Fractal Analysis as Method for studying Social Hierarchy in Prehistoric Settlement Plans

with case studies from the Linear Pottery and Trypillia cultures (5.500 - 3.500 cal. BCE)

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Preface

Thanks to everyone.

Remember to add abstracts

Furholt, Grier, et al. (2020), Furholt, Müller, et al. (2020), Furholt, Müller-Scheeßel, et al. (2020) are three different publications. Furholt, Grier, et al. (2020), Furholt, Müller, et al. (2020), Furholt, Müller-Scheeßel, et al. (2020) are the same three publications in the same order. gfdsdfgs , Get on with it!

Part I

Frameworks

Chapter 1

Introduction

1.1 Background of the study

- Studying social hierarchy in prehistory through fractal analysis of settlement plans
- In Europe, the Neolithic is the long and messy transition period between mobile hunter-gatherer groups in the Palaeo- and Mesolithic, and the first city states in the Bronze (Aegean) and Iron Ages (Mediterranean and Central Europe)
- Early farming economy, influence from the Near East.
- Large variety in scale and content of archaeologically defined culture groups. Single farmsteads and small hamlets in many phases – some with hardly any settlement evidence at all **examples mid-neo, use** Shennan (2018). Other phases include exceptionally large settlements, probably hosting populations of several thousand inhabitants, like at Maidanetske in central Ukraine around 3.800 BCE (see 3.3). While in some settings, like in Linear Pottery society in much of continental Europe north of the Alps towards 5.100 BCE (see 3.2), the dead were buried in simple pit graves, with very little distinction in treatment between individuals, in other phases some individuals were buried with tremendous amounts of precious goods like in Varna, Romania, or under colossal burial mounds like in Carnac, France, both in the mid-5th millennium (Shennan 2018)**check ref**.

- Seen at a very large scale – across the continent and through the Holocene – the development of society from small scale and relatively egalitarian towards large scale and more hierarchical seems evident (though not to everyone, see Graeber and Wengrow (2021) and Section **??**). When we look more closely however, this evolution is anything but linear, as both population sizes and levels of hierarchical organisation seem to fluctuate considerably, sometimes over short time spans as from the Trypillia **C2 to D1??, check this**, when the so-called mega-sites are abandoned and their former inhabitants regroup into much smaller settlements during a transition of maybe only **check and ref** years.

- In many cases, the level of social hierarchisation and complexity in a given Prehistoric society is very hard for researchers to evaluate, since many indicators of such structures are either lost from the archaeological record, or were never included in the first place [Perreault (2019); Section 3.1]. Archaeological traces that are often interpreted as signs of social complexity and hierarchy may furthermore be deceiving. Seemingly monumental structures were in many cases built through small additions over centuries, rather than in one colossal construction campaign [**example, Carnac alignments? Danish megaliths?**]. In many megalithic burial contexts, it may be impossible to know how large a segment of the society that had access to such inhumations (**rephrase**).

- New methods for investigating hierarchy: fractal analysis. Borrowed from other disciplines, not much tested in archaeology. Example from human geography, use:(Batty 2005; Batty and Longley 1994; D'Acci 2019; Jahanmiri and Parker 2022; Lagarias and Prastacos 2021; Tannier and Pumain 2005) (say what fractal analysis does, don't explain what it is here)(explain just the word fractal and cite section).

1.2 Research question and objectives

The overall goal of the present study is to test and assess the utility of fractal analysis techniques as tools for studying hierarchical social organisation in prehistoric societies. Two methodological approaches are under special scrutiny: the distribution fitting approach and the image analysis approach (Brown and Liebovitch 2010; Brown, Witschey, and Liebovitch 2005). These are applied to architectural data series from well-preserved and documented archaeological samples within Neolithic Linear Pottery and Trypillia contexts, as well as to synthetic data series. This thesis is thus not to be considered a culture-historic study of Linear Pottery or Trypillia society, but mainly a methodological study. However, results from the proposed analyses of these case studies may also contribute, as side-effects, to their respective fields of research.

For the distribution fitting approach, house-size distributions within settlements are modelled following a given procedure, and the retained model (the best fit) is interpreted in terms of social generating mechanisms. In particular, it is argued here that so-called power-law distributions reflect hierarchical structure, so that the identification of these within the studied samples may indicate the presence of some social hierarchisation process which warrants further interpretation.

With the image analysis approach, the spatial layouts of archaeological and synthetic settlement plans are analysed through the calculation of fractal dimension and lacunarity – summary statistics which serve as quantifications of irregular spatial patterns or image textures. I argue here that geometrically irregular settlement plans are indicative of relative independence between households, while settlements that develop within geometrically regular grids indicate stronger overarching social structures, with a continuous range of possibilities in-between. The goal here is to test to which extent quantitative measures like fractal dimension and lacunarity may help differentiating between varying degrees of planning in prehistoric settlements.

While both these methodological approaches are well developed and integrated to other disciplines (e.g. Lagarias and Prastacos 2021), their usage in archaeology have so far remained anecdotal (Diachenko 2018). A further overall goal of this thesis is to identify and explore possible limitations in the nature of archaeological data that may limit the applicability of fractal analysis methods within this discipline. For example, does fractal analysis of settlement plans require a data quality that would be practically unattainable in archaeological settings? But also inversely, as it is impossible to explore all potential applications within the framework of one doctoral thesis, suggestions for future research are provided in the last chapter.

1.3 Defining hierarchies

The term *hierarchy* is central to the present study. Though commonly used in daily speech, defining the word is not as straight-forward as one might think, so some clarification on how it is understood here might be needed. In a volume dedicated to exploring the meanings and uses of hierarchy as a study object within a range of natural and social sciences, Denise Pumain provides a panorama of definition nuances, but also highlighting the characteristics that are commonly found in most cases (Pumain 2006). Among these characteristics are:

- A pyramidal organisation of elements, ordered by a very unequal size distribution of a certain quality or variable, from a few large elements on top to many small elements at the bottom
- When seen as a system, the whole is constituted of sub-systems, which are again constituted of sub-sub-systems, and so forth. These can either be ordered into clearly distinguished levels (stratified), or in other cases be scaled in a continuum (branched or tree structure)
- In physical, biological and social hierarchical systems, the structure is often accompanied by a flow of energy, material, information or control in one or both directions between the top and bottom levels

Hierarchies are found in humanly constructed classification and taxonomical systems, where morphological distinctions are considered more important or fundamental at the higher end of the hierarchy, while being more detailed or specific at the lower end. Many hierarchical social systems, like religious (from Greek *hieros* – sacred, and *archê* – government), military or corporate organisations, include strongly reinforced regulations of subordination, which in modern society has led to somewhat negative connotations to both hyper-rational and despotic rule(Pumain 2006:5–6). While one prevalent explanation for the frequency of hierarchical structures in nature and society is indeed that they “represent the best solution for many optimisation problems” (*ibid*. p.7), that does in no way mean they need to be consciously planned. On the contrary, in most cases hierarchies seem to emerge spontaneously, often from growth processes with systems splitting into sub-systems once they reach a certain critical size limit. There is also no compulsory link between social hierarchies and despotism, as it matters little to the overall structure whether the top element is elected for a limited period or born into an inherited leading position. More detail on how hierarchical structures emerge and how they can be described as fractals, is given in Chapter 2. A further discussion on the specifics of social hierarchies is given below in Section 1.4, and on the differences between spontaneously emergent versus consciously planned structures in Chapter 7.

A possible confusion with a somewhat different meaning of the term hierarchy should however be mentioned already here. If hierarchical structures are abundant in nature in both physical (inert) and biological systems, social hierarchies on the other hand – understood as intra-species populations of individuals organised in pyramidal hierarchical, i.e. multi-level relationships to each other – seems to be almost exclusively found among human groups. At the same time, a different type of hierarchy is frequently described by biologists which is common among animals, namely *dominance hierarchies*, also known as pecking order (Strauss et al. 2022). These structures are hierarchical in the sense that there is difference in rank between group members, and they also seem to emerge spontaneously in the animal populations where they are described. But unlike social hierarchies, these are purely *linear*, in the sense that each group member is situated in rank above one part of the group and below the rest, so that the whole group forms a rank chain in the form A > B > C … n. The rank of an individual will typically decide their access to food and reproduction relative to the other members, and may be settled and resettled in a number of ways depending on the species and population under study, but typically involving some level of violence or threat and subordination in face-to-face encounters (Strauss et al. 2022).

