Doing research in the U.S.A.: survivable multi-agent systems

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Research conducted in the United States is often viewed as a model that other countries try to reproduce or adapt to their own culture. The United States maintain a competitive edge in virtually all aspects of research activities: research organizations are well funded and can easily attract world-class talent. Because flexibility and optimism are deeply rooted in the American culture, scientists and research organizations accept and nurture sweeping and frequent changes. Universities, for-profit corporations and institutions perform a very broad spectrum of research activities, and cultivate strong relationships that foster innovation.
In this article, I examine from the trenches some aspects of the research structure in the United States. Since moving to California six years ago, I have been working in organizations conducting research under sponsorship by several federal research agencies. I describe my experience as a researcher both for a large and a small company. I illustrate the research activities by presenting UltraLog, a program sponsored by the Defense Advanced Research Projects Agency (DARPA).

La recherche aux États-Unis d'Amérique est souvent considérée comme un modèle que les autres pays essaient de reproduire ou adapter à leurs propres cultures. Les États-Unis maintiennent un avantage concurrentiel dans pratiquement tous les aspects des activités de recherche : les organismes de recherche sont bien financés et peuvent facilement attirer des talents du monde entier. Parce que la flexibilité et l'optimisme sont profondément enracinés dans la culture américaine, les scientifiques ainsi que les organismes de recherche acceptent et encouragent les changements rapides et fréquents. Les Universités accomplissent, au profit des entreprises et institutions, une large gamme d'activités de recherche et entretiennent des relations solides qui favorisent l'innovation.
Dans cet article, j'examine, depuis le terrain, quelques aspects de la structure de la recherche dans ce pays. Depuis mon installation en Californie, il y a six ans, j'ai travaillé dans des organisations conduisant des activités de recherche financées par plusieurs agences fédérales. Je décris mon expérience de chercheur dans une grande et aussi une petite entreprise. J'illustre les activités de recherche en présentant Ultralog, un programme financé par la DAPRA (Defense Advanced Research Projects Agency).

Corporate and University Teamwork in Research Projects

The Defense Advanced Research Projects Agency is the central research and development organization for the Department of Defense. Its mission statement is to manage and direct selected basic and applied research and development projects for the DoD. It pursues research and technology where risk and payoff are both very high and where success may provide dramatic advances for traditional military roles and missions.

Working under DARPA sponsorship is a great way to cross-pollinate research ideas between corporations, government institutions and universities. DARPA issues requests for proposals that mandate or encourage teaming between companies and universities. There is a strong incentive to build teams that include both large and small companies, commercial organizations and universities. As a result, DARPA-sponsored programs put together people who have very different objectives and interests, which in turn helps to promote innovation, even if it brings with it some management challenges. Professors at universities are interested in long term basic or fundamental research, and their primary goal is not to develop products. On the other hand, the growth engine of many companies and research labs is to transform basic research into products. Working with universities allows these companies to stay on the cutting-edge

of technology innovations. In their business model, government or corporate sponsored research is used to grow organically by using the research to develop their future products.

For example, my team has been working with several universities on a research program for survivable multi-agents systems. I started this research project while working at Network Associates Laboratories, a large commercial research and development organization specialized in computer security. Later, the entire research team joined a small company to continue the same work. Stanford University and the University of West Florida have provided policy reasoning and deconfliction tools using a first order logic theorem prover and knowledge representation tools, which we have incorporated into the survivable systems research project. We have also worked with the University of Memphis, which performed research in the area of intrusion detection and prevention using novel concepts such as genetic algorithms. Working with universities was instrumental to the success of the research project, and the universities have been very open to work with the corporate world.

The ideas developed by these universities were in their infancy five years ago. While very promising, their research concepts were not developed enough for any company to bet its future products on that kind of technology. Several years of cooperation with these universities have given our research team deep insight into how to apply the technology to commercial applications.

The research work performed by Stanford University and the University of Florida allows for the unambiguous and formal reasoning about policy constraints, where the policy data are expressed using the OWL web ontology language. Coupled with an inference engine, we have used the technology to develop Proteus, a tool set that allows system designers to build a system by choosing desired system properties. Proteus analyzes properties for consistency and resolves detected conflicts autonomously. The tool is used to design systems that require a high degree of information assurance.

Security, Robustess, Performance, and Functionality.

Few companies can afford to track advances in basic research and understand their realm of application, because it often takes months or years to obtain a glimmer of understanding of what a particular research concept is all about. Cooperation between corporations and universities in many projects helps to break the dividing wall between institutional research and commercial development. Universities can keep a watch on real-life applications and understand business needs. Businesses can educate themselves about ongoing research performed by universities.

