Engineering Systems Doctoral Seminar

ESD.83 – Fall 2011

Session 6

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TA: Rebecca Kaarina Saari
Guest: Professor Stuart Kauffman

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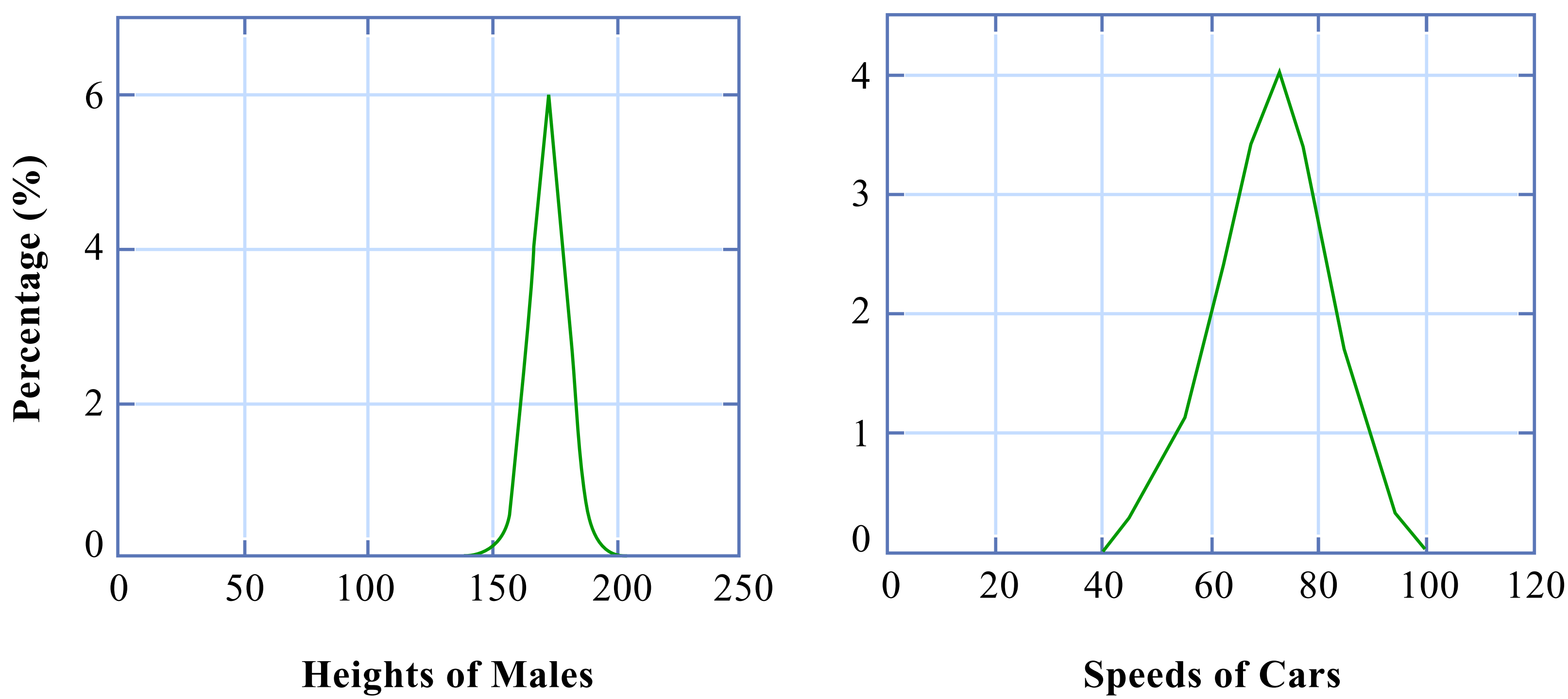
Session 6: Agenda

- Welcome and Overview of class 6 (5 min.)
- Dialogue with Professor Kauffman (55min)
- Break (10 min.)
- Discussion of other papers (30-40 min)
- Theme and topic integration (Magee)
  - High variance, normal distributions and power laws
  - Research Process I (more in later sessions)
  - Visual Thinking and analysis of data
- Next Steps -preparation for week 7- (5 min.)

Degree Distributions

- Define p_k as the fraction of nodes in a network with degree k. This is equivalent to the probability of randomly picking a node of degree k
- A plot of p_k can be formed by making a histogram of the degrees of the nodes. This is the degree distribution of the network.
- Histograms
  - Normal (and nearly so)
  - Skewed (and heavily skewed)
- Suggest some normal or nearly normal distributions..and some not likely to be normal



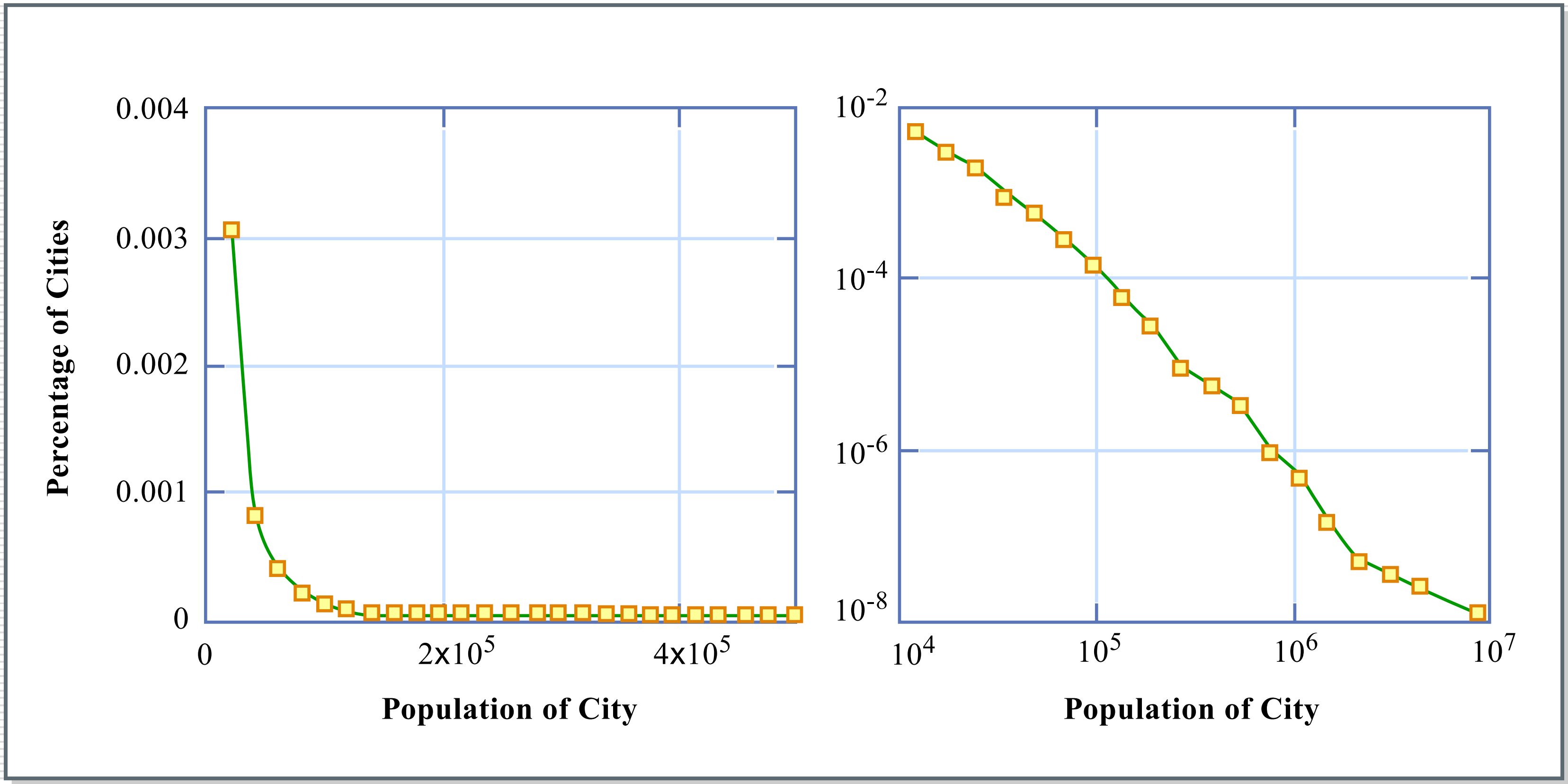
Histogram of heights in centimeters of American males. Data from the National Health Examination Survey, 1959-1962 (US Department of Health and Human Services).

