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Systems Orthodontics

From Clinical Reasoning to Computation, and Back

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Chapter 1
Introduction

All parts of the organism form a circle.
Therefore, each part is both the beginning and the end.
Hyppocrates (460-370 BC).
"Knowing how an adjustment can be achieved is useful.
Not knowing how an adjustment can be achieved is harmful.
灵枢经 Lingshu Jing (The spiritual pivot) (2600 BC ?) [1]

The burgeoning field of orthodontics presents clinicians with a deluge of new knowledge and treatment options. This "information explosion," often stemming from outside sources, combined with an ever-growing arsenal of tools and patients' diverse motivations, creates a complex decision-making landscape for orthodontists. Human cognition has limitations, typically handling only seven variables at once. Orthodontic cases, however, can involve many more. Appearances can be deceiving: the sheer number of variables and their interplay over time render averages and general rules unreliable. Orthodontic challenges often present qualitatively, meaning we cannot find normalcy by comparison but within the individual.

Furthermore, information quality could be better, with subtle, non-linear processes adding to the confusion. Imperfect observation further complicates matters. A minor initial error in landmark placement can snowball during growth, leading to inaccurate predictions and potentially disastrous outcomes. Additionally, around 20% of children lose their initial facial "memory" as development progresses, as chaotic mechanisms override the skeletal system's regularity.

Orthodontists navigate a dynamic, intricate, and sometimes unpredictable landscape. While knowledge and tools abound, careful consideration and individual-centred approaches are crucial for navigating this complexity and achieving optimal outcomes [2]. Based solely on clinical and radiographic data, the orthodontist has no way of early identification of patients changing growth trajectories [3–7], We stand at a pivotal moment in our understanding of ourselves and the world. Our reality is no longer one of the simple narratives but a complex ecosystem of interconnected variables, where each element ripples through the whole. Unforeseen events like global pandemics shake our confidence in our ability to predict and control. Compared to past eras, with their limited possibilities, our world presents a dizzying array of variables, rendering traditional risk assessment models obsolete.

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Faced with this elusive and interconnected reality, many turn to complexity theory and its powerful partner, artificial intelligence, for answers. This "man-machine match" holds immense potential, illuminating the hidden connections between diverse phenomena across various disciplines. It unveils a tapestry of specificity, weaving together seemingly disparate threads into a coherent narrative.

When we apply computational methods in the medical field, they strive to identify recurring patterns in the past behaviour of patients. Such patterns help make predictions. These machines enable doctors to access aspects of reality more profoundly and comprehensively than simple clinical observation. But only with conditions. Future health forecasting based on patients' past data assumes that the past determines what happens in the future: we shall soon see that this assumption presents several problematic aspects once applied to the orthodontic discipline. Predicting future dental problems requires two key ingredients: a detailed understanding of the past and insightful rules to analyse it.

Firstly, predictive algorithms need access to comprehensive data on past dentofacial structures and functions, like digital scans and growth records. This data serves as a historical reference point.

Secondly, we want usable knowledge arising from this data. In orthodontics, this involves grouping patients with similar facial features and growth patterns, creating a "family tree" for comparison.

Orthodontists can identify potential future issues by comparing a specific patient's morphology to these groups. Traditionally, three main categories of malocclusions ("archetypes") served as this comparison point. However, with modern technology, we can delve deeper. Algorithms deal with big data, uncovering hidden connections between facial features, medical history, and potential future problems. This fact opens the door to individualised predictions of malocclusions even for children in their mixed or deciduous dentition, answering a question often posed by anxious parents [8–13]. Complexity theory [14] (related to "chaos theory" [15], and "theory of dynamic systems" [16]) describes seemingly unconnected systems whose behaviour does not depend upon the behaviour of a single constituent element. Imagine a bustling anthill, a vibrant city, or even your own body made up of billions of cells. These are all examples of complex systems where many individual parts interact in intricate ways.