This kind of cooperation also blurs the line between engineers and researchers, providing greater mobility opportunities between the research world and corporations.

Change as a Way of Doing Research

In France, most of the research is performed by specialized organizations such as CNRS, INRIA, CNES or INRA. By contrast, research in the United States is performed in a continuous spectrum of organizations, involving small and large companies, universities, and government agencies.

Research sponsors encourage bold innovative proposals, not only in their technical approach but also in their organizational structure. For example, it is not unusual for a small company to act as a prime contractor with partners that are several orders of magnitude larger. Research labs are often reorganized to fit new needs, without causing much outcry. In fact, the research community often promotes or endorses organizational changes. Most researchers find ways to continue working together despite a continuous stream of mergers, spin-off, spin-in, spin-out and acquisitions.

A telling example is the history of Trusted Information System (TIS), which was founded in 1983 to conduct advanced research in computer security. Some of their research projects led to great innovations, and eventually some of the prototype systems were turned into products. Most notably, TIS and the Massachusetts Institute of Technology were responsible for introducing e-mail systems in the White House when Bill Clinton asked how he could read his e-mail messages.

TIS was sold to Network Associates in 1998, which also acquired several companies, but eventually Network Associates decided to go back to its core business by selling most divisions, including the research labs.

After so many mergers and acquisitions, one could expect an implosion of the research teams, but the research community has been extraordinarily resilient to changes, and many researchers continue to work together.

Over the past few years, many companies like Network Associates, IBM, HP, Xerox, have reorganized, acquired, and sold parts of or entire research organizations. Many view this as a necessary step to adapt the research world to new challenges.

DARPA has a hiring policy that strongly encourages mobility among researchers, scientists and managers. Most DARPA programs are run by managers who have many years of mixed experience in the Government, universities and commercial organizations. Managers are hired on a three to five-year term basis, after which they must quit DARPA.

During that period, they must develop new programs that seek innovative and disruptive technologies, build research teams by bringing together universities, small and large companies, and oversee research programs, ensuring that contractors perform their work successfully.

Many DARPA programs are envisioned and run by different managers. A manager develops the program vision and the successor runs the program. After their term, DARPA managers go back to the Industry or Universities often with a great Rolodex.

The research work environment is very energetic. All the work is performed by non-Government employees, and funding is never guaranteed even after winning proposals. Some managers like to use catch phrases such as “sleep is optional”, set extremely aggressive deadlines, and drive out low-performers. This fast-paced environment is sharpening as federal deficits have recently become abyssal and force the government to concentrate its research efforts on essential technology.

Small Business Innovation Research

Many researchers in the United States view organizational changes positively. Over the past few spin-offs and acquisitions I have witnessed, several individuals have taken these changes as an opportunity to start a company.

Starting a company to do basic research or applied research requires significant funding. Entrepreneurs have the option of using venture capital, but there are two disadvantages: first, the VC firm will usually own a large share of the company, so the upside potential is lower and the risk of losing control of the company is higher; more importantly, VC firms are reluctant to back startup companies that plan to do research for the government, because profit margins are limited by regulations.

Instead, many entrepreneurs decide to refinance their home as a funding resource. Over the past few years, home values in the United States have increased dramatically, providing a large equity potential for would-be entrepreneurs. It is very easy to refinance a home at any time with very limited costs. Because interests are tax deductible, it is relatively cheap to borrow money, and many rules provide tax advantages to company founders.

In 2002, while I was working at Network Associates, the management announced a 25% operating margin target for all lines of business. However, because the government restricts profit margins on research contracts, there was no legal way to reach the target doing government contracting. So Network Associates told our group we had two months to find a new place. Fortunately, we managed to keep our research projects and we decided to join a small company, Cougaar Software, Inc. Everybody in the team was very excited about the prospect and we did not lose any employee.

This is very typical of many research labs. Because Wall Street analysts are particularly interested in short-term profit, many public companies cannot afford to think about long term research. The horizon of most commercial organizations is just a few quarters ahead. In fact, many companies are finding it increasingly difficult to own research labs, because the benefits of running research labs are not obvious and in conflict with short term profitability requirements. For example, many Government research contracts stipulate that the profit margin should be no more than 8%. At the same time, Wall Street analysts may ask Chief Financial Officers to attain a much higher profit margin. So a company performing both basic research and commercial work with short term earnings potential will seriously consider selling or spinning out their research labs.