Histogram of speeds in miles per hour of cars on UK motorways. Data from Transport Statistics 2003 (UK Department for Transport).

Image by MIT OpenCourseWare.

M. E. J. Newman, cond-mat/0412004v2

A heavily skewed distribution



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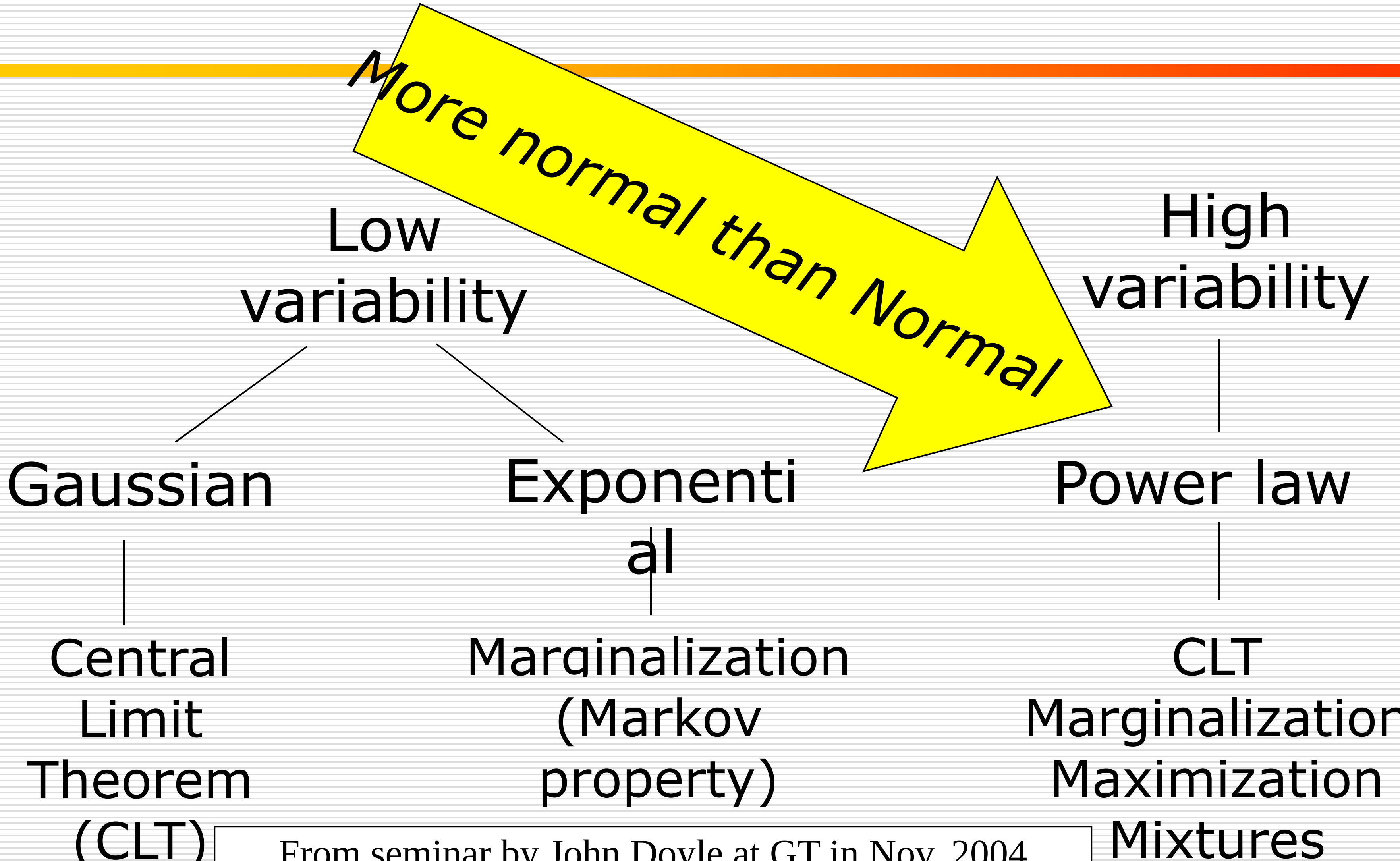
M. E. J. Newman, cond-mat/0412004v2

Degree Distributions II

- Define p_k as the fraction of nodes in a network with degree k. This is equivalent to the probability of randomly picking a node of degree k
- A plot of p_k can be formed by making a histogram of the degrees of the nodes. **This is the degree distribution of the network.**
- Histograms
  - Normal (and nearly so)
  - Skewed (and heavily skewed)
- → Reasons for normal vs. skewed?
- Power law (skewed) $$p_k \sim k^{-\alpha}$$
- Why power laws?

