The Surveying Revolution of 1550-1650: An Examination and Implications for the Current Geospatial Revolution — Part I

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BACKGROUND

- Four distinct surveying ‘revolutions’
  - Consider ‘revolution’ as involving changes in technology, technique, theory and mindset
- The ‘After’ is very different to the ‘Before’
- Change is not incremental, but fundamental

REVOLUTION ONE

- **The creation of surveying accompanying the shift from hunter-gatherer social structures to agrarian social structures**
- **Part of the 'priesthood' who have special knowledge**
- **Used for managing land rights, organizing taxation as towns were developed, construction, etc.**
- **Developed separately and in many places, over time**

REVOLUTION ONE

- **Before: there was basic navigation by natural features and limits to tribal areas by natural features: adapt to the natural world**
- **After: there were methods that were repeatable, and a realization that structure could be imposed on the world by measurement**
- **Methods were heuristic, but developing**
- **Going from nothing to something, and that something has a name, even if it's only a description of the technology in use: "rope-stretcher"**

REVOLUTION TWO

- **Change from heuristic approaches of Egyptian and Babylonian surveyors to deductive approach of Greek mathematicians**
- **Surveying became the application of theory: structured and with consequences or corollaries, e.g., Hero's *dioptra*, Eratosthenes' measurement of the Earth**
- **Change of thinking and mindset: surveying as a discipline with a theoretical foundation**

REVOLUTION TWO

- **Abstract mathematics can provide deeper explanations for the world than can heuristics**
- **From theory comes provability, and theory can lead to the development of instruments to provide that proof**
- **The universe can be structured from the human mind, and from that comes the idea that the human mind is a critical element and somehow separate from the rest of the universe**

THE ROMAN HOLIDAY

- Roman surveyors took Greek surveying and advanced its practical application by attention to detail
- They did not create any new theory, and abandoned much
- Rectangular system, simplifying the mathematics to arithmetic
- Surveying was local, mapping was pictorial

THE DARK AGES

- With the decline and fall of Rome, surveying remained little changed for another millennium
- The focus remained local, arithmetic rather than mathematical, pictorial mapping
- There wasn’t anything else

THINGS START TO MOVE...

- Early developments in related knowledge around the 1200s
- Black Death (1348-1350) changed social, political and economic structures in Europe
- Fall of Constantinople (1453) brought scholars westward: new ideas from Ancient Greece and Islam
- Gutenberg introducing movable type for printing in mid-1450s
- Discovery of the New World (1492) changes European thinking about geography: a shift from ‘Europe and the East’ to a global consideration
- By 1500, the Renaissance is in full swing in Europe

THINGS START TO MOVE...

- With the Renaissance comes a growth in knowledge at an unprecedented rate
- In parallel, the development of the scientific method: ideas are not considered correct until they are tested
- Developments in medicine, astronomy, chemistry and physics
- Introduction of the Hindu-Arabic number system

THINGS START TO MOVE...

- Breakdown of feudal system, leading to changes in value of land, and a greater need to know about it and manage it (original meaning of 'surveying' in English was 'land management' or overseeing)
- Efforts to standardize weights and measures, including secularizing trade and commerce
- The creation and rise of the professions, working with an open knowledge system; and the decline of the guilds, working with a closed knowledge system
- Increase in importance of universities in the new knowledge environment
- Professions start to develop 'continuing professional development' systems

TECHNOLOGICAL DEVELOPMENTS

- **Indexing in libraries introduced around 1500**
- **Angle-measuring instruments developed by about 6-7 different people independently across Europe from 1512 to 1560**
- **First surveying textbook in English in 1523 (mostly land management), others in other languages around this time**
- **Triangulation first described in 1529**
- **Plane table around before 1550**

