Active Symbolism: Towards a New Theoretical Paradigm for Statistical Cartography

Marc P. Armstrong

Professor, Collegiate Fellow, Associate Dean

College of Liberal Arts and Sciences

The University of Iowa

The Essence of the Argument

Ask not what you can do with your machine – ask what your machine can do for you.

Conventional Mapping Practice Problem

- Interactive process in which defaults are often accepted
- User goals are typically ill-defined and uninformed
- Therefore, maps produced are often inadequate
- This is a particularly imprudent practice
- We can do better…

Inspiration:
Herbert Simon, *The Sciences of the Artificial*

The natural sciences are concerned with how things are...

Design, on the other hand, is concerned with how things ought to be, with devising artifacts to attain goals.

Simon, 1996, p. 114

Needed: Statistical Cartography Paradigm Shift

- Switch from sequence of actions taken by a user to → scads of maps created by software agents
- Solution(s) are then selected to satisfice criteria based on cartographic theory and praxis
- Role shifts from an ill-defined sequence of software mediated tasks to a higher level of design and choice
- Evolution of earlier work: Xiao, N. and Armstrong, M.P. 2012. Towards a multiobjective view of cartographic design. *Cartography and Geographic Information Science*, 39 (2): 76-86.

Software Agency

- Paradigm change cedes greater control to **active agents**
- Also higher tiers of coordinating agent supervisors (local and global) to search for global, rather than local, optima
- Agents produce a bazillion maps, some of which are good with respect to theoretical criteria
- Evolutionary framework is useful here
- The devil is, of course, in the details

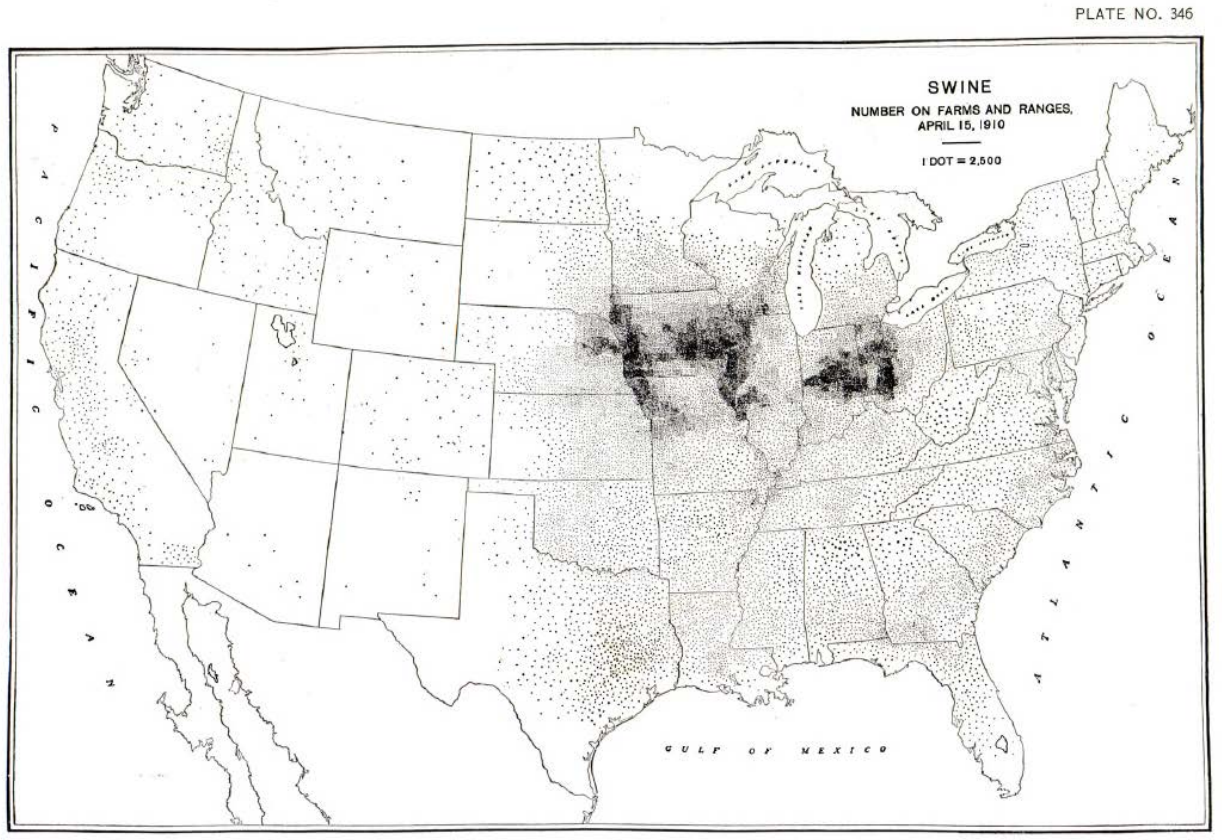
Illustrative Focus on Dot Maps

Each dot symbol is an active agent
that can move, and change value & size

"Unfortunately, present-day software
for dot mapping generally does not include
satisfactory approaches for dot placement."

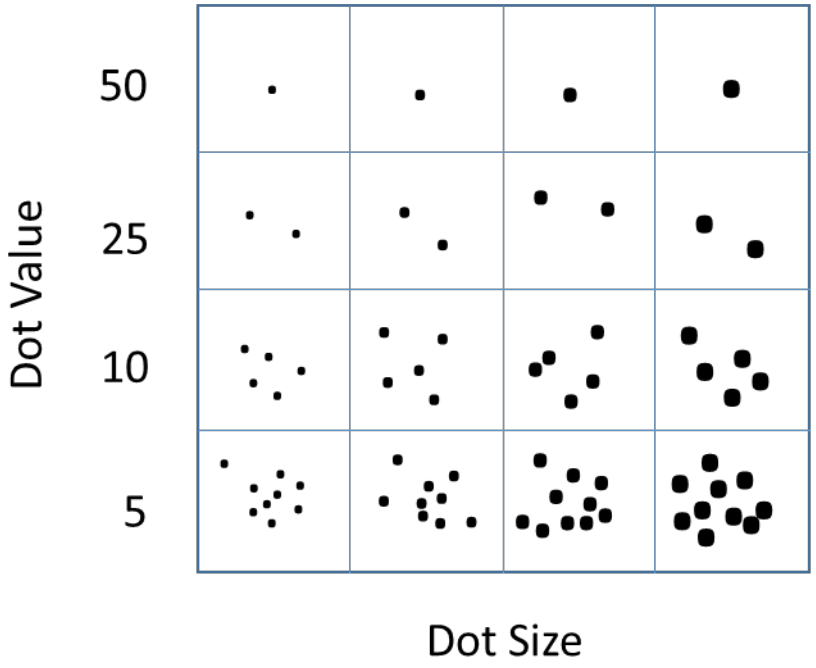
Slocum *et al.*, 2009

n.b. Since this comment, progress has been made:
Kimmerling's work is especially noteworthy

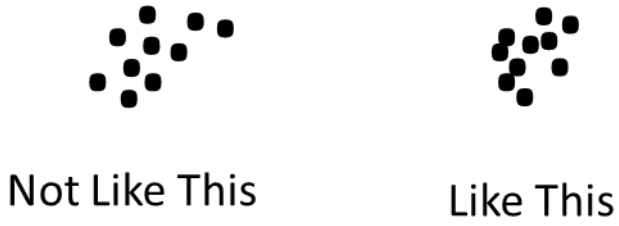


Source: U.S. Bureau of the Census, 1914. Plate No. 346.