Power laws are ubiquitous



From seminar by John Doyle at GT in Nov. 2004

Summary (sessions 1,2, 3, and 4)

- Research must involve both observation of the world and models/theories (abstractions) to be progressive (cumulative)
- Qualitative and quantitative approaches are necessary in such research with qualitative stronger in initial work. The initial quantitative models are most important and may not be very "constraining" (predictive)
- Iteration between models and observations is essential

A Research Process

1. Development of conceptual understanding (qualitative framework)
2. Development of quantitative model
3. Observe (system)
4. Analyze observations
5. Generalize or simplify/complicate model

A Research Process 2

1. Development of conceptual understanding (qualitative framework)
2. Development of quantitative model
3. Observe (system)
   - Design a specific version of a known procedure
   - Develop a new observational procedure
   - Find, and/or extract and combine data
4. Analyze observations
   - Use existing models to "reduce" data to model-relevant
   - Develop new models to "reduce" data
   - "Consilience" among observations of various kinds
5. Generalize or simplify/complicate model

Strategies for Advancing Engineering Systems as a Field

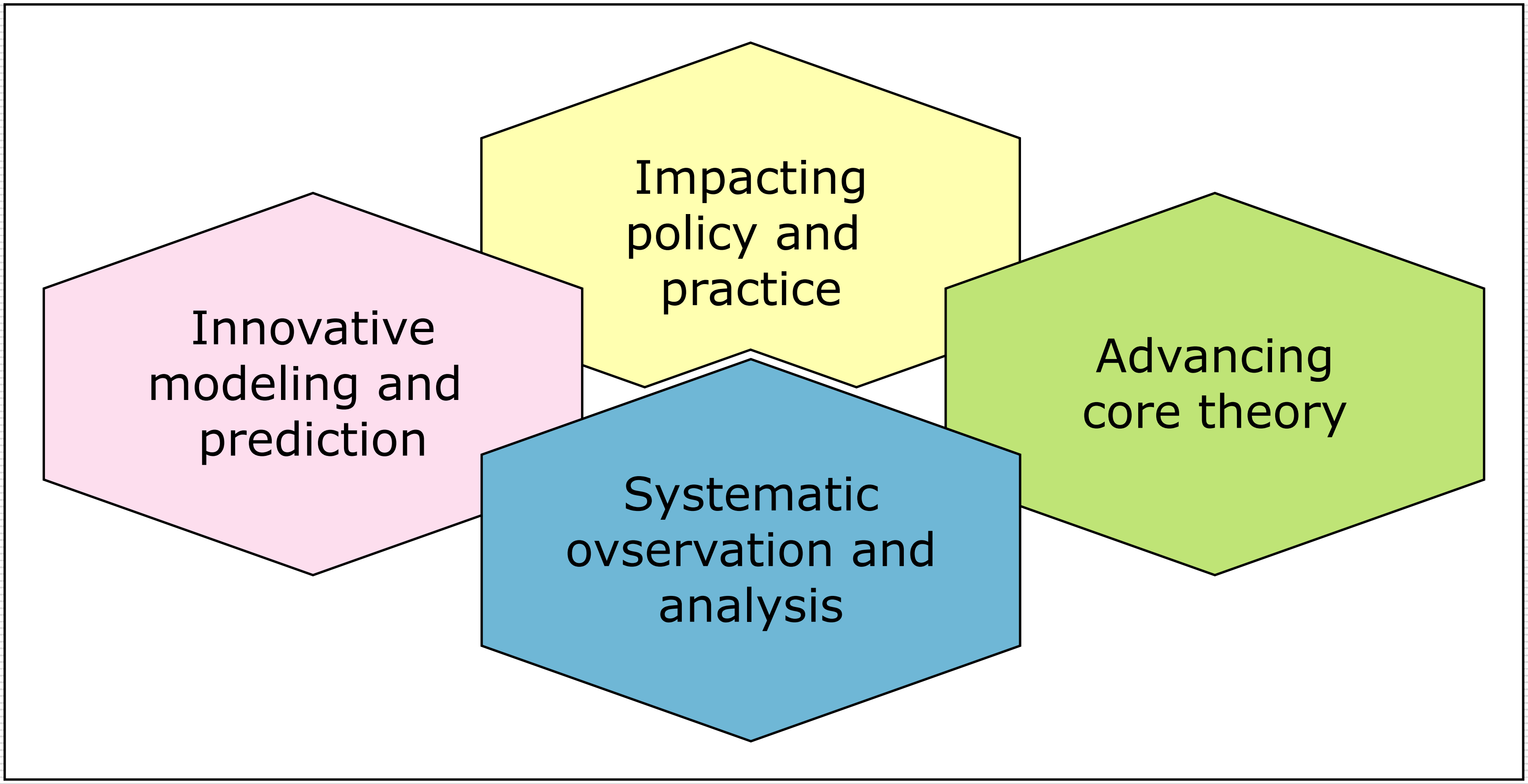


Image by MIT OpenCourseWare.

Visual thinking and data visualization

“Modules” for thinking

- Logical (including formal mathematics)
- Narrative (time and event correlation)
- Numeracy (or quantitative thinking)
  - Having appropriate *intuition* about magnitude
  - Ability to quickly calibrate
  - *Ability to make reasonable estimates* about the system relatively quickly
  - Knowing the numbers and the way they *change over time*
  - *Common sense in using numbers* to assess impact
- Visual thinking (the largest “dedicated” brain area) and clearest “module”
- All of these are used in thinking about systems (so “systems thinking” is not a module)

Self-Observations on Thinking

- As you think to solve the following puzzle, ***observe your thoughts*** to the best of your ability
- "One morning, exactly at sunrise, a Buddhist monk began to climb a tall mountain. The narrow path, no more than a foot or two wide, spiraled around the mountain to a glittering temple at the summit. The monk ascended at varying rates of speed, stopping many times along the way to rest and eat the dried fruit he carried with him. He reached the temple shortly before sunset. After several days of fasting and meditation, he began his journey back along the same path, starting at sunrise and again walking at variable speeds with many pauses along the way. Of course, his fastest speeds and average speed while descending were higher than those he achieved while climbing"
- Prove that there is a single spot along the path that the monk will occupy on both trips at precisely the same time of day.

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Self Observations on Thinking

- How was your thinking ***represented***? How did you know you were thinking?
- Did you ignore some facts?
- Did you use other mental operations to explore the problem?
- How difficult was it to "observe" your own thinking?

