Engineering Systems Doctoral Seminar

ESD.83 – Fall 2009

Class 8
Faculty: Chris Magee and Joe Sussman
Guest: Professor Dan Frey
Professor of Engineering Systems
and Mechanical Engineering

MIT ESD
Massachusetts Institute of Technology
Engineering Systems Division

Session 8: Agenda

- Welcome and Overview of class 8 (5 min.)
- Dialogue with Professor Frey (55min)
- Break (10 min.)
- Discussion of other papers (lead Bruce Cameron, 30 -40 min)
- Theme and topic integration (Magee)
  - Carryover from session 7
  - Continued discussion of assignment 1
  - Report from the Front
  - Analysis of observations "structure"
  - Visual Thinking and analysis of data
- Next Steps -preparation for week 9- (5 min.)

Summary (sessions 1,2,4,7&8)

- 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

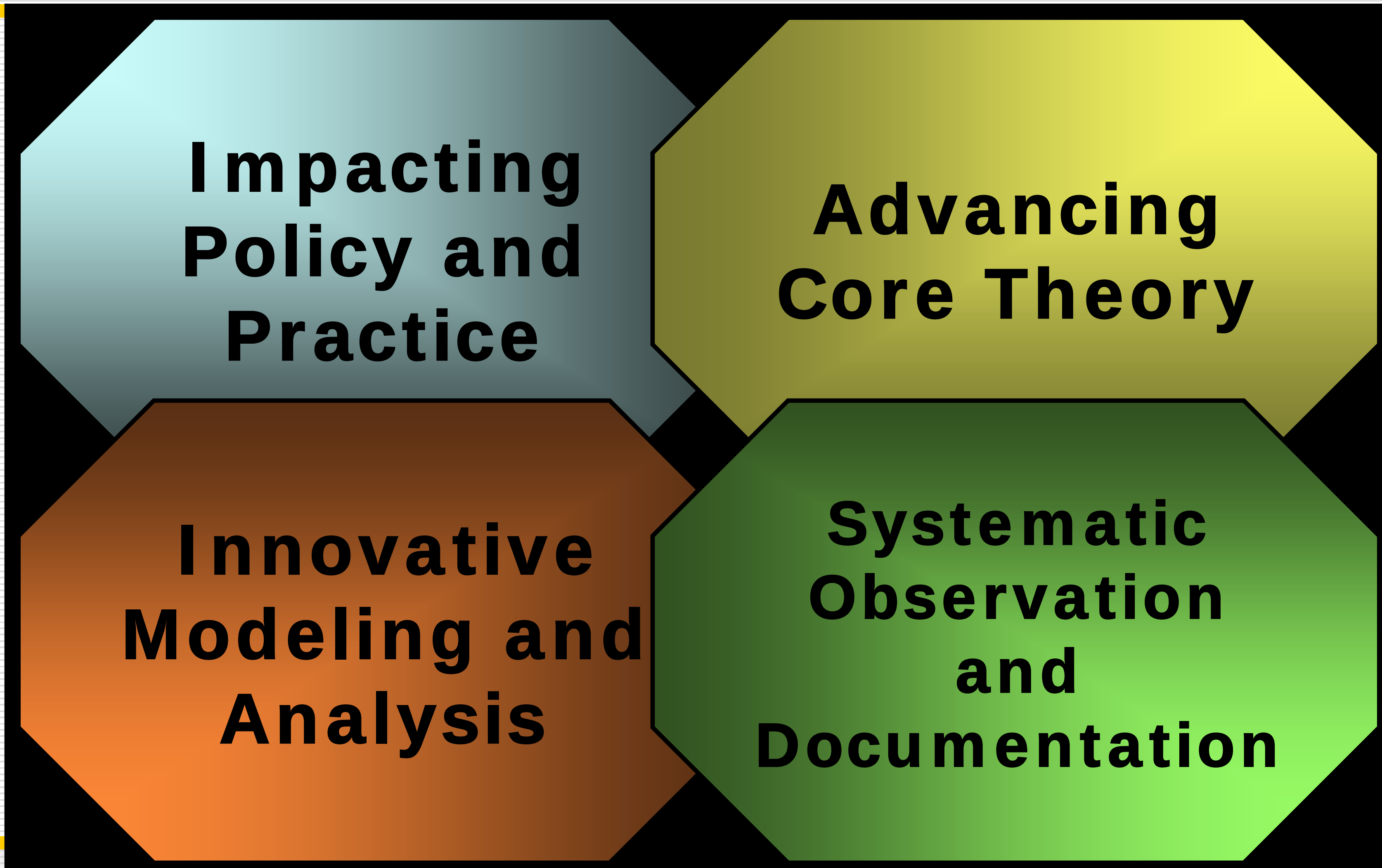
A Research Process

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

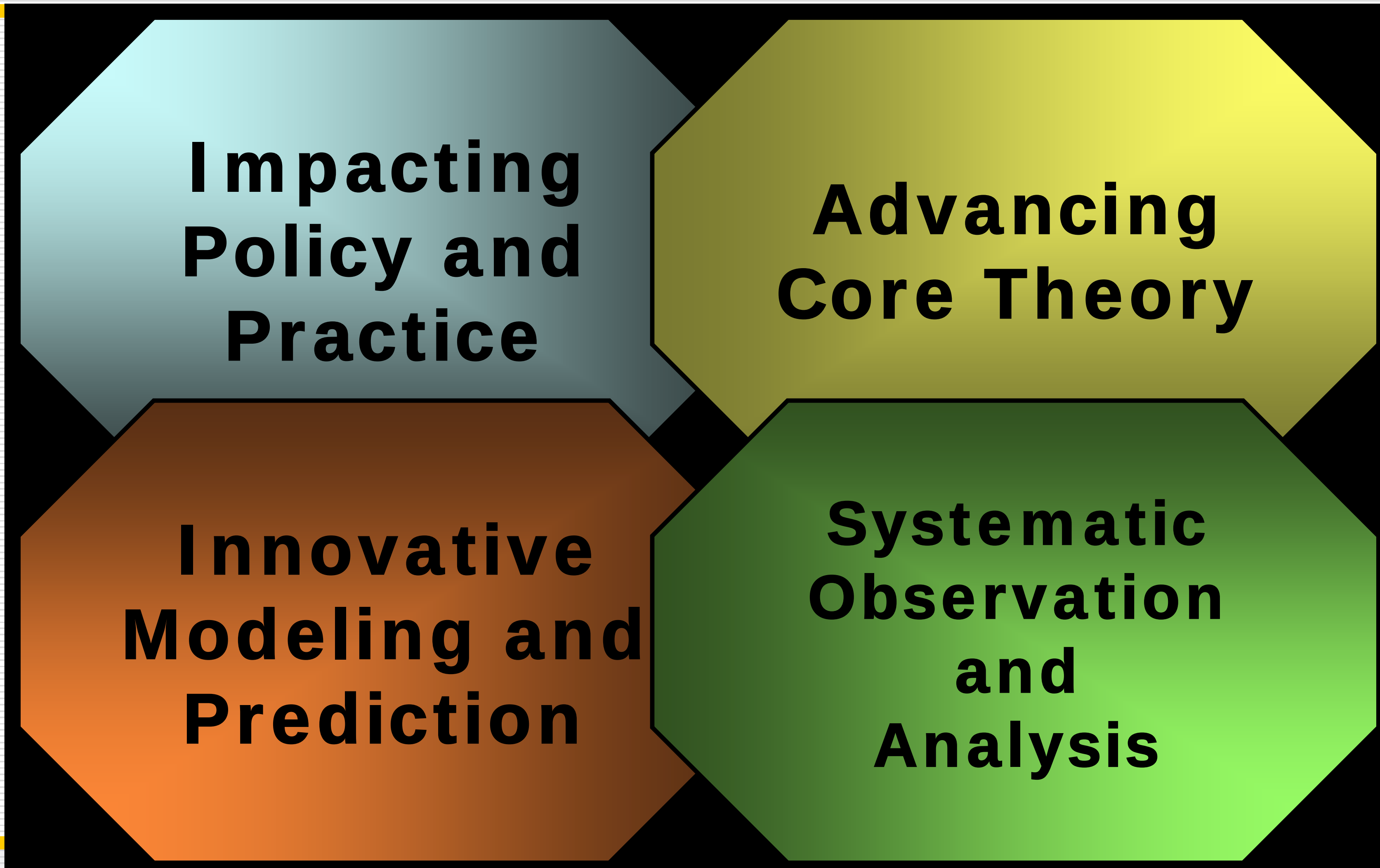
A Research Process 2

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



Strategies for Advancing Engineering Systems as a Field



A Research Process 3

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

- Research styles (1,2,3,4,5 repeat; 1,3,5 repeat; 1/3, 2/4, 5/1; 3, 4, 1, 2; etc.)

