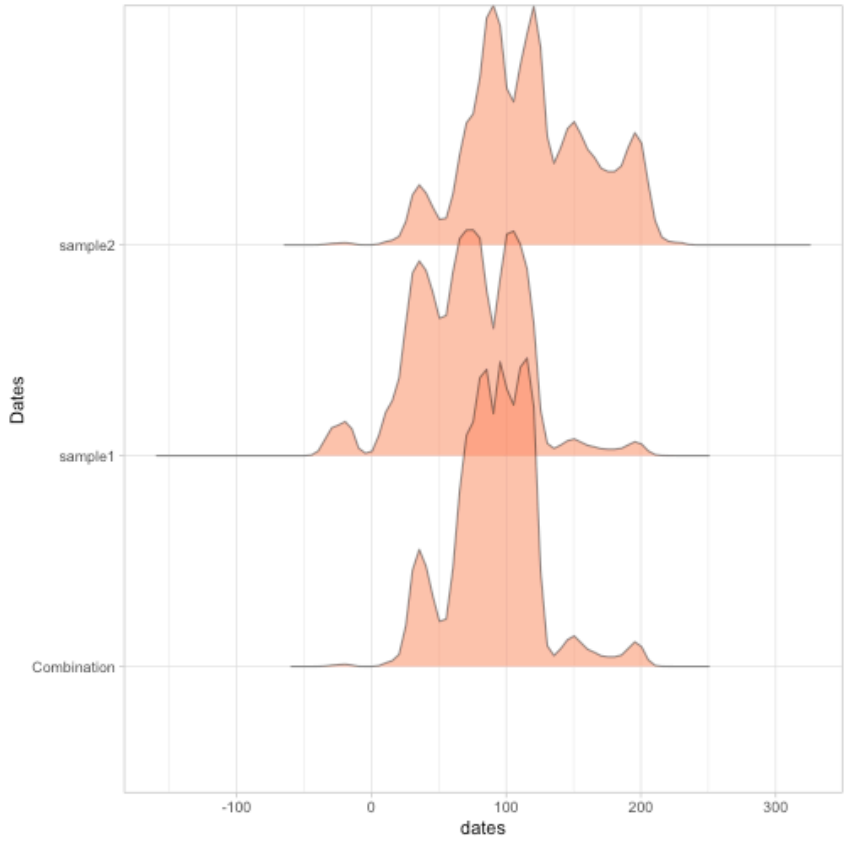
```
dist_range <- 1800:2100
comb <- dnorm(
    dist_range, mean = sample1, sd=2
    ) *
  dnorm(
    dist_range, mean = sample2, sd=2
    )
comb <- comb/sum(comb)
```



Combine

An experiment

And calibrate the combination:



Combine

If a single process can be more accurately dated by several dates:

- e.g. the dating of a single grave can be estimated more precisely, if more than one date of the buried person (equal to - body!) is present
- Same event - multiple dates for it
- Works without Bayes: Assumption: The dates of dating all should be equal (Bayes gets even better...)

Attention: Never combine if you are not sure that there are the event is actually one and the same (Simultaneity!)

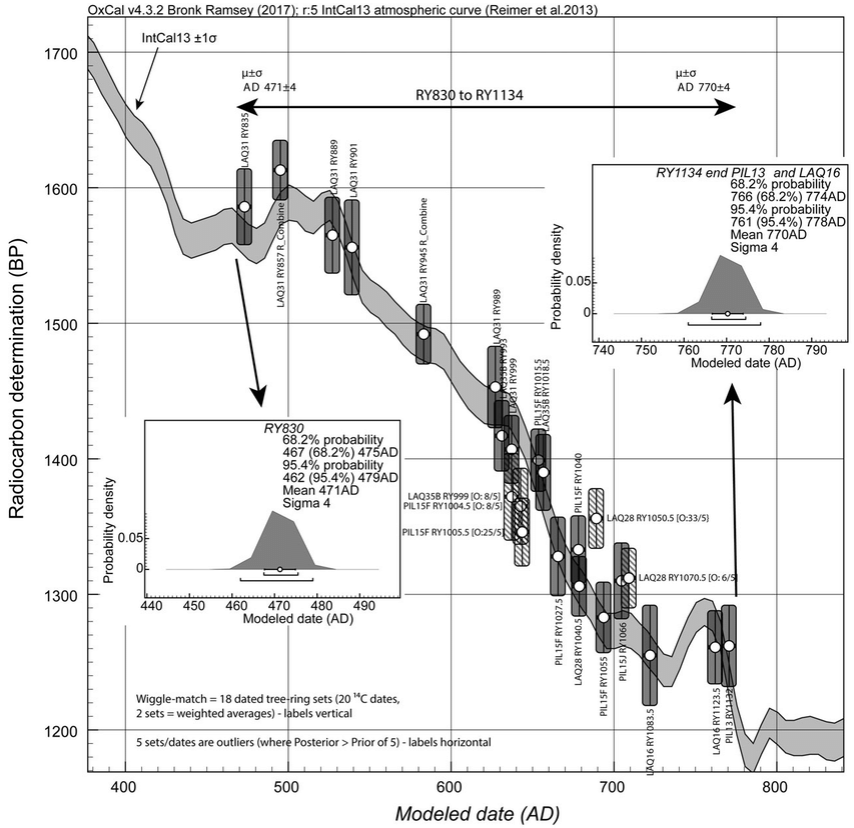
```
Combine("C")
{
 R_Date("A",2000,20);
 R_Date("B",2020,30);
};
```

Wiggle Matching

If we know the (relative/absolute) temporal distance between events:

- e.g. tree rings: we know, how many years passed between individual samples
- e.g. depositional processes: we know the relative distance between samples
- Works without Bayes, but also (very well) with Bayes

Attention: Again, we make strong assumptions about the temporal arrangements of our samples!