Dot Map Parameters

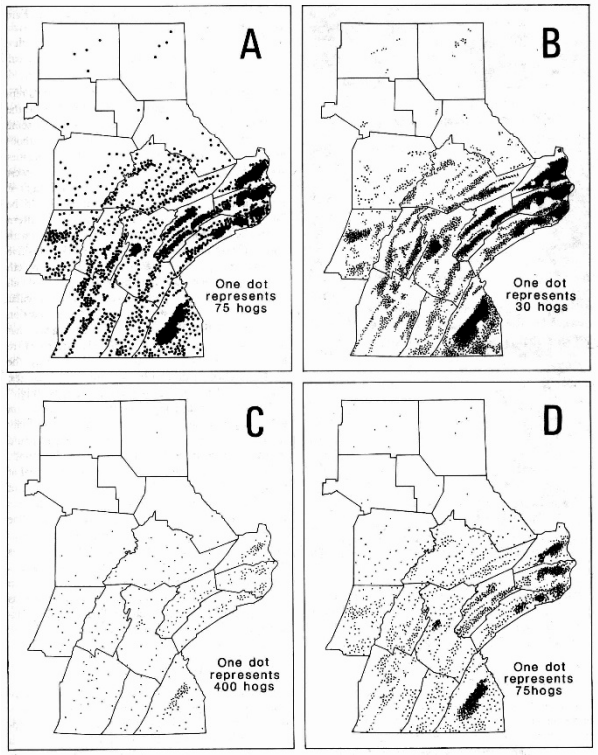


The dot value and size tradeoff (after Dent, 1999: 165)

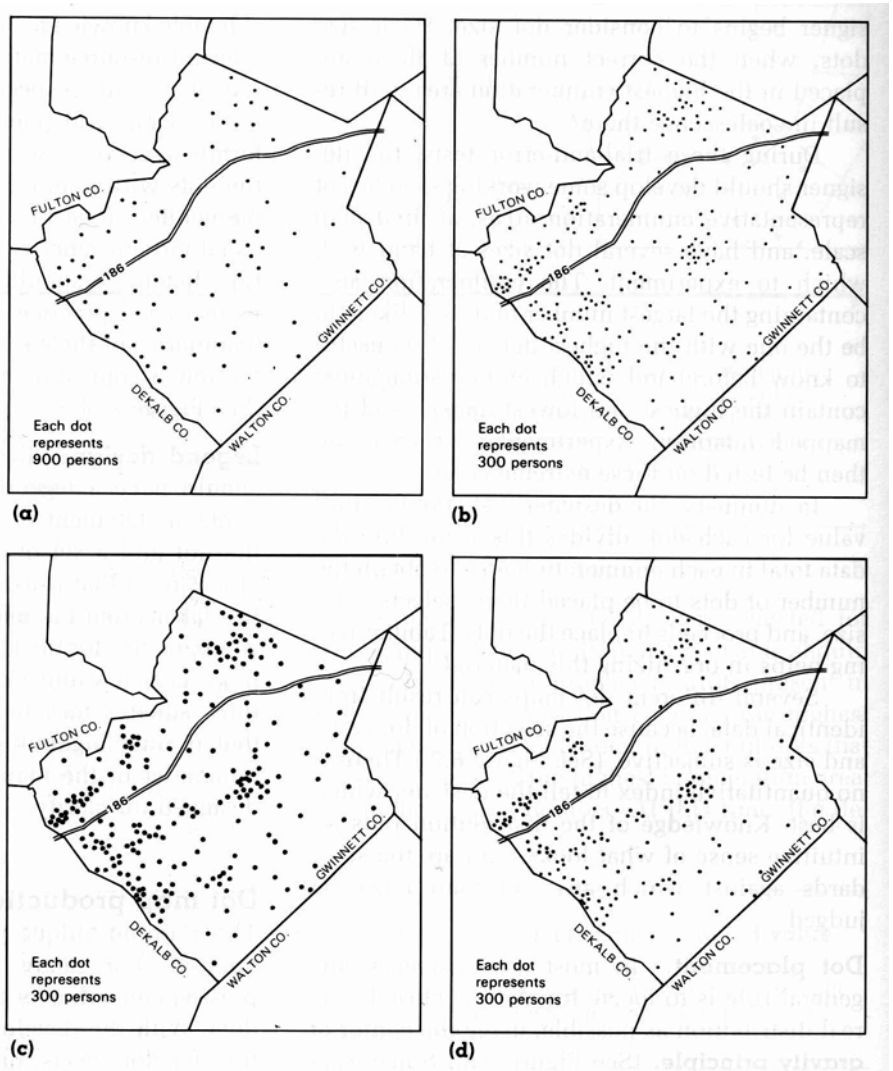


An ill-defined coalescence objective (after Dent, 1999: 166)

Tradeoff Examples: Goldilocks



Cuff and Mattson Fig 2.21



Dent Fig 6.7

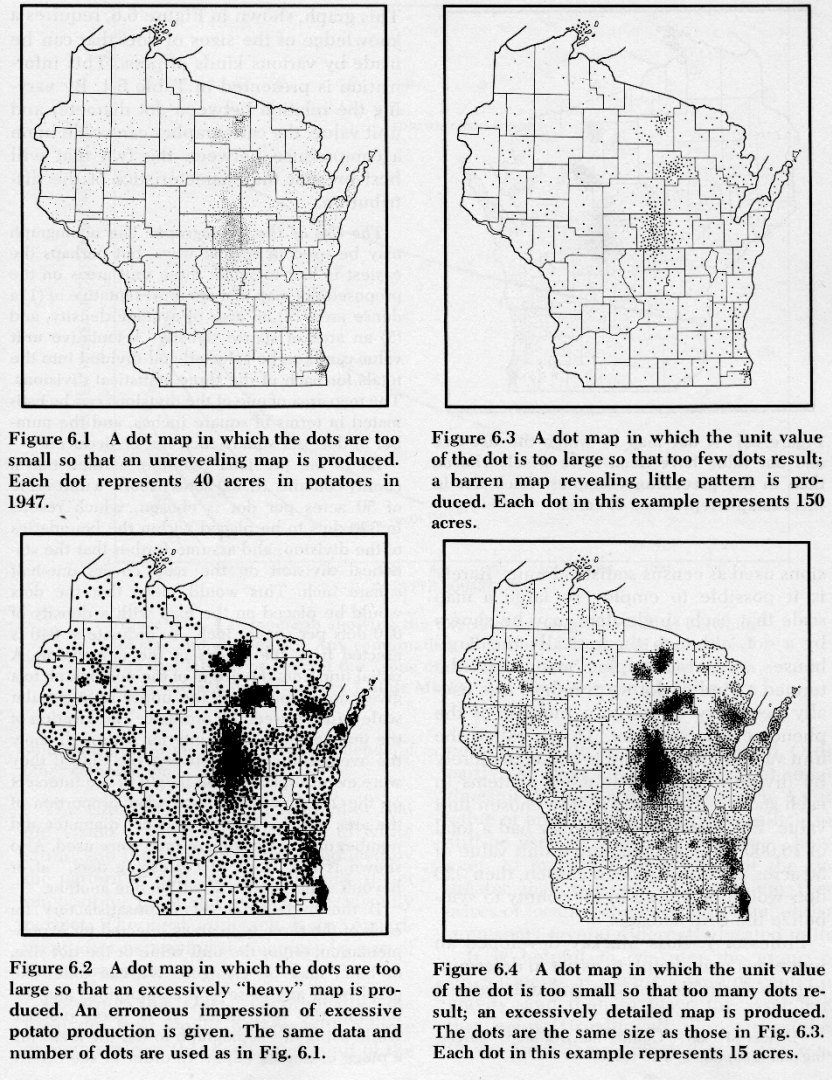


Figure 6.1 A dot map in which the dots are too small so that an unrevealing map is produced. Each dot represents 40 acres in potatoes in 1947.

