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The TurtleKit Simulation Platform: Application to Complex Systems

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Abstract

This paper presents the TURTLE KIT simulation platform. This platform relies on the combination of a Logo simulation model with high level programming languages. Indeed, the agent model and the environment are largely inspired by the StarLogo system but can be easily extended thanks to the use of the Java programming language. This paper presents the TURTLE KIT main features and illustrate them through experiments on artificial complex systems.

1 Introduction

Agent-based simulations (ABSs) is an attractive alternative to equation-based models [17]. ABSs allow to directly model individuals, their behaviors and their interactions and thus to model complex systems [6]. There is today plenty of tools which provide different means to develop, execute and analyze such models. Most of the existing platforms have been designed according to a particular area of research such as ecology (CORMAS [5], ECHO [10]), robotic (MISSION LAB [14]), multi-agent coordination (MASS [9]), etc. Still, some platforms are not dedicated to a research field but address a particular audience. For instance, SWARM [3] defines a generic simulation mechanism and affords important libraries of environment, agent architectures, simulation tools, etc. The underlying idea is to give advanced programming tools that enable to develop simulators that fit the experiment requirements. So this platform is designed for advanced users. At the opposite, other platforms such as STARLOGO [2] or NETLOGO [1], which are based on the Logo language, have been originally designed to quickly develop simulations for educational purposes. Thus, they intentionally focus on simplicity and do not afford advanced programming tools for extending the platform possibilities. They are designed for newbie users.

This paper presents the TURTLE KIT platform [15], which relies on a Logo-based simulation model. However, TURTLE KIT keeps the simplicity of Logo programming approaches while giving all the possibilities afforded by high level programming languages. So TURTLE KIT is dedicated to both newbie and advanced users. The paper first presents TURTLE KIT main features and then shows how it can be used and extended.

2 TURTLE KIT overview

2.1 Logo programming approach

The Logo language was designed in the late sixties at the Massachusetts Institute of Technology (MIT). The motivation was to provide a learning tool that did not require programming skills. The principle is to manipulate a graphical animat, a turtle, typing simple commands to make the turtle move and draw shapes on the screen. For instance the forward 10 command makes the turtle move forward 10 steps. Logo programs are usually collections of small procedures that define turtle behaviors which can be combined to achieve more complex behaviors.

In platforms like STARLOGO or NETLOGO, the idea is to provide a simulation environment made of several turtles (MultiLogo), and thus to model multi-agent systems (MAS). TURTLE KIT is directly inspired by this approach. Turtles are agents that live on a two-dimensional world which is spatially discretized into patches. Each patch contains local properties such as its color, pheromone concentrations, etc. Turtles have the ability to interact with the world, other turtles and patches, using turtle commands: they can move, perceive their local environment and modify the properties of patches and other turtles. So, implementing a simulation with MultiLogo-like languages relies on defining procedure commands which are collections of primitive commands and other procedure commands:

    to wiggle
      fd 1  rt random 50  lt random 50
    end
For instance the wiggle procedure consists in using the right turn (rt), left turn (lt), forward (fd) and random primitive commands to define a random walk. The wiggle procedure can then be used into another new procedure to define a more complex behavior and so on.

2.2 Using high level programming languages

The main advantage of MultiLogo platforms is that they propose an agent-based programming language that focuses on simple agent/environment models. Despite this simplicity, they provide an exhaustive list of primitive commands and very complex and interesting behaviors can be easily obtained starting from simple primitive commands. However, MultiLogo platforms have been designed to ease programming and they intentionally do not afford advanced programming tools which could be used to extend the platform capabilities. For instance, it is not possible to display the world according to various point of views simultaneously whereas having various graphical representations of the world is crucial when studying complex systems [5]. On the other side, high-level platforms provide code extension facilities (inheritance, modular programming, etc.).

Developing TURTLE KIT, our main goal is to bridge the gap between using Multi-Logo models and using high level programming features. Hence, TURTLE KIT is an open source platform written in Java providing a default set of classes which can be used or extended regarding the simulation requirements. Thus programming facilities such as inheritance are naturally available.

