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Nano-Scape: Experiencing Aspects of Nanotechnology through a Magnetic Force-Feedback Interface

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ABSTRACT
In this paper we describe an interactive system called "Nano-Scape" which we developed in 2001 for the public exhibition „Science + Fiction" at the Sprengelmuseum in Hannover. The project was supported by the Volkswagenstiftung Germany and has been on tour through Europe and Asia. The aim of "Nano-Scape" is to let visitors intuitively experience aspects of nanotechnology by interacting with invisible self-organizing atoms through a magnetic force feedback interface.

Categories and Subject Descriptors
B.4.3 [**Input/Output and data communications**]: Interconnections (Subsystems) – *Interfaces*

General Terms
Design, Experimentation, Human Factors.

Keyword
Art and Media, Interfaces, Novel Hardware Devices, User Interaction, Edutainment, Interactive Art, Nanotechnologies

1. BACKGROUND
The goal of the „Science + Fiction" [1] exhibition was to bring together artists and scientists to reflect on some of the burning social issues such as „Identity in a Global Culture," „Brain Research" and „Nanotechnologies" and to analyze their perception in the sciences and in popular culture.

Our task as media artists was to bring the theme of „Nanotechnologies" closer to the public awareness. We decided to do this by producing an intuitive experience where users can interact with invisible self-organizing atoms using a magnetic force feedback interface. Before describing the system in detail, let us briefly summarize three research areas that influenced our system design.

1.1 Nanotechnology and its Applications
A nanometer (nm) is a billionth of a meter and nanotechnologies work at the molecular level, atom by atom, to create large structures with fundamentally new molecular organization. Nanotechnology is concerned with materials and systems whose structures and components exhibit novel and significantly improved physical, chemical, and biological properties, phenomena, and processes due to their nanoscale size. The goal of the nanosciences is to exploit these properties by gaining control of structures and devices at atomic, molecular, and supramolecular levels and to learn to efficiently manufacture and use these devices. [2, 3] New applications in the nanotechnologies include engineering, information technologies, medicine, biology, chemistry and industries and in the area of media art and edutainment, artists and designers have started to look at nanotechnologies and their creative potential as well. [4, 5]

1.2 Haptic User Interaction
A second area of research that influenced our system design is Human Computer Interaction and in particular haptic interfaces. Haptic user interfaces often rely on force-feedback systems to create a strong sense of reality and immersion when users interact with virtual objects in VR or MR spaces. Some vibrotactile displays use full-body suits [6, 7] to create haptic stimulation of the whole body when users interact with graphical or auditory information, while other systems rely on partially placed tactors to stimulate certain regions of the body [8, 9].

A system similar to the one we aimed to create is called "Proactive Desk" designed by Noma at al. [10]. The "Proactive Desk" allows users to handle real objects on an interactive desk that is linked to a camera tracking system, a linear induction motor under the table and projected images on the table. When users touch and manipulate some of the objects on the "Proactive Desk", these objects react back by vibrating, or by pushing backwards.

1.3 Self-Organization and Complex Systems
The third area of research that influenced our design is Self-organization in Complex Systems. The operational model of the complexity paradigm is a complex adaptive system (CAS). Complex adaptive systems (CAS) consist of many interacting and adapting components. Although there is no exact definition of what a Complex System is, there is now an understanding that when a set of evolving autonomous particles or agents interact, the resulting global system displays emergent collective properties, evolution, and critical behavior that exhibits universal characteristics. Such a system is fundamentally novel and not deducible into its mere parts. [11, 12] These agents or particles may be complex molecules, cells, living organisms, animal groups, human societies, industrial firms, competing technologies, etc. All of them are aggregates of matter, energy, and information that display the following characteristics. They: couple to each other, learn, adapt and organize, mutate and evolve, expand their diversity, react to their neighbors and to external control, explore their

options, replicate and organize a hierarchy of higher-order structures.

