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LLMS - The Death of GIS Analysis?

An Investigation into Using Large Language Models
to Make GIS Analysis Simpler, Faster, and More
Accessible

Specialization Project in Computer Science and Geomatics, June 2024

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Abstract

Sammendrag

Preface

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Contents

Abstract	i
Sammendrag	ii
Preface	iii
List of Figures	vi
List of Tables	vii
1. Introduction	1
1.1. Background and Motivation	1
1.2. Goals and Research Questions	1
1.3. Research Method	2
1.3.1. Literature Study	2
1.4. Contributions	2
1.5. Thesis Structure	2
2. Theory	3
2.1. Large Language Models	3
2.1.1. The GPT Family	3
2.1.2. The BERT Family	3
2.1.3. Google Products	3
PaLM 2	3
Codey	3
2.2. LLM providers	3
2.2.1. OpenAI	3
2.2.2. Microsoft Azure	5
2.2.3. Google Cloud	5
2.2.4. Amazon Web Services (AWS)	5
2.2.5. Anthropic	5
2.3. Geospatial Standards	5
2.3.1. International Standardization Work	5
OGC Standards	5
STAC Api Standard	5
2.3.2. Norwegian Standardization Work	6
SOSI	6

Contents

Geovekst	6
Norge digitalt	6
2.4. User Groups	7
2.4.1. General Public	8
2.4.2. GIS Professionals	8
2.4.3. City Planners	8
2.4.4. Business Analysts	8
2.4.5. Academics and Researchers	8
2.4.6. Emergency Services	8
2.5. Regulatory Bodies and Privacy Concerns	8
2.5.1. Local Regulations	8
2.5.2. The European Union (EU)	8
2.6. Related Work	8
2.6.1. GIS with LLMs	8
2.6.2. Retrieval Augmented Generation	9
LangChain	9
Microsoft Semantic Kernel	9
AutoGPT	10
3. Experiments and Results	11
3.1. Experimental Plan	11
3.2. Experimental Setup	11
3.3. Experimental Results	11
4. Discussion	12
4.1. Evaluation	12
4.2. Discussion	12
5. Conclusion and Future Work	13
5.1. Contributions	13
5.2. Future Work	13
5.2.1. Test regime	13
Bibliography	14
Appendices	16
A. Task Description from Norkart	17
B. API Schemas	19
B.1. OGC API - Features	19
B.2. STAC API	20
C. Code Examples	21

List of Figures

- 2.1. Actor map for stakeholders, providers, and other groups and organizations that could have some relevance to an autonomous LLM-based GIS-agent. 4

List of Tables

1.1. Literature study search results.	2
2.1. Categories and frequency of ChapGPT usage (Skjuve et al., 2023, March, pp. 16–17).	8

1. Introduction

1.1. Background and Motivation

The field of [Large Language Models \(LLMs\)](#) is an emerging one. [Fan et al. \(2023, October, p. 2\)](#) found that the proportion of papers about [LLMs](#)¹ to arXiv has skyrocketed since 2020, with a six-times increase in percent points from 2022 to 2023. They write that prompt engineering has been extensively used as a way to improve code generation ([Fan et al., 2023, October, p. 7](#))

1.2. Goals and Research Questions

The overarching goal of this specialization project is to investigate how [Large Language Model \(LLM\)](#) can be utilized to make [GIS](#) analysis simpler, faster, and more accessible. As exemplified in the task description provided by Norkart (see [appendix A](#)), such a system should be able to create a meaningful response to a query such as:

"Find all buildings within a 100-meter belt that are above 100 meters above sea level and have docks."

The task then is to investigate how modern language models can be used to perform classical [GIS](#) analyses using standard [GIS](#) technologies like PostGIS and geospatial data catalogues adhering to [OGC](#) or [STAC](#) standards. Based on the task description I have constructed three research questions that I will attempt to answer in this specialization project report:

1. What is the potential of LLM-based GIS analysis?
2. How can OGC API Features be used in an overlay analysis using ChatGPT-4?
3. How can we give ChatGPT-4 access to external tools?