While these systems may seem chaotic initially, an outstanding order emerges from these countless interactions. Think of it like a swarm of bees working together, each small but collectively achieving astonishing feats. This "swarm intelligence" is a hallmark of complex systems. For example, an anthill needs a certain number of inhabitants and interactions to assess its needs, like finding food. Similarly, plants compete for sunlight, exhibiting complex, collective behaviour. Interestingly, even the seemingly unrelated process of teeth exchange in our mouths shares similar dynamics to these larger systems. Dental elements "compete" for space, creating a complex interplay that shapes our smiles.

To apply the logic of complex systems to the facial system, orthodontists do not have to know every intricate characteristic of the constituent elements to understand how the dentofacial system works and progress [17] they must refer to the general, systemic laws underlying the auto-organisation of living systems, to hidden competencies focused on maintaining homeostasis, and to spatial and temporal regularities mixed with indeterminacy and random facial growth fluctuations. Complexity theory helps to understand how each piece of information behaves about its surroundings in a system where each element is strictly dependent on the others. The effects originating from the mutual interaction between the elements generate "emergent properties" and local organisational zones that behave as *basins of attraction* and canalisation of defects ("patterns of contagion"). A grand unified theory of complex systems still needs to be included; after all, it is not easy to find a formula to describe and formalise the movements that occur in an ant colony, in organising a tornado, or in the transactions of traders on Wall Street. Reading these phenomena requires a decentralised model of thinking, which sees the development of these systems as the effect of an interactive phenomenon between local organising agents and global constraints. During facial growth, small changes in provincial zones and growth anticipations or time delays in critical areas can produce vastly different final skeletal scenarios. This book explores these phenomena, conducted with unprecedented investigative skills offered by computer science.

Orthodontics is the science of change over time and of consistency of the facial system concerning change. The orthodontist professes an inherent holistic science that includes balance, harmony, mutual protection between components, stability, acceptable developmental compromises, and more. They must find the best possible combination of these components before making decisions. They seek linear explanations to more complex problems and attempt to define general rules, reproducibility of phenomena, and alignments of causes and effects. But more is needed.

Intervening at the right time using the appropriate corrective tools on the proper facial areas makes it possible to reorient the existing facial pattern, guide the adaptive remodelling of the facial components, facilitate the resolution of local discrepancies, release the proprioceptive stimuli necessary to achieve the natural organisation and propensity of the masticatory organ: the best occlusal-skeletal equilibrium.

Complexity theory and computer tools procedures add evidence to the equilibrium concept. Dentoskeletal equilibrium is the state of stillness related to the resultant of the forces acting on the components of the system and the forces external to the system. The quantitative measurement of these forces could be more problematic in static and dynamic situations, as are controlled experiments to clarify the disparate aspects of tooth movements under the influence of those forces [18]. The balance results from the intraoral forces acting on the crowns and the forces acting on the root from the surrounding bone through the periodontal ligament. The troops (muscular, occlusal, adjacent tooth elements, etc.) must be in equilibrium to maintain the system's stability over time. But this is only sometimes the case. Sometimes, there is no clear relationship between the forces we apply and tooth movements. We know less about the subject than we think we do.

1.1 Orthofield

In this book (Chap. 3), we will see that defining a concept of optimised dental equilibrium in the form of overall system harmony is not trivial, despite the help of computational algorithms, since we need to define a basic idea as a relational form of the system. And yet, that is what the orthodontist wants. Orthodontists must deal with a “Orthofield” surrounding the dentofacial complex, acting on the elements of that complex in a manner analogous to the action of a physical field [19]. As a magnet is surrounded by a force field influencing everything within its range, the “orthofield” in orthodontics can be considered a dynamic zone of hidden forces constantly shaping teeth and jaws as they grow.

We must consider how this “orthofield” evolves in space and time during growth for successful orthodontic treatment. Timing is crucial. Interrupting these forces at the wrong moment can cause the original growth pattern to reassert itself, potentially hindering desired outcomes.

