Indirect Dating With Mixture Density Networks

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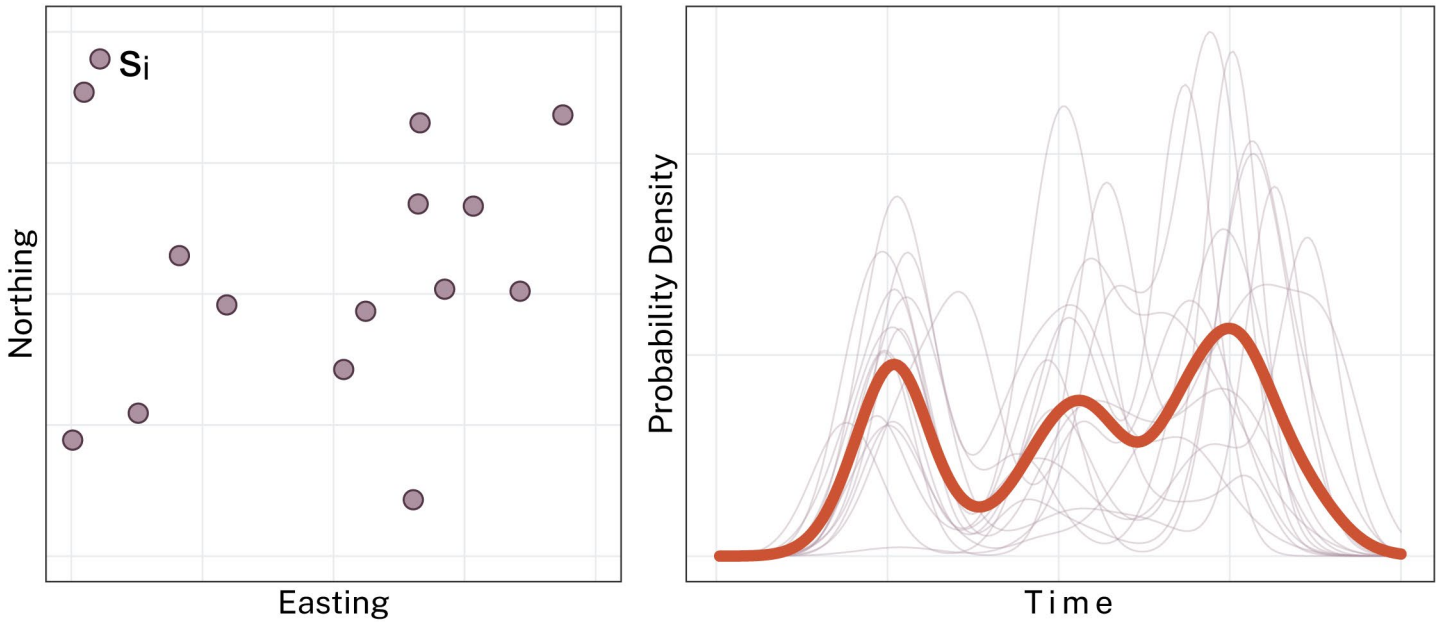
The goal

Estimate a **regional chronology $p(t)$** that effectively summarizes the **individual chronologies $p_i(t)$** of all sites s_i in a region of interest.



Why care?

For **businesses**

population size drives **labor costs** and **consumer demand** for goods and services.

For **governments**

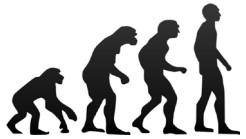
population distribution is critical for **allocating services** and ensuring **political representation**.

For **individuals**

population provides for intangibles like **prosocial needs**.

And for science?

Climate and **population** are the **levers** of human history!



The first humans

Anatomically modern humans emerge in Africa

~300 kya

The first migrants

Humans begin migrating out of Africa

~75 kya

The first domesticates

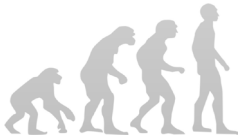
Subsistence economies shift from food collection to food production

