Nautiskt 3D-GIS med sikte på kognitiv avlastning och beslutsstöd

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Thomas Porathe: A 3D Nautical GIS targeting Cognitive Off-loading and Decision Making

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A 3D Nautical GIS system aimed at nautical navigation is proposed in this paper. The system simplifies navigation by adding three major features to existing chart systems: *the egocentric view*, allowing geographical data to be viewed from a bridge perspective and thereby removing the problem of mental rotations; *the seaways*, displaying traffic separated fairways and individual track lines, and *the NoGo area polygons* displaying warning areas for waters too shallow for the ship in question in the current tidal situation.

Keywords: Navigation, wayfinding, route guidance, 3D maps, 3D-GIS

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Introduction

A lot of people find map reading difficult, particularly in environments where landmarks are scarce and easy to confuse. This is often the case in coastal and archipelago navigation or when hiking in mountain or forest areas. When we walk in a forest where trees are high and obscure the view, we are pleased when we find a path or a track going in the right direction. This is not only because it is easier to walk on a path, but also because some of the burden of navigation will be lifted of our shoulders. «People have walked this way before» and the path will now do the navigation for us. Man is a path follower. We make paths and we build roads. If we ask for instructions we get a list of instructions such as: «Go strait two blocks, turn left after the church, then pass the bridge…» Roads make wayfinding easier. The ancient Romans were famous for their roads. They used lists for wayfinding and called them *itineraries.* They also listed places and distances such as Venta Silurum VIIII, Abone XIIII, Traiectus VIIII…[1] [1].

Historians including Janni,[4], Broderssen [2] and Whittaker [8] suggest that the Roman empire was built on a different understanding of space based on *road thinking*. Janni calls this spatial understanding *hodological* after the Greek word *hodos,* which means road. They argue that very litte evidence of, and few references to our kind of spatial maps are found, whereas there are frequent references to itineraries. One of the very few «maps» that actually has survived as a medieval copy of a Roman original from the 4th century is the Tabula Peutingeriana (see Figure 1). The map is 7 meters long and only 35 cm wide, and depicts Europe and Asia from Britain on the far left to India on the right.

This type of schematic map is well known from modern public transportation. The British graphical designer Henry Beck is often referred to as the inventor when he revised the London Underground map in the 1930's. However, we know that maps in the modern sense existed in the antique era, for example the maps of Agrippa and Ptolemy. But somehow the itineraries must have been more practical in actual wayfinding. Maybe we can learn something from this?

The first written nautical information to survive to our days is the *peripili* of the an-

1. From the Antonine Itinerary no. 14 Isca Silurum to Calleva Atrebatum over England. The itineraries consisted of names of places and the distance between them in thousands of paces. One Roman pace was a double step, about 1.4 meters, so the Roman mile (1000 paces) would be about 1.48 km.

cient Greeks. Scylax of Caryanda wrote a set of sailing directions in the fifth century B.C. of which some fragments remain. They consist of lists of names and distances between safe havens along the coasts of the Mediterranean and the Black Sea [3]. The first nautical chart does not appear until the end of the 13th century. Not until the 18th century has the chart become the major means of conveying navigational information; before that, the hodological view of sailing directions prevailed. As mentioned above, the sailing directions first appeared as lists of places and distances, then incorporated geographic landmarks and navigational warnings. In the 15th century the French pilot Pierre Garcie started to add *coastal views* to sailing directions. These were simple woodcuts of the coast and islands as seen in an egocentric perspective from the deck of the ship (see Figure 2).

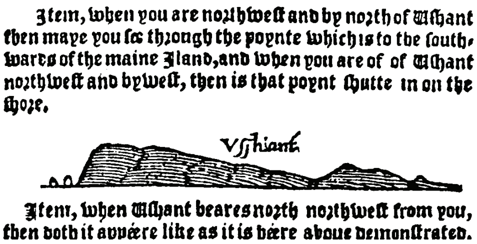

Fig. 2. A coastal view Île d'Ouessant at the western tip of Bretagne in France. A woodcut from Robert Norman's 1590 Safegarde of Saylers [7].

Sailing directions and coastal views are losing their importance today, as satellite based systems present accurate positions on precise electronic charts. But as the speed of ships increase, decision times become shorter. More and more modern equipment crowd the bridge and information overload becomes a problem. The need to limit the amount of information and present it at just the right time becomes apparent.