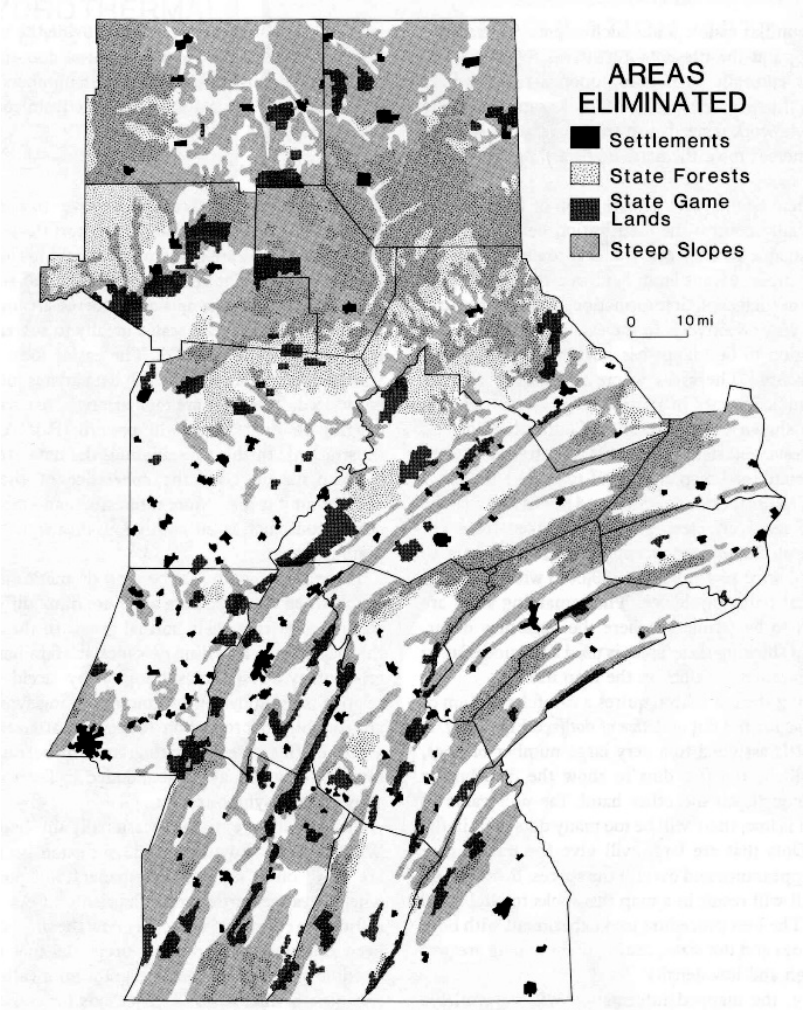
Figure 6.3 A dot map in which the unit value of the dot is too large so that too few dots result; a barren map revealing little pattern is produced. Each dot in this example represents 150 acres.

Figure 6.2 A dot map in which the dots are too large so that an excessively "heavy" map is produced. An erroneous impression of excessive potato production is given. The same data and number of dots are used as in Fig. 6.1.

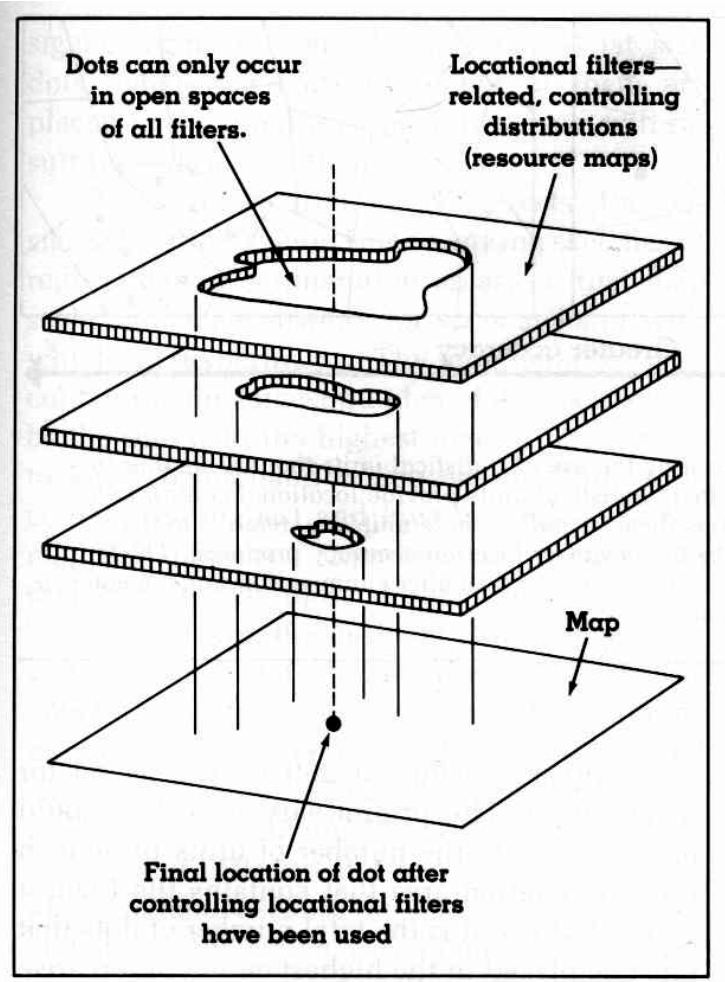
Figure 6.4 A dot map in which the unit value of the dot is too small so that too many dots result; an excessively detailed map is produced. The dots are the same size as those in Fig. 6.3. Each dot in this example represents 15 acres.

Robinson and Sale, Chapter 6

Limiting Factors

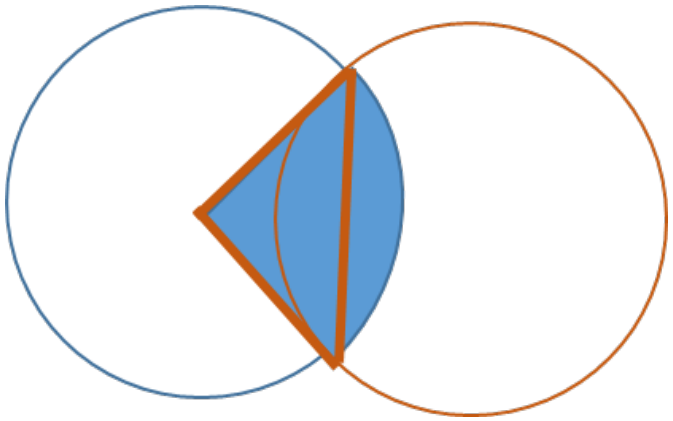


Cuff and Mattson Figure 2.20



Dent Figure 6.3

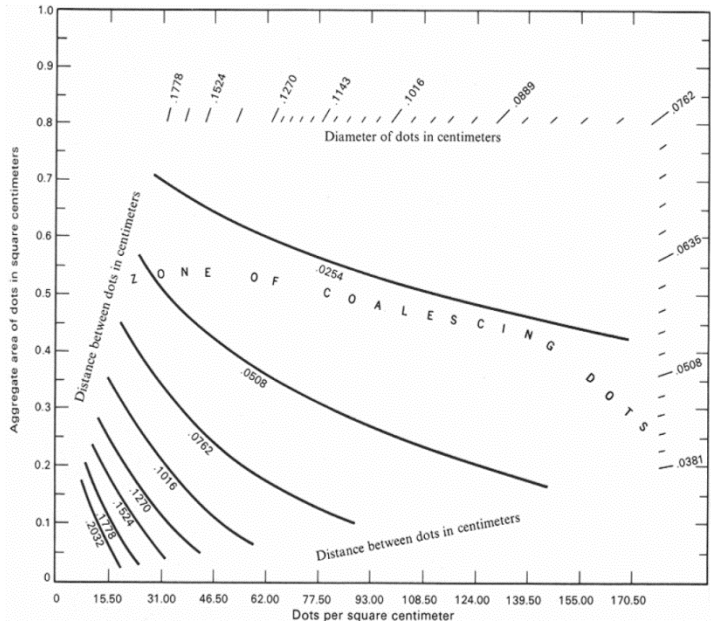
Coalescence: Complex & Compute Intensive