2.3 Agent oriented programming

Initially, TURTLE KIT has been developed to validate the simulation tools we implemented in the MADKIT (www.madkit.org) multi-agent platform [16]. Since MADKIt is a generic MAS development environment, it provides support to design organizations, interactions between agents, debugging, system probing, distribution, etc. TURTLE KIT naturally benefits of these features. Moreover, TURTLE KIT is a MAS itself and every module of TURTLE KIT is a regular MADKIT agent having the ability to communicate with any other agent using messages. For newbie users, all these features are encapsulated and can be ignored. However, advanced users can use these features to extend the default tools of TURTLE KIT (see section 3.2).

2.4 TURTLE KIT turtles

TURTLE KIT turtles are written in Java. Every kind of turtle is implemented in single Java class that inherits of the super class Turtle that implements the basic Logo-like procedures. Implementing TURTLE KIT turtles simply consists in defining Logo procedures using the Java programming syntax. So, the wiggle procedure code is as follows:

```java
public void wiggle(){
    fd(1); turnRight(random(50)); turnLeft(random(50));
}
```

Each turtle can achieve a collection of actions during a single simulation step. A turtle behavior is defined as an automaton that represents a sequence of atomic behaviors which are Logo primitive sequences. So, when activated, a turtle executes all the primitives associated with an atomic behavior. Then the behavior the turtle wants to do next is returned. Figure 1 illustrates this mechanism through a classical example: the termite behavior.

Figure 1. The termite behavior

For instance, the findNewPile behavior code is entirely executed when the turtle’s turn comes. Then in the next simulation step, the turtle will execute either findNewPile or find empty patch. The findNewPile behavior is implemented as follows:

```java
public String findNewPile(){
    if (getPatchColor() == Color.yellow)
        return("findEmptyPatch");
    else{
        wiggle(); return("findNewPile");
    }
}
```

2.5 The environment model

Although the environment is discretized into a patch grid, turtles move in a continuous way. For instance, if a turtle has a 45 degree orientation and moves of one unit (fd(1)), the turtle will have its x and y coordinates increased by $\sqrt{2}$. It is thus possible to make the turtles doing particular moves such as a perfect circle. The patch grid is rather used to define the turtles local environment, enabling them to perceive and act on the world using primitive commands (setPatchColor(Color.yellow); dropPatchVariable("Pheromone",1500); etc.). The patch grid also defines a plain diffusion model that permits to simulate the diffusion and evaporation of substances (see section 3).
2.6 Observers and Viewers

As in SWARM, it is possible to probe the model using the 
Observer agent of TURTLE KIT. The observer is also a regular 
MADKIT agent and can interact with any available agent 
within MADKIT. Especially, an observer may send data to 
MADKIT agents which are specialized in doing particular 
tasks (e.g., drawing line charts, data analysis, etc.). An ob-
server can also create a probe according to a group/role cou-
ple to extract data according to organizational characteristic, 
probing only turtles playing a particular role. Users can ex-
tend the Observer class regarding their needs. Furthermore 
it is possible to launch as many observers as required (see 
sections 3.1.3 and 3.2.4).

To graphically represent the simulated world, we have 
implemented particular observers: the Viewers. 
TURTLE KIT affords a default viewer that displays the world 
in a classical way (the color of the patches and turtles). 
However, many viewers have been implemented to define 
new point of views: turtles displayed by role, substances 
displayed by types, etc. This is done by overriding the de-
default viewer’s paintPatch and paintTurtle methods. Then, 
through multiple representations, using several specialized 
viewers, it is possible to graphically extract many aspects of 
a model (see sections 3.1.3 and 3.2.3).

2.7 The Scheduler agent

The Scheduler is designed to organize the simulation ac-
tors activity: environment, observers, viewers and turtles. 
This agent can be ignored in the platform default configu-
ration. However it can be extended to achieve a particular 
scheduling: activating a particular kind of turtle twice per 
turn or activating the display only when a particular condi-
tion is verified.

2.8 The Python Command Center

Java has one shortcoming: the code must be compiled 
and cannot be interpreted at runtime. But interacting with 
the simulation is a desirable feature when studying complex 
systems. To this end, TURTLE KIT permits the use of the 
Python language: we have implemented the Python Com-
mand Center (PCC) which allows to take control of the tur-
tles by typing commands or loading a predefined script. No-
tably, this feature allows to dynamically execute compiled 
Java behaviors during a regular simulation to interact with 
the simulation (see section 3.1.5).