Today the hodological view could be the «just-in-time» presentation of geographical information, tailored to fit the limitations of the human brain.

The 3D Nautical Chart

High speed and short decision time have played a major role in several accidents at sea. One problem has been related to map reading and the inability to maintain a correct situational awareness. In an information design research project at Mälardalen University in Sweden a 3D nautical chart has been proposed [5]. Three concepts form the basis for the chart system: the egocentric view, the seaways and the dynamic NoGo area polygons.

The Egocentric View

By tradition, geographical information is most commonly presented to the bridge crew in an exocentric, north-up orientation. When comparing map information with the physical world it is necessary to mentally rotate the map to align it with the physical world. The linear relationship between the time needed to mentally rotate an object and the degree of rotation needed was discovered by Shepard & Metzler in 1971 [6]. The implication for the mariner is that decision making on southbound courses will be slower than on northbound.

The suggested solution is to allow the navigator to access the map database in an egocentric perspective (see Figure 3). The egocentric view would display a scene on the display similar to what the navigator sees outside the windows, but with the navigational information added.

The chart can be viewed as simply a traditional chart in an exocentric orthographic perspective, but at any time the user can dive

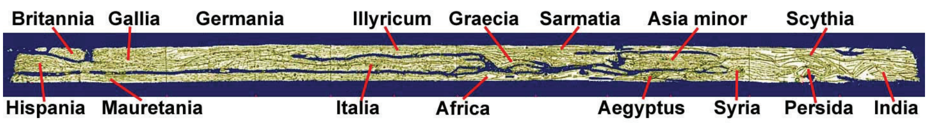

Fig. 1 Tabula Peutingeriana is a 7 meters long and 34 cm wide schematic «map» of the world

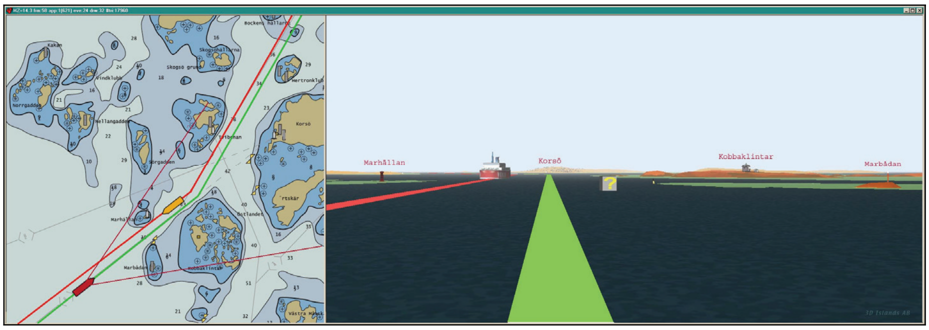

Fig. 3. The exocentric and the egocentric view of the 3D chart. From the authors' prototype chart of the entrance to Mariehamn in the Åland archipelago.

down into the chart and view it as a dynamic coastal view from an egocentric perspective.

To allow this, land height information had to be added to the map database. Different prototypes have been built using elevation contours and photogrammatically measured bare earth elevation models, but laser scanned data have so far given the best results. A 2 m by 2 m grid is used as a target resolution for the elevation data and the terrain skin is draped with orthophoto with resolution 25 cm per pixel. With this data resolution the visual iconicity is good enough to allow direct recognition (see Figure 4).

The Seaways

Roads are cognitive tools that facilitate decision making. A secondary property is that

Fig. 4. A photo from the physical world (top) and a screen dump from the same position in the 3D chart (bottom). Vinga lighthouse in the Gothenburg archipelago. Photo by the author.

