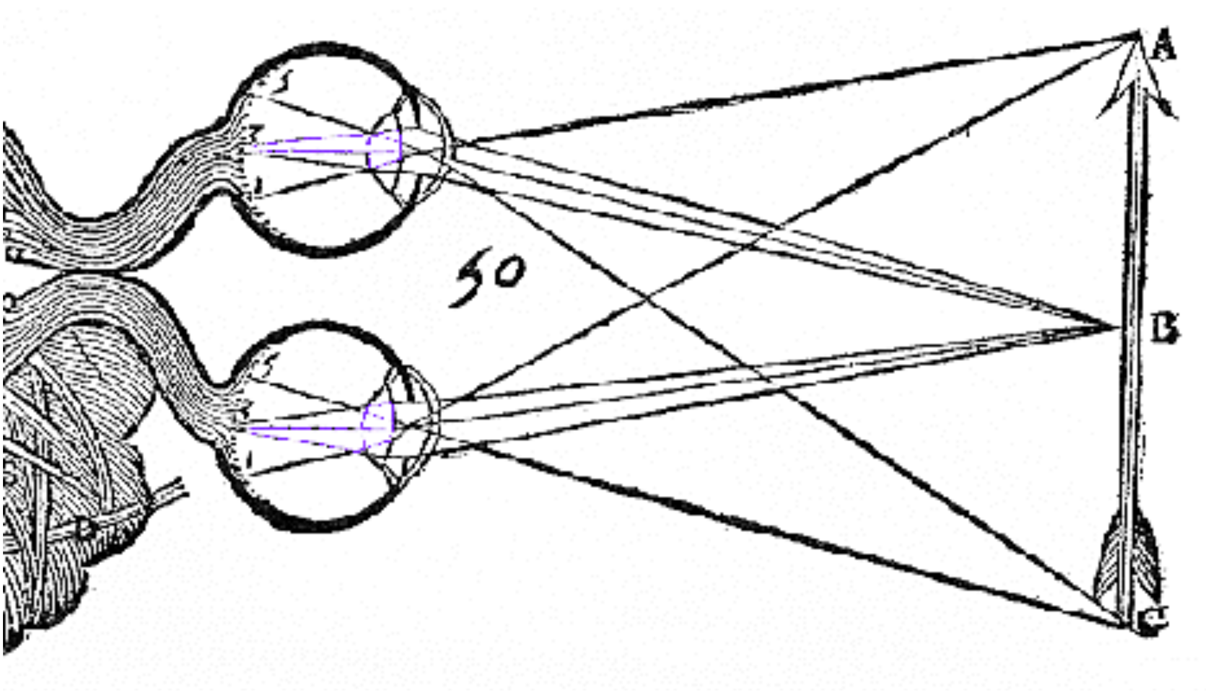
MAKE MUSIC WITH LIGHTS



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CONTENT

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The following text was delivered as a talk at a meeting of a Seattle arts society organized by Bonnie Bird in 1937. It was printed in the brochure accompanying George Avakian's recording of my twenty-five-year retrospective concert at Town Hall, New York, in 1958.

THE FUTURE OF MUSIC: CREDO

I BELIEVE THAT THE USE OF NOISE

Wherever we are, what we hear is mostly noise. When we ignore it, it disturbs us. When we listen to it, we find it fascinating. The sound of a truck at fifty miles per hour. Static between the stations. Rain. We want to capture and control these sounds, to use them not as sound effects but as musical instruments. Every film studio has a library of "sound effects" recorded on film. With a film phonograph it is now possible to control the amplitude and frequency of any one of these sounds and to give to it rhythms within or beyond the reach of the imagination. Given four film phonographs, we can compose and perform a quartet for explosive motor, wind, heartbeat, and landslide.

TO MAKE MUSIC

If this word "music" is sacred and reserved for eighteenth- and nineteenth-century instruments, we can substitute a more meaningful term: organization of sound.

WILL CONTINUE AND INCREASE UNTIL WE REACH A MUSIC PRODUCED THROUGH THE AID OF ELECTRICAL INSTRUMENTS

Most inventors of electrical musical instruments have attempted to imitate eighteenth- and nineteenth-century instruments, just as early automobile designers copied the carriage. The Novachord and the

Solovox are examples of this desire to imitate the past rather than construct the future. When Theremin provided an instrument with genuinely new possibilities, Thereministes did their utmost to make the instrument sound like some old instrument, giving it a sickeningly sweet vibrato, and performing upon it, with difficulty, masterpieces from the past. Although the instrument is capable of a wide variety of sound qualities, obtained by the turning of a dial, Thereministes act as censors, giving the public those sounds they think the public will like. We are shielded from new sound experiences.

The special function of electrical instruments will be to provide complete control of the overtone structure of tones (as opposed to noises) and to make these tones available in any frequency, amplitude, and duration.

WHICH WILL MAKE AVAILABLE FOR MUSICAL PURPOSES ANY AND ALL SOUNDS THAT CAN BE HEARD. PHOTOELECTRIC, FILM, AND MECHANICAL MEDIUMS FOR THE SYNTHETIC PRODUCTION OF MUSIC

It is now possible for composers to make music directly, without the assistance of intermediary performers. Any design repeated often enough on a sound track is audible. Two hundred and eighty circles per second on a sound track will produce one sound, whereas a portrait of Beethoven repeated fifty times per second on a sound track will have not only a different pitch but a different sound quality.

WILL BE EXPLORED. WHEREAS, IN THE PAST, THE POINT OF DISAGREEMENT HAS BEEN BETWEEN DISSONANCE AND CONSONANCE, IT WILL BE, IN THE IMMEDIATE FUTURE, BETWEEN NOISE AND SO-CALLED MUSICAL SOUNDS.

THE PRESENT METHODS OF WRITING MUSIC, PRINCIPALLY THOSE WHICH EMPLOY HARMONY AND ITS REFERENCE TO PARTICULAR STEPS IN THE FIELD OF SOUND, WILL BE INADEQUATE FOR THE COMPOSER, WHO WILL BE FACED WITH THE ENTIRE FIELD OF SOUND.

The composer (organizer of sound) will be faced not only with the entire field of sound but also with the entire field of time. The "frame" or fraction of a second, following established film technique, will probably be the basic unit in the measurement of time. No rhythm will be beyond the composer's reach.

NEW METHODS WILL BE DISCOVERED, BEARING A DEFINITE RELATION TO SCHOENBERG'S TWELVE-TONE SYSTEM

Schoenberg's method assigns to each material, in a group of equal materials, its function with respect to the group. (Harmony assigned to each material, in a group of unequal materials, its function with respect to the fundamental or most important material in the group.) Schoenberg's method is analogous to a society in which the emphasis is on the group and the integration of the individual in the group.

AND PRESENT METHODS OF WRITING PERCUSSION MUSIC

Percussion music is a contemporary transition from keyboard-influenced music to the all-sound music of the future. Any sound is acceptable to the composer of percussion music; he explores the academically forbidden "non-musical" field of sound insofar as is manually possible.

Methods of writing percussion music have as their goal the rhythmic structure of a composition. As soon as these methods are crystallized into one or several widely accepted methods, the means will exist for group improvisations of unwritten but culturally important music. This has already taken place in Oriental cultures and in hot jazz.

AND ANY OTHER METHODS WHICH ARE FREE FROM THE CONCEPT OF A FUNDAMENTAL TONE.

THE PRINCIPLE OF FORM WILL BE OUR ONLY CONSTANT CONNECTION WITH THE PAST. ALTHOUGH THE GREAT FORM OF THE FUTURE WILL NOT BE AS IT WAS IN THE PAST, AT

ONE TIME THE FUGUE AND AT ANOTHER THE SONATA, IT WILL BE RELATED TO THESE AS THEY ARE TO EACH OTHER:

Before this happens, centers of experimental music must be established. In these centers, the new materials, oscillators, turntables, generators, means for amplifying small sounds, film phonographs, etc., available for use. Composers at work using twentieth-century means for making music. Performances of results. Organization of sound for extra-musical purposes (theatre, dance, radio, film).

THROUGH THE PRINCIPLE OF ORGANIZATION OR MAN'S COMMON ABILITY TO THINK.

This is a lecture on composition which is indeterminate with respect to its performance. That composition is necessarily experimental. An experimental action is one the outcome of which is not forseen. Being unforseen, this action is not concerned with its excuse. Like the land, like the air, it needs none. A performance of a composition which is indeterminate of its performance is necessarily unique. It cannot be repeated. When performed for a second time, the outcome is other than it was. Nothing therefore is accomplished by such a performance, since that performance cannot be grasped as an object in time. A recording of such a work has no more value than a postcard; it provides a knowledge of something that happened, whereas the action was a non-knowledge of something that had not yet happened.

There are certain practical matters to discuss that concern the performance of music the composition of which is indeterminate with respect to its performance. These matters concern the physical space of the performance. These matters also concern the physical time of the performance. In connection with the physical space of the performance, where that performance involves several players (two or more), it is advisable for several reasons to separate the performers one from the other, as much as is convenient and in accord with the action and the architectural situation. This separation allows the sounds to issue from their own centers and to interpenetrate in a way which is not obstructed by the conventions of European harmony and theory about relationships and interferences of sounds. In the case of the harmonious ensembles of European musical history, a fusion of sound was of the essence, and therefore players in an ensemble were brought as close together as possible, so that their actions, productive of an object in time, might be effective. In the case, however, of the performance of music the composition of which is indeterminate of its performance so that the action of the players is productive of a process, no harmonious fusion of sound is essential. A non-obstruction of sounds is of the essence. The separation of players in space when there is an ensemble is useful towards bringing about this non-obstruction and interpenetration, which are of the essence. Furthermore, this separation in space will facilitate the independent action of each performer, who, not constrained by the performance of a part which has been extracted from a score, has turned his mind in the direction of no matter what eventuality. There is the possibility when people are crowded together that they will act like sheep rather than nobly. That is why separation in space is spoken of as facilitating independent action on the part of each performer. Sounds will then arise from actions, which will then arise from their own centers rather than as motor or psychological effects of other actions and sounds in the environment. The musical recognition of the necessity of space is tardy with respect to the recognition of space on the part of the other arts, not to mention scientific awareness. It is indeed astonishing that music as an art has kept performing musicians so consistently huddled together in a group. It is high time to separate the players one from another, in order to show a musical recognition of the necessity of space, which has already been recognized on the part of the other arts, not to mention scientific awareness. What is indicated, too, is a disposition of the performers, in the case of an ensemble in space, other than the conventional one of a huddled group at one end of a recital or symphonic hall. Certainly the performers in the case of an ensemble in space will be disposed about the room. The conventional architecture is often not suitable. What is required perhaps is an architecture like that of Mies van der Rohe's School of Architecture at the Illinois Institute of Technology. Some such architecture will be useful for the performance of composition which is indeterminate of its performance. Nor will the performers be huddled together in a group in the center of the audience. They must at least be disposed separately around the audience, if not, by approaching their disposition in the most radically realistic sense, actually disposed within the audience itself. In this latter case, the further separation of performer and audience will facilitate the independent action of each person, which will include mobility on the part of all.

There are certain practical matters to discuss that concern the performance of music the composition of which is indeterminate with respect to its performance. These matters concern the physical space of the performance. These matters also concern the physical time of the performance. In connection with the physical time of the performance, where that performance involves several players (two or more), it is advisable for several reasons to give the conductor another function than that of beating time. The situation of sounds arising from actions which arise from their own centers will not be produced when a conductor beats time in order to unify the performance. Nor will the situation of sounds arising from actions which arise from their own centers be produced when several conductors beat different times in order to bring about a complex unity to the performance. Beating time is not necessary. All that is necessary is a slight suggestion of time, obtained either from glancing at a watch or at a conductor who, by his actions, represents a watch. Where an actual watch is used, it becomes possible to foresee the time, by reason of the steady progress from second to second of the second hand. Where, however, a conductor is present, who by his actions represents a watch which moves not mechanically but variably, it is not possible to foresee the time, by reason of the changing progress from second to second of the conductor's indications. Where this conductor, who by his actions represents a watch, does so in relation to a part rather than a score—to, in fact, his own part, not that of another—his actions will interpenetrate with those of the players of the ensemble in a way which will not obstruct their actions. The musical recognition of the necessity of time is tardy with respect to the recognition of time on the part of broadcast communications, radio, television, not to mention magnetic tape, not to mention travel by air, departures and arrivals from no matter what point at no matter what time, to no matter what point at no matter what time, not to mention telephony. It is indeed astonishing that music as an art has kept performing musicians so consistently beating time together like so many horseback riders huddled together on one horse. It is high time to let sounds issue in time independent of a beat in order to show a musical recognition of the necessity of time which has already been recognized on the part of broadcast communications, radio, television, not to mention magnetic tape, not to mention travel by air, departures and arrivals from no matter what point at no matter what time, to no matter what point at no matter what time, not to mention telephony.

. . . .

An Indian lady invited me to dinner and said Dr. Suzuki would be there. He was. Before dinner I mentioned Gertrude Stein. Suzuki had never heard of her. I described aspects of her work, which he said sounded very interesting. Stimulated, I mentioned James Joyce, whose name was also new to him. At dinner he was unable to eat the curries that were offered, so a few uncooked vegetables and fruits were brought, which he enjoyed. After dinner the talk turned to metaphysical problems, and there were many questions, for the hostess was a follower of a certain Indian yogi and her guests were more or less equally divided between allegiance to Indian thought and to Japanese thought. About eleven o'clock we were out on the street walking along, and an American lady said, "How is it, Dr. Suzuki? We spend the evening asking you questions and nothing is decided." Dr. Suzuki smiled and said, "That's why I love philosophy: no one wins."

APPENDIX C

The Rules of Hacking

Rule #1: Fear not (Chapter 2)!
Rule #2: Don't take apart anything that plugs directly into the wall (Chapter 2).
Rule #3: It is easier to take something apart than put it back together (Chapter 2).
Rule #4: Make notes of what you are doing as you go along, not after (Chapter 2).
Rule #5: Avoid connecting the battery backwards (Chapter 2).
Rule #6: Many hacks are like butterflies: beautiful but short-lived (Chapter 2).
Rule #7: In general try to avoid short circuits (Chapter 2).
Rule #8: In electronics some things are reversible with interesting results, but some things are reversible only with irreversible results (Chapter 4).
Rule #9: Use shielded cable to make all audio connections longer than 8 inches, unless they go between an amplifier and a speaker (Chapter 7).
Rule #10: Every audio connection consists of two parts: the signal and a ground reference (Chapter 7).
Rule #11: Don't drink and solder (Chapter 7).
Rule #12: After a hacked circuit crashes you may need to disconnect and reconnect the batteries before it will run again (Chapter 13).
Rule #13: The net value of two resistors connected in parallel is a little bit less than the smaller of the two resistors; the net value of two resistors connected in series is the sum of the two resistors (Ohm's Law for Dummies) (Chapter 14).
Rule #14: Kick me off if I stick (Zummo's rule) (Chapter 17).
Rule #15: You can always substitute a larger 1.5-volt battery for a smaller one, just make sure you use the same number of batteries, in the same configuration (Chapter 17).
Rule #16: It's always safer to use separate batteries for separate circuits (Chapter 17).
Rule #17: If it sounds good and doesn't smoke, don't worry if you don't understand it (Chapter 18).
Rule #18: Start simple and confirm that the circuit still works after every addition you make (Chapter 18).
Rule #19: Always leave your original breadboard design intact and functional until you can prove that the soldered-up version works (Chapter 19).
Rule #20: All chips may look alike on the outside without being the same on the inside—read the fine print (Chapter 20)!
Rule #21: All chips expect "+" and "–" power connections to their designated power supply pins, even if these voltages are *also* connected to other pins for other reasons—withhold them at your own risk (or entertainment) (Chapter 20).
Rule #22: Always use a resistor when powering an LED, otherwise the circuit and/o LED might blow out (Chapter 21).
Rule #23: Distortion is Truth (Poss's Law) (Chapter 22).
Rule #24: It is easier to drill round holes than slots (Chapter 26).
Rule #25: Never trust the writing on the wall-wart (Chapter 29).

THE LAWS OF THE AVANT-GARDE

Law #1: Do it backwards (Chapter 4).
Law #2: Make it louder, a lot (Chapter 7).
Law #3: Slow it down, a lot (Chapter 13).

Considering a New Music

chapter 3

in this chapter

- ☑ Dealing with a new tonal palette
- ☑ Timbre and chance
- ☑ The power of tone
- ☑ Experimental and chance music

The 1960s was a "clothing optional" decade. What to do with all that bare flesh? Perfume it, sunbathe it, paint it, electrify it!

And that's what we did. You see, the bent mini amp's body contacts, when bridged by a person's fingers, would make the instrument respond as an electronic oscillator. Varying the pressure of finger contact would tune the oscillator in the same way that turning the pitch dial on an oscillator would, from super low to ultra high.

But what was even more interesting was that the electricity could be passed through many people at one time. Clad or semi-clad, we'd have people hold hands, persons at each end of the human chain touching a body-contact, thereby placing everyone within the live circuit. The bent mini amp would respond with a loud, sustained pitch as long as nobody moved.

Whichever persons broke the chain could then play each others' bodies, because various body parts sounded different depending on the completeness of contact. A bare arm, for example, made a good contact and resulted in a pure tone, whereas a hairy arm made poorer contact and resulted in a scratchy tone. Moisture made for nice contacts. Kissing even better. So there was a lot of hugging, smooching, slurping, and worse, all to the tune of an oscillator gone wild as we gyrated around the floor, holding onto each others' whatever.

