Immersive Analytics for the Ecological Cognitive Stimulation Approach

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Abstract. The continuous attenuation of the old people's cognitive functions is one of the most common problems encountered nowadays. However, the absence of curative treatments for the mild cognitive impairment like Alzheimer's disease pushes the specialists to propose alternative solutions, for medicinal treatments, which can be based on tele-operating robots, remote monitoring platforms and software applications for cognitive stimulation.

In this paper, we move from the classic cognitive methods of the stimulation related to the old person to ecological solutions that exploit the person's data to propose adaptive activities. Ecological solutions use environment, connected objects data and person profile, for building activities of the cognitive stimulation that adapts to the corresponding situation. To build activities, efficiently, we propose to exploit immersive analytics potential to analyze and visualize the available huge amount of data through constructing virtual environments for the simulations, leading to better decisions that may influence the life of the persons.

Keywords: Cognitive stimulation · Immersive technology
Personal assistance systems · Application of cognitive stimulation

1 Introduction

The continuous reduction of the cognitive functions of the old populations is one of the most common problems nowadays. This fact requires a solution to understand better its difficulties and to remedy it in a playful way [6]. Moreover, the absence of curative treatments for the MCI (Mild Cognitive Impairment) or the disease of Alzheimer pushes the specialists to propose some other techniques more suitable than the medicine for the reorganization and the increase of the connections between neurons as well as the activity of the neurons mediators to the old brain [19]. In this context, the Cognitive Stimulation (CS) has been developed as no-medicinal practice [8] to stimulate and to protect as long as possible the cognitive and social capital of people. Also, it's necessary to find the capacities altered further to traumas or pathologies. It is a proposed solution in the programs of assistance and care as workshop memory [16, 39] to people affected by disorders of the cognitive functions associated with the age and/or to the neuron-degenerative diseases [19, 34]. There are different methods used with the CS. They are

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all poor in integrating the ecological aspect that takes into consideration the natural environment of the person and the collaboration of different actors to propose the appropriate activities.

In this work, we propose a new approach that mixes the *ecological* cognitive stimulation with the immersive analytics. It has the capacity to adapt to the context and to the profile of the patient in a transparent and natural way based on the cognitive stimulation activities. Concerning the immersive analytic, it is an emerging research thrust. It investigates how new interaction and display technologies can be used for analytic reasoning and decision making. These technologies can correspond to touch surfaces, immersive virtual and augmented reality environments, sensor devices and other, rapidly evolving, natural user interface devices [4]. It is based on tools and techniques of interaction and collaboration. It allows people working and discussing together to understand better the complex and large-sized data in order to ensure the analytic reasoning and the perception of the data to take an adequate decision for the person and his difficulty mentioned [10, 13, 17, 35]. We propose its integration in our work for the following reasons: the necessity of collecting and visualizing data to the elderly person to stimulate his surrounding, the necessity of the interaction and the collaboration between the different actors (local at home and away) to analyze the collected data by different devices and to make an adaptive decision related to the specific situation, and the necessity of perceiving, sometimes, a cognitive activity as a natural activity using the virtual reality.

To achieve our goal, the environment of the patient is equipped with connected objects, with software and possibly with a set of actors and the immersive environments. Based on the collected data, we propose to the concerned person a set of CS activities according to his state, his profile, his environment and his habits.

The originality of our article is related to the construction of CS activities from elements of the person's environment and cooperation between the *ecological* approach and the use of the tools of the immersive analytics, which is based on innovative techniques to offer to this person a service of a CS at home "*ecological ambient*" and reliable by the collected data analyses which are circulated between different actors of our system, to build, as a consequence, an adaptive activity in the detected situation.

Our present article is organized as following: The second section introduces the domain of the CS in terms of knowledge and existing computing tools to execute the services of the CS. It introduces also some of existing tools and techniques related to the immersive analytic. In the third section, and from the limits of exciting cognitive stimulation methods, we define our contribution. We propose a global architecture and our approach in the fourth section. Next, we treat in detail an example of ecological scenario "Deliverer Pizza", to finish with a conclusion and some perspectives.

2 State of the Art

In this section, two main points are treated. The first one is related to the existing methods of cognitive stimulation. The second one is related to the solutions of the immersive analytic.

