Flockwall: A Full-Scale Spatial Environment with Discrete Collaborative Modules

Michael Fox
Cal Poly Pomona

HARDWARE

ABSTRACT
The paper highlights a built example of a human-scale spatial environment composed of discrete collaborative modules. The primary goals were to develop and understand strategies that can be applied to interactive architecture. The design and construction were carried out in an academic context that was displayed to a public audience of approximately 200,000 people over the course of three days. In addressing the performance parameters of the prototype, the concept focused on several key strategies: 1) geometry 2) movement 3) connections 4) scale and 5) computational control, and human interaction. The final objective of the approach was to create an innovative design that was a minimally functional spatial environment with the capability for evolving additional multi-functionality. Heavy emphasis was placed on creating a full-scale environment that a person could walk through, interact with, and experience spatially.

1 INTRODUCTION
Although today, we are surrounded by smart and networked architectural devices and appliances, they are not considered from and architectural point of view in terms how and when they are used and how they work together. Interactive architecture in general is built on the convergence of embedded computation (intelligence) and a physical counterpart (kinetics) that satisfies adaptation within the contextual framework of human and environmental interaction. The combination of these two areas will allow an environment to have the ability to reconfigure itself and automate physical change to respond, react, adapt, and be interactive. The inherent sensing, processing, and output are now beginning to be taken out of the computer and are instead, embedded in the objects of everyday life themselves. The individual devices therefore have a remarkable ability to communicate with each other even while being specifically task oriented. Decentralization then is a powerful control strategy for such systems of individually networked devices (in this case) whereby there is no central control system, and consequentially, the more the system relies on lateral relationships, the less it can rely on overall commands. When such a structure is applied to a large system, there is a potential for emergent behavior. An emergent behavior can occur when a number of simple systems operate in an environment that forms more complex behaviors as a collective.

2 THE FUTURE OF ROBOTICS IN ARCHITECTURE
We must change our preconceptions of interactive architecture to understand the potential role of robotics in architecture with respect to decentralized control. To illustrate, we will use the example of a smart kitchen with an “intelligent” mechanical counter top which can raise and lower itself when needed and a smart cabinet above which can assist you in retrieving food items as desired. Both the countertop and the cabinet understand the actions of each other and while only one may deduce a response based on environmental sensing, the other may operate accordingly based on the actions of the other device. For example, as the countertop senses the height of an individual it may lower itself to accommodate a specific food preparation need, and the cabinet will use the information of the countertops’ action and lower itself and organize the food items accordingly to a learned pattern of behavior of what the person typically eats at a specific time of day.

The above scenario, while perhaps not commonplace, is very realistic and achievable by today’s technological means. We will expand the scenario further now by imagining that both the countertop and the cabinetry are not mechanically driven “devices” but are rather composed of thousands of smaller mechanical modules (the size of dice) which make up the devices themselves. The distributed sensing and control would now happen not at the level of the countertop and the cabinetry but at the level of each of the tiny modules. The geometrical flexibility, sensing capabilities and robustness of each of the larger "devices" would then be greatly enhanced.

Let us then extend the example above whereby the countertop and the cabinet are not composed of small modules but are composed of bionanotechnological materials which can morph their shapes to adapt at a very high degree of resolution. The materials are not veneers to traditional devices but are the fabric of the devices themselves with sensing and control operating biomimetically at a very small scale. At this level the countertop and cabinet can control additional attributes such as temperature, texture, color, opacity, etc. These new interactive assembly systems will bring new unprecedented levels of customization and reconfigurability to the architectural palette. Such an extrapolation of advancements in both robotics and new materials demonstrates an architectural future whereby adaptation becomes much more holistic and operates on a very small internal scale (Fox 2009).

3 THE CHANGING FACE OF ROBOTICS

Designers are moving away from traditional uses of automated mechanical devices in architecture to systems that are made up of a number of small robots. For many applications ranging from cleaning carpets and windows to adjustable furniture, we are seeing a distancing from the precedent of figural humanoid robots to transformable discrete systems. Most architectural applications are neither self-organizing nor do they have higher level intelligence functions of heuristic and symbolic decision-making abilities. Most applications or "devices" in architecture do however exhibit a behavior based on low-level intelligence functions of automatic response and communication.

