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Moving the Limits of Military Experience

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Abstract

Past experience is important as an aid for making good decisions, both for planning and conduct of military operations. But today's methods for gathering experience have substantial limitations.

Assume that a large number of common operational pictures (COPs) from a given command and control information system (C2IS) are saved in a database. By using new in-memory technology originally developed for use in Business Intelligence, extended with an advanced interface to a geographical information system (GIS), powerful applications for interactive analysis of such historical databases can be realized. Such applications will provide opportunities to achieve considerably higher insight into what has happened in military missions, both on the macro and detailed levels, than what has been possible until now. This idea has been explored through a prototype application, with very promising results.

Experience - Important As An Aid For Making Good Decisions

In the vast majority of decision-making situations people meet in the practical life, they will not think the matter through from scratch, but rather to a large extent base their decisions on experience. Military operations are no exception in this respect. The more relevant experience you have, the better and faster decisions you will be able to make. This relationship is thoroughly documented in research within intelligence and human decision making (Gottfredson 1998; Sternberg 2003). A person's *intelligence* (IQ) is essentially innate. But the ability to be able to make good and quick decisions in the practical life; by some researchers called *practical intelligence*, is largely determined by experience. In this regard, it should be noted that much of the research that has been carried out within the discipline called artificial intelligence, has concentrated on programming a lessons-learned database into a computer.

Many process models for military command and control have been published. The most famous one is probably Boyd's Observe-Orient-Decide-Act (OODA) loop. It is documented mainly by lectures and courses (Boyd 1987). In the OODA loop, the collection and use of experience is regarded as an important basis for making decisions. Also, in many other process models for command and control, lessons learned are incorporated as an important feature (Grant and Kooter 2005).

Today's Methods for Gathering Experience

Everyone that participates in military missions gain their own personal experience. Some of the knowledge gained in this way is difficult to convey to others; so-called *tacit knowledge*. Research has shown that this type of knowledge is very valuable (Sternberg 2003). It is difficult to find methods or tools that can improve this kind of gathering experience; it must be obtained "the hard way" by participating in military exercises or missions.

But most of the lessons learned by individuals can be conveyed to others. Such contributions can be collected, compared, integrated, documented and saved in text data bases; possibly supplemented by pictures and videos. In NATO, there has in the latest years been much emphasis on systematic work of this kind (Vaagland 2009).

North Atlantic Council, which is the most senior political governing body of NATO, distributed in 2008 a "Lessons Learned Policy." NATO has already established good routines for collecting military experience and learning from it. On the strategic level, NATO has established a *Joint Analysis Lessons Learned Centre* (JALLC). One of its tasks is to host and manage *NATO's Lessons Learned Database*, where experience is captured, stored and processed. In addition to the activities of this kind organized by NATO centrally, the member countries have their own activities and lessons learned databases. For example, the US army has its *Center for Army Lessons Learned* (CALL) with its own lessons learned database.

The ways of gathering experience mentioned so far have substantial limitations. Any person has limited capabilities for observing and remembering situations and events. And only a small fraction of what happens can be captured by pictures and videos. Furthermore, even if such methods could give a complete set of data describing what happened in a given mission, it would be impossible for humans to analyze it to derive all interesting information (such as statistics, extreme situations, correlations, causalities, etc). Such analyses are far more demanding than what a human brain can manage.

Some existing computer based applications can perform analyses of historical data for military missions; but in a very limited scope. Such applications have been realized by extending command and control information systems (C2IS). A central purpose of C2IS is to provide a *common operational picture* (COP), which is a set of data describing the situation, including such things as position and status of own and enemy forces, actions and events, as well as plans. It serves as a decision aid for immediate actions (Ferris 2003). COPs are to a large extent filled up with data by using sensors.

Any C2IS must be built around a database, in which the COPs are stored. A standard for the data content of such databases is proposed by MIP, The Multilateral Interoperability Programme (MIP

2005). MIP has participants from 24 nations, both within and outside NATO. The purpose of the standard is to ensure interoperability between different C2IS and similar information systems.

A COP is intended to reflect the situation at any point in time. That is, most of a given COP is normally deleted as soon as a new COP is established. However, in many C2IS there is functionality for saving selected parts of the COPs and for performing simple analyses on such historical data. A common type of analysis is to show the track of a given vehicle in a map.

