Preface

The Process Grammar has been applied by scientists and engineers in many disciplines, including medical diagnosis (e.g., cardiac diagnosis); geology (e.g., the analysis of volcanic islands); computer-aided design (to establish new CAD operators); meteorology (to analyze weather patterns); biological anatomy (e.g., MRI human brain scans, dental radiographs); engineering bridge design; chemical engineering; etc.

The Process Grammar is based on a theorem that I proved in the 1980s called the Symmetry-Curvature Duality Theorem. Researchers have shown that this theorem defines an enormous number of aspects of biology, e.g., anatomy with applications in radiotherapy, surgery, and psychiatry, the tracking of DNA molecules, musculoskeletal development, the morphology of leaves in botany, the morphology of fish, etc; also geology, e.g., for the analysis of drainage patterns, etc; also graphics, e.g., for interactive rendering and cartoon vectorization, etc. The considerable applications of this theorem demonstrate that the theorem is *fundamental to morphology*. Its importance to morphology is explained by the Process Grammar.

In fact, every rule in the Process Grammar is an instance of a rule in a much larger system, my New Foundations to Geometry, that I have elaborated in my book *A Generative Theory of Shape* (Springer-Verlag, 550 pages).

Chapter 2 of the present book gives a brief introduction to these New Foundations, so that the reader is then shown how the Process Grammar is an instance of these New Foundations.

The central proposal of my New Foundations to Geometry is that shape is equivalent to memory storage. Therefore, in the New Foundations, geometry is the mathematical theory of memory storage, invented by the New Foundations. This opposes the Standard Foundations to Geometry, which are based on the invariants program. My argument is that invariants are memoryless.

The New Foundations to Geometry, being a generative theory of shape, define any shape by a sequence of operations needed to create it. Furthermore, the New Foundations require that this sequence be intelligent. In fact, the New Foundations gives a mathematical theory of intelligence, and base the entire New Foundations on this mathematical theory. The two most basic principles of this mathematical theory of intelligence are Maximization of Transfer and Maximization of Recoverability of the generative operations. The New Foundations give a Mathematical Theory of Transfer, and a Mathematical Theory of Recoverability. In the Mathematical Theory of Transfer, transfer is modeled by a group-theoretic structure called a wreath product. In the Mathematical Theory of Recoverability, the fundamental claim is that the only recoverable operations are symmetry-breaking ones. Furthermore, the Mathematical Theory of Recoverability gives a mathematical theory of symmetry-breaking that is fundamentally opposed to the conventional theory of symmetry-breaking used in physics, chemistry, etc. In the New Foundations, the Mathematical Theory of Transfer and the Mathematical Theory of Recoverability are unified, by claiming that any memory store is structured by a group invented in the New Foundations, called a symmetry-breaking wreath product.

An important fact is that the New Foundations are fundamentally a theory of *complex* shape. This is used to solve problems in many disciplines. For example, it solves major well-known problems in object-oriented software. Furthermore, it solves the interoperability problem in Computer-Aided Design (CAD). For example, consider mechanical CAD, which is the design process in mechanical engineering – forming the basis, for example, of the aerospace and automotive industries. It is generally accepted that mechanical CAD proceeds by a process called *feature attachment*. This is the process of the successive addition of structural units and components. The New Foundations give a mathematical theory of feature attachment. Furthermore, as another example of complex shape, the New Foundations give a mathematical theory of musical composition. A remarkable result is that the New Foundations show that feature attachment in mechanical CAD is mathematically equivalent to musical composition.

The Process Grammar is a *component* of the New Foundations to Geometry. To help the reader understand this, note the following: In the New Foundations, Geometry is the Mathematical Theory of Memory Storage. According to the First Fundamental Law of Memory Storage, given by the New Foundations, all asymmetries are memory stores. The different components of the New Foundations are the application of the laws of memory storage, given by the New Foundations, to different asymmetries. The Process Grammar is one such component of the New Foundations. The asymmetry used as memory storage in the Process Grammar is *curvature variation*.

