Digital Ecosystems Software Modeling from a Niche Perspective

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Abstract
A digital ecosystem is a new technico-social networked platform and collaborative environment derived from properties observed in natural ecosystems. Such properties as openess, loosely-coupling, auto-organizing and niche oriented could be used to design new type of applications. In this paper we provide an ecosystem model implemented as a multi-agent system from a niche based perspective. We are introducing the concept of niche from a philosophical perspective and then provide a definition af fundamental and realized niche.
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1. Introduction

Natural ecosystems have been shown to be dynamical systems, evolutionary, scalable, that can solve complex problems without a centralized control hierarchy, with a number of interesting properties such as self-organization, self-management, scalability and sustainability. By analogy to such biological ecosystems, a digital ecosystem (DE) is defined as *an open, loosely coupled, domain clustered, demand driven, self-organizing and agent-based environment, in which each species is proactive and responsive for its own benefit and profit* [1]. The services that a DE could offer are multitudinous and heterogeneous, and currently there is no technology specifically designed to compare them and to create new services based on existing one, in this paper we make an attempt to structure these services using concept of ecological niche from natural ecosystems.

A natural ecosystem is defined as a biological community of interacting organisms and their physical environment. These ecosystems expose some key properties which make them useful in study of complex systems [2] as DE. Among these properties we consider: openess, loosely-coupling, self-organization, feed-back and self-control, niche construction and evolution. We first introduce some of these properties and ecological niche in natural ecosystems and then proceed to digital ecosystems.

1.1. *Openess*

A natural ecosystem doesn't have a clear border, the splitline between an ecosystem and it's boundaries is unclear and permeable. Although we can identify a forest, a mountain lake, a river delta, oceans stratified ecosystems as a natural ecosystems their border is very difficult to define. This systems are opened and permeable, receiving continuously flow of energy and matter from the surrounding, and exports energy and matter to the external environment. The exchange rate of energy and substance can be influenced by the species charachteristics wich populates the natural ecosystem.

In a digital ecosystem the permeability and information exchange with the outside environment will depend on the arhitecture of the system components and the digital species charactheristics wich populates it.

1.2. *Loosely-coupled*

The natural ecosystem will display interactions between both its components (habitat and biocoenosis) and the components of the biocoenosis. The question is which regulatory measures appear in situations where a species reproduce excessively and consume resources in the environment. In this cases the adjustment may come from the competition inside of the species over the resources that are more limited and from the outside due to a reaction of the prey species. There are no precise rules of adjustment, there is no direct or linear relation between cause and effect, one small cause cand produce important effects and reverse.

We can conclude that natural ecosystems are composed of loosely coupled interdependent elements that interact and influence each other, with expansion trends and control measures that lead to evolution, adaptation and identifying new niches.

1.3. *Self-organization and self-control*

Natural systems distinguish themselves through ability of adaptation, self-control and creating of new orders. The spontaneous order derived from the response to environmental pressures (extern entropy) is generally known as self-organization. Natural ecosystems possess relatively little entropy compared with the space around them. They are able to build complex structures (order) within their boundaries by diverting low-entropy input and exporting high-entropy output. Entropy is essentially a measure of how organized a system is, the number of ways in which a system may be arranged, often taken to be a measure of disorder, the higher is entropy, the higher is disorder. The digital ecosystems have similar low entropy, because agents are acting in context of restricted conditions.

Self-organizing systems are resilient, almost insensitive to disturbances or deviations and displaying a conspicuous ability to rehabilitate. By extent, the reduced threshold of deviations of natural ecosystems, and capacity to rebuild itself, results from its shared control and their redundant structure: the elements that have not been damaged resume the performance, act in concert and compensate (even rebuild) the flawed components. The control of a self-organizing system is shared within the entire system. Each composing element is part in the process, be it little or great. Digital ecosystems are self-organizing systems which can form different architectural models through group intelligence, where local interactions between agents determine the global behavior.

1.4. ***Feedback loops***

Natural ecosystems do not expose a linear evolution, namely the consequences are not proportional with the causes. A fairly irrelevant phenomenon may generate unpredictible effects. This nonliniar behaviour can only be revealed through the feedback coupling that develops amongst its elements. As part of a chain of cause-and-effect that forms a circuit or a loop, the event is said to *feed back* into itself. This sort of reliance between causes and effects is in fact typical for organizations, ecosystems, human systems, etc. This principle corresponds to the existence of loops and feedback mechanisms that occur within self-organising systems. The feedback mechanism is defined as *the influence wielded by part of the output over the input.* These mechanisms bear a significant part in any complex system. Returning a part of the output back into the system creates a self-control mechanism.