The morphogenetic facial pattern contains potentials that are not immediately clinically manifest because there is a stop to their activity. Over time, different phenomena of intrusions in the system, such as oral respiration or adverse habits, can disturb or delay the appearance of the morphogenetic pattern. Moreover, we cannot take for granted that the patient’s orthofield agrees with our treatment plan, nor that the timing of the unfolding agrees with our interceptive attitude to dysmorphisms. We try to establish harmony, balance, and optimal aesthetic relationship, but we need to know in depth what the proper balance expressed by the orthofield is. We need to know all the ingredients of these abstractions. An untimely interceptive intervention may be performed before a distortive orthofield has fully emerged, making relapse inevitable (never consider the facial aesthetics of the child as the aesthetics of the adult) [19].

When studying the face, we deal with complex concepts like how features form, how they vary among people, and how they interact. This feature creates a gap between the “average” measurements we often rely on and the unique reality of each patient. Despite this limitation, we can still predict future growth based on their facial structure. However, this prediction isn’t a fixed path like a train schedule but rather a map highlighting various possibilities. We select specific features and differences to analyse, transforming them into valuable information. However, to truly understand how individual genes translate into specific facial features (genotype to phenotype), we need better tools to explore the intricate processes involved.

Complexity is endemic in orthodontics, so for each phenomenon we see, we must expect an opposite phenomenon and an opposite statement, which is not wrong but only has less plausibility. Our patient’s representation is inevitably idealised and seasoned with a large margin of inaccuracy. We efficiently run into many sources of bias: incorrectly identified patients, missing data, insufficient samples, underestimates, and misclassifications. We do not know what influence the altered parameters have on other parameters or the preferential corridors for spreading defects. The degree of knowledge we have about the craniofacial system is related to what we know about the information shared between system components. We consider the facial system an integrated and stable unit with a solid *morphological integration* that does not always protect against disharmony.

No single relief can fully describe a complex system: one to two degrees or millimetres of error are generally allowed for each angular or segmental cephalometric measurement so that even the best knowledge of the patient is inevitably approximate knowledge. But how wrong is the approximation? The internal structural organisation of the craniofacial system, together with stimuli from the environment, random growth events, and adaptive capacity, channels global facial changes through specific directions. As stated, models based on the laws of biomechanics explain only some things. The balanced model we impose on the patient is an arbitrary arrangement which the patient's orthofield may not entirely accept. Currently, research and practising orthodontists can transfer these processes into the computable realm, using intricate mathematical manipulations leading to continuously updated descriptive and predictive probabilistic models [20]. The appreciation of the whole ortho field drives us to pay more attention to the individual patient and to adopt methods of treatment which emphasise personal response to the general laws of orthodontics.

If we want to define who is abnormal from an orthodontic point of view, it is necessary to have a clear idea of normality. The laws of statistics are amongst the best available methods for scientific research. The reference to average angles of inclination of the *dental axes, overjet, overbite, and proximal horizontal & vertical contacts* between tooth components should be considered suitable for every patient. Some patients may exhibit a discrepancy in the sum of diameters of the upper and lower incisors, which would indicate a variation in the degree of acceptable or preferable tooth inclination, overbite, and overjet [19]. There may be a discrepancy between the basal bone and the teeth, which may recommend extractions in one patient and contraindicate them in another. Moreover, the different verticality of the skeletal pattern imposes different optimal inclinations of the dental elements.

Facial morphology throughout life is so unsettled that a stable representation is problematic. All system components are variable, and the only definable thing that remains stable over time is the shape of the teeth. The orthodontist pursues the ideal dental occlusion, hoping to achieve a better balance of all surrounding structures, putting the muscles in the best possible contact with the proprioceptive reflexes generated by the dental cusps. These criteria will fit as many patients as possible. Yet, relapses are frequent annoying problems for the orthodontist. One more time, cephalometry doesn't tell us the whole story.

