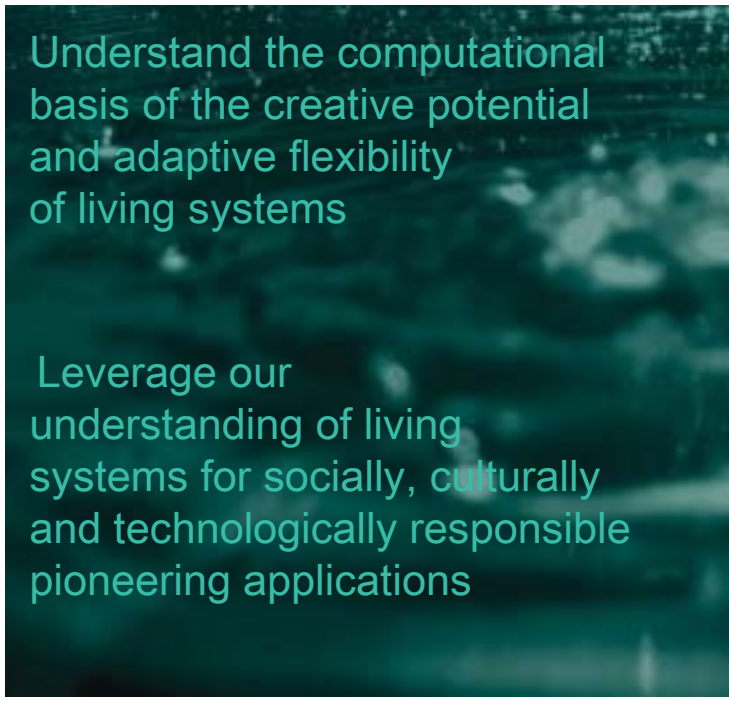
Center for Living Technology

Proposal for an interdisciplinary Center connecting academia and industry
June, 2001

Science

New social and technological opportunities are being revealed by our growing understanding of the origin of information processing and ongoing adaptation in living systems. Research is now bridging the gap between the nonliving and the living, between design and emergence, between low-level mechanisms and complex functionality. A spectrum of platforms from molecules to machines to human organizations, investigated in concert by experiment, simulation, and theory, is enabling an integrated, multi-level attack on harnessing the distinctive useful properties of living systems. These properties include autonomy, robustness, sensitivity, adaptation, ongoing creativity, modular structuring, integrated design, a unification of physical and symbolic descriptions, and collective intelligence. With industry support and an informed social conscience, the time is ripe for a concerted effort to capitalize on the broad new potential of what could literally be termed "living" technology.

Living systems have inspired recent cutting-edge approaches to computation and engineering, e.g., DNA computation and evolvable hardware. These, however, only hint at the vast potential of harnessing the power of evolvable living systems. The Center will aim to realize this potential by directly coupling technology developed at the Center with artificial living systems, both in vitro and in silico.



Commercial Applications

Traditionally, both biotechnology and information technology have increasing application to biology. The Center proposes to reverse this direction of influence, using our understanding of living systems to create new kinds of technology. Most short-term applications will be in bio-, nano- and information technology. Long-term applications will impact most known technologies, creating new markets. The long term commercial mission for the Center will harness:

– self-reproducing and self-repairing molecular synthesis:
Customized self-reproducing and self-maintaining chemical entities open up new avenues in biotechnology, nanotechnology, medicine, material and environmental science as well as space exploration.

– self-organizing and evolvable machines:
Self-organizing and evolvable machines have the potential to enhance current industrial processes, extending the reach of fully programmed manufacturing, as well as enabling new applications as “creative machines”.

– environments where open-ended evolution is possible:
Understanding and controlling nature’s creative powers enables humans to design environments which support sustainable improvements at all levels. These include the internet, machines, manufacturing, proto-organisms and chemical synthesis. This experience with artificial environments will allow responsible commercial interactions with the biosphere.

