

## SUMMARY OF THE THESIS

The goal of this work was to determine if bigraphs can support the process of designing behavior for a swarm of unmanned aerial vehicles performing a given task, and if so, to what degree. To do so, it was necessary to first recognize current types of tasks that a swarm may be given to accomplish and common problems related to behavior design. It was also essential to become familiar with current state of the art in bigraphs applications.

There are two main results of this work. The first one is a methodology for designing behavior of UAV swarm members. It's goal is to create a schedule, assigning activities from a predefined set to be performed by swarm elements at discrete moments of time. The developed methodology consists of a set of methods to construct various formal structures that reflect different aspects of the modeled system and an algorithm that utilizes these structures to create a schedule of activities. A collection of best practices how to transform real-world entities into said structures were also included. The second result of this work is an algorithm to verify the correctness of models constructed using the methodology.

The developed methodology is based on bigraphs. They enable describing states of a modeled system as well as changes that can occur within it.

An extension of *transition systems* commonly used in bigraphs literature has been proposed, named *tracking transition system*. It allows analyzing which elements of the system can participate in activities feasible in different states.

To study how participation in one activity affects possible future involvement in cooperative activities, a new formal structure named *state space* has been developed.

Tracking transition systems consist of a set of bigraphs and objects called *transitions*. Each transition between an input state and an output state indicates how participation in one of predefined activities rearranges involved objects. This structure does not take time associated with activities under consideration.

A state space as defined in this thesis can be constructed from any tracking transition system. It reduces states of a system to vertices of a directed multigraph. A function reflecting how time required to execute an activity affects each participating object is assigned to each arc in such directed multigraph. A novel algorithm to find all walks (in graph theory sense) in a directed multigraph has been developed as a part of this work. It uses two kinds of matrices, each with finite series as elements. The novelty of this algorithm lies in the fact that it produces results with a single multiplication of said matrices. To multiply elements of these matrices is to perform a convolution of respective series.

The thesis consists of six chapters. The first one is devoted to informal introduction to unmanned aerial vehicle swarms and bigraphs. It covers current applications of both UAV swarms and bigraphs. The term "swarm" is also explained in the context of computer science. The second chapter formally introduces terms and structures already defined in literature. It goes from basics, like functions and graphs, to complex structures like bigraphs. This chapter also includes the definition of tracking transition systems. The third chapter is dedicated to state space and the algorithm finding all walks between a pair of vertices.

An introductory example is included to explain the concepts covered in the chapter, without delving into complex use cases. The next chapter defines the algorithm to verify correctness of models created with the developed methodology. Scope of verification and main difficulties are discussed there as well. In the fifth chapter various use cases for the developed methodology and the algorithm for verification are presented. Each use case is meant to address a different aspect related to behavior design for a swarm. Examples included in this chapter range from a single-stage task that inherently requires cooperation between drones, to scenarios including increasing a number of UAVs and a number of stages of a given task during a development process. A thorough verification examples of correct and incorrect models are included. Using software tools developed as a part of this thesis, an estimated relation between the number of task elements and the size of a system is discussed in this chapter. Performance of one of the developed tools is compared with the current state of the art software library designed to do similar operations. Based on the gathered results, practical limitations of the developed methodology are listed and discussed. The final, sixth chapter summarizes all of the presented results and discuss further research directions.

**Keywords:**

UAV swarm; coordination; planning; bigraphs;