~12 kya

The first cities

Cities like Ur and Catalhoyuk are established in Mesopotamia and Anatolia

~6 kya



The first humans

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~300 kya

~75 kya

The first migrants

Humans begin migrating out of Africa

Neolithic Revolution

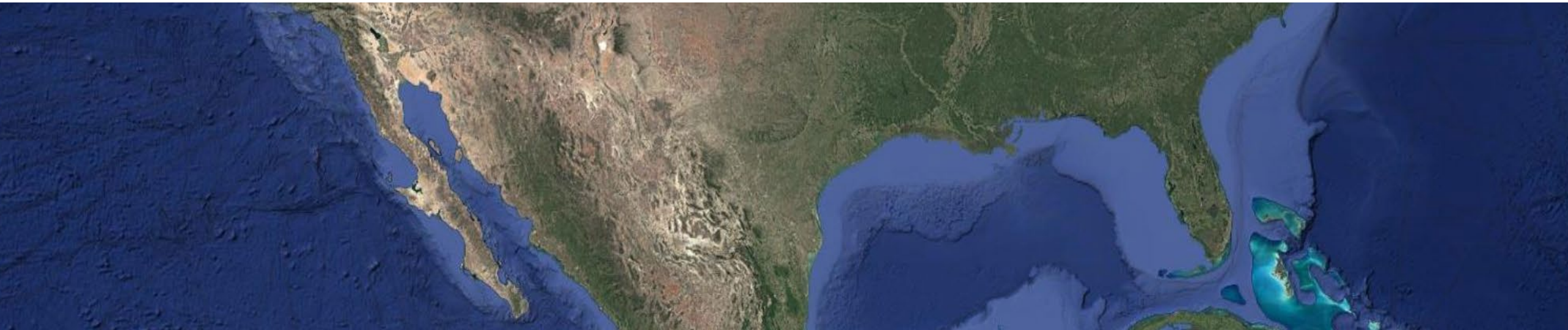
The first cities

Cities like Ur and Catalhoyuk are established in Mesopotamia and Anatolia

The first domesticates

Subsistence economies shift from food collection to food production

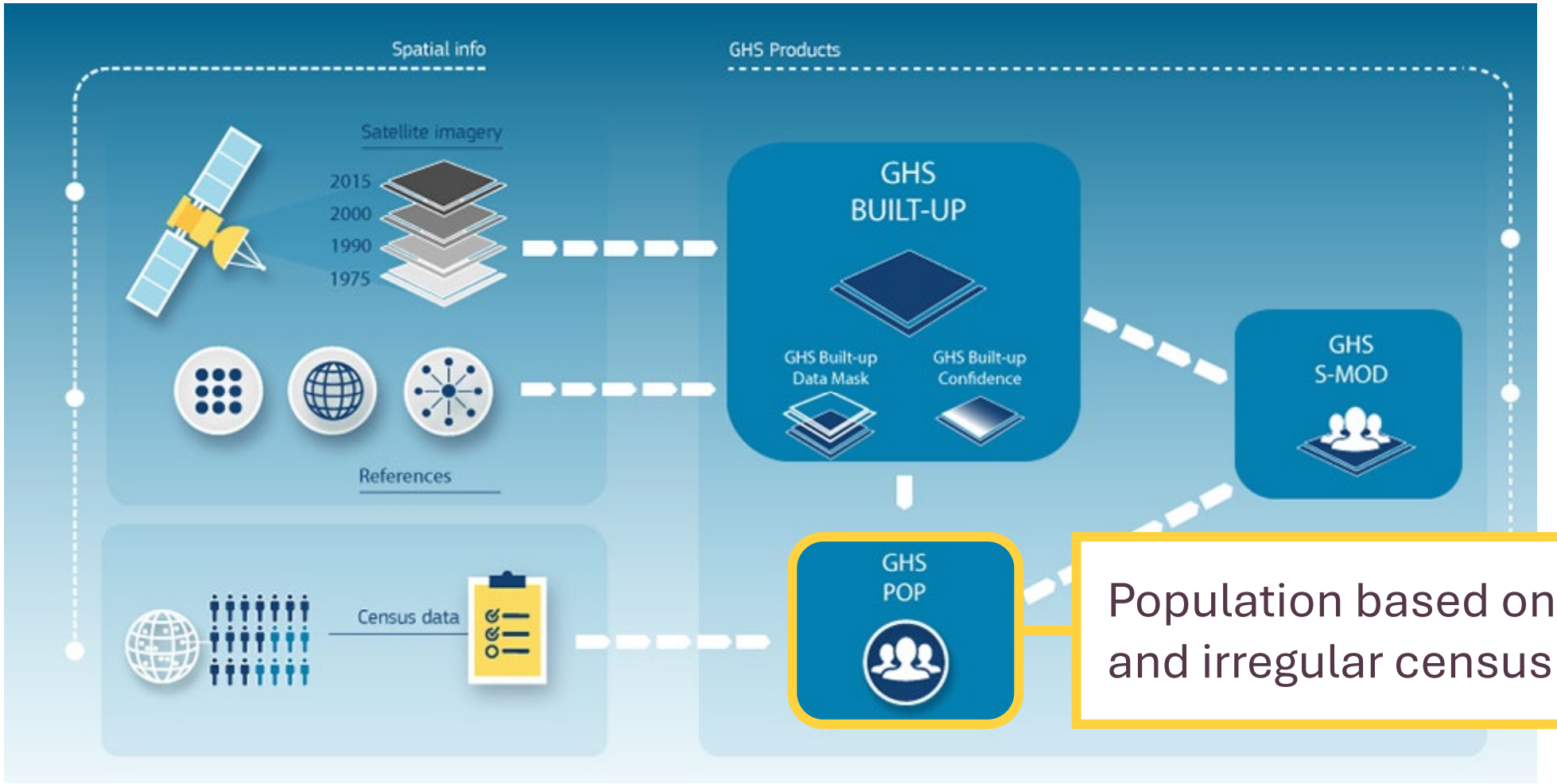
Most of my research focuses on the Neolithic in Western North America