Advancing a field 2

- What makes a field cumulative in its knowledge acquisition process?
- Cyclic learning seems to be most important. The pathologies in the preceding slides are non-cumulative
- Modeling, theory and objective observation are important aspects of the research cycles—Watts reading
- **The transition from purely qualitative to quantitative and predictive does not occur discontinuously- are simple models and "surrogative reasoning" good starting points? (Frey and earlier Boyd/Richerson)**
- Productivity in ES requires becoming more cumulative in our research process

Data Analysis Discussion

- Methods of analysis from assignment 1
- Mapping the Millennium- Experiment or Observational Study?
- Report from the Front- experiment or ?
- What is learned from these cases (and some others like the earth's core, galaxy structure etc.)
- The models and theories deployed in data analysis are as elaborate (sophisticated) as the models for understanding the system

ES Observational Techniques- "structure" from class 7

- Need for extensive data analysis and experiment vs. observational study are key differentiating factors among observational techniques
- Case studies (N = 1)
  - Implications of a singular fact ("The World is Green"; "Engineering Design is Successful"?)
  - In-situ: Ethnographic study, surveys, interviews, document study, email studies, minutes, calendar analysis, quantitative and qualitative, etc.
  - Historical analysis: primary and secondary documents, interviews, quantitative and qualitative, etc.
- Medium N- as above but time limited
- High N (possibility of experiment)-

ES Data Analysis Discussion

- Do mathematically elaborate (RFF and Hall) Observational Methods exist in complex Socio-technical systems?
- Can we invent new ones?..involving unexpected “instrumental” variables
- Note also that the RFF case and Mapping the Millennium have another commonality (not present in assignment 1 articles)- what is it?

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.

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

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*)

Visual Capabilities/Thinking and *Design* of Systems Representations

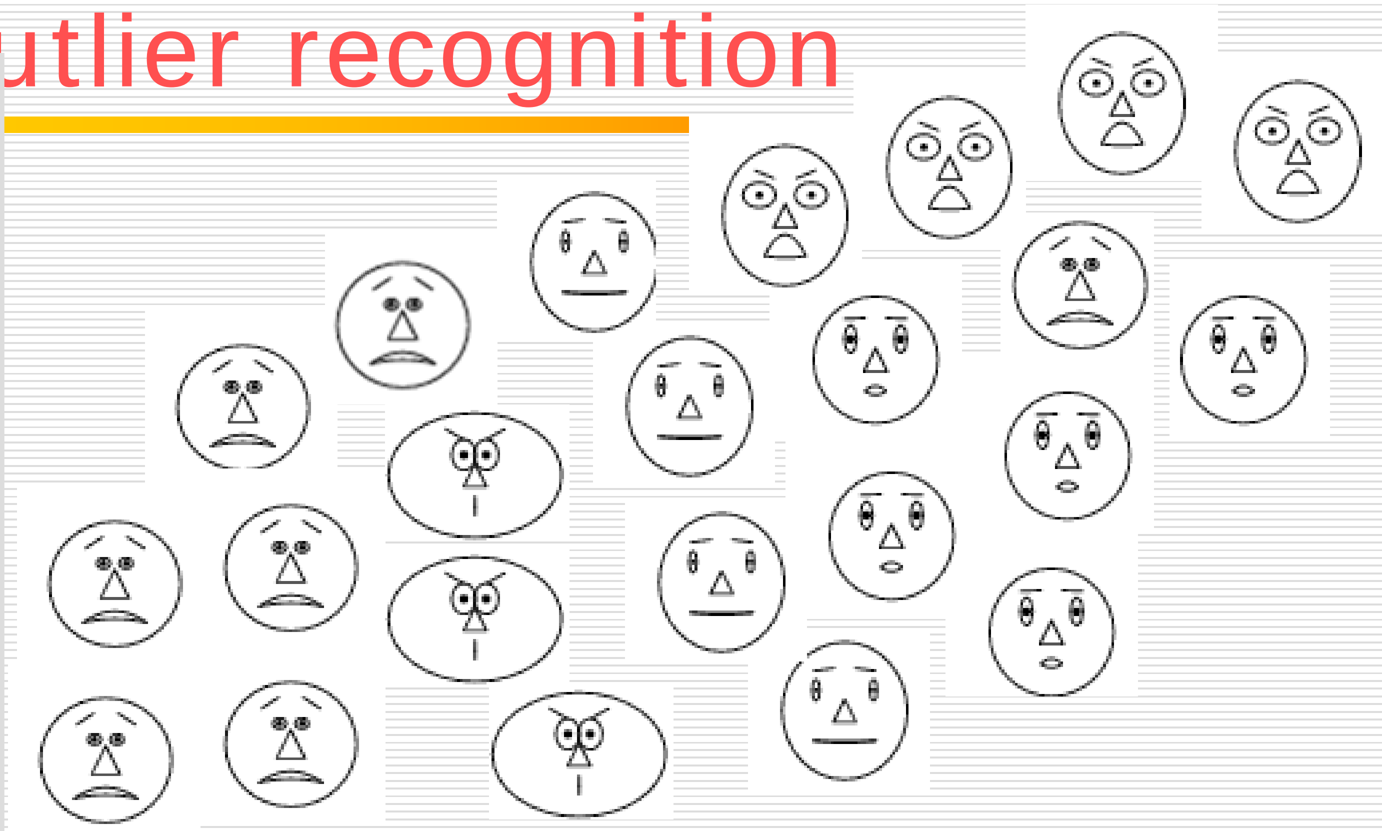
- For clarity of Communication
  - Using data visualizations and system representations that recognize the human skills in pattern recognition, outliers, comparative visual reasoning, causal chains etc, is essential for effectiveness
- Variety of representations and innovation is constantly needed-this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



