The Prehistory of Dynamic & Interactive Graphics: Visualizing Time and Motion

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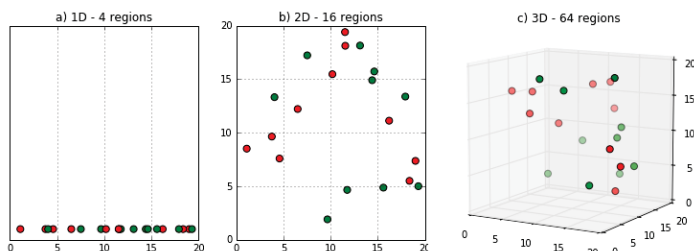friendly@yorku.ca   http://datavis.ca

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Outline

- Curses & blessings of dimensionality
  - Space: 1D → 2D → nD
  - Going higher: Maps, Time, Animation
- Visualizing time & motion
  - Muybridge: The horse in motion
  - E.-J. Marey: Chronophotography
  - Falling cats
- Early statistical animations
  - RANDU
  - PRIM-9

The curse of dimensionality

- We are often taught to fear increasing dimensionality of data and graphics
  - *...when the dimensionality increases, the volume of the space increases so fast that the available data become sparse.*
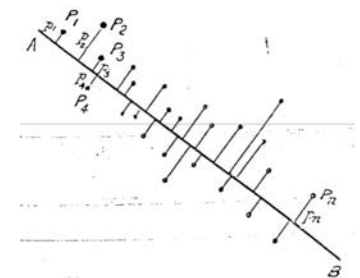

nD:
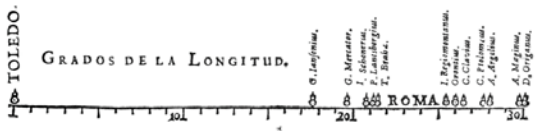4^n regions

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The blessings of dimensionality

- Yet, much of the progress in the history of statistics and data visualization can be thought of as an expansion from
  - 1D   → 2D   → nD
  - univariate → bivariate → multivariate problems
- A key insight in statistics was that once you had solved a 3D problem, the nD case was not far behind
  - Galton (1886) bivariate correlation ellipse → Pearson (1901) plane of closest fit → PCA (Hotelling, 1936)

But in data visualization, graphical capabilities stopped at 3D!
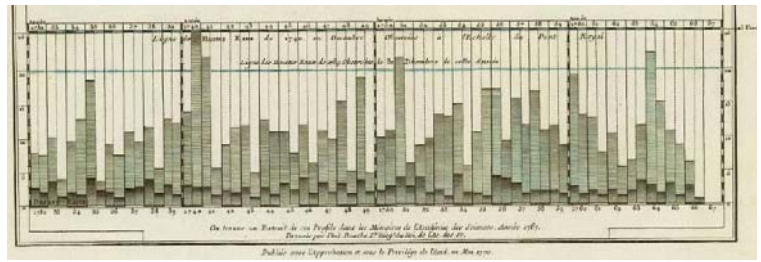
Static graphs: Spatial dimensions
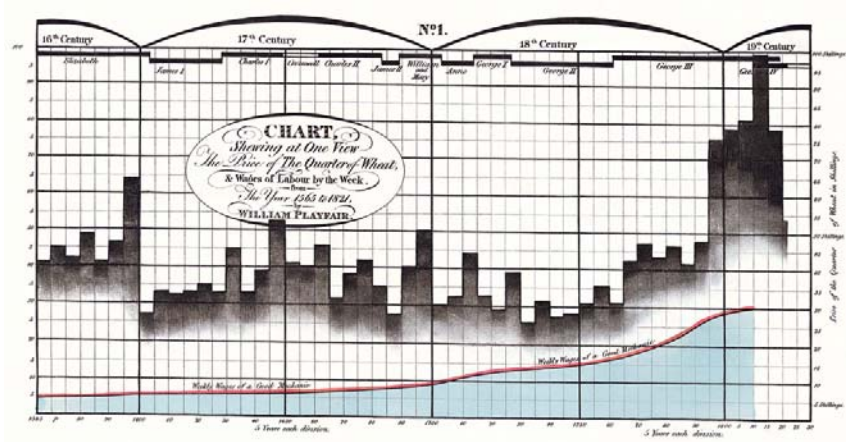
1D graphs