TECHNOLOGICAL DEVELOPMENTS

- **Early vernier developed around 1540, angle measurement to 30 minutes of arc**
- **Improvements in levels developed in 1547 *et seq*.**
- **Telescopes developed from about 1570**
- **1574 wire was advocated for distance measurement, rather than hemp cord**
- **These developments started to combine and improvement became rapid**

PROGRESS

- **After a slow start around 1500, things start to pick up the pace around 1550, then development speeds up again**
- **The ability to disseminate information leads to similar developments in many places, and knowledge shared across Europe**
- **Digges textbook (1556) was based on his own developments, his studies at Oxford, and what was happening across Europe**
- **Trig functions are developed based on the angle, not the sides or other linear components**
- **Development is building to a critical mass…**

THE CRITICAL PERIOD

- While the various technological developments come together and sweep prior technology and techniques away, it is still a case of 'better, faster, cheaper'
- Then there is a critical period of change:
  - Bergi first discusses logarithms in 1607, Napier extends them in 1614, Rathborne encourages their use in his 1616 surveying text, Napier's bones developed in 1617, and the slide rule in 1620
  - Kepler produces a telescope for surveyors in 1610
  - Snell develops baseline extension for triangulation, resection, and starts large-scale triangulation in 1615

DEVELOPMENTS CONTINUE

- **In a little more than a decade, triangulation on a continental scale is developed, together with a computational system to go with it**
- **Pascal builds an adding machine in 1640**
- **Quality telescopes can be mounted on the theodolites, and the vernier proper is developed in 1631**
- **Gethaldi develops algebraic geometry in 1630, and Descartes (1637) and Fermat (1640) develop analytical geometry, from which co-ordinates were developed**

DEVELOPMENTS CONTINUE

- **Moving cross-hair in a telescope developed in 1639**
- **Chains and bars developed from 1590 onwards for distance measurement**
- **Developments in mathematics, mechanics, optics and computational techniques continue, fueled by the changes already made**

CRITICAL CHANGES

- **The period 1610-1620 saw the introduction and widespread adoption of a system that radically changed surveying:**
  - **From local to continental, then global: triangulation**
  - **From arithmetic to mathematical: computation devices and new theory in geometry**
  - **From pictorial to representational in mapping: co-ordinate geometry**

CRITICAL CHANGES

- Revolutions occur in how people think, not so much in what they do
- The change in mindset was both radical and complete:
  - Note that the historical collections in the US completely lack anything from before the 1550-1650 revolution
  - Immigrants to the US colonies from the second half of the revolution have completed eliminated pre-revolution technology

CRITICAL TECHNOLOGIES

- **The two technologies underpinning the critical change in the third surveying revolution are angle measurement and computational methods**

- **Angle measurement was about 100 years coming, from Waldseemüller's *polimetrum* of 1512 to Snell's extension of triangulation around 1612**

- **Who could have foreseen the impact of the *polimetrum* at the time?**

- **With the two technologies together, continents could be measured and mapped**

WHAT HAPPENED NEXT?

- With the ability to measure continents, people tried to do it
- Big triangulations were a big deal until the 1950s
- With co-ordinate geometry came new map projections and ways to compute them
- New questions arose: what is the exact size and shape of the Earth?
- Surveying had switched from purely local to global in less than a century

WHAT HAPPENED NEXT?

- There was a lot of new technology for surveying and mapping: plane tables, levels, theodolites, triangulation, computational tools, even the tripod was developed in this period
- New technologies mean new techniques
- Theory was expanding to try to fill the gaps
- The mindset was changed, and there was no going back

WHAT HAPPENS NEXT?

PHOTO AND LUNCH!