1.2 Malocclusions

Malocclusion expresses a peculiar form of equilibrium, a bottleneck in the defect disposal flow of the craniofacial system. It contains hidden information about the operating morphological generative forces we must fight against. Network science offers the possibility of mapping the topology of facial morpho-functional dynamics and defining the direction of competitive or collaborative influences between different skeletal zones. Currently, in the orthodontic discipline, a change in the system of thinking is taking place about the choice of treatment to be used to guide atypical facial growth back to normal. We have just said that the operator cannot refer to stable, perennial, and reproducible orthodontic morphologies, which can fix patients into defined categories linked to prescribed forms and progressions. And that the division into Class I, II, and III malocclusions represents a simplification of a more complex reality. In complex biological systems, form couples with the process; opposing components cooperate through morphological oscillations during the growth process, and collisions of morphologies and temporal fluctuations of constituents represent 'memory mechanisms'. Thus, it takes work to get a reproducible picture of the system you are dealing with.

Wherever processes of growth and morphological configuration of living matter take place in nature, information must be present since every morphology is the formal expression of a content: "…form, structure and movement of any entity are merely a materialisation of energy, more or less concentrated and in transformation" [21]. This energy leaves traces in each facial morphology: in biomechanical information, force, mass, shape, and energy are not separable, as information transmission needs a material medium. We will see why the global structure of the dentoskeletal system couples to local morphological characteristics and why we must consider local data about the characteristics of the whole skeletal imbalance.

1.3 Self-Organisation

The *self-organisation* of complex systems gives rise to the spontaneous formation of space-time feature *modules* (also *motifs,* or *communities,* in Network analysis, see Fig. 3.3), groups of densely associated components connected with loose links related to antagonism or cooperativity among components. In biological systems, modules have always been considered ubiquitous, elementary forms of organisation. We will see their role during facial growth. The self-organisation in complex systems represents how simple rules determine complex behaviours. In nature, it happens when, in different dimensions, the cells of a growing organism aggregate to form tissues and organs. The desert wind produces circular sand structures, as simple local rules [22], with the participation of gravity, wind, and friction between grains of sand [23]. But the simplicity of rules can be illusory; it might give us the impression that we can derive simple explanatory stories for complicated phenomena.

To make sense of the things of the past, we should be able to separate the past stable trend from past random deviations. The interaction between dentoskeletal parts is determined by growth and collisions between structural differences in the facial system, according to reciprocal chains of growth-form determination. Describing these phenomena requires a reliable classification of morphological and relational entities to be offered to computational systems. The higher the uncertainty of the process, the more noise exists in past information that needs to be ignored or probed somehow in the ways we see. In Chap. 4, simple algorithmic procedures such as *Fast and Frugal Trees* can improve response accuracy about growth and treatment outcomes by minimising irrelevant or misleading information. This procedure allows small patient samples and less processing to produce better inferences [24]. The goal is to determine the environmental structures in which a given treatment decision shortcut (*heuristic*) is booming despite the superficiality of the analysis.

In daily professional life, orthodontists do not solve the patient's problem once and for all, they have to solve it continuously over time. This approach is essential because orthodontic issues tend to recur, and the face of the child is constantly changing. Some problems are simplistically read as side effects: in reality, they were problems and processes that had not been visualised and which later come to the attention of the clinician. The bite opening may not be due to the treatment but to oral respiration or incorrect tongue posture. At each evolutionary stage, new laws, concepts, and generalisations are needed.

Heuristics cause the programme to focus on only part of the search space. These forms of mathematical simplification run the risk of representing probabilities in the data in a simpler way than they are. In orthodontics, the i.i.d. hypothesis commonly used by analysts (the probabilities in the data are independent and identically distributed) may be an oversimplfication due to the presence of very different morphological constraints between patients.

The order of living matter is an order of morphological forms; where there is a form, one moves away from homogeneity, disorder, and entropy. Codes linked to the patterns of space-time structures contain computational information: once received, the information allows decisions between different possible evolutionary choices ("evolutionary bifurcations"). Some dominant defects propagate their information to nearby elements over time, following contagion patterns resembling those of infectious diseases. Such a similarity allows doctors to hypothesise the contours of the "possible adjacent", the most probable morphological evolution and canalisation of local skeletal components. Some elements in the network are compartmentalised, insensitive to the stimuli of the neighbours, and therefore tend to remain "invariant". Every defect found in the system plays the role of the centre of convergence of a series of past or current, actual or possible, probable or improbable relationships. Cephalograms provide a geometric framework of the existing skeletal structure as a sum of past development, but geometric data alone does not provide predictive information. Yet, as we will see in the next chapter, some predictive orientation is possible by following the network of influences and the cumulative effect of the skeletal arrangement on growth [25, 26].