Chapter 3 begins by describing the inference rules invented in the Process Grammar for recovering process-history from curvature variation. This uses the type of differential symmetry axis called PISA, invented in the Process Grammar, that has very different properties from the other differential symmetry axes called the Medial axis, the Medial axis (MA) symmetry set, and the SLS. The properties of the PISA axes are crucial. To understand this, one should first observe that there are four types of curvature extrema: a positive maximum M^+, negative minimum m^-, positive minimum m^+, and positive maximum M^-. Using the PISA axis, the Process Grammar defines M^+ and m^- as penetrative extrema, and defines m^+ and M^- as compressive extrema. This is because, the PISA axis gives, to the four extrema, the following *strongly plausible causal explanations*: penetrative processes for the M^+ and m^- extrema, and compressive processes for the m^+ and M^- extrema. Thus the PISA axis fulfills a basic principle of the New Foundations to Geometry, that *shape is defined by causal explanation*.

The standard literature on shape fails to do this. The reason is that the standard literature fails to make the correct distinction between penetrative and compressive extrema, and does so because it fails to understand compressive extrema. The New Foundations show that compressive extrema are fundamentally important to understanding shape in biology, geology, meteorology, vehicle design, architecture, paintings, etc. However, the standard literature fails to understand this, and this is because it fails to understand compressive extrema. The reason is this:

The PISA axis is the only differential symmetry axis that describes the *correct history* of a compressive extremum, i.e., the trajectory of the curve point that became the compressive extremum as a result of the flattening process, and the PISA axis is the only axis that describes the force that created the flattening. It does so because it leads to the extremum from the concave side of the curve. In contrast, the MA symmetry set, being on the convex side and pointing away from the extremum, does not give the history of the extremum in the flattening process that created the extremum. Furthermore, the SLS axis, being on the convex side and pointing towards the extremum, does not give the history of the extremum in the flattening process that created the extremum.

The basis of the correctness of PISA is the following: In the region of a m^+ or M^- extremum, the PISA symmetry axis *correctly* violates one of the fundamental properties of symmetry of the last 2500 years: that a symmetry axis must be on the *convex* side of an object. This violation of conventional symmetry makes the PISA symmetry axis the *correct* way of describing the history of compressive extrema, and is the reason why, *prior to the invention of the PISA axis, compressive extrema have always been failed to be described correctly*.

Chapter 3 also describes the six Level 3 Process Grammar operations: These operations are: Cm^+ squashing continues till it indents; CM^- resistance continues till it protrudes; BM^+ shield-formation; Bm^- bay-formation; Bm^+ breaking-through of a protrusion; BM^- breaking-through of an indentation. The first two are called the C process-continuations, and the other four are called the B process-bifurcations.

Using the process-inference rules of the Process Grammar, these six operations have the following causal explanations: The C process-continuations are caused by the continuation of a compressive process till it penetrates. The BM^+ and Bm^- operations are caused by a compressive process that opposes a pre-existing penetrative process. The Bm^+ and BM^- operations are caused by a penetrative process that opposes a pre-existing compressive process.

The Process Grammar claims that these operations are fundamentally important to morphology, and Chapter 3 demonstrates that the conventional theories of morphology completely fail to model these, because they completely fail to model compressive extrema, which are fundamentally important to the causal structure of all these operations.

That is, Chapter 3 shows that the PISA axis gives the correct causal explanation of the C process-continuations, whereas the MA symmetry set and the SLS axis do not. Furthermore, the PISA axis gives the correct causal explanation of the B process-bifurcations, whereas the MA symmetry set and SLS axis do not.

Chapter 3 also shows how the group theory invented in the New Foundations to Geometry, for complex shape, also defines the structure of these process-bifurcation operations. In fact, Chapter 3 shows how this same group theory, which models *mechanical CAD* and *musical composition*, in the New Foundations, also models these *process-bifurcations in morphology*.

Now note the following: The process-bifurcations elaborated in Chapter 3 are the 3-fold process-bifurcations of the Process Grammar. These operations are applied at an existing curvature extremum. Chapter 4 then elaborates the 2-fold process-bifurcations of the Process Grammar. These are called pair-creations. These operations are applied at a point away from an existing extremum, i.e., at a point on a spiral. The Process Grammar claims that such an operation simultaneously realizes two design intents.

