Zeitschrift: Trans : Publikationsreihe des Fachvereins der Studierenden am Departement Architektur der ETH Zürich

Herausgeber: Departement Architektur der ETH Zürich

Band: - (2001)

Heft: 8

Artikel: FLLW Intraveous

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DOI: https://doi.org/10.5169/seals-918987

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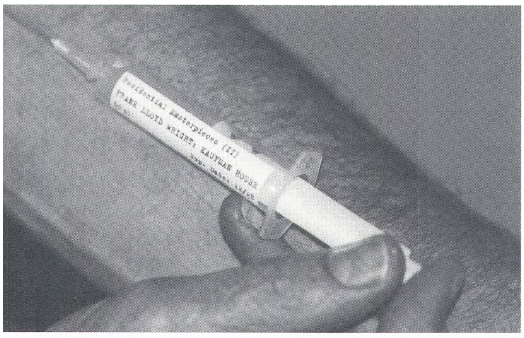
FLLW Intravenous



With trembling hands, he opened the package and loaded the syringe. Moments later, the needle found a vein in his punctured forearm, and he leaned back in the chair, exhaling. While the injected Nanobots prepared to dock at his central nervous system, he thought about the past few weeks. His life had changed. He had neglected his office, ignored most of his clients, and barely seen his family. Phaidon‘s latest ArchiChip® series had completely captured him…

His vision started to blur. It got cooler. In the twilight, the well-known silhouette appeared: slightly obscure at first, then increasingly distinct. Inhaling the fresh forest air, he listened to the murmuring of the stream below, and finally crossed the bridge towards the brightly lit Kaufman House…

The scenario described above could be categorized as science fiction. Despite appearing a trifle farfetched, though, it is a fiction based on actual progress in scientific fields that have gained tremendous momentum in recent years - particularly neuroscience and biomedical engineering. There is little doubt that an integration of electronic technology with the human nervous system will become increasingly common. Fundamentally new possibilities with regard to the perception of and interaction with remote environments are imaginable. This article will illustrate the above-mentioned progress by presenting results of two interdisciplinary research teams, and speculate on consequences for the field of architecture.

An underlying theme in the introductory hypothesis is the future development of „Real Reality“ (as opposed to „Virtual Reality“) systems. As described by Ramesh Jain, a pioneer in multimedia information technology, the interaction with remote environments is based on data, information and experience[1] - the first being the raw material for both of the latter. If data is observed facts or measurements, information is derived from data within a specific context. Experience is direct observation or participation, and its intensity can be represented as a continuum. A text provides a shared experience with its author; more engaging experiences require immersion in a richer set of data and information; and if the data changes in response to user action, then the user becomes a participant. To create those interactive and immersive environments, data must be collected using multiple perspectives and multiple sensors - so that the complete environment captures all attributes relevant to human beings: sight, hearing, touch, taste, and smell. The result leads to what Jain terms „Real Reality“: „Virtual reality systems fabricate a detailed model of an environment and render it in response to user actions. In video games, for example, the environment is modeled by the system, and the user interacts with the modeled environment as if he were really there. „Real reality“ is the next step. Real rea-

1 Dr. Ramesh Jain, *Digital Experience*, originally published in *Communications of the ACM magazine*, March 2001, see also *www.praja.com/webdocs/whitepapers/de.pdf*

lity systems will allow a user to experience and interact with real - not modeled - environments, using all human senses.“[2]

Such complex data sets of catalogued environments could be accessed through a variety of interfaces. Increasing portability of computing power is leading from the stationary PC to wearable computers - small devices worn on the body, providing constant access to computing and communications resources.[3] A merging of microscopic machines with the biological body - a direct neuron-computer interface - can be seen as the logical next step. Since human neural systems respond to and produce electrical signals, implanted microelectrodes can affect the body in a variety of ways by stimulating specific nerves or muscles. Examples are familiar devices like cardiac pacemakers as well as more recent developments like the cochlear prosthesis, a set of electrodes that is implanted in the inner ear.[4]

