Modeling the Dynamics of Cultural Diversification

Introduction

Welcome to the **Modeling the Dynamics of Cultural Diversification** educational module! Through these modules we will present a series of tutorials to help you explore the concepts and methods used to examine the emergence, persistence, and extinction of cultural diversity through time. We will build from a macroevolutionary framework that examines changes in population-scale cultural diversity. We view the approaches presented in these tutorials as particularly useful for explaining cultural dynamics that occur over larger and longer frames of analysis, where observed phenomena can not be easily traced to individual-level mechanisms, and/or individual-level data may be incomplete.

In this introductory tutorial we will:

- Discuss biological macroevolution and how it motivates cultural macroevolution.
- Highlight questions approachable from a cultural macroevolutionary perspective
- Introduce macroevolutionary methods that will be applied in future modules
- Lay out the structure of these tutorials.

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a. Macroevolution

Macroevolution broadly refers to the evolutionary patterns and processes of groups larger than a single population. The field emerged through the increasing realization that evolutionary dynamics (i.e. stability, change, speciation, and extinction) occurring at higher levels of organization have their own dynamic patterns and processes. More concretely, macroevolutionary themes include:

- Identification of changes in rates of evolution and the breadth of diversity
- Describing the impact of historical events, specific traits, and evolutionary mechansims on the histories of groups
- Tracing the common ancestry of higher-level groups
- Explaining the ecological distribution of higher-order groups and traits.

The field of cultural macroevolution takes inspiration from the mechanisms and methods used in macroevolutionary biology. Broadly speaking, the types of the questions asked in Anthropology, Archaeology, Cultural Sociology, and History often parallel those asked in Biological Systematics, Paleobiology, and Biogeography. The macroevolutionary perspective allows us to characterize and

explain population-level patterns of change in the diversity of cultural forms over long time-scales (Mesoudi 2017).

