Evolving Computational and Data Collection Needs in Geomatics: Field Requirements and Capabilities

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SUMMARY

Throughout the history of geomatics field data collection, the emphasis was on providing meaning and intelligence to support the collected observations. Whether the data collection was done in a field book, on a plane table, or using tallies carved into a stick, more information was required than raw observations. As field work became electronic in nature, means of recording the observations was streamlined, but means of recording the meaning and intelligence lagged. Field codes allow some addition of meaning and intelligence, but they slow data collection. Computational support advanced from simplified methods, through log books and slide rules, to basic calculators and laptop computers.

The advent of laser-scanning produced point clouds with high-quality spatial measurement data, possibly some reflectance data, and almost no meaning and intelligence. The addition of meaning and intelligence was deferred to post-processing. This followed the same pattern as used in photogrammetry and remote sensing, where the spatial location and reflectance data are collected almost instantaneously, while the meaning and intelligence is added later.

As faster field data measurement systems have been developed, computational and storage systems have been upgraded, while earlier systems have faded out. The HP-41 and HP-48 calculators that could collect several days' work with a total station are completely overwhelmed by the size and speed of current data collection. 'Big data' is a normal day's work in many surveying organizations. At the same time, the demands of GIS applications include more elaborate attribute data for many measured features. The needs for portability, connectivity, data transfer speed, storage capacity and a flexible user interface often clash during development of field data recorders and computational devices. The need to integrate spatial data from multiple sources, often in the same piece of field work, is of growing importance.

In this paper, the authors review critical aspects of spatial data collection over the years, analyzing different trends in technology and techniques, as well as future needs. Suggestions for areas of development are advanced, together with suggestions for solutions to conflicting needs.

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1. BACKGROUND

Throughout its history, surveying has involved extensive field data collection. The data collected, by whatever means and into whatever storage medium, could be grouped as follows.

Temporal data: what is the date of the survey, and how old are certain measured items.

Spatial data: location (usually relative) of specific points of interest.

Meaning data: what is the specific point of interest and its associated attributes.

Intelligence data: how each specific point of interest connects to other points of interest.

As an example, a cadastral surveyor may determine the location of a series of points by offset distance from a base line, as well as distance along the base line (relative spatial location), noting the type of fences (meaning) associated with those points at the date of the survey, along with their age (temporal), and indicating how the fences were connected (intelligence). Similarly, a plane table survey would locate specific points in the landscape (meaning) at the date of survey (temporal) by intersection measurement (spatial), then sketch in the connections between all the points (intelligence).

While different types of surveys emphasize different types of data and how much is collected for each type, the four overall types are present in almost all surveys. Further, all these data types are collected in the field at the time of the survey.

The earliest surveys involved parcels of land in Mesopotamia and Egypt, and as polygons were being described and used to represent a specific parcel, meaning and intelligence were included with the spatial data in a metes and bounds description from around 3600 BC (Werner, 1966, p. 936). The temporal nature of the survey data being from before and after floods or development was also included with the overall collection of data. Mesopotamian mathematics (e.g., Fowler and Robson, 1998) allowed computations of figures with considerable precision, with records in clay tablets.

Clay tablets and papyrus were sufficient for data collection for millennia, with a move to parchment and eventually paper as the recording medium. Computations could be minimized by the used of tables of pre-computed values, with mental arithmetic skills being far greater in those days. Measurement took longer than recording the data and data volumes were quite low.

By setting out the survey using regular polygons, as well as orthogonal measurements, processes were simplified for measurement, data recording and subsequent computation. Plane table surveys from the mid-16th century were also only as fast as the surveyor drawing the map in the field. For millennia, the process of data recording kept pace with the speed of measurement, the speed of measurement meant that only the most essential measurements were made, and meaning and intelligence could be incorporated in the data recording process at the time of measurement.

This particular methodology reached its apex with tacheometry. Someone visited every point with a leveling staff/rod, later a prism on a pole, then a GNSS receiver in RTK mode. Observations were made to the point and various meaning and intelligence components were collected at the same time.

