Communicating with Machines: Bezier Curve as 'Informational Ontology'

Novel methods of parametric processes have created a specific formal aesthetic; one which is similar to what the cultural theorist Siegfried Kracrauer referred to as a 'mass ornament' informing all scales of objects, from tooth brushes to buildings. These objects are usually characterized as having smooth surfaces of free forms consisting of some homogeneous plastic-like material, initially referred to within the architectural discipline as 'non-standard' forms or 'blobs.' And while these complex surfaces are striking in their appearance as buildings, the formal means employed to bring about these creations never seem to be rationally justified, or appear arbitrary. One way to access the aesthetic value of these new forms may be to delve into the industrial heritage of many of the curve tools employed in software programs used to create them.

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INTRODUCTION

Just as the capabilities of machine tool design influenced the aesthetic form of streamlined industrial design products during the mechanical age, the embedded curves and splines of contemporary digital software originated in the mechanical engineering departments of car and airplane manufacturers from the postwar era. Yet the use and reproduction of such smooth, curvy forms were not accomplished easily until recently. One of the biggest problems in the postwar period for the design offices of car and airplane manufacturers featured the problem of accurately reproducing complex curved surfaces in scaled models, and the precise transfer of these curves and surfaces from a blueprint or model to digital form (referred to as the blueprint-to-computer challenge). Many of the digital tools involving curves and surfaces embedded within architectural software are the result of this challenge. The industries involved in the blueprint-to-computer challenge included companies such as the aircraft manufacturers North American Aviation and Boeing, engineers at MIT, and car manufacturers General Motors, Citroën, and Renault. This paper will specifically focus on the work of Paul de Casteljau at Citroen and Pierre Bezier at Renault.

The purpose of this paper is twofold; the first is to historically trace the transcribing of complex smooth surfaces and their underlining algorithmic source within the field of industrial design by reconstructing the emergence of the original technical ensemble of CAD/CAM machines which came together to resolve the blueprint-to-computer problem within the framework of architectural discourse. The result of this technical challenge was the creation of the Bezier curve—a parametric instrument that functions as a crucial component in creating contemporary digitally designed smooth curved surfaces. Its use in digital design today is ubiquitous—with any contemporary architect designing with CATIA, AutoCAD, or Rhino using some form of Bezier curve. Through his invention, Bezier would go on to create the UNISURF system, which was the precursor to CATIA, a software suite essential to the work of architect Frank Gehry and the basis of the Digital Project software developed by Gehry Technologies.

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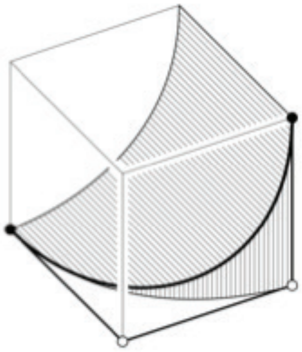

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Figure 1: The first model of the Citroen DS was built before de Casteljau’s solution, however by 1966 his work would have been applied to any re- tooling of stamping machines. Pictured above, the Citroen DS 1966. Car body panels could be easily removed from the entire car using a simple tool that came with the car. This image illustrates the manner in which the surfaces were calculated using ‘patches.’

Figure 2: Bezier’s ‘basic curve’ within a parallelepiped.

The second, more speculative aspect of this paper is to claim that Pierre Bezier’s response to the blueprint-to-computer challenge stands as an indicative conceptual model of what French philosopher Gilbert Simondon proposed as a new way of thinking about information, creating what he termed as a new form of ‘informational ontology.’[1] At the same time that de Casteljau and Bezier were working on streamlining the design and manufacturing of smooth car body components, the philosopher Gilbert Simondon was creating a novel approach to rethinking the relationship between humans and machines. At the core of understanding this relationship was the problem of information and how it performed as a form of medium in which to communicate between humans and machines and to inform certain technological processes.[2] This was taken up by U.S. mathematicians Norbert Weiner, Claude Shannon, and John von Neuman, however Simondon had a novel insight built upon their theories. I will argue that the technical operation of the blueprint-to-computer challenge and its resolution—the Bezier curve—serves as a paradigm of Simondon concept of Informational Ontology; as a sort of intermediary, or mediation between matter and form, that contributes to a new non-hylomorphic model.

