Migration: Maps and Models

An Introduction

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Migration: Maps and Models

Professor Waldo Tobler

Abstract:

Most change in the world is due to movement; the movement of ideas, people, materials, money, disease, genes, animals, insects, and so on. In particular the movement of people has always been very important in our dynamic world. A current estimate is that many millions of people migrated last year. The field is so large that it is difficult to provide a comprehensive treatment. Instead I concentrate on just a few introductory aspects of the subject, first with a review of an important historical reference. Next, bringing the material closer to the present with a short look at some work introducing spatial modeling in a discrete framework. This is followed by a geographical model that results in displays of potential-driven vector fields. These provide an alternate view of the geography of migration.

After deciding on this topic I looked it up on the internet.

Quite amazed and overwhelmed, this is what I found.

Migration: Google Searches

Number of Hits

Migration: 131,000,000

U.S. migration maps: 111,000,000

Migration of people: 76,200,000

Population migration: 52,000,000

Migration maps of people: 47,600,000

Population migration maps: 42,900,000

Human migration: 38,800,000

Migration models: 35,900,000

Migration maps: 23,600,000

Geographical migration of people: 8,680,000

American migration 5,750,000

What Is Generally Covered.

How many migrants are there? 210,000,000 a year.

3% of 7 billion. Or 97% who don't migrate.

Who migrates.

Distinction between migrants & movers. By gender, age, education, income, purpose.

Why people migrate: pick a reason:

Census lists 20 reasons, by class of persons: last=other=idiosyncratic.

Lots of types

Commuting as daily migration, farm workers following seasonal crops.

lmmigrants, refugees, retirees, family members, ethnic groups, legal, illegal ...

Sources of information.

Official statistics, questionnaires, interviews, gravestones, genetics (using DNA).

Where migrations take place.

Intercontinental, international (between countries), internal (within countries), regional

Impact: On leaving place; On arriving place.

History, Stories, Lesson Plans.

What kinds of people study migration?

Geographers, historians, demographers, sociologists, anthropologists, economists, epidemiologists, geneticists, and other 'ists.

Unfortunately, many do not read the material outside of their own field!

A Few Especially Informative Sites.

Human migration - wikipedia
U.S. Bureau of the Census; United Nations; EuroStat
National Geographic Society
Other non government organizations
Pew Research Center
Forbes Magazine, with interesting interactive county to county maps.

And many more, including books.
In the local library: "An Atlas of American Migration"
A recent publisher's flyer lists 25 new books on migration in his inventory.
An issue of The Economist cites a new study lauding the benefits of migration for innovation.
Etc.
But many of the publications must be considered as ephemeral "Current Events" suitable for newspaper or magazine coverage and not contributions to scholarly study. They often cover the dramatic events of human experience, or 'what's happening in country C at time T and some contemporary consequences'.
So I ask:
Can one entice general principals from the potential of 210 x 10^6 histories and stories?
I think that the answer is yes, and hope to give you some idea of this.
Or how one might approach the subject.

As a geographer, when I got interested in movement and migration in the 1970's I found that I wanted to see the data on maps.

So I went back to look at some of the materials and maps coming from the high point of the introduction of social statistics and graphics in the 1850's.

The beginnings of social statistics:

Names associated with this included:

Dupin

Harness

Minard

Playfair

Quetelet

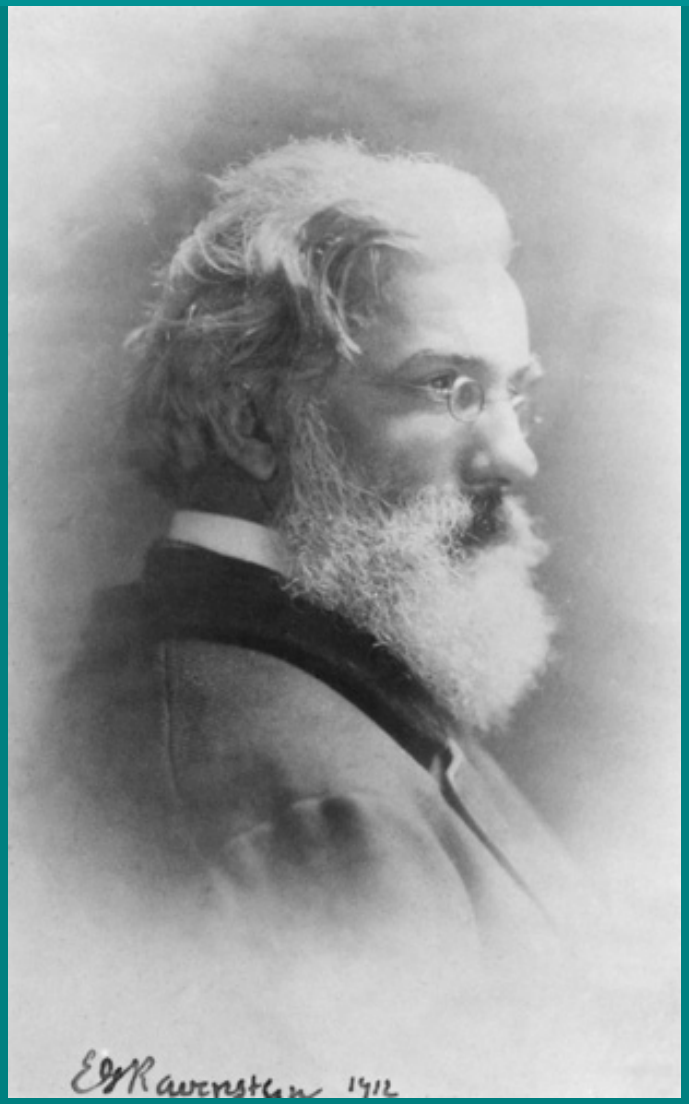
Galton

and others.

Several of them produced geographic maps.

And then I found an interesting migration map in a paper from a slightly later period.

In 1885 E. G. Ravenstein of Great Britain published the map in the Statistical Society Journal.



Courtesy of the Royal Geographical Society

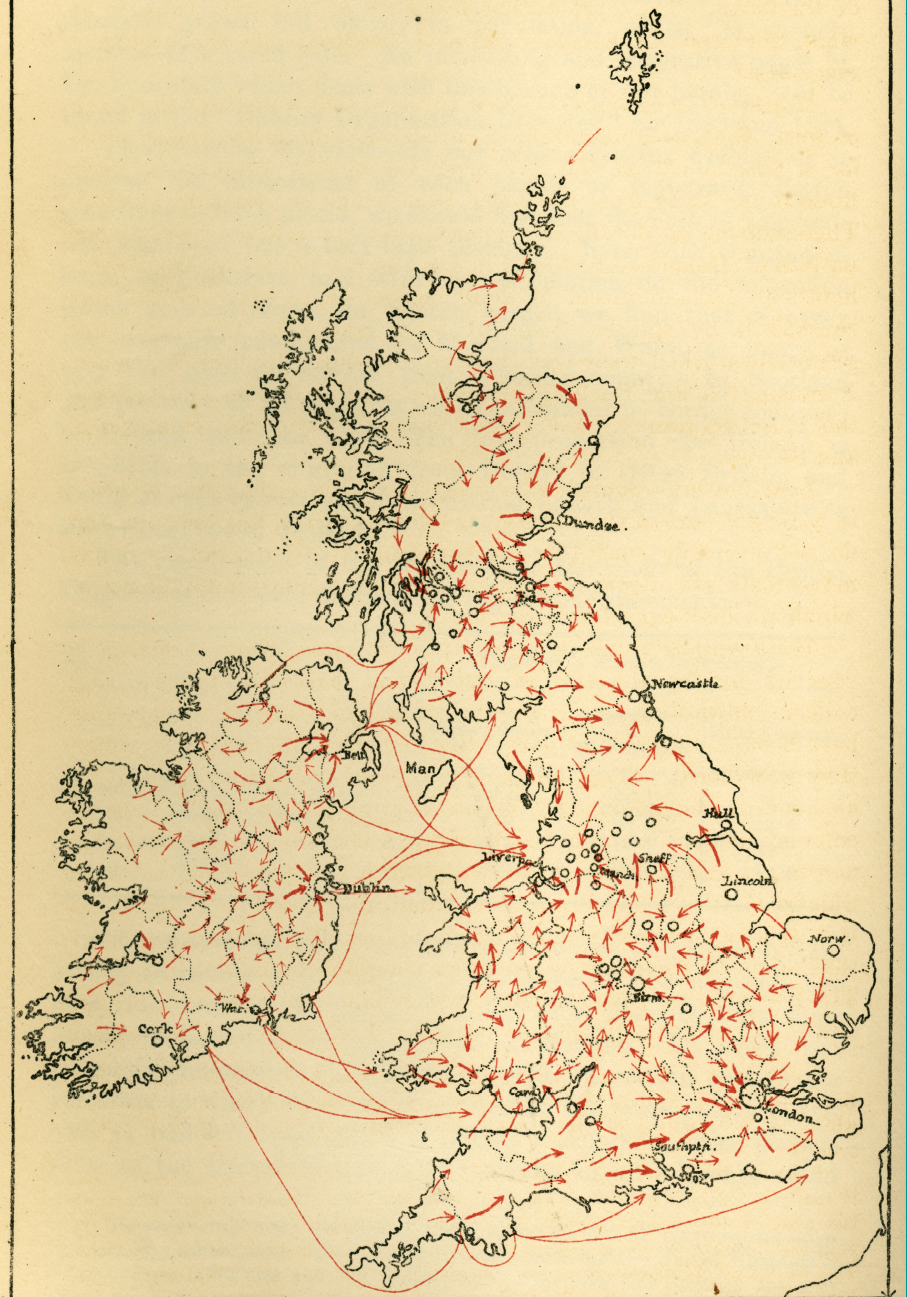
The ‘Currents of Migration’ map accompanied his paper in this journal but was not mentioned in the text.

It just appeared along with eleven other maps.

The data available to Ravenstein consisted of 1881 census: County of Birth and County of Current Residence.

I have long admired this map but there is no description of how it was prepared.

CURRENTS OF MIGRATION.



Some features of the map

County boundaries are shown pecked.

Migration is illustrated using red arrows.

They show migration from county to county.

Some cities are named and shown as circles.

Magnitude is occasionally suggested.

Distance decay effects are noticed.

Migration fields can be detected.

It all seems very clear and simple.

A very nice map!

When enlarged several of the properties are more visible.

For this reason zoom into Ireland

Cities named:

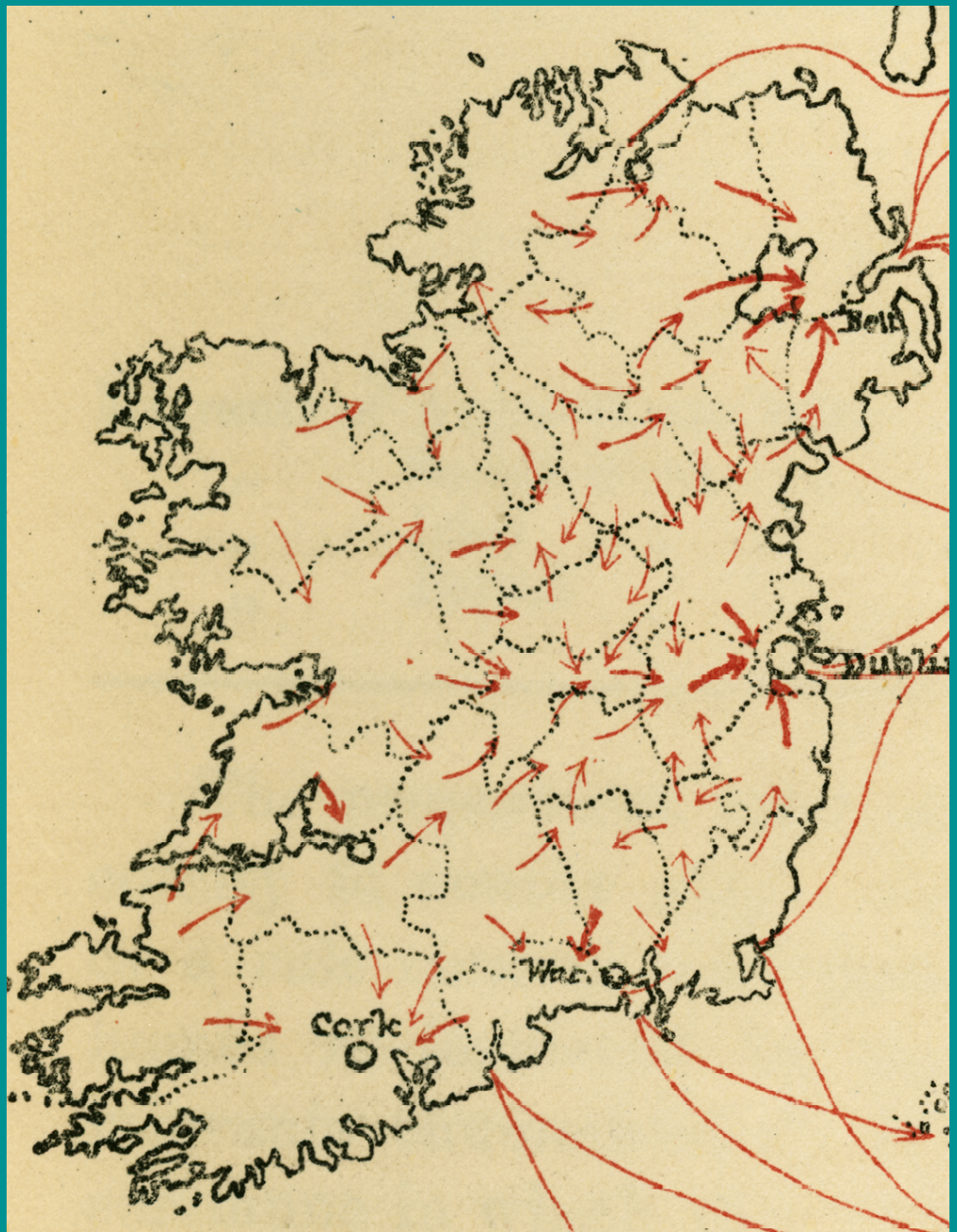
Belfast

Dublin

Waterford

Cork

Irish Currents of Migration



Then concentrate on the Dublin area.

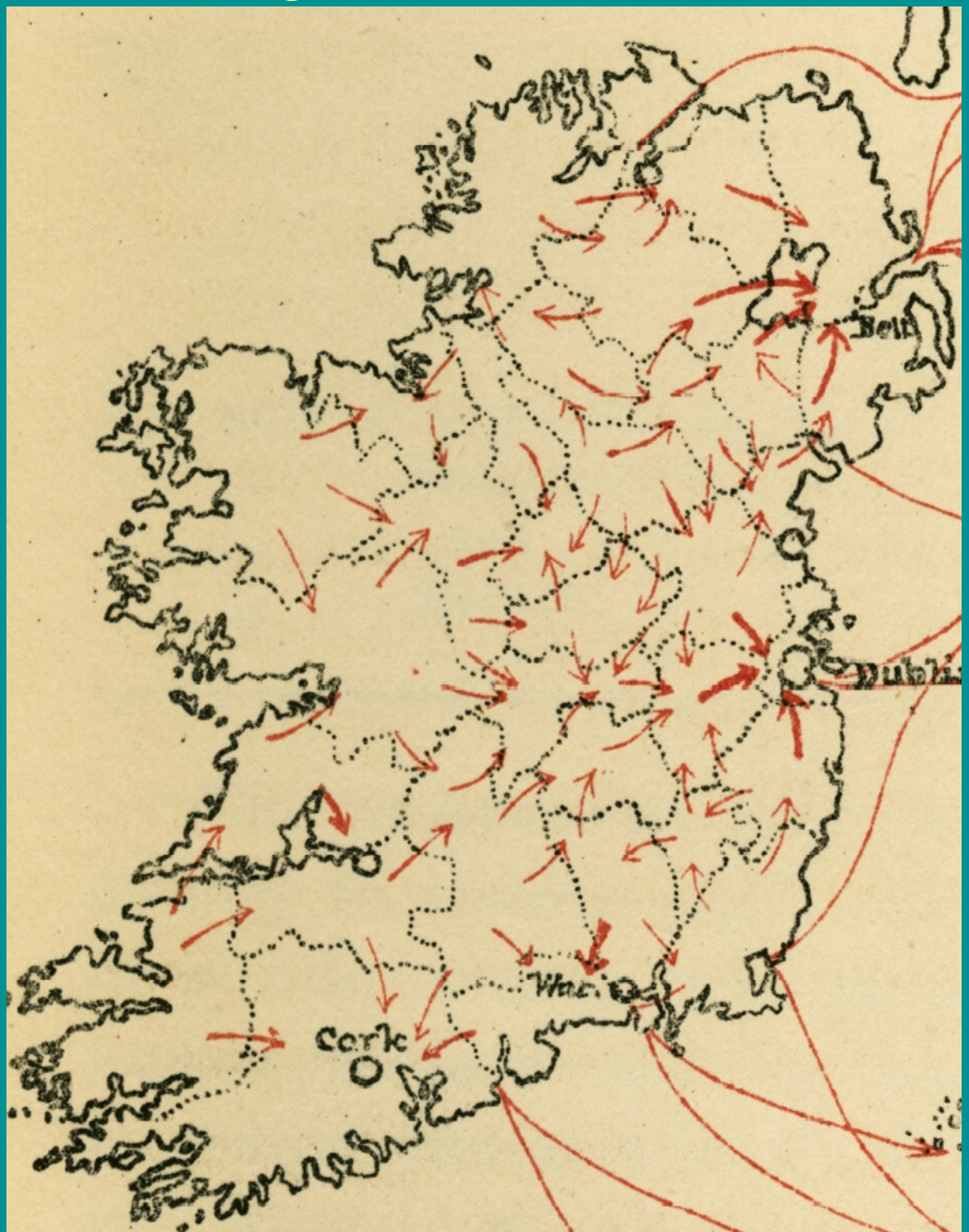
Several of the properties mentioned are now more prominent.