We propose that new interactive assembly systems will bring new unprecedented levels of customization and reconfigurability to the architectural palette. It is then an architectural question as to how these pieces should come together and how these configurations will respond to the constant flow of information between inhabitants and space; to re-envision the creation of dynamic space.

When a large architectural space is responding to a single element, then a centralized system can be effective in executing a command to a single agent, but when there are many unknown stimuli such as groups of individuals behaving in unknown ways and an exterior environment which is constantly changing, then decentralized intelligence can be a very effective way to handle the sensing and response (perception and action). The beauty of this when applied to a large system is the emergent behavior. Although there may be no centralized control structure dictating how individual parts of a system should behave, local interactions between individual modules can lead to the emergence of global behavior. There are many biological reasons for swarm behavior related to efficiency in foraging, hydrodynamics and aerodynamics, protection and reproduction, among others. An emergent behavior can occur when a number of simple systems operate in an environment that forms more complex behaviors as a collective. The rules of response can be very simple and the rules for interaction between each system can be very simple but the combination can produce interactions that become emergent and very difficult to predict. The more decentralized a system is, the more it relies on lateral relationships, and the less it can rely on overall commands.

Since it will be possible to build space out of parts that have the ability to reconfigure themselves, it will be up to architects and designers to design how these pieces will come together and how these configurations will respond to the constant flow of information between inhabitant and space. As architects and designers begin to adopt the technology of modular reconfigurable robotic systems, they will begin to re-envision the creation of dynamic space. Architects in the future may design an architectural environment composed of a palate of autonomous reconfigurable parts. These materials come together to create a layering of responsiveness and an overall intelligence that is embedded in the structure itself; the material and texture of the space is the intelligence of the space.

In the near future, modular reconfigurable space will hugely impact the way people live in space, and the relationships between users and the space itself. Our furniture and entire spaces might someday be comprised of a multitude of interconnected assemblies of robotic modules that can reconfigure themselves for a variety of needs or desires. How such systems in our everyday buildings affect our behaviors and change our behaviors are the issues that architects will be forced to confront in the near future. Only when architects confront these scenarios of interaction and construct actual environments will they truly take an active role in the larger dialogue of where the technology is going and what it will mean to everyone.

4 FLOCKWALL: BACKGROUND AND PROBLEM DEFINITION

The challenge proposed was to work collaboratively to design and construct a full-scale environment composed of numerous discrete autonomous parts. The prototype environment was to be comprised generally of self-similar robotic modules. The goal for each module was to move autonomously with 3 degrees of freedom (X, Y and Z). The physical prototype was valuable for several reasons: 1) It serves as a vehicle for exploring strategies for decentralized control, dictating how individual parts of a collective system could behave. 2) It will serve to demonstrate the possibilities of architectural space-making with unprecedented levels of customization and adaptability. The final environment is innovative for two reasons: 1) Operating at an architectural scale that allowed for natural human interactions, and 2) introducing an additional degree of freedom from what has knowingly been constructed in the past.

Flockwall: A Full-Scale Spatial Environment with Discrete Collaborative Modules

The design and construction was carried out in an academic context that was displayed to a public audience of approximately 200,000 people over the course of three days. It is important to mention that time was a valuable commodity and the entire design process, prototyping, fabrication and construction was carried out in 10 weeks. The objectives for the course were general and aimed at developing the skills to explore, and design interactive architectural environments. They included: 1) Learning hands-on robotics for connecting circuits, sensors and motors to kinetic structures. 2) Understanding interactive principles through comprehensive precedent studies. 3) Understanding contextual situations for applications of robotic architectural solutions. 4) Learning basic mechanical and technological principles of kinetic design 5) Understanding contemporary ideologies of interactive design. 6) Understanding the potential to build robotics into systems that make up architectural space. 7) Prototyping a system that can demonstrate (as opposed to simulate) design intention.

4.1 DEFINITION OF TECHNICAL OBJECTIVES

In addressing the performance parameters of the prototype, the concept focused on several key strategies: 1) geometry, 2) movement, 3) connections, 4) scale, 5) computational control, and 6) human interaction. The overall objective of the approach was to create an innovative design that was minimally functional with the capability for evolving additional multi-functionality.