1.4 Systems Thinking and Complexity

If in a complex system, "the whole is more than the sum of the parts", the meaning of a skeletal characteristic is perceived in a broader context, to a more comprehensive function, or a system's whole facial *propensity*. The state of a growing complex system depends on the previous one and the conditions of the following one. Some features propagate through specific pathways that work as ‘sources’ of defects, disposed of in different ‘sink’ structures. *Systems thinking* starts with the assumption that it is not so much the single abnormal variable that characterises the outcome but rather the interconnection between structures. Although we cannot predict all the final endoskeletal details, the general shape of the new morphologies and the new forms of organisation may be relatively predictable and straightforward.

In biomedical research, more than simply measuring things is required. We must delve deeper into what those measurements tell us about how things work and why. Network analysis is a robust framework for that purpose. As applied to orthodontics, it shows us how everything in the face and jaw connects—directly or indirectly, strongly, or weakly. Think of it like a complex web where everything somehow influences everything else. Complexity theory takes this a step further. It studies how patterns and structures emerge from this web of interactions. So, for orthodontists, the key is to:

1. **Identify the essential pieces**: What parts of the face and jaw are we studying?
2. **Look for patterns**: How are these parts connected and interacting at a specific time?
3. **Conclude**: What underlying principles govern these interactions?

By doing this, we can move beyond just measurements and better understand how the face and jaw develop and change. The contingency is ineradicable as living matter exhibits a combination of simple fundamental laws combined with the operation of chance. The logic of contingency teaches us not to limit ourselves to understanding what can happen considering what has happened but also to consider the counterfactuals, the possibilities lost in that event (patient), which instead found expression in another [27].

New approaches in science are helping us understand complex systems like the human body. Using math from “complexity science,” we can combine complex data with individual details to create a more complete picture of a patient’s health. This procedure allows us to see beyond apparent symptoms and understand the hidden connections between different body parts. This idea is beneficial when predicting how someone might develop, particularly when we must fully understand the underlying processes. However, it is essential to remember that computers cannot replace human judgment. While algorithms can analyse data and identify patterns, they need more biological understanding and foresight for complex systems. They can locate “competition” between different parts of the body, but they cannot grasp the bigger picture or predict future consequences. Ultimately, orthodontic treatments aim to restore balance and harmony within the body. The treatments can sometimes create temporary disruption, but the goal is to minimise disharmony and encourage healthy development.

As Sheldon Baumrind said, “Orthodontic therapy is applied biology”. Indeed, the common denominator of the onset of cytoskeletal disharmony is that it is a collective biological process born from repeated local interactions that generate collective information and mutual cascading effects on the entire system. The factors that persist the longest significantly impact the system [28]. As the dysmorphosis spreads, the whole system enters a new *phase:* the challenge is to anticipate the transition process between acceptable and unacceptable facial morphology, choosing the right tools and procedures to identify the underlying latent phenomena before they cause an overall distorting effect. In any case, the ultimate purpose of the system's whole proprioceptive information is to safeguard and optimise occlusal contact.

We must rephrase that orthodontists must look for a rule that values past craniofacial observations in predicting future events. They must look for historical data vectors applicable to the problem space. Since orthodontics is a discipline of contingencies rather than general rules, nothing can make an orthodontic treatment based on misleading contingencies assumptions efficient. Framing contingencies and giving them proper weight is the first step. Computational machines extract patterns from data regularities; in orthodontics, randomness can overwhelm regularity. In a dynamic system subjected to flows of biomechanical forces, relationships of domination, or mutual congruence between variables, are formed. A deep Spee curve determines an extrusion of the upper premolars as much as the extrusion determines a deep Spee curve. The relationships of forms are associated with relationships of forces. Geometric *attractors* respond to the topology of relationships: some are subject to the forces of growth, others simply to forces generated by the meeting of reciprocal physiognomy.

