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The Glass Bead Game

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Chapter 1.

The Glass Bead Game

Visual Knowledge

> "This same eternal idea, which for us has been embodied in the Glass Bead Game, has underlain every movement of Mind... with the dream of pairing the living beauty of thought and art with the magical expressiveness of the exact sciences."
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> Hermann Hesse, *The Glass Bead Game*

Our lives are filled with images. Everyday we see signals, read signs and learn symbols. We find our way with maps, look for news and bargains in newspapers, calculate our bills and taxes. We turn printed music into wonderful sounds, often without conscious effort. Icons fill our churches, synagogues and mosques, dot our computer screens, and are sprawled on billboards, clothing and advertisement pages. Architecture and art conspire to fill our views with meaningful shapes and form. Pictures capture an instant in time, while movies and video entertain us with visual motion. We live in a visual world, full of information transmitted by light.

Writing is the verbal made visual, put into physically lasting form as combinations of letters incised in clay or stone, on a printed page, or on a computer screen. We understand the words as we see them because the visual impression on our retinas ultimately connects with the language centers of our human brain. Similar mental processes occur for mathematics and music. Mathematical symbols represent something specific, some thought or quantity, or a relationship between abstract concepts. Notes on a score represent pitch and duration. We see the symbols, visually, and we know what they represent. But how do we know?

Vision is the most powerful of our senses. More visual neurons are needed to transmit sensory information to the brain than for any of the other senses. The retina, the light-sensitive layer at the back of the eye, has a special status above all other sensory organs as a direct extension and outgrowth of the brain itself. In the early fetus, portions of the nascent brain extend forward in the brain cavity to develop eventually into the retina. The mature retina is composed of multiple interconnected layers of neurons that take the images coming into the eye and begin to analyze them for spatial relationships. After the retina performs considerable neural computation, the visual information is coded into electrochemical impulses that are the language of the brain and of intelligence.

This all happens before the signals are even sent upwards to the visual cortex of the brain. Thus we already have intelligence in our eyes. Natural selection has driven the evolution of organisms who have advanced image acquisition and analysis capabilities because the visual image is an information format with significant advantages for survival. None of the other senses can give the type of explicit spatial information that eye and vision can, especially the ability to provide information about distant predators or prey. What is it about the image that makes it so informative?

A visual image such as a picture is a parallel data structure. That is, all points in the picture or scene either emit, transmit or reflect light all at the same time––in parallel. A single square centimeter of a picture has well over a million points of light all emitting together. When the image falls on the retina, hundreds of thousands of micron-size receptive fields in the retina process and send information simultaneously to the brain. The parallel data rate is over a megabyte per second–– comparable to the data transfer rate of a computer hard drive. By considerable contrast, during oral communication the ear receives words one at a time––that is, serially––at the rate of only a few bytes per second. The parallel processing capability of the eyes, and their highly advanced structure and function, certainly far exceeds the information speed that the serial mode of the ears can offer.

There is a trite saying that a picture is worth a thousand words. This statement implies that in the instant a picture is seen, the equivalent information content of one thousand words is conveyed to the brain. Is this true? And what information has been conveyed? To answer these questions, it is necessary to consider how visual communication (through images) differs from language communication (through spoken or written words). The abstract thoughts and concepts elicited by language and words have an entirely different quality than information sent by images and pictures. Images carry texture and form, and above all provide spatial relationships "at a glance". They present a whole world that can only be alluded to by language.

THE GLASS BEAD GAME

It is natural to ask how far the advantages of light and image can be taken. The search for a universal language of symbols that can express the essence and subtleties of all knowledge has had a long and energetic history. Some of the greatest minds of western thought have attempted to develop such a language. One of the first was Gottfried Wilhelm Leibniz who envisioned a universal "character" which could express all knowledge and act as an instrument of discovery of new concepts and truths. Indications that a universal language might be possible came from the growing awareness at that time of Chinese character writing, as well as of Egyptian hieroglyphic writing. The opening up of the Far East and the growing infatuation with Egyptian artifacts presented seventeenth century scholars with a treasure of new possibilities that seemed alien and mind-expanding to the Europeans. The imagination was further fueled by misconceptions and imperfect understanding of the meanings of the scripts. There was an impression (albeit false) that the characters represented things directly, and were divorced from the peculiarities of the spoken language. Nonetheless, the existence of these forms of writing was cited as proof that a universal language was possible, which could impart ideas and concepts directly, through written characters. The difficulty was in finding an efficient means to do this.