The Surveying Revolution of 1550-1650: Implications for the Current Geospatial Revolution — Part II

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THE FOURTH REVOLUTION

- Nominal starting date is 1950, when technology developed during WWII starts to become available for surveying
- Some important developments occurred before 1950, because improvement had been continuous since 1650:
  - Major improvements in optics around 1900
  - Calculus in late 1600s
  - Least squares in early 1800s

THE FOURTH REVOLUTION

- Developments between the revolutions enable 'better, faster, cheaper' improvements in how things were done
- Improvements in triangulation, traversing, plane tables, leveling, computations, etc., but no fundamental change in how spatial data are acquired
- Surveying remains focused on measurement, because measurement was physically difficult, and as much art and skill as science

THE FOURTH REVOLUTION

- **Some more disruptive innovations start to appear in the 1800s, but they are small and apparently harmless**
- **With the focus on measurement and its errors, the thinking is largely analytical: breaking problems down into smaller pieces**
- **Because there is no other way that is known to produce results of the same quality, everyone remains focused on current methods**

THE FOURTH REVOLUTION

- Things started to accelerate after 1950, and the acceleration continued
- Most changes were incremental or sustaining innovations:
  - They moved things along at a steady rate, e.g., total stations and GNSS, which allow better, faster, cheaper mapping point-by-point, just like a plane table

DISRUPTIVE TECHNOLOGIES

- **These technologies undermine the status quo by being sufficiently different, and initially seeming inconsequential**
- **Sufficiently different: not a change that an established operation would consider, because it needs a different business model for success**
- **Inconsequential: seems small and non-threatening to the status quo**

WHAT IS THE KEY TECHNOLOGY?

- I would argue that the primary disruptive technology of change for the fourth revolution is photogrammetry
- Most of the others since 1950 have been supportive technologies: with total stations and GNSS, you still digitize your map one point at a time at a 1:1 scale
- Photogrammetry is quantitatively and qualitatively different

WHY PHOTOGRAMMETRY?

- **When we do traditional surveying, we measure one point at a time, and if we are doing the job well, we also record what the points was, and how it connects to all the other points we are measuring: ‘meaning’ and ‘intelligence’ are added at the source**

- **When we did photogrammetry, we’d take the photos and ‘measure’ them in the plotter, and draw the map**

WHY PHOTOGRAMMETRY?

- In fact, the measurements had all been done at the moment of exposure of the photo; we were just making explicit the meaning and intelligence in the images

- Key changes:

  - A huge number of measurements at once (every pixel)

  - Defer extracting the meaning and intelligence until later (if at all)

WHY PHOTOGRAMMETRY?

- Photogrammetry appears in 1849, as a different way to do mapping, compared to a plane table
- 'Different' in that orientation was determined from the photos afterwards, but intersection as a primary location method remained
- It seems like something comfortable that augments a current technology: more 'better, faster, cheaper'