THE PROBLEM: BLUEPRINT-TO-COMPUTER CHALLENGE

The blueprint-to-computer challenge can be simply understood as a complex problem of establishing a mode of communication between humans and machines. By the early 1960s, there existed devices such as servo-mechanisms, transistors and other circuitry through which machines were provided directions and information, however this was at the very basic level of communication. Drawings were still the main form of communicating a design through all stages of production, and the process of transforming a design to a model stage was a time-consuming and labor-intensive task. The master model served as the standard reference throughout the entire production.

Translating the design drawing to a 3D model entailed many intuitive steps involving a series of technical specialists such as stylists, body designers, plasters, tool designers, and pattern makers. The body designer was a highly skilled tracer or lofter. His tools included compasses, French curves, lathes and physical splines. His mathematical knowledge was based in descriptive geometry, and his task was to translate the shape dictated by the stylist by creating a model that underwent a series of examinations and corrections before one of the designs was finally selected.[3] A drawing could only provide an approximation, and most of the time rendered a questionable definition of the contours of the bodywork, and so the team had to constantly refer back and forth to both drawing as the model, initially built from wood, and then later made of artificial resins and fiber glass overlaid onto a metal frame. Despite all of the work directed toward the creation of this model by technicians, these methods were inaccurate, with many discussions, modifications, delays and expense in creating a final master model.[4]

During the late 1950s, the development of numerically-controlled (NC) or Computer Aided Machines (CAM), were able to produce 3-dimensional shapes by machining wood or steel. These shapes, in turn, would be used to create the machine tools of cars and airplanes in order to stamp or mold with dies the bodywork components such as a car fender or airplane fuselage. At the time, basic shapes such as planes, cylinders and spheres could be machined using the language developed by at the Illinois Institute of Technology, Automatic Programmed Tooling (APT) language. Using this NC language of simple commands such as select tool, move tool to point (x,y), lower tool, a technician could communicate to CAM machines how to cut basic forms.

Most of the knowledge regarding these technological operations was not based in computer programming, but entailed breaking down into small tasks the expertise of cutting metal, a skill traditionally completed by patternmakers and die-setters.[5] The greatest challenge in this technical process arose when the components to be machined entailed complex curved surfaces. These required an accurate description which the machine could understand.

THE SOLUTIONS—DE CASTELJAU AND BEZIER

The solution was to formulate a new process from on that was traditionally understood as unscientific and intuitive; consisting of debates by stylists, designers, and model-makers; into an acurate mode of communication resulting in a precise, machined 3-dimensional form. In 1958 Paris, there were two different yet coinciding attempts to reimagine how humans can communicate with machines, and two characters who were able to resolve the blueprint-to-computer challenge. At this time Simondon completed his PhD dissertation, and mathematician/physicist Paul De Casteljau, while working at the automotive company Citroen, invented a solution for calculating complex curved surfaces. Soon afterward in 1962, Pierre Bezier at Renault developed a solution similar to De Casteljau.

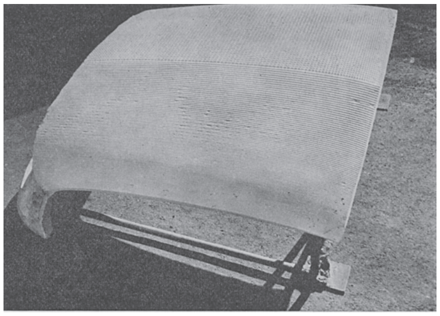

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Figure 3: A clay model component of a car roof.