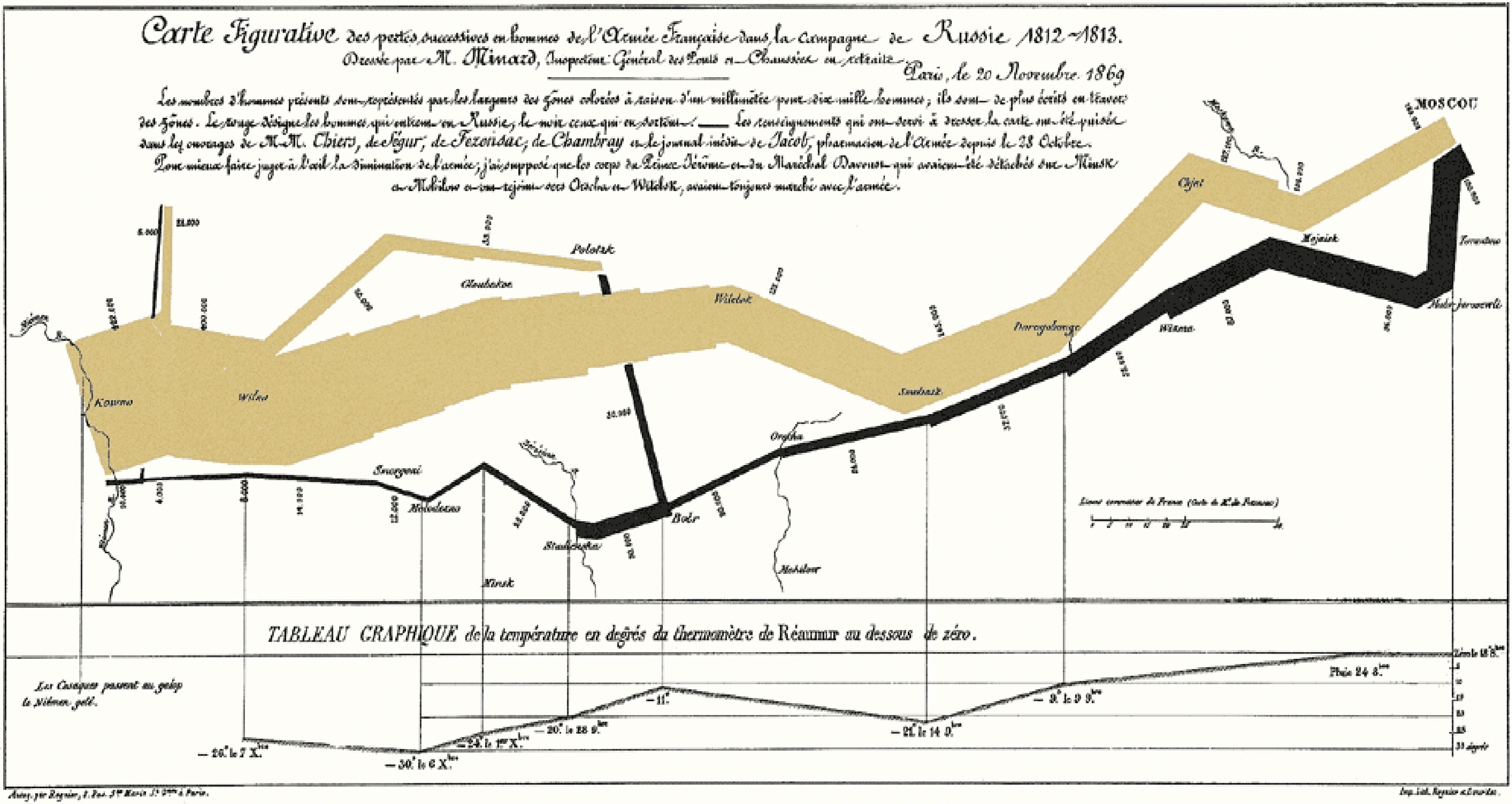
Redrawn from Tufte 1983 p142

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

- Minard/Tufte and statistical thinking
  - Review and Discuss the Napoleon March Graphic

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



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 than 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

Examples of Visual Representation & Application to Complex Systems I