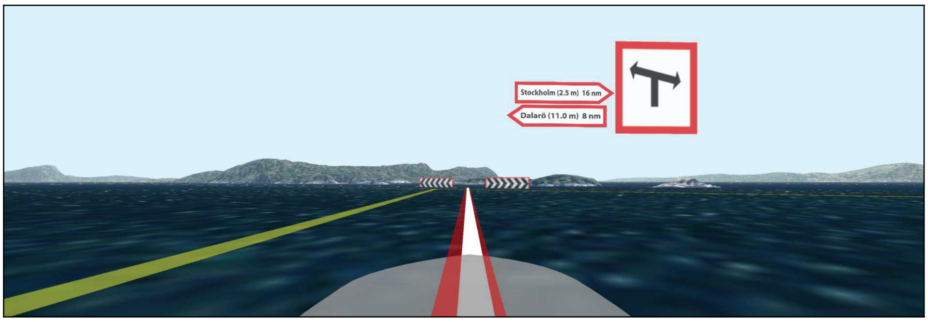

Fig. 5. Examples of seaways, an individual track line and signs displayed in the chart.

they provide us with a smooth surface to drive on. Once on the right side of the road, the driver is relieved of constant decision making until he reaches a cross road, and once there he is aided by road signs.

At sea, a similar system is used in traffic separation schemes or by depicting the fairway as a single line in the chart. Many downloadable waypoint libraries throughout the world use one and the same track for both directions. The suggestion here is to use experience from land road networks and to traffic separate all fairways, adding traffic signs displayed in the 3D chart as needed (see Figure 5).

Individual track lines. Based on the route of the individual ship separate «own ship's track» should be displayed. These tracks could also be broadcasted from port authorities to approaching ships leading them to the correct berth, they could be used for remote piloting and they could also be broadcasted through the AIS system to, together with a symbol of the ship, show other ships and their intended route.

The NoGo area polygons

Normally, the areas free for a ship to navigate have to be calculated based on the soundings displayed in the chart, the current draught and squat of the ship and the water level. If something unexpected should happen in confined waters, this calculation has to be done under time stress. By entering relevant data from on-board sensors and tidal information from on-line sources, NoGo areas could be calculated in real time and displayed in the chart system. With reliable bathymetric data, these polygons could be displayed for any depth in high resolution, not just the pre-drawn depth contours of the chart (see Figure 6).

Laboratory Testing

The Experiment Setting

A laboratory experiment was designed to test the general concept of navigation using the egocentric view. A 6 m by 6 m large studio area was prepared to serve as the confined waters of a complicated archipelago. A small cart was used as a «ship.» Forty five subjects drove the cart along a designated track in the archipelago. The track was the only allowed «navigation channel» in the otherwise «shallow waters» where a «grounding» was registered. The track could only be viewed on the chart, not on the studio floor. Some boxes, a chair and a paper tube were used as visual navigation aids (see Figure 7).

As an indoor GPS system, the position and heading of the cart was tracked by an infrared tracking system (accuracy < 2 cm, 120 Hz) which sent the data back to a laptop computer fitted on the cart. The various map types tested could be displayed on the laptop computer.

The Map Types

Four map types were tested (see Figure 8). In each map the NoGo areas were marked in red and the allowed track in yellow. The four navigational aids (two boxes, a tube and a chair) were also marked. The four map types were:

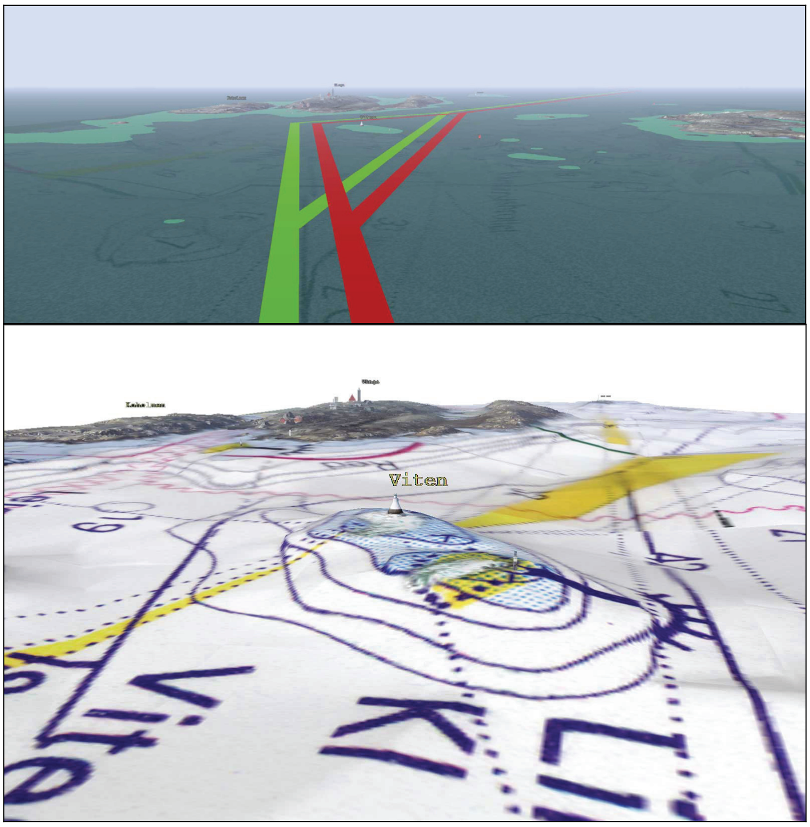

Fig. 6. The northern entrance to Gothenburg harbour looking west, out to sea, from a position east of Vinga lighthouse. Top: The in- and outbound seaways and the NoGo area polygons are set to show depths less than 10 meters. Bottom: the sea surface is removed, showing the traditional chart texture used to drape over the bottom topography. The resolution of the bathymetrical data is in this case no better than in the normal chart. The intention is to have high resolution data.

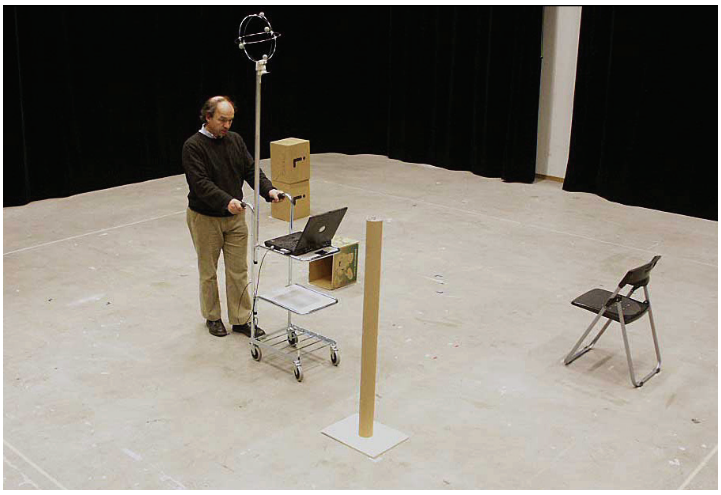

Fig. 7. The experiment area: 6 m by 6 m square marked on a studio floor. Some boxes, a paper tube and a chair were used as navigational aids. The chart is displayed on a laptop screen (see Figure 8).

The Paper Map. A traditional paper map, similar to map A in Figure 8 but without the green arrow. The subjects held the map in their hand while they drove the cart through the track. They were allowed to orient the map as they whished.

*The North-up Map***.** The map was displayed on the laptop screen and functioned as an electronic chart in north-up mode (see Map A in Figure 8). The map was static on the screen and the green arrow moving over the display showed the position and the orientation of the cart.

*The Head-up Map***.** The map was displayed on the laptop screen. In this case the small green arrow was static in the centre of the lower portion of the screen (see Map B in Figure 8). Instead the map moved and rotated as an electronic chart in head-up mode.

*The 3D Map***.** A simple 3D model of the «archipelago» was made and displayed on the laptop screen (see Map C in Figure 8). The position of the cart was marked by a green pole and the virtual camera viewed the scene from an over-the-shoulder egocentric position.

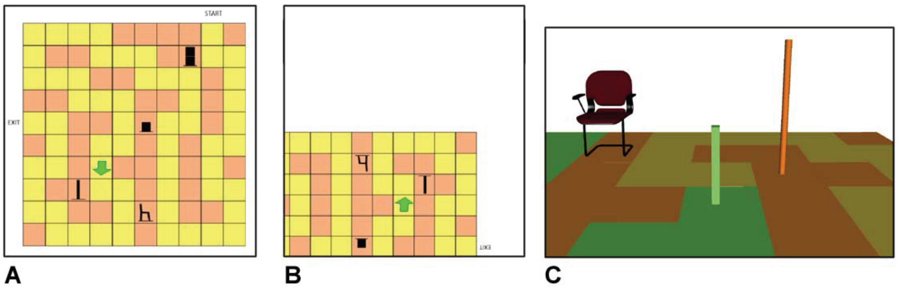

Fig. 8. Three of the four map types used in the experiment. Here they show the position the cart in Figure 7. A is the north-up map (static map, moving arrow), B is the head-up map (static arrow, moving map) and C is the 3D map (static green pole, moving environment). The fourth map was a paper printout of map A (without the green arrow).