Area of Lens = 2 * (Area Sector – Area Triangle)

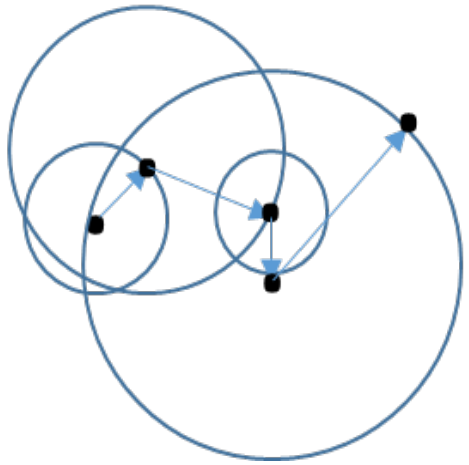
Nomograph

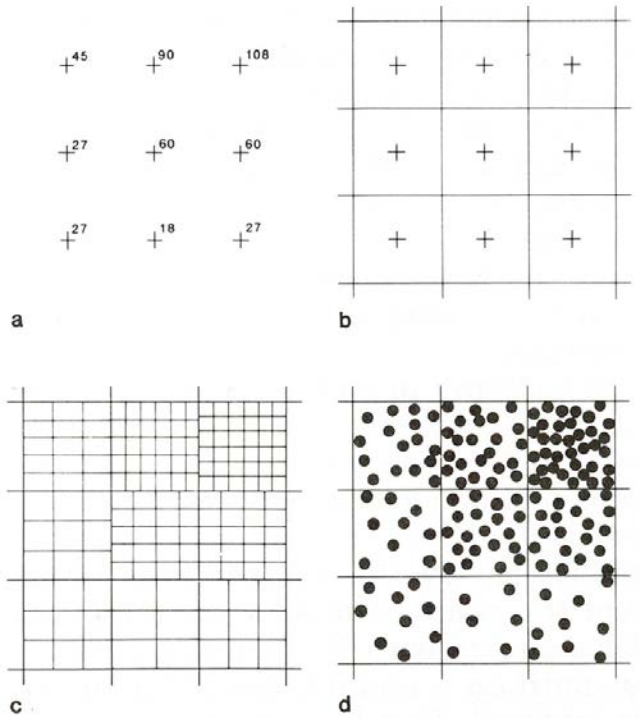
due to J.R. Mackay, 1949



downloads2.esri.com/MappingCenter2007/.../Kimerling_2008_UR_Colloquium.pdf

Placement: Random/Fractional Browning Motion



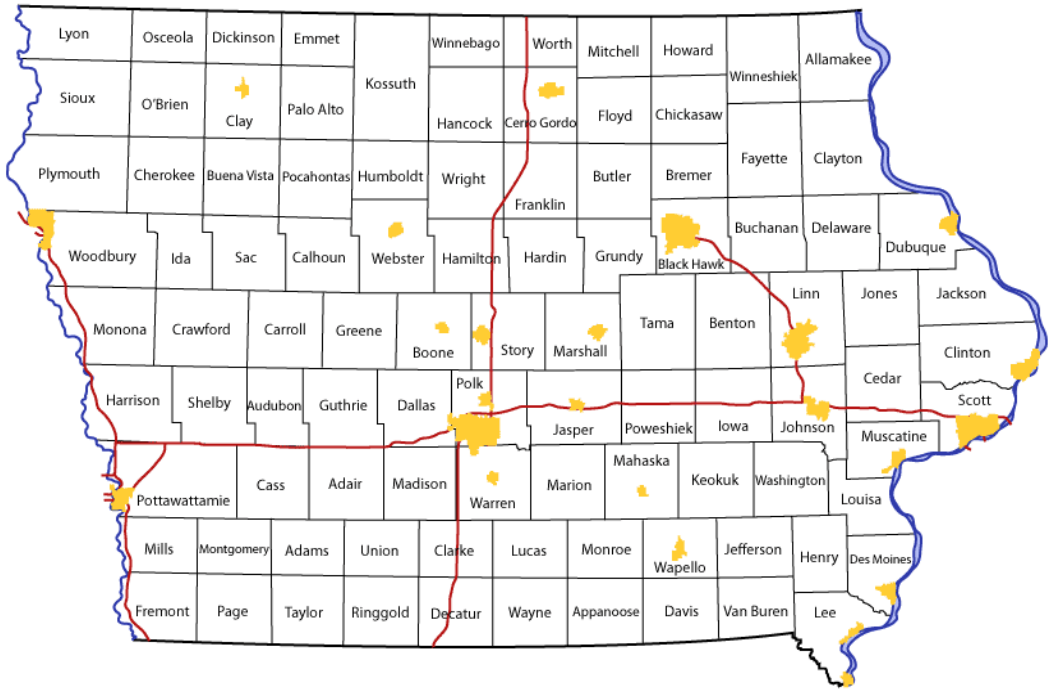


- Usual to not show borders of data enumeration areas: up one level
- Random placement does not work well
- Geographic biasing is better
- Lavin and others have advocated for hierarchical decomposition to guide placement (but for continuous phenomena)

