Simulation of electromagnetic waves propagation in free space using Netlogo multi-agent approach

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ABSTRACT

In this paper, we propose a Netlogo multi-agent formulation for modeling electromagnetic waves propagation in free space using Maxwell's equations. This modeling approach contrasts with traditional ones, which are typically built up from sets of interrelated differential equations. The multi-agent systems paradigm choice is due to its effectiveness for modeling and simulating the complex systems which are characterized by a wide variety of interactions between entities which compose it. The based agent simulation provides a means to apprehend dynamic characteristics and to represent their functionings, which facilitates their study. The obtained results describing the spatial variation of electric field are in good agreement with the theoretical ones.

CCS CONCEPTS

• Computing methodologies → Multi-agent systems • Computing methodologies → **Simulation by** animation • Computing methodologies → Intelligent agents *• Computing methodologies*→ Agent / discrete models • **Applied computing**→ Physics

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KEYWORDS

Multi-agent, Netlogo, Electromagnetic waves modeling, Maxwell's equations.

1 INTRODUCTION

Multi-agent modeling makes it possible to conceptualize and simulate an organized set of agents interacting with each other and their environment, and allows the formalization of complex systems with multiple and varied spatial, temporal, and organizational scales. The system is then composed of a set of agents, located in an environment and interacting according to certain relations. An agent is an entity characterized by being at least partially autonomous.

The complex systems and complexity are the core scientific problem of the 21st century. A complex system is a system with a large number of elements, building blocks or agents, capable of interacting with each other and with their environment. The agents can be all identical or different; they may move in space or occupy fixed positions, and can be in one state or multiple states. The common characteristic of all complex systems is that they display organization without any external organizing principle being applied [1]-[2].

NetLogo is a multi-agent programming language and modeling environment for simulating complex natural and social phenomena. Through this platform, modeler can give instructions and order to a large number of agent to model. In [3]-[4] we find the basic principle of Netlogo and its language programming and some examples exhibit the using of this platform and its different components.

There is different works based on agent-based modeling using Netlogo. In [5] we find the model of network worm propagation proofing the impact of worms in a complex network , as well as in [6] authors explain social learning behavior as a complex system simulated in NetLogo influenced by routine activity, in addition to that the dynamic model is very interesting for some phenomena changing in time explaining the dynamic model of teaching behavior based on complex system theory and modeling methods.

By incorporating judiciously the polarization vector and Maxwell's equations, The FDTD method based on the auxiliary differential equation (ADE) technique has effectively modeled the interaction of femtosecsond pulses in silica fibers [7]-[8]. The Z-transform technique combined with the FDTD method, gave consistent results for the simulation of solitons in nonlinear dispersive media [9]-[10]. In order to simulate the wave's propagation in dispersive media with complex permittivity, methods based on the discrete convolution of the dispersion relation are presented in [11].The nonlinear Schrödinger equation was applied to model the propagation of short optical pulses in Kerr media [12]. The Alternating-Direction Implicit Finite-Difference Time-Domain (ADI-FDTD) has been introduced as an unconditionally stable implicit method to solve the problems of EM radiation in nonlinear dispersive media [13].

In this paper, we introduce the multi-agent based modeling of electromagnetic waves propagation in free space. This later is a complex dynamic process change in time and space and with different media. We focus on free space to open the window of using Multi-agent modeling with electromagnetic waves through Netlogo approach. We choosed the Netlogo platform, because it combine two interesting part, simulation and graphical views and programming section in one platform.

2 FORMULATION

The Maxwell equations governing EM wave propagating in the free space can be written as follows [13]:

$$\frac{\partial \overline{E}_x(t)}{\partial t} = \frac{1}{\varepsilon_0}(\nabla \wedge \overline{H})_x$$
$$\frac{\partial \overline{E}_y(t)}{\partial t} = \frac{1}{\varepsilon_0}(\nabla \wedge \overline{H})_y$$
$$\frac{\partial \overline{E}_z(t)}{\partial t} = \frac{1}{\varepsilon_0}(\nabla \wedge \overline{H})_z \qquad (1)$$

$$\frac{\partial \overline{H}_x(t)}{\partial t} = -\frac{1}{\mu_0}(\nabla \wedge \overline{E})_x$$
$$\frac{\partial \overline{H}_y(t)}{\partial t} = -\frac{1}{\mu_0}(\nabla \wedge \overline{E})_y$$
$$\frac{\partial \overline{H}_z(t)}{\partial t} = -\frac{1}{\mu_0}(\nabla \wedge \overline{E})_z \qquad (2)$$

Where ε_0 is the dielectric constant of free space, E and H are the electric and magnetic fields.