However, there is a fundamental problem that places a clear restriction on such analyses built into C2IS. This problem is that data are stored on disks, which is the default kind of storage device used for databases. Disks are satisfactory for regular use of databases. But they are in part based on mechanical operations and are therefore very slow compared to pure electronics. For this reason, it is only feasible to perform simple and planned analyses against them.

Business Intelligence

Business Intelligence refers to computer-based techniques for analysis of business data, providing decision support for strategy and future actions. Thus far, the application area has mainly been concentrated on analyzing historical data. Business Intelligence is now used extensively in all kinds of companies and is generally considered to be of vital importance (Williams and Williams 2003; Watson and Wixom 2007; Lonnqvist and Pirttimaki 2006).

In Business Intelligence, one faces the very problem described above for the analysis of historical data in C2IS, namely poor response times as long as data are stored on disks. The amounts of data analyzed in Business Intelligence are usually very large. For this reason, a main concern in this discipline has been to find effective techniques for analyzing large amounts of historical data.

The term Business Intelligence became commonly used in the nineties. But the discipline is about 40 years old. A theory of Business Intelligence started to evolve in the eighties. The most important initial contributions were given by Inmon and Kimball. Their ideas are published in books which have been revised several times (Inmon 2005; Kimball 2008). These books are frequently used as references, covering theory of traditional business intelligence technology. Inmon's main contribution is an architecture for systems based on data warehouses. The essence of it is depicted in figure 1. Data to be analyzed are originally stored in databases or other structured data collections. Using an ETL-tool (ETL - Extract, Transform, Load), data are first transformed and moved to a *data warehouse.* Then, they are transformed and moved to a set of *data marts*; application specific data collections which are optimized to give high performance for analyses. Using an analysis tool, the users can carry out analyses on the data marts.

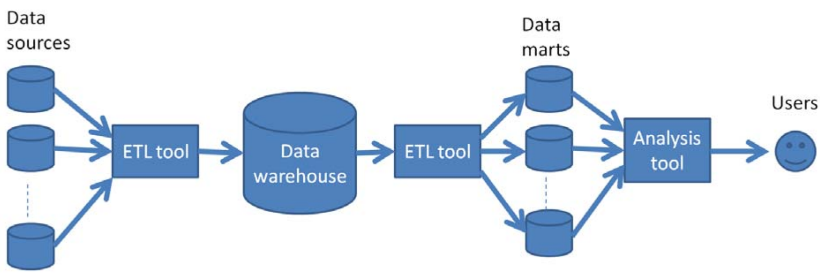

Figure 1. Data flow in the Inmon Architecture

Inmon's architecture is not used extensively in its original form. Several variations are used; the most common one is to drop the data marts and to carry out the analyses directly against the data warehouse, which must be optimized for analyses. However, Inmon's proposal is often used as a reference.

Kimball's main contribution is the so-called *cube*, a star shaped kind of data structure. This data structure has been prevailing in the last 30 years. By structuring data warehouses or data marts as a set of cubes, one achieves acceptable response times for a set of predefined reports and variations of them. Much research on optimizing the performance of cubes for different kinds of situations has been published (Gorla 2003). However, the price that has to be paid for reduction of response times is introduction of other problems. It is usually a time consuming task to program and operate the necessary transformations from source data to cubes. The transformations which may be complex, increase the risk of data corruption in the data transfer. Cubes represent generally a very limited amount of information. The designer of a data warehouse must be careful to assure that the queries that are planned can be answered, and that this can be done in an effective way. If it turns out that it cannot, or the requirements change, the data warehouse must be reprogrammed.

In short, the use of cubes imply increased development and operating cost, increased risk of data corruption and reduced flexibility.

In the last years, it has become apparent that many advantages can be obtained by keeping data warehouses in the computer's primary storage (RAM). This is called *in-memory data warehouse technology*. The difference in read speed between RAM and disk is like the difference between one second and 24 hours (!). This eliminates the response time problems that exist when using disks. The limitations of RAMs that existed some years ago, size and price, are no longer significant. On 64 bits computers, there is no practical limit of the RAM size. The cost of RAM is now acceptable and is decreasing rapidly.

