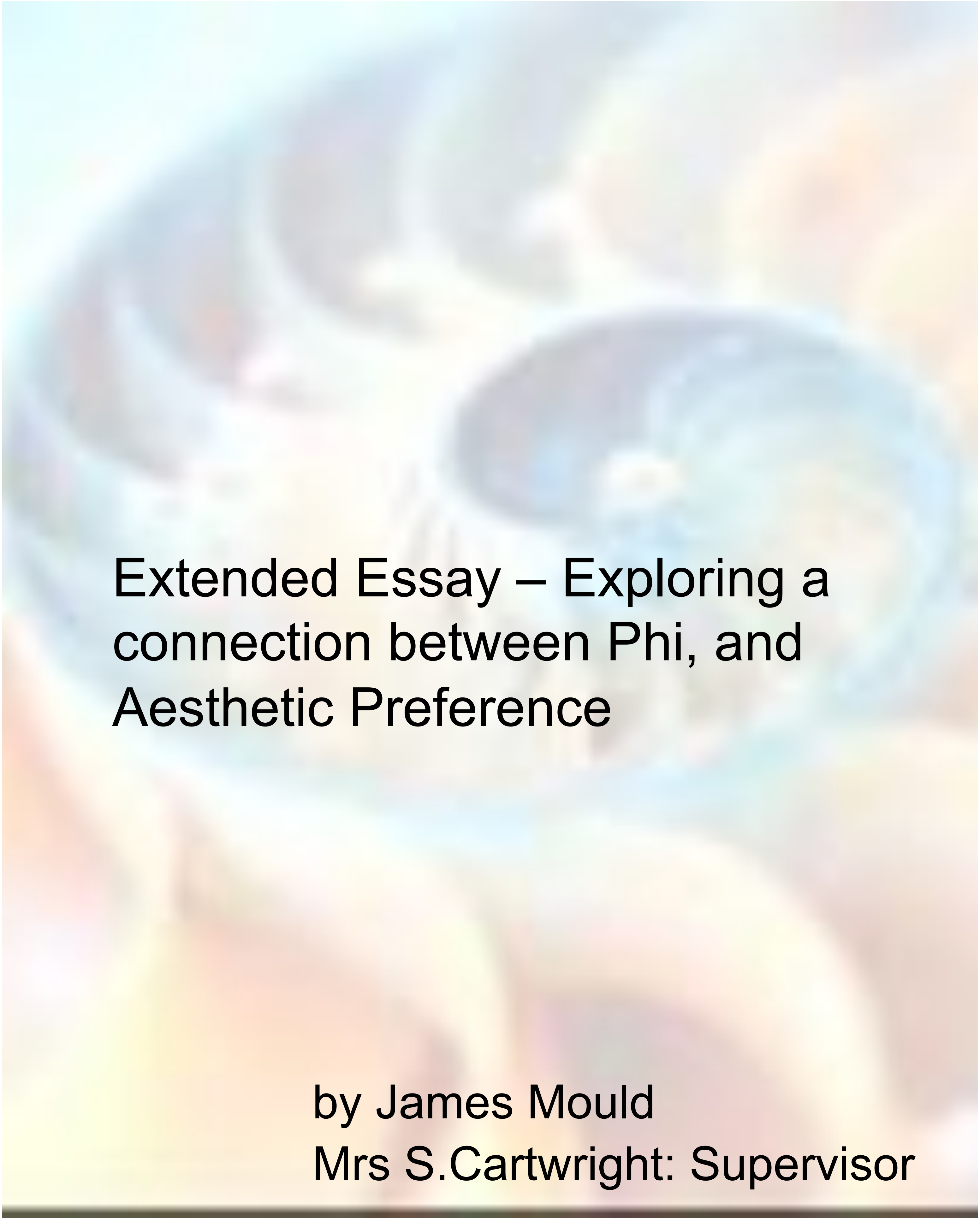

Extended Essay – Exploring a connection between Phi, and Aesthetic Preference

by James Mould
Mrs S.Cartwright: Supervisor

Proportion	Visual
Nature	Preference
Application	Efficiency
Derive	Universal
Archetype	Optimum

This essay gives an introduction to the origin and nature of Phi, and provides links between its frequent occurrence in the natural world, particularly the human body, and its subsequent application in human design. It then goes on to explore and explain the idea of a visual preference for things exhibiting the Golden ratio, based on scientific and psychological theories, which are supported by conclusions drawn from the analysis of data, obtained by primary research which has been conducted by the author.

Acknowledgements

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Extended Project – Exploring a connection between Phi, and aesthetic preference

Introduction

Shakespeare's The Merchant of Venice quotes "Beauty is in the eye of the beholder". But is this really the case? What gives something visual its aesthetic appeal? Whether it is a building, a sculpture, a face, or simply a composition, people have their own, often differing opinions on what is pleasing to the eye; but is there a universal correlation, which links the characteristics of an object, to its aesthetic appeal? And does the answer lie within the realms of mathematics?

This subject has always interested me, particularly because there are patterns, and trends within nature itself which seem to indicate that there might be one or more fundamental principles, which offer an insight into the aesthetic world.

It is my intention to explore this line of thought, and to conduct my own research as to whether there is a subconscious recognition of a consistently pleasing composition within the human mind.

There are many strands of mathematical ideas and concepts to explore, and some of the more familiar examples are:

Symmetry - Many mathematical principles are based on ideals, and apply to an abstract, perfect world. However, this perfect world of mathematics is reflected in the imperfect physical world [*"Maths in Nature", (n.d)*]. Faces which are more symmetrical, when a line is drawn from forehead to chin, are generally thought to be more aesthetically pleasing.

[Gruendl.M, 2001]

Fractals - Many natural objects show a repeated shape at smaller and smaller scales within the structure of the object itself. Examples include clouds, snow flakes, crystals, mountain ranges, lightning, and even broccoli [Wikipedia, 2008]. Computer analysis has even found fractal patterns in the paintings of Jackson Pollock, amidst the apparently chaotic splattering and dripping of paint.

Pi - Any circle holds a perfect relationship where the circumference divided by the diameter equals pi. It was first realised, albeit inaccurately, by the ancient Egyptians, and the number itself has subsequently been calculated to several billion decimal places.

However, the principle which interests me the most, and indeed the principle which can be most significantly recognised in aesthetic opinion is the Golden Ratio, so it is this that I shall be exploring in my essay.

Firstly I shall identify the mathematical link between the Fibonacci sequence, and the Golden Ratio using an example from the natural world. Then I plan to explore other examples, and identify the reasoning behind why we see these natural repeat patterns. Following on from this, I shall investigate how this has affected human perception of pleasing form, and how we have applied it to our fundamental areas of design, such as art, and architecture.

I shall also look to conduct my own research, if possible, into universal recognition of pleasing composition, and will try to assess how significant the Golden Ratio is, in relevance to this.

Patterns in Nature

If we look into nature itself, we can observe certain repeated trends and patterns which seem to work, because they follow a numerical sequence.

If we consider certain plant forms, these patterns are apparent.

Looking at the head of a sunflower like this, two series of curves are noticeable, each spiralling in opposite directions from the centre. However the numbers of spirals are not equal for each direction. In this case, there are 21 clockwise (shown in red) spirals, and 34 anti-clockwise spirals (shown in blue).

It has been found, that the number of spirals in general, are either 21and 34, 34 and 55, 55 and 89, or 89 and 144. Why is this?

These trends are not merely a product of chance, in fact they directly relate to a sequence of numbers which has been known about for centuries.

The Fibonacci sequence is a series of numbers, named after Leonardo of Pisa, known as Fibonacci. The sequence starts at 0, and the second number is 1. Each subsequent number equals the sum of the previous two numbers

Therefore the first 12 terms of the sequence are: 0,1,1,2,3,5,8,13,21,34,55,89,144

Mathematically, any Fibonacci number f_n can be represented by the general formula: $f_{n+2} = f_{n+1} + f_n$.

Already then, we can see a link between this sequence, and the sunflower spirals

0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144

It is my intention to explore and explain this phenomenon in greater detail, later in the paper.

Deriving the Golden Ratio from the Fibonacci sequence

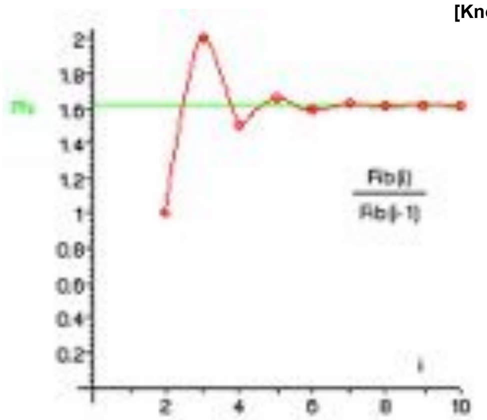
The first twelve terms of the Fibonacci sequence

0, 1 , 1 , 2 , 3 , 5 , 8 , 13 , 21 , 34 , 55 , 89 , 144

If you take any two consecutive numbers from the sequence, and calculate the ratio between them, an interesting pattern can be observed.