A classic example – perhaps most of all in popular culture – is dominance hierarchy among wolves, led by an alpha male (e.g. Cafazzo, Lazzaroni, and Marshall-Pescini 2016; Packard 2003). Though it has been much discussed whether or not this trope model actually fits wolves (see Mech 1999; Muro et al. 2011), any reported dominance hierarchies among larger groups of wolves and stray dogs are linear rather than pyramidal, even when they are illustrated as pyramidal (e.g. Fig.1 in Rodríguez et al. 2017). Similar social organisation systems are found among a wide variety of species – mammals, birds, fish, particularly but not only among group-hunting carnivores – and are generally interpreted as an evolutionary mechanism (Strauss et al. 2022, with references). Cases of branching, multi-level social hierarchies among animals are on the other hand extremely rare, but have been reported to operate among hamadryas baboons in Ethiopia, with "clan leaders" forming relays of information flow and decision making between the "one-male units" within a total population ("band") of about 200 individuals (Schreier and Swedell 2009). Eusocial insects like ants and wasps provide a more well-known example of hierarchical organisation among animals (Shimoji and Dobata 2022), also indicating – if it should be necessary – that it is not a matter of cognitive abilities or brain size, but rather of social function (e.g. building a hive or a village together) and population size above a certain threshold.

The reason to dwell upon this qualitative distinction between linear and pyramidal hierarchies, is that the prevalence of the former in nature is sometimes put forward as an argument for social hierarchies among hunter-gatherer groups in the Palaeo- and Mesolithic [find precise reference here –> Graeber, if else strawman, Hayden 2007, pp. 231-6] **fill in this one**. While it is a good point that there is no reason there couldn't be linear dominance hierarchies among small forager groups, and that such systems hardly can be described as egalitarian by those who live them, we cannot assume that pyramidal social hierarchies have always been part of human culture, but rather that they – much like agriculture – at some point came to be as historical phenomena.

Bottom line hierarchy: pecking order/linear dominance hierarchy may be prevalent in any part of human prehistory, but could also be very hard to study from material remains. Branching (i.e. fractal) hierarchies as well as social stratification should leave material traces, and are most probably related to population size (see below), and thus less likely to be found within pre-Neolithic societies. They should be regarded as historically situated phenomenons – much like agriculture, pottery, writing or the steam engine – justifying the search for and explanation of their possible origins (*contra* e.g. Graeber and Wengrow 2021). The issue of the universality or particularity of social inequality and hierarchy is discussed in more detail **in the final chapters of this thesis (specify).**

- Inequality Kohler and Smith (2018), Midlarsky (1999), Price and Feinman (2010), Price and Feinman (1995). The difference between the concepts of social hierarchy and social inequality lies in the former relating to social and/or political organisation and the distribution of power, while the latter to economy and the distribution of wealth or income. Societies where these two are completely unrelated may be theoretically conceivable – that is, where wealth does not entail power and *vice versa* – but historically they have tended to go hand in hand, albeit not necessarily in a straightforward way. HERE discuss a bit on delegated power, democracy, taking turns etc., and such systems being impeded by wealth (lobbying, corruption++). Keep it simple, point is to prepare for the interpretation of Trypillia mega-sites as *both* egalitarian and hierarchical (and maybe LBK as *both* unequal and unstratified..).

1.4 What is social hierarchy?

- Political assumptions – all hierarchical social structures are not despotic top-down rule. Democracies can also be very hierarchical. Matter of scale rather than political system Graeber and Wengrow (2021). But, tendencies? Use Pumain (2006), also Furholt, Grier, et al. (2020). Use Redhead and Power (2022): status and leadership, multiple overlapping networks. Emergence of hierarchies: "Positions in the dominance hierarchy is determined by a combination of attributes of individuals, stochastic processes, and social context" Strauss et al. (2022).

- Nested and non-nested social hierarchies, hierarchical hunter-gatherers? Hamilton et al. (2007), Whitridge (2016) (or use in Chapter 11?)

- Biologically defined thresholds to group size? Dunbar's number and controversies, Dunbar (2022), West et al. (2023) (add published papers). Scalar stress Johnson (1982), Alberti (2014), Zhou et al. (2005). Also Carneiro (1986), Dubreuil (2010)

- Temporal dynamics of social hierarchies: cyclicity (Peters and Zimmermann 2017), sawtooth waves (Scheidel 2017), punctuated equilibrium [Gould (2007); zimmermann?]. Archaeo. example South Sweden Neo/BA: Nordquist (2001). Transitions villages to urban: Birch (2014)

- Tools for classifying societies, or evolutionary model? Discussion of Johnson and Earle (1987), Testart (2005), Service (1971), Earle (1997).
  - Lineage and Chiefdom societies Earle (2002), Sahlins (2020)

An additional category of social structure, which has had a certain success in archaeology, was described by Claude Lévi-Strauss as *house societies* (Lévi-Strauss 1982). Here a house is a social unit, often centred around a material estate but also involving titles, heirlooms, land ownership, rights to hunting grounds etc. and where membership is not determined from genealogy in a systematic manner, as is the case with more regularly structured lineage or clan societies. House membership may be gained through more competitive social action, privileging those that possess the resources to engage in activities such as gift exchange and *potlatch*-style feasting. This opens up for more complex configurations, and house membership will often entail a certain level of prestige. Inheritance may furthermore follow (male) descent or (female) affinity – that is from grand-father to grand-son via mother – in a pragmatic way depending on which option is in the best interest of the house, as long as it can be justified in more or less precise kinship-related terms. A segment of society of varying size will not afford to partake in this competition, and as a result, house societies can be viewed as being in a somewhat unstable transition state between lineage and class societies. Lévi-Strauss originally pinned the term on Kwakiutl society in the American north-west coast (as described by Franz Boas), but argued for its generality by associating it with the feudal system of medieval Europe. The concept has since been applied to a wide range of cases from ethnography (especially in the South-East Asian and Pacific regions), as well as to prehistoric contexts **insert examples**, reflecting a relevance that extends far beyond European feudalism. Ian Kuijt (2018) recently provided an interpretation of Neolithic Çatalöyük where he proposed that

Refs. house societies [Joyce and Gillespie (2000), Bnf; Beck (2007); Kuijt (2018); Lévi-Strauss (1982); Bickle et al 2016 (reload in Zotero)].

-

- Anti-evolution critique in Yoffee (1993), Yoffee (2005), Fontijn and Brück (2013), Kienlin and Zimmermann (2012), Lund, Furholt, and Austvoll (2022), Furholt, Grier, et al. (2020).

Review in Dubreuil (2010). Anarchistic critique/heterarchy: Crumley (1995), Haude and Wagner (2019), Graeber and Wengrow (2021). Paleaeolithic social inequality: Honoré (2022) ++.

1.5 Main findings here?

Maybe leave to the end, and fill in, like abstract.

1.6 Research ethics

- Social complexity and evolution. Are less complex societies simple? Is that a bad thing?
- Open science and open-source scripts
- Terminology and spelling (British English for text. For geographical place names, Slovak special characters are kept as far as possible, even though it can be a pain in the xxx to render in Rmarkdown on Windows OS, and the 2010 Ukranian National transliteration system with only ASCII characters and no soft sign)
- Abstracts in Slovak and Ukranian (and not only in Norwegian)

1.7 Structure of the thesis

This thesis is structured as a monograph in four parts. In the first part the overall framework of the study is exposed, with the general introduction above, the overarching theoretical framework in Chapter 2, and the background of the study material in Chapter 3. Parts II and III are devoted to each their methodological approach to the material: Part II to the study of hierarchy in size distributions, and Part III to the quantification of image textures. Each of these parts consists of three chapters, the first of which – Chapters 4 and 7 – exposes the theoretical and interpretative background of the applied methods and their relevance to archaeology. The following chapters –

Chapters 5 and 8 – detail the technical specifics of the two approaches and their implementation in this study, and the last chapters within these parts – Chapters 6 and 9 – provide the actual analyses and summaries of results. In Part IV, the findings are summarised and further discussed. Chapter 10 gives an attempt of interpreting the results in the context of the culture-historical setting of the European Neolithic, while Chapter 11 reviews the possibilities and limitations of the fractal analysis framework in archaeology. Concluding remarks and suggestions for further study are given in Chapter 12.

Some readers might react to an apparent deviation from the academic tradition of devoting a separate chapter to research history. This is a deliberate choice, not to suggest that historiography is unimportant, but rather as a result of the fundamentally interdisciplinary scope of the study. In fact, there is very little extant history of applying fractal analysis in archaeology – the few studies that, to my knowledge, have been done in this direction are discussed primarily in Sections 4.3 and 7.3. Fractal analysis itself holds a research history of its own (see Section 2.2), and so does the study of Linear Pottery (Section 3.2) and Trypillia societies (Section 3.3), not to mention the general study of social complexity in prehistory (mainly Section 3.1). In short, instead of trying to shoehorn these parallel histories into a clearly delimited but rather hybrid chapter, I have opted for what I believe to be a more useful approach, namely to fit them in more seamlessly where they belong, in the various associated theory and methods chapters.