The migration in-field is now clearly visible.

As is the spatial edge of Dublin's draw.

Detail west of Dublin

Now look at this again and notice the detailed effects



Now a peek at Southern England

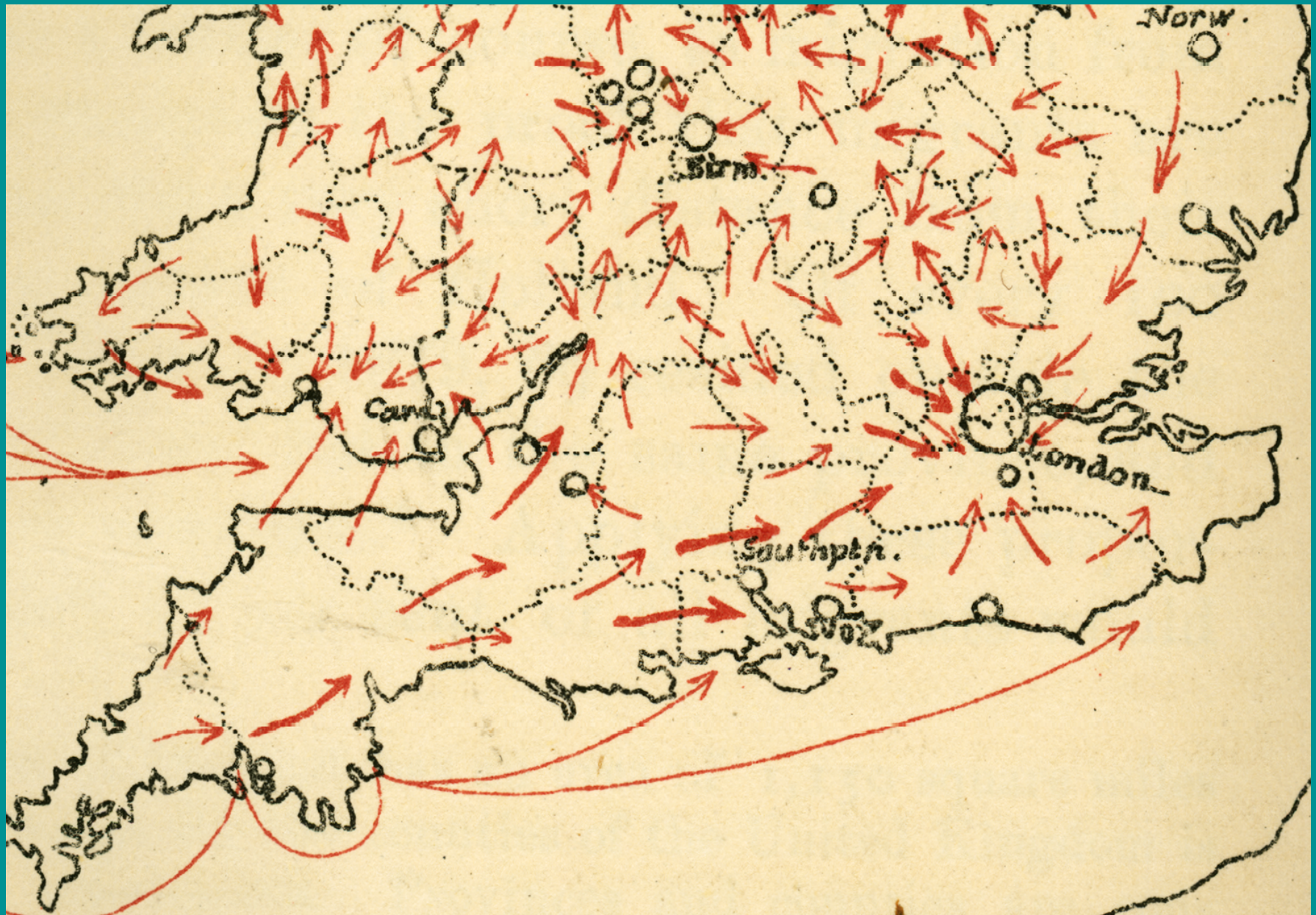
Similar effects can be seen around several cities.

London

Birmingham

Cardiff

Southern Great Britain



To produce a similar map of California migration.

Needed are:

1st a migration table.

I used the US Census 1985-1990 California county-to-county table.

2nd a map of county boundaries.

From the map produce an adjacency table.

Next, select the dominate migration between all pairs of adjacent counties.

And then draw the arrows.

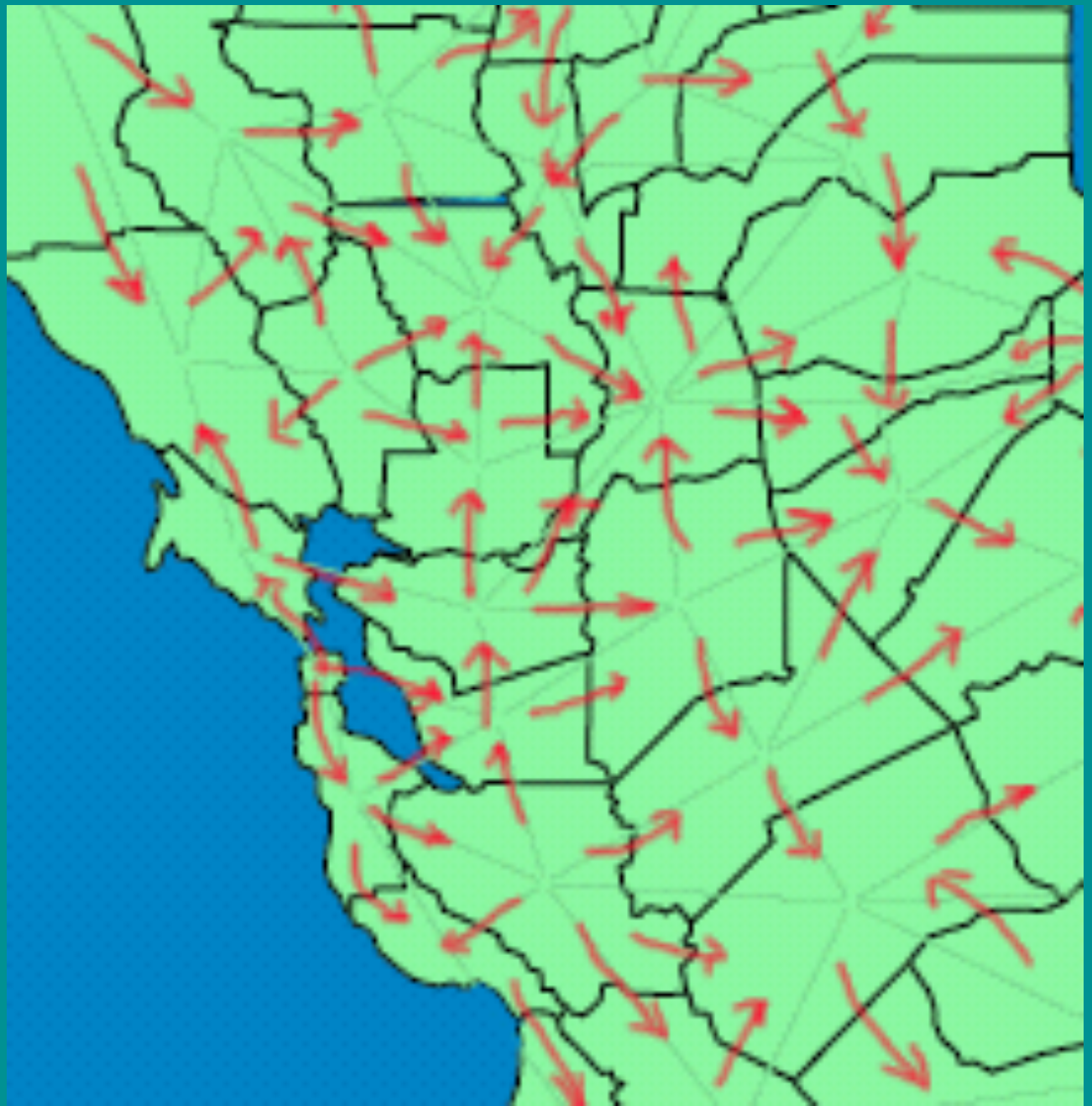
The, typically smaller, amount of longer distance migration is not shown.

My attempt to make a Ravensteinesque map of California

In the Los Angeles vicinity

Shadow lines are between centroids used to help in sketching.

In the San Francisco vicinity



Not mentioned to this point was

The title of Ravenstein's paper

It is:

"The Laws of Migration"

It was a remark of one of the Statistical Society members "that migration appeared to go on without any definite law, which first directed my attention to [the] subject…"

Ravenstein then proposed several laws.

Something to notice about these laws!

There is no attempt to explain why migration takes place.

No causes, no why!

Just description.

Exactly like Newton's laws of motion, 200 hundred years earlier, which also described but did not explain.

Previously objects were just thought to move "because it was their nature".

Subject for discussion: Do laws apply to social science?

One of Ravenstein's Migration Laws

" … even in the case of 'counties of dispersion', which have a population to spare for other counties, there takes place an inflow of migrants across that border which lies furthest away from the great centers of absorption" (1885, 191)

Can you think of an example?

What has been happening at the southern border of Mexico?

The border with Guatemala.

Mexico has an illegal immigrant problem!

Another of Ravenstein's laws

[We have] "proved that the great body of our migrants only proceed a short distance" (1885:198)

Is it still true?

Apparently so since it has been observed many times in many societies and places.

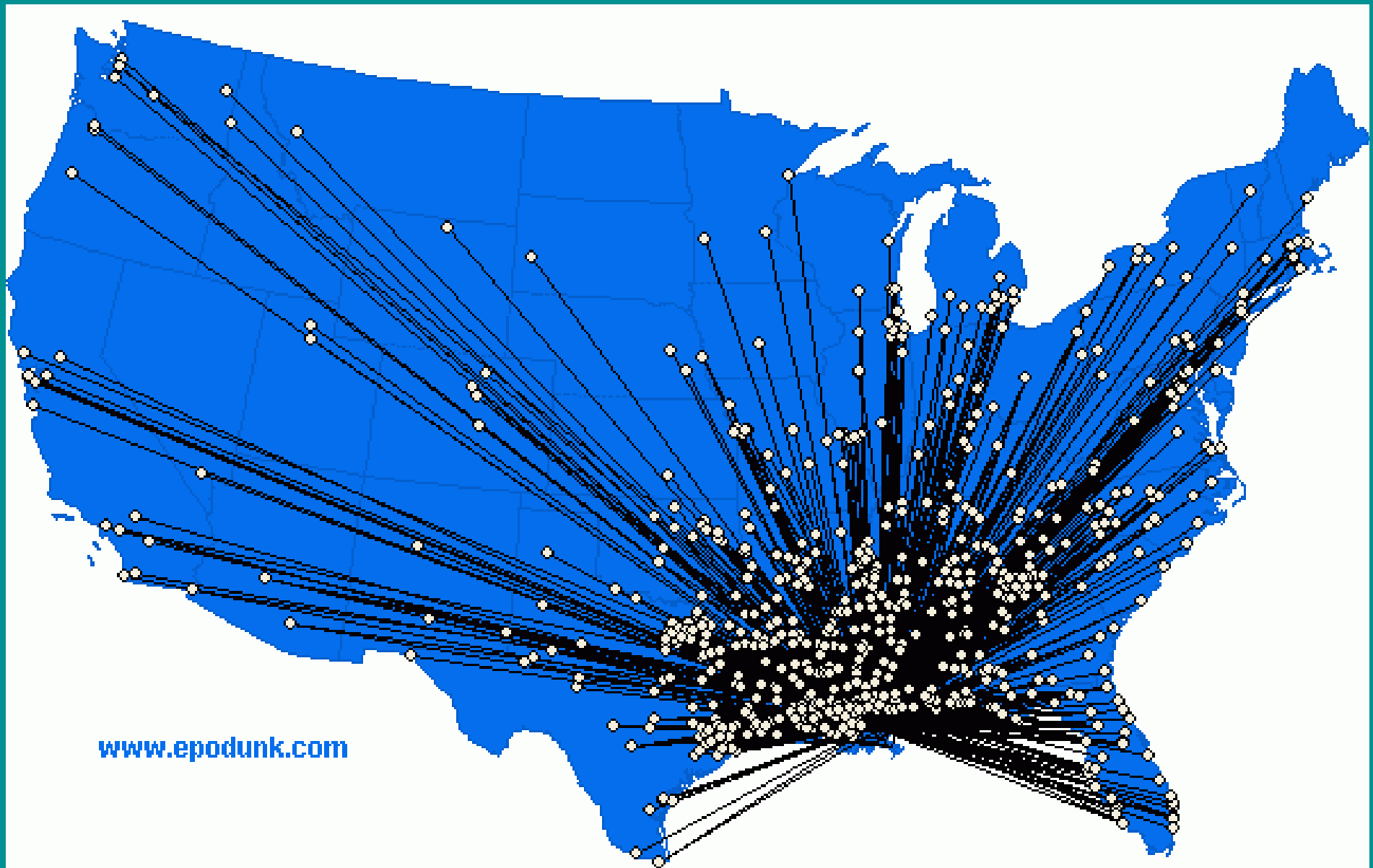
L. Long, et al, 1988, "Migration distamces…", *Demography*, 25: 633-640.

D. Mok, et al., 2010, "Does Distance Matter in the Age of the Internet?", *Urban Studies,* 47(13):2747-2783

For example:

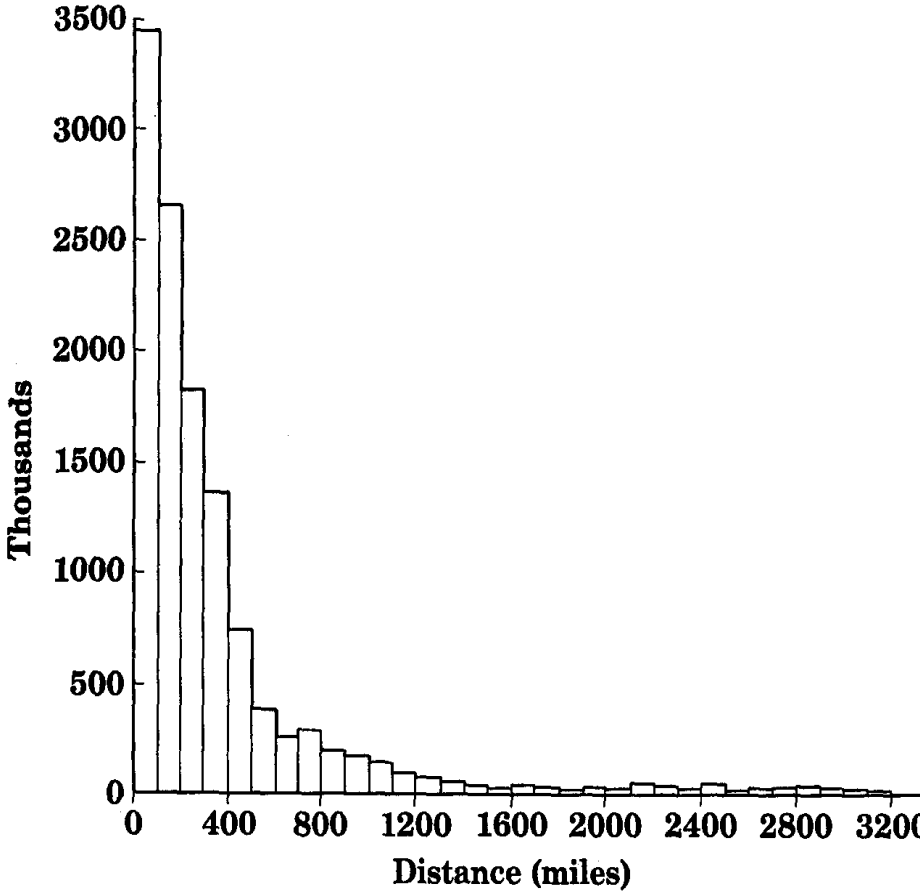
Movement from Katrina

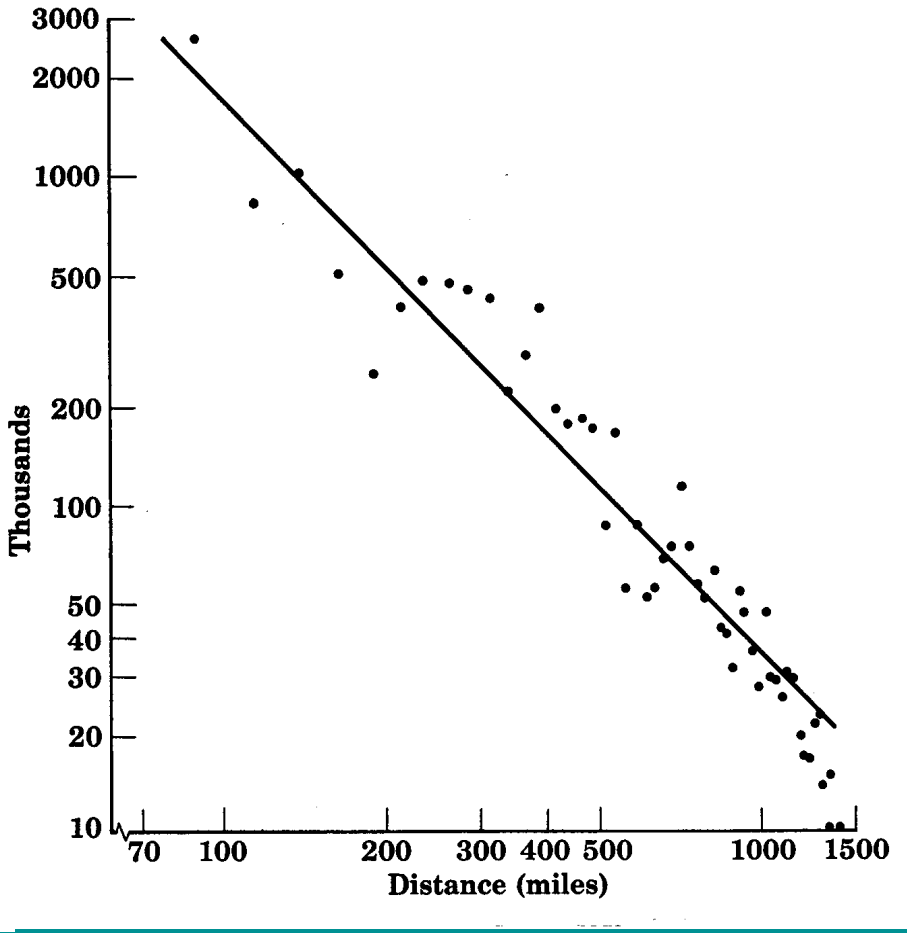
Where people relocated



The friction of distance

With scatter diagram in logarithmic form showing the slope





There are several simple implications of this 'friction' as shown by the distance decline.