Estimating population

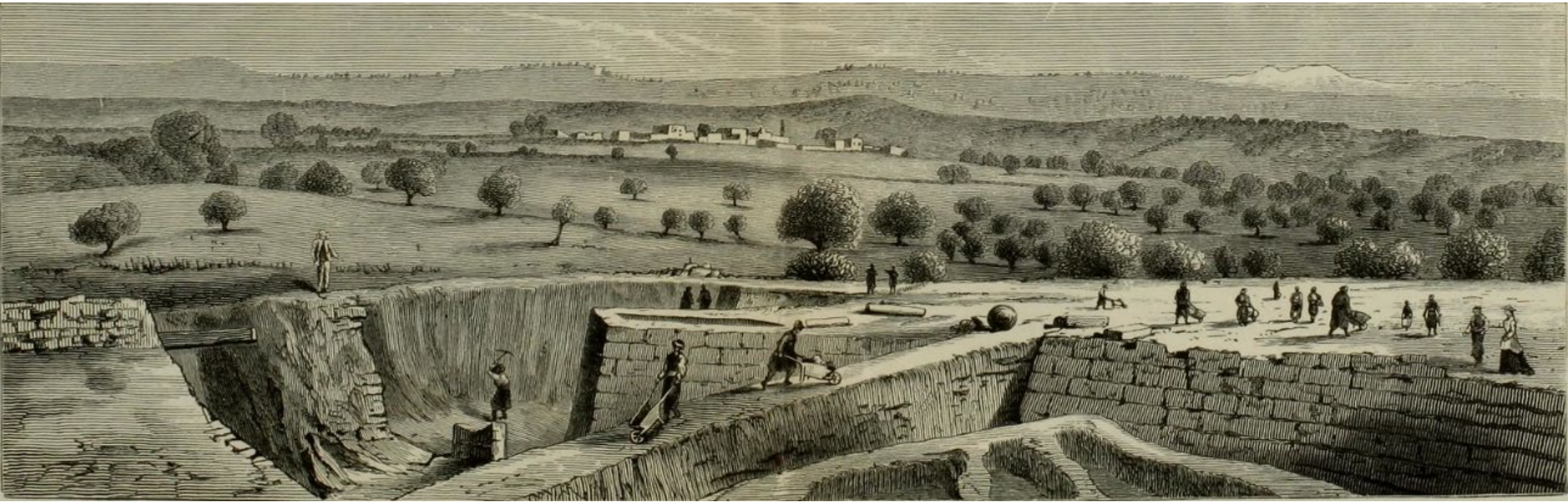
Simple formula:
more **people**  more **stuff** 

Global Human Settlement Layer



Population based on built-area and irregular census sampling.

But the archaeological record is a **palimpsest** .



Solution: date the built-up area

Direct dating

Count tree rings in construction timbers.

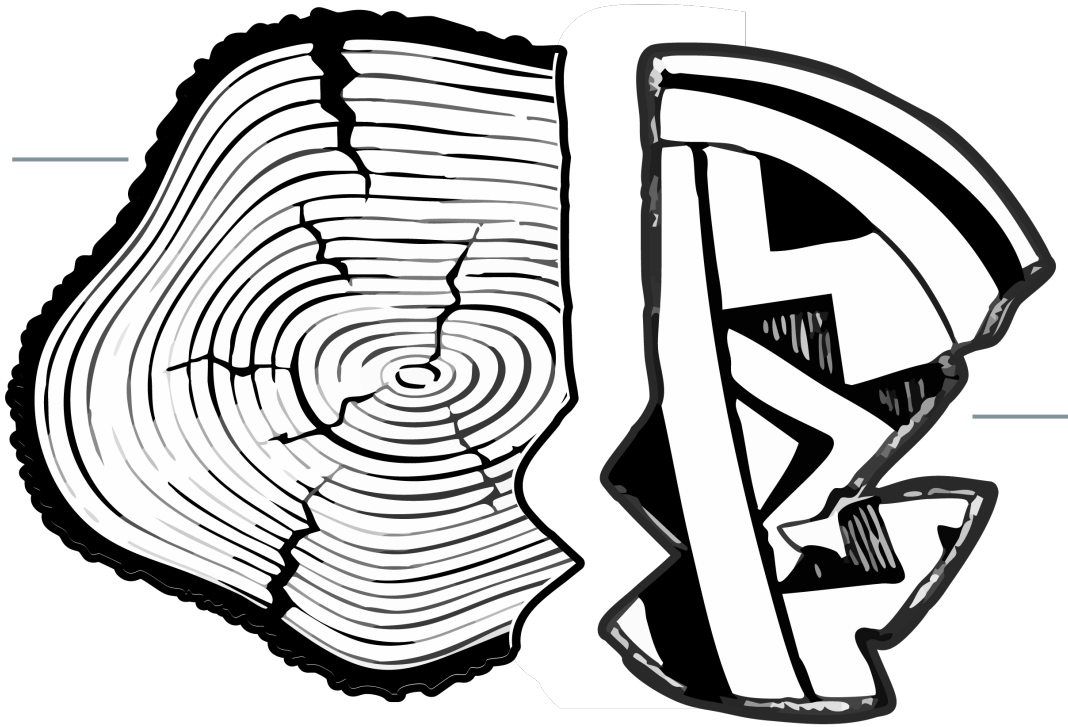
Direct dating

Count tree rings in construction timbers.