DE CASTELJEU—CITROEN

After returning from the war in Algeria, the French mathematician Paul De Casteljau was hired for the position of physicist at Citroen in Paris in 1958. His tasks was difficult, but De Casteljau forever changed the manner in which car bodies were modeled.[6] By this time, car specialists believed that almost all of the electrical, electronic, and mechanical problems of the automobile were resolved, except for about 5%, which comprised calculating the surfaces of component parts.[7]

> The construction plans presented to me were often the ones nobody else was able to put into practice. They were peppered with characteristics which contradicted any kind of mathematics: three non-coplanar tangents for determining the tangent plane in one point, only virtually visible contours.[8]

De Casteljau would ultimately invent a parametric solution based on the properties of Bernstein's functions. According to Computer Science scholar Gerald Farin, the significance of de Casteljau's work was that it closed a technological gap within NC technology by formulating an algorithm that allowed for 3D modeling capabilities. His work formed the basis of all Computer Aided Design graphics; its significance was founded upon the idea of control points to create curves.[9] His work eventually evolved into the current standard of modeling, what is known today as NURBS.[10] (NURBS are a broader use of the control-point-based polynomial curves). This process allowed for the total elimination of blueprints as a means of communicating a design, and instead the mathematical configuration of an algorithm could be implemented and sent directly to CAM machine tools. De Casteljau was never awarded recognition of his invention until the 1970s since Citroen did not allow his results to be published. In the meantime, another Frenchman working at Renault came up with a similar solution.

BEZIER'S SOLUTION

Pierre Bezier, a mechanical and electrical engineer, worked at Renault designing special machines such as the transfer-lines for mass-production of car parts.[11] In 1962, he developed the Bezier curve, which would serve as the basis for an entire process that would eliminate much of the time and money lost during traditional methods of car body modeling, and most importantly, his approach increased the accuracy and smoothness of car body components. Today the Bezier curve is still considered the most fundamental parametric curve form.[12]

His solution was a system called UNISURF, which was an interactive process for defining space curves and surfaces. Unlike de Casteljau, Bezier possessed an intimate knowledge of the production process and therefore his approach was from the point of view of a mechanical engineer. The heart of the UNISURF system was Bezier's initial idea to represent a 'basic

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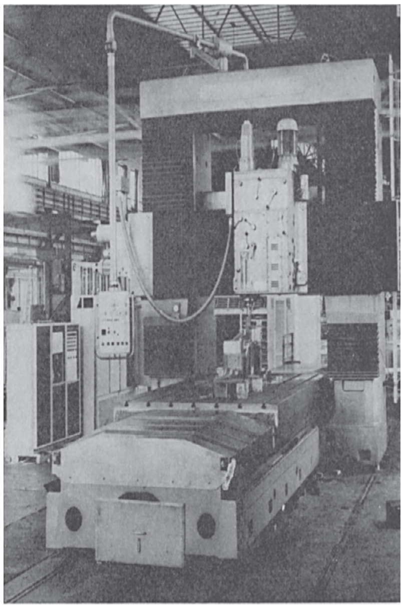

Figure 4: A Heyligenstaedt tool milling machine. The object is formed as it moves on a trolley below and is extruded through a parallel-piped frame from above. Excesses material is milled away in this process.

curve' as the intersection of two elliptic cylinders. The two cylinders were defined inside a parallelepiped. The key for Bezier was to discover an equation system that did not define a surface or curve through the 2-dimentional representation in drawing, nor the 3-dimensional form of the milling machine, but as Bezier explained, "we preferred to find the set in which a curve or a given surface is represented by a relation the shape of which is defined once and for all."[13] This meant that "vectors representing each curve segment [possessed] its own set of reference points dependent upon their geometric features: end points, intermediate points, tangents, curvature, etc."[14] This parametric approach was significant in that it created the surface "independent from its position to the coordinates of the machine."[15] Moreover, the significance of Bezier's curve was the control points which "allowed a separation of the mathematics underlying a design system from the actual use of it."[16] Bezier would move on to polynomial formulations of this initial concept. The result was a bit different than that of De Casteljau, nevertheless the underlying mathematics was the same using Bernstein polynomials for the representation of curves and surfaces. (Bernstein's polynomials were invented at the beginning of the 20th century but there was no practical application at the time and therefore it remained 'dormant' until de Casteljau and Bezier discovered its use in recreating curves.)[17]