Lavin, 1986

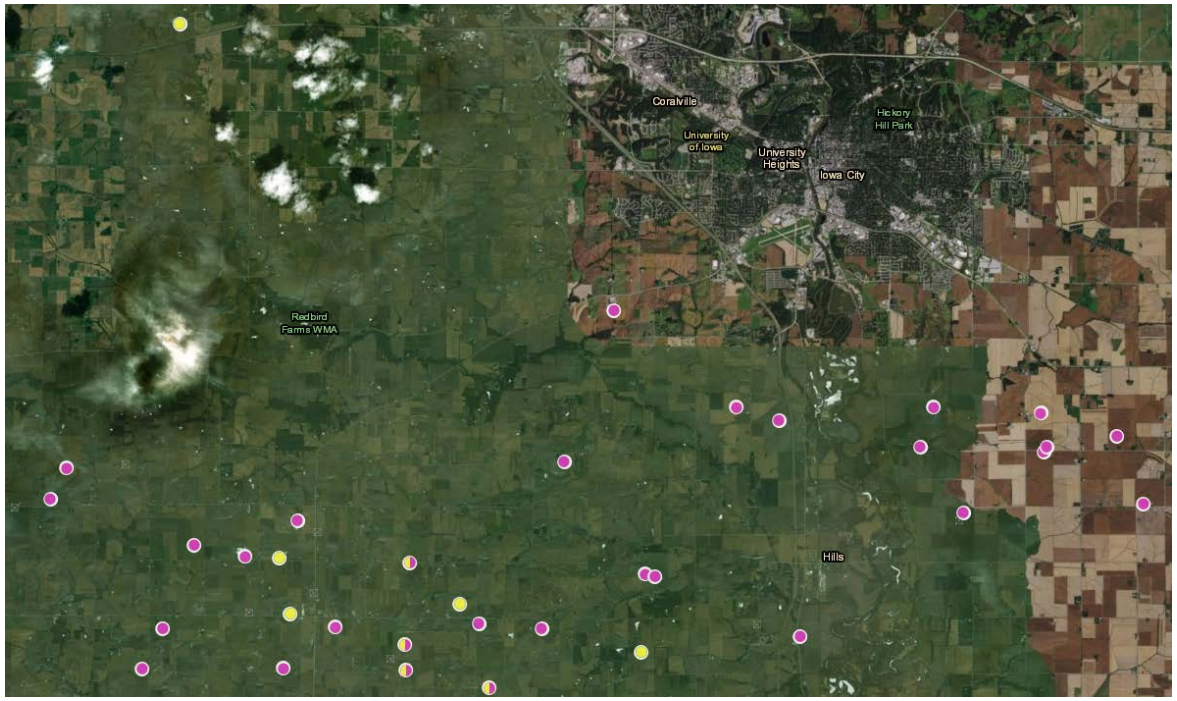
Underlays to Bias Dot Movement

Human Population Distribution



https://iowadot.gov/maps/digital-maps/city-and-county-maps

Hogs and Confined Feedlot Operations



https://programs.iowadnr.gov/maps//afo/

Iterative Agent Moves to Gravity Attractor

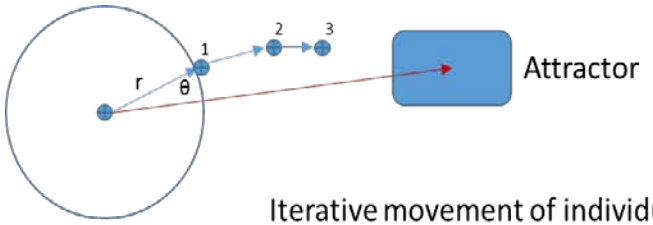
Use Coulomb's Law?

$F = (k * Q_1 * Q_2) / d^2$ where

Q_1 = Charge of 1 (dot symbol)

Q_2 = Charge of 2 (underlay symbol)

k = proportionality constant

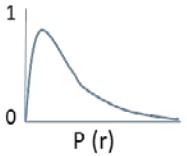


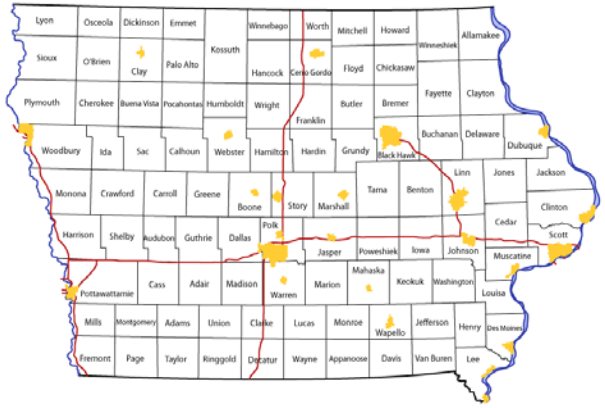
Iterative movement of individual dot symbols using polar coordinates

Θ = pull to gravity attractor at each step using cosine weight; small angle = large weight