1.5. ***Ecological niche***

The ecological niche of a species represents the functional space it occupies in an ecosystem, namely the process of eating, reproducing and the cumulus of territorial behaviors of that species that cannot be shared with other species [6]. Consequently, ecological niches only partially coincide with the habitat merely designating a living space instead of all the relations that the species may have with other species and with ecosystem as a whole [7]. In other words, the habitat is the location or *address* of a species while the niche consists of their *profession.* Ecological niches condition the existence of a species in an ecosystem without being disturbed or competing with other species. This may be due to the fact that other species do not consume the same resources or have other habits that do not interfere with the species in question.

If a free niche emerges within an ecosystem, not occupied by a population, sooner or later it will deal with new populations either through means of evolution or by immigration of existing populations of species from other ecosystems. If two or more species occupy the same niche then, in conformity with competitive exclusion principles [8] one species will outnumber the other and the latter will disappear or be forced to evolve, to differentiate, and to identify a new niche.

According to Hutchinson [3], a niche is *an abstract hyper volume within a multi-dimensional space determined by the relevant environmental properties. Every part of its interior corresponds to a state of the environment which permits the corresponding species to exist indefinitely.*

For every species there is a *fundamental* niche [3,4] defined as the total hyper volume satisfying the conditions under which a species could live and reproduce, and the *realized* niche defined as the part of fundamental niche which is actually occupied by that species at a given time (because of the competitive pressure). Both fundamental and realized niches are volumes in an abstract space of environmental parameters. The physical space occupied by an organism, by contrast, sustains an actual instantiation of the realized niche of its species in some given physical location.

2. **Digital ecosystems**

According to [1] a digital ecosystem is defined as *an open, loosely coupled, domain clustered, demand driven, self-organizing and agent-based environment, in which each species is proactive and responsive for its own benefit and profit.* A DE is a socio-techno-economical system used by individuals, organizations, research groups, and knowledge creators that enable knowledge creations and diffusion, that are easier to access compared to other socio-technical systems, facilitating the user recognition by of the knowledge base they really need. In a DE human beings interact with each other and with digital agents that interact similarly among themselves.

An open environment is a transparent climate where all interactions are visible. The loosely coupled aspect refers to a freely bound and open relationship between species in the digital ecosystems. Domain clustered refers to an environment which consists of the field where some species have common interest. The demand-driven species actively shares a community based on their own interests. A self-organizing species is capable of acting autonomously, making decisions and carrying out tasks in the digital ecosystems. An agent-based environment contains human individuals, information technologies and tools that facilitate interaction and knowledge sharing within DE[24].

We define the species as the type of participants in DE who come from certain domains, follow the rules of DE, interact with other species in the same domain, are proactive and responsive, and perform their tasks in order to achieve social or economic profit. There are three types of species in DE: biological species (individuals), business and digital species. Services in the DE can involve multiple forms including personal services for humans, business services for organizations, and web services for agents [25, 26]. Agents of the digital species can play multiple roles in the DE environment, some agents play the role of service provider (server) others act as a service requester (client). An agent can be server and client at the same time. There is no centralized control structure or fixed role assignment, there is no established global architecture, and the communication and collaboration is based on group intelligence.

2.1. *The niche model*

The ecological niche receives attention from people with diverse backgrounds: ecologists, bio-techs, computer scientists and philosophers. They all emphasize different aspects of the ecological niche, use different established vocabularies, and have their preferred representation. The understanding of a digital ecosystem design can start by defining agents, their functions, domain and conditions of operation, in other words the niche. In the sequel we shall obtain a definition of niche using concepts from Formal Concept Analysis together with the concept of affordance.

2.2. *The niche model*

The original definition of affordance, given by J.J. Gibson in [9], describes all actions that are physically possible within an ecosystem. This was later adapted to describe action possibilities of which an agent is aware. Affordances are complemented by an agents capability to act on them, just like other qualities are complemented by an agents capability to observe them. By analogy to the behavior of producing observation values, we accept actions as behavior afforded to agents by environment.

Ecological characters of affordances refer to the fact that they are also relational, namely based on two or more things put together; therefore, affordances are facts of the environment and facts of agents behavior, and sets of affordances constitute niches. This implies that the a niche in the ecological sense of the word is a complex set of relationships amongst various affordances.

Gaver [10] divided affordances into three categories: hidden, perceptible and false.

