BISON
IST-2001-38923

Biology-Inspired techniques for
Self Organization in dynamic Networks

Project Presentation

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Project Coordinator: Università di Bologna (Italy)
Partners: Telenor Communication AS (Norway),
Technische Universität Dresden (Germany),
IDSIA (Switzerland),
Santa Fe Institute (USA)

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Abstract

The document provides a short overview of the BISON project, including the motivation for the project, its objectives, an outline of the work to be undertaken, and a description of the consortium. The appendices provide a short presentation summarizing the goals of the project as well as a longer overview including some technical details.

Contents

1 Motivation

The complexity of modern Network Information Systems (NIS) has reached a level that puts them beyond our ability to deploy, manage and keep functioning correctly through traditional techniques. Part of the problem is due to the sheer size that these systems may reach with millions of users and millions of interconnected devices. The other aspect of the problem is due to the extremely complex interactions that may result among components even when their numbers are modest. Our current understanding of these systems is such that minor perturbations in some remote corner of the system will often have unforeseen, and at times catastrophic, global repercussions. In addition to being fragile, many situations arising from the highly dynamic environment in which they are deployed require manual intervention to keep NIS functioning. What is required is a paradigm shift in confronting the complexity explosion problem to enable building robust NIS that are self-organizing and self-repairing. BISON proposes to draw inspiration from nature and biological processes and develop techniques and tools for building robust, self-organizing and self-repairing NIS as ensembles of autonomous agents that mimic the behavior of social insects and immune networks. What renders this approach particularly attractive from a dynamic network perspective is the fact that global properties like adaptation, self-organization and robustness are achieved without explicitly programming them into the individual artificial agents. Yet, given large enough colonies of agents, the global behavior is surprisingly adaptive and can cope with arbitrary initial conditions, unforeseen scenarios, variations in the environment or presence of deviant agents. This represents a radical shift from traditional algorithmic techniques to that of obtaining the desired system properties as a result of emergent behavior that often involves evolution, adaptation, or learning.

2 Objectives

BISON will explore the use of ideas and techniques derived from complex adaptive systems (CAS) to enable the construction of robust, self-organizing and self-repairing information systems for deployment in highly dynamic network environments.

3 Description of Work

BISON will cast solutions to important problems arising in Ad-Hoc and Virtual networks, Peer-to-Peer and Grid computing systems as desirable global properties that the system should exhibit. We will then ask the question "which individual component behaviors and interactions can lead to these desired global properties as the emergent behavior of a CAS?" An answer to this question will give us a framework for constructing solutions to the original problem that inherit the attributes of CAS, including adaptability and self-organization. We expect to make progress towards this goal by restricting the class of problems and by drawing inspiration from biological systems such as insect colonies and immune networks.

4 Milestones and Expected Results

- Month 6: (a) Project Presentation (b) Simulation Environment Architecture (c) Structure/functions of dynamic networks (d) Abstract models for candidate CAS
- Month 12: (a) Models for basic services (b) Models for advanced services (c) Structure/function CAS matrix
- Month 18: (a) Simulation environment (b) Evaluation plan (c) Simulation environment for AHN, P2P networks
- Month 24: (a) Implementation of basic services (b) Implementation of advanced services (c) Evaluation for basic services (d) Evaluation for advanced services
- Month 36: Demonstrators

Expected results of BISON include techniques and tools for synthesizing CAS inspired by social insects and immune networks, as well as an open-source software infrastructure for experimentation.

5 Participants

Università di Bologna	Italy
Telenor Communication AS	Norway
Technische Universität Dresden	Germany
Istituto Dalle Molle di Studi sull'Intelligenza Artificiale	Switzerland
Santa Fe Institute	USA

6 Project Details

Start Date	January 1, 2003
Duration	36 months
Total Cost	EUR 2,251,594
Community Funding	EUR 1,128,000

7 Co-ordinator Contact Details

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A Short Presentation

Biology-Inspired techniques for Self Organization in dynamic Networks

Project Number: IST-2001-38923

http://www.cs.unibo.it/bison

Project funded by the Future and Emerging Technologies arm of the IST Programme

BISON Project Goals

- Develop techniques and tools that are suitable for building network information systems with life-like properties
- Exploit ideas from complex adaptive systems to achieve robust and self-organizing solutions for problems arising in dynamic environments
  - Overlay networks
  - Ad-hoc networks
  - Peer-to-Peer systems
  - Grid computing