One is to define trade areas or areas of influence.

Another implication is the ability to estimate movement (migration, communication, etc.) between places.

Construct mean information fields for Markov simulations.

Or consider two places at different locations: where the curves cross (intersect) may be the place of equal influence.

This is easily extended to the spatial case of influence zones and leads, inter alia, to central place theory.

Question: Given transportation innovations, has the slope of the line changed with time? If so, by how much (per year, decade)?

Another of Ravenstein's laws

"In forming an estimate of displacements we must take into account the number of natives of each county which furnished the migrants, as also the population of the … districts which absorb them" (1885:199)

Population of source place,

Population of destination place.

Combine these with 'distance' to get the social "gravity model":

$$M_{ij} = P_i P_j / D_{ij}$$

A very curious equation!

That we will come back to later

On one side the number of migrants between places I and J.

On the other side populations of places I and J multiplied.

Giving people squared.

Why not just added?

And then decremented by kilometers.

But it seems to fit the data quite well.

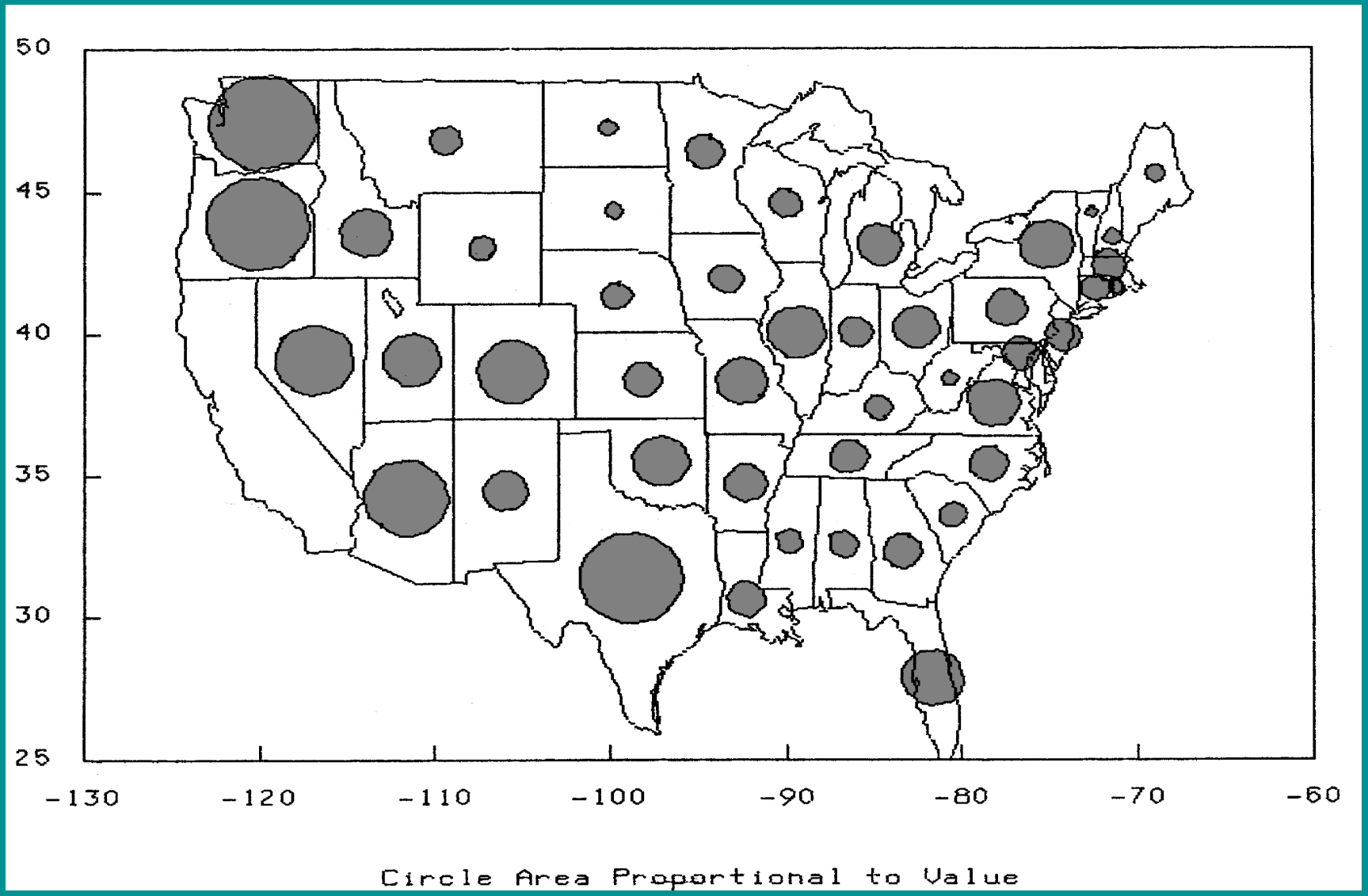
Exponents are often applied to the people and distances, improving the fit.

The analogy is to Newton's gravity equation.

With masses squared and divided by distance.

Migration from California

Notice that the circles get smaller as moves are away from California.
Unless the the destination states have bigger populations.



Two more of Ravenstein's laws

"Each main current of migration produces a compensating counter current" (1885:199)

"The process of dispersion is the inverse of that of absorption, and exhibits similar features" (1885:199)

1965-1970 US Census Bureau

Migration by the nine census regions.
Rows indicate the 'from' regions, columns the 'to' regions.

Interregional Migration Estimated by the US Bureau of the Census (1973)

	1	2	3	4	5	6	7	8	9
1 New England	—	180,048	79,223	26,887	198,144	17,995	35,563	30,528	110,792
2 Mid-Atlantic	283,049	—	300,345	67,280	718,673	55,094	93,434	87,987	268,458
3 East North Central	87,267	237,229	—	281,791	551,483	230,788	178,517	172,711	394,481
4 West North Central	28,977	60,681	286,580	—	143,860	49,892	185,618	181,868	274,629
5 South Atlantic	130,830	382,565	346,407	92,308	—	252,189	192,223	89,389	279,739
6 East South Central	21,434	53,772	287,340	49,828	316,650	—	141,679	27,409	87,938
7 West South Central	30,287	64,645	161,645	144,980	199,466	121,366	—	134,229	289,880
8 Mountain	21,450	43,749	97,808	113,683	89,806	25,574	158,006	—	437,255
9 Pacific	72,114	133,122	229,764	165,405	266,305	66,324	252,039	342,948	—

Source: U.S. Bureau of the Census (1973).

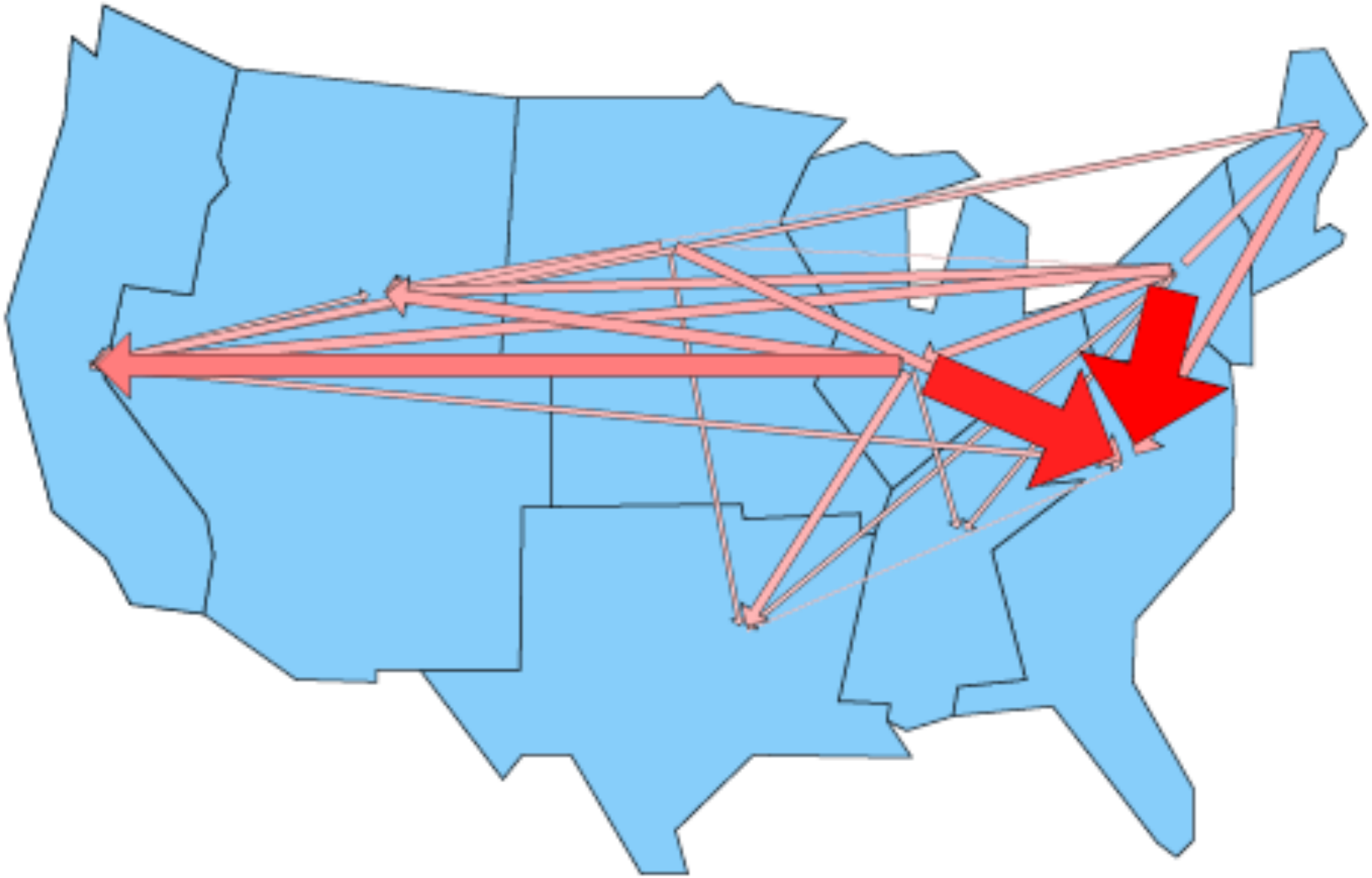
A census migration table can be used to illustrate these laws.

A typical migration study uses a square table of rows and columns.
As the number of rows and columns increase the spatial resolution increases.
The numbers in the table indicate the volume of the migration.
The sum of the row values equals the sum of the column values.
And this number is the total of all the migration.
The diagonal of the table is often ignored and left blank.
These country tables generally cover internal migration only.
No international migration of where people come from (Immigration)
& where they go (Emigration).
Countries count incoming people, but don't keep detailed track of ones leaving,
and where they go.

An example of such a table is next.

Internal migration by 9 census divisions.

1965-1970 data.



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9 Pacific	72,114	133,122	229,764	165,405	266,305	66,324	252,039	342,948	—

Source: U.S. Bureau of the Census (1973).

Important points about this migration table.

The internal in-migrations and out-migrations are both large numbers.

Adding all the numbers in the table gives the total migration: 12,313,422

Edge values (row sum & column sum):

Adding cross the rows gives the out-migration for each region.

For New England the sum is 679,180

Adding down the columns gives the in-migration for each region.

For New England the sum is 675,408

In fact all the ins and outs are highly correlated, as Ravenstein's law suggests.

Cross diagonal values:

Adding the numbers across the diagonal gives the total (gross) migration.

For New England & Mid-Atlantic this sum is 180,048 + 283,049 = 463,097

The table is not symmetric. The difference is the net migration.

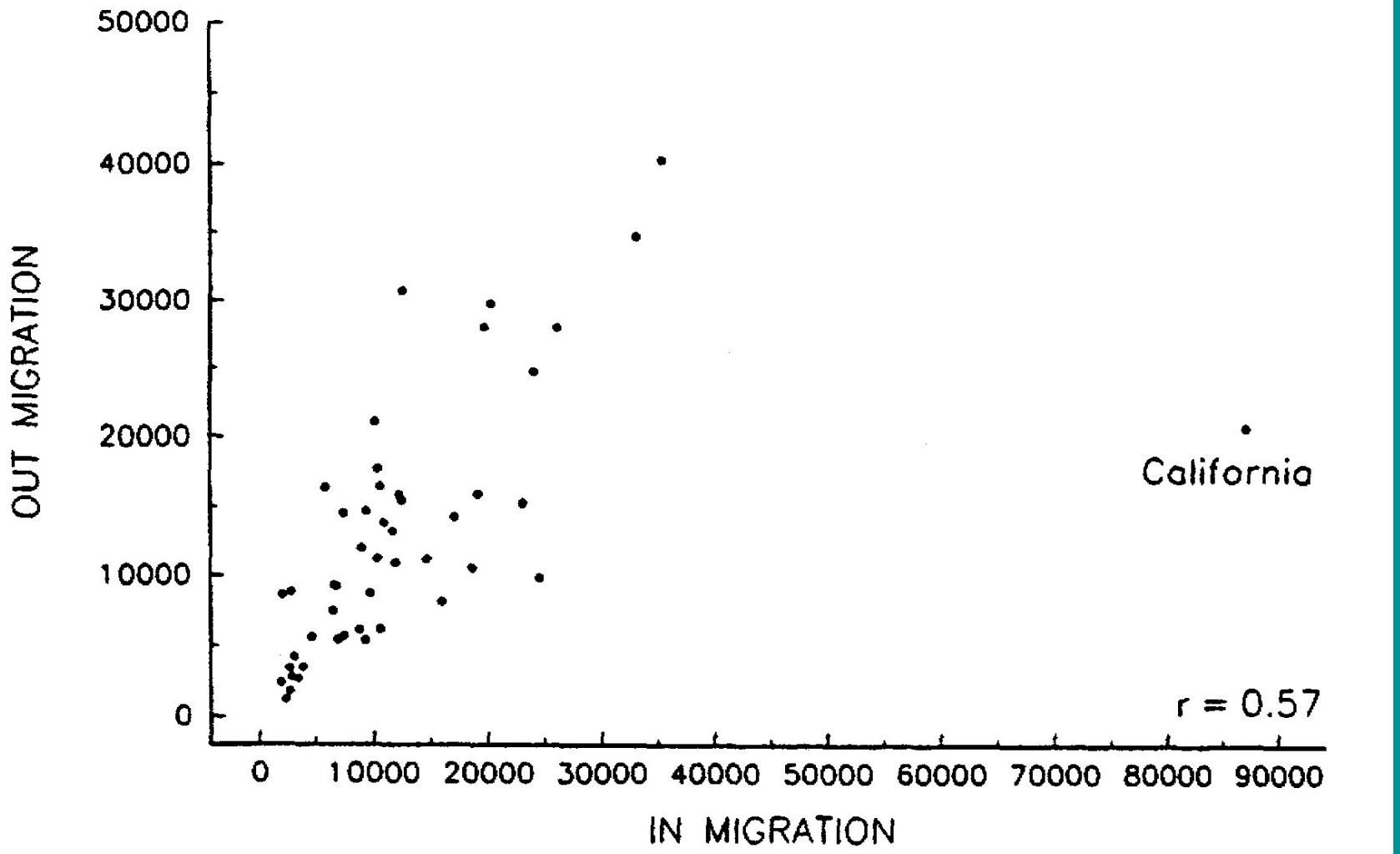
Look across the diagonals to see this.

For New England & Mid-Atlantic the difference is

283,049 - 180,048 = 103,001

In and out migration, 1935 to 1940

Forty eight observations, by state, with dust bowl effect!