Sure, this was art. But was it music?

Dealing with a New Tonal Palette

Although many music writers quickly become mired in the complexities of what music is or should be, I don't. This has always been an easy subject for me because I never look to category over emotion. As with every color on the painter's palette, every sound elicits an emotion. This in itself transcends style.

All music is sculpture. Whether using the equal tempered scale and 4/4 measure or free-form music "concrete," it's sculpture. Although most popular music is often dreadfully beat oriented, the very nature of sound asks to be seen also as free poetry, open prose. It's not just sound constructed to dance to, to sell to the masses, but also an emotional construct, devoid of economical pressure or "dance-ability," existing instead as storyteller, perhaps, guiding us by sound much as a painter guides us by means of image.

Do we dance to paintings? Must we to music? Are these phenomena so different? If we don't dance to music, must it still be orchestral arrangements, operas, hymns, and other such "programs"? Understanding music and sound in this way, freeing it from "popular" structures, allows its fabric to further unfurl.

One of my greatest lessons here occurred in study hall back in high school, though it had little to do with the curricula. I entered into the quiet of the immense auditorium, found a seat, and settled down to fold the propaganda that my civics teacher had handed out into paper airplanes that could reach the stage, 40 seats away.

Suddenly the air conditioning system shut off and the room actually did become quiet. I noticed an immediate reaction to the cessation of sound. Not realizing that I'd been tense at all, I clearly became relaxed when the sound stopped. All sounds, we know now, affect our emotions whether we are conscious of the sounds individually or not.

To me, this prompts much thought about the power of composing music, a wave-form phenomenon, as one might use color in painting. Another wave-form phenomena, color arrangement, is accepted, even recognized, in paintings from traditional to abstract. Extending this idea to sound encourages one to seek the pure emotional value of sonic tone as painted hue. All compositional limitations are removed; all musical combinations are invited. Alien music, at least alien to earthling conventions, can be *heard.*

problem. Scientific interest in stroboscopic patterns has proven enduring, but so too has the cultural interest.

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Cultural theorist Jean Fisher, in her essay "Truth's Shadows," suggested a link between Brion Gysin's "'dizzying' fall out of rational space-time" and late-twentieth-century developments around the concept of the syncope, expounded upon by the French philosopher Catherine Clément. Syncope is defined in music as a displacement of the beats or accents in a passage, and in medical terms as a temporary loss of consciousness caused by a fall in blood pressure. Fisher suggests Gysin's experiences "coincide rather beautifully with 'syncope'—a momentary loss of breath, a blackout, an ecstatic insight, eclipse of thought, an off-beat that introduces dissonance into a rhythmic flow." In syncope, time is suspended, or as Clément wrote in her 1994 treatise *Syncope: The Philosophy of Rapture*, "time falters," like the subject in Grey Walter's experiments who felt he had been "pushed sideways in time," or the cyclist who "passed out" for an instant when exposed to flickering light, or Gysin's sense of being "swept out of time." Clément observed: "Physical time never stops. That may be, but syncope seems to accomplish a miraculous suspension. Dance, music, and poetry traffic in time, manipulate it, and even the body manages to do that by an extraordinary short circuit." She characterized the phenomenon as an eclipse of rational thought, an ecstatic insight, an off-beat that suspends or more accurately interrupts consciousness and, as Fisher suggests, "anticipates a shift towards 'inspiration', or imaginative invention." Epilepsy is prominent in the story of the syncope, inducing what Clément termed "an apparent death," and then an awakening. But, she argued, syncope is also found in other physical disturbances—like a woman who faints in public, only to be revived with a slap or smelling salts. Her first words will inevitably be, "Where am I?" The real question, Clément argued, since she has just come to, or come back, should be "Where was I?" Except that when an individual

returns from syncope "it is the real world that suddenly looks strange." In *The Aesthetics of Disappearance*, the French theorist Paul Virilio applies the term "picnolepsy" (from the Greek word for frequent) to the minute ruptures in the narrative of consciousness which occur most often in childhood. One moment a child is fully engaged in what is happening around him, in another he is absent, far removed from his surroundings. Virilio suggests that since the child has missed events that those around him believe he has experienced, he is forced to learn early on to simply fill in the void from his imagination: "There is a tendency to patch up sequences, readjusting their contours to make equivalents out of what the picnoleptic has seen and what he has not been able to see." Clément suggested Western society has systematically suppressed syncope, fearing the consequences of the loss of self and the resulting void. Notably, however, she observed that syncopal interruptions are intensifying in contemporary culture, gaining strength and frequency. Wrote Clément: "If classic epilepsy has now fallen to pieces, if it is seeking a cure, the lure of syncope has not ceased; on the contrary, it is renewing itself, modernizing, finding in the urban landscape and modern techniques the necessary food for the disturbing process of devouring time."

Certainly the number of triggers has increased exponentially. No longer consigned to the forests, flicker-fits can be induced by new environmental stimuli such as faulty florescent lights, computer monitors, movies with special effects, video and computer games, flashing lights on emergency vehicles and discotheque lights. Public attention has increasingly focused not on flicker's potential, however, but on the dangers of flicker-induced seizures. Awareness was such that even swimming pools began to be viewed as potential flicker triggers. In his autobiography, *Judgment Day: My Years With Ayn Rand*, Nataniel Branden, an apostle of Rand (author of *The Fountainhead* and *Atlas Shrugged*), and leader of the Objectivist movement of enlightened selfishness which her ideas spawned, describes the death of his wife, Patrecia, by drowning. It was postulated that she had been standing close to the pool in the late afternoon, when bright sunlight would have been radiating through leaves and off the water of the pool. Wrote Branden: "The result presumably was a 'flicker phenomenon,' a pattern of change in the frequency of light, hitting her eyes, triggering electrically unstable brain cells, and precipitating a seizure." The alarm was sufficient to have reached even the political theater. In 1971, the Greater London Council banned discotheque lights with flicker rates greater than 8 flashes per second. Most other jurisdictions failed to follow its lead. From the Acid Tests to disco dance floors to raves, stroboscopic light has retained its magical properties. This is most at evidence at raves, a dance culture based on repetitive electronic music and methylenedioxymethamphetamine (MDMA), an empathogen known as Ecstasy which intensifies sensory perceptions manifested in spectacular light shows driven by strobe. Even the dances feature twitches and jerks reminiscent of an epileptic seizure. Because of the innocent-making effects of Ecstasy, raves also assumed the aesthetic of juvenalia, with circus-like side shows at some raves including Mind Machines—goggles which, like the Synchro-Energizer, pulse a strobe directly into the eyes of the wearer. The paraphernalia of ravers also included lightsticks, hand-held electronic strobes, flashing belly lights and other pulsing lights worn as fashion accessories.[50] The combination of Ecstasy, strobe and the trance-like music produced an ecstatic state that seemed to suspend time, a state that the techno-pop band The KLF captured in "3 AM Eternal."

In 1990, in the British House of Commons, MP David Shaw raised a further alarm over the sale of devices that generate stroboscopic light, asking the government to issue a statement about "the potential dangers to health . . . from the use of consumer products which can produce flicker or stroboscopic light sources with a flicker rate in excess of five flashes per second." The government's considered response was that such devices did not pose a "general threat to safety." While a rare condition, concern about photosensitive epilepsy has continued to increase as the inventory of suspected triggers has grown. Clinical cases have been published widely in scientific and medical journals. New conditions, such as "television epilepsy" and "video game epilepsy" have been identified. In some of these articles, W. Grey Walter's pioneering work is cited. One British study investigated 143 cases of photosensitive epilepsy over a six-month period, of which 23 (16 percent) were traced to electronic video games, and another 23 were traced to TV. Other computer graphics or electronic screens were identified in 12 cases (8 percent). In about half the cases no obvious trigger could be found, although some of them were thought to have been provoked by sunlight. After several teenagers suffered seizures while playing Nintendo video games, the company began to include warning information with its Game Boy products saying the games could cause a "shigeki,"or strong stimulation, from bright flashing lights, producing various undesirable symptoms. In 1993, a British TV commercial for Pot Noodles which featured bright flashes and shifting graphics induced seizures in three viewers. After an investigation, the Independent Television Commission, the regulatory body for the country's commercial broadcasters, established guidelines prohibiting flashing lights or flickering images at more than three flashes per second, and indicating repetitive "psychedelic" patterns should be avoided.

The most dramatic manifestation occurred, however, on Tuesday, December 16, 1997, when Japanese schoolchildren, and some adults, tuned in to watch an episode of the animated TV series *Pocket Monsters* (contracted to *Pokémon*), the country's highest rated series in the 6:30 P.M. slot. Broadcast simultaneously on thirty-seven stations, it is estimated 10 million people were watching that evening. *Pokémon* is based on a Nintendo video game which had been transformed into a cultural phenomenon by the "largest marketing effort in the history of toys." The episode called "Computer Warrior Polygon" featured the characters fighting inside a computer. At 6:51 P.M. viewers were watching a scene where vaccine missiles were launched to destroy a computer virus, followed by "a bizarre, flashing explosion with high frequency red and blue flicker stimulation" which occupied the whole screen, alternating at twelve flickers per second. Suddenly, some of the viewers went into a trance-like state, as if they had been hypnotized. Others experienced altered vision, and shortness of breath. Some passed out, while others experienced seizures. Hospitals all over Japan received admissions, although most of the patients were home before midnight. In all, some 12,000 viewers reported some disorienting symptoms after watching the original episode, or the "highlights" when they were helpfully rebroadcast by some TV news programs later the same evening. Of those, 685 Japanese children and adults suffered seizures. The incidence was minute compared with the total numbers of viewers, but it was still the largest ever single occurrence of flicker-induced symptoms. Ryutaro Hashimoto, the Japanese prime minister, only added to the general confusion when he responded to the incident by observing: "Rays and lasers have been considered for use as weapons. Their effects have not been fully determined." A Research Committee on Photosensitive Attack was subsequently established by Japan's Ministry of Welfare and Health, and it concluded that changes in luminance, color and pattern were responsible for the phenomenon, although mass hysteria inflated the numbers. None of the researchers investigated the possibility that symptoms may have been evoked that were neither injurious nor frightening. Indeed, for a vastly greater proportion of viewers the contrary may have been true as a large market for bootleg tapes of the flashing light episode developed among fans around the world, and the clip was featured on a number of Web sites.

Italian scientists, in a paper in *Nature Neuroscience*, predicted that the phenomenon would only increase with the proliferation of triggers, suggesting the mechanism of stroboscopic light will have an enormous impact on human consciousness in the centuries to come.

Hypersonic sensation is felt as a faint energy enveloping the media art event and pointing to its capacities to create linkages outside its actual spatiotemporalities. It is hypersonic in the sense that it involves the concealed sonic aesthetics of the new media artwork and its capacity to affect a body viscerally, pointing to how one can "hear without ears." Sensation, as mentioned above, is defined as a noncognitive feeling that points to the affective emptying of perception's conscious activity. For Deleuze (2003), and, following him, Massumi (2002a), sensation is the immediate and visceral registering of potential that adds a felt surplus to experience. As Steven Connor explains in "The Shakes: Conditions of Tremor," there are feelings and sensations that take on a life of their own outside and beyond the bodies "who live them, who are their bearers or instances" (2008, 207). The media art examples in the following pages are arguably able to tap into the realm of hypersonic sensation where this autonomous feeling resides.

This level of the event deals with the potential shocks and forces concurrently autogenerated in a body and external to it and which do not belong to any known aspects of experience. Psychoacoustic (hypersonic effect), neurophysiological (auditory hallucinations), and ultrasonic (audio spotlight) strata of this realm probe the idea that perception is affective by rule rather than exception. The particular art projects that connect to these strata, extending their technoscientific ideas to aesthetic domains, expose a mode of sensation that is not just imperceptible but indeed not entirely human. Deprived of auditory sense and lost within its autogenerated shocks, a body seems to hover constantly between corporeal defect and incorporeal sensation, between consciousness and hallucination.

Hypersonic Effect and Hypersonic Affect

It is generally known that sounds above the frequency range of 20 kHz cannot be perceived by the human ear. However, a team of Japanese researchers led by Tsutomu Oohashi (Oohashi et al. 2000) discovered an alternative type of hearing. According to the published outcomes of their research, complex sounds of high frequencies not only affect human response but, in a way, complete perception. The team experimented with gamelan soundscapes from Bali that are extremely rich in high-frequency components (HFCs). The study demonstrated that during the convergence of very high (inaudible) and lower (audible) frequencies, perception appears to expand.

At this level, a body becomes more receptive to external impulses than when it is exposed to either high or low frequencies alone. This combined impact of inaudible and audible forces was termed by the scientists "the hypersonic effect."

The scientists established that "the (perceptual) sensitivity of human beings may not be parallel with the 'conscious' audibility of air vibration" (Oohashi et al. 2000, 3,549). HFCs may be conveyed through passages distinct from the usual air-conducting pathways and can thus affect the central nervous system and deep-lying brain structures directly. The hypersonic effect includes the potential participation of nonauditory sensory systems for which vibration does not necessarily translate to sound. Oohashi et al. note that when the entire body is exposed to consciously unrecognizable air vibrations, deeper structures of cerebral flow, which do not belong to the conventional auditory perception system, are enhanced and activated.

Consciously inaudible vibrational stimuli are microscopic perceptions that do not pass through the conventional air-conducting auditory system. As unidentified inaudible effects, they constitute an integral but hidden part of a body's capacity to perceive (sound). They suggest that conventional sensory perception may be only a part in the manifold layers of sensation that encompass and produce a body. Hence, for the purposes of this work, they are better understood as affects, amodal forces of feeling that impinge upon a system and that may or may not surface to sensory perception. As the researchers reported, hypersonic effect involves certain nonconscious mechanisms that induce the activation of "electroencephalogram rhythms" when they are exposed to HFCs (ibid., 3,551). The impact of phantom rhythms on a body blurs external stimuli together with internal qualities to the extent that it is no longer clear if these stimuli derive from an external or internal source. The hypersonic effect seems to enable a coexistence between what is within the auditory capacity of a body and a potential energy that surpasses hearing. It constructs an intensive zone where hypersonic effect becomes affect: a rhythmic energy that seeps in underneath conscious perception and contaminates it with its own sensations.

Oohashi et al. emphasize that further investigation into the phenomenon must necessarily include somatosensory perception. The somatosenses—including proprioception (body position), kinesthesia (movement), and the visceral (internal) senses—feature a high sensitivity to affect. In the first place, they are nonhierarchical because of the symbiotic formations between them and their dynamic relationship with the brain, the nervous system, and auditory perception. This nonsensory system includes visceral sensibility: a "gut-level-feeling" that functions like "a second brain" affecting and affected by vibrational stimuli.[1] According to Massumi, "The immediacy of visceral perception is so radical that it can be said without exaggeration to precede … sense perception" (2002a, 60). Viscerality pertains to an autonomous function of the body's innards, its ability to process what is consciously inaccessible to it. Visceral sensations are absorbed by the body immediately before they are processed by the senses and contemplated by the brain. Before the ear grasps sound and inaudible vibration becomes audible wave, hypersonic affect is registered in the viscera as a shock to the gut that precedes sensory awareness and allows a body to feel presubjectively.

A body is thought to absorb hypersonic excitations as soon as they emerge—at their presubjective and preperceptive states. The sensation, then, is neither an innate quality nor does it depend exclusively on external stimuli. Following the relationship between viscerality and sensation, the process may be significantly more complex. Hypersonic affect can be defined as an incipient sensation emerging at the moment of collision between high-frequency vibrations and the visceral anticipations of a heightened body. This impingement enables the detachment of a body from a specific mode of experience and the emersion of a nonsensory, nonconscious, machinic subjectivity. Digital works that can be said to unveil this condition tend to focus on indiscernible fields of energy—electromagnetic, vibrational, intensive, and hypersonic.

Invisible Aesthetics

Sonocytology is a method for accessing cellular vibrations at the level below perceptible sound, discovered by nanotechnology professor James Gimzewski. Sonocytology studies cellular vibrations using an ultrasensitive instrument called the atomic force microscope (AFM), essentially a tiny "finger" on the scale of a nanometer.[2] The AFM is normally used to read surfaces through touch, like a blind person reading Braille. However, Gimzewski's team used it to detect the motion of cells producing numerous minuscule vibrations per second, under various conditions. For example, when

SOLAR ENERGY MILESTONES

FOR THOUSANDS OF YEARS PEOPLE HAVE USED SUNLIGHT TO WARM THEIR HOMES. SOCRATES (470-399 B.C.) TAUGHT THE IMPORTANCE OF PLACING HOMES SO THE SUN'S WARMING RAYS COULD WARM THE INTERIOR ROOMS DURING WINTER.

HERE ARE JUST A FEW HIGHLIGHTS OF HISTORIC SOLAR ENERGY DEVELOPMENTS:

DESTRUCTION OF ROMAN FLEET (212 B.C.) - ARCHIMEDES IS REPORTED TO HAVE IGNITED INVADING ROMAN SHIPS BY MEANS OF REFLECTED SUNLIGHT.

DIAMOND MELTED (1695) - TWO ITALIAN EXPERIMENTERS SUCCEEDED IN MELTING A DIAMOND USING FOCUSED SUNLIGHT.

SOLAR FURNACE (1774) - THE FRENCH CHEMIST ANTOINE-LAURENT LAVOISIER MADE A SOLAR FURNACE THAT MELTED PLATINUM.

SOLAR-POWERED PRINTING PRESS (1878) - A LARGE PARABOLIC REFLECTOR COLLECTED ENOUGH SUNLIGHT TO POWER A PRINTING PRESS.