Rather than underlying processes, orthodontic "laws" are expressions of constraints acting on developmental individual potential. An overjet can have an additional dimension in an insufficiency of the vertical dimension. An incisal protrusion can have a further dimension in camouflaged natural crowding. A large Goniac angle indicates the mandibular ramus's difficulty in keeping up with the vertical growth of the alveolar district. In the ontogenetic skeletal model, it is necessary to include the formal connections between current morphologies and past events, specifying the dynamics that led to what is visible in the system. Some computational models may deconstruct the facial system, others a re-composition of its constituents and past events.

As stated, many aspects of orthodontic reality present themselves to our gaze in networks, i.e. aggregates of nodes connected in a dense manner (See Fig. 4.5). This state of things allows a conceptual framework favouring the minimisation of contingent growth phenomena. As the interdependence structure between variables can represent craniofacial morphology, the *topology*, i.e., the structural organisation, constrains the range of possible behaviours and describes the information in different system zones. Due to the need for more sufficiently general formalism in craniofacial research, understanding structure-dynamics relationships is still a significant goal. The Network analysis can be a response to understanding how seemingly insignificant variables can become crucial once combined with other variables.

In every situation of uncertainty, probabilities are involved: the advantage of probabilistic reasoning over logical, analytical rationale lies in the possibility of arriving at rational descriptions, even when there is not enough deterministic information about how the system works. If two events, x and y, are highly correlated, it is reasonable to assume that knowing that x is accurate can help understand the probability of y. Network analysis discovers the most influential probabilities among the variables, i.e., the probable coevolution, and can remove the least influential ones that do not reach the acceptable correlation threshold. But the actual data to offer the computational system should be the data conjugated with its background noise, skeletal constraints, residual growth, reciprocal collisions of forms, lean zones each component influences or is influenced by, and so on.

Change is an intrinsic quality of living matter. All parts of a biological system have a turnover: in the human body, the pancreas replaces its cells every 24 h. What counts is the state of the pancreatic system, which must maintain its functions over time, not individual cells. Living systems perform a continuous optimisation process of improvement of adaptive capacities. Computational systems express a tension towards optimisation of their level of competence through a constant adjustment of the assimilation process of the elements. We will consider offering Artificial Neural Networks cephalometric data to obtain information on the need for problematic circumstances, such as dental extractions. The data learned in each layer of neural network computation passes to subsequent layers towards increasingly complicated levels of abstraction. In doing so, the learning machine modifies its internal state by changing the strength of certain connections. It looks for regularities in the data to extract patterns. However, as stated, the realm of orthodontics is one of irregularities. Thus, there is a risk that, instead of being an operational decision support, excessive multiple abstractions could paradoxically distance the orthodontist from the empirical reality of the patient, cast in a cloud of different combinations of signs, symptoms, evolutionary paths, conditional dependencies, and adaptive processes. When it comes to excluding any quality that is not numerical and considering patients as pure quantitative multiplicity, there is the risk of identifying as consistent patterns simple random feature fluctuations that do not represent any underlying structure [29].

As in any complex biological system, the facial system can exhibit an *emergent* behaviour that does not derive from the morphological characteristics of specific constituents. It emerges naturally from the organising relations of the parts. This phenomenon forces the orthodontist to reconsider the value of the parameters: we will see that a high degree of membership in a morphological cluster implies that the robust connectivity acting into the cluster contains more growth information than the absolute value of individual features at precise moments in time. Thus, membership is truly a biological characteristic.

Orthodontic preventive surveillance consists precisely of preventing the system from entering a *self-organised criticality* [30] during the growth process and bearing in mind that by applying a therapeutic device, we act both on the anatomy of the system and the biology of growth. Inevitably, we extensively modify the network of interactions in the craniofacial ecosystem without knowing all the players involved and having a precise idea of the long-term effects. In a system based on instability, where elements link to each other, we must continually redo the calculations during treatment. The adaptation of facial components to the environment is not only reactive, but it also expresses a form of preventive cognition drive to plan a response to future occurrences and environmental changes. These dynamics are not very different from strategies implemented in the plant kingdom to prevent the effects of seasonal changes [31].