A new storage and retrieval mechanism, specifically designed for data warehouses kept in RAM, is the patented *associative query logic*, upon which the tool QlikView is based (Apicella 2002). It is based on data compression in order to make the best possible use of

RAM. Through a simplified data structure, it allows fast development of applications which are powerful, flexible and easy to use (Sendin-Rana et al. 2010; Hatch and Lock 2009).

While the traditional technology based on cubes may be satisfactory for applications where predefined reports are adequate, associative query logic gives a basis for realizing systems that can perform complex, ad hoc analyses on very large data structures, with short response times. This opens up for use of data warehouse technology in quite new application areas.

We are not aware of other in-memory storage and retrieval mechanisms that can offer similar advantages as associative query logic. However, this is likely to change. During the next few years, we expect a rapid development of basic mechanisms and associated tools for in-memory data warehouse technology. We can expect a theory of such principles to be further developed, as well as new commercial products based on them.

Purpose of Our Work

Our basic idea is: *To use data warehouse technology to analyze historical data for military missions.*

Our research problem has been: *To investigate the potential of this idea.*

To do this investigation, we have carried out a research project, which has been supported by the Concept Development and Experimentation Program of the Norwegian Armed Forces.

A prerequisite is that it has been stored a large number of COPs for the military missions to be studied, giving a historical database for each mission. The goal of the project has been defined by the following research questions:

- *Is it feasible to realize applications, based on data warehouse technology, which can be used to analyze such historical databases?*
- *If it is, what should be chosen as the basic technical principles?*

Method Used

Prototyping, with a succeeding evaluation, is a valid and much used methodology in software engineering research. A prototype that meets the general requirements is usually regarded as a "proof of concept" (Gregg et al. 2001). Our project is based on this approach.

The method used consists of the following steps:

1. Clarify the requirements. Use existing theory and experience to choose a basic technical solution.
2. Realize a prototype application and test it.
3. Present and demonstrate the prototype application for military personnel, to have their evaluations of its potential.

The last step is carried out only informally; the intention is just to have a qualitative indication of the potential of this kind of application from a representative set of military officers.

Requirements

The new kind of application is in several ways different from traditional Business Intelligence applications. Therefore, existing methods and tools based on data warehouse technology need modifications and extensions in order to be useful. Differences that affect the technical solution for analysis are:

1. *It is essential to be able to perform ad hoc analyses over a wide spectrum of possibilities.* Military exercises/missions are usually very different from each other. Therefore, the analyses cannot be standardized. Analyses should be carried out on an ad hoc, interactive basis. This is in contrast to traditional Business Intelligence, where use of predefined reports and variations of them is satisfactory for many applications.

2. *There must be an advanced interface to a geographical information system (GIS); to visualize positions and movements in a map, and to utilize the geo-analytic capabilities of the GIS.* In traditional Business Intelligence, simple functionality of this kind is sufficient. As far as we know, only a few tools for Business Intelligence have a GIS interface at present, and they are all of the simple kind.

3. *Privacy is an issue.* If the historical database includes data about individual person's movements and actions, we need some functionality to limit the access to such data.

Compared to traditional Business Intelligence, there are also differences regarding the collection of data to be analyzed:

4. *Most of the data must be measured by sensors, and automatically transferred to a computer.* In traditional Business Intelligence, data are entered by persons from terminals.

5. *The total time interval to be analyzed is much smaller, and events are occurring much more frequently than in traditional Business Intelligence.*

These differences do not affect the technical solution for analysis. But they influence the cost of gathering data, and consequently the availability of data to be analyzed.

Results

Design decisions

Based on our own experience and a study of literature, associative query logic is chosen as the basic principle for data storage and retrieval. The Business Intelligence tool chosen is QlikView, which includes functionality for ETL as well as for analysis. The GIS chosen is ArcGIS. An advanced, application independent interface between the two tools has been realized as a part of the project.

The historical database contains fictive data. This has given good opportunities for making it representative for what can be expected to be the contents of historical databases of this kind in the next years. It is based on the main ideas of the MIP standard. It includes data describing movements, actions and statuses of objects (vehicles/persons), weather conditions and plans. Here, it is assumed that each object carries a GPS and a number of sensors. The database contains only a small amount of data; the reason is that we had tested the tools' ability to handle large amounts of data in a previous project.