THE FOURTH REVOLUTION

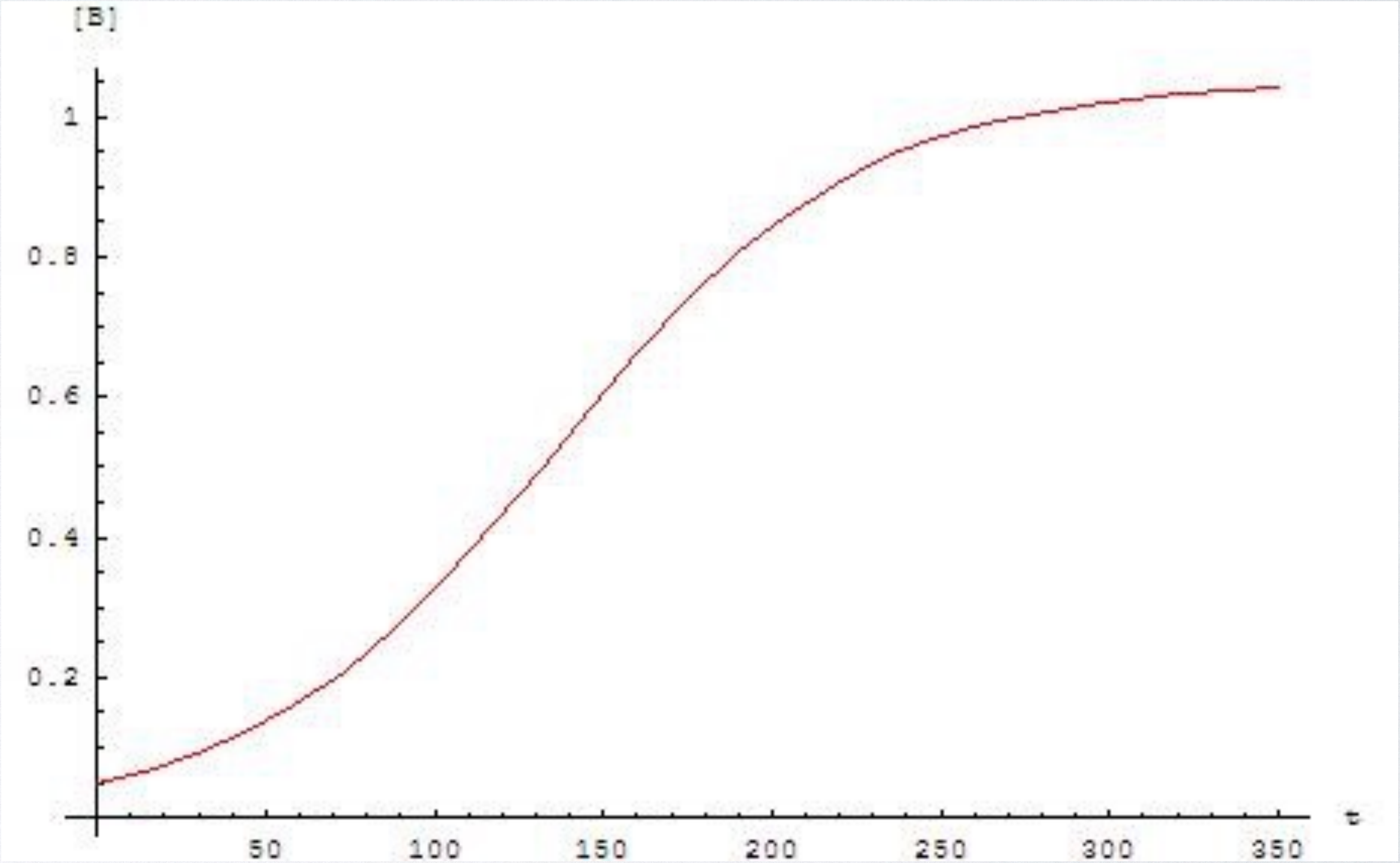
- While aircraft were available from the early 20th century, they were far more reliable after WWII
- This enabled widespread use of aerial photography for mapping: the plane table disappears in developed countries
- Aerial photography triggers development of plotters as the volume of data grows exponentially

THE FOURTH REVOLUTION

- **Developments in electronic distance measurement allow some odd experiments (e.g., trilateration), but primarily reinforce existing techniques**
- **New technology is fitting into existing methodologies**
- **Total stations are originally named “electronic tacheometers”**
- **This enables ‘better, faster, cheaper,’ but not significantly different**

CHANGE IN REVOLUTIONS

- **Developments seem to follow a sigmoid curve**
- **Slow initial development, often with a 'start' a long way back**
- **Rapidly increasing rates of change**
- **Rate of change slows**



CHANGE IN REVOLUTIONS

- For it to be a revolution, there has to be a major and fundamental change

- Another way to look at it is jumping to a different sigmoid curve

- There is a short period of overlap, then the old declines because the new takes over

EXAMPLE TECHNOLOGY

- GPS was first incorporated into existing methods:
  - GPS was first used as a method of augmenting existing control
  - Then it was used to augment basic networks
  - Then it was used to augment topographic surveying
  - These all use existing techniques and maintain the 1:1 digitizing idea
- GPS didn't start to be truly disruptive until combined with other technologies