According to computer scientist Ray Kurzweil, natural and man-made neural systems will collaborate so smoothly in the future that by 2030, humans will customarily increase their brain capacity with nanobots - microscopic robots that are able to move to millions of different positions in the brain. Ultimately we „will get to a point where it is not important anymore if our thinking and personality are part of our biological body or not.“[5] Scientific evidence for this prediction might be scarce, but practitioners like Dr. Hajo Funke, neurologist and head physician in Hamburg, acknowledge that „Kurzweil‘s vision is based on two indisputable facts: rapidly decreasing computer size and rapidly expanding insight into the codes of the central brain systems.“[6]

The evolution of computing power thus far is described quite accurately by Moore‘s law, which states that computing speeds and densities double every 18 months - in other words, every 18 months computers become twice as fast and have twice as much memory for the same cost. Having first been observed in the mid 1960s by Dr. Gordon Moore, who became Intel‘s CEO in 1975, this phenomenon has held true for at least five decades. And despite the fact that conventional, silicon-based microchips are expected to reach their physical limits within the next ten to fifteen years, emerging new technologies will ensure further progress in the semiconductor industry. Particularly nanotechnology - a technology based on the manipulation of individual atoms and molecules to build structures to complex, atomic specifications - is viewed by many researchers as the next major leap in this direction.[7] One of the first breakthroughs in nanotechnology was accomplished by IBM scientists who in 1989 assembled 35 xenon atoms to spell out their employer‘s name. Currently, research focuses on nanotubes, carbon cylinders measuring five to ten atoms in width (1/10000th of a human hair) which are regarded as the most promising replacement material for silicon in advanced chip production. Hence even if

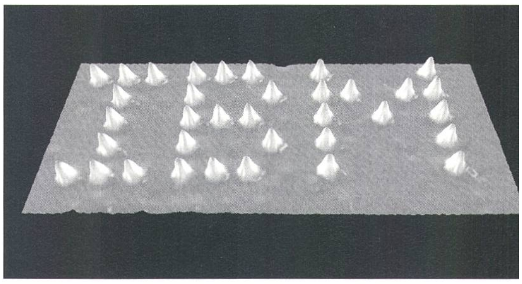


fig 2: Nanotechnology: 35 xenon atoms assembled by IBM engineers in 1989.

2 Ibid.
3 M. Billinghurst et al., *An Evaluation Of Wearable Information Spaces*, IEEE Virtual Reality International Symposium, Los Alamitos, 1998.
4 For various examples see J. Patrick Reilly, *Applied Bioelectricity - From Electrical Stimulation to Electropathology*, Springer Verlag, New York, 1998.
5 Ray Kurzweil, computer scientist and inventor, has published numerous books, articles, and interviews, many of which can be found at *www.kurzweilAI.net*. This quote is taken from: Reverse Engineering a Proven Design: The Brain, in: *The Age of Spiritual Machines*, Viking Press, 1999.
6 Interview with the author, Berlin, August 2001.
7 A summary is given by John Spooner, *Nanotechnology Breakthrough Forwards the Chip Revolution*, ZDNet News 2001 (www.zdnet.co.uk/news).

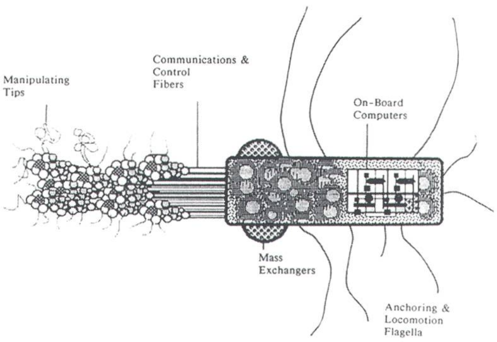


fig 3: Nanotechnology: Design for a cell repair machine

nanoscale robots or machines are not in production yet, the continuing applicability of Moore's law is very likely.

