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MASTER'S THESIS

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A Model for Automatic Optical Scaling of Type Designs for Conventional and Digital Technology

by
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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing Management and Science in the College of Graphic Arts and Photography of the Rochester Institute of Technology

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ABSTRACT

In the history of type design, two methods have been used to scale type--to produce enlarged or reduced letterforms from a reference size. With original handcut fonts, designers performed *optical scaling* (scaling by eye) that varied the proportions of letterform features over a range of sizes in a *nonlinear* manner. That is, letterform feature proportions were size dependent. This was an entirely manual and intuitive process. More recently, however, the use of the lens, as well as computational and other technologies, has allowed letterforms to be scaled automatically from a *reference character*, a simple *proportional* enlargement or reduction. To date, little work has been done to combine these two methods, that is to say, to automatically perform nonlinear scaling of a reference character in order to approximate the optical scaling performed by skilled type designers and punchcutters.

This research developed a mathematical model of optical scale in type design, consisting of two parts: (1) a model of the scaling of individual letterform features; and (2) a model of the scaling of entire letterforms. The model was tested by applying it to the original handcut fonts that supplied the initial data for the research in order to generate *synthetic* letterforms. These nonlinear synthetic letterforms were then compared with the originals, as well with proportionally scaled letterforms generated from the originals. The goal was to determine how well the nonlinear letterforms generated by the model approximated the original optically scaled handcut letterforms. In addition, the performance of the proportionally scaled letterforms was compared with the originals, as well as with the nonlinear, synthetic forms.

produce computer-generated digital letterforms that simulated optical scale in handcut fonts.

This research is an investigation into the automatic optical scaling of type designs. This thesis describes a model of individual feature scaling, a model of letterform scaling, and a method of testing the letterform scaling model. In this study, letters were produced by both the nonlinear and proportional scaling models, and were evaluated both visually and technically.

The rest of this chapter is a summary of the changes in the technology of type design and manufacturing and how these affected the scaling of type designs.

Hand Punchcutting

Before 1885, the process of designing and producing lead printing types from handcut punches remained practically unchanged since the time of Gutenberg (1450). Letters were designed and steel punches were handcut for every character in every point size. A punchcutter had to follow a rigorous discipline to cut every character in every size. Giambattista Bodoni (b.1740 d.1813), an accomplished type designer and hand punchcutter, states:

> Truth to tell, not many people would think that the number of the matrices for one Roman comes up to one hundred and ninety-six, and one needs another one hundred and eighty-four for the Italics of the same width and type-face, to be interposed with Roman type when necessary. So, to make an accomplished equipment of types, three hundred and eighty matrices are needed for one text.[1]

Sometimes the designer was the punchcutter, but more often, the designer worked closely with a punchcutter. Of the designers of fonts in this study, it is known that William Caslon and Giambattista Bodoni were type designers and punchcutters as well as the matrix makers and type casters for their fonts, while William Besley worked with the punchcutter Benjamin Fox to arrive at the Clarendon design. Unfortunately, it is not known

[1]Giovanni Battista Bodoni, Manuale tipographico del cavaliere Gambattista Bodoni, 3 vols, trans. Angelo Ciavarella (Parma, Italy: Franco Maria Ricci, 1965), p. 107.

who officially "designed" and cut Akzidenz Grotesque. Drawings and sketches usually in a single size were used as a guide and the other sizes were visualized and interpolated by eye, given the experience of the punchcutter.

Human visual perception was integral to the punchcutting process. Every aspect involved the action and judgment of the punchcutter. His eyes and hands manipulated every edge of the form. No mechanical or optical system could duplicate the way a hand punchcutter worked.

> The relation of small to large must be made evident not by uniformity but by skilful variations. Yet there must be a pattern letter in the reader's eye that is reproduced as well as possible in every one of a range of sizes. The punch-cutter must see this letter in his mind's eye and cut it in all the necessary sizes with the right adaptation to scale. It must be a letter that is as suitable for large as for small types, handsome enough for the main line of a title-page and clear enough for a footnote. Many of our modern types fail at one or the other extreme: some in their large sizes are obviously mechanical enlargements, others have small sizes that are illegible.[2]

One's familiarity with the letter forms came from repeated practice of drawing and visualizing the forms until they became second nature to the hand and eye. This was essential to the success of their producing a font which appeared uniformly smooth to the eye.

A punchcutter's tools consist of sharpened steel gravers, files, awls, gauges, a vise, sharpening stones, a facing tool, a strong magnifying glass, and smoke proofing tools. With the pre-visualized letters or drawings and tools, they cut punches, and sometimes on a good day, finished three.[3] See Figure 1.

When the punchcutter judged a character to be correct in design and scale by making smoke proofs, the punch was hardened and struck into a brass or copper bar, which became the *strike*. Sometimes during the process of forcing the punch into the bar of

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[2]Harry Carter, "Letter Design and Typecutting," Journal of the Royal Society of Arts (October 1954), p. 885.

[3]Paul Koch, "The Making of Printing Types," The Dolphin Number One (1933), p. 25.

copper or brass, the punch would break or twist. It then became necessary for the punch to be replaced. Also the strike could be misplaced on the bar and the whole striking process started over. Once the strike was good, it was "justified" by a justifier. This was a process of filing and smoothing the strike to base and width align, making sure all the edges were perfectly parallel and square, flush with other printers' types, and with level face. It then became a matrix for casting type. The justifier played an integral role with the designer and the punchcutter in the success of the font. This position, which has been overlooked in more modern times, took years of training and specialized talent, and once gained, allowed the justifier to become a very important member of the "team" in typefounding.

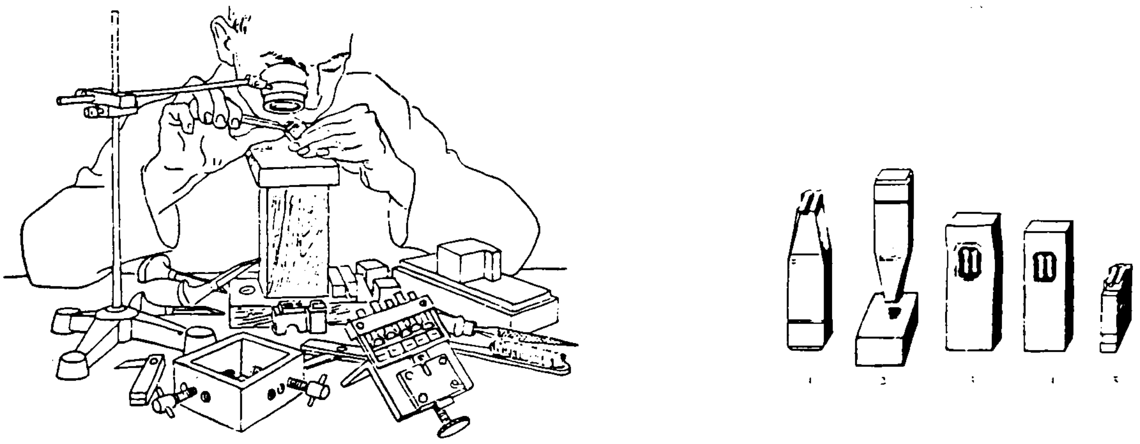

Figure 1. A hand punchcutter at his workbench: 1. handcut punch, 2. striking the matrix, 3. unjustified strike, 4. squared matrix ready for casting, 5. cast type.[4]

[4]Karl Klingspor, Uber Schonheit von Schrift und Druck - Erfahrungen aus funfzigjahriger Arbeit von Dr. Karl Klingspor (Frankfurt am Main, Germany: Georg Kurt Schauer, 1949), p. 74.

> Mechanically, it is a highly skilled operation and something more than mechanical accuracy is needed, because an eye for counteracting optical delusions and producing a harmoniously spaced and aligned alphabet is essential. A good justifier is the condition for success in making printer's type. In the past he has generally taught punch-cutters how to make alphabets that work well, and it is his judgment of a punch that the trade accepts.[5]

The scale relationship of letters was of the utmost importance to the punchcutter and required painstaking attention to detail. Achieving a smooth progression of size and eveness of weight from small to large was a difficult task, but it gave the font a unified appearance and harmony. Characteristics of sizes were compensated for. The smaller forms are traditionally relatively more open in the counters, larger in x-height, slightly heavier in stem weight, wider in character width, and with shorter ascenders and descenders. The larger sizes are relatively more enclosed in the counters, smaller x-height, lighter in stem weight, more narrow in widths, and with longer ascenders and descenders. When different sizes of a design were used together they related well. Different sizes were made to be used together as well as with their italic companions. The fonts were not considered successful if they seemed overbearing in one size, clumsy in another, or awkward when seen together.

> A sense of scale and the adaptation of letters to the various sizes of type so as to make them all as comfortable to the eye as possible is a very important part of the letter-cutter's art. It is a mistake to think that a range of types from great to small can all be made from one set of drawings. I said that before he can begin cutting a letter, a punch-cutter must have the whole fount in his mind's eye; but in fact he must do more. He must conceive a fount that is susceptible of a production in all the various sizes in which type is needed.[6]

For four hundred years the processes in hand punchcutting remained almost unchanged. Every character, in every size, was carefully considered as an inherent part of the process. The techniques of nonlinear scaling where features change at different rates based upon the human visual system became firmly entrenched. Together, they presented a standard which, though desirable, modern type manufacturers found expensive and time

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[5]Carter, "Letter Design and Typecutting," p. 882.
[6]Ibid., p. 884.

consuming to emulate.

Mechanical Punchcutting

In 1885, Linn Boyd Benton filed for a United States patent to apply pantographic principles to the mechanical engraving of punches and matrices. Benton's punchcutting and matrix cutting machine marked the beginning of the mass production of punches for automatic mechanical typecasting, such as the Linotype and Monotype machines. These automatic typecasting machines needed vast quantities of punches and precise replacements for the ones broken in use, as well as matrices. No punchcutter or group of punchcutters could ever fufill this need and, obviously, without the punches with which to replace the worn or engraved matrices there could be no typecasting. The invention of Benton's machine contributed largely to the financial success of the Mergenthaler Linotype Company and Lanston Monotype. Precision, speed, price, and the relative ease with which mechanically cut punches were made paved the way for the widespread use automatic typecasting, and ultimately, printing.

The pantograph machine operates on a reduction ratio principle. An operator traces around the outline of an enlarged relief image, which is the "pattern". Adjacently, overhead and upside down, a sharpened steel cutting tool, functioning as a drill, shaves away steel from the exactly positioned punch. After many circuits around with differing sizes of drills, the punch is finished to the specified point size. All surfaces are perfectly smooth, and it is ready to be struck.

Three to five different sized patterns are needed to approximate nonlinear scaling of a full range of point sizes on the pantograph machine. The smaller sized patterns, which are approximately two inches, retain characteristics of smaller point sizes such as relatively wider character widths, thicker stroke widths, larger x-height, wider bowl widths, and shorter ascenders and descenders. Larger patterns, approximately four inches tall, were used to retain the characteristics unique to larger point sizes, such as relatively narrower character widths, thinner stroke widths, smaller x-height, more enclosed bowls, and longer ascenders and descenders. When the entire font was cut from several size scaled patterns the type was better able to capture the nonlinear qualities of handcut types.

Mechanical punchcutting also changed the working process of the type designer. Except for a few notables, such as Fred Goudy, the designer was in general not the pantograph operator.

> In hand cutting, the punch can be called the only original work of art in the whole process of making type. It is that single and unique object by which one can obtain as many as 500 matrices, each matrix being capable of forming millions of types. But in machine cutting the unique object is the drawing, from which any number of patterns can be made, each pattern serving for any number of punches of the letter."[7]

For mechanical punchcutting the number of decisions involved in the creation of a font was greatly reduced. With three or four patterns (at most) for each letter, the different machine settings could interpolate the sizes in between based on a linear scaling relationship. The pantograph offered repeatable results, which at long last the automatic typesetting industry was awaiting. The family of type that the designer had once conceived in his mind's eye, could now be done automatically on the machine, instead of from a punchcutter's hand. In an attempt to imitate the nonlinear relationships in hand punchcutting, the standard machine settings sometimes were changed and the letters were slightly distorted. This imitating was not common practice and done only at the discretion of the designer, instructing the pantograph operator. The types of this time were generally considered to be ". . . too much influenced by the facility of the pantographic drill which can cut the Lord's prayer in relief on a 1/6 inch square."[8] It was also felt that something

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[7]Beatrice Ward, "Cutting Types for Machines: A Layman's Account," The Dolphin Number Two (1935), p. 64.

[8]Harry Carter, "Optical Scale in Typefounding," Typography 4 (1937), p. 3.

precious was being lost with all the new mechanical primness.

> Virtue went out with the hand-cutter when the mechanic came in with his pantograph and the rest of the gear. The new engineers were not what the old engravers were. They could mass-produce, or reproduce, punches; they could not create, or recreate, the engraved quality that had belonged to typography in the roman letter since 1465."[9]

Still, people embraced the new technology because of the improved speed, precision, lower cost, and availability, while trying to maintain some of the previous typographic values of creativity and design integrity. Some companies did better than others at this, but the primary goal of the day was to build a library of pre-existing older designs in a full range of sizes and make them available to a mass market. See figure 2.

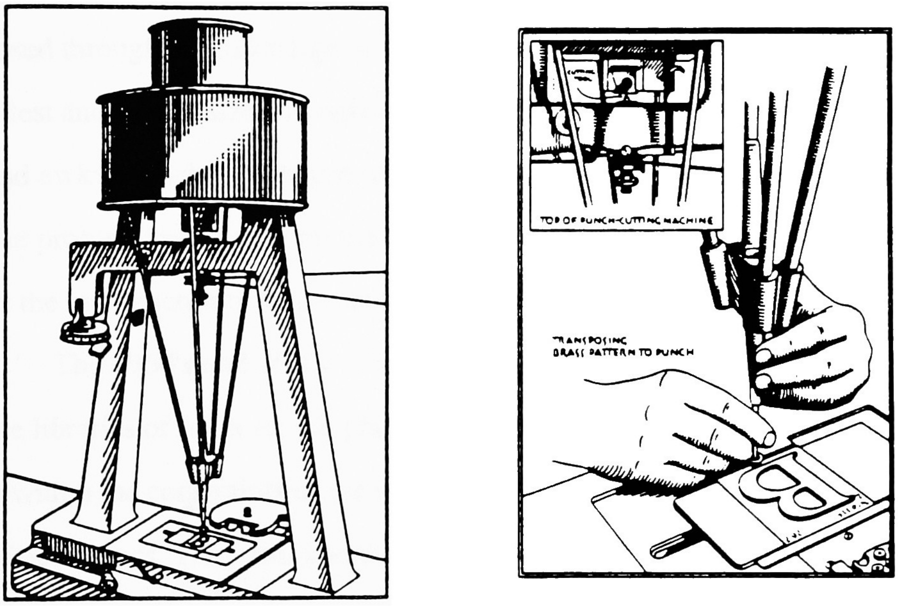

Figure 2. Lanston Monotype pantographic mechanical punchcutting machine with a close-up of a brass relief pattern and the cutting tool.[10]

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[9]Stanley Morison, A Tally of Types (Cambridge, England: Cambridge University Press, 1973), p. 99.

[10]Ward, "Cutting Types for Machines: A Layman's Account," p. 62.

Phototypesetting

Phototypesetting entered the market in the early 1960's with the same goals as automatic typecasting: desire for increased precision and speed of typesetting with reduced manufacturing costs while covering a full range of designs and sizes. A type designer would create a set of drawings used as "master" images which were then classified into three broad point size categories: small, medium, and large. Manufacturers introduced these masters to reproduce the full range of sizes with more authenticity to the original design, and to help minimize distortions inherent in the system. But, purchasing three film strips cost more than purchasing one, and very often users did not buy the full range of masters to reproduce the size range. Instead, they frequently used a single sized intermediate master and arbitrarily extended its range. Using a variable optics system to size characters as they are exposed through the full range of sizes introduced even greater distortion, especially at the smallest and largest sizes. A typeface design ideal at twelve point for text proved too bulky and awkward when enlarged to display size, and when reduced was too light and thin. The problem here was with the users, who failed to buy the differently sized masters, not with the manufacturers who supplied them.

The 1960's and 70's was a period of extensive type duplication. New and complete libraries of fonts for the phototypesetting industry were needed. Type designers worked within the constraints of the new hardware and made their compromises in the name of economics. They still had their familar tools of pens, pencils, brushes and were able to integrate the camera, a new tool, easily into the design environment. They were not able to exercise the freedom of their predecessors, the punchcutters, or the mechanical engravers, in considering every character in every size of the series. Instead, a few sets of drawings were made and the other sizes were photographically interpolated. Generally, emphasis continued to shift towards automation of production and manufacturing, reduced manufacturing costs, and increased composition speed, all while adapting to the new technology. What had started out as a craft (punchcutting), where every step of the process involved human hands touching the objects involved, was indeed turning away from that, and into an industrial business.

Digital Typography

In the late 1960's, digital typesetting entered the market and introduced another significant change in the methods of manufacturing type. There were new problems unique to this technology. The traditional methods of creating drawings with pens, pencils, and brushes presented complex difficulties, especially at lower resolutions, when transferring drawings into a digital format. As Fred Goudy, an accomplished type designer, said in reference to copying type designs, "You just can't pour all the honey out of a jar. Some of it is always left behind."[11] This is especially true of converting pre-existing type designs into a digital format. The challenge to the present day type designer is to faithfully reproduce and maintain stem, serif and hairline weights as well as smooth edges and diagonals over a range of sizes in digital typography.

In the process of transferring a pre-existing type design into a digital representation, the image is broken up by a grid laid over the characters. The resolution of the grid can vary from very coarse to very fine, and each element in the grid is a piece of information that gets stored away. In the conversion from analog to digital there is an inherent loss of detailed information, because some of the elements will only be partially filled. Instead of "painting" by hand in a continuous movement with a sable brush filled with ink, a machine, the computer, is "stamping" and storing discrete points as data. New tools need to be incorporated into computer aided design systems that address and minimize the differences between media.

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[11]Charles Bigelow, "Aesthetics vs. Technology, Part II," The Seybold Report on Publishing Systems 11 (February 8, 1982), p. 11-9.

A significant factor in design fidelity is the resolution of the grid, also called the raster, laid over and enforced on the character. To draw a character on the inner face of a cathode ray tube (CRT), the lines traced by the flying spot of light can be placed either very close together for higher resolutions, or farther apart for lower resolutions. For higher resolution rasters, the problem of character distortion from information loss is minimized by the increased number of discrete points that define the character. Conversely, as raster resolution decreases, there are fewer points to define the character, and the consequent loss of character information can reduce character legibility. (See figure 3 below.)

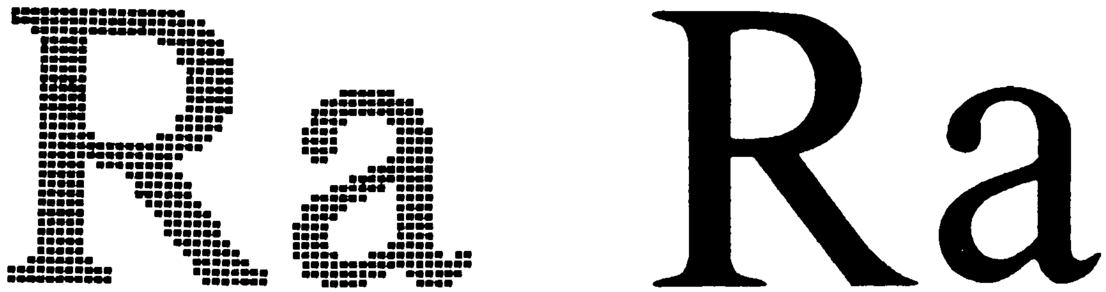

Figure 3. Times Roman R and a in high and low resolutions.

In one sense, the raster resolution (dots per inch) defines the possibilities of character weight and scale, while design requirements dictate the important inter-relationships between the parts of letters. Capital letter height, x-height, ascender and descender heights, stem width, hairline width, and bowl widths are predetermined within the EM square by a type designer. These relationships vary with size and do not always fit neatly into the inflexible requirements of the raster, especially at lower resolutions, where design fidelity becomes a major issue. As the character is adapted to the raster, the smooth edges will be made to map onto the discrete points of the screen. The pixels (PIC-ture EL-ements) that are filled by the character will be recorded. Any point that is not mostly filled by the character may be discarded. This process is system dependent, but all systems must use this or a similar method to digitize characters. Over a range of sizes, the design can become uneven in height, weight, and color by being too dark or light, or too wide or too narrow. This makes the reproduction of any design, as well as the creation of a new design, difficult to maintain with the inherent limitations of the raster.

The problems of faithful design reproduction are compounded by the fact that digital type is modelled after a set of drawings, which in turn have been linearly scaled in both directions, to complete the full range of point sizes. A single size drawing, distorted by the raster, then interpolated to every point size, can represent a serious typographic compromise that type designers are often forced to make.

The basic method for exposing type onto the inner face of the cathode ray tube (CRT) is by accessing a reference image already filed and recorded in digital storage. With the decreasing cost of computer memory, the trend has been to store representations of fonts in digital form, on magnetic tape or on hard disc. However the fonts are stored, they will activate "stroking patterns" that will in turn cause the writing spot to paint the letter onto the phosphor coated inner surface of the CRT display.

When type is scaled from a digital master, it is manipulated by proportionally reducing or enlarging the length of the stroke and the spacing values between the strokes with respect to a reference image. This is done by the set of instructions which scale the letter from the reference image. At the core of the instruction set is an equation that specifies how to create the new size. This set of instructions is a formalization of a similar kind of action that the type designer/punchcutter intuitively did when they created a range of sizes. For proportional scaling, also called *plain scaling*, the model looks something like this:

$$d = (h/H)\,D$$

where d = new length

D = reference length

h = new height

H = reference height

Since the invention of phototypesetting, few attempts have been made to implement traditional nonlinear scaling techniques in the type design. Digital font production might now make use of it, except for the fact that proportional scaling is faster, cheaper, and better understood. Nonlinear scaling methods have remained largely unexplored.

CHAPTER II

LITERATURE REVIEW

The literature directly addressing the topic of optical scale in type design is rare and usually found piecemeal, in books and essays. Historically, type designing and casting were considered a "secret art," one that privileged men learned behind the closed doors of the private typefoundry. Also, as a design activity, there really were no set rules; one just learned on the job. Knowledge was handed down from the master to the apprentice through word of mouth and by experience. Harry Carter's book, A View of Early Typography, covers the many aspects of this topic in detail. The design knowledge was primarily visual and intuitive, and largely nonverbal. The workmen in the shop were basically craftsmen and spoke the same language of craft. A pointing of the finger or a nodding of the head was often all it took to indicate a design correction. Or sometimes it was a a phrase scribbled in the margin--"too light" or "like this"--with an arrow pointing to a serif or a bowl.[1] Examples of this kind of communication can be seen even today in John Dreyfus' article, "The Dante Types."

When it came to matrix-making and typecasting, it was a slightly different story. Joseph Moxon wrote extensively and in great detail about these early printers hand crafts in his book entitled Mechanick Exercises on the Whole Art of Printing in 1683. In 1764, Pierre Simon Fournier published his Manuel Typographique, in which he describes

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[1]John Dreyfus, "The Dante Types," Fine Print: The Review for the Book Arts 11 (October 1985), p. 218.

the practices and philosophies of punchcutting from a particularly French point of view. These books, a few other chapters, paragraphs, and a few vague sentences elsewhere represent the sum of writing about optical scale in relation to punchcutting. As mechanical punchcutting began to dominate the scene, and the few surviving punchcutters retired, their influence waned. The new "industry" was getting underway.

Years later, during the popularization of mechanical punchcutting, Beatrice Warde published an essay called "Cutting Types for Machines: A Layman's Account." This article clearly outlines the process of mechanical punchcutting and its relation to manual punchcutting. It compares the linear scaling achieved by the camera lens to the nonlinear scaling achieved by manual punchcutting, and discusses the manner in which artwork is prepared in the different type design processes.

In 1937, Harry Carter, a noted historian of typography and printing, published what most type aficionados believe to be the definitive article devoted to this subject, called "Optical Scale in Typefounding." It discusses the problem of optical scale in terms of the technology of the day--in terms, that is, of lead printing types. He distinguishes the different qualities and uses of early printers' types and points out the evolutionary changes that occurred in the history of the typefounding "business": "It is clear to anyone who can examine enlargements of hand-cut types that the good punchcutters varied the design, or at any rate the functional features of it, to suit the scale on which they worked."[2] From his perspective, the economics of labor, time, and adaptation led the industry towards linear scaling techniques.

The introduction of phototypesetting in the early 1960's did not substantially change the methods for designing type as much as it radically affected the environment in the composing rooms in most industrialized nations. Mechanical punchcutting design

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[2]Carter, "Optical Scale in Typefounding," p. 3.

methods were applied, and, in conjunction with the new technology, streamlined operations by several orders of magnitude. Because the existing technology was unwilling to address the problem of optical scale in type design, there was very little literature written on the topic during this time. The technical innovations of the time up to modern digital typography, as well as the political shifts, are documented in Seybold's Fundamentals of Modern Photocomposition, published in 1979.

In 1967, digital typesetting machines entered the market and initiated a substantial change in the type design process. As computers increased their capacity for larger, cheaper storage, and more sophisticated programming environments were created, correct optical scaling became more viable. One of the most prolific and articulate writers on this topic is Charles Bigelow, who has written a series of articles on digital typography for The Seybold Reports on Publishing. These articles provide, in lay terms, a clear historical and technical description of the achievments and problems in the evolution of font design and manufacturing. He explains how the computer can become a more valuable tool for designers, especially when traditional notions of integrity, beauty, grace, and legibility in letterfoms can be incorporated. He expresses a clear understanding of the limitations as well as the potential inherent in computer aided type design. High, mid, and low resolution problems are specifically addressed and philosophical as well as artistic guidelines are prescribed for problem solving. His careful considerations are likely to benefit both engineers and artists.

Also pertinent is the article "Automatic Scaling of Digital Print Fonts," written by Richard Casey, Theodore Freidman, and Kwan Wong. Their research dealt with the high fidelity conversion of a digital image defined in one resolution to another resolution, using linear scaling techniques. Their software program was designed to reduce the human effort involved in this time consuming task.

Another software program was written by Philipe Coueignoux in 1975 for his MIT doctoral thesis, "Generation of Roman Printed Fonts". In his program, called CSD, an acronym for Character Simulated Design, characters are defined by unique elements called "primitives", any number of which can be combined to make a letter of the roman alphabet, a logo, or an icon. The primitives are a set of routines which define a grammar of parts--that is to say, they provide a way of talking about the construction of letters. His program assumed that skilled designers would understand and incorporate nonlinear optical scaling techniques in their design of fonts.

In September 1985, Richard Southall, who had been working with Donald Knuth at Stanford University on the Metafont project, published "Designing New Typefaces With Metafont," a paper that addresses the complex problems of symbolic type design--that is, the design of type using symbolic or verbal means (such as computer programs), rather than direct graphical means (such as pencil and paper). The paper initially provides a "conceptual framework" in which a consistent terminology is presented for type design and production. Within this framework Southall carefully traces the different historical processes and artifacts involved in digital type design, manufacturing, and printing.

Southall insists that even when computer-assisted design tools are used to design letterforms, the final judge of their success is still the eye. "The programmer's remark that 'the character shapes must be right, because the programs are right' is not entirely a malicious fabrication by the designers. All one can say in reply is that it is the character shapes, not the programs, that the reader sees."[3] The programmer's remark will not be true until adequate models of the perception and behavior of letterforms have been

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[3]Richard Southall, "Designing New Typefaces with Metafont," Stanford University Computer Science Report (September 1985), p. 32.

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CHAPTER III

FONT HISTORY

The purpose of these font histories is to provide additional background material and place the fonts used in this study within a historical context. It will also show why these fonts are unique in typographic history and the contributions they made to this research. By tracing the models of the four original designs in this study, a deeper understanding of the designers, forms, structures, and influences will be revealed. This information will be the foundation of the evaluation for the critique of the fonts generated by the various algorithms in this study. It is important to know the artistic influences on the shapes and aesthetic preferences of the designers, as well as the influence exerted by the new designs themselves.

Each type design in this study was carefully chosen because it was produced from handcut punches and it represented a new and longlasting design. They represent classifications from Old Style (Caslon), Clarendon (Clarendon), Modern (Bodoni), and Sanserif (Akzidenz Grotesque). They are also each unique in design, and when analyzed together provide a broad basis for a theory of the behavior of optical scale in type design. Also given is a practical understanding of the processes and tools of the artists as well as an understanding to of the extent to which their tools influenced the designs. It is interesting to compare the 16th and 17th century typefounding scenario with today's modem day digital typefounding business.

Caslon

William Caslon was born at Halesowen, England in 1692. As a young man he apprenticed himself to an engraver of ornamental gunlocks and barrels in London. In 1716, he started his own business doing silver-chasing and cutting tools for bookbinders. During this time he did some lettering for bookbindings and handcut punches of type. Around 1720, with the help of William Boyer, an influential London printer who recognized his skill, he began his initiation into letter-founding at the prestigious James foundry workshop.

His first commission from The Society for Promoting Christian Knowledge, was to cut a font of fourteen point Arabic for a Psalter and New Testament. At the bottom of the proof sheet he printed his name in twelve point roman letters which he had designed and cut. These letters were so admired and successful that he was persuaded to cut the rest of the letters in both roman and italic. In 1725, these fonts were completed and marked the beginning of his own business in letter designing and cutting. It wasn't until 1734 that his first complete broadside specimen sheet was issued showing fourteen faces of roman and italic, seven faces of two-lines, seven faces of flowers, and also seventeen faces of foreign types. (See figure 4 for a reproduction of the 1734 specimen sheet.) Most types printed on this sheet were cut by Caslon, with a notable exception being the French Canon size roman, which was acquired from a purchase of fonts from the Andrews foundry and originally derived from Joseph Moxon's foundry.

During the next fifty years Caslon's types received international success until approximately 1780, when Bodoni's Modern design came into vogue, and superseded use of most other designs. From 1780 to 1840, there were no printed specimens of Caslon's type being offered from the English typefoundries. By 1840, the Moderns in use in England had deteriorated to a visually disreputable state, mostly by poor imitation of Bodoni's graceful, elegant and delicate designs. His design had been carried to a distasteful

A SPECIMEN

By WILLIAM CASLON, Letter-Founder, in Chiſwell-Street, LONDON.

ABCD
ABCDE
ABCDEFG
ABCDEFGHI
ABCDEFGHIJK
ABCDEFGHIJKL
ABCDEFGHIKLMN

French Canon.

Quouſque tandem abutere, Catilina, pati-

Quouſque tandem abutere, Catilina, patientia noſtra?

Two Lines Great Primer.

Quouſque tandem abutere, Catilina, patientia noſtra? quamdiu nos etiam

Quouſque tandem abutere, Catilina, patientia noſtra? quamdiu nos etiam furor

Two Lines Engliſh.

Quouſque tandem abutere, Catilina, patientia noſtra? quamdiu nos etiam furor iſte tuus elu-

Quouſque tandem abutere, Catilina, patientia noſtra? quamdiu nos etiam furor

Double Pica Roman.

Quouſque tandem abutere, Catilina, patientia noſtra? quamdiu nos etiam furor iſte tuus eludet? quem ad finem ſeſe effrenata jac-
ABCDEFGHJIKLMNOP

Double Pica Italick.

Quouſque tandem abutere, Catilina, patientia noſtra? quamdiu nos etiam furor iſte tuus eludet? quem ad finem ſeſe effrenata jac-
ABCDEFGHJIKLMNO

Great Primer Roman.

Quouſque tandem abutere, Catilina, patientia noſtra? quamdiu nos etiam furor iſte tuus eludet? quem ad finem ſeſe effrenata jactabit audacia? nihilne te nocturnum præſidium palatii, nihil urbis vigiliæ, nihil timor populi, nihil con-
ABCDEFGHIJKLMNOPQRS

Great Primer Italick.

Quouſque tandem abutere, Catilina, patientia noſtra? quamdiu nos etiam furor iſte tuus eludet? quem ad finem ſeſe effrenata jactabit audacia? nihilne te nocturnum præſidium palatii, nihil urbis vigiliæ, nihil timor populi, nihil con-
ABCDEFGHIJKLMNOPQR

English Roman.

Quouſque tandem abutere, Catilina, patientia noſtra? quamdiu nos etiam furor iſte tuus eludet? quem ad finem ſeſe effrenata jactabit audacia? nihilne te nocturnum præſidium palatii, nihil urbis vigiliæ, nihil timor populi, nihil conſenſus bonorum omnium, nihil hic munitiſſimus
ABCDEFGHIJKLMNOPQRSTVUW

Pica Roman.

Melium, novis rebus ſtudentem, manu ſua occidit. Fuit, fuit iſta quondam in hac repub. virtus, ut viri fortes acrioribus ſuppliciis civem perniciosum, quam acerbiſſimum hoſtem coercerent. Habemus enim ſenatuſconſultum in te, Catilina, vehemens, & grave. non deeſt reip. conſilium, neque autoritas hujus ordinis: nos, nos, dico aperte, conſules deſumus. De-
ABCDEFGHIJKLMNOPQRSTVUWX

Figure 4. William Caslon and Sons 1734 Specimen Sheet.

extreme by exaggerating the thick strokes to an extra-extra bold weight and decreasing the thin strokes until they were almost illegible scratches. See figure 5.