With the advent of photogrammetry in the middle of the 19th century, this well-established process had a viable alternative. All the spatial data that were measured were measured at the instant of exposure of the film (the temporal data). No intelligence data were collected, while the meaning data consisted of light intensity (later color) associated with each measured location, effectively an attribute of the location. The plotting of the photogrammetric data involved processing to convert measurements within each image to 3-D locations in a larger reference system, i.e., a series of transformations, commonly built on the Helmert transformation, together with the determination of meaning and intelligence by inference through photo interpretation. This is the first instance where meaning and intelligence are deferred for later processing, rather than being largely determined in the field.

The use of LiDAR, whether airborne or terrestrial, follows the same process as photogrammetry, which is why it can be considered an analogue of photogrammetry. 3-D location data are collected at a specific time with minimal attribute data, usually a simple image and possibly some intensity or return delay data. Spatial location of the measured point is determined using various transformation, commonly built on the Helmert transformation. The meaning and intelligence are then inferred by interpretation of the available data. Satellite remote sensing follows a similar pattern.

The main advantage of using photogrammetry and its analogues is that spatial data collection can be made highly efficient, while the addition of meaning and intelligence can be deferred. When meaning and intelligence are made explicit in the field, the rate of data collection may be no faster than one to two points per minute. Mobile LiDAR may collect several million points per second, while an airborne photogrammetric system may collect over 2 billion pixels per second (e.g., Leica DMC-4).

The productivity improvement by focusing all the effort on spatial data acquisition now exceeds a billionfold for photogrammetry and its analogues. The temporal data (time of measurement) are collected simultaneously. However, the acquisition of meaning and intelligence data is deferred and so does not have similar productivity improvement, although some of this acquisition of meaning and intelligence can be deferred indefinitely.

2. ELECTRONIC RECORDING

With the release of the Zeiss ELTA in 1968, the first electronic tacheometer or 'total station,' all the measurement data (angles and distances) were available in electronic form in a single instrument. Recording these data electronically allowed significant improvements in overall efficiency of measurement operations, as well as a reduction in recording errors. However, there was no immediately obvious means of efficiently recording the meaning and intelligence with the measurements in a simple digital form.

Many recording schemes for survey work are semi-graphical in nature. A field sketch is used to provide some meaning and intelligence for the overall dataset, while detailed textual annotation provide additional meaning. Getting this information into the same dataset as the instrument measurements is non-trivial once data recording is electronic.

One reason for the difficulty is that the intelligence component can be both large and connected across multiple points, including many that have not yet been measured. Graphic representations can be information dense and include a great deal of implied information. The aphorism "A picture is worth a thousand words" (1 kilobyte) is very true in surveying situations and as humans are very visually oriented in their thinking and communication, graphical representations can carry more information than may be initially apparent. But how can this be collected electronically?

An early approach was to attach a feature code to each measurement. Simple numerical codes were developed that could be keyed into an instrument or data recording device, using the numeric keypads that many instruments required for efficient operation. While many of these feature codes initially offered only meaning data, expansion of the code systems allowed inclusion of some intelligence, e.g., the start of a curve, intersection points for a curve. Feature codes became more complex, requiring operators to memorize them or have a code book handy to look up codes, which slowed down operations. Keying in the feature codes could be facilitated by loading a collection into the instrument or data recorder, but it was still only marginally more efficient than recording the meaning and intelligence information in a field book, especially for complex surveys.

The nature of these feature code systems differed between organizations, based on the organization's purpose and mandate. This meant that it was necessary to have look-up tables to allow translation of the information in one organization's measurement datasets to match how the same or similar information was represented in processing software and CAD. No translation system could match every need, so it is still necessary to tailor conversion methods in various software packages. This reflects issues that have plagued spatial data transfer for decades.

A development in the last couple of decades has been using various tablets and other data recorders to collect GIS data in the field. Approximate locations can be obtained using the device's built-in GNSS capabilities and form one part of the collected data. Attribute data can also be collected, conveniently when an operator is at the point in question. However, this attribute data is commonly collected directly in attribute data tables, often with a forms-based interface, which allows complex textual entries to be made, in addition to numerical and code data. This leads to increasing amounts of meaning and intelligence being gathered at the point of interest. However, this form of data collection is just digitizing at a 1:1 scale, where every point must be visited (unless imagery is collected, in which case the operator can just go close to the point). Such a digitizing approach removes all the economic advantages of data collection using point cloud approaches.