Researching the potential of using [LLMs](#) in GIS could uncover new methodologies for spatial analysis, predictive modeling, and decision-making. The aim with [RQ 1](#) would be to assess the capabilities and limitations of integrating machine learning algorithms with [Geographic information systems \(GISs\)](#), and also touch on how a mature [LLM](#)-based [GIS](#) could impact the daily work of (human) [GIS](#) professionals.

¹Including articles whose title or abstract includes "LLM", "Large Language Model", or "GPT".

1. Introduction

Column1	arXiv	Google Scholar	Web of Science	PapersWithCode
Autonomous AI	2342	234	2	342
GIS	2342	234	2	342
Conditional random field	2342	234	2	342
Geospatial standardization	2342	234	2	342
LLM	2342	234	2	342
GPT	2342	234	2	342
BERT	2342	234	2	342
Transfer learning	2342	234	2	342
Foundation model	2342	234	2	342
Embedding	2342	234	2	342
Fine-tuning	2342	234	2	342
Prompt engineering	2342	234	2	342
Retrieval-augmented generation	2342	234	2	342

Table 1.1.: Literature study search results.

RQ 2 focuses on the feasibility of using the **OGC API** - Features Standads in a typical overlay analysis within a conversational **AI** context like ChatGPT-4, having the users be able to express themselves using natural language queries. An answer to **RQ 2** would describe how **OGC APIs** can be called and manipulated in a flexible manner during a conversation to perform spatial queries or analyses, like intersecting layers or filtering features based on certain criteria.

RQ 3 delves into the technical and ethical considerations of expanding ChatGPT-4's capabilities through integration with external tools, such as **GIS** software or data analytics platforms. It would explore options for secure and efficient data exchange, and assess the implications of such access in terms of data privacy and user consent.

1.3. Research Method

1.3.1. Literature Study

I set out by deciding on some search terms, and used a "snowball sampling" technique to find relevant articles. [Table 1.1](#) shows the number of search results on various sites.

1.4. Contributions

1.5. Thesis Structure

Fix
table
data
and styl-
ing

2. Theory

Chapter 2 of this specialization project will talk about the leading technologies in the field of **Large Language Model (LLM)**, which in itself is a subfield of **Natural Language Processing (NLP)**. section 2.1 will go over the leading **LLM** models, their strengths and weaknesses, and briefly mention differences in model architecture. Section 2.2 will name the most prominent providers of **LLM** services.

Figure 2.1 shows an actor map which includes stakeholders, providers, and other groups and organizations that could have some relevance to an autonomous LLM-based GIS-agent. Following subsections will go over the different groups and explain why they are included in the actor map.

2.1. LLMs

2.1.1. The GPT Family

Generative Pre-trained Transformers (GPTs) are a type of **LLM** first introduced by OpenAI in 2018 (Radford and Narasimhan, 2018).

2.1.2. The BERT Family

Bidirectional Encoder Representation from Transformers (BERT) is a family of language models developed at Google (Devlin et al., 2019, May), first presented in 2018.

2.1.3. Google Products

PaLM 2

Codey

2.2. Large Language Model (LLM) Providers

2.2.1. OpenAI

Being the most widely famous actor within the field of **LLMs**, OpenAI has gained great influence through their vast portfolio.

2. Theory

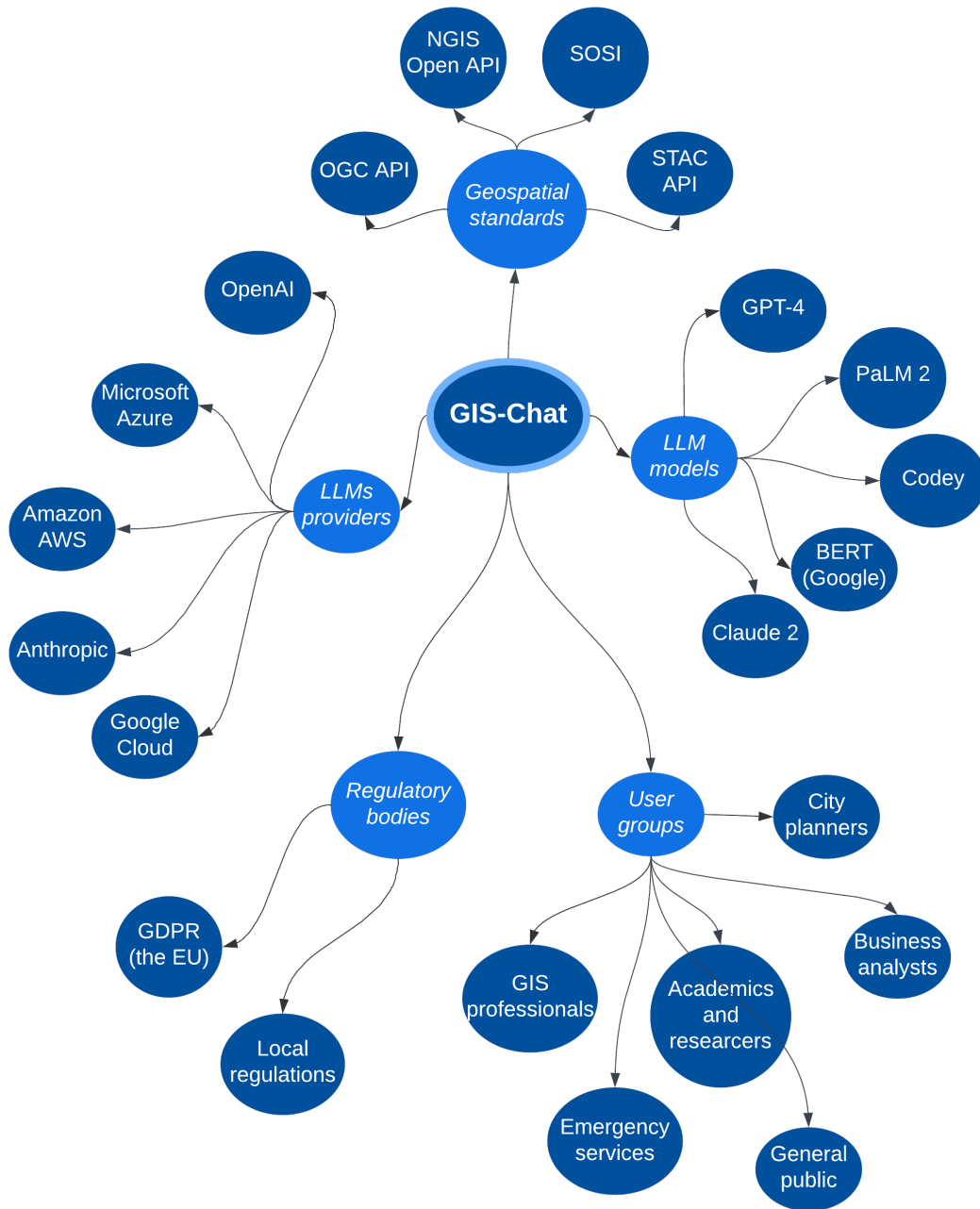


Figure 2.1.: Actor map for stakeholders, providers, and other groups and organizations that could have some relevance to an autonomous LLM-based GIS-agent.

2. Theory

2.2.2. Microsoft Azure

2.2.3. Google Cloud

2.2.4. Amazon Web Services

2.2.5. Anthropic

2.3. Geospatial Standards

2.3.1. International Standardization Work

OGC Api Standard

The [Open Geospatial Consortium \(OGC\) API](#) Standards serve as the glue in the field of [Geographic information system \(GIS\)](#), paving the way for interoperability and data exchange between diverse systems. Leveraging common web protocols like [HTML](#) and supporting multiple data formats including [JSON](#), [GML](#), and [HTML](#). The [OGC API](#) standard provides a modular architecture consisting of a core specification and various extensions. This modularity allows for flexibility, enabling users to customize their services according to specific needs. According to their webpages, they provide 80 different standards, each for a specific geospatial purpose. Notable examples are 3D Tiles, CityGML, GeoTiff, and [OGC API - Features](#) ([OGC, 2023, October](#)).

[OGC API](#) Standards function as modern replacements to older standards like [WMS](#) and [WFS](#), and presents an evolved and more adaptable framework for spatial data operations, setting the stage for future innovations in the [GIS](#) domain.

STAC Api Standard

The [SpatioTemporal Asset Catalog \(STAC\) API](#) is a standardized way to expose collections of spatial temporal data for online search and discovery. Built upon a [JSON](#) core, it aims to be a uniform and flexible environment from which developers can customize the API infrastructure to their domain. [STAC API](#) provides a powerful query language that allows users to search by various parameters like time, location, and keywords, making widely applicable. The [STAC](#) community has also defined specification in order to remove the complexity associated with having to create unique pipelines when consuming different spatial-temporary collection. The significance of the [STAC API](#) lies in its ability to democratize access to large volumes of geospatial data. By offering a common standard for data cataloguing and discovery, it reduces the barriers that often exist due to incompatible data formats. Developers or [GIS](#) professionals can take advantage of this through built-in tooling in QGIS, a desktop [GIS](#) for viewing, editing, and analysing spatial data, or through third-party packages in the Python and R programming languages. The API is also accessible through the command line interface when using [GDAL](#) ([STAC Tutorials n.d.](#)).

As [OGC](#) board member Chris Holmes puts it: "The [STAC API](#) implements and extends the [OGC API — Features](#) standard, and our shared goal is for [STAC API](#) to become a

2. Theory

full OGC standard." (Holmes, 2021, January).

2.3.2. Norwegian Standardization Work

Geospatial standardization work has been on the agenda of Norwegian governing powers for decades and have materialized in frameworks/collaborations like [Geovekst](#) and [Norge digitalt](#), as well as the [SOSI](#) file format. [Subsection 2.3.2](#) will delve into the work that has been done and what is expected for the future. The reasoning for the conclusion of this section is that the constraints of this specialization project is set by the Norwegian borders, and thus it is important to be aware of the standards that apply.

[SOSI](#)

[Samordnet Opplegg for Stedfestet Informasjon \(SOSI\)](#) is a Norwegian file format for storing and exchanging geospatial data. It was first introduced in 1987 and has since approached international standards, the most important arenas currently being [ISO/TC 211](#) and [OGC](#) (Mardal et al., 2015). [SOSI](#) is the adopted Norwegian standard for creating and delivering digital geographic data, administered by the Norwegian Mapping Authority (Statens kartverk) (Mæhlum and Rød, 2023).

In a [SOSI](#) dataset, terrain points, lines, and polygons are represented by their coordinates and classified into various object types according to the [SOSI](#) object catalog standard. However, there are few GIS systems that can read [SOSI](#) data directly, so data in [SOSI](#) format usually needs to be converted to another [GIS](#)-readable data format (Mæhlum and Rød, 2023).

[Geovekst](#)

[Geovekst](#) is a collaborative initiative in Norway aimed at collecting, managing, and distributing geospatial information. Established in 1992, it is a partnership between national, regional, and local government bodies, as well as several private companies. [Geovekst](#)'s primary focus is on creating a comprehensive, standardized geographical database for Norway that is easily accessible and updated regularly. It has played a vital role in various planning and development projects across the country, from urban planning to environmental conservation.

Unlike other geospatial initiatives, [Geovekst](#) emphasizes shared responsibilities and costs among its partners. This cooperative model ensures consistent data quality and efficient use of resources. It utilizes a variety of data sources, including aerial photographs, laser scans, and mapping, making it a rich resource for both public and private sectors. Moreover, its open-access policy allows for wider dissemination of geospatial information, thus encouraging innovation and informed decision-making across multiple disciplines.

[Norge digitalt](#)

Established in 2005, [Norge Digitalt](#) is a more recent framework compared to [Geovekst](#) and is the name of Norway's national spatial data infrastructure. [Norge Digitalt](#) primarily

2. Theory

involves governmental bodies (national, regional, and municipal), but also educational and research institutions and companies with responsibilities on a nation-wide scale; examples include Telenor and local and regional energy companies (Norge Digitalt, 2023, p. 6). Norge Digitalt aims to coordinate and streamline all geospatial activities in Norway, making it easier for users to discover, access, and use spatial data.

One key feature of Norge Digitalt is its focus on international standards and interoperability. While Geovekst is primarily a national initiative, Norge Digitalt aims to integrate Norway's geospatial data with that of other European countries. It supports a wide range of data formats and follows international standards, including those set by the Open Geospatial Consortium (OGC). The framework also provides various tools and services, like metadata catalogues and web services, making it a comprehensive solution for geospatial data management and distribution in Norway.

2.4. User Groups

There are several user groups that could take advantage of an AI-based agent with general geographic and GIS knowledge. Questions can span from simple retrieval questions such as "How many people live in Trondheim" and "How long is the drive from Oslo to Bergen?", to more complicated questions that require problem-solving abilities and reasoning. While it is difficult to obtain dataset over common queries, Kumar (2023, May), creator of the chatbot app Pocket AI¹, shared a dataset of ~13k user queries from his app along with classifications of these. Salient categories were:

- "task oriented" (23.1%)
- "informational" (20.2%)
- "social" (16.2%)
- "personal advice and self-improvement" (13.1%)

The main takeaway from these numbers is that the main motivation for use is productivity.

This aligns with the results of Skjuve et al. (2023, March) from their questionnaire-based study performed in late January 2023, about three months after its release (OpenAI, 2023, March). The goal with the study was to find out *why* people use ChatGPT. They found that most participants (55%) are motivated by productivity, and specifically applying it for routine tasks, information retrieval, text generation and writing support, and software development (Skjuve et al., 2023, March, pp. 17–21). Table 2.1 shows all categories and their frequencies. There were 197 samples in total, and more than one category could be assigned to each sample. It is worth noting that the study is likely to have included early adopters, and might therefore make the results less representative for the time at which this report is written (26th October 2023), now that use patterns have become more established (Skjuve et al., 2023, March, p. 37).

¹<https://github.com/varunon9/pocket-ai>

2. Theory

Table 2.1.: Categories and frequency of ChapGPT usage (Skjuve et al., 2023, March, pp. 16–17).

Category	% (n)
Productivity	55% (109)
Novelty	51% (101)
Fun and amusement	20% (41)
Creative work	18% (34)
Social interaction and support	9% (18)
Other	7% (15)

Given that the main reason people use conversational AI is for productivity, whether in a professional, academic, or personal context, such technology could be highly beneficial in a geospatial setting. 67 out of the 197 participants in Skjuve et al. (2023, March, p. 18) highlighted "ChatGPT's ability to understand complex queries" and that it is "efficient in alleviating the need to experiment with different phrasings of the query", as is often needed when 'Googling' for an answer to a specific question. This ease of information retrieval, along with its problem-solving abilities (Skjuve et al., 2023, March, p. 20), could also make conversational AIs highly relevant for geospatial purposes, and in the field of GIS. The following sections will elaborate on the potential user groups presented in Figure 2.1 that could benefit from such an artificial, and spatially aware, companion.

2.4.1. General Public

2.4.2. GIS Professionals

2.4.3. City Planners

2.4.4. Business Analysts

2.4.5. Academics and Researchers

2.4.6. Emergency Services

2.5. Regulatory Bodies and Privacy Concerns

2.5.1. Local Regulations

2.5.2. The European Union

2.6. Related Work

2.6.1. GIS with LLMs

Roberts et al. (2023, May) investigated extent of GPT-4's geospatial awareness through a set of case studies with increasing difficulties.

2. Theory

Li and Ning (2023, May) states that “autonomous GIS will need to achieve five autonomous goals: self-generating, self-organizing, self-verifying, self-executing, and self-growing.”, and provide a “divide-and-conquer”-based method to address some of these goals. Furthermore, they propose a simple trial-and-error approach to addressing the self-verifying goal. They also highlight need of a memory system in a mature LLM-based GIS system, referring to the use of vector databases in autonomous agents like AutoGPT (Richard, 2023, October). Even with its shortages, the solution that (Li and Ning, 2023, May) provide, called LLM-Geo, is able to solve provide good solutions in various case studies by providing executable assemblies in a Python environment when provided with URLs to relevant data sets, along with a user-specified query.

Zhang et al. (2023, July) uses the LangChain framework (Chase, 2022, October) in order to combine different GIS tools in a sequence in order to solve different sub-goals, and focuses on using the semantic understanding and reasoning abilities of LLMs like (e.g., ChatGPT) to call externally defined tools, employing the LLM as an agent or controller. The authors take great inspiration from the AutoGPT framework (Richard, 2023, October). The externally defined tools are described (manually) by its name and description. Said description contains information about the input parameters and output types of the tools/functions. Tools are defined for geospatial data collection, data processing and analysis, and data visualization. The effectiveness of the system is showcased in four case studies.

2.6.2. Retrieval Augmented Generation

Retrieval Augmented Generation (RAG) is tightly interwoven with explainable AI, being a framework for retrieving facts from an external knowledge base to allow a LLM-based agent access to accurate up-to-date information (Martineau, 2023, August). A common problem when working with language models, especially those designed to be general-purpose, is hallucination; that is, when the model provides an answer that is completely wrong but in a very convincing manner. While progress is being made with newer models even the better ones, like GPT-4, gives an incorrect answer about 1 out 5 times, and even worse for certain categories of queries (for instance ‘code’ and ‘business’) (OpenAI, 2023, March, p. 10). Retrieval Augmented Generation can help mitigate this problem.

LangChain

LangChain (Chase, 2022, October) is an open-source project that provides tooling that can be used to create autonomous AI agents. It is designed to help with prompt management and optimization, creating chains of calls to LLMs, data augmentation, autonomous agent creation, and memory-related tasks.

Microsoft Semantic Kernel

Microsoft Semantic Kernel is an SDK that functions as the brain of an autonomous agent and provides connectors to models and memory, and connects to triggers and actions.

2. *Theory*

AutoGPT

[Richard \(2023, October\)](#) will try to split a task into subtasks and use the internet and other tools in an automatic loop to solve the task/subtasks.

3. Experiments and Results

3.1. Experimental Plan

3.2. Experimental Setup

3.3. Experimental Results

4. Discussion

4.1. Evaluation

4.2. Discussion

5. Conclusion and Future Work

5.1. Contributions

5.2. Future Work

5.2.1. Test regime

In order to test the feasibility of different language models to serve as the brain of an autonomous GIS agent, a testing regime should be developed. In the examples of autonomous GIS agents described in the literature study of this report (see ??), results have generally been presented in the form of case studies (Li and Ning, 2023, May; Zhang et al., 2023, July). This type of qualitative testing is entirely appropriate to showcase the possibilities of the technologies but may be insufficient when comparing performance of different systems. In the latter case a quantitative approach would probably be preferable.

One idea is to create a test dataset which consists of inputs and corresponding desired outputs of typical GIS tasks. Inputs would in this case be natural language queries inputted by a mock user, and the output would be what you would expect a GIS professional to return when given the same tasks/queries. Inputs should reflect the varying level of GIS knowledge in the different user groups (see section 2.4). Outputs could be files with typical geospatial extensions (.shp, .geojson, .sosi, etc.), or they could adhere to API schemas specified by geospatial standards (see section 2.3).

While the inputs should be fairly simple to construct there are several questions to be answered in regard to the outputs:

- How does one evaluate the accuracy of the output?
- How should the AI agent respond when the user does not specify an output file format?
- How does one evaluate the usefulness of outputs to questions that should not return geospatial files, e.g. answers to general questions about geo-related subjects?

These are questions outside the scope of this specialization project. They will, however, be pursued in my master thesis.

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Appendices

A. Task Description from Norkart

Oppgave med omfang som kan tilpassast både prosjekt og masteroppgave

LLMs - GIS-analysens død

(kan justerast seinare)

BAKGRUNN

Nyere modeller for kunstig intelligens har demonstrert spesielt gode evner til å kunne lære av store mengder ustrukturert og semi-strukturert informasjon. ChatGPT fra OpenAI tok verden med storm – og chat-baserte systemer florerer. Kan chat-baserte modeller skapes for å hente ut GIS-data effektivt? Norkart har en stor dataplattform hvor brukere utvikler mot API'er som i stor grad har GIS/Geografiske data i bunn. GeoNorge er en stor datakatalog hvor brukere slår opp, eller søker kategorisert for å finne data. QGIS, Python, PostGIS, FME og andre verktøy brukes ofte til å gjennomføre GIS-analyser – hvor en GIS-analytiker/data-scientist gjennomfører dette.

«Finn alle bygninger innenfor 100-meters-belte som er over 100 kvm og har brygger»

Er dette mulig å få til med dagens tilgjengelige chat-modeller?

OPPGAVEBESKRIVELSE

Oppgaven har som hovedmål å undersøke hvordan nyere språkmodeller kan benyttes for å gjennomføre klassiske GIS-analyser ved å bruke standard GIS-teknologi som PostGIS/SQL og datakataloger (OGC API Records fks). Hva finnes av tilgjengelig chat-løsninger? Hvordan spesialtilpasse til GIS-anvendelser? Hvor presise kan en GIS-Chat bli?

Relevante delmål for oppgaven:

1. Kartlegge state-of-the-art
2. Utvikle proof-of-concepts
3. Analysere begrensninger og kvalitet

Oppgaven vil med fordel deles i prosjektoppgave og masteroppgave

- Prosjektoppgave
 - State-of-the-art: Ai-modeller og multi-modal maskinlæring
 - Innhente og utvikle datagrunnlag og API-tilgjengelighet
- Masteroppgave
 - Utvikle proof-of-concepts med tilgjengelige åpne modeller/teknologi
 - Gjennomføre eksperimenter for analyse av kvalitet

A. Task Description from Norkart

Detaljert oppgavebeskrivelse utvikles i samarbeid med studenten.

ADMINISTRATIVT/VEILEDNING

Ekstern veileder: (en eller flere)

Mathilde Ørstavik, Norkart

Rune Aasgaard, Norkart

Alexander Nossun, Norkart

Aktuelle vegleiarar og ansvarleg professor ve NTNU (den som har fagansvar nærast oppgåva):

Terje Midtbø (GIS, kartografi, visualisering)

Hongchao Fan (3D modellering, fotogrammetri, laser)

B. API Schemas

B.1. OGC API - Features

OGC API specification for a 'collection' object¹:

```
type: object
required:
  - id
  - links
properties:
  id:
    description: identifier of the collection used, for example, in URIs
    type: string
    example: address
  title:
    description: human readable title of the collection
    type: string
    example: address
  description:
    description: a description of the features in the collection
    type: string
    example: An address.
  links:
    type: array
    items:
      $ref: link.yaml
  example:
    - href: http://data.example.com/buildings
      rel: item
    - href: http://example.com/concepts/buildings.html
      rel: describedby
      type: text/html
  extent:
    $ref: extent.yaml
  itemType:
    description: indicator about the type of the items in the collection (the default value is 'feature').
    type: string
    default: feature
  crs:
    description: the list of coordinate reference systems supported by the service
    type: array
    items:
      type: string
```

¹<https://schemas.opengis.net/ogcapi/features/part1/1.0/openapi/schemas/collection.yaml> (retrieved October 25, 2023)

B. API Schemas

default :

– <http://www.opengis.net/def/crs/OGC/1.3/CRS84>

example:

– <http://www.opengis.net/def/crs/OGC/1.3/CRS84>

– <http://www.opengis.net/def/crs/EPSG/0/4326>

B.2. STAC API

C. Code Examples