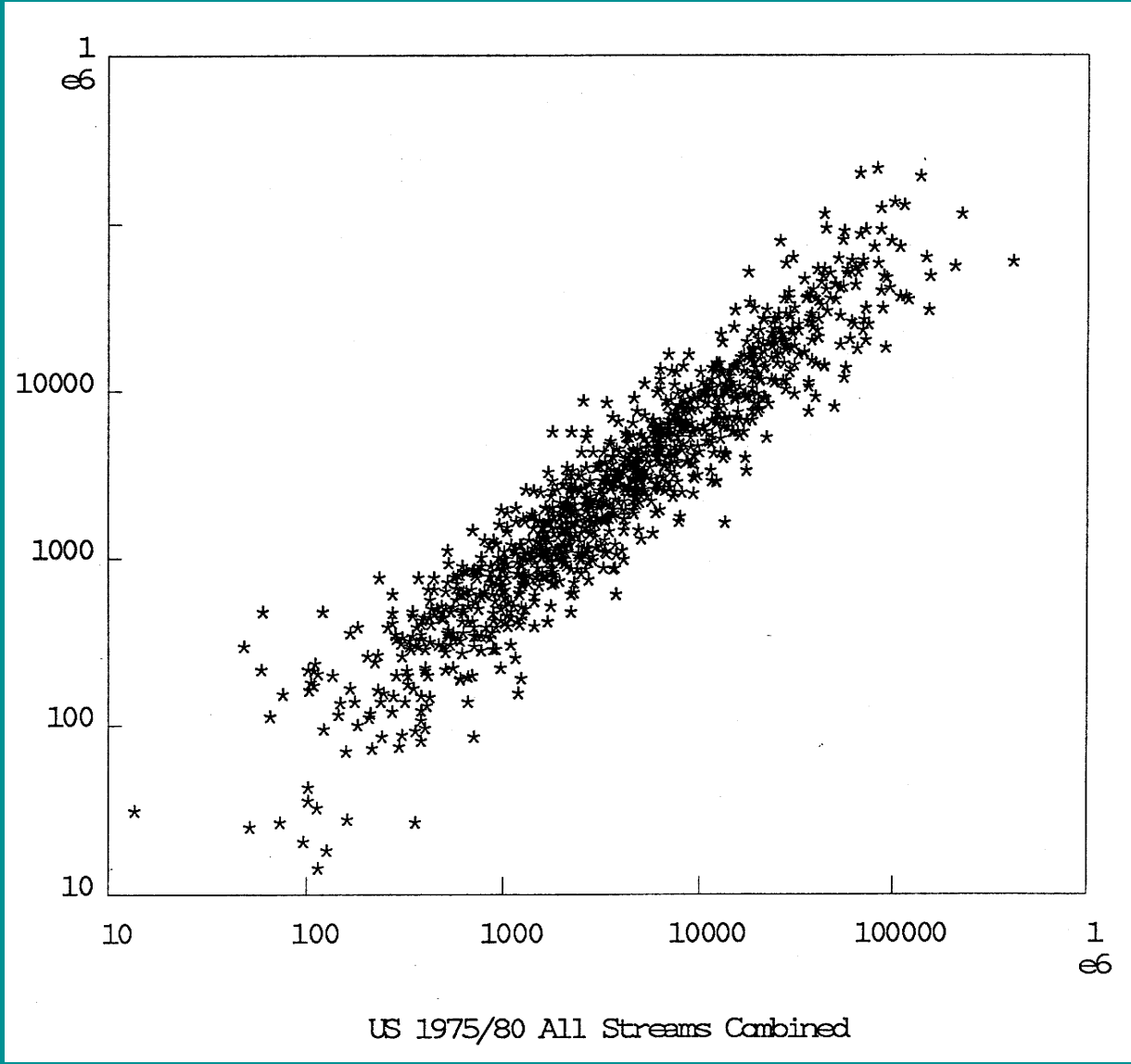


Subsequent decades give almost identical results, without the dust bowl affect relating to California. California is no longer an exception.

For the student: Bring several of the next slides/tables up to date!

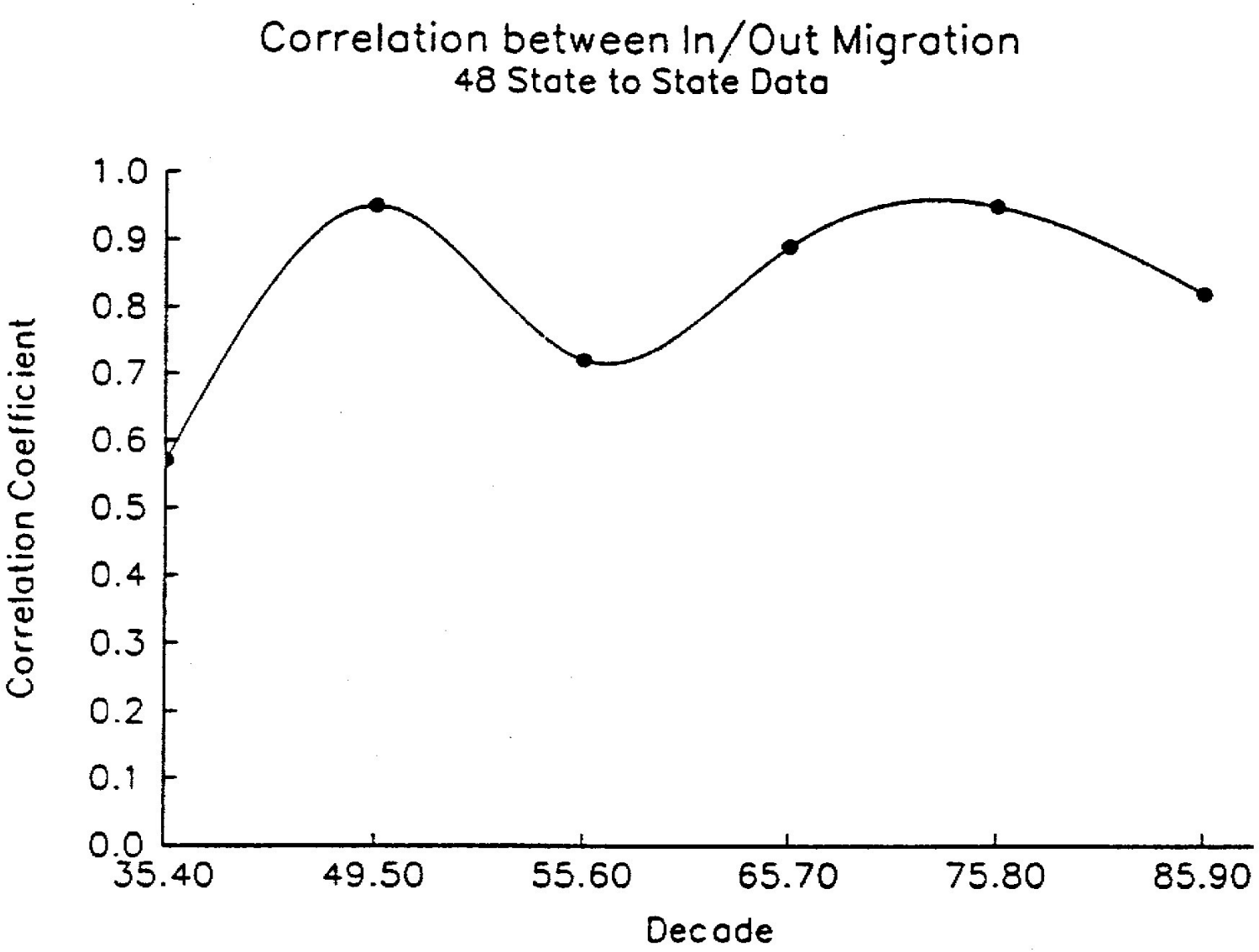
Total: In versus Out migration

All migration, N= 2,256. Log scale.



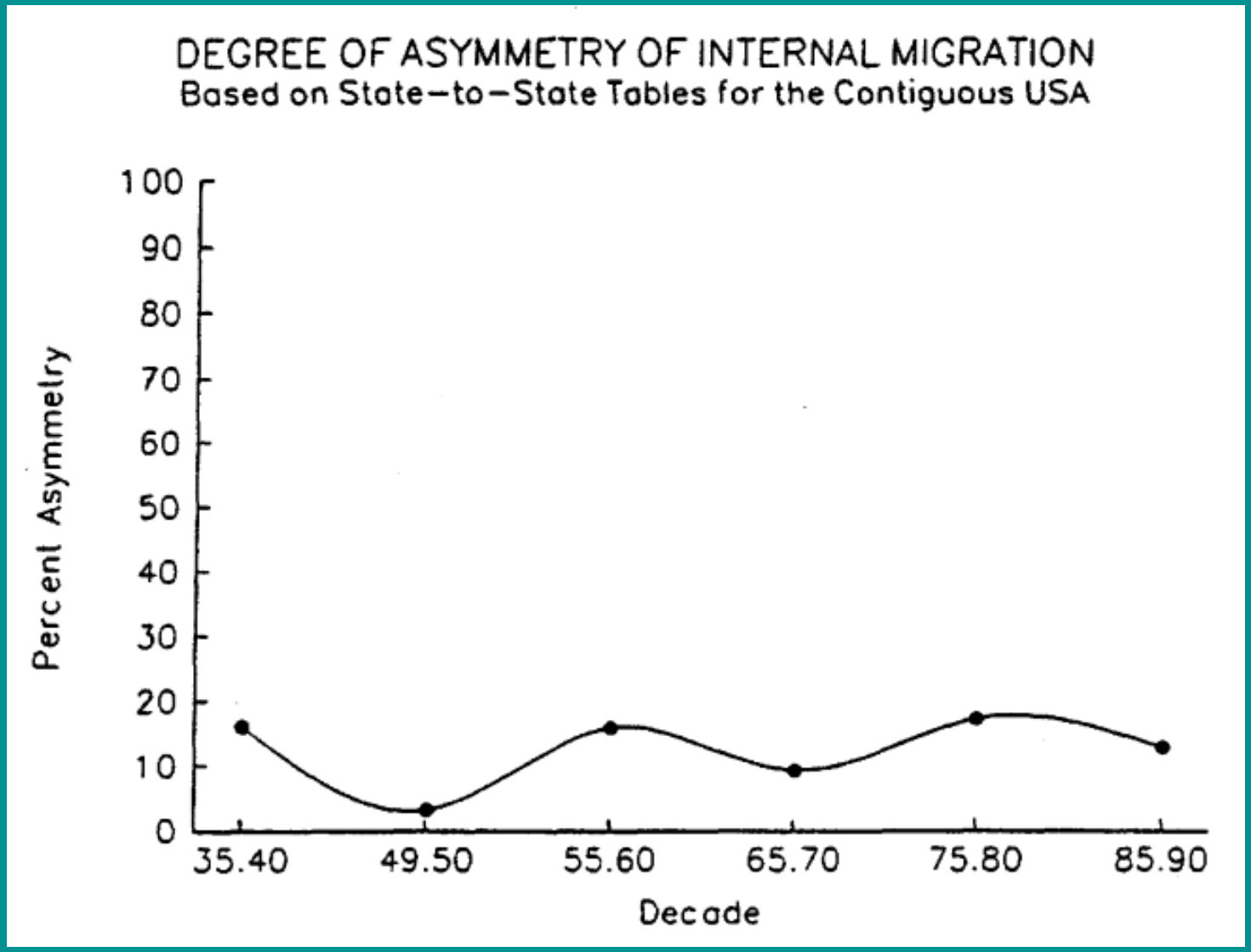
In and out migration correlation

over 6 decades



US migration asymmetry over six decades

The asymmetry is small and stays under 20%. This is really the change due to migration.



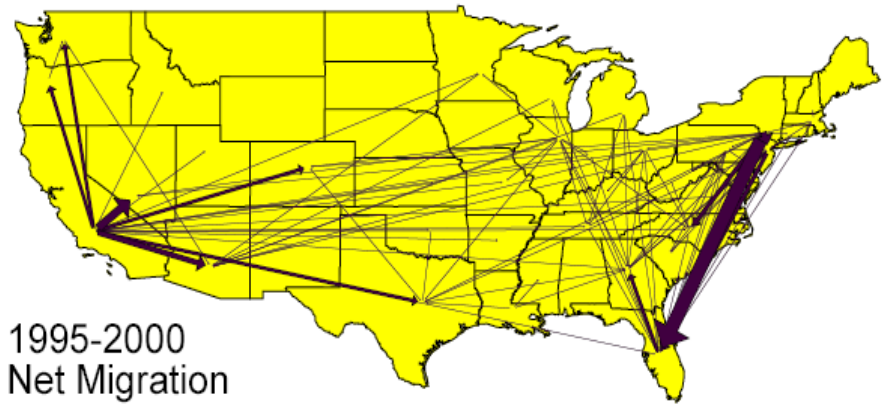
Another of Ravenstein's laws

"Migratory currents flow along certain well defined geographical channels." (1889:284)

Four decades of net migration maps

Migration patterns persist for a long time

Thus there is temporal coherence (auto-correlation)



An aside

These maps were made by a simple computer program that is available free from CSISS.ORG

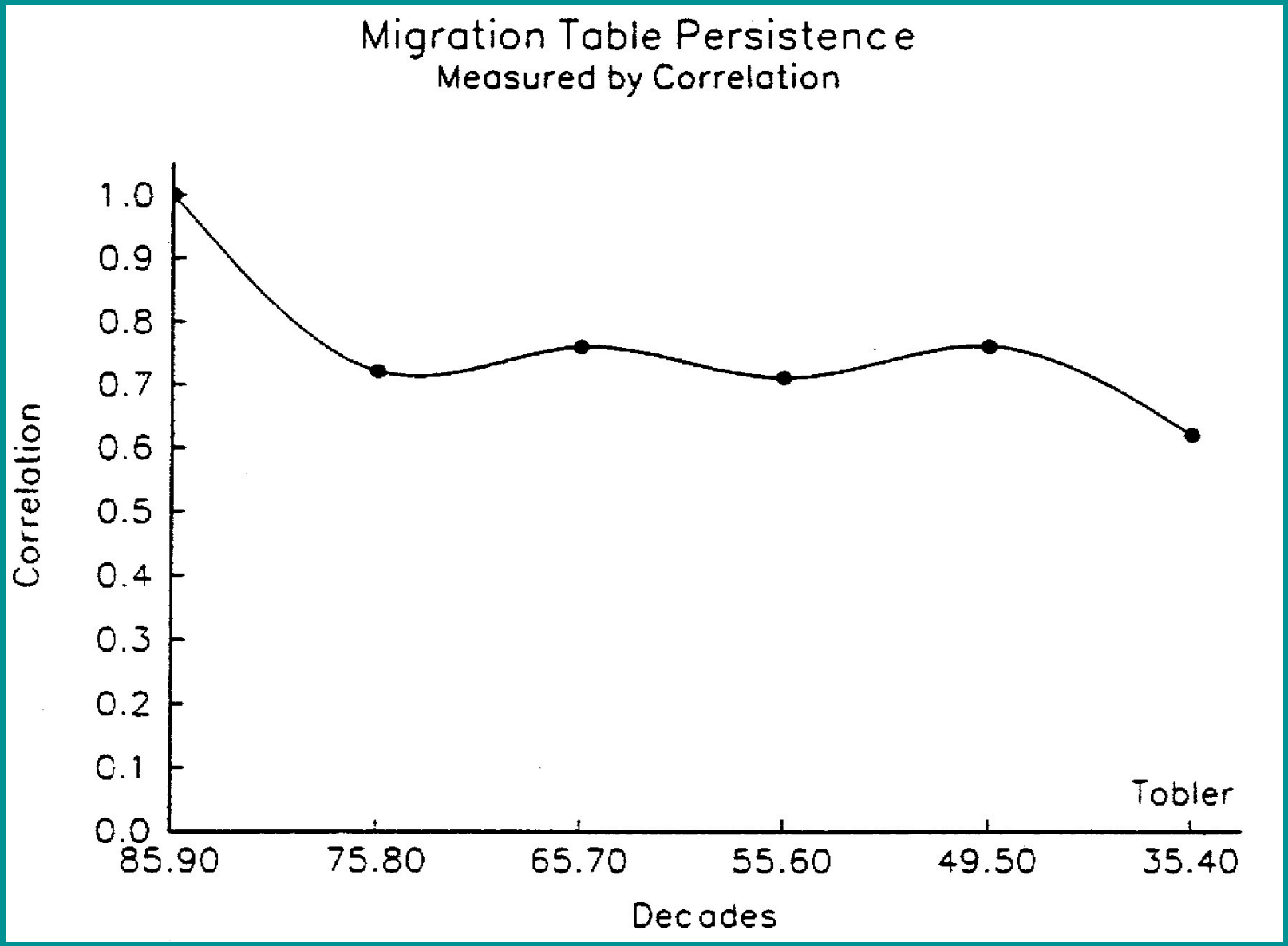
With tutorial and examples.

The Center for Spatially Integrated Social Science, in the Geography Department at UCSB.

Under spatial tools / Tobler's Flow Mapper

Correlation between the tables

Slowly decreases in time, but over .6 correlation after 50 years



Why does the correlation between migration tables decline over time?

On the assumption that much migration is due to person to person interaction.

And, although there is great persistence in the tables,

personal contacts weaken with retirements,

and changes in relationships occur over time.

I speculate that this is the ‘cause’ for the decline.

An alternate speculation might be that the opportunities generating migration might have disappeared.

Openings fill up, population density gets too high with overcrowding,

all niches are filled, etc.

Here we have another opportunity for research.

What has been learned since Ravenstein?

A lot of detail in a huge literature.

Better census collections and recording.

Registration systems.

Much more about the impact and consequences.

More detail regarding age and gender.

Much better analysis capability.

But, not many new laws.

Think of this as a challenge!

The U.S. Census provides much migration information

This formerly came in the form of information collected every ten years and presented in tables of varying resolution.

Some countries, such as Sweden and Japan, have continuous population registers.

For example Japan has a change of residence table for 26 regions every month and going back some 70 years.