So we see two conflicting approached to digital geospatial data collection. One emphasizes raw speed and collection of point clouds that are post-processed to add meaning and intelligence. This is the photogrammetric analogue. The other emphasizes geospatial data collection point by point, with a growing emphasis on a growing body of attribute data collected at the time of measurement. This is the tacheometric analogy.

It seems that all our data collection methodologies are based on these two approaches, each of which comes with significant downsides in an increasingly electronic world. Is there another path, or can these be improved enough to get by?

3. COMPUTATIONAL AND STORAGE SUPPORT

There has always been a significant computational support component for surveying work. For centuries, if not millennia, considerable effort was expended to minimize computational needs, owing to the difficulty of undertaking computations in those times. Surveying was undertaken along orthogonal lines. Approximations and graphical solutions abounded. While the development of significant computational support tools, such as logarithms, the slide rule and the earliest adding machines in the period 1607 to 1642, while algebraic and analytical geometry were developed between 1630 and 1640 (Hazelton, 2012), thereby allowing the first use of co-ordinates for plane surveying. Rathborne (1616) describes the use of "the peractor, (a segment of a circle covered with sine lines for the reduction of slope distances)" (Werner, 1967, p. 36).

Even with these developments, surveying had several unique computational needs. The introduction of co-ordinates meant that at least ten significant figures were needed for many computations, which precluded use of the slide rule and required special log tables. Even so, simplifications and approximations were still widely used, e.g., Meyer and Gibson (1980) used a binomial expansion to simplify some computations with circular curves, something that became unnecessary with the arrival of pocket electronic calculators and spreadsheets during the preceding decade.

To this point, field records could be kept in a written form in field books. Writing down the observations did not significantly slow most measurement procedures and the volume of data remained small. With a field book, it was easy to include field sketches and other notes to help interpretation of the measurements, as well as provide the meaning and intelligence for the spatial and temporal data.

With the advent of electronic measurement systems, the need for field computation grew. While slide rules and tables could help reduce stadia observations in the field, log tables were required for traverse reductions, and larger log books were needed for the reduction of astronomical observations, electronic data was able to be moved very easily into co-ordinates, and this tended to need greater computational power. Calculating one’s position in the field and then the instrument settings for marking out a series of points defined by their co-ordinates required electronic computing power for the work to be able to be completed it in a reasonable time. HP calculators, designed with surveyors as one of the target markets, were quickly adopted by the profession and appeared everywhere, even working as data recorders as a variety of storage methods were adopted and included. The ability to store 256 KB of data provided storage for several days of work for almost all applications, noting that field sketches and other information were commonly in a field book.

Specialized data recorders advanced from little more than storage boxes with a simple control interface to complex handheld devices with alphanumeric keypads, large graphic screens and large data capacities, as well as the ability to connect with and control a wide range of instruments. Many run common operating systems, such as MS Windows, allowing other software to be uploaded for field use (although the software commonly has to be recompiled to operate on the specific processor used in the data recorder).

LiDAR dramatically increased the need for field computational support, initially in two ways. LiDAR can produce multiple megabytes of data per second, and can keep producing it for long periods of time, meaning conventional buffers can be overloaded. Conventional ethernet, when it was developed in 1983, operated at 10 megabits per second, allowing little more than one megabyte per second. In 1995, 100 megabit ethernet was introduced and in 1998, gigibit per second ethernet was introduced using fiber-optic cable. Fast ethernet or other high-bandwidth connection systems were necessary to handle the flow of data. High data flow rates sustained over time required large storage capacity, which had to be available close to the instrument.

Aerial scanners and digital cameras, as well as airborne LiDAR and more recently radar-based systems like SAR and InSAR (also IfSAR), also require high bandwidth for large data flows, as well as large amounts of readily available storage. In the 21st century, a critical characteristic of geospatial work in general has been very large data flows, very large storage requirements, and software than can handle very large amounts of data.

Any effort at field computing using all this data required computational platforms that can work with large amounts of data at a reasonable speed. Fortunately, modern laptops can often handle these requirements, but it has doomed the pocket calculator to niche uses. Handheld devices are of limited utility where large volumes of data must be handled, so survey crews are moving closer to having a laptop in every vehicle, which is likely to expand to include more office equipment, e.g., additional mass storage, as data volumes increase.