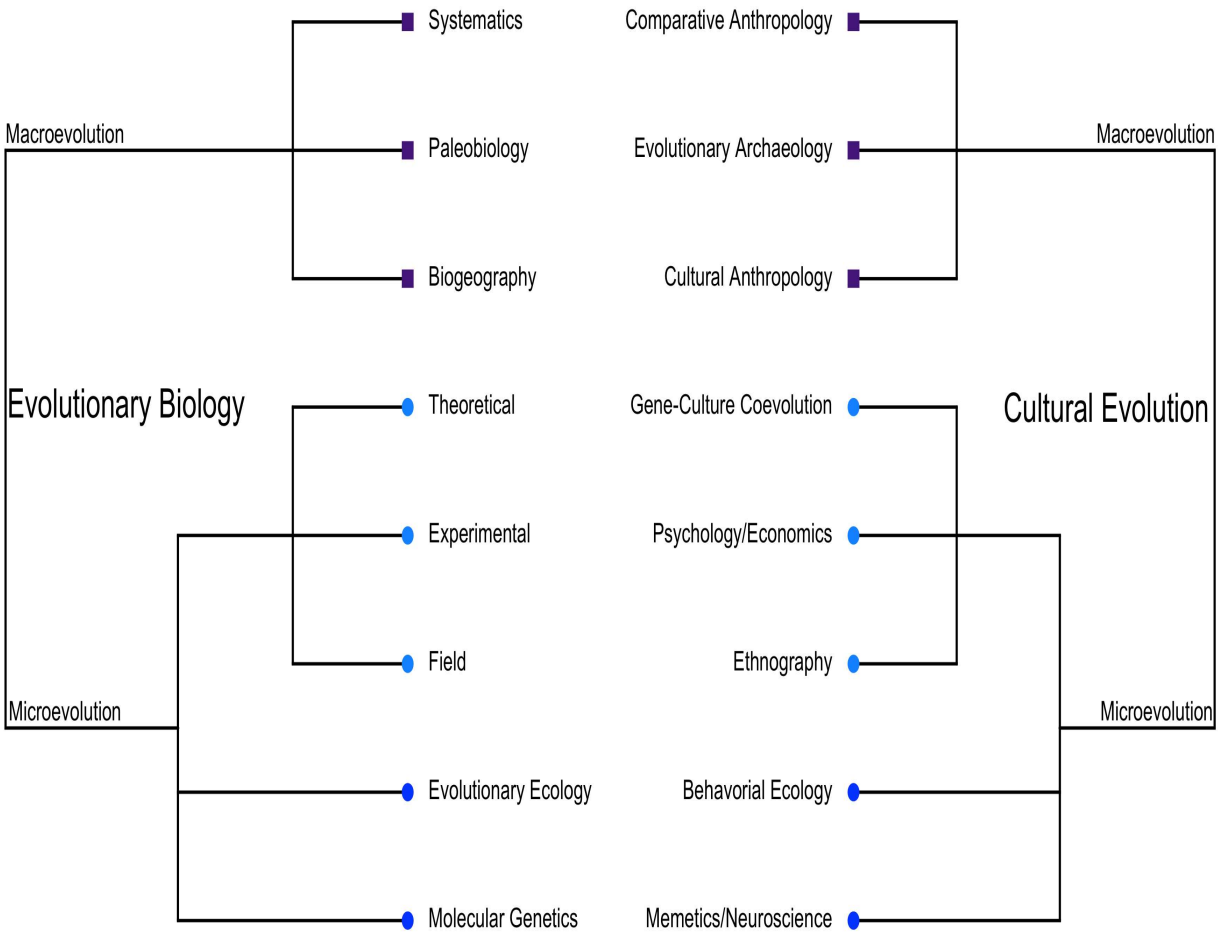

Figure adapted from Mesoudi, Whiten and Laland 2005

For those of you new to cultural evolution, please watch the brief video lecture introduction to

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#@title
from IPython.display import HTML

