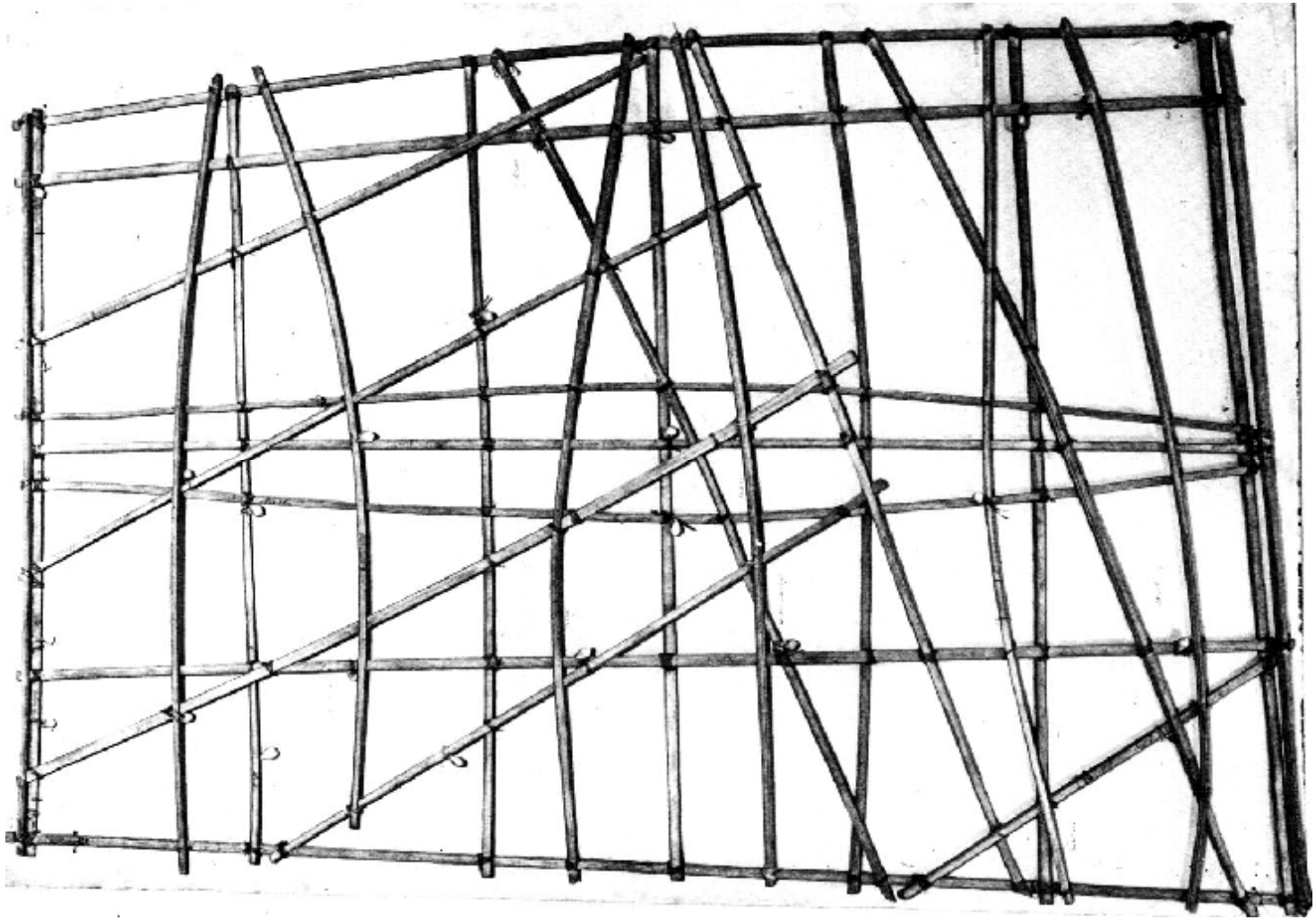
Psychological Perspectives on Visualizing Uncertainty



Barbara Tversky
Stanford University

Two catalogs

- Reasoning under uncertainty
- Perception & cognition of visualizations

First catalog

- Reasoning under uncertainty
  - Confirmation bias
  - Anchoring
  - Framing
  - Conjunction Fallacy

Confirmation Bias

- Look for confirming, not disconfirming evidence
- 2 4 6, what's next?
- Dog, what's in class?

Wason & Johnson-Laird

Confirmation Bias

- Look for confirming, not disconfirming evidence
- Community discussion; contrarians
- How to correct bias in individuals?

Anchoring

- 9 x 8 x7 x 6 x 5 x 4 x3 x 2 x 1 = ?

- 1 x 2 x 3 x 4 x 5 x 6 x 7 x 8 x 9 =?

K, T & others

Anchoring

- 9 x 8 x7 x 6 x 5 x 4 x3 x 2 x 1 = 4,200

- 1 x 2 x 3 x 4 x 5 x 6 x 7 x 8 x 9 = 500

Answer: 40,000

Anchoring

- Estimates: size of country, GNP, etc.
- Salespeople: show expensive first, etc.

Imagine that the U.S. is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the exact scientific estimates of the consequences of the programs are as follows:

If program A is adopted, 200 people will be saved.

If program B is adopted, there is a 1/3 probability that 600 people will be saved and a 2/3 probability that nobody will be saved.

Which of the two programs would you favor?

Imagine that the U.S. is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the exact scientific estimates of the consequences of the programs are as follows:

If program A is adopted, 200 people will be saved.

72% A

If program B is adopted, there is a 1/3 probability that 600 people will be saved and a 2/3 probability that nobody will be saved.

Which of the two programs would you favor?

Imagine that the U.S. is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the exact scientific estimates of the consequences of the programs are as follows:

If program C is adopted, 400 people will die.

If program D is adopted, there is a one-third probability that nobody will die and a two-thirds probability that 600 people will die.

Which of the two programs would you favor?

Imagine that the U.S. is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the exact scientific estimates of the consequences of the programs are as follows:

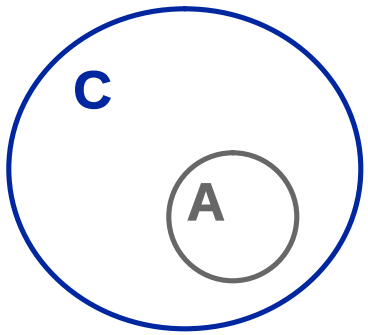
If program C is adopted, 400 people will die.

If program D is adopted, there is a one-third probability that nobody will die and a two-thirds probability that 600 people will die. **72% D**

Which of the two programs would you favor?