The second basis of Kurzweil's assumptions is the discovery of novel methods to analyse the human brain. In order to precisely interact with this complex organ, a detailed map is needed of its internal structure. The interneuronal patterns of the nervous system have to be discovered - a neuron being an individual nerve cell (a processing element) wired to thousands of other neurons via synapses (weighted connections). One strategy for analysis is a layer-by-layer examination of a recently deceased brain using two-dimensional scanning equipment. But although a dead brain will reveal a lot about living brains, it is clearly not the ideal laboratory - the „deadness" is bound to reflect itself in a deterioration of its neural structure[8]. Therefore, emerging noninvasive means of scanning - without disturbing the living tissue - seem more promising. Magnetic resonance imaging (MRI), for example, produces increasingly detailed representations without the use of radiation found in x-ray and CT scanning. It utilizes a physics phenomenon discovered in the 1930s called nuclear magnetic resonance in which magnetic fields and radio waves, both harmless, cause atoms to give off tiny radio signals. A related technology called optical imaging, developed at Israel's Weizmann Institute, even enables scientists to view the firing of individual neurons. First results hint at a remarkable regularity: researchers who investigated the patterns of neural activity when the brain was engaged in processing visual information commented that „our maps of the working brain are so orderly they resemble the street map of Manhattan rather than, say, of a medieval European town."[9]

Two examples of prominent research teams will illustrate how the abovementioned technologies could be implemented. Both of these interdisciplinary projects are targeted at specific problems: a team in Boston is developing a prototype of a „bionic eye" to help patients with specific forms of blindness, while a group in Los Angeles works on „replacement parts for the brain" to restore the function of damaged brain regions. Ultimately, the solutions developed by these specialized groups will have a much broader application. General problems of integrating electronic technology with the human nervous system - a coexistence that remains highly unnatural - will be resolved, and design constraints for implants determined. As soon as those systems aimed at treating specific diseases or disorders will be functioning and commonplace, the concept of „wiring" healthy bodies to expand its capabilities will become quite tempting.

8 see Note 5.
9 Hübener, Shoham, Grinvald, Bonhoeffer, *Spatial Relationships among Three Columnar Systems in Cat Area 17*, Journal of Neuroscience, 1997.

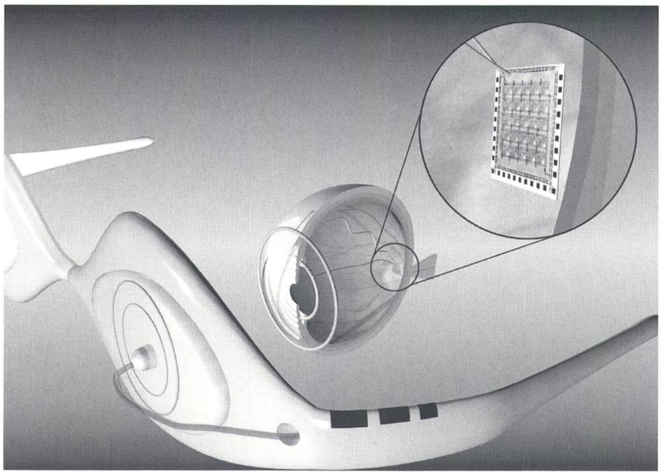


fig 4: Implantable neuro-simulator device for a retinal prosthesis, developed at John Hopkins University.