1644: First visual representation of *statistical data* – M. F. van Langren

1770: Bar chart of high and low tide levels of the Seine – Philippe Buache, (pre-dates Playfair!)
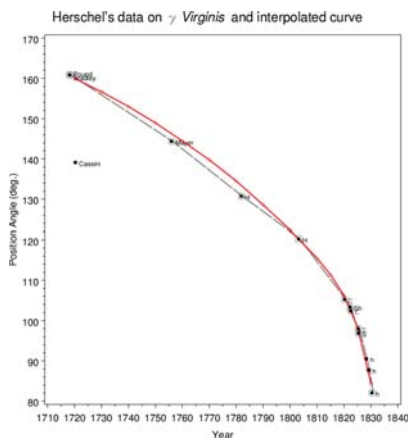

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2D plots: Time as an axis

1821: William Playfair, multivariate time series showing data for 1565--1820.
(a) price of wheat (histogram bars)
(b) weekly wages of a "good mechanic" (line graph)
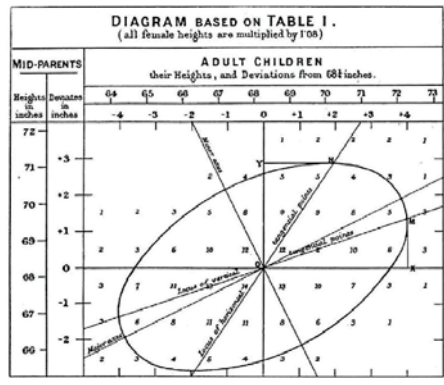(c) reigns of ruling monarchs (segments)

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2D plots: Y vs. X

1833: JWF Herschel, the first scatterplot of empirical data
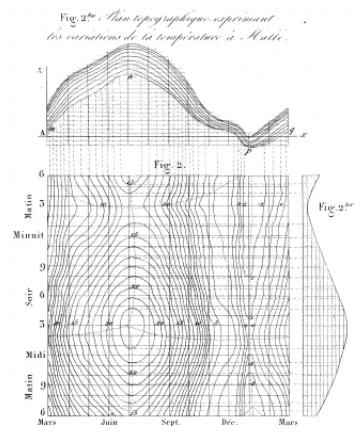
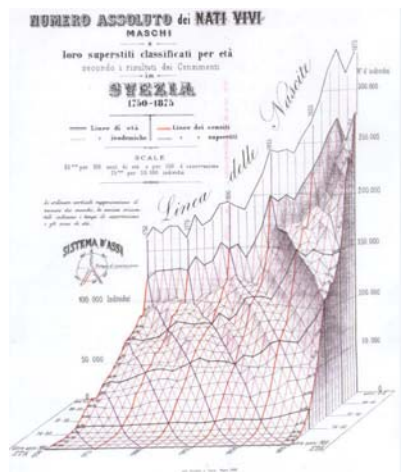**1866**: Francis Galton, correlation diagram explaining regression

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3D graphs: Escaping flatland

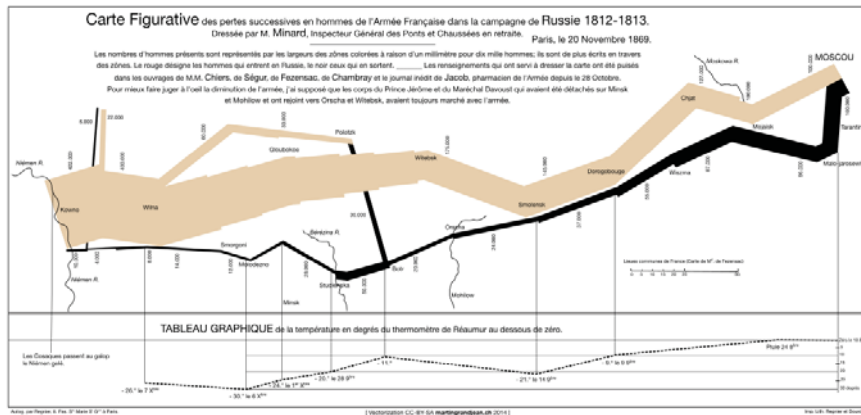**1843: Contour** map of a 3D table- Leon Lallanne Temperature ~ f(Hour, Month)

1879: 3D population pyramid - Luigi Perozzo Population ~ f(Year, Age)

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How to move to higher dimensions?

- Add 1D, 2D, 3D representations to a map

Carte Figurative des pertes successives en hommes de l'Armée Française dans la campagne de Russie 1812-1813.