At Renault, Bezier's objectives for developing Renault's system UNISURF entailed the following: 1) To decrease the time spent between the operator choosing relevant data and the moment he would see a visual outcome of this data. This translated into approximately a few seconds to create a line and a few minutes for a 1m^2 surface.[18] 2) The system must accommodate more than simply straight lines, circles, and conics; it must be able to create a large spectrum of curves. 3) The method should not require additional mathematical knowledge other than the usual field of descriptive geometry from the operator. 4) Its accuracy should be 5 x 10-5 and it should be reliable, easy to maintain and repair.[19]

In this new system, the process starts out with a 1:5 scale model created by the stylists containing defined character or feature lines. The feature line coordinates are then transferred by the designer to the drawing machine, selecting the vectors that define each curve segment in order to assist in calculating the path of the tracer. While UNISURF assisted in the creation of complex 3D surfaces, these surfaces still had to be drawn as divided segments by the designer, with each segment simple enough to be determined by one polygon.[20] Then the polygons would be 'stitched' together when the last side of each polygon would be made collinear with the first side of the adjacent polygon. This is how an entire surface would gradually be patched together creating a mesh of curves using a ruled surface as the starting reference point.

Once the curved surface segments are blended, an operator inputs the data of apexes of character polygons through a printer keyboard. The automated mechanisms making up the drawing machine was originally a CAM milling machine, however instead of have a cutting tool bit installed, an operator replaced it with a pencil or stylus. As Ken Kensley, an engineer from the Boeing Aerospace Factory explained, the detecting and correcting of errors in parts programming was first conducted on a milling machine using a pen in which to have the machine first 'draw' the component part. He explained, "Thus the first ever use of an NC machine tool was as a computer-controlled drafting machine, a technique vital later to the advent of CAD."[21] Once the NC drawings were completed, the finalized designs would be sent, via punched tape, to the milling machine where model component parts would be cut out of soft materials such as plaster, plastic, and wood.

After this network of control points was established, the designer created a machined surface using a polystyrene foam block. Once a foam model version of the patch was completed, it was then made into a clay model version. After the final shape of the clay model surface patch was resolved, it would again transform into another model, again sculpted by the machine tool using the same punch tape, however the model material was a plaster block rigged to a metal frame. In order to ensure accuracy in the setting of each block, the plaster blocks were fastened to a central parallelepiped bearing which corresponded to a set of dowel holes in the plaster block. Final smoothing of the machined surfaces was done by hand. Once all of the components were machined, they were fitted together to create the final full-scale model, and the tool design process, which used similar methods to the model making system, would begin.

INFORMATIONAL ONTOLOGY

As the above process demonstrates, the origin of smooth surfaces in computer-aided design originated within a technical chain of operations in order to create a model, and then a series machine tools, to mold or stamp flat-blanks of metal into complex curved forms. When we think of smooth surfaces in architecture, we rarely imagine that their technological origins lay within the ability to cut sheet metal, or later machine 3D dimensional forms using numerical control, however as we have seen, this is its genealogy and it creates a **media ecology**. Yet the blueprint-to-computer challenge was not merely a process of forming metal, more importantly it was a significant moment in which we can understand a new mode of information in the manner material is used and understood as a **medium** with inherent intellegence and information. The development of mathematical algorithms which helped to communicate one form of 2D representation into 3D form using a technological ensemble of machines. De Casteljau and Bezier improved upon this intermediary language in order to translate complex surfaces. There is a reciprical relationship between the material and machines used to form metal, where both are 'informing' each other. The essence of theis transaction is in Bezier algorithm, and we see this occur today in the contemporary architecture practice of material computation.

Simondon's interpretation of information, specifically cybernetics (or the communication between humans and machines) was unique in that unlike the theories of mathematicians John von Neuman and Claude Shannon, he believed information was not defined by its source and receiver, but from the relationship between the two, what he termed as information's interoperability, i.e. information's changed mode of processing information.[22] This understanding entailed building upon the Mathematical Theory of Communication approach (MTC) by introducing the four new concepts of metastabilty, transduction, concretization, and individuation of informational ontology.