The operator uses computerised procedures to check the deviation from the a priori expected result, i.e., to limit the reliability of the conceptual model. They formulate hypotheses a posteriori, trying to find plausible reasons to explain how one or more elements from the past induce behaviour. Suppose we want to get the most out of the data. In that case, we need to rely on accurate, descriptive parameters and threshold risk values, knowing that morphological boundaries change over time and that what is irrelevant changes according to the situation. As in many medical fields, to clarify the natural history of dysmorphic orthodontic features (not being able to count on how many patients followed over time without undergoing treatment), it is necessary to refer to the quality of the data. We will see that valuable tricks exist to focus on high-quality data, working on subspaces of data, recurring to *synthetic patients*, reasoning in terms of global characteristics, stratifying subjects in segments by age and gender, or reasoning in terms of *qualified* patients, with highly expressive capacity about the topic of interest.

Like all organic systems, the facial system tries to overcome growth imbalance by using specific forms of homeostasis, in which opposing forces try to balance each other. The orthodontic anamnesis is not a chronological narrative of independent events but an insight into a developmental process. The most challenging step for the orthodontist clinician resides in moving from the list of problems to treatment priorities. It is the moment to synthesise the patient's wishes and realistic treatment options [32]. Treatment planning involves the clinician's subjective judgment, supplemented by consideration of the most critical problems experienced by the patient. The orthodontist should tell the child's parents that there might be different aspects to consider, less visible but crucial. Detecting a morphological anomaly in a specific facial area may be intolerable for the patient. Still, it may need to demonstrate more relevance concerning the balance of the entire facial system. It may be part of the flexibility necessary for the system to absorb more relevant but less visible pathological phenomena located elsewhere or may derive from the interconnection of other data not sufficiently considered. Facial areas located near bone growth centres function as *hubs* which cause radiation of defects to other structures. Network science visualises that each characteristic has its specific interactive map with different structures; this plays a role when formulating the judgment regarding treatment priorities [33]. While addressing orthodontic misalignment in a single spatial plane may take less than a year, most orthodontic concerns encompass diverse issues impacting skeletal structure, dental and alveolar components, and functional aspects. Notably, each such issue exhibits multidimensional characteristics. In complex systems, elements acquire environmental information and adapt their relationships accordingly. Within the facial system, the sheer volume of interconnected problems and the age-related structural increase in complexity (shifting from smooth surface contact in deciduous teeth to the interlocking cusps of permanent teeth) contribute to issues becoming not merely additive or proportional but rather exponentially complicated.

1.5 Signals and Noise: The Use of AI

Powerful tools like decision trees and artificial intelligence are helping doctors map facial features to diagnoses and treatments. These tools learn from past data to predict outcomes for new patients, offering valuable insights.

However, doctors must combine this new information with their existing knowledge and experience. Understanding the "why" behind a patient's improvement or worsening goes beyond data analysis. Doctors must consider the intricate factors at play to make the best decisions. Unlike humans, computers learn in artificial universes where everything is on equal footing. This property means they can identify patterns but may need help grasping the underlying causes. Just because they know "what" happens doesn't tell them they know "why." In medicine, focusing on individual molecules only sometimes explains the entire disease.

Similarly, assuming a direct cause-and-effect relationship from correlations can be misleading for complex systems like the human body. Machine learning algorithms don't have this challenge. They find patterns and make predictions, but they need to gain the conceptual understanding a doctor possesses. Essentially, these tools are potent allies but not replacements for human judgment. The value lies in combining the strengths of both—data-driven insights and experienced intuition—to ensure the best possible patient care. Imagine powerful tools that can analyse mountains of data to predict health risks like diseases or facial abnormalities. Unlike doctors, however, these tools (algorithms) don't understand the "why" behind their predictions. They're like black boxes that crunch numbers and give answers without explaining the logic. Think of it like searching for buried treasure with a metal detector. You get beeps based on hidden metal but don't see the metal or understand its meaning. Similarly, algorithms find "critical points" in the body that suggest specific outcomes but can't explain why or how.