But these are **costly** 💰 and **destructive** 💥 !

Direct dating

Count tree rings in construction timbers.



Indirect dating

Relies on diagnostics with known start and end dates.

The model

An AI solution

We can estimate a regional chronology conditioned on some data x using a **Mixture Density Network**:

$$p(t|x) = \sum_{k=1}^{K} \pi_k(x)\, N(t \mid \mu_k(x), \sigma_k(x))$$

with

- K component Gaussians
- $\pi_k(x)$ mixing weights
- $\mu_k(x)$ means
- $\sigma_k(x)$ standard deviations

Loss function

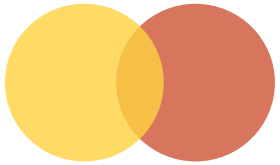
Goal of MDN is to minimize **Negative Log Likelihood**:

$$-\log \mathcal{L}(\mathrm{t}|\mathrm{x}) = -\log p(t|x)$$

with *log-sum-exponent* trick to avoid numerical underflow.

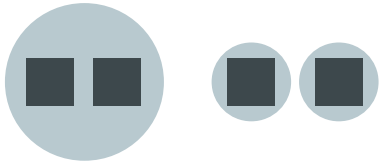
Still a gaggle of challenges

- Aligning data sets across sites

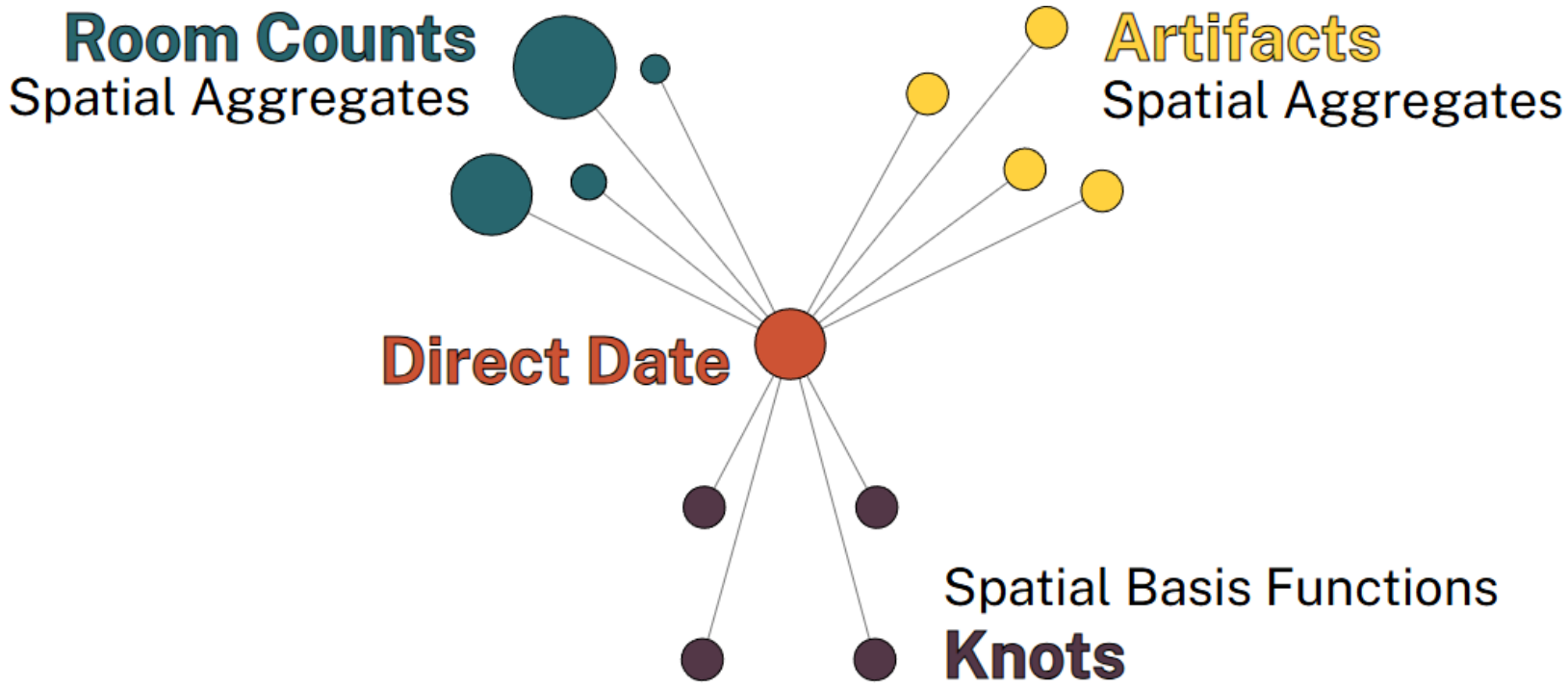


- Accommodating variable site sizes

- Addressing inconsistent site definitions



Coping strategy



Intuition: We want to loosen the requirement of direct association and look instead at the wider context.