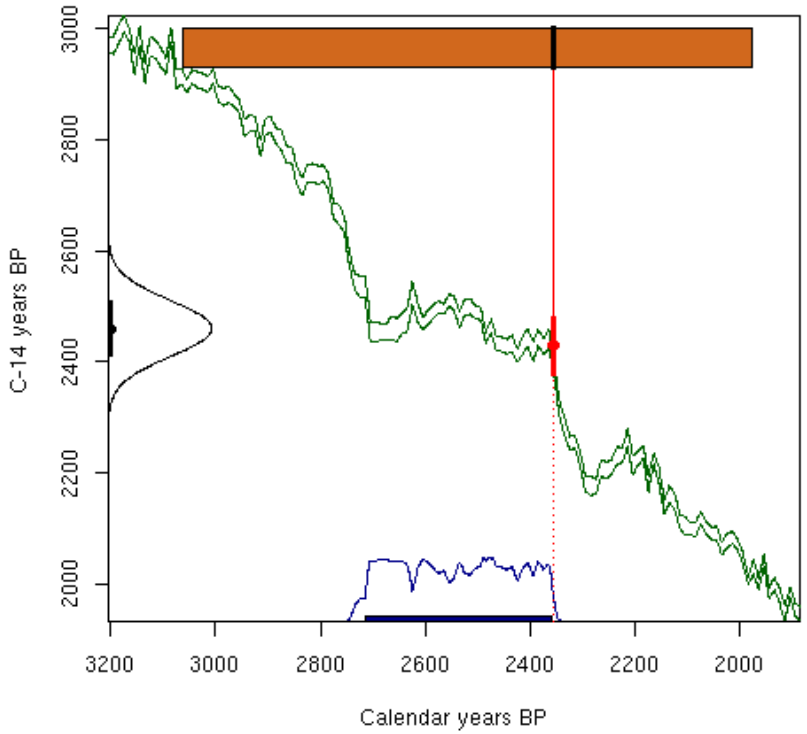


Source: Turkon et al. 2017

Wiggle Matching

How it works

If we have just one date, straight forward calibration:

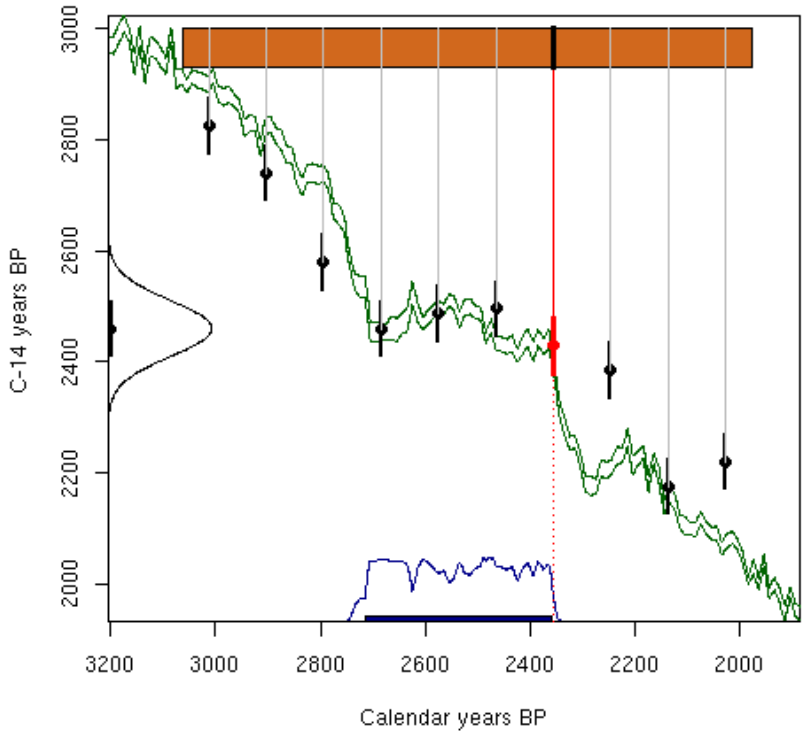


Source: Maarten Blaauw

Wiggle Matching

How it works

If we have multiple dates, where we know the [absolute/relative] temporal distance, the individual calibration might not represent the best combined fit!



Source: Maarten Blaauw

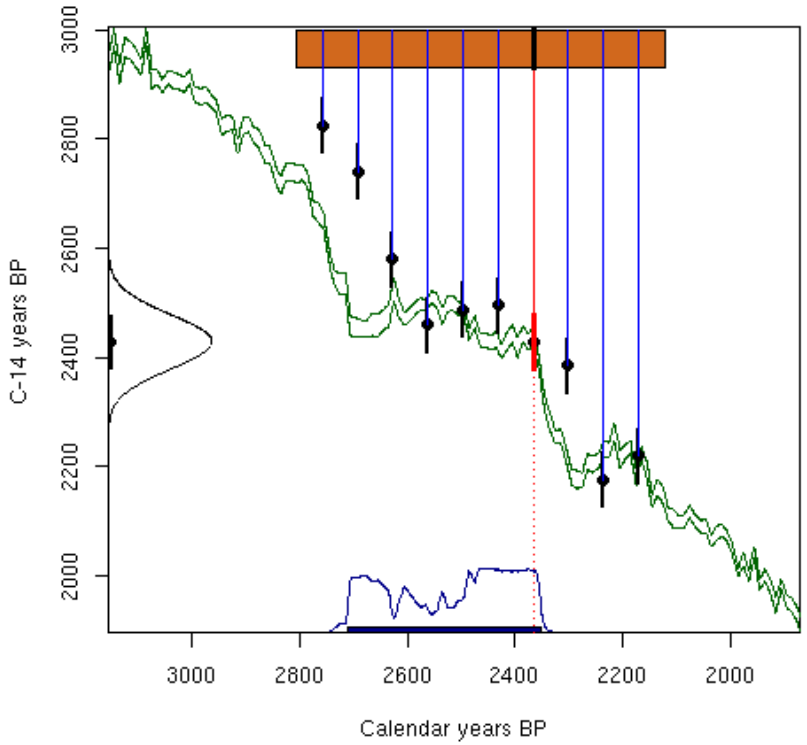
Wiggle Matching

How it works

But we can calculate the best combined fit! This reduces also the individual uncertainity of the dates!