An additional note should be made here regarding the writing style of the different parts and chapters. It is my belief that a major obstacle for fractal analysis methods to become more integrated into the standard tool kits of archaeological research, is the excessively technical nature of much of the associated literature. archaeology as a discipline remains profoundly rooted in the Humanities, as seen in the inbuilt structure of teaching, research and funding institutions in most (at least European) countries. Fractal analysis is derived from pure mathematics, and most applications so far have been developed within the natural sciences (**ref necessary?**). Archaeologists who are trained within a humanistic scholarly tradition cannot be expected to hold a skill level of mathematics more advanced than what is achieved in high school, and code programming is hardly taught at all within the walls of Humanities faculties. Technical details regarding the methods and analyses applied in this thesis are therefore – as much as possible – limited to the devoted Chapters 5 and 8, and readers who are interested in these may also refer to the online code repository for more details and reproducibility **cite repository**. In the rest of the thesis I have opted for a more narrative approach, in an attempt to invite a somewhat larger audience of archaeologists into the fascinating complexities of fractals.

END Chapter

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Figures and tables with captions will be placed in `figure` and `table` environments, respectively.

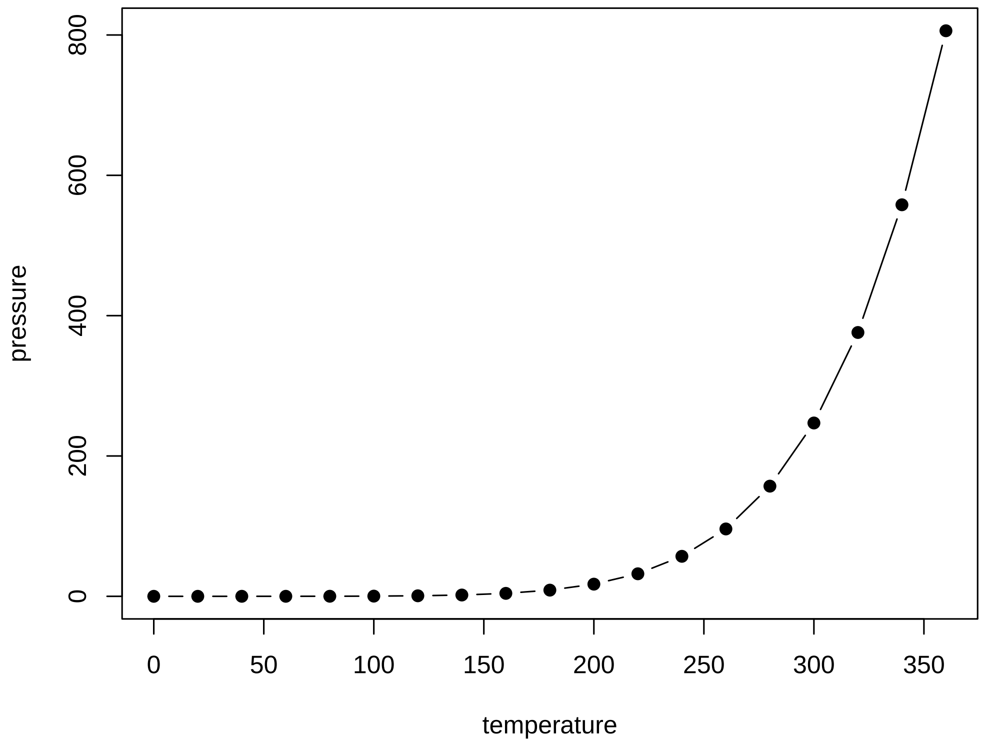

Figure 1.1: *Here is a nice figure!*

Reference a figure by its code chunk label with the `fig:` prefix, e.g., see Figure 1.1. Similarly, you can reference tables generated from `knitr::kable()`, e.g., see Table 1.1.

You can write citations, too. For example, we are using the **bookdown** package (**R-bookdown?**) in this sample book, which was built on top of R Markdown and **knitr** (Xie 2015).

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Test: Mandelbrot (2021). jløkj fdsasdfadfasdfadf new text

Table 1.1: *Here is a nice table!*

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4.6	3.1	1.5	0.2	setosa
5.0	3.6	1.4	0.2	setosa
5.4	3.9	1.7	0.4	setosa
4.6	3.4	1.4	0.3	setosa
5.0	3.4	1.5	0.2	setosa
4.4	2.9	1.4	0.2	setosa
4.9	3.1	1.5	0.1	setosa
5.4	3.7	1.5	0.2	setosa
4.8	3.4	1.6	0.2	setosa
4.8	3.0	1.4	0.1	setosa
4.3	3.0	1.1	0.1	setosa
5.8	4.0	1.2	0.2	setosa
5.7	4.4	1.5	0.4	setosa
5.4	3.9	1.3	0.4	setosa
5.1	3.5	1.4	0.3	setosa
5.7	3.8	1.7	0.3	setosa
5.1	3.8	1.5	0.3	setosa

Chapter 2

Theoretical framework: Complexity and Fractals

2.1 Very short introduction to Complexity Theory / Dynamical Systems Theory

Lit. use Daems (2021), Baden and Beekman (2016), Ross and Steadman (2017), Smith (2011) and Bentley and Maschner (2008).

For Dynamical Systems, use Devaney (2020), but don't go into detail.

Describe complexity, dynamical systems, chaos, feedback loops, criticality, emergence. Scale West (2017) NA

Social complexity is more than social hierarchy, and all societies – whether they are classified as simple or complex within a social evolutionary framework – can arguably be studied as complex systems, since they always consist of various sub-systems and populations of individuals acting and interacting in a variety of ways (Daems 2021:6). The sense of social complexity that is traditionally understood in archaeology, derived from social evolution theory, is somewhat narrower and relates more to the specific characteristics of organisational scale (i.e. hierarchy) than to complexity per se. Studying the scale of social organisation from a complex systems perspective rather than from a social evolutionist one holds several advantages:

1. The switch from discrete evolutionary stages to continuous spectra allows for more nuanced evaluation of the society in question, avoiding false binaries like simple-complex
2. The complex systems approach arguably has a stronger explanatory power than the more classificatory social evolution schemes
3. Complexity theory offers a better alternative for ethical reasons, as it avoids the underlying colonial and eurocentric connotations associated with classifying societies into simple and complex

As a further elaboration on the latter point, an analysis of a society from a complexity theoretical viewpoint is not a matter of establishing whether or not the society can be characterised as a complex system. When the scale of social organisation is the object of study – as in the present thesis – the word hierarchy is both more accurate and, if not neutral, at least more balanced than social complexity, since it is not obvious whether or not it is a good thing for a society to be characterised as hierarchical. The study of the dynamics of social hierarchy over time is thus not a story of progress, as the 19th century studies of social evolution too often were.

[@hamilton2007].

Mention the most common applications in archaeology, as discussed in Daems (2021), p. 13: network science, settlement scaling, cultural evolution and agent-based modelling.

2.2 Very short introduction to Fractals and Fractal Analysis

Lit. use Mandelbrot (2021), Falconer and Falconer (2013) (general), also Brown and Liebovitch (2010), Brown et al. (2005) and Diachenko (2018) (for archaeology)

The term *fractal* was pinned by the French-American mathematician Benoît Mandelbrot (1924-2010), from the latin word *fractus* meaning broken or irregular, to describe patterns that because of their apparent limitless complexity defied concise description within the framework of Euclidean geometry (Falconer and Falconer 2013:116–20). Such patterns – both theoretical and empirical – had been described and analysed by mathematicians and researchers within other disciplines since the end of the 19th century, but were mostly regarded as curiosities and exceptions, and Mandelbrot was the first to link all these previous studies within a unified theoretical framework (Mandelbrot 1975, 2021).

In one influential paper, drawing on previous work by mathematician Lewis Fry Richardson, Mandelbrot (1967) argued that a rugged linear feature like a coastline cannot be fully described through traditional geometry with a set of line segments, since this would result in a curve of infinite complexity. More importantly, he showed that the traditional measure of lines – the length – will inevitably depend on the scale of observation when applied to a coastline. If measured in kilometres, a coastline will always appear shorter in total length, than if it is measured in metres, since smaller bays and inlets can then also be accounted for. But this phenomenon continues seemingly without limit, since the same coastline measured in centimetres will appear much longer, and in millimetres far longer again, and so on. Length as a measure of rugged linear features thus seems inadequate, which may become a problem in practical settings when comparing coastlines between countries that operate with different measurement units and procedures. The same problem occurs when describing irregular patterns in the plane (like island or continent outlines) with area or in three-dimensional space (like clouds or galaxies) with volume. As a solution, Mandelbrot proposed the use of the *fractal dimension* as a descriptive tool for characterising such patterns.

Fractals as hierarchy

Self-similarity and scale invariance

Processes/mechanisms that produce fractals:

- Cascading bifurcations and confluences (splitting or merging - tree structure/arborescence/branching, and relation to size. Terminology borrowed from biology and fluid dynamics (including turbulence/turbulent flow)

The role of randomness - tidy and messy fractals (romanesco broccolis are not more fractal than regular broccolis, only more regular. Also: a system may be both random and deterministic, often only depending on scale of observation (chaos).