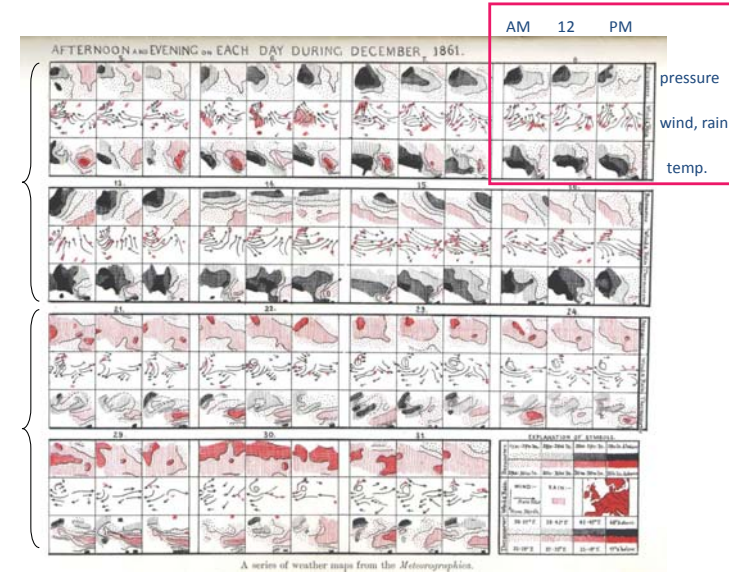| Data dimensions:	Latitude	Direction	Time
	Longitude	Size of army	Temperature

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Higher dimensions: changes over time

1863: Francis Galton's depiction of weather patterns over Europe for the month of Dec., 1861

4 variables summarized in each sub-panel

Graphic: 3x3x31 grid, mapping {pressure, wind/rain, temperature} x {AM, 12, PM} x day {1:31}
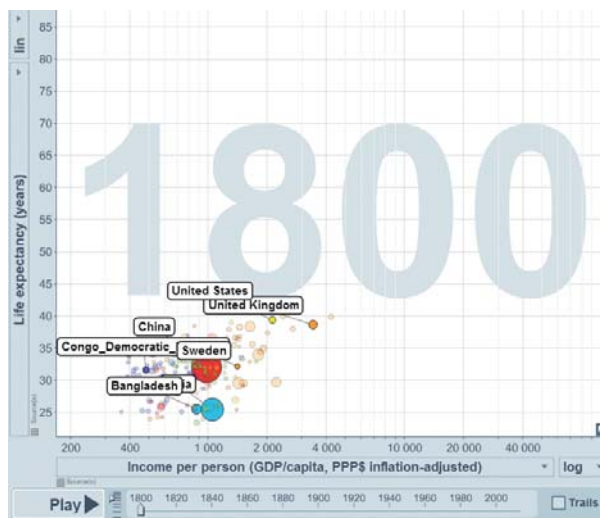
(try this with your software!)

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Animation & Interactivity

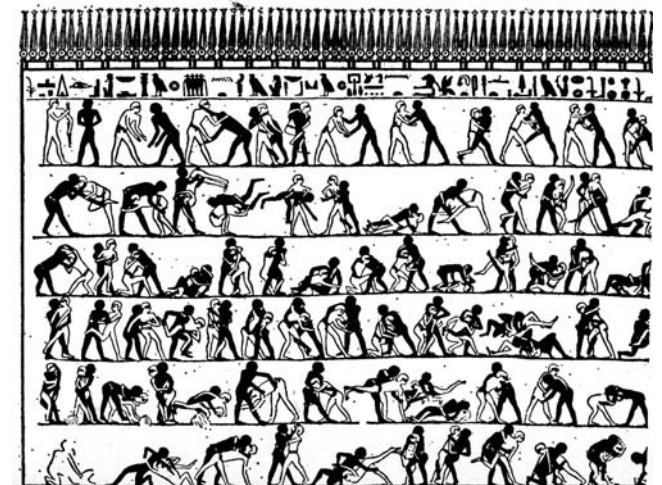**2006**: Hans Rosling, Gapminder moving bubble chart

Liberating the X axis from time opened new vistas for data exploration

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Early prehistory: Graphic stories

Early Egyptian animated graphic
Wrestling scene on east wall, tomb of Baqt at Beni Hasan (ca. 2000 BCE).

Who knew there were so many positions?