OTHER TECHNOLOGIES

- Most new technologies in recent years have followed the photogrammetry concept:
  - Collect massive amounts of simple [X, Y, Z, attribute] data
  - Defer determination of meaning and intelligence
- This gives billion-fold productivity improvements in data collection, but much less than that in information generation

OTHER TECHNOLOGIES

- LiDAR, digital photogrammetry, SAR and InSAR, and terrestrial scanning all work on these principles
- Huge amounts of R&D being put into speeding the automation of information creation from these masses of data

CHANGES AHEAD

- For the geospatial industry, there will be major changes in technology adoption and use, already well under way
- Traditional measurement will be largely abandoned in favor of newer methods, except in a few special cases
- Measurement will become so easy and ubiquitous that 'measurement specialist' will be very rare

CHANGES AHEAD

- Change from measurement to management:
  - Data and information management
  - Land management
  - Greater involvement in decision processes and cycles
  - Focus in solving the client's problem, rather than giving them what they ask for (they are often clueless in a rapidly changing technology environment)

CHANGES AHEAD

- Shift in where meaning and intelligence are added:
  - It doesn’t matter where the data are from, if you know their quality parameters
  - As measurement is now by a device, rather than a person, the actual measurement data is almost standardized
  - Anybody can do data acquisition, but data integration is the critical activity: adding the meaning and intelligence

CHANGES AHEAD

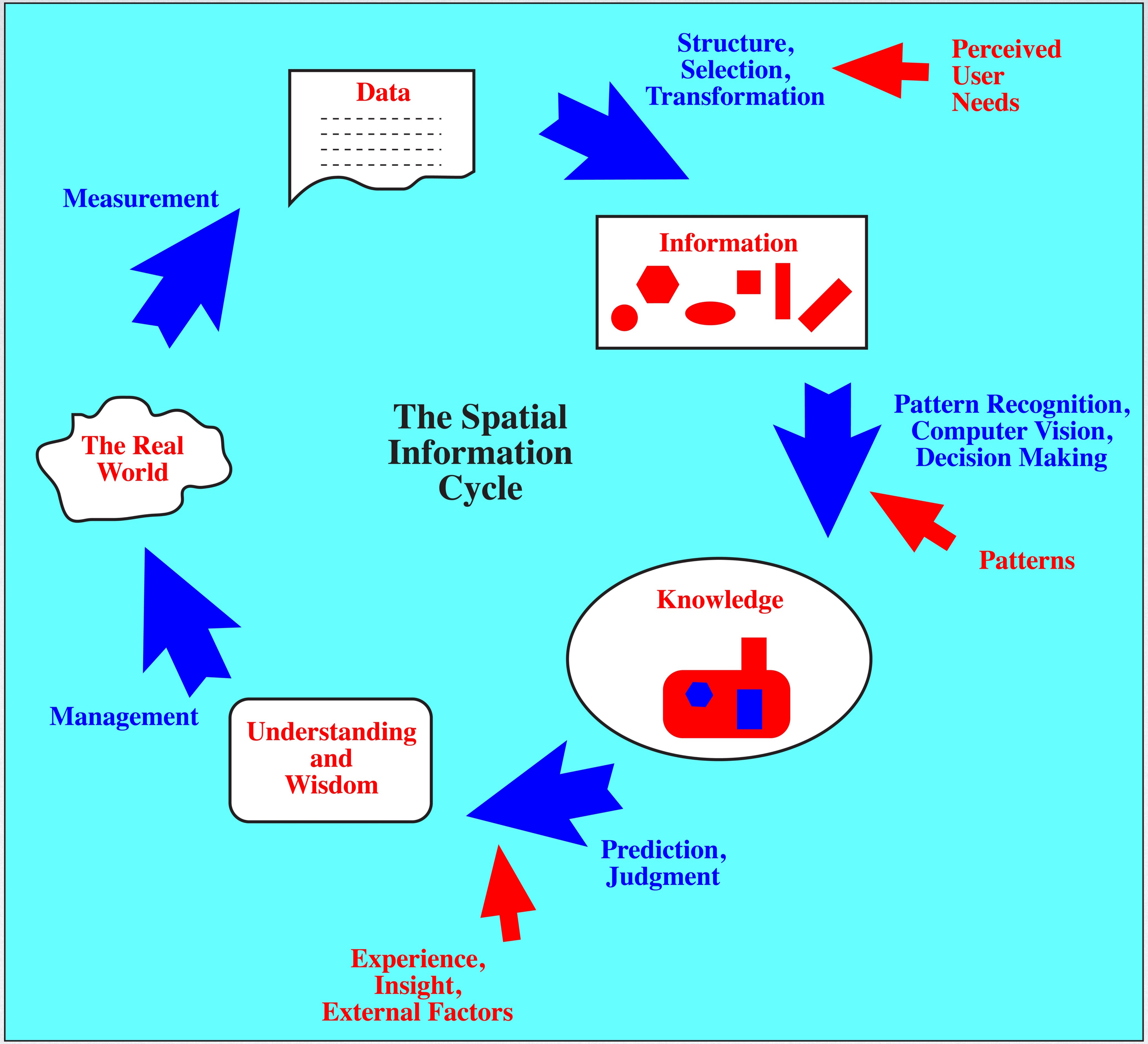
- Major changes in statistics and least squares:
  - Statistics was based on data scarcity: now we have too much!
  - Inferential statistics works poorly when over-supplied with data
  - Least squares focused on point location quality, but only a small part of the data is points