Leibniz founded the Academy of Sciences in Berlin specifically to launch his project of the search for a universal character. He outlined the goals of the project in his *Dissertatio de arte combinatoria* of 1666. Many of his activities related to the project, even his development of the calculus. He corresponded extensively with Johann Bernoulli, a co-inventor of the calculus, to discuss fine points of notation, striving to find the best and most efficient symbols. The standardized notation we use today for Calculus was contributed almost exclusively by Leibniz, superceding Newton's clumsy notation developed at the same time. However, Leibniz was unable to find the time in a busy life to tackle the problem of the universal language thoroughly. Others took up the call. Some have been as recent as Carl Jung with his symbols of transformation, and Alfred North Whitehead Whitehead and Bertrand Russel with their symbolic logic.

Perhaps the most imaginative picture of the potential of light and image was painted by the 20th century Nobel Prize winning novelist Hermann Hesse (1877-1962). The novel *Die Glasperlenspiel* (The Glass Bead Game) was the last novel of the author and precipitated his receiving the Nobel prize in literature in 1946. Hermann Hesse was born in 1877 in the southern German town of Calw by the edge of the Black Forest on the Nagold river. He lived a tempestuous youth and fared badly in school. His voracious appetite for literature was self-fueled as he worked in bookshops in Tübingen and later in Basel, Switzerland. A loner and outsider, he immersed himself in books and began a literary career. His first novel, published in 1904 when he was 27 years old, was *Peter Camenzind*. This novel brought the unknown writer rapid fame and won for him the Bauernfeld Prize of Vienna. He married Maria Bernoulli (of the famous mathematical Bernoulli family) the same year. The following years brought more literary success as Hesse explored the inner turmoil of his youth.

Hesse became acquainted with the theories of Carl Jung, which had a profound influence on Hesse's life and writing. In particular, Hesse was fascinated by Jung's ideas concerning dreams and universal symbols. As more novels followed, including *Demian*, *Siddhartha*, *Steppenwolf* and *The Journey to the East*, Hesse's writing continued to look inward with increasing emphasis on symbolism and vivid imagery. The culmination of his inward growth appeared in 1942, a the age of 65, with *Das Glasperlenspiel (The Glass Bead Game)*.

The novel describes a utopian intellectual community called the Order that occupies itself with the study and playing of the Glass Bead Game. This monastic community exists in some future time, in a country named Castilia that is dedicated solely to the purposes of the Order and of the Game. The story of the Game, and in particular of Joseph Knecht, the Master of the Game, known as the Magister Ludi, unfolds through the narrative of a fictitious biographer.

The Game is an idealized version of the universal language envisioned by Leibniz. The narrator tells how the fictitious originator of the Game "...invented for the Glass Bead Game the principles of a new language, a language of symbols and formulas, in which mathematics and music played an equal part, so that it became possible to combine astronomical and musical formulas, to reduce mathematics and music to a common denominator [NOTE: Hesse, pg. 27]." It is the tale of an idyllic society dedicated to the playing of a game of pure knowledge. Within this game, abstract concepts are represented by a set of glass beads, or icons. The visual and spatial arrangement of these beads by players allow all aspects of human knowledge to be related one to another: mathematics to art, music to astronomy, philosophy to architecture, and infinite combinations of these. The winner of the game was the player who succeeded in weaving the most striking or surprising connections and themes among seemingly disparate concepts. Though fanciful, the "Glass Bead Game" is a model for the visual representation of knowledge.

A quote from Leibniz in 1678, three centuries before, evokes the spirit of the Game: "The true method should furnish us with an Ariadne's thread, that is to say, with a certain sensible and palpable medium, which will guide the mind as do the lines drawn in geometry and the formulas for operations, which are laid down for the learner in arithmetic [NOTE: Leibniz, 1678]." It is easy to form an impression of Leibniz as the Magister Ludi conducting a sublime Glass Bead Game, the players forming their threads of colored glass beads, this one representing a theorem of logic, that one an astronomical observation, and between them a musical theme branching to a mathematical formula, all interrelated, all sharing common forms that span the breadth of human knowledge condensed into symbols.