Initial Core Faculty

The Center’s four initial core faculty members are all pioneers in the contemporary effort to model and synthesize the fundamental properties of living systems. They are internationally-recognized leaders in the simulation of complex adaptive systems, in how to handle such systems experimentally, in the analysis of the large data sets that those systems generate, and in managing a knowledge based commercial enterprise based on such systems. The core faculty are also all committed to developing our understanding of living systems into responsible social, cultural, and technological applications. The active utilization of and potential affiliation with this multi-disciplinary Center by existing faculty is a service to the host institution and a necessary component to full success.

Mark A. Bedau
Ph.D. (Philosophy) UC Berkeley, 1985
Professor of Philosophy and Humanities at Reed College and Visiting Professor of Zoology at the University of Oklahoma.
Unifying principles of adaptation in living, intelligent, and social systems Simulation and analysis of evolutionary dynamics Philosophical foundations of complex adaptive systems Social and cultural implications of synthesizing living systems. (mab@reed.edu)

John S. McCaskill
D.Phil. (Chemistry) Oxford, 1982
Professor of Theoretical Biochemistry at the University of Jena and head of the Research Division, Biomolecular Information Processing, at the German National Research Center for IT (GMD).
Theory and simulation of molecular self-organization and evolution Experimental evolvable hardware and systems (electronic, microfluidic, molecular) Molecular information processing: architectures and implementations Evolutionary design of constructive biomolecular processing systems. (mccaskill@gmd.de)

Norman H. Packard
Ph.D (Physics) UC Santa Cruz,1982
Managing director and cofounder of the Prediction Company and scientific board member of the Santa Fe Institute for Complex Adaptive Systems, New Mexico.
Chaos and complex dynamics of physical systems Biological dynamical network models Predictive models of complex time series and statistical analysis of evolution Financial modeling for large-scale trading and management of applied research. (n@predict.com)

Steen Rasmussen
Ph.D (Physics) Technical University of Denmark, 1985
Staff Scientist at Los Alamos National Laboratory and head of Los Alamos’ Astrobiology team.
Proto-biology and the bridge between nonliving and living matter Physics of self-organization Collective intelligence and dynamics of socio-technical systems Simulation technology. (steen@vega.lanl.gov)

Research Thrusts

Theory and simulation of living processes
- Dynamics of self-organization and evolution
- Evolvability and adaptive flexibility
- Guidance and control of evolutionary processes
- Emergence of functionality and dynamical hierarchies

The distinctive properties of life-like systems will be investigated by combining the development of theoretical frameworks with the creation and study of model systems (simulations) and the development of analytical tools for complex data sets.

Experimental evolution and self-organization of living systems
- Evolvable electronically configurable hardware: both for evolutionary simulation and autonomous design, and for coupling to molecular systems
- Evolvable interface hardware: micro- and nano-reactor networks and photonic interfaces
- Self-organizing supramolecular chemistry: assembly and evolution of proto-life in vitro
- Molecular evolution and biomolecular information systems: in vitro directed molecular evolution, molecular ecosystems and DNA computing.

Theoretical and simulation investigations will be coupled with experimental development of practical systems for directed and open-ended molecular self-organization and evolution, as well as evolvable hardware.

Social and cultural impact of living technology
- Self-organization and collective intelligence
- Costs and benefits of living technology
- Risk management and safety guidelines for research and development
- Philosophical and ethical ramifications of living technology

The development of living technology raises new and complicated philosophical, social, and ethical issues. Scientific and commercial research and development at the Center will proceed in tandem with scientifically and humanistically informed investigation of the broader social and cultural implications of this new technology.

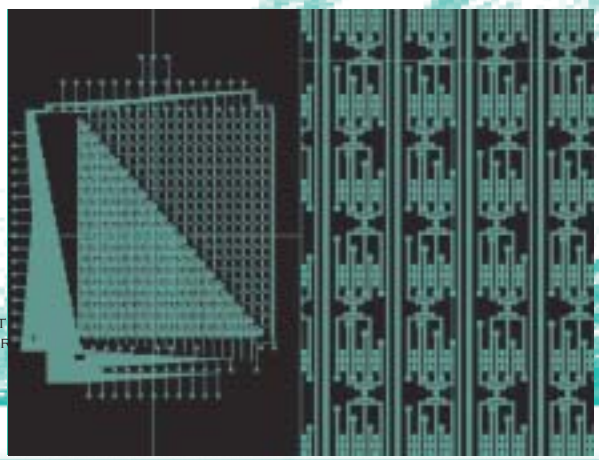
Early Applications

Applied evolution and self-organization
- Evolutionary design of electronic, microfluidic and integrated biomolecular systems for biotechnology
- Molecular self-organization of novel (living) materials, linking molecular self-assembly with evolutionary techniques.
- Evolvable information and communication networks and their design for information technology