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Laws of Motion: Visualizing time

- Origins of the cinema, computer animation & dynamic statistical graphics can **all** be traced to: scientific questions about human & animal motion

1517: Leonardo da Vinci drew figure studies of cats, horses & dragons in motion, but these were merely anatomical & static

Leonardo da Vinci, *Horses, St George and the Dragon, and a lion*, c. 1517

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The horse in motion

- The first steps evolved in the late 1800s from perplexing questions of locomotion of the horse
  - Do feet move differently in a walk, trot, cantor & gallop?
  - Is there any moment when all 4 feet are simultaneously off the ground? ("Unsupported transit")
- Lots of observationally-based speculation, but no means to acquire sufficient "data" (sound, footprints not good enough)
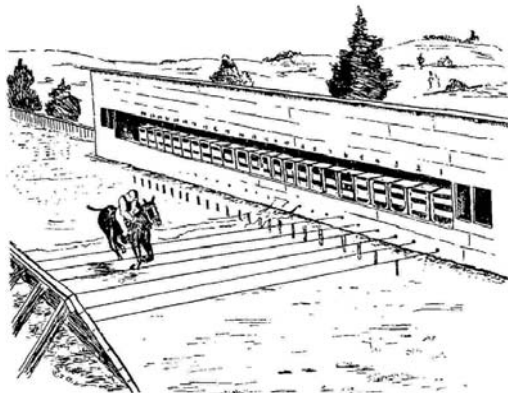
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Leland Stanford & Edweard Muybridge

- Leland Stanford (railway baron, Gov. of Calif.) hires photographer Edweard Muybridge

Muybridge devises a system of multiple cameras arranged in a line, with shutters triggered by strings across the path
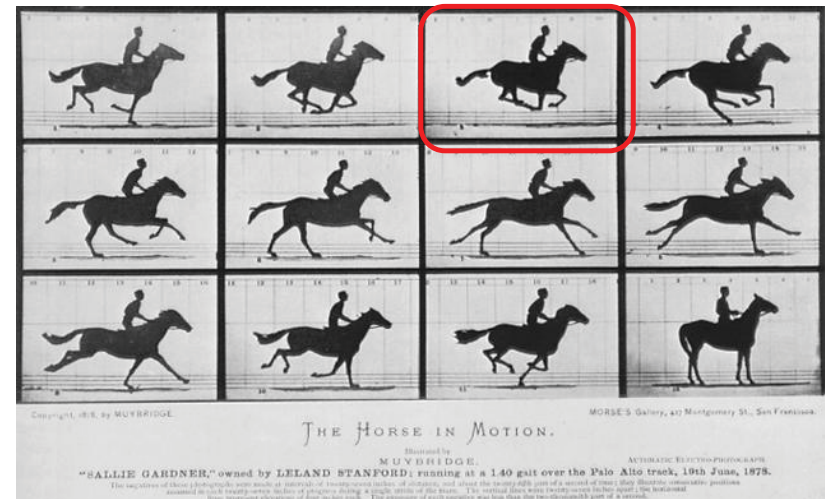
Motion could now be recorded & analyzed

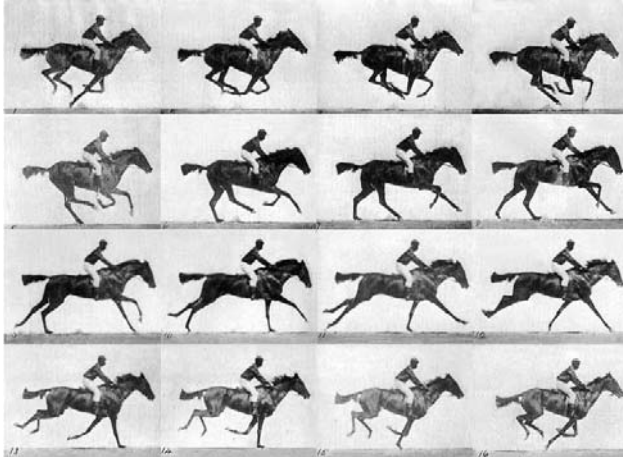
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The Answer: Sallie Gardner

1878: 12 frames recorded of the horse, Sallie Gardner, answers the question -- and also reveals the sequence of thrust of fore- and back-legs

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Implicit vs. explicit animation

A later series of another horse (Annie G.) used better cameras, allowing one to see the horse's muscles as its legs pushed and pulled.

Implicit animation: Time shown as small multiples

Implicit vs. explicit animation

The same images, superposed and recorded as an animated gif

How the horse gallops is now perfectly clear.