3 Experiments

To illustrate the capabilities of TURTLE KIT, we present 
two experiments involving the design of complex systems.
The first experiment involves a newbie use of TURTLE KIT 
to produce multi-level emergence (MLE) of complex struc-
tures within a MAS. The second simulation, implemented 
with an advanced use of TURTLE KIT, develop an evolu-
tionary approach to construct multi-agents organisms.

3.1 Multi-level emergence

3.1.1 Background

In nature, emergence generally exists in the form of multi-
level emergent structures (also called multiple emergence) 
[7]. It is the production of emergence in a system composed 
of subsystems which are themselves the product of previous 
emergences. In [4], we have proposed a MAS model to pro-
duce MLE. This model distinguishes the environment, the 
interactions and the agent model. The theoretical model has 
been developed by simulating each step of its conception 
on TURTLE KIT. Those simulations involved low-level pro-
gramming skills.

3.1.2 The agents

The agents interact via emission and perception of pheromones. The structuring of the emergence is the result 
of attractive/repulsive interactions between the agents. The 
agents own a state which rules the agents’ attraction/repul-
sion behaviors by modifying the agents’ interaction abili-
ties. The agents are able to mutate modifying their own 
state. To develop the final MLE model, several kinds of 
agents have been easily implemented and tested thanks to a 
modular programming. The agents pattern has been define 
by inheriting the Turtle class. The subclass, called MleTur-
tle, implements the agent’s behavior automaton. This au-
tomaton involves four atomic behaviors: perception, emis-
sion, mutate, move. Several kinds of agents have been then 
implemented inheriting the MleTurtle class. To design the 
final prototype, a refining of each behavior has been done 
through the use of numerous subclasses.

3.1.3 Using the TURTLE KIT viewers and observers

To characterize the emergent phenomenon, standard view-
ers have been used. The standard viewers permitted us to: 
(1) observe the agents as a function of their state and (2) 
observe the diffusion of interactional pheromones.

One of the important tasks for the analysis of the system 
behavior was to observe and characterize the emergent phe-
nomenon. Figure 2 shows a simulation observed by four 
different viewers: 1, 2 and 3 display the turtles and one 
pheromone, 4 is a standard view. These viewers permit-
ted us to observe the formation of circular multi-emergent 
structures while analyzing the role of pheromones in the 
emergent structuring process.
TURTLE KIT observers have been used to analytically study the system's behaviors. Various observers have been implemented to extract quantitative information from the system: counting particular agents (with a particular state, behavior or position), measuring distances between agents, making computations on quantities of pheromones (average, maxima, standard deviation, etc.), and so on. For instance, figure 3 shows a mathematical measurement of the structural organization in a typical simulation for each level of emergence (level 1 in black, level 2 in gray). This computation is based on the average of distances between agents involved in the same structures. The chart is drawn by a MADKIT agent interacting with the observer.

Figure 3. Structural complexity in the system.

def randomMove(self): # (1) Random move procedure
    self.randomHeading() # in a Python agent
    self.fd(10)

public void randomMove(){ // (1) in a Java agent
    randomHeading(); fd(10);
}

# (1) direct call of the behavior within the PCC
askTurtles("randomMove")

# (2) Random move using a script in the PCC
askTurtles("randomHeading()")
for i in range (0,10):
    askTurtles("fd(1)")

3.2 Evolutionary experiments

3.2.1 Background

Mimicking the mechanisms of complexity appearance in living systems, the field of embryogeny (growth of embryos) explores the possibilities to design artificial complex systems [12]. How a single evolved cell can give birth to complex organisms?