Self Observations on Thinking

- How was your thinking ***represented***?
  - Internal voice, talking to oneself..
  - Bodily gestures, tasting the dried fruit, *seeing* the monk move on the path
- Did you ignore some facts?
  - "Glittering" temple, dried fruit, spiral path?
- Did you use other mental operations to explore the problem?
  - Rotation or "superimposition", mathematical derivation, logical rules
- How difficult was it to "observe" your own thinking?
  - Very difficult and ambiguous

Generalized Observations on Thinking

- How was your thinking ***represented***?
  - There are multiple representations used for thinking.
- Did you ignore some facts?
  - We think by performing a number of active mental operations and abstraction is a key one.
- Did you rotate or superimpose to explore the problem?
  - Such operations are nearly impossible in language
- How difficult was it to "observe" your own thinking?
  - Most people infer operations by observing the resulting representation

Generalized Observations on Thinking

- Thinking is perceived by our consciousness in multiple ***representations***
- Thinking involves a variety of mental ***operations***
- Thinking occurs above and **mostly below** the level of our conscious awareness.
  - ***Operations*** are usually chosen and performed below the ***level*** of our conscious awareness

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Flexible Thinking

- Why might it be useful to be more flexible in our thinking procedures?
- What are some elements of thinking flexibly?
- How might we be flexible in our ***Level*** of thinking?
- How might we be more flexible in our thinking ***operations***?
- Flexibility in Thinking ***Representations*** is essential to flexibility in operations
- see McKim's book -*Thinking Visually* and Arnheim's *Visual Thinking*)

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Visual Capabilities/Thinking and *Design* of Systems Representations

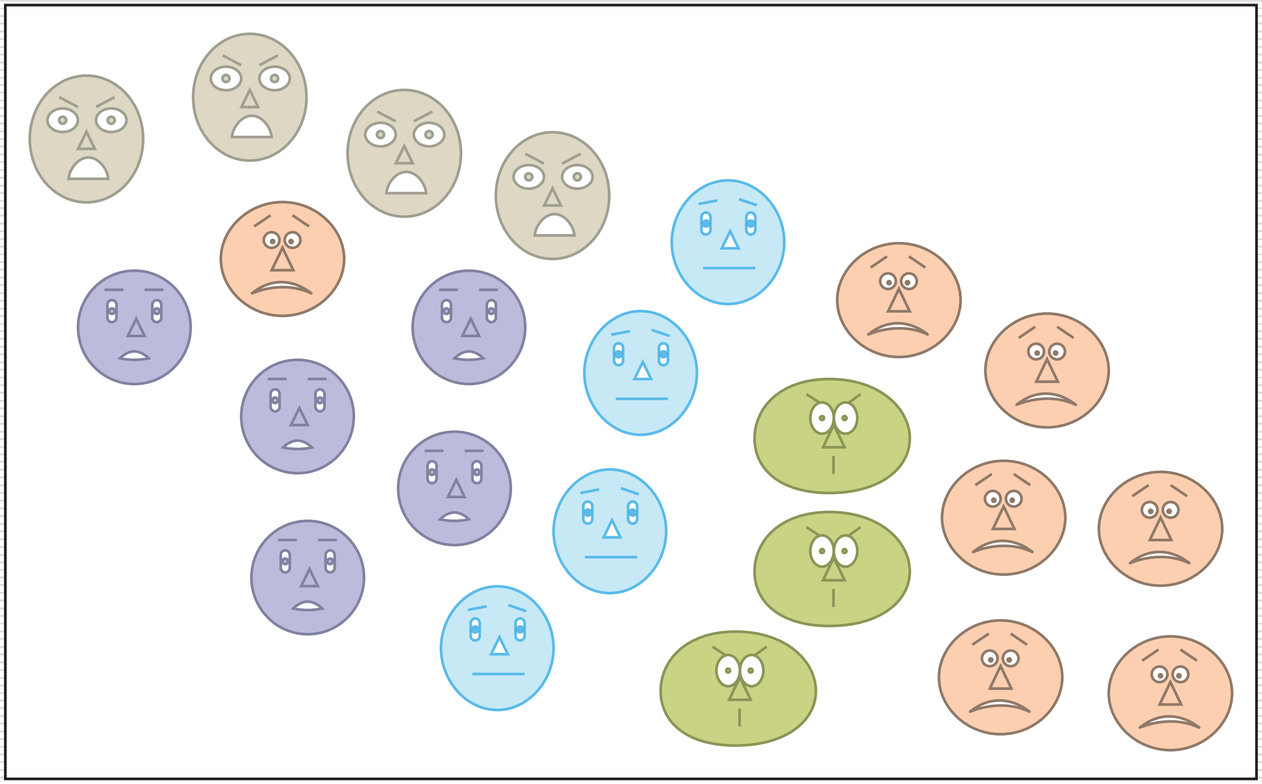
- For clarity of Communication
  - Using data visualizations and system representations that recognize the human skills in pattern recognition, outliers, comparative visual reasoning, causal chains etc, is essential for effectiveness
- Variety of representations and innovation is constantly needed-this is an important skill (methodology?)

Notes on human capabilities

Physiological and evolution-based

- 150 Million bits at a glance (Tufte 1999)
- *uninterrupted* (local) visual reasoning (Wimsatt 1990)
- object re-identification (Wimsatt 1990)
- outlier recognition/boundary recognition (Wimsatt 1990)
- pattern recognition (Wimsatt 1990)
- understanding/inferring motion (Wimsatt 1990, Marey 1895)
- inferring causal chains (Wimsatt 1990)

Outlier recognition



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Redrawn from Tufte 1983 p142

Chernoff faces: Eric W. Weisstein. "Chernoff Face." From MathWorld--A Wolfram Web Resource. http://mathworld.wolfram.com/ChernoffFace.html