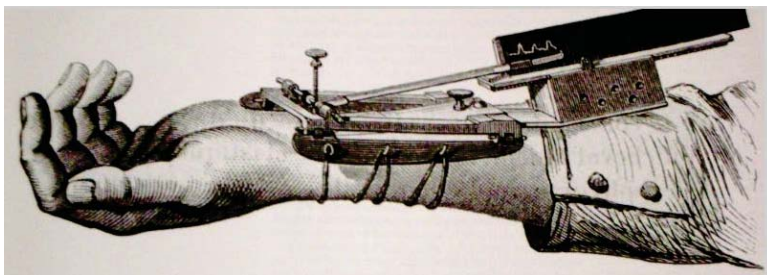But that can't be seen as easily in the small multiples display

Muybridge (1887), *Human and Animal Locomotion*, plate 626. Youtube video: https://www.youtube.com/watch?v=pzrT1BAnQdE

E.-J. Marey: A science of visualizing motion

- Physiology: How to make internal physiological processes subject to visual analysis?
  - Invented many graphic recording devices (heart rate, blood pressure, muscle contraction, etc.)
  - "Every kind of observation can be expressed by graphs"

Marey's sphygmograph, recording a visual trace of arterial blood pressure

E.-J. Marey: La Méthode Graphique

- How to make human and animal motion subject to precise scientific study?
- e.g., aerial locomotion of flying insects & birds
  - What is the frequency of wings of different species?
  - What are the mechanisms of wings to produce lift and forward motion?

A harness, designed to register the trajectory, force and speed of a bird's wing in flight
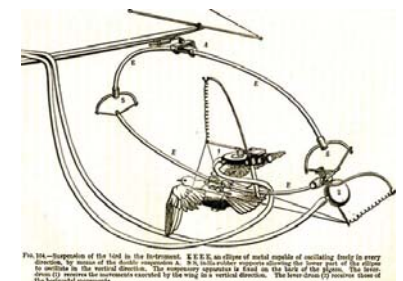
Marey (1870) *Animal Mechanism*

Chronophotography

- Marey wasn't satisfied:
  - Pen-recorded traces extended graphic scope, but only captured parts of a dynamic phenomenon
  - Muybridge's sequential photos lacked the capability to study simultaneous changes in complex motion
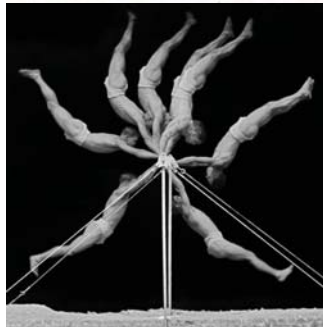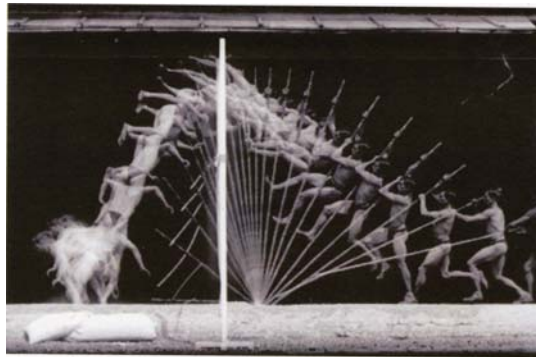

The photographic gun, allowing recording of 12 frames/sec. at intervals of 1/720 of a second

Chronophotography

Visual analysis of the start of a sprint

The runner takes about ½ second (7 frames) to make it to an upright position
Successive frames alternate between power push from the hind leg to landing on the opposite leg

Rather than separate frames, this technique allowed one to see motion continuously in a single static image.
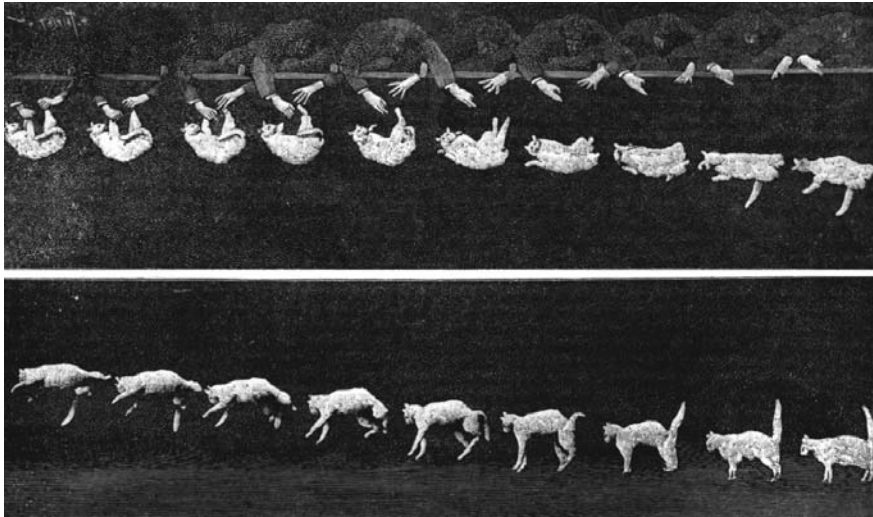

Source: https://lightsmellsloud.wordpress.com/tag/etienne-jules-marey/

These techniques provided a new understanding of human and animal motion.