- Many examples at web sites referenced in the last slide in this set of slides
- Tufte data visualization overarching Principles for design
  - Increase the number of dimensions than can be represented on plane surfaces (escaping flatland)
  - Increase the data density (amount of information per unit area)
- Ideas to improve subway system comparison

Design of Systems Representations ..continued

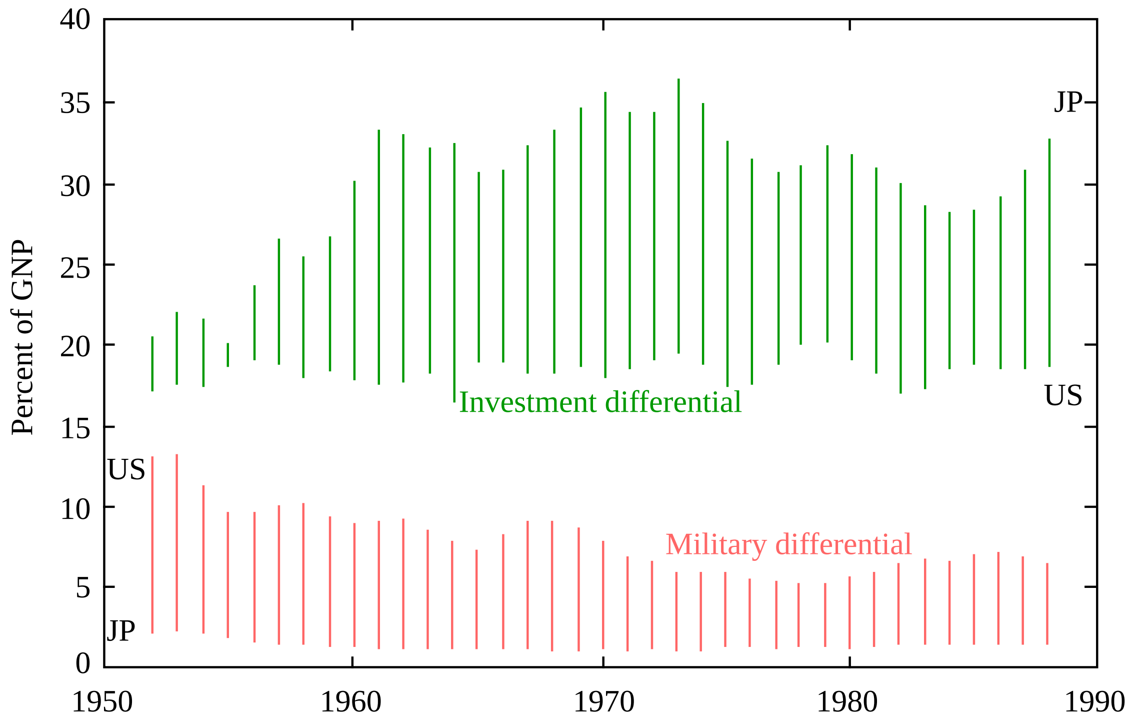
Details draw the viewer in to the graphic