2.1 Methods and Means of Cognitive Stimulation

The objectives of CS are multidisciplinary [5, 26]. They are based on two plans. The first one is cognitive [38] such as: maintaining of the residual cognitive resources, optimization of the cognitive functioning (memory, language, and attention), diminishing the learning process, improvement of the performances as well as diminishing the evolution of the Alzheimer's disease. The second one is based on psychological and social order [14] such as: the strengthening of self-respect, the preservation of an optimal autonomy, the transfer of the performances in the patient's daily activities and the optimization of the social dimension (motivation, sociability).

The cognitive methods and the means of the stimulation, dedicated to old people who suffer from disorders, cognitive light such as novice Alzheimer or MCI which are accommodated either in EHPAD (Establishment of Accommodation for Dependent Elderly) or at home, are various compared to the evolution of the technologies.

In the beginning and in institutions (hospitals or retirement home), the CS corresponds to workshops realized by a group of patients [37]. Those groups are animated by the psychologists or other specialists who propose a set of the cognitive exercises closer to the everyday life [25]. The starting up of the exercises and the activities of the CS are with the so-called method "Pencil-Paper" (cards) which is the oldest and the simplest. This method was used by the occupational therapist Amélie Wallyn who worked with the team ESAD (Specialize Alzheimer team and Related diseases at home), the specialist of the orthophony Annie Cornu and the specialist in gerontology Emmanuelle Goury and the author of the work "Workshops' Memory" [12].

The applications and the systems announce the passage of the most classic cognitive methods of the stimulation with "Pencil-Papers" to new information and communication technologies and the therapeutic implementation of the new tools within the framework of the no-medical coverage of the patient reached by neurodegenerative disease.

The CS applications and systems search to stimulate cognitive functions in old people affected by cognitive disorders, but they do not have the same methods and techniques for implementing CS services [9, 24].

There exist the most famous applications and software used in institutions, hospitals which offer different formats of service of the stimulation cognitive as electronic mail, games, calendar and directory of contact such as: PRESCO, Tvneurones, "Mots de tête" [24], "Ateliers memoire" [28], "Les Senteurs de la maison et du jardin" [28], "MonAgenda Memoire" [19], ACTIVital [24, 29–31], Cognifit [33], Stim'Art [22] and kwido [23].

We also give an overview on new technologies and robotics in the field of personal assistance which purpose is the stimulation of cognitive functions, for example MemAlz [9], QuoVADi [15], CompanionAble [21], ROBADOM [41] Nabaztag robot [41], TANDEM [32] and project TIPATSMA of the touch pad [11]. Globally, these systems are based on robots as well as on platforms of assistance to take care after the elderly, to help the patient to find his bearings in time and space, to facilitate the communication with the surrounding and the security in case of risk or wandering, and to improve the quality of life of patients and caregivers.

2.2 Immersive Analytic

Immersion is characterized by the implementation of techniques, giving to perceive, to the use of artificial sensory feedbacks that are sufficiently realistic and ecological from perceptive point of view to provide the patient with the illusion to be immersed in a virtual world [38].

The information presented in the virtual scene during the immersive experience can be addressed to several sensory channels, mainly the visual and auditory ones, but can also mobilize of another sense [2].

The immersive environments are used in the situations where there are big quantities of data that require being visualized and analyzed with developed technologies in an interactive context and collaborative environments to drive a tack of decision afterward [38]. Many immersion techniques are proposed in literature. They offer to use the possibility of becoming an actor of the virtual world where it gives him the possibility to interact with the virtual components [18].

Immersion can reach a higher level when it uses CAVE (Virtual Automatic Environment) [3]. This system consists of series of projectors that project picture on 3 to 6 sides of a cube having the size of a room [38]. It allows seeing objects or people in 3D, floating in the air and can even move around as if they were physical objects. The CAVE system is equipped well with speakers installed at angles. It can reproduce a sound environment as well as motion sensors. Infra-red cameras are used as trackers and a computer, which is coupled with a projector in 3D, is necessary for every wall to calculate in real time the picture to be projected according to the movements' user. A central computer is used to calculate the movements of the user and adapt the video to his movements [27]. As advantage, the system tracking of CAVE allows a strong interactivity of the user of the application who can see his body in particular his hands and his arms [27]. Figure 1 gives a general conception of CAVE.