Marey's assistant, Georges Demenÿ, opened a laboratory for the scientific photography of sport at l'École de Jonville in Paris.

Falling cats: The first cat video

- The next popular problem to stir interest in dynamic graphics was: "Why do cats almost always land on their feet?"
- Mathematical physicist James Clerk Maxwell at Cambridge attempted to solve the problem experimentally:
  - What is the minimum height for a cat to right itself?
  - The defenestration of cats was soon banned at Trinity College.
- The exact mechanism was unknown.
  - To physicists: the cat had to obey laws of physics: conservation of angular momentum
  - To Marey, just another scientific problem to be solved with the photographic gun

By 1894, Marey had an answer: the inertia of the cat's own mass was used in separate actions of it's front and back halves
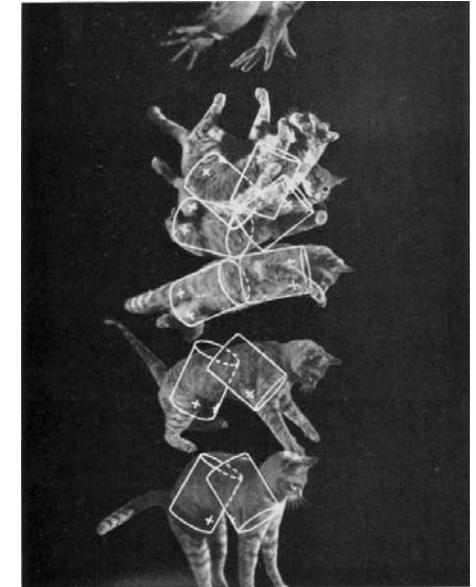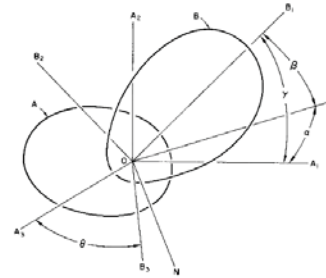

Note that the cat is nearly upright by the end of the first row of frames

A complete solution in physics was not achieved until 1969

Kane & Scher: mathematical model for a falling cat as two connected cylinders

9 parameters, connected by many equations

Visual proof: overlay model prediction on photos of a falling cat.

Computer graphics animation

- Still before dynamic statistical graphics, the next innovations stemmed from computer science, beginning ~ 1960s
  - 3D rendering, photo-realistic lighting models
  - wire-frame models for real objects
  - texture-mapping: add skin, hair, etc.
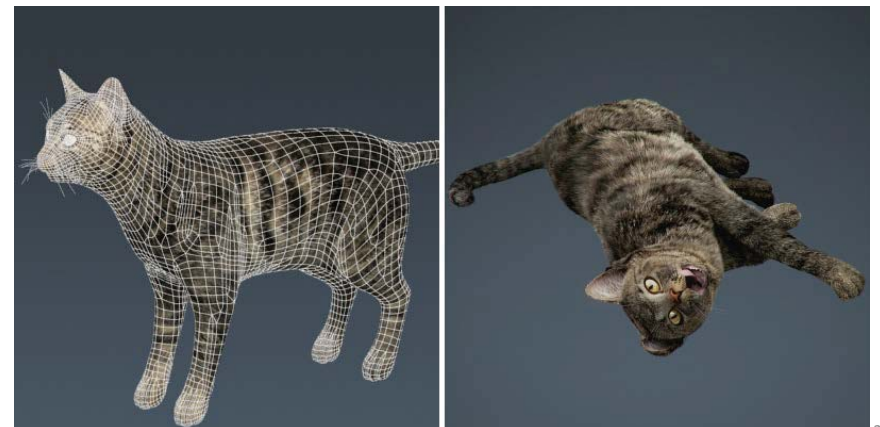 - calculations for motion: rotate, zoom, deform