The Experiment

The test subjects were forty five volunteers: available students, staff from the university and their family members 21 were female and 24 male and age ranged from 16 to 63.

Each subject drove the cart four times through four different track designs. One new track for each map type. The length and the number of turns in each track was about the same. The order of the different track designs was always the same. The order of the four map types was randomized, so that one subject would start with the egocentric 3-D display on track 1 and the next subject might start with the paper map on the same track.

The test subjects were instructed that the purpose was to drive the cart along the track (yellow squares) as fast as possible without groundings (entering into the red areas on the map). It was explained to the subjects that this was not a competition and that the purpose of the experiment was to test the efficiency of different maps, not the skill of the participants. They should pick a strategy (from quick and sloppy to slow and careful) that they felt comfortable with and try to keep to that same strategy throughout the experiment. Then they were guided through a practice session. When the subject felt ready, the experiment started.

The time on track and the number of groundings were automatically logged by the system during the experiment sessions

After the sessions the subjects were interviewed briefly about their previous navigation experience and they were asked to fill in a ranking form where they ranked the four map types according to user friendliness. They also took a standard spatial ability test.

Results

The results (left side of Figure 9) showed

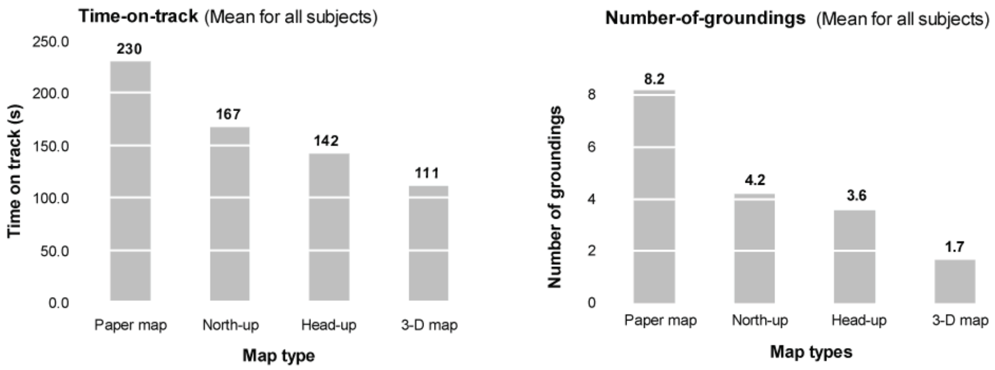

Fig. 9. The left diagram shows the mean time on the track for all subjects and the four map types. The right diagram shows the mean number of «groundings» made by the subjects for the four map types.

that the 3D chart was «fastest» with a mean time-on-track for all 45 participants of 111 seconds. The head-up chart came in second with a mean of 142 seconds followed by north-up map with 167 seconds and the paper chart with 230 seconds. In this test, decision making was 28% slower using a head-up map compared to a 3D map and 50% slower using a north-up map.. Decision making using a traditional paper map was over 100 % slower than with the 3D map.

The mean number of «groundings» followed the same trend. Use of the 3D map resulted in the lowest number of groundings, a mean of 1.7 groundings for the whole group. The mean number of errors was 3.6 using the head-up map, 4.2 using the north-up map and 8.2 using the paper map. Compared to navigation with a 3D map, wayfinding with a head-up map gave more than twice as many groundings. A north-up map gave one and a half times more groundings and the paper map resulted in almost five times as many groundings as the 3D map.

The difference in time on track was statistically significant at the 1% level for the four map types ($F_{(3,132,0.01)} = 46.6$, $p < 0.01$). The influence of the map type on the number of groundings was also statistically significant at the 1 % level ($F_{(3,129,0.01)} = 3.94$, $p < 0.01$).

