A Logical Framework for Adaptive System Interoperability

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Motivation

Modern software systems are increasingly open and distributed, consisting of highly dynamic collections of interoperating components.

These systems need to adapt to changes in the execution environment and application requirements resulting from addition of new components, replacement of existing components, and changes in interconnection topology.

Our goal is to develop the scientific basis and methods for supporting adaptive interoperability of open, distributed information-intensive systems.

Motivation II

Current support for interoperation of components – such as in CORBA, COM, and Java Beans – is syntactic in nature and provides limited flexibility in identifying objects to which remote procedure calls are made.

Adequate support for coordination, mobility, scalability, and adaptability requires more flexible models of interoperation.

Mobile agents offer a promising technology for efficient use of networks in applications such as parallel search and data mining.

Motivation III

As an agent moves into different types of environments, it has to adapt to new requirements such as:

- security,
- fault-tolerance and
- resource conservation

that must be dynamically addressed.

We will address requirements for adaptation by developing new models of middleware which provide richer semantic interfaces.

Motivation IV

Our models will provide the ability to safely access and manipulate protocols and resources, for example, to ensure that:

- quality of service requirements, and
- hard real-time deadlines

can be met. This will allow secure and predictable interoperation of mobile agents and host systems.

Why a Logical Framework?

There are many sources of complexity in open distributed systems: in particular, asynchrony of operation, mobility, interaction with the physical world, which make it hard to design and verify systems which are demonstrably predictable, secure, efficient and resilient.

We will use rewriting logic as a logical framework to formalize such systems, express their properties, and reason about their behaviors.

One goal of the formalization is to enable development of tools which allow training of users through techniques such as scenario-based models, and development of appropriate human-computer interfaces which facilitate situation awareness of the critical factors in systems interoperation.

Why a Logical Framework? (II)

A suitable logical framework, such as rewriting logic, should naturally express different models of distribution, mobility, synchronization, resource use, security, real-time, etc.

Furthermore, if a model is executable, it simplifies the problem of design and implementation. One can begin with high-level models and analyze and verify their properties.

Specifically, to gain high assurance, the high-level models can be analyzed using a range of formal methods such as symbolic simulation, model checking, and theorem proving. High-level models can then be systematically refined into executable code, thus reducing the introduction of errors in the implementation cycle.

The Team

Our approach is multidisciplinary – it builds on research expertise in logics, formal methods, programming languages, middleware, mobile computing, and networks. The multidisciplinary team includes:

- José Meseguer, UIUC, (logics and formal methods)
- Gul Agha, UIUC, (agent based languages and systems)
- Carl Gunter, UPenn, (network programming languages and semantics)
- Catalin Roman, Washinton Univ., (mobility and coordination)
- Nalini Venkatasubramanian, UC Irvine, (middleware and quality of service).

Research Plan

A unifying theme will be the use of formal models to support the design and analysis of new methods for supporting interoperability. In a first stage we will:

- Design language abstractions for process and network mobility. The language constructs must enable us to represent different aspects of mobility.

- Develop a model of reflective middleware for adaptive interoperability. Such a model must capture hybrid systems and real-time requirements. The middleware must also support dynamic composition and customization of interaction protocols.

Research Plan (II)

In the second stage we will:

- Specify a number of protocols for coordination and control of basic services in terms of the abstractions for mobility and the reflective middleware model.

- Using our logical framework, we will study how these services can satisfy requirements such as security, fault-tolerance, self-organization, quality of service, self-synchronization and real-time control.

Research Plan (III)

In the third and final stage we will:

- build prototype implementations, and
- do case studies to evaluate and refine our methods.

DoD and Industrial Collaborations

The technology we will develop has many potential DoD applications. It addresses the fundamental challenges of utilizing information-intensive systems in an increasingly mobile force, and developing systems which must integrate with software from different commercial and custom sources.

Moreover, the need for dynamic teaming and global alliances requires new, more powerful technology for adaptive system interoperability.

DoD and Industrial Collaborations (II)

We have established a number of collaborations with research teams at:

- the Naval Research Laboratory:
  - Dr. Catherine Meadows
  - Dr. Constance Heitmeyer
- the Naval Postgraduate School: Dr. Cynthia Irvine

which will provide realistic domain specific applications and facilitate transition of our research results.

DoD and Industrial Collaborations (III)

In addition, two industrial organizations:

- Ford Motor Company, and
- Reactive Network Solutions

have expressed their interest in collaborating with us and transitioning our research to the commercial sector.

Student Training

Our research will make important contributions to the research training of graduate students.

Besides the training of about a fifteen graduate students who will do their dissertations on different aspects of the project, a larger number of graduate students will be trained in these techniques through:

- research seminars
- the development of a graduate course, and
- dissemination of the research ideas through lectures, research papers, and a project website.