Parametric 3D apple
-- 3 equations for (x,y,z) in spherical coordinates

Wire-frame model of a cat

The cat is "rigged" with a digital skeleton which allows the model to be arbitrarily manipulated in 3D space.
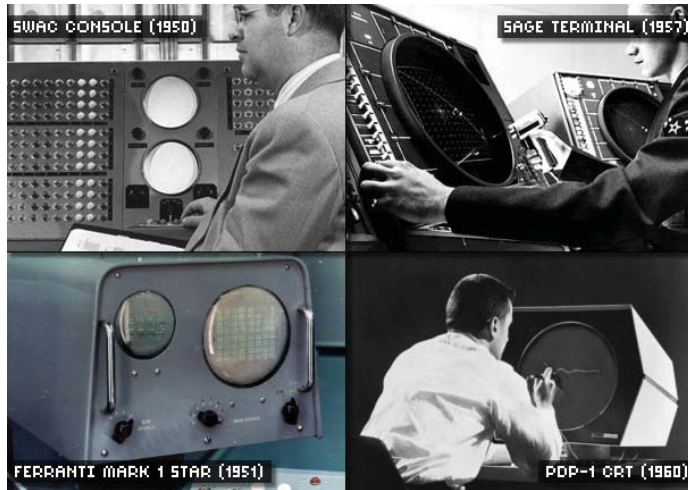- Digital "fur" or other surface texture is easily applied.
- CGI methods developed ~ 2000

Digital display devices

The biggest limitation in the early development of dynamic and interactive graphics was in graphics display devices.

Only B/W, but for the first time, dynamic displays became possible.

By the late 1950s, pen-like input devices allowed rudimentary direct interaction

The first statistical animation

1962: Joseph Kruskal and others at Bell Labs produced a "movie" of the iterative algorithm for multidimensional scaling (MDS): finding a configuration of points in space to match input distances. (20 sec., 60 frames, recorded on film from a CRT)
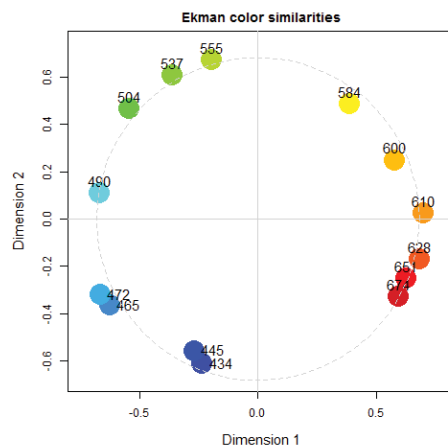
initial configuration (Frame 1)

Eppur si muove
(And yet it moves)
-- Galileo, 1633

final solution (Frame 60)

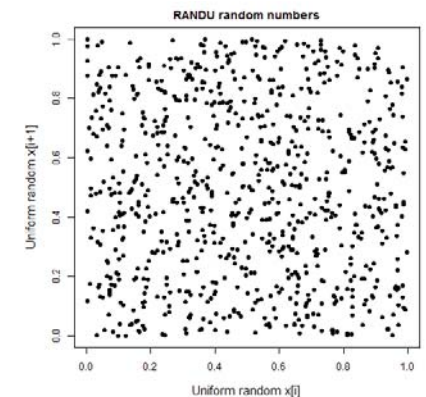Demonstration that MDS finds a correct solution for perceptual data on color similarity

Ekman color similarities

A lot more of the early history of dynamic graphics can be seen in the **Video Library,** http://stat-graphics.org/movies/

Visualizing the flaw in RANDU

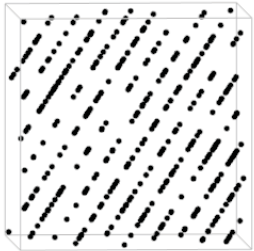- Monte Carlo simulation developed rapidly in the 1950s--60s as means to solve intractable problems statistically.
- A random-number generator called RANDU from IBM was fast, easy to use, and became widely-used.

Simple 2D plots and lots of statistical calculations showed that this seemed to produce numbers with all appropriate properties of independent, uniformly distributed random numbers.

RANDU random numbers

Visualizing the flaw in RANDU

- 1968: George Marsaglia discovered analytically a dependency in successive (x,y,z) triples
  - From one perspective, all points line up on 15 planes

PRIM9: First travels in high-D space

- The flaw in RANDU was visually opaque because there were no computer systems capable of display in > 2D
- This changed in 1973 with PRIM-9, developed at Stanford Linear Accelerator (Tukey, Friedman & Fisherkeller)
  - PRIM-9: *Picturing, Rotating, Isolation and Masking in up to 9 dimensions*.
  - Used a $400,000 graphics display
  - Powered by an IBM mainframe, $500/hr.
  - Many ideas incubated here (selection, brushing, grand tours, etc.)