The subjects were asked to rank the user friendliness of the different map types from 1-4, where «1» was the easiest and «4» the most difficult map to use. The 3D map was classified as the easiest with a mean index of 1.13 followed by the head-up map with a mean index of 2.29. North-up was rated 3.24 and the paper map 3.33. The paper and the north-up maps were considered almost equally difficult to use.

For a more thorough presentation of this experiment and how age, sex, navigational experience and spatial ability influenced the results, see [5].

Discussion

The Egocentric View

Navy and high speed passenger ferries commonly navigate at speeds of about 40 knots today. There have been several accidents in Scandinavia where the bridge officers have lost their orientation and not been able to regain it quickly enough. Speeds at sea continue to increase. Examples are the so-called RIB boats used for tourist excursions and the new Norwegian fast patrol boats in Skjold class that can have a speed of 60 knots. But it is still the same human brain behind the wheel.

There is less time for decision making and there is more information to consider in our ever more effective information systems. We need to think of ways to display the right information at the right time and in a way that is unambiguous and easy to understand.

One could say that there was a point to the hodological perspective of the ancient Romans and the step by step navigation of the itineraries which hid unnecessary information and just gave what was needed to reach the next stop.

A transfer of this concept to a modern nautical perspective and the conning situation might be to present the navigator with an egocentric map with high resolution in the foreground and a low resolution overview in the background, a track to go and the dangers in the vicinity. This is what is offered by the egocentric view, the seaways and the NoGo area warnings.

The laboratory experiment described above showed the efficiency of egocentric conning. Planned sea tests during 2007 will show if this also applies in real life situations.

A Nautical GIS

Of course an ideal nautical chart should contain all the geographical information relevant to the mariner. Today the mariner has to search several different sources to gather necessary route information (e.g. pilot books, lists of light and fog signals, tide tables).

The 3D nautical chart prototype consists of both a digital, «flat» map and a so- called 2.5-D terrain skin draped with orthophoto and map texture. The ultimate goal of this project is to suggest a Nautical GIS where all information relevant to the mariner could be stored and easily updated without having to regenerate the whole terrain skin. An ideal GIS might consist of a true 3D database storing currents, temperatures and salinity of the sea in volume *voxels* allowing for time-based simulation of tidal currents, for instance. Such a database structure would need huge amounts of data storage space and processing power, however, and we will not be there for a long time. But we will eventually.

It should be possible to update the bathymetrical database with areas of high resolution as these data become available, so the database resolution needs to be dynamic.

In cartography the concept of *map generalisation* has improved the legibility of maps. They are not just an air photo, they display the information which is relevant for the target group. In the same way, the photorealistic rendering of the present egocentric view will need further research to attain a higher level of generalisation and improve legibility. Cartoon rendering techniques offer interesting possibilities here (see Figure 10). This will be one area of future research.

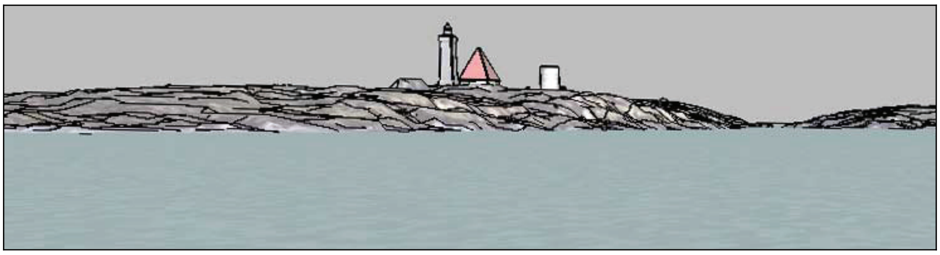

Fig. 10. Here is an example of so-called «cartoon rendering» techniques applied to Vinga lighthouse in the 3D chart. Future research will show if this is a way to improve the legibility of egocentric view maps.

Conclusions

This paper has summarized an ongoing research project at Mälardalen University in Sweden. In the coming year the chart will be evaluated and tested at sea and its possible consequences in practical navigation will be predicted, in cooperation with the Maritime Academy at Chalmers University of Technology.

The chart addresses human factors issues in the maritime domain and attempts to address some of the problems of information overload by removing the need for cognitively demanding tasks and presenting information in a way more adapted to the human brain.

The experimental results presented in this paper are promising and followup studies are planned to further test the proposed chart's applicability.

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