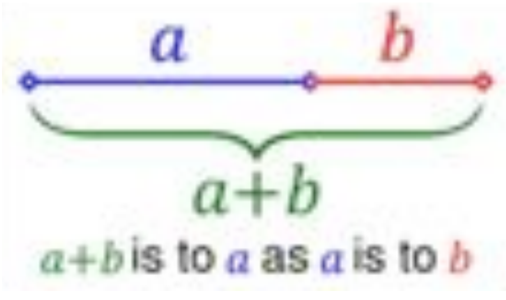
1,0	Ratio = 1 to 0 = 0
1,1	Ratio = 1 to 1 = 1
2,1	Ratio = 2 to 1 = 2
3,2	Ratio = 3 to 2 = 1.5
5,3	Ratio = 5 to 3 = 1.6666
8,5	Ratio = 8 to 5 = 1.6
13,8	Ratio = 13 to 8 = 1.625
21,13	Ratio = 21 to13 = 1.61538
34,21	Ratio = 34 to 21 = 1.61538
55,34	Ratio = 55 to 34 = 1.61764
89,55	Ratio = 89 to 55 = 1.6181
144,89	Ratio = 144 to 89 = 1.6179

[Knott. R, 1996]



It becomes easier to see what is happening if we plot the ratios on a graph.

As the sequence continues, we can see that the graph converges toward the decimal value 1.618 (Phi), although it never actually reaches Phi itself, since it is an irrational number. Another way of expressing this ratio, using algebra, makes the distinction clear.



It is this ratio, which seems to produce an ideal aesthetic proportion, and is applicable throughout many areas of visual design.

For this project, I shall be focussing on the idea of pleasing proportion, and specifically conducting research into aspects of personal preference. In particular, I shall be looking closely at the Fibonacci sequence and Phi, though I may give reference to other proportional ideas, such as symmetry.

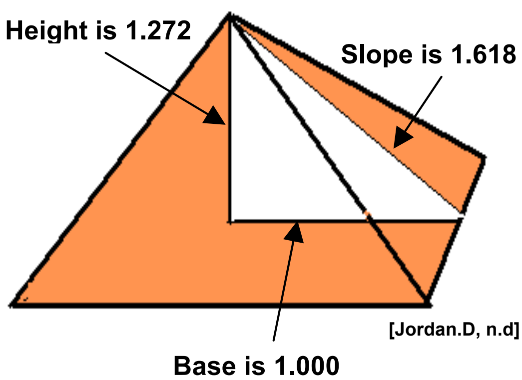
<u>A Brief History of Phi</u>

It's difficult to determine when phi was initially discovered, and by who

, however it has always existed, even if mankind did not realise it was there, or was not able to comprehend the way it worked. From the microscopic, to the scale of whole galaxies, this ratio can be observed, time and time again. So how did humankind come to realise the existence of this extraordinary principle?

Due to its frequent appearance in mathematics, and real life calculations, phi was first studied by the ancient mathematicians, such as the Egyptians and the Greeks.

The Ancient Egyptians used phi in the construction of the great pyramids, whereby the relative ratio of the sloping edge, to the base length is 1.61804, which differs only from phi in the fifth decimal place. Therefore the vertical height of the great pyramid has a ratio of 1.272, which is exactly the square root of



[Jordan.D, n.d]

phi. This is said to be because a "phi pyramid" is the only pyramid upon which it is possible to accurately plot the location of the stars in the sky. The Egyptians believed that if the stars could be projected onto the surfaces of the pyramid (and assuming that they could resonate within) then conversely, those within the pyramid (the buried pharaohs) could "project" outwards to the stars, using the structure as a vehicle to what they believed was the spiritual world, and eternity [Jordan.D, n.d]. Scholars disagree whether the Egyptians were aware of phi at the time, and this uncertainty, to me, poses the question; if there is a subconscious recognition of pleasing form (phi), is it inherent, or learned? The author of source for this information, [Jordan.D, n.d] is heavily religious; however, regardless of his perspective and reasoning, the facts remain accurate, and so I deem the information to be reliable.

Later on, Pythagoras the Greek mathematician (560-480 BC) proved that the proportions of the human figure largely corresponded to the golden ratio. He demonstrated that each part of the human body is formed in an exact golden proportion to all the other parts**.** These discoveries had a significant effect on Greek art and architecture. Each part of their major buildings, sculpture, and detailed decoration, was constructed with relevance to this proportion.

Phidias (500 BC - 432 BC) was a Greek sculptor and mathematician who studied phi, and was one of three architects who were commissioned to design the Parthenon, in Athens He applied the golden ratio to the plans for the Parthenon, which is possibly the clearest example of its application into design and architecture.

(a) Original photograph of the Parthenon

(b) Parthenon with the original roof structure drawn over the picture.

(c) The picture is overlaid with a golden rectangle, showing the perfect proportion.

(d) Rectangle is split into concentric golden rectangles, at major intervals in the buildings design.

[Britton.J, 2005]

Plato (circa 428 BC - 347 BC), was perhaps the first person to take a philosophical approach to the idea of phi. He presented his views in a document, known as Plato's "Timaeus", in which he addresses ideas on the nature of the physical and spiritual world, as well as the properties and purpose of the universe. He considered the golden ratio to be an integral factor in all of these lines of thought, the most binding of all mathematical relationships and possibly a key to the structure of the universe itself.

Leonardo of Pisa (later known as Leonardo Fibonacci) is one of the most prominent figures in the history of human understanding of phi. As the son of a merchant in the early 13th century, he was able to travel freely across the Byzantine Empire, and visited many of the Middle Eastern Arabic countries, and parts of India. While travelling, he was able to study both the mathematics of the scholars and the calculating methods in popular use at the time. During his journey through Asia, he learnt how to use the modern decimal system, and is renowned for introducing it to the Latin-speaking world, in a book he published in 1202 [Knott.R, 1998] called “Liber abaci” (book of calculating). This book first described the rules we are now all taught at primary school for adding numbers, subtracting, multiplying, dividing, and even fractions. Having risen to acclaim, with his *Liber abaci*, Leonardo Fibonacci went on to write several other books on mathematical and geometric methods and became widely recognised as “the greatest European mathematician of the Middle Ages”. The first chapter of part one of the *Liber abaci* begins; *These are the nine figures of the Indians: 9 8 7 6 5 4 3 2 1. With these nine figures, and with this sign 0 which in Arabic is called zephirum, any number can be written, as will be demonstrated.* [Quinney. D.A, Knott. R, 1997]

The Fibonacci sequence

The sequence of number for which he was later to become celebrated, is first introduced in chapter twelve, part three of the *Liber abaci*, in a mathematical problem regarding the breeding patterns of rabbits.

How Many Pairs of Rabbits Are Created by One Pair in One Year?
A certain man had one pair of rabbits together in a certain enclosed place, and one wishes to know how many are created from the pair in one year when it is the nature of them in a single month to bear another pair, and in the second month those born to bear also.

Assuming that ; [Enzensberger.H, 2000]

Rabbits take one month to reach sexual maturity

Upon reaching maturity, each pair of rabbits produces one male/female pair, per month

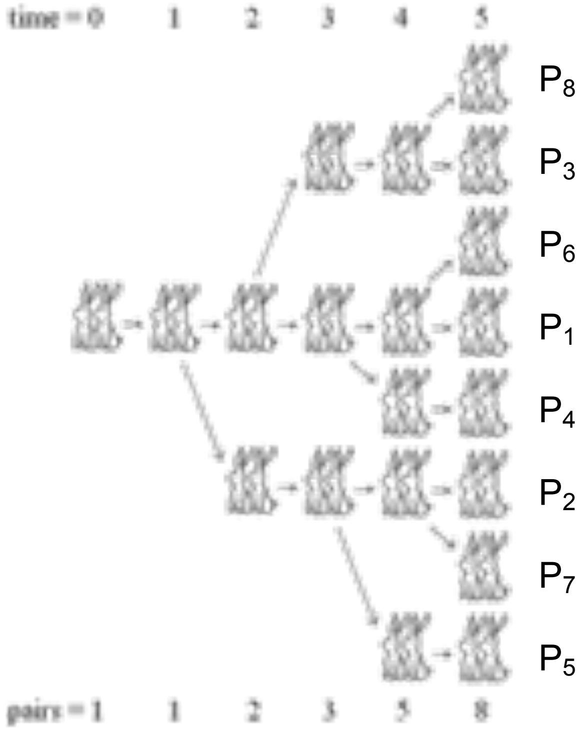
We assume that rabbits never die

We also assume that these rabbits live in ideal conditions

The explanation of this hypothetical question is best demonstrated with a diagram; [Loy.J, n.d]

- We start with 1 pair of newly born rabbits (P_1)
- The rabbits take 1 month to mature
- At the end of 2nd month, the rabbits produce 1 newly born pair (P_2), so now we have 2 pairs of rabbits. ($P_1 + P_2$)
- At the end of 3rd month, we have 3 pairs of rabbits (P_1 + newborn pair (P_3) + P_2)
- At the end of 4th month, we have 5 pairs of rabbits ($P_1 + P_4$) + ($P_2 + P_5$) + P_3

Etc.



When tabulated, the series looked like this

Number of months	0	1	2	3	4	5	6	Etc.
Number of pairs of rabbits	1	1	2	3	5	8	13	Etc.

From this information, it was a simple task to recognise the pattern of the series; the value of each term being equal to the sum of the two previous terms. Hence, the famous sequence was first uncovered, thanks to a mathematical enquiry into the breeding potential of rabbits!

Leonardo Da Vinci seems to be the first person to actually illustrate phi as the divine proportion, through illustrations he made of the five platonic solids [Wikipedia, 2008] for a dissertation published by Luca Pacioli in 1509 entitled "*De Divina Proportione*". It was likely that Da Vinci was the first person to refer to it as the "sectio aurea," which is Latin for golden section.