If more processing is to be done while the field crew are in the field, some processing applications may not be able to be implemented in a mobile setting. A complex artificial intelligence (AI) analytical capability may only be able to be built using multiple processors, and quantum computing needs to operate under carefully controlled physical conditions. Both these technologies are poised to become more common in geospatial analysis, but are currently impractical to take into the field. Data would need to be uploaded to such remote systems and results returned if they were needed while in the field.

One novel development in recent decades has been the growing need for a data link while in the field. Using virtual base station methodologies requires a data link, and more organizations are providing a means of uploading data to the main office computer system from the field. The ability to download the same data as would be available in the main office while in the field is often an advantage as the field crew adapts to changing circumstances. How good, in terms of reliability and speed, the data link may be is completely dependent on the carrier chosen, and the quality can vary greatly over even short distances, once one leaves built-up areas. As data processing needs increase, so will data communication needs, and this will make the survey vehicle at least part office. Survey vehicles may have to be adapted significantly to meet these changing needs.

4. COME THE REVOLUTION…

The history of geospatial science tends to consist of long periods of relatively slow development, where improvements gradually make things better, faster and cheaper. Then there are periods of rapid change and development, where how everyone things about the geospatial sciences gets shifted in a major way. Often, there are periods before the rapid changes where technologies slowly build in capabilities. Then something triggers a massive series of changes, new technologies come together *en masse*, techniques change rapidly, and everyone's thinking shifts to a different paradigm. The progression is akin to the punctuated equilibrium model of evolution (Eldridge and Gould, 1972).

The first two revolutions in geospatial science happened slowly and were in step with parallel developments in human thought. The first happened thousands of years ago when humans realized that they could think about the world as separate from themselves, and that they had agency to control or deal with some aspects of it. The second happened largely with the Ancient Greek developments in mathematics and thinking, although a significant part of this was lost and had to be rediscovered.

The third revolution occurred nominally between 1550 and 1650 AD. Technologies that had been quietly developing over the previous 200 to 300 years came together and improvements and developments started accelerating. In the critical years 1612 to 1620, techniques to extend triangulation baselines were created, logarithms, slide rules and the first adding machine were developed, and algebraic, analytical and co-ordinate geometry were invented. The resulting change in thinking moved surveying and mapping from local, simplified and pictorial, to global, complex and mathematical (Hazelton, 2012).

The fourth revolution started around 1950, triggered in part by the developments from World War II. The rate of change and development accelerated, but the change in thinking has taken a while to arrive. GNSS is not in itself revolutionary, because it is point positioning (just like field astronomy) done better/faster/cheaper; GNSS integrated with sensors is revolutionary. Photogrammetry is revolutionary because it allows massive spatial data collection in an instant, but it took some time to realize this because plotting was still laborious. Photogrammetric analogues, like pushbroom scanners, SAR and LiDAR, move the data collection side of the discipline to high-speed collection of the spatial and temporal data components, but tend to defer the collection of meaning and intelligence data. These analogues are not in themselves revolutionary, as they simply extend the photogrammetric paradigm. Technologies like drones of various types similarly extend the photogrammetric paradigm, allowing better/faster/cheaper operations.

Technologies like blockchain, AI and quantum computing have the potential to be revolutionary, but haven't manifested this yet. They still have a significant degree of development and integration required.

The other main revolutionary aspect of the current revolution has been a combination of very low-cost and ubiquitous geospatial sensors and the Internet. This has allowed almost everyone on Earth to have fast and easy access to massive amounts of geospatial information, and to collect their own (usually imagery with GNSS location attached) and share it widely. Individuals can also share location data which allows travel patterns to be discerned.

This is precipitating the largest change from the current revolution (to date). Almost everyone on Earth can be a geospatial data collector. The role of the surveyor, as a measurement expert, can therefore broaden from primarily measurement and data collection, to being able to assess the quality and utility of geospatial data from almost anywhere and be able to integrate it into a larger project. The shift from geospatial measurer to geospatial manager will have major changes in how the discipline sees itself in the future.

There will always be a need for high-quality measurements and data. But a growing part of our work will be management and integration, rather than primary data collection. And has been shown in several places, no amount of legislation and regulation will stop the democratization of geospatial data collection and distribution.