The bionic eye

Light (=visual information) enters the human eye through cornea and intraocular lens before it is received by the retina, a multi-layer system containing several different cell types. Photoreceptors in the outer retina process the incoming information and transfer it by stimulating ganglion cells, the output cells of the eye. Extensions of these ganglion cells merge to form the optical nerve, through which the information is transmitted to the brain. Certain diseases render this system dysfunctional, ultimately resulting in complete loss of vision. Some of those are characterized by a degeneration of the photoreceptors, while the output cells remain relatively intact - a phenomenon that has led researchers to experiment with implants that electrically stimulate those output cells and use the intact optic nerve to transmit recorded visual information to the brain. Optional strategies to restore at least limited vision for blind patients include the direct stimulation of the visual cortex - the part of the brain that is responsible for perception - but those projects have not progressed as far yet.[10]

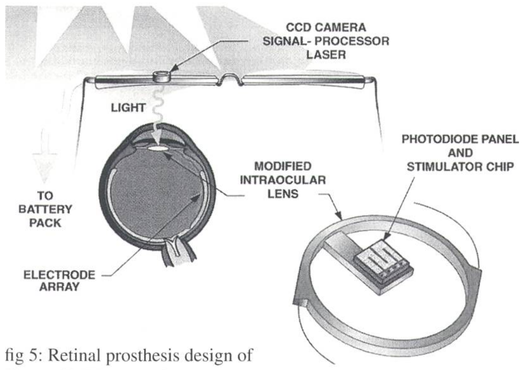


fig 5: Retinal prosthesis design of Harvard/MIT research group.

Several research teams around the world are currently working on retinal prostheses, each of them pursuing a slightly different path. The design presented here is a collaboration of Harvard- and MIT scientists headed by John Wyatt and Joseph Rizzo.[11] They propose to insert a thin, flexible array of electrodes at the inside of the retina, a delicate implant that needs to be fed with visual data and electrical power. To provide the latter, intraocular batteries were considered, but they proved to be still too large, heavy, and short-lived. Instead, energy and information are both beamed in from outside the eye with an optical device: a small, near infrared laser allowing simultaneous transmission of electric power and visual data through a single channel. The laser receives data from a microchip connected to a miniaturized camera and transmits a beam through the pupil to a tiny photodiode panel mounted inside the eye. The intensity of the laser is modulated by the obtained visual data. A stimulator chip in the eye decodes the data and uses it to control the strength, location and timing of the electric stimulation delivered to the retina.

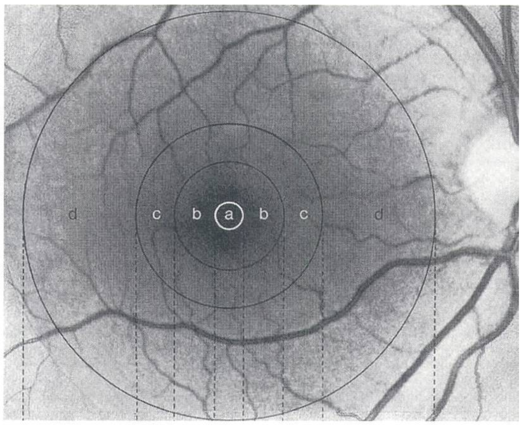


fig 6: Photograph of the human retina.

A significant advantage of this layout is its inherent flexibility. Since the algorithms that encode a visual scene as a set of electric impulses reside entirely in the external electronics, they can be modified and optimized. This is important because it is not yet clear what method for translating an image to a stimulus pattern (i.e., what pulse magnitude, duration, polarity, timing, and location) will provide the best vision for a given subject. What has been proven through animal testing is that an „implant can be placed (…) with no decline in visual function".[12] Consequently, it is also conceivable to insert it into a healthy human eye and feed it with various types of visual information that don't necessarily relate to the immediate surroundings.

10 Rizzo and Wyatt, *Prospects for a Visual Prosthesis*, Neuroscientist 3:251-262, 1997.
11 Rizzo, Loewenstein, Wyatt, *Development of an Epiretinal Electronic Visual Prosthesis: The Harvard-Medical Massachusetts Institute of Technology Research Program*, in: *Retinal Degenerative Diseases*, Kluwer Academic/Plenum Publishers, 1999.
12 Humayun, de Juan, et al., *An Implantable Neuro-Stimulator Device for a Retinal Prosthesis*, International Solid-State Circuits Conference, 1999.