[Mathematician's Pictures, n.d]

Consequently, the Renaissance artists frequently used the Golden Mean in their architecture, artwork and sculpture to achieved balance and beauty. Leonardo Da Vinci, for instance, used it to define all the fundamental dimensions of his painting of "The Last Supper," from the proportions of the table where Christ and his disciples were seated, to the measurements of the walls and windows in the background.

Johannes Kepler (1571-1630) was an astronomer who discovered that the Earth and planets travel in elliptical orbits around the sun. He gave three fundamental laws of planetary motion, and also did important work in optics and geometry. It was he, who first proved that the ratio between consecutive terms in the Fibonacci series converges to Phi.

He quotes: *"Geometry has two great treasures: one is the theorem of Pythagoras, the other the division of a line into mean and extreme ratios; that is phi, the Golden Mean."* **[Calter.P, 1998]**

However it took until 1909 for an American mathematician, Mark Barr to name the irrational number "Phi", and denote Φ as being the symbol to represent it. By this point phi had several names, such as the golden section, the golden ratio and the divine proportion. The letter "phi" is taken from the first Greek letter in the name of Phidias, the Greek sculptor who worked on the design of the Parthenon in Athens (see page six).

And so, this unusual number was finally given a universally recognised name, and just as before, has since become the subject of interest for scores of illustrious scholars and researchers.

Phi and the Natural World

The variety of ways we can observe the proportions of phi in nature, and the extent and consistency of occurrences that we see, it seems that there is no other specific number which recurs so regularly throughout life on Earth. In fact, there are so many examples, that to include them all would simply be unfeasible. Therefore, I shall present several examples, at different scales of magnitude, and then explain why this recurring phenomenon is so regularly included in their designs.

The microscopic level – DNA

The DNA molecule contains the genetic information used in the growth and development of all known living organisms. Each molecule takes the form of a double helix spiral **[DNA Models, n.d]**

[DNA Models, n.d]

Interestingly, each full cycle of a DNA strand measures 34 angstroms long by 21 angstroms wide (1 angstrom equals 0.1 nanometres). Since 34 and 21 both feature in the Fibonacci sequence, the ratio between them approximates phi.

The cross-sectional view of a strand of DNA forms an outline of a decagon:

[Anon, n.d]

A decagon is essentially two pentagons, with one rotated by 36 degrees. Since the cross section displays a double helix spiral, each single helix must trace the shape of a regular pentagon. The ratio of the diagonal of a pentagon to its side is exactly phi, so by these proportions, even DNA, the very building blocks of life itself includes phi as an integral feature in its design. A possible explanation for this could be the same reason that sunflower seeds grow outwards from the centre of the flower head in Fibonacci spirals (see page 3): It is simply a matter of efficiency.

As seeds form in the centre of a sunflower head, and migrate outwards, each new seed appears at a certain angle in relation to the preceding one. If this angle is a rational number (e.g. 90 degrees), then the seeds adopt a “rectilinear” distribution, that is to say they grow outward in straight lines, which is clearly not the most effective use of the space (fig.1). However, if the angle between seed is irrational, and can be approximated by a simple fraction, then a more efficient pattern of “spiralling arms” forms (fig.2). Hence, to fill the space optimally, it is essential that the most irrational number is chosen. The number which can be least approximated by a fraction is the golden mean [Knott.R, 1996], and so the angle derived from it, or the “golden angle” (137.5 degrees) obtains the optimal filling, with same spacing between all the seeds (fig.3).

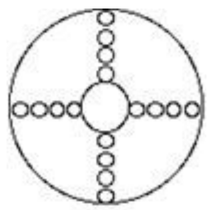


fig.1

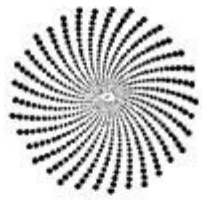


fig.2

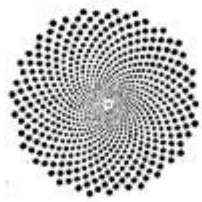


fig.3

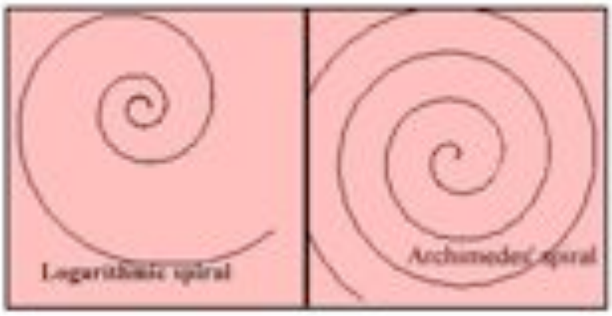
[U.C.N.W.,Bangor, 1996]

I have confidence in the reliability of the sources for the mathematics and reasoning behind this explanation, since the information comes from a site, written by a professor at the University of Surrey, who has sourced his information from several topical publications.

[Richards. F.J, 1951]
[Cook, Sir T.A 1979]
[Coxeter.H S M, 1989]
[Church.A.H, 1904]

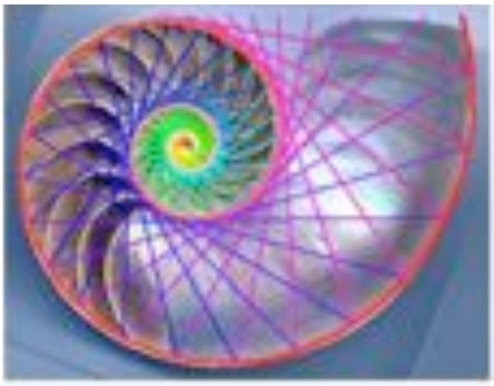
<u>The macroscopic scale</u>

The nautilus is a deep sea cephalopod which has remained relatively unchanged for millions of years. If we examine a cross section of the creature's shell, we can observe a logarithmic spiral, extending from the centre of growth.



[Laputan Logic, n.d]

There are two main types of growth spiral, logarithmic, and an addition spiral (Archimedes spiral) [Wassenaar. J, 2006]. In essence, the Archimedes' spiral demonstrates a growth that simply adds at a constant rate, whereas a logarithmic spiral represents a growth which increases in proportion to its size. Hence, a golden spiral is a proportional logarithmic growth with a ratio of phi, 1.618.



I took a picture of a nautilus shell from an image search on Google [Laputan Logic, n.d], and overlaid it with a graph of the golden spiral [Lumen.A, 1999]. The two images were a remarkably close match, which leads me to the conclusion that the growth of a nautilus' shell approximates the golden spiral. But why is this?

In terms of the nautilus' growth, the logarithmic nature of the golden spiral enables the creature inside to grow steadily without needing to change its shape. This beautiful efficiency precludes the need for this organism to evolve any further, so in essence it has reached the optimum form for survival in its environment. The fact that the species has remained relatively unchanged for millions of years gives evidence for this fact.

The telescopic scale

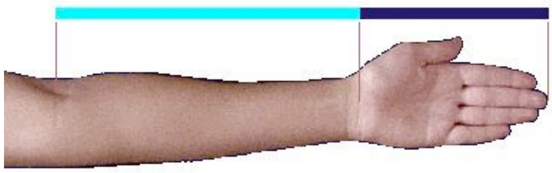
At a much larger scale, hurricane cloud formations, and even whole galaxies exhibit logarithmic growth spirals, many of which hold proportions (especially close to the centre) which have a value which is very close to phi.


[Anon, 2007]
[Kollerstrom.N, 2006]

Interesting, that even at the very extreme scales of magnitude, this irrational number seems to be an integral factor in the shape of what exists.

Phi and the Human Body

Although at first it may not seem obvious, the human body exhibits an extraordinary number and variety of phi relationships. A good place to observe examples of this is the arm and hand. For instance; the ratio of your forearm, to your hand shows a near-perfect phi proportion.



[Golden Files, n.d]

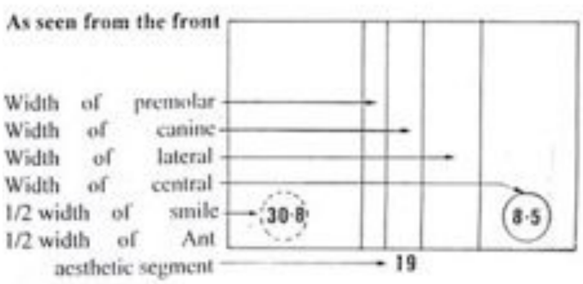
Furthermore, the hand itself can be broken down into very accurate proportions, based on the first four terms of the Fibonacci sequence. In fact, the proportions of the distances between the fingertips, knuckles, and wrist relate exactly to the Fibonacci numbers between the 3rd and 6th term of the sequence.

[Hand, n.d]

Our teeth, ideally, adhere to a golden mean relationship. The four front teeth, from the central incisor to the premolars are in golden proportion to one another, and they form the most noticeable part of your smile. Since it is fairly easy to recognise whether a person's teeth are pleasantly aligned or crooked, we can assume that the golden ratio yields the best dental aesthetic.

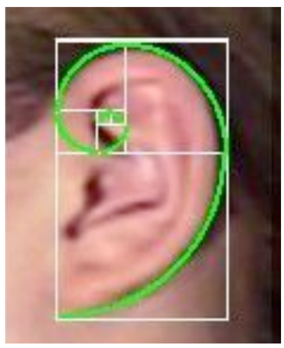
[Phipoint solutions, 1997]

Consequently, dentists have come up with a grid [Levin.E, n.d] which can be used to assess the aesthetics of the eight front teeth. The following diagram shows one of these grids being used, and the front teeth are clearly shown in the increments predicted.