5. FIELD SUPPORT NEEDS

The most pressing current need for field work is being able to improve the addition of meaning and intelligence data to the overall data collection process as close to the source as possible. This needs to be done as efficiently as possible, otherwise there is the risk of greatly slowing spatial data collection.

If we deploy AI to assist with this process back at the office, the AI tends to have to work largely alone. In the field, it is possible to focus AI differently and include human-in-the-loop processes. This will require significant processing power and visualization capabilities in the field, hence the importance of the vehicle-based 'office' and connectivity to external process and storage.

When large amounts of data are collected rapidly, they will be in the form of an image or an image analogue, such as a point cloud. Good visualization tools will allow pieces of the point cloud to be selected quickly and easily, using irregular boundaries, and selected for a particular meaning or attribute. Using 3-D goggles and haptic gloves would allow volumes to be shaped by hand to match required attributes or meanings. AI could be trained to find edges and refine the volume, based on the known and deduced characteristics of specific objects. Devices like 3-D styluses can be used to sketch in intelligence and connectivity information, with AI being used to make the information more refined. If this data can be incorporated with the spatial data and available for later processing, it may be possible to speed up the post-data-collection processes, trading off a little extra time in the field for less time post-processing.

With a vehicle-based office, it will be possible to check attributes and meaning data, together with intelligence data, while moving through an area. Checking between the visualization and reality should allow faster processing, with suitable AI helping to shape the results to something more meaningful, as well as speeding up the process. If an area has to be walked through, a wearable computer with visualization googles and gloves could be used for field verification and the addition of meaning and intelligence. The foundations for this kind of development are based on long-standing work in visualization, together with augmented and virtual reality, e.g., Wu and Hazelton (2019). Allowing immediate presentation of augmented reality data over collected point cloud data while still in the field can allow rapid checking for data completeness.

By breaking the point cloud or imagery collected in the field into smaller pieces, the computing resources required for visualization and AI are reduced in the vehicle office. A high-speed link can move data to a central repository for more heavy-duty processing, but the link may not be able to support real-time visualization in a data-rich environment, hence the need for local processing prior to uploading.

6. WAYS FORWARD

The first trend that can be seen happening is the continual increase in the volume of data being collected and managed. Mohney (2020) suggested that the commercial satellite imaging companies were collecting significantly more than 100 TB per day, and this figure was growing rapidly. Data stores are moving into exabyte territory. However, this isn't driving developments in hardware, because geospatial data isn't seen as critical or highly profitable, largely because of low potential sales volumes compared to other disciplines. Consequently, hardware available for geospatial computational support will tend to lag geospatial needs, especially for mobile applications, as data sizes continue to expand.

Similarly, data communications bandwidth growth will be based more around what the mass of consumers need, rather than the needs of geospatial professionals. This means that there will be a need for more capable storage and computing power with the field crew. And current experience suggests there will be many areas where there is no signal.

Rapid shrinking of processors and mass storage, together with decreased power demands by newer equipment, makes it easier to provide a very capable mobile office. But that office will need to keep growing as the amount of collected data increases with the addition of new sensors and new job requirements.

The widespread availability of masses of geospatial data from multiple sources, some of them being ordinary people with smartphones, means that the need to collect fresh data may be reduced somewhat if realistic alternatives exist. This means that the geospatial practitioner needs to be more than a measurement expert: they need to be an expert on the nature of the measured data and on ways of ascertaining the quality and usefulness of geospatial data of uncertain provenance. This additional expertise is not replacing measurement expertise; it is augmenting it.

With an emphasis on very large data sets, geospatial professionals must also be experts in data storage, data security, data exchange, databases and data formats. Management of geospatial data will be critical, as the simple methods of the past for dealing with a few megabytes of data won't work when petabytes and exabytes are in regular use. Ensuring that meaning and intelligence data, along with metadata, is part of all archived data will be important for the utility of that data well into the future. Archiving geospatial data, then finding and retrieving the correct pieces decades later, is going to be a skill set of growing importance for geospatial professionals into the future.

As data volumes grow larger, the ability to bring together many processors to tackle large jobs is going to be of growing importance. While cloud solutions such as amazon's AWS are one option, building and managing multi-processor systems, as well as developing software to facilitate parallel processing on these systems, is going to be important. This area will get a lot of support, as data is growing in other disciplines, but the geospatial area tends to build very large datasets that have very specific needs. Off-the-shelf software may not be readily available for some time.