BISON Project Expected Results

- A coherent set of heuristics that can guide the search for biology-inspired complex adaptive system giving a desired global behavior

- A systematic framework for constructing solutions to technological problems that inherit the attributes of biology-inspired processes, including self-repair and self-organization

BISON Project Details

- Partners
  - University of Bologna, Italy (Coordinator)
  - Telenor Communication AS, Norway
  - Technical University of Dresden, Germany
  - IDSIA, Lugano, Switzerland
  - Santa Fe Institute, USA
- January 1, 2003 start date, duration 36 months
- Total cost of €2,251,594 with community funding for €1,128,000
- Co-ordinator

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B Long Presentation

Biology-Inspired techniques for Self Organization in dynamic Networks

Project Number: IST-2001-38923

http://www.cs.unibo.it/bison

Project funded by the Future and Emerging Technologies arm of the IST Programme

Motivation

- The complexity of modern Network Information Systems has reached a level that puts them beyond our ability to deploy, manage and keep functioning correctly through traditional techniques
- Due (in part) to:
  - sheer size that these systems may reach
  - extremely complex interactions that may result among components

Dynamic Networks

- Recent technologies to consider
  - Peer-to-Peer computing
  - Grid computing/storage
  - Ad Hoc Networks (wireless/mobile)
  - Virtual/Overlay Networks (over wired infrastructures)
- These are instances of *Dynamic Networks*
- Extreme scale and dynamism further stress traditional techniques and methods

Approach

- We believe that solutions to practical problems that arise in dynamic networks have to be based on metaphors drawn from natural or biological processes if they are to be
  - Robust
  - Scalable
  - Self-organizing
  - Self-repairing

BISON Objectives

- Develop techniques and tools that are suitable for building network information systems with life-like properties

- Exploit ideas from complex adaptive systems (CAS) to achieve robust and self-organizing solutions for problems arising in dynamic networks

The “Harvesting” Approach

- Current application of CAS ideas to technological problems can be characterized as *harvesting:*
  - Comb through nature looking for a biological system or process that appears to have some interesting properties and apply it to a technological problem by modifying and adapting it through an enlightened trial-and-error process
- Ant-based message routing, document sharing
- Immune system-based search-and-rescue

The “Synthesis” Approach

- BISON will go beyond harvesting to a CAS *synthesis* phase
  - Develop a coherent set of heuristics that can guide the search for CAS giving a desired global behavior
  - Systematic framework for constructing solutions to the original problem that inherit the attributes of CAS, including self-repair and self-organization

Technical Work Packages

Foundations for biology-inspired CAS in dynamic networks

- Study social insects and immune system-inspired CAS, applied to the technological niche of dynamic networks, elucidating principles or regularities in their behavior
- Develop a systematic understanding and exploitation of heuristic approaches (via CAS) to problem solving

Technical Work Packages

Biology-inspired CAS techniques for basic services

- Study biology-inspired techniques for implementing low-level services, such as routing, searching, discovery and monitoring, in dynamic and mobile networks

Technical Work Packages

Biology-inspired CAS techniques for advanced services

- Study biology-inspired techniques for implementing higher-level services, such as resource sharing, in dynamic and mobile networks