The animation refers to a situation where we have a depositional model (not absolute distances). With tree rings, it becomes even more contraint (rigid), and by that, the amount of usable information can even be increased.

Technically: similar to the example of Bayesian calibration presented in the presence session.



Source: Maarten Blaauw

Wiggle Matching

If we know the (relative/absolute) temporal distance between events:

- e.g. tree rings: we know, how many years passed between individual samples
- e.g. depositional processes: we know the relative distance between samples
- Works without Bayes, but also (very well) with Bayes

Attention: Again, we make strong assumptions about the temporal arrangements of our samples!

```
D_Sequence( "Wiggle-match example")
{
 R_Date( "P-14095", 3413, 22);
 Gap( 10);
 R_Date( "P-14096", 3430, 23);
 Gap( 10);
 R_Date( "P-14097", 3432, 22);
 Gap( 10);
 R_Date( "P-14098", 3431, 22);
 Gap( 10);
 R_Date( "P-14099", 3379, 22);
 Gap( 10);
 R_Date( "P-14100", 3371, 23);
 Gap( 10);
 R_Date( "P-14101", 3371, 22);
 Gap( 5);
 Date("Felling date");
};
```

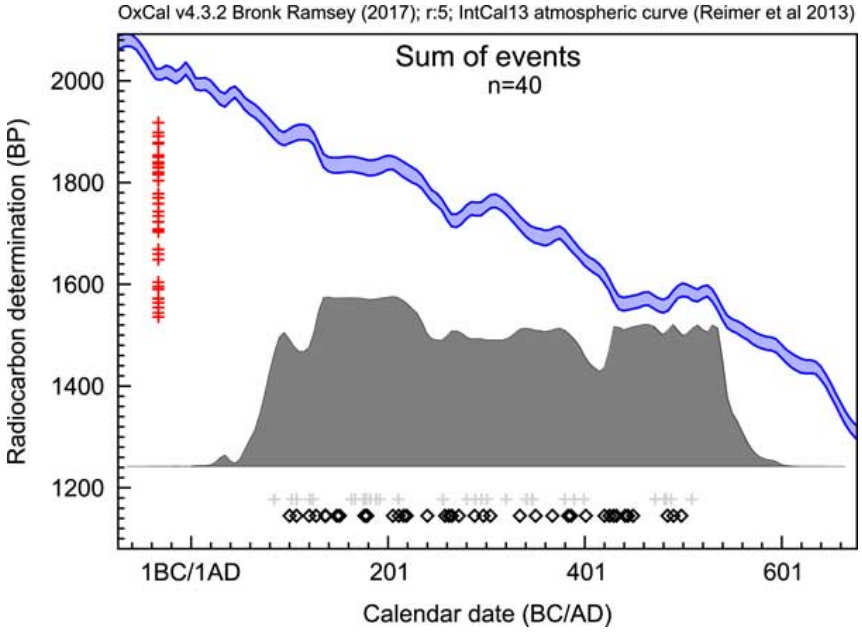
Summed Probability

If we want to have a (rough) overview of the overall distribution of the data of a series of related events:

- e.g. the total use of a burial ground
- e.g. the total occupancy of a settlement
- Very simple statistics, statistical scatter of data is not taken into account

Attention: The OxCal manual states:

> Combining probability distributions by summing is usually difficult to justify statistically but it will generate a probability distribution which is a best estimate for the chronological distribution of the items dated (Sum). The effect of this form of combination is to average the distributions and not to decrease the error margins as with other forms of combination.



Source: Bronk Ramsey 2017

Sum

An experiment

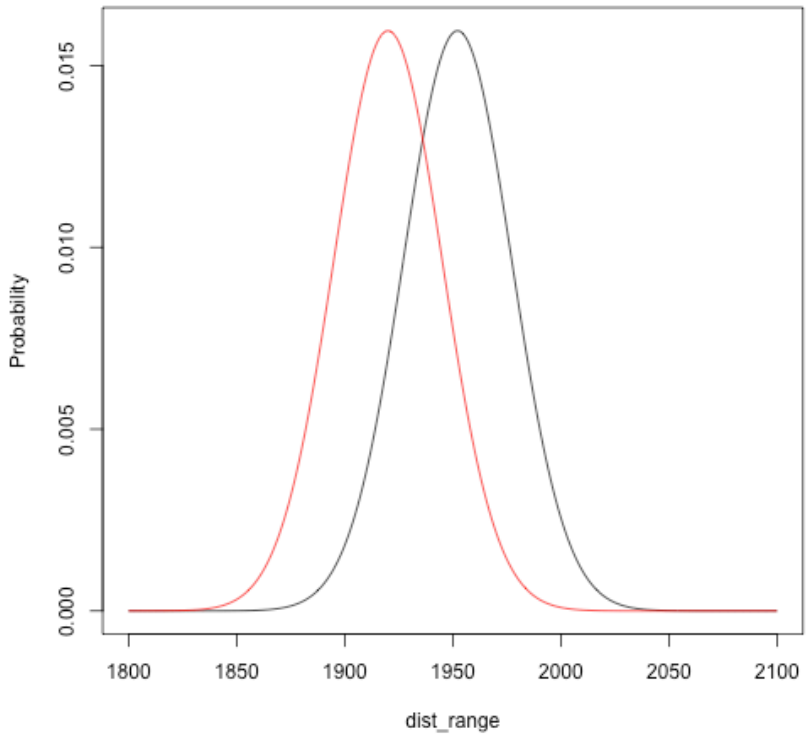
Remember our two dates?

```
sample1
```

```
## [1] 1952.187
```

```
sample2
```