4.2 A COLLABORATIVE AND MULTI-DISCIPLINARY DESIGN PROCESS

Designing interactive architecture is not inventing, but appreciating and marshalling the technology that exists, and extrapolating it to suit an architectural vision. There are many important lessons to be learned in both distributed computation and small-scale robotics that can feed into a future paradigm of architectural space-making. Students were provided with various lectures on kinetic and mechanical design, computational control and distributed intelligence and modular robotics. These lectures served as an important foundation for architectural explorations in designing and evaluating the system strategically to facilitate dynamic situational activities and explicitly understand the potential to build them into systems that make up architectural space.

HARDWARE

4.3 GEOMETRIC EXPLORATIONS RELATIVE TO SPATIAL EXPERIENCE

Initially numerous collaborative brainstorming sessions were carried out that focused on the scale of the environment, the types of human interactions and the scale of the modules. The design process moved forward with individual design proposals on a number of issues such as the module design, the number of modules, spatial configurations, movement, etc. Specific design proposals were then voted on and winning proposals in each area were quickly developed.

Primarily the geometric explorations focused on how the modules could combine with each other to make a surface or collaborative forms and the objectives of dynamic space-making. The type of flocking behavior that was desired and could be achieved was also explored. A matrix of various geometries was explored which would satisfy the objectives of movement, connection and scale.

4.4 MODULE DESIGN

It was decided that the scale of the prototype should consist of modules which are approximately 12 inches by 12 inches primarily as a means to realize the objectives of scale from an architectural and human standpoint within a limited amount of time and money. The initial scale was also based on the size of the necessary mechanical parts that will be in each module. Conceptually, the project will feed into a biological paradigm of architectural space-making, which will most certainly involve reexamining and adjusting the scale of such modular parts.

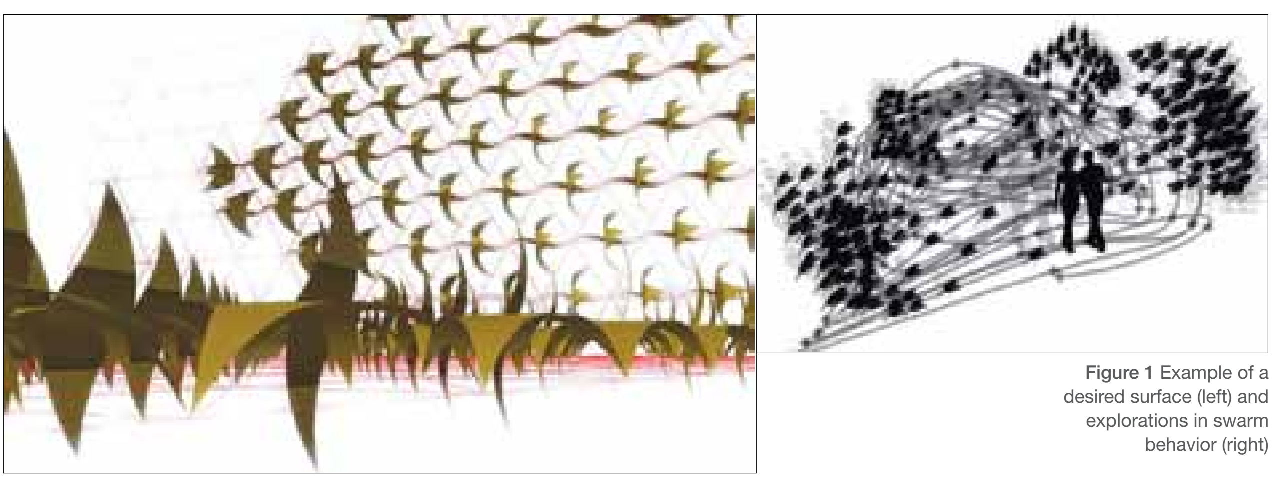

Figure 1 Example of a desired surface (left) and explorations in swarm behavior (right)

Flockwall: A Full-Scale Spatial Environment with Discrete Collaborative Modules

4.5 FLOCKWALL: SUPPORTING STRUCTURE

Once the scale and geometry of the module was developed the type of space-making possibilities necessitated an integrated approach for the structure that would support the modules. This structure also fed into the ways and means of movement that could facilitate the overall spatial objectives. The support structure was explored collaboratively and in parallel through another course with a different lead instructor. The primary objectives were in the area of digital modeling procedures of complex geometries under the use of parametric design methods and automated output in form of rapid prototyping. The entire structure was water-jet cut from aluminum and hand assembled by means of snapping the pieces together.