A challenging possibility for a spatial matrix time series of over 1800 observations,

Migration data arrives in variable sized packets.

Referring here to census-type data tables:

These are based on irregularly shaped polygons.

Of widely varying sizes, shapes, and orientations.

The larger the number of units the finer the detail.

Examples from some European countries:

The more closely one looks the more detail.
The tables can get very large.
Growing as the square of the number of units.

Official Demographic data in Western Europe

Country	Date	Source	Area name	Number of areas	Av. pop. (000)
Austria	1991	Census	Gemeinde	2333	3
Belgium	1991	Census	Communes	596	17
Denmark	1991	Register	Kommuner	276	19
Finland	1991	Register	Municipalities	445	11
France	1990	Census	Communes	36 545	2
Germany	1991	Surveys	Gemeinde	16 147	5
Greece	1991	Census	Demoi/Koinotites	6039	2
Ireland	1991	Census	DED Wards	3438	1
Italy	1991	Census	Comuni	8097	7
Luxembourg	1991	Census	Commune	118	3
Netherlands	1991	Register and Survey	Gemeenten	702	21
Norway	1991	Census and Register	Municipalities	440	10
Portugal	1991	Census	Concelhos/Municipios	305	34
Spain	1991	Census	Municipios	8056	5
Sweden	1990	Census and Register	Kommuns	284	30
Switzerland	1991	Census	Communes	3021	2
UK	1991	Census	Wards	10970	5

Source: based on Waters, 1995, p. 41.

As the units get smaller the resolution increases.

The more closely one looks the more detail is seen.

But

The tables can get very large.

Growing as the square of the number of units.

Thus there is pressure to reduce the data.

But without limiting the detail.

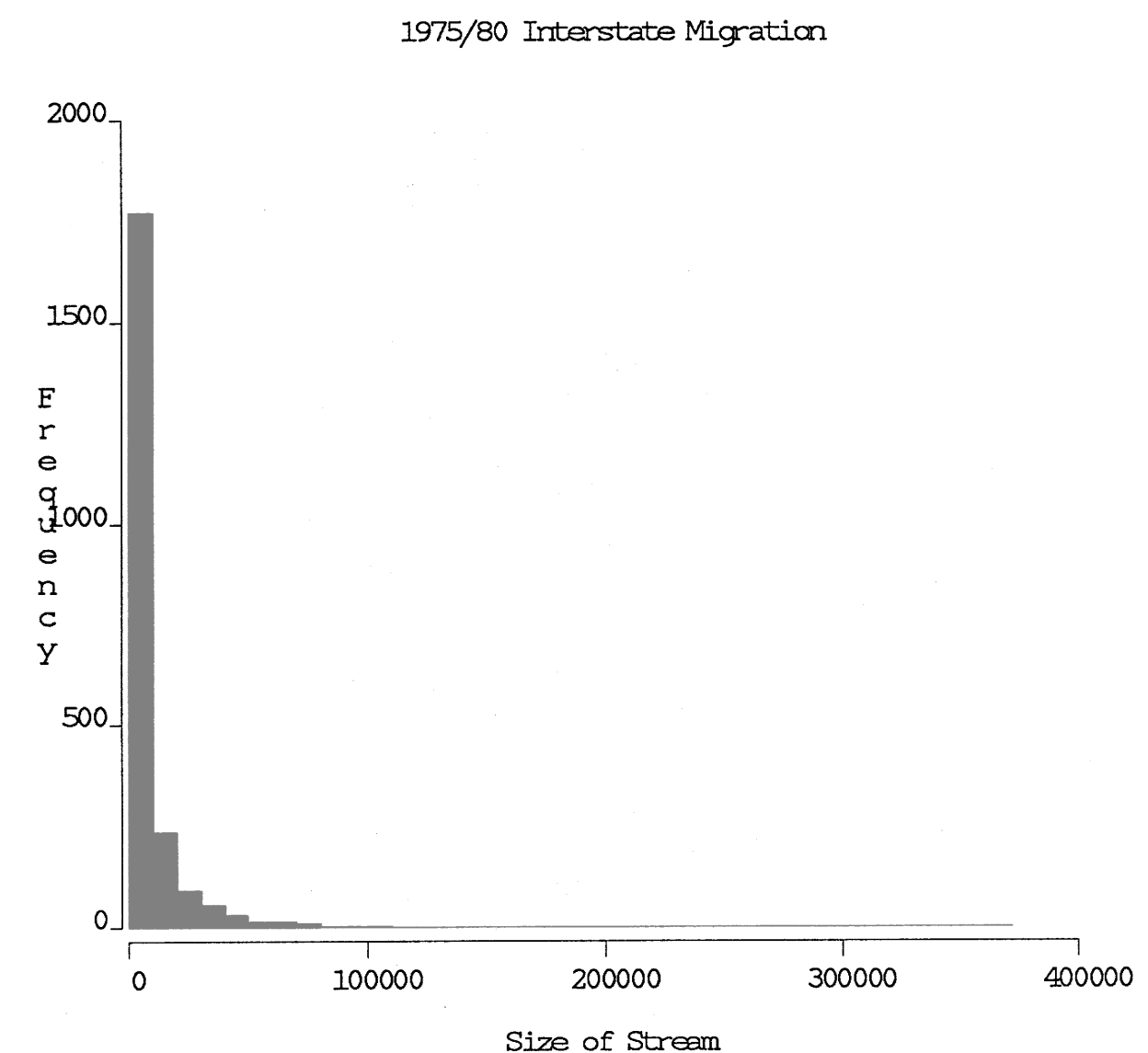
How to do this?

Many techniques have been tried,

none completely satisfactory.

Small migration streams predominate

Many small migration amounts, a few large migration amounts



An optimal deletion rule:

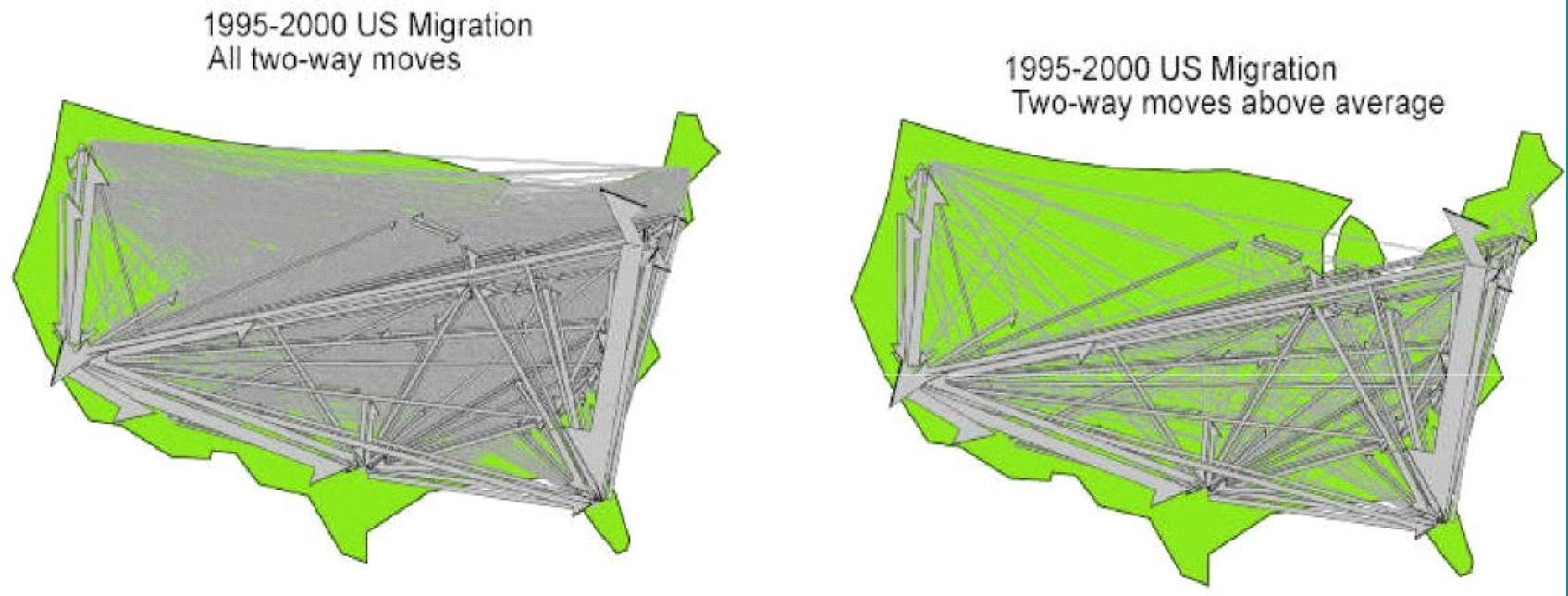
Remove everything below the average.

Thresholding of a Migration Table.

For the 48 by 48 table of 1975 to 1980 migrations between states of the coterminous United States the following results are obtained:

		Total Moves	Above Mean	% Above Mean	% of migrants above the mean
Bidirectional	$M_{I,J}$	2250	535	23.7%	78%
Gross	$M_{I,J} + M_{J,I}$	1128	280	24.8%	78.6%
Net	$M_{I,J} - M_{J,I}$	1127*	228	20.2%	81.8%

*One would expect 1128 here but the Arizona to New Hampshire movement exactly equals that in the opposite direction in the published table, yielding a net movement of zero.



An alternative

Reducing the resolution by combing districts.

In the United States, increasing detail:

Census districts (4), Census regions (9)

States (50), Counties (3100)

etc.

Moving up or down in the hierarchy changes the resolution.

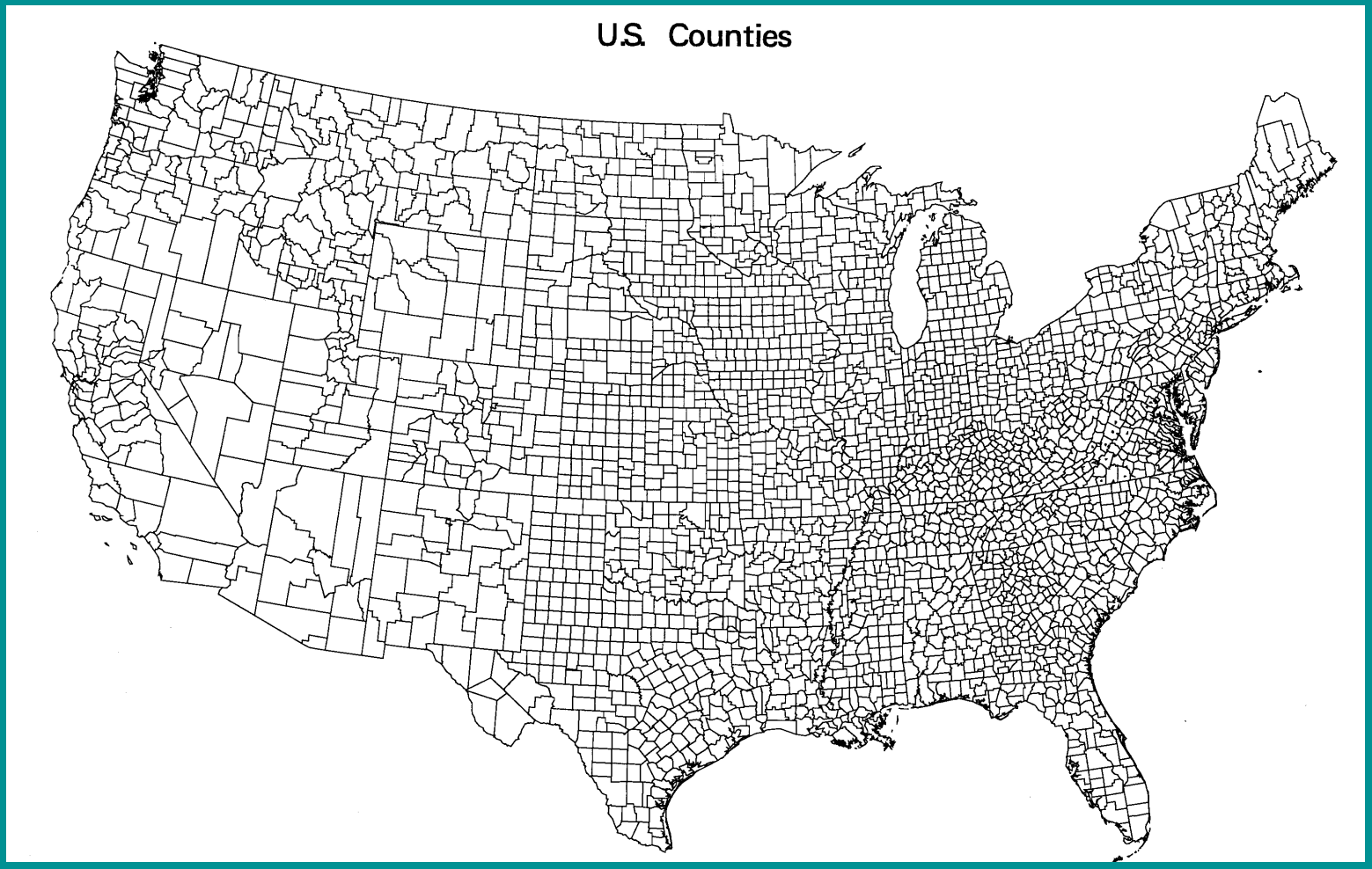
This acts as a spatial filter and changes detail.

The closer one looks the more complex the world!

Ultimate detail: individuals.

County Units

3100+ units or 9,606,900 potential migration table entries



Average resolution ~55 km. Patterns >110 km detectable.

Still not sufficient to see movement within cities.

If you got this kind of resolution in photographic film you would reject it, wouldn't you?

The US Census publishes the county to county migration tables.

The 9×10^6 numbers in a county to county table are not a lot for a computer. But for humans?

This quantity of information could not be comprehended without some visualization techniques or without a model.

Most of the cells in the county to county table would be empty.

If the US county migration table has only 5% of the cells with non-zero entries that is still almost half a million numbers!

I do not think that I could cope with that much information without some aids in the form of techniques or theory.

U. S. Census Migration Tables

1935-1940

1949-1950

1955-1960

1965-1970

1975-1980

1985-1990

1995-2000

Generally based on a 15% sample.

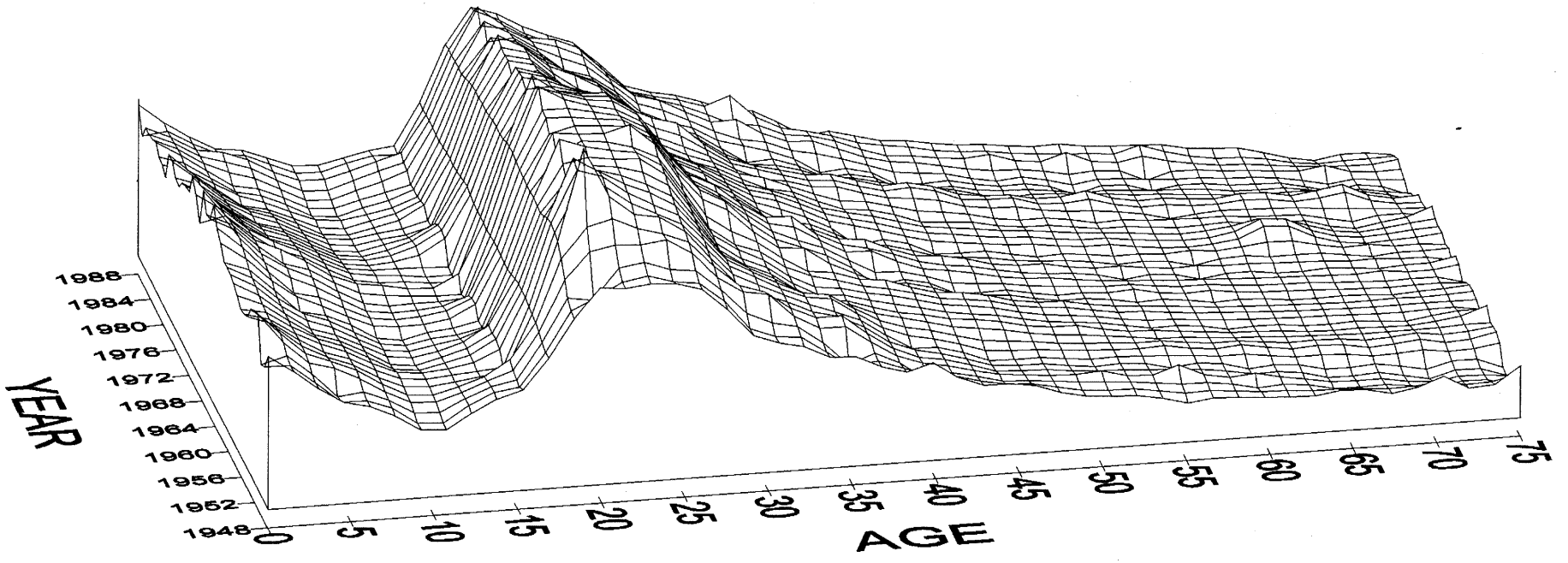
The census has now changed its method of recording migration data.

But Some information is also available from annual IRS tax records, as for the next slide.

Annual Migration Rates

by Five Year Age Groups. USA 1948-1988

The forty year stability of the age pattern clearly qualifies as a migration law.
And this seems to hold for virtually all societies.



Edmonston (1991)

There is also a great deal of spatial coherence in migration patterns

In the US case the state boundaries hide the effect, therefore they should be omitted.