The relationship with (self-organised) criticality and chaos: deterministic *and* unpredictable

Fractals embedded in

- Space (hence "fractal geometry"): geomorphology, plants, ocean and wind currents, galaxies, also human constructed features (see Chapter xx for details)
- Time series: earthquakes, finance (not applied in this study, though should be done later)
- Networks/abstract: hierarchical organisations, income distributions, word counts, 1/f or pink noise, www. Barabási and Albert (1999) etc. (see Chapter xxx for details). Fractal social networks: West et al. (2023).
- Pure mathematics: Julia and Mandelbrot sets, strange attractors (don't go into details!)

No, not everything is fractal: e.g. Central Limit Theorem

Fractal analysis for studying irregular phenomena (methods described in more detail Chapters xxx), and thus as a tool for quantitative empirical research.

2.3 Very short introduction to micro-macro approaches in social theory

- Lévi-Strauss and Structuralism
- Braudel and World Systems
- Giddens and Structuration Theory
- Delanda and Assemblage Theory

For social hierarchies, he refers to Weber's classification of legitimation strategies, as being founded on sacred tradition, personal charisma or rational bureaucracy (see also Graeber and

Wengrow 2021, pp.). Delanda furthermore places Bourdieu's concept of *habitus* on the mid-range between micro and macro processes, as an explanation of social action that is not entirely individual dependent, but not emergent properties of society-as-a-whole either.

- Latour and Actor-Network Theory

What these approaches all have in common, is that they are entirely qualitative (**check**).

- That's not a problem in itself.
- Quant approach is both possible for the stated purpose, and desirable for reasons of comparative analysis.
- Data deluge (refer to chap. on geomagn data). The goal here is to establish a quantitative framework for studying social complexity and hierarchy in archaeological/prehistoric settings. Further articulating fractal analysis with existing social theoretical approaches is not the primary goal here, as it could constitute a separate research project. In the present thesis, bla bla.

END chapter.

Math can be added in body using usual syntax like this

p is unknown but expected to be around 1/3. Standard error will be approximated

$$SE = \sqrt(\frac{p(1-p)}{n}) \approx \sqrt{\frac{1/3(1-1/3)}{300}} = 0.027$$

You can also use math in footnotes like this[1].

We will approximate standard error to 0.027[2]

[1] where we mention $p = \frac{a}{b}$

[2] p is unknown but expected to be around 1/3. Standard error will be approximated

$$SE = \sqrt(\frac{p(1-p)}{n}) \approx \sqrt{\frac{1/3(1-1/3)}{300}} = 0.027$$

Chapter 3

Material and data: social complexity in the European Neolithic

3.1 Studying social hierarchy in archaeology and prehistory.

- Grave goods
- Burial monuments
- The denominator problem
- The use of ethnography
- Other approaches (osteological, isotopes, craft specialisation **refs**)
- This project: house-size distributions and settlement layouts (details in subsequent chapters), just very short argumentation.
- Comparative approach: Neolithic technology (not bronze axes), wood and wattle-and-daub architecture, (near) complete settlement plans/extensive documentation

For this project I opted for the use of houses and built environments as proxy for social hierarchy. In this way I hope to largely avoid the denominator problem associated with burials. While it is true that for many archaeological culture groups in late prehistory habitats are poorly preserved and hard to discover, leaving us still with a limited understanding of them (the case in many Michelsberg, Corded Ware and Bell Beaker groups, only to mention a few **check**), in groups where habitats are well preserved, there is little reason to suspect that the available record would not cover the whole range of social statuses if these societies were hierarchical. Unlike burials, every individual in a sedentary society – with few exceptions like homeless persons in more recent urban contexts – will normally have at least one fixed place to stay overnight, and these homes will in most cases be constructed within the same fundamental framework of techniques and building materials, depending more on culture specific traditions and environmental factors than on social status (**citation?**). As an example, in a society where mudbrick is the main building material, like in the Neolithic Near East and Anatolia, nearly all constructions are made in mudbrick, regardless of the social status of the inhabitants. In Europe north of the Alps, wattle-and-daub construction was the almost exclusive building technique for any architectural feature from the early Neolithic until the Roman conquest, and well into the Middle Ages north of the *limes*. One can of course enumerate exceptions, but more importantly houses are in any stratified society also a marker of social status, which can be exhibited in a range of ways, from decorations, use of more precious raw materials as well as size. That is precisely the reason for using houses as a proxy for social status and hierarchy in archaeological settings. But the point here is that there should be little taphonomic differentiation between groups of high and low status within a given archaeological context, at least in prehistory, and at least not as much as can be expected for burials, meaning that we can expect to find samples of houses that are representative of the social structure of the archaeological culture in question. On sites where there is taphonomical loss of architectural structures, as long as the overall building tradition is homogeneous, there is no reason this loss should affect one segment of the society more or less than others.

Some caveats do remain, however, for the use of houses as proxy of social status. Firstly, there may be a documentation bias favouring larger houses, since they may be easier to discover both during excavation and in remote-sensing surveys (**citation?**). In samples with very skewed house-size distributions, there may also be a further taphonomic bias towards large houses, since smaller houses – being far more numerous – are statistically in greater risk of being affected by post-depositional disturbances. Both of these biases are hard to evaluate empirically, though computer modelling could potentially give indications of their importance. This, however, is not within the scope of the present study.

A second, and maybe more important issue, is that of the contemporaneity of houses. When the goal is to investigate the social structure of a settlement as reflected in its architecture – be it through the size distribution of buildings or their spatial layout – all the analysed features should ideally have been in use at the same point in time. This is however very hard to achieve in most archaeological settings, and many researchers choose to either ignore the issue, or to accept a temporal resolution that is far wider than what their research questions should logically allow for (Perreault 2019). One way of limiting this problem is to select study samples with little to no stratigraphic overlap, which might indicate short occupation span, though as shown below this indicator can also be deceiving. For both study areas selected for this thesis – the Linear Pottery in south-west Slovakia and the B2/C1 Trypillia of central Ukraine – settlement plans show very little overlap between houses, even though some of them probably developed over more than three centuries, as shown by radiocarbon dates and modelling (see below). Such settlement plans may be impossible to differentiate into separate coeval time samples without precise dating of construction and abandon of every individual house, counting in the thousands on the Trypillia mega-sites (an alternative method is presented only for the Linear Pottery settlements in Section 3.2). On the other hand, the fact that there is so little overlap between houses despite temporal differences clearly illustrates how these settlement plans emerged over time, not as a *tabula rasa* in each generation but rather with new constructions respecting the location and orientation of older ones long after abandonment. Though such practices are indeed interesting, it is not at all obvious, however, to which extent they may reflect or even relate to social factors such as hierarchy. With settlement types with much higher degree of stratigraphic overlap, like the tell sites of the Balkan and Near Eastern Neolithic traditions, it may be easier to distinguish more or less coeval occupation phases, but they are again harder to document extensively – because of the high density of archaeological finds and features, excavation surfaces typically cover only very small portions of the settlement, while remote sensing performs less well and not allowing for temporal disentanglement of constructed features (**citation**). In any case, the issue of temporal resolution of the data and its influence on analytical results is crucial, and will be discussed repeatedly throughout this thesis, with a summary in Chapter 11.

Comparative technology

Meaning of “house”

3.2 The Linear Pottery culture complex

- General intro to the culture

Formation, characteristics – striking difference from earlier Mesolithic cultures, hence the term “Neolithic Revolution” pinned by Vere Gordon Childe for the seemingly abrupt transition to agriculture in continental Europe with what he called the Danubian Ia **ref**. Whittle (2022), check with Trigger!

expansion trajectory: east: Saile (2020),

Questions of contact and even creolisation with local hunter-gatherer groups in the margins of the Linear Pottery settlement area – Limbourg and La Hoguette pottery groups in northern France and Belgium, Swifterbandt in the Netherlands??, Ertebølle in northern Germany??, Bug-Dniestr in Ukraine and Moldova (Saile 2020) – as well as with other already established Neolithic groups in central France (Roussot-Larroque 2022) and the lower Danube (Saile 2020), remain hotly debated

- Organisation of Linear Pottery society: egalitarian or hierarchic?
- Linear Pottery architecture and house construction