- 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

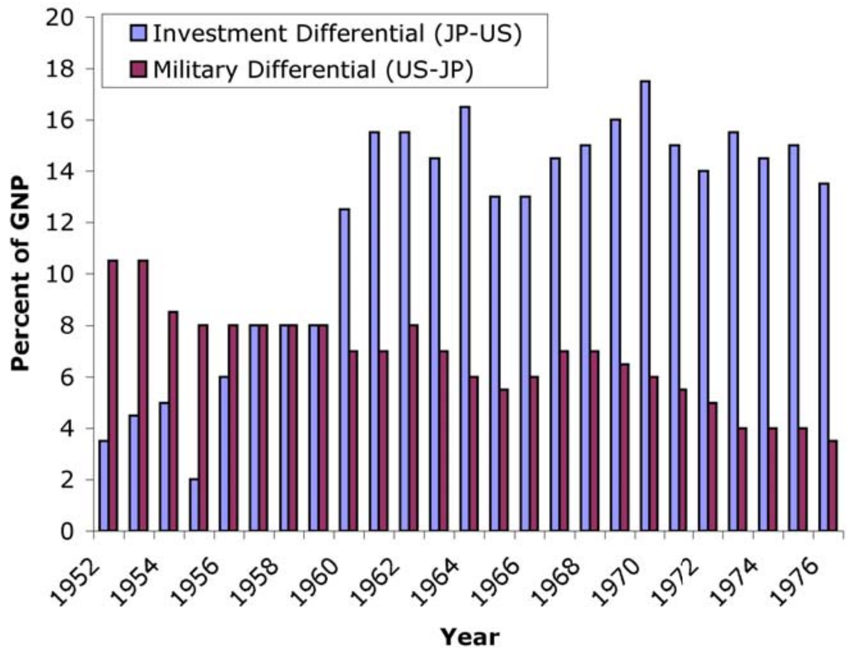
Disaggregate

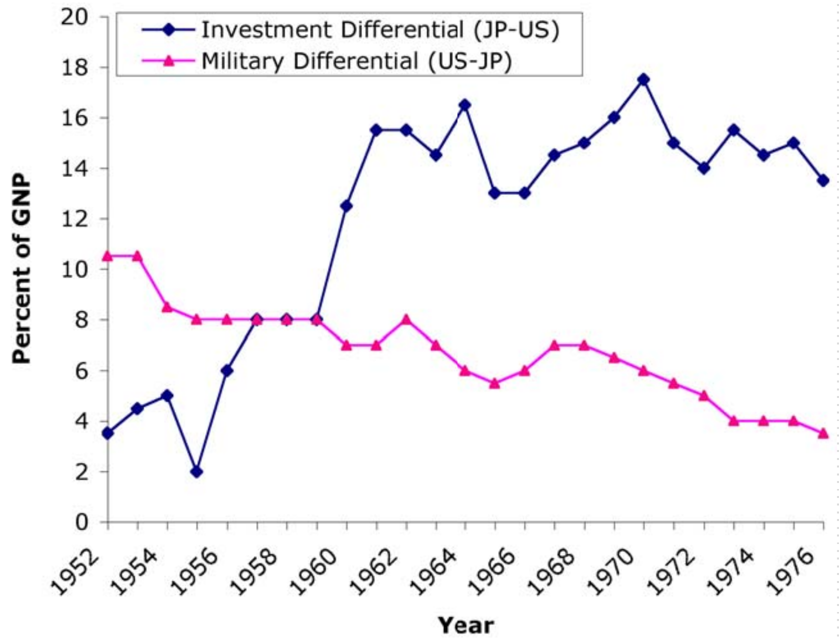


U.S. - Japan Investment and defense differentials. Sources: Drawn from gross fixed capital formation and GNP/GDP figures from OECD Economic Outlook, various issues. Military figures from Arms Control and Disarmament Agency and from Stockholm Institute for Peace Research.