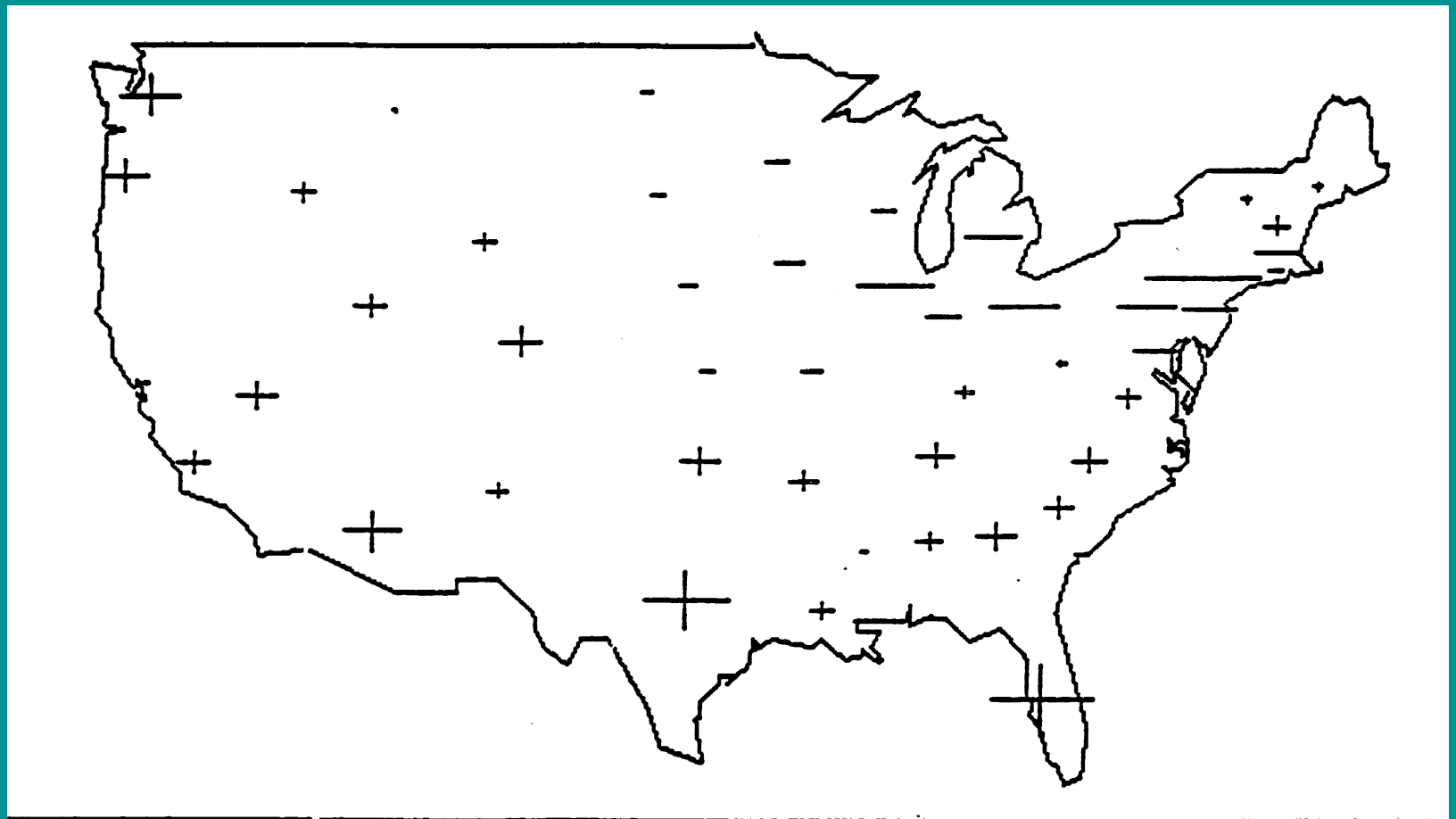
There is also temporal coherence.

W. Tobler, 1995, "Migration: Ravenstein, Thornthwaite, and Beyond", *Urban Geography,* 16(4): 327-343.

Gaining and Losing Migration States

Symbol positioned at the state centroids, and proportional to magnitude of the change.

The map is based on the marginals of a 48 x 48 state to state migration table and shows the accumulation and depletion places. Draw a boundary around the losing states. This demonstrates that states are not the appropriate size for studies of migration and also that there is a great deal of correlation amidst state migration data.



Did you like the previous map?

In my opinion this simple plus/minus map represents the in/out migration much more effectively than the usual choropleth shading.

The size of the symbols could of course be accompanied with a scale of magnitudes and this might be useful.

Also less expensive than color printing, and useful for regression residuals.

Moving on to more recent work.

Significant individuals in 20th century migration studies

Harold Hotelling ~ 1920's MA thesis; famous statistician

Warren Thornthwaite ~ 1930's Climatologist

George Zipf ~1940's Human behavior & principle of least effort

John Q. Stewart ~1940's gravity model

Torsten Hagerstrand ~ 1950's Migration in Sweden

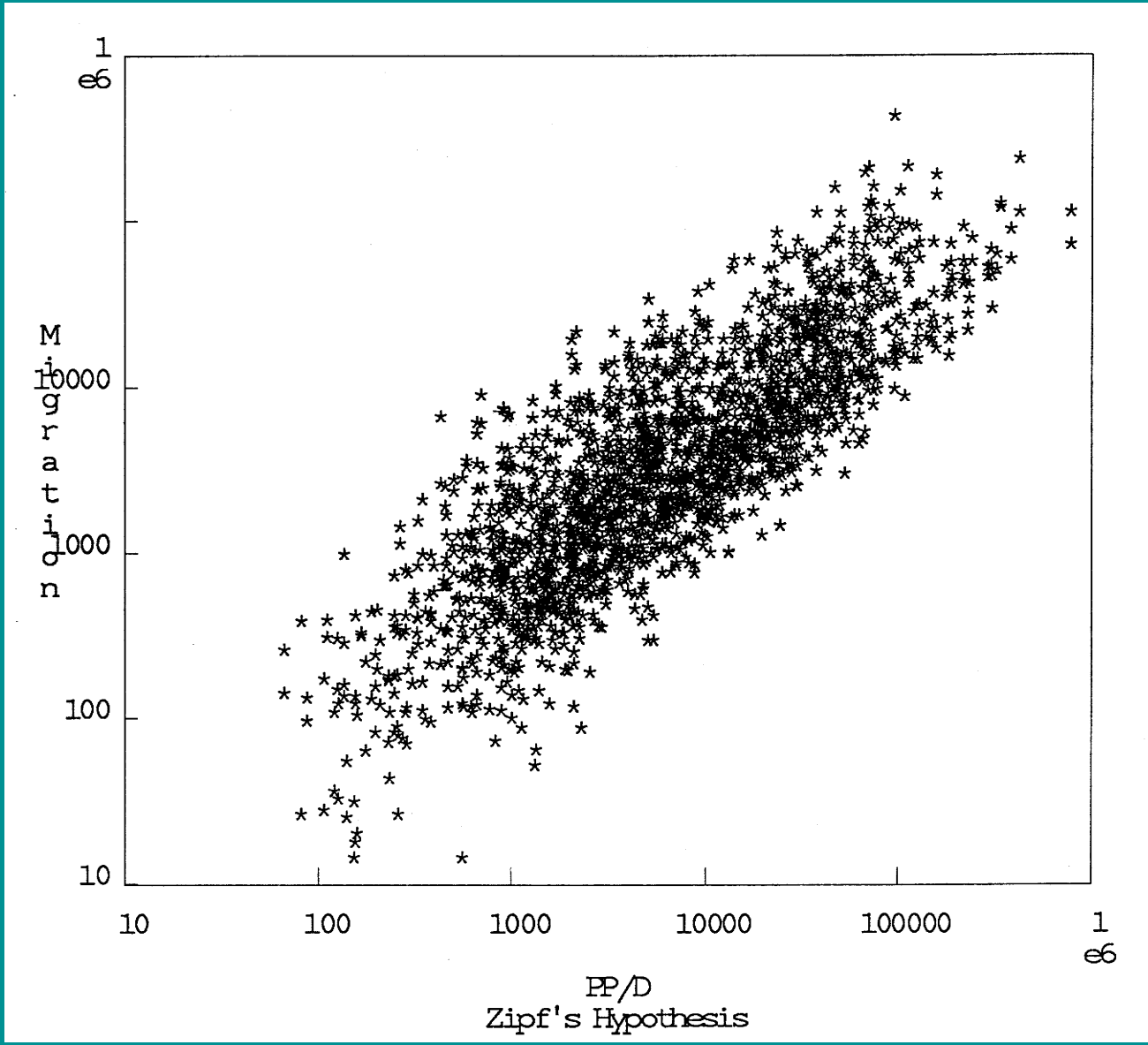
William Warntz ~ 1960's Potential models

Alan Wilson ~1970's Entropy model

I consider here only the work of G. K. Zipf

Predicted versus actual

2256 observations, 1975-1980 migration. Log scale.



The Zipf model is now generally called the social gravity model

In this model the movement from place i to place j is proportional to the sizes of the places and inversely proportional to the distance between the places:

$$M_{ij} = k\, P_i P_j / d_{ij}.$$

Variants include exponents and the Wilson entropy model.

How well does it work? Typical correlations are about 80%.

This is often evaluated using logarithms.

The next step is to estimate 'causes' of , or 'reasons' for, migration.

This is usually done using a regression equation of the form

$$M_{ij} = ß\, X + \varepsilon.$$

Distance does not cause migration - it attenuates it.
So people look for 'Reasons': the X in this equation.

$$M_{ij} = ß\ X + \varepsilon.$$

β is a vector of coefficient estimates relating to the several postulated 'causes' X.
The error term ε is minimized by the least squares technique.

The list of the causes (X's) is chosen in advance, on the basis of some theoretical conjectures, is often rather long, but can never be exhaustive.

Some of the many 'causes' are properties of the i^{th} place, others of the j^{th} place, others are of the differences between the places.

Here properties of the migrants themselves are typically not modeled. Instead different regressions are applied to difference classes of migrants.

One example for the United Kingdom used 59 variables!
I've never seen another equation using this many variables.

Another researcher examined 140 variables reducing the final selection to 14.

The literature on this subject is very large.

A Push-Pull Model

A colleague and I have developed a slightly different migration model.

Quite an old idea,

but only now put into mathematical form.

As an equation it is $M_{ij} = (R_i + E_j) / d_{ij}$

Using R for 'repulsing' (☹ = push) and E for 'enticing' (☺ = pull).

Both occur simultaneously at every place, but in varying amounts, and both can be positive or negative.

Tinkering with the equation allows the addition of both populations, borders, and exponents.

The model says that movement from i to j equals Push from i, plus Pull from j, both reduced by distance between i and j.

This does not look very different from the gravity version.

The difference is in the numerical estimation process.

No regression equation is used.

The model works like this:

For migration in some geographic area,
given
the out-movements (row sums),
the in-movements (column sums),
and the distances between the places,

the algebra then allows the computation of the full table.

This can be compared to the actual values, if known.

But, importantly, it also gives **numerical** estimates for the pushes, and pulls.

But these values are descriptions, not ‘causes’ or ‘reasons’, with which they may be correlated.

Some more advanced materials, developed on the basis of the push-pull model.

Instead of using a discrete model, as in the foregoing presentation consider a geographically continuous representation.

That is, imagine that the number of places increases greatly.

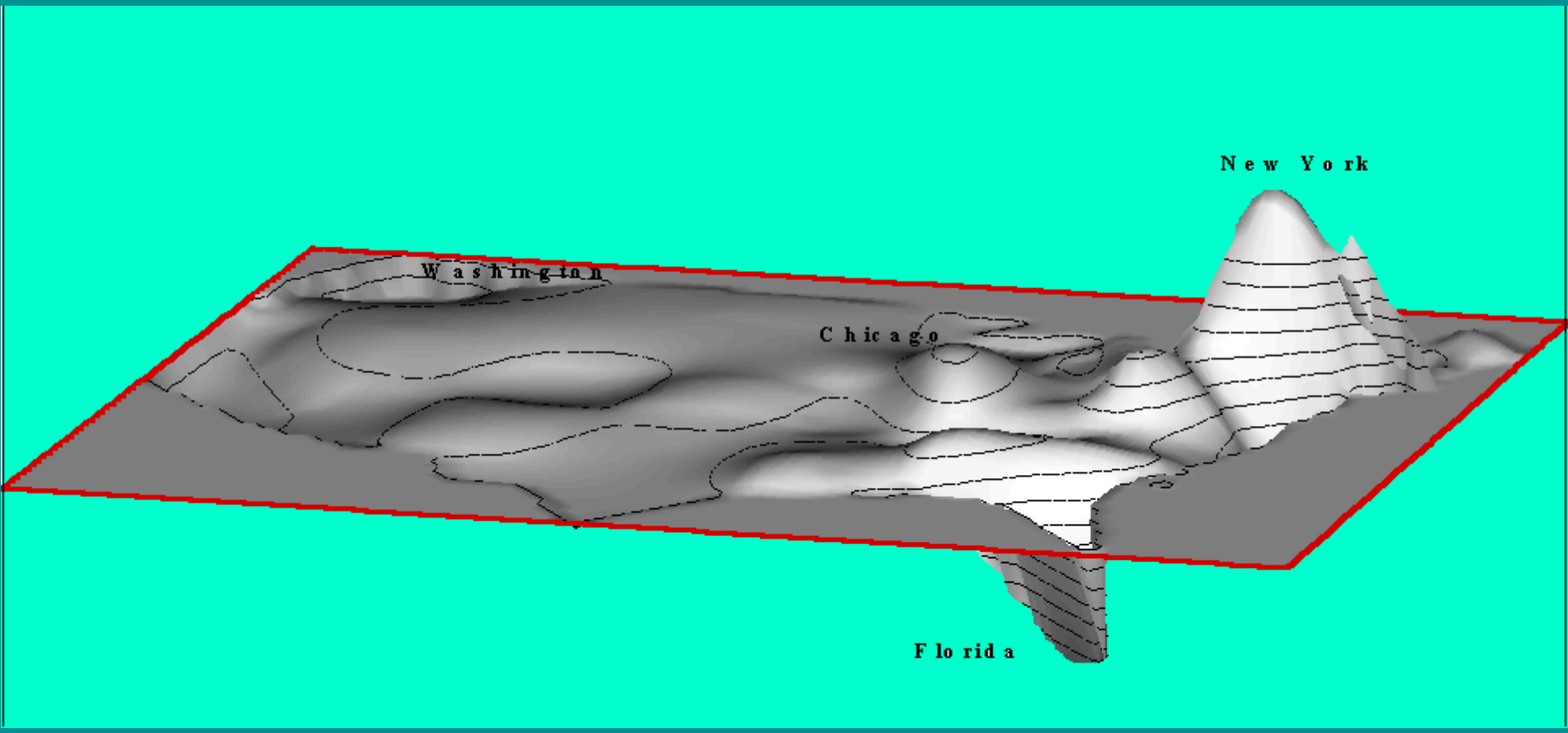
Then do some interpolation of the data to obtain a continuous field.
Doing this allows a different interpretation of the data and a different graphic

such as:

The Pressure to Move in the US

Movement is from the high to low

Based on a continuous model. Using state data



How did I do this?

Discretize the U.S. by imposing a raster.

This raster technique is advantageously used at several geographical scales, including for cities.

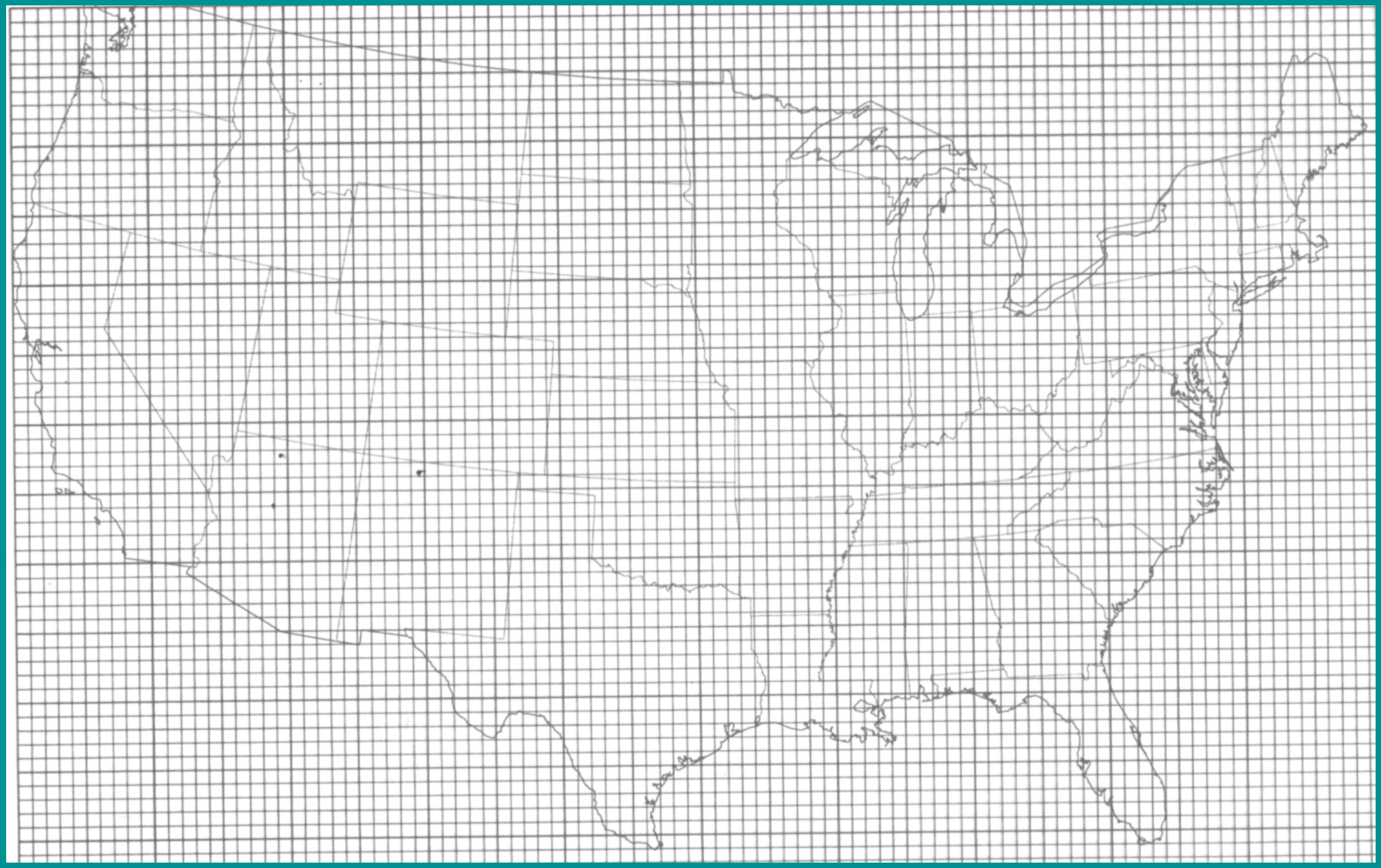
And thus eliminate the irregular size, shape, and orientation of the data collection zones.

