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Geographic Information Systems: A Review of Its Evolution, Challenges, And Future Trends

Dr Rakesh Verma[1], Manu Kotwal[2]

[1]J&K Forest Services.
[2]GIS Lab, Deptt. of soil and water conservation, J&K, Jammu.

ABSTRACT
Geographic Information Systems (GIS) have undergone a significant evolution since their inception, transforming from specialized tools for governmental and military applications into ubiquitous platforms that permeate various facets of modern society. This paper provides a comprehensive review of the historical development of GIS, highlighting key milestones and technological advancements that have shaped its trajectory. It further delves into the contemporary challenges faced by geospatial sciences, particularly in the era of Big Data, and explores emerging trends such as cloud GIS, real-time GIS, space-time GIS, and augmented reality. The paper concludes by outlining future research directions to address the complexities of an increasingly interconnected and data-rich world, emphasizing the need for interdisciplinary approaches, enhanced interoperability, and robust security measures to harness the full potential of geospatial information for societal benefit.

Keywords: Geographic Information Systems, GIS evolution, Big Data, Cloud GIS, Real-time GIS, Space-time GIS, Augmented Reality, Geospatial Science, Challenges, Future trends.

INTRODUCTION
The main challenges of the XXI century are caused by the large amount of geospatial information through GIS. Throughout time there have been many attempts to define Geographic Information Systems (GIS). Yet there is still no consensus on its definition and to restrict it to one is limited. In the acronym - Geographic Information Systems - geographic refers to the Earth's surface and near-surface, therefore, all human production and activity, as well as non-human are possible to spatialize using GIS. GIS is recognized as an analytical and decision-making tool with many uses in different fields. It is used in many industries including commercial, educational and/ or governmental. It is a powerful tool for land administration, statistical mapping, transport, network and environment management, remote sensing images, water/waste management, maintenance and management of public lighting, regional and urban planning, tourism planning, healthcare planning and/ or crime and security management. In broad terms GIS is a special class of information systems that keeps track not only of events, activities, and things, but also their location. Computerization has opened a vast new potential in the way people communicate, analyze one’s surroundings and make decisions. The available data represents layers of the real world that can be stored, processed and presented later to answer future needs (Bernhardsen, 2002). In the process of acquisition, processing and spatial representation there is the involvement of multiple inputs and outputs that can be managed on databases, which invariably seek analytical and graphical spatial embodiments. In the graphical display, vector or raster elements can be chosen, depending on the degree of the database´s

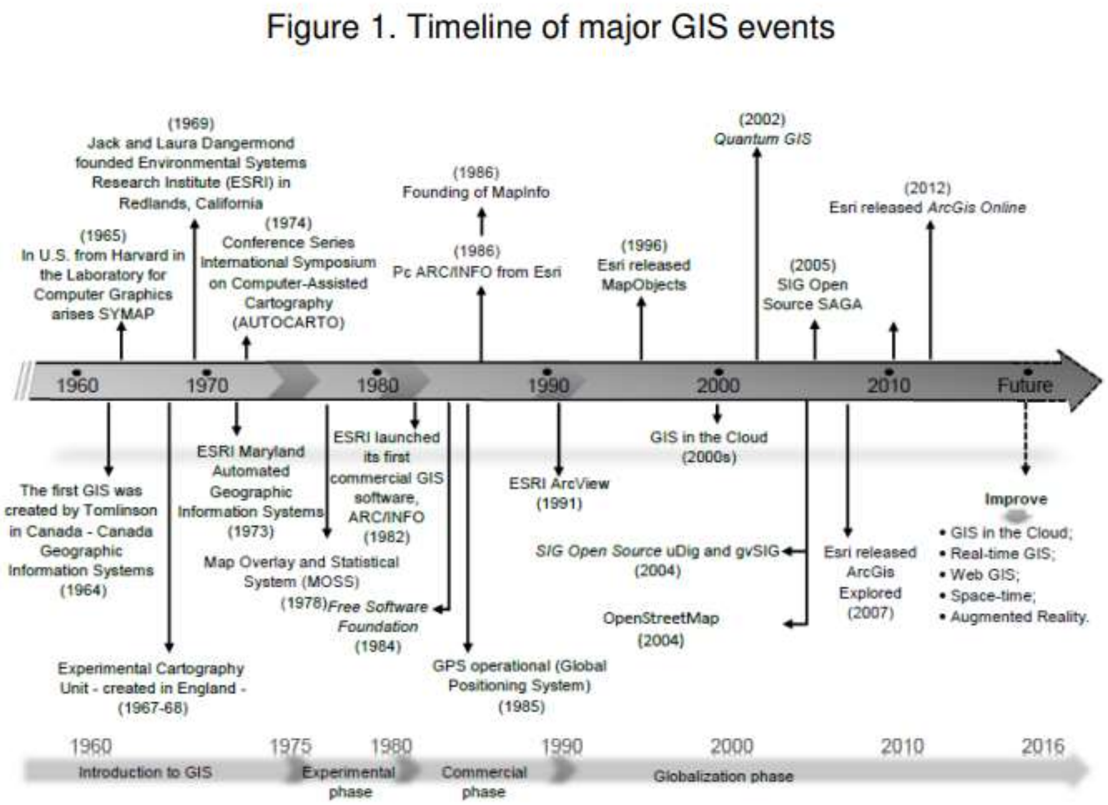
specificity and the type of results expected. These databases can be collected at different scales, using a plurality of data types, including population census, aerial photography or satellite imagery. It allows one to address multiple operating phases in the process of planning management on a multi-scale perspective with the challenge of discovering more effective and efficient solutions. Due to this nowadays, it is frequently used as a support system for spatial decision making (SDSS) (Crossland, 2005). A well-designed GIS should be able to provide a good computer system, whereas traditional GIS are intended for users operating on local servers. Traditionally, GIS includes hardware and software. The hardware are the physical parts of the computer itself and its associated peripherals (e.g. plotters and printers); while the software is interoperable, supporting the many available data formats (in the life cycle´s infrastructure) and its implementation may be custom designed for an organization.

Even so, GIS may be divided into two groups, typically known as ""GIS carries" and ""GIS users"", which are responsible for the management and analysis. The heart of GIS technology is its ability to conduct spatial analysis, overlay data and integrate other systems and solutions. Geoprocessing operations facilitate linking or merging data, and of the spatial characteristics of the data; the search for particular characteristics or features in an area, the faster update of data and at a more reduced cost and the alternative access to data models (maps, graphs, address lists, reports and summary statistics) which may even be tailored to meet particular needs. Furthermore, GIS features a number of operational advantages that have allowed the proliferation of new fields of endeavor in open access systems across multiple forms of acquisition, management, interpretation and spatial information analysis. This can be seen in the first item where a background and GIS starting point is explored. The main goal of this paper is to underwrite the concept of the evolution of GIS and to identify new ways of accommodating recent scientific approaches with its vast range of application possibilities.

THEORETICAL BACKGROUND - THE STARTING POINT

GIS is the onset of a new stage of cartography. This type of system´s evolution is relatively recent, between the 50s and 60s of the XX century, but knowledge and technology have rapidly grown recent years. The upsurge of technological systems with computerized cartographic applications arose from the need to solve certain problems, in such areas as the military and public administration. Many contributors and diverse influences, regarding concepts and principles, data and issues of spatial infrastructure, software promoters, areas of application, all allowed for its cohesive growth (Figure 1). The organizational structures of GIS are so diverse, along with its multitude of roots, opening up an array of software packages of both public and private domain (Hendriks, 2005). Nowadays, the applicability of this type of systems has widened to the commercial, non-profit and academic areas.

Figure 1. Timeline of major GIS events



Source: Authors' own elaboration.

The mid 1960s witnessed the initial development of GIS in combining spatially referenced data, spatial data models and visualization. The actual roots of GIS are complex and difficult to determine (Miller & Goodchild, 2015).

Most authorities cite the Canada Geographic Information System (CGIS), designed around 1965, with a project led by Tomlinson (Bruno & Giannikos, 2015; Mordechai Haklay & Zafiri, 2008; Tomlinson, 1967). The objective was to obtain means for summaries and tabulations of areas of land from the Canada Land Inventory. For the registration of these lands, a massive federal-provincial effort was made to assess the use and potential of the Canadian land base. CGIS arose from the need to answer the challenges of accurately measuring the areas of irregular geographic patches of homogeneous utilization and to overlay/compare different themes (Goodchild, 2006). The period of the 1970s was characterized by the rapid evolution, and ability of automatic computer mapping, the use of data format and the answering of a wide range of technical issues. In the 1980s, democratization of computer access allowed for the expansion of GIS use. These innovations led to the first commercial viability of GIS, it started to become popular as a standard computer application in government departments, universities, and private corporations. Accordingly, the ability to select, sort, extract, classify and display geographic data on the basis of complex topological and statistical criteria was available to users (M. Goodchild, 2006; Pourabbas, 2014).

The 1990s saw map analysis and modeling advances in GIS, turning these systems into real management information tools, as computing power also increased. During this decade, the Open GIS Consortium (OGC) was founded, with the objective of developing specific, publicly available, geoprocessing actions.

OGC is an international industry consortium, which include government agencies and universities. In 2000, the appearance of web 2.0 and, more recently, the Web 3.0 (the semantic web) allowed for the Open Source GIS to grow. Open source is a software that allows code source access to be open, free, to be distribute and modified. Nowadays, it is possible for programmers to add new functions very quickly and at a low cost due to recent GIS advances. Mobile and internet devices, cloud computing, NoSQL databases, Semantic Web, and Web services offer new ways of accessing, analyzing, and elaborating geospatial information in both real-world and virtual spaces, both for open source and commercial GIS (Pourabbas, 2014).

Despite the progress made during the twenty-first century, there are still numerous challenges that lay ahead for geospatial sciences in various fields as shown in Table 1 (Yue et al., 2013).

Table 1. The challenges for geospatial sciences for different types of data intensity

Intensity	Description
Data accumulation	Collect of a multitude of data from space by day and accumulation at a similarly high rate.
Processing	Intensive modes of processing information in different spatiotemporal spectra.
Competition	Action of a multitude of end users accessing parallel to information (reception of a large number of users simultaneously are possible, because of development of the several services (e.g., Google Maps and Bing Maps).
Spatiotemporal	A set of spatial and temporal dimension. It can be distinguished into two types of information – dynamic or static.

Source: Adapted from Yue et al., 2013.

DATA ANALYSIS AND TREATMENT SYSTEMS

Common citizens are constantly asking questions regarding spatial dimension. A GIS can be defined as a computer system operated by people, which comprises of different aspects to be efficiently operated. Firstly, a GIS has the hardware, software and data components. Those multidimensional components can be articulated to give us the basis for the development of spatial analysis. However, human interaction is crucial to develop a conceptual model approach, to plan, to operate and to analyze the information. Nowadays, GIS may be very helpful to different company sizes, organizations and people where geographic patterns can be modelled and predicted. Spatial/Geographical data is representing real world through layers or objects where spatial positioning is crucial. Typical geographical data have descriptive or spatial information (Faiz & Krichen, 2012). It can be used to represent discrete data, typically through a vector-based representation (points, line polygons), or as a continuous data through a cell-based or raster mode that uses a matrix representation.

The most interesting part of a GIS project is the Spatial analysis (Heywood, Cornelius, & Carver, 2011). It is related with the to the ability to visual analysis of maps and imagery, computational analysis of geographic patterns, finding optimum routes, site selection, and advanced predictive modeling. The world is complex, but the exponential growth of technology, such as Global Position Systems (GPS), real time-sensors or GIS has made possible there simplification (ESRI, 2013). GIS are efficient tools for recording, exploiting, analyzing and displaying geographical data which can be applied in transportation, health,

environment, urbanism, political activities, water/waste management, geomarketing, security, tourism, viticulture/ oenology, education or crime. These extensive types of applications covering both private and public sectors are briskly growing. Open-source and proprietary software development have been contributing to this development, due to its recent growth and recognition.
Apart from the rasters and vectors in spatial modeling, more recently three and four-dimensional data has also been investigated (Lin et al., 2013). The interest in Virtual Geographic Environments (VGEs) has equally grown rapidly during the last years. It is characterized as being a bridge between the three scientific requirements of Geographic Information Science: multi-dimensional visualization, dynamic phenomenon simulation and public participation (Lin et al., 2013).

GIS TRENDS

Currently, the key trends that face in GIS concerns are geospatial web, cloud GIS, space-time GIS, augmented reality and real-time GIS. Web-based in GIS combines information systems and geographic web technology (Chakraborty et al., 2015). WebGIS is responsible for a paradigm shift in the production of geospatial data, going from a model based on national governments, as key players to the collaboration of public and private institutions. (Goodchild et al., 2007; Grossner et al., 2008). The enhanced participation of different actors in the generation of geospatial data, makes it increasingly difficult to distinguish the producers from the users (Budhathoki & Nedovic-Budic, 2008), mainly due to the availability of free software and open source tools (Crampton, 2009). With the opening of GIS to the world, a multitude of actors involved in mapping data on the web, allows one to help to solve end-user problems (Elwood, 2009). GIS based on the web are accessible not only from a computer but also from different devices, including laptops, smartphones or tablets (Chakraborty, 2015).
The opening of the source code, and the use of free software aims to contribute to an increased openness, collective voluntary participation, study, use and modification of the software (Chakraborty et al., 2015). At the beginning of the 21st century, a new and leading geolocation-based service of crowdsourcing at a massive scale known as Open Street Map project (OSM) started on a massive scale. This project improves Volunteered Geographical Information' and aims at to creating a free digital map of the world. These collaborative platforms are empowering citizens to create a global patchwork of geographic information (Goodchild, 2007; Haklay, 2010). The international non-profit Open Geospatial Consortium was founded in 1994. Is a voluntary organization which led the process of developing standards for geospatial and location services (Haklay et al., 2008). Among the three most relevant standards OGC include: Web Feature Service (WFS), Web Map Service (WMS) and Web Coverage Service (WCS) (Giuliani et al., 2016; Parker & Dominguez, 2015). This new form of using GIS on the web environment using a distributed and asynchronous requires a client-server architecture (C/S). This is characterized by a client request of a service, such as mapping, decision analysis, data processing or storage data while the server provide the service (Mekonnen & Gorsevski, 2015). Web GIS exits benefited by providing the best agents solutions to problems that traditional GIS (Chang & Park, 2006). More recently, Web-GIS has become to a cloud GIS, based on the model of "Software as a Service" (SaaS) (Kerski, 2015). Cloud computing are increasingly widespread and make possible to run cloud applications in a shared data center accessed by internet. The emergence of cloud GIS solved problems associated with the increase of precision and with the scope of spatial-temporal information. In general, there is an accumulation of multiple data records and this data set, varies on a daily basis (Hey, 2012) and allows network access to a set of configurable data (servers, storage, applications and services) (Yang et al., 2011). The recent emergence cloud GIS

provides the ability to build a GIS service enabled for use in the cloud and can be made to scale up or down according to user needs. GIS cloud is equipped with new models of maintenance and use of geospatial data for a variety of users and to solve computing problems (Yu et al., 2014). This service provides users the ability to act in the manner of 'pay-as-you-go'. This mechanism of action has been a dream for several decades and has recently become a reality (Armbrust et al., 2010).

The GIS cloud has several characteristics namely: (i) software installation is not necessary; (ii) the computer´s internal storage is not used; (iii) it enables collaborative action between different actors (flexibility); (iv) it adapts services to demand and actual charge capacity; (v) it enhances greater interoperability between various source codes; (vi) it decreases the time taken by decision-makers to implement deliberation processes´ of and (vii) the implementation of the entire system on a scale of top-down (Armbrust et al., 2010; Blower, 2010; Yu et al., 2014). Cloud computing is a powerful technology that enables greater profitability in energy consumption and economic resources (Buyya et al., 2009; Lee & Chen, 2010; Marston et al., 2011). It performs massive-scale and complex computing and eliminates the need of maintaining software, hardware or dedicated space (Assunção et al., 2015; Hashem et al., 2015). Associated with this is the tremendous growth of data generated, in scale and volume, which puts data processing challenges in terms of time and of task requirements (Hashem et al., 2015). Regarding this Big Data, a concept specifying the four Vs is emerging, namely, volume of data, variety of data collectors, velocity of data transfers, and processes of value for the discovery of a large number of hidden data in large data sets (Gantz & Reinsel, 2011; Hashem et al., 2015). The advance of these technologies may enable the construction of spatial data infrastructures (SDI) and cyberinfrastructures (Schäffer, Baranski, & Foerster, 2010; Yang et al., 2010). Some public cloud computing platforms are already available, including Microsoft Azure, Google App Engine or Amazon EC2. In any case a cloud can be public or private. The public cloud is available to the general public while a private cloud is only used within an organization. Despite the progress achieved in recent years and fundamental analysis is practical and real applications and support the conceptual analysis (Yue et al., 2013). Cloud computing includes multiple domains, such as energy and mineral sciences, weather, traffic and simulation management systems, landscape ecology, water management, disaster management or human and environmental health (Yang et al., 2013). According to these authors the main obstacles to the success of cloud GIS are associated with policy, management, acquisition and operational requirements. Looking ahead, multiple threads are identified:

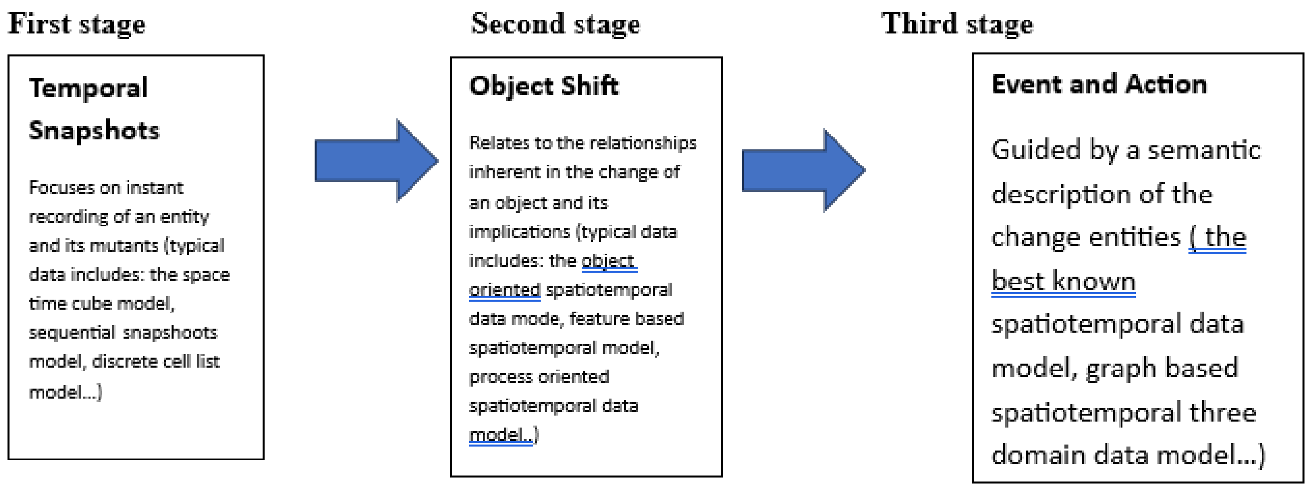
- cumulative advances for interdisciplinary approaches, side by side in geoscience and digital earth;
- cloud interoperability standards based on OGC, OGF, NIST, ISO, IEEE and through a systemic architecture;
- integration of innovational interactive systems for viewing and access;
- real-time simulation for decision support;

Security levels defined by a computer through a platform with distribution of certain information, and their collaboration with the integration of multiple platforms. It aims at the achievement of a science for the citizen, crowd sourcing and technology challenges for the dynamics of education. Another type of evolution in GIS is linked to the Hägerstrand framework (space-time model). In this context, space-time studies individual patterns, considering the various constraints in a particular spatial-temporal environment (Hägerstraand, 1970; Hägerstrand, 1989). There have been a number of efforts to ensure the incorporation of concepts in a GIS (e.g., (M. F. Goodchild, 2013; Miller, 1991; Neutens et al., 2007; Shaw & Yu, 2009). This system presents a three dimensional orthogonal structure that consists of the union between two spatial dimensions and a temporal dimension. The spatial dimensions, structured 2D scale, represent the location of individuals, while the dimension of time represents the timing of the individual movement in a spatiotemporal system (Miller, 2004). Several variables can represent the characteristics of the daily activity of an individual: location, time, duration, sequence and frequency of the type of activities (Ren & Kwan, 2009). It must be associated with at least one activity. Distinguished two types of activities: the movable and stationary activity. Mobile activity refers to a local motion toward another, while the stationary activity leads to a fixed location. Representation in Hägerstrand system is done in two ways: by vertical line segment when it comes to a stationary activity and a sloping straight line when there is movement toward a certain place (Chen et al., 2011).

In recent years, attempts have been incremented to store and manage the activities of an individual based on their spatial and temporal characteristics (Chen et al., 2013; Wang & Cheng, 2001). This type of analysis has been mainly used in studies that assess individual accessibility (e.g., (Delafontaine, Neutens, Schwanen, & Van de Weghe, 2011; Kwan, 1998; Miller, 1999; Neutens, 2015; Neutens et al., 2007). These studies demonstrate that the considerations of space-time contribute to the presentation of more complex models and real human activities (Shaw & Yu, 2009). Real-Time GIS model was assumed as a new paradigm of information science to capture the real characteristics of human undertakings (Hey, 2012) and transforming historical changed data to real-time data (Gong, Geng, & Chen, 2015). The authors divided the model into three stages: temporal snapshots (1st stage), object-shift (2nd stage) and events and action (3rd stage) (Figure 2).

Figure 2. Three stages of real-time models

A flowchart or diagram depicting three stages of real-time models:



Source: Adapted from Gong et al. (2015).

Real-Time GIS analyses have also sought to incorporate collaborative functions. These types of tools can be differentiated into several types, namely: the same time - same place; same time - different location; different time - same place; different time - different location (Sun & Li, 2015). The Real-Time Collaborative Geographic Information System (RCGIS) enables analysis of interactions in agile and flexible systems, equipped with collaborative principles. The unprecedented growth of geographically referenced information combined with the recent digital augmentation reality (AR) of places growth will become increasingly important in the future (Graham, Zook, & Boulton, 2013). AR had its recognition in 1992, when Caudell and Mizzel developed works for Boeing and designed a digital transport display in the head, so as to enable a framework of airplane schemes (Yew et al., 2016). However, the concept of air is much older. This was used during the II World War period of with a project developed with the presentation of information on the camera´s windshield. In this sense, there must be a relationship between reality and the information made available on digital media. For this, there must be a technological device (smartphone or other wireless equipment), tracking and computer software. AR is summarized in three distinct properties: (1) the combination of real and virtual objects in the real world; (2) to run interactively in real time; and (3) the registration of real and virtual objects and their connection (Azuma, 1997). AR has received several applications for PC, smart phones, tablet and other devices and will it will increase in the future.

These advances in several types of GIS technologies may create significant digital divisions, disadvantaging the poor, ethnic and racial minorities and rural area residents. Open source applications create exclusion to those who can only see and contribute with these features (Elwood, 2009).

FUTURE RESEARCH DIRECTIONS

Information technology and Geographic Science are growing shoulder to shoulder and rapidly. Development of GIS technology and applications must grow behind the scope of Big Data, Cloud GIS, Real-time GIS and Augmented Reality challenges. For future research, a more rigorous approach should be implemented and guided by, technology interoperability, integrated multidisciplinary approach, security, understanding how to integrate citizens collected data and deeply understand, how to collect and analyze real time data. The occurrence of data needed will be exceeded by the abundance of real time data leading to the challenges on of how to detach different sources to canvass their quality and include them in spatial analysis. For this, more thorough and integrated analysis models are required and at the same time, more spread applications by multiple technological devices will be required, to provide the spatial information.

CONCLUSIONS

The expansion and advances of GIS technology has created the necessary conditions to proliferate different working approaches in multiple areas, such as geography, cartography, remote sensing, image processing, education or environmental sciences. This section presents the evolution of GIS from its conception to the present day/ time. Moreover, it shows the main challenges posed by multiple skills acquired by the GIS in recent decades, namely presenting a shift from traditionally confined public planning areas to multi collaborate users, from desktop to the web and from real to virtual and augmented reality. In fact, maps have always been used for the removal of political borders, but today, networking abilities has generated conditions for GIS intelligence statements. The development of the web has supported new challenges associated with GIS, particularly in areas connected with augmented reality, real-time GIS information, GIS space-time or Cloud GIS. Associated to this increase, Big Data challenges and Geographic Science (GS) problems are visible. The cumulative advances in the relationship between GIS and Web can hence contribute to the expansion of generated and manipulated information, the interoperability between servers, users and networking. Geographic information will reinforce its position in our daily life and for GS, these trends will be more than ever, an eye catcher for further research.

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