MIT Portugal

SEA RI
Systems Engineering Advancement Research Initiative

The Influence of Institutional Background on the Approval of Engineered Systems

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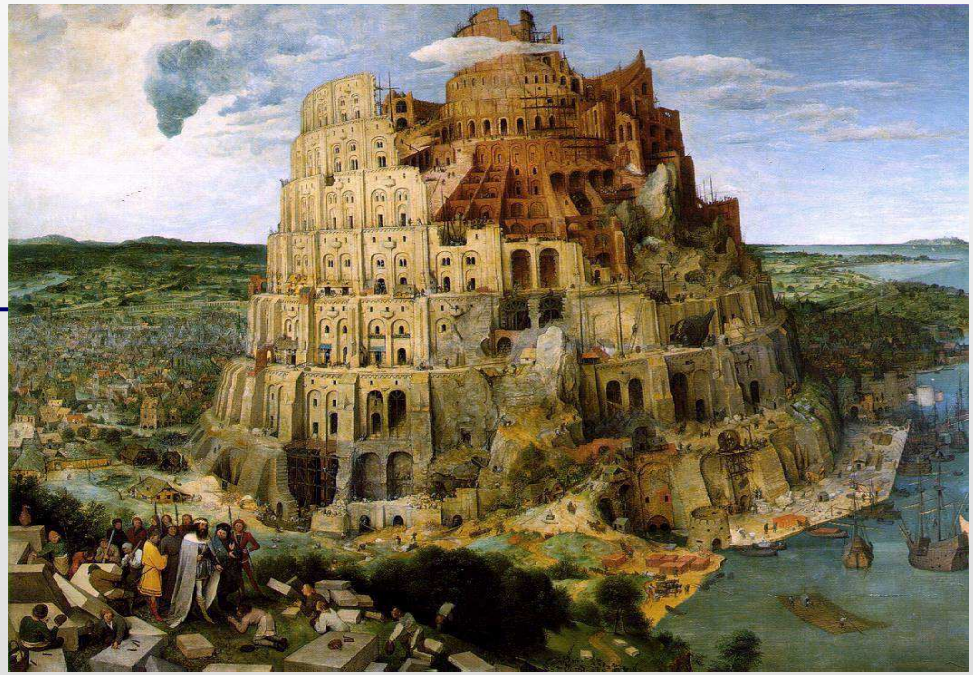
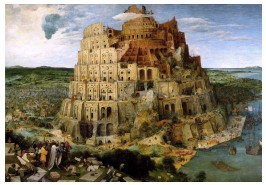


Brueghel's "Tower of Babel" – The Tower of Babel is arguably the first recorded example of a large-scale engineered system to fail due to linguistic confusion.

The Problem: Technology Assessment in Regulated Industries



- **Expert Group Decision-making**: Innovation diffusion in regulated sectors more subject to professional & political judgment

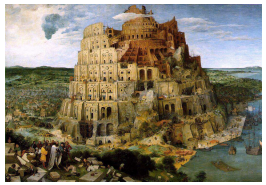
  (Nelson 2005)

- **Different perspectives & values** make it difficult to generate consensus on interpretation of data