SOLAR STEAM ENGINE (1901) - A. G. ENEAS DESIGNED A SOLAR STEAM ENGINE THAT PUMPED IRRIGATION WATER IN ARIZONA. SUNLIGHT WAS COLLECTED BY 1,788 MIRRORS INSTALLED IN A FIXTURE THAT RESEMBLED A GIANT UMBRELLA 33.5 FEET (ABOUT 10 METERS) IN DIAMETER.

SOLAR ENGINE (1908) - JOHN BOYLES AND H.E. WILLSIE DEMONSTRATED A 15-HORSE-POWER ENGINE POWERED BY POOLS OF WATER THAT CAPTURED AND STORED THE HEAT FROM SUNLIGHT.

SOLAR ELECTRICAL PLANT (1913) - FRANK SHUMAN AND C.V. BOYS BUILT THE WORLD'S FIRST SOLAR-POWERED ELECTRICAL PLANT NEAR CAIRO, EGYPT. THE HUGE FACILITY USED SEVEN SOLAR COLLECTORS, EACH 204 FEET (ABOUT 62 METERS) LONG. THE COLLECTORS HAD A TOTAL AREA OF 13,000 SQUARE FEET (ABOUT 1,208 SQUARE METERS). THEY AUTOMATICALLY TRACKED THE SUN.

SOLAR OVEN (1925) - C. G. ABBOT OF THE SMITHSONIAN INSTITUTION COOKED MEALS USING A SOLAR-POWERED OVEN AT HIS SUN OBSERVATORY ON MOUNT WILSON, CALIFORNIA.

SOLAR FURNACE (1950'S) - FRENCH SCIENTIST FELIX TROMBE DESIGNED THE WORLD'S LARGEST SOLAR FURNACE. THIS FACILITY, WHOSE 9,000 MIRRORS ARE INSTALLED ON THE SIDE OF A BUILDING, CAN REACH THE TEMPERATURE OF THE SUN'S SURFACE, 10,000° FAHRENHEIT (ABOUT 5,538° CELSIUS).

SILICON SOLAR CELL (1954) - GERALD PEARSON, DARYL CHAPIN AND CALVIN FULLER OF BELL LABORATORIES DEVELOPED THE FIRST SUCCESSFUL SILICON SOLAR CELL. THIS DEVELOPMENT LED TO THE MODERN ERA OF PHOTOVOLTAIC SOLAR POWER CONVERSION.

MID-EAST OIL CRISIS (1970'S) - THE OIL CRISIS OF THE 1970'S STIMULATED SIGNIFICANT NEW RESEARCH IN SOLAR ENERGY. OLD KINDS OF SOLAR ENERGY SYSTEMS WERE IMPROVED AND NEW KINDS WERE DEVELOPED.

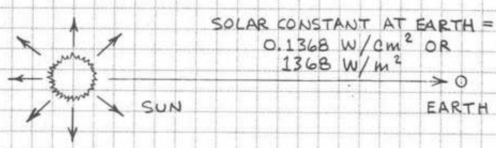
THIN-FILM SOLAR CELL (1980'S) - MANY KINDS OF SOLAR CELLS HAVE BEEN DEVELOPED, BUT THIN-FILM CELLS OF SILICON AND OTHER SEMICONDUCTORS ARE AMONG THE MOST IMPORTANT. THEY CAN BE MADE AS FLEXIBLE SHEETS MUCH LARGER THAN STANDARD SILICON SOLAR CELLS.

ENERGY FROM THE SUN

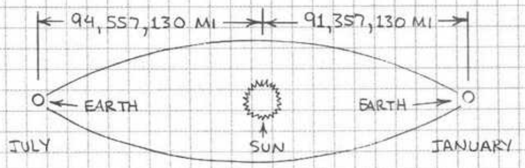
THE SUN EMITS AN INCREDIBLE AMOUNT OF ELECTROMAGNETIC RADIATION. THE TOTAL RADIATED POWER IS 3.83×10^{23} KILOWATTS (KW) OR 383,000,000,000,000,000,000,000,000 WATTS. MOST OF THIS RADIATION IS LOST TO SPACE. ONLY A TINY FRACTION IS INTERCEPTED BY EARTH AND THE OTHER PLANETS. ACCORDING TO THE SOLAR ENERGY INDUSTRIES ASSOCIATION (SEIA), ALL THE ELECTRICITY CONSUMED IN THE UNITED STATES COULD BE PROVIDED BY PHOTOVOLTAIC SOLAR CELL MODULES COVERING 0.3 % OF THE LAND AREA OF THE U.S.

THE SOLAR CONSTANT

THE MEAN AMOUNT OF SUNLIGHT AT THE TOP OF EARTH'S ATMOSPHERE IS CALLED THE SOLAR CONSTANT. MEASUREMENTS MADE BY SEVERAL SATELLITES SHOW THAT THE SOLAR CONSTANT IS 136.8 WATTS PER SQUARE CENTIMETER.



THE SUNLIGHT INTENSITY AT EARTH VARIES BECAUSE EARTH'S ORBIT AROUND THE SUN IS SLIGHTLY ELLIPTICAL. THE MEAN DISTANCE OF EARTH FROM THE SUN IS 92,957,130 MILES (149,600,000 KILOMETERS). IN EARLY JANUARY EARTH IS ABOUT 1,600,000 MILES (2,575,000 KM) CLOSER TO THE SUN. IN EARLY JULY EARTH IS ABOUT 1,600,000 MILES (2,575,000 KM) FARTHER FROM THE SUN. (SEE DRAWING ON FACING PAGE.)



THE DIFFERENCE IN THE INTENSITY OF SUNLIGHT BETWEEN PERIHELION (CLOSEST POINT) AND APHELION (FARTHEST POINT) IS ABOUT 6.7%. USE THE SOLAR CONSTANT TABLE TO FIND THE SOLAR CONSTANT FOR THE FIRST DAY OF ANY MONTH.

SOLAR CONSTANT TABLE

MULTIPLY THE MEAN SOLAR CONSTANT (1,368 WATTS PER SQUARE METER OR 136.8 MILLIWATS PER SQUARE CENTIMETER) BY THE CORRECTION NUMBERS IN THIS TABLE TO FIND THE ACTUAL SOLAR IRRADIANCE ON THE GIVEN DATES.

JANUARY	1.0335	JULY	0.9666
FEBRUARY	1.0288	AUGUST	0.9709
MARCH	1.0173	SEPTEMBER	0.9828
APRIL	1.0009	OCTOBER	0.9995
MAY	0.9841	NOVEMBER	1.0164
JUNE	0.9741	DECEMBER	1.0288

FROM KINSELL L. COULSON, "SOLAR AND TERRESTRIAL RADIATION," ACADEMIC PRESS, 1975.

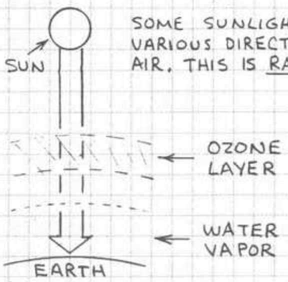
EXAMPLE: WHAT IS THE SUN'S IRRADIANCE AT THE TOP OF THE ATMOSPHERE ON MAY 1? THE IRRADIANCE ON MAY 1 IS 0.9841 OF THE MEAN SOLAR CONSTANT OF 136.8 MILLIWATTS PER SQUARE CENTIMETER. 0.9841×136.8 IS 134.625 MILLIWATTS PER SQUARE CENTIMETER.

SUNLIGHT AND THE ATMOSPHERE

A SOLAR CELL ON A SATELLITE RECEIVES AT LEAST 15% MORE SOLAR ENERGY THAN AN IDENTICAL SOLAR CELL ON EARTH. FOR EXAMPLE, AT NOON ON JULY 1 THE SOLAR IRRADIANCE AT ALBUQUERQUE, NEW MEXICO, IS ABOUT 100 MILLIWATTS PER SQUARE CM (100 mW/cm²) IF THE SUN IS NOT BLOCKED BY A CLOUD. FROM THE SOLAR CONSTANT TABLE (P.9) THE IRRADIANCE AT THE TOP OF THE ATMOSPHERE ON JULY 1 IS 0.9666 × 136.8 mW/cm² OR 132.2 mW/cm². THUS ONLY 75.6% OF THE INTENSITY OF THE SUNLIGHT AT THE TOP OF THE ATMOSPHERE REACHES ALBUQUERQUE ON JULY 1. ALBUQUERQUE IS ABOUT 1 MILE (1.6 KILOMETERS) ABOVE SEA LEVEL AND THE AIR IS OFTEN DRY. LESS SUNLIGHT REACHES REGIONS NEARER SEA LEVEL, ESPECIALLY WHEN THE AIR IS MOIST. MUCH LESS SUNLIGHT IS RECEIVED EVERYWHERE DURING WINTER AND WHEN CLOUDS BLOCK THE SKY.

HERE ARE SOME OF THE CHIEF FACTORS THAT AFFECT SUNLIGHT:

1. WATER VAPOR, OZONE AND OTHER GASES IN THE ATMOSPHERE ABSORB SUNLIGHT.

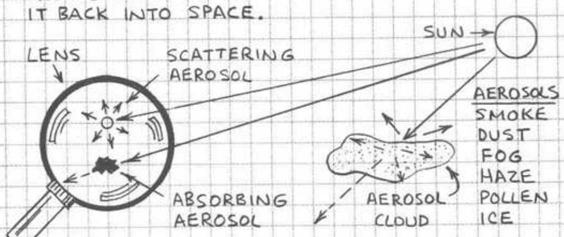


SOME SUNLIGHT IS SCATTERED IN VARIOUS DIRECTIONS BY MOLECULES OF AIR. THIS IS <u>RAYLEIGH SCATTERING</u>.

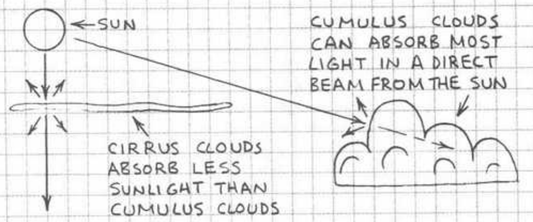
OZONE ABSORBS ULTRAVIOLET AND ORANGE LIGHT AND VARIOUS INFRARED WAVELENGTHS

WATER VAPOR ABSORBS VARIOUS INFRARED WAVELENGTHS

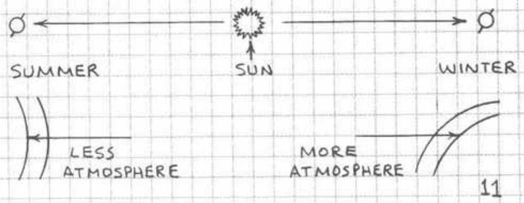
2. AEROSOLS ARE TINY PARTICLES AND DROPLETS IN THE ATMOSPHERE THAT CAN ABSORB CONSIDERABLE SUNLIGHT OR SCATTER IT BACK INTO SPACE.



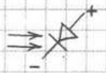
3. CLOUDS ARE FORMED FROM ENORMOUS NUMBERS OF TINY WATER DROPLETS OR ICE CRYSTALS. CLOUDS ABSORB AND SCATTER LIGHT.



4. THE TILT OF THE EARTH CAUSES SUNLIGHT TO PASS THROUGH MORE ATMOSPHERE DURING FALL, WINTER AND SPRING.



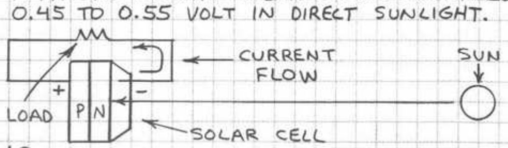
SOLAR CELLS



MANY SEMICONDUCTORS WILL GENERATE ELECTRICITY FROM SUNLIGHT. THE MOST COMMON AND BEST DEVELOPED SOLAR CELLS ARE MADE FROM SILICON. SINCE SILICON FORMS 27.7% OF EARTH'S CRUST, SILICON SOLAR CELLS ARE POTENTIALLY INEXPENSIVE. BUT TRANSFORMING SILICON INTO SOLAR CELLS IS AN EXPENSIVE PROCESS THAT REQUIRES CONSIDERABLE ELECTRICITY.

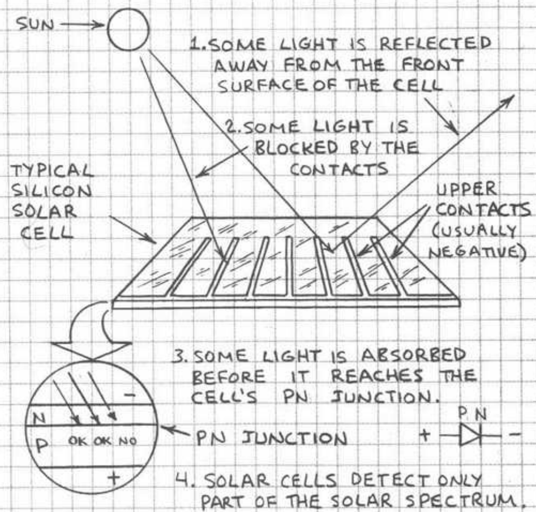
HOW SOLAR CELLS WORK

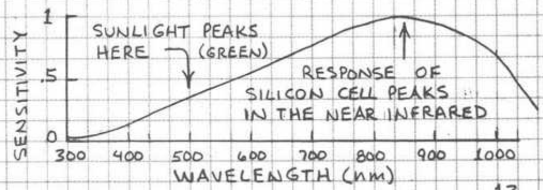
LIGHT CONSISTS OF PACKETS OF ENERGY CALLED PHOTONS THAT TRAVEL IN A WAVE-LIKE FASHION. WHEN PHOTONS STRIKE SILICON ATOMS THEY DISLODGE ELECTRONS. THE MISSING ELECTRONS LEAVE BEHIND POSITIVELY CHARGED ATOMS. THESE ATOMS ATTRACT FREE ELECTRONS IN THE SILICON. THIS RANDOM MOVEMENT OF ELECTRONS CAN BE CONVERTED INTO A FLOW OF ELECTRONS IF A PN JUNCTION IS FORMED IN THE SILICON. ELECTRONS DISLODGED BY PHOTONS NEAR THE PN JUNCTION ARE ATTRACTED TO THE P SIDE OF THE JUNCTION. THE RESULT IS A FLOW OF ELECTRICAL CURRENT WHEN LIGHT IS PRESENT. THE LEVEL OF CURRENT IN AMPERES IS DIRECTLY PROPORTIONAL TO THE LIGHT INTENSITY. THE POTENTIAL OF THE CURRENT IN VOLTS IS UNRELATED TO THE LIGHT INTENSITY. A TYPICAL SILICON SOLAR CELL GENERATES 0.45 TO 0.55 VOLT IN DIRECT SUNLIGHT.



SOLAR CELL EFFICIENCY

IF EVERY PHOTON STRIKING A SOLAR CELL DISLODGES AN ELECTRON, THE CELL WILL TRANSFORM NEARLY 100% OF THE LIGHT THAT STRIKES IT INTO ELECTRICITY. THE ACTUAL EFFICIENCY OF REAL SOLAR CELLS IS FROM ABOUT 5% TO 20%. THERE ARE SEVERAL REASONS FOR REDUCED EFFICIENCY:

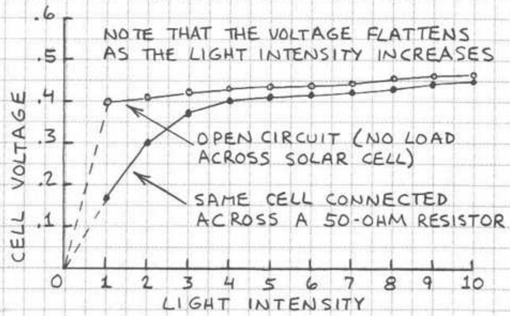




SILICON SOLAR CELL RATINGS

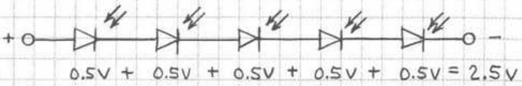
IT IS IMPORTANT TO READ AND UNDERSTAND SOLAR CELL RATINGS, ESPECIALLY WHEN THE CELLS ARE TO BE USED TO CHARGE A STORAGE CELL OR BATTERY.

SILICON SOLAR CELL VOLTAGE



INCREASING SOLAR CELL VOLTAGE

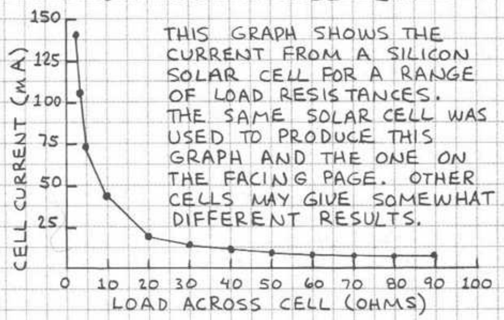
WHEN SOLAR CELLS ARE USED TO CHARGE STORAGE CELLS OR BATTERIES, SEVERAL CELLS MUST BE CONNECTED IN SERIES TO OBTAIN A SUFFICIENTLY HIGH VOLTAGE.



TYPICAL SERIES ARRAY:

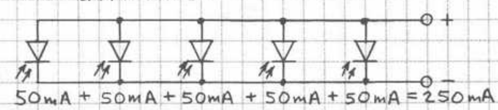
A STRING OF SOLAR CELLS CONNECTED IN SERIES OR IN PARALLEL (SEE BELOW) IS CALLED AN ARRAY. ALL THE CELLS IN AN ARRAY SHOULD BE EQUALLY ILLUMINATED. SHADING ONE CELL IN A 6.5-VOLT ARRAY DROPPED THE OUTPUT TO 6.2 VOLTS.