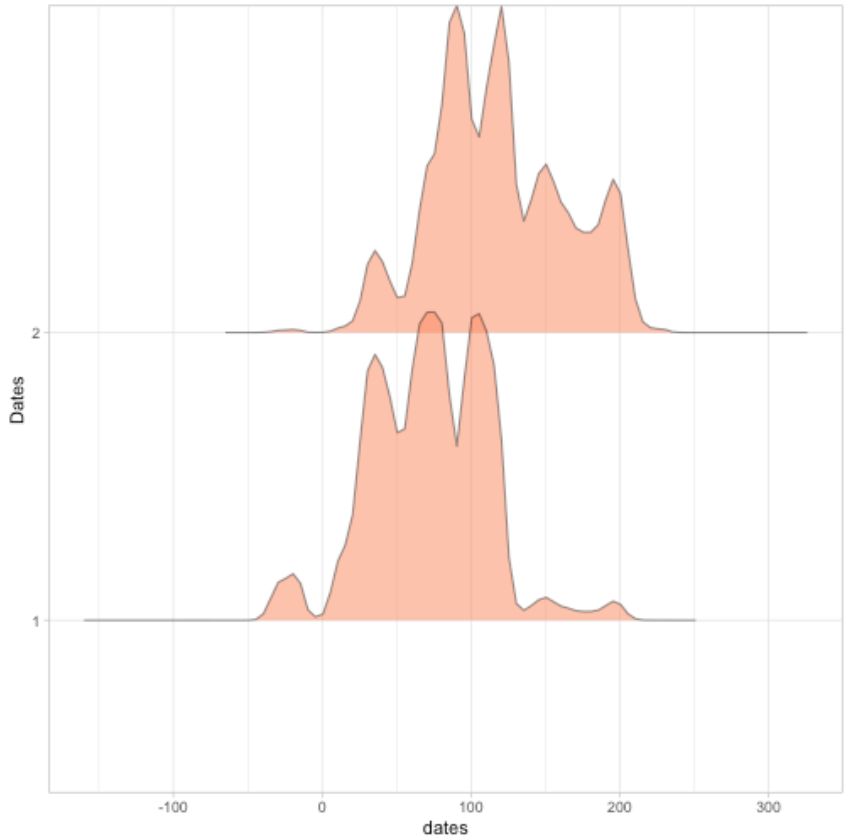
```
## [1] 1920.018
```



Sum

An experiment

Calibration individually



Sum

An experiment

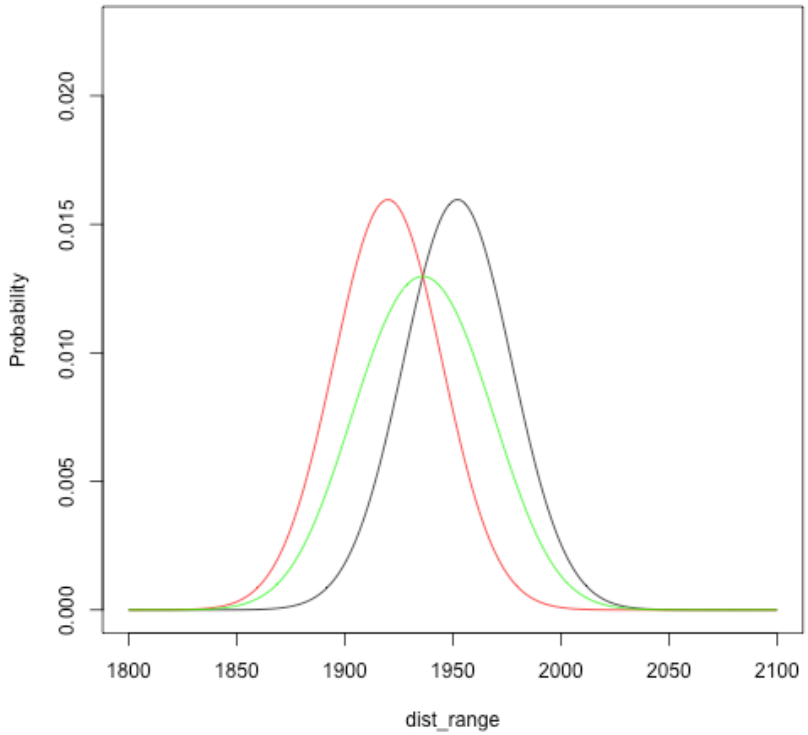
Now we combine the measurements using the sum:

$$p_{sum} = p_1 + p_2$$

Or more general:

$$p_{sum} = \sum_i p_i$$

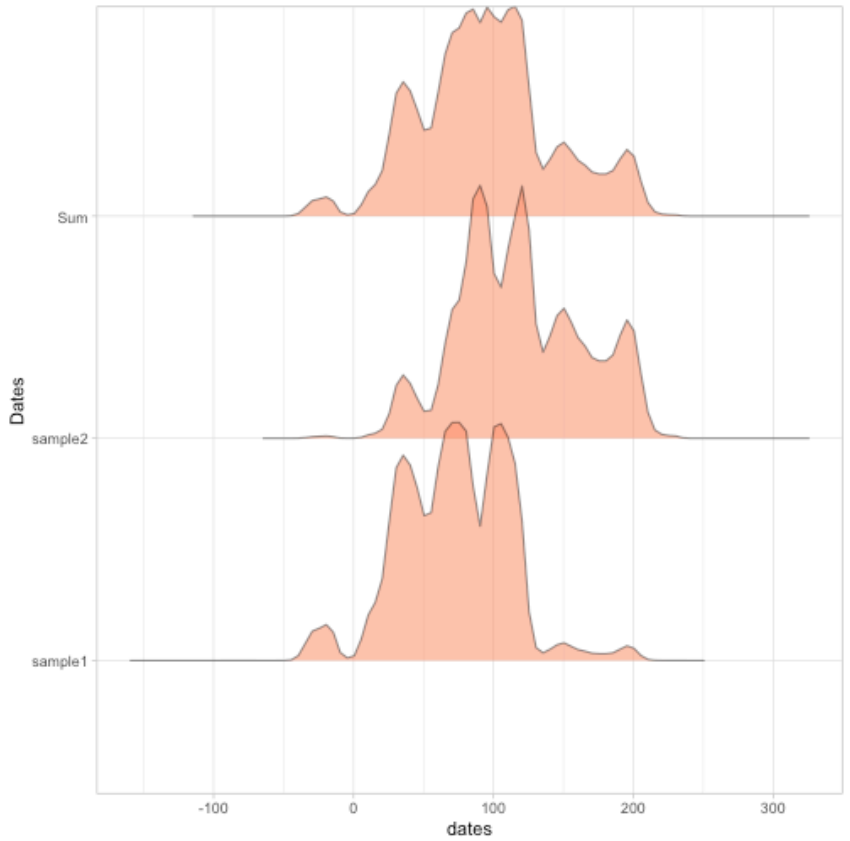
```
sum <- dnorm(
    dist_range, mean = sample1, sd=2
    ) +
  dnorm(
    dist_range, mean = sample2, sd=2
    )
sum <- sum/sum(sum)
```