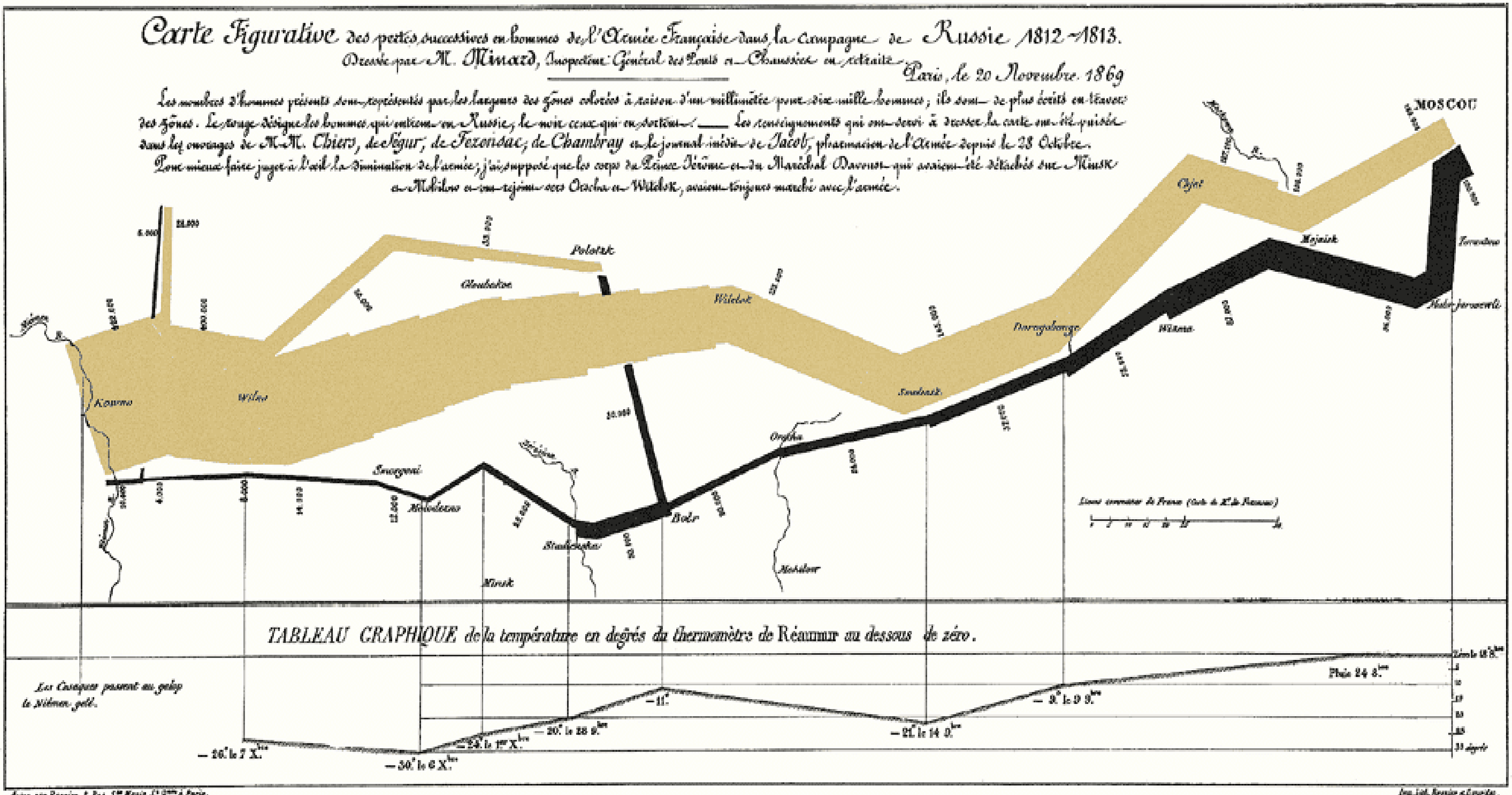
Examples of Visual Representation & Application to Complex Systems

- Categories from the Small-world paper
  - What do they mean?

Examples of Visual Representation & Application to Complex Systems

- Categories from the small world paper
  - What do they mean?
- Minard/Tufte and statistical thinking
  - Review and Discuss the Napoleon March Graphic

- Napoleon March 1812-13 to Moscow
  - Graphic (by Charles Minard, 1869)



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Examples of Visual Representation & Application to Complex Systems

- Minard/Tufte and statistical thinking
  - Review and Discuss the Napoleon March Graphic
- Tufte data visualization: overarching Principles for design
  - Increase the number of dimensions that can be represented on plane surfaces (escaping flatland)
  - Increase the data density (amount of information per unit area)

Guidelines for Excellence in Statistical Graphics (Tufte)

- **Show** the data
- Induce reader to perceive **substance** not methods or "chartjunk"
- Avoid Distortion of data message
- Present **many numbers in small space**
- Make large data sets **coherent**
- Encourage the eye to **compare** different pieces of data
- Reveal several **levels** of data detail
- Serve a relatively clear **purpose** (description, exploration, tabulation, decoration)
- Closely **integrate** with statistical and verbal descriptions of a data set

Discussion of Rosling Video

- Number of "dimensions" or variables
- Possible "new observations" from video (new to you not the world)

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Maps and detail

World Trade Center damage report removed due to copyright restrictions. Original image can be viewed here: http://www.cnn.com/SPECIALS/2001/trade.center/damage.map.html

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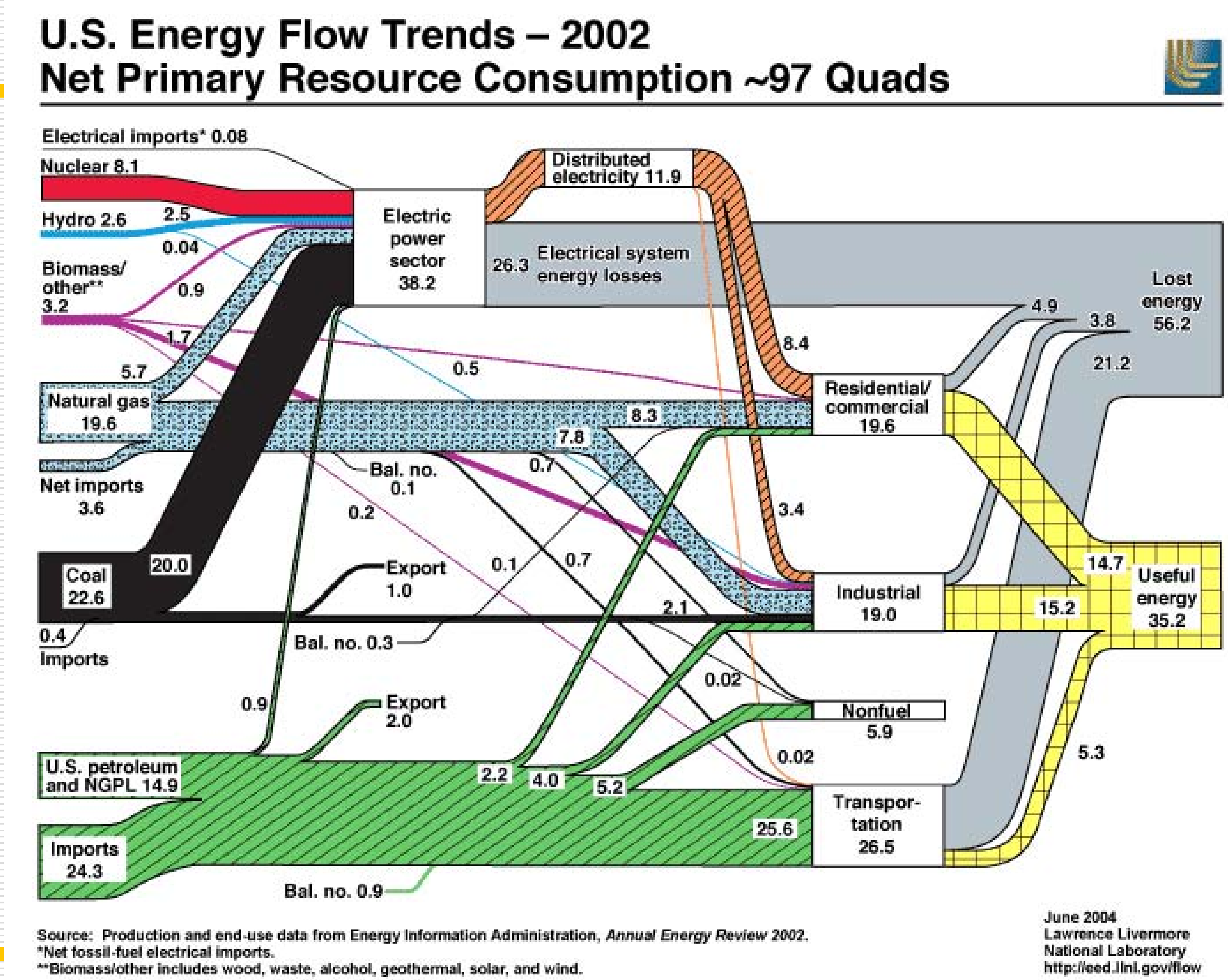
Flow and quantification visualization