A each state will be covered by several raster cells.

Assign the row sums and the column sums for the migration table of each area to the appropriate part of the raster.

“Rasterize” the USA to form a lattice.

Use a point-in-polygon program to assign nodes to individual states.
Then assign in and out values to these nodes.



Spread the total in and out migration moves from each state to cover all cells within the state.

Do some pycnophylactic smoothing of these data.

Then subtract the outs from the ins to get the net change due to migration of the people.

Lots of cells will get positive values (people arriving) and lots will get negative values (people leaving).

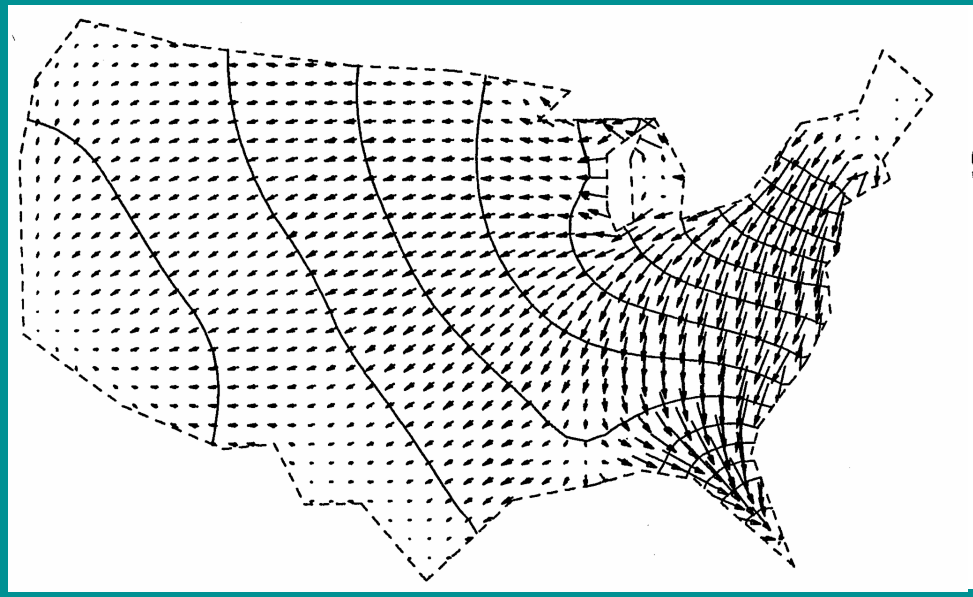
Think of the negative values as high hills and the positive values as valleys.

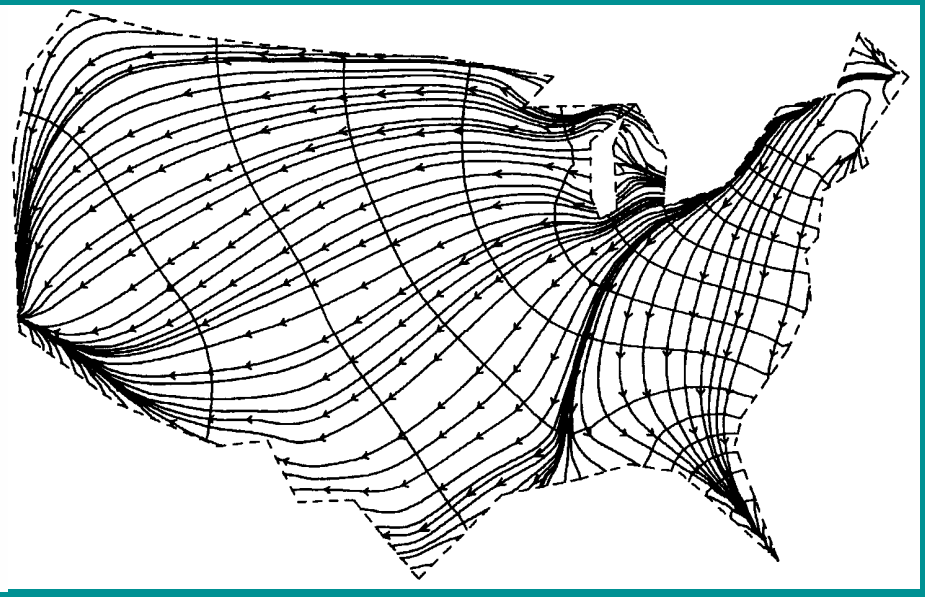
Now let the ‘people’ trickle down from the hills into the valleys, somewhat like topography eroding, to get the next map.

Or think of a weather map, with atmospheric pressure and wind.

The migration pressure shown as contours

And with gradient vectors connected to give streaklines:





Repeating one of Ravenstein's laws.

"Migratory currents flow along certain well defined geographical channels." (1889:284)

I speculate that this is because people communicate with each other.
Thus information flows back and forth as does the migration.
Information flows can be mapped just as migration if one has the data.

Recall that several million people migrate during the 5 year census period

The next map shows an ensemble average,

not the path of any individual.

The streakline density has been overemphasized for this effect.

But observe, not unrealistically, that the people to the East of Detroit tend to go to the Southeast.

Minnesotans to the Northwest, and the remainder to the Southwest.

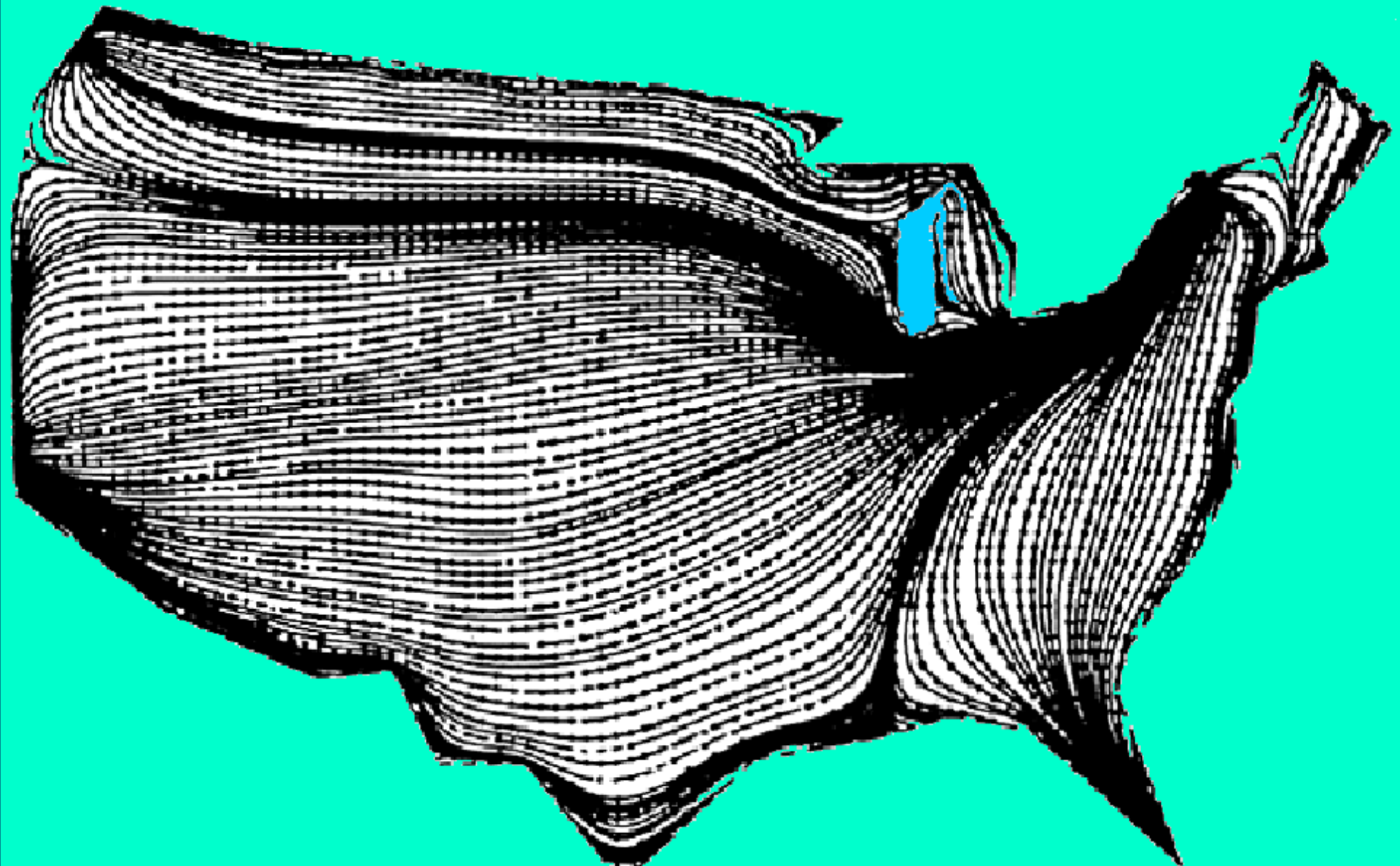
With a small number going Northeast to New England.

Due to the linear nature of the equations and the low resolution of the data this flow appears to be laminar.

16 Million People Migrating

An ensemble average. Note the distinct migration domains.

Spatially coherent structures in the internal US migration.



The vector fields can illustrate other trends.

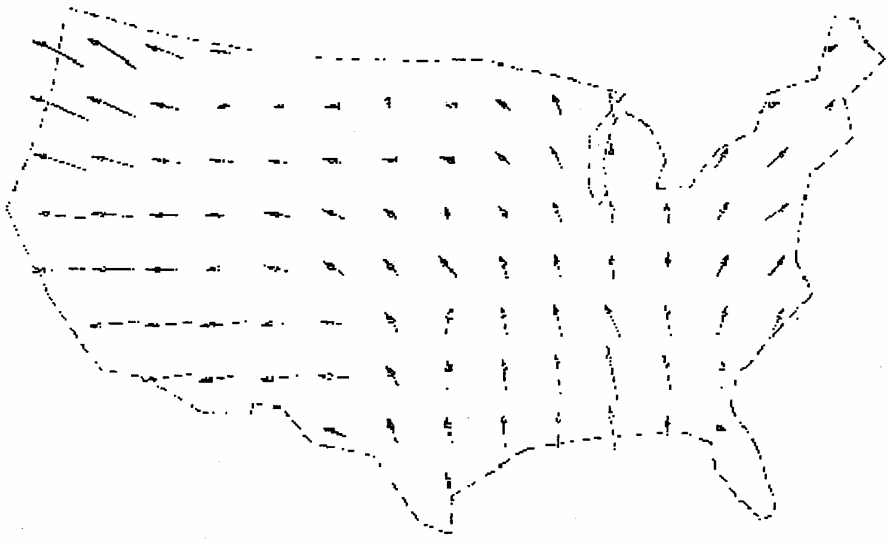
For example, in the 1940's the Cenus Bureau used only a crude social classification of the migrants, and this is reflected in the next map pair.

The difference is quite apparent.

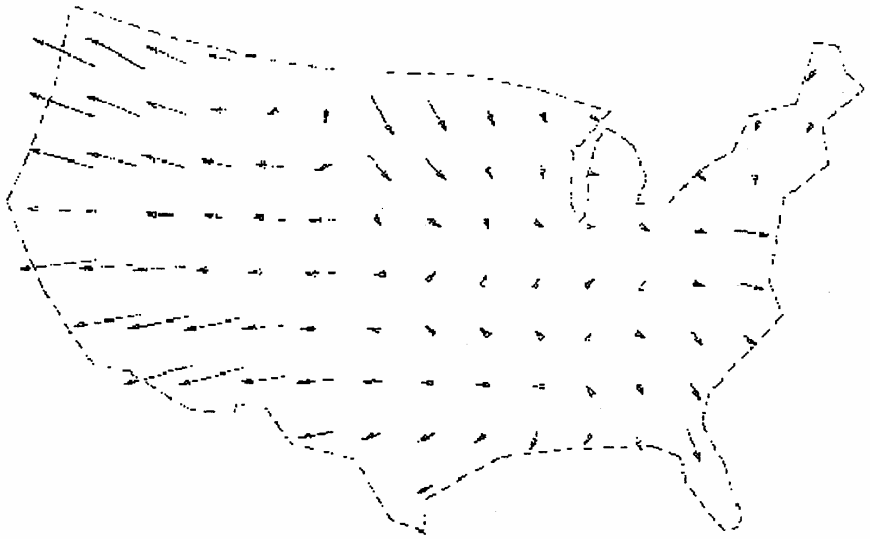
Comparison of non-white and white net migration

1935-1940 five year census migration data, by state

Non White migration



White migration



And the pattern at different times.

An example of the impact of showing the migration as a vector field.

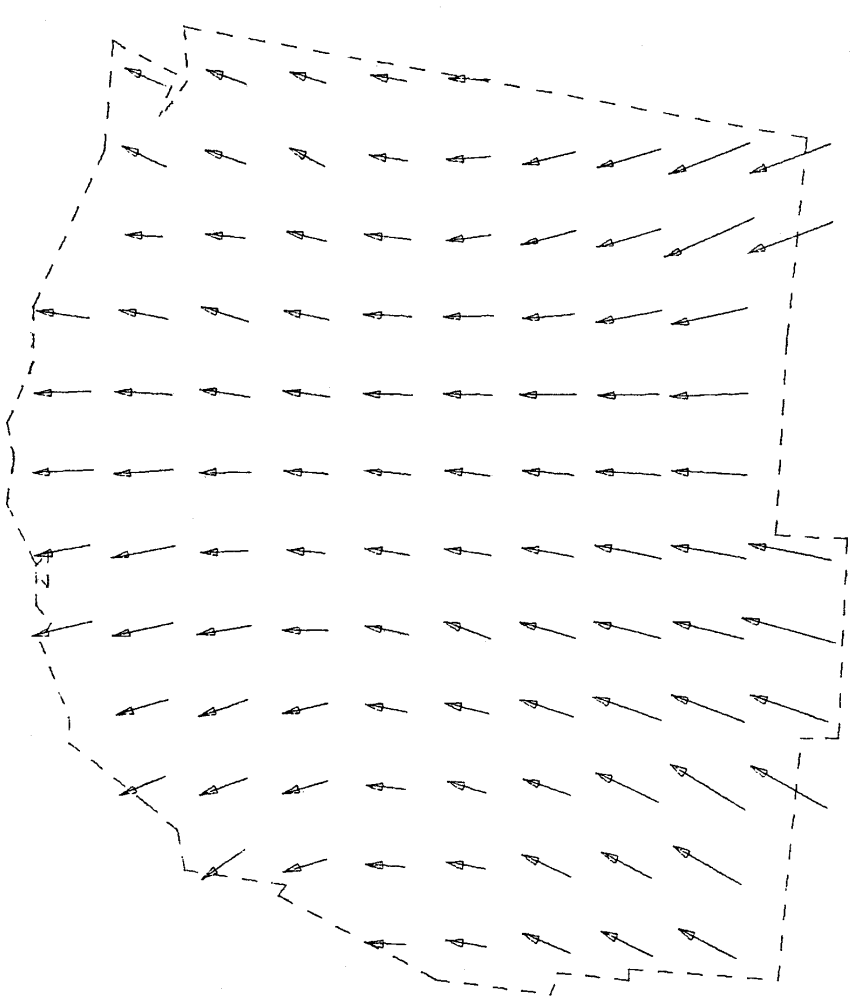
Using a time interval of thirty years.