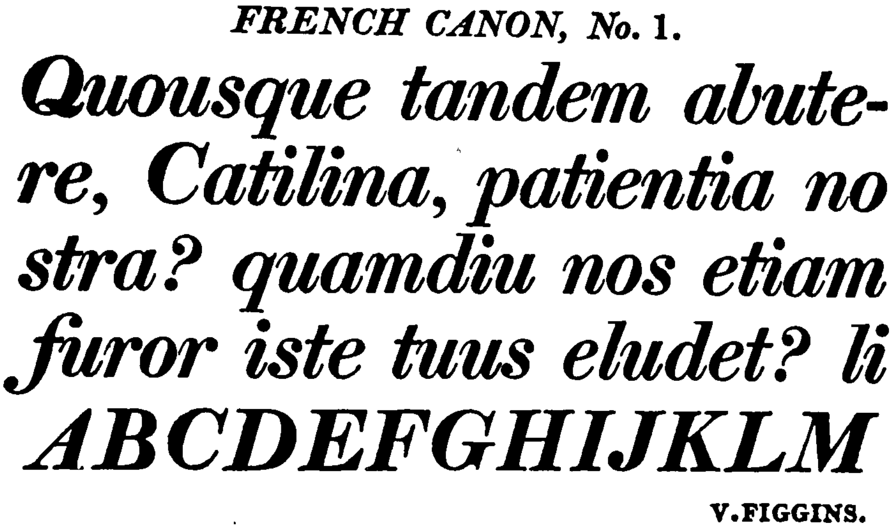
FRENCH CANON, No. 1.
*Quousque tandem abute-
re, Catilina, patientia no
stra? quamdiu nos etiam
furor iste tuus eludet? li
ABCDEFGHIJKLM*
V.FIGGINS.

Figure 5. Exaggerated English Modern style.[1]

With many of these fad types no longer suitable for text setting, in 1844 the British were ready for the revival of their Old Style designs, primarily those of the Caslon foundry in London and John Baskerville of Birmingham.The Caslon foundry was able to supply their customers fonts from their original matrices, an advantage, since other foundries had destroyed their matrices, believing Old Style designs to be outdated. William Caslon the elder died in London in 1766, at the age of seventy-four. The foundry was carried on by his family until 1874, when Henry William Caslon passed on, and the business was taken over by his manager T. W. Smith, whose sons assumed the name of

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[1]Berthold Wolpe, ed, Vincent Figgins Type Specimens 1801 and 1815 (London: Printing Historical Society, 1967).

Caslon, and continued operating the foundry. In 1937, when the firm of H. W. Caslon & Co. was dissolved, the Caslon punches were distributed to Stephenson, Blake & Co. Ltd. of Sheffield, England, and to the St. Bride Printing Library, London, England.

Caslon's design style was influenced by the Dutch Old Face designs cut by Christopher van Dyck between 1648 and 1670. These designs were in use throughout England preceeding Caslon in 1720. The English had adopted the Dutch type because of a lack of experienced type designers at home as well as the quality and availability of the Dutch fonts. It was thought that, "The Dutch artists appeared for the time to have the secret of the true shape of the Roman letter. . . ."[2] Caslon used the Dutch Old Face design as a model for his designs while giving them some new characteristics. Caslon's fonts were preferred for their "human, comfortable, friendly to the eye, English" qualities. ". . .[H]e introduced into his fonts a quality of interest, a variety of design, and a delicacy of modelling, which few Dutch types possessed."[3] He also had absorbed some of the qualities of the roundness of English handwriting into his designs and this added to their appeal. Caslon's fonts were well liked for their minor imperfections, which gave them interest and revealed something about the human hand that made them.

> His letters when analyzed, especially in the smaller sizes, are not perfect individually; but in mass their effect is agreeable. That is, I think, their secret -- a perfection of the whole, derived from harmoniousbut not necessarily perfect individual letterforms. To say precisely *how* Caslon arrived at his effects is not simple; but he did so because he was an artist.[4]

His later contemporary and rival, John Baskerville (1758), was criticized for his types being too perfect, the main strokes being too thin, and for his printing techniques blinding the reader. In actuality, their types were not substantially different. See figure 6.

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[2]Daniel Berkeley Updike, Printing Types, Their History, Forms, and Use, A Study in Survivals, 2 vols (Cambridge, Massachusetts: Harvard University Press, 1922), p. 100.

[3]Ibid., p. 105.

[4]Ibid., p. 106.

PICA ROMAN.

Melium, novis rebus ſtudentem, manu ſua occîdit. Fuit, fuit iſta quondam in hac repub. virtus, ut viri fortes acrioribus ſuppliciis civem pernicioſum, quam acerbiſſimum hoſtem coërcerent. Habemus enim ſenatuſconſultum in te, Catilina, vehemens, & grave: non deeſt reip. conſilium, neque autoritas hujus ordinis: nos, nos, dico aperte, conſules deſumus. De-
ABCDEFGHIJKLMNOPQRSTVUWX

Eraſme ecrit â Bilibaldus Pirkheymer en 1522. Plerique inſidiantur homini, propemodùm conjurati ut illum perdant. Ubi quid novi operis prodit, quod

Tis very advantagious for ingenious men to communicate their sentiments to each other it discovers a generosity, improves

BUT Job anſwered and ſaid,
2 Oh, that my grief were throughly weighed, and my calamity laid in the balances together!

Figure 6. Caslon[5], Dutch Old Face[6], English handwriting[7], and Baskerville original handcut specimens[8].

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[5]William Caslon, Type Specimen Sheet, 1734.

[6]Stanley Morison, On Type Faces (London: The Medici Society of Seven Grafton St. London W. and The Fleuron Limited, 1923), p. 48.

[7]Alfred Fairbank, A Book of Scripts (Harmondsworth, England: Penguin Books Limited, 1949), p. 48.

[8]John Baskerville, A Baskerville Birmingham Bible (Birmingham, England: John Baskerville, 1769).

Caslon's fonts are slightly condensed with long descenders, closely fitted, and the face is small in comparison with the body of type. Baskerville's fonts are more open, especially in the counters, more consistent in both shape and line, and wider in set than Caslon's. These more perfect features betrayed Baskerville's skill and training as as a writing master. Although Baskerville never received the national attention and acclaim that Caslon did, he was to have an influence abroad, both in Italy and France, that later impacted the use of Caslon's fonts.

The Caslon fonts in this study were taken from the original 1734 Caslon specimen sheet. Ten different sizes that correspond to a unified design were carefully selected and measured.

Clarendon

In 1808, Robert Thorne moved his foundry to No. 2 Fann Street, Aldersgate, where he stayed in business until 1820, as the Fann Street Foundry. In 1820, the foundry was put up for auction and was purchased by William Thorowgood. In 1828, Dr. Fry of the Type Street Foundry retired and his collection of learned and oriental founts, as well as his text, blackletter, titling founts, along with his ornaments, were purchased by the Fann Street Foundry. This acquisition almost doubled their holdings. Robert Besley became partners with Thorowgood in 1838 and the firm became Thorowgood & Besley. During this time, in 1845, Benjamin Fox, who was an experienced and accomplished punchcutter, issued the Clarendon series, under Thorowgood & Besley.[9] In 1849, Thorowgood retired and the firm became Besley & Company, with Benjamin Fox being the partner. Alderman Besley retired in 1861, when the firm was joined by Charles Reed. The foundry assumed the name of Reed and Fox and joined in the revival of eighteenth century letters, when, it is

[9]Talbot Baines Reed, The Old English Letter Foundries, edited by A.F. Johnson (London: Faber and Faber Limited, 1952), p. 296.

thought, Fox probably cut a face called Medieval. Fox died in 1877, and the firm became Sir Charles Reed & Sons. After the death of T.B. Reed, the firm was made a limited company and was under the management of A. W. Tillie until 1905, when the stock was bought by Messrs. Stephenson, Blake & Co. of Sheffield.

When Benjamin Fox first introduced his Clarendon design it was intended as a heavy face to accompany lighter roman text designs, as in dictionary and display usage. The design is based on a condensed Modern roman style which had been made popular abroad by Bodoni, Didot, and Fournier. There was also an influence from an imitation of an outline copper engravers font as well as a similarity to some architectural lettering of the day. It is also the first design of what has been recognized as a "related bold". In 1845, when Clarendon was first issued, it had the special priviledge of being registered under the designs copyright amendment act and was protected from plagiary for the next three years. Upon expiration, it was widely copied and became the stock in trade of printers of the day, much to the dismay of Thorowgood & Besley. With this popularization, the name Clarendon became synonomous with the kind of bold design of the original. Clearly, many of the designs were poor copies of the original as everyone jumped on the bandwagon, but the more prestigious typefoundries did use the Besley & Co. design for their own reproductions.

> Any attempts to depart from the original design, whether to escape the charge of plagiary or to suit national demands, only served to demonstrate how triumphantly Benjamin Fox had overcome the difficulties inherent in relating an extended and condensed type to the conventional modern-face roman.[10]

The Clarendon designs are more refined than their related square serifed Egyptians because of their lighter, more graceful, bracketed serifs and lighter, more delicate main strokes. A recognizable feature is the curly tail of the capital R. There is also a strong

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[10] James Mosley, "An Essentially English Type," The Monotype Newsletter #60 (London, England: Monotype Corporation Limited).

horizontal emphasis from the bracketed serifs which combined with the large x-height make it a very legible design. It has an overall grace and elegance which the Egyptians do not have. See figure 7.

> The Clarendon design remains one of the great successes of British typefounding. Bringing his superb technical skill to the inventive profusion of early nineteenth century letter design, Benjamin Fox produced a type based securely in the English tradition of letter design which had the compliment paid it of the sincerest form of flattery.[11]

Printing was first performed by obtaining impressions from solid blocks, type being invented at a much later period, there having

MECHANISM OF PRINTING

BROADCASTING COMBINE

Makers of wireless receiving products form organisation to protect interests

Figure 7. Clarendons[12] vs. Egyptians[13].

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[11]Ibid., p.

[12]Types, Materials, Machinery Stephenson, Blake & Co. Ltd (London, England: Stephenson, Blake & Co. Ltd., 1922).

[13]Printing Types, Borders, Initials, Electros, Brass Rules, Spacing Material (Sheffield, England: Stephenson Blake & Co. Ltd, 1949).

The larger designs (48 pt., 60 pt., 72 pt., 96 pt.) depart somewhat from the relative unity of the smaller text sizes (5 pt. to 36 pt.). In 1956, a modern version of Clarendon was reissued from the original matrices under the name Consort, by Stephenson & Blake typefounders of Sheffield.

The Clarendon fonts in this study were taken from the original 1845 specimens. Eleven different sizes that correspond to a unified design were carefully selected and measured.

Bodoni

Cavaliere Giambattista Bodoni was born in Saluzzo, Italy in 1740. In this small town in Northern Italy, he grew up the son of a master printer, Francesco Agostino Bodoni. He served his apprenticeship with his father, where he learned the art of printing and engraving. When he was eighteen, he moved to Rome and worked in the Vatican printing house and typefoundry. He worked as a compositor for the Sacrae Congregationis de Propaganda Fide, the center of the missionary enterprises of the church. His early work there was to renovate the printing house where, two hundred years earlier, famous designers and punchcutters such as Garamond, Le Be, and Robert Granjon were employed. Around 1762, he left Rome and in 1768 was appointed Royal Printer to Ferdinand, Duke of Parma, with the task of establishing a royal printing house. His experience in Rome of working with punches and matrices of the finest designs gave him the inspiration to be a letter designer and cutter.

With only one press, types from Pierre Simon Fournier Junior, one of the most influential foundries in Europe, and two assistants, Bodoni was the director of the royal printing house. In 1769, the printing house began to produce materials following the current French style in typography with ornamental letters, flowers, and vignettes. Later, in 1771, as his own style emerged, he relied on the simple elegance of types of his own design. In developing his own style he had been heavily influenced by the effects of Philippe Grandjean and the French *Académie des Sciences romain du roi* in 1692, Pierre Simon Fournier Junior of France (1736), and John Baskerville (1757), an important printer and type designer from England.

Quousque tandem
abutêre, Catilina,
patientiâ nostrâ?
quamdiu etiam fu-
ror iste tuus nos e-
ludet? quem ad fi-
nem sese effrena-

Figure 8. Specimen of Bodoni.[14]

Bodoni's types were of a new class of designs which came to be known as Modern Roman. Their main characteristics are a thin flat bracketed serif at right angles to the main stroke, the same thickness as the minor lines of the letters, which were very thin and sharp in contrast to the heavier main stroke. This greater contrast between thick and

[14]Giovanni Battista Bodoni, Manuale tipographico del cavaliere Giambattista Bodoni, 2 vols., trans. Giovanni Marderstig (Parma, Italy: Officina Bodoni, 1968), p. 34.

thin lines was a significant step away from the popular Old Style designs much in use at the time. See figure 8.

Bodoni cut many varieties of designs in the same size for his own pleasure and, moreover, because he was not compelled to sell his types for a livelihood.

> Bodoni minutely varied his weight, his extruders and his serifs, as well as condensing or expanding, in order to ensure that he could obtain precisely the effect in printing that he wished in different volumes. Yet all the designs were variants of a basic Modern letter form.[15]

Bodoni's clean precise type, sharply printed with intense black ink on smooth white paper, in the simple and spacious composition style he had developed, was remarkably novel and appealing, especially when compared to the more ornate French style or the rather ordinary muddy printing of the day.

This new "Modern" style brought him international attention, with an especially important note of praise of his types from an American contemporary, Benjamin Franklin. His designs and printing style were successfully copied in France by his European rival, the Didot's, as well as all over Italy, Spain, and Switzerland. As ducal printer, most of his expenses were paid by the government, and he also had the luxury of working for his own profit by selling his types. Throughout his career letter designing and cutting were his passion. It is said that he spent his life perfecting his punches for them to be as perfect as possible. Below he is speaking of his punches.

> For as long as I live these are a permanant fund, whether I remain where I am or whether I go elsewhere, they will remain my faithful companions, . . . they are more than that, I will say, they are my sons, and a father's love, which cannot bear to see faults in them, renders them dear to me so that I could not endure them to be torn from my side.[16]

Bodoni emphasized four qualities in creating a type design. Regularity, neatness

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[15]Morison, A Tally of Types, p. 31.

[16]Bodoni, Manuale tipographico del cavaliere Gambattista Bodoni, p. 93.

and refinement, good taste, and grace are the main qualities that act together to create a good solid type design. Bodoni's notion of regularity is really about an understanding of the deeper structure of letter parts relating to the whole design.

> Analysing the alphabet of any language, one not only can find similar lines in many different letters, but will also find that all of them can be formed with a small number of identical parts, combined and disposed in various ways. Since, making equal all that needs no distinction and marking the differences that are required in the most outstanding way, we finally give the form of every letter fixed laws and rules which produce harmony without ambiguity, variety without dissonance and equality and symmetry without confusion. It is a natural advantage of this art to print each letter in the same way, though melting thousands of them in matrices pressed by the same punch. But it depends on the skill of the puncher who measures, and the parts, which many letters can have in common, should be exactly the same in all of them. . . .[17]

Bodoni's emphasis on neatness and refinement, and good taste are reflections of his background as a craftsman. It is an important aspect of learning via apprenticeship that one absorbs these sensibilities from the respected Master of the shop. Good taste is really an understanding of typographically correct models for type design, based primarily on knowledge of handwriting. Grace falls into a more subjective and spiritually oriented category.

> . . Grace is the fourth and last quality required by the beauty of types. Everybody knows how difficult it is to define that beauty, charm, and loveliness which is called grace. But since it certainly wants to look natural and instinctive, it has to be so spontaneous and effortless, that we will not be wrong in seeking it in whatever is rare and perfect and seems a pure gift of God and nature, though it often results from a long exercise and habit, making difficulties so easy that finally they are beautifully done, even without thinking of them.[18]

It is these qualities that, when working together, combine to make a beautiful type design. Bodoni's types reflect his ideas of beauty and perfection. The numbers in which he produced them and the passion with which he created and perfected them has been a model few other type designers have attained.

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[17]Ibid., p. 102.

[18]Ibid., p. 103.

Cavaliere Giambattista Bodoni died in 1813, at 73 years of age. In 1818, according to his last wishes, his widow and partner in printing, Paola Margherita Dall' Aglio, issued the final and most significant work, "Manuale Tipografico del Cavaliere Giambattista Bodoni", in two volumes, large quarto, with portrait frontispiece, 619 pages in length, on handmade paper, with spacious margins, showing his modern types as well as his exotic and learned fonts. She was a close witness to his 50 years of devotion to his art and states:

> His Manual will put the final seal on his glory, since this book, the result of fifty years of work and deep reflection on his art, for the execution of which he has prepared and adjusted more than 55 thousand matrices, will be the monument that will do the most honour to printing and to the Century of Bodoni.[19]

The Bodoni fonts in this study were taken from a Giovanni Mardersteig reprint of the original "Manuale Tipografico". Sixteen different sizes that correspond to a unified design with slightly condensed width and large x-height were carefully selected and measured.

Akzidenz Grotesque

There currently exists very little critical public documentation about Akzidenz Grotesque, even from the original typefounder, except for some obscure information amongst a handful of private printers and typefounders, and printing historians. The following information is gathered from such limited sources.

Akzidenz Grotesque was developed in house at the H. Berthold Typefoundry of Berlin in the late 1890's entirely from handcut punches. There were originally only five versions of the design regular, demi, bold, condensed, and extended. The fonts had originally been made up from a number of unrelated gothics, with various names, and in a varying range of sizes, to work together as a series, which it did with moderate success.

[19]Ibid., p. 97.

Later in the 1950's, they felt they had to compete with other foundries in creating a "family" of types, like Futura designed by Paul Renner in 1930 for the Bauer foundry or Univers designed by Adrian Frutiger in 1957 by Deberny & Peignot. Their solution was to rework the Akzidenz Grotesque designs and in the late 50's they came out with the "Standard" series. The design was carried on and refined until in the 1970's Berthold went out of the hot metal type business. Standard is still available in film as well as digital format for Berthold typesetting machines. In 1951, the Haas foundry introduced Helvetica, designed by M. Miedlinger, which was based on the early sanserifs. It almost immediately became the "darling" of sanserifs, and swept all else before it for the last thirty years. Since then, it has become the industry standard for a sanserif design.

In the late 1890's, most typefoundries were either selling or cutting sanserifs and Berthold was no exception. The movement had originated in England, where in 1816 William Caslon IV introduced a font of sanserif design in all capital letters. Later in 1830, the lowercase was added to complete the specimen. Around this time in 1832, Figgins & Thorowgood were showing "Grotesque", which was their sanserif design, while Blake and Stephenson were showing their "San Surryhs" and Americans were showing their sanserif designs under the name of "Gothic". All these different names apply to the same basic design.

The early English sanserif designs were slightly heavy and their capitals were of equal width. It wasn't until the German influence that the capitals were proportionally fit. The design is characterized by marks of monotone weight with no serifs attached to the ending of any of the strokes. A more modern inerpretation of this design has been done by Herman Zapf, with his popular design "Optima", where the ends of the strokes have a tapered effect. This kind of design rests somewhere between a serif and sanserif design.

There is no known punchcutter or particular designer of these fonts. From an article, translated from German into English, about Akzidenz Grotesque, which was published by Berthold on their one hundredth anniversary, it is said, "Its earliest form was shown in England in 1834 under the rubric of 'French Grotesques' or 'Lapidary Type.' Our Akzidenz Grotesque was developed in the last years of the 19th century. The work of the punchcutter is here hidden in a modesty which omits every personal trait."[20] It is assumed, because of exisiting technology at its issue and available knowledge about the font, that it has been cut by hand and used the traditional burins, gravers, files, and awls of the day. It is also unknown who the "designer" of Akzidenz Grotesque was, or even if there was one. It is considered more likely that Berthold had their own "house" designers and technicans interpret a design from the existing popular sanserifs. This method is much different than a type designer conceiving in his mind's eye a design and carrying out that design in a range of sizes. But, they needed to have sanserif fonts in their library to satisfy their customers who wanted them for advertising, "jobbing", and display purposes. Despite these differences in production methodology, it has been and is a handsome and successful design. See figure 9.

It hasn't been until more modern times that sanserifs are so widely used and loved even in text and publishing. Nowadays, one can find entire books, front to back, filled with sanserif type.

The Akzidenz Grotesque fonts in this study were taken from a copy of H. Berthold's early specimen sheets which were letterpress printed characters of fonts cast from the original matrices. Thirteen different sizes that correspond to a unified design were carefully selected and measured.

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[20]"Type specimen," (Berlin: H. Berthold Typefoundry), Probe nr. 472.

80769 24p Min ca 14kg 50a 16A

Die Akzidenz-Grotesk

80770 28p Min ca 16kg 46a 14A

Die Akzidenz-Groti

80771 36p Min ca 18kg 32a 10A

Die Akzidenz-G

80772 48p Min ca 24kg 24a 8A

Die Akzider

ABCDEFGHIJKLMNOPQRSTUVWXYZ
1234567890
abcdefghijklmnopqrstuvwxyz

Figure 9. Specimen of Akzidenz Grotesque.[21]

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[21]Ibid.

CHAPTER IV

HYPOTHESES

Type design has been a craft, no less so than in its early days. Every character was uniquely conceived and individually cut into metal by hand; no two characters were ever exactly alike. Individual characters had specific design features that were similar to each other but their propotions were size dependent. For instance, uppercase stem widths are approximately the same for capital letters in a given design. For handcut fonts these design features were non-proportional over a size range. As new manufacturing technology emerged, so did new design techniques. Computers were replacing brushes, ink and pencils as the main drawing tools, and manufacturing technology began to emphasize automation.

Computers do not "naturally" know how to do anything; they do not work on intuition, nor are they guided by emotion. In order for a computer to generate a character, it must have a set of instructions, a program, describing how to do it. It has been difficult to specify a set of instructions for optically scaling characters. By developing a model for the optical scale of type design it should be possible formalize a set of instructions that a computer can use.

This research set out to test four major hypotheses:

1. Handcut fonts have nonlinear design characteristics over a range of sizes

2. This nonlinear behavior can be modelled mathematically using quadratic feature equations

3. The typographic features and characters which were measured in this study provide, typographically, a solid basis for a model of optical scale in type design

4. The nonlinear scaling model will be more successful at scaling low resolution fonts than will plain scaling techniques

Here is a more detailed examination of the four hypotheses listed above.

Handcut fonts have nonlinear design characteristics over a range of sizes. This research is investigating and testing the "traditional" (nonlinear) techniques of optical scale in type design. There is an assumption that when fonts were individually cut by hand type designers had the freedom and flexibility to alter the design characteristics to adjust for their size. These subtle visual changes are assumed to be size dependent. It is conjectured that changes in feature proportions are especially noticeable for smaller sizes of fonts in the range of six through twelve point.

This nonlinear behavior can be modelled mathematically using quadratic feature equations. The goal of this research was to produce a mathematical model of the behavior of the optical scale of type designs. The model was derived from measurements of features of handcut characters. It is hypothesized that this model can be successfully applied back to high resolution digital images of original handcut characters and the resulting characters will look very close to the originals.

The typographic features and characters which were measured in this study provide, typographically, a solid basis for a model of optical scale in type design. In type design there are many complicated visual relationships at work. This research is concerned with individual features and their relationships at a single point size as well as their changes over a range of sizes. Characters that were selected for this study were used as control characters which have key features such as the weight and form of stems, curves, diagonals, bowls, etc. that must be realized in a similar manner in all the other characters in the design to provide a certain uniformity. These characters and features provide the typographic solidity needed for an acceptable scaling model.

The nonlinear scaling model will be more successful at scaling low resolution fonts than plain scaling techniques. Modern digital character generation resolutions vary from 100 to 1000 spots per inch and higher. It is more difficult to scale low resolution type designs since there are fewer pixels to define character shapes and maintain feature weights. At the lowest resolutions character features can beome distorted and illegible. The nonlinear scaling model will be used to automatically scale low resolution fonts (300 spots per inch). The scale and growth factors will be analyzed to discover the lowest useful resolution range at which the model can be applied. It is conjectured that the growth factor in the nonlinear scaling model will be especially useful in maintaining features weights that plain scaling techniques lose due to round off error.

CHAPTER V

METHODOLOGY

This chapter will describe the major methods used in this research, namely those for:

1. Building a model of the scaling of individual letterform features
2. Building a model of the scaling of entire letterforms
3. Testing the letterform scaling model

Modeling the Scaling of Individual Letterform Features

The goal of this portion of the research was to develop a model for the changes in particular letterform features within a given typeface over a range of sizes using handcut fonts. After selecting the typefaces, features, and characters, a specific method was employed on all the typefaces in this study. The method consisted of the following steps:

Step 1. Video scanning the original handcut type specimens

Step 2. Measuring the features over the available size range

Step 3. Plotting feature data to capital letter height

Step 4. Modeling the plotted measurements

These steps will be further detailed:

Step 1. Video scanning the original handcut type specimens: The original handcut type specimens were video scanned with a Bausch and Lomb Omnicon FAS-II Image Analysis System which converted them into very high resolution digital bitmaps.

Step 2. Measuring the features over the available size range: Individual feature parts of the letterforms were isolated and measured as they were available in the size range. Data was collected and used in step 3.

Step 3. Plotting feature data to capital letter height: Feature measurements were plotted against capital letter height. Capital letter height was chosen as a more consistent and universal reference to typeface size rather than the more traditional conventions of reference, such as point size. Variations in geographic location, manufacturing techniques, measuring devices and systems make these more traditional references to typeface size unreliable. Point size was maintained as an important, but secondary, reference to size in the overall evaluation.

Plotting feature values against capital letter height resulted in graphs such as the following:

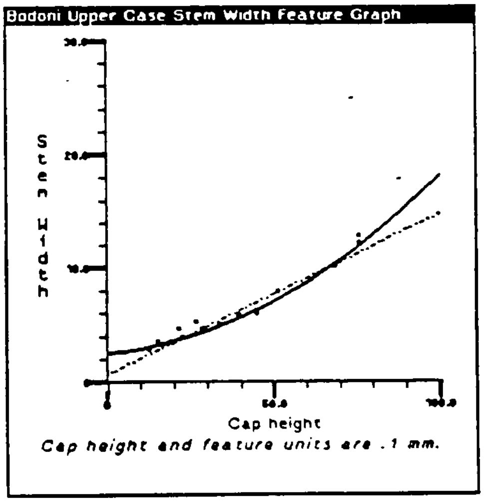


Figure 10. Example of a feature plot with sample data

Step 4. Modeling the plotted feature measurements: Linear and quadratic regression analysis was performed to fit the data points. Linear and quadratic equations for each feature resulted from this analysis; they will hereafter be called *feature equations*. They are a model of the change in a given feature with respect to size.

Using this four-step method requires making four additional decisions: which typefaces to investigate, which characters within the chosen typeface to investigate, which features to model, and at which sizes.

The fonts that were used in this study are Caslon (England - 1734), Clarendon (England - Thorowgood & Besley - 1845), Bodoni (Italy - 1818), and Akzidenz Grotesque (Germany - Berthold - 1890). These fonts were carefully selected because they were manufactured from handcut punches and covered a broad range of type styles. They represent specimens from Old Style, Clarendon, Modern, and Sanserif type classifications.

Specific typographic features and characters were chosen to measure because features and characters are what type designers concentrate upon when they are designing a typeface. These features are x-height, bowl width, stem width, serif length, serif width, ascender height, descender depth, average counter width of lowercase "m", total character width (serif edge to serif edge) and capital letter height. (See Appendix V for illustrations of these terms.) The following characters, which are typically used as *control characters* in designing a typeface, were selected for measuring in this study: R, M, S, H, V, O, a, h, m, o, q, and x. Control characters are characters which have key features such as weight and form of stems, curves, diagonals, bowls, etc. that must be realized in a similar manner in all the characters in the design to provide a certain uniformity. All of the designs were available in a size range of at least 6 to 36 point.

Modeling the Scaling of Entire Letterforms

The feature equations provide a model of the scaling of individual features for a given typeface. A second method was required to create a model of the scaling of entire letterforms. The method consisted in applying numerical analysis techniques to the set of feature equations for a given typeface. This method consisted of the following steps:

Step 1. Designing a mathematical model for nonlinear scaling

Step 2. Using numerical analysis techniques to generate automatically the four nonlinear scaling parameters for a given point size. Possible hand tuning of the scaling parameters

Step 3. Performing step number two for every size

These steps will be further detailed:

Step 1. Designing a mathematical model for nonlinear scaling: The following equations are used as mathematical models for the automatic scaling of type designs.

plain scaling model $d = (h/H)\, D$

nonlinear scaling model $d = A(h)D + B(h)$

where d = new length

$A(h)$ = scale factor

D = reference length

$B(h)$ = growth factor

h = new height

H = reference height

In the nonlinear scaling model there are two terms. The scale term, A(h), is roughly equivalant to the scale term in the plain scale model. It is a multiplier that, when multiplied by the reference length, produces a new "scaled" length. The growth term is another length which is either added or substracted. The nonlinear scaling equation was especially designed with the growth term B(h) because it was trying to model the "predicted" behavior of handcut type. The operations of interest in this study were the simultaneous operations of both scaling by A and growing by B in both horizontal and vertical directions. See the illustration below of scaling and growing.

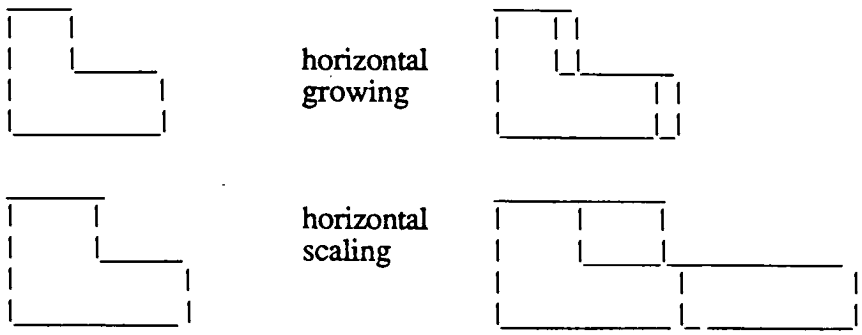


Figure 11. Visual display of horizontal growing and scaling.

It is important to notice in the illustration that growth is independent of the initial size of the image; it will just add some new distance to the existing distance. The effect is just the opposite for scaling because the image increases in proportion to its original size and can become significantly larger or smaller. Generally, scaling has potentially a larger effect and growth a smaller, and more local, effect.

Step 2. Using numerical analysis techniques to generate automatically the four nonlinear scaling parameters for a given point size. Possible hand tuning of the scaling parameters: Once the nonlinear scaling parameters were calculated automatically, they were used to generate letterforms at a given size. In some cases, the nonlinear growth factors were experimentally hand tuned to improve the visual appearance of the letterforms. For a more detailed description of the numerical analysis used to automatically derive the horizontal and vertical scale and growth factors from the feature equations see Appendix II.

Step 3. Performing step number two for every size. The four horizontal and vertical parameters for a given size of a given typeface are called A_h, B_h, A_v, B_v. The set of them for the entire size range is necessary to test the model.

Testing the letterform scaling model

The goal of this portion of the research was to test the letterform scaling model. For any given typeface, the method consisted of the following steps:

Step 1. Applying the nonlinear scaling model to the reference image to generate the word "Catilina" at a target size (high resolution)

Step 2. Applying the plain scaling model to the reference image generate the word "Catilina" at a target size (high resolution)

Step 3. Converting images produced from step one into 300 spots per inch images

Step 4. Converting images produced from step two into 300 spots per inch images

Step 5. Evaluating images from step one and two by comparing them to the original handcut fonts

Step 6. Evaluating images from step three and four by comparing them (loosely) to the original handcut fonts

These steps will be further detailed:

Step 1. Applying the nonlinear scaling model to the reference image to generate the word "Catilina" at a target size (high resolution): To test the model, it was applied to 12 point original handcut test characters that had been digitized and converted to high resolution bitmaps. These 12 point characters act as one large bitmap "master" template of reference letters from which a series of sizes can be generated by applying the horizontal and vertical scale and growth factors. The Bodoni and Akzidenz models were applied to type designs outside of the research to discover how general a nonlinear scaling model they might be and how to make them even more general so that they could be applied to any type design.

Step 2. Applying the plain scaling model to the reference image generate the word "Catilina" at a target size (high resolution): To test the model, it was applied to 12 point original handcut test characters that had been digitized and converted to high resolution bitmaps. These 12 point characters act as one large bitmap "master" template from which a series of sizes can be generated by applying scale factors.

Step 3 and step 4. Converting images produced from step one into 300 spots per inch image: The low resolution characters were generated by a simple scan conversion from high to low resolution for both the plain and nonlinear specimens. The final low resolution bitmap images are at 300 spots per inch.

Step 5. Evaluating images from step one and two by comparing them to the original handcut fonts. The nonlinear and plain scale evaluation is in chapter VII.

Step 6. Evaluating images from step three and four by comparing them (loosely) to the original handcut fonts. The low resolution fonts were analyzed on their own as well as loosely compared to the original handcut specimens. The low resolution application is evaluated in chapter VII.

CHAPTER VI

RESULTS OF RESEARCH

There are four basic products of this research.

1. Creation of linear and quadratic feature equations. Salient features of four main fonts were analyzed and linear and quadratic feature equations were created as models of feature change across change in font size. These results can be found in appendix II.