Sum

An experiment

And calibrate the sum:



Summed Probability

If we want to have a (rough) overview of the overall distribution of the data of a series of related events:

- e.g. the total use of a burial ground
- e.g. the total occupancy of a settlement
- Very simple statistics, statistical scatter of data is not taken into account

Attention: The OxCal manual states:

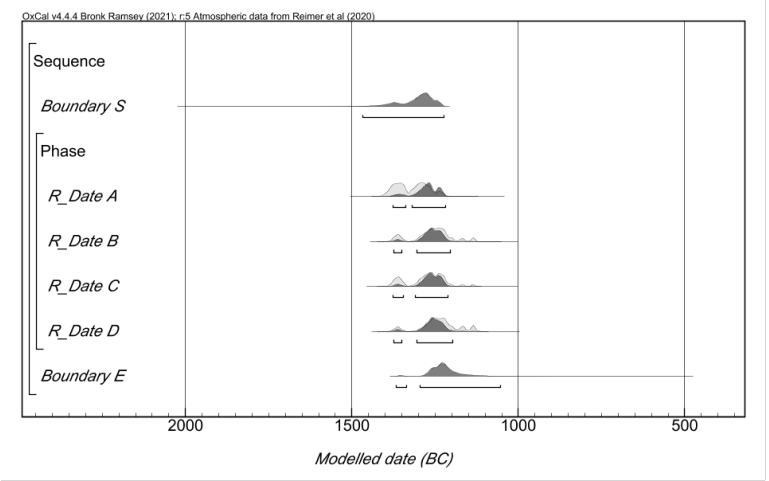
> Combining probability distributions by summing is usually difficult to justify statistically but it will generate a probability distribution which is a best estimate for the chronological distribution of the items dated (Sum). The effect of this form of combination is to average the distributions and not to decrease the error margins as with other forms of combination.

```
Sum("C")
{
 R_Date("A",2000,20);
 R_Date("B",2010,30);
 R_Date("C",1980,31);
};
```

Duration/Basic Modelling

If we want to have a better overview of the overall distribution of the data of a series of related events:

- e.g. the total use of a burial ground
- e.g. the total occupancy of a settlement
- We introduce Boundaries: We assume, the dates may be wrong, and the actual use phase might have started/ended somewhen around the first/last date (adding contraints)



Name Show all Show structure		Unmodelled (BC/AD)			Modelled (BC/AD)			Indices A_{model}=118.6 $A_{overall}$=120.2					Select All Visible	Page break
		from	to	%	from	to	%	A_{comb}	A	L	P	C		
▼ Sequence													2	
Boundary S					-1469	-1223	95.4					96.7	3	
▼ Phase													4	
R_Date A		-1400	-1226	95.4	-1377	-1219	95.4		89.3			99.3	5	
R_Date B		-1384	-1128	95.4	-1376	-1205	95.4		119			99.3	6	
R_Date C		-1388	-1133	95.4	-1376	-1211	95.4		117.7			99.2	7	
R_Date D		-1377	-1127	95.4	-1375	-1197	95.4		115.5			99.3	8	
First					-1384	-1226	95.4					99	9	
Last					-1367	-1164	95.4					99.5	10	
Span					0	143	95.4					98.3	12	
Boundary E					-1369	-1066	95.4					97.2	11	

Duration/Basic Modelling

We add some commands:

- what is sequential: **Sequence**
- what can not be sequenced: **Phase**
- what represents a border between events that belong together: **Boundary**

And some Queries:

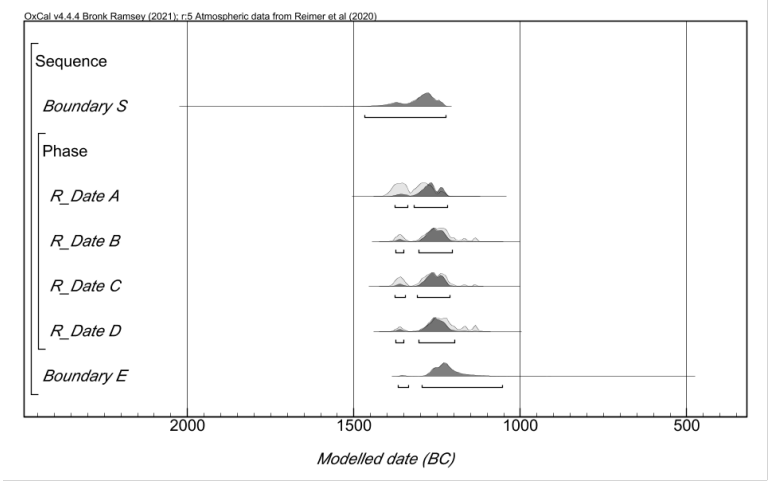
- **Span**: How long has the total event taken place