SILICON SOLAR CELL CURRENT

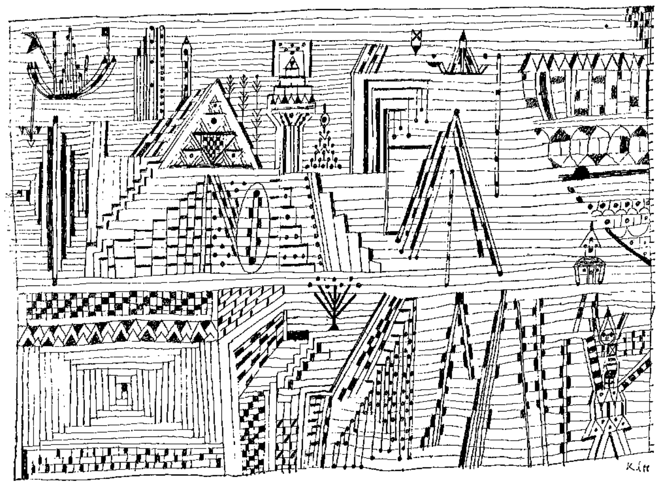


INCREASING SOLAR CELL CURRENT

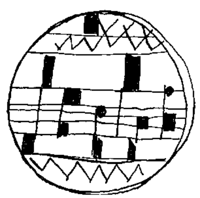
CONNECTING SOLAR CELLS IN PARALLEL INCREASES THE OUTPUT CURRENT. THIS IS ESPECIALLY USEFUL WHEN CHARGING LARGE STORAGE BATTERIES.



TYPICAL PARALLEL ARRAY:



1927/o 1: *Berlde (city by the water)*. Pen and Ink.



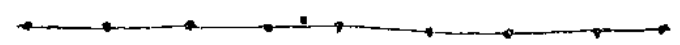
Constellation with inner structure. Schematic excerpt from the watercolour:
1928/T 4: *Something freer in rigid garb.*

The limping rarities of five- and seven-part time are unevenly loaded two-beats:

2+3 or 3+2 (five) 3+4 or 4+3 (seven)

In representing rhythmic structure we take the quantitative view; absolute time measurements are transposed into absolute linear measurements (quantitative rhythm) [1]. The disadvantage is that the units of rhythm (designated by bars) are not strictly defined by linear measurements.

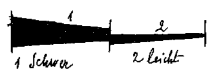
Where is the bar?



1

What do special symbols of this sort mean?

2

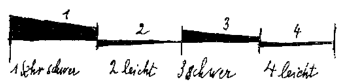


3

heavy light

4

heavy medium heavy light



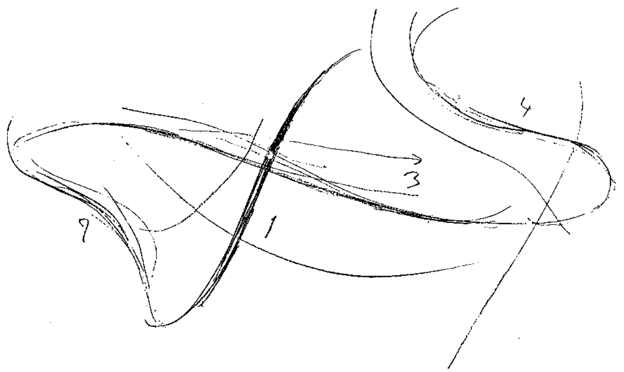
5

very heavy light heavy light

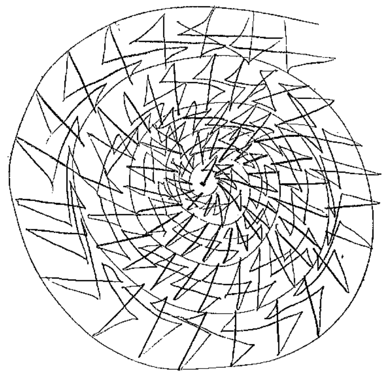
They indicate different degrees of accent [2]. This points the way to another kind of picture that will do more justice to rhythmic structures and clearly bring out the quality of the measures. It consists in representing the relations between emphases,[1] in treating the rhythmic structures qualitatively (accented or dynamic rhythm) [3, 4, 5].

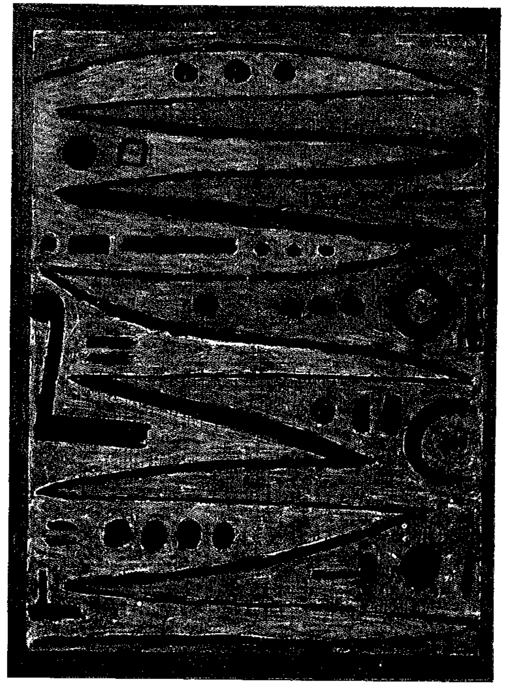
[1]Crossed out: 'of the qualities'.

The form of four-part time, gently curved (factural rhythm)

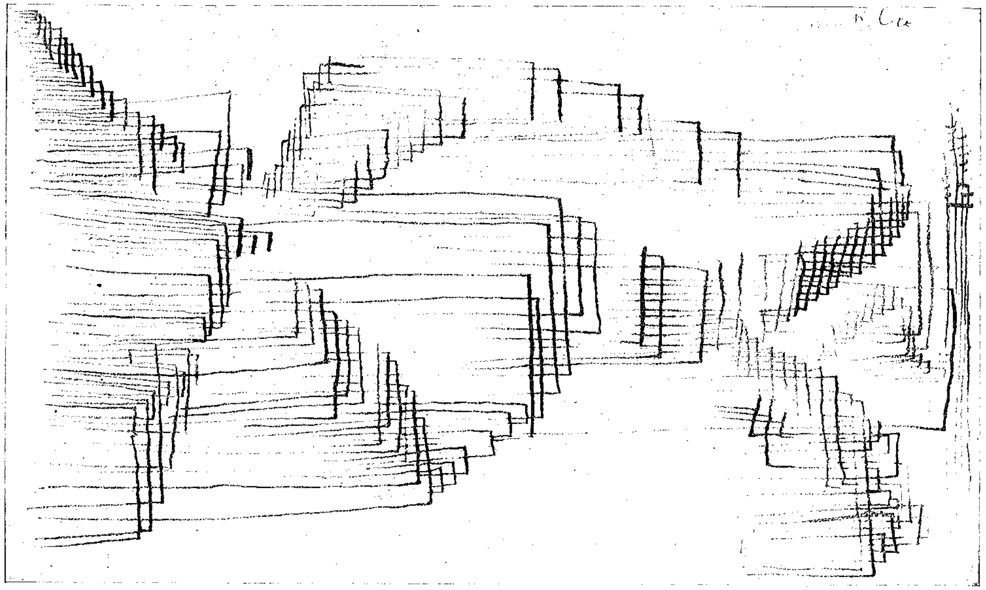


Many beats in four-part time linked by rhythmic connections
(Dynamisation of the factural rhythm)





1938/1: *Heroic strokes of the bow.* Oil on Plaster.



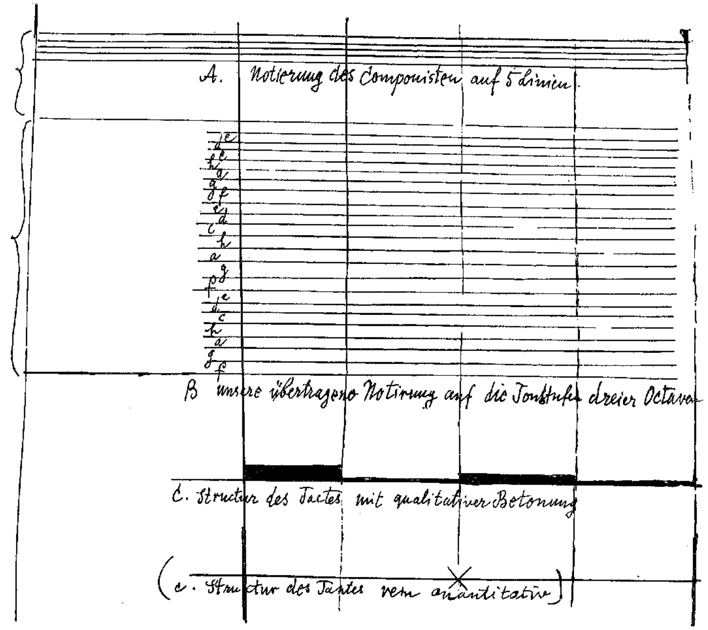
1927/D 8: *Slate quarry*. Pen and ink drawing.

The composer's notation on 5 lines — A

Our notation transferred to the keys of 3 octaves — B

Structure of the beat qualitatively stressed — C

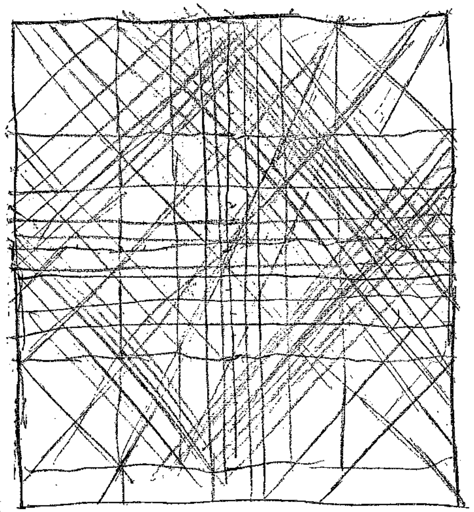
Purely quantitative structure of the beat — (c)



On this foundation I can now try to execute a musical theme pictorially, whether in one voice or polyphonically.
I choose two bars of a three-part passage by Bach, and micro-copy it according to the following scheme [1].

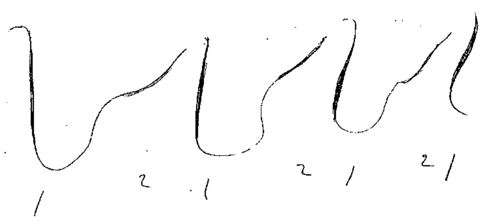
Since music without dynamics sounds mechanical and expressionless, I select qualitative representation C and give the line more or less weight according to the tone quality, while the quantitative representation in B expresses itself in the vertical lines for bars and parts of bars.[1]

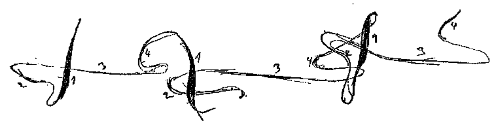
[1]Example from a three-part passage by Johann Sebastian Bach; folder attached to p.286.



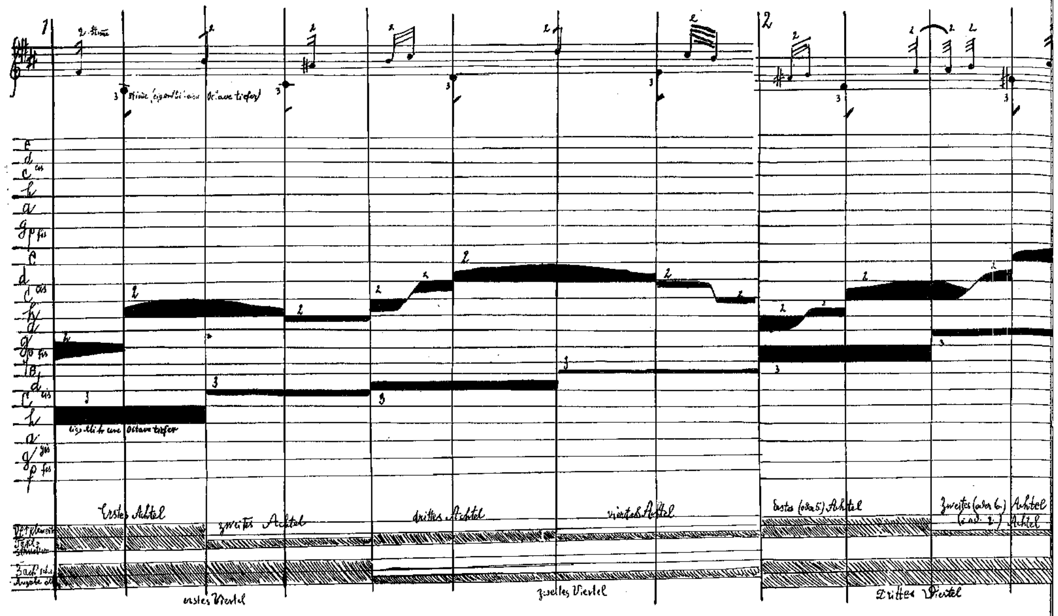
Key of Fes-is mur

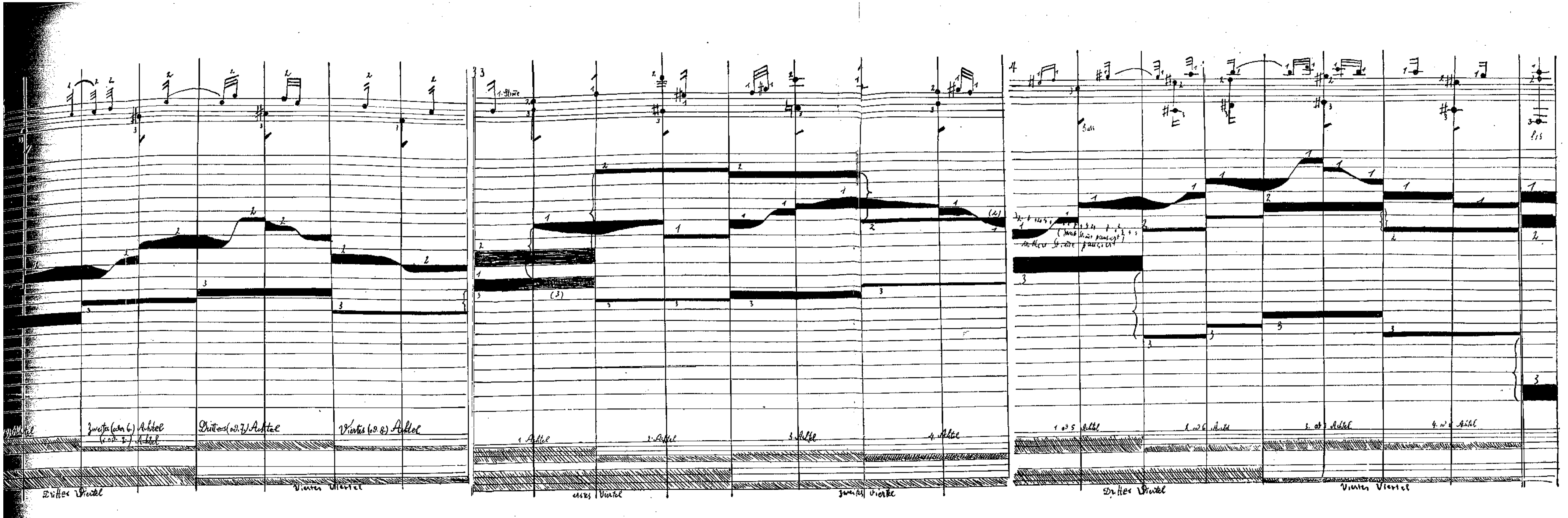
Pencil drawing done on trip to Egypt in the winter of 1928-1929.





Rhythmic forms with many parts, gently curved. Factural rhythms

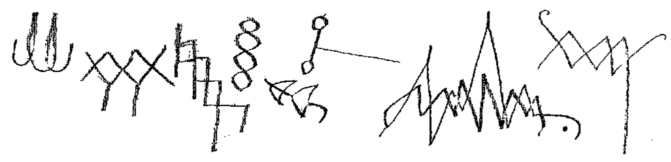




Pictorial example
after a three-part movement
by J. S. Bach (see pp. 285–287).

A number of things may be learned from the example of the three-part passage (folder), which is an attempt to represent in simple pictorial form an object that is abstract and at the same time compellingly real.

First we learn that such representation is possible. Next we perceive the vertical and horizontal relations between the two or three 'voices'. And we see how they are related in respect of individualisation. Sometimes two, sometimes three voices sound at once (and there might be just one). The two voices (second and third voices) of the first measure are very different in individual quality. The lower one is clearly structural in character while the upper one is individual. Then the first voice comes in a little below the second, tries to jump over it, but does not succeed at first; only after the second voice has paused for a moment, does the first become dominant. With the individual entrance of the first voice, the second voice is reduced to a structural character and takes a register in harmonious contrast to the third, which descends a little at this point, so forming an arch beneath which moves the first, individual voice. After a resigned pause, the second runs parallel to the third. From the very start the third remains faithful to its structural character, up to the point where the second begins to run parallel to it: here we can discern a timid attempt at individuality.



Detail from 1934/N 6: *A curtain is drawn*, Pencil drawing.