2. Creation of linear and nonlinear scaling parameters. From the feature equations, plain and nonlinear scaling models were created for each of the four main fonts in this study. Each model consisted of horizontal scale and growth parameters and vertical scale and growth parameters. These results can be found in appendix III.

3. Creation of letterforms from original handcut fonts. The parameters of the plain and nonlinear scaling models were used to generate high and low resolution letterforms for the four main fonts at a range of sizes. In some cases, additional tuning was done to the parameters of the nonlinear scaling model before the letterforms were generated. These results can be found in this chapter, as figures 12 to 27. They will be discussed in the next chapter.

4. Creation of letterforms of two additional fonts. In addition, two of the scaling models were applied to fonts outside this study to generate high and low resolution letterforms at a range of sizes. These results can be found in this chapter, as figures 28 to 35. They too will be discussed in the next chapter.

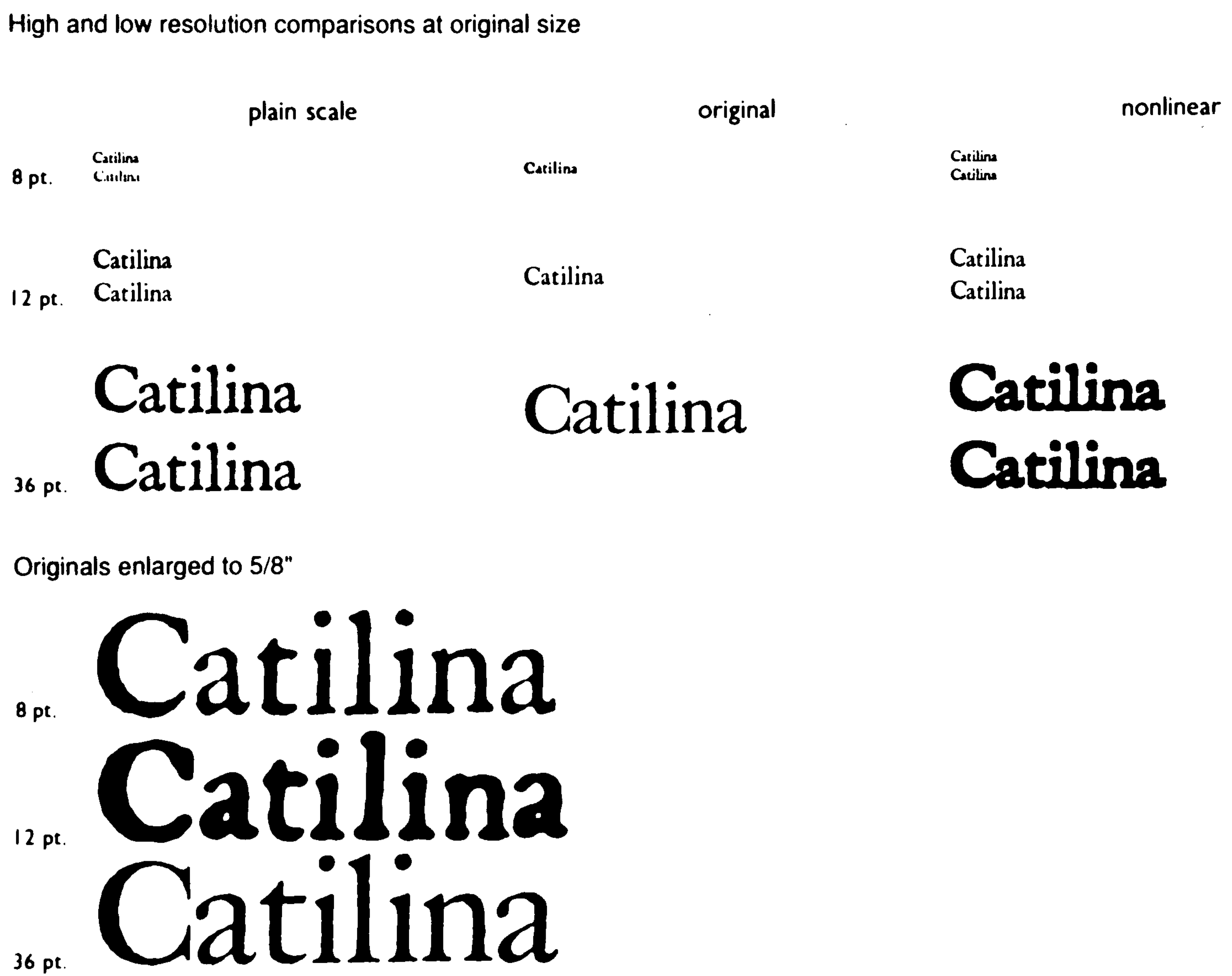


Figure 12. (Caslon CWO) Comparison of synthetic letterforms with original, handcut letters.

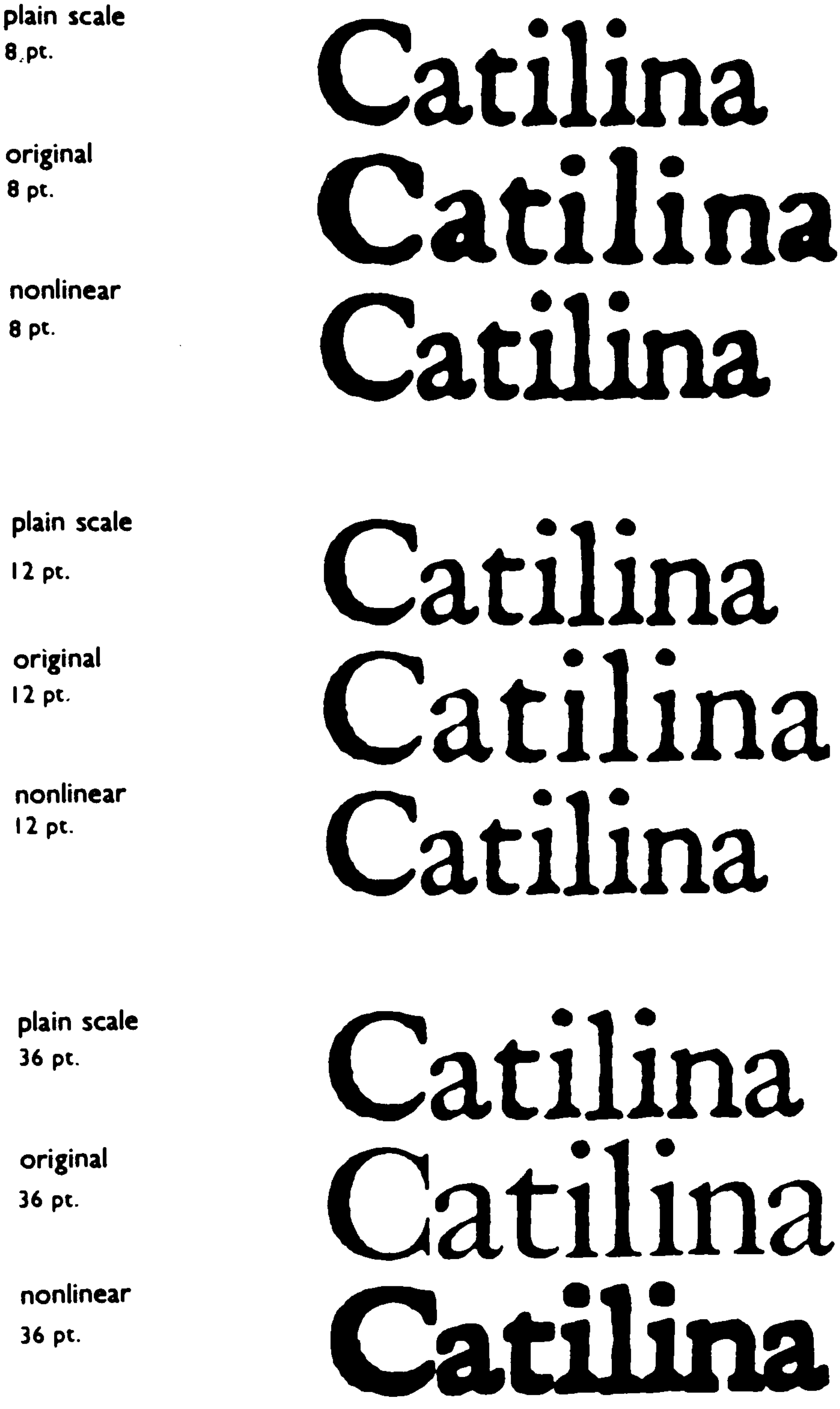


Figure 13. (Caslon EHR) Enlargements of synthetic and original sizes at high resolution.

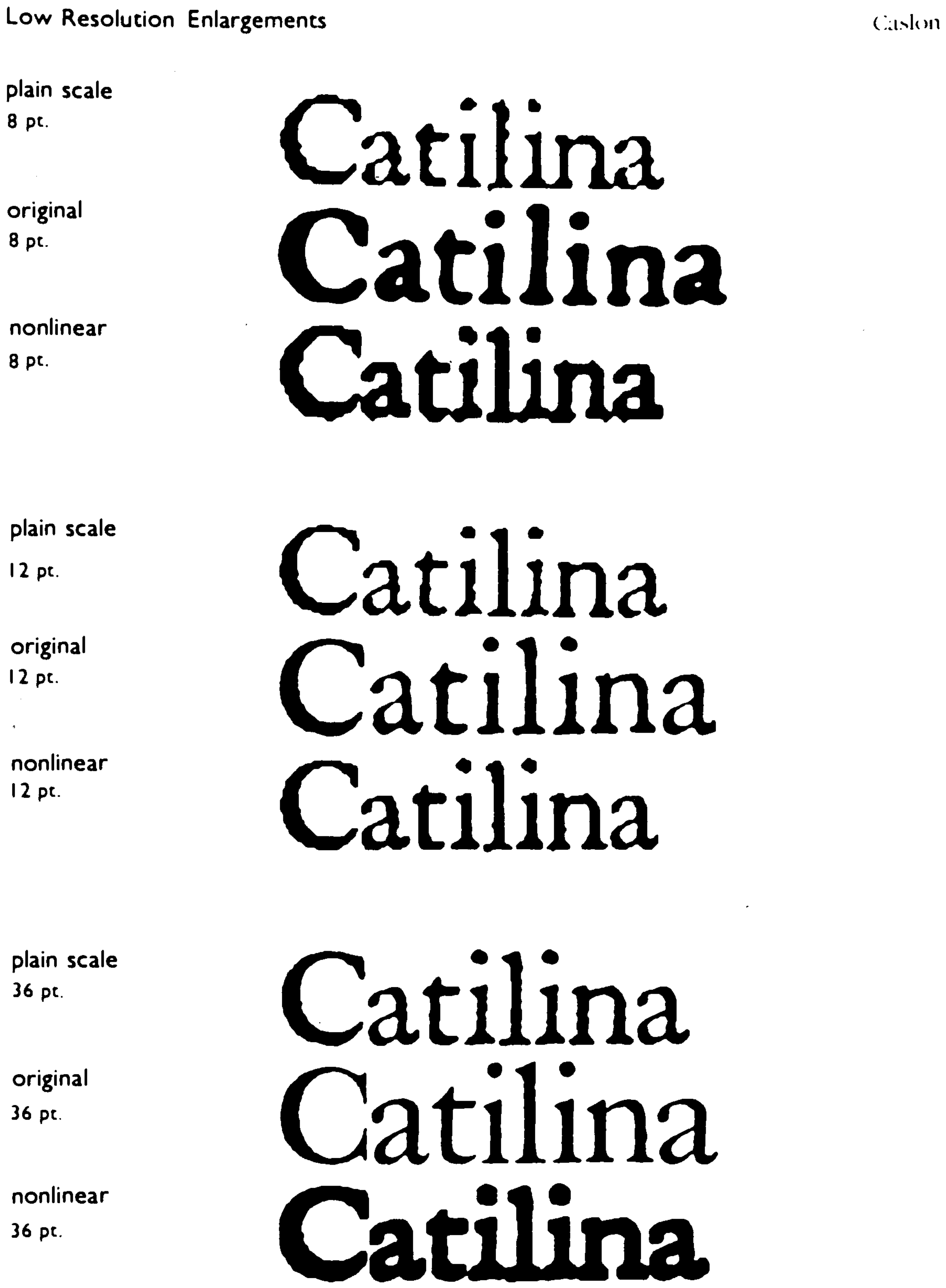
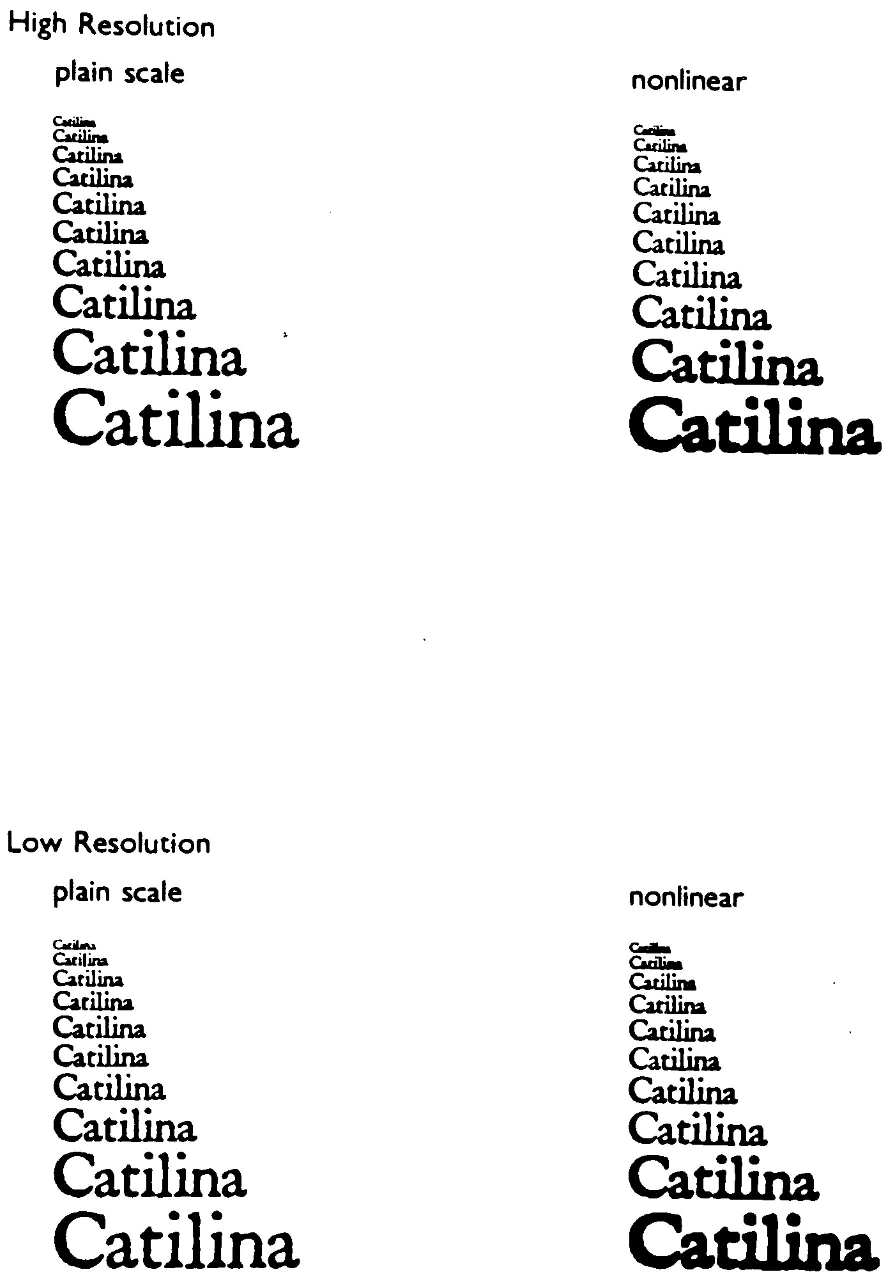


Figure 14. (Caslon ELR) Enlargements of synthetic and original sizes, low resolution.



Caslon sizes are: 6, 8, 10, 11, 12, 14, 18, 22, 28, 36

Figure 15. (Caslon RS) Full size range of synthetic letterforms at high and low resolutions.

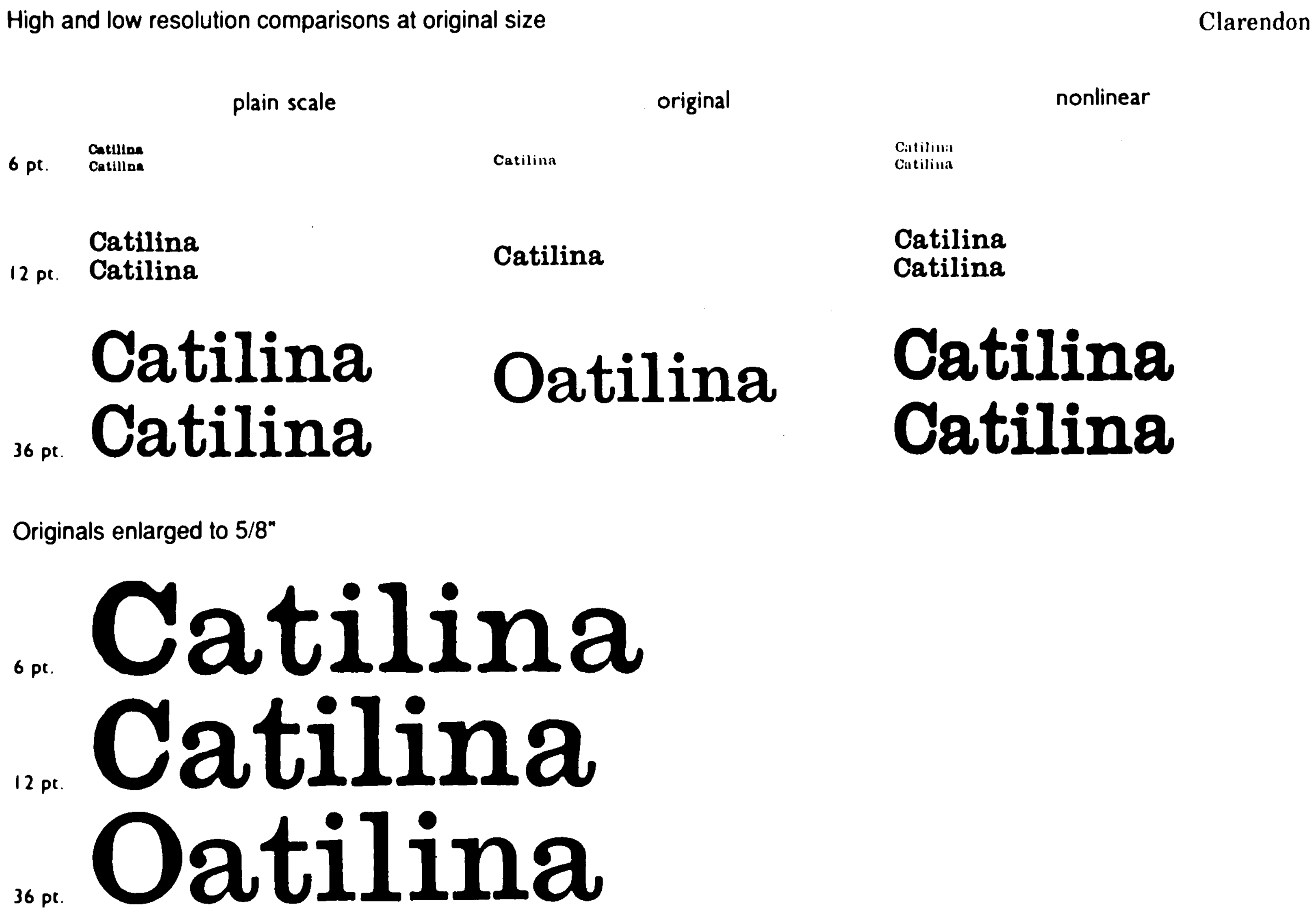


Figure 16. (Clarendon CWO) Comparison of synthetic letterforms with original, handcut letters.

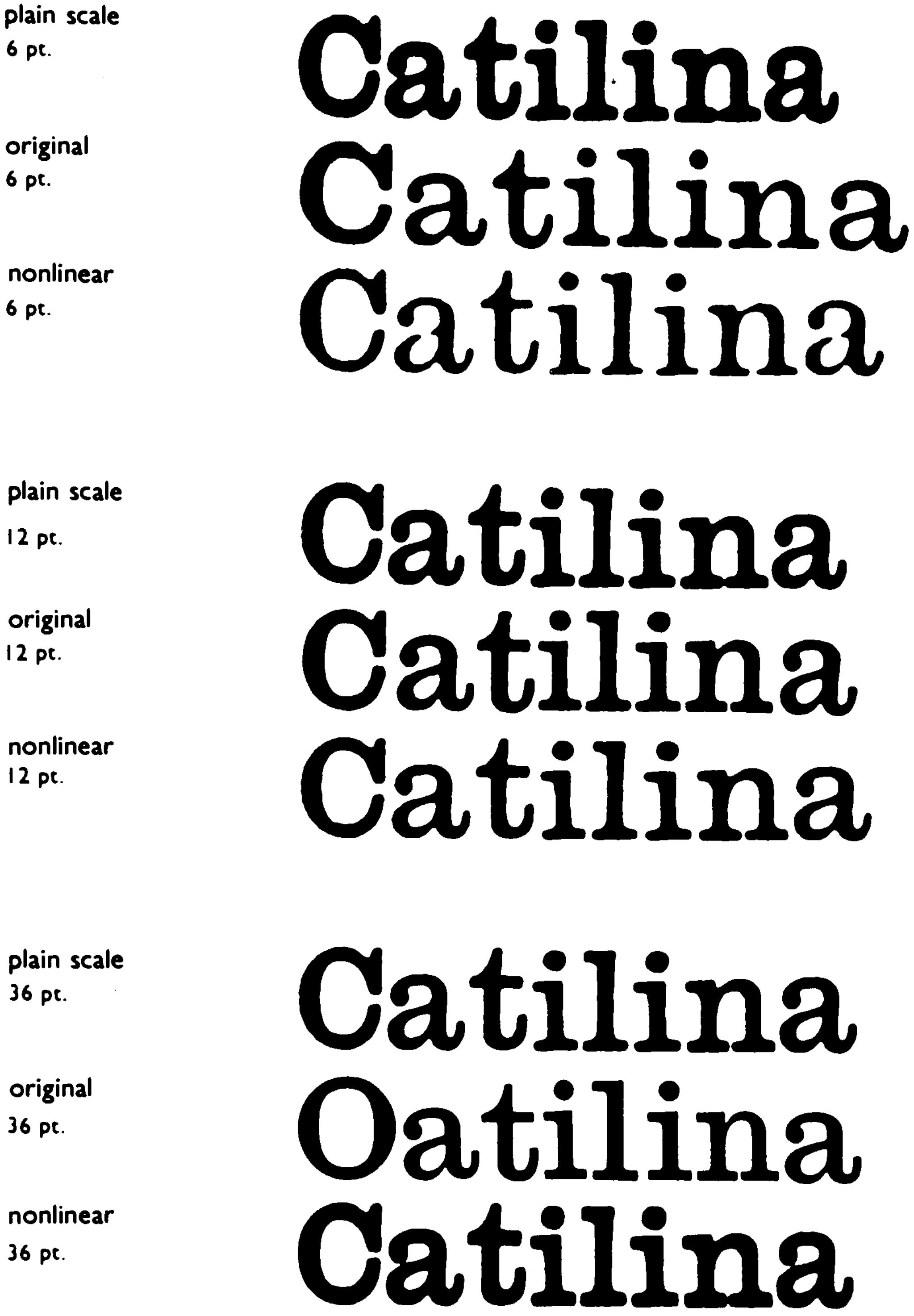


Figure 17. (Clarendon EHR) Enlargements of synthetic and original sizes, high resolution.

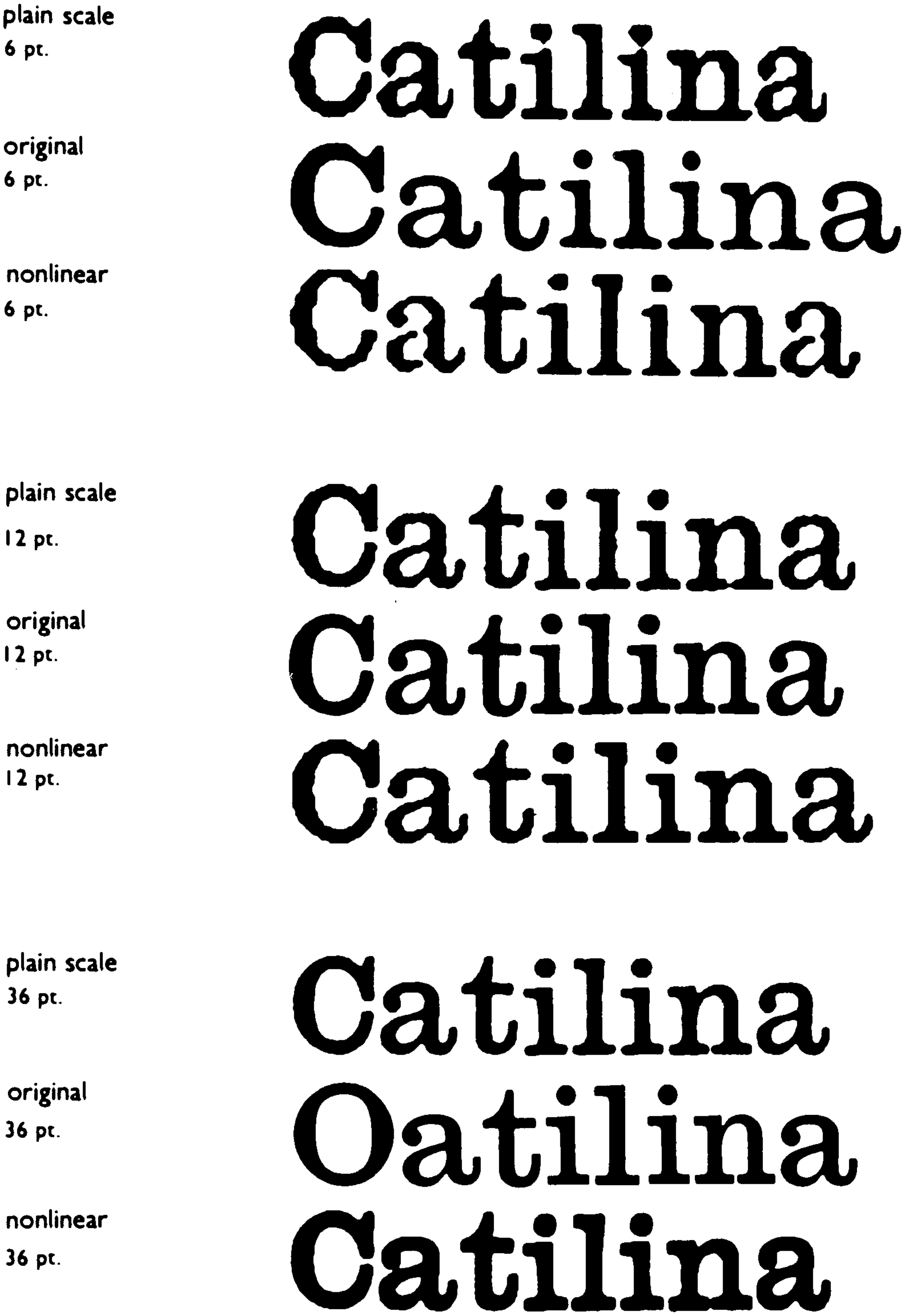
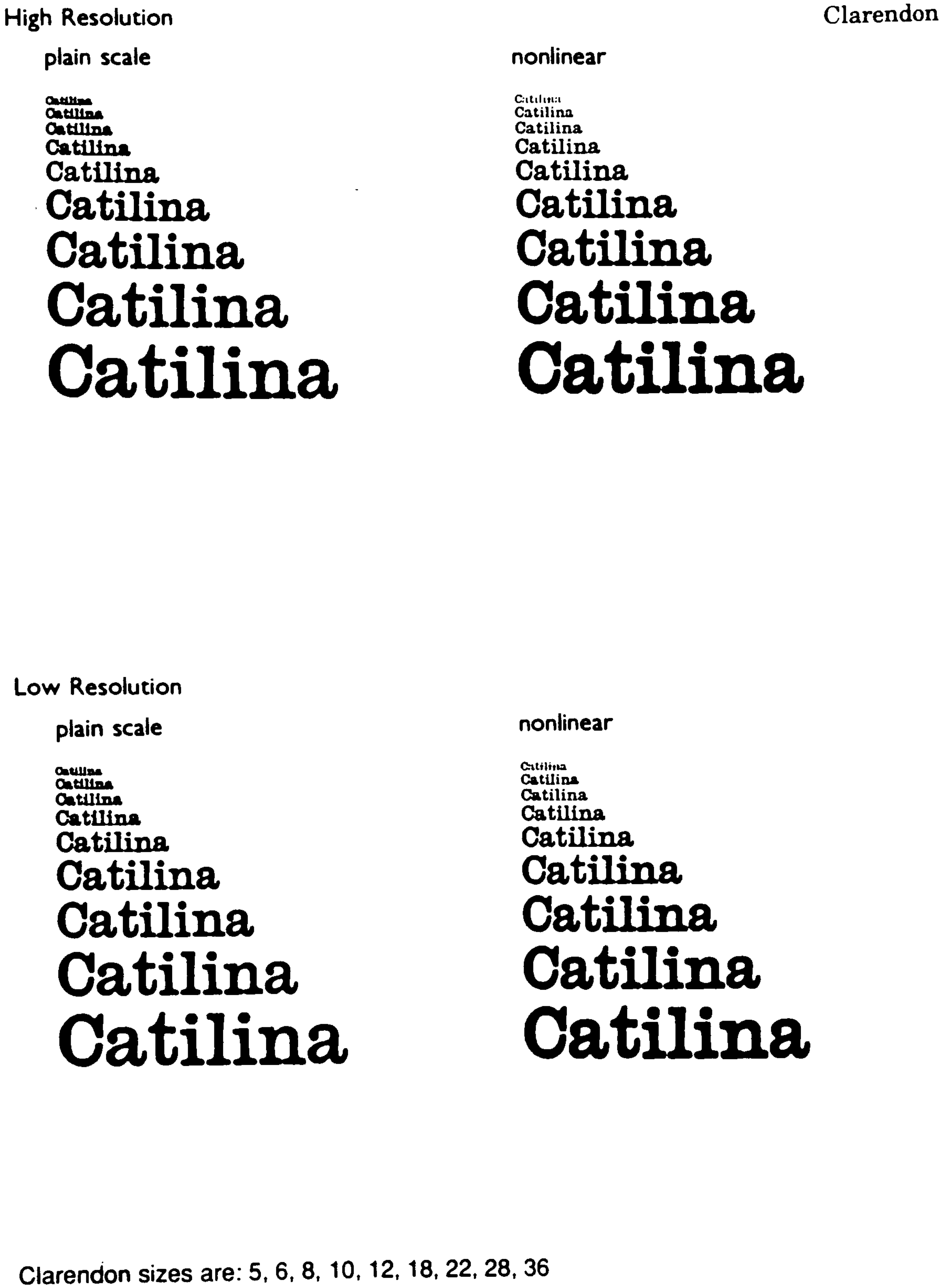


Figure 18. (Clarendon ELR) Enlargements of synthetic and original sizes, low resolution.



Clarendon sizes are: 5, 6, 8, 10, 12, 18, 22, 28, 36

Figure 19. (Clarendon RS) Full size range of synthetic letterforms at high and low res.

Figure 20. (Bodoni CWO) Comparison of synthetic letterforms with original, handcut letters.