[Phipoint solutions, 1997]

Our outer ear, much like the nautilus shell mentioned earlier, follows a golden spiral around its outer edge. This could possibly be related to phi's relevance in harmonics [Phipoint solutions, 1997], although these are simply my own speculations, and as far as I am aware, no specific research has yet explored this idea.



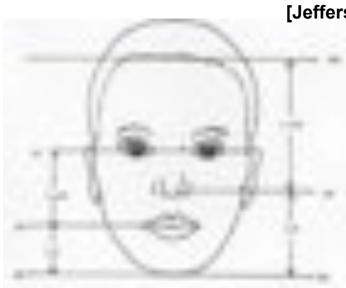
[Ear Spiral, n.d]

Phi and Facial Aesthetics

Ideally, a human face conforms to phi in many areas, from the facial shape itself, to the relationships between features. Furthermore, the "golden structure" of the face is a universal proportion, and applies to all individuals, regardless of age, gender or race.

[Jefferson. Dr Y., 1996]

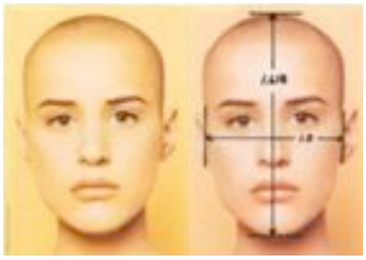
This diagram shows the ideal vertical proportions of a human face. For example, if the distance from the chin to the base of the nose is 1, then the distance from the chin to the hairline (the full face) will be phi, 1.618.



This diagram gives a few examples of the ideal lateral or transverse proportions of the face. An example of this is the ideal ratio between the width of the nose, and the width of the mouth, which should approximate phi.

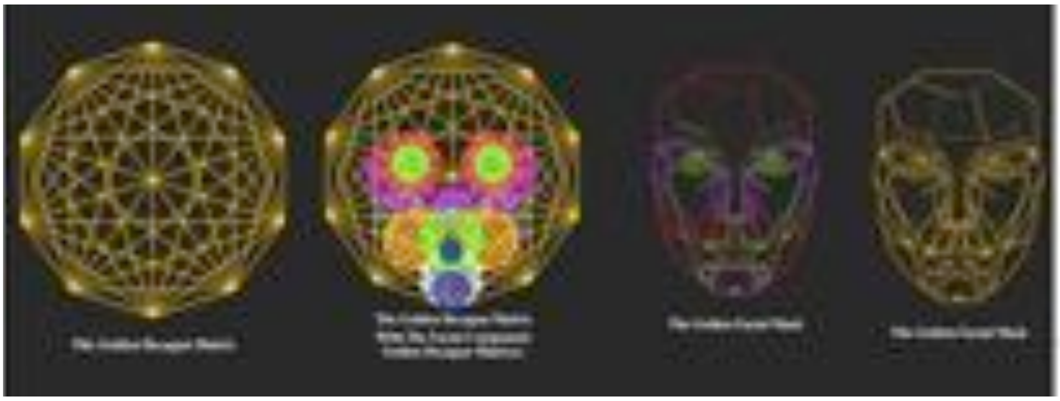
[Jefferson. Dr Y, 1996

This image of an attractive female face, taken from a magazine article demonstrates how real these ratios are.

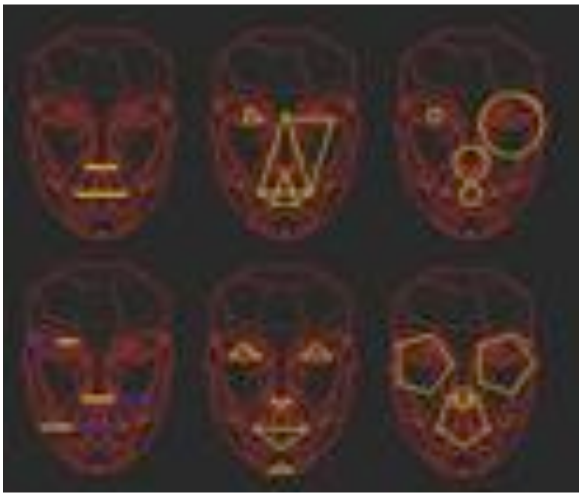


I am confident in the reliability and validity of the sources which I have thus far used, because firstly, much of the information and research has come from either academic institutions, such as the university of Surrey, or specialists in their field such as Edward Levin, and Dr. Yosh Jefferson. Furthermore, these sources often support their views by referring to case studies, and indeed, many of the principles forming the reasoning for these views can be strongly supported by examining visual samples taken from nature, or the manmade environment.

A Californian doctor, Steven Marquardt, who specialises in facial aesthetics, developed a geometric framework, which when superimposed over a picture of a human face, will give a measure of how attractive the face is, based on how closely the two images fit. This aptly named “Marquardt mask” is based on Phi, and a sample of archetypal attractive faces, having all of its dimensions derived from the golden decagon matrix.



[Marquardt Beauty Analysis. Inc, n.d]



The Marquardt mask is entirely constructed from golden ratio lines and the diagram on the left shows some of the key relationships within the mask itself, including several of the basic “golden” shapes, such as the triangle, the pentagon, and the decagon. **[Marquardt Beauty Analysis. Inc, n.d]**

According to Dr. Marquardt, this mask functions universally for any race, or age group, and for the most part, will work on both male and female faces **[Phipoint solutions, 1997]**.

The diagram on the right shows the same mask, applied to beautiful women of different ethnicities. Despite their differences in race, the mask is still a surprisingly good fit, and seems to give evidence for the idea of a universal proportion, which yields beauty.

[Marquardt Beauty Analysis. Inc, n.d]

However, the mask has received criticism from many people, who claim that its design is flawed. They maintain that the mask does not distinguish clearly enough between different levels of attractiveness, once the differences become more subtle – still noticeable though, by the human eye. They also argue that the "goodness of fit" is misleading.
Their argument is that Marquardt primarily used high-fashion models, to demonstrate the mask's aesthetic, since they were voted to be attractive by a survey of individuals. These critics claim that the more masculine and defined features of high fashion models, as opposed to the more rounded "feminine" features of a typical woman give the mask's fit a misleading bias towards more masculine, European female faces, which contradicts the general public's preference for above-average facial femininity in women.

However, what these critics neglect to include in their argument, is that the mask was designed to be applied to both male and female faces. Therefore, I would suggest that it would be almost impossible to incorporate both genders' characteristics into a generic design, capable of determining facial attractiveness to the same degree as the human eye. Thus, it may not be prudent to adhere to the mask unreservedly, but instead, regard it as an accurate estimate for the majority of facial types. I think then, if we take the Marquardt mask as a close approximation to ideal facial aesthetic, it is not unfair to propose that faces with Phi proportions integral in their structure, can be deemed to be attractive.

But why is this the case? Why do faces which conform to Phi appear beautiful?
The answers to these questions are best explained by looking, firstly, at a cross section of an ideal human skull.

Letters A,B,C,D,E,F,G and H, highlight specific point within the structure of the skull. If a line is drawn between each consecutive pair of letters, AB,CD,EF,GH, and then extrapolated back, ideally they should all converge at point "X" which lies at the back of the skull, approximately horizontal with points C and D.

[Jefferson. Dr Y, 1996 page.14]


[Jefferson. Dr Y, 1996 page.14]

Short Face Syndrome

The four lines converge to a point, well outside of the skull, giving this person a “short face”.

A shorter face tends to indicate abnormal jaw development, causing extreme pressure on the jaw joint. This can result in headaches, since the jaws are positioned in a way which restricts blood flow to the brain. Subconscious teeth grinding under stress, exaggerates this problem.


[Jefferson. Dr Y, 1996 page.14]

Long Face Syndrome

The four lines converge to a point, well inside of the skull, giving this person a “long face”.

People with a longer than ideal face, tend to have narrow sinus cavities, which inhibit airflow and can create problems breathing through their nose. Subsequently, these people tend to breathe through their mouth, which can lead to abnormal facial and dental development.

Comparatively, those with an “ideal” facial structure tend to have fewer health issues, and are less susceptible to abnormal development as they grow. Dr. Yosh Jefferson, an American dental practitioner, has completed extensive research on this subject, and concludes that by developing in accordance with the Divine Proportion, the human body can perform closer to its potential, with the minimum input of effort, thus conserving energy. Conservation of tissue is also upheld, whereby the body uses the least amount of cells and resources needed to perform a task.

It would seem then, that once again, as with the DNA, and the seed heads, and the nautilus shell, and the various proportions of the human body; the inclusion of Phi in their design is due to an underlying practicality, a form of usefulness, or perhaps more accurately, a universally optimum efficiency, which gives the organism concerned, the best chance of survival, or prevalence in its environment. If this is the case, then one could speculate that the "perfect" irrationality of Phi, when applied, translates into a "perfect" design for capability of an object, within its immediate limitations.

Why then, do we recognise and favour things with "ideal" designs?