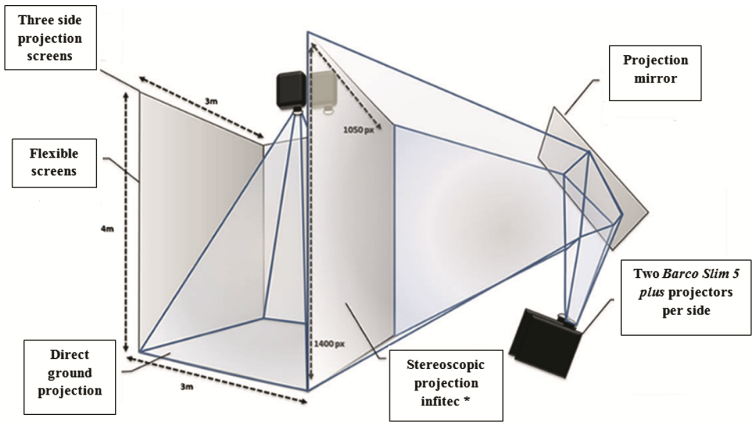

Fig. 1. General conception of CAVE [34].

3 Limits of Exciting Cognitive Stimulation Methods

The methods of cognitive stimulation are diverse and evolved with the evolution of the new technologies whether the person is housed in EHPAD, or at home. In the classic therapeutic methods, activities use traditional methods with "Paper and Pencils", or the information and communication technologies and the applications of cognitive stimulation. The applications and the current cognitive systems of stimulation pursue the same objectives as the classic methods. They try to offer various services to facilitate everyday life and maintain the cognitive functions of the person.

Based on the literature review on the different methods and the technique existing, we notice that they have limits which require improvements to meet the needs of an elderly person with cognitive impairment. We can give as example:

- The flow of the cognitive stimulation is frequently in EHPAD, consequently, the transfer of skill of the institution to the home is not proven;
- Certain patients refuse the presence to the cognitive trainings;
- the control of the therapeutic session by animators, hinders the level of the intimacy of the person;
- The proposal of the different exercises (multi-domain cognitive and different levels of difficulties). They are intended for the professionals and the representative of health who are always the intermediaries between the patient and the proposed exercises;
- The absence of adaptation to the profile of the patient;
- The absence of interaction between the different actors and the elements of the environment;
- The absence of reactivity, which is itself based on the interaction between the environment and the system of therapy;
- The absence of cooperation between the different agents of different cognitive domains related to the activities of the cognitive stimulation to propose the same cooperative solutions;
- Dependence of the objective of the cognitive stimulation activity on only the result obtained;
- The inter-dependence between the different stages of an exercise that requires the best answer to move on to the next stages.

As a solution, we propose a new method of the CS. It integrates the elements of the natural environment of the patient and the new technical of the immersive analytic which offers the interactive and collaborative aspect between the different agents of our system as well as the different devices of recognition of the movements and the gestures of the person.

4 General Architecture

The development of methods of assistance and cognitive stimulation to old people requires innovative communication methodologies that move beyond traditional tools

and their limitations. Among these tools, we offer an Immersive Virtual Environment (IVE) technology that offers the potential benefits of understanding how individuals perceive and respond to build and natural environments [36]. These technologies complement the most traditional methods used in public health research [36] and more specific in the field of psychiatry and personal assistance services. In this context, we take the example of the ATOLL (Test-Apartment Oriented Living Lab) method in 3D (home in 3D) which goal is to facilitate the environment virtual life of the patient and his entourage, the adaptation and the technical and material assistant in his house [1].

Our proposed architecture is based on a set of physical and software actors which goal is to help the old people in their daily lives in a natural and transparent manner (talking about a multi-agent system), a knowledge base and devices of display and collections of the data (connected objects). Also, it integrates the immersive technologies because they have the ability to replace static concepts (exp. images) with dynamic ones that ensure the observation of individuals on the ground to achieve meaningful relationships [36] and to prove the ecological aspect (the realistic representation of an environment) [40].

Our architecture uses two types of the virtual environments: groups of different actors related to the system to offer the possibility of collaboration and interaction for analyzing data coming from connected objects to build cognitive activity adapted to the profile of the person and to the detected problem, and a second supports the visualization and processing of a cognitive activity.