Self-organization is also one of the driving forces in the study of evolutionary nanotechnologies [13, 14], where researchers study how atoms or molecules can self-assemble to create new structures with new properties that go beyond the mere accumulation of their single entities ("the whole is more than the sum of its parts").

2. NANO-SCAPE: an interactive magnetic nano sculpture

For our "Nano-Scape" system we aimed to combine the three above sketched research areas: nanotechnologies, haptic user interaction, and self-organizing systems. Our goal was not so much to show pure data or facts, but to intuitively let users experience aspects of nanotechnology through a haptic user interface and to show how intricate and complex interactions on a nano-scale level can be.

2.1 System Set-Up

"Nano-Scape" combines a electromagnetic force-feedback interface with a camera-based hand-tracking system and an atomic force simulation. Users of this system can interactively feel invisible magnetic forces of simulated atoms that seem to "float" above a large glass tables surface. Figure 1 shows three users as they interact with these invisible atoms. The atoms' interaction forces can be felt by the users who wear special magnetic ring interfaces while they move their hands above the glass tables surface.

Figure 1 shows three users as they interact with the "Nano-Scape" system.

2.2 Magnetic Force-Feedback Interface

The electromagnetic feedback is produced by electromagnets integrated in each of the 4 tables. Each table hosts 4 coils that produce a magnetic field of up to 6000 Gauss. The strength of the magnetic field varies depending on the user's hand position and our atomic force simulation. Figure 2 shows the 4 tables containing the electromagnets, that consist of 4 coils each. Users wear a set of magnetic rings with integrated permanent magnets of around 2000 Gauss strength. When users move their hands in a distance of 5-15 cm above the table's surface, their hand positions are captured by infrared cameras installed in a distance of 2 meters above each table's surface.

The tracking of the user's hand position is done through white markers attached to each magnetic ring and our in-house camera tracking software. Figure 3 shows a user's hand with the magnetic ring interface and the 2 markers.

Figure 2 shows the electro magnets in each table.

Figure 3 shows a magnetic ring interface worn by the user.

When as user moves her hand above the table's surface, the camera tracks the exact position of the magnetic ring and sends this information to an atomic-force simulation. This simulation calculates the attraction and repulsion forces between simulated atoms.

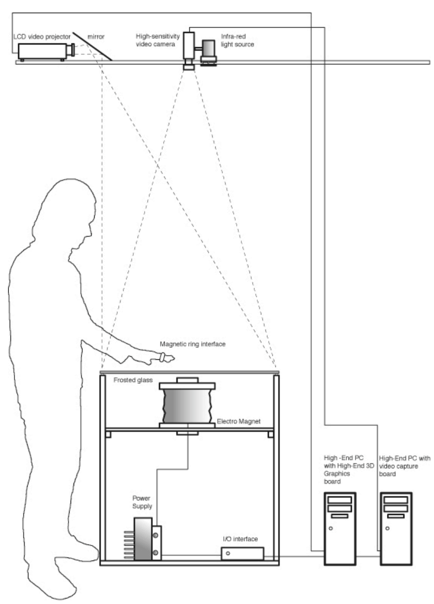

Figure 4 shows the "Nano-Scape" system diagram.

The correlation between electromagnets, camera tracking and the magnetic ring interface is shown in the system diagram in Figure 4. The system also includes an I/O interface and the two PCs which run the hand tracking software and the atomic force simulation.