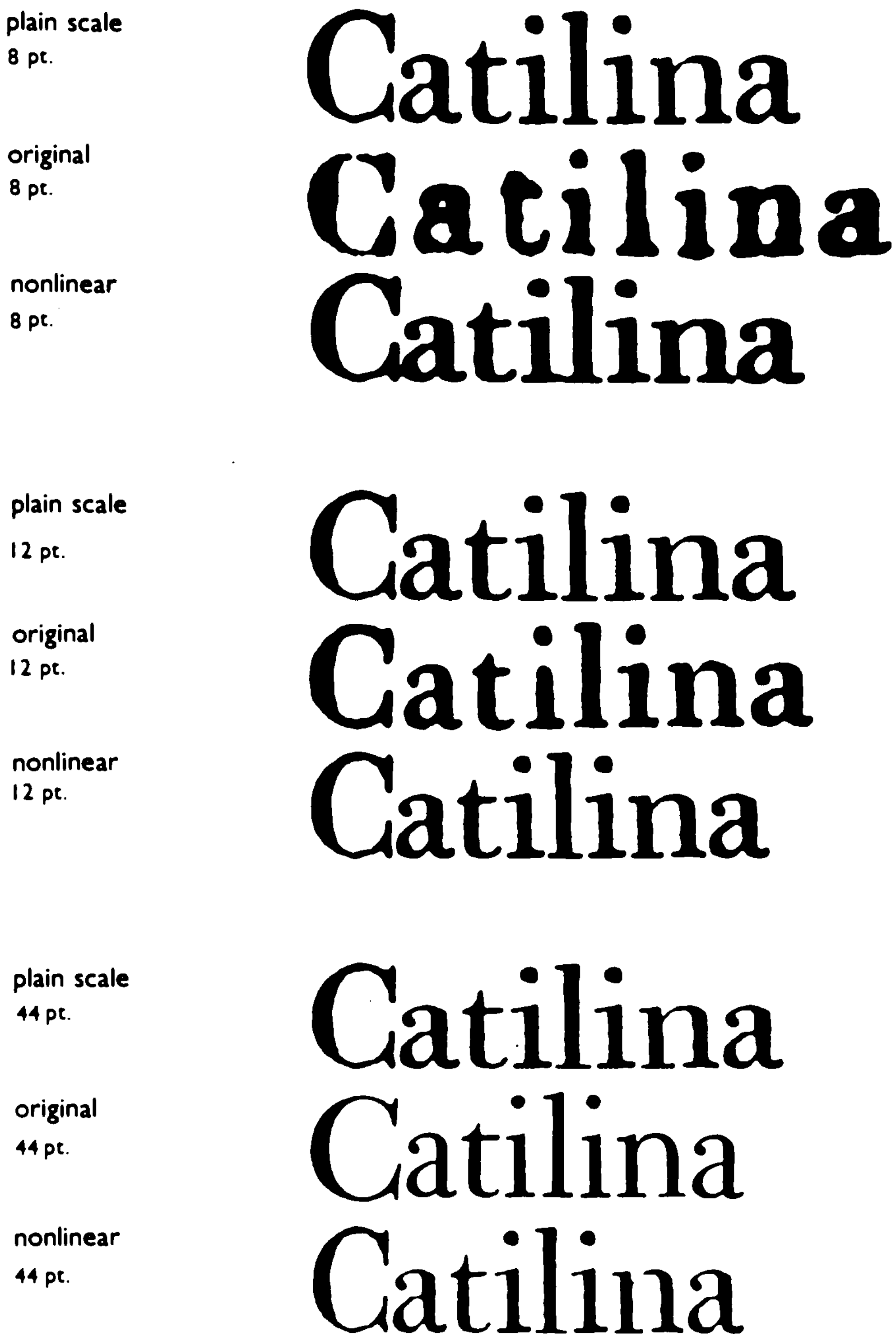


Figure 21. (Bodoni EHR) Enlargements of synthetic and original sizes, high resolution.

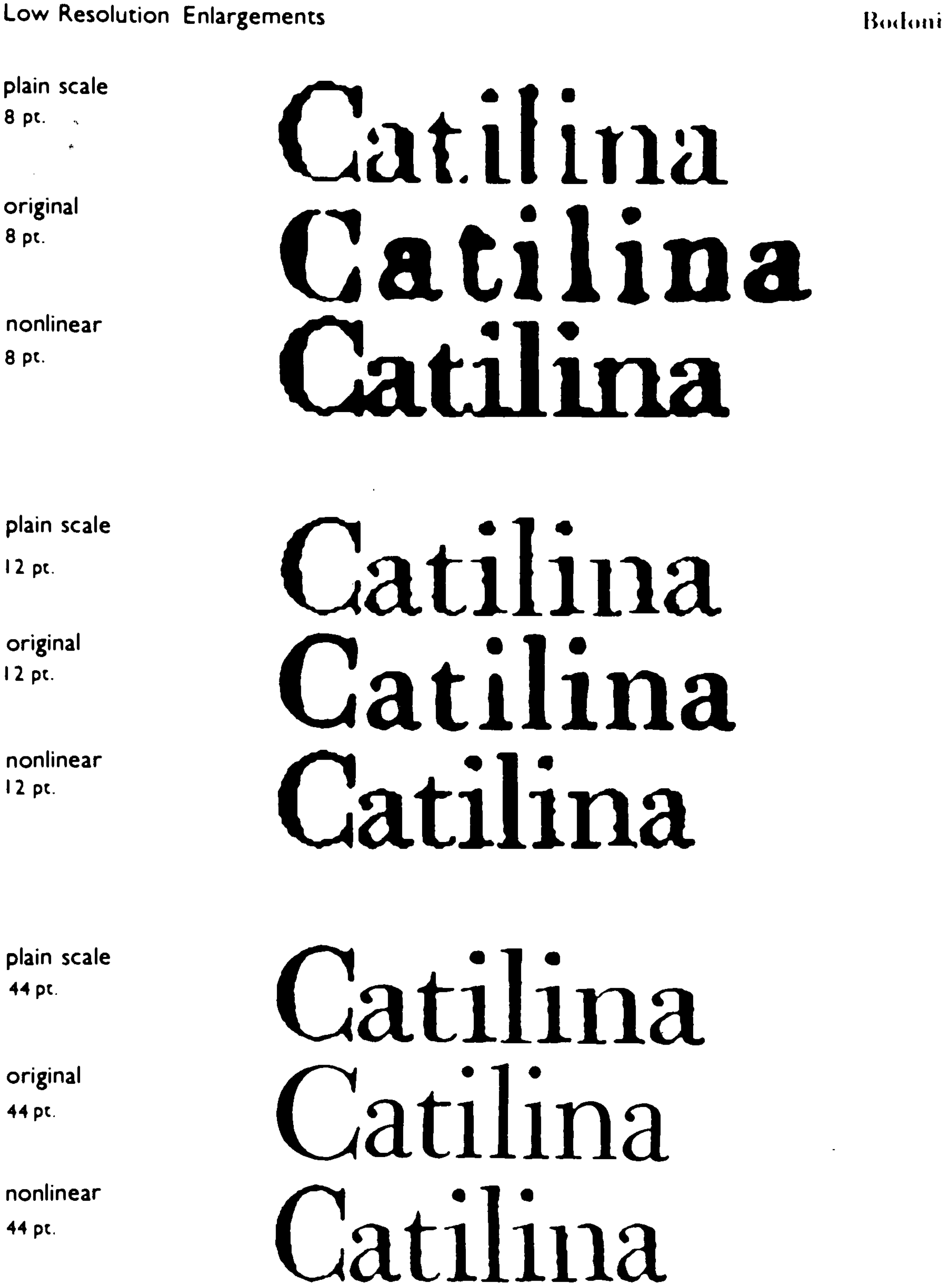
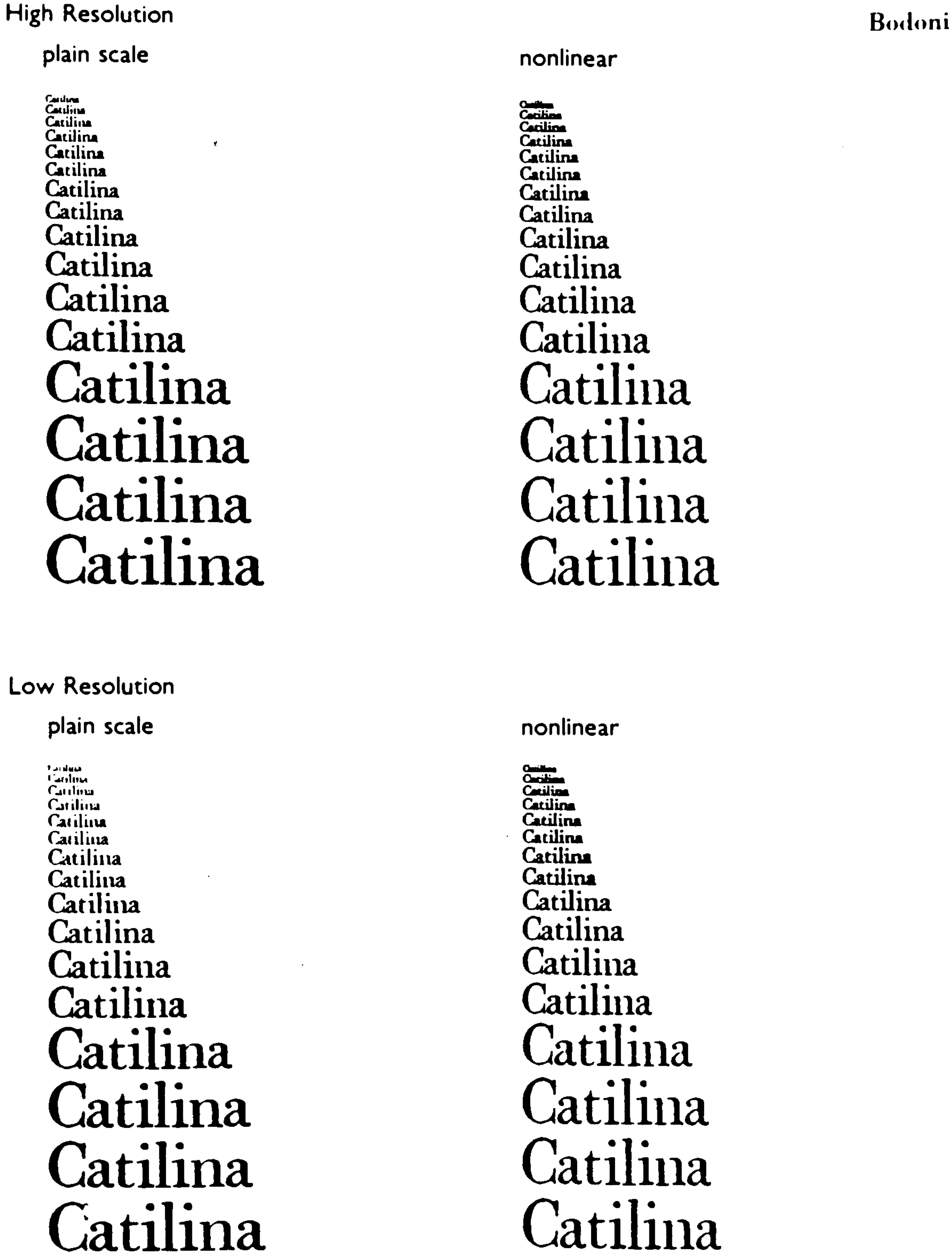


Figure 22. (Bodoni ELR) Enlargements of synthetic and original sizes, low resolution.



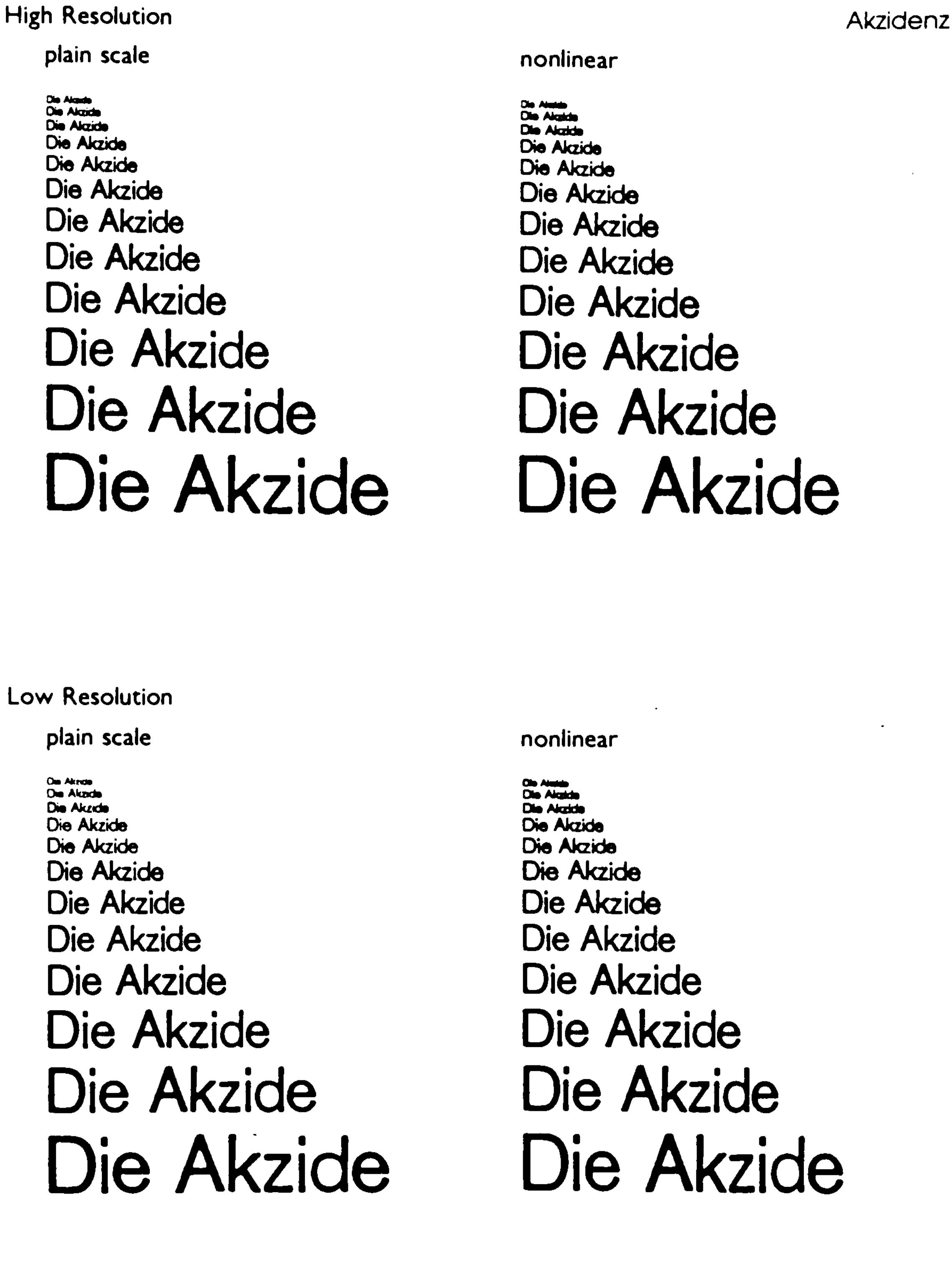
Bodoni sizes are: 5, 6, 7, 8, 9, 10, 11, 12, 14, 18, 20, 22, 24, 28, 36, 44

Figure 23. (Bodoni RS) Full size range of synthetic letterforms at high and low res.

Figure 24. (Akzidenz CWO) Comparison of synthetic letterforms with original, handcut letters.

Figure 25. (Akzidenz EHR) Enlargements of synthetic and original sizes, high resolution.

Figure 26. (Akzidenz ELR) Enlargements of synthetic and original sizes, low resolution.



Akzidenz sizes are: 4, 5, 6, 8, 10, 12, 14, 16, 20, 24, 28, 36

Figure 27. (Akzidenz RS) Full size range of synthetic letterforms at high and low res.

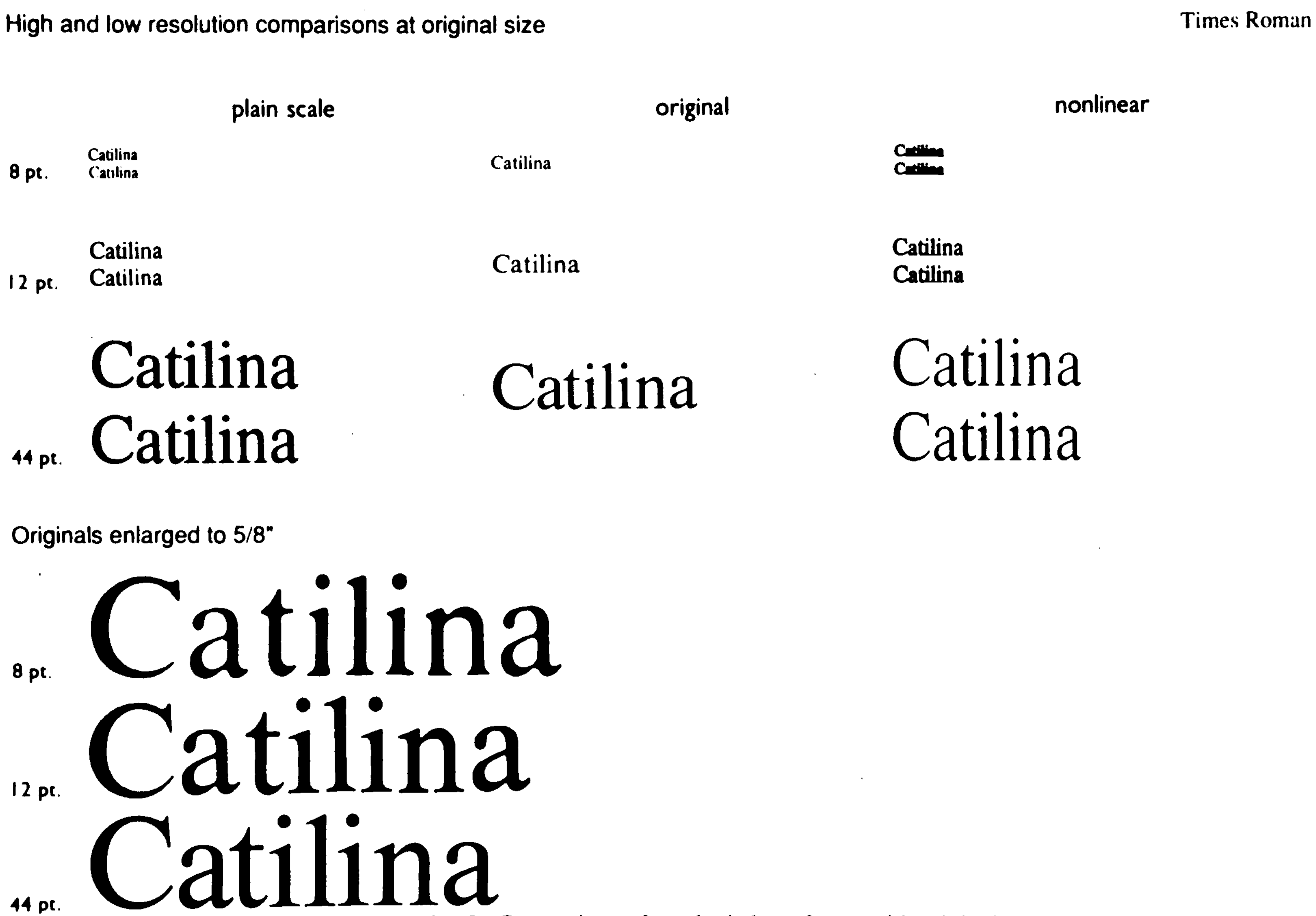


Figure 28. (Times Roman CWO) Comparison of synthetic letterforms with original, handcut letters.

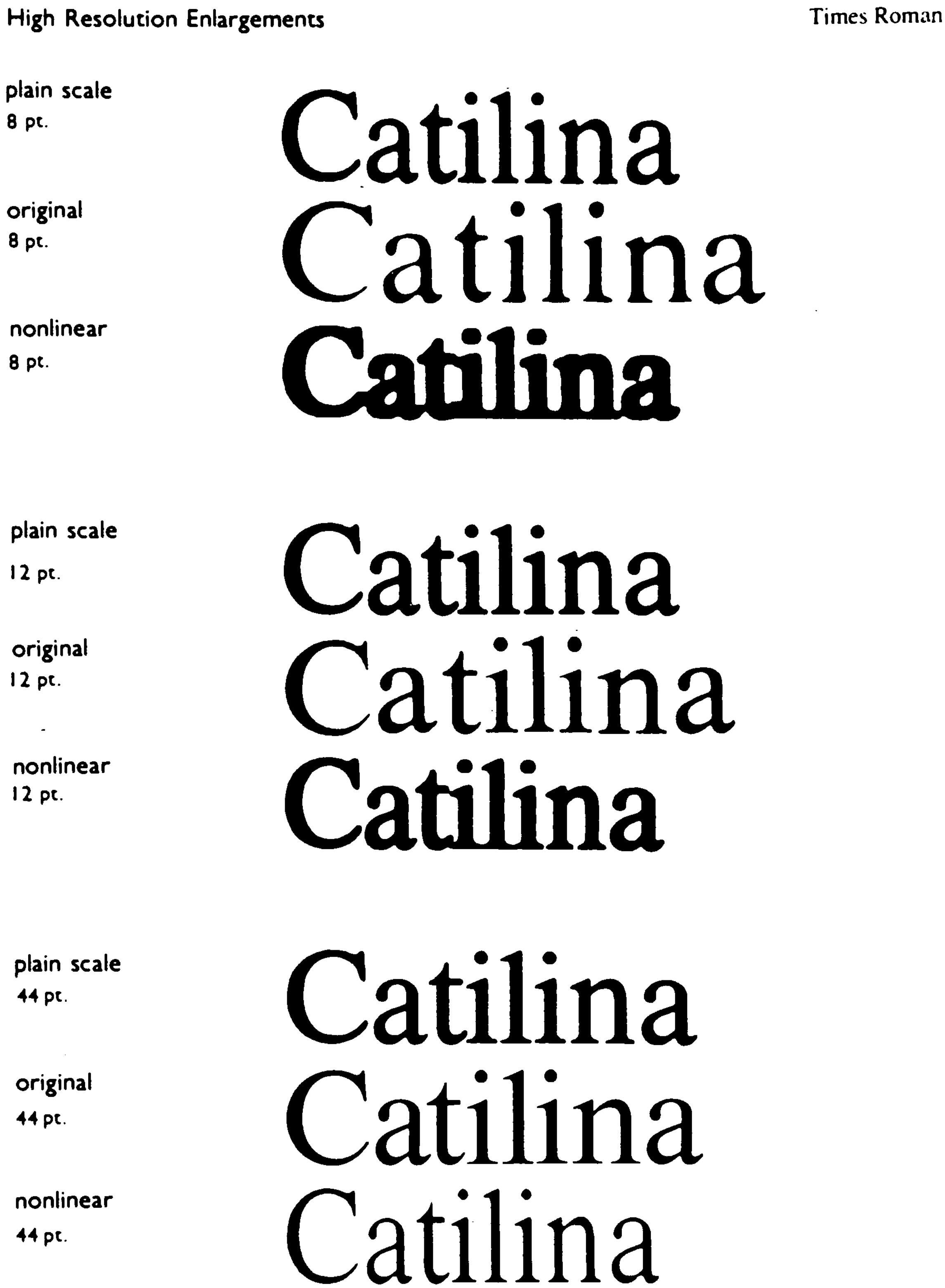


Figure 29. (Times Roman EHR) Enlargements of synthetic and original sizes, high res.

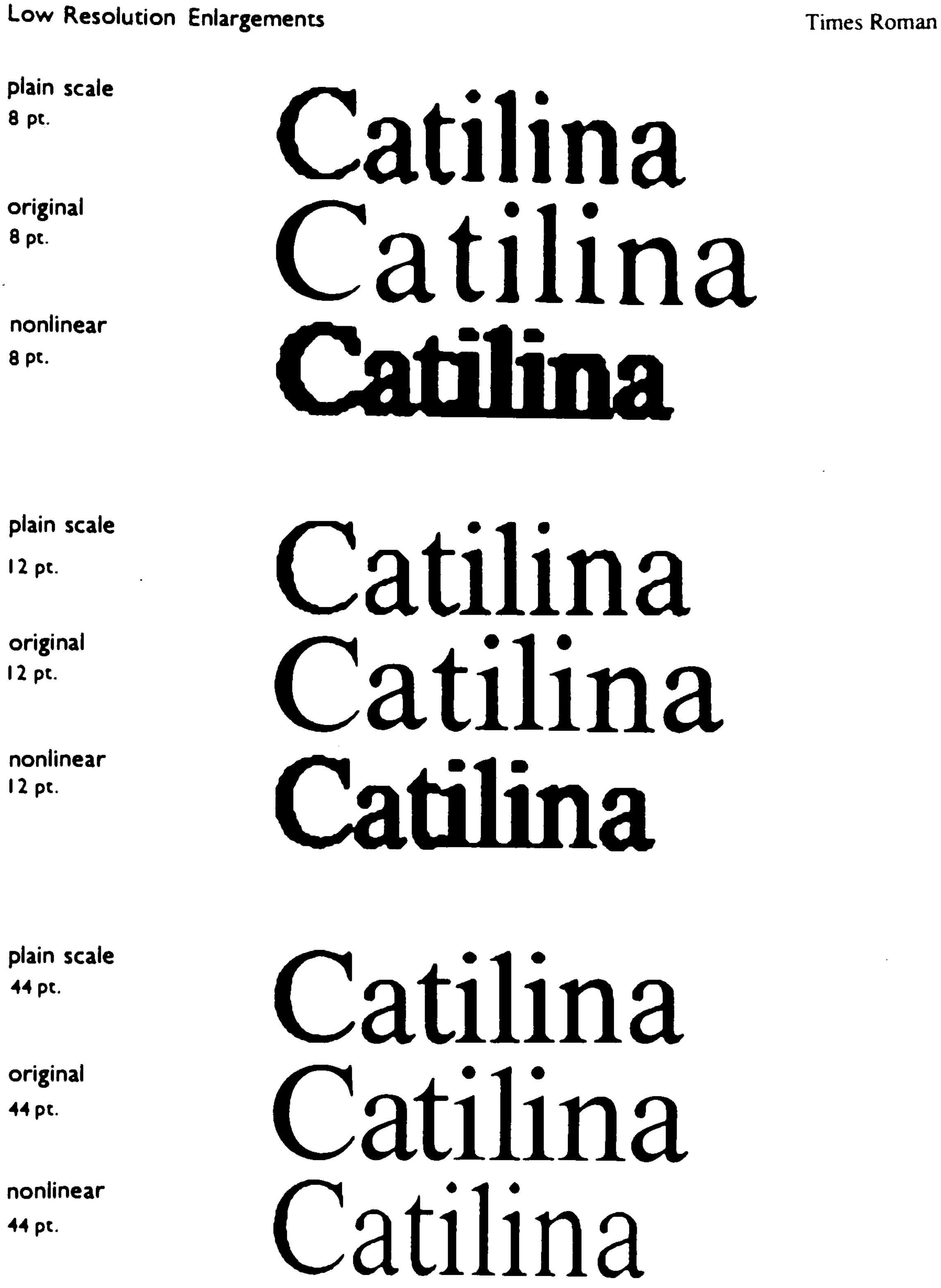
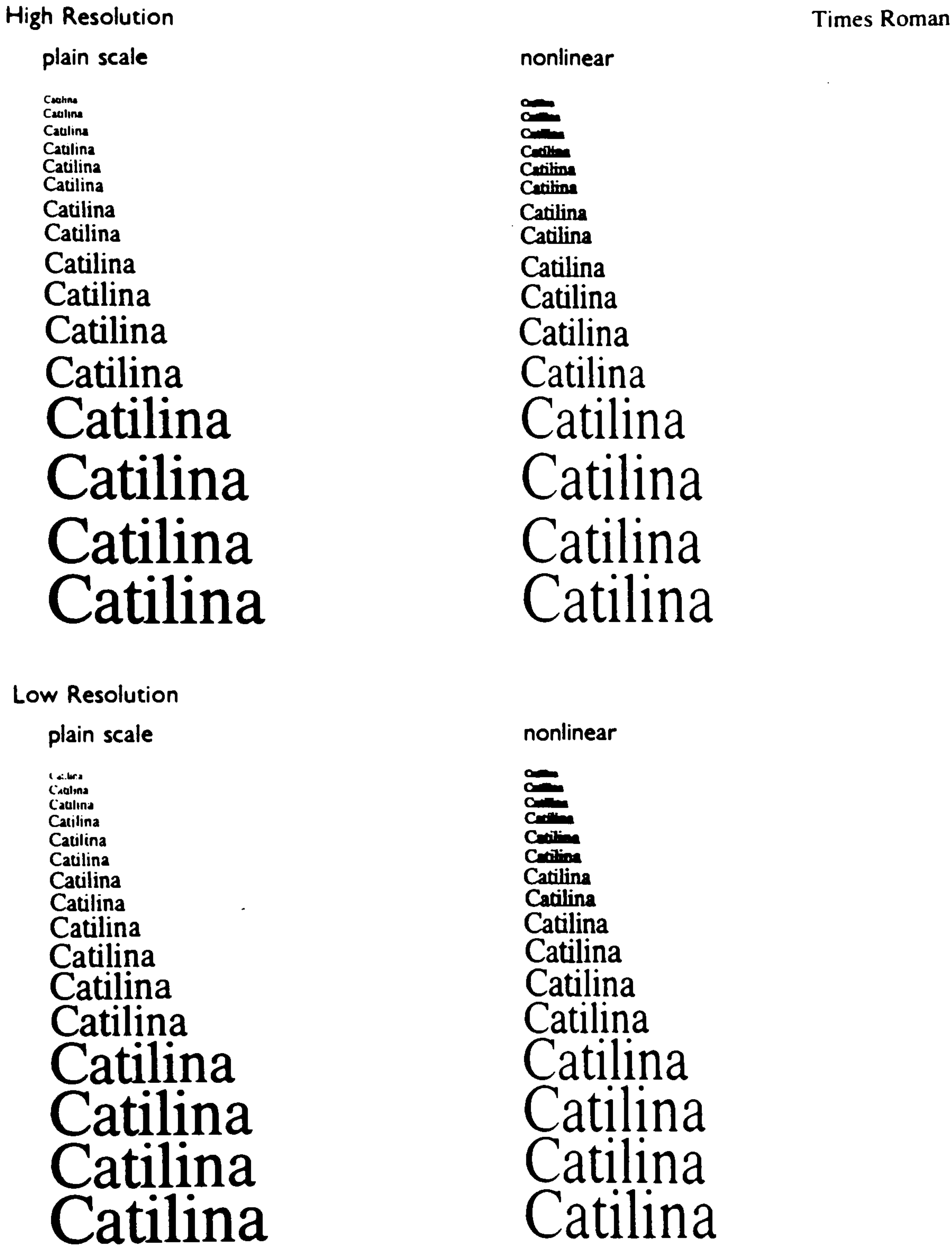


Figure 30. (Times Roman ELR) Enlargements of synthetic and original sizes, low res.



Times Roman sizes are: 5, 6, 7, 8, 9, 10, 11, 12, 14, 18, 20, 22, 24, 28, 36, 44

Figure 31. (Times Roman RS) Full size range of synthetic letterforms at high and low res.

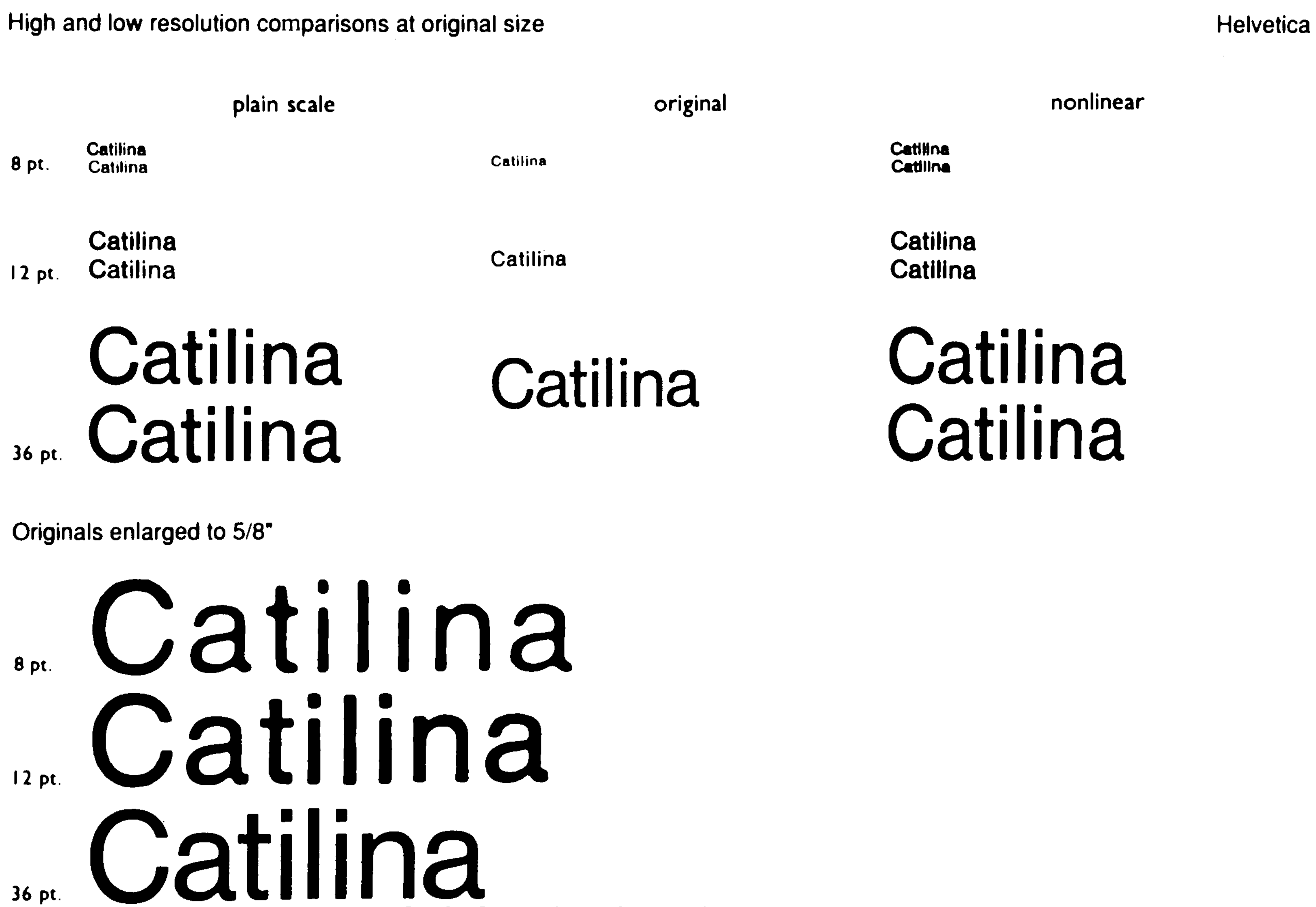


Figure 32. (Helvetica CWO) Comparison of synthetic letterforms with original, handcut letters.