Figure 2 presents our solution that is composed by actors and following devices that build the patient's natural environment:

- Physical actors: patient, doctors and human agents (delivery person, friends, family, …);
- Software actors: are the components of the MAS and are the responsible for the interpretation of the data and the decision. They perceive and interact with the environment of the person to propose an activity:
  - *Follow-up* agents: are associated to the connected objects, interpret the data sensors and transmit sensor data to *Cognitive-Domain* Agents;
  - *Cognitive-Domain* agents: receive messages from *Follow-up* agents, identify problems, consult the basis of symptoms of problems and transmit the report to the *Execution* agent;
  - *Execution* agent: receives an analysis report of the problem of the *Domain-Cognitive* agents, propose and start the cognitive and request additional information to agents;
  - *Evaluation* agent: receives from the *Follow-up* agent, the information of change of state of the patient, determine the state of the patient, evaluate the activities of the patient and provide the *Execution* agent with the recommendations to propose a new activity.
- Connected objects: Motion sensor, Sensors of emotions, Location sensor, Other devices and Smartphone applications;
- The CAVE virtual reality system:
  - Is used by the medical staff to analyze the clinical condition of the patient at distance by using the Mapping Cognitive Function with Subdural Electrodes and

Registration of Cerebral Evoked Potentials on 3D MRI. It is an example of sensory evoked potentials mapped onto a 3D surface model of a human head. It is efficient at revealing the global spread of activity in the brain and recording voltage potential measurements over brief time intervals [7];

- Mixes real and virtual objects in the same space so that a person has an occluded view of his own body when interacting with virtual objects. So the second utility of CAVE in our solution is to offer to our patient the opportunity to navigate in the large spaces where his whole body is in the virtual space;
- Uses the Walk-through architectural [7]. Its models are stored in the standard DXF file format. This architecture adds a DXF-CAVE translator to bring these models into CAVE. This translator interprets the data and matches it to the geometry of CAVE. It is possible, then, to represent the model of a house with several furnished rooms. This is achieved thanks to the software actors and the connected objects that give enough information about the physical space;

The patient can navigate the space by physically walking through the CAVE or by using the baton as a control device to move over greater distances [7].

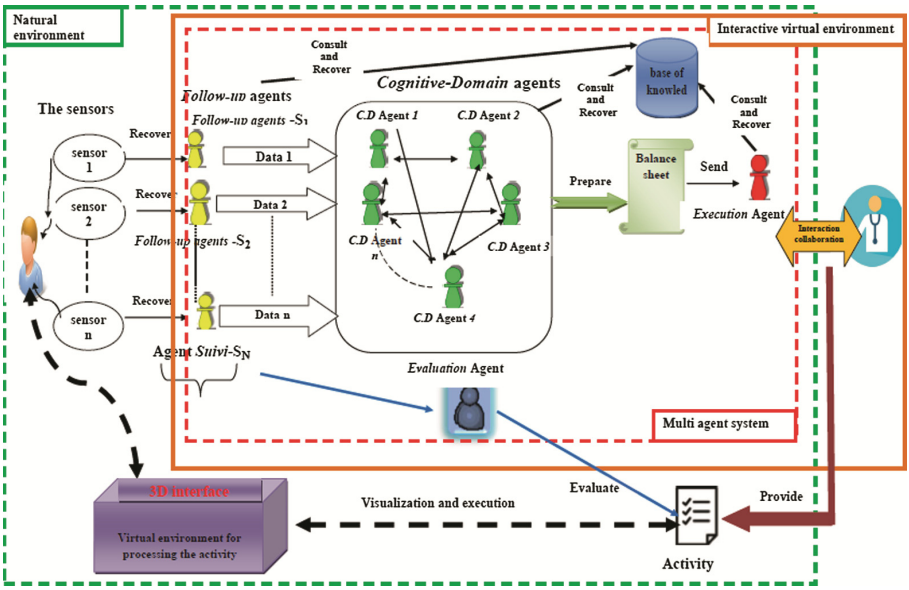

Fig. 2. General Architecture

Our system is based on different data from different sources. These data are interpreted and analyzed by the different actors of our system up to proposing the adaptive activity. Based on [20], we propose in our approach 4 data levels as presents in Fig. 3:

– Physics Level: are the raw sensor data. They are collected by different objects connected to the environment and sent to other types of receiver (*Follow-up* Agents) for the interpretation;

- Information Domain level: corresponds to the interpretations. It is about 2 levels; the first one corresponds to the data sensors of the agents *Follow-up* and the second one to the agents *Cognitive-Domains* that interpret the data sent by the agents Follow-up to give afterward its synthesis (Information). In certain cases, we need the intervention of the *Evaluation* agent at this level;
- Knowledge domain level: the information provided by the synthesis of the second interpretation is transformed into knowledge by the intervention skills of every *Cognitive-Domains* agent to identify the detected cognitive problems (cognitive report);
- Reasoning level: the responsible agents (*Execution* agent and *Evaluation* agent) are based on analyses and previous interpretations to propose the adaptive cognitive activity in the context and in the profile of the person.

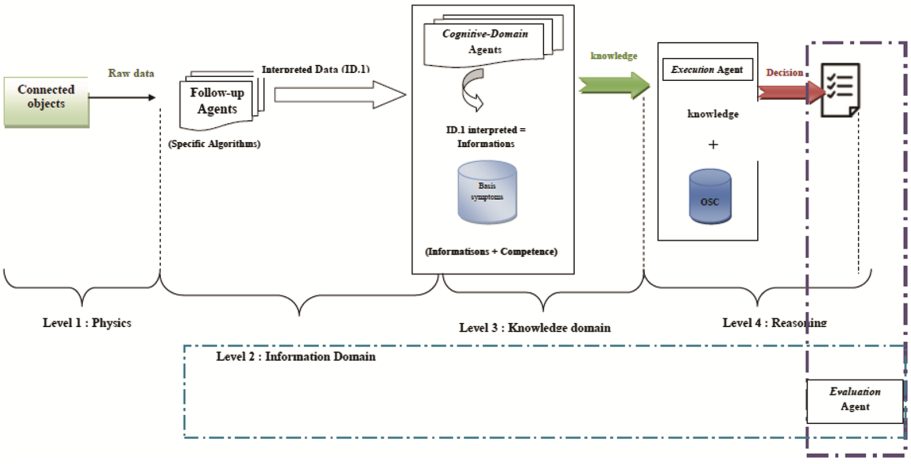

Fig. 3. Data Representation

5 Illustration of an Ecological Scenario of CS

To clarify our approach, we illustrate an example of an ecological scenario, which consecrates the CS activities from the natural environment.

5.1 The Description of the Patient

Let us take the case of an 80-year-old retired teacher. He is clinically considered as a person MCI. He has a light trouble in his memory and his attention because of his age and the problems accumulated during his professional career. He lives alone because his children are very far and they do not visit him during the holidays.

5.2 The Ecological Scenario

Our patient stays in his housing environment to keep the relation with the elements of his environment and to feel concretely the interaction with them.

The habitat environment is equipped with devices of motion recognition and the gesture and agents (physical and software).

We imply the exercises of the everyday life of our patient and we describe his concrete situation. We propose, then, that the person, after preparing his lunch, goes to the living room. He notices that there is an SMS on his telephone, but he cannot read it. The patient looks for his glasses to read the SMS, but he does not find them. He, unsuccessfully spends more than 10 min looking for them.

In such a situation, the sensors of movement (Leap Motion) record several movements of the patient in different places of the house. The emotion sensor provides information indicating that the patient is stressed. This data is retrieved by the *Follow-up* agents associated with the sensors. The report was made how at some point; the person has been nearby its glasses without paying it attention.

The data-sensors interpreted by the *Follow-up* agents are sending to the agents of Cognitive Domain. Every agent of *Cognitive-Domain* receives the data and consults its base of symptoms to identify the detected problem.

Then the *Attention* agent cooperates with the *Memory* agent to produce a report to the *Execution* agent.

The *Execution* agent decides to use objects that draw the attention of the patient to locate his glasses. A message sent by the *Execution* agent to the sound sensors placed on the glasses. The patient realizes that the sound comes from the kitchen, he goes to the source of the sound and finds his glasses and read finally his SMS.

At this moment, the patient realizes that the salad planned for his lunch is not enough. He decides to buy a pizza.