The Prototype Application

Figure 2 and 3 depict the structure of the prototype application. It corresponds to the Inmon architecture (figure 1), with extensions which are due to the geo-analytic functionality introduced. In addition to the historical database, there is another data source; the personal database of the Norwegian Armed Forces. We could easily have included the same kind of data for the vehicles, by fetching relevant data from a logistics database. In addition to the primary data, fetched from the data sources, *derived data*, which are derived by geographic analyses, are stored in the data warehouse. An example is the *terrain type* (found in the map) for each position present in the database. There is only one data mart, which is fetched into RAM each time the application is started.

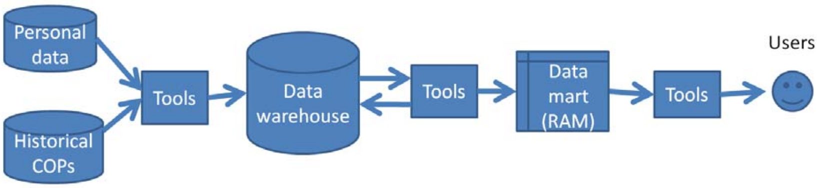

Figure 2. Data Flow In The Prototype Application

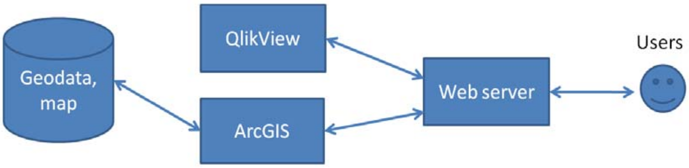

Figure 3. Interaction Between Tools

The system is based on the Norwegian language. Below are shown examples of elements of screen dumps, where data and texts are translated into English. Figure 4 depicts some charts. They are displayed for any data selection. In figure 5, some "list boxes", containing data elements, are shown on the left hand side. Here, a data selection, Event type: "Gunshot", is made (colored green). All data elements that are related to the selected one are colored white; the other ones are grey. On the right hand side is a map, showing the positions of the objects (vehicles/persons) that are selected.

In the map module, there are two alternatives for showing the positions of objects: Discrete points (as in figure 5) and density distributions. The latter is used when a large number of positions are displayed.