Taking other humans firstly as an example, since it is something to which we can all relate; the recognition of "beauty" within our population is a misleading phrase. More appropriately we recognise "humanness"- that is to say, we have a subconscious recognition of the most archetypal and efficient example of our species. We form this archetype as a way to identify ourselves for protection, bonding, mating, and other such survival purposes. We also need to be able to distinguish healthy or disease free individuals within our species, to ensure strong, and healthy offspring. Perhaps we are drawn towards features which exhibit a Phi proportion (recognition of efficiency) because we, as humans, are a very visual species. We effectively identify each other by sight; our sense of smell isn't good enough for recognition, in the way that dogs distinguish members of their species. If someone shouts our name, we turn to visually identify who they are. Therefore, in essence, our perception of human beauty is the combination of qualities in another human being, which evokes in us, a sense of attraction, or strong positive emotion. Within our own species, perception of beauty is simply a recognition of what we subconsciously imagine "humanness" to appear to be. Since this seems to be dictated by the golden proportions we visualise in ourselves or an "ideal" members of our species, I think it is fair to suggest that this is why we find other objects which exhibit Phi characteristics, of particular visual or aesthetic appeal, and indeed why we base a significant amount of our own designs on this ratio. Given that we both recognise and appreciate designs with a Phi characteristic; a new question is posed:

Is our recognition of Phi an inherent trait, or a learned ability?

In exploring this question, I firstly made three hypotheses:

- People find objects designed with respect to Phi, the most aesthetically pleasing.
- The recognition of Phi as the most pleasing form becomes more profound as a person matures into adulthood.
- The appreciation of Phi is – for the most part – a learned ability

I conduct my own primary research, to test the validity of my hypotheses. This took the form of a questionnaire which included questions based on aesthetic preference to assess the choices people make under certain conditions.

The techniques I used in writing the questionnaire were based on different investigational methods, stated by previous psychological experimentalists, such as Gustav Fechner's[Wikipedia, 2007] investigations and the Stone and Collins Hypothesis [Stone and Collins,

The first variable on my questionnaire was the age category. Initially I had planned to conduct research by using three age groups, these being roughly 8-10 years, 16-24 years, and 30+ years [appendix.1a]. This would have enabled me to assess whether there was a correlation between the percentage of participants who identified or applied the golden ratio, and their increasing age, thus supporting the idea that recognition of Phi is a learned ability. Unfortunately, due to the rules which govern the practice of psychology [British Psychological Society, 2000], I was prohibited from interviewing anyone under the age of 16 years, without first obtaining parental consent for each individual concerned. Considering my time and resource limitations, I adapted my planned questionnaire by using two age groups, 16-24 years and 25+ years [appendix.1b]. I also changed the sizes of the shapes in Qu.6, to have equal areas.

The second and third questions identify the gender of the participant, and whether they are right or left handed. These questions were conceived in order to further my interpretations of questions 4, 5 and 6, if time and/or word count allowed.

For questions 4, 5 and 6, I looked at the methods of investigation, described by Gustav Fechner, a German experimental psychologist in the 19th century.

He conceived three famous methods of investigation, which are used to assess the aesthetic choices of a participant:

<u>Fechner's Three Methods</u> **[Green.C, 1995]**

(1) The method of choice (Wahl), in which subjects choose, from among a number of alternatives, the item that they like (or dislike) the most;

(2) The method of production (Herstellung), in which subjects are asked to draw, or otherwise create, an object of a certain kind that has features or proportions they find most agreeable (or disagreeable); and

(3) The method of use (Verwendung), in which the experimenter examines pre-existing objects of the kind being studied, and determines whether they conform to certain hypotheses about the determination of aesthetic pleasure.

For the fourth question on my survey, I asked my interviewees to draw a freehand rectangle in a space provided. This conforms to the Fechner's second method, the method of production. Here, I will be observing not only the ratio of the shape drawn, but its orientation on the page.

The fifth question is relevant to Fechner's first and second method, in that, the participant is asked to construct a vertical line which divides a given horizontal line. They are given control over the placement and construction of the line, within fixed limitations. Here looked to see whereabouts on the line people tend to find most appealing.

The sixth and final question is purely relevant to Fechner's first method. Participants are asked to choose from a selection of five similar shapes, the one which they find most appealing. There are four sub-questions, each with a selection of five named shapes.

For example, 6(a) contains five horizontal rectangles; 6(b) contains five rhombuses and so on. In order to keep this a fair question, each shape has the same surface area, so

interviewees' choices are not influenced by size, and each set of five shapes are arranged randomly, so that there is no instant recognition of ascending or descending ratio order.
In order that I verified my hypotheses, I looked at the correlation between age categories, and the three aesthetic preference questions (4, 5, and 6). However, further linkages or speculations involving gender, and right or left handedness shall be duly noted.

I used a sample of twenty people for each age category, which I feel was sufficient enough to draw conclusions from, and in each group there was a fair proportion of males to females, thus eliminating any potential bias. My raw data is included in Appendices. 2(a) and 2(b).
I have categorised the full list of results into tables[appendix.2(a)(b)], and then made and annotated several individual tables, which explain the results to specific questions

The results from question four, where participants were asked to draw a rectangle of their choice gave some very insightful results. By taking the shortest side of the rectangle drawn, and dividing it by the longer side, I was able to calculate a ratio which – if ideal – would correspond to 0.618, Phi. Since the scale at which these rectangles were drawn was relatively small (drawn to fit about a quarter of an A4 page), I have taken Phi to two decimal places (0.62) as any further accuracy at this scale would be negligible.
In the 16-24 age group, remarkably 10% of participants drew their rectangle with a side-to-side ratio of 0.62[appendix.3a], which is Phi correct to two decimal places. I then looked at the cumulative percentage of people whose ratios were within 0.03, and 0.1 of Phi. 40% of the 16-24 year olds had a ratio within 0.03 of Phi, and furthermore, 60% were within 0.1 of the "ideal" proportion.
When I analysed the 25+ age group, I found very similar results. As with the 16-24 group, 10% of the 25+ category also drew a rectangle with a Phi proportion, accurate to two decimal places, 0.62[appendix.3a]. Results within 0.03 and 0.1 were calculated as 35% and 65% respectively. Although proportionately 5% more of the 25+ group were within 0.1 of

Phi, than the 16-24's, this is not a significant enough margin to give evidence for my hypothesis that recognition of the golden ratio increases with age. Had I been able to interview a younger group, I would have predicted a considerably lower percentage since there is less of a difference in maturity between, say, a 16 and a 30 year old, than there is between an 8 and a 16 year old. However what it does show, is that overall, 63%**[appendix.3a]** which is almost two thirds of all interviewees drew their rectangle of choice with a ratio which only deviated from the golden mean by 0.1. This supports my hypothesis that people find objects with a proportion of Phi, or very close to Phi, aesthetically pleasing. So much so, in fact, that this is the proportion which they seem to choose for their own "design".

But why is this?

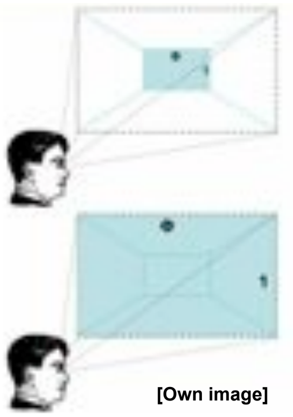
Earlier in this essay I mentioned recognition of "ideal" visual human aesthetics as a large factor, and I believe that there are other contributing factors besides this, again with a visual basis.

For example, I phrased question four; "*In the space below, please draw a rectangle*." I would say that was a fairly neutral question, so why then did 98% of my total survey choose to draw a horizontal rectangle **[appendix.3a]**? I gave no limitations on orientation, yet a hugely significant percentage chose to do this.

An investigation carried out in 1960, by L.A.Stone and L.G.Collins, called the *"perimetric hypothesis"* **[Green.C, 1995]** offers a possible explanation to one of these contributing factors. Since humans see with binocular vision, which is essentially two overlapping points of focus, creating one central focal point, and a depth of field, it is possible to approximate the total visual field as being similar to the shape of a horizontal rectangle. Therefore it is possible, that this is a reason why such a high proportion of the survey drew horizontal rectangles. The familiarity of viewing things through our horizontal parameters may translate into finding horizontal objects more "comfortable" to view.

[Own image, "Bath", 2008]

Furthermore, Stone and Collins found that if a rectangle is drawn around the edge of the visual field, it has a height-to-width ratio of approximately 0.768. This may, at first, seem irrelevant; however, they found that a rectangle drawn fully inside the visual field has a height-to-width ratio of approximately 0.565. The average of these two rectangles is about 0.665, a value which is within 0.05 of Phi.



[Own image]

Is it then, possible to suggest that we find objects which hold the golden ratio, pleasing to observe, because they are able to "fit" perfectly into our field of view? That is to say, if magnified, these objects would be able to completely fill our range of vision.

Question five provided results that although relevant to my first hypothesis, were also relevant to my second one, regarding increasing recognition of the golden section with increasing maturity that is, up until a certain age of full mental awareness. I stress that with the analysis of this question, I have taken the ratio of the larger division of the line against the whole original line, and thereby the range of results is going to be between a minimum of 0.50 and a maximum of 1.00. Once again, Phi is taken as 0.62.

For both age categories, 5% of participants divided the line at exactly 0.62[appendix.3b]. However, as we deviate slightly from the golden mean, differences between groups become noticeable. 30% of the 16-24 year olds had placed their vertical dash within 0.03 points of accuracy. If we compare that with a rather more substantial 45% in the 25+ age group, it would appear that possibly with an increase in age – and unlike question four – given certain parameters as opposed to free reign over the choices made, adults of 25 years and over are more likely to identify the golden mean as their preferred ratio. Diverging once more from 0.03 to 0.1 points of accuracy either side of Phi, this difference increases further. 90% of the 25+ category are within 0.1 of Phi, as opposed to only 55% of the 16-24's[appendix.3b]. Despite using a small sample, the results gained indicate support for my second hypothesis. Had I been able to interview a younger age group, I would have expected a much smaller percentage in regards to the golden mean, and a much larger emphasis on symmetry. This is based on my third hypothesis, that recognition of Phi is a learned ability, and that for a less mature human individual, i.e. a child – symmetry is a more instant recognition of balance and perfection, thereby a significant proportion of children may approximate a ratio of 0.5.