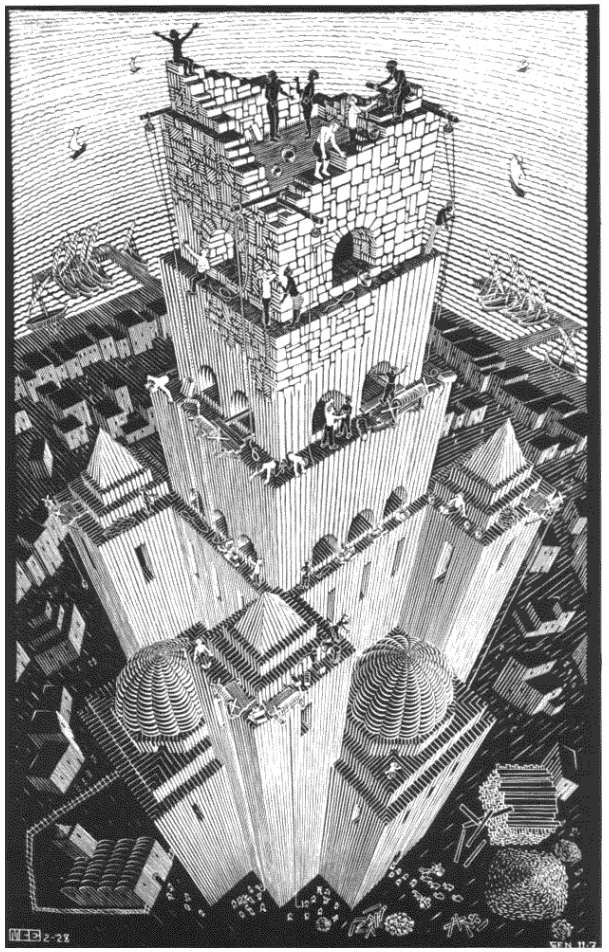
  > *"…politics…shape how policymakers respond to analytical recommendations...all bring distinct readings of the evidence to decisions that may have heart-rending* ***implications for quality, cost, and fairness****…"*
  >
  > *(Gelijns, Brown et al. 2005)*

- **Institutional Framing**: Experts' interpretations influenced by institutional frames *(Douglas 1986)*
  - **Institution**: e.g., a particular profession, specialty, or organization

Relevance to Engineering

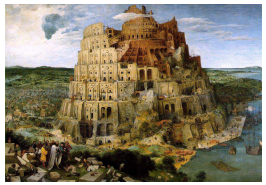


- Multi-stakeholder technical decision-making (e.g., design reviews)
  - Pooling **expertise** and **evidence** from **multiple domains**
  - System evaluation and problem solving
- Medical device approval is
  - **Large-scale**: Impacts billions of lives
  - **Social**: Multi-stakeholder decisions
  - **Technical**: Device and process design
- "Design knobs" to leverage multiple perspectives & sources of expertise to improve performance



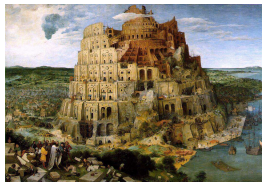
"Tower of Babel" M. C. Escher

Domain of Interest: Medical Device Approval



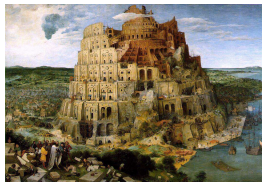
- The **Food and Drug Administration** oversees medical device safety, efficacy and innovation *(Merrill, 1994)*
  - Medical technology can save lives or be overused/harmful
    (Cutler, 2001; Devers, Brewster et al., 2003; Dalkon Shield)
  - Device approval is expensive, complex & strategically important
- Interdisciplinary **expert advisory panels** oversee most innovative devices *(Sherman, 2004)*
- Do panels' recommendations improve decision outcomes?
  - Conflict of interest & "specialty bias" *(Friedman 1978*; Lurie, Almeida et al. 2006)

Key Questions



1. How do the institutional backgrounds of individual advisory panel members interact to impact a given device's approval?
2. How do advisory panel members' different institutional backgrounds affect their initial perceptions of a device, and how do those perceptions change and interact during the decision-making process?
3. How might we design approval processes so as to enable desirable behavior on the part of medical device approvals?

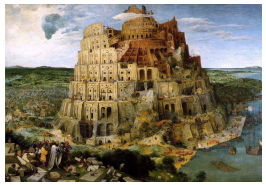
Data Source: FDA Advisory Panel Meeting Transcripts



- **Data availability**: Convenient unit of analysis; hundreds of potential samples
  - 21 committees over 11 years with ~2 meetings per year
- **Data consistency & validation**: Committee members' votes are recorded in "court-reported" transcript & minutes
- **Relevance to Problem**: Device approval is a group decision with uncertain consequences within complex socio-technical system
- **Domain Relevance**: FDA currently revising its advisory panel procedures, device evaluation criteria and conflict of interest rules