# Youtube
HTML('<iframe width="560" height="315" src="https://www.youtube.com/embed/iuKfzbz
```

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b. Conceptualizing Cultural Diversity

Like the natural world, human culture displays an astonishing amount of diversity. But what exactly do we mean by cultural diversity? At the individual level, our unique experiences lead to distinct differences in personal knowledge, skills, beliefs, tastes, and values. We refer to these as **mental**

representations or ideas that each individuals has about world (Sperber 1996). These mental representations are produced publicly though the creation or appropriation of material public representations or **cultural things** (speech, text, tools, art, money, etc.) during social interaction (Koch et al., in progress).

Despite variation between individuals, some (suites of related) representations can be easily "recognized by participants and analysts alike as tokens of the same type" (Foster 2018). From an evolutionary perspective, these suites of related representations persist over time through cultural inheritance. In our work, we call these long-lasting representations **cultural lineages**, or "suite[*s*] of cultural features [*representations*] that persist generation after generation [*due to cultural inheritance*], and display relatively minor changes through time" (Gjesfjeld et al. 2020).

From a macroevolutionary perspective, cultural lineages are "**born**" when their representations circulate amongst an appreciable number of individuals. A cultural lineage "**dies**" when its representations are collectively forgotten, unused, or discontinued within a population. Since we cannot measure mental representations, it is easiest to quantify the birth and death times of cultural lineages using the appearance and disappearance of material cultural things.

At an even broader scale, we can identify groups of related lineages, which we call **cultural forms** (Koch et al., in progress). These forms define the frame of analysis, but they are essentially cultural lineages at a higher level of organization. This allows us to conceptualize culture at any given time as the diversity of extant cultural lineages within a form. It also allows us to understand cultural change as shifts in the diversity of lineages within the form over time.

To make this more concrete, the empirical work in these tutorials will focus on two **cultural forms**: a technology (automobiles) and an art genre (Metal music). Within the minds of individuals, these cultural forms are constituted by webs of associated mental representations. Publicly, these cultural forms are given shared meaning through material public representations (e.g. cars or songs) and names for these representations (e.g. car model, band names). Analytically, we recognize a specific car model (e.g. Ford Mustang) as a cultural lineage that represents the suite of public and mental representations associated with that name. In Metal music, we recognize a specific band as a cultural lineage that represents the social, aesthetic, and musical representations associated with that name. Ultimately, both of the our cultural lineages (car models, band names) are considered to have a commercial and cultural reality that persists through time despite minor changes in features or physical appearances.

If this framing sounds useful, you can read more about it [here](add SocArxiv url). It is worth noting

that the methods and mechanisms presented here are intelligible under a variety of theoretical frameworks including Dual Inheritance Theory (DIT) and Memetics.

c. Methods used in Cultural Macroevolution

Across these CES tutorials, we will highlight methods with conceptual foundations in macroevolution. **The main features of macroevolutionary approaches highlighted here are:**

- A focus on inherited and recognizable public representations (i.e. cultural lineages) rather than the mental representations of a single individual. This means we do not require complete individual-level data for macroevolutionary analyses.
- An emphasis on explaining historical changes in cultural lineages and/or cultural forms over longer time frames and beyond individual or small-group interactions.
- The testing of evolutionary mechansims as explanations for changes in cultural diversity.

Cultural Phylogenies

One of the most widely used macrevolutionary tools is phylogenetic inference. Broadly speaking, the use of phylogenies in evolutionary studies has three important roles (Boyd et al. 1997):

- Phylogenies allow for the classification of groups that are believed to be descendent from a common ancestor.
- Phylogenies allow for inference about history and how groups might have been related to each other in time.