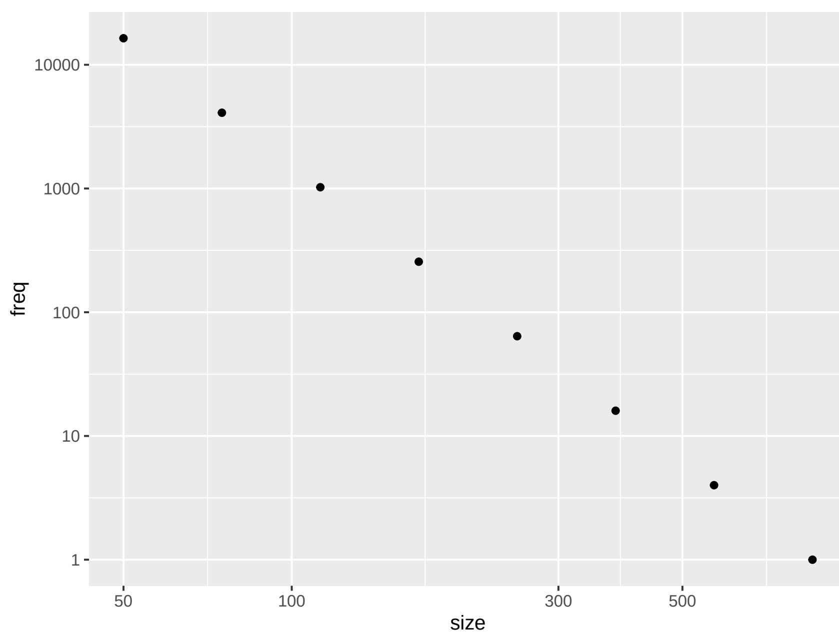
origin of the longhouse: Bánffy and Höhler-Brockmann (2020), Coudart (2015), Last (2015)

house typology, construction, and use: Modderman et al. (1970), Coudart (1998)

house orientation: “origin” hypothesis: Bradley (2001)

```
## -- Attaching core tidyverse packages ---------------
## v dplyr     1.1.1     v readr     2.1.4
## v forcats   1.0.0     v stringr   1.5.0
## v ggplot2   3.4.2     v tibble    3.2.1
```

```
## v lubridate 1.9.2     v tidyr     1.3.0
## v purrr     1.0.1
## -- Conflicts -------------- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflict
```



- The Žitava valley and research project

3.3 The Cucuteni-Trypillia culture complex

- General intro to the culture

Recent dating, see Harper et al. (2023).

- Trypillia architecture and house construction
- Trypillia social organisation: current debate

Side note on Varna: Lichardus (1991; also Gimbutas), as discussed in Kadrow (2013), proposed that the social inequality observed at Varna in the mid-5th millennium, was already then adopted from pastoral North Pontic steppe cultures (*check this and delete if unsure*); cf. Chapman et al. (2006) – three social levels interpreted from grave goods, but not clear if these are really discrete or constructed on a continuum. The term *fractal* is here used purely as a metaphor for complex personhood structures, rather in opposition to the described social hierarchy.

- The B2/C1 and the mega-sites of the Southern Bugh – Dnipro interfluve

3.4 Reading site plans from geomagnetic imagery

- Caveats: fill in here.

3.5 Synthetic data

- And why I'm not (this time) relying on ethnographic data.
- Don't go into technicalities here, just the reasoning.

Part II

Size distributions

Chapter 4

House sizes and social meaning

4.1 Possible reasons for house-size difference

In archaeology there are two recurrent and seemingly contradicting assumptions underlying interpretations of house-size differences within a society. In studies where the goal is to provide population size estimates, this is often calculated from total living area, adding together the areas of the houses in question, and multiplying by a mean value of surface per inhabitant (**give examples**). This mean value is generally obtained from multiple ethnographic parallels. With this assumption – that every inhabitant requires a similar amount of living space (**mention actual values from literature**) – the size of a house effectively reflects its number of inhabitants. The second assumption, which is more frequently seen in studies focussing on wealth inequality and social stratification, is that house-size differences are expressions of differences in some sort of wealth or power (**give examples**). In this view, a larger house would have belonged to a wealthier household, capable of procuring more raw materials and activating a larger labour force for its construction and maintenance, in which case there would be significant disparities in living space per individual. Even though there is not necessarily any contradiction between these two interpretations from an anthropological point of view, most archaeologists seem to be unable to consider both possibilities simultaneously. From a methodological point of view, each of these assumptions will tend to mask our ability to see traces in the archaeological data relating to the other assumption – that is, with existing methods we cannot convincingly provide estimations of both population size and level of social inequality from the same data, even though house sizes frequently form the basis of both argumentations. Far from proposing a solution to this issue, my argument here is that a variety of social institutions known from ethnography and historical sources can explain some level of correlation between the two variables. Dowry and bride price are geographically and temporally widespread practices that link number of offspring (daughters, sons or both, depending on cultural context) with wealth. Clan leaders may draw upon kinship ties and dependencies in order to obtain the workforce needed to construct a larger house (**citation needed**). Nevertheless, if the notion of wealth is at all to be applied meaningfully to non-capitalistic societies, it should designate cases where there is significant and persistent material disparities between members of a population, and not simply point to different household sizes. House sizes could thus potentially reflect a somewhat more complex culture-specific interplay between household size and wealth, meaning that for a given house size, one could assume a range of possible values of the two parameters (**insert fig/illustration**). This relationship between household size, wealth and house size should be studied more in detail empirically through the available ethnographic data, rather than reducing its complexity to a mean surface area per inhabitant for the entire population. Such a study, however, lies beyond the scope of the present thesis. Here I will largely leave aside the question of population and household size, focussing on distribution types of house size data, arguing that the most unequal distribution type considered here – the power-law distribution – is unlikely to emerge only from random differences in household size and standard marital patterns, favouring thus interpretations relating to wealth and/or power differences.

Even though the goal here is not to investigate household sizes but to focus on the material aspect of house-size distributions, some fundamental issues of terminology should be addressed. The use of the word *house* (in the wider material sense rather than the Lévi-Straussian sense, see Section 1.4) is indicative of an underlying assumption that the building in question was in use primarily for domestic purposes – essentially, a fixed architectural unit where someone would spend their nights at least most of their time, and in many cases also cook and eat their main meal during the day – though proving this directly is not always straightforward in archaeology. For the cultural contexts discussed here – the Linear Pottery and Trypillia groups in the Neolithic-Chalcolithic – there is however little evidence for buildings with specific non-domestic (e.g. economic, religious or administrative) purposes, with the probable exception of the so-called mega-structures or assembly houses in the Trypillia mega-sites, which are discussed more in detail below. This lack of evidence does not imply that there was no specialised economic, religious or administrative activity in these societies, as ethnography and history clearly shows that such activity must reach a certain degree of specialisation before it materialises in distinct buildings devoted exclusively for these functions. Artisans, shamans and chiefs could be specialised to some extent but still perform their activity at their domestic home or more diffusely outdoors or without any fixed location (e.g. Costin 1991:25). It is in any case of common usage to speak of houses when discussing architectural units in Neolithic Europe and other prehistoric contexts, maybe because of a lack of a better generic word, but this usage should not prevent archaeologists from recognising other non-domestic functions of buildings whenever there is evidence for it. The *household* is furthermore the designation of all the people, genealogically related or not, usually living under the same roof or within the same architectural unit, constituting a functional whole economically and socially, and potentially including more than a single family unit, as well as servants or slaves, depending on the context.

Kinship studies within anthropology have shown over the last decades that in most societies, contrarily to common misconception, kin affiliation is *not* simply a matter of biological relatedness. In an attempt of grouping together all possible justifications for kinship ties, Marshall Sahlins (Sahlins 2013) defined kinship as "mutuality of being" – that some real or imagined substance is shared, and that this substance is not necessarily genes, as is mostly the case in modern Western societies (with adoption as the main exception). A variety of non-genetic foundations of kinship are widely accepted in different cultures, like sharing of name, time or place of birth or childhood, food source, shared experiences, blood ties, and so on. At the same time, archaeology as a whole has arguably been very slow in taking this diversity of kinship configurations into account, far too often taking for granted the modern Western (especially post-war 20th century) ideal of patrilineal nuclear families as the default configuration for all of human history (e.g. Ensor 2021). That being said, anthropological kinship studies such as that represented by Sahlins typically shows little concern with material culture, and is mostly silent on the question of who – at the end of the day, quite literally – sleeps under the same roof, making it hard to interpret domestic architecture in terms of kinship structure and social organisation. The recent comeback of kinship studies in archaeology has been far more focussed on linking isotope and aDNA data with social structures, largely fuelled by the rapid developments of the related methodologies [e.g. Carpenter and Prentiss (2022) ;]

- Kinship and households: who lives in a house? Sahlins (2013), Ensor (2013), Ensor, Irish, and Keegan (2017).. archaeology: Carpenter and Prentiss (2022), Madella (2013), Joyce and Gillespie (2000), Blanton (1994), Carsten and Hugh-Jones (1995), Hofmann and Smyth (2013), Wilk and Rathje (1982)
- Do clan leaders have bigger houses? check Haude and Wagner (2019), Kahn (2021), Bradley (2013), Wilk (1983).