Using centered differencing scheme between time steps

$t^{n+1} = (n+1).\Delta l$ and $t^n = n.\Delta l$, we can write the discretized equation for the electric and magnetic fields in regular space

$\Delta x = \Delta y = \Delta z = \Delta l$ as follows:

$$\begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix}^{n+1} = \begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix}^{n} + \frac{\Delta t}{\varepsilon_0}\begin{pmatrix} \nabla \wedge \overline{H}_x \\ \nabla \wedge \overline{H}_y \\ \nabla \wedge \overline{H}_z \end{pmatrix}^{n+\frac{1}{2}} \qquad (3)$$

$$\begin{pmatrix} H_x \\ H_y \\ H_z \end{pmatrix}^{n+1} = \begin{pmatrix} H_x \\ H_y \\ H_z \end{pmatrix}^{n} - \frac{\Delta t}{\mu_0}\begin{pmatrix} \nabla \wedge \overline{E}_x \\ \nabla \wedge \overline{E}_y \\ \nabla \wedge \overline{E}_z \end{pmatrix}^{n+\frac{1}{2}} \qquad (4)$$

3 MULTI-AGENT ALGORITHM

Multi-agent based simulation is nowadays used in a growing number of areas, where it progressively replaces the various micro-simulation, object-oriented or individual-based simulation techniques previously used. It is due, for the most part, to its ability to cope with very different models of "individuals", ranging from simple entities (usually called "reactive" agents) to more complex ones ("cognitive" agents). The easiness with which modelers can also handle different levels of representation (e.g., "individuals" and "groups", for instance) within an unified conceptual framework is also particularly appreciated, with respect, for instance, to cellular automata [14].

In this work, we have chosen to use the multi-agent systems paradigm due to its effectiveness for modeling and simulation the complex systems which are characterized by a wide variety of interactions between entities which compose it. The based agent simulation provides a means to apprehend dynamic characteristics and to represent their functioning, which facilitates their study.

We will present, in this paper, a multi-agent based simulation of the electromagnetic waves propagation using Netlogo environment.

a. Netlogo

NetLogo is a programmable modeling environment for simulating natural and social phenomena. It was authored by Uri Wilensky in 1999 and has been in continuous development ever since at the Center for Connected Learning and Computer-Based Modeling. Is particularly well suited for modeling complex systems developing over time. Modelers can give instructions to hundreds or thousands of "agents" all operating independently. This makes it possible to explore the connection between the micro-level

behavior of individuals and the macro-level patterns that emerge from their interaction [2].
The NetLogo world is made up of agents. Agents are beings that can follow instructions. In NetLogo, there are four types of agents: turtles, patches, links, and the observer.

- Turtles: are agents that move around in the world.
- Patch: is a square piece of "ground" over which turtles can move.
- Link: are agents that connect two turtles.
- The observer: looking out over the world of turtles and patches.

b. Modelisation

In our simulation, we have used two agents for simulate the electromagnetic waves propagation:
Agent E and Agent H.
Figure 1 presents the class diagram of our simulation.

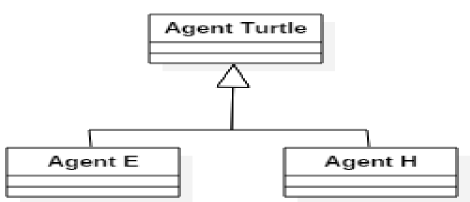

Figure 1: Class diagram of Netlogo multi-agent simulation.

- Agent turtles: the super class of all agents used. In this work, we have chosen the turtles agent types of Netlogo environment.
- Agent E: simulates the incident electric field in a nonlinear environment.
- Agent H: simulates the incident magnetic field in a nonlinear environment.