- A false affordance is an apparent affordance that does not have any real function, meaning that the agent perceives nonexistent possibilities for action.
- A hidden affordance indicates that there are possibilities for action, but these are not perceived by the actor.
- For a perceptible affordance there is information observable by the agent that can lead to an action.

This means that, when affordances are perceptible, they offer a direct link between perception and action, and, when affordances are hidden or false, they can lead to fallacious results and errors.

First formal definition of affordances was provided by Turvey in 1979 [11]. Affordances are qualities [12] of the objects in the environment of an agent. This does not require the affordances to be perceived by the agent, as they can exist independently of perception. Considering the ontological nature of affordances, we can say that affordances are the qualities that emerge from a quality of an object present in the environment, inviting agents to act. Following definition of affordance is adapted from [13].

Let A be an agent and O an object in agents environment, let P be a property of A and q be a property of O.

$AF(Ap, Oq)$ is an affordance of the pair formed by agent A and object O denoted by $P(A, O) = AF(Ap, Oq)$ if and only if there is a property r such that:

- $P(A, O) = AF(Ap, Oq)$ has property r;
- Neither A nor O possess r.

Then p is said to be the efficiency of A and q is said to be an affordance of object O. Original definition of Turvey contains another clause:

$$P(A, O) = AF(Ap, Oq) \text{ has neither } p \text{ nor } q;$$

but we consider it too restrictive. The two clauses are sufficient to bind affordances and efficiencies together.

2.3. *Concepts*

Formal Concept Analysis (FCA) is a well-known technique for data analysis that involves the synthesis of a formal concept as a collection of objects that exhibit a common set of attributes. FCA offers a formalization of concepts understood in the philosophical tradition, namely where a concept is considered a unit of thought constituted by its extension and its intension[14].

A formal context $K := (G, M, I)$ is a triple where G is a set of formal objects, M is a set of attributes and I is a relation between the objects and the attributes. $I \subseteq G \times M$ is a binary relation where $(g, m) \in I$ is read *object g has attribute m* and is written gIm. A formal context can be represented as a table where the rows represent objects (G), the columns attributes (M) and the incidence relation I by a series of marks within table [15, 16].

Let be $A \subseteq G$, we define $A' = \{m \in M | \forall g \in A,\ gIm\}$.

Let be $B \subseteq M$, we define $B' = \{g \in G | \forall m \in B,\ gIm\}$.

A formal concept of the formal context K is a pair (A, B) with $A \subseteq G$, $B \subseteq M$, $A = B'$, and $B = A'$. The sets A and B are called the extent and the intent of the formal concept (A, B). The set A can be considered as a set of objects (instances of a class) and set B – the class definition (a list of attributes common to all instances). The concept (A_1, B_1) is a subconcept of concept (A_2, B_2) denoted by $(A_1, B_1) \leq (A_2, B_2)$ if and only if $A_1 \subset A_2$ (or equivalent $B_1 \supseteq B_2$).

The set of all formal concepts of K together with the order relation $\leq$ is always a complete lattice denoted $B(K)$. For a set (A_i, B_i) of formal concepts of K the greatest subconcept, the join, and the smallest superconcept, the meet, are respectively given by:

$$\bigvee_{i \in I} (A_i, B_i) = ((\bigcup_{i \in I} A_i)'', \bigcap_{i \in I} B_i)$$

$$\bigwedge_{i \in I} (A_i, B_i) = (\bigcap_{i \in I} A_i, (\bigcup_{i \in I} B_i)'')$$

The concept lattice provides *hierarchical* conceptual clustering of the objects (via the extents) and a representation of all implications between the attributes (via its intents). The subconcept - superconcept relation is transitive, which means that a concept is subconcept of any concept which can be reached by traveling hierarchy upwards from it. If a formal concept has a formal attribute then its attributes are inherited by all its subconcepts. This corresponds to the notion of *inheritance* used in the class libraries of object-oriented modeling.

3. Niche in Digital Ecosystems

3.1. *Fundamental niche*

Let T be a formal context with associated objects and properties (T is given by the problem about to be solved). To resolve problem T we will define the concepts of niche, agent, species and community of agents within a DE.

Let N_T represents a fundamental niche within the DE and S_T (a species associated with niche N_T) is a the set of agents programmed to solve the problem:

$$S_T = \{A | A := (Agent_T, N_T)\}.$$

N_T is defined as a touple:

$$N_T = (Con(T), Aff(S_T), Res(T)),$$

where $Con(T)$ are concepts of formal context T, $Aff(S_T)$ are affordances set defined by problem for species S_T, and $Res(T)$ are data processed and produced by agents (could be databases, fraglets [17] or other types of data consumed by agents).