The importance of the Glass Bead Game is not the physical implementation of a set of rules that defines a game. In fact, Hesse was careful never to describe the actual rules by which the game was played. Furthermore, it must be admitted that universal language schemes (and there have been many) all have failed by being too cumbersome and naive. However, the idea of the Glass Bead Game that is of interest here is that symbols and rules can be visual and that knowledge can be represented and manipulated visually. The Glass Bead Game is therefore an allegory of a new language, the language of light and image needed to run the architecture of the future machines of light. We take this allegory along with us we explore in this book the machines of light that use optical languages to inform and guide their functions.

THE HUMAN BOTTLENECK

The measure of any technology is the degree to which we live better by it. This may be posited as the principal thesis of technological humanism. One way that we live better is by reassigning human tasks to alternative agents. James Bailey, in his book *After Thought* [NOTE: After Thought, James Bailey (Basic Books, 1996)], writes about successive stages of reassignment of human tasks. In the first stage we reassigned our muscle tasks to animals. Horses provided transportation, and oxen pulled our carts. The reassigned work remained on the scale of human effort––one man could drive a few horses. The revolution came after the second stage when we reassigned our muscle tasks to machines, such as power engines and locomotives. This stage spurred the industrial revolution where the scale of the reassigned work extended far beyond human capability, and the change in society was irreversible. In the third stage we have reassigned our mind tasks to machines such as calculators and computers. The reassignment of human tasks to machines demands that we first understand the functions that humans perform, then understand how to reassign these functions to machines.

For instance, an important goal of artificial vision systems is the detection of features in an image, such as straight edges in a photograph, or the detection of a specific pattern in a crowded picture, like finding Waldo in the Sunday comics. The machines that perform these complicated image recognition tasks have drawn heavily on the mechanisms of human visual perception as a model of a working visual recognition system. To understand how these machines work, it is necessary to explore human capabilities (and human incapacity, where machines have a chance to go beyond.

A critical incapacity that we suffer during visual communication is our limited speed of comprehension as we read. For instance, if the parallel data structure of images allows us to see with speeds comparable to the data rate of a computer hard drive, why do we read so slowly? If a picture is worth a thousand words, then why don't we communicate with pictures? Why do we use words at all?

At the simplest level, the limitations are physiological and governed by evolution. The human brain has "co-evolved" side-by-side with the evolution of verbal communication. We send and receive information by uttering and then hearing sounds as we communicate serially using language. The physiological structures of our vocal chords and ears have developed to communicate effectively in this manner. However, despite the superior processing speed of the eye and vision over ear and hearing for receiving information, there is no exclusive biological optical equivalent to the vocal chords. We cannot send visual information to another person in a way that utilizes fully the data capacity of the eye. Sign language is certainly one way in which language can be sent visually. This is a highly efficient and expressive manner of communication, possessing favorable qualities that have no equivalent in spoken language. But one of the important findings of the past decades is that the speed of sign language transmission remains comparable to the speed of spoken words.

The difficulty lies in a bottleneck—τhat of language comprehension. The process of reading words or signs partially bridges the gap between the verbal and the visual. The process starts out purely visually as the signs or symbols enter the eye and are sent as electrical impulses to the visual cortex. However, once in the visual cortex, the neural impulses must connect to the language processing centers of the brain for comprehension, just as in the case of oral communication––αnd the language processing centers of the brain work primarily serially, a word, or a sentence fragment, at a time. In this process of "comprehension," the parallel advantage of vision is lost.

BEYOND ANTHROPOCENTRICITY

Human limitations need not be machine limitations. The physiological structure of our brains is an accident of evolution. There is no reason to believe that the specific manner in which we process language is the only possible way. Human limitations do not have to be designed into our machines of light. We are free to try new things, to find new ways of interconnecting neurons and nodes in structures that are radically different from what nature has produced.

This freedom opens up many possibilities. We can view this as an opportunity to explore and test alternative hypotheses concerning how intelligence functions. The way a system "thinks" will almost certainly reflect the architecture of the system. Different structures will "think" in different ways. Rather than trying to make computers mimic the way we think, it might be wisest to find different ways of thinking altogether. By exploring, we might find ways around the biological models.