Programmable construction hardware
- Reconfigurable electronic, micro- and nanosystem hardware: in particular as interfaces to living technology
- Programmable molecular systems for integrated biochemistry, molecular diagnostics and drug design
- Hybrid programmable machines such as DNA computers that use self-organization and evolutionary potential at a molecular level

Data mining and prediction in large data sets
- Data-analysis tools for analyzing and extracting semantic value from high density, non-stationary data streams (such as terabytes per day of click-stream data), using the evolutionary potential of reconfigurable hardware and molecular systems
- Programmable data creation and extraction from complex systems such as molecular biosystems under adapting experimental configurations

Collective intelligence technology
- Distributed intelligence in evolving systems
- Web-based consensus building and conflict clarification
- Decision support and management tools for large organizations



Layout of a multi-layer microfluidic chip carrying out selection based DNA Computing for combinatorial problems.

Budget

- 4 senior faculty positions
- Start-up funds for experimental and computational infrastructure: ~$10M
- Ongoing support, including technical support staff: ~$3M per year.

The costs cited are estimated to cover all activities in the thrusts above. To the extent existing infrastructure could be used (e.g. clean room), these costs would be lowered. The above costs are those required in the initial phase of the Center, but the ongoing host institutional costs will be diminished or covered by industrial participation and by patent revenue.

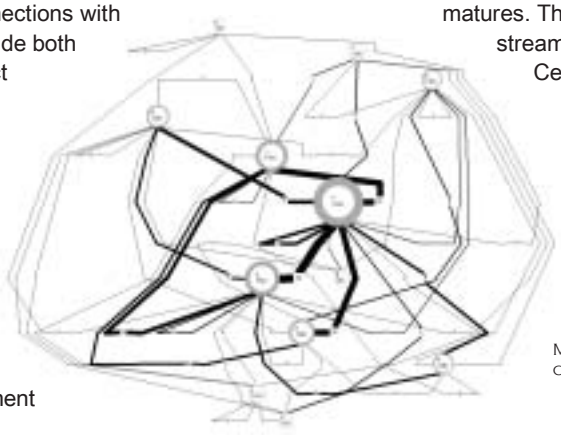
The Center anticipates significant support from four areas:
- The academic host
- Governmental and private national funding agencies
- Commercial partners
- Patent licenses

All of these funding sources will be pursued simultaneously at the Center's inception, though the first will dominate at inception. Revenue from patent licensing will dominate as the Center matures. The need to capture patents for this revenue stream creates significant pressure to create the Center immediately, in order to capture patents concerning the Center's founding vision and approach.

Organization and Support

The interdisciplinary Center will exist within an academic institution. It will have a core faculty, but it will have ties with a wide range of departments through a variety of shared activities. The Center will further the educational mission of its academic host by augmenting the host's current strengths, connecting existing departments with a range of forefront activities spanning basic research to development of applications. The Center will provide a spectrum of new opportunities for existing faculty and students at all levels, and it will help recruit and retain the highest quality faculty and students. It will contribute to a strong international network of scientific expertise.

The Center will also cultivate connections with commercial partners that will provide both resources and avenues for product development. Promotion of the migration of basic research into commercial environments will involve
- Liaison and joint ventures with industry for support and technology transfer
- Business planning for spin-off companies
- Patent research and writing
- Decision support and management tools



MIND MAP FOR COLLECTIVE INTELLIGENCE.

The research thrusts will be accompanied by infrastructure development that will serve (i) to enhance research efforts and to create an attractive research environment for visiting researchers, and (ii) to foster successful spin-off efforts and technology transfer.