Technical Work Packages

Evaluation and demonstrators

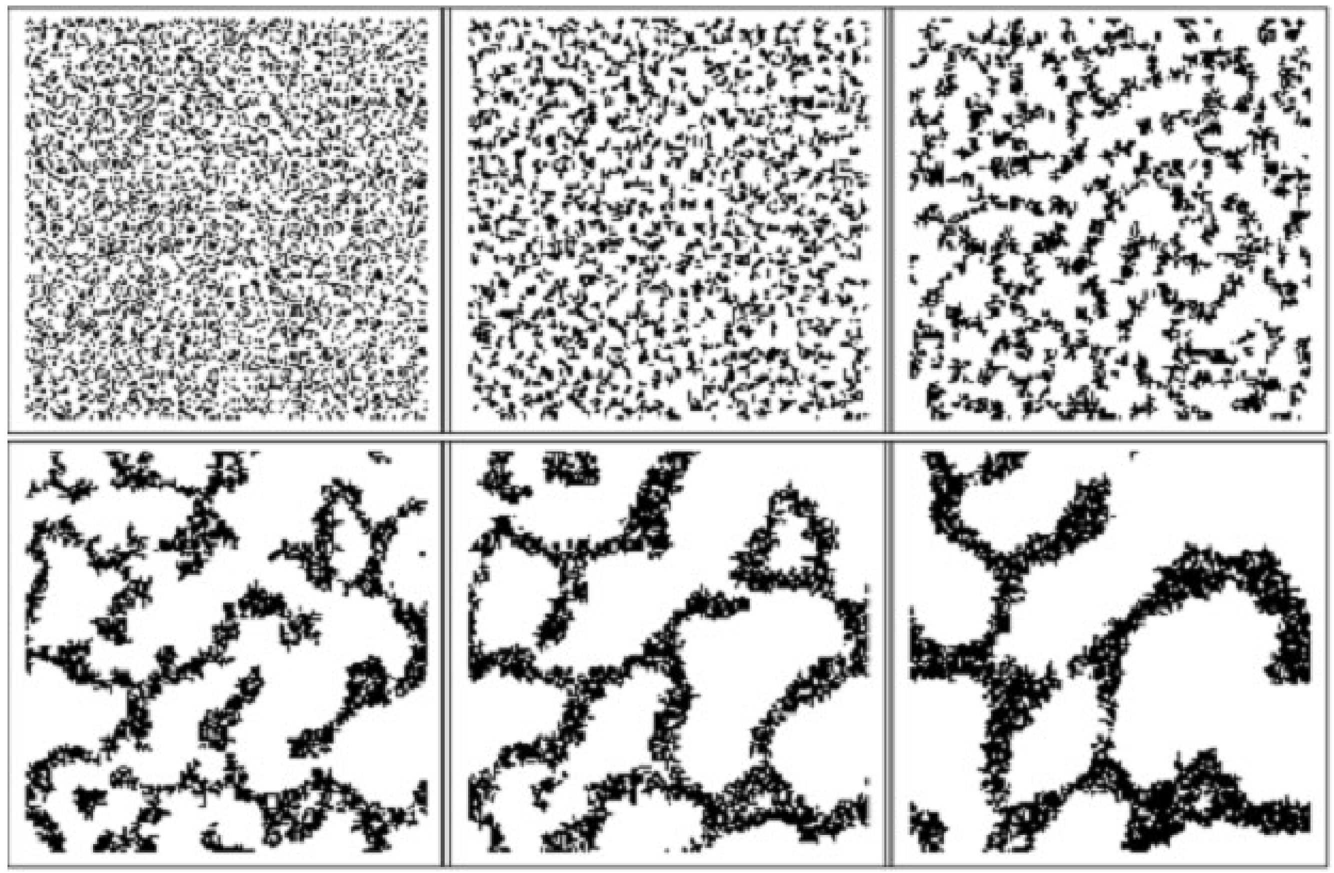
- Build an open-source simulation environment for evaluating the developed techniques in realistic settings
- Build Network Monitoring and Ad-Hoc Network Routing demonstrators

CAS Synthesis Example

Consider the termite-inspired CAS described by Resnick:

1. Wander around randomly until bump into a wood chip
2. If carrying wood chip, drop it and continue to wander
3. Else, pick up the wood chip and continue to wander

Example



From William Flake
" *The Computational Beauty of Nature*"

Example (cont)

If the technological task to be solved is characterized by a clustering phenomenon, then the harvesting approach may stumble upon Resnick termites

- Consider the following problem that may arise in a Grid computing context:
  - The computational load imposed by a grid application should be “balanced” over all potential nodes

Example (cont)

More formally, we define a predicate on the system state based on λ_i (average load at node *i*)

$$GP: \quad \forall i,j \quad |\lambda_i - \lambda_j| \leq \varepsilon$$

Our goal then is: given the above GP, synthesize a CAS that approximates it

Load Balancing Termites

Here is one possibility obtained through an "inversion" heuristic:

1. Wander randomly observing load at visited nodes, updating a moving "average load" λ
2. While visiting node *i*, if $\lambda_i - \lambda > \varepsilon$, then pick up some percentage of the excess load and continue to wander
3. If at least *n* nodes with local load less than λ have been visited, drop the load being carried

Load Balancing Termites (cont)

- This solution is
  - Robust (no prior knowledge of topology, initial conditions)
  - Scalable
  - Adaptive (to changing topology, system size, load, number of termites)
  - Self-repairing (some fraction of the termites can exhibit deviant behavior)
- Without having been "programmed" explicitly