The ability to develop geospatial-specific AI tools will be a useful skill for future geospatial professionals. During the early days of digital computers (into the 1980s) there was almost no software readily available for a wide range of common geospatial tasks, partly because of the wide variety of hardware platforms. Being able to code something to do the job became a necessary part of a professional's skill set. The initial period of AI adoption will follow a similar path, so having an equivalent skill set in AI development will be important.

The trend to democratization of spatial data collection is an opportunity for geospatial professionals in many ways. Using someone else's data that is in the public domain can be a lot cheaper and easier than collecting the same data yourself. If it is understood how to ascertain the quality of the data, it becomes much easier to integrate that data with a wide range of other data from multiple sources. This can greatly simplify the project. Of course, all this is easier if laypeople collecting the data can do so in a way that facilitates its use in geospatial applications, so there is an opportunity to educate laypeople about how to tweak their activities to ensure that the resulting data is as usable as possible. This outreach can also pay dividends in recruitment for the profession, something that is badly needed in many parts of the world. The more people who are aware of the activities of the discipline and can feel involved, however vicariously, the better the opportunities for recruitment.

As progressively greater computing and storage power is moved into the field to support the very wide range of geospatial data being collected today, it will be necessary to have a well-planned and managed system for the field hardware, the field software, and the communications. Tight integration of hardware will be needed to ensure efficient operation in the field, so that whatever devices and sensors are in use, the collected data can be transferred to the database quickly and easily. Communicating between the field system and the office system will be necessary for efficient and effective operation, especially for large projects. This will require significant bandwidth and power to run everything, meaning that building the system will require much more than just being able to plug a laptop into the vehicle's 12V outlet and a smartphone. Small businesses may even be able to dispense with a significant office system and concentrate everything in the vehicle, but as the vehicle is a 'high risk' area, back-ups of the data (and at a different location) will be critical, as well as ruggedized components.

Finally, there is the 'X' device or system. This is the piece of technology that apparently comes out of nowhere and changes everything (Jones, 1995). We don't know what this will be, but it usually arrives from an unexpected location. In the early days of computerization, the bigger a computer was, the more powerful it was. But miniaturization changed all that. Today, the average smartphone has significantly more raw computing power than a Cray Y-MP supercomputer. Similarly, the power and flexibility of smartphones allow us to use them as controllers for some devices (especially GNSS receivers), data links for GNSS work with virtual base stations, management tools for survey projects, and a link to the office computer system allowing upload and download of relevant data. Smartphones also allow us to analyze a lot of information about laypeople's behavior in various environments, allowing crowdsourcing of information.

7. CONCLUSIONS

Over the millennia geospatial data collection has evolved, and at times jumped ahead, as different technologies have been introduced. Notable in recent decades has been the exponential growth in the size of data collection for many jobs, driven by the development of technologies based on image and image-analogue collection. GIS data needs, based around extensive attribute data, have contributed to this increase. With much of these data being in digital form, the need for greater processing and storage in the field with the data collection team has become apparent.

One reason for the increase in data is that images and image-analogues tend to defer collection of meaning and intelligence data, in favor of far faster spatial data collection. The meaning and intelligence data are added later based on interpretation of the spatial data. Moving a significant part of this work back to the field should make overall data collection more efficient and effective, but it requires significant storage and processing capabilities in the field. The development of a comprehensive field office in vehicles is becoming more likely, with visualization capabilities beyond those of laptops being needed.

The potential of using AI to accelerate the inclusion of some part of the meaning and intelligence data with the spatial data close to the time of spatial data collection is one way to make data collection more efficient. In effect, creating an augment reality model while also doing the spatial data collection has the potential to make geospatial data collection more efficient and effective, as well as reducing potential errors in the meaning and intelligence part of the database.

With the growth of geospatial datasets, deeper understanding of databases and data management will be necessary to deal with these larger datasets. Combined with the need to integrate geospatial data from multiple sources and assess the quality of these datasets, the ability to go beyond geospatial measurement into quality assessment and data management will be critical to success.

Multiple sources for data, especially from laypeople via the internet, provide opportunities for outreach. Over time, this can help improve the quality of the data as well as afford opportunities for recruitment to the profession.

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BIOGRAPHICAL NOTES

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