Intelligent model building has already progressed through one stage––τhe reassignment of mind tasks to machines. This stage started with little more than mechanical calculators, first implemented by Pascal and Leibniz in the 17th century and by Babbage in the 19th century. It continued with the greatly improved speed and accuracy of the first electronic calculators in the middle part of the 20th century. Yet today, our advanced computers remain exceedingly unintelligent, and are far outstripped in reasoning by the human brain. But they do have certain advantages. The continuing increase in speed is one particular asset. What is currently demonstrated as artificial intelligence is mostly made possible by the tremendous and ever-increasing computing speed of modern day computers. The high-speed information processing abilities of computers make up for lack of insight. They get it right, but primarily by brute force.

Thus, this stage is not the revolution that some make it out to be. Mathematical computation is noticeably speeded up by machines, but the calculations themselves remain the same as we would do by hand. The speed of solution has increased beyond human capability, but the structure has not. The real revolution is beginning only now and lies mostly in the future. This will be the stage when the reassigned mind tasks evolve beyond human design. This is made possible using adaptive and genetic algorithms that change their own structure in response to changing inputs, without human intervention. Such algorithms have the potential to evolve into intelligent systems with no human analog (possibly evolving beyond human comprehension.

Part of this revolution in intelligent model building is the current interest in artificial neural networks which draws directly from the structure of biological systems. Scientists have analyzed how the functions of the brain are distributed over neurons, and are now trying to translate those structures into electronic or photonic models. Networks of nodes and their interconnections mimic some of the structure of biological networks of neurons and their synapses. However, it is an open question whether mimicking the brain's structure is sufficient to produce an "intelligent" system. Biological model building is still in an early stage of development, with significant work ahead before a real breakthrough may be possible. Furthermore, basing intelligence on the biological nerological model may not even be the best solution. Newer, nonbiological technologies may have more to offer.

For instance, optical technology is primed to participate in intelligent model building. The basic advantage of the optical computer is the massive parallelism of the image. For a digital computer, the unit of information is the binary unit, known as the "bit". For every tick of the internal clock only a handful of bits are processed even in the most advanced electronic computers. The bit does not carry much weight: only a "yes" or "no" answer. In some types of optical computer, on the other hand, the unit of information is an image. For every tick of the internal clock, the entire image, with all the information in it, is processed all at once. The parallelism of the image improves the data rate enormously.

If the only advantage of optical computers were in parallel processing, then it would represent only an incremental step forward. Higher data rates may mean more computing power, but do not represent expanded function. Optical computers promise something more. They promise abstract and associative "reasoning" based on images and symbols which exist within a language of spatial and spectral (color) relationships. For an optical computer, a picture may well be worth *more* than a thousand words. A picture may be the program that tells the computer what functions it must perform and what concepts must be employed.

Optical computers are in their infancy. The rudimentary and specialized devices built so far in the laboratory are far from the flexible, programmable machines that will be able to make conjectures and leaps of imagination. Some of the current limitations are in materials and in technology. More importantly, a fundamental new architecture must be found! With images and symbols as the information units of these computers, entirely new structures must be developed. The new structures can be free of the limitations of human physiology and free of the limitations of electronic computers. And the new architecture will need a new language in which to express itself. It must be an optical language where images are like words and the grammar is made up of visual projections and associations — we will need something akin to the language of the Glass Bead Game.

THE INTELLIGENCE OF LIGHT

Recurring throughout this book, as I explore human visual communication and review the progress towards the next-generation machines of light, are three basic themes concerning the language of light and image:

First, that all manner of human communication, whether audible through speaking and listening, whether visual through writing and reading or the use of sign language by the deaf, or whether tactile through the use of Braille, share a common rate for comprehension that is limited by biological physiology. I call this theme the Serial Comprehension Bottleneck because all these communication channels must pass through the same cognitive centers of the brain to lead to understanding and the ability to make informed decisions.

Second, that images and words cannot be equivalent, even when considering the same written and spoken word, because the visual and auditory channels use different media that initially access different parts of the brain. Specifically, the visual channel is a massively parallel data channel that has unique attributes and advantages that far outstrip verbal and serial communication, if they can only be accessed. I call this theme the Parallel Advantage of Light and Image.

Third, and finally, that the biological and physiological limitations underlying the human Serial Comprehension Bottleneck need not be machine limitations. We can build machines that can perform functions that we cannot. Speed alone is not such an advance. Rather, new machine architectures will utilize information in ways that go beyond human capabilities. This process of searching for new visual architectures based on a visual language of spatial and spectral relationships may allow machines to find new ways of thinking that utilize the Parallel Advantage of Light and Image. I call this third theme the Architecture of Light.