Figure 2 CNC milled module variations (left) and the chosen design (right)

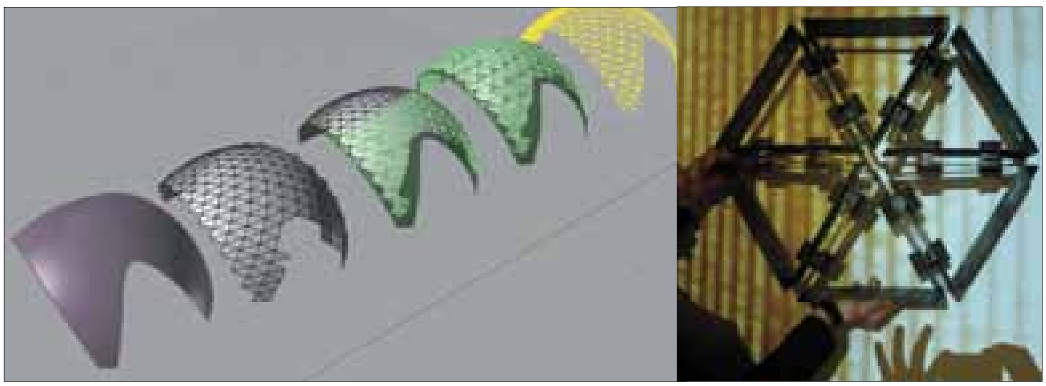

Figure 3 Variations in structure geometry (left) and full-scale prototype (right)

Figure 4 Variations in structure geometry (left) and full-scale prototype (right)

4.6 MODULE DEVELOPMENT

The design process was implemented from an architectural (as opposed to engineering) standpoint. The final module assemblies were extrapolated to simulate various architectural applications of space-making. This aspect is unique from engineering approaches to modular robotics in speculating how such an approach to adaptive space-making can be applied in realistic situations. The modules did have several real constraints that had to be considered in the development including: 1) Weight 2) Power 3) Lighting, and 4) Mechanics. It was important that each module had self-contained lighting for which 2700MA batteries were used to power three LED lights for up to 15 hours at at time. It was also important that each module could be opened quickly like a clamshell to repair mechanical problems and change batteries. With these issues in mind the module was formed out of two lightweight shells of plastic. Once a final CNC was made a negative PVC mold was created from which hundreds of the final shells could be vacuum-formed.

Figure 5 Module wiring (left) and mass-production and assembly (right)

4.7 MECHANICAL DEVELOPMENT

Each module was connected to a track made of 80 pound fishing line and a pulling line that went to a take-up reel on a servo to collect the filament. A 32 pound torque servo was used and many variations of spool sizes were explored to find a correct match of desired speed and strength. All of the servo mounts were then designed and milled from solid PVC to bolt to the supporting structure.

Figure 6 Architectural applications of space-making with modular robotics

4.8 DESIGN OF THE BASE

The base was very important in that the modules were to be fixed to the structure above but have two degrees of movement at the base. It was decided that this movement be prescribed to a certain extent by cutting "paths" in the base that the module track would follow. The base was constructed of typical wood framing with a top layer of HDPE. The "tracks" were then affixed to a 1/8" rod of polypropelene which ran in the HDPE "tracks". The tracks then moved in a straight line in one direction and were forced to move sideways in the other direction by the grooves cut into the base.

Figure 7 The full base assembled on site (left) The base with shadows of the structure.

4.9 COMPUTATIONAL CONTROL

The control was carried out by means of a custom interface written in JAVA which controlled each pair of servos (per module). The software allowed us to generate different flocking behaviors within the context of the structure and accommodated choreography of each of the 56 servo motors. The software will also allow for our future objectives of elaborating on scenarios of discrete modules creating architectural space. Initially each servo was set to limits related to the specific length of the path that it would follow. Each of the vertical and horizontal paths had differing limits. Once the limits were set we could initialize the system to have all of the flock-bots set at a zero position which was down and to the left. This enabled us to reset the system and to initiate a choreographed setting. The program would allow each flock-bot to move according to it's neighbors movement. As a system this allowed us to simulate good flocking behavior with limited sensing. The behavior then is controlled computationally but cannot therefore detect localized interference. An analogy might be a flock of birds navigating around a pole; although the first bird could avoid the pole the entire flock might not clear the obstacle. The system is set up for us to experiment further with a second level of control whereby each flock-bot has sensing capability and can therefore have more localized control.