Question six deals with Fechner's first method, the method of choice. Participants were asked to choose from five similar shapes, each bearing a different proportion. Respectively, these ratios were 0.35, 0.5, 0.618 (Phi), 0.8 and 0.9 [appendix.1c]. There are four parts to this question. A point to bear in mind is that if there was an even distribution of votes, each variation per group of five would exhibit 20%. Thus – taking an arbitrary 40%, which may not seem very significant – it is worth noting that this is double the even distribution percentage, and can therefore be considered of some significance.

Part (a) is comprised of five horizontal rectangles, and as predicted, and in accordance with trends seen in question four, the golden rectangle was by far the most popular choice. In both the 16-24's and the 25+ age category, 60% of participants opted for the rectangle with the Phi ratio, nearly two thirds of the entire survey [appendix.3d].

Part (b) features five rhombuses, with the proportions quoted above. I had predicted a fairly random distribution of votes for this question, based on the assumption that since a rhombus, or diamond shaped outline is very different from our binocular field of vision, it is something which we are unaccustomed to, and therefore would be less likely to develop a preference for. The results matched my expectations and the percentages for the rhombuses with ratios of 0.35, 0.5, 0.618, 0.8 and 0.9, respectively were;

For the 16-24 year olds; 25%, 30%, 10%, 20%, 15% [appendix.3c].

For the 25+ year olds; 20%, 25%, 15%, 10%, 30% [appendix.3c].

Thus, taking the overall results, since a larger sample yields more reliable results, the distribution, as follows, is surprisingly close to the even, 20% per/ratio distribution;

Overall; 22.5%, 27.5%, 12.5%, 15%, 22.5% [appendix.3d]

This gives further evidence to Stone and Collins's *"perimetric hypothesis"* [Green.C, 1995], since there seems to be no statistically significant preference towards any individual rhombus.

Part (c) includes five ellipses, with their horizontal and vertical axes in the relevant proportions. The shape of the horizontal ellipse, much like the rectangles in (a) can approximate the human visual range, therefore I had predicted a majority weighting towards the "golden ellipse". The results confirmed this, as 50% of 16-24's and 35% of the 25+ group favoured the ellipse with the 0.618 ratio [appendix.3c]. However, despite approximating the field of vision, like the horizontal rectangle, the weighting towards the golden ellipse was less significant than that of the golden rectangle. I believe this is because the ratio between the horizontal and vertical axes of an ellipse is less easily distinguishable than the sides of a rectangle, hence I would expect fewer participants to identify the dimensions of the ellipse, and so the margin of preference for the ellipses in (c) is accordingly less than that of the rectangles in part (a).

Interestingly, if we take parts (a) and (c) to be of a similar nature, as shown by the corresponding preference, possibly based on the *"perimetric hypothesis"*, and we look at the second highest preference, after the golden ratio, for each; a new pattern emerges. For both (a), and (c), the second most preferred ratio for the 16-24 age group was the 0.9 group, with 25% of the votes for (a) and (c) respectively [appendix.3c]. On the other hand, the second choice groups for the 25+ age group were both 0.8, with 15% and 25% of the votes for (a) and (c) respectively [appendix.3c]. It seems that the younger age group prefer the 0.9 ratio (disregarding Phi, for a moment), perhaps because it is tending towards 1.00, which would be a perfect square. Is it possible then, that this indicates a trace of the (predicted) preference which children may have, towards symmetry and balance, before they develop a subconscious appreciation of the golden ratio? Certainly the 25+ age group's second choice group, 0.8 is much closer to the golden mean, and in addition to the 35% preference towards the golden ellipse, a further 35% of the remaining votes were cast in favour of the two proportions closest to Phi.

The fourth and final section of question six, part (d) shows five vertical rectangles, which happen to be the exact same rectangles featured in (a), simply rotated 90 degrees, and arranged in a different order, so as not to draw attention to the similarities. As predicted, fewer people identified the golden rectangle when placed vertically, as they did when in the horizontal position, however, cumulatively the 0.618, and the 0.8 rectangle amassed 62.5% of the total votes, 27.5% and 35% respectively [appendix.3c]. It seems that people still approximate Phi, under these conditions, but to a lesser degree of accuracy? Or is a vertical rectangle with a ratio of 0.8 simply more appealing?

This account of some research by Gustav Fechner may offer an explanation;

"Employing the his third method of investigation, the method of use, Gustav Fechner collected data from some 20,000 paintings in 22 museums and art galleries, to see whether artwork tended to be framed in golden proportions. Contrary to his prediction, however, the golden rectangle did not characterize the height-to-width ratio of the paintings. Vertical paintings, often portraits, on average, displayed a 5:4 ratio..." [Green.C, 1995]

If then, it can be said that we prefer vertical rectangles with a proportion of 5:4, (0.8), because it is what we are used to seeing in objects such as (as an arbitrary example) portrait paintings, then this provides support for my third hypothesis that our visual preferences are largely dependant on the recall of what is familiar to us, and the expectation that something – by being familiar – is somehow correct, or pleasing.

Although for the more speculative ideas I have thus far presented, a larger sample of data would probably be required to give conclusive results, I think that there is enough evidence to remark upon the validity of my initial hypotheses.

I think it is fair to say that people find objects with Phi integral in their design, the most aesthetically pleasing, whether choosing from a selection or constructing their own dimensions. Furthermore, there are trends which suggest an increased perception of Phi, as a person matures into adulthood, though unfortunately due to limiting factors, I cannot yet form a definite statement, as the current data does not cover a broad enough age range. My third hypotheses has received substantial support from the results of the questionnaire, which gives evidence that recognition of Phi is, to an extent, based on familiarity and recall – which although derives from inherent traits, present due to their efficiency – cannot be established without a certain amount of exposure to the environment in which we exist

Certainly when we create our own environments in which to exist, we base much of the details on the golden section, possibly unknowingly, and probably for the simple reason that it “feels” like the right thing to do. Art, Architecture, television screens, credit cards, and even cereal boxes are designed to golden ratio dimensions.

Even the paper, on which this essay is printed, has a ratio which approximates Phi.

To further my investigation, I could have explored the notion of whether gender affects aesthetic preference, and I also think it would be interesting to conduct more thorough research into the neurological aspect of Phi. Perhaps investigating the idea that the left and right side of the brain control different thinking characteristics, so are there any patterns between left or right handed people?

In an attempt to condense the fundamental principles of my investigation into a single paragraph, I would present the following notion:

We find objects with Phi as an integral part of their design pleasing, because from what we have experienced, it signifies familiarity, thereby carrying an expectation of correctness, and stimulates comfort, reassurance, and positive emotion within us. The reasoning behind the familiarity of Phi is that we can consciously and subconsciously observe it, in the archetypal examples of species and design. The reason we observe it, chiefly in these archetypes is that application of Phi seems to provide an underlying practicality, and efficiency, which gives these certain examples “ideal” characteristics, thus inspiring the recognition of “ideal designs” which we perceive to be beauty. Since these designs are based on efficiency, which seems to often derive from Phi, it is a natural progression to then link Phi with perceived beauty. If asked why Phi appears to yield the most efficient design, then I simply could not provide a reasoned answer. I could only speculate that since it is taken to be the most irrational of all irrational numbers that, it holds some advantageous property, of which I cannot quantify. Perhaps the explanation of beauty is that which can be appreciated and observed, yet in itself, is incomprehensible. Much like the convergence of successive Fibonacci ratios, each one becoming closer and closer to Phi, but never reaching it. Only the infinite term of the sequence could ever be considered the “Golden Ratio”, thus suggesting that perfection is attainable, only as a concept. Assuming there is an answer, and regardless of where or how it lies, it seems oddly ironic to me that one of the fundamental keystones of how we perceive beauty or perfection is based on the paradox of a number being “perfectly imperfect”.

Summary

Phi is a ratio, derived from a series of numbers known as the Fibonacci sequence. It has been used in art and architecture for thousands of years, because it is thought to yield a proportion, which gives an ideal aesthetic. It is also observable in nature, on many scales; from the structure of DNA, to the shape of a galaxy. I conducted some primary research, the results of which supported the idea that Phi is an aesthetically pleasing ratio. I then looked at how this idea could link back to Phi's prevalence in nature. The reason seemed to be efficiency. Objects with Phi in their design often possessed ideal characteristics for success in their environment. I then looked at the notion that our perception of beauty could be based on recognition of efficiency in design. This appreciation for good design could be the reason we frequently incorporate Phi into our own environment, often subconsciously. I feel that there are strong links between sections in the essay, and aspects of philosophy and psychology, which gives depth to the essays fundamental grounding in mathematics, science, and the arts.