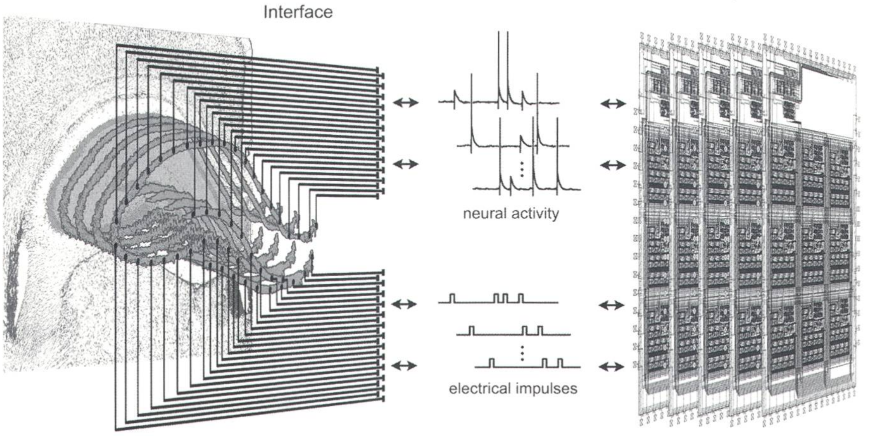


fig 7: Brain prosthesis,
a neuromorphic interface connects the
intact neural tissue to the chip module.

Replacement parts for the brain

In Los Angeles, Ted Berger and his team at USC work on developing „brain-implantable biomimetic electronics“: prosthetics for the central nervous system to restore the function of damaged brain regions.[13] While Berger acknowledges that the achievement of such a goal - repair of the human brain - is many years in the future, he proposes that the „path to an implantable prosthetic is now definable“.[14] Such microchip replacement parts would offer a remedy for the cognitive and memory loss related to Alzheimer‘s disease as well as speech and language deficits resulting from stroke. The design approach presented here is based on the replacement of damaged neurons in central areas of the brain with silicon neurons that are permanently implanted into the damaged region. This prosthesis both receives as inputs and sends as outputs electrical activity to parts of the brain with which the impaired region previously communicated. Thus, the computational function of damaged brain is replaced, and the transmission of that result to other regions of the nervous system restored.

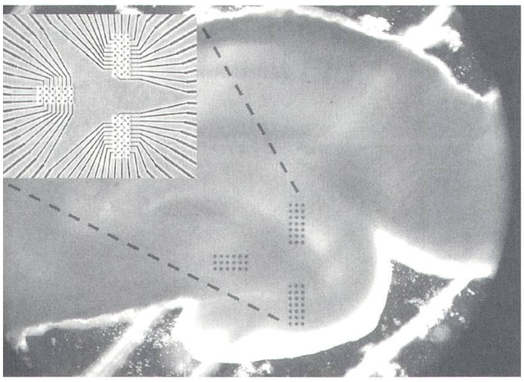


fig 8: An electrode array designed for stimulation and recording of neural activity is placed over a corresponding slice of the hippocampus.

Berger identifies six essential requirements for such type of device:[15] First, a microchip replacing a given brain tissue must be truly biomimetic. Its incorporated neuron models need to have the properties of real biological neurons in order to „imitate“ the impaired brain region adequately. Second, the replacement neurons must be capable of being concatenated into network models simulating complex physiological/cognitive functions. The artifical population of neurons has to interact convincingly in the context of larger networks of interconnections. Third, the prosthesis must be miniaturized sufficiently to be implantable, which demands an implementation of the neural network models in at least microchip circuitry. Given the known signaling characteristics of neurons, such an implementation will „most likely involve hybrid analog/digital device designs“.[16] Fourth, the resulting microchip or multichip module must communicate with existing, living neural tissue in a bidirectional manner. Given that both electronic and biological neural systems generate and respond to electrical signals, this is feasible. Fifth, any brain prosthesis will have to adapt to the individual patient due to the variability in structural and functional characteristics of the brain. And finally, power supply is a critical issue given the implantation into the depths of the brain (versus the periphery as with a retinal implant). Since cellular and molecular mechanisms found in the brain are highly temperature sensitive, any solution must minimize heat generation to remain biocompatible.