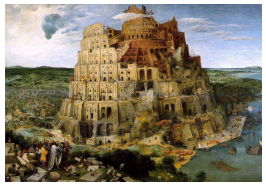
  (Lurie, Almeida et al. 2006)

Approach: Studying Institutional Background via Language



- **Group membership** influences perception of data
  (Douglas and Wildavsky 1982; Elder and Cobb, 1983)
- Group membership **is reflected in language** (problem definition; jargon; symbolic redefinition)
  (Douglas and Wildavsky 1982; Cobb and Elder, 1983; Elder and Cobb, 1983; Nelson 2005)
- Analysis of language use patterns **provides insight into institutional frames** – **semantic** focus
  (Nelson 2005; Cobb and Elder, 1983; Elder and Cobb, 1983)
- Use of Natural Language Processing algorithm – **Latent Semantic Analysis** (LSA)
  (Deerwester, Dumais et al. 1990; Landauer, Foltz et al. 1998)

Latent Semantic Analysis



- Originally developed for information retrieval; later applied to
  1. Student essay evaluation *(Landauer and Dumais 1997)*
  2. Measurement of textual coherence *(Foltz, Kintsch et al. 1998)*
  3. Knowledge assessment *(Rehder, Schreiner et al. 1998)*
  4. Information visualization *(Landauer, Laham et al. 2004)*
  5. Quantitative analysis of design team discourses *(Dong, Hill et al. 2004)*
  6. Measurement of conceptual coherence in design *(Dong 2005)*
- Enables consistent analysis of large numbers of texts

The Latent Semantic Analysis Algorithm

Transcripts

SOCRATES: Welcome, Ion. Are you from your native city of Ephesus?

ION: No, Socrates; but from Epidaurus, where I attended the festival of Asclepius.

SOCRATES: And do the Epidaurians have contests of rhapsodes at the festival?

ION: O yes; and of all sorts of musical performers.

Parser
Stemmer
Stop-list

Word-document matrix

$$X = \begin{pmatrix} 1&0&0&0\\ 1&0&0&0\\ 1&0&0&0\\ 1&0&0&0\\ 1&0&0&0\\ 0&1&0&0\\ 0&1&0&0\\ 0&1&0&0\\ 0&1&1&0\\ 0&1&0&0\\ 0&0&1&0\\ 0&0&1&0\\ 0&0&1&0\\ 0&0&0&1\\ 0&0&0&1\\ 0&0&0&1 \end{pmatrix}$$

Log Entropy Weighting

Singular Value Decomp.

Latent Semantic Analysis

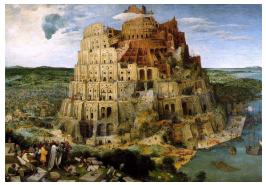
$$X' = W * S * D^T$$

$$W = \begin{pmatrix} -0.4&0.0&0.0&0.0\\ -0.4&0.0&0.0&0.0\\ -0.4&0.0&0.0&0.0\\ -0.4&0.0&0.0&0.0\\ -0.4&0.0&0.0&0.0\\ 0.0&-0.5&0.1&0.0\\ 0.0&-0.5&0.1&0.0\\ 0.0&-0.5&0.1&0.0\\ 0.0&-0.3&-0.2&0.0\\ 0.0&-0.5&0.1&0.0\\ 0.0&-0.1&-0.5&0.0\\ 0.0&-0.1&-0.5&0.0\\ 0.0&-0.1&-0.5&0.0\\ 0.0&0.0&0.0&-0.6\\ 0.0&0.0&0.0&-0.6\\ 0.0&0.0&0.0&-0.6 \end{pmatrix}$$

$$S = \begin{pmatrix} 2.2&0.0&0.0&0.0\\ 0.0&2.1&0.0&0.0\\ 0.0&0.0&1.3&0.0\\ 0.0&0.0&0.0&1.7 \end{pmatrix}$$

$$D^T = \begin{pmatrix} -1.0&0.0&0.0&0.0\\ 0.0&-1.0&0.2&0.0\\ 0.0&-0.2&-1.0&0.0\\ 0.0&0.0&0.0&-1.0 \end{pmatrix}$$

Dimensionality Reduction



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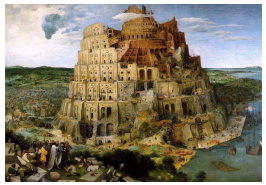
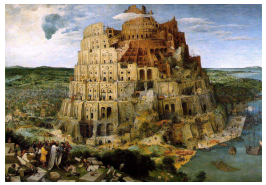
Measuring Semantic Coherence



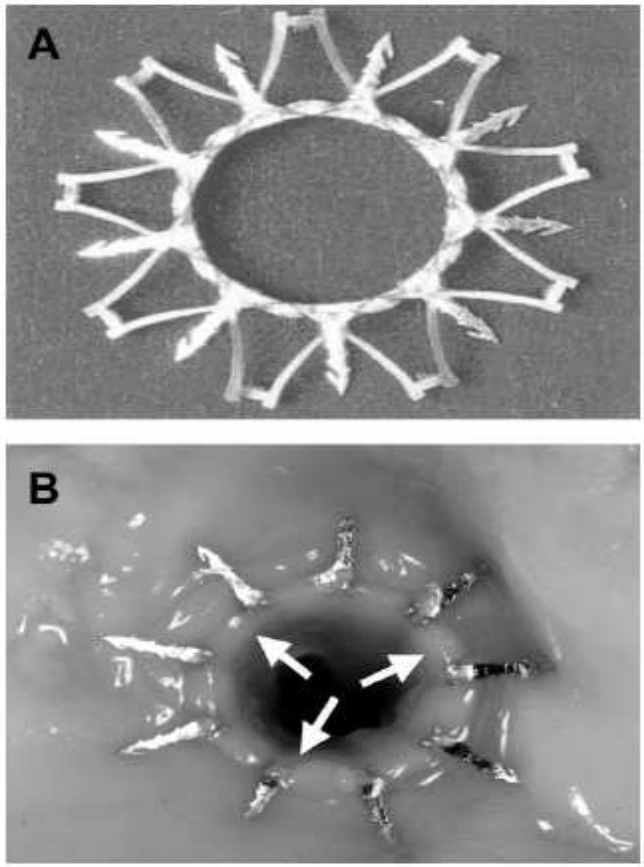
- Each utterance/word is a vector in a high-dimensional semantic space.
  - Cosine between two vectors is their "semantic coherence"
    (Foltz, Kintsch et al. 1998; Dong, 2005)
- **Coherence**, C, is a metric of how much two utterances are using the same **terminology in context** *(Dong, 2005)*
  - Similar (i.e., the same or associated through some intermediates) documents/words will have higher cosines than dissimilar words
  - C>0 indicates similar words, similar contexts ("parallel")
  - C=0 indicates totally different words ("orthogonal")
  - C<0 indicates similar words, different contexts ("anti-parallel")

The Cardica PAS-Port Case



- Review of April 22, 2005 Circulatory Systems Devices Panel Meeting
  (Gross 2005)
- Intended to reduce stroke risk after coronary artery bypass graft
- Device ultimately rejected
  1. Data not pooled correctly
  2. FDA increased confidence interval lower bound for patency rate during clinical trials (failed predicate device)
  3. The data not collected under IDE in the United States

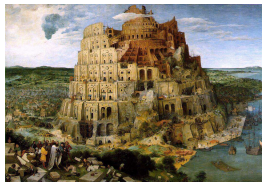
  (Maisel 2005)



A, The Cardica, Inc PAS-Port Proximal Anastomosis Implantable Connector. B, View from the aorta after device deployment and saphenous vein graft (arrows) anastomosis.

Source: (Maisel 2005)

Preliminary Cluster Analysis

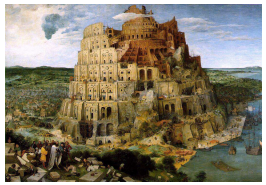


- Stakeholders clustered, using spherical k-means algorithm; k=2
- Analysis with more clusters suggests threshold effect – results get noisy