The federal government has a strong commitment to use small companies for advancing basic and applied research. A series of laws and regulations favor small companies over large corporations in some research areas. One program that helps small companies to conduct research is the Small Business Innovation Research (SBIR) program. Its purpose is to harness the innovative talents of small technology companies for U.S. military and economic strength. In 2004, the funding level was roughly $1 billion, with a typical investment of $750,000 per project, allowing hundreds of companies to jump-start their business.

The goals of the SBIR program are to stimulate technological innovation, increase private sector commercialization of federal R&D, increase small business participation in federally funded R&D, and foster participation by minority and disadvantaged firms in technological innovation.

Over the past several years, the SBIR office has been measuring the success of its programs in monetary terms. With a $750,000 project investment, small companies hope to turn their research effort into products that will translate into higher profit margins. However, the results are mixed. Some of the research projects have led to great innovations, but not necessarily in a cost-effective manner. Even though small companies are

typically very flexible and innovative, the failure rate is still fairly high.

My company has participated in DARPA-sponsored and SBIR programs to grow from two employees in 2001 to twenty employees today. Most notably, we have been involved in building survivable multi-agents systems under the UltraLog program. One of our objectives is to use the federally-funded research to develop our commercial products.

The Cougaar survivable multi-agent system

The Cognitive Agent Architecture (Cougaar) is an open source, distributed Java-based architecture for the construction of large-scale distributed agent-based applications and is one of the most sophisticated distributed agent architectures available today. Cougaar is the result of over eight years of research and development and over $150 million in investment by DARPA under the Advanced Logistics Program (ALP) and its successor, the UltraLog program. Initially, the efforts under the ALP program focused on developing an advanced automation framework for global logistics planning and execution. Cougaar agents provide advanced time-critical reasoning, planning, execution, monitoring, and assessment with much greater speeds and better handling of vast amounts of information than conventional technologies.

Over the past five years, the focus has been on building highly survivable multi-agent systems. The objective of the UltraLog Program was to develop and demonstrate technology that enables massive-scale, distributed multi-agent systems. Those systems must operate over the unclassified Internet, and be provably survivable in extreme information warfare and kinetic wartime environments. UltraLog's goal is to operate with up to 45% information infrastructure loss in a chaotic environment, with no more than 20% capabilities degradation, and no more than 30% performance degradation for 180 days of sustained military operations in a major regional contingency.

The approach to the UltraLog Project has been to research, develop and integrate advanced survivability technologies from the areas of security, robustness, and scalability to extend and enhance the capabilities of massive-scale distributed multi-agent systems. These survivability properties are defined as follows:

Robustness: An UltraLog system should survive the loss of software or hardware components (including computers, network devices, and applications) with minimal loss of functionality. Robustness techniques provide mechanisms to conserve, allocate, or reallocate resources in order to achieve an acceptable level of performance even while losing components.

Security: An UltraLog system should perform its mission under a spectrum of information warfare and kinetic attacks. In particular, the system must be able to counter a large set of security threats such as insider and outsider attacks, while maintaining important properties such as user accountability, information integrity and confidentiality.

Scalability: The UltraLog infrastructure should not have any intrinsic scalability issues. It should be possible to implement Cougaar applications which scale to the degree that the application logic allows.

UltraLog has been designed to operate over an extremely diverse and heterogeneous networking environment. Prototype applications using the UltraLog system have been built to operate over a mixed set of land lines, wireless and mobile ad-hoc networks.
The UltraLog communication sub-system can adapt to changing conditions, such as restricting communication to critical messages when bandwidth becomes scarce or switching networking protocols on the fly. Agents may be moved proactively or reactively to optimize and conserve the use of network resources.

The UltraLog program has defined a rigorous set of requirements, assessment and metrics for functionality, security, robustness, scalability and performance. A set of methodologies specify how environmental parameters and survivability properties can be assessed using qualitative and quantitative metrics. For example, infrastructure loss and correctness can be measured quantitatively. A technique known as multi-attribute utility functions is then used to roll-up the assessed properties into a survivability score.

The table below provides some examples of multi-attribute utility functions.

Multi-Attribute Utility functions

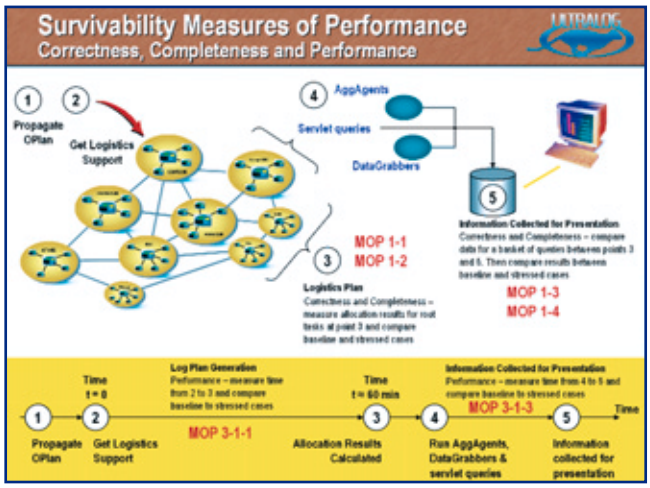
Completeness: A Multi-Attribute Utility (MAU) analysis score based on the percentage of information elements that have been successfully computed by installed business rules. Completeness is a function of time.