2.3 Atomic Force Simulation

Our atomic force simulation is based on a group of around 120 simulated atoms that constantly react to each other depending on the forces that reign between them. We loosely modeled the system on atoms with no valence electrons, based on Kaxira's description [15]. He describes „atoms with all their electronic shells completely filled, which in gaseous form are very inert chemically, i.e. the noble elements Ha, Ne, Ar, Kr and Xe. When these atoms are brought together to form solids they interact very weakly. Their outer electrons are not disturbed much since they are essentially core electrons, and the weak interaction is the result of slight polarization of the electronic wave function in one atom due to the presence of other atoms around it. Fortunately, the interaction is attractive. This interaction is referred to as „fluctuating dipole" or van der Waals interaction. Since the interaction is weak, the solids are not very stable and they have very low melting temperatures, well below room temperature. The main concern of the atoms in forming such solids is to have as many neighbors as possible, in order to maximize the cohesion since all interactions are attractive. The crystal structure that corresponds to this atomic arrangement is one of the close-packing geometries, that is, arrangements which allow the closest packing of hard spheres. The particular crystal structure that noble-element atoms assume in solid state form is called face-centered cubic (FCC). Each atom has 12 equidistant nearest neighbors in this structure, which is shown in Fig.1.2 [15]," here shown in Figure 5.

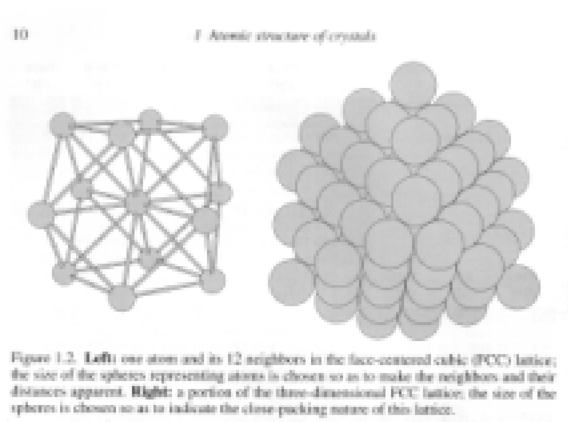

Figure 5 shows a face-centered cubic (FCC).

Since our system needed to be interactive and calculating forces of 12 neighbors for each atom would have been too computationally intensive, we decided to create a simplified 2-D simulation of these van der Waals forces.

We modeled a set of 100 atoms, where the forces between them are based on the criteria to „have as many neighbors as possible, in order to maximize the cohesion since all interactions are attractive" as described by Kaxira. The resulting image of this simulation, where all atoms are at equilibrium state in terms of attractive and repulsive forces towards their neighbors. A snapshot of our simulated atoms in almost equilibrium state is shown in Figure 6.

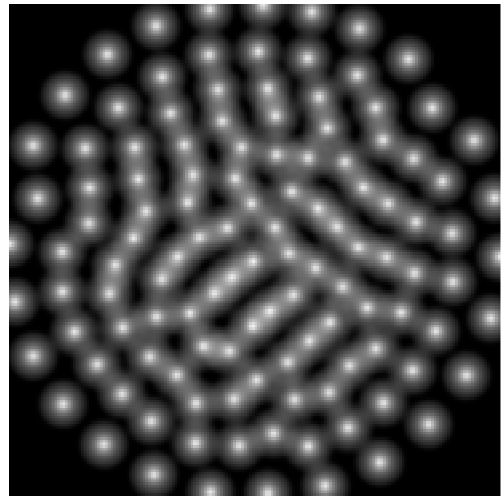

Figure 6 shows our simulated atoms as they negotiate maximum cohesion between them.

2.4 Magnetic Force-Feedback Interaction with Atomic Force Simulation

Once the system is disturbed by the user's hand movement, the system will take the actual position of the user's magnetic ring into account and recalculate the forces between the neighboring atoms. Since all 120 atoms are linked to each other, each smallest disturbance will lead to a re-arranging of forces between all the atoms while they try to go back into the equilibrium state. Figure 7 shows a snapshot of the simulation after a user has interacted with the system. The red spot indicates the position of the users hand, and the white spots are simulated atoms as they struggle to re-arrange themselves, forming occasional clusters or empty spaces.