A glance at the quantities in the example (folder) also teaches us that the differences of measure are based on simple numbers near one another. If very small numbers were related to very large ones in this example, it would mean that the music contained ornaments,

which, when used frivolously, are called flourishes.

Syncope:[1] temporally speaking: the accent is anticipated, moved from its normal position to the preceding unaccented note.
Positionally: one or more dividing lines are bridged over by longer tones (hovering bridges).

[1]Syncope: 'Cutting-together', i.e. rhythmic connection between two halves of a tone divided by bar, the shifting forward or backward of tones by half, rarely by a quarter, of their value, with parallel shift of accent. In pictorial terms: shift of structural rhythm; the shift between two structural values is connected or bridged over by a third (hovering bridges).

Comparison between Karl Pribram's <<Holographic Brain Theory>> and more Conventional Models of Neuronal Computation

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Chapter 1: Introduction

One of the problems facing neural science is how to explain evidence that local lesions in the brain do not selectively impair one or another memory trace. Note that in a hologram, restrictive damage does not disrupt the stored information because it has become distributed. The information has become blurred over the entire extent of the holographic film, but in a precise fashion that it can be deblurred by performing the inverse procedure.

This paper will discuss in detail the concept of a holograph and the evidence Karl Pribram uses to support the idea that the brain implements holonomic transformations that distribute episodic information over regions of the brain (and later <refocuses> them into a form in which we remember). Particular emphasis will be placed on the visual system since it's the best characterised in the neurosciences. Evidence will be examined that bears on the validity of Pribram's theory and the more conventional ideas that images are directly stored in the brain in the form of points and edges (without any transformation that distributes the information over large regions). Where possible, the same evidence (for the visual system) will be used to evaluate both theories.

1. Holonomic theory where Fourier-like transformations store information of the sensory modalities in the spectral (or frequency) domain. The sensory stimulus is spread out (or distributed) over a region of the brain. A particular example (in the case of vision) would be that particular cortical cells respond to the spatial frequencies of the visual stimulus.

2. The more conventional theory that particular features of the untransformed sensory stimulus is stored in separate places in the brain. A particular example (in vision) would be that particular visual cortical cells respond to edges or bar widths in the visual stimulus.

It will be necessary in this report to first explain the concepts of a hologram and Fourier transforms before the physiological experiments can be understood. Bear in mind that the discursion into these other fields serves a purpose for later in the report.

Karl Pribram's holonomic theory reviews evidence that the dendritic processes function to take a <spectral> transformation of the <episodes of perception>. This transformed <spectral> information is stored distributed over large numbers of neurons. When the episode is remembered, an inverse transformation occurs that is also a result of dendritic processes. It is the process of transformation that gives us conscious awareness.

Chapter 2 will outline the basic concept of a hologram and start to introduce Pribram's holonomic brain theory.

Chapter 3 will briefly describe the conventional accepted view of the pathway of neural processing (with particular emphasis on the visual system). The main computational event in this view is the generation of the action potential.

Chapter 4 will review the evidence for the alternative holonomic view. The holonomic theory is based on evidence that the main computational event of neurons is the polarizations and hyper polarizations at the dendritic membranes of neurons. The evidence will be reviewed that supports the notion that these dendritic processes effectively take something close to a Fourier transform.

Chapter 2: Holograms

What is holography?

The word <holography> is derived from Greek roots meaning <complete writing>. The idea is that every part of <the writing> contains information about the whole. A hologram (the material manifestation of a holograph) is a photographic emulsion in which information about a scene is recorded in a very special way. When the hologram is illuminated, you see a realistic, three-dimensional representation of the scene. If you cut the holographic photographic plate up into small pieces, the whole image can still be extracted from any of them (although with some loss of clarity). Pribram uses the term holonomy to refer to a dynamic (or changing) hologram.

The hologram relationship

The basic idea of a hologram can be understood without even considering the holograms found in novelty stores. The idea is simply that each part contains some information of the whole. Or, stated another way, the information (or features) are not localised, but distributed. To clarify this concept, consider the following thought experiments (demonstrations). As will be demonstrated, light is in the holographic domain before it gets transformed (focused) by a lens.

Demonstration #1.

Remove the converging lens in a slide projector that forms the image. Place a slide in the projector and project the light onto a screen. No image will form. Technically, the light incident on the screen is in a holographic form. Each point on the screen is receiving information from every point from theslide. If a converging lens is placed at a location between the screen and the slide projector an image can be formed on the screen. The lens can now be moved to new locations in a plane cutting through the light path to the screen and in each case a complete image is formed (Taylor, 1978).

Demonstration #2.

The above principle can be demonstrated with using a camera. Consider taking pictures of an object (for example, a far-away mountain). You take a picture, then move over a few feet and take another one. You move over a few more feet and take another one. Upon getting the pictures developed, they all look about the same. This demonstrates the idea that the information necessary to form the image was present at each of the locations that you took the pictures. Additionally, if you look at an object very far away, then tilt your head to the side, you can still see the object. The light incident on your eye in both positions was sufficient to form the whole image.

Demonstration #3.

Take a pair of binoculars. Just look through one side focusing at a distant object. Now place your fingers in front of the lens so that only light coming from in-between your fingers enters the monocular. You will still see the whole image. If you bring your fingers together so that the light enters only through tiny slits, the whole image will still be present, only dimmer (and there will be some loss of resolution). If you rotate your hand, exposing the light to different parts of the lens, the whole image can still be formed. This is another representation that the light incident at the surface of the lens at any point is in a holographic form.

Demonstration #4.

A pinhole camera represents a special case where an image can be formed without using a lens (without taking a transformation). Note that if the pinhole is moved over a bit, the image still forms. This demonstrates the rudimentary idea of the whole being included in a part (the part being the area of the pinhole). All of the information necessary to produce the image is contained in the area of the pinhole. A lens functions to allow the light incident on a larger area to all be transformed (focused) to form an image. This will improve both image resolution and light gathering capability.

It is perhaps unfortunate that most physiology textbooks use a figure something like the following (figure 1) to describe the operation of the eye.

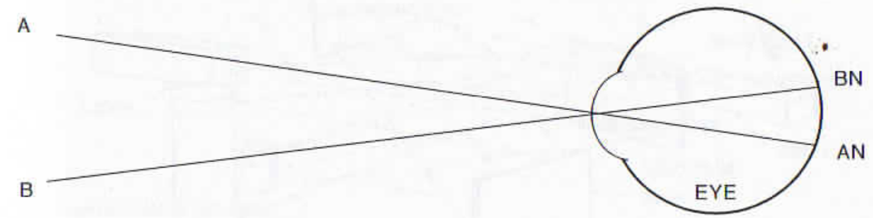


Figure 1

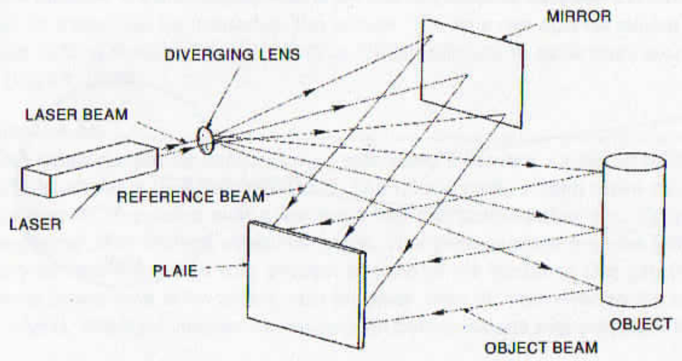
The above figure doesn't express the transform-taking aspect of a lens. The above figure is really more indicative of a pinhole camera. Figure 4 (shown later in the report) gives a better depiction of what happens at the lens of the eye.

Mathematically (in one implementation), a Fourier transform converts a function of time f(t) into a function of frequency F(jw) where the j indicates that it is a complex function of frequency. In other words, a Fourier transform can convert a signal from the time domain to the frequency domain. A Fourier transform could also be used to convert something from a spatial locational domain (the coordinates in space) to a frequency domain (more about this later).

The idea (the mathematics) of the Fourier transform is independent of what the data sets represent. It will be argued that if the brain performs a Fourier transform for visual stimuli, then it is possible that it also performs a Fourier transform for the other senses also (hearing, taste, smell, touch).

The same principle can be shown with optics. Consider, for example, that a large telescope lens (or mirror) can resolve two distinct images (for example two stars that only have a small angle seperating them in respect to us). A smaller telescope lens (or mirror) will not be able to resolve (separate) those two stars. Likewise, small parts of a hologram, although they have information of the whole, will suffer some resolution deficit.

One way to make a hologram:



Making an ordinary photograph:

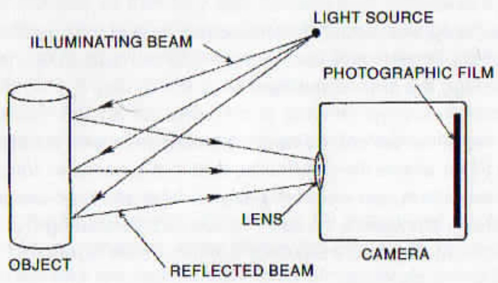
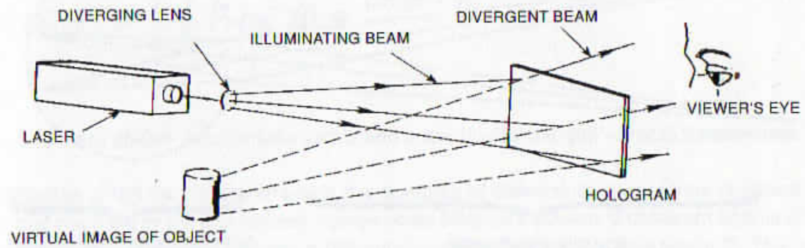


Figure 2: Reproduced from Kasper and Feller, The Complete Book of Holograms, 1987, pp 4-5.

As seen above in figure 2, the holographic plate records an interference pattern between the diverged laser light and the scattered laser light bouncing off the object. The pattern recorded on the holographic plate is in the holographic domain. All parts of the holographic plate contain information of the whole. Light bouncing off each point on the object is distributed (spread out) to every location on the holographic plate). Alternatively, the pattern recorded on the photograph is an image (non-holographic). The image features are located at particular locations on the photographic plate. Light scattered off the object (now in the holographic domain) is transformed to the non-holographic (image) domain by the lens of the camera (which does an effective inverse Fourier transform) by focusing the image on the photographic film. For the photograph, there is a one-to-one mapping between the two-dimensional projection of points on the object to locations on the photographic plate. Correspondingly, there is a one-to-all mapping for the holographic plate.

Reconstructing the scene holographically



Viewing an ordinary photograph

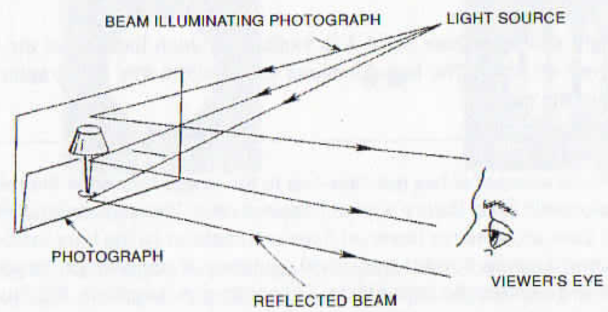


Figure 3: Reproduced from Kasper and Feller, The Complete Book of Holograms, 1987, pp 4-5.

In the case of the photograph (see figure 3), light is scattered off the photograph (which is now in the holographic domain) and becomes incident on the eye which does a transformation (focuses) which forms an image on the retina. For the holograph, laser light is shined through the holographic plate (picking up the holographic information from the plate) and becomes incident on the eye which does a transformation (focuses) which forms an image on the retina. The holographic nature of the light incident on the lens is shown in figure 4.

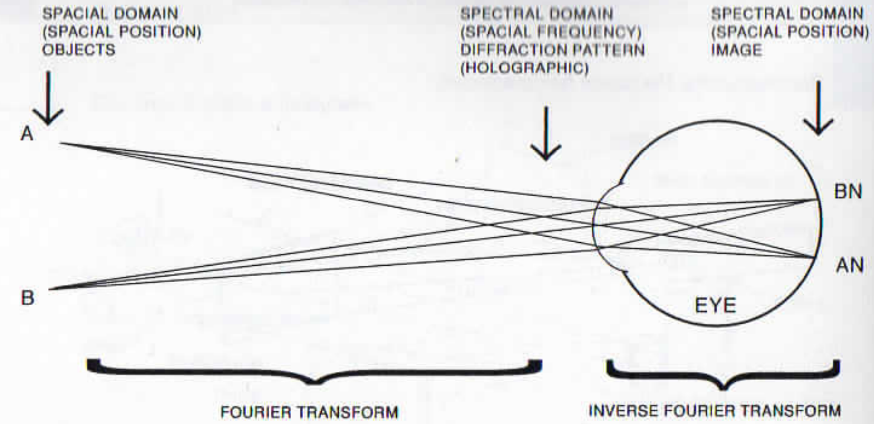


Figure 4: Diagram expressing the holographic nature of light incident on the surface of the lens of the eye.

The light scattered from point A is incident at each location of the lens (likewise for the light scattered off of B). The lens functions to transform this holographic domain to an image of A and B at the retina.

The discussion so far has just taken us to the image formed at the retina. The interesting part of the holonomic brain theory is what happens next. The focal point of the above discussion is that a lens does an effective (inverse) Fourier transform on the light incident to it. The Fourier transform (and inverse Fourier transform) consists of convolution integrals which mathematically smear or de-smear the information. For continuous functions, the Fourier transform and inverse Fourier transform are as follows (for transforms between the time and frequency domain):

$$X(F) = \int_{-\infty}^{\infty} x(t)\, e^{-j2nFt}\, dt \qquad x(t) = \int_{-\infty}^{\infty} X(F)\, e^{j2nFt}\, dF$$

The Fourier transform also has meaning between a spatial domain (for instance the position in two dimensional space) and spatial frequency. Mathematically, the two-dimensional spatial Fourier transform is

$$F(a, \beta) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y)\, e^{-j2n(ax + \beta y)}\, dx\, dy$$

and the inverse transform is

$$f(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} F(a, \beta)\, e^{j2n(ax + \beta y)}\, da\, d\beta$$

where x and y are spatial coordinates and a and b are horizontal and vertical frequencies.

One realisation of the Fourier transform is the principle of diffraction. If you shine coherent light through one point there will just appear a large white blob on a screen. If coherent light is shined through two separated points, though, a diffraction pattern will appear (see figure 5). The orientation of the (sine-wave) grating is caused by the relative orientation of the two points.

Figure 5: Copied from Taylor, Images, 1978, page 27.

In each figure pair, coherent light shining through the point(s) on the left would create the (diffraction) pattern seen on the right. The right hand side of each figure pair represents the Fourier transform of the left-hand side of the figure pair.

Mathematically, the diffraction patterns seen are explained by taking (two-dimensional) Fourier transform of the points. The right-hand side of each figure pair is the Fourier transform of the left-hand side (and visa versa).

If coherent light (or light from a point source) is shined through two slits, a diffraction pattern can be demonstrated as seen in figure 6. Note a large blob in the middle and smaller blobs tapering off to either side. The separation and angular position of the spectral blobs is dependent on the separation and orientation of the slits.

Figure 6: Reproduced from Taylor, Images, 1978, page 42-43.

The left hand side of each pair indicates the geometry of the slits. The right-hand side of each pair shows the optical diffraction pattern.

Figure 7 shows the mathematical Fourier transform of three different patterns (square-wave grating, checkerboard, and plaid) into their respective spatial frequency domains. The spectrum of the square-wave grating has odd numbered harmonics that taper off in amplitude to each side. Note that the plaid shape is made up of the addition of vertically and horizontally oriented square-wave gratings. Similarly, the spectral representation of the plaid is the superposition of the spectral representation of the vertical square-wave grating and what the spectrum would be (not shown) for a horizontal square-wave grating. Pay particular attention to the dominant four components to the plaid spectrum (the heaviest four dots towards the centre). Now compare those dominant dots to the corresponding ones in the spectrum of the checkerboard. Note that there is a 45º rotation. This can be intuitively understood because you can perceive rows of white and black squares running at the 45º orientation for the case of the checkerboard. This fact will become very important in the physiological experiment to be described later in the report.

Stimuli and the corresponding Fourier spectrum. (A) square-wave grating. (B) checkerboard with squares. (C.) checkerboard with rectangles wider than tall. (D) plaid.