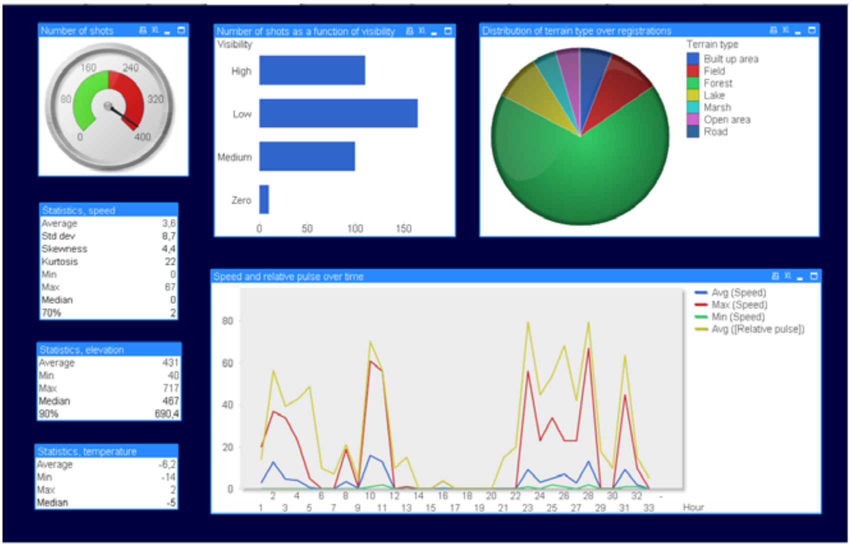

Figure 4. A Set of Charts

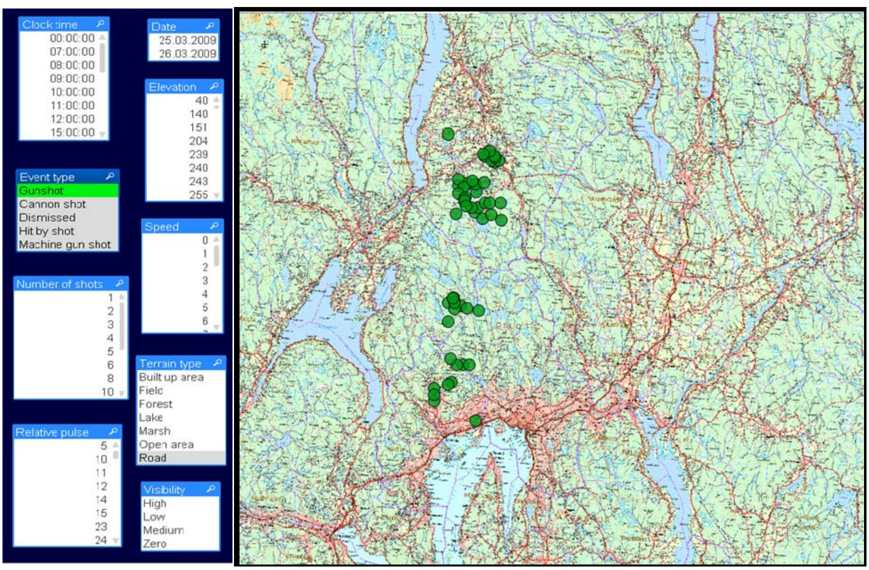

Figure 5. ***List boxes*** **where a data selection is made, and a map, showing the positions of the objects selected**

Answers to Research Questions

Our research questions have been answered in a very positive way. Through the prototype application it is shown that implementation of the new kind of application that we are considering is feasible. It is shown that associative query logic is a very suitable basic principle for storage and retrieval. Implementation of an advanced interface to a GIS is a complex task, but it is practicable.

The prototype application has been presented and demonstrated for a limited number of military officers with a spectrum of different tasks and ranks (up to major-general) in the Norwegian Armed Forces. They have been asked to give their informal evaluations of the potential of systems of this kind. The responses have been very positive.

Further Work

The Concept Development and Experimentation Program of the Norwegian Armed Forces is supporting a new project in which our research is continued. The new project has a practical purpose in addition to an experimental one. While research focus in the project reported was on technical issues, focus in the new project will be on investigating the value for users.

We are going to use a C2IS that is used just for training purposes. It provides COPs with a very rich set of data.

The project will be carried out through the following steps:

1. Develop an application for practical, daily use.

2. Let military personnel use it for analysis of a large number of exercises, over a long period of time.

3. Document the experiences.

The results will determine whether similar applications for other C2IS in the Norwegian Armed Forces will be developed.

General Benefits

The approach outlined has two essential features:

1. By saving a large number of COPs, a huge amount of historical data can be obtained for a given military mission.

2. By analyzing such a collection of historical data as a whole, one can obtain a large amount of important information that is not inherent in the small pieces of data as long as they are considered individually.

The second feature is the most important one. And this is where our approach moves the limits of the art of the possible.

We cannot yet refer to experience with using our approach for real life purposes, as we are not aware of any existing applications of the kind we are discussing. So let us instead, as a background for discussing the general benefits, make a comparison with something similar that is done, without computer aids, in football (soccer). To play a football match is analogous to conduct a military mission.

Norway has traditionally been a low ranked nation in football. However, in the nineties, Norway had a golden age, and was in a short period ranked as number 2 on the FIFA world ranking. The national team coach at that time was Egil Olsen, with the nickname "Drillo". The most remarkable factor in Drillo's way of working was his way of obtaining experience. He did this largely by systematic analyses of previous matches. His most important aids for the purpose were a video player and videos of a number of previous football matches. By careful examination of the videos, he worked out various statistics, showing probabilities for different kinds of situations and actions to result in goals. Based on this, he worked out his playing strategy for the national team.

Drillo's strategy has received much criticism. It has been argued that it was primitive and gave boring matches. However, the results showed that it was in fact very effective. The interesting thing here is that Drillo based his strategy on *statistics*, while the opponents based their criticism on simpler criteria, like intuitive reasoning, the desire of entertaining matches and what they could remember from matches they had watched (probably mostly spectacular events; few trivial details).

Drillo had just simple aids in his analyses. Therefore, his preparation of statistics was a time consuming work. For the same reason, it had clear limitations. If he had had a computerized aid of the kind that we are discussing, he would have been able to carry out much more differentiated and accurate analyses.

