

# Modeling and Controlling the Structure of Heterogeneous Mobile Robotic Systems: A BigActor Approach

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**Abstract**—In this paper we address the problem of modelling and controlling heterogeneous mobile robotic systems at a structure-level abstraction. We consider a system of mobile robotic entities that are able to observe, control, compute, and communicate. They operate upon an abstraction of the structure of the world that entails *location* and *connectivity* as first-class concepts. Our approach is to model mobile robotic entities as bigActors [18], a model of computation that combines bigraphs with the actor model for modeling structure-aware computation. As case study, we model a mission of heterogeneous unmanned vehicles performing an environmental monitoring mission.

## I. INTRODUCTION

In this paper we investigate the use of the BigActor Model [18] as a formalism for modeling and controlling systems of networked mobile robotic systems with dynamic structure.

Modeling and controlling systems with dynamic structure is a topic that has been raising attraction in the Cyber-Physical Systems and Robotics communities. Olfati-Saber et al. present in [17] a theoretical framework for analysis of consensus algorithms for multi-agent networked systems focusing on the robustness to changes in network topology. Martinez et al. discuss in [10] methods to model spatially distributed dynamic networks of robotic agents based on proximity graphs and spatially distributed maps. SHIFT [4] and R-Charon [8] are two languages for modeling networks of hybrid systems where the network topology may vary with time. The Collaborative Sensing Language (CSL) is a language introduced by Love et al. [9] for specifying controllers for missions of networked vehicles with ad-hoc resource pool. Karman et al. [7] present a process algebra for modelling mission specifications of interactive Unmanned Air Vehicles (UAVs). Pereira and Sousa present in [19] a strategy for dynamic allocation between teams of UAVs using Dynamic Programming. The control strategy also considers interactions with a human operator (known as mixed-initiative interactions).

The literature is also rich on models of computation where structure is a first-class concept. Kahn Process Network (KPN) [6] models deterministic sequential processes communicating through unbounded First-In First-Out channels. Milner introduced the Calculus of Communicating Systems where processes communicate synchronously [13]. KPN and CCS assume static structures. The  $\pi$ -calculus [14] introduces dynamic structure by allowing channel names to be communicated through other channels. The Actor Model, introduced by Hewitt and Agha [1], also enables modeling concurrent distributed entities with dynamic structure although the structure is implicitly entailed in the actor addresses that each actor knows. In [15] Milner introduces Bigraphs which models dynamic structures by means of two graphs: one for modelling *location* and another for modelling *connectivity*.

Pereira et al. introduces the BigActor Model [18] - a hybrid model of computation for structure-aware computation. BigActors are distributed concurrent computation entities that interact with a dynamic structure of the world modelled as a bigraph reactive system.

In this paper we investigate the use of bigActors for modelling and controlling networks of heterogeneous mobile robotic systems. Each robot hosts one or more bigActor that can: observe the structure, perform internal computation, communicate with other bigActors and change the structure by requesting control actions. The structure of the world is abstracted as a bigraph which provides a notion of *location* and *connectivity* of the robotic entities.

We use a collaborative control mission of unmanned vehicles as a case study. We model an environmental monitoring mission where teams of unmanned vehicles collaborate for searching, and tracking oil tankers and sample the water at their vicinities to serve as a proof for water contamination. This case study is motivated by recent evidences of illegal bilge dumping in the west coast of Africa [20] and in the coast of Vietnam [21], raising awareness for this environmental problem. The evidences were collected using satellite imagery correlated with information of Automatic Identification System (AIS).

**Example 1.** Consider three kinds of unmanned vehicles - UAVs, Autonomous Surface Vehicles (ASVs), and Autonomous Underwater Vehicles (AUVs). UAVs have the capability to search and track oil tankers. A UAV can also send a request to an AUV to sample the water at the vicinities of an

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## **Table of Contents Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach**

1. Understanding the eBook Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - The Rise of Digital Reading Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - Advantages of eBooks Over Traditional Books
2. Identifying Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - User-Friendly Interface
4. Exploring eBook Recommendations from Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - Personalized Recommendations
  - Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach User Reviews and Ratings

- Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach and Bestseller Lists
- 5. Accessing Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach Free and Paid eBooks
  - Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach Public Domain eBooks
  - Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach eBook Subscription Services
  - Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach Budget-Friendly Options
- 6. Navigating Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach eBook Formats
  - ePub, PDF, MOBI, and More
  - Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach Compatibility with Devices
  - Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - Highlighting and Note-Taking Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - Interactive Elements Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
- 8. Staying Engaged with Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
- 9. Balancing eBooks and Physical Books Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - Setting Reading Goals Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - Fact-Checking eBook Content of Toughneb Of Heterogeneous Polymeric Systems A Modeling Approach
  - Distinguishing Credible Sources

13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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