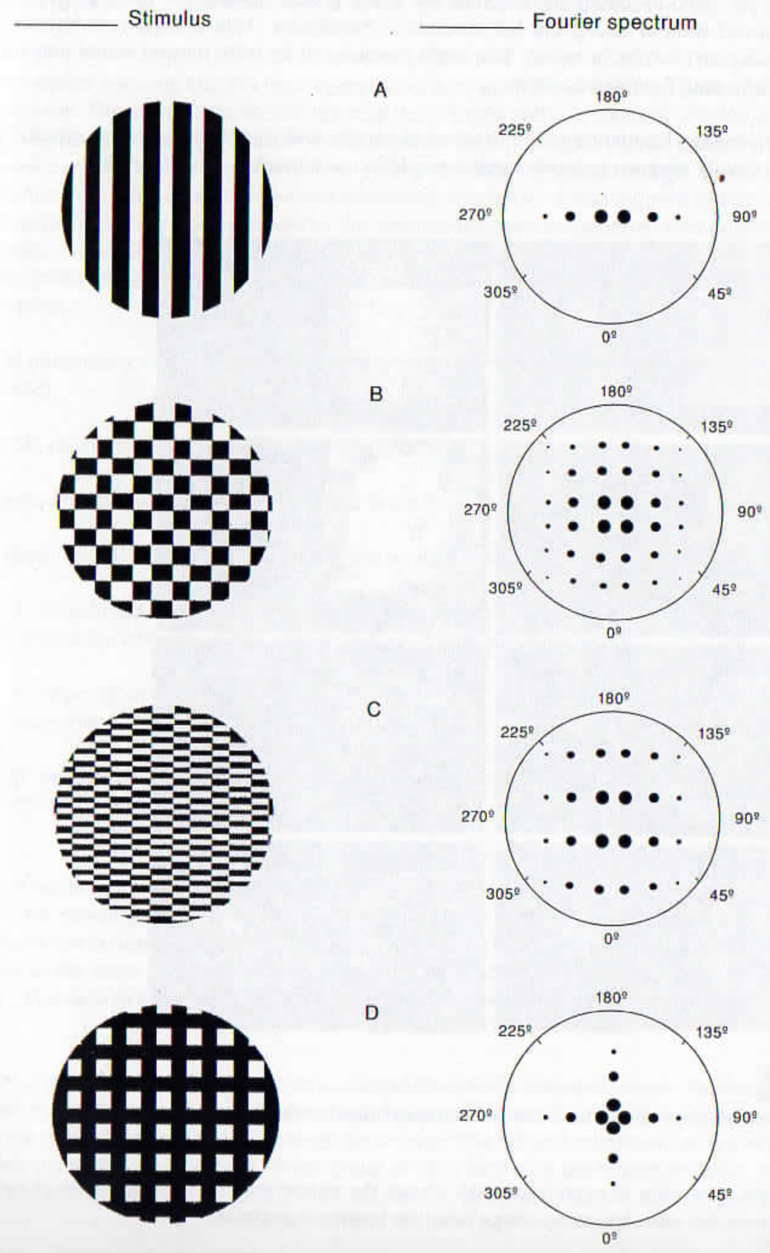


Figure 7: Copied from De Valois et. al., 1979, page 485.

Before proceeding, a couple of examples will be shown of the effect of not using the entire spectral domain in performing the inverse Fourier transform. This demonstrates the holographic idea of the <whole> being stored in all the parts. It also shows that fairly good images can be achieved without taking the full theoretical transforms. This is important because neural processing isn't infinite in extent. The brain (because of its finite nature) would only be able to take a truncated Fourier transform.

When an inverse Fourier transform is taken of smaller and smaller areas of the spectral domain, the <whole> is always captured, but the resolution deteriorates. See figure 8.

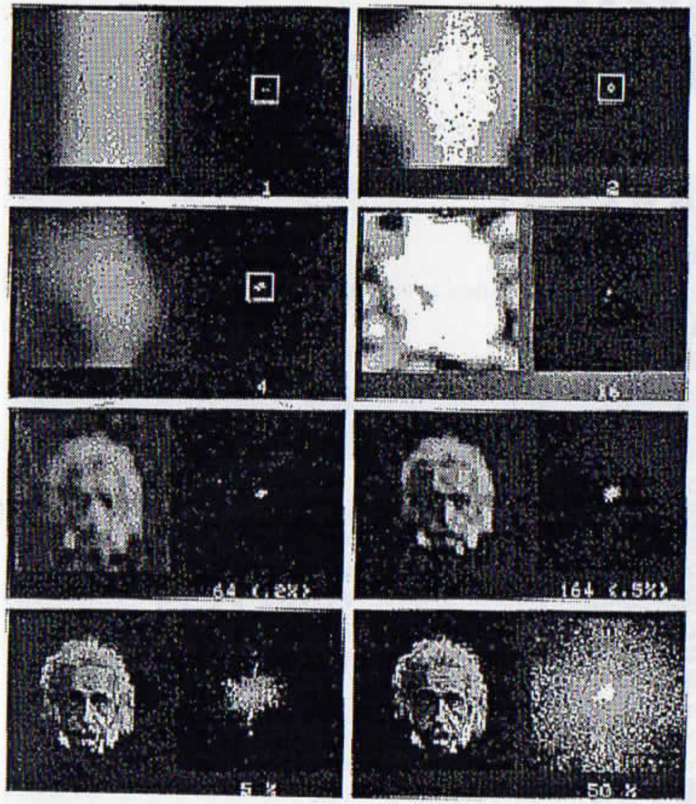


Figure 8: Reproduced from De Valois & De Valois, Spatial vision, 1988, page 17.

The right-hand side of each figure pair shows the spectrum. The left hand side of each figure pair shows the corresponding image after the inverse transform.

Chapter 3: Euclidean based geometric model

The conventional theory is that the main computational event in neurons is the generation of the action potential. The firing of the action potential (for a single cell or a network of cells) indicates the triggering of a particular perception. In the extreme case (the <grandfather cell>) the firing of a single cell can trigger a certain memory or perception. More typically, though, it would be the near simultaneous firing of a whole collection of cells in a network that triggers the perception. The perception would then be mediated by the action potential's propagation (through the axon) to other parts of the brain. It would be the integrative emergent response of <the other parts of the brain> (including parallel coupling to other sensory modalities) that yields the sensation of the perception.

For visual perception, there is the following information flow (Kendel, Principles of Neural Science, p. 438)

Retina: cells respond to small circular stimuli

Lateral geniculate nucleus: cells also respond to small circular stimuli

Primary visual cortex: transforms the concentric receptive field in at least three ways.

1. Visual field decomposed into short line segments of different orientation, through orientation columns. Early discrimination of form and movement.

2. Information about colour is processed through <blobs> which lack orientation selectivity.

3. Input from the two eyes is combined through the ocular dominance columns (one the steps necessary in depth perception.

Central connections of the visual system are remarkably specific. Separate regions of the retina project to the lateral geniculate nucleus in the thalamus in such a way that a complete visual field for each eye is represented in the nucleus. Different cell types in the retina project to different targets in the brain stem. Each geniculate axon terminates in the visual cortex, primarily in layer four. The cells in each layer have their own patterns of connections with other subcortical regions.

Cells in the visual cortex are arranged into orientation-specific columns, ocular dominance columns, and blobs. Some of these neurons have horizontal connections. Information flows both between the layers and horizontally through each layer. The columnar units seem to function as elementary computational modules. Each group of cells acts as a dedicated circuit to process an input and send it on.

Experimental Evidence

Hubel and Wiesel (1959, 1962) described and classified simple and complex cortical cells. They concluded that both simple and complex cells responded optimally to bars and edges of a certain orientation. An alternative view was that each cortical cell might be selective for a particular portion of the two-dimensional Fourier spectrum (a certain frequency component at a particular orientation) of the visual stimulus (Robson, 1975; De Valois, Albrecht & Thorell, 1977). The issue was raised that a true edge detector would need non-linear dynamics and it was unclear whether the cortical cells exhibited the necessary non-linear dynamics.

The two different views were (1) that the cortical cells function as non-linear edge detectors or (2) as linear spatial frequency filters. These two views each have different predictions about how the cortical cells would respond to a visual stimulus. By making use of gratings and checkerboards as the visual stimuli, De Valois et. al.,1979, were able to distinguish between these two possibilities.

Figure 7 (from earlier in the report) shows different patterns (that can be presented as visual stimuli) and the corresponding frequency spectrum. Each spectrum here is plotted in polar form where the distance from centre represents the spatial frequency of the stimulus and the angle (from 0º) represents the phase information or the orientation of the spatial frequency of the stimulus. The size of the dots represents amplitude. In rectangular coordinates the spectrum would be interpreted as frequency components in the vertical and horizontal directions.

For example, a square-wave grating with vertical bars (see figure 7) would manifest a frequency (repeating pattern) in the horizontal direction. The spectral depiction of this image would be decomposed into various frequency components all in the horizontal direction. This would be plotted (in the representation used here) as dots along the horizontal axis. A spectral plot of a square-wave grating with horizontal bars would consist of dots along the vertical axis.

When an animal is presented with the spatial visual field (the left-hand side of each figure pair) the question can be asked: <<Are the cortical cells responding to information in the original spatial domain or information in the frequency (spectral) domain?>> In what representation is the information getting to the cortical cells? Can an experiment be devised to distinguish between these two possibilities? For example, is a particular cortical cell responding to the presence of a line in the visual field or to the fundamental Fourier component (at a certain orientation) of the spectrum? This issue was resolved by comparing the response of the same cortical cell to different visual fields (De Valois et. al., 1979).

A series of experiments were performed in both cats and monkeys (De Valois et. al., 1979) to see if the cortical cells responded to differences in the Fourier spectrums. The first experiment was designed around the observation that spectral Fourier fundamentals for the checkerboard were rotated at 45 degrees relative to the Fourier fundamentals of either the square-wave grating or the plaid (see figure 7). Vertical square-wave gratings, plaids, and checkerboards each have vertical edges in the same orientation. Therefore, if a cortical cell was functioning as an edge detector, the cell should respond optimally (most number of spikes or action potentials per sec) to square-wave gratings, plaids, and checkerboards all in the same orientation. If, however, the cortical cells were responding to the spectral fundamentals, the cortical cell should respond optimally to a checkerboard pattern that is rotated 45 degrees relative to either a square-wave grating or a plaid pattern that was oriented to produce the optimal response.

In both cats and monkeys, the procedure would be as follows. A micro-electrode would be inserted into a visual cortical cell to measure the number of action potentials (spikes) per second. The optimal stimulus parameters were first determined for the cell. The receptive field was located and the animal was positioned so that the receptive field was centred on the scope display. Then by experimenting with different sine-wave gratings, the optimum orientation and the optimum spatial frequency for the cell was determined. The optimum temporal frequency was determined by drifting the best grating pattern across the respective field at different rates. If the cortical cell was functioning as a true edge detector, one would expect the square-wave grating, the checkerboard, and the plaid to all induce maximal spikes/sec in the cell at the same orientation. The cortical response to the square-wave grating was determined with various angular rotations. Then the cortical response (# spikes/sec) was determined from the checkerboard at various angular rotations. The visual cortical cells responded optimally to the checkerboard pattern which was rotated 45 degrees relative to the square-wave grating that was rotated to produce the optimal response (see figure 9). This was evidence that the visual cortical cell was responding to the Fourier fundamentals, not as an edge detector.

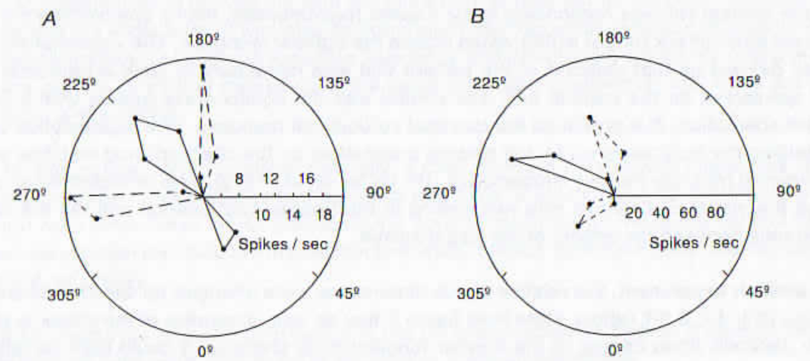


Figure 9 :
Copied from De Valois et. al., 1979, page 489.

In another experiment, checkerboards stimuli of different check dimensions (1/1, 2/1. 0.5/1) were presented (to the animals) for comparison with the square-wave grating visual stimulus. The altered (orthogonal) dimension of the checkerboard checks should not matter if the visual cortical cells are responding to the unaltered edges. If, on the other hand, the visual cortical cells are responding to the fundamental Fourier frequency, the different checkerboard patterns would have to be rotated some to get the maximal spikes/sec from the cells. Note how the Fourier fundamentals (the biggest dots) are at a different angle from the centre in comparing figure 7B to 7C). It was indeed found that the different checkerboard patterns had to be rotated an amount that matched exactly to what would be predicted from the mathematics of the Fourier transform (the location of the Fourier fundamentals). When the data was re-plotted with the points rotated according to the mathematically predicted position of the Fourier fundamentals, it was found that a very good match existed. This was further evidence that the visual cortical cell was responding to the angular location of the Fourier fundamentals and not the edge of the squares (or grating) seen in the untransformed pattern.

In another experiment, plaid checkerboard patterns with the same dimensions were presented (with various rotations) as the visual stimulus to the experimental animals. Again, if the cortical cell was functioning as an edge detector, it would be predicted that the cell would respond optimally to the two patterns at the same orientation (when the edges are at the same orientation). It was found, though, that the cortical cell responded optimally to a checkerboard pattern that was rotated 45 degrees relative to the orientation of the plaid pattern (that had been oriented to give an optimal response).

The next batch of experiments were centred around the observation that the Fourier fundamentals for the checkerboard (with squares of the same width as the bars of the square-wave grating) were located farther out (from centre) than the Fourier fundamentals for the square-wave grating. Thus, a test could be done to see whether the cortical cells were responding to the width (separation between lines) or to the spatial frequency of the optimally presented pattern. If the cortical cell was responding to the separation between edges, then the best match should be for a checkerboard with squares of the same width as the bars in the square-wave grating. If the cortical cell was responding to the Fourier fundamentals, then a checkerboard with a different sized check (or bar width) would induce the optimal response. The <contrast sensitivity> was defined as that contrast of the pattern that was necessary to yield a particular number of spikes/sec for the cortical cell. The control was the square-wave grating with a bar width (and orientation) that produced the maximal cortical cell response. The experimental bar width (yielding the best response for the optimal orientation) for the checkerboard matched what was predicted from the Fourier mathematics (De Valois et. al., 1979). This provided more evidence that the visual cortical cell was responding to the Fourier fundamental and not the edges (or distance between the edges) of the visual stimuli.

In another experiment, the relative check dimensions were changed for the checkerboard patterns (2/1, 1.1, 0.5/1 ratios). Note from figure 7 that as one dimension of the check is changed, the distance (from centre) of the Fourier fundamentals changes. It could then be determined what width (given a certain ratio) produced the best result (when oriented optimally). If the visual cortical cells were responding to the check width, then the different height/width ratios shouldn't influence the cell's response. If the cell was responding to the Fourier fundamentals, then it should respond optimally to different check widths when the height/width ratio changes.

It was found that the cortical cell responded optimally to checkerboard patterns of different widths and that these widths matched what was predicted from the Fourier mathematics (De Valois et. al., 1979). When the data was plotted according to the theoretical prediction, the cortical cell was shown to be responding to the spatial frequency (the distance from centre of the Fourier fundamental) for the various optimally oriented patterns. This was further evidence that the cortical cells were responding to the Fourier transform of the presented visual stimuli.

All of these experiments were repeated for multiple visual cortical cells in both the cat and monkey yielding similar results (data not shown in this report).

The next set of experiments examined whether cortical cells could be found that were sensitive to higher harmonic components of the Fourier spectrum. If so, then this would be powerful evidence that these cortical cells are acting like spatial-frequency filters (and not as edge and bar detectors). The higher spectral harmonics of the square-wave grating are at the same orientation as the fundamental frequency but the higher harmonics of the checkerboard are at other orientations (see figure 7). If a cortical cell exhibits sufficiently narrow spatial tuning, it could potentially respond separately to the fundamental and the third harmonics of patterns. For instance, imagine a square-wave grating with more narrow bars such that the fundamental frequency falls on what was the third harmonic for a square-wave grating with wider bars. A cortical cell sensitive to this spectral position, would respond to either stimulus (and the stimuli would be presented at the same orientation). For the checkerboard, the situation would be a little different. A smaller sized checkerboard pattern sufficient to produce a Fourier fundamental at the same frequency location as the third harmonic (that a larger sized checkerboard pattern would produce) would have to be rotated some for the optimal response (to get the angle of the fundamental to fall on where the third harmonic would be for the other pattern).

It was demonstrated that a cortical cell (responding to a square-wave grating of a certain frequency and orientation) would also respond optimally to a square-wave grating with bar widths three times the size (which would be one third the spatial frequency) with the same orientation. The Fourier fundamental of the grating with the more narrow bars fell on the third harmonic of the grating with the wider bars. It was also demonstrated that the same cortical cell responding to a sine-wave grating (optimally at a certain frequency and orientation) would not respond to a sine-wave grating of 1/3 that frequency at the same orientation (remember that there are no harmonics for a sine wave).

In order for the cortical cell to respond optimally, a checkerboard pattern with check size of a certain size had to be rotated relative to the optimal rotational orientation of a checkerboard with checks that were three times larger producing the optimal response for the same cortical cell. This observed rotation matched the theoretical predicted rotation from the Fourier mathematics (De Valois et. al., 1979).

Similar experiments have been performed with the rat somatosensory system (Pribram, 1994) where the cortical cells were also found to respond to spectral information.

Other aspects of the holonomic theory

Pribram says that both time and spectral information are simultaneously stored in the brain. He also draws attention to a limit with which both spectral and time values can be concurrently determined in any measurement (Pribram, 1991). This uncertainty describes a fundamental minimum defined in 1946 by Gabor (the inventor of the hologram) as a quantum of information. Dendritic microprocessing is conceived (by Pribram) to take advantage of this uncertainty relation to achieve optimal information processing. Pribram then says that the brain operates as a <dissipative structure> where the brain continually self-organises to minimise this uncertainty. The next few sections will attempt to explain the concept of the <uncertainty principle> and the concept of <dissipative structures> that self-organise.