The difficulty is that the patient cannot phone to the pizzeria. He unsuccessfully keeps on trying to find the phone number of a pizzeria. The person loses patience, which is noticed by his face expressions. Usually, the movement capture's data, emotions and the *MonitoringOperation* application's data which is installed on the Smartphone of the patient, will be sent by the *Follow-up* agents to the *Cognitive-Domain* agents of the multi-agents system.

Moreover, once the agent of cognitive domain consults its base of symptoms, the *SocialLink* and *Memory* agents intervene. They produce a report, which is sent to the agent *Execution*. The latter proposes to display in touch screen on the wall, the phone directory of the person who contains picture of 3D contacts. From than the person clicks on the picture, the number will be displayed. In the 2nd click, the person can call the deliverer of pizza and pass one command as it is shown in Fig. 4.

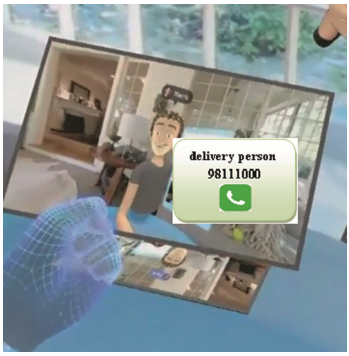

Fig. 4. Example of an animated directory

After the delivery person arrived with the command and has given the invoice to the patient, the latter looks for his means of payment. After 10 min, the delivery person gets impatient. Indeed, the person was incapable to assemble the required sum to pay his invoice.

The patient returns to the delivery person, stressed and desperate; according to the data sensors which is registered by the Follow-up agents and sent to the Cognitive-Domain agents. The latter registers the data, identifies the problem, but, decides to postpone the sending of the report to the Execution agents (of an activity) at a moment when the patient will be in better condition.

Consequently and because the person is a regular customer, he puts the person in confidence and helps him to collect the due sum.

At the end of the day, the Follow-up agents consult and retrieve the data from sensors of state of the patient to know if the emotional state of the patient changed. The sensor of emotion informs that the patient is comfortable and calmed.

The new data is sent towards the Cognitive-Domain agents. The Memory agent and of SocialLink identifies that the met problems during the day are related to the domain of the memory and the social links because for a long time the person does not manage to go out of his habitat and is met by people to talk of degenerative osteoarthritis in the knees. The 2 agents send the balance sheet to the Execution agent. The Execution agent decides to leave the person lives outside his house, but virtually. By the means of the virtual environment CAVE, the actors of the system propose a view of a park where there are the children of the person who are present virtually to speak together and get amused during 45 min (see the Fig. 5).

Fig. 5. The proposed virtual cognitive activity

The table below (Table 1) describes an example of instantiation of the "Deliverer Pizza" scenario data with the actors presented previously.

Table 1. The background of every agent in the scenario "Deliverer Pizza"

Connected objects	*Follow-up Agent*	*Cognitive-Domain* Agents	Delivery man
- Sensor-location: (X, Y) - Sensor-movement-foot: 3 (standing vertical) et 0 (no movement) - Sensor-emotion: Bracelet: 80 pulsation/mn, 25 cycle/mn et17 mmhg Infrared camera: eyebrows downward, eyelids inferiors upward and lips firmly pressed	- Patient in his room since 5 mn - Stable patient (0) - Patient is stressed and/or sad	- Difficulty in developing the techniques of learning exploiting the memory-preserved abilities of the patient - The difficulty doing a mental calculation by storing a few moments the intermediate calculations before giving the final result Report (Reporter sends it) Cognitive domain: Memory Broadcasting mode: Asynchronous	Assist the patient to assemble the due sum

6 Conclusion and Perspectives

The number of old people with mild cognitive disorders light is important. They need a real assistance in their life. For this reason, we have proposed, in this work, an ecological cognitive stimulation approach that remedies the disadvantages of the classical method. The latter presents several disadvantages as discussed previously.

The ecological cognitive therapy uses elements of the natural environment. It builds specific activities related to the corresponding patient based on the data sent by the connected objects. We have improved this therapy by integrating the immersive analytic.

The latter offers the capacity of simulating the environment of the patient using different software actors as well as connected object to well understand his behavior.

As perspective, firstly, we propose analyzing the collected data to make right decisions related to the patient's situation. Secondly, we propose generating automatically from the knowledge base, the ecological scenarios.

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