As shown in the illustration, the proposed implant consists of two major components: a neurocomputational chip module (the processing unit) and a neuron-silicon interface (the electrode connection to the biological brain). The latter

13 Prominent Researchers in this field were brought together for a conference: *Toward Replacement Parts for the Brain - Intracranial Implantation of Hardware Models of Neural Circuitry*, held in Washington D.C., August 1999.
14 Theodore Berger et al., *Brain-Implantable Biomimetic Electronics as the Next Era in Neural Prosthetics*, Proceedings of the IEEE, Vol. 89, July 2001.
15 Ibid.
16 Ibid.

is particularly interesting with regard to the the general issue of electronically stimulating the human brain. Its major design concern is the density of interconnections: virtually all brain functions are mediated to a degree by a mass action of neural elements - changing the activity of one neuron in a system is unlikely to have any substantial influence on the system function. Therefore, the interface must be designed so that a large number of neurons are affected. If further developed, this device will have wide-spread application.

The current research in the fields of neuroscience and biomedical engineering will lead to a variety of new developments and - ultimately - products. It was presented here in the context of systems that one day might permit the experience of remote environments in a highly engaging manner with all primary senses. Other devices could allow us to manipulate the perception of the built environment according to individual preferences. Thus architecture would become a flexible framework or screen, the specific characteristics of which are projected directly onto the user's retina. In a more general context, the article proposes a technological vision based on expanding human capabilities by integrating computing power into the personal space of the user. As such, it can be read as an alternative to tendencies of decentralizing intelligence away from individual human beings into various types of „smart" devices. As soon as neurocomputational, „brain-like" microchips are reasonably developed, humans will have options of delegating decisions to machines, increasing their own capabilities through technology - or refraining from both. The prospects are mind-bending.

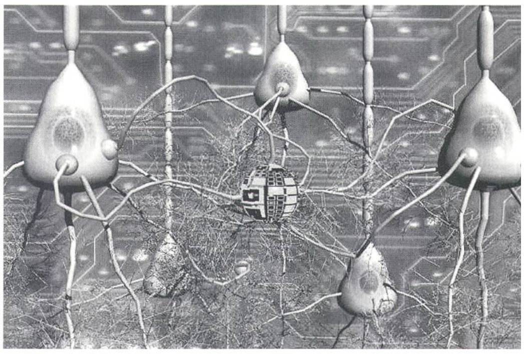
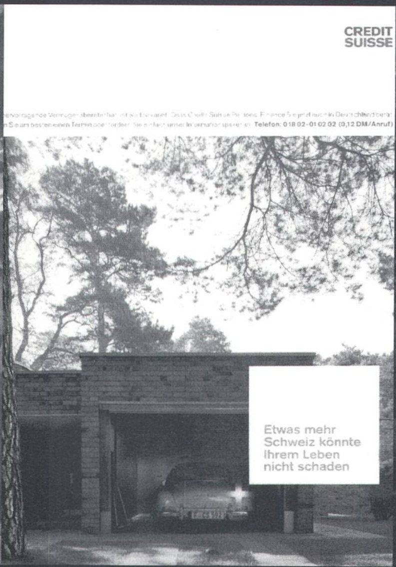


fig 10: Design for a Brain Cell Enhancer, nanorobot docking at the central nervous system

The author is indebted to Walid Soussou (Department of Neuroscience at USC, Los Angeles) and Dr. Hans Joachim Funke (Ev. Krankenhaus Alsterdorf, Hamburg) for advice and inspiration.