We have developed a bio-inspired model that makes agents evolve to form artificial organisms. This model is inspired by the functioning of particular genes in natural
embryos development [13] and implements techniques from the evolutionary computing field [8]. The agents represent cells that replicate and interact to construct organisms. An evolution process is used to explore the space of behaviors encoded in the agents’ genetic inheritance. The French flag model of Wolpert [18] has been the inspiration for the first task the model has to achieve: the goal has been to evolve a population of agents able to form organisms that create flag patterns. The evolutionary algorithm works as follows: (1) generate a initial random population (2) assign a note/fitness to the formed organism (3) select individuals according to fitness for reproduction (4) reproduce offspring using two parents (5) evaluate each offspring and assign fitness (6) replace old population by offspring using particular strategies [11] (7) unless a high level of similarity with the predefined pattern is reached, return to step 4.

Dealing with evolutionary computation requires the use of numerous tools: evolution engine, fitness manager, reproduction operators, etc. To develop such simulations, we have greatly improved the TURTLE KIT standard tools.

3.2.2 Extending the TURTLE KIT launcher

The study of evolutionary systems requires a systematic use of the simulation process. To this end, we have improved the formal description of the implemented simulations and developed Launcher agents able to parse XML files. The simulations are thus described by defining agents, environment, observers and viewers in XML formalisms. The XML Launcher has been implemented by simply overriding the initialization functions of the standard Launcher and by providing adequate Java libraries to parse XML.

3.2.3 Extending the TURTLE KIT viewers

New viewers have been implemented to achieve two mains goals: (1) dynamic visualization of diffusing substances and (2) ad-hoc interventions in the environment. We first have developed a universal viewer which allows the mapping of the substances concentrations with the viewer RGB (red, green, blue) canals. This technique has permitted us to provide a dynamic view of diffusing substances by defining the displayed colors as functions of substances quantities. Figure 4 shows a simulation observed by four different viewers. Every viewer monitors a lot of diffusing substances represented by various scales of the RGB colors. In the first viewer, the substances dropped by agents are invisible because external substances are present in too great proportions. Thus, when scaling the visualization with the external substances, the substances dropped by agents become visible. It is important to note that the visualizations can be managed and modified at runtime (new viewers, new colors, display agents on/off, etc.).

Secondly, we have developed an environment editor that permits user interactions with the environment via mouse clicks. It allows: the instantiation of new turtles within the environment, the modification of patches colors, the interaction with simulated agents via a simple popup, etc. These features have permitted us to design in a ad-hoc manner the predefined flag patterns required for the step 2 and 5 of the evolutionary algorithm. To evolve a French flag pattern, we have first drawn the predefined French flag by modifying the colors properties of the patches (See figure 5). Then this predefined pattern has been used as a mask to give fitness. Figure 5 shows the growth of a multi-agents organism from a single evolved agent (after 250 generations).

3.2.4 Extending TURTLE KIT observers

The Observer is naturally the main class to extend to manage the evolutionary process. So, we created new classes of observers, the Managers. Managers are designed to handle various types of artificial genetic objects (genes, genomes, pools, etc.). The Managers interact with the scheduler and the launcher to randomly generate pools of genes, give genetic inheritance to simulated agents, manage the reproduction process, save genetic objects to reuse them, and so on. The possibility to design interactions between the observers and other MADKIT agents allowed us to break through the standard functioning of TURTLEKIT. Indeed, the Managers have permitted us to develop a coherent evolutionary model without modifying the TURTLEKIT simulation engine.

4 Conclusion

The TURTLEKIT platform aims at providing to advanced users the simplicity of a Logo simulation model while
proposing flexibility, modularity and extensibility. We have shown the importance of using multiple views of one single simulation in order to extract the required information. We have also exhibited that agent oriented programming have permitted us to develop sophisticated simulation models without modifying the original simulation engine. In fact, we can clearly distinguish two ways of using TURTLE KIT:

- **LOGO-like programming**: dedicated to newbie users, this approach simply involves the definition of the behavioral automaton of the agents. All simulations tools are directly managed by TURTLE KIT.

- **SWARM-like programming**: for advanced users, it is possible to extend greatly the possibilities of TURTLE KIT by inheriting and modifying the existing classes, enabling (1) the extension of the platform modules (scheduling, probing, visualization, agent creation, etc.) and (2) the implementation of additional features required by a particular experiment.

TURTLE KIT is available for download on the MAD-KIT web (www.madkit.org). It features a user guide, the TurtleKit api, tutorial simulations and advanced projects.

**References**