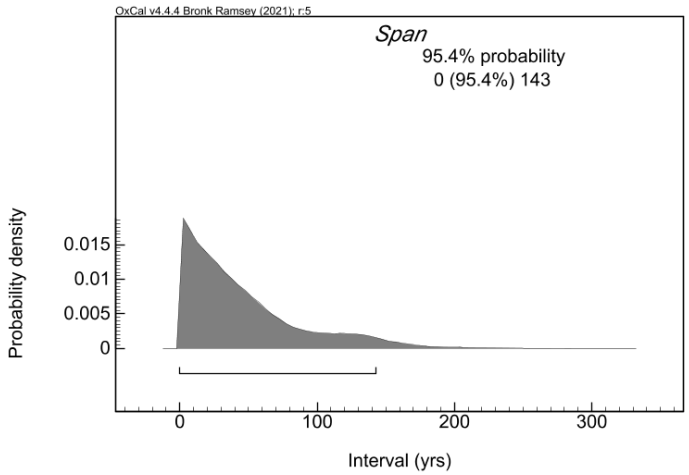
```
Sequence()
    {
     Boundary("S");
     Phase()
     {
      R_Date("A",3050,25);
      R_Date("B",3010,25);
      R_Date("C",3020,25);
      R_Date("D",3000,25);
      Span();
     };
     Boundary("E");
    };
```

Duration/Basic Modelling

We get *modelled* information -> Posterior probability distributions

- Individual dates are "compressed", because of the fact that they are assumed to belong together
- The span of the occupation can be estimated, taking into account, that the invidual dates have random (statistical) scatter





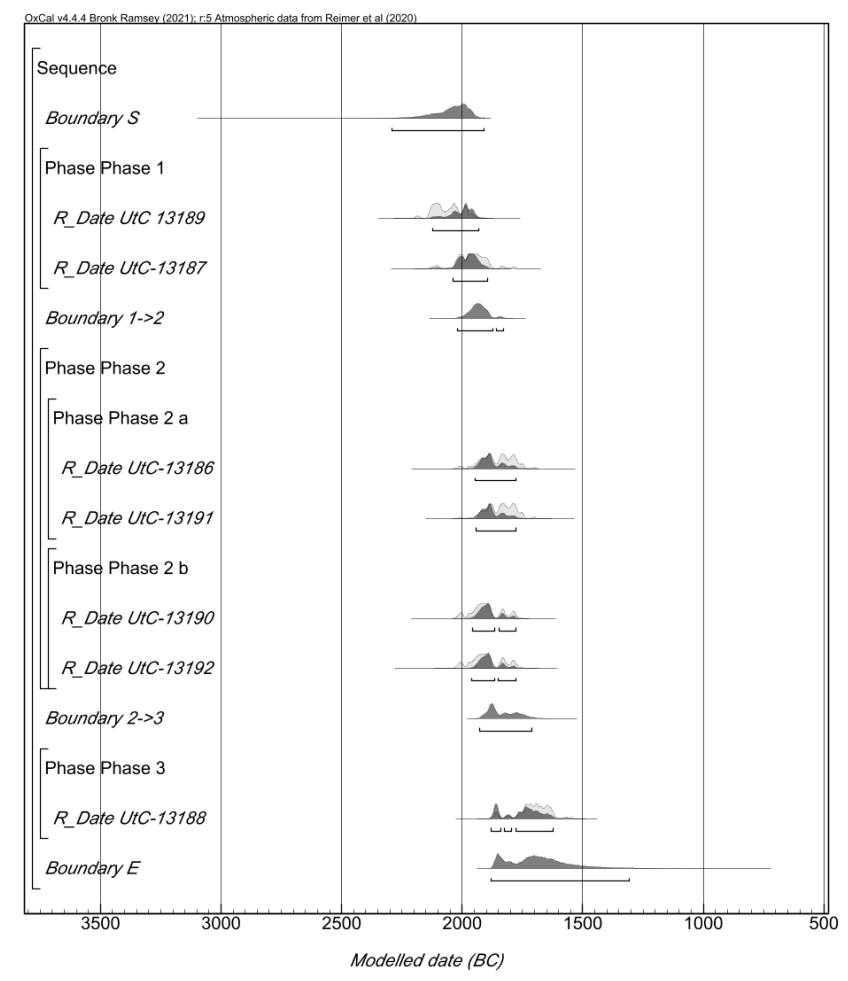
Name Show all Show structure		Unmodelled (BC/AD)			Modelled (BC/AD)			Indices A_{model}=118.6 $A_{overall}$=120.2					Select All Visible	Page break
		from	to	%	from	to	%	A_{comb}	A	L	P	C		
▼ Sequence													2	
Boundary S					-1469	-1223	95.4					96.7	3	
▼ Phase													4	
R_Date A		-1400	-1226	95.4	-1377	-1219	95.4		89.3			99.3	5	
R_Date B		-1384	-1128	95.4	-1376	-1205	95.4		119			99.3	6	
R_Date C		-1388	-1133	95.4	-1376	-1211	95.4		117.7			99.2	7	
R_Date D		-1377	-1127	95.4	-1375	-1197	95.4		115.5			99.3	8	
First					-1384	-1226	95.4					99	9	
Last					-1367	-1164	95.4					99.5	10	
Span					0	143	95.4					98.3	12	
Boundary E					-1369	-1066	95.4					97.2	11	

Sequential Calibration

If we have stratigraphical (sometimes also other) external information about the temporal distance between events:

- e.g. layers of an excavation, where we know the order of the dates
- sometimes, but not so reliably: typological considerations can also be incorporated
- Works only with Bayes

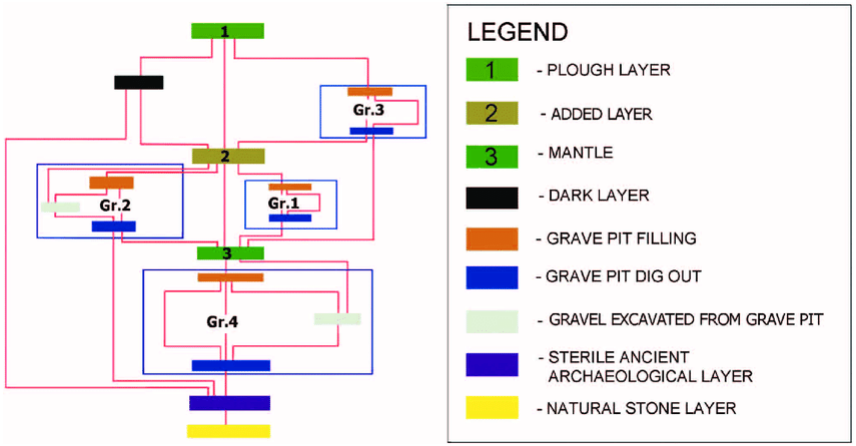
Attention: Again, we make strong assumptions about the temporal arrangements of our samples!