Spatial aggregates

For q direct dates, r sites with recorded artifacts, and m artifact types, define aggregate $q\ x\ m$ artifact matrix $\boldsymbol{A}$ as:

$$\boldsymbol{A} = \boldsymbol{W}\boldsymbol{F}$$

where

- $\boldsymbol{W}$ is a $q\ x\ r$ spatial weights matrix
- $\boldsymbol{F}$ is a disaggregate $r\ x\ m$ artifact count matrix

Intuition: $\boldsymbol{A}$ tells us how much *stuff* is around each direct date.

Spatial basis functions

For a regular grid of k knots, define a $q\ x\ p$ artifact matrix $\boldsymbol{B}$ as:

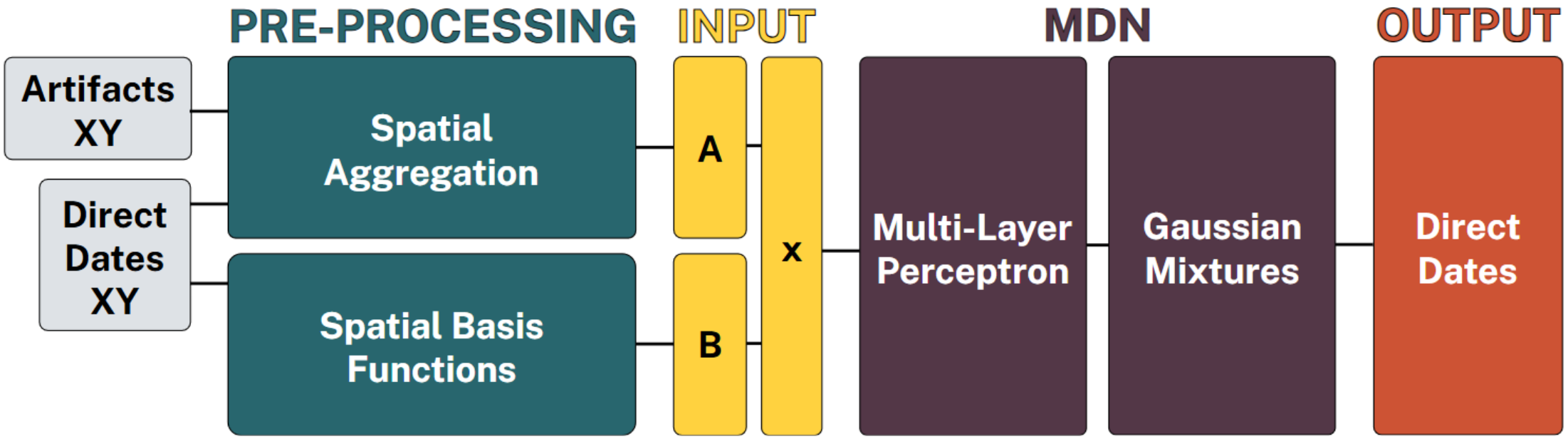
$$\boldsymbol{B} = b(i,j)$$

where

- $b(i,j)$ is a spatial basis function that accounts for the distance between direct date $i \in 1, \ldots, q$ and spatial knot $j \in 1, \ldots, p$.

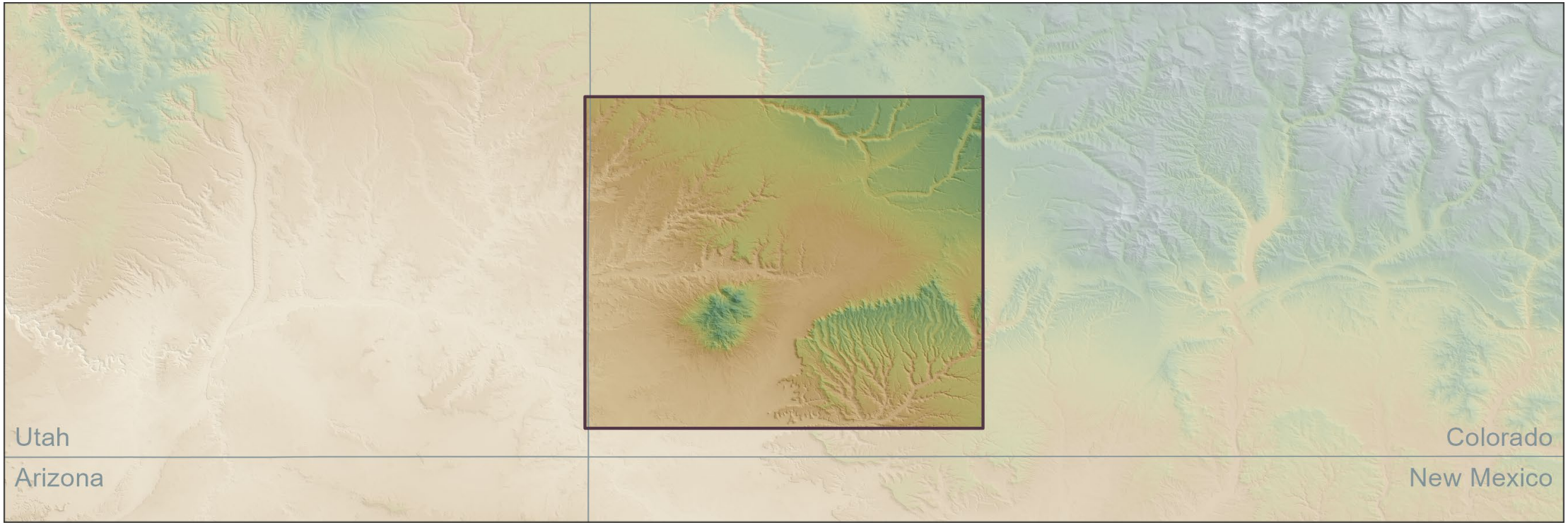
Intuition: $\boldsymbol{B}$ tells us how direct dates are related in space.