Metastability encapsulated Simondon's idea that information is not a static thing, but rather it existed within a state of metastability, and that information and its "nexus or pivoting point" was interoperable and interdeterminate, meaning that information changed according to an event, thereby changing its very nature with a new informational entity emerging. Transduction is the open informational potential of two different fields of information which converge in order to begin a process (of individuation) in which a third informational structure will emerge. The "actual action of changing informational properties."[23] All three of these properties explaining a new informational ontology also describe the blueprint-to-computer problem and its resolution. The Bezier curve is parametric, which means that it is formed relatively; it is totally dependent upon, and will change according to, the input of variable data through the use of control points. This epitomizes Simondon's definition of metastability. The blueprint-to-computer problem and its outcome is itself a form of transduction, meaning information from two disparate sources of knowledge—in this case, mathematics and metallurgy—come together to create a third informational structure of computing found in Bezier's UNISURF.

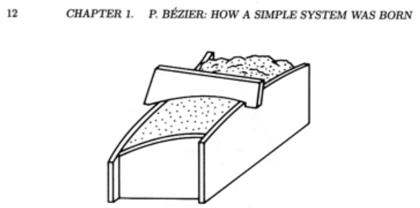
12 CHAPTER 1. P. BÉZIER: HOW A SIMPLE SYSTEM WAS BORN

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Figure 5: An image from Bezier's article, "How a Simple System Was Born." The caption states: "A surface is obtained by scraping off excess material with wooden templates."

ENDNOTES

1. Gilbert Simondon, *L'individuation psychique et collective*, (Paris: Aubier, 2007), 29. This is the second half of Simondon's major thesis *L'individuation a la lumiere des notions de forme et d'information*.
2. Gilbert Simondon, *On the Mode of Existence of Technical Objects,* Ninian Mellamphy trans. (Paris: Aubier, Editions Montaigne, 1958) 1–17.
3. Pierre Bezier, "Style, Mathematics and NC," *Computer-Aided Design,* vol. 22, no. 9, Nov. 1990: 524.
4. Ibid.
5. Norman Saunders, "Computer-Aided Design (CAD) in the Boeing Airplane Division in Renton," in A. Tatnall, ed., *Reflections on the History of Computing*, IFIP AICT 387, pp. 49, 2012.
6. Hanns Peter Bieri, Hartmut Prautzsch, "Preface," *Computer Aided Geometric Design*, 16 (1999) 580.
7. Paul de Faget de Casteljau, "De Casteljau's autobiography: My time at Citroen," *Computer Aided Geometric Design* 16 (1999) 583.
8. Ibid., 584.
9. Hanns Peter Bieri, Hartmut Prautzsch, "Preface," *Computer Aided Geometric Design*, 16 (1999) 580 -581.
10. Ibid.
11. Pierre Bezier, "Style, Mathematics and NC," *Computer-Aided Design*, vol. 22, no. 9, Nov. 1990: 524.
12. Gerald Farin, "A History of Curves and Surfaces in CAGD," In G. Farin, J. Hoschek, and M. S. Kim, editors. *Handbook of 3D Modleing and Graphics,* Elsevier, 2002.p 7.

The proposition of the blueprint-to-computer problem as a model of Simondon's informational ontology is further elucidated when we understand his concept of individuation. Information, according to Simondon, should not be reduced to a series of signals, or as simply content, but that it should be understood in terms of code.[24] To best illustrate this concept, Simondon provides us with the example of traditional brickmaking, where the material—wet clay and a parallelepiped wooden mold 'in-form' a brick. Through this description Simondon attempts to counter the simple Aristotelian hylemorphic model of form and matter, which, according to Simondon is reductive of technological operations. Instead the individual, be it a technological object, say in this case, a wet clay and mold, is not something that is immediately formed and created in one blow, but it is instead it is a process of materials acting upon one another, with the mold forming the formless clay, and the emergent properties of clay also contributing to the ultimate form of the brick. In this technical operation, it is the **mediation**, according to Simondon, which should be considered, not simply the clay and the mold. Similar to Bezier's UNISURF resolution to the blueprint-to-computer challenge, Simondon's informational ontology is the result of two technological chains coming together, a modulation, as he explains in his example of brickmaking,