Sequential Calibration

Adding Stratigraphical Informations

- what is sequential: **Sequence**
- what can not be sequenced: **Phase**



Sequential Calibration

Adding Stratigraphical Informations

You can make this arbitrary complicated!

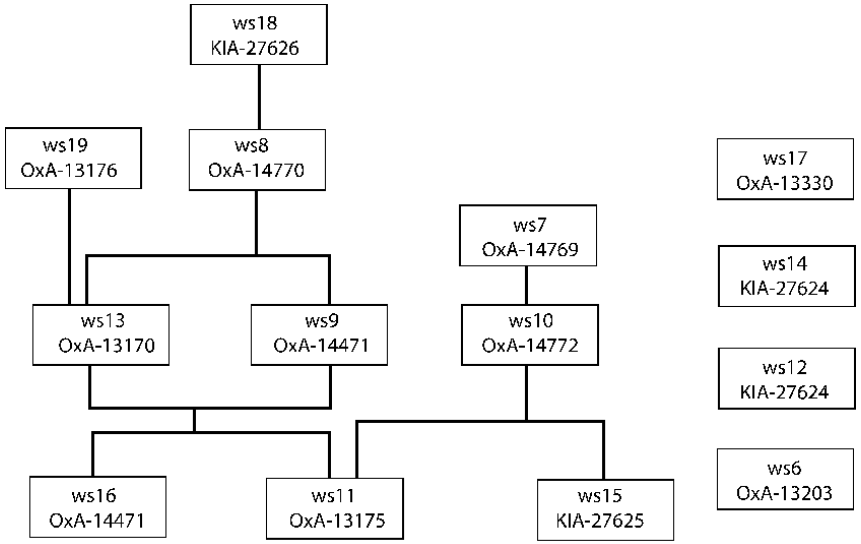
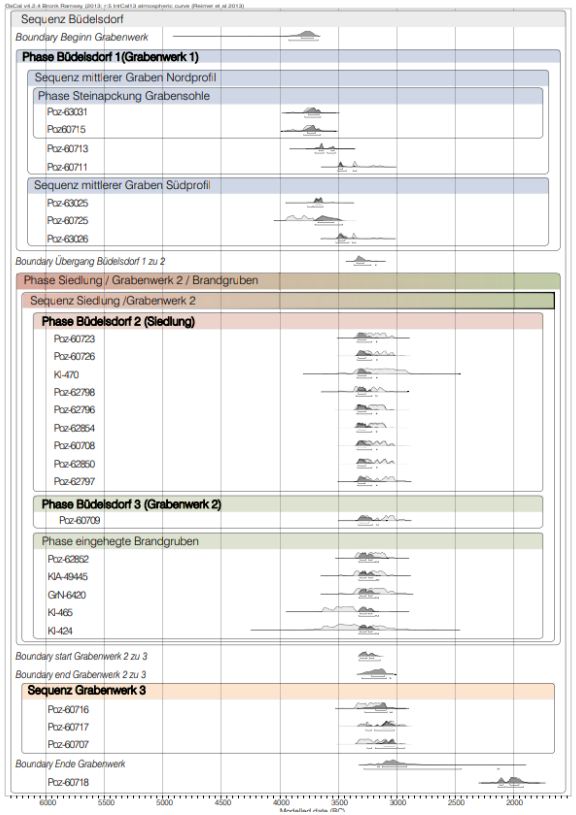


Figure 5 Harris matrix of stratigraphic relationships between articulated/partially articulated skeletons from Wayland's Smithy I.



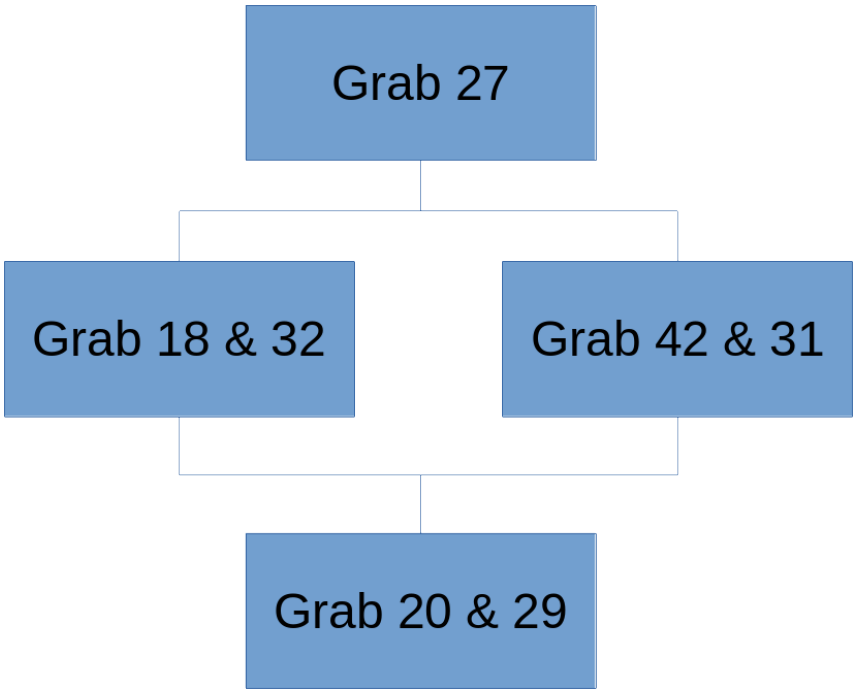
Sequential Calibration

Adding Stratigraphical Informations

- what is sequential: Sequence
- what can not be sequenced: Phase

14C dates

- Grab 29 (UtC 13189) 3671 ± 33 BP
- Grab 20 (UtC-13187) 3600 ± 38 BP
- Grab 31 (UtC-13190) 3560 ± 36 BP
- Grab 42 (UtC-13192) 3559 ± 41 BP
- Grab 18 (UtC-13186) 3531 ± 40 BP
- Grab 32 (UtC-13191) 3521 ± 37 BP
- Grab 27 (UtC-13188) 3409 ± 38 BP