Model graph


PRE-PROCESSING
INPUT
MDN
OUTPUT
Artifacts XY
Direct Dates XY
Spatial Aggregation
Spatial Basis Functions
A
B
x
Multi-Layer Perceptron
Gaussian Mixtures
Direct Dates

Test case

Greater Mesa Verde Region

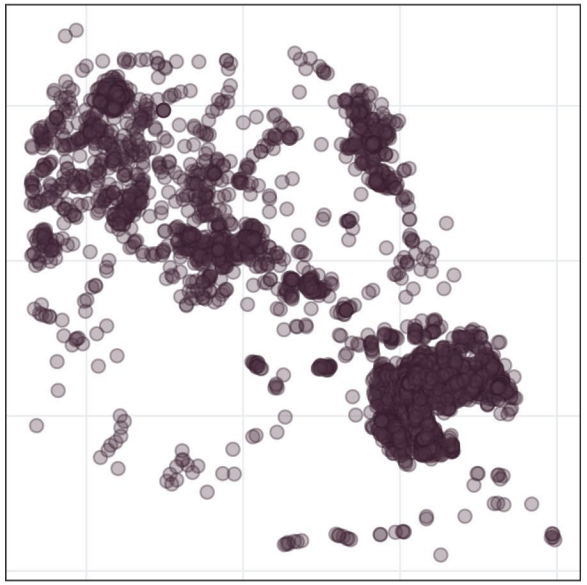


Yellow Jacket Pueblo

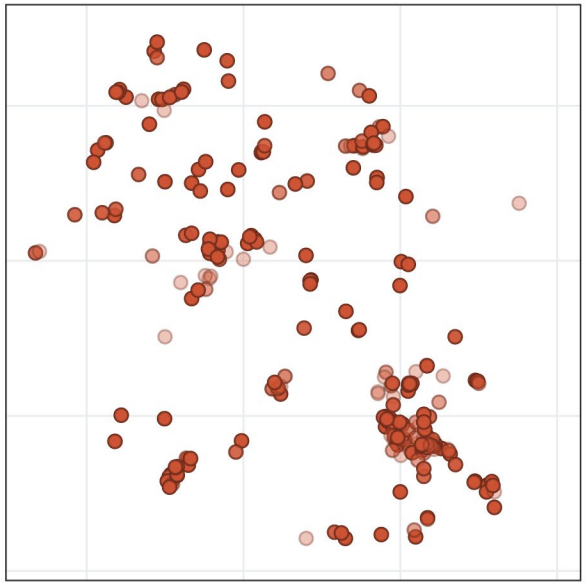
Drawing by Charles Peterson