Persons who possess enough food resources to create obligations through gifts and feasting… What is wealth? House construction as communal activity Goodale, Quinn, and Nauman (2021)

P. Květina and J. Řídký point out both architecture (construction, size, orientation) and settlement layout as possible distinctive features between Big Men (achievement-based) and Chief societies, arguing that the former type may be recognised by a dispersed intra-settlement layout combined with uniform architecture, while the latter type would tend towards more regular settlement layout and more marked differences in architecture (! Květina and Řídký 2019:13). EXPAND UPON THIS.

Discuss some archaeo references

- Schiesberg 2010 2016, go through refs in Zotero, family size and houses for the LBK

Functional difference:

- Ethnography of initiation houses, communal/assembly houses, ritual houses, including Barley (2011), Godelier (1986), Wilk (1983), Fraser (1968), Haude and Wagner (2019)
- Caveats: building materials and constraints, climate (heating), mobility, multi-floored, see Porčić (2012), residence pattern and floor area in Porcic (2010).

4.2 Interpreting distribution types and their underlying mechanisms

- Power-law distributions, hierarchy and scale invariance.

Start here.

- Normal distributions and the Central Limit Theorem.
- Exponential distributions and growth rates.
- Combinations: Log-normal, stretched exponential, parabolic fractal
- Notes on terminology: Power law, Pareto and Zipf, Newman (2005). Lack of consensus on notation, also for scaling parameter. Difference between PDF and CDF, continuous and discrete.
- A law (distribution) is not a law (of nature), see Grove (2011) for review of the long-lasting confusion in archaeology (e.g. Hodder (1979)), also "rank-size rule"

4.3 Fitting heavy-tailed distributions in archaeology

- Lit. use Strawinska-Zanko et al. (2018), Crabtree et al. (2017), Maschner and Bentley (2003), Grove (2011) ++
- Zipf law and Settlement Scaling theory, Bettencourt (2021), Gomez-Lievano, Youn, and Bettencourt (2012), Lobo et al. (2020). Connection with Central Place Theory, e.g. Müller-Scheeßel (2007), Chen (2011). Why I'm not doing settlement scaling in this study.
- Not fitting distributions in archaeology, just assuming they are heavy-tailed, or avoiding the question: ex. Brink (2013) (could include lots more!)

END chapter

Chapter 5

Methods: Distribution fitting

5.1 Heavy-tailed distributions, testing for power laws

- Technical characteristics of power laws, Newman (2005), do I need more?
- Old style distribution fitting (which is used in Brown and Liebovitch (2010) and Brown et al. (2005) and check. Mitzenmacher (2004), Harrison (1981)
- New style presented in Clauset, Shalizi, and Newman (2009), Stumpf and Porter (2012), implemented in R with the poweRlaw package Gillespie (2015), and used in Strawinska-Zanko et al. (2018) and Crabtree et al. (2017).
  - Finding best x-min value for power-law iteratively with maximum likelihood estimation (the actual fitting) and KS-testing (selecting the best fit).
  - Comparing this fit with that of other model candidates, setting the same x-min and selecting the best through AICc scores (this deviates from the procedure in Clauset et al. (2009) and Gillespie (2015), but is commonly done in other contexts when comparing multiple models at once (e.g. Dauphiné 2011).

The difficulty of comparing power-law models with other common candidate models (like log-normal or exponential), is that they, unlike the others, by definition need a specified lower bound above 0, denoted x_{min}. Comparison of multiple models with AIC scores is only meaningful when done over the same range of data (this also applies to the Vuong's log-likelihood test for pairs of models proposed by Clauset et al. 2009). However, comparing multiple models over the range in a data set which has already been recognised as providing the best possible fit for a power-law model, gives this latter model a potential advantage over the other ones. Log-normal models, for instance, can explain the entire range of a data distribution, where a power law can only explain the tail of the highest values. The fact that these two model types have frequently and for a long time represented competing explanations for the same empirical data sets, may reflect this apparent incomparability between them (Harrison 1981; Mitzenmacher 2004). One can suspect then that this procedure of distribution fitting and model selection would favour power-law models unreasonably. At the same time, one of the main findings of the Clauset et al. (2009) study, was that power-law behaviour was only confirmed beyond reasonable doubt in one out of 24 empirical data sets which had been reported as power-law distributed in earlier studies, leaving the impression that the methodology would be conservative rather than lenient. In many cases however, the study remained inconclusive, especially regarding comparisons between power-law and log-normal models to empirical data sets (comparisons between power-law and other models were generally more conclusive). The authors admitted "*In general, we find that it is extremely difficult to tell the difference between log-normal and power-law behavior. Indeed, over realistic ranges of* x *the two distributions are very close, so it appears unlikely that any test would be able to tell them apart unless we had an extremely large data set*" (Clauset et al. 2009:689). Extremely large data sets are of course a luxury that is rarely afforded in archaeology, and if these two models are that close in many situations, one can ask whether picking one over the other really matters in the end. This question is further developed in Chapter 11.

REWRITE: So I decided to do a small pre-analysis, to check if synthetic log-normal distributions get power-law tails with this methodology, and under which circumstances.

First: real vs retained distribution model, with set param values (ln, exp, and pl), and different n.

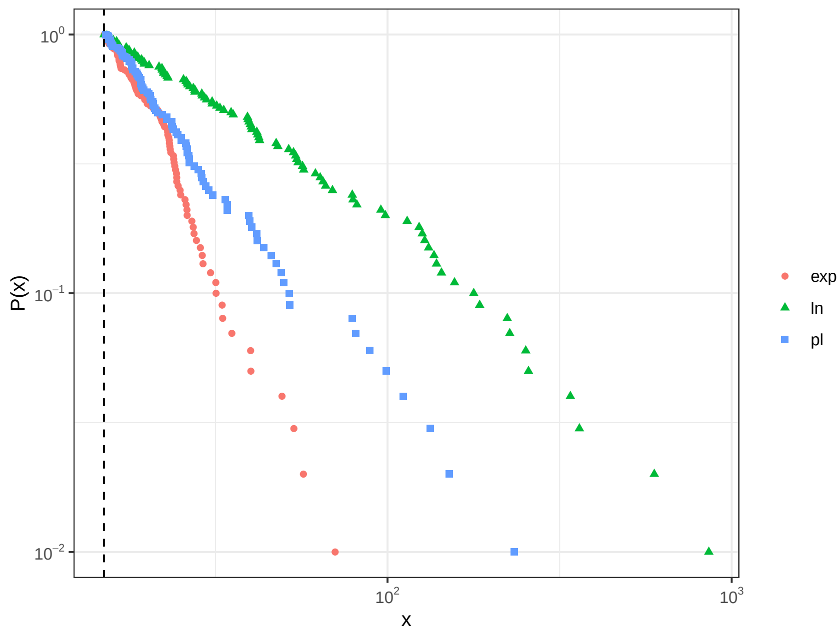


Figure 5.1: *Synthetic data series drawn from three different distribution types: exponential ($\lambda = 0.125$), power-law ($\alpha = 2.5$) and log-normal ($\mu = 0.3$, $\sigma = 2$), all with $n = 100$ data points and $x_{min} = 15$. Plot equivalent to Fig.5a in Clauset et al. (2009), with deviations due to random fluctuations. Scales are logarithmic, and all three series appear as straight lines, though only one is a true power law.*

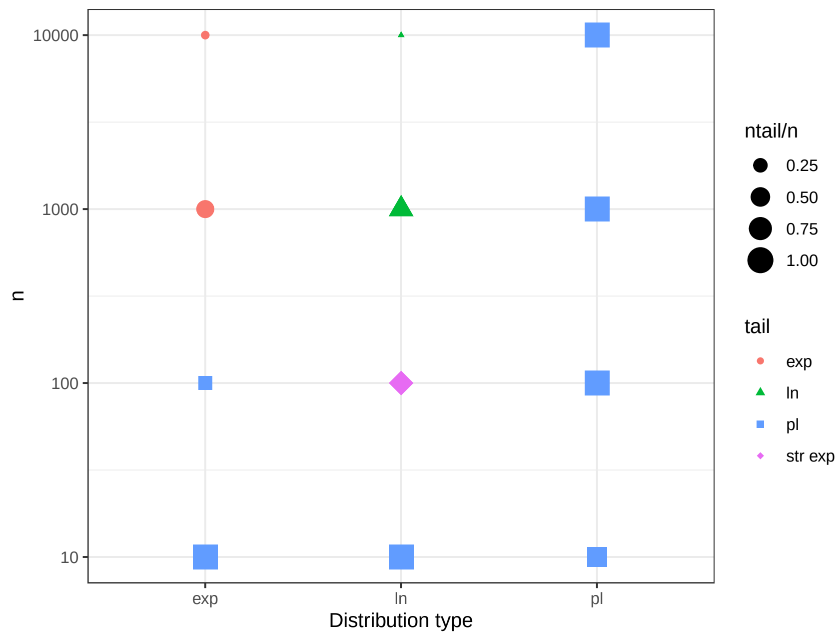


Figure 5.2: *Selected tail models for the same synthetic data sets, each with four sample sizes ($n = 10^1, 10^2, 10^3, 10^4$). For each tail model, x_{min} is set at the value which gives the best power-law fit. Shade indicates fraction of data points included in the tail model. For power-law distributions, all samples are correctly identified, while this is the case only for large samples ($n > 10^2$) of log-normal and exponential samples, smaller samples being interpreted as having power-law or stretched exponential tails.*