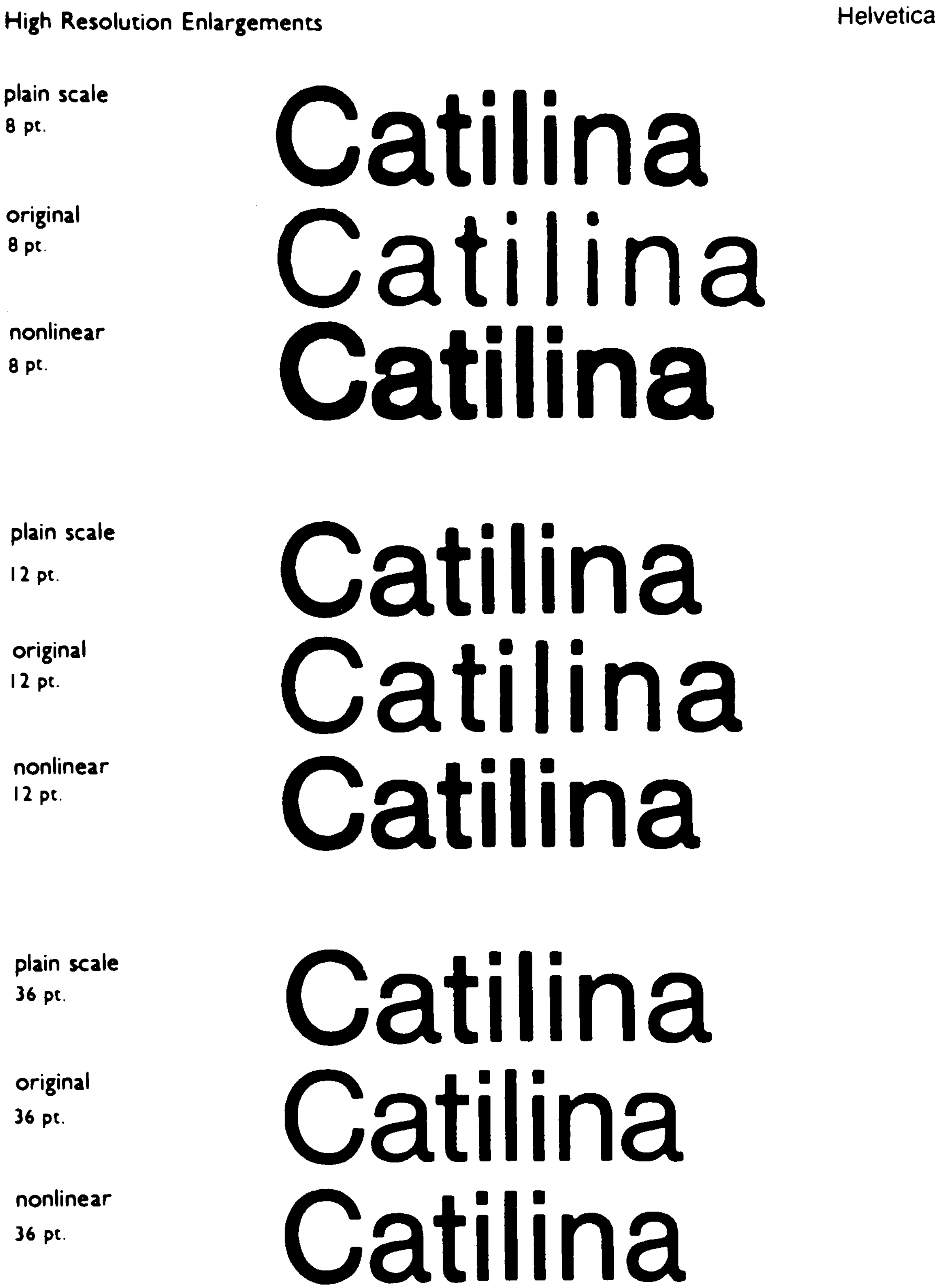


Figure 33. (Helvetica EHR) Enlargements of synthetic and original sizes, high resolution.

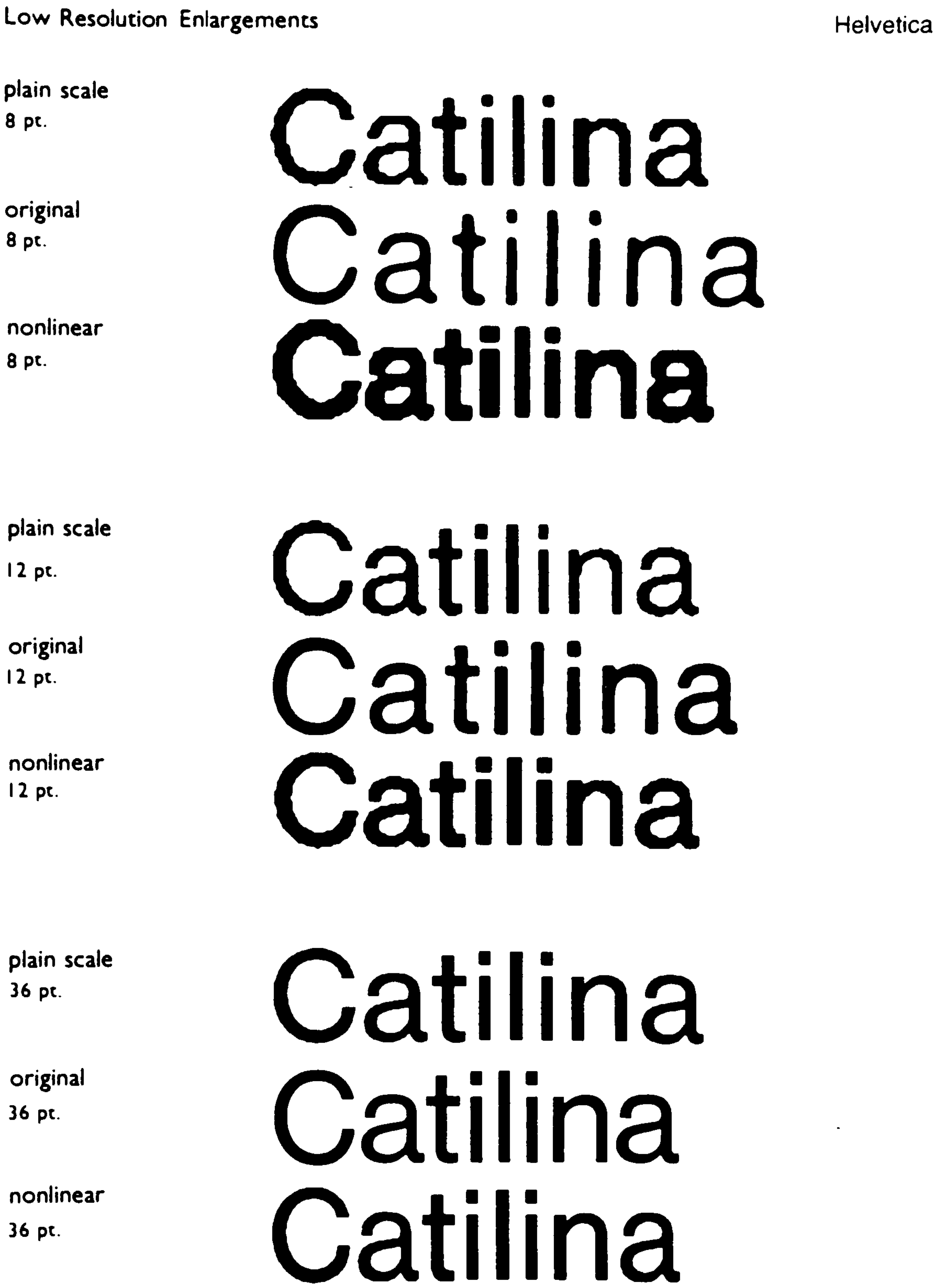


Figure 34. (Helvetica ELR) Enlargements of synthetic and original sizes, low resolution.

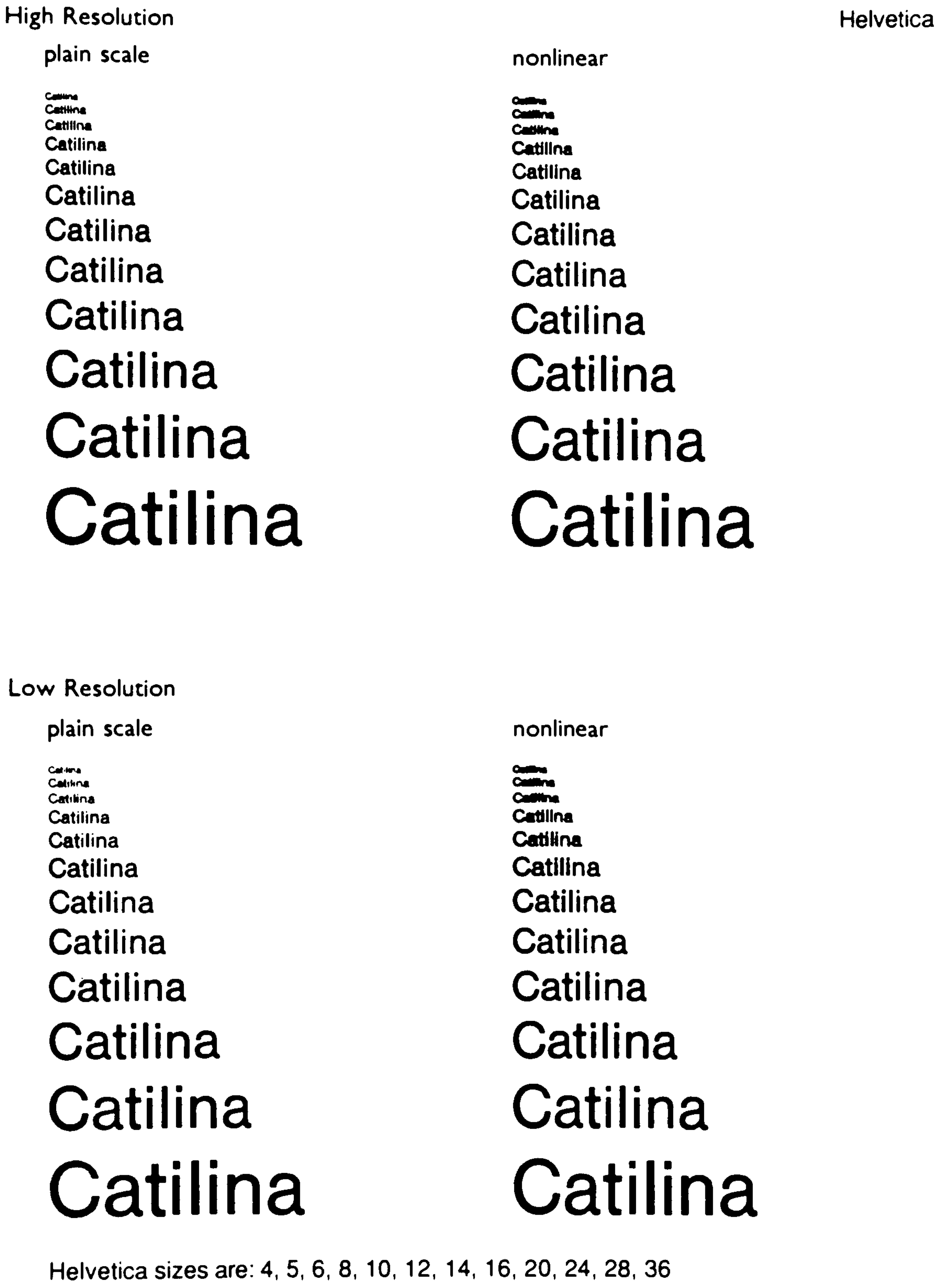


Figure 35. (Helvetica RS) Full size range of synthetic letterforms at high and low res.

CHAPTER VII

ANALYSIS OF DATA AND DISCUSSION OF RESULTS

This chapter will cover an analysis of the major results of this research which are as follows:

1. A model of the scaling of individual letterform features
2. Letterforms resulting from the application of the general scaling model

Scaling of Individual Letterform Features

The goal of this section of the analysis is to review the problems and solutions in using handcut fonts for this research and to discuss the behavior of the feature equations.

Handcut type specimens

In order to provide adequate data for the measurement of their features, the fonts in this study had to meet certain criteria. They had to be handcut specimens as near as possible to the original specimens, available in a wide range of sizes, and with a character set sufficient to meet feature measurement requirements.

The handcut type specimens measured in this study were as near to the original as possible. Ink squeeze, overinking, paper surface and inconsistency of design throughout the size range had an effect on the measuring of character features, especially at the smaller sizes. The following discussion will help clarify the problems and the solutions that were worked out to minimize the impact of these problems.

Ink squeeze is the result of lead type being smashed into paper during the letterpress printing process. The ink, which is in between the lead type and the paper, is forced to move from the pressure of the impression cylinder in the printing press and is "squeezed" aside. This effect was compensated for when the characters were measured by measuring the "true" shape of the character, which was delineated by a white line contour just inside the outer edge of the character on the printed specimen. This white line represents the "true" edge of the character, while the rest of the ink is from the "squeeze" effect. In high quality letterpress printing the effect of squeeze is minimized by proper alignment of the impression cylinder, smoothness of paper surface, the "squareness" (mechanical trueness) of the type and proper ink tack.

Over-inking was a more difficult problem, especially at smaller sizes. Features like counters, serifs, stem widths, and character widths became distorted and some human judgment was exercised. This distortion could have been the result of either improper ink tack or overinking or both. If the ink were too fluid in consistency the images printed would tend to have slightly ragged edges. This problem was especially difficult when specimens did not contain a full character set for all sizes in which case reasonable character substitutions had to be made.

Paper surface introduced some distortion as well. At the time that these fonts were made, rag paper was very often used to print type specimens. Despite a smooth appearance, rag paper has a fairly irregular surface of hills and valleys in which to trap ink. This is not at all like modern coated papers which have fillers such as clay added to smooth over the surface. The paper printing surface had an effect that was most evident when the inked area was smaller, in particular at smaller sizes. When these smaller images were enlarged they looked blotchy and hardly recognizable as letterforms even though at actual size they seemed quite acceptable.

The most difficult problem was inconsistency in design over a size range. This was especially true of Caslon, Clarendon, and, to a lesser extent, Akzidenz Grotesque and Bodoni. During the time period in which these fonts were manufactured, conventions had not been established about consistency of design throughout a range of sizes. Further, typefoundries did not by convention offer a "complete" range of sizes of one design. There did not exist a refined composition aesthetic largely because of a lack of availability of fonts. After all, some of the most prized designs (e.g. Jenson's Roman of 1470) were available in only one size.

Previous sections have indicated the large amount of labor involved in producing one size of a given type design. It took the typefounding industry several hundred years before they could offer their customers several designs in standardized sizes and bodies. This is very different from modern digital typefoundries that have very sophisticated ideas about design, availability of sizes, and standards on which to base them.

Feature equations

Feature equations model isolated features over a range of sizes. The behavior of the feature can be analyzed and it can be determined whether it is linear, proportional, or nonlinear. The equations can be used to predict information for a size that was not measured.

The features measured in this research are x-height, bowl width, stem width, serif length, serif width, ascender height, descender depth, average counter width of lowercase "m", total character width (serif edge to serif edge) and capital letter height. The following characters, which are typically used as control characters in designing a typeface, were selected for measuring in this study: R, M, S, H, V, O, a, h, m, o, q, and x.

Features were measured on characters through the available size range, usually 6 to 36 point. For a given feature, measurements were plotted against capital letter height.

Using this data, linear and quadratic regression analysis were performed and produced linear and quadratic equations. These feature equations were the best fit of the data to either a line or curve. They describe the behavior of the feature with respect to point size. They describe whether a given feature of a given font is nonlinear and, if so, whether it is nonlinear within the size range under consideration. Equations with unusually large or small quadratic terms were plotted with their raw data to try to determine the cause of their behavior. See Appendix IV. It was determined that they were heavily influenced by lack of or spotty data, especially at larger sizes, inconsistency of design, and noise in measuring, especially at small sizes.

This research wanted to determine when the quadratic feature equations would show a noticeable "nonlinear" effect within the size range at which the model would be applied. For the quadratic equation $f = ah^2 + bh + c$ it is important to know at what values will ah^2 (the quadratic term) be big enough, fast enough, against the backgound of bh, to show a nonlinear effect in the size range of 6 to 36 points.

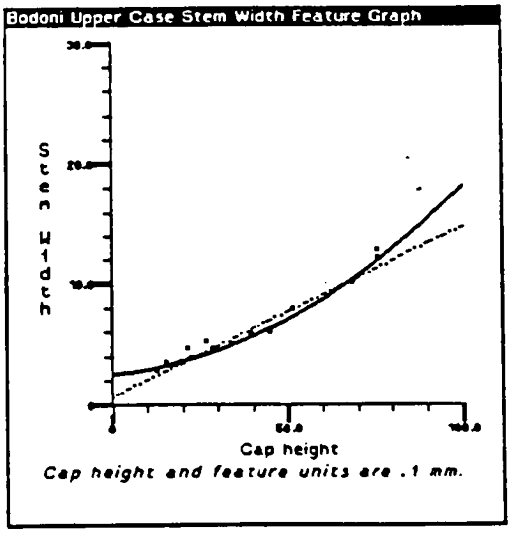


Figure 36. Feature equation plot showing nonlinear effect within the size range 6 to 36 points.

This was determined by the value of the coefficent of the quadratic term being greater than .001. Almost all the features measured in this study show a nonlinear effect within their size range. Even the features that are considered "linear" are not proportional (having lines that go through the origin). This means that the feature is proportionally larger at smaller sizes with respect to capital letter height. The following list describes the nonlinear and linear features for each font in this research.

These were the features determined to be nonlinear for each typeface:

1. left m counter width	Akzidenz
2. upper case stem width	Caslon, Bodoni
3. capial letter width M	Caslon, Clarendon
4. capital letter width H	Caslon, Akzidenz
5. capital letter width O	Caslon Bodoni, Akzidenz
6. capital letter width V	Clarendon, Bodoni, Akzidenz
7. capital letter width R	Caslon, Bodoni
8. character width m	Bodoni
9. character width x	Bodoni
10. lower case o bowl width	Caslon
11. lower case q bowl width	Caslon, Akzidenz
12. x height	Caslon
13. ascender height	Caslon, Clarendon, Bodoni
14. descender height	Caslon, Clarendon
15. lower case o bowl height	Caslon
16. capital letter H cross bar width	Caslon

These features were determined to be linear:

1. right m counter width	all

2. lower case stem width all
3. lower case e cross bar width Caslon
4. lower case o bowl width all

As hypothesized, the results show that the small sizes are non-proportional to the larger sizes and follow the predicted trend. "Predicted" behavior is that small fonts are wider, have thicker stroke, serif, and hairline weights, larger x-heights, and more enclosed counters. As type increases in size the characters become more narrow, stroke, serif and hairline weights become proportionally lighter, the x-height proportion decreases, the counters become more open and airy and the design can evolve toward a more sculpted chiseled look. It is useful to know that the feature equations do show a nonlinear effect within their size range especially since that is the desired net effect of the nonlinear scaling model.

Letterforms Resulting from the Application of the Nonlinear Scaling Model

The goal of this section of the analysis is to critique the letterforms which were the result of applying the different scaling model parameters to original handcut characters. The models were considered successful if they produced fonts that looked like the original handcut fonts that were measured. Some of the scaling parameters derived from the initial data were hand tuned to improve the visual appearance of the letterforms. Small compensations were made to the vertical growth factors for Bodoni and Akzidenz. The resulting images of these fonts are not a strict interpretation of the data.

The plain and nonlinear scaling parameters were applied to fonts inside of the research and are compared to the original handcut type specimens. The nonlinear and plain scaling model that resulted from Bodoni and Akzidenz Grotesque were applied to fonts outside of the research, Times Roman and Helvetica, and compared to the original versions of those fonts. All fonts were converted to low resolution and evaluated and the range of resolution over which the nonlinear scaling model could be applied was determined for the low resolution application.

For each font in this study there is an "illustration set" of four photographs. For easy reference, each of these photographs will be identified by a two-part label, consisting of the font name and one of the following acronyms: CWO, EHR, ELR, RS. These are as follows:

1. CWO (Comparison With Originals). Original handcut fonts in small, medium, and large sizes enlarged to 5/8". Also includes specimens of small, medium, and large at real size of originals and plain and nonlinear scale at both high and low resolution
2. EHR (Enlargements at High Resolution). Small, medium, and large sizes of the plain scale, original, and nonlinear specimens enlarged to 5/8" at high resolution
3. ELR (Enlargements at Low Resolution). Small, medium, and large sizes of the plain scale, original, and nonlinear specimens enlarged to 5/8" at low resolution
4. RS (Real Size). Complete size range at real size of plain scale, and nonlinear scale at both high and low resolution

For example, the label "(Caslon RS)" refers to the illustration of the Caslon font at real size. This happens to be figure 15. Figure numbers, however, will not be further used in this discussion.

For each font in this research there will be a visual evaluation covering the following points:

1. Evaluation of original handcut fonts.
2. Comparison of small, medium, and large plain and nonlinear scale compared to the originals using the enlargements and at real size.
3. Evaluation of plain and nonlinear scaling model over the entire size range at real size for both high and low resolution.

Specific key typographic features will be mentioned in the comparison: stem width, serif length and width, character width, x-height, counter shape, and hairline width. Character spacing was not addressed in this research. The visual analysis will focus on the effect of the model on character shapes and features. "Predicted" behavior will be discussed in relation to the plain and nonlinear specimens. The twelve point original specimen, which is the same as the plain scale specimen, is the *reference image* used to generate all the other specimens for a particular font.

Font Review

Caslon

1. *Evaluation of original handcut fonts* (Caslon CWO). A careful review of Caslon original fonts show that the greatest feature changes lie between the 8 point and the 12 to 36 point designs. The 8 point stem width and hairline are heavier, the counters are smaller, but the character width is the same or smaller proportional to the 12 and 36 point design. The 36 point size has more open counters and a more sculpted look of finer details but does not change in character width, stroke or hairline weight, or x-height proportion. This varies from the "predicted" behavior where a design went from progressively heavy to lighter character widths, stroke, and serif weights over a size range. It is important to remember that Caslon's fonts were the work of several hands over a period of ten years and that his fonts were prized for their "skillful variation"[1]. Perhaps this is what was meant.

2. *Comparison of small, medium, and large plain and nonlinear scale compared to the originals using the enlargements and at real size* (Caslon EHR). The 8 point synthetic plain scale and nonlinear scaled versions of Caslon are very similar except that

[1]Updike, Printing Types, Their History, Forms, and Use, A Study in Survivals, p. 106.

while they are both lighter in horizontal and vertical stroke weights than the original 8 point Caslon, the nonlinear is slightly heavier in overall weight.

The twelve point sizes are very similar except that in both the plain and nonlinear scale the hairline and serif weight is slightly heavier than the original. It is to be expected that they would be very similar since the original twelve point image is the "master" used to scale the all the other sizes in both the linear and nonlinear techniques.

The 36 point nonlinear specimen is equally heavy in both the horizontal and vertical directions. There is no hairline weight to speak of, the serifs are as thick as the main stem weight, the counters are small and generally speaking there is nothing thin, delicate or chiseled about it. It is historically unknown that any type design had features that got larger and larger as it got bigger. It is thought that the model behaved this way due to lack of data at larger sizes. For example, there weren't that many characters to measure at large sizes and what did get measured had more weight since any error was averaged over fewer characters. (There were full character sets available in the 6 to 14 point size range.) Also, when the size being generated is furthest from the 12 point reference image, the more error is likely to be introduced. The 36 point plain scale version did much better than the nonlinear version. Although it is slightly thicker in vertical weights such as the hairline and serifs, it more closely approximates the original than the nonlinear specimens. The 36 point original is slightly different in design than the 8 and 12 point and since the 12 point design was used to generate the other sizes, the synthetic 36 point size will not look as different as the original.

3. *Evaluation of plain and nonlinear scaling model over the entire size range at real size for both high and low resolution* (Caslon RS). At real size the difference in horizontal and vertical weight between the two scaling models is noticeable. The plain scale technique produced fonts that are thinner and although only slightly thinner, at small sizes it

is significant enough to make a very noticeable difference. Sometimes in type design it takes only a small difference to make a very big difference. The extra weight that the smaller sizes gained in the nonlinear specimen makes it easier to read and provides the viewer with the illusion that there is a smooth gradation of weight throughout the size range. This is true for the low resolution specimen as well (Caslon ELR). It can be seen that at lower resolutions, the larger the size, the more closely the character can be reproduced. Conversely, in lower resolutions as the point size decreases, the more problems there are in reproducing accurate or at least consistent character shapes.

Clarendon

1. *Evaluation of original handcut fonts* (Clarendon CWO). A close look at the enlargements of the original Clarendon specimens shows that there is very little feature change over the size range. The character widths as well as the stem, serif, and hairline widths remain almost the same. The 12 point specimen shows a very small increase in overall weight but not enough to be of any real significance. The main difference between the sizes is the larger size looks more sculpted with finer details and has slightly more narrow character widths than the 6 point designs. This is suprisingly different than the "predicted" behavior where a design went from progressively heavy to lighter character widths, stroke, and serif weights over a size range. Clarendon was designed and produced anonomously over a few years and therefore did not have the consistency of vision or experience of one person. While it was a popular face in its day known for its strength and reliablity, it lacked some of the refinement that is currently under study.

2. *Comparison of small, medium, and large plain and nonlinear scale compared to the originals using the enlargements and at real size* (Clarendon EHR). The 6 point plain scale specimen is heavier than the original and the nonlinear specimen. It has the "dipped in chocolate" effect with almost uniform horizontal and vertical weights. Also,

since the character widths are more narrow and are overall heavier in weight, especially in the serifs, this closes some of the counter forms and makes the characters harder to recognize. The nonlinear scale version does almost the opposite from this. It has lighter vertical weight which is especially noticeable in the serifs and in the hairlines (some of which are broken). On the other hand, the horizontal stroke weight and character widths are closer to the original specimen than the plain scale version. Both the plain and nonlinear versions have larger x-heights than the original which is more characteristic of the 12 point design.

The 12 point plain scale version is overall slightly heavier in horizontal and vertical directions. The nonlinear specimen is still a little thin in the horizontal stem weights while the vertical weight of the serif and hairline is the same compared to the original.

The 36 point plain scale specimen is heavier in weight than original specimen, although not as heavy as the nonlinear specimen. The plain scale specimen has thicker vertical weight in the serif and the hairline while the horizontal weight of the stem is very close to the original. Overall it has a less refined chiseled look than the original but is still within typographic acceptance. The same cannot be said for the nonlinear specimen. It is overall as heavy in horizontal and vertical directions as the 6 point plain scale specimen. It has lost the distinction of the hairline weight with the serifs almost closing the counter forms, and lacks any of the refinement and grace of the original. It is thought that this happened to Clarendon for the same reason it happened to the Caslon nonlinear specimens at the larger sizes. There were fewer characters to measure, less consistency of design, and greater error in trying to reproduce a larger size of the design. For the most part the original Clarendon design behaved linearly except that the hairline and serif widths of the 36 point are larger than the 6 point size. This data skewed and exaggerated the vertical scale and growth factors of the 36 point nonlinear model. If the hairline and serif weight had been less thick it would be much closer to the original even though the horizontal stem weight is slightly heavy.

3. *Evaluation of plain and nonlinear scaling model over the entire size range at real size for both high and low resolution* (Clarendon RS). At real size the heavier weight of the 6 point plain scale is not too objectionable. This is especially true of the low resolution characters. Both versions are definitely easier to read than the 6 point original or nonlinear specimens. At 12 point there is less of a noticeable difference between the two scaling techniques. The most noticeable difference is at the larger sizes where the nonlinear specimens become very thick and blocky, almost Egyptian in design. The counters are noticeably filled in by their serifs and the forms lack any grace or definition. They seem almost muscle bound by the weight of their stems and serifs. The plain scale version suffers slightly from this as well. This is why a design at a small size should not simply be proportionally enlarged.

Bodoni

1. *Evaluation of original handcut fonts* (Bodoni CWO). The original Bodoni fonts exhibited the "predicted behavior". This can be seen quite clearly from looking at the original 8, 12, and 44 point specimens. The 8 point have proportionally thicker horizontal stem strokes, wider character widths, heavier serif and hairline weight, larger x-height, and more enclosed counters. The 44 point original design has proportionally lighter more delicate features which have evolved from the 8 and 12 point. Also, it has a more sculptural rhythmic feeling from the thinner serifs and hairlines, and a greater emphasis on the vertical stokes. Bodoni's designs reflect his joy in perfection. It is important to remember that he had been heavily influenced by Philippe Grandjean who cut the first "modern face" from the specification set by the French *Académie des Sciences romain du roi* and that it was known that he spent his life "lovingly perfecting" his punches for them to be "omnibus

absolutissame", as perfect as possible. He grew up the son of a master printer, devoting his life to the art and craft of type design and printing. He is singlehandedly responsible for the preparation and adjustment of over 55 thousand *of his own* matrices during his lifetime of work. From this background it is no wonder that his designs show the most consistency discovered in this research.

2. *Comparison of small, medium, and large plain and nonlinear scale compared to the originals using the enlargements and at real size* (Bodoni EHR). The 8 point plain scale version of Bodoni is lighter in both horizontal and vertical weights. The character widths, stem stroke, serif and hairline weights are all thinner than both the original and the nonlinear specimens. The nonlinear specimen has the same horizontal stem weight and more closely approximates the vertical serif and hairline weight. It is hard to distinguish the vertical serif and hairline weights of the originals due to noise in the letterpress printing process, but it is safe to say that the nonlinear specimen is closer in vertical weight than the plain scale specimen.

The 12 point nonlinear specimen is very similar to the 12 point original and plain scale specimen. The vertical hairline and serif weights are slightly heavier while the horizontal stem weights appear visually the same. It can be seen that the original 12 point stem, serif and hairline weights are intermediately and evenly placed between the 8 and 44 point designs and therefore not favoring either the smaller or larger sizes.

The 44 point plain scale specimen horizontal stroke and character widths are proportionally heavier while the vertical hairline and serif weights are lighter than the original 44 point specimen. Since the character widths are wider, the bowls are more open than the original specimen. The nonlinear specimen is a better approximation to the original than the plain scale specimen because the horizontal and vertical weights match more closely. The horizontal character width is narrow like the original and the stem weights are very close. The main difference between them is that the 44 point original's hairline and serif weight have less contrast than the nonlinear. The greater contrast between thick and thin in the 36 point nonlinear specimen is due to the growth factor. The "predicted behavior" for large sizes is that they become lighter in horizontal and vertical directions. Growth at large sizes becomes negative and means that weight is actually subtracted. This affects the features with the lightest weight first (like the hairlines and serifs). This effect can be seen where there are broken characters, which means there were zero pixels for some features, like hairline weights. The 12 point original design had thin hairlines and it can be predicted that if there was any negative growth it would be hard to hold the hairline feature without some other constraint. The hairlines of the 12 point plain scale specimen are thinner than the 44 point original which shows that this is one feature that did not act as "predicted". It got heavier instead of lighter. This shows Bodoni's constraint of "thinner but not to zero" at large size approach. The nonlinear model is generalized to scale and grow pixels and does not handle "features" (stem width, x-height, etc...). It also has no constraints built into it for handling special cases, e.g. when there are zero pixels.

3. *Evaluation of plain and nonlinear scaling model over the entire size range at real size for both high and low resolution* (Bodoni RS). At real size the smaller sizes of the nonlinear specimens are more legible than the plain scale versions. The extra weight that they have really adds to the illusion of a proportionally even gradation in weight over the size range. The plain scale specimens look proportionally thin and weak at small sizes and are harder to read but at large sizes look acceptable. The large sizes of the nonlinear specimens very closely model the originals except for the broken hairlines, which have already been discussed. Extra weight in the s'em and serif width seems to be the most important difference in legibility between the plain and nonlinear specimens at small sizes. The effect of the growth factor is evident in the low resolution nonlinear specimens

(Bodoni ELR). In the small sizes of the plain scale specimens, with only a scale factor being used, the hairlines weights become zero due to round off errors and the feature is lost. In the nonlinear specimens even if the scale factor rounds the number of pixels to zero, there is still the growth factor which will add a specified number of pixels and prohibit it from being zero (with the model behaving in the "predicted" way). This leads to some interesting conclusions about what kind of designs might be better suited for lower resolutions. These ideas will be discussed in detail in a later section devoted to the evaluation of the low resolution application of the model. The Bodoni nonlinear model is considered to be the most succesful in the study because, overall, it most closely emulated the original specimens.

Akzidenz Grotesque

1. *Evaluation of original handcut fonts* (Akzidenz CWO). Azidenz Grotesque is a sanserif design that has fewer features that would exhibit many of the specific "predictable behaviors". There are no serifs or hairlines, the design is monotone in horizontal and vertical weight. The remaining features which change in relation to size are: stroke weight, character width, x-height, and counter width. The original specimens have proportionally uniform horizontal and vertical stroke weight and x-height over the entire range of sizes. The two "predictable" features are proportionally more narrow character widths and counters (though the counters do not get more open) at larger sizes. Also, the larger sizes have a sculptural look to them, the sharp edge of the letterforms gives a precise, clean, simple line to the design.