Conjunction Rule

$$P(A + B) \leq P(A) \text{ [or } P(B)]$$



Conjunction Fallacy

- Availability
- Representativeness
- Mental Models

Four groups

	produce in 60 sec's	estimate in 4 pgs
_ _ _ _ _ n _	2.9	4.7
_ _ _ _ i n g	6.4	13.4

Availability

- Homicide/suicide
- AIDS/kidney disease

Two groups asked

- What is more *representative* of Hollywood actress:
  - to be divorced 4 or more times
  - to vote Democratic
- What is more *probable* of Hollywood actress:
  - to be divorced 4 or more times
  - to vote Democratic

Two groups asked

- What is more *representative* of Hollywood actress:
  - to be divorced 4 or more times 65%
  - to vote Democratic
- What is more *probable* of Hollywood actress:
  - to be divorced 4 or more times
  - to vote Democratic 83%

Representativeness

- is not extensional
- does not entail counting instances
- not bounded by frequency or class inclusion

Probability and Representativeness

- Under right circumstances, people distinguish them

- Under other circumstances, people use representativeness to judge probability

Bill is 34 years old. He is intelligent, but unimaginative, compulsive, and generally lifeless. In school, he was strong in mathematics but weak in social studies and humanities

- **Bill is a physician who plays poker for a hobby**
- **Bill is an architect**
- **Bill is an accountant (A)**
- **Bill plays jazz for a hobby (J)**
- **Bill surfs for a hobby**
- **Bill is a reporter**
- **Bill is an accountant who plays jazz for a hobby (A and J)**
- **Bill climbs mountains for a hobby**

Linda is 31 years old, single, outspoken and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations

- **Linda is active in the feminist movement (F)**
- **Linda is a bank teller (T)**
- **Linda is a bank teller and is active in the feminist movement (T and F)**

BILL

A > A + J > J 87%

LINDA

F > T + F > T 85%

Effects are robust

- Grad students in decision science **fail**
- Only critical items
  - naive **fail**
  - sophisticated **pass**
- Give arguments, valid or invalid
  - naive **fail**
  - sophisticated **pass with valid**
- Experts (physicians) **fail**
- Payoffs **fail**

Massive flood somewhere in North America in which more than 1000 people drown

An earthquake in California causing a flood in which more than 1000 people die

Massive flood somewhere in North America in which more than 1000 people drown **2.2%**

An earthquake in California causing a flood in which more than 1000 people die **3.1%**

Forecasting experts estimated probability

A complete suspension of diplomatic relations between USA and USSR sometime in 1983

A Russian invasion of Poland and a complete suspension of diplomatic relations between USA and USSR sometime in 1983

Forecasting experts estimated probability

A complete suspension of diplomatic relations between USA and USSR sometime in 1983 **.14%**

A Russian invasion of Poland and a complete suspension of diplomatic relations between USA and USSR sometime in 1983 **.47%**

How to reduce error

- make inclusion blatant
- use schooled subjects
- emphasize frequency

Second catalog

- Perception & cognition
  - Grouping
  - Symmetry
  - Common Fate
  - 3 D
  - Meaningful use of space & elements
  - Animation

Which map is correct?

Sign.majority pick incorrect

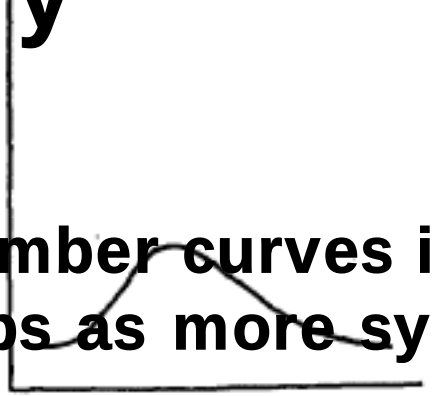
Grouping: USA/Europe, SAmer/Africa aligned in memory

Which map is correct?

Sign.majority pick incorrect

Symmetry

People remember curves in graphs and rivers in maps as more symmetric than they were.



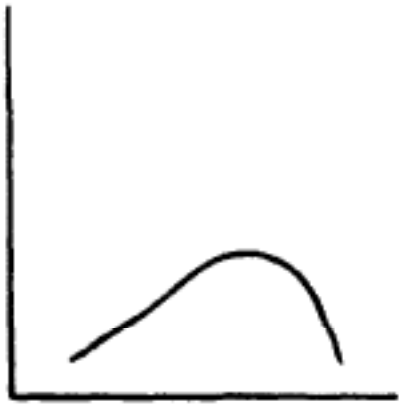
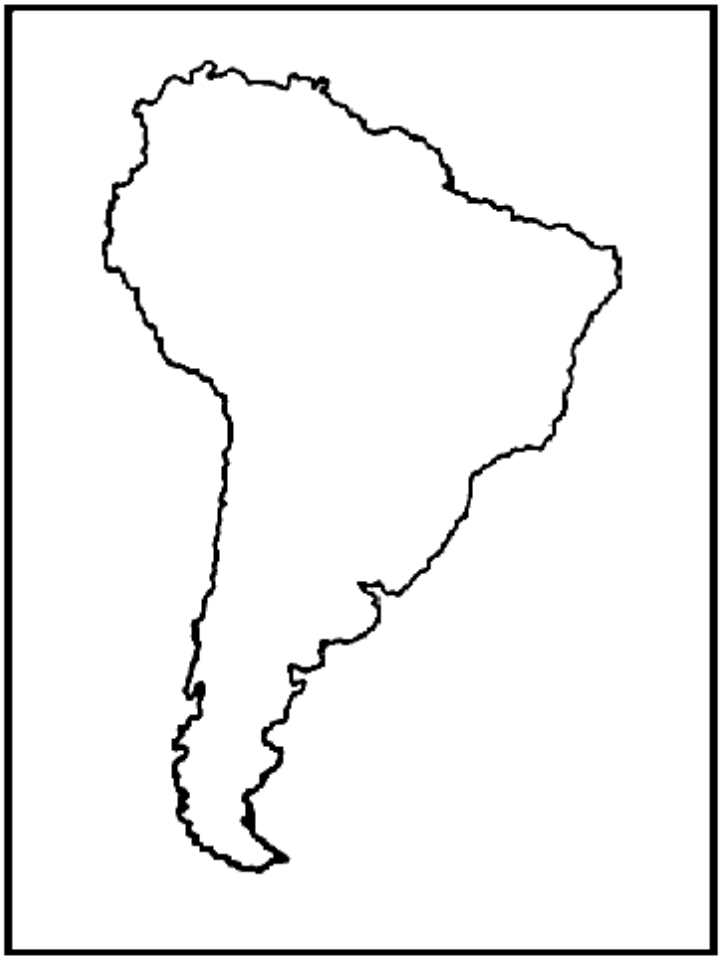
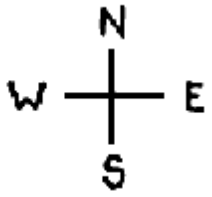
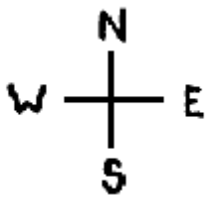


Figure 1. Examples of critical curves in the first symmetry study. (Both shapes appeared skewed both left and right and oriented horizontally and vertically.)







