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Autonomous GIS Agents

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Intelligent agents are a result of AI research beginning in the late 1980s to early 1990s [8]. Today, these agents are used in a variety of forms within the field of Geographic Information Science (GIS). What I aim to contribute to the field with this writing is a summation of what describes these agents, and walk through two common utilizations of them in our field. But first, it is only right to flesh out the following question: What is an agent? Pattie Maes [5] defined autonomous agents broadly, but intentionally so, because truthfully, agents are everywhere:

"Autonomous agents are computational systems that inhabit some complex, dynamic environment, sense and act autonomously in this environment, and by doing so realize a set of goals or tasks for which they are designed."

She goes on to describe several forms that an autonomous agent can take on, one of which she calls "knowbots," or software agents, as opposed to artificial life agents. Next, I will be noting the properties of these agents, so that we might have a framework for understanding them. Li et al. [7] lay out 4 essential properties of agents:

1. Autonomy: human intervention is not necessary when the agent is performing
2. Interactivity: agents can communicate with humans and other agents somehow
3. Reactivity: agents can perceive, adapt and react to their environment
4. Proactiveness: they do not only react, but are able to be driven by some innate goal

Some agent techniques have additional properties, but the properties listed above give us the basis for understanding agents in different forms. Many agent researchers have contributed their own definitions of agents to fit their agenda. I think it only makes sense to sift through some of the other agent definitions that are out there to get a feel for the span of definitions that exist.

Shahriari and Tao [9], define an agent as

"...a computational entity which acts on behalf of other entities in an autonomous fashion; performs its actions with some level of proactivity and/or reactiveness; and exhibits some level of the key attributes of learning, cooperation and mobility."
They also provide the same properties as Li et al., leaving out "interactivity."
Franklin and Graesser [2] made a point to distinguish between autonomous agents and computer programs, and define autonomous agents as:

"a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future."

They go on to say that all software agents are programs, but not all programs are agents due to the special properties of an agent. They also provide more properties that an agent can embody, such as: temporally continuous learning, mobile, flexible, character. For our purposes I am going to assume that agents must have the original 4 properties laid out by Li et al. [7], but also acknowledge that they can embody other properties that might classify them as a different type of agent.

Throughout my research of this topic, Artificial Life Geospatial Agents (ALGA) and Software Geospatial Agents (SGA) were often judged side-by-side because they are two commonly used forms of agents that exist in the field. Sengupta and Sieber [8] put it best when they said "Since their inception, agents have become a popular technology for a variety of computer applications, ranging from managing human-computer interactions to simulating social interactions."Artificial Life Geospatial Agents are models that simulate behavioral responses of an entity (the agent) to its external stimuli. Their responses are the output of methods such as: genetic algorithms, heuristic methods, reinforcement learning, game theory, linear programming, etc. These agents would be ones that simulate social interactions. Figure 1 conveys a visual representation of agent-based models, in which these ALGAs live. In contrast, Software Geospatial Agents are created to act independently on behalf of a user, another software agent, other software, or hardware. These agents are task-driven. They can manage human-computer interactions. Franklin and Graesser [2] explain that both ALGAs and SGAs are "situated within and a part of an environment that senses that environment and acts upon it, over time, in pursuit of its own agenda and so as to effect what it senses in the future."

One such application of an ALGA was performed by Falco et al. [1], for the purpose of energy analysis. These researchers used an agent-based modelling approach to simulate the utilization of electric vehicle (EV) driver's (agents) usage of the electrical distribution grid. The drivers have a set of actions to fulfill routines, many of which involve driving their EVs (objects). A probability distribution function determines the travel path characteristics. They exist in an environment which consists of an electrical network, road network and city structure.