Aesthetics Questionnaire

1. Please tick the box which corresponds to your age. **8 – 10** ☐ **16 - 24** ☐ **30+** ☐

2. Are you : Male ☐
Female ☐

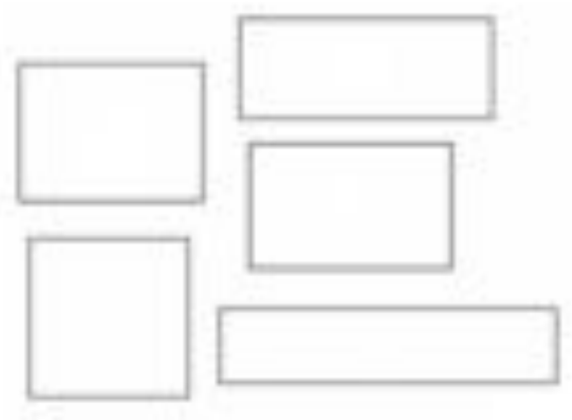
3. Are you : Right handed ☐
Left Handed ☐

4. In the space below, please draw a rectangle.

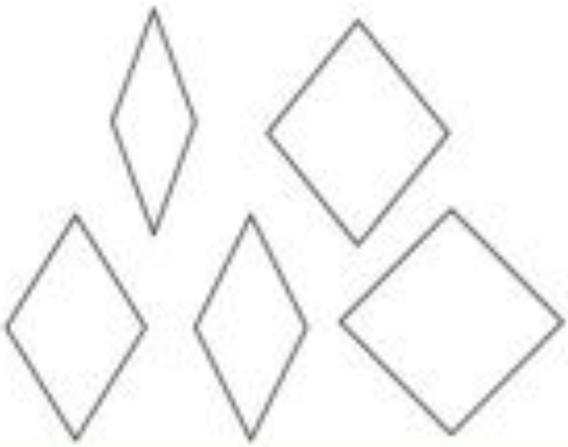
5. Mark the line below with a vertical dash at a point of your choosing.

6. Place an “X” in the shape of your choice

(a)

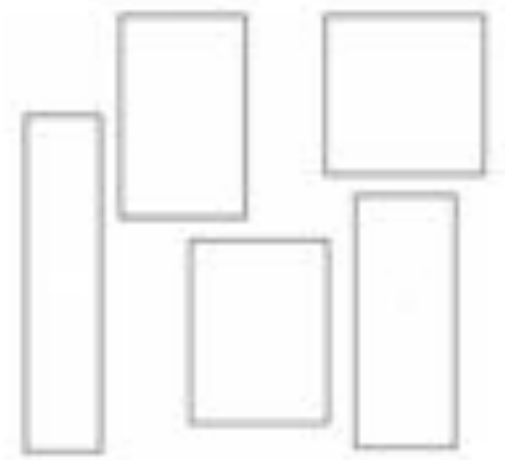


(b)



(c)

(d)



Appendix.1(a)

Person	Qu.1	Qu.2	Qu.3	Qu.4	Qu.5	Qu.6 (a)	Qu.6 (b)	Qu.6 (c)	Qu.6 (d)
1	16 - 24	female	RHD	0.52	0.8	0.9	0.35	0.35	0.35
2	16 - 24	male	RHD	0.5	0.52	0.9	0.35	0.35	0.35
3	16 - 24	male	RHD	0.59	0.6	0.8	0.5	0.618	0.9
4	16 - 24	male	RHD	0.43	0.75	0.9	0.9	0.9	0.5
5	16 - 24	female	RHD	0.38	0.84	0.5	0.8	0.9	0.8
6	16 - 24	female	LHD	0.51	0.74	0.618	0.5	0.618	0.8
7	16 - 24	female	RHD	0.58	0.5	0.618	0.5	0.8	0.8
8	16 - 24	male	RHD	0.64	0.58	0.618	0.8	0.618	0.618
9	16 - 24	male	LHD	0.68	0.67	0.618	0.9	0.618	0.618
10	16 - 24	male	RHD	0.42	0.6	0.618	0.35	0.618	0.618
11	16 - 24	female	RHD	0.51	0.64	0.8	0.618	0.618	0.9
12	16 - 24	female	LHD	0.62	0.71	0.618	0.8	0.618	0.8
13	16 - 24	male	RHD	0.65	0.66	0.9	0.35	0.9	0.8
14	16 - 24	male	RHD	0.53	0.73	0.618	0.618	0.8	0.8
15	16 - 24	female	RHD	0.6	0.65	0.618	0.8	0.5	0.8
16	16 - 24	male	RHD	0.61	0.62	0.618	0.35	0.9	0.618
17	16 - 24	male	RHD	0.44	0.75	0.618	0.5	0.618	0.618
18	16 - 24	female	LHD	0.62	0.51	0.9	0.9	0.618	0.8
19	16 - 24	male	RHD	0.32	0.89	0.618	0.5	0.618	0.618
20	16 - 24	female	RHD	0.59	0.65	0.618	0.5	0.9	0.8

Person	Qu.1	Qu.2	Qu.3	Qu.4	Qu.5	Qu.6 (a)	Qu.6 (b)	Qu.6 (c)	Qu.6 (d)
1	25+	female	RHD	0.33	0.75	0.618	0.618	0.5	0.9
2	25+	male	RHD	0.56	0.51	0.35	0.35	0.35	0.35
3	25+	male	RHD	0.66	0.57	0.618	0.618	0.8	0.8
4	25+	female	RHD	0.48	0.74	0.9	0.9	0.8	0.9
5	25+	male	LHD	0.62	0.6	0.618	0.5	0.8	0.35
6	25+	female	RHD	0.62	0.65	0.8	0.8	0.618	0.8
7	25+	male	RHD	0.51	0.72	0.618	0.9	0.9	0.618
8	25+	female	RHD	0.61	0.55	0.5	0.35	0.618	0.8
9	25+	female	RHD	0.65	0.66	0.618	0.35	0.5	0.8
10	25+	male	RHD	0.59	0.6	0.8	0.5	0.8	0.9
11	25+	female	RHD	0.4	0.52	0.618	0.35	0.5	0.5
12	25+	male	RHD	0.64	0.67	0.618	0.5	0.618	0.618
13	25+	male	RHD	0.54	0.62	0.618	0.618	0.618	0.35
14	25+	female	RHD	0.5	0.61	0.618	0.5	0.35	0.5
15	25+	female	RHD	0.57	0.53	0.8	0.9	0.9	0.9
16	25+	male	RHD	0.69	0.65	0.35	0.9	0.618	0.35
17	25+	female	LHD	0.48	0.65	0.618	0.35	0.9	0.618
18	25+	female	RHD	0.6	0.6	0.5	0.9	0.618	0.618
19	25+	female	RHD	0.49	0.65	0.618	0.9	0.618	0.8
20	25+	male	LHD	0.58	0.7	0.618	0.5	0.8	0.618

Appendix.2(a)

Interviewee	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6 (a)	Question 6 (b)	Question 6 (c)	Question 6 (d)
1	16 - 24	female	RHD	0.52	0.8	0.9	0.35	0.35	0.35
2	16 - 24	male	RHD	0.5	0.52	0.9	0.35	0.35	0.35
3	16 - 24	male	RHD	0.59	0.6	0.8	0.5	0.618	0.9
4	16 - 24	male	RHD	0.43	0.75	0.9	0.9	0.9	0.5
5	16 - 24	female	RHD	0.38	0.84	0.5	0.8	0.9	0.8
6	16 - 24	female	LHD	0.51	0.74	0.618	0.5	0.618	0.8
7	16 - 24	female	RHD	0.58	0.5	0.618	0.5	0.8	0.8
8	16 - 24	male	RHD	0.64	0.58	0.618	0.8	0.618	0.618
9	16 - 24	male	LHD	0.68	0.67	0.618	0.9	0.618	0.618
10	16 - 24	male	RHD	0.42	0.6	0.618	0.35	0.618	0.618
11	16 - 24	female	RHD	0.51	0.64	0.8	0.618	0.618	0.9
12	16 - 24	female	LHD	0.62	0.71	0.618	0.8	0.618	0.8
13	16 - 24	male	RHD	0.65	0.66	0.9	0.35	0.9	0.8
14	16 - 24	male	RHD	0.53	0.73	0.618	0.618	0.8	0.8
15	16 - 24	female	RHD	0.6	0.65	0.618	0.8	0.5	0.8
16	16 - 24	male	RHD	0.61	0.62	0.618	0.35	0.9	0.618
17	16 - 24	male	RHD	0.44	0.75	0.618	0.5	0.618	0.618
18	16 - 24	female	LHD	0.62	0.51	0.9	0.9	0.618	0.8
19	16 - 24	male	RHD	0.32	0.89	0.618	0.5	0.618	0.618
20	16 - 24	female	RHD	0.59	0.65	0.618	0.5	0.9	0.8

Appendix.2(b)

Interviewee	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6 (a)	Question 6 (b)	Question 6 (c)	Question 6 (d)
1	25+	female	RHD	0.33	0.75	0.618	0.618	0.5	0.9
2	25+	male	RHD	0.56	0.51	0.35	0.35	0.35	0.35
3	25+	male	RHD	0.66	0.57	0.618	0.618	0.8	0.8
4	25+	female	RHD	0.48	0.74	0.9	0.9	0.8	0.9
5	25+	male	LHD	0.62	0.6	0.618	0.5	0.8	0.35
6	25+	female	RHD	0.62	0.65	0.8	0.8	0.618	0.8
7	25+	male	RHD	0.51	0.72	0.618	0.9	0.9	0.618
8	25+	female	RHD	0.61	0.55	0.5	0.35	0.618	0.8
9	25+	female	RHD	0.65	0.66	0.618	0.35	0.5	0.8
10	25+	male	RHD	0.59	0.6	0.8	0.5	0.8	0.9
11	25+	female	RHD	0.4	0.52	0.618	0.35	0.5	0.5
12	25+	male	RHD	0.64	0.67	0.618	0.5	0.618	0.618
13	25+	male	RHD	0.54	0.62	0.618	0.618	0.618	0.35
14	25+	female	RHD	0.5	0.61	0.618	0.5	0.35	0.5
15	25+	female	RHD	0.57	0.53	0.8	0.9	0.9	0.9
16	25+	male	RHD	0.69	0.65	0.35	0.9	0.618	0.35
17	25+	female	LHD	0.48	0.65	0.618	0.35	0.9	0.618
18	25+	female	RHD	0.6	0.6	0.5	0.9	0.618	0.618
19	25+	female	RHD	0.49	0.65	0.618	0.9	0.618	0.8
20	25+	male	LHD	0.58	0.7	0.618	0.5	0.8	0.618