When the spiral, on which a pair-creation operation is applied, is the *side* of a pre-existing extremum, the Process-Grammar calls the pre-existing extremum, an anchor-extremum.

In the case where the application-point of a pair-creation operation has non-zero curvature, the operation simultaneously produces a penetrative and compressive extremum. Therefore, the Process Grammar is the only morphology theory that correctly describes this situation, whereas other morphology theories cannot.

The Process Grammar elaborates six pair-creation operations, $\pi\emptyset^{\uparrow+}$, $[C(3)\pi]0^{\uparrow}$, $\pi\emptyset^{\uparrow-}$, $\pi\emptyset^{\downarrow+}$, $[C(3)\pi]0^{\downarrow}$, $\pi\emptyset^{\downarrow-}$, and elaborates their types of applications in relation to the various anchor-extrema.

Chapter 5 describes the theory of *parts* given by the Process Grammar. It follows from the theory of parts defined by the New Foundations to Geometry. Recall that the New Foundations are based on two basic principles: Maximization of Transfer and Maximization of Recoverability. Correspondingly, the New Foundations define *parts* as *phases* of the recovered causal history, such that they *maximize transfer and recoverability* in the recovered causal history.

This is fundamentally different from the standard research on geometry, because the standard research defines a part as a segment of the whole, where both the segment and the whole are defined independently of recoverable causal history. That is, standardly, a part is defined *non-causally*. For example, the literature in computer vision is full of diagrams of an animal body which is separated into rigid closed shapes corresponding to arms, legs, torso, head, etc., all floating independently in space. Thus, there is no conception that an arm actually grew out of the body.

The fact that the New Foundations to Geometry define *parts* as *phases* of the recovered causal history, such that they *maximize transfer and recoverability* in the recovered causal history, has the consequence that, in the Process Grammar, a part is defined as a recovered process and the recovered subsequent history of that process; i.e., its subsequent Process Grammar operations.

Notice therefore that, because the standard research literature fails to understand compressive extrema m^+ and M^-, i.e., fails to understand the processes that produced them, it fails to understand them as parts. This is a fundamental reason why the standard literature is stupid, in accord with the technical definition of intelligence given by the New Foundations.

The two extrema m^+ and M^- define two parts, which the Process Grammar call respectively, *shields* and *bays*, which Chapter 5 demonstrates, in detail, are fundamentally important to morphology.

According to the Process Grammar, *shields* and *bays* should be regarded as extremely important to many disciplines such as biological morphology, automotive, aerospace and architectural design, computer vision, robotics, etc. Nevertheless, these disciplines tend not to notice shields and bays; and on the rare occasions when the disciplines notice them, the disciplines describe them incorrectly.

In contrast, the Process Grammar defines them correctly, and, in so doing, shows the fundamental importance of these structures.

Chapter 5 shows that examples of shields in biological morphology are the forehead, top and back of the human head, the chin and jaw, the chest, the tips of fingers, the knee-cap, the heel of the foot. Also, examples of shields in road vehicles are the front, top, back, and sides of cars, buses and vans. This unifies biological morphology and automotive design. For example, according to Chapter 5, the forehead of the human head is the same structure as the front of a van. In fact, both are what the Process Grammar calls bi-directional shields in the sense that they are shields both in the vertical and horizontal direction.

It is important to understand that conventional geometry, such as the highly popular Medial Axis of Blum, completely fails to describe shields. Blum invented and published the Medial Axis as an analysis of biological morphology. Yet it completely fails to describe what Chapter 5 demonstrates are fundamental and frequent in biological shape: i.e., shields. A major claim in Chapter 5 is that the fundamental importance of shields in biological shape is because biology requires shields for *protection*. In contrast to Blum's Medial Axis, the symmetry axis invented in the Process Grammar, the Process-Inferring Symmetry Analysis (PISA) not only recognizes the existence of shields but describes them correctly by revealing their protective structure. The same applies to shields in automotive, aerospace and architectural design.