2. *Comparison of small, medium, and large plain and nonlinear scale compared to the originals using the enlargements and at real size* (Akzidenz EHR). The 8 point plain scale specimen is proportionally heavier in the horizontal and vertical stroke thicknesses than the 8 point original Akzidenz specimen. The 8 point plain scale character widths are

wider and more round, the x-height is slightly taller, and the counters are smaller than the original 8 point specimens. The nonlinear specimens are proportionally heavier but have many of the same visual attributes of the 8 point plain scale specimen. The stroke weights are approximately twenty-five percent heavier than the original 8 point Akzidenz. The 8 point nonlinear specimen has proportionally heavier horizontal and vertical stroke thicknesses, wider rounder characters, taller x-height and smaller more enclosed counter forms than the original. It is not exactly clear why the nonlinear specimens are heavier than the originals but it might be because the measurements were made from original letterpress printed specimens. Small sizes are the hardest to measure accurately because of the problems of adjusting for ink squeeze, printing paper surface, and ink tack. Any distortion or irregularity due to these problems was a greater influence at smaller sizes.

The 12 point plain scale and original are the same group of letterforms. The 12 point nonlinear specimen is slightly heavier than the 12 point original. It has many of the same characteristics of the 8 point nonlinear specimen except that it is overall slightly lighter in horizontal and vertical weight. It is thought that the reason the 12 point nonlinear is heavier in horizontal and vertical weight is for the same reasons as the 8 point nonlinear specimens. There was still some error from measuring the letterpress printed specimens which contributed to its extra heaviness.

The 36 point plain scale specimen is proportionally slightly heavier in horizontal and vertical stroke weights than the 36 point original Akzidenz. The character widths remain proportionally wide although the counter forms are beginning to look more open. This is an illusion due to the lack of stroke thickness which the smaller sizes had and the larger sizes lack. The x-height remains constant proportional to the 36 point original specimens. The 36 point nonlinear specimens have a greater similarity to the originals than the plain scale versions. They have a more condensed character width and the horizontal and vertical stroke thicknesses are the same.

3. *Evaluation of plain and nonlinear scaling model over the entire size range at real size for both high and low resolution* (Akzidenz RS). At real size the main difference between the plain scale, nonlinear specimens and the originals is the weight gained at small sizes. The extra weight is an aid to legibility and gives the size range a more smooth even look going from small to large. The mid and large size weights are similar enough that there is not a really noticeable difference at real size. There the difference to the trained eye is the subtle condensation of the letterforms.

The low resolution specimens (Akzidenz ELR) show the same results, except that the small sizes of the plain scale specimens looks much weaker than the nonlinear specimens. A lot of the uneveness, particularly in the stem weights, is due to the low resolution conversion process and roundoff error. It can be seen that the smaller sizes of the nonlinear specimen do look better than the plain scale specimens and the same low resolution conversion process was used on both.

It is unclear why the nonlinear model produced fonts that behaved in the "predicted fashion" even though the original Akzidenz fonts did not. The original specimens did have some of the characteristics but not as many as Bodoni's fonts did. This brings up an interesting possibility that maybe there are only a few key features that need to be measured to build a nonlinear scaling model to behave in the "predicted" way.

Application of model to other fonts

Models derived from Bodoni and Akzidenz Grotesque were applied to two fonts outside of the research, namely Times Roman and Helvetica. These fonts are included in the illustration set with specimens of original English Monotype Times Roman and foundry Stempel Helvetica for comparisons. The goal of this exercise was to learn some things about how general the nonlinear scaling models might be and, perhaps, how to generalize them even more. In the analysis the features that will be focused on are horizontal and vertical stroke, serif, and hairline weight as well as x-height, character width, and counter heights and widths. Character spacing was a feature that changed in proportion to size but was not addressed in this research, instead the focus was on the relation of feature parts and character shapes.

Times Roman

The Bodoni plain scale and nonlinear scaling parameters were applied to a Times Roman reference image (a specimen of the word "Catilina"), and an entire size range was generated. Enlargements of the 8, 12, and 44 point synthetic images were made and can be compared to original 8, 12, and 44 point English Monotype Times Roman specimens. The plain scale versions come from a 12 point phototypesetting specimen and can be compared against the original Times Roman design.The comparison is a little difficult to judge because the Bodoni model will tend to make a design behave in the "predicted" way and the original design that the model is applied to may not have been designed to "look" that way.

1. *Evaluation of original handcut fonts* (Times Roman CWO). The original English Monotype Times Roman specimens show that over the size range, 8 to 44 point, the horizontal stroke weight does not significantly change. The characters become gradually more narrow with thinner serifs and a smaller x-height. Generally, the hairlines behave in the "predicted" manner and at large sizes share a certain harmony to the finer serifs. The counterforms change in relation to the condensation of the character while the overall design stays relatively constant.

2. *Comparison of small, medium, and large plain and nonlinear scale compared to the originals using the enlargements and at real size* (Times Roman EHR). The 8 point plain scale has overall proportionally lighter features than the 8 point nonlinear specimens

but is slightly heavier than the 8 point original Times Roman. The original has wider characters, thinner hairline and serif weights with approximately the same stroke weights as the plain scale specimens. The nonlinear specimen is excessively heavy in horizontal and vertical stroke weights and does not match the 8 point original Times Roman specimen but better approximates the 8 point original Bodoni specimen. The 8 point original Bodoni specimens had proportionally heavier horizontal and vertical stroke weights which the nonlinear Times Roman specimens inherited by using the Bodoni model.

The 12 point plain scale and the nonlinear specimen are heavier in horizontal and vertical weights than the original. The 12 point original has lighter horizontal and vertical stoke weights in the stem, hairline and serifs than the plain scale version. The nonlinear specimen is the heaviest of the grouping with a horizontal and vertical stroke weight that is twenty-five percent heavier than the original. This reflects the behavior of the original Bodoni fonts rather than the the behavior of the original Times Roman specimen.

The 44 point specimens show the same basic similarities that the smaller sizes have in inheriting characteristics from the Bodoni model. The plain scale version does not get lighter, finer, narrow, or more sculpted as the original design does. The nonlinear specimen gets a lot lighter in both horizontal and vertical directions but lacks any graceful refinement that the original has. In fact, it gets so much lighter that there are problems where the arch of the lowercase "n" connects to the main stroke and on the lowercase two-story "a" where the lower bowl connects to the main stroke. This overall lightness is not characteristic of the original Times Roman design but much more similar to the Bodoni design.

3. *Evaluation of plain and nonlinear scaling model over the entire size range at real size for both high and low resolution* (Times Roman RS). At real size the small sizes of the plain scale specimens look very light and weak. This lightness in the small sizes

makes the whole size range looks uneven in overall weight. The larger sizes appear proportionally too dark and weighty. The nonlinear specimens have almost the opposite effect, being heavy and dark at small sizes and a little too light and narrow at large sizes. Overall, a more even effect of gaining a little weight at small sizes and losing a little weight at large sizes, especially in the horizontal strokes, was desirable.

Helvetica

The Akzidenz Grotesque plain scale and nonlinear scaling parameters were applied to a Helvetica reference image (a specimen of the word "Catilina"), and an entire size range was generated. Enlargements of the 8, 12, and 36 point synthetic images were made and will be compared to original 8, 12, and 36 point Stempel foundry Helvetica specimens. The plain scale versions come from a 12 point phototypesetting specimen and can be compared against the original Helvetica design. The comparison between Akzidenz Grotesque and Helvetica is easier to judge because the Akzidenz Grotesque design is very similar to the Helvetica design.

1. *Evaluation of original handcut fonts* (Helvetica CWO). The enlargements of original 8, 12, and 36 point Helvetica specimens are interesting to analyze. They show that the horizontal and vertical stroke weights, x-height, character widths, and counter forms are almost uniform over the size range. The larger sizes have a sharper, cleaner edge giving it a more refined sculptural look which is more characteristic of larger designs.The biggest difference between the sizes is the way the character spacing is handled, which this study does not address. Overall the Helvetica design exhibits very little of the "predicted" behavior.

2. *Comparison of small, medium, and large plain and nonlinear scale compared to the originals using the enlargements and at real size* (Helvetica EHR). The 8 point plain scale specimen is heavier in horizontal and vertical stroke weight than the original. This

makes the character widths a little wider and the bowls more enclosed than the original. The original is proportionally lighter and and wider set than both the plain and nonlinear specimens. The nonlinear is proportionally the heaviest in overall weight and is slightly wider in character widths. The extra weight tends to fill in the counters on the lowercase "a" and render the character almost illegible. The x-height is constant for all sizes. This is the behavior of Akzidenz Grotesque at small sizes also.

The 12 point plain scale specimen is thicker in horizontal and vertical weight but is overall a closer match to the original than the nonlinear specimen. The horizontal stroke weight of the nonlinear specimen is the heaviest of the grouping and produces wider characters which have relatively smaller counter forms. The original has thinner stroke weights and therefore more open counter forms.

All the 36 point specimens look quite similar and the differences are very subtle. The plain scale specimen is slightly heavier in horizontal and vertical stroke weight, has wider character widths and subtly different counter forms than the original. The nonlinear specimen is closer to the original in horizontal and vertical stroke weight, character widths, and counter forms. The original has a wider more sculpted counterform in the lowercase "a" than either the 8 or 12 point design but otherwise the design remains roughly proportional to the smaller sizes.

3. *Evaluation of plain and nonlinear scaling model over the entire size range at real size for both high and low resolution* (Helvetica RS). At real size the smaller sizes of the plain scale specimens look weak and extra small. The nonlinear specimens have a legibility problem due to counter forms of characters filling in and tight spacing which becomes less visible at 8 point. Then it can be seen that the size range has a more uniform, even look which the plain scale size range does not have.

Low Resolution

All six fonts used in this study were converted to low resolution and can be seen in the ELR figures in each illustration set. The small, medium, and large sizes were enlarged to 5/8 inch so that a more detailed examination could be made. They are also shown at real size in comparison to the original specimens which they are modeling and in a full size range.

It is difficult to make any conclusive statements about them visually because of how rough the characters look after using the simple scan conversion technique going from high resolution to low resolution characters. There the problem is that the small size characters have the fewest pixels, and consequently look very jagged with irregular horizontal and vertical stroke weights. More "intelligent" scan conversion techniques could have maintained horizontal and vertical stoke weights but this one did not. The human eye can smooth over many of these irregularities in the small sizes as can be seen in viewing the low resolution specimens at real size. The visual review is therefore limited and the following mathematical analysis will be discussed.

The most interesting issue of the application of the nonlinear model to low resolution fonts is the discovery of the range of resolution over which it can be applied. Consider the two automatic scaling techniques discussed in this research: plain scaling and nonlinear scaling. The main difference between them is the nonlinear model allows for growth:

nonlinear scaling equation $d = A(h)D + B(h)$

plain scaling equation $d = (h/H)D$

It is assumed that both scaling models will work at high resolution. This can be seen by looking at the high resolution specimens which were generated at 1200 spots per inch. The following equation is a guide in calculating the the lower resolution at which the nonlinear model is applicable.

Assume that the scaling term A(h) has rounded to zero and that B(h) is the only term left to (possibly) return a value. Then it is interesting to discover when B(h) > .5 pixels at a given resolution.

With the base equation $B(h)/250 > .5/R$

where B(h) values are in 1/10 mm

1/10 mm = 1/250 inch

and R = resolution

Solve for R : $R > 125/B(h)$

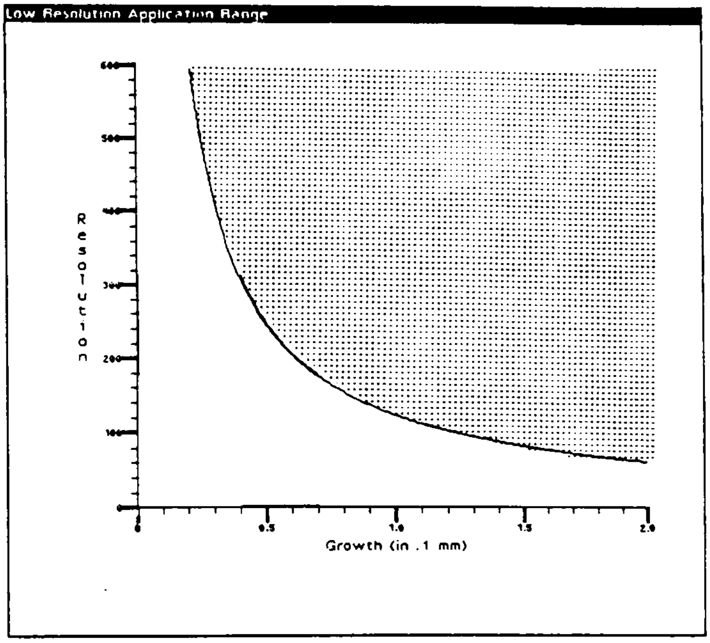


Figure 37. Range of resolution for which the nonlinear scaling model can be applied using the values of B_v and B_h

The above graph illustrates this equation. Given B(h) values from the three most successful fonts in this study where growth varied from .4 to .7 (discarding the Clarendon data), it can be seen that the lowest working resolution, conservatively speaking, is 200 spots per inch. At resolutions less than that the B(h) value can be zero and have no effect. When that happens, A(h) is the only term left in the equation and it is considered roughly equivalent to the plain scaling model.

For resolutions greater than 200 spots per inch the growth term, B(h), will be greater than .5 pixels and therefore have the possible effect of adding weight. This is especially useful for type designs whose hairline or thin weights might be totally lost due to roundoff error at low resolutions. For designs such as Bodoni this effect can be seen at the small sizes by comparing the plain and nonlinear scale techniques. This leads to some interesting ideas about what designs are better suited to low resolution conversion for different scaling techniques.

For plain scaling low resolution designs it is better to start with a design that doesn't have really thin hairline and serif weights to maintain or is overall a "light" design (for example Helvetica Light). The more contrast there is in a design, the more likely for the hairlines and serifs to disappear with plain scaling at lower resolutions. Instead, a design which is more even in horizontal and vertical weight would be an easier to maintain finer features. To go to the extreme of horizontal and vertical evenness in a type design, for example Akzidenz Grotesque or Helvetica, the design will be maintained as long as features like stem width are greater than .5 pixels. If stem width were less than .5 pixels then the whole design disintegrates. This would affect "lighter" weight designs more readily than Roman designs.

The nonlinear scaling model is more adaptable at scaling higher contrast and lighter low resolution type designs because the growth factor enables adding weight, even if the scale factor rounds the distance to zero. It is also hypothesized that the nonlinear scaling model might be especially useful with italic designs since they tend to be lighter with finer details.

CHAPTER VIII

CONCLUSIONS

As an introduction, the hypotheses will be restated to refresh the reader of the original intent of this research. They will be followed by conclusions made by this research.

1. *Handcut fonts have nonlinear design characteristics over a range of sizes.*

2. *This nonlinear behavior can be modelled mathematically using quadratic feature equations.*

3. *The typographic features and characters which were measured in this study provide, typographically, a solid basis for a model of optical scale in type design.*

4. *The nonlinear scaling model will be more successful at scaling low resolution fonts than plain scaling techniques.*

It can be concluded from this research that handcut fonts do have nonlinear design characteristics especially at small sizes. These features in particular were determined to be nonlinear within the size range under consideration:

1. left m counter width	Akzidenz
2. upper case stem width	Caslon, Bodoni
3. capital letter width M	Caslon, Clarendon
4. capital letter width H	Caslon, Akzidenz
5. capital letter width O	Caslon Bodoni, Akzidenz
6. capital letter width V	Clarendon, Bodoni, Akzidenz
7. capital letter width R	Caslon, Bodoni

8. capital letter width S	Caslon, Bodoni
9. character width m	Bodoni
10. character width x	Bodoni
11. lower case o bowl width	Caslon
12. lower case q bowl width	Caslon, Akzidenz
13. x height	Caslon
14. ascender height	Caslon, Clarendon, Bodoni
15. descender height	Caslon, Clarendon
16. lower case o bowl height	Caslon
17. capital letter H cross bar width	Caslon

These features, on the other hand, behaved linearly:

1. right m counter width
2. lower case stem width
3. lower case e cross bar width
4. lower case o bowl width

The original handcut fonts from Bodoni show the strongest trend toward "predicted" behavior. The small fonts have wider and thicker stroke, serif, and hairline weights, larger x-heights, and more enclosed counters. As they increase in size, the characters become more narrow, stroke, serif and hairline weights become proportionally lighter, the x-height proportion decreases, the counters become more open and airy and the design evolved toward a more sculpted, chiseled look.

Quadratic feature equations seem to be good for modeling optical scale in type design. Some of the models in this study produced letters that looked like the original handcut fonts. Some of the original fonts measured in this study did not demonstrate the "predicted" behavior and it was difficult to model their inconsistencies with quadratic equations. The quadratic equations that were most successful were for fonts that had an overall consistency of design. The nonlinear model produced scale and growth factors that did at least as well or better than plain scaling at small sizes and reasonably well at large sizes. This technique shows promise.

When the models were applied to fonts other than those used to generate them, they produced results that looked more like the original design than the design they were being applied to. The effect was to influence the design with the design characteristics of that particular model. For most designs, applying the nonlinear scaling model can be a simple approach which will increase legibility of designs, especially at small sizes.

A knowledge of the type design process was central to the selection of typographic features and the designing of the nonlinear scaling model. It can be seen from the illustrations that the nonlinear scaling model did produce characters with the "predicted" behavior.

The lowest working resolution for the nonlinear model was calculated by determining when the growth term, B(h), would be greater than .5 pixels. Using sample values of B(h) from the data, it was discovered that if the resolution is less than 200 spots per inch then B(h) can be less than .5 pixels. This is when the nonlinear model becomes the same as the plain scaling model. For resolutions of greater than 200 spots per inch the growth term can be used to produce the effects of optical scale in handcut fonts. With current printing technology, this primarily affects low resolution dot matrix printers and cathode ray tube screen fonts.

CHAPTER IX

RECOMMENDATIONS FOR FURTHER INVESTIGATION

In this study there were thirteen features and twelve characters being measured for every available point size in a given font. This was an extremely large amount of data to manage and from which to extract useful information. In retrospect, the study could have streamlined this phase by building the scaling model on two features, like stem width and hairline weight, and using them as the primary features. It would be useful to determine these one or two important features and see how they relate to type designers ideas about design.

This research concentrated on optical scale of handcut Roman designs. It would also be valuable to study the relations of optical scale in Italic, Bold, and Bold Italic handcut fonts (where a homogeneous size range and design is available). The streamlining of the measuring process just mentioned would be extremely helpful for such a future investigation.

Given that this research produced a set of linear equations based on the very same measurments that the quadratic equations are based upon, it would have been interesting to generate letters with them and compare them to "phototypesetting" proportional scale factors. Regression and numerical analysis could have been performed on them and horizontal and vertical linear scale factors could have been calculated. These could then have been compared numerically and visually, the visual comparison being the more important.

In the numerical analysis phase of this research, the error was averaged equally over all the features of a given type. Another approach might be tried, in which features were weighted by some method, perhaps according to frequency of use or feature frequency at a given capital letter height or a feature hierarchy based on type design practices.

Of the four parameters generated for the nonlinear scaling model, it was the vertical growth factor that was the least successful in modeling optically sound letterforms. Additional study is needed to understand why this parameter in particular showed the sensitivity it did. Better methods are needed to derive scale and growth factors.

There is a lot of interest in discovering and creating a more generalized approach to the automatic optical scaling of type designs. This research went as far as creating a letterfom scaling model for a given font. It would be possible to use the two most successful letterform scaling models to try to produce a general letterform scaling model that could be applied to any font. A method that might be used for such a model might be as follows. Using the two nonlinear scaling models, build a more general model by averaging the horizontal and vertical scaling and growth factors. Test them by generating letters and visually analyze them. A series of iterative tests could take place where the scale factors could be incremented and decremented and letters generated. This would produce a series of letters across a range of visual acceptability. This would determine the latitude for each of the values for each of the fonts where the range of data would provide information about a more general model of optical scale in type design.

As a final suggestion, one might analyze the specification set up by the scientific commission in 1692 to revise the typography of the Imprimerie Royale. It would be interesting to know what part of the specification was not used when Grandjean "let his eye be the supreme judge."[1]

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[1]Andre Jammes, La Reforme de la Typographie Royale Sous Louis XIV Le Grandjean (Paris: Libraire Paul Jammes, 1961) p. 27.

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APPENDIX I

NUMERICAL ANALYSIS

This appendix describes the details of deriving the parameters for the nonlinear scaling model.

The following features were selected for measuring: x-height, bowl width, stem width, serif length, serif width, ascender height, descender depth, average counter width of lowercase "m", total character width (serif edge to serif edge), and capital letter height. The following characters were selected for measuring the above listed features: R, M, S, H, V, O, a, h, m, o, q, and x.

Once the features were measured over a range of sizes, the data was plotted and linear and quadratic equations were derived through regression analysis. The quadratic equations were used for the numerical analysis because it was thought that they would fit the data better than the linear equations.

The two scaling models under comparison in this research are the following:

plain scaling model $d = (h/H)\,D$

nonlinear scaling model $d = A(h)D + B(h)$

where d = new length
$A(h)$ = scale factor
D = reference length
$B(h)$ = growth factor
h = new height
H = reference height

The goal of this research was to use the nonlinear scaling model to generate letters and compare them to handcut fonts. This was done by taking the feature equations as input and through numerical analysis calculating the scaling parameters A_h, A_v, B_h, and B_v for each size of a given font. First the features were typed according to what kind of distance measurement they were. Listed below are the classifications of the measurements types. See figure 38.

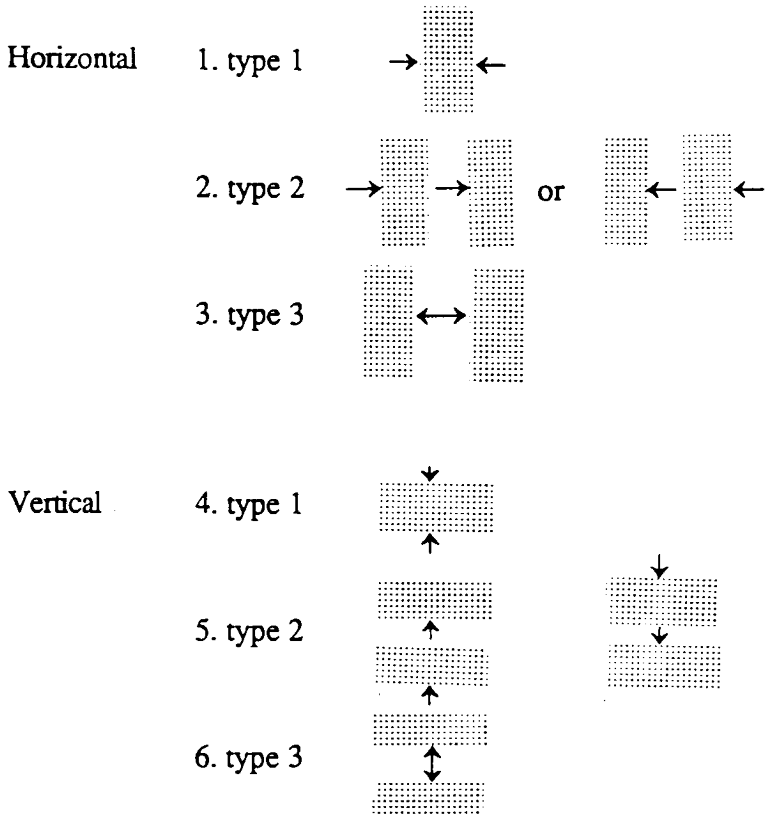

Figure 38 . Classifications of horizontal and vertical measurements

For each distance type of any feature measured, scale and growth factors were implemented as follows. See figure 39.

	type 1	type 2	type 3
Scaling by A	Ad	Ad	Ad
Growth by B	d + B	d	d - B
Scaling by A and Growth by B	Ad + B	Ad	Ad - B

Where: A = Scale factor
B = growth factor
d = feature value

Figure 39. Implementation of scale and growth factors.

The explanation will start first by calculating the horizontal parameters. With the original feature versus capital letter height data, $d_i(h) = ah^2 + bh + c$, where d_i represents some measured feature and h represents the capital letter height, the least-mean-square error was derived:

$$d_i'(h) = A(h)D_i + B(h)S_i$$

where $S_i = +1, 0, -1$ depending upon the feature type

(see figure 38 to note feature types)

D_i = value of the i^{th} feature on the12 point capital letter height

The error for all the features at a given height was calculated by:

$$E(h) = 1/N_h \sum_{i=1}^{N_h} (d_i(h) - d_i'(h))^2$$

where N = number of horizontal features considered

and E = least-mean-square error

Minimizing with respect to A(h) and B(h) to make the error be as small as possible:

$$\frac{\delta E(h)}{\delta A(h)} = 0 \qquad \frac{\delta E(h)}{\delta B(h)} = 0$$

which by substitution then becomes:

$$(\Sigma S_i D_i)\, A(h) + (\Sigma\, S_i^2)\, B(h) = \Sigma\, S_i\, (ah^2 + bh + c)$$

$$(\Sigma D_i^2)\, A(h) + (\Sigma\, S_i D_i)\, B(h) = \Sigma\, D_i\, (ah^2 + bh + c)$$

This is a system of two linear equations with two unknowns and can be solved for A(h) and B(h) for all horizontally measured features.

To calculate the vertical parameters, A_V, B_V, a similar operation was repeated except that the twelve point capital letter height must map exactly on the regression line because they were used as "masters" to generate the full size range of synthetic characters from the new nonlinear scaling model.

The vertical measurement of capital letter height needed to be tightly controlled so that the heights over a range of sizes corresponded to the heights of the original characters measured.

$$A(h)H + B(h) = h$$

$$B(h) = h - A(h)H$$

where: H = 12 point capital letter height
A = scale factor
B = growth factor

And to further calculate the vertical least-mean-square error:

$$E = 1/N_V \sum_{i=1}^{N_V} (ah2 + bh + c - A(h)D_i - (h - A(h)D_i)S_i)^2$$

To minimize with respect to A(h):

$$\frac{\delta E(h)}{\delta A(h)} = 0$$

which returns:

$$\sum_{i-1}^{N_V} (D_i - S_i D_i)^2 \ A(h) = \sum_{i-1}^{N_V} (D_i - S_i D_i)(ah^2 + bh + c - hS_i)$$

and from this equation A(h) can be solved for. The final result is the two vertical parameters.

APPENDIX II

FEATURE EQUATIONS

This appendix contains a list of the linear and quadratic feature equations for all four fonts in this research. These equations are a result of linear and quadratic regression analysis performed on the data and represent the best fit of a line or curve to the measured data. The fonts are represented by specific code numbers as follows: Caslon - 01, Clarendon - 02, Bodoni - 03, Akzidenz - 04. The following features are included in this list.

1. average m counter width
2. stem width
3. capital letter width
4. lowercase bowl width
5. serif width
6. serif length
7. capital letter height
8. x-height
9. ascender height
10. descender depth
11. lowercase o bowl height
12. capital letter H cross bar width
13. lowercase e cross bar width.

For the following equations:

let y = predicted value

x = capital letter height

s = standard deviation

left "m" counter width

01	$y = -1.14 + .289\ x$ $s = 0.7499$	$y = -.432 + .249\ x + .0004x^2$ $s = 0.7808$
02	$y = 1.49 + .227\ x$ $s = 0.4426$	$y = 1.38 + .231\ x - .0000\ x^2$ $s = 0.4640$
03	$y = .110 + .223\ x$ $s = 0.5425$	$y = -.984 + .287\ x - .0007\ x^2$ $s = 0.4839$
04	$y = -1.26 + .302\ x$ $s = 0.8132$	$y = .619 + .199\ x + .0010\ x^2$ $s = 0.4835$

right "m" counter width

01	$y = -1.01 + .249\ x$ $s = 0.6385$	$y = -.587 + .270\ x + .0003\ x^2$ $s = 0.6738$
02	$y = 1.70 + .223\ x$ $s = 0.5080$	$y = 1.44 + .232\ x - .0000\ x^2$ $s = 0.5146$
03	$y = -.0058 + .233\ x$ $s = 0.4835$	$y = -.778 + .278\ x - .0005\ x^2$ $s = 0.4588$
04	$y = -1.21 + .304\ x$ $s = 0.5856$	$y = .0339 + .236\ x + .0007\ x^2$ $s = 0.4028$

upper case stem width

01	$y = .336 + .146\ x$ $s = 0.3879$	$y = 2.12 + .0075\ x + .0025\ x^2$ $s = 0.3268$
02	$y = -.251 + .196\ x$ $s = 0.3100$	$y = .0797 + .185\ x + .0001\ x^2$ $s = 0.2641$
03	$y = .702 + .142\ x$ $s = 0.6677$	$y = 2.61 + .0272\ x + .0013\ x^2$ $s = 0.4875$
04	$y = 1.16 + .109\ x$ $s = 0.5192$	$y = .319 + .148\ x - .0003\ x^2$ $s = 0.3925$

lower case stem width

01	$y = .494 + .113\ x$ $s = 0.5970$	$y = -.517 + .170\ x - .0006\ x^2$ $s = 0.5675$
02	$y = .0918 + .152\ x$ $s = 0.5361$	$y = -.617 + .178\ x - .0001\ x^2$ $s = 0.3650$
03	$y = .885 + .0939\ x$ $s = 0.5143$	$y = 1.20 + .0754\ x + .0002\ x^2$ $s = 0.5172$
04	$y = .865 + .100\ x$ $s = 0.4043$	$y = .522 + .117\ x - .0001\ x^2$ $s = 0.3866$

capital letter width M

01	$y = .524 + 1.30\ x$ $s = 1.266$	$y = -3.21 + 1.58\ x - .0049\ x^2$ $s = 1.258$
02	$y = -.465 + 1.40\ x$ $s = 3.406$	$y = 4.68 + 1.15\ x + .0017\ x^2$ $s = 2.282$
03	$y = 3.44 + 1.09\ x$ $s = 2.162$	$y = 3.09 + 1.11\ x - .0002\ x^2$ $s = 2.248$
04	$y = .123 + .936\ x$ $s = 0.2297$	$y = -1.48 + 1.06\ x - .0009\ x^2$ $s = 0.07025$

capital letter width H

01	$y = .450 + 1.10\ x$ $s = 2.165$	$y = -7.74 + 1.73\ x - .0107\ x^2$ $s = 1.998$
02	$y = 5.04 + 1.12\ x$ $s = 3.465$	$y = .263 + 1.29\ x - .0008\ x^2$ $s = 2.372$
03	y = insufficent data	y = insufficent data
04	$y = .981 + .799\ x$ $s = 0.4224$	$y = 1.82 + .732\ x + .0010\ x^2$ $s = 0.4527$

capital letter width O

01	$y = 3.33 + .878\ x$ $s = 1.637$	$y = -2.17 + 1.19\ x - .0034\ x^2$ $s = 1.038$
02	$y = -2.18 + 1.01\ x$ $s = 1.620$	$y = -1.57 + .992\ x + .0001\ x^2$ $s = 1.676$
03	$y = .501 + .905\ x$ $s = 1.790$	$y = 2.26 + .802\ x + .0011\ x^2$ $s = 1.799$
04	$y = 2.80 + .836\ x$ $s = 0.5976$	$y = .674 + .978\ x - .0016\ x^2$ $s = 0.2103$

capital letter width V

01	$y = 3.66 + .874\ x$ $s = 0.8593$	$y = 3.84 + .857\ x + .0004\ x^2$ $s = 0.9921$
02	$y = 1.56 + 1.18\ x$ $s = 1.226$	$y = 15.9 - .345\ x + .0386\ x^2$ $s = 1.324$
03	$y = .548 + .984\ x$ $s = 1.157$	$y = 15.1 - .780\ x + .0516\ x^2$ $s = 1.216$
04	$y = 2.29 + .785\ x$ $s = 1.010$	$y = .717 + .884\ x - .0012\ x^2$ $s = .9555$

capital letter width R

01	$y = -.527 + 1.03\ x$ $s = 1.259$	$y = 10.0 + .0216\ x + .0224\ x^2$ $s = 1.186$
02	$y = 1.51 + 1.10\ x$ $s = 2.071$	$y = 1.07 + 1.12\ x - .0001\ x^2$ $s = 2.199$
03	$y = 2.16 + .864\ x$ $s = 2.073$	$y = 8.34 + .512\ x + .0039\ x^2$ $s = 1.636$