- Phylogenies can help explain why groups of things may share some similar features due to common ancestry.

The phylogenetic approach has been widely discussed and applied in cultural evolution. Broadly, we can view a cultural phylogeny as a depiction of the inferred evolutionary relationships among a set of cultural lineages (e.g., languages, cultural groups, stone tool types, etc.). Because of their ubiquity, we only provide a supplementary tutorial for those users who might be interested in a basic introduction to methods for constructing phlogenetic trees using cultural data. This tutorial can be found here.

Diversification Rate Analysis

In these tutorials, we will focus on a suite of models for the less known analysis of **diversification rates** (i.e., birth and death rates). Diversification rate analysis allows us to identify and characterize

the influence of evolutionary mechanisms and major events on the histories of cultural forms. Among others, the following phenomena are observable by examining diversification rates:

- Major historical events
- Cultural competition
- Mass extinctions and key innovations
- Extrinsic environmental influences

The approaches we highlight in these tutorials can be broadly viewed as similar to a paleobiological approach to macroevolution. This work parallels a long history of using the fossil record to estimate rates of organismal speciation and extinction. Broadly speaking, the focus of these analyses moves away from reconstructing the precise historical relatedness between species or cultural traits (phylogeny) and towards understanding the broader mode and tempo of evolutionary change.

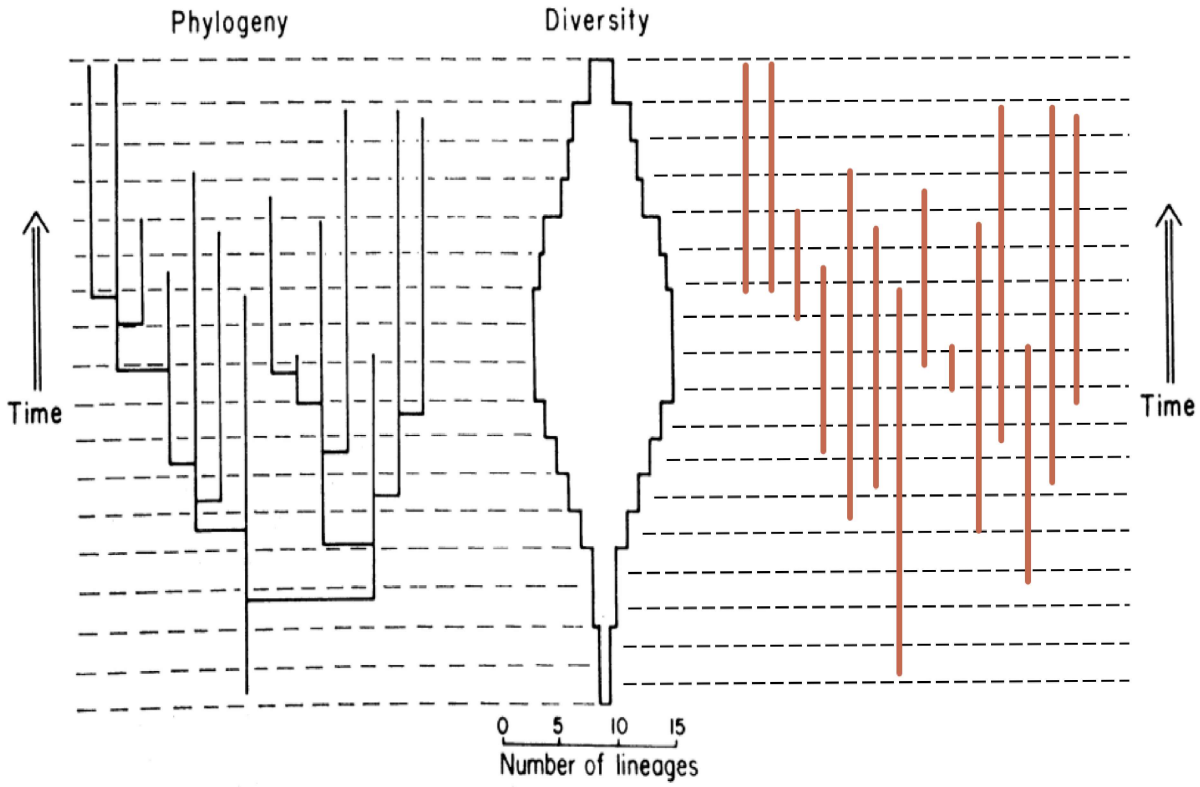

Image adapted from Raup et al. 1973

In practice, these approaches tend to focus on long-term changes in diversity by examining the occurrence of lineages across time (see image above). This is advantegous to many domains of cultural macroevolution as we do not require explicit knowledge of phylogenetic relationships. Therefore, these methods can be used with a wide range of material and historical data sets.

When should you use the macroevolutionary methods presented here?

Both theoretically and empirically, it is often difficult to trace cultural change over long time periods and high levels of cultural organization back to individual interactions. It therefore makes more sense to formulate questions, mechanisms, and models in terms of cultural forms (i.e. diversity of cultural lineages), rather than the people that produce them. For this reason, the macroevolutionary methods highlighted here seek to explain cultural change from the data that *are* observable over larger and longer frames of analysis (i.e. the material products of culture).

As a result of these considerations, the methods presented here are good for abductive construction of historical narratives from pre-theorized mechanisms, rather than the deductive elucidation of cultural mechanisms. Microevolutionary simulations, experiments, and ethnographies excel at the latter. However, in most macroevolutionary analyses, theoretical mechanisms are strongly encoded into the models we use, and empirical analysis proceeds by comparing different models.

One advantage of a macroevolutionary approach is that we can propose causal hypotheses in the face of incomplete individual-level data. This is especially relevant in the era of Web 3.0 and social media where much of our socio-cultural life is performed online, and we may know very little about the authors of every tweet, post, or blog entry.

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d. Table of Contents

These tutorials are broken down into four modules.

1. **Diversity and Diversification.** In this tutorial we introduce users to metrics for diversity and diversification rates. We build a simulator to explore the diversification of lineages within a cultural form. Empirically, we contextualize these analyses within diversity of car models that make up American automobiles throughout the 20th century (Gjesfjeld et al. 2020).
2. **Introduction to Birth-Death Processes and LiteRate.** In this tutorial we introduce the linear birth-death process as a statistical model for cutting through stochasticity in diversification rates. We also introduce LiteRate, an unsupervised machine-learning algorithm built on birth-death processes designed to identify statistically-signifcant shifts in diversification rates (Silvestro et al., 2019). Finally, we show users how to run LiteRate on their own data. Empirically, the module introduces the diversification of Metal bands active from 1968-2000 as a means to understand the history of the Metal music genre.
3. **Interpreting LiteRate Results**. This tutorial shows users how to check the convergence of LiteRate's Markov chain Monte Carlo algorithms, as well as how to plot LiteRate results.