Let's consider N_T a fundamental niche and a species S_T defined to execute in N_T. A DE is defined as

$$DE_T := (S_T.N_T).$$

3.2. ***Realized niche***

A many-valued context [15] is a set structure $K := (G, M, V, I)$ where G, M, and V are sets and I is a relation between G, M , and V $(I \subseteq G \times M \times V)$ such that $(g, m, v_1) \in I$ and $(g, m, v_2) \in I$ always imply $v_1 = v_2$. The elements of G are called objects, M is a set of attributes, and V are attribute values. A tuple $(g, m, v) \in I$ is read: *the object g has the attribute value v for the attribute m.* An attribute m may be considered as a (partial) mapping from G to V, therefore one may write $m(g) = v$ instead of $(g, m, v) \in I$.

A conceptual scale for an attribute $m \in M$ is a one-valued context $S_m := (G_m, M_m, I_m)$ with $m(G) \subseteq G_m$. The context $R_m := (G, M_m, J_m)$ with $g\, J_m\, n \Leftrightarrow m(g)\, I_m\, n$ is called the realized scale for the attribute $m \in M$. We assign to each attribute $m \in M$ a conceptual scale S_m which is defined as a formal context $S_m := (G_m, M_m, I_m)$ with $m(G) \subseteq G_m$. The choice of these scales is a matter of interpretation. The task is to select S_m in such a way that it reflects the implicitly given structure of the attribute values.

The many-valued context $K = (G, M, V, I)$ together with the family of conceptual scales $S_m := (G_m, M_m, I_m)$, $(\forall m \in M)$ define the realized formal context:

$$RConK = (G, \bigcup_{m \in M} \{m\} \times M_m, J)$$

with relation J defined with:

$$\forall g \in G,\ (m, n) \in \bigcup_{m \in M} \{m\} \times M_m,\ g\, J\, (m, n) \in m(g)\, I_m\, n$$

A realized niche RN_T is defined as:

$$RN_T = (RCon(T), Aff(C_T), Res(T)),$$

where $RCon(T)$ is the realized context of many-valued context context T, $Aff(C_T)$ is a set of affordances associated with community of digital agents C_T, and $Res(T)$ is a collection of data processed by community.

Let's consider RN_T a realized niche in the DE, a community C_T in DE is a species active in RN_T niche. The community of agents C_T active within their a (realized) niche define a running instance of digital ecosystem

$$DE_T := (C_T, RN_T).$$

The agents that form a community are active and can directly or indirectly communicate with each other or through the environment (acting on niche). The agents can also communicate with members of other communities.

In the sequel we propose a simple algorithm (a sketch) for defining a DE, the structure of agents is omitted. A DE algorithm can execute until all resources are consumed or until we can deliver an acceptable result to a concrete query.

3.3. ***Basic algorithm***

- CON: concepts of problem T;
- RES: Resources;
- AFF: Affordances;
- N_T: is the niche;
- S_T: agent type with a niche of type N_T;
- C_T: Comunity of agents;

```
Start;
Initialize niche;
Initialize resources;
Initialize community C;
Register agents for affordances;
StartCommunity;
while( RES )
{
        Wait for results;
        EvaluateStatus;
        If(result)
                Break;
        Create new Agents as needed;
        or KillAgents as needed;
}
Stop.
```

An implementation of the previous algorithm is under development for a digital ecosystem prototype system for retrieval of mathematical content from web resources.

4. **Conclusions**

A digital ecosystem is a new network and collaborative environment that goes beyond traditional applications, models like client-server, peer-to-peer and web services, it transcends the traditional collaborative environments from centralized, distributed to an open, resilient, interactive environment. This paper has discussed general issues about digital ecosystems from a niche perspective. The results suggest that incorporating ideas from theoretical ecology can contribute to model digital ecosystems. There is huge potential to take proper scientific concepts (like fundamental and realized niche) used in ecological research, and apply them into digital world in reasoning about resources, run-time environment and behavior populations of digital agents.

Niches represents for digital ecosystems what input data represents for traditional programs. Niches can play the role of output, as agents' actions can lead to changes in the environment and therefore in the niche. Once changed, we believe that new niches are created that in turn can induce activation of other populations of agents.

Using FCA and concept lattices in building niches in digital ecosystems provide a number of advantages in study of niches. Using FCA in combination with Conceptual Graphs and Description Logics can be used to model concepts, judgments and conclusions. The structure and properties of the digital niches specific to different domains is a topic for future research. Using these tools in the study of structure and properties of digital niches, specific to different domains is a topic for future research.

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