cos 10 = 0.985

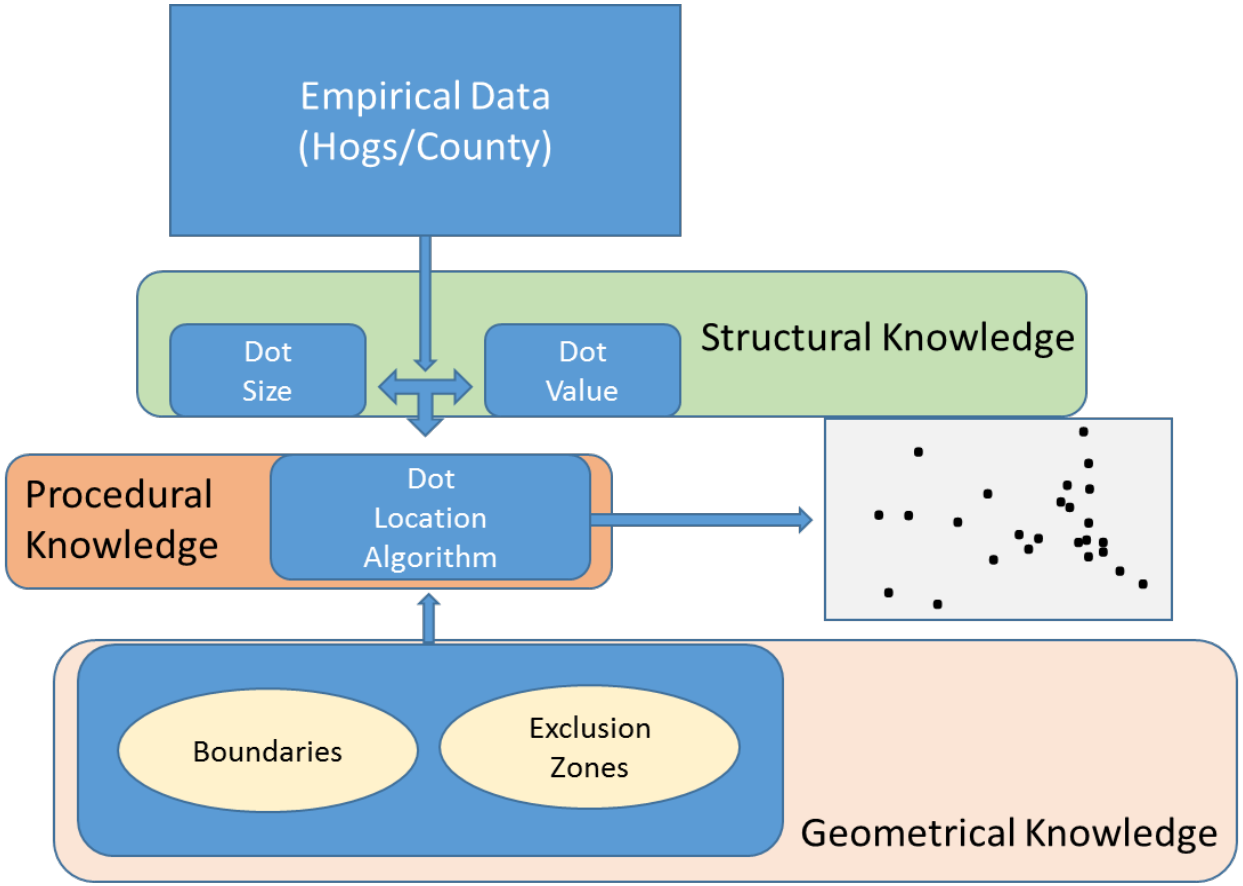
cos 45 = 0.707





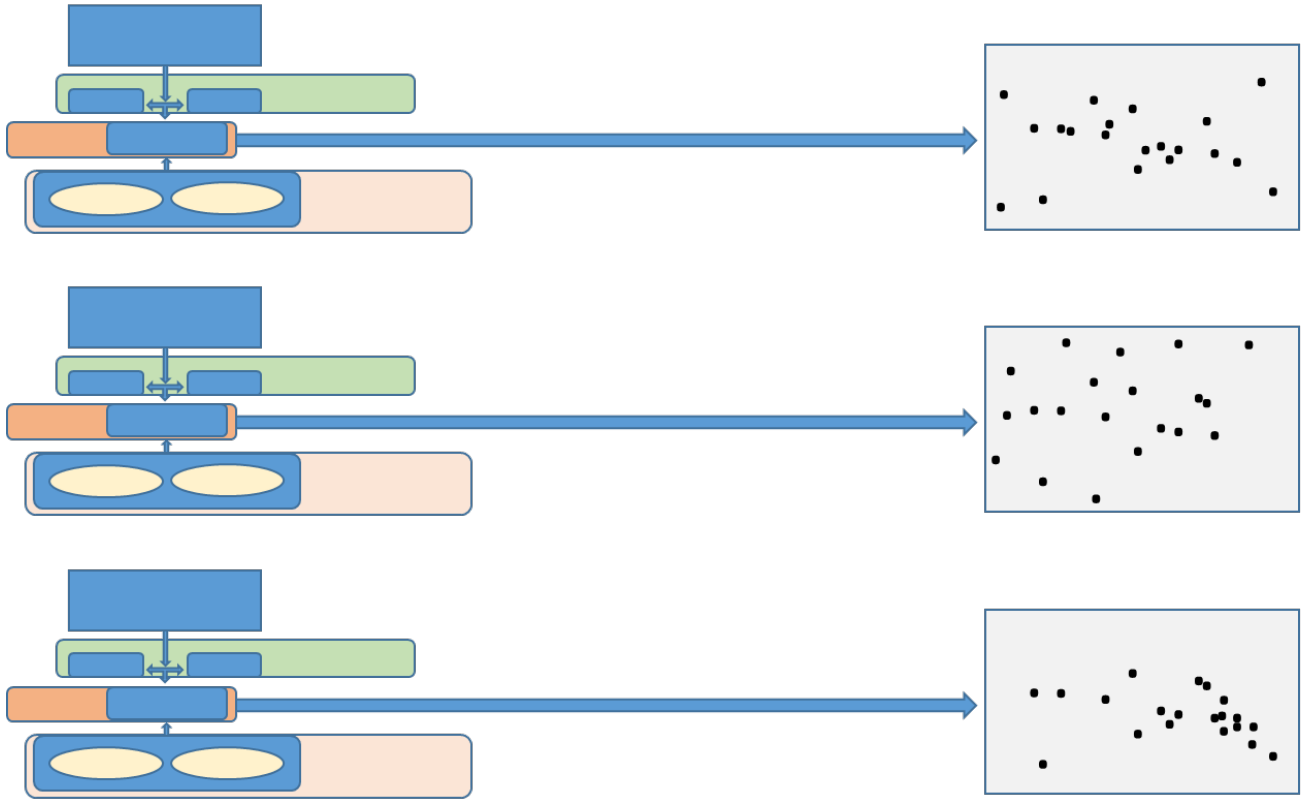
Iowa DOT

Data & Knowledge to Produce a Dot Map



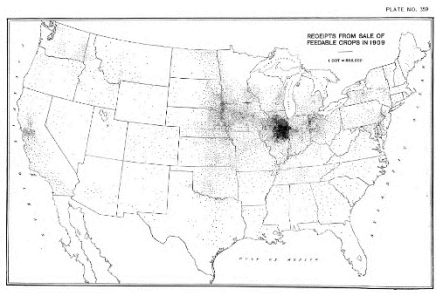
- Agents employ knowledge to produce maps
- Each dot is an agent; parallel opportunity
- Higher level agents control neighborhoods
- Global agent