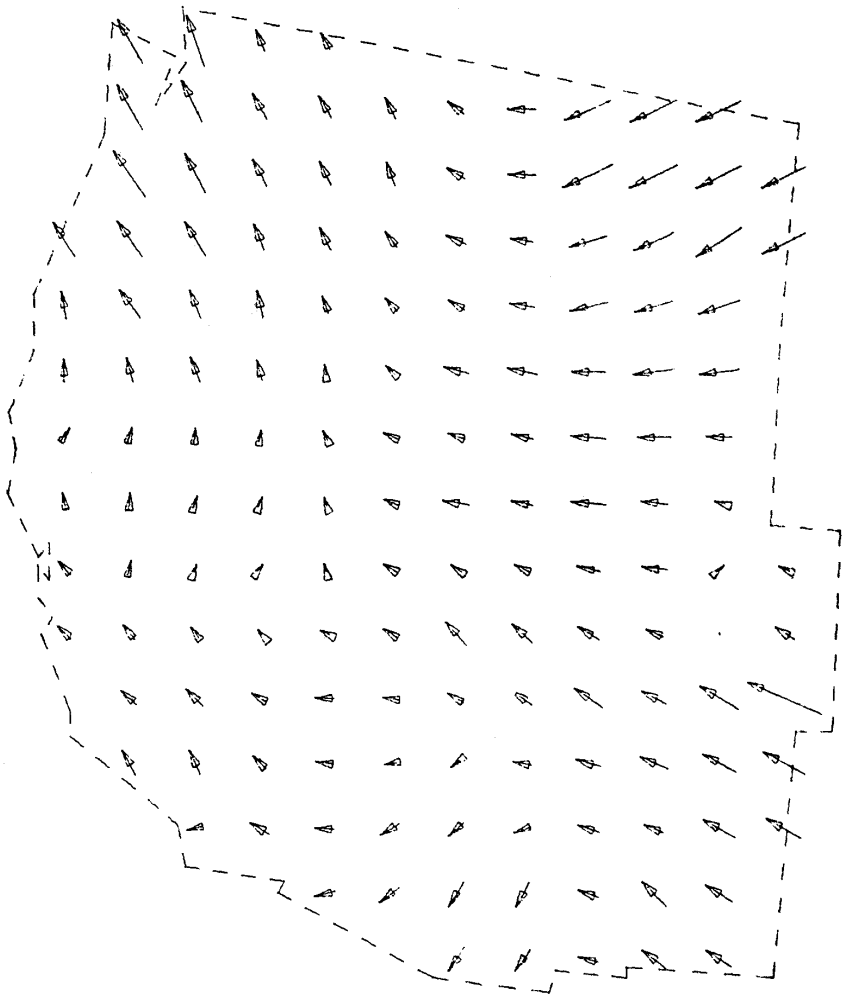
Comparison of net migration patterns at an interval of thirty years.

Migration in the Western United States by State Economic Areas

Left: 1935-1940. Right: 1965-1970.

As derived the model is static. Combing several dates is needed to make it dynamic.





These continuous migration maps seem to make good sense.

Is it surprising that they resemble maps of wind or ocean currents given that we speak of migration flows, eddies, and backwaters, and use many such hydrodynamic terms when discussing migration and movement phenomena?

The foregoing maps have captured some of this effect in a realistic manner

Clearly one advantage of the continuous potential model is in the clarity that it provides of the overall pattern and domains.

The model is also useful for showing resolution.

As an example, the vector representation provides a clear view of the consequences of data aggregation.

This is seen in migration vector fields at several levels of resolution in Switzerland.

This country comprises 41,293 sq. km.

Measuring average resolution as the sq. root (Area / Units).

3.6 km resolution. 3090 Gemeinde or 9,359,610 units.

14.7 km resolution. 184 Bezirke or 33,672 units.

39.2 km resolution. 26 Kantone or 650 units.

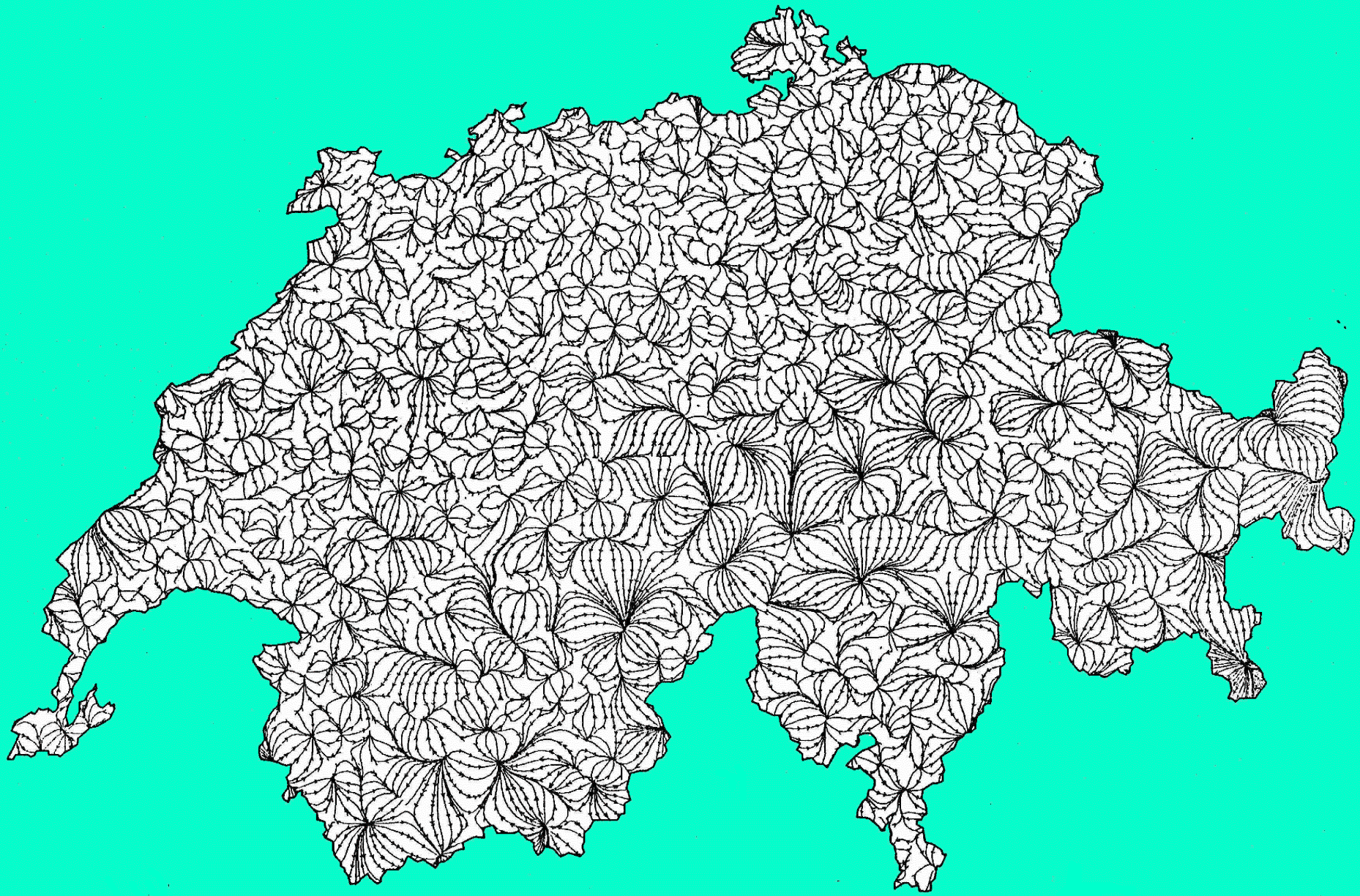
Maps by Guido Dorigo, University of Zürich,
based on a program by Waldo Tobler

Three levels of Swiss administrative units for three details of migration resolution.

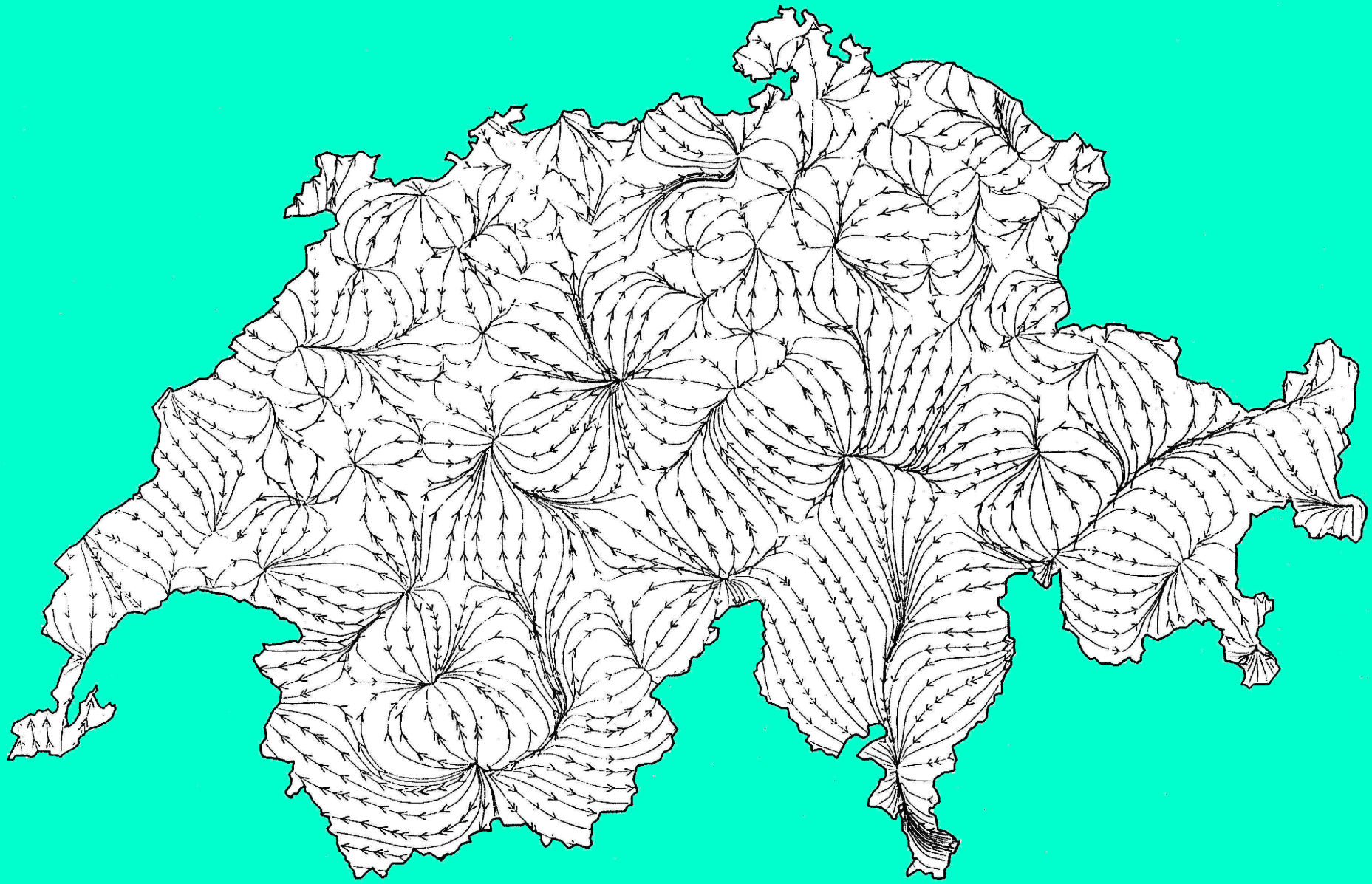
Communities	Districts	Cantons
3090 units, 3.6 km resolution	184 units, 14.7 km resolution	29 units, 39.2 km resolution

Notice that the resolution is not uniform throughout the country.
This is typical and represents historical, economic, and physical considerations.
The resolution variance is important as well as the average.

Migration “Turbulence” in the Alps. 3090 units - 3.6 km resolution

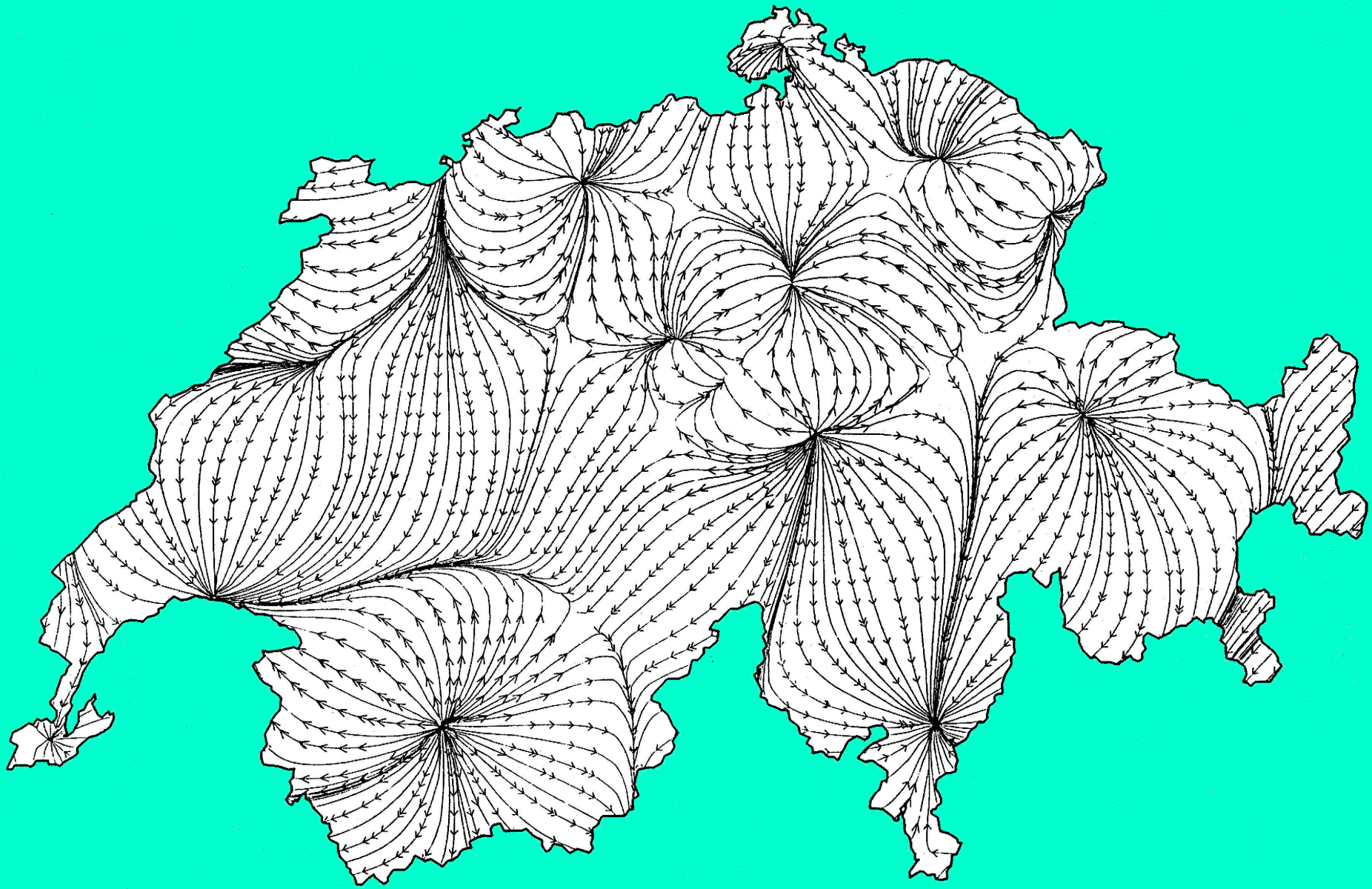


Less of the Fine Detail. 184 units - 14.7 km resolution



The Broad Pattern Only 26 units - 39.2 km resolution

Changing the resolution has the effect of a spatial filter.



The effect of aggregating the data.

As can be seen in the preceding three views it performs like a low pass filter, removing the high frequency components.

And is a form of map generalizeration.

And decreases the resolution.

On Spatial Filtering see: J. Holloway, 1958, “Smoothing and filtering of time series and space fields” Advances in Geophysics, 4: 351-389.

To Conclude:

What I have presented are a few ways of

describing, analyzing, and presenting,

the migration of people

but not

explaining, justifying, evaluating consequences,

nor attempts at forecasting.

Thank you for your attention.

Questions?

Ernest George Ravenstein

Born 30 December 1834, Frankfurt, Germany.
Died 13 March 1913, at age 79, Hofheim, Germany.
1852 Traveled to London to work with Petermann.
Worked at the Royal Geographical Society in London.
Received the first Gold Medal of that society.
Noted for cartographic work on maps of Africa.
President, Geographical Section of the British Association.
Published a facsimile of Martin Beheim's 1492 globe.
Circa 1885 he wrote three famous papers on Migration.

Ten Migration Laws by Ravenstein

(1) “... even in the case of 'counties of dispersion', which have a population to spare for other counties, there takes place an inflow of migrants across that border which lies furthest away from the great centers of absorption”. (1885:191)

(2) “The more distance from the fountainhead which feeds them, the less swiftly do these currents flow”. (1885:191)

(3) [We have] “proved that the great body of our migrants only proceed a short distance”. (1885:198)

(4) “In forming an estimate of displacements we must take into account the number of natives of each county which furnishes the migrants, as also the population of the ... districts which absorb them”. (1885:198)

(5) “Migrants enumerated in a ... center of absorption will ... grow less with the distance proportionally”. (1885:199)

(6) “The process of dispersion is the inverse of that of absorption, and exhibits similar features”. (1885:199)

(7) “Each main current of migration produces a compensating counter current”. (1885:199)

(8) “Counties having an extended boundary in proportion to their area, naturally offer greater facilities for an inflow ... than others with a restricted boundary”. (1885: 175)

(9) [Migration streams] “sweep along with them many of the natives of the counties through which they pass [and] deposit, in their progress, many of the migrants, which have joined them at their origin”. (1885:191)

(10) “Migratory currents flow along certain well defined geographical channels”. (1889:284)

A few references on the history of social graphics:

H. Funkhouser, 1937, "Historical development of the graphical representation of statistical data", Osiris, 3:269-404.

M. Friendly, D. Denis, ~2008, Milestones in the history of thematic cartography, statistical graphics, and data visualization. http://datavis.ca/milestone/

T. Hankins, 1999, "Blood, Dirt, and Nomograms", Isis, 90:50-80.

G. Palsky, 1996, "Des Chiffres et les Cartes", Comite des Traveaux Historiques et Scientifiques, Paris.