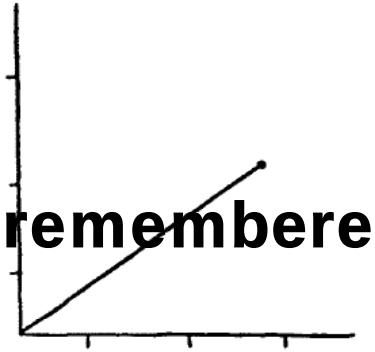
Common fate: South American is uprighted

Common fate & cognition

Line in axes

n if in graph, remembered closer to 45 degrees

nif in map, remembered closer to axes



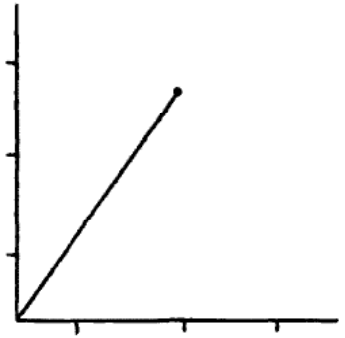
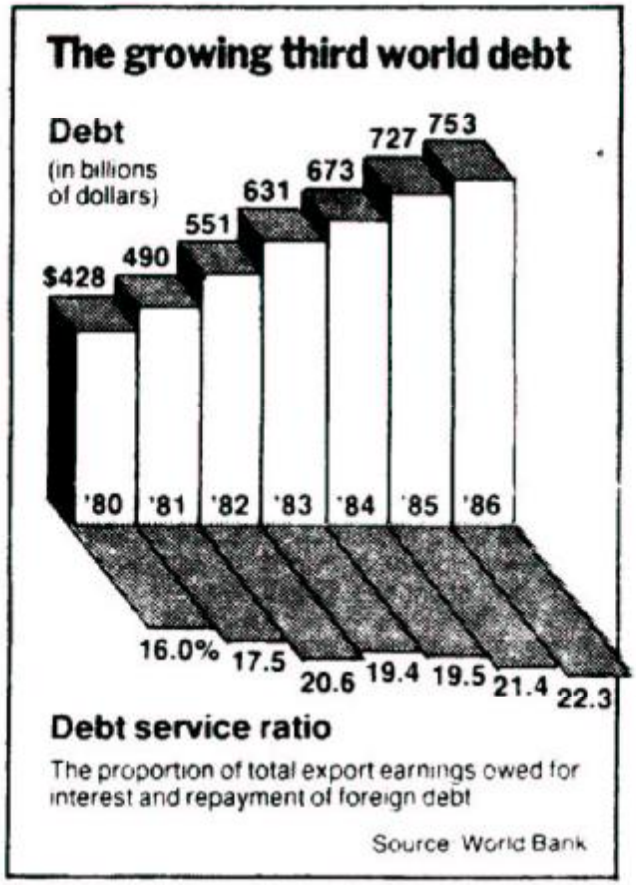


Figure 3. Examples of critical lines in the first slope study. (Angles varied from 20° to 70°.)

3D

- 3D bars read less accurately
- 3D hard to interpret
- 3D unstable

3D Reverses



Kruskal

Graphics consist of

- **Elements**
- **Spatial relations among them**

- **These can convey meaning directly**

Elements

- Iconic
- Metaphoric: Figures of depiction
  - Synecdoche: part for whole
  - Metonymy: associate for whole

	SUMERIAN	EGYPTIAN	HITTITE	CHINESE
MAN				
KING				
DEITY				
OX				
SHEEP				
SKY				
STAR				
SUN				
WATER				
WOOD				
HOUSE				
ROAD				
CITY				
LAND				

Elements

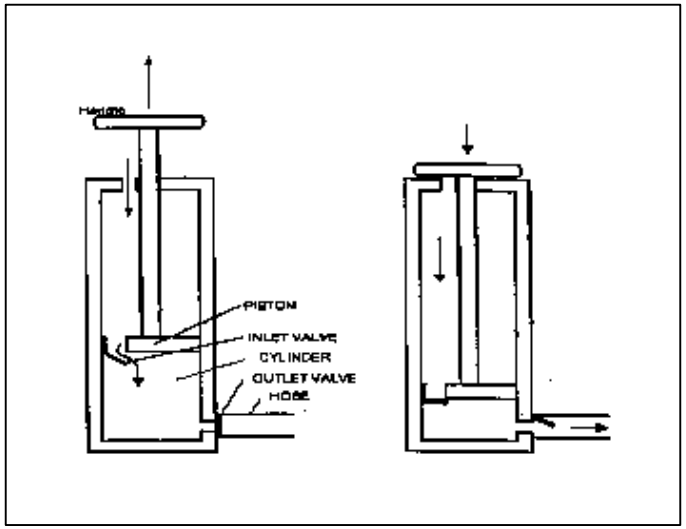
- Iconic
- Metaphoric: Figures of depiction
- Schematic (meaningful abstract forms): lines, curves, crosses, blobs, bars, and arrows

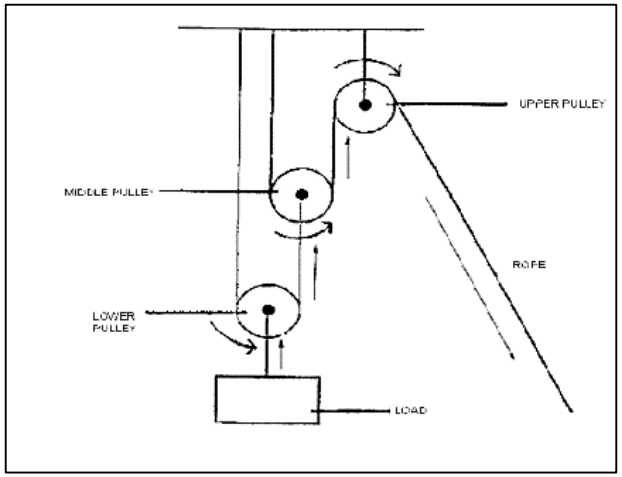
Arrows

- Natural interpretation of directionality
  - Arrow heads
  - River beds
- Many uses, interpretations