Figure 8 Wiring on site (left) Nighttime wiring on site of 56 modules

Flockwall: A Full-Scale Spatial Environment with Discrete Collaborative Modules

4.10 INSTALLATION

The installation was completed in two days with the exhibit running for three days. It was displayed to a public audience of approximately 200,000 people over the course of three days. Almost all of the visitors walked through the exhibit and stood in the center for a period of time to understand the behavior. While it was not clear what the flock-bots were responding to it was clear that they were moving with intent when a visitor passed through the environment. The initial goal of flock-bots clustering around an individual was not as clear as we had intended due to the speed of the bots (which was limited because of motor torque) and also because of the unanticipated massive crowds of people who visited the exhibit. Most of the time there was a steady line of people walking through the environment and the experience was rushed to the extent that the bots never completed a motion before a new instruction was given to them. This caused the flock-bots to hover around the center. In the end we initiated a choreographed behavior demonstrating a full range of movement that was much more successful experientially but was not true to our design intents because it was disconnected from individual users passing through the space.

Figure 9 View of the final exhibit at night

Figure 10 Two views of the final exhibit at night

CONCLUSION

In conclusion, we were successful in obtaining all of the general and technical objectives of this project. The dynamic environment was a terrific and has the potential to be easily be developed further in terms of space-making scenarios. Such real-world prototypes that must withstand extremely robust conditions are very important in the development of interactive architecture from a standpoint of real human interactions. In terms of future development, the possibilities of this environment are limited by two important concerns. The first is that a supporting structure was needed at all. A clear vision of such an environment would not need such a structure or the three-dimensional "paths" that we provided for the modules. The second issue is that of scale. The future of interactive architecture will most certainly involve re-examining and adjusting the scale of individual modules. As physical robotic parts scale down, it will become increasingly possible for future systems to be built out of nanotechnological, and bionanotechnological means. Such new interactive assembly systems will bring new unprecedented levels of customization and reconfigurability.

HARDWARE

Flockwall: A Full-Scale Spatial Environment with Discrete Collaborative Modules

ACKNOWLEDGMENTS

THIS PROJECT WAS MADE POSSIBLE BY THE GENEROUS SUPPORT OF THE FOLLOWING GRANTS:
RESEARCH, SCHOLARSHIP AND CREATIVE ACTIVITIES (RSCA) GRANT
COACHELLA VALLEY MUSIC AND ARTS FESTIVAL EXHIBIT GRANT
PRESIDENTIAL TRAVEL GRANT (CAL POLY POMONA)
MINI GRANT FOR PROFESSIONAL DEVELOPMENT (CAL POLY POMONA)
I WOULD LIKE TO THANK THE EXPERT CONSULTANTS ON THE MODULAR ROBOTICS DESIGN STUDIO INCLUDING DARIUS MILLER AND DR. PHYLLIS NELSON, AND PROFESSOR AXEL SCHMITZBERGER. I WOULD ALSO LIKE TO ACKNOWLEDGE THE STUDENTS FROM CAL POLY POMONA INCLUDING: ERIC CARBONNIER, OREN HARRIS, ANNA ONG, MICHELLE VORACHACK, ADRIANNA ARAMBULA, SARAH HOVSEPIAN, DAISY YIU, CYNTHY HARRIS, TAYLOR GOODRICH, ROXANNA SALCEDA, GREG LADJIMI, JONATHAN NG, KIM BLACK, MEHRANGEZ DANISHWAR.

REFERENCES

BAINS, SUNNY “MODULAR BOTS LEARN ART OF SELF-REINVENTION.” EE TIMES, OCTOBER 15, 2007.

BEESLEY, P., S. HIROSUE, J. RUXTON, M. TRANKLE, AND C. TURNER [EDS.]: 2006, RESPONSIVE ARCHITECTURES: SUBTLE TECHNOLOGIES, RIVERSIDE ARCHITECTURAL PRESS.