Correctness: A MAU based on an analysis of the results from installed business rule calculations and their level of fidelity.

Confidentiality: A MAU based on the percentage of sensitive data that were available to an unauthorized person, process, or device. Policy determines the authorization and sensitivity.

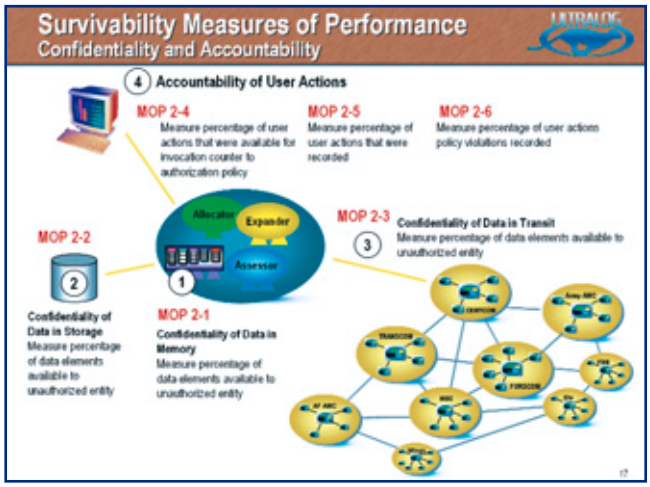
Accountability: A MAU based on the percentage of selected user actions that were successfully invoked counter to system authorization policy and the percentage of selected user actions that were not recorded counter to system policy.

Performance: A MAU based on the ability of the system to develop or redevelop the plan (completeness as a function of time) and collect information for presentation to the user in a timely manner.



UltraLog has pursued research breakthroughs in four main areas:

1. **Security:** Investigate information pedigree, white-noise generation, dynamic random routing, agent gateways, dynamic Public Key Infrastructure (PKI) management, recovery reconstruction protection, dynamic communications and security measures, information rovers, correlation and isolation of compromised agents and other techniques to achieve a secure, intrusion tolerance, trusted system even under directed information warfare attack;
2. **Scalability:** Investigate assured convergence, automatic dampeners, adaptive configuration, resource pooling/proxy, variable fidelity processes, sliding temporal horizons, reactive plan space management and other techniques to achieve a highly scalable and stable system even under very chaotic wartime environments;
3. **Robustness:** Investigate non-local persistence, fault tolerance and recovery, distributed consistency checking, partial state validation, dynamic communications-aware redundancy, dynamic adaptation, automatic recovery of lost agents, dynamic allocation of agents, agent mobility, predictors, and other techniques to achieve a state of high survivability; and
4. **Systems Integration and Development:** Synergistically combine security, scalability and robustness techniques that provide the highest level of capability while ensuring the overall functionality of the distributed logistics enterprise is preserved. Though many of the research efforts have been accomplished independently and in parallel, the real challenge comes in the integration synergy of the various techniques to produce the desired systemic effects.



Over fifteen companies and research organizations have participated in the UltraLog program, including very small companies and large companies, as well as several universities. UltraLog participants have advanced the state of the art in system survivability by researching and developing methodologies, algorithms, and software artifacts. In particular, Cougaar Software, Inc (CSI) – where I currently work - has been the architect and developer of the security services and has participated in the development of the robustness services.

UltraLog participants have also presented papers at several conferences. Many of the survivability techniques developed under the UltraLog program have been integrated into the Cougaar architecture and the open-source Cougaar project.

The Cougaar system has been used in a variety of projects, such as advanced logistics applications for ultra-large organizations, mobile ad-hoc networks management, simulation and monitoring of the nation's critical infrastructure, which includes systems, assets, and industries upon which the national security, economy, and public health depend.

Conclusion

Many DARPA programs put universities and companies together, where people must work with extremely diverse talents and discover ways to transform research ideas into innovative products. With huge federal Government deficits, the balance is currently shifting towards down-to-Earth research and development. Companies must again reinvent themselves to respond to evolving challenges.