Tukey explains how PRIM-9 is used to explore 9-dimensional particle physics:

- *Together, choice of 2D view and freedom to rotate give more than 2D understanding*
- *Dynamic effects of rotation allow us to see 3D structure unavailable in static views*
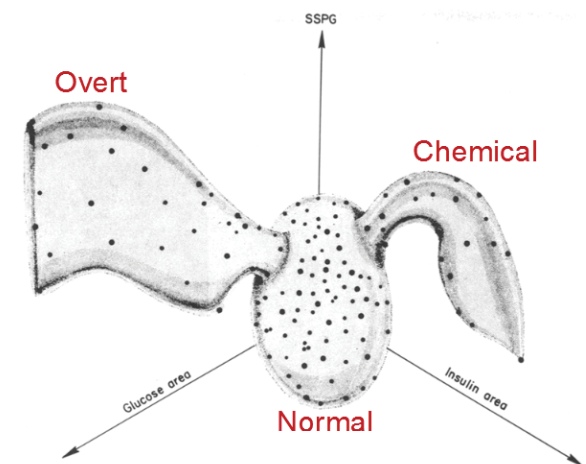
Diabetes classification: PRIM-9 discovery

1978: Reaven & Miller used PRIM-9 to visualize data on glucose response and insulin

PRIM-9 visualization confirmed a theory of two types of Type 2 diabetics:
- Chemical diabetics
- Overt diabetics

An effect seen vaguely in 2D became an OMG! moment with dynamic 3D graphics
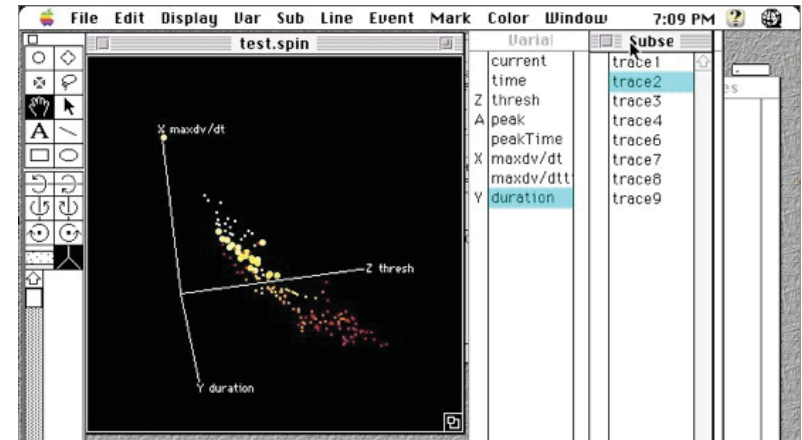
Next steps: Hardware

- Dynamic 3D graphics was painfully slow for larger data sets.
- Specialized 3D graphics hardware:
  - Early 1970s: Simple LSI graphics chips for video games
  - 70s—80s: Graphics co-processors (GPUs) with increasing graphics capabilities
  - 80s—90s: Silicon Graphics develops high-performance 3D graphics workstations
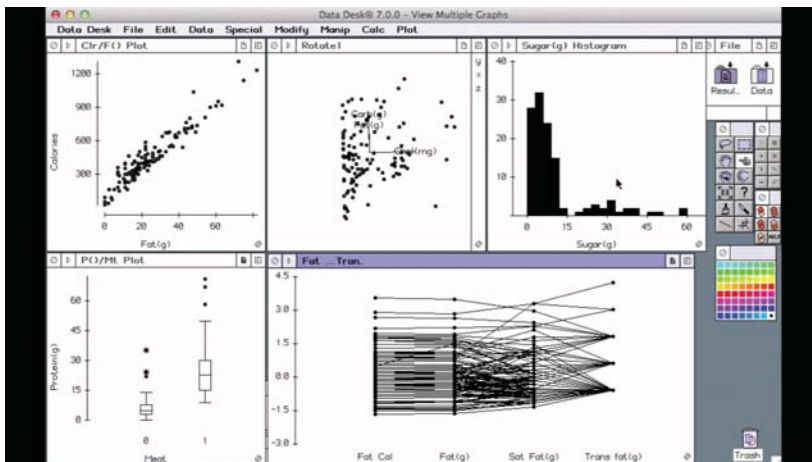

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Next steps: Software

- MacSpin – Andrew & David Donoho (1984—85). At ASA meetings 1986, "dynamic graphics became as portable as a 25-lb Macintosh"

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Next steps: Software

- DataDesk – Paul Vellman(1984—85).

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Conclusions

- From the start, advances in data visualization had to contend with the limitations of 2D static displays
- Fundamental ideas and methods we use today for dynamic and interactive graphics were nurtured by scientific problems in other fields
- What could be done for data visualization expanded as limitations of technology were relaxed.
- Advances in software continue to drive new developments

Further information: friendly@yorku.ca   Web: http://datavis.ca

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