> If one divides the two ends of the technological chains, the parallelepiped and the clay in the quarry, one tests the impression of realizing, in the technical operation, an encounter between two realities of heterogeneous domains, and institutes a **mediation**, by communication, between an inter-elementary order, macro-physical, larger than the individual, and an intra-elementary order, micro-physical, smaller than the individual.[25]

Simondon's concept of individuation is epitomized in the technical ensemble of the parametric Bezier curve and the UNISURF system. This becomes evident after understanding how Bezier first envisioned his solution to the blueprint-to-computer problem in an article titled, "How a simple system is born." He equates his realization of the UNISURF solution to the process of creating a core using a technique of the foundry. He writes,

> The basic idea of UNISURF came from a comparison with a process often used in foundries to obtain a core: sand being compacted in a box. The shape of the upper surface of the core is obtained by scraping off the surplus with a timber plank cut as a template; of course, a shape obtained by such a method is relatively simple since the shape of the plank is constant and that of the box edges is generally simple. To make the system more flexible, one might change the shape of the template at the same time as it is moved. In fact, this idea takes us back to a very old, and sometimes forgotten, definition of a surface: it is a locus of a curve which is at the same time moved and distorted.[26]

Accompanying Bezier's above description is a small sketch showing how a surface is created by scraping off the excess material with wooden templates. This example demonstrates how the creation of form is not one single action, but a series of technological operations and embodied energies. It also shows that part of the forming making process entails the intermediary of the geometry, in this case, the Bezier curve, and exemplifying Simondon's dictum: "The notion of form must be replaced by that of information."[27] This is this a similar understanding of materiality we have in architecture today in regard to material computation. In the words of Achim Menges, "materiality no longer remains a fixed property and passive receptor of form, but instead it can be transformed into an active generator of design and an adaptive agent of both structural perfoamnce and architectural perfomativiety." As architects we may be able to create smooth surfaces with the use of digital software, however equally important as the technical advancements was the evolution of a new way of understanding the use of information (as embodied in the material and the process of making machines). Simondon's explanation posits information as a field or environment in which other data, such as an algorithm, is able to cut and shape data in the same manner that a brick it formed. Information as a medium.

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13. Pierre Bezier, "Example of an Existing System in the Motor Industry: The Unisurf System," *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences*, (Feb. 9, 1971) vol. 321, no. 1545, pg. 210.

14. Ibid., 211.

15. Ibid.

16. Gerald Farin, "Geometry in Design: The Bezier Method," J.R. Rice, ed. *Mathematical Aspects of Scientific Software,* (New York: Springer-Verlag, 1988), pp. 89-90.

17. Gerald Farin, "A History of Curves and Surfaces in CAGD," pg. 5.

18. Pierre Bezier, *Numerical-Control. Mathematics and Applications*, (London: John Wiley and Sons, 1972), PAGE.

19. Pierre Bezier, "Example of an Existing System in the Motor Industry: The Unisurf System," pg. 209.

20. Pierre E. Bezier, "How Renault Uses Numerical Control for Car Body Design and Tooling," *Society of Automotive Engineers Congress Proceedings*, Detroit, Mich., (Jan. 8-12, 1968): 6 (need to check page number).

21. Ken McKinley, "Computer-Aided Manufacturing (CAM) in the Boeing Aerospace Factory in Seattle," A. Tatnall, ed., *Reflections on the History of Computing*, IFIP AICT 387, pp. 44, 2012.

22. Gilbert Simondon, *L'indivuduation psychique et collective*, (Paris: Aubier, 2007), 50.

23. Ibid., 22.

24. Ibid., 28.

25. Gilbert Simondon, *L'individu et sa genese physico-biologique*. Paris: Presses Universitaires de France, 1964. Translation from Taylor Adkin.

26. Pierre Bezier, "How a Simple System Was Born," in Gerald Farin, ed., *Curves and Surfaces for Computer Aided Geometric Design. A Practical Guide*. (Boston: Academic Press, [1988], 1993), pg 7.

27. Gilbert Simondon, *L'individuation psychique et* collective, pg. 28.

28. Achim Menges, "Material Computation," http://architecture.mit.edu/computation/lecture/material-computation.