Arrows for Mechanical Systems

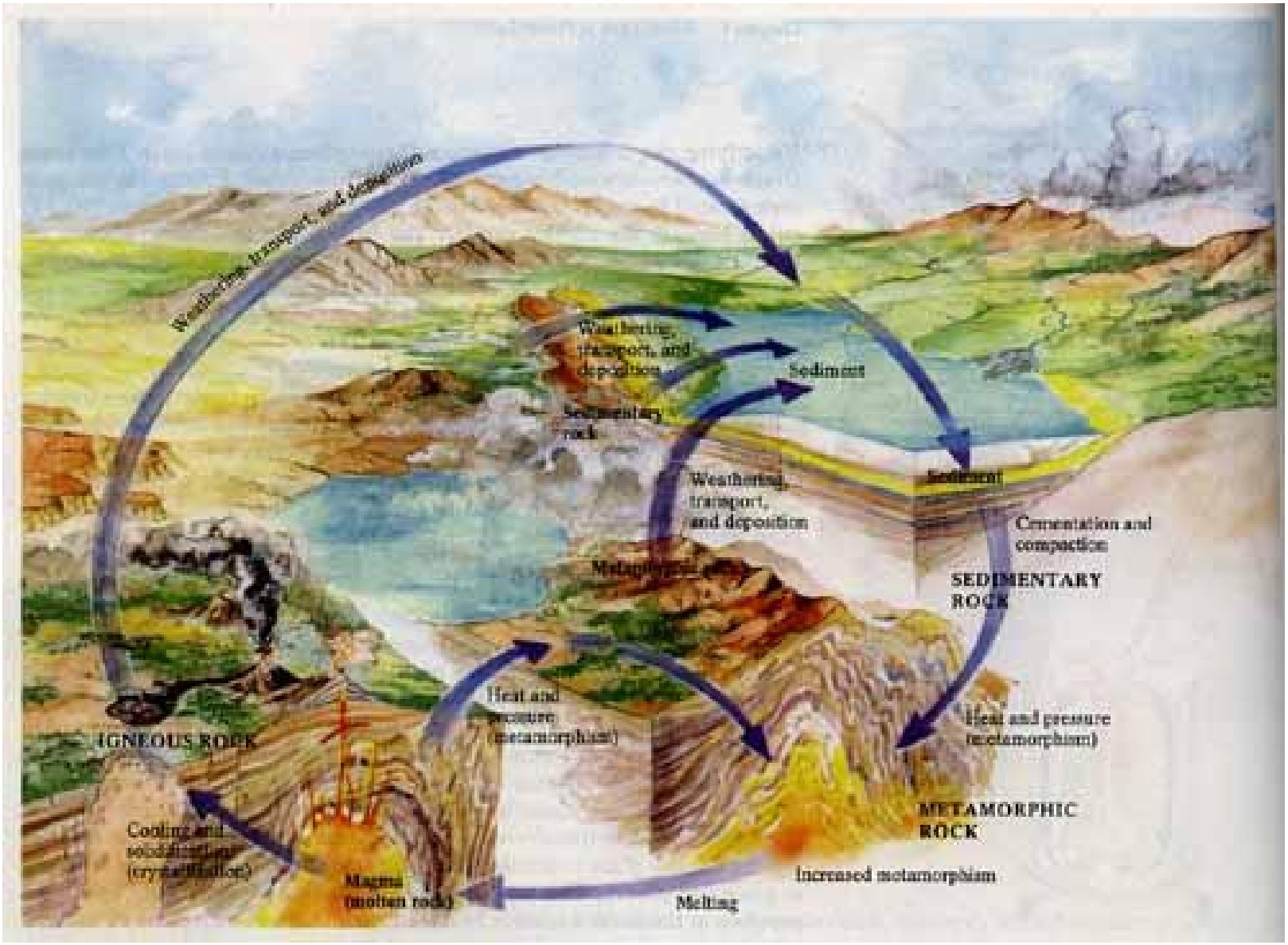
QuickTime™ and a
Planar RGB decompressor
are needed to see this picture.