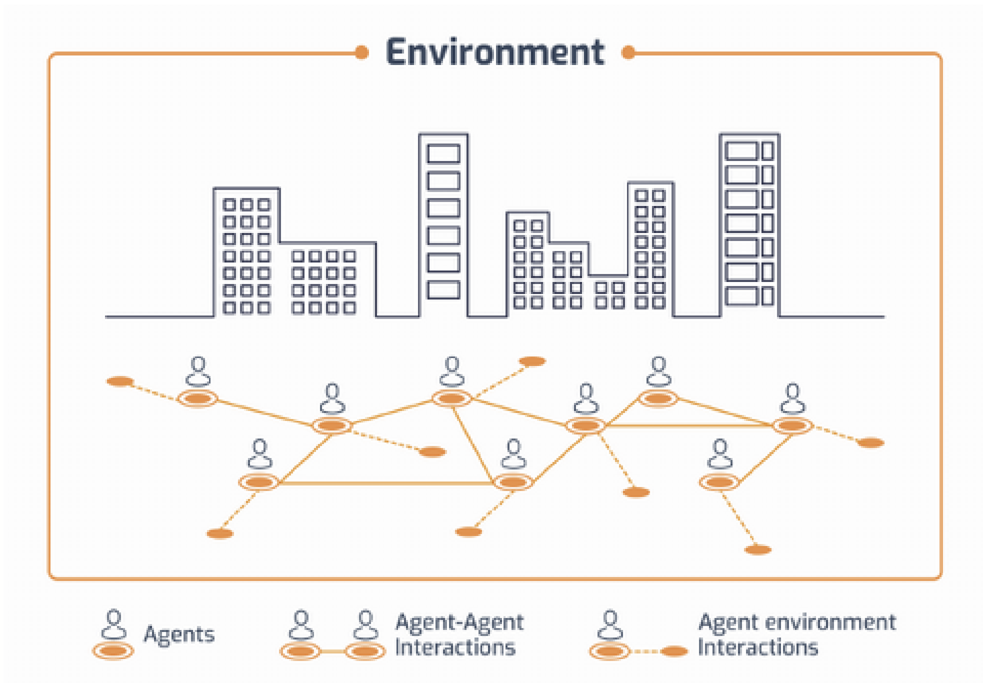

Figure 1. Ramadiah, A., Galbiati, M., & Soramaki, K. (2021). Agent-Based Simulation of Central Bank Digital Currencies. SSRN Electronic Journal.

Next, I provide some examples of Software Geospatial Agents, but know that there are many more. Oftentimes these agents have different capabilities and frameworks.

Applications of SGAs:

- LLM-Find
    - (Ning et al., 2025)
- GlobeFlowGPT
    - (Kononykhin et al., 2024)
- LLM-Geo
    - (Li & Ning, 2023)

LLM-Find is a geospatial data retrieval agent that uses GPT-4o as its decision core. It is able to select a source and generate the Python code necessary to fetch the data. To do this, there is a source index with source names, descriptions, and a handbook inventory with technical data fetching instructions. GlobeFlowGPT is an agent that was made to perform geospatial analysis and interpretation. It is made up of four components: a database with datasets, LLM orchestrator (based on GPT-3.5), a tool pool for various geospatial task performance, and an MLLM for visual output and interpretation. LLM-Geo is an agent that can break down a spatial question into a set of sequential tasks and combine the tasks to get at the more complex questions that might be asked of it. GPT4 is at its core, and its execution takes place in a Python environment. The user needs to provide the datasets alongside the spatial question. LLM-Geo is able to generate requested visualizations.

All of these agents are functioning on some set of rules or instructions fed to them, even the ALGAs that are used in many different fields. All three of these SGAs are autonomous in the sense that the user feeds it something initially, whether that be a spatial question or some input data, and these agents run until they provide some output for the user. We know that they are interactive because they can take in some natural language query, decipher it, then determine how to break down the problem in order to perform the task. They are reactive in that they can accept a query and, in the environment where they operate, perform the steps that it thinks are necessary to achieve the unique task, treating different queries slightly differently.The proactivity of SGAs can be proven because they have shown that they can be somewhat successful in their own case studies, where they were goal-oriented enough to retrieve data, produce a map, or produce an answer in natural language when asked.

How do the ALGAs measure up to the very meaning of being an agent? In the energy analysis application, we understand that the drivers (agents) of these EVs operate on a set of possible actions that can be taken. Once these rule sets are determined, the drivers become autonomous entities within their model environment. These agents interact most importantly with the electrical network to recharge their EVs, potentially overwhelming the system from time to time. They have to react to certain environmental elements that are dynamic throughout their individual routines. These drivers are proactive in the sense that they have a set of actions, some of which they will perform on a given day, and in doing so, they will fulfill some routine as part of the simulation.

There appear to be similarities in the use cases of both of these types of agents that occupy the field. We are able to utilize these agents because they operate on a set or multiple sets of instructions/rules that are fed to them by subject matter experts. We know the steps required to compute certain algorithms that make up the agent’s decision making core, and we know what task(s) are needed to answer various spatial questions. An agent is filled with the body of knowledge that we actually obtain, and they can operate on that knowledge independently of us, adding an element of uncertainty which helps to expand our minds to certain possibilities.

When using these agents, humans are important to the synthesis of the outputs and the validation of them. Ultimately, we can use these agents to make GIS more accessible and approachable, or “easy,” as Zhu et al. [10] would put it. However, we still need the very critical human work to understand what the output means and what kind of action it requires.

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