04	$y = -.336 + .812\ x$ $s = 0.6806$	$y = -.131 + .802\ x + .0001\ x^2$ $s = 0.7076$

capital letter width S

01	$y = .930 + .576\ x$ $s = 0.3358$	$y = 2.03 + .471\ x + .0023\ x^2$ $s = 0.3776$
02	$y = .266 + .804\ x$ $s = 1.393$	$y = -.718 + .838\ x - .0002\ x^2$ $s = 1.368$
03	$y = 1.61 + .591\ x$ $s = 0.6313$	$y = .974 + .639\ x - .0008\ x^2$ $s = 0.6589$
04	$y = .963 + .781\ x$ $s = 0.9868$	$y = -.404 + .856\ x - .0007\ x^2$ $s = 0.9042$

character width m

01	$y = -1.43 + 1.15\ x$ $s = 1.779$	$y = -.597 + 1.10\ x + .0005\ x^2$ $s = 1.890$
02	$y = 5.91 + 1.14\ x$ $s = 3.422$	$y = .610 + 1.33\ x -.0009\ x^2$ $s = 1.601$
03	$y = 4.97 + .869\ x$ $s = 2.174$	$y = 1.65 + 1.06\ x - .0021\ x^2$ $s = 2.080$
04	$y = .509 + .908\ x$ $s = 0.6668$	$y = 1.02 + .880\ x + .0003\ x^2$ $s = 0.6761$

character width x

01	y = insufficent data	y = insufficent data
02	$y = 2.26 + .865\ x$ $s = 0.8890$	$y = 2.22 + .868\ x - .0000x^2$ $s = 1.089$
03	$y = -.234 + .748\ x$ $s = 0.7252$	$y = 5.07 + .172\ x + .0148\ x^2$ $s = 0.7131$
04	y = insufficent data	y = insufficent data

lower case o bowl width

01	$y = -2.24 + .430\ x$ $s = 0.7116$	$y = -.597 + .337x + .0010\ x^2$ $s = 0.6323$
02	$y = 1.19 + .317\ x$ $s = 1.464$	$y = -.0638 + .361\ x - .0002\ x^2$ $s = 1.348$
03	$y = -1.74 + .353\ x$ $s = 0.6795$	$y = -1.51 + .339\ x + .0001\ x^2$ $s = 0.7027$
04	$y = -.775 + .396\ x$ $s = 0.7746$	$y = .332 + .345\ x + .0004\ x^2$ $s = 0.6356$

lower case q bowl width

01	$y = -2.09 + .393\ x$ $s = 1.239$	$y = 1.05 + .216\ x + .0019\ x^2$ $s = 1.052$
02	$y = .988 + .300\ x$ $s = 1.178$	$y = .210 + .327\ x - .0001\ x^2$ $s = 1.154$
03	$y = -1.23 + .338\ x$ $s = 0.6985$	$y = -1.70 + .365\ x - .0003\ x^2$ $s = 0.7142$

04	$y = 5.14 + .189\, x$ $s = 4.378$	$y = -3.67 + .599\, x - .0032\, x^2$ $s = 2.212$

upper case serif width

01	$y = -.266 + .113\, x$ $s = 1.053$	$y = 3.64 - .203\, x + .0058\, x^2$ $s = 0.9497$
02	$y = .462 + .139\, x$ $s = 0.6141$	$y = .927 + .118\, x + .0001\, x^2$ $s = 0.5656$
03	$y = 1.14 + .0294\, x$ $s = 0.3019$	$y = 1.78 - .0097\, x + .0004\, x^2$ $s = 0.2645$
04	y = sanserif	y = sanserif

upper case serif length

01	$y = .463 + .408\, x$ $s = 1.142$	$y = 1.99 + .284\, x + .0023\, x^2$ $s = 1.157$
02	$y = 1.72 + .534\, x$ $s = 1.744$	$y = -.749 + .644\, x - .0006\, x^2$ $s = 0.9612$
03	$y = 2.61 + .336\, x$ $s = 2.276$	$y = .892 + .441\, x - .0012\, x^2$ $s = 2.268$
04	y = sanserif	y = sanserif

lower case serif length

01	$y = -.905 + .341\, x$ $s = 0.7697$	$y = -.913 + .341\, x - .0000\, x^2$ $s = 0.7987$
02	$y = -.740 + .435\, x$ $s = 1.206$	$y = 1.40 + .342\, x + .0007\, x^2$ $s = 0.7320$
03	$y = 1.76 + .247\, x$ $s = 1.132$	$y = .303 + .332\, x - .0009\, x^2$ $s = 1.093$
04	y = sanserif	y = sanserif

capital letter height

01	$y = -.0000 + 1.00\, x$ $s = 0.5499$	$y = -.0000 + 1.00\, x + .0000\, x^2$ $s = 0.5566$
02	$y = .132 + .996\, x$ $s = 1.071$	$y = -.0838 + 1.00\, x - .0000 x^2$ $s = 1.075$
03	$y = -.0000 + 1.00\, x$ $s = 0.4641$	$y = .0039 + 1.0000\, x + .0000\, x^2$ $s = 0.4680$
04	$y = -.0001 + 1.0\, x$ $s = 0.6667$	$y = .0001 + 1.0\, x + 0.0\, x^2$ $s = 0.6736$

x height

01	$y = -.723 + .676\, x$ $s = 0.9872$	$y = 2.12 + .510\, x + .0018\, x^2$ $s = 0.7486$
02	$y = 2.61 + .638\, x$ $s = 2.989$	$y = -1.82 + .801\, x - .0008\, x^2$ $s = 1.645$
03	$y = .913 + .582\, x$ $s = 0.9618$	$y = 1.39 + .553\, x + .0003\, x^2$ $s = 0.9638$
04	$y = .227 + .684\, x$	$y = 1.56 + .618\, x + .0006\, x^2$

	$s = 0.8812$	$s = 0.7073$
ascender height		
01	$y = -.327 + .400\,x$ $s = 1.364$	$y = -4.59 + .640\,x - .0026\,x^2$ $s = 0.9655$
02	$y = -2.64 + .354\,x$ $s = 3.962$	$y = 2.90 + .160\,x + .0010\,x^2$ $s = 2.466$
03	$y = -.805 + .421\,x$ $s = 3.597$	$y = 2.24 + .243\,x + .0019\,x^2$ $s = 3.646$
04	$y = -.860 + .327\,x$ $s = 0.5329$	$y = -1.30 + .347\,x - .0002\,x^2$ $s = 0.5224$
descender height		
01	$y = -.272 + .410\,x$ $s = 0.8220$	$y = -1.99 + .507\,x - .0011\,x^2$ $s = 0.7605$
02	$y = -4.45 + .356\,x$ $s = 3.532$	$y = .820 + .173\,x + .0009\,x^2$ $s = 1.539$
03	$y = -1.09 + .460\,x$ $s = 0.8244$	$y = -2.16 + .523\,x - .0007\,x^2$ $s = 0.8073$
04	$y = -1.42 + .329\,x$ $s = 0.9578$	$y = -.169 + .260\,x + .0007\,x^2$ $s = 0.8930$
lower case o bowl height		
01	$y = -3.37 + .615\,x$ $s = 1.158$	$y = .466 + .398\,x + .0024\,x^2$ $s = 0.7504$
capital letter H cross bar height		
01	$y = .465 + .0817\,x$ $s = 0.6384$	$y = 4.38 - .217\,x + .0051\,x^2$ $s = 0.3417$
lower case e cross bar height		
01	$y = .428 + .0550\,x$ $s = 0.3508$	$y = -.319 + .0971\,x - .0005\,x^2$ $s = 0.3224$

APPENDIX III

SCALING DATA

This appendix contains parameters for the plain and nonlinear scaling models. These parameters were applied to the 12 point handcut reference image to generate the full size range of plain and nonlinear scale specimens.

<u>Nonlinear scale model scaling parameters</u>

Let A_h = horizontal scale

A_v = vertical scale

B_h = horizontal growth factor

B_v = vertical growth factor

Caslon nonlinear scale and growth factors (units are in .1 mm)

pt.size	cap ht.	A_h	A_v	B_h	B_v
6	14.132	.469	.459	.398	.716
8	17.776	.592	.593	.291	.427
10	22.432	.751	.761	.199	.161
11	25.891	.871	.884	.162	.040
12	29.246	.987	1.00	.152	-.015
14	30.616	1.04	1.05	.155	.020
18	35.880	1.22	1.22	.206	.054
22	44.974	1.54	1.52	.441	.538
28	60.470	2.10	1.99	1.27	2.40
36	77.463	2.75	2.45	2.80	5.92

Clarendon nonlinear scale and growth factors (units are in .1 mm)

pt.size	cap ht.	A_h	A_v	B_h	B_v
5	13.913	.439	.444	-.302	-1.10
6	17.312	.540	.540	-.277	-.942
8	19.752	.612	.609	-.257	-.828
10	25.116	.770	.760	-.207	-.566
12	33.790	1.03	1.00	-.110	-.113
18	48.438	1.45	1.41	.099	.730
22	58.710	1.76	1.70	.279	1.38
28	71.800	2.14	2.06	.549	2.28
36	86.926	2.57	2.50	.916	3.42

Bodoni nonlinear scale and growth factors (units are in .1 mm)

pt.size	cap ht.	A_h	A_v	B_h	B_v
5	12.493	.456	.414	.796	.398
6	14.975	.536	.505	.714	.357
7	16.751	.593	.570	.657	.329
8	19.233	.673	.661	.579	.289
9	21.654	.751	.750	.504	.252
10	22.504	.779	.780	.477	.239
11	26.650	.912	.932	.354	.177
12	28.216	.962	.990	.309	.154
14	33.830	1.14	1.20	.150	.075
18	39.207	1.31	1.39	.006	.003
20	44.790	1.49	1.60	-.136	-.068
22	51.138	1.69	1.82	-.286	-.143
24	68.160	2.23	2.44	-.638	-.319
28	75.688	2.47	2.71	-.799	-.340
36	75.619	2.43	2.67	-.752	-.376
44	79.916	2.60	2.86	-.837	-.419

Akzidenz Grotesque nonlinear scale and growth factors (units are in .1 mm)

pt.size	cap ht.	A_h	A_v	B_h	B_v
4	12.264	.389	.360	.646	.646
5	15.091	.474	.447	.609	.609
6	16.843	.527	.502	.586	.586
8	22.026	.683	.663	.523	.523
10	25.456	.786	.772	.483	.483
12	32.403	.993	.987	.410	.410
14	38.434	1.17	1.20	.351	.351
16	42.874	1.30	1.31	.312	.312
20	50.263	1.52	1.54	.254	.254

24	62.549	1.87	1.92	.177	.177
28	74.923	2.21	2.31	.126	.126
36	94.900	2.76	2.93	.093	.093

Helvetica nonlinear scale and growth factors using data from Akzidenz Grotesque (units are in .1 mm)

pt.size	cap ht.	A_h	A_v	B_h	B_v
4	12.264	.3877	.360	.6457	.6457
5	15.091	.4737	.447	.6085	.6085
6	16.843	.5267	.502	.5861	.5861
8	22.026	.6829	.663	.5228	.5228
10	25.456	.7857	.772	.4833	.4833
12	32.403	.9924	.987	.4091	.4091
14	38.434	1.1703	1.186	.3510	.3510
16	42.874	1.300	1.313	.3120	.3120
20	50.263	1.514	1.5301	.2542	.2542
24	62.549	1.866	1.9209	.177	.177
28	74.923	2.214	2.3065	.1253	.1253
36	94.900	2.7622	2.9118	.0932	.0932

Times Roman - nonlinear scale and growth factors using data from Bodoni (units are in .1 mm)

pt.size	cap ht.	A_h	A_v	B_h	B_v
5	12.493	.4557	.4065	.7955	.397
6	14.975	.5359	.5006	.7143	.357
7	16.751	.5933	.5678	.6571	.328
8	19.233	.6733	.6617	.5787	.289
9	21.654	.7513	.7531	.5037	.252
10	22.504	.7787	.7852	.4777	.239
11	26.650	.9119	.9414	.3538	.177
12	28.216	.9622	1.000	.3082	.1541
14	33.830	1.1420	1.211	.1499	.075
18	39.207	1.3136	1.412	.00607	.003
20	44.790	1.4914	1.620	-.1353	-.067
22	51.138	1.6928	2.485	-.6380	-.319
28	75.688	2.4651	2.761	-.7994	-.3997
36	74.619	2.4317	2.722	-.7517	-.376
44	79.916	2.5971	2.915	-.8370	-.418

Plain scale model scaling factors

Caslon linear scale factors (units are in .1 mm)

pt.size	cap ht.	scale factor
6	14.132	.48
8	17.776	.61
10	22.432	.77
11	25.891	.88
12	29.245	1.00
14	30.616	1.05
18	35.880	1.23
22	44.974	1.54
28	60.470	2.07
36	77.463	2.65

Clarendon linear scale factors (units are in .1 mm)

pt.size	cap ht.	scale factor
5	13.913	.41
6	17.312	.51
8	19.752	.58
10	25.116	.74
12	33.789	1.00
18	48.437	1.43
22	58.710	1.74
28	71.799	2.13
36	86.926	2.57

Bodoni linear scale factors (units are in .1 mm)

pt.size	cap ht.	scale factor
5	12.493	.44
6	14.975	.53
7	16.751	.59
8	19.233	.68
9	21.654	.76
10	22.504	.79
11	26.650	.94
12	28.216	1.00
14	33.830	1.20
18	39.206	1.39
20	44.790	1.59
22	51.138	1.81
24	68.160	2.41
28	75.688	2.69

36	74.618	2.64
44	79.916	2.83

Akzidenz Grotesque linear scale factors (units are in .1 mm)

pt.size	cap ht.	scale factor
4	12.264	.38
5	15.091	.47
6	16.843	.52
8	22.026	.68
10	25.456	.78
12	32.403	1.00
14	38.434	1.19
16	42.874	1.32
20	50.263	1.55
24	62.549	1.93
28	74.923	2.31
36	94.90	2.93

Times Roman linear scale factors (units are in .1 mm)
Using scaling data from Bodoni.

pt.size	cap ht.	scale factor
5	12.493	.44
6	14.975	.53
7	16.751	.59
8	19.233	.68
9	21.654	.76
10	22.504	.79
11	26.650	.94
12	28.216	1.00
14	33.830	1.20
18	39.206	1.39
20	44.790	1.59
22	51.138	1.81
24	68.160	2.41
28	75.688	2.69
36	74.618	2.64
44	79.916	2.83

Helvetica linear scale factors (units are in .1 mm)
Using scaling data from Akzidenz Grotesque

pt.size	cap ht.	scale factor
4	12.264	.38
5	15.091	.47
6	16.843	.52
8	22.026	.68
10	25.456	.78
12	32.403	1.00
14	38.434	1.19
16	42.874	1.32
20	50.263	1.55
24	62.549	1.93
28	74.923	2.31
36	94.90	2.93

APPENDIX IV

FEATURE GRAPHS

This appendix contains a set of feature graphs with linear, quadratic, and raw data plotted against capital letter height.

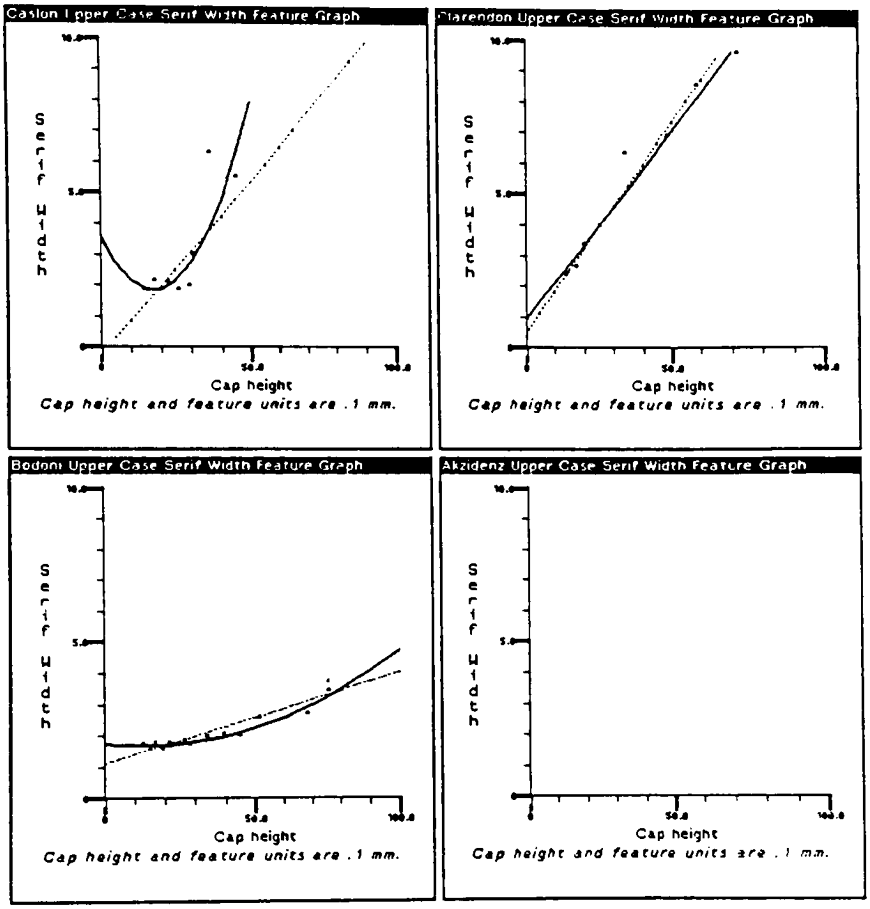

Figure 40. Upper case serif width.

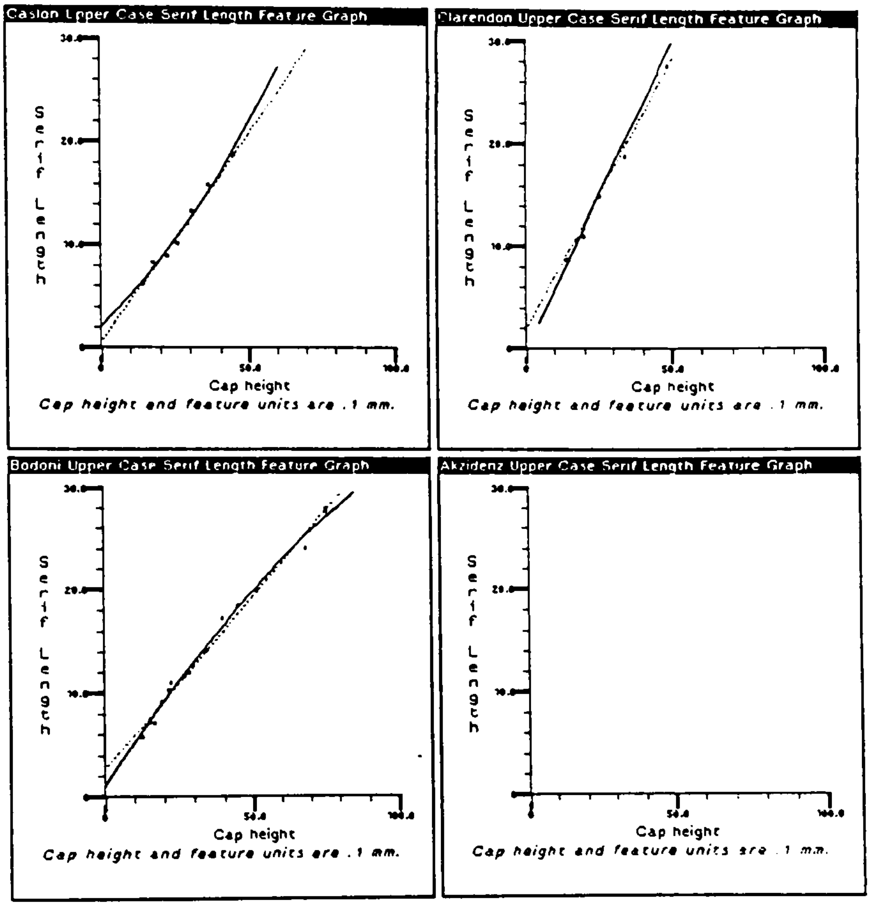

Figure 41. Upper case serif length.

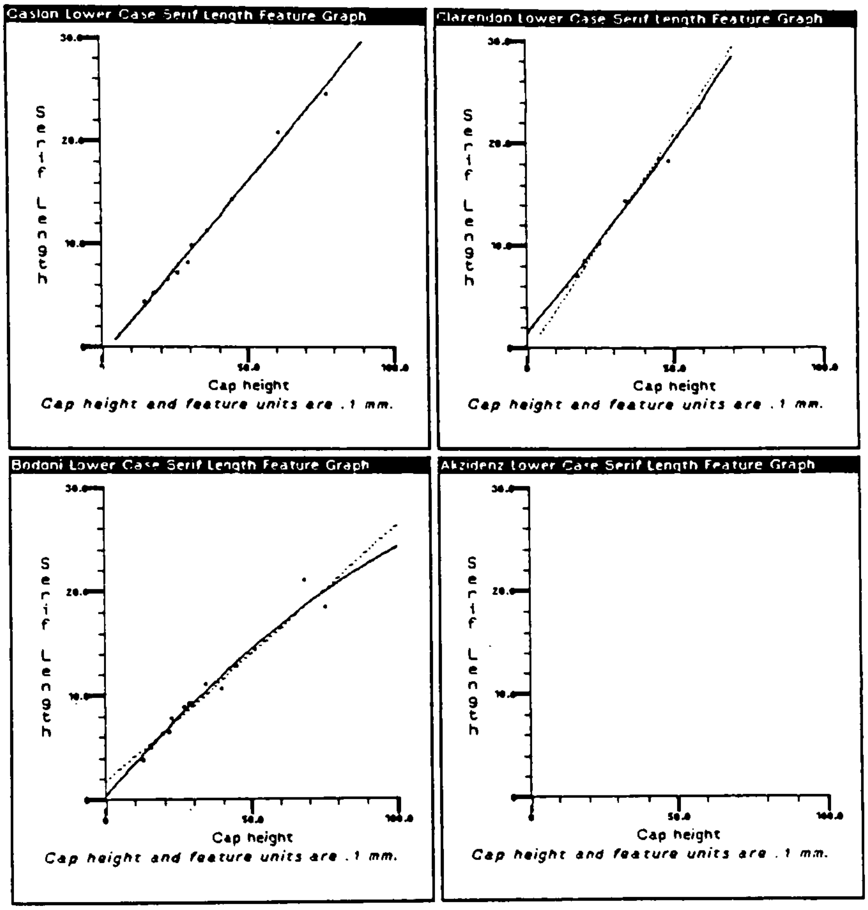

Figure 42. Lower case serif length.

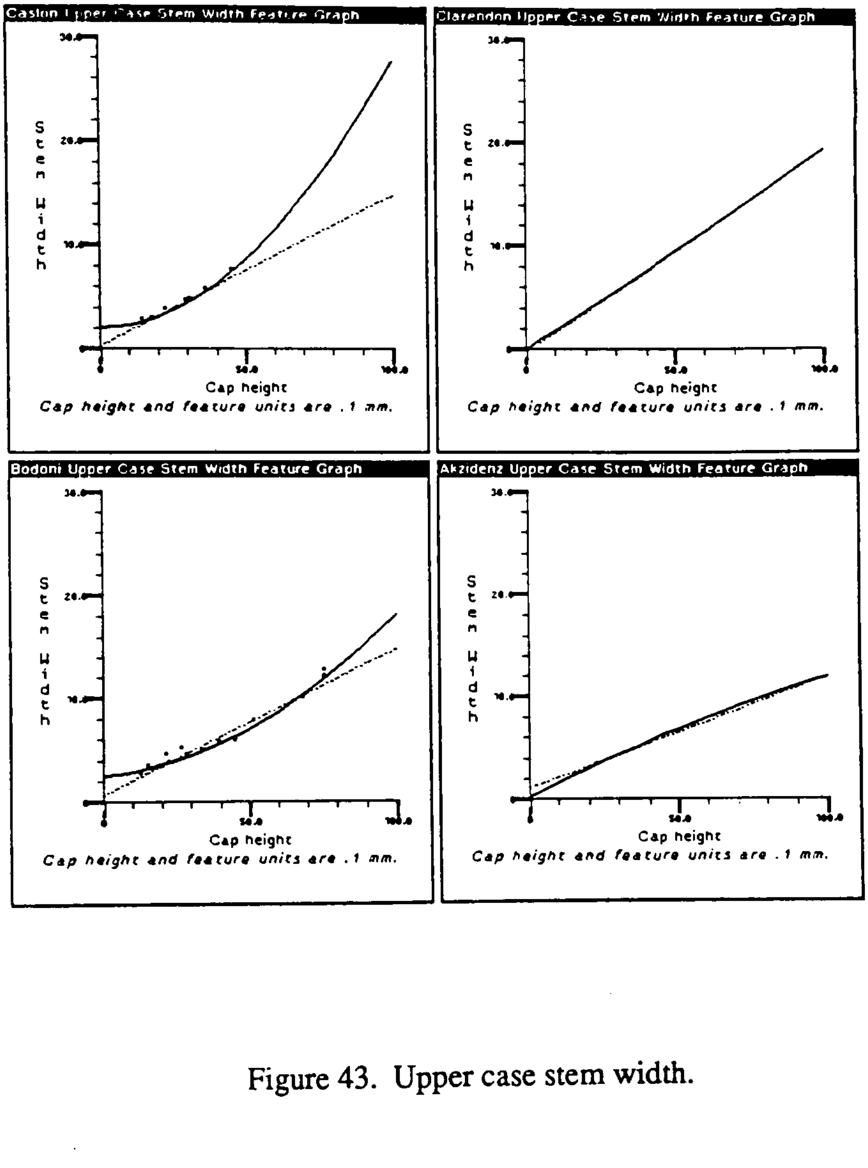

Figure 43. Upper case stem width.

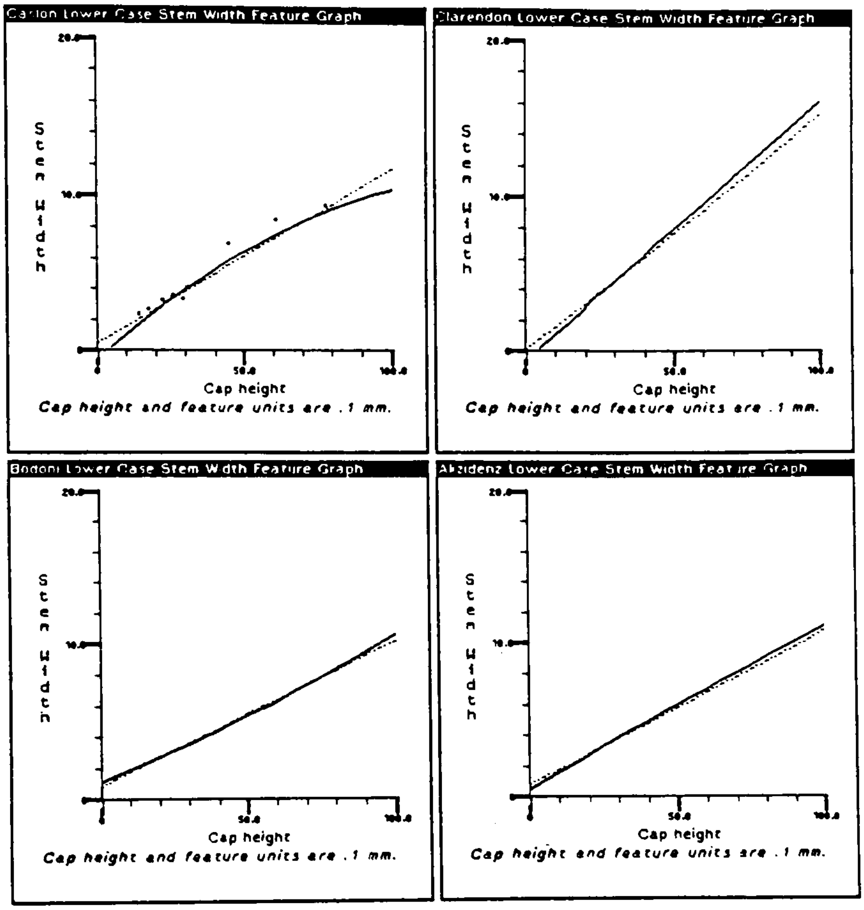

Figure 44. Lower case stem width.

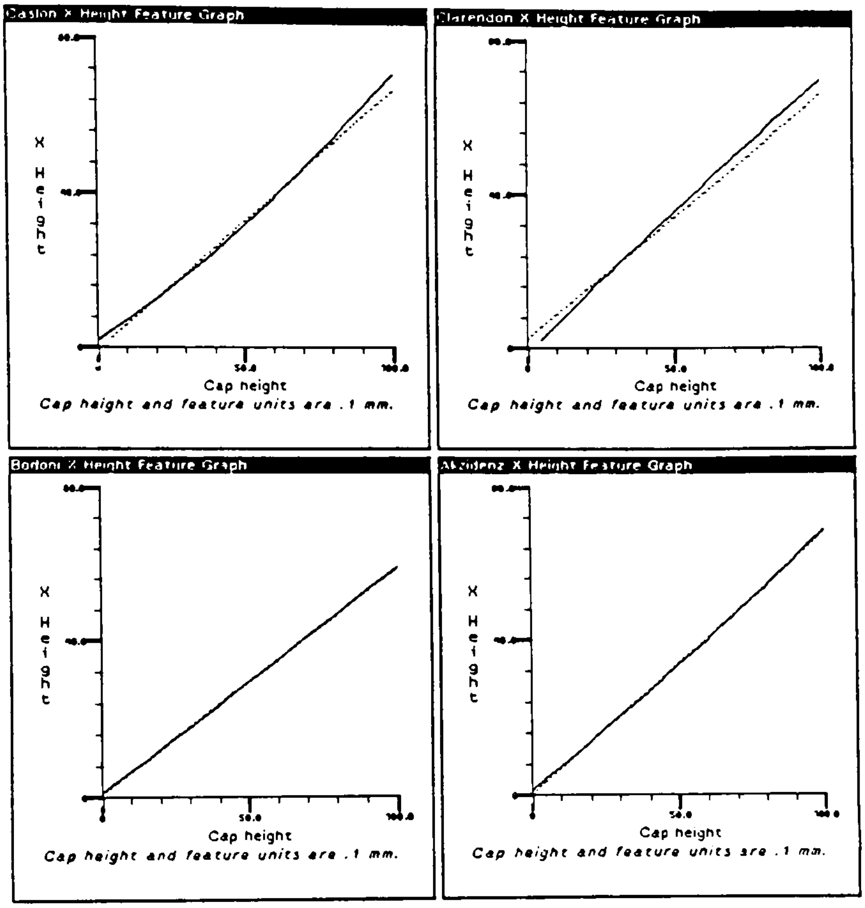

Figure 45. X-height.

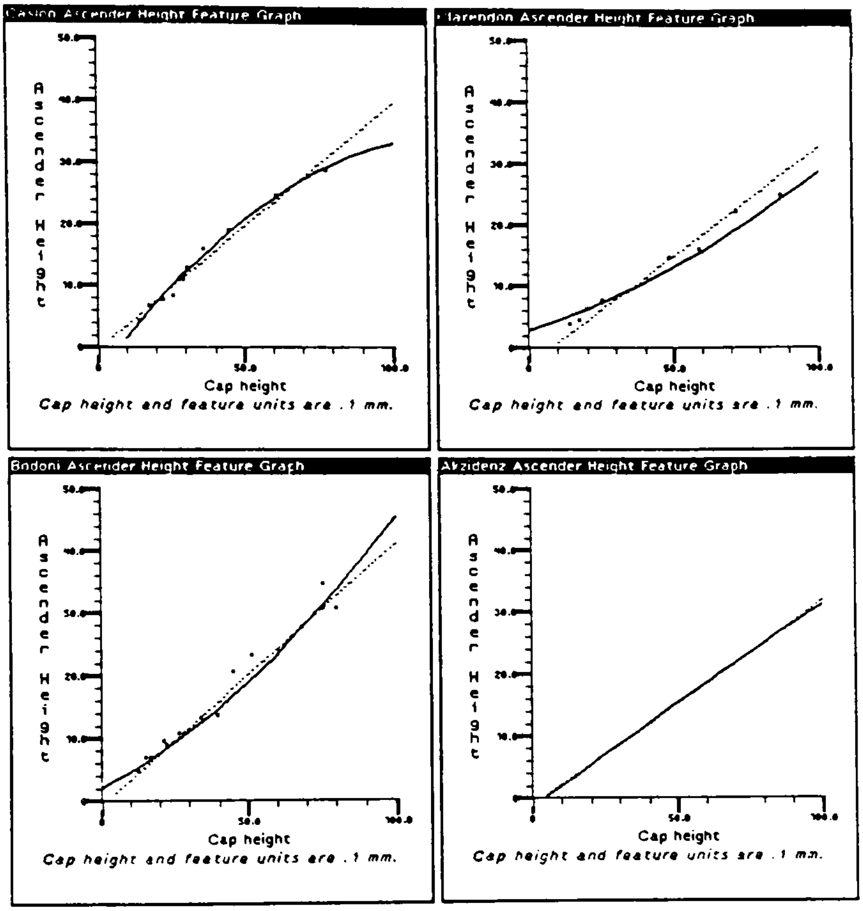

Figure 46. Ascender height.