However, their strength lies in seeing the bigger picture. They consider everything in the body simultaneously, knowing everything is interconnected (though not equally or simultaneously). This holistic picture allows them to identify hidden patterns and predict future problems, like disease onset or facial growth issues. Instead of following specific instructions, they explore network connections within the data, assigning importance (weights) to different factors based on their influence. These "weights" tell us how much each factor contributes to the predicted outcome. The next chapter will delve deeper into specific algorithms like Factor Analysis. These tools can predict a patient's risk of developing a disease or malocclusion by considering both evident and hidden factors—something even highly skilled doctors can only do with a different level of detail and speed.

Conversely, through experience, orthodontists develop a unique understanding of facial growth, allowing them to interpret subtle clues and identify general patterns in various cases. This "pre-empirical culture" acts as a lens through which they filter and analyse new observations. Even when data is unclear, their intuition, honed by experience, helps them form hypotheses and trace potential causes. They naturally seek the simplest explanation that fits the evidence, leveraging their innate ability to connect the dots. Doctors refine their mental model of the jaw and mouth over time, allowing them to extract meaning from even the most minor details. They understand how treatments interact with natural growth, recognising the interconnectedness and complexity of the entire system. Ultimately, the success of treatment hinges on anticipating how the facial system would develop without intervention. In other words, it requires considering hidden variables and the intricate interplay between various components [34]. While machine learning excels at finding patterns in large datasets, its predictions for individual cases based on these patterns can be unreliable due to inherent uncertainty and the unique characteristics of each patient [35]. These individual variations are crucial in orthodontics, where facial development follows unique and dynamic pathways. While some morphological patterns may persist with slight variations due to the underlying laws of development, unforeseen changes or "catastrophes" can also reshape the facial structure. To effectively navigate this complexity, orthodontists rely on two fundamental principles: understanding the natural developmental boundaries of different facial areas and analysing the likelihood of future changes in each individual. Tools like the Sakey diagram can aid in visualising these factors and guiding treatment decisions that respect the unique growth potential of each patient.

As discussed above, the facial structures and tissues are not static but continuously interact and change. This ongoing process eventually produces a cohesive and defined structure. However, this "orthodontic space" is not uniform, as different components comprise diverse materials. As living systems grow, they become more organised and structured. This growth involves processing information and reducing the potential for future variations in their development. While cephalometric data provides valuable insights, this insight is just a momentary snapshot of a constantly evolving landscape influenced by a complex interplay of skeletal, dental, muscular, and other elements. Internal mechanisms and the level of interaction between these elements can create self-reinforcing patterns, limitations, and corrective processes that make predicting future outcomes based solely on past data problematic. Ultimately, the growth process determines the range of possible outcomes and future development. Orthodontic data often come from various sources and periods, making it inconsistent. However, analysing the spatial arrangement of these elements is crucial. Different parts influence each other within specific timeframes and to varying degrees. In this complex system, everything is interconnected, with each facial feature shaped by its relationship to others. Even seemingly isolated data points gain meaning when placed in this context. Any change in one element affects the entire system, altering its overall characteristics.

This book avoids the danger of being one more manual offering a foundational approach to the diagnosis and prognosis of orthodontic discipline, even if it sometimes stands on the edges of orthodoxy. It discusses the effects produced by the reciprocal influence between biological growth constraints and morphological constraints in facial structure. This relation happens when every element, directly or indirectly, meets every other system component. It simply intends to push the orthodontist to master heterogeneous concepts and a kind of tolerant, more expanded thinking, which has become a necessity of thought in many fields today. The basic idea is that there is more to the orthodontic patient than we can see and that computers can help us understand more, providing us with mathematical documentation of the different models of dentofacial self-organisation.

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