The uncertainty principle

Quantum physics

In quantum physics, the uncertainty principle can be described in the following way (paraphrased from Pagels, 1982): Consider that you have a device that can simultaneously measure the position and momentum of a single electron. Every time you push a button, the device displays numerical values for the position and momentum, although, each time you press the button, you will get slightly different measurements for the momentum and position. If enough measurements are taken, then a statistical analysis can be performed. Heisenberg defined the term delta q as indicating the spread or uncertainty of the position measurements around some average value and delta p as indicating the spread or uncertainty of the momentum measurements around some average value (for the series of measurements). He then found that (delta q)x(delta p)>=h where h is Planck's constant. For a series of measurements, the positions can be expressed as an average +/- some uncertainty. Likewise for the momentum. No matter how good one makes a quantum measuring device, the products of the uncertainties can never be less than Planck's constant. For example, if you could build a measuring device that exactly determined the position (where delta q = 0) then you would not be able to determine anything about the momentum (delta p = infinity). There is a similar uncertainty relation for the energy of a particle and the elapsed time. For a series of measurements, the product of the uncertainty of the energy (delta E) and the uncertainty of the elapsed time is always greater or equal to Planck's constant. (delta E)x(delta t)>=h.

Communication theory

In communication theory, a variation on the uncertainty principle also holds (Gabor, 1946). The measurement of the frequency can be made with arbitrary precision. Likewise, the measurement of the time of occurrence can be made with arbitrary precision. But there is a limit to the precision when these measurements are taken simultaneously. One can exactly measure either the frequency (of for example a tone) or the time (of occurrence) but not both at the same time. For instance, if the time of occurrence were known (indicating an impulse function) there would be frequency components all up and down the spectrum. If, on the other hand, the frequency

information was exactly known, one would not know any information about when it occurred. A single peak (or peak pair if you consider the corresponding negative frequency) in the spectrum implies that the tone has infinite extent in the time domain. Analogously to the quantum uncertainty principle, when frequency and temporal measurements are made simultaneously, there is a limit to the precision possible. Pribram claims that the brain functions as a dissipative structure to seek to decrease this uncertainty in the direction of its theoretical limit.

Dissipative structures

The second law of thermodynamics holds that the entropy always increases in any isolated system (figure 10). This simply means that if something is left to itself, it will move towards equilibrium... it will move towards maximal disorder... its internal energy state will tend to be minimised. There has not been, to date, any confirmed observation that this law is invalid.

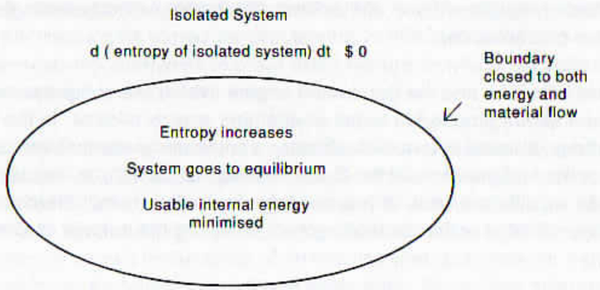


Figure 10

An isolated system can itself be divided into a subsystem that is open to energy flow and the subsystem's environment (see figure 11). As such, the whole combined isolated system still obeys the second law of thermodynamics, but it is possible that the subsystem can experience a decrease in entropy at the expense of its environment.

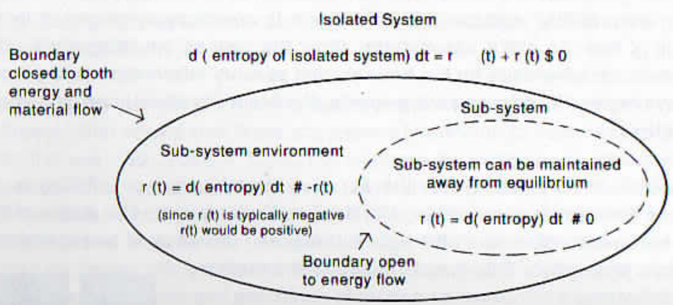


Figure 11

The entropy increase in the <sub-system environment> is guaranteed (by the second law) to more than offset the entropy decrease in the subsystem. Also note that the sub-system can only be maintained away from equilibrium as long as there is usable energy in its environment. When the environmental entropy is maximised (no usable energy), the subsystem is guaranteed to itself proceed to equilibrium.

There is a special class of such subsystems (as described above) where the subsystem's organisation comes exclusively from processes that occur within the sub-system's boundaries. This class of subsystems was labeled <dissipative structures> by I. Prigogine, 1984 (who won the Nobel prize for his work). Pribram believes the brain to be such a <dissipative structure>.

One way of modelling a structure that goes to equilibrium is to minimise a mathematical expression for the internal energy (which is the same as maximising an expression for the entropy). This is called the least action principle. This would not be appropriate, though, for a <dissipative structure> since it is not going towards equilibrium. <Dissipative structures> self-organise around a different <least action principle>. In the holonomic brain theory, Pribram has the entropy being minimised (which maximises the amount of information possible to store) as the <least action principle>. Thus, the system (the brain) self-organises such that more and more information can be stored.

In Hopfield networks and the Boltzmann engine (which are computer models of neural processing), computations proceed in terms of attaining energy minima. In the holonomic brain theory, computations proceed in terms of attaining a minimum amount of entropy and therefore a maximum amount of information. In the Boltzmann formulation the principle of least action leads to a space-time equilibrium state of least energy. In the holonomic brain theory, Pribram describes the principle of least action as leading to maximising the amount of information (minimising the entropy).

Independently, (in unrelated work) Schneider and Kay (1994) have proposed a variation on the second law of thermodynamics which may be applicable to Pribram's holonomic theory.

<<The thermodynamic principle which governs systems is that as they are moved away from equilibrium, they will utilise all avenues available to counter the applied gradient. As the applied gradients increase, so does the system's ability to oppose movement from equilibrium.>>

It would be interesting to see if there is a connection between the work of Schneider and Kay and Pribram.

The holonomic brain theory maintains that the brain is continuously engaged in correlation processes. This is how we make associations (how the senses are integrated). There is an obvious computational advantage for the brain storing sensory information (and perceptions) in the spectral (or holographic) domain as opposed to the brain directly storing individual features and characteristics.

The holonomic brain theory claims that the act of <remembering> or thinking is concurrent with the taking of the inverse of something like the Fourier transform. The action of the inverse transform (like in the laser shining on the optical hologram) allows us to re-experience to some degree a previous perception. This is what constitutes a memory.

Chapter 5: Conclusions

General comments

The medium of the optical holography, the silver grains on the photographic film, encodes the Fourier coefficients. In the holonomic brain theory, the Fourier coefficients are stored as the micro process of polarisations and depolarisations occurring in the dendritic networks.

Both Pribram's theory and the more conventional theory have the brain divided up into various functioning communicating modules. One main difference is in how the information is stored in these brain modules. For example, in the case of vision, the conventional theory has specific features stored in certain dedicated cells. These different sub-modules then have parallel pathways to other modules that produce the combined visual experience. This would be somewhat analogous to a computer performing signal processing directly on an image. For example, dedicated circuitry for edge detection would interface with other circuitry for other features like colour. Every feature of the image gets stored (or processed) in different dedicated <circuitry>. These <circuits> then have parallel pathways to other brain regions in which the collective subjective experience of the perception is formed.

The holonomic theory (for the example of vision) summarises evidence that the image formed on the retina is transformed to a holographic (or spectral) domain. The information in this spectral <holographic> domain is distributed over an area of the brain (a certain collection of cells) by the polarisation of the various synaptic junctions in the dendritic structures. At this point, there is no longer a localised image stored in the brain. Correlations and associations can then be achieved by other parts of the brain projecting to these same cells. Conscious awareness (and memory) is the byproduct of the transformation back again from the spectral holonomic domain back to the <image> domain. Possibly the most radical part of the holonomic theory is Pribram's claim that a <receiver> is not necessary to <view> the result of the transformation (from spectral holographic to <image>). He claims that the process of transformation is what we <experience>. Memory is a form of re-experiencing or re-constructing the initial sensory sensation.

Conventional neuro-physiology effectively pushes back the line between observer and what is observed (between subject and object). In signal processing, there always needs to be an end-user to view the processed or transformed signal. At best, conventional neuro-science leaves until later the ultimate explanation of the observer. Who would bet their grant money (career) on being able to answer this question in a couple of years? Aspects of Pribram's holonomic brain theory attempt to address this question.

The conventional view is that the brain is a computational device. There is a growing body of literature, though, that shows that there are severe limitations to computation (Penrose, 1994; Rosen, 1991; Kampis, 1991; Pattee, 1995). For instance, Penrose uses a variation of the <halting problem> to show that the mind cannot be an algorithmic process. Rosen argues that computation (or simulation) is an inaccurate representation of the natural causes that are in place in nature. Kampis shows that the informational content of an algorithmic process is fixed at the beginning and no <new> information can be brought forward. Pattee argues that the complete separation of initial conditions and equations of motion necessary in a computation may only be a special case in nature. Pattee argues that systems that can make their own measuring devices can affect what they see and have <semantic closure>.

It is possible that the brain transcends computational behaviour. If this is the case, then it will be very interesting to see what aspects of Pribram's holonomic theory are in collaboration with these non-computable ideas.

Conclusions

Karl Pribram's holonomic brain theory weaves several concepts together in forming the holonomic brain theory. A partial list is the following:

1. The apparent spectral frequency filtering aspect of cortical cells.

2. The relationship between Fourier transforms and holograms.

3. The fact that selective brain damage doesn't necessarily erase specific memories.

4. The computational advantage to performing correlations in the spectral domain.

5. His idea of conscious experience being concurrent with the brain performing these Fourier-like transformations (which simultaneously correlate a perception with other peviously stored perceptions). He believes that conscious experience is the act of correlation itself and this correlation occurs in the dendritic structures by the summation of the polarisations (and depolarisations) through the processes in the dendritic networks.

6. The brain is a <dissipative structure> and self-organises around a least-action principle of minimising a certain uncertainty relation.

Most conventional experimental neurophysiologists are content just to gather neurological data independent from any global theory of the brain/mind and leave a theory of the brain to future generations. As such, Karl Pribram is not referenced in many of the major neuro-physiology textbooks (such as *Principles of Neural Science* by Kandel, Schwartz, and Jessell, 1991). This is unfortunate because it helps to have a theory in asking important experimental questions. With a different theory comes different questions which can lead to new and different experiments that can bring forth novel information.

Hopefully, Pribram's ideas (or variations on them) will eventually find their way into the consciousness of the conventional neurophysiologist (and appear in most textbooks) once the current fascination with molecular biology runs its course. Then the attention of physiologists may again be directed back toward a system's organisation and away from simply analysing its parts.

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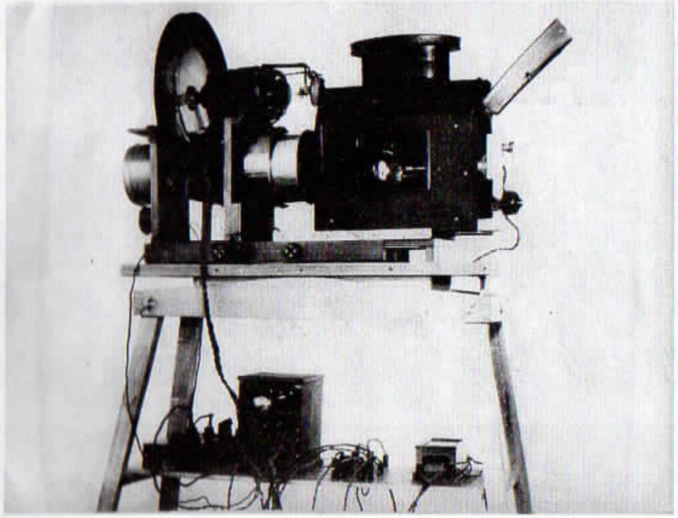
musical intervals as experienced in physical space. In this instrument each oscillator has an independent pitch control and loudspeaker. Listening to the sounds produced by this instrument allows people to experience the final 'mix' directly in their brains. Any beats or sub-harmonics appear as pure psychoacoustical phenomena — the result of interpretation by the mind. For many years this instrument was used for training choir conductors and singers.



Ilumovox — the Light Theremin. An instrument for controlling the colour of a light beam during a musical performance. Petrograd, 1923-24. Courtesy of Lydia Kavina.

VISUAL MUSIC

In 1923 Leon Theremin built the Illumovox. It was an instrument for controlling the colour of a light beam during a musical performance by different means including body movement and gesture. It was widely used in numerous experiments and shows. The basic operating principle of the Illumovox was also utilized in different versions of Terpsitones, the polyphonic Theremin and even in the construction of a scientific device for tracking the movement of piano pedals. It served as an artistic visual extension of a performance as well as a kind of visual indicator of the performance. In fact the range of Theremin's interests was even wider, including experiments into increasing human sensitivity thresholds by means of hypnosis and beyond. In this context research into the human perception of multilayered multimedia art forms gained special importance. Theremin recollected in one of his articles:

As of the 1920s the author was engaged in the development of light-music devices which he demonstrated at concerts in the Soviet Union, Germany, France and the USA during the period 1922–39. Light effects accompanying the melody were achieved by means of light projection on the performer's body with a colour corresponding to the pitch of the sound and the brightness changing proportionally to the intensity of the sound.

The author conducted experiments following the demonstration of coloured stroboscopic images with symmetry corresponding to the harmonious steps of a melody that provided interesting entertainment results.

Albert Einstein, who was involved in the activities of Leon Theremin colour-music laboratory in New York, was engaged in the presentation of geometrical colour figures accompanied by music. Later he participated in research conducted by the laboratory's collaborator Mary Ellen Bute (the well-known modern American director of abstract film).

The subsequent colour-music presentations were approved by the audience and received positive reviews. Further experiments were conducted by the author by means of electronic schemes and the polarised optics (1939).

The author also carried out experiments on the application of various methods of light projection by means of different light sources, taking into account features of psycho-physiological influence on spectators and listeners. The strong influence of the high-rise and lateral displacement of the light projections was noted. A very slow lowering of the projection along the auditorium walls resulted in a sensation of lifting or launch, while return displacement of a projection — a sense of falling at various speeds. At the same time coincidence of movements with structures corresponding to melodic and harmonious design created a very strong psycho-physiological influence.

A long-term projection of light dots with variable intensity and chromaticity combined with musical soundings leads to a quasi-hypnotic influence on some listeners. The application of stereoscopic (three-dimensional) structures and their variations provides a substantial increase of psycho-artistic influences (in comparison with the use of a usual plane projection).

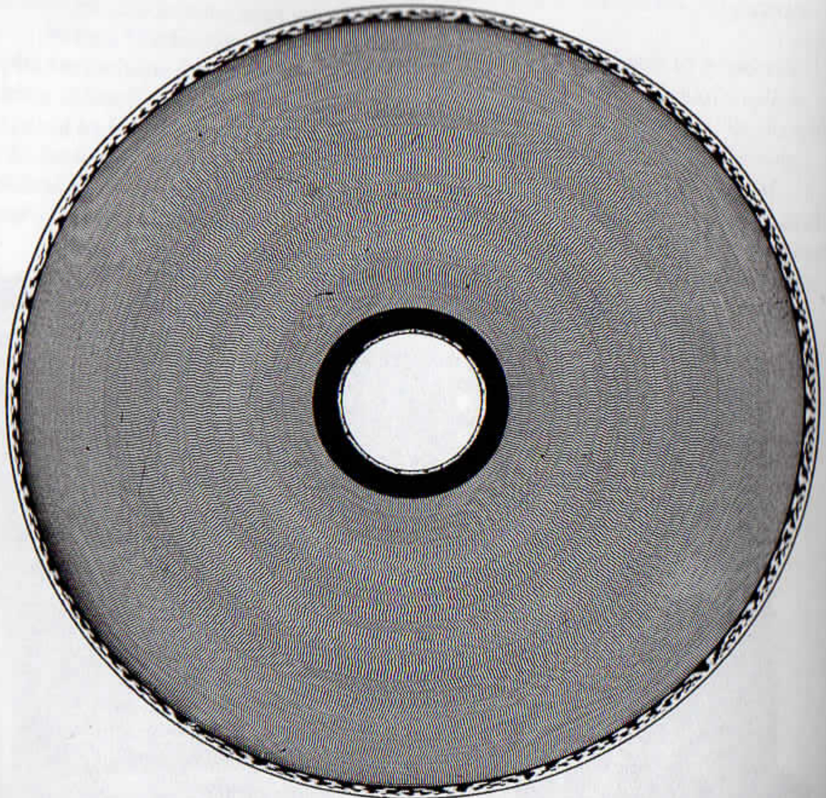
Experiments on the coordination of colour-light perceptions with various degrees of rhythm were conducted by means of the Rhythmicon which could generate fluctuations of rhythm in the range of one to twelve beats per measure, reproduced with pitches, corresponding to rhythm number. It was noticed that the audience demonstrates an increase of artistic involvement as a result of the perception of poly-rhythmic soundings combined with optical processes with a colour system based on three- and five- component schemes.