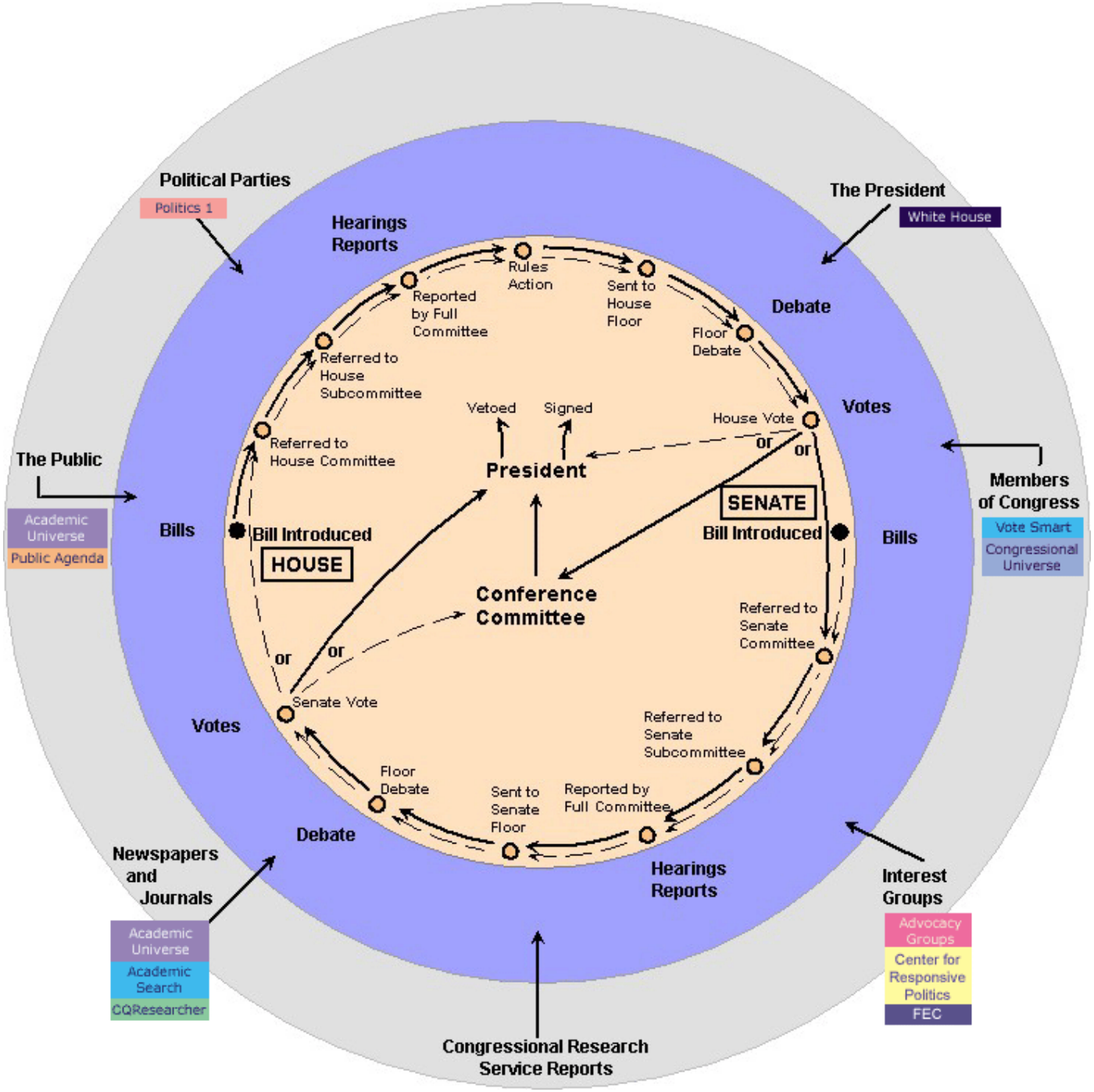




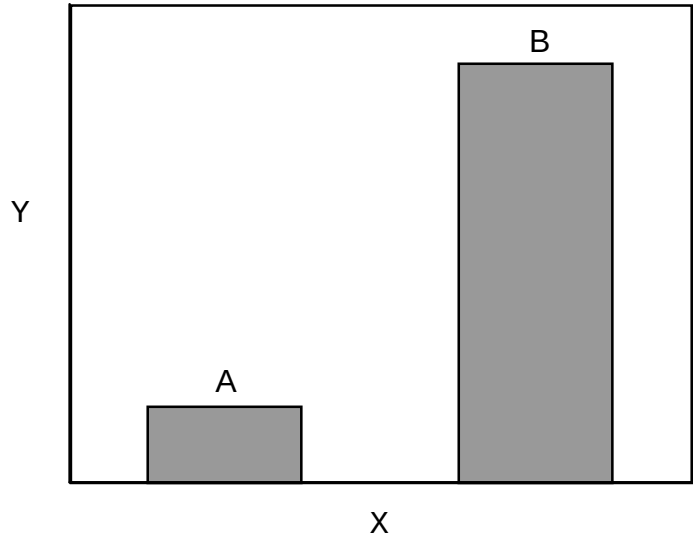
Arrows

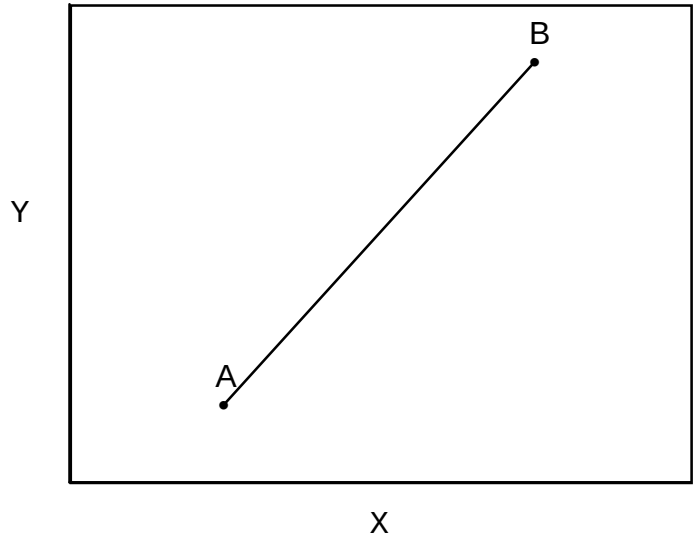
- Asymmetric--> symmetric <--> extent <-->
- Connecting, pointing, labeling
- Temporal: sequence
- Causal
- Movement: direction, manner
- Movement; change over time, increases/decreases
- Forces


Weathering, transport, and deposition
Weathering, transport, and deposition
Sediment
Sedimentary rock
Weathering, transport, and deposition
Sediment
Cementation and compaction
SEDIMENTARY ROCK
Heat and pressure (metamorphism)
Heat and pressure (metamorphism)
IGNEOUS ROCK
METAMORPHIC ROCK
Cooling and solidification (crystallization)
Magma (molten rock)
Increased metamorphism
Melting


Political Parties
Politics 1
Hearings
Reports
The President
White House
Debate
Votes
Members
of Congress
Vote Smart
Congressional
Universe
Bills
The Public
Academic
Universe
Public Agenda
Bills
Votes
Debate
Hearings
Reports
Newspapers
and
Journals
Academic
Universe
Academic
Search
CQResearcher
Interest
Groups
Advocacy
Groups
Center for
Responsive
Politics
FEC
Congressional Research
Service Reports
Rules
Action
Reported
by Full
Committee
Referred to
House
Subcommittee
Referred to
House Committee
Bill Introduced
HOUSE
Vetoed
Signed
President
Conference
Committee
House Vote
or
or
SENATE
Bill Introduced
Sent to
House
Floor
Floor
Debate
Referred to
Senate
Committee
Referred to
Senate
Subcommittee
Reported by
Full Committee
Sent to
Senate
Floor
Floor
Debate
Senate Vote
or
or

Producing Descriptions from Graphs





Please describe in a sentence what is shown in the graph above:

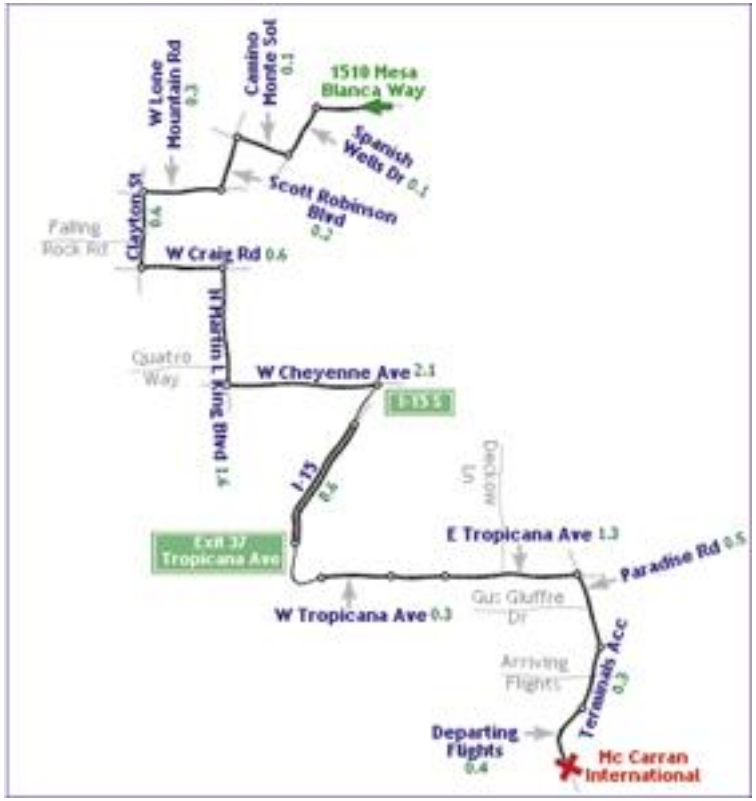
Two classes of description

- Discrete
  - higher—lower
  - greater—less
  - more—fewer
  - stronger—weaker
- Trend
  - rising—falling
  - increasing—decreasing
  - function
  - relationship
  - trend