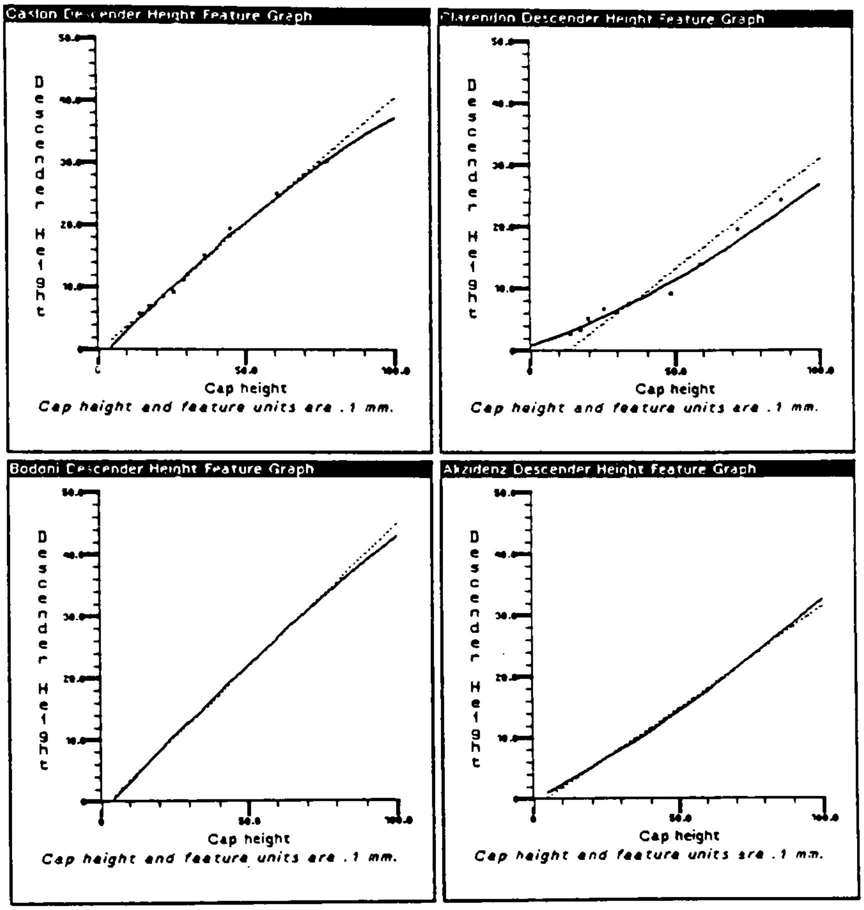

Figure 47. Descender height.

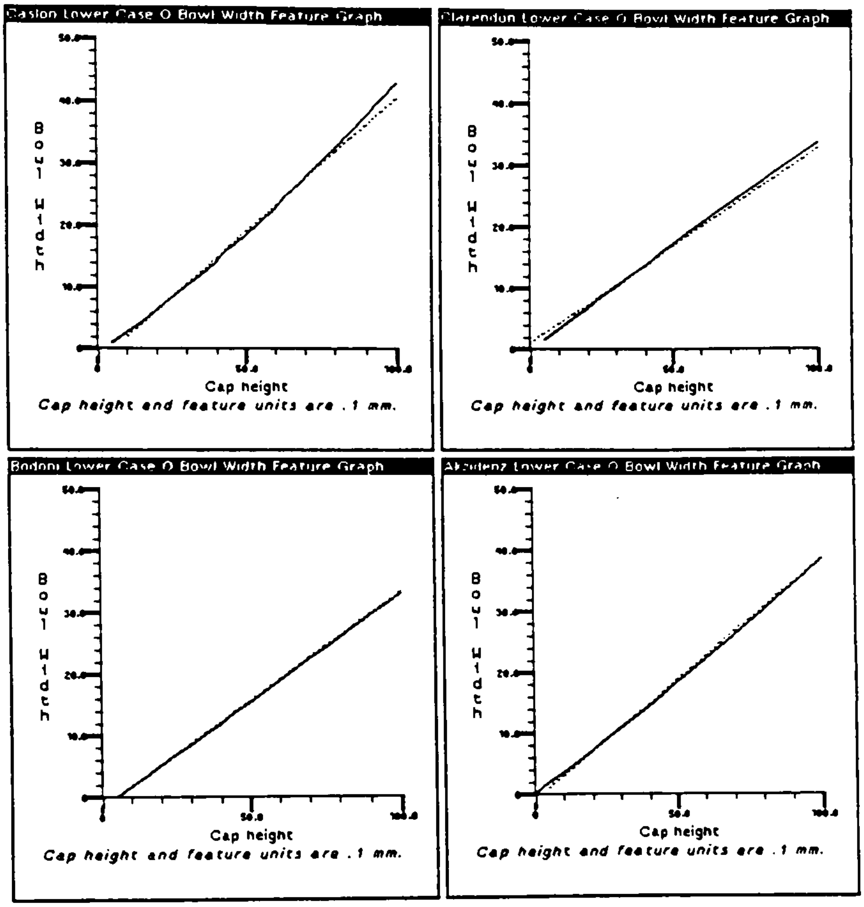

Figure 48. Lower case o bowl width.

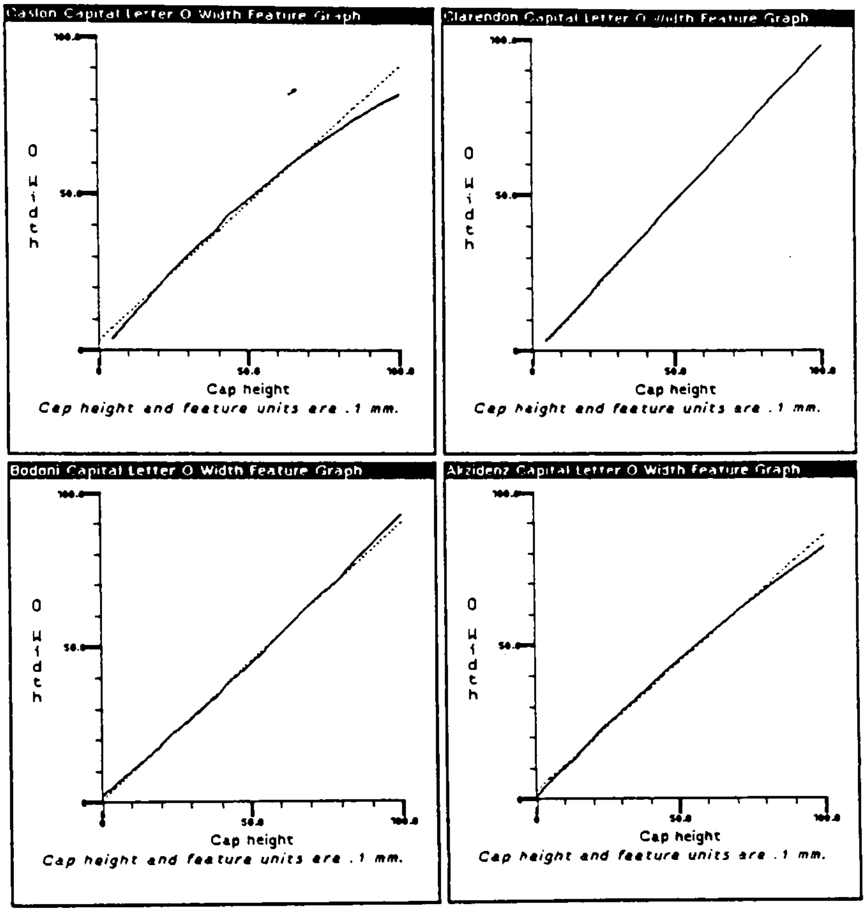

Figure 49. Capital letter o width.

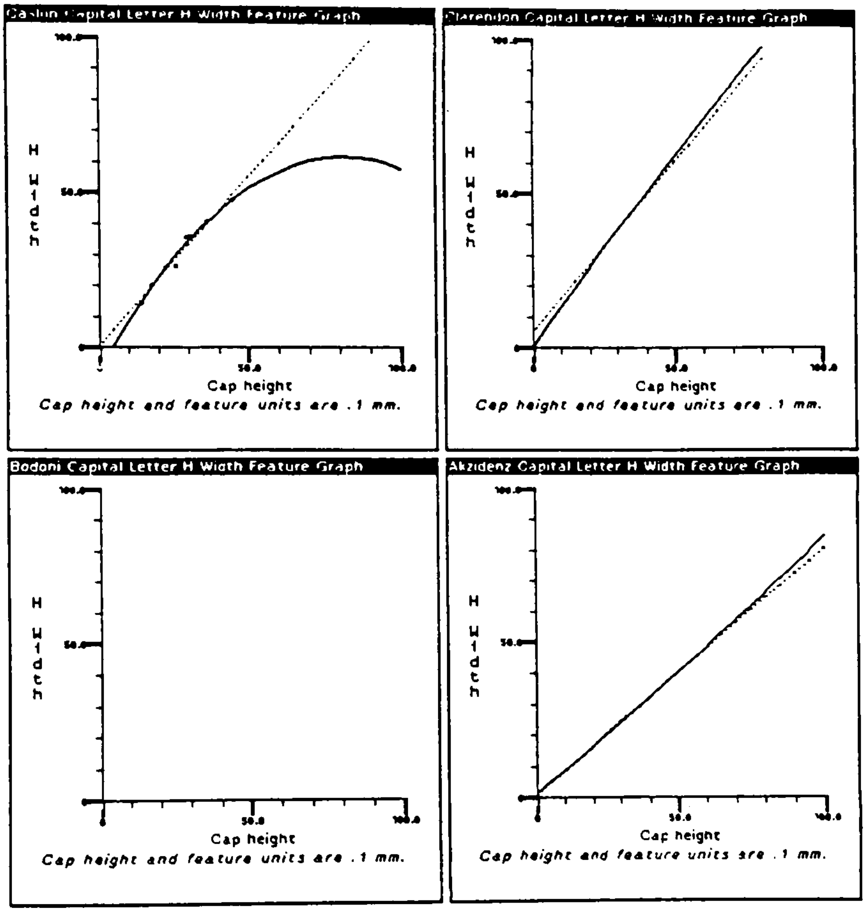

Figure 50. Capital letter H width.

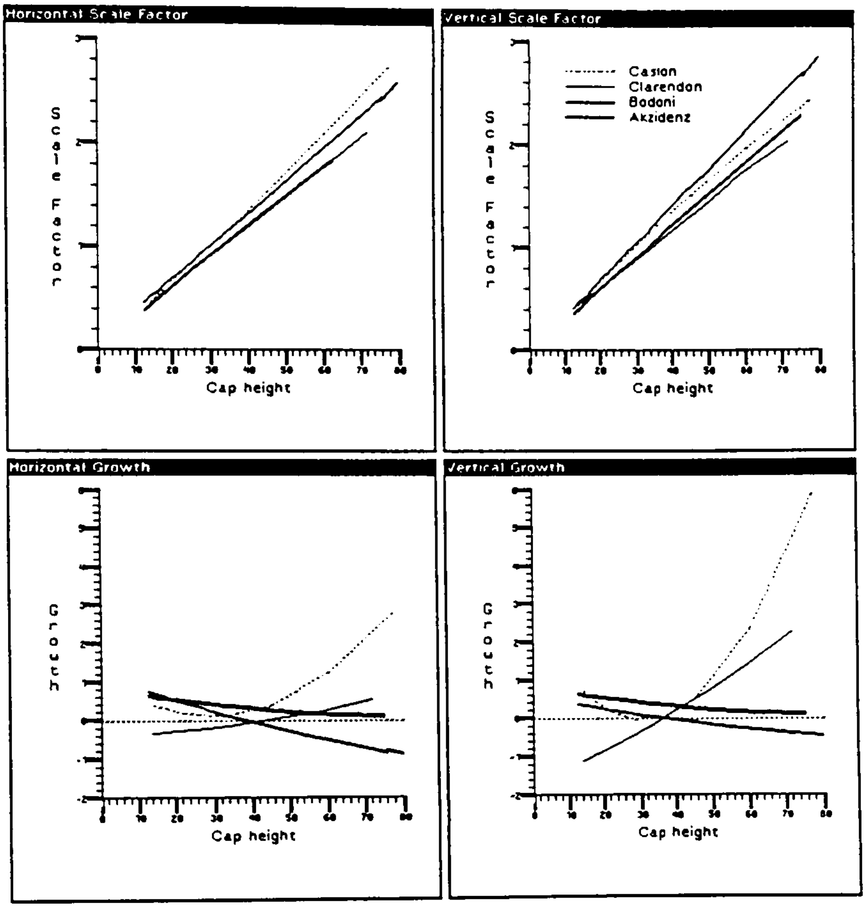

Figure 51. Horizontal and vertical scale and growth parameters.

APPENDIX V

LETTERFORM NOMENCLATURE

This appendix contains figures 52-57, which depict and label the parts of Roman letterforms.[1]

[1]Gaskel, Philip, "A Nomenclature for the Letterforms of Roman Type," Visible Language 10 (Winter 1976): pp. 46-51.

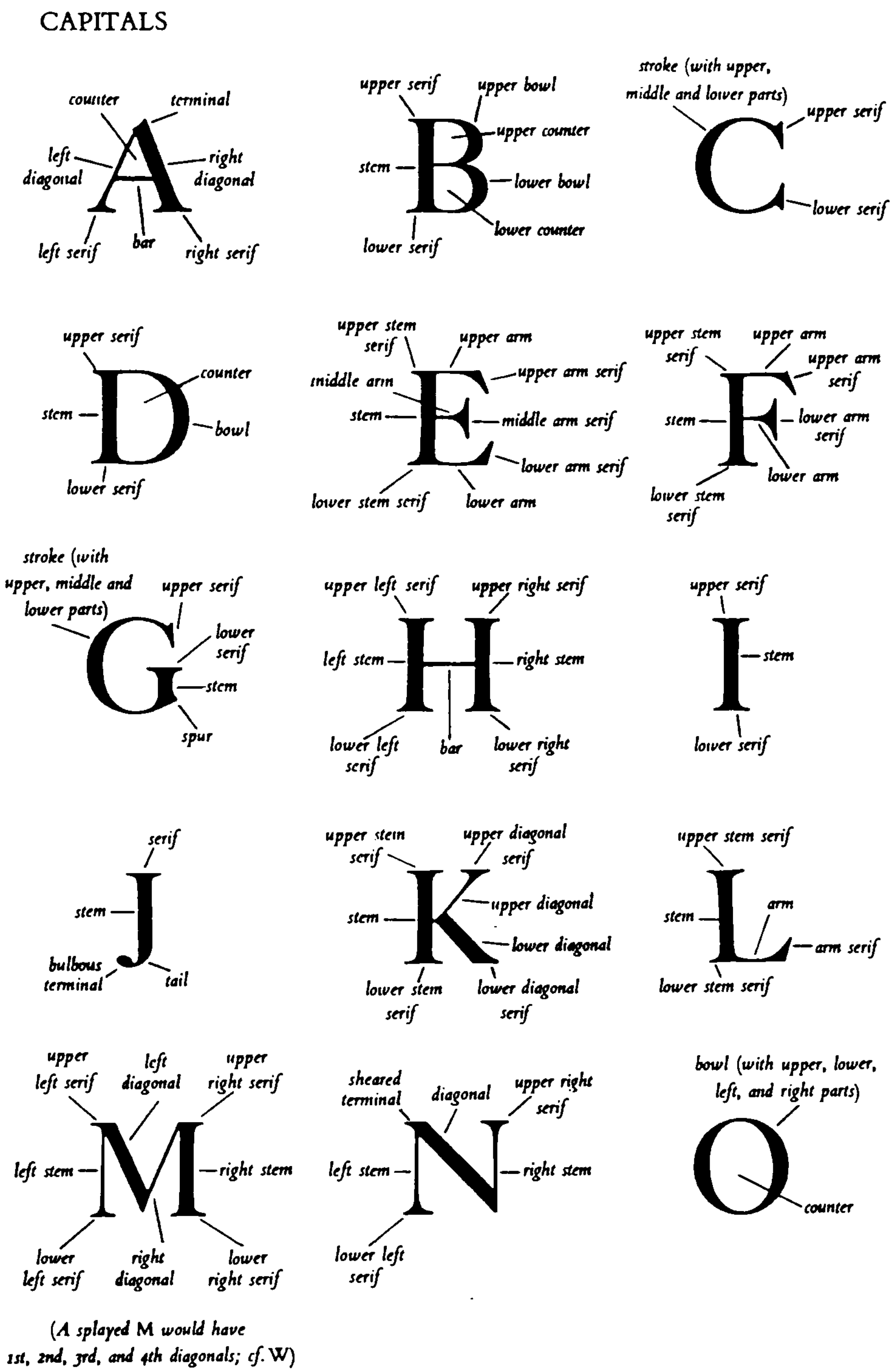

Figure 52. Capital Letterform Nomenclature.

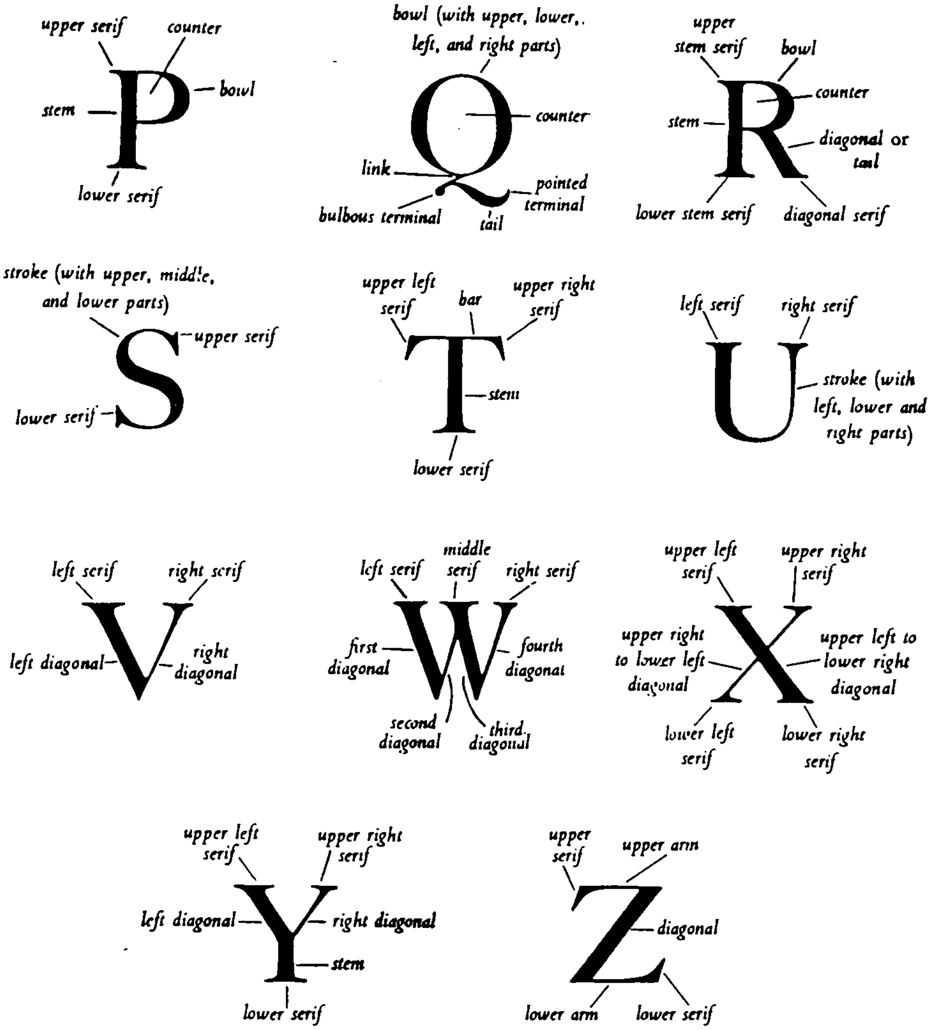

Figure 53. Capital Letterform Nomenclature (continued).

MINUSCULES

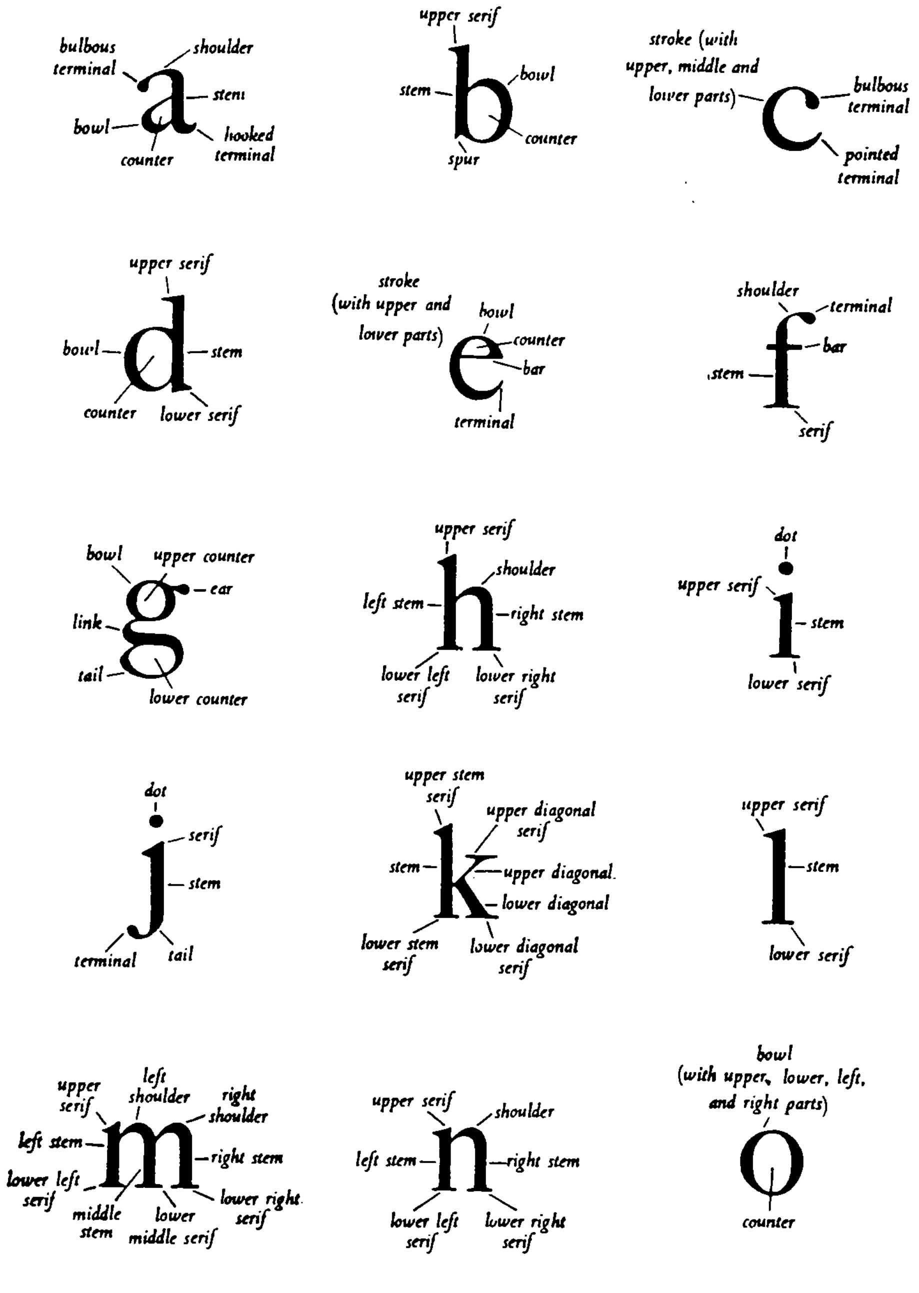

Figure 54. Lower Case Letterform Nomenclature.

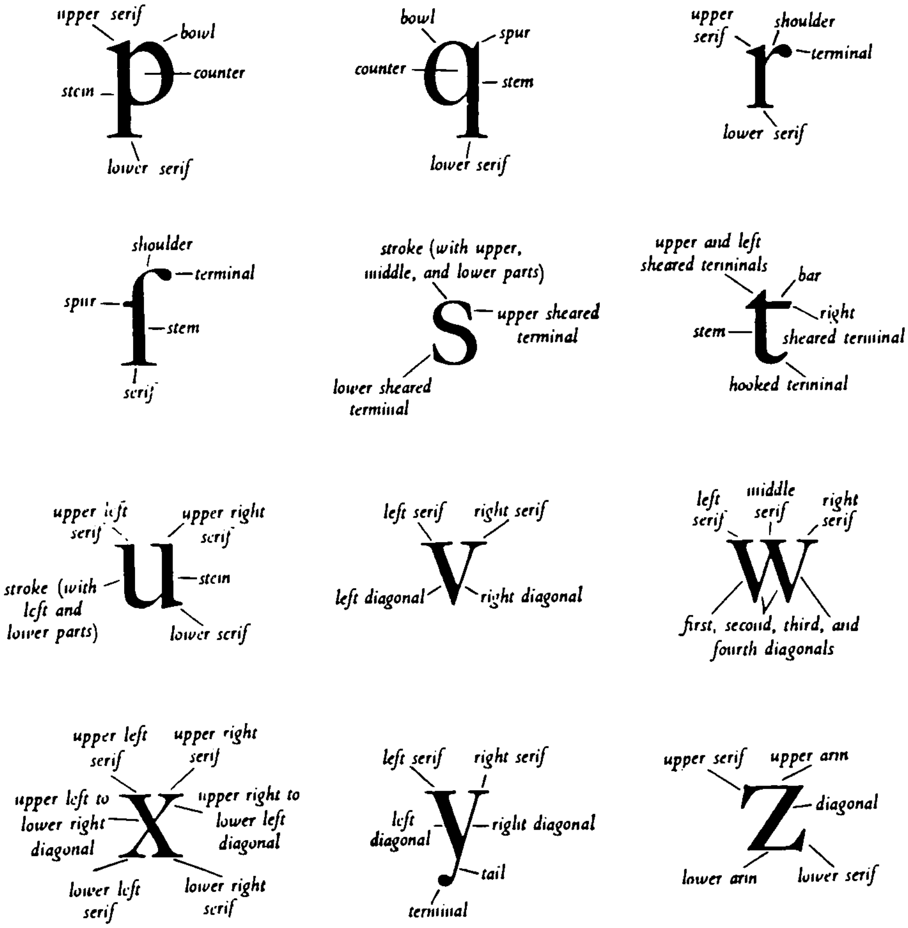

Figure 55. Lower Case Letterform Nomenclature (continued).

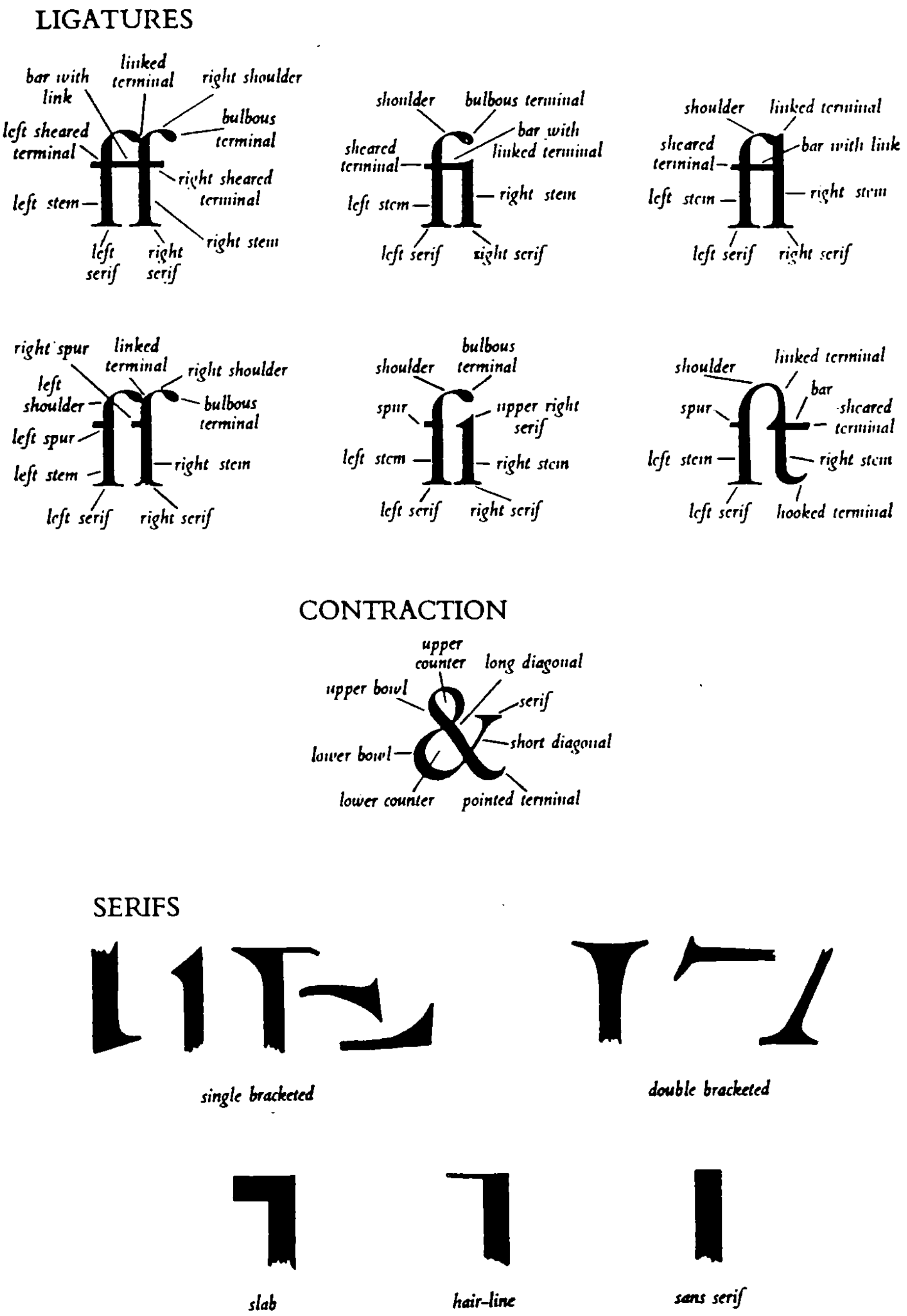

Figure 56. Ligature and Serif Nomenclature.

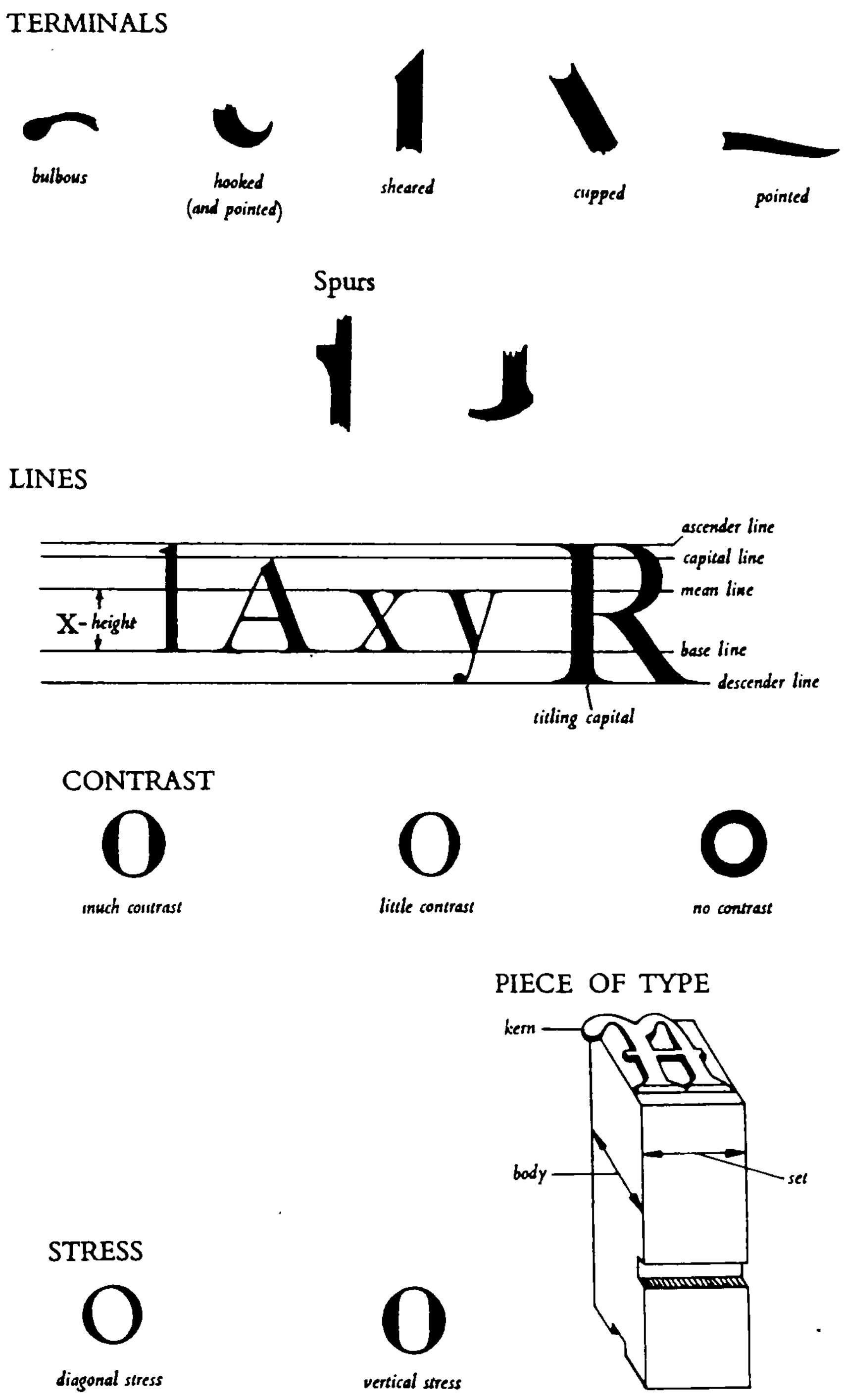

Figure 57. Additional Nomenclature.