Appendix.3(a)

Question 4 16 - 24		
0.52	p/m 0.00 = 2	10%
0.5	p/m 0.03 = 8	40%
0.59	p/m 0.1 = 12	60%
0.43		
0.38	h'zal	100%
0.51	v'cal	0%
0.58		
0.64		
0.68		
0.42		
0.51		
0.62		
0.65		
0.53		
0.6		
0.61		
0.44		
0.62		
0.32		
0.59		

Question 4 25+		
0.33	p/m 0.00 = 2	10%
0.56	p/m 0.03 = 7	35%
0.66	p/m 0.1 = 13	65%
0.48		
0.62	h'zal	95%
0.62	v'cal	5%
0.51		
0.61		
0.65		
0.59		
0.4		
0.64		
0.54		
0.5		
0.57		
0.69		
0.48		
0.6		
0.49		
0.58		

Question 4 all			
0.52	0.33	p/m 0.00 = 4	10%
0.5	0.56	p/m 0.03 = 15	38%
0.59	0.66	p/m 0.1 = 25	63%
0.43	0.48		
0.38	0.62		
0.51	0.62	h'zal	98%
0.58	0.51	v'cal	2%
0.64	0.61		
0.68	0.65		
0.42	0.59		
0.51	0.4		
0.62	0.64		
0.65	0.54		
0.53	0.5		
0.6	0.57		
0.61	0.69		
0.44	0.48		
0.62	0.6		
0.32	0.49		
0.59	0.58		

Appendix.3(b)

Question 5

16 - 24

0.8	p/m 0.00 = 1	5%
0.52	p/m 0.03 = 6	30%
0.6	p/m 0.1 = 11	55%
0.75		
0.84		
0.74		
0.5		
0.58		
0.67		
0.6		
0.64		
0.71		
0.66		
0.73		
0.65		
0.62		
0.75		
0.51		
0.89		
0.65		

Question 5

25+

0.75	p/m 0.00 = 1	5%
0.51	p/m 0.03 = 9	45%
0.57	p/m 0.1 = 18	90%
0.74		
0.6		
0.65		
0.72		
0.55		
0.66		
0.6		
0.52		
0.67		
0.62		
0.61		
0.53		
0.65		
0.65		
0.6		
0.65		
0.7		

Question 5

all

0.8	0.75	p/m 0.00 = 2	5%
0.52	0.51	p/m 0.03 = 15	38%
0.6	0.57	p/m 0.1 = 29	73%
0.75	0.74		
0.84	0.6		
0.74	0.65		
0.5	0.72		
0.58	0.55		
0.67	0.66		
0.6	0.6		
0.64	0.52		
0.71	0.67		
0.66	0.62		
0.73	0.61		
0.65	0.53		
0.62	0.65		
0.75	0.65		
0.51	0.6		
0.89	0.65		
0.65	0.7		

Appendix.3(c)

Question 6 (a)	Question 6 (b)	Question 6 (c)	Question 6 (d)
16 -24			
0.9	0.35	0.35	0.35
0.9	0.35	0.35	0.35
0.8	0.5	0.618	0.9
0.9	0.9	0.9	0.5
0.5	0.8	0.9	0.8
0.618	0.5	0.618	0.8
0.618	0.5	0.8	0.8
0.618	0.8	0.618	0.618
0.618	0.9	0.618	0.618
0.618	0.35	0.618	0.618
0.8	0.618	0.618	0.9
0.618	0.8	0.618	0.8
0.9	0.35	0.9	0.8
0.618	0.618	0.8	0.8
0.618	0.8	0.5	0.8
0.618	0.35	0.9	0.618
0.618	0.5	0.618	0.618
0.9	0.9	0.618	0.8
0.618	0.5	0.618	0.618
0.618	0.5	0.9	0.8
0.35 = 0	0.35 = 5	0.35 = 2	0.35 = 2
0.5 = 1	0.5 = 6	0.5 = 1	0.5 = 1
0.618 = 12	0.618 = 2	0.618 = 10	0.618 = 6
0.8 = 2	0.8 = 4	0.8 = 2	0.8 = 9
0.9 = 5	0.9 = 3	0.9 = 5	0.9 = 2
0.35 = 0%	0.35 = 25%	0.35 = 10%	0.35 = 10%
0.5 = 5%	0.5 = 30%	0.5 = 5%	0.5 = 5%
0.618 = 60%	0.618 = 10%	0.618 = 50%	0.618 = 30%
0.8 = 10%	0.8 = 20%	0.8 = 10%	0.8 = 45%
0.9 = 25%	0.9 = 15%	0.9 = 25%	0.9 = 10%

Question 6 (a)	Question 6 (b)	Question 6 (c)	Question 6 (d)
25+			
0.618	0.618	0.5	0.9
0.35	0.35	0.35	0.35
0.618	0.618	0.8	0.8
0.9	0.9	0.8	0.9
0.618	0.5	0.8	0.35
0.8	0.8	0.618	0.8
0.618	0.9	0.9	0.618
0.5	0.35	0.618	0.8
0.618	0.35	0.5	0.8
0.8	0.5	0.8	0.9
0.618	0.35	0.5	0.5
0.618	0.5	0.618	0.618
0.618	0.618	0.618	0.35
0.618	0.5	0.35	0.5
0.8	0.9	0.9	0.9
0.35	0.9	0.618	0.35
0.618	0.35	0.9	0.618
0.5	0.9	0.618	0.618
0.618	0.9	0.618	0.8
0.618	0.5	0.8	0.618
0.35 = 2	0.35 = 4	0.35 = 2	0.35 = 4
0.5 = 2	0.5 = 5	0.5 = 3	0.5 = 2
0.618 = 12	0.618 = 3	0.618 = 7	0.618 = 5
0.8 = 3	0.8 = 2	0.8 = 5	0.8 = 5
0.9 = 1	0.9 = 6	0.9 = 3	0.9 = 4
0.35 = 10%	0.35 = 20%	0.35 = 10%	0.35 = 20%
0.5 = 10%	0.5 = 25%	0.5 = 15%	0.5 = 10%
0.618 = 60%	0.618 = 15%	0.618 = 35%	0.618 = 25%
0.8 = 15%	0.8 = 10%	0.8 = 25%	0.8 = 25%
0.9 = 5%	0.9 =30%	0.9 = 15%	0.9 = 20%

Appendix.3(d)

Question 6 (a)	Question 6 (b)	Question 6 (c)	Question 6 (d)
all			
0.9	0.35	0.35	0.35
0.9	0.35	0.35	0.35
0.8	0.5	0.618	0.9
0.9	0.9	0.9	0.5
0.5	0.8	0.9	0.8
0.618	0.5	0.618	0.8
0.618	0.5	0.8	0.8
0.618	0.8	0.618	0.618
0.618	0.9	0.618	0.618
0.618	0.35	0.618	0.618
0.8	0.618	0.618	0.9
0.618	0.8	0.618	0.8
0.9	0.35	0.9	0.8
0.618	0.618	0.8	0.8
0.618	0.8	0.5	0.8
0.618	0.35	0.9	0.618
0.618	0.5	0.618	0.618
0.9	0.9	0.618	0.8
0.618	0.5	0.618	0.618
0.618	0.5	0.9	0.8
0.618	0.618	0.5	0.9
0.35	0.35	0.35	0.35
0.618	0.618	0.8	0.8
0.9	0.9	0.8	0.9
0.618	0.5	0.8	0.35
0.8	0.8	0.618	0.8
0.618	0.9	0.9	0.618
0.5	0.35	0.618	0.8
0.618	0.35	0.5	0.8
0.8	0.5	0.8	0.9
0.618	0.35	0.5	0.5
0.618	0.5	0.618	0.618
0.618	0.618	0.618	0.35
0.618	0.5	0.35	0.5
0.8	0.9	0.9	0.9
0.35	0.9	0.618	0.35
0.618	0.35	0.9	0.618
0.5	0.9	0.618	0.618
0.618	0.9	0.618	0.8
0.618	0.5	0.8	0.618

0.35 = 2	0.35 = 9	0.35 = 4	0.35 = 6
0.5 = 3	0.5 = 11	0.5 = 4	0.5 = 3
0.618 = 24	0.618 = 5	0.618 = 17	0.618 = 11
0.8 = 5	0.8 = 6	0.8 = 7	0.8 = 14
0.9 = 6	0.9 =9	0.9 = 8	0.9 = 6

0.35 = 5%	0.35 = 22.5%	0.35 = 10%	0.35 = 15%
0.5 = 7.5%	0.5 = 27.5%	0.5 = 10%	0.5 = 7.5%
0.618 = 60%	0.618 = 12.5%	0.618 = 42.5%	0.618 = 27.5%
0.8 = 12.5%	0.8 = 15%	0.8 = 17.5%	0.8 = 35%
0.9 = 15%	0.9 = 22.5%	0.9 = 20%	0.9 = 15%

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