Sequential Calibration

Adding Stratigraphical Informations

- what is sequential: Sequence
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14C dates

- Grab 29 (UtC 13189) 3671 ± 33 BP
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- Grab 32 (UtC-13191) 3521 ± 37 BP
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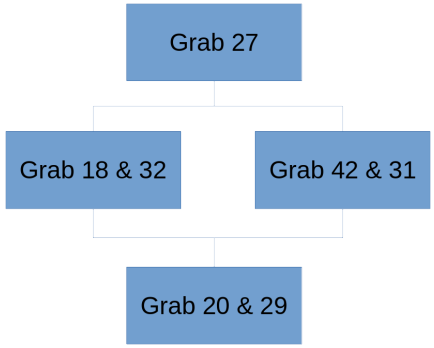



```
Plot()
{
 Sequence()
 {
  Boundary("S");
  Phase("Phase 1")
  {
   R_Date("UtC 13189", 3671, 33);
   R_Date("UtC-13187", 3600, 38);
  };
  Boundary("1->2");
  Phase("Phase 2")
  {
   Phase("Phase 2 a")
   {
    R_Date("UtC-13186", 3531, 40);
    R_Date("UtC-13191", 3521, 37);
   };
   Phase("Phase 2 b")
   {
    R_Date("UtC-13190", 3560, 36);
    R_Date("UtC-13192", 3559, 41);
   };
  };
  Boundary("2->3");
  Phase("Phase 3")
  {
   R_Date("UtC-13188",3409,38);
  };
  Boundary("E");
 };
};
```

Sequential Calibration

If we have stratigraphical (sometimes also other) external information about the temporal distance between events:

- e.g. layers of an excavation, where we know the order of the dates
- sometimes, but not so reliably: typological considerations can also be incorporated
- Works only with Bayes

Attention: Again, we make strong assumptions about the temporal arrangements of our samples!

Name Show all Show structure		Unmodelled (BC/AD)			Modelled (BC/AD)			Indices A_{model}=105.6 $A_{overall}$=107.5					Select All Visible	Page break
		from	to	%	from	to	%	A_{comb}	A	L	P	C		
Sequence													2	
Boundary S					-2293	-1909	95.4					96.9	3	
Phase Phase 1													4	
R_Date UtC 13189		-2190	-1949	95.4	-2125	-1931	95.4		82.2			99.6	5	
R_Date UtC-13187		-2127	-1783	95.4	-2039	-1896	95.4		110.1			99.8	6	
Boundary 1->2					-2019	-1830	95.4					99.7	7	
Phase Phase 2													8	
Phase Phase 2 a													9	
R_Date UtC-13186		-2008	-1744	95.4	-1947	-1778	95.4		109.6			99.8	10	
R_Date UtC-13191		-1950	-1743	95.4	-1943	-1778	95.4		98.4			99.7	11	
Phase Phase 2 b													12	
R_Date UtC-13190		-2023	-1772	95.4	-1959	-1777	95.4		119.7			99.8	13	
R_Date UtC-13192		-2027	-1768	95.4	-1960	-1776	95.4		121.7			99.8	14	
Boundary 2->3					-1927	-1713	95.4					99.4	15	
Phase Phase 3													16	
R_Date UtC-13188		-1876	-1565	95.4	-1881	-1622	95.4		85.2			99.2	17	
Boundary E					-1882	-1306	95.4					95.5	18	

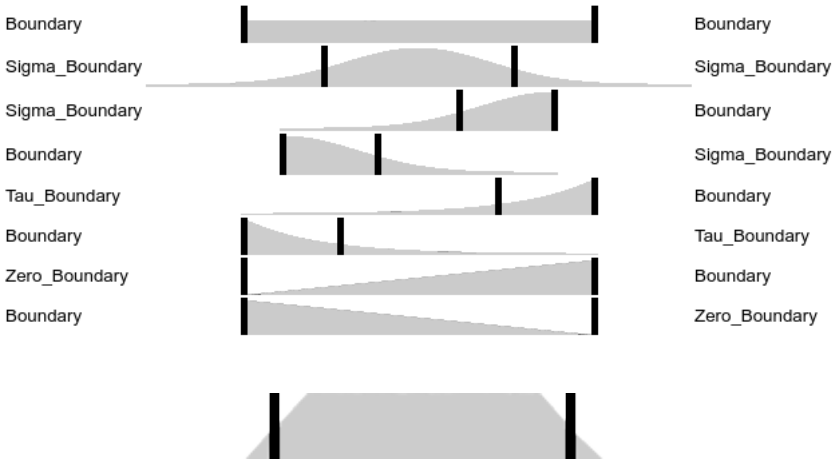
Sequential Calibration

Types of Boundaries

- Boundary([Name], [Expression]);
- Sigma_Boundary([Name], [Expression]);
- Tau_Boundary([Name], [Expression]);
- Zero_Boundary([Name], [Expression]);

Also interesting: Trapezoidal boundaries for gradual transition (eg. cultural phases)

```
Boundary("MidStart")
     {
      Transition("Duration Start");
      Start("Start Start");
      End("End Start");
     };
```



OxCal

Further possible topics

- outlier analysis (Outlier & Outlier_Model)
- Deposition models (D_Sequence, V_Sequence, P_Sequence, U_Sequence,)
- ...

more at the OxCal help page

Any questions?

You might find the course material (including the presentations) at

https://berncodalab.github.io/caa

You can contact me at

martin.hinz@iaw.unibe.ch