Chapter 5 also shows that bays are important structures in architectural design, such as the design of bridges, doorways, ceilings, windows, etc. Again, Blum's Medial Axis completely fails to describe these, and PISA axis not only describes them but does so revealing their functional structure.

After Chapter 5 gives an extensive demonstration of the importance of shields in biological morphology, vehicle design, and architecture, Chapter 5 then gives an analysis of car design as the successive application of Process Grammar operations. A fundamental property of this analysis is that it demonstrates that the important functions of a car are processes inferred from the curvature extrema in the successive stages defined by the Process Grammar operations. This means that the Process Grammar recovers the *layers* of *design intents* in the car.

In fact, the recovery of design intent is one of the main achievements of the laws of recoverability given by the New Foundations to Geometry.

This is relevant for solving major problems that exist in the integration of large-scale engineering systems and product lifecycle management.

For example, the manufacturing of a major engineering product, such as an aircraft, involves supply chains that tend to use different design softwares that cannot exchange their model information. What would solve this interoperability problem is the recovery of design intent. Furthermore, over the product lifecycle, the recovery of design intent would also solve the reuse, adaptability, and maintenance problems.

A crucial fact is that the mathematics of recoverability, invented by my New Foundations to Geometry, solves these problems. This is corroborated by the fact that aspects of this mathematics have been applied by scientists and engineers in over 40 disciplines. Furthermore, certain members of the International Standardization Organization (ISO) are implementing my mathematics to establish international standards in engineering design.

Before discussing bays, Chapter 5 gives a geometric analysis of *grasping* and shows that the PISA axis is totally correct in describing the forces of grasping; and that the Medial Axis symmetry set is totally wrong in describing the forces of grasping.

Chapter 5 then goes on to demonstrating the important role of the parts that the Process Grammar calls bays in defining arches in architecture.

A crucial aspect of Chapter 5 is that it demonstrates the following:

The Process Grammar gives a unification of biological morphology and vehicle design.

In the analysis of parts, Chapter 5 also defines the crucial concept of *restricting* the *zone-of-influence* of a process, a concept that the standard literature completely fails to understand. Furthermore Chapter 5 also defines the Process Grammar operations that perform this zone-of-influence restriction.

Chapter 6 then gives an extensive analysis of what the Process Grammar calls 5-fold parts; that is, parts with 5 extrema. These include parts that standard morphological theories completely fail to understand and represent, for example, parts that the Process Grammar calls *triple-shields* and *triple-bays*. This book shows that triple-shields are fundamentally important in biological morphology and vehicle design.

Chapter 6 defines three scenarios that produce 5-fold parts, and the Process Grammar operations that realize those scenarios.

This book shows that the Process Grammar operations capture important *intended functions*, in both biological morphology and manufacturing design. Consequently, the Process Grammar operations define new CAD operations that achieve fundamentally important *design intents*. Therefore, since this book defines over 30 Process Grammar operations, there is this important consequence:

This book defines over 30 important new CAD operations.

Another aspect of the book is that it invents a new singularity theory of shape, called Interactive Singularity Theory. This singularity theory of shape is elaborated in Chapters 8 – 13.

A crucial fact is that Interactive Singularity Theory's definition and organization of singularities match the *causal* structures which the Process Grammar has proved are fundamentally important to biological morphology and manufacturing design. In contrast, conventional singularity theories of shape have completely failed to match the fundamentally important causal structures of biological morphology and manufacturing design. As an example, Chapter 7 shows that Catastrophe Theory is inadequate for modeling morphology.

A crucial aspect of Interactive Singularity Theory is that it gives the organization of relationships between the morphological operators, i.e. their Interactive Structures, in a way that matches the *causal* structure of the operators correctly given by the PISA axes.

For example, Chapter 12 shows that a crucial situation defined by the Process Grammar – a situation in which a process opposes and breaks-through a compressive process, resulting in a zone-restricted penetrative process – is given by what Interactive Singularity Theory calls Interactive Structure, in a way that matches the causal structure of those situations as correctly given by the PISA axes. In contrast, conventional singularity theories of shape cannot model this.

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