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Map abstractions and layering

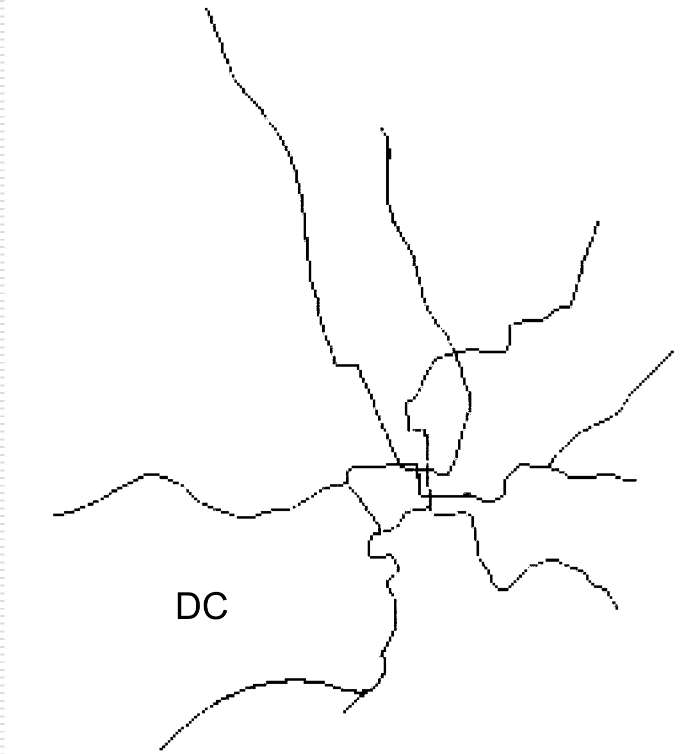
Image of MARC commuter rail system removed due to copyright restrictions. Map can be viewed here: http://mta.maryland.gov/sites/default/files/WMATA-Metro-System-Map.pdf