Jan H. Ipach arbeitet als Architekt in Berlin und Los Angeles.


„Das machen wir doch schon."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nicht schaden


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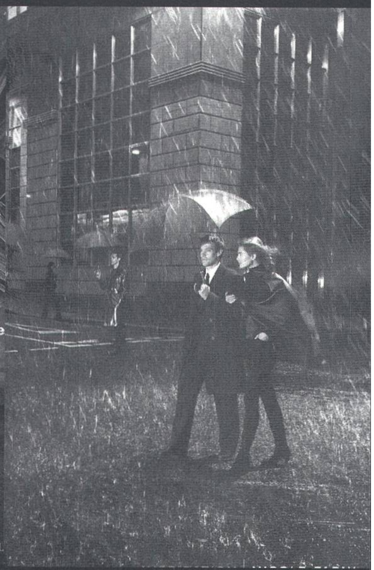

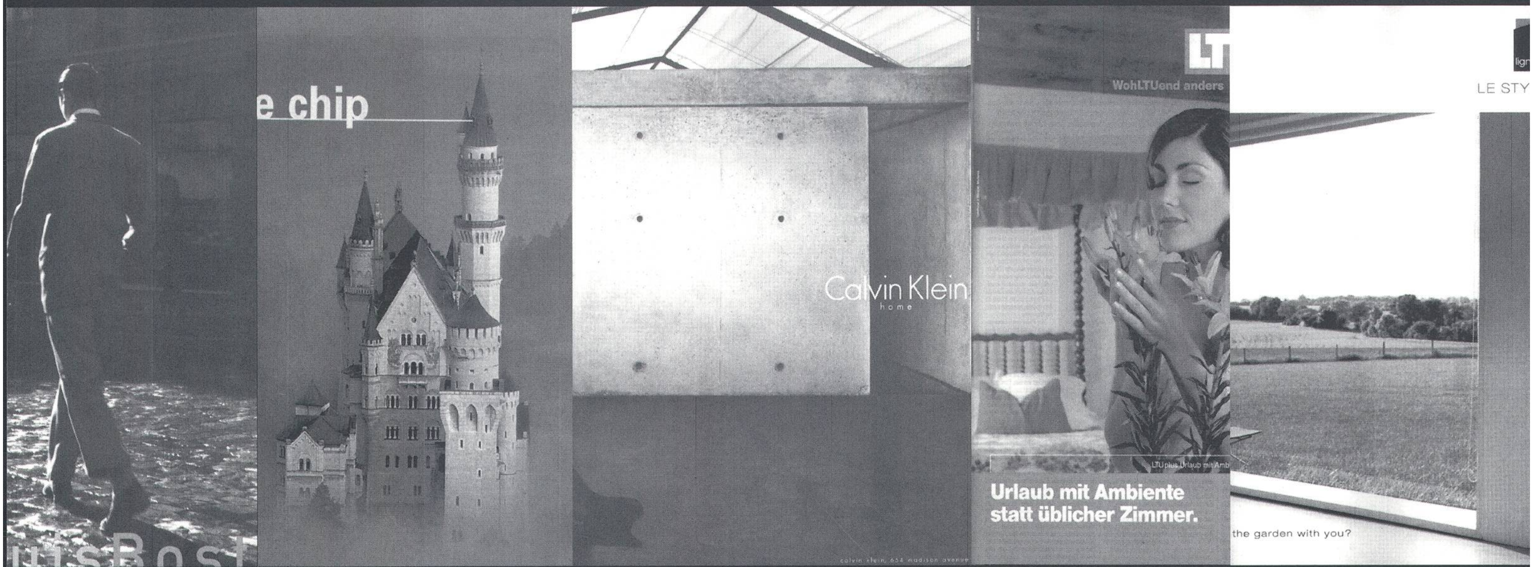
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