# Increasing the Analyst's "Bandwidth" for Perception and Understanding of Large, Multivariate Collections of Data

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Intelligence analysts are typically presented with large volumes of data within which they seek to find patterns, anomalies and relationships. These data may come from many sources and from many modalities but will be displayed in the form of words, numbers, and/or images. The analyst's typical display is a screen that supports only pixels used to form characters and images. Further, the displays are almost always two-dimensional and employ a standard color palette. Some preliminary analysis could be (and likely will be) done utilizing computer science techniques such as artificial intelligence and machine learning; however, the human analyst will, in many (if not most) cases be the ultimate adjudicator of what is relevant and what patterns, anomalies and relationships are meaningful, leading to knowledge and understanding of value to their agency and to the nation.

The sixteen members of the U.S. Intelligence Community (IC) have different missions, but all depend on analysts that daily work with increasingly larger volumes and complexity of data. At this point, analysts rely on visual representation of the data that they seek to analyze (we exclude such specialized areas as voice analysis from this white paper). Yet, the vast majority of humans are equipped with multiple senses that they employ simultaneously to comprehend and exist in a complex, dynamic environment. Why then, do we limit analysts to only the visual sense in performing their critical tasks? In 2011, Tilton noted:

> *Currently, GIS systems present almost all products on a desktop computer with a flat screen and pull-down menus. Most of the features displayed are specific enough that they require years of community training to even recognize the terms used. Most of our users shouldn't need to understand these internals to make use of GEOINT information. This is not to say the data shouldn't be available, since for detailed analytics these elements can be key, but that they shouldn't be the first things offered up as information. In a world where 12-year-olds play immersive online war games, and we can view IMAX 3-D movies for $9-$12, our desktop displays are absolute dinosaurs. Beyond crafting the roadmap requirements to specify new data interaction techniques, NGA should be working constantly to take advantage of work from other communities on intuitive access and display of information at a user level. Technologies such as augmented reality, 3-D heads up display, ruggedized wrist pads, HD touch screens, smart paper and smart boards, and apps for iPad/iPhone/ Droid should be at least 10 percent to 15 percent of our R&D organizational emphasis. This emphasis will become more critical as 'digital natives'—who are more likely to look for multi-sensory input and data manipulation [emphasis mine]—increasingly take a role in our work force.*[i]

Although this represents the view from the geospatial intelligence community, we argue that it can be applied to the entire IC as they seek to increase the "bandwidth" of their analysts to effectively deal with larger and more complex data. A more recent (late 2016) narrative contains the following section in describing the National Geospatial Intelligence Agency'sresearch and development needs:

> Multisense Feedback (Haptics/Audio)
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> *To improve the efficiency and intuitive capability of our future analysts, the experience of information should move beyond the visual and take advantage where possible of our other*

> *senses.* [emphasis mine] Computer devices already exist for interaction with information provided as sound, movement, pressure, and temperature, and there are efforts to enable synthetic odors as well. The main reason for incorporating these multi-sensing constructs into an analyst's workspace is to enable true and effective multitasking. Humans in the natural environment respond simultaneously from inputs to all senses without being forced to focus conscious attention on every stimulus. A good example is the experience of driving a car. Unless you are a new student driver, the process of accelerating, changing lanes, stopping, etc. is one of integrated touch/sight/ sound activity all done in harmony at a nearly autonomic level. You don't think, "I'm going to let up on the gas now, while looking each direction and listening for car horns so that I can move over one lane." Your body just executes the maneuver sequence. In a properly configured environment designed to support realtime decision-making and activity-based intelligence, the stimulus to examine a different viewing geometry, back away from the scene, focus on a change detected remotely or by in situ sensors on scene, etc. could be given in cues of sound, vibration, or temperature changes on the immersed analyst's extremities. After a suitable training period, similar to that involved in learning to drive, the analyst would be able to intuitively take reflex actions to manipulate elements of the data stream while maintaining focus on its larger meaning.[ii]

We propose two parallel and integrated lines of research: (1) a series of controlled experiments on the use of multisensory displays to examine the analyst's ability to use more than their visual sense alone to explore and analyze large sets of complex, multivariate data and, predicated on the results of this research, (2) the development of a theory of multisensory perception specifically targeted on members of the IC that will allow effective "mapping" of variables onto different sensory displays to increase the analysts' "bandwidth" to find useful patterns, anomalies and relationships that inform their knowledge and understanding of what the data contains.

We have already explored the first of these lines of research in the context of large sets of multivariate geophysical data and found that it can be effective in enabling geophysicists and other experts in hydrocarbon exploration and production to explore the vast amounts of data used in their industry. This work has been reported in several peer-reviewed publications.[iii] In the experiments described in these publications we used three-dimensional visual displays that also incorporated sound and haptic feedback. Thus, we were able to simultaneously present multivariate data to the analyst utilizing and mapping data onto the following senses:

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|---|---|
| Visual: | three spatial dimensions (typically a surface)<br>color palette<br>shading |
| Auditory: | amplitude (volume)<br>frequency<br>timbre (spectral content) |
| Haptic: | friction (stickiness)<br>vibration |

Thus, at least ten different variables could be displayed simultaneously using our system. We found that, after a short exploratory session, experienced analysts were able to find artifacts in the data that could not be readily found by the visual sense alone. We even used the system we built at a major research conference and had random analysts in large numbers use the system with very little training. To further extend our system, the auditory sense could be augmented by incorporating the spatial direction of a sound source, and the haptic sense could also be used to also present texture (roughness). Ultimately, smell and even taste could be explored, since displays addressing those senses are available, adding further to the number of variables that could be simultaneously presented to the analyst.

Others have worked on developing theories of multisensory perception.[iv] While we are not aware of any current effort to develop such a theory specifically for IC analysts, the task can be informed by ongoing research that is more general or directed to other application areas.

The intelligence analysts' tasks will not get any easier. Both the volume and the multivariate nature of intelligence data will continue to grow (likely in an exponential, rather than linear, manner). If we have any hope of the analysts doing their jobs effectively in the future, it is imperative that we enable them to employ more than their visual sense.

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[i] From Barry C. Tilton, Rethinking the GEOINT R&D Roadmap; *Geospatial Intelligence Forum*; United States Geospatial Intelligence Foundation, 9(1) February, 2011; pp. 21-23. Available at http://www.kmimediagroup.com/files/GIF%209-1_FINAL.pdf

[ii] From Immersive GEOINT: Surrounding Analysts with Information; *2016 State of GEOINT Report*; United States Geospatial Intelligence Foundation, 2016; pp. 5-9. Available at http://usgif.org/system/uploads/4510/original/2016_SoG_book.pdf

[iii] C. Harding, R.B. Loftin, and J. Casey. Multi-Modal Investigation of Geoscientific Data—Adding Touch and Sound to 3D Visualization of Surface-based Data. In *Proceedings of the 2000 Annual Meeting of the Society of Exploration Geophysicists*, Calgary, Alberta, Canada, August, 2000.

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C. Harding, I. A. Kakadiaris, J. Casey and R. Loftin. A Case Study in Multi-Sensory Investigation of Geoscientific Data. In *Proceedings of the Joint Eurographics - IEEE TCVG Symposium on Visualization*, Ascona, Switzerland, May 28-30, 2001.

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[iv] See, for example, http://www.visionsciences.org/documents/knill_memorial/3_Robert_Jacobs.pdf for a summary of work by Robert Jacobs, *et al.*, at the University of Rochester and http://nobaproject.com/modules/multi-modal-perception by Lorin Lachs at California State University, Fresno.