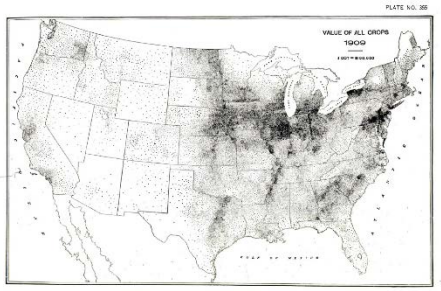
Coarse-Grained Parallelism

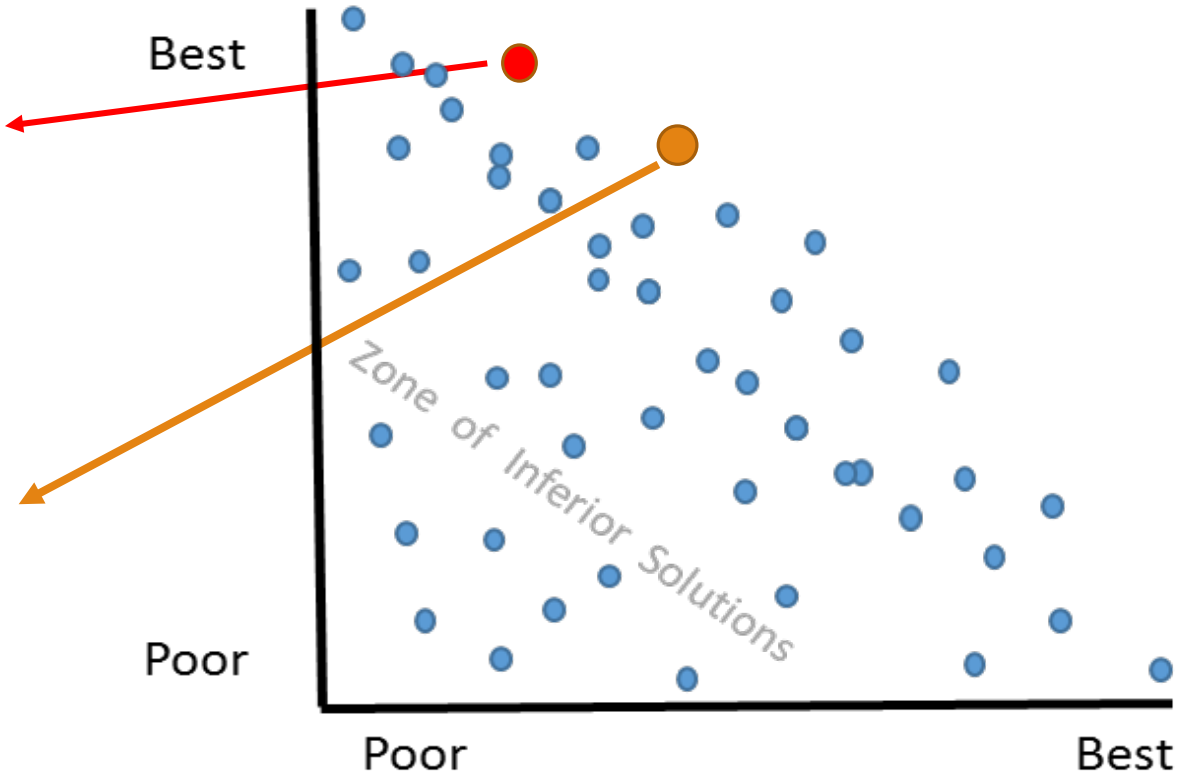


Outcome:
1000’s of Dot Maps per Second

Solution Space for Two Criteria





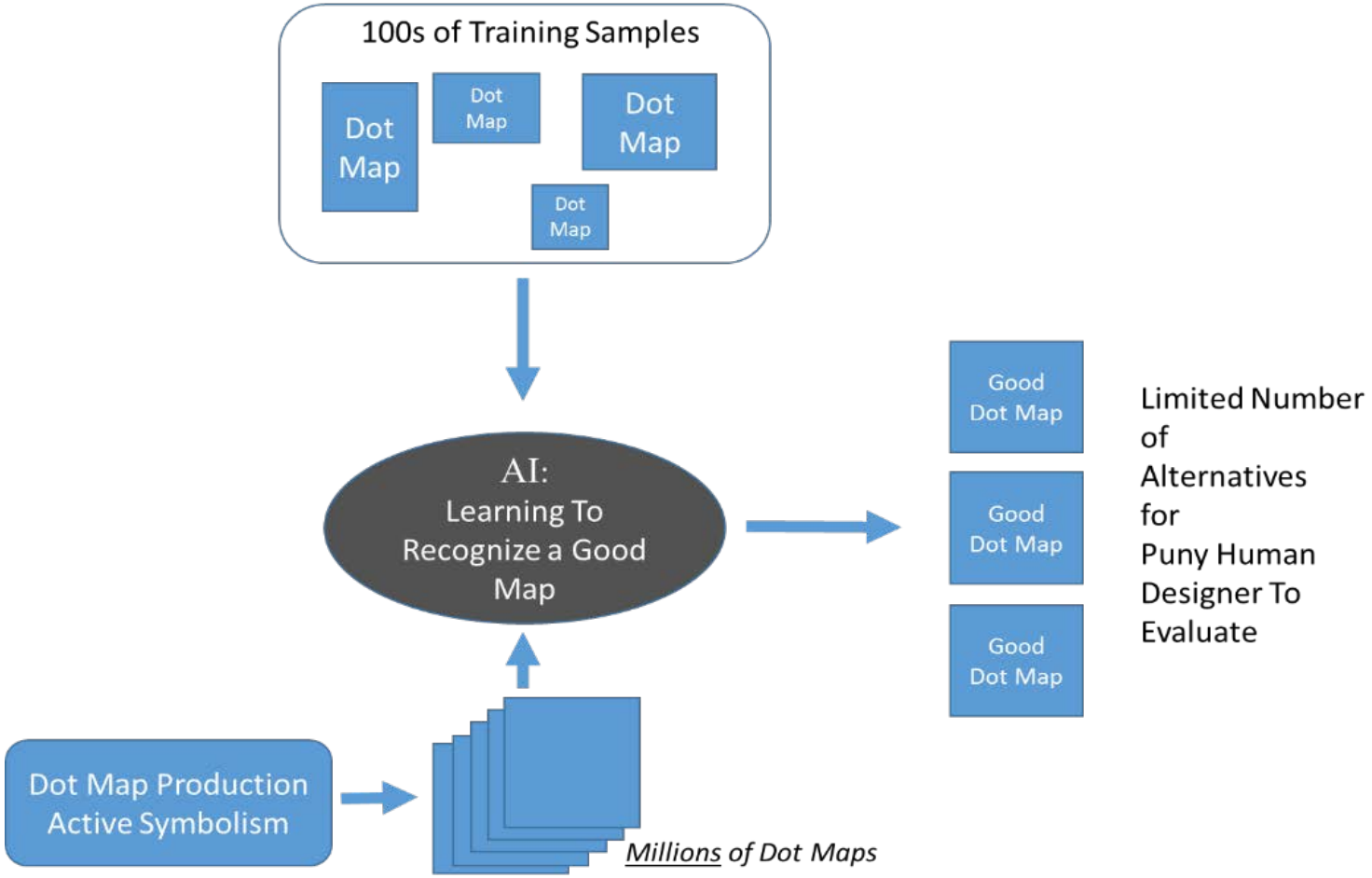


- Each dot is a dot map.
- Solutions farthest from the origin define a trade-off frontier from which a user can choose good options for evaluation
- Criteria can be based on points or populated grids & include coalescence, entropy, *K*, *L*, kernel density…

A Different Approach

Use AI to Find Good Solutions

AI & Deep Learning



- Image assessments implemented using large numbers of high quality training sets (dot maps) and convolutional neural nets (CNNs)
- Training maps input so the machine can learn characteristics of well-designed dot maps
- CNN training is based on repetition and self-correction

PLATE NO. 340

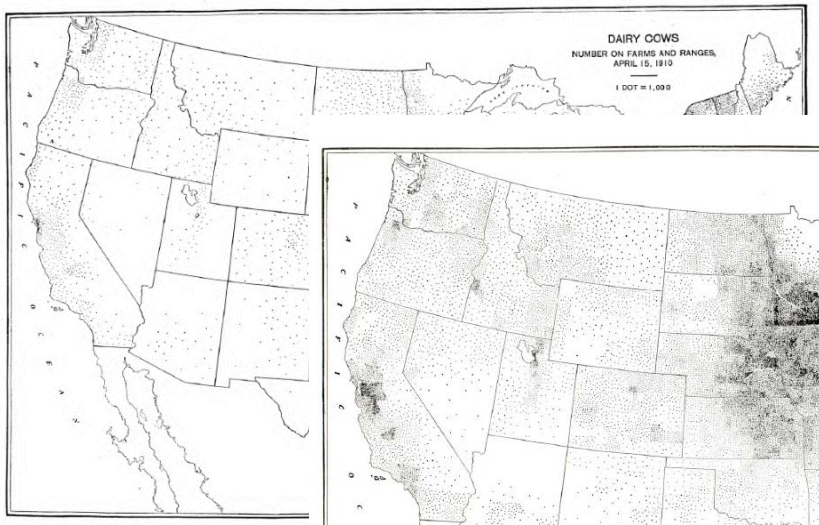


PLATE NO. 344

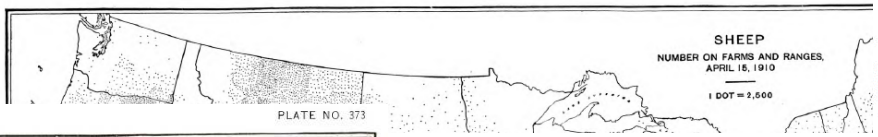
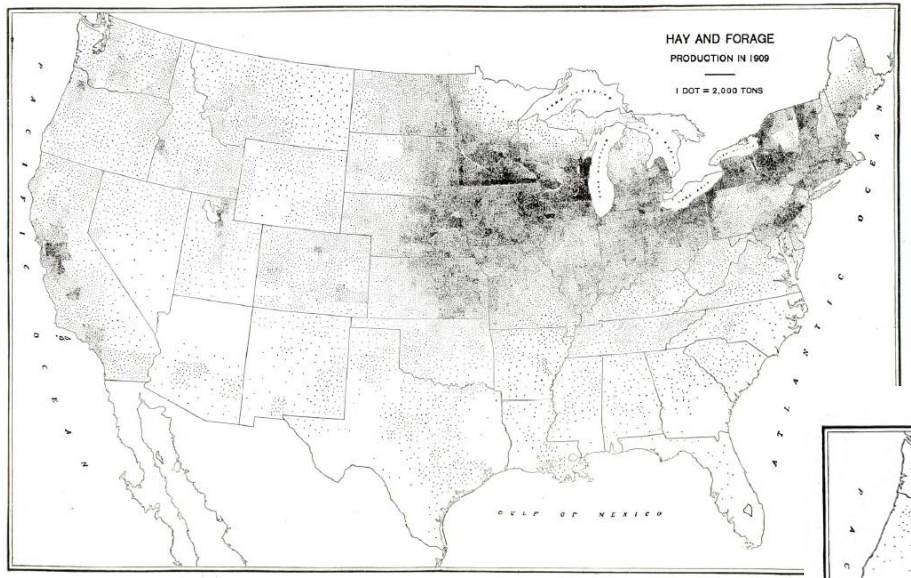


PLATE NO. 35

PLATE NO. 373



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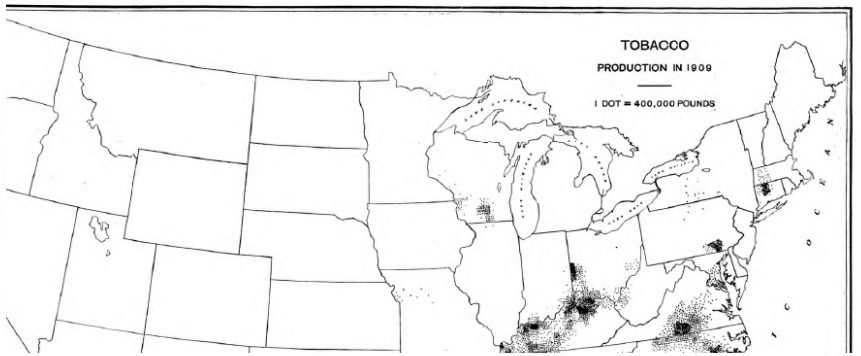