The algorithm below described the work of agent E. in our simulation, the two agents E and H work in the same way.

Algorithm to calculate E field

Algorithm: electric field (E)
Start
Initialization (initialize E)
Receive (H)
Calculate (E)
Send (E)
Return E
End

Algorithm to calculate H field

Algorithm: electric field (H)
Start
Initialization (initialize H)
Receive (E)
Calculate (H)
Send (H)
Return H
End

To simulate the electromagnetic waves propagation, the agent E (resp. H) works as follows:

- Initialize the electric (resp. magnetic) field.
- Receive the value of magnetic (resp. electric) field from Agent H (resp. E)
- Calculate the electric (resp. magnetic) field.
- Send the value of electric (resp. magnetic) field to Agent H (resp. E)
- Return the result as the way presented in the following paragraph.

4 NUMERICAL RESULATS

In order to show the efficiency of the new Netlogo multi-agent model, we present spatial variations of electrical field propagation in free space characterized by the following:

- $E_0 = 1V/m$
- $f_0 = 1.37.10^{14}\ Hz$

Fig. 2 shows the spatial evolution of the incident pulse in free space.

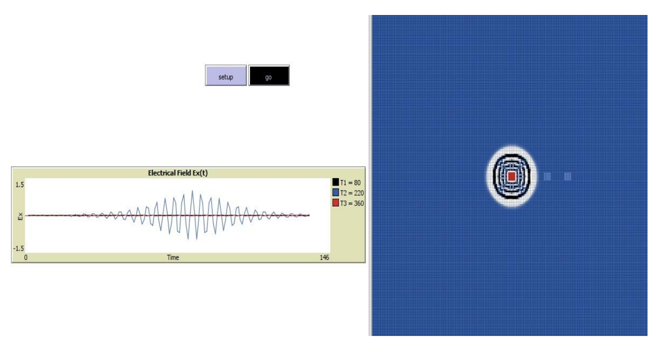

Figure 2: Netlogo multi-agent results of the incident pulse propagation in free space.

Fig. 3 shows the spatial evolution of the short pulse propagation, at time steep t=220 fs in free space.

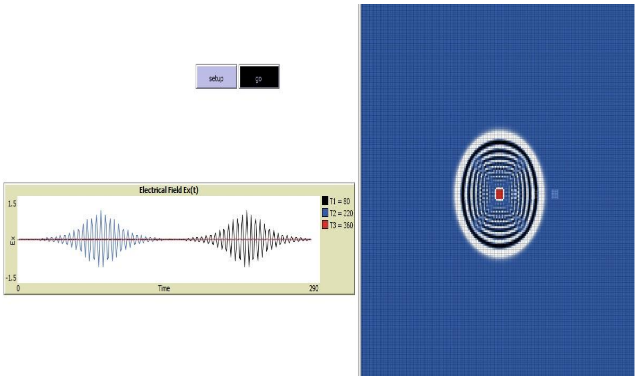

Figure 3: Netlogo multi-agent results of the short pulse propagation at t=220 fs in free space.

Fig. 4 shows the spatial evolution of the short pulse propagation, at time steep t=360 fs in free space.

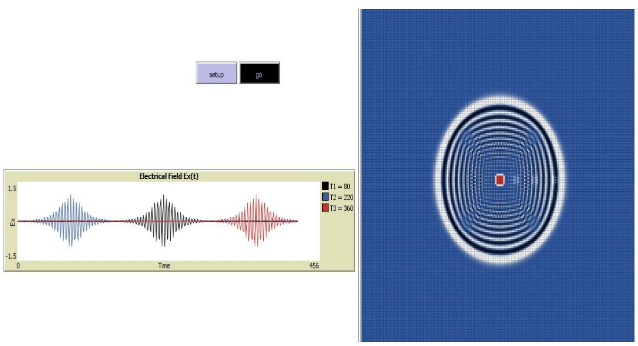

Figure 4: Netlogo multi-agent results of the short pulse propagation at t=360 fs in free space.

5 CONCLUSION

We have efficiently analyzed Maxwell's equations for modeling reflected optical pulses propagation in free space using the Netlogo multi-agent model. An excellent agreement was obtained between this model and the theoretical results.

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