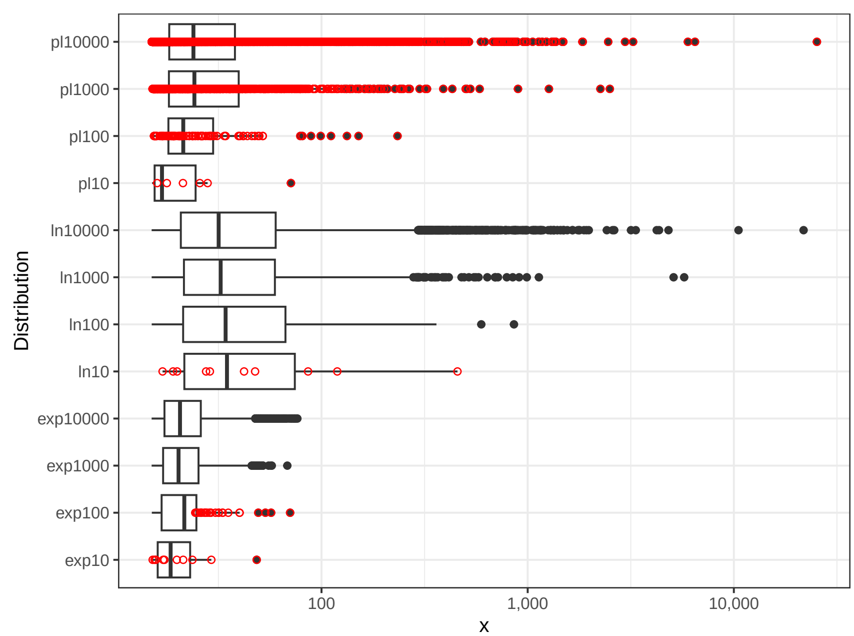


Figure 5.3: *Boxplot of all the synthetic data sets, overlaid (in red) with the data points interpreted as power-law tails. X axis is logarithmic – note however that the log-normal distributions do not appear symmetric since they are truncated with a lower threshold.*

Second: Ln giving pl tail, fixed n and no truncation, range of meanlog and sdlog.

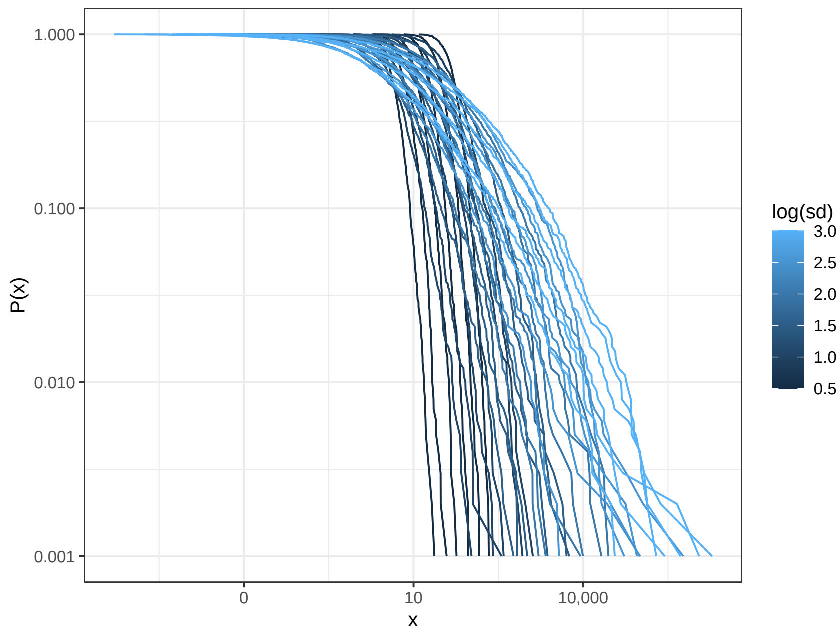


Figure 5.4: *bla bla bla.*

Next.

In his extensive review of power-law generating mechanisms, Mark Newman (2005:347–48) showed algebraically how log-normal distributions can be mistaken for power laws especially when the range of the data that is being analysed is short, and when the value of □is high. More specifically, since the PDF of a log-normal on log scales is a quadratic function – i.e. a parabola – sufficiently smaller sections of this will be nearly indistinguishable from straight lines, and can thus be well modelled as a power law. The curvature of the function is characterised by its quadratic term, which is a fraction with *x* in the numerator and □in the denominator, written $-\frac{(\ln x)^2}{2\sigma^2}$, essentially causing a flatter curvature with higher values of □since this term then will vary more slowly with x (see Eq. 84 in Newman 2005 for more details). This phenomenon does not seem to be apparent in the example above, possibly since the range of □used here is moderate (Newman's example is with $\sigma = 10$). though we do see in Figure 5.4 that higher □values generate more regular curvatures rather than the abrupt curvatures caused by low values. Figures 5.5 and 5.6 show that power-law tails are identified – given the methodology presented above – in log-normal distributions with □ranging from 0.5 to 3.0 and with □between 1.5 and 4.0, with no obvious pattern within these ranges.

The identified power-law tails stretch across the log-normal data in a range from 0.3% (3 data points out of 1000) to 23.5%.

new line

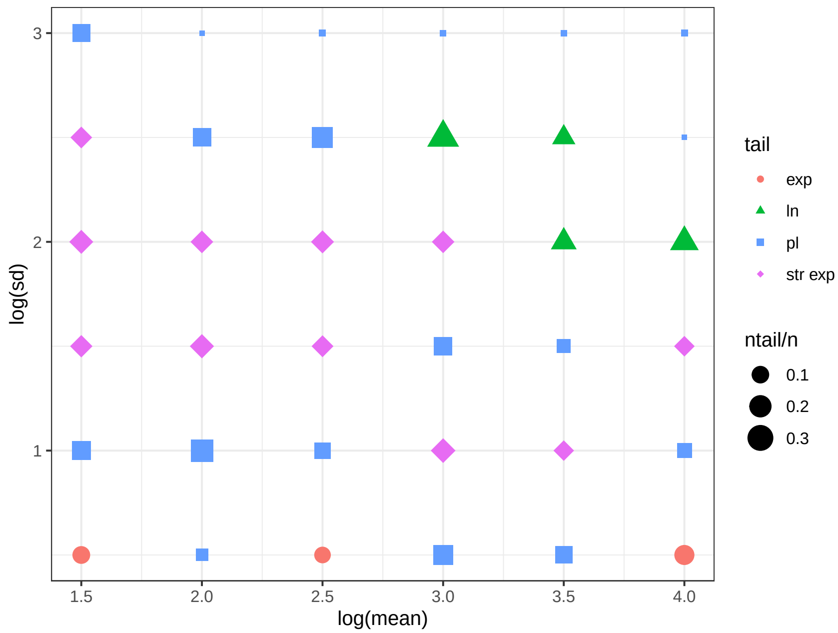


Figure 5.5: *Jada jada.*

Next

End section, test so far.

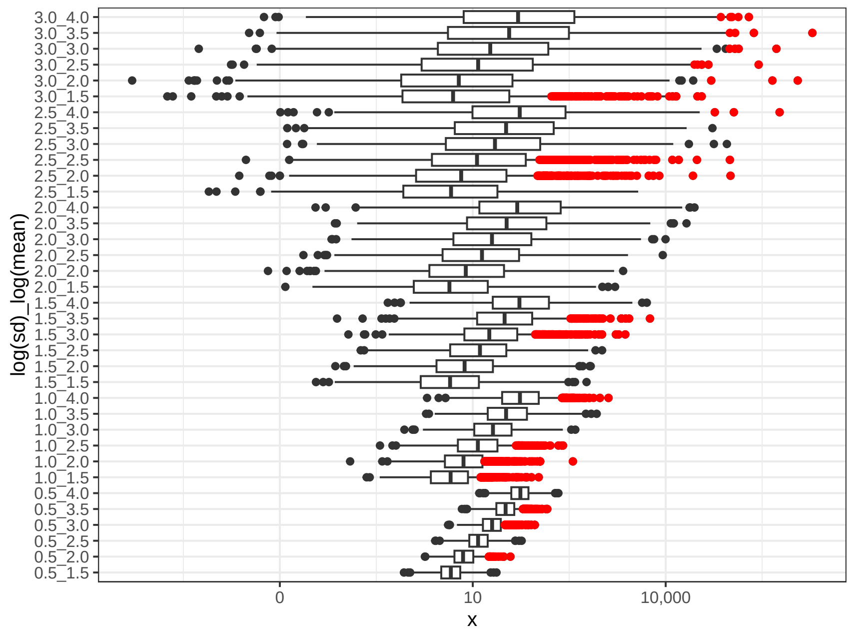


Figure 5.6: *Tut og kjør.*

5.2 Methodological procedure

- Reminder of main goal for this part of the study: identify power-law structures in the house-size distributions of the Linear Pottery and Trypillia samples.
- Synthetic data genaration:
  - Why?
    1. Process: how long/much does it take for a normal distribution to become power-law? And reverse sense? (multiplicative process)
    2. Temporal resolution issue: does the temporal palimpsest of several phases with e.g. log-normal distributions produce false power-law signals? (additive process)
  - How?
    * Random number generation and iterated multiplicative (1.) or additive (2.) sequences, with K-S testing (Gillespie 2015) at each stage. Report when the distributions become power laws.