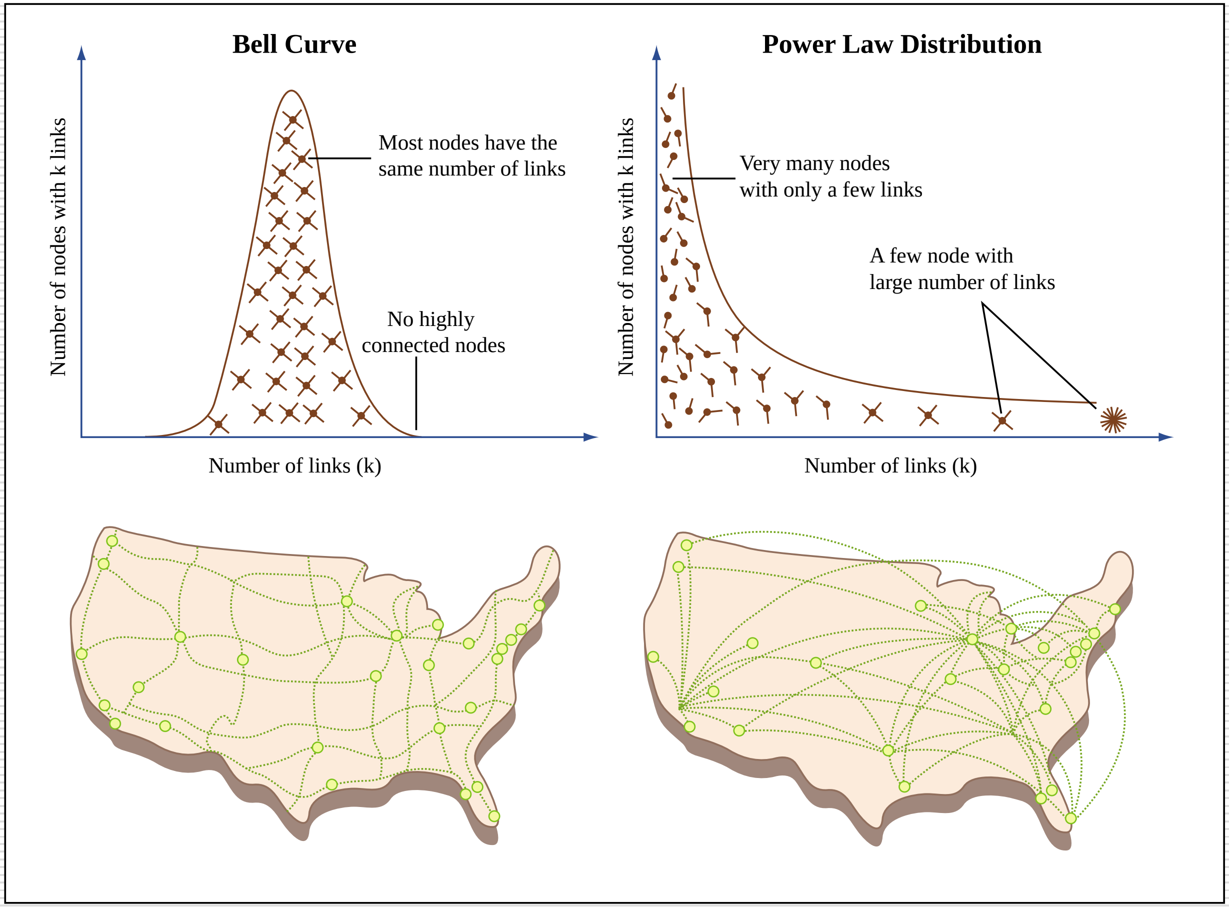
Oye 1992

Alternatives to disaggregating





Aggregate – Network complexity



Barabasi 2002

Image by MIT OpenCourseWare.

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

Useful Information Visualization Resources

- Fantastic, entertaining and enlightening videos on Data Visualization and further detail about the work
  - http://www.ted.com/index.php/speakers/view/id/90
  - http://www.gapminder.org/
- Comprehensive website with pointers to various sources of information on visualization
  - http://www.visual-literacy.org/
- Gallery of Data Visualization
  - http://www.math.yorku.ca/SCS/Gallery/noframes.html#BrightIdeas
- Unified Resource for the visualization of Complex Networks
  - http://www.visualcomplexity.com/vc/
- Link to IBM Visual Communication Lab website
  - http://www.research.ibm.com/visual/
- Successful company that develops products for Data Visualization
  - http://www.touchgraph.com/
- *Technology Review articles*
- Creative Data Visualization on a popular bookmarking website (digg.com). http://www.technologyreview.com/Infotech/19079/?a=f
- Description of a very useful tool (ManyEyes)
  - http://www.technologyreview.com/Infotech/18516/?a=f

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
- E. R. Tufte, *Envisioning Information*, 1990
- E. R. Tufte, *Visual Explanations*, 1997

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