Empirically, we show how shifts in diversification rates delineate a multi-stage trajectory for the evolution of Metal music over time.

4. **Modeling Evolutionary Mechanism in Diversification Rates**. In this tutorial we expand our simulator to model evolutionary mechanisms within diversification rates like significant extinctions, key innovations, and competition. We describe how to translate simulations to statistical models, and apply a competition model to the Metal data.

In addition, we provide a supplemental tutorial that examines the concepts and methods behind the use of phylogenetic approaches.

- **Cultural Phylogenies**. This supplemental tutuorial shows users the types of questions addressable using phylogenies, explains how phylogenies are constructed, and contrasts this approach to diversifcation rate analysis. Empirically, we demonstrate some phylogenetic analyses on a dataset of Austronesian languages (Gray, Drummond and Greenhill 2009).

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e. How to Use These Tutorials

These tutorials are built in the Google Co-laboratory Environment. Colab is a free resource linked to Google accounts that runs Python notebooks on the cloud and attaches to your Google Drive. When you open a Colab notebook, Google creates a virtual machine for you with Python and the most relevant scientific packages preinstalled. Because it is a complete virtual machine, you can also install your own Python packages, download software from Github, link files from your Google Drive, run command line programs, and use a GPU/TPU. We will make use of some of these features throughout the tutorials.

Because most of the diversification rate tools developed by our group are written in Python, Colab seemed like a natural choice. This means that you can try all of our software without installing anything on your computer, and you can actually run the necessary Unix commands to install and run our tools on the command line of your Mac or Linux box *within the tutorials*.

Unfortunately, Colab is based in Python and can run specific code chunks in R, but it does not (yet) fully support the simultaneous running of both R and Python. Probably like you, we do a lot of our data manipulation and plotting in R, so there is a mix of Python code and R code throughout the tutorials.

Running the tutorials

To use the tutorials simply:

- Read the text blocks and following the links to important websites and videos.
- Run the Python code blocks in each tutorial ***in sequential order*** by clicking on the play button. No need to run or install anything on your computer. If you do not run the code blocks in sequential order, you will get errors. All the code used to produce the images and analysis is provided for those users interested in the details of the code.
- Please feel free to fool around with any parameter widgets when available before re-running code blocks.
- While R code blocks can be run using the `r2py` package within the notebook, is it probably easiest to copy R code blocks into RStudio on your computer.

Deep Dives

We designed the modules for two types of users: 1) those who are looking to apply these methods to their own datasets and 2) those who are more interested in the underlying statistical models and algorithms. We focus on providing intuitive explanations of our models in the main text, but please see the "Deep Dive" content for deeper technical details of the math and algorithms to learn more.

Most importantly, we want these tutorials to help foster a new perspective on methods useful for the macroevolutionary analysis of culture. If you have any additional questions or suggestions for these tutorials please feel free to contact the lead developers: Bernard Koch or Erik Gjesfjeld.

Citing the theory and methods

If you enjoyed these tutorials and end up using these methods, please cite both of the following papers:

Gjesfjeld, Erik, Daniele Silvestro, Jonathan Chang, Bernard Koch, Jacob G. Foster, and Michael E. Alfaro. 'A Quantitative Workflow for Modeling Diversification in Material Culture'. PLOS ONE 15, no. 2 (6 February 2020): e0227579. https://doi.org/10.1371/journal.pone.0227579.

Koch, Bernard, Daniele Silvestro, and Jacob G. Foster. n.d. "The Evolutionary Dynamics of Cultural Change (as Told Through the Birth and Brutal, Blackened Death of Metal Music)." SocArXiv. osf.io/preprints/socarxiv/659bt.

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Silvestro, Daniele, Nicolas Salamin, Alexandre Antonelli, and Xavier Meyer. ‘Improved Estimation of Macroevolutionary Rates from Fossil Data Using a Bayesian Framework’. Paleobiology 45, no. 4 (2019): 546–70. https://doi.org/10.1017/pab.2019.23.

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