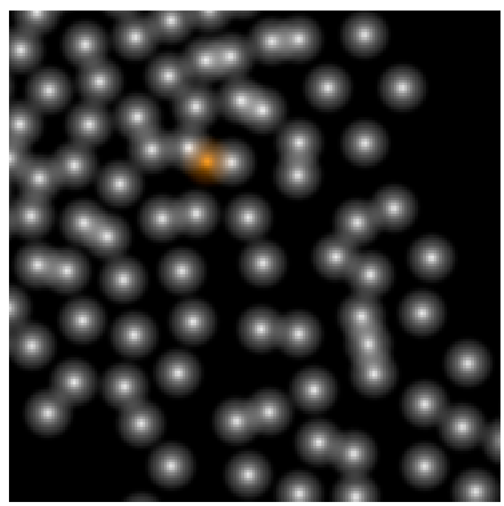

Figure 7 shows the atomic force simulation with one user.

A user can feel the effect of her interaction onto these simulated atoms through the magnetic force feedback interface. This feedback is achieved by connecting the actual forces received by the red atom from its neighboring atoms, to the strength of the electromagnetic field produced between the electromagnet and the permanent magnetic ring interface. In other words, our simulation calculates the given strength of the forces that occur onto the red atom and sends these data back to the electromagnet which produces a corresponding electromagnetic field that can be picked up and felt by the user through his magnetic ring interface.

When the user for examples moves her hand very strongly over the table's surface and thus strongly disturbs the invisible atoms, the electromagnetic feedback forces onto the user's ring will also become very strong, sometimes to the point where the magnetic ring will start to vibrate. On the other hand, when the system is almost at equilibrium, the forces felt by the user are smaller as well.. However each interaction disturbs the system, so the user will never be able to experience the system in full equilibrium.

2.5 Multiple User Interaction

"Nano-Scape" is designed for multi-user interaction and four users can simultaneously interact with the atomic force simulation. The simulation is actually the same for all four tables, so when all four users interact, their ring positions will become visible as four red spots in the same simulation. Since each slightest interaction will bring the atomic simulation out of balance, the self-organization of the atoms can become very complex, and sometimes almost chaotic when all four users interact. A snapshot of such a situation is shown in Figure 8.

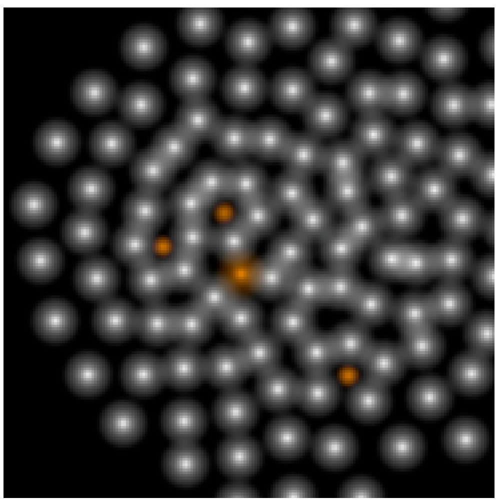

Figure 8 shows how four users interacted simultaneously.

The users of the system do not see the atomic force simulation since it is displayed on a monitor outside of the installation space.. This was a conscious decision, firstly because the nano-world is usually not visible and secondly, because as displaying visual information would have distracted the users from feeling the atomic forces. Gault describes touch as a very strong "break-in" sense: coetaneous sensations, especially if aroused in unusual patterns [16] and we also found in one of our previous haptic interfaces that visual or auditory information can impair the haptic experience. [17]

3. CONCLUSION

We have developed an intuitive interactive installation which was able to raise public awareness of nanotechnologies by showing how complex and intricate interactions of atoms are on a nano-scale level. We combined several areas of research, including nanotechnologies, haptic user interaction, and self-organizing systems. In the future we aim to further explore how the nanosciences in general can inspire new forms of artistic expressions by designing the "strange futures, holding worlds beyond our imagining", that Drexler describes [18].

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