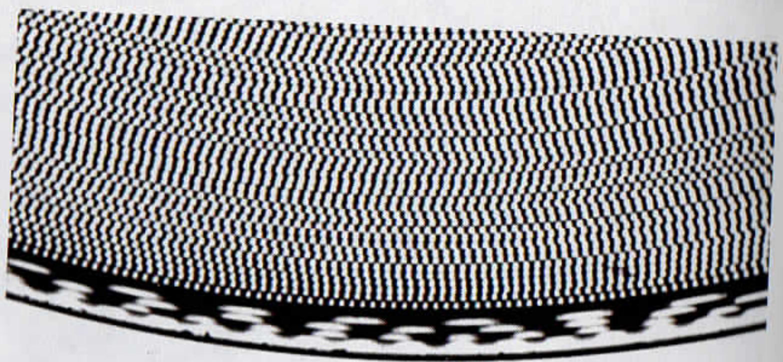
Currently the Laboratory of Leon Theremin is conducting experiments into the coordination of harmony of the sounding of the polyphonic Theremin with chromaticity, corresponding to steps of melodic tones.[28]

EAVESDROPPING AND MICROWAVE ATTACKS

On 4 August 1945, the Young Pioneers (an association of Soviet school-age children) presented a carving of the Great Seal of the United States to U.S. Ambassador Averell Harriman. It hung in the ambassador's

28 Theremin, L.S. 'Eksperimenti v oblasti svetomuziki v laboratorii L.S. Termena'. (Experiments in the field of colour-music in the laboratory of L.S. Theremin). Documentation from the conference 'Svet I muzika' (Light and music), Kazan, 1979. p.19-20. Trans. AS.





g 7.51 (Both images) Optical disk for the ANS Synthesizer. Curiously, the size of the optical disk, developed by Murzin in the late 1930s, was exactly the same as a modern CD. TCA.

THE ANS SYNTHESIZER

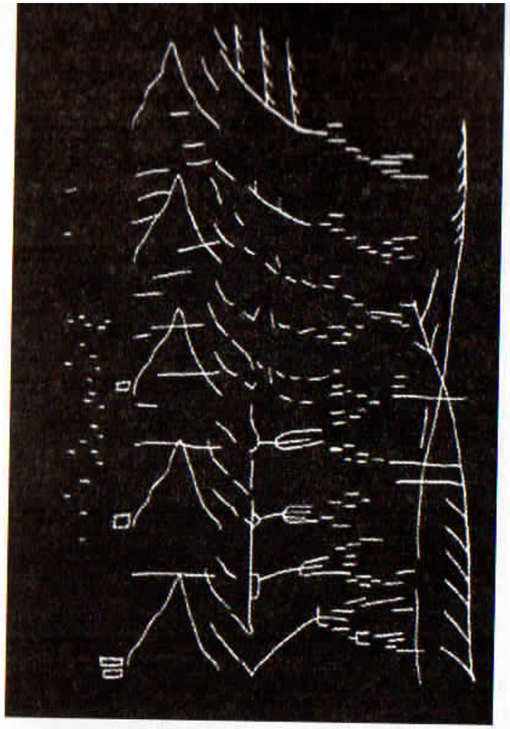
In 1938 Yankovsky met Evgeny Murzin (1914-70), a young inventor fascinated by the idea of a universal tool for sound synthesis. (See also p.234.) By 1939 the concept of the instrument had been developed and in 1957 Murzin completed the development and patented[51] a photo-electronic musical instrument called the ANS Synthesizer. (Its name was derived from the initials of influential composer Alexander Nikolayevich Scriabin.) It was remarkably close to the concept of Evgeny Sholpo's Mechanical Orchestra. The instrument was based on a set of optical sine wave oscillators, adjusted on fixed frequencies, forming a diskrete scale, covering the whole audible range with intervals between successive pitches unperceivable by the human ear. Control over the system and the process of sound synthesis was carried out by means of a special graphical score with the diagram, representing a spectrum of a sound by means of drawn transparent strips, having appropriate shape and slopes, allowing the full set of sine wave tones to be operated synchronously and independently, controlling the sound on a spectral level, directly manipulating the overtones, and erasing the difference between the pitch harmony structures and the spectral tissue of a sound.

In fact the ANS Synthesizer is based on the same principles of photo-optical sound recording – used in cinematography – as the Variophone by Evgeny Sholpo. It incorporates a set of rotating optical disks with photo-printed round optical sound tracks. While in the Variophone one rotating disk produced a single sound, in the ANS each optical disk contained 144 independent sound tracks. Four disks, used in the first version of the instrument, could produce simultaneously 576 sine waves with frequencies covering the whole audible range with accuracy of seventy-two steps per octave (the scale proposed by Yankovsky). This number of pure tones makes it possible to obtain a smooth variance of pitch. The minimum interval is 1/72 of an octave, or 1/6 of a semitone, which is only just perceptible to the ear. Such precise gradation of the pitch makes it possible to synthesize a greater number of pitch divisions per octave than the traditional Western musical scale's twelve semitones. The second version of the ANS was constructed in 1964 and generates 720 tones covering the entire audible frequency range. Unlike the Variophone, intended to produce optical recording of sound on film as a result of a non-realtime process, ANS was a realtime instrument, producing the sounding result directly during work.

Conceptually the instrument develops Boris Yankovsky's ideas: working with the ANS Synthesizer the composer manipulates the spectrum of sound instead of the waveform. Murzin did, however, develop a unique musical interface – the graphical score.▪ Working with the ANS the composer etched a sonogram – a dynamical spectrum of sound development in time – onto a large sheet of glass covered with a tar-like non-drying mastic. The glass is then cranked (by hand or by motor) across the light beams. Scraping off a part of the mastic at a specific point on the plate allows light from the corresponding optic phonogram

figs 7.52, 7.55

51 Murzin, E. 'Photoelectrichesky sintezator muziki' (The Photoelectric Synthesizer of Music). Copyright Certificate No. 118 695, USSR, applied for 24.06.1957.



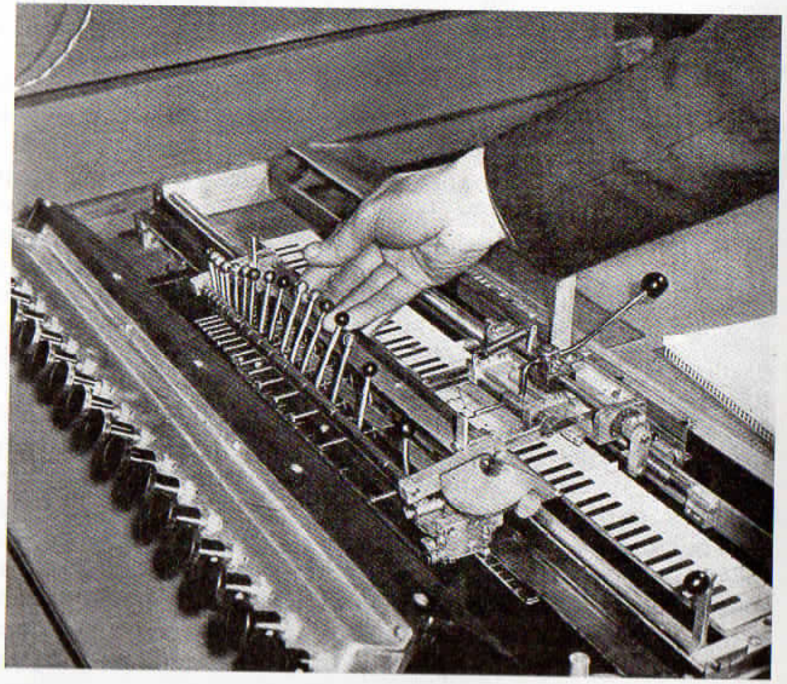


fig 7.52 The graphical score of the ANS. TCA.

fig 7.53 The coder of the first version of the ANS. Journal *Znanie sila*, N.3, Moscow, 1960, p.29. AS library.

to penetrate the reading device and be transformed into a sound. A similar principle of the graphical score was used in the legendary UPIC computer system, developed by Iannis Xenakis in 1977 in the Parisian CEMAMu (Centre d'Etudes de Mathematiques et Automatiques Musicales). The non-drying mastic allows for immediate correction of the resulting sounds: portions of the plate that generate superfluous sounds can be smeared over, and missing sounds can be added. The speed of the score can also be smoothly regulated, all the way to a complete stop. All this makes it possible for the composer to work directly and materially with the production of sound.

Twenty bandpass amplifiers are on the left side of the main front panel of the ANS. In the centre of the synthesizer is the reading device and the pitch scale and coder.▪ The black board on the right side is the operating field, or the score. On the lower front panel are keys for controlling the twenty bandpass amplifiers and a joystick for controlling the tempo. The performance tempo depends upon the score-reading rate and can be varied without changing the pitch and timbre of the sounds. The graph of the coded melody looks similar to its notation in music in that the horizontal axis represents time while the vertical denotes pitch.

figs 7.53, 7.55

fig 7.54 The group of composers working with the ANS: standing, from left: Eduard Artemyev, Alfred Shnitke, Alexander Nemtin, Edison Denisov; sitting, from left: Oleg Buloshkin, Sofia Gubajdulina and Stanislav Krejchi. Moscow, 1968. Courtesy of Julia Murzina.

In 1967 in Moscow, with the ANS Synthesizer at its core, the studio of electronic music was established. Among the composers working with the ANS were Alfred Shnitke, Sofia Gubajdulina, Edison Denisov, Eduard Artemyev, Alexander Nemtin and Stanislav Krejchi.

The instrument was used for scoring many films, in particular, the early films of Andrey Tarkovsky. However in spite of the obvious success of the project, Boris Yankovsky was never involved in its further development.

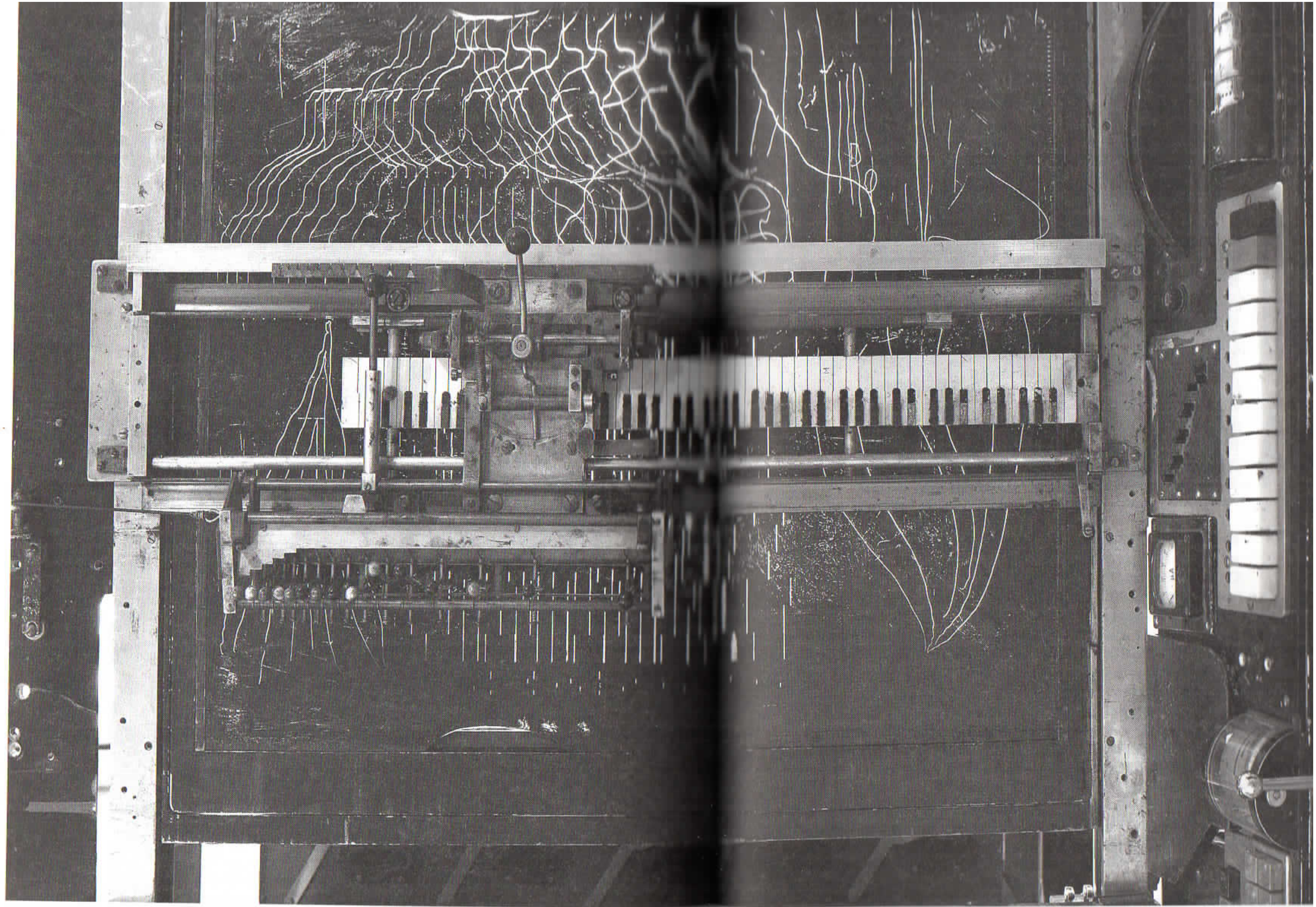


fig 7.55 The score with the coder of the ANS. TCA.

Evgeny Murzin. c. 1960. Journal *Znanie sila*, N.3, Moscow, 1960, p.27. AS library.

EVGENY MURZIN (1914-70) was an inventor who completed his studies in 1938 at the Moscow Institute of Engineers of Municipal Construction, and by 1941 had finished postgraduate studies at the same institute. During WWII he attended courses at the Dzerzhinsky Military Academy in Moscow.

During the war he worked as a military technician and inventor in military research laboratories. Later, as a military inventor and senior lieutenant, Murzin was directed to a secret scientific research institute. There he directed the development and tested the fighting conditions of various control devices for ground artillery. In 1945, after the war, Murzin finished his master's thesis on these subjects. Later he was involved in the development of equipment for audio investigations for ground artillery, and instruments and methods for engaging fighter-interceptors with enemy bombers. In 1945-50 Murzin was the assistant of the lead technician in his laboratory. From 1951-53 he was largely responsible for the production of equipment for the fighter corps of the air defence of the USSR.

In 1938 Murzin proposed the project of the ANS sound synthesizer which was finally built in 1958. In 1967 Murzin was appointed head of the first Soviet Electronic Music Studio at the Scriabin Museum in Moscow.

BACK TO SYNAESTHESIA

In December 1958 in Moscow, Evgeny Murzin applied for a patent entitled 'Visual Prosthesis for General Use by the Totally Blind',[52] concerning an apparatus which mapped 'viewed' images across into sound, thereby producing a kind of artificial synaesthesia. In general the proposed system was based on the same principles as the ANS Synthesizer.

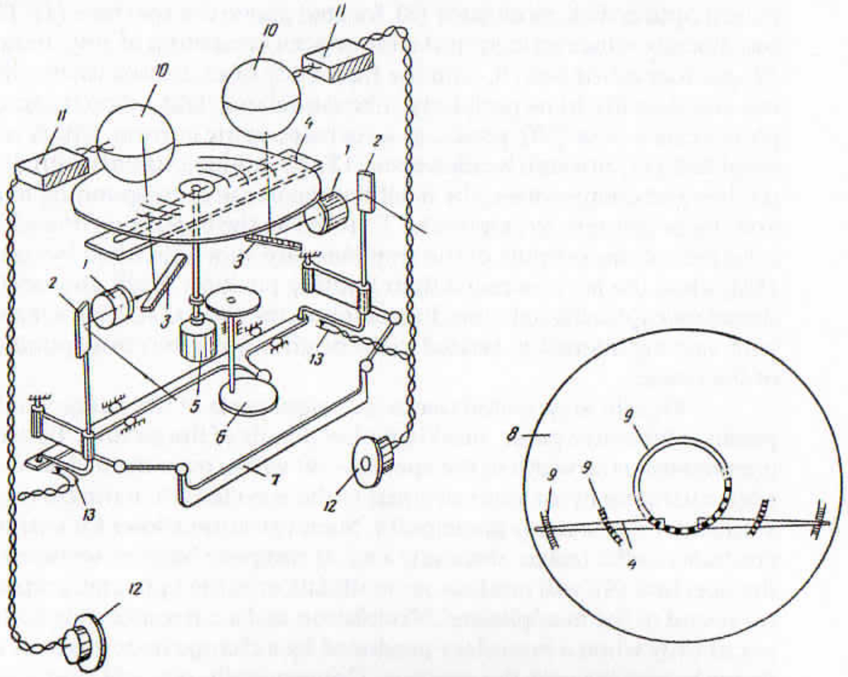


fig 7.57 Visual Prosthesis. Diagram from the Copyright Certificate. TCA.

This visual prosthesis system was conceived as an optoelectronic camera mounted on the head of the user. It contained two lenses (1), and two scanning mirrors (2), which are directed forward in eye-like fashion. These mirrors periodically scan the user's notional field of view, sending an image through each lens to a motionless mirror (3), and then on through an aperture (4), which passes only a thin vertical slice of the 'visible' projected image. The scanning of the mirrors is carried out mechanically by means of an eccentrically mounted wheel (6), rotated by an electric motor (5). The images in both halves of the aperture (4) only coincide at a given moment for those objects that are located at equal distances, coordinated according to the parallactic angle of the mirrors. Differences between the left and right images reaching each half of the aperture due to the spacing of the mirrors, produces, in effect, a stereoscopic image. In order to define

52 Murzin, E. 'Zritelny protez obshego polzovania dlia sovershenno slepih'. Copyright Certificate No. 151 060, USSR, applied for 30.12.1958. Supplementary Copyright Certificate No. 151 059, applied 30.12.1958, USSR 'Sposob preobrazovania v zritelnom proteze obshego polzovania opticheskogo izobrazhenia v zvukovie signali' (Visual Prosthesis for General Use by the Totally Blind).