CHANGES AHEAD

- Major changes in data sources:
  - Volunteer Geographic Information (VGI)
  - Crowdsourcing
  - Monitoring in the surveillant society
  - Amateur uses of highly advanced technologies

CHANGES AHEAD

- Shift in emphasis to data/information/knowledge integration:
  - Starts with adding the meaning and intelligence with data from multiple sources
  - Change in thinking from analytic to synthetic
  - Moving spatial experts deeper into the decision process
  - GIS is the example technology


Data
Structure,
Selection,
Transformation
Perceived
User
Needs
Measurement
Information
The Spatial
Information
Cycle
The Real
World
Pattern Recognition,
Computer Vision,
Decision Making
Patterns
Knowledge
Management
Understanding
and
Wisdom
Prediction,
Judgment
Experience,
Insight,
External Factors

CHANGES AHEAD

- Redefinition of ‘surveying’ and the surveying profession:
  - When measurement doesn’t matter, what is the role of surveyors?
  - Ultimately, surveyors’ role is guaranteeing and quantifying the quality of the connection between the masses of spatial data (the abstraction) and the real world
  - That means REALLY understanding measurement and all the associated technologies

CHANGES AHEAD

- Changes to higher education and the education of professionals:
  - Universities were developed to concentrate scarce knowledge so it could be easily shared
  - What is their role once knowledge is no longer scarce and sharing is easy?
  - How do we deal with a rate of knowledge creation that is faster than the rate of program and course development?
  - What can a university offer that cannot be had with on-line material?

CHANGES AHEAD

- Changes to higher education and the education of professionals:
  - If there is little difference between data, information and knowledge, then universities are irrelevant
  - We have masses of data available, but relatively little knowledge
  - Professional expertise is much more than a body of facts
  - The place to focus is in the differences

CHANGES AHEAD

"Social relations are closely bound up with productive forces. In acquiring new productive forces, men change their mode of production; and in changing their mode of production, in changing their way of earning their living, they change all their social relations."

- **At the same time as these changes are happening, we are also moving from the Industrial Age to something else — we don't know what yet**

- **So all manner of other changes are happening, rather like the Renaissance happening around the third surveying revolution**

CHANGES AHEAD

Hang on, it’s going to be a trip!