- Present data set with categories (settlements, quarters/neighbourhoods, time samples for Vráble)
- Parameter settings: dist. types, xmin, testing the pl hypothesis etc. Minimal house-count cutoff (min. sample size). Isolating top house.

END chapter

Chapter 6

Results: Distribution fitting

6.1 Synthetic distributions

1. Multiplicative process

A multiplicative process is one in which a term is multiplied with itself a number of times, and can be mathematically described through an exponential function. This is commonly denoted

$$f(x) = ab^x$$

, read as "the function of *x* equals *a* times *b* to the power of *x*", where *b* is the main term which is multiplied with itself *x* number of times, and *a* being a constant of proportionality. In such functions, *b* determines the *shape* of the function – if between 0 and 1, the function models exponential decrease or decay as *x* grows larger, and if $b > 1$ the function models exponential growth. This term corresponds to the *rate* parameter for exponential distributions detailed in Section 4.2. The *a* term determines the *scale* of the function, similarly to the y-intercept of a linear function of the type $f(x) = ax + b$ (in this case *b*), and though in an exponential function this *a* is multiplied rather than added to the variable term (b^x), its value gives the y-intercept since $ab^x = a$ when $x = 0$. Furthermore, the link between exponential and linear functions is illustrated more clearly when we log-transform the former, that is: $f(x) = log(b)x + a$, which is essentially a linear function where *a* is the y-intercept and *b* is the slope (# Show with fig! and go on).

#Insert figure, ill. exponential functions.

1. Additive process

Lumping of samples may be done for two main reasons (in archaeology): 1 - the sample size is too small, and lumping together several contemporary samples can raise the sample size to an acceptable level (spatial lumping), or 2 - it is impossible to temporally disentangle elements within a settlement, i.e. reduce temporal resolution to coeval elements, in which case one has no option but temporal lumping (accepting a low temporal resolution). The problem can be further broken down to two case types: a) all lumped samples are really drawn from the same distribution, and b) they are not similarly distributed (**illustrate with table**). For spatial lumping this degree of similarity can be assessed, but not necessarily for temporal lumping. But even when it can be assessed, the lumping needs to be justified in social terms. As an example, several spatial samples (e.g. villages in a region) can have house-size distributions with no significant differences between them (ANOVA), but at the same time be functionally entirely independent, in which case it is more logical to augment the sample size of a single one through simulation and evaluate plausibility through bootstrapping, rather than by lumping of all samples, **rewrite this more clearly**. On the other hand, house sizes can be significantly different between quarters or suburbs within a city or metropolitan area, or even between cities in a region or country, but if they all function together in a coherent system, they may reflect a spatial segregation between different strata in the society, and it makes much sense to lump and analyse them together.

When it comes to temporal lumping, given that a settlement does not undergo substantial cultural changes during its timespan, a workaround to evaluate whether the house-size distribution evolves significantly over time may be to target a number of size categories for ^{14}C dating, and to check that they all stretch over the entire range of the settlement's duration, and if yes, accept to analyse the whole distribution as one. **recheck this after I have my results, maybe move it all to summary**. □

6.2 Settlements

House-size distributions of whole settlements (both Linear Pottery and Trypillia)

6.3 Quarters/neighbourhoods

House-size distributions of separate quarters (Nebelivka) and neighbourhoods (Vráble). Can I include separate Nebelivka neighbourhoods as well? (prob. too small, but check)

6.4 Temporal samples (Vráble)

If time, I can add more Žitava sites here, but not necessary. I can also analyse temporal samples of Vráble neighbourhoods separately.

6.5 Summary of findings

END Chapter

Part III

Settlement Plans

Chapter 7

Village planning in Prehistory

7.1 Settlement layout and social structure

Or the social organisation of village layout. Research background:

Lit. use Furholt (2016), Fraser (1968), Ensor (2017), Ensor (2013), also check Souvatzi (2017).

For cities, see Kostof (1991)

Artursson et al. (2010) (Bronze Age, descriptive/interpretive approach). Cleuziou, Braemer, and Coudart (1999) (book in MAE)

Use the Trypillia volumes. Also Müller-Scheeßel (2019), Trebsche, Müller-Scheeβel, and Reinhold (2010)

Transition from village to urban (again): Birch (2014).

Factors affecting village layout:

- Political structure (but, as with hierarchy, an organised layout does not necessarily equate top-down despotic decision making).
- Kinship, matrimonial and locality structures
- Cosmology (e.g. Linear Pottery house orientations)

- Economic and ritual functions of village elements (constructed and non-constructed)
- Local landscape setting (to be factored out)

7.2 The geometries of conscious planning vs. emergent behaviour

- I need to find some references here!
- Euclid: grids, lines, circles – how humans think in shapes. Social settings: architect/planner, strong common institutions/ideals (examples?)
- Mandelbrot: irregular, self-similar, scale independent (i.e. fractal) shapes – emergent, not consciously preconceived. Self-organisation. Does the "no pattern" case exist? Emergence from repetitive sequences of simple choices/mechanisms. Examples.
- Binary or continuum? Needs to be studied empirically.

7.3 Fractal image analysis in archaeology

END Chapter

Chapter 8

Methods: Fractal image analysis

fdasdf

8.1 Fractal dimension and lacunarity

- Box-counting, lit. Mancuso (2021), Li, Du, and Sun (2009), Klinkenberg (1994)
- Gliding-box algorithmsc, Allain and Cloitre (1991), Hingee et al. (2019), Cheng (1997), Plotnick et al. (1996)
- Caveats:
  - Fractional box-counting dimension does not equal self-similarity in a simple way
  - My summary L is not equal to the one used in *FracLac* and thus by Farías-Pelayo (2017)

8.2 Image preparation

- Procedure for archaeological samples, same as in article
- Procedure for synthetic sample

END Chapter

Chapter 9

Results: Image analysis

9.1 Synthetic settlement plans

Relationship between image density (built-up area) and fractal dimension, evaluated in Thomas, Frankhauser, and De Keersmaecker (2007), where they show that these two parameters, under certain conditions (constant observation window, prefactor values close to 1), are exponentially correlated, which is also what I found in my article. They show that observation window size and shape, as well as centroid placement, have little influence on D, while they have more influence on density when the pattern is not homogeneous. They do show, however, that images with the same density may have quite much variation in D, which is reflected in the layouts. Judging from their examples, more clustered layouts give higher D values, while more dispersed or dusty layouts give lower D, when density is constant. I ignore the use of prefactor values. According to Thomas et al. (2007), density is a crude measure of the overall intensity of the pattern, while fractal dimension is characterises the morphological structure, though it is not directly descriptive.

9.2 Settlements

9.3 Quarters/neighbourhoods

9.4 Temporal samples (Vráble)

9.5 Summary of findings

END Chapter

Part IV

Synthesis

Chapter 10

Discussion: Social complexity in Linear Pottery and Trypillia settlements

fdsasdf

END Chapter

Chapter 11

Discussion: Fractal Analysis and Archaeological data

fdsasdf

Also mention here fractals or related concepts used as a metaphor, with no mathematics involved (e.g. Chapman et al. 2006; Sherratt 2004; Sindbæk 2022; Whitridge 2016).

END Chapter

Chapter 12

Conclusion and Outlook

12.1 Things I would like to have done, but that didn't fit into this study

- Ethnoarchaeology: Measure house sizes and settlement layouts in contemporary settings, and relate to social organisation (largely overlooked by ethnographers)
- Test distributions and settlement layout analysis on other settings: Lake dwellings, later/historic periods, other materials (e.g. megaliths)… Add more complex distribution models, add observation windows on images. Try on remote sensing imagery.
- Settlement Scaling on Neolithic settings
- Time series: Hurst exponent and scale invariance in temporal development of e.g. regional settlement or population
- Integrate – bridge the gap – between opposite theoretical (nat. and soc./hum.) approaches to the same phenomena
- Chaos and strange attractors in Archaeology
- More?

12.2 Concluding remarks

END Thesis

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Appendix A

This is my first appendix

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Appendix B

This is my second one

Bla bla bla