Graphic “Language”

- Semantics: schematic elements
  - Not iconic
  - Gestalt/geometric meanings
  - Categorical
- Syntax: combine elements by rules

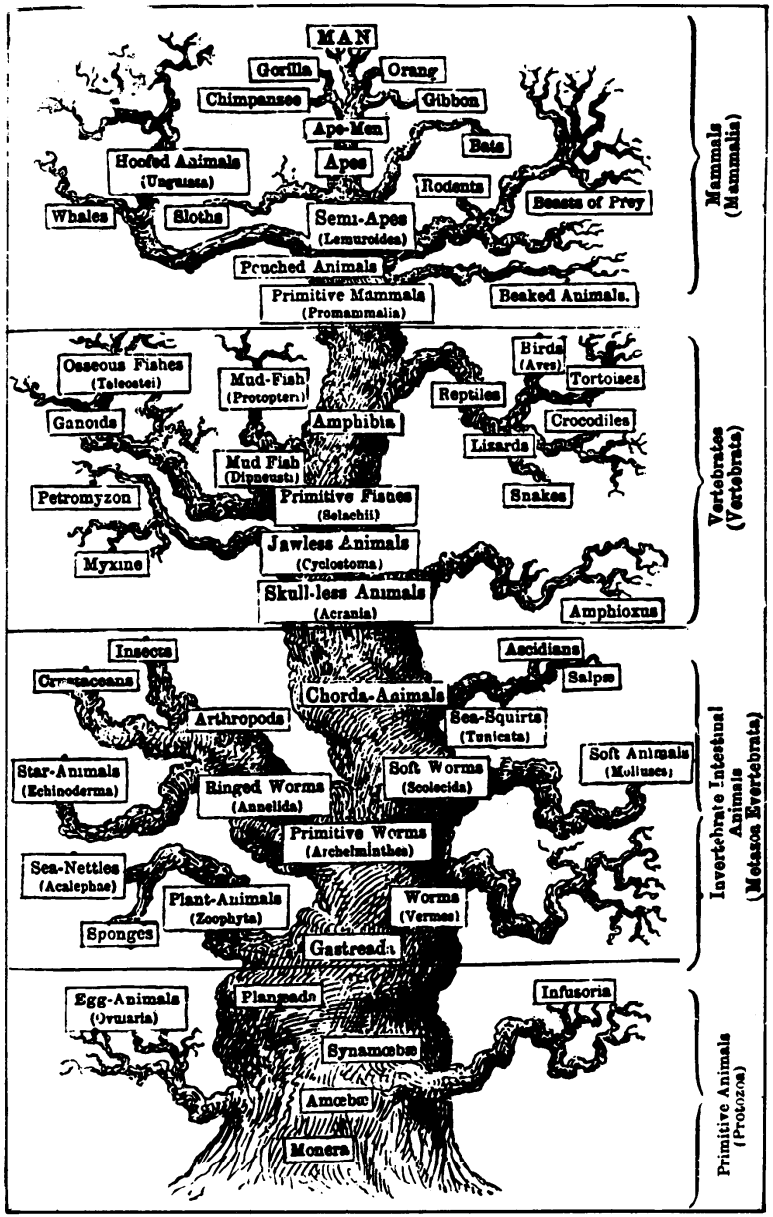
Linedrive map at mapoint.com



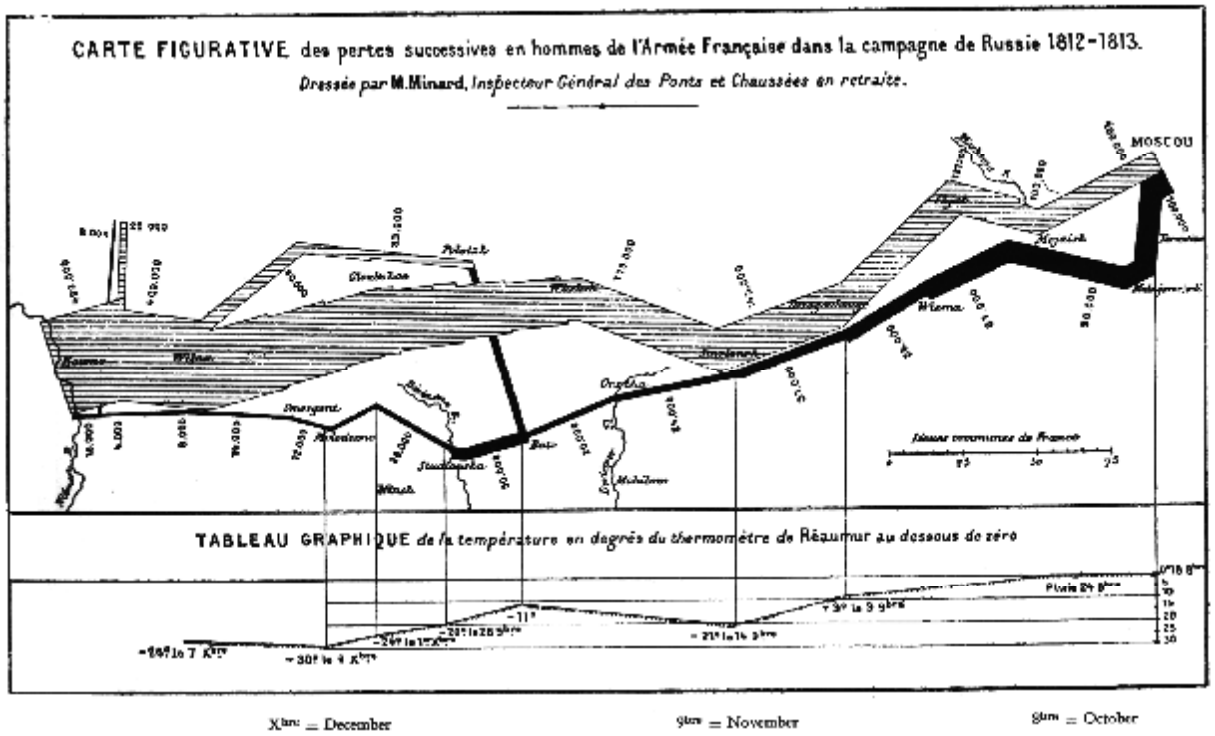
Agrawala & Stolte, 2001

Meaningful use of space

- Proximity in space signifies proximity on abstract dimension
- Directionality
  - Vertical loaded: up is more, better, stronger
  - Horizontal neutral
  - Parallels in language & gesture


MAN
Gorilla
Orang
Chimpansee
Gibbon
Ape-Men
Bats
Apes
Hoofed Animals
(Ungulata)
Rodents
Whales
Sloths
Semi-Apes
(Lemuroides)
Beasts of Prey
Pouched Animals
Primitive Mammals
(Promammalia)
Beaked Animals.
Mammals
(Mammalia)
Osseous Fishes
(Teleostei)
Mud-Fish
(Protopteri)
Birds
(Aves)
Tortoises
Reptiles
Ganoids
Amphibia
Crocodiles
Lizards
Mud Fish
(Dipneusti)
Petromyzon
Primitive Fishes
(Selachii)
Snakes
Jawless Animals
(Cyclostoma)
Myxine
Skull-less Animals
(Acrania)
Amphioxus
Vertebrates
(Vertebrata)
Insects
Ascidians
Crustaceans
Salps
Chorda-Animals
Arthropods
Sea-Squirts
(Tunicata)
Soft Animals
(Molluscs)
Star-Animals
(Echinoderms)
Ringed Worms
(Annelida)
Soft Worms
(Scolecida)
Primitive Worms
(Archelminthes)
Sea-Nettles
(Acalephae)
Plant-Animals
(Zoophyta)
Worms
(Vermes)
Sponges
Gastreada
Invertebrate Intestinal
Animals
(Metazoa Evertebrata)
Egg-Animals
(Ovularia)
Planaeada
Infusoria
Synamoebae
Amoebae
Monera
Primitive Animals
(Protozoa)

Mixing spatial metaphors



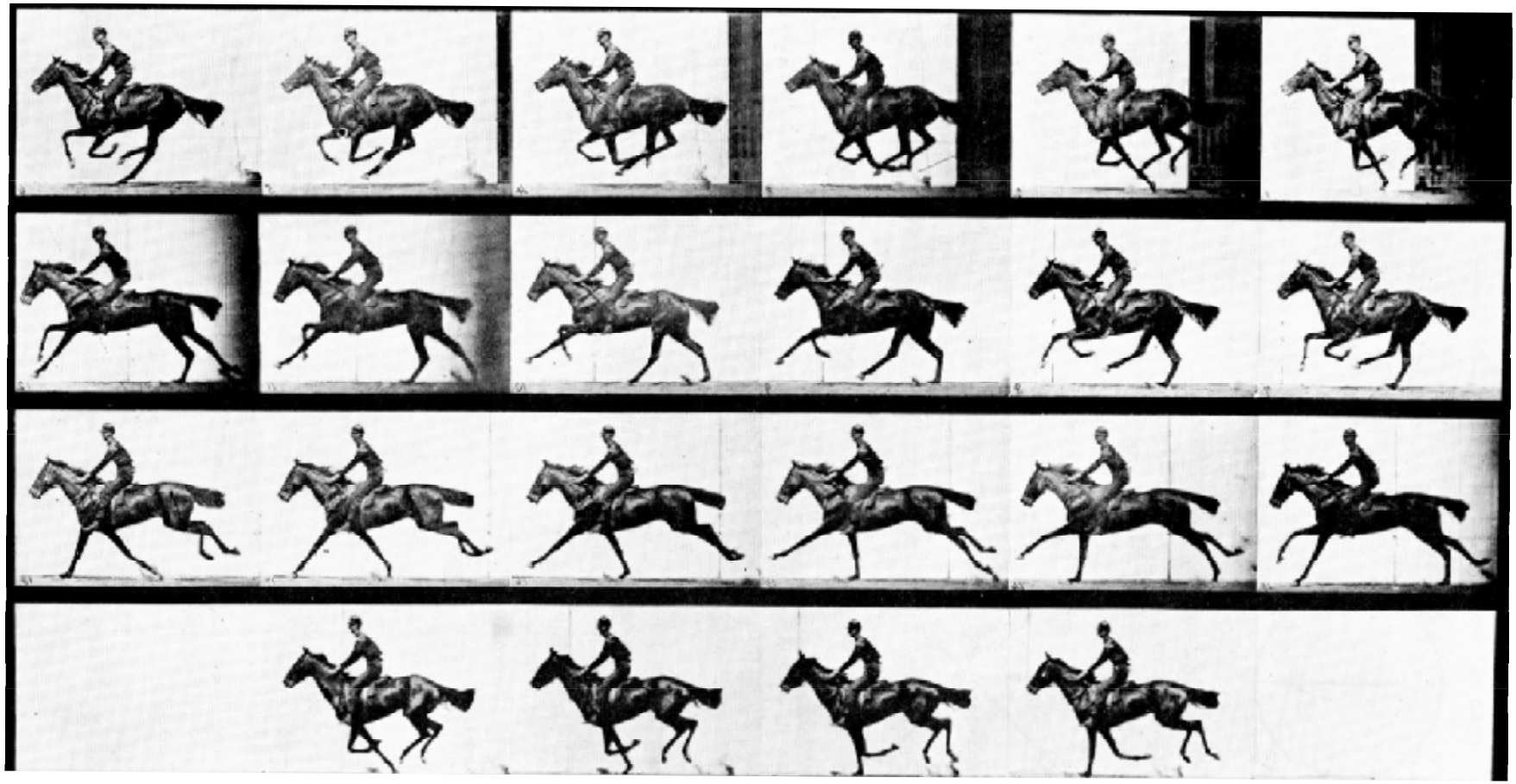
Cognitive Principles for effective graphics

- **Congruity: Structure & content of external representation should match structure & content of desired mental representation**

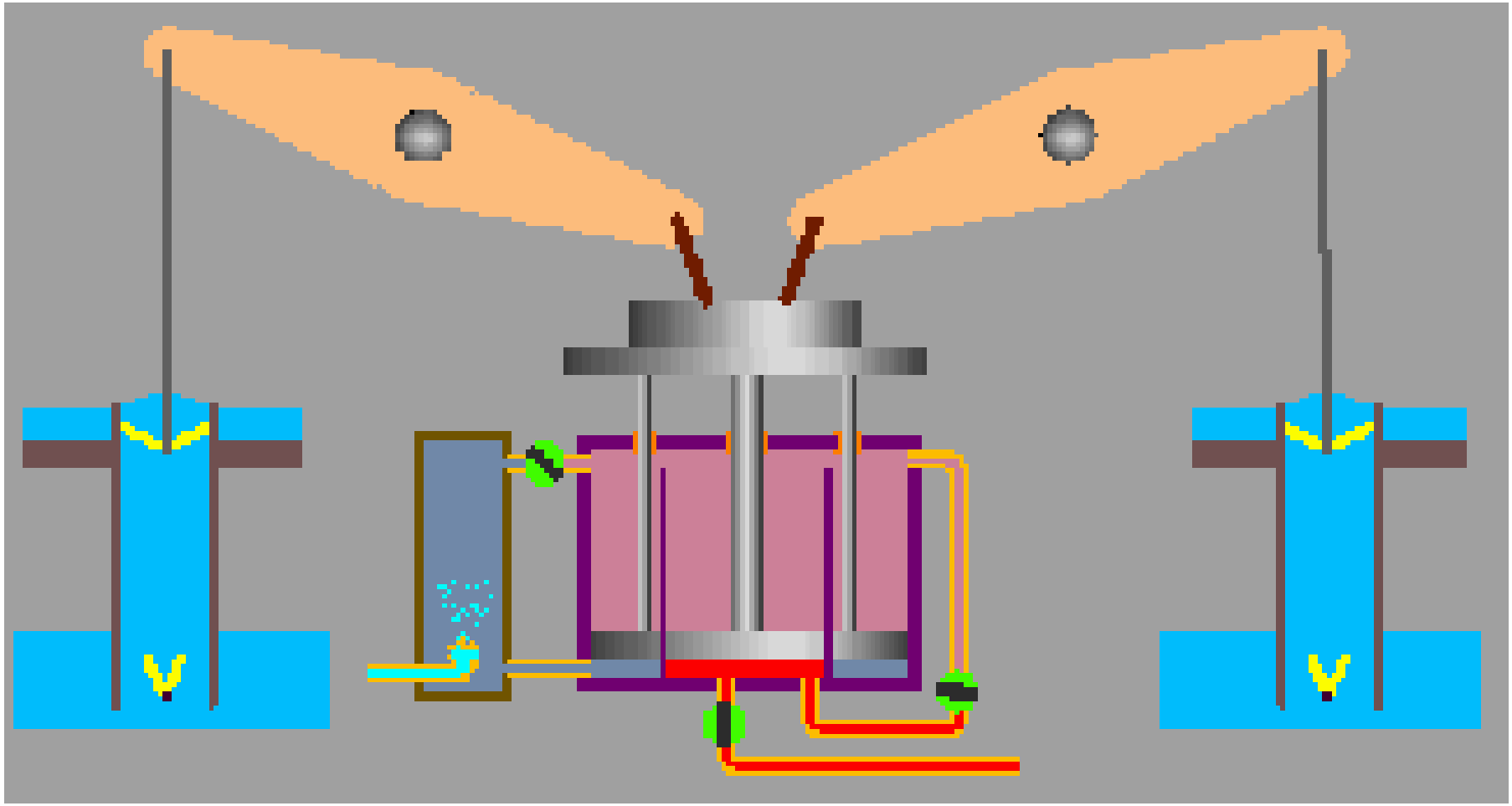
- **Apprehension: Structure & content of external representation should be readily and accurately perceived and comprehended**

Conveying change over time

- Animations use change in time to convey change in time
- But:
  - Animations hard to perceive



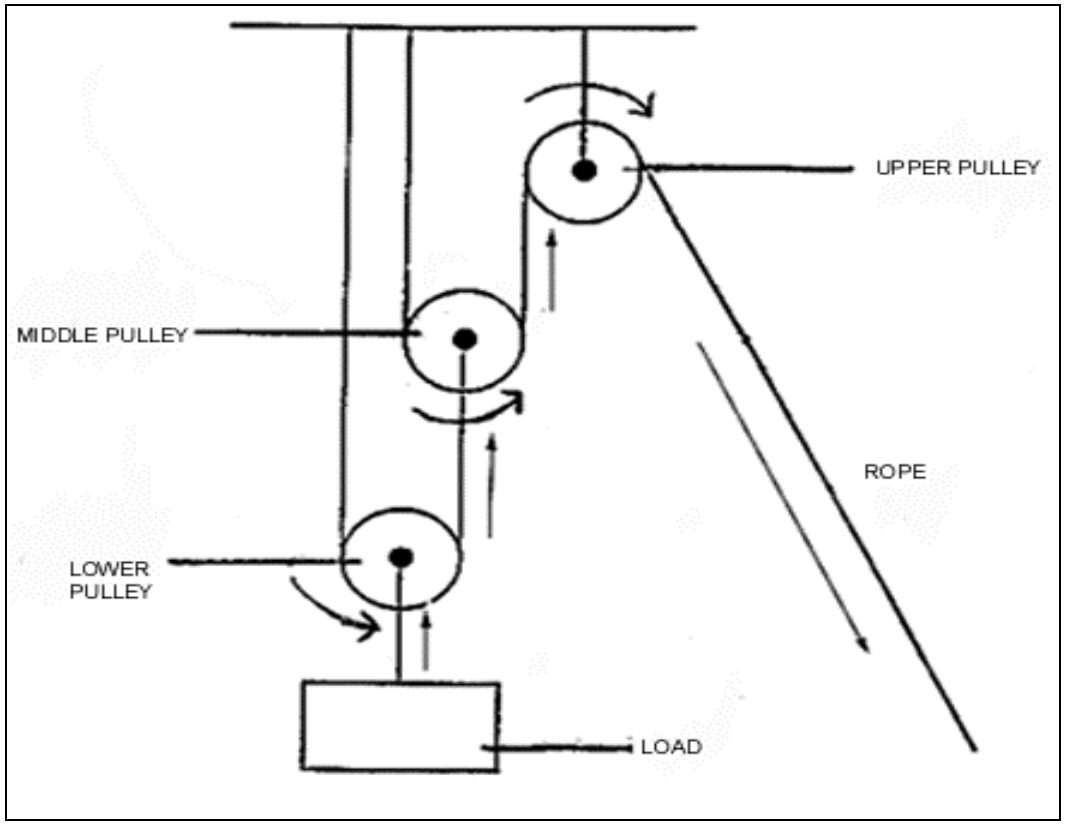
Animations hard to perceive



Conveying change over time

- Animations use change in time to convey change in time
- But:
  - Animations hard to perceive
  - Animations conceived as discrete steps

Pulleys: continuous but conceived discretely



Conveying change over time

- Animations use change in time to convey change in time
- But:
  - Animations hard to perceive
  - Animations conceived as discrete steps
  - Showing isn’t explaining

Why diagrams communicate effectively

- Spatial inferences easy (e. g., proximity, distance, direction)
- Spatial metaphors available (e. g., time, value, strength)
- Elements interpretable (icons, figures of depiction, schematic abstract forms)