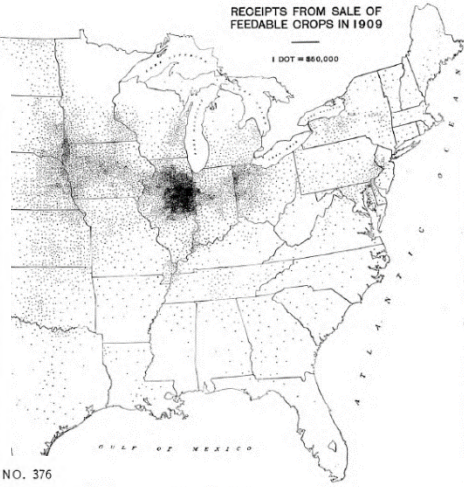


PLATE NO. 376

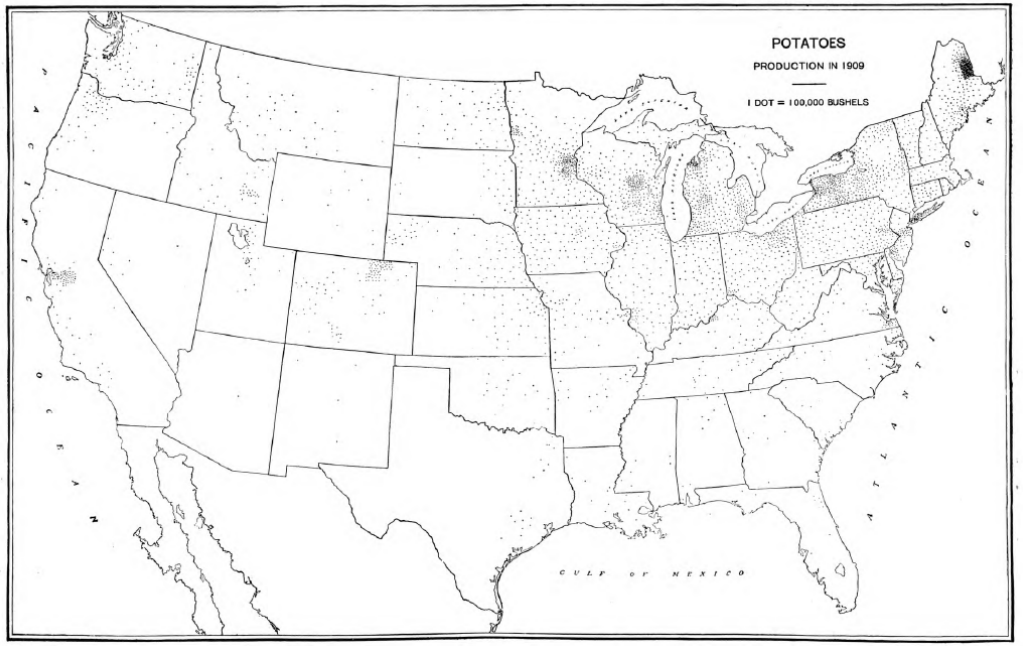
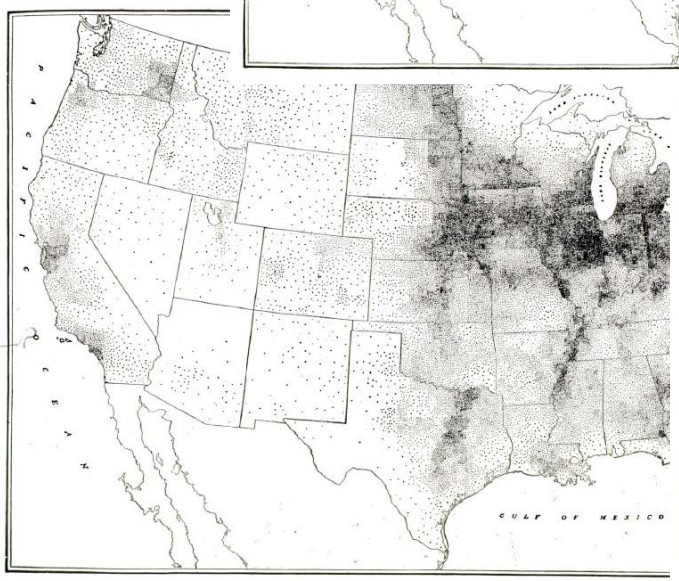


PLATE NO. 346



CNN Algorithm Teaches Itself

- Key: measuring dot coalescence (trade-offs between dot value and size) in the input training samples
- Requires a gridding step *à la* G. Dutton and S. Lavin
- Algorithm iteratively adjusts its parameters (synaptic strength) to get better matches between training maps and those input to it (from active symbol process) for evaluation
- Process repeats until there is close correspondence between input maps and the training maps
- After the system is trained, it can evaluate novel input maps

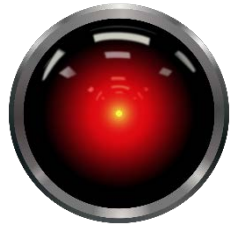
Summary

- Conventional desktop mapping environments are inadequate; skill is incorrectly presumed
- Active symbolism plumbs the cartographic literature for rules and recommendations that are used by agents to produce alternatives
- This universe is then evaluated and solutions, each good with respect to at least one criterion, are presented to the cartographer
- Alternative approach uses deep learning to aid in choice process
- This removes humans from the minutiae of software tasks in the absence of an overarching design framework– aka fumbling about

Extending Active Symbolism Paradigm

- Graduated symbol: trade-offs related to unit values, plotting radii, overlap and transparency; heuristic optimization maximizes these dimensions of each map
- Choropleth: already in evolutionary framework to tradeoff characteristics related to data classification (*e.g.*, GVF, spatial autocorrelation); other choropleth attributes can be included to provide a more complete analysis

Other Future Trends



- Higher levels of automation and guidance will be introduced into map production (this *is* **Auto**Carto!)
- Aided by custom environments, such as TensorFlow and Google's Tensor processing unit (TPU), optimized for AI applications
- Domain-specific hardware-software co-design is key point in recently released ACM Turing Lecture by Hennessy and Patterson (2018)

http://iscaconf.org/isca2018/turing_lecture.html

Concluding Comment

- Active symbolism does not advocate for full automation
- Some control over the solution process is retained to keep with Herbert Simon’s decision processes of: intelligence, design, choice
- Ultimately, the active symbol approach aims to augment the capabilities of human designers, rather than replace them

The End

Agents Use Knowledge

- **Geometrical**: feature descriptions of absolute and relative locations (*e.g.*, boundaries and topological relations)
- **Structural**: expertise encoded from cartographic practice and derived from cartographic literature (*e.g.*, coalescence in dot maps)
- **Procedural**: selection and deployment of operators to perform mapping tasks

AI: Is it a thing?

- Yes. It is certainly now in the news.
- The Select Committee on Artificial Intelligence was announced May 10 during a White House summit organized by the Office of Science and Technology Policy
- “To realize the full potential of AI for the American people, it will require the combined efforts of industry, academia and government.” *Michael Kratsios, deputy U.S. chief technology officer*
- “Artificial intelligence (AI) is transforming every segment of American industry. … The effects of AI will be profound.” *France Córdova, NSF Director*