BROWN, GARY. “INTRODUCTION.” IN TRANSPORTABLE ENVIRONMENTS 2, EDITED BY ROBERT KRONENBURG, JOSEPH LIM AND WONG YUNN CHII. LONDON: SPON PRESS, 2002.

CHEN, I .M., AND J. BURDICK. “DETERMINING TASK OPTIMAL MODULAR ROBOT ASSEMBLY CONFIGURATIONS.” PAPER PRESENTED AT THE IEEE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION, NAGOYA, JAPAN, 1995.

ELDERSHAW, CRAIG AND YIM MARK, DAVID DUFF, KIMON ROUFAS, YING ZHANG “MODULAR SELF RECONFIGURABLE ROBOTS,” PAPER FOR THE ROBOTICS FOR FUTURE LAND WARFARE SEMINAR AND WORKSHOP, DEFENSE SCIENCE TECHNOLOGY ORGANIZATION, ADELAIDE, AUSTRALIA, 2002.

FOX, MICHAEL. “BEYOND KINETIC.” TRANSPORTABLE ENVIRONMENTS 2. EDITED BY ROBERT KRONENBURG, JOSEPH LIM AND WONG YUNN CHII. LONDON: SPON PRESS, 2002.

FOX, MICHAEL. “REDESIGNING THE BRICK” CAADRIA CONFERENCE. DOULIOU, TAIWAN, 2009.

LIPSON, H. “PRINCIPLES OF MODULARITY, REGULARITY, AND HIERARCHY FOR SCALABLE SYSTEMS.” JOURNAL OF BIOLOGICAL PHYSICS AND CHEMISTRY 7, NO. 4 (2007): 125–128.

KEMP, MILES. “META-MORPHIC ARCHITECTURE.” M.ARCH THESIS PROJECT: SOUTHERN CALIFORNIA INSTITUTE OF ARCHITECTURE, 2004.

KUROKAWA, H. ET AL., “M-TRAN II: METAMORPHOSIS FROM A FOUR-LEGGED WALKER TO A CATERPILLAR,” PROC.IROS03, PP. 2452–2459, 2003.

NAGPAL, R. SELF-ASSEMBLING GLOBAL SHAPE, USING IDEAS FROM BIOLOGY AND ORIGAMI. IN THOMAS HULL ED. ORIGAMI3 3RD INTERNATIONAL MEETING OF ORIGAMI SCIENCE, MATHEMATICS AND TECHNOLOGY (3OSME), A.K. PETERS, 2002.

PASK, G. (INTRODUCTION TO)FRAZER, J. AN EVOLUTIONARY ARCHITECTURE, LONDON: ARCHITECTURAL ASSOCIATION PUBLICATIONS, THEMES VII, JOHN FRAZER AND THE ARCHITECTURAL ASSOCIATION, 1995.

PRIEST, JOHN W., AND JOSE M. SANCHEZ. PRODUCT DEVELOPMENT AND DESIGN FOR MANUFACTURING, A COLLABORATIVE APPROACH TO PRODUCIBILITY AND RELIABILITY, 2ND ED. BOCA RATON, FL: CRC PRESS, 2001.

STERK, T.:2005, BUILDING UPON NEGROPONTE: A HYBRIDIZED MODEL OF CONTROL SUITABLE FOR RESPONSIBLE ARCHITECTURE, AUTOMATION IN CONSTRUCTION, VOL. 14, ISSUE 2, PP. 225–232.

WELLER, M.P. E Y-L DO. ARCHITECTURAL ROBOTICS: A NEW PARADIGM FOR THE BUILT ENVIRONMENT, PROCEEDINGS OF THE 11TH INTERNATIONAL CONFERENCE ON DESIGN SCIENCES & TECHNOLOGY (EUROPIA.11). 353–362.

YING ZHANG, KIMON ROUFAS, MARK YIM, CRAIG ELDERSHAW, MASSIVELY DISTRIBUTED CONTROL NETS FOR MODULAR RECONFIGURABLE ROBOTS. 2002 AAAI SPRING SYMPOSIUM ON INTELLIGENT DISTRIBUTED AND EMBEDDED SYSTEMS. YIM, M., DUFF, D. AND ROUFAS, K. POLYBOT: A MODULAR RECONFIGURABLE ROBOT INTL. CONF. ON ROBOTICS AND AUTOMATION (ICRA), IEEE, 2000, 515–519.