The data

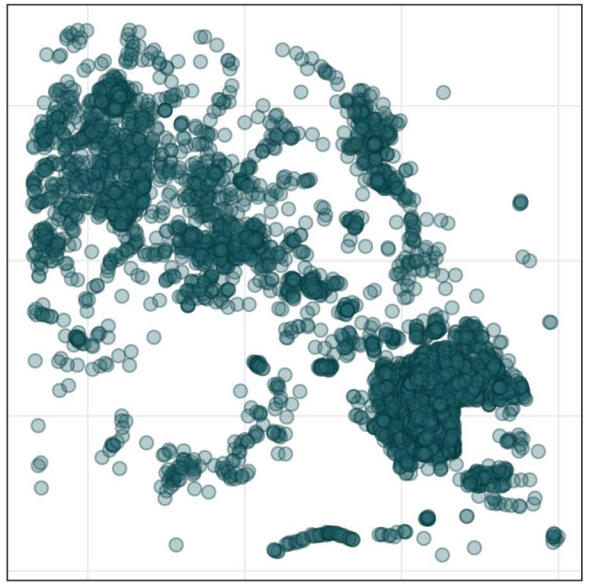
Ceramics XY



Tree Rings XY

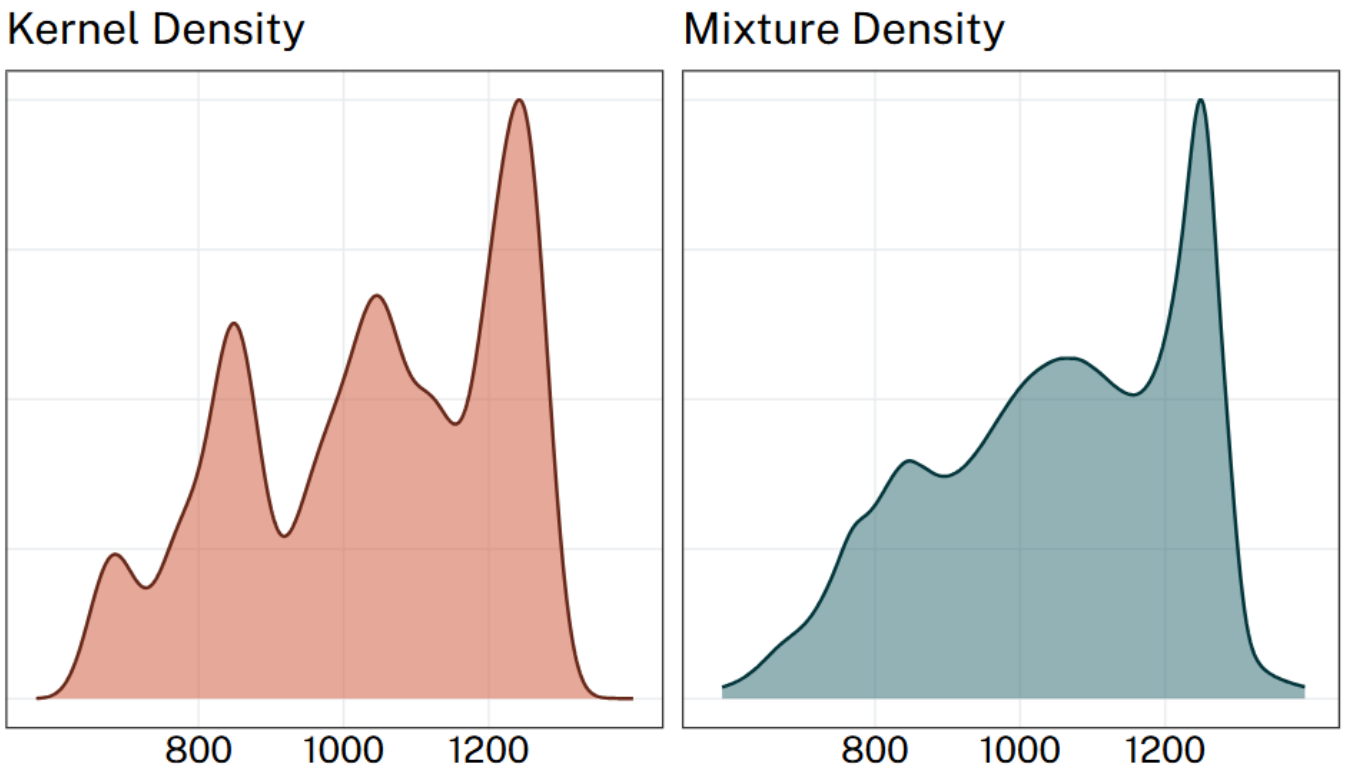


Rooms XY



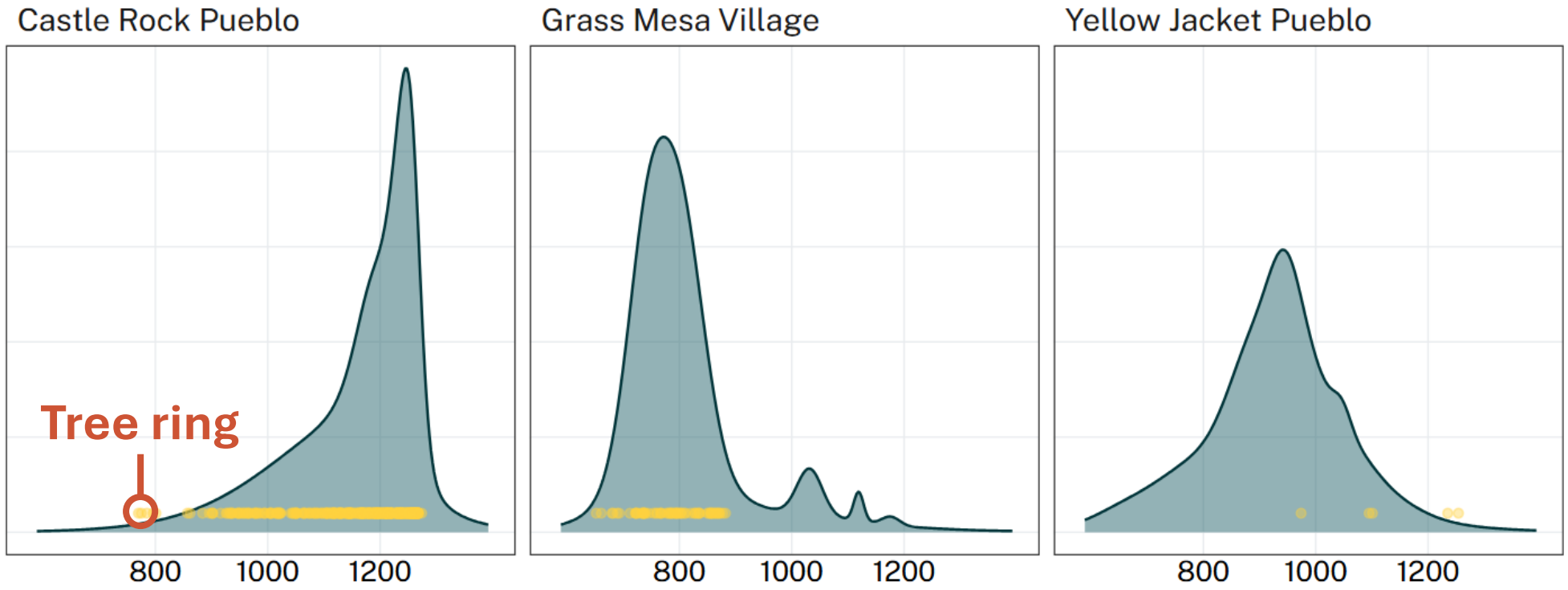
Very preliminary results

Regional chronology

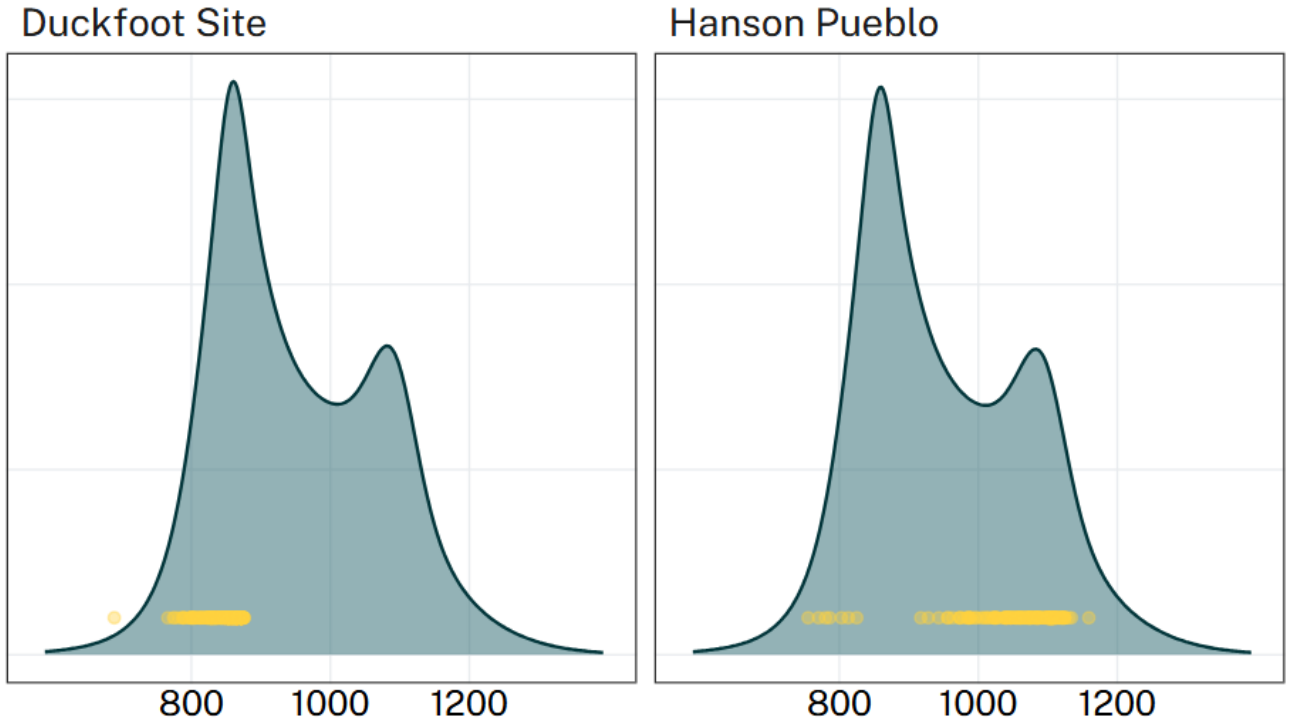


Over-specified with K = 128 mixture components

Site chronologies



More site chronologies



These sites are right next to each other.

What next?

Model **does not account for duration**, just construction events.

Spatial tools for handling **data-misalignment** are inflexible.

AI methods are **not accessible** to most archaeologists.

Thanks!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