Map abstractions and scale

scale: 1 km = 7 pixels

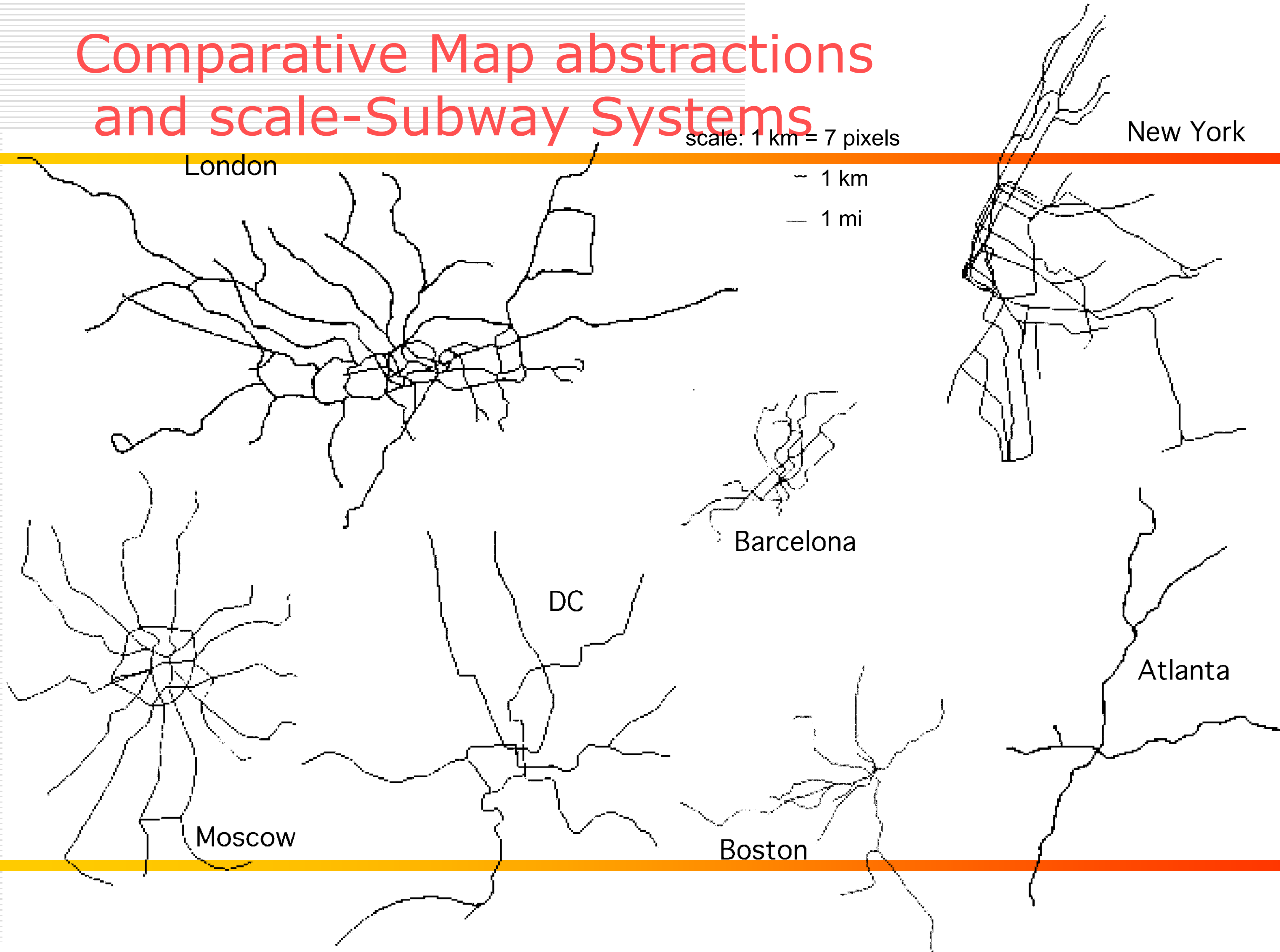
1 km

1 mi



http://www.fakeisthenewreal.org/subway/index.html

Comparative Map abstractions and scale-Subway Systems



http://www.fakeisthenewreal.org/subway/index.html

Design of Systems Representations ..continued

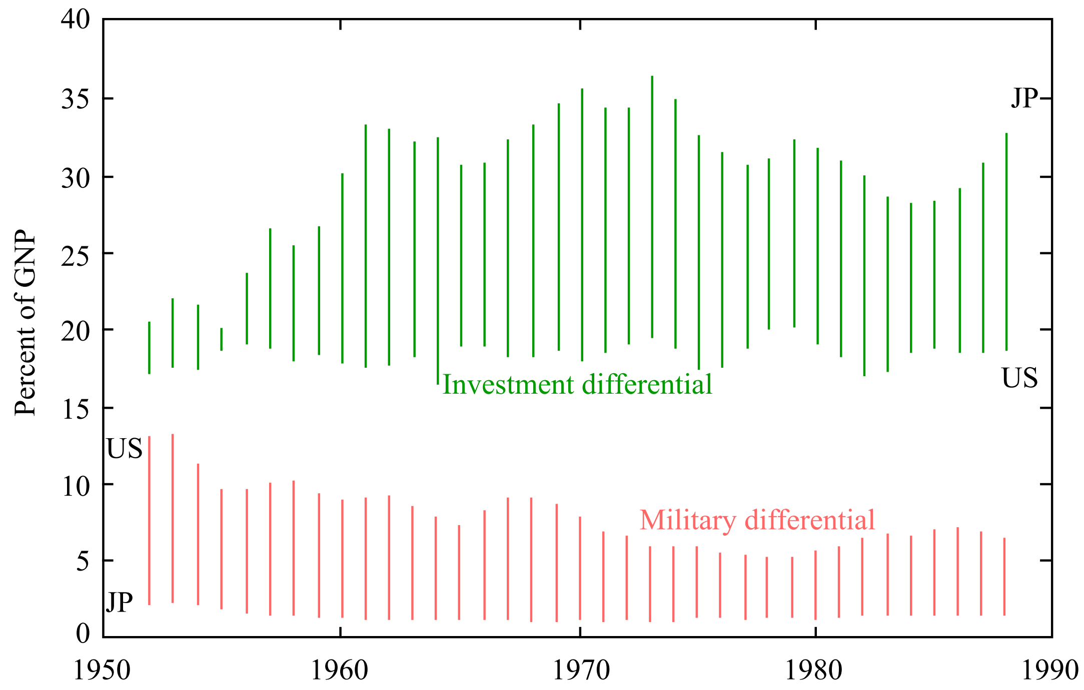
Details draw the viewer in to the graphic

- convey major point
- provide other information
- add credibility
- suggest questions

There are reasons to compress dimension (*aggregate)* and reasons to show more dimensions (*disaggregate)*

It is often useful to *reference familiar aspects* of the system in image design

Disaggregate

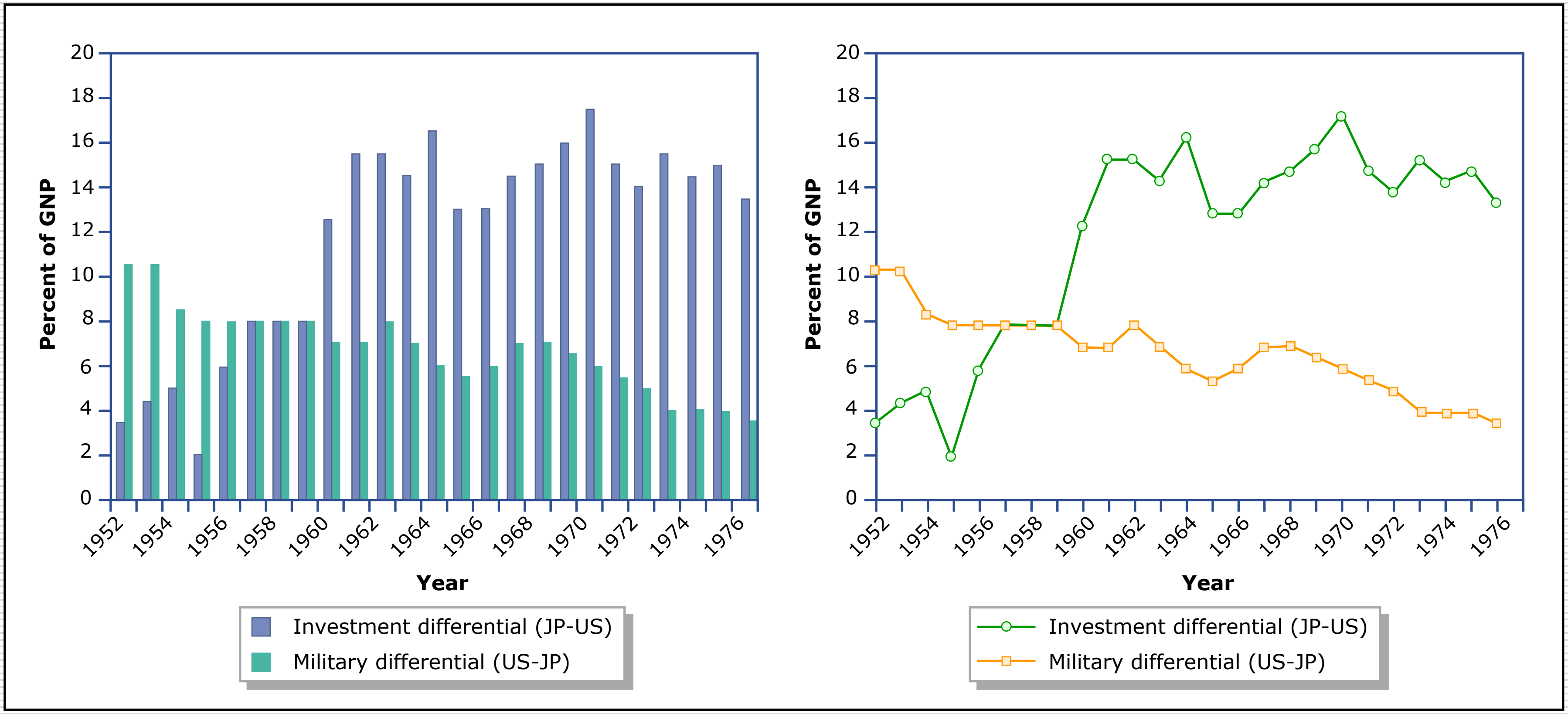


U.S. - Japan Investment and defense differentials. Sources: Drawn from gross fixed capital formation and GNP/GDP figures from OECD Economic Outlook, various issues. Military figures from Arms Control and Disarmament Agency and from Stockholm Institute for Peace Research.

Image by MIT OpenCourseWare.

Oye 1992

Alternatives to disaggregating



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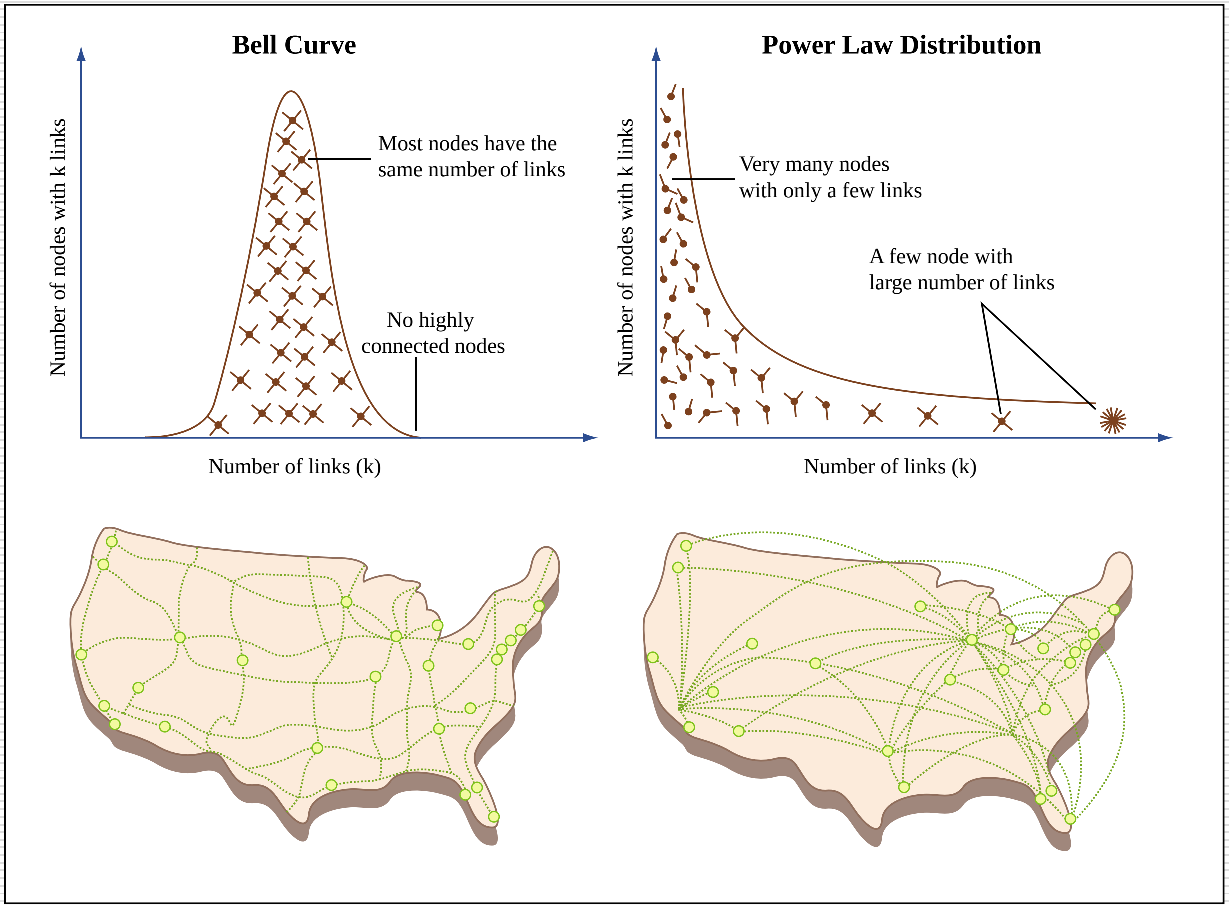
Aggregate – Network complexity



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Barabasi 2002

Small multiples (Tufte)

Image removed due to copyright restrictions.

Choice of Representation

"The form of a representation cannot be divorced from its *purpose* and the *requirements of the society* in which the given visual language gains currency."

Gombrich 1956 *Art and Illusion:* Psychology of Visual Perception

The Minard graphic of Napoleon's march into Russia had what purpose? What did Minard want it to do? Did he succeed?

For holistic systems thinking and/or for a balanced systems perspective, what does this imply?

Systems Thinking and Representation

- **Related parts make up a whole-** graphs, networks, maps and other ways of understanding interconnections and synthesizing wholes
- **Practical application and implications-** Multiple representations of real systems for solution of real problems
- **Relationships and temporal shifts-** Feedback diagrams and patterns, frameworks for seeing interrelationships rather than things
- **Structure and behavior-** Hierarchy diagrams and relationships whose purpose it to highlight emergence and control
- Much innovation yet needed in these areas

Systems Representation –Learning objectives

- Explore your own thinking process
- Appreciate the value of Thinking Flexibly
  - Modes-Visual, language and mathematics
  - Levels of thinking..
  - Operations: patterns and matching (accuracy and speed, decomposition and holistic approaches)
- Appreciate the value of effective visual representation for communication and thinking
- Form basis for building skill at Systems Representation and Data Visualization
  - Maps, graphs, matrices, lists, sketches, pictures,
  - What to think about in choosing representations
  - Understand some basic human capabilities
- Examine how Engineering Systems Topics are related to visual thinking and representation

References

- R. Arnheim, *Visual Thinking*, University of California Press , 1968
- R. H. McKim, *Experiences in Visual Thinking, 1971*
- R. H. McKim, *Thinking Visually: A strategy Manual for Problem solving,* 1980
- E. R. Tufte, *The Visual Display of Quantitative Information*, 1983
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- E. R. Tufte, *Visual Explanations*, 1997

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