Most of Drillo's observations were probably made by someone else previously. The difference was that he analyzed a very large number of such observations as a collection, thereby obtaining much important information that was not inherent in the individual observations.

When it comes to military missions, it will be impossible to do analyses in the same way as Drillo did in his time. Firstly, it will be impossible to make video recordings of everything that has happened. And even if it were possible, the size and complexity of most missions make it impossible to carry out an analysis by manual methods. A computer based system like the prototype system we have presented will be able to execute analyses of the type Drillo performed. But this is only a small part of what is possible. While Drillo probably spent a lot of time on his simple analysis of a set of football matches with 22 players and duration 90 minutes, one can in few minutes do extensive analyses of operations with thousands of objects (people and vehicles) over very long periods of time. And these analyses can be substantially broader, more detailed, and more differentiated. In addition to almost all statistics that are theoretically possible, one will easily be able to find all the events and conditions that are extreme or in other ways remarkable and do further investigations for them, including finding all relevant relationships in time and space. One can carry out the analyses on an ad hoc basis, with negligible response times.

In short: One will be able to get an insight into what has happened that it is very difficult or impossible to establish by other known methods and tools.

Limitations

A supposition of our approach is that there has been established a comprehensive historical database describing the missions to be analyzed. At this point, there is still a limitation in most, but not all, C2IS.

The C2IS for which we are preparing an implementation provides a very rich set of data. The system is to be used just for training purposes. Effects of weapons are simulated by laser and/or radio signals. Such effects include, in addition to shooting with guns and cannons, the use of mines and gas. The status and position of objects (vehicles/persons) are recorded frequently. A number of event types are recorded, including shots fired and where they hit, and effects of mines and gas. All such data are saved in a historical database, which gives a very detailed description of what has been going on, for own forces as well as the "enemy".

However, in most C2IS to be used in real life missions, there is considerably less data than in dedicated training systems like the one mentioned above (Domingo et al. 2006). The amount of data may vary among types of missions. We know C2IS where there is functionality to equip each soldier with a GPS and some sensors, but where it is used only optionally.

The limited data content is due partly to technological limitations. The most important one is that it is difficult to detect data concerning foreign forces. Information on foreign forces can be gathered by for example pictures, videos and other kinds of intelligence. But it is difficult to transform such information quickly into formatted data elements, which are necessary to serve as a basis for analysis using the kinds of tools that we have described. Formatted data can be derived from several sensor types, for example radar (Bolderheij and Ramdaras 2010) and by sensor networks (Ngo 2006). But such technology has at present significant limitations.

It is much easier to record data concerning own forces. This can be done by equipping each vehicle and person with a GPS and a number of sensors. The technology needed for this is now mature, and is used extensively in the civilian life. But the use of it is limited in many C2IS. Economy is an important limiting factor (Intergraph Corporation 2010).

However, sensor technology is evolving rapidly and the prices are decreasing. This makes it reasonable to expect considerably more data to be available in the COPs of most C2IS in the near future.

Conclusion

By saving a large number of COPs for a given military mission, a huge amount of data can be obtained. But the value of the information one can extract from it depends on the tools available. It would be far too time consuming, and of limited value, to read the data items individually. The most valuable information can only be obtained by analyzing the data collection as a whole.

Through the use of new in-memory data warehouse technology and an advanced interface against a GIS, we have demonstrated how valuable information can be obtained in an easy way; information that is difficult or impossible to obtain by other means.

At present, many C2IS provide a rather limited set of data in their COPs. This limits the applicability of our approach. However, the evolution of sensor technology makes it reasonable to assume that the amount of data in most C2IS will increase in the next few years. This will gradually improve the value of the analyses that can be carried out.

The kind of application that is outlined is a new one. Therefore, it will probably be met with some skepticism in the short term. But our evaluation has shown that the value of the solution is fully grasped by anyone having attended a demonstration of our prototype application. In fact, the audience gets quite enthusiastic. No doubt, there is a great potential for applications of this kind.

The research reported is continued by implementing an application for use in the real life. This will bring the innovation into practical use. Simultaneously, the value as a decision support tool for military officers will be studied. This will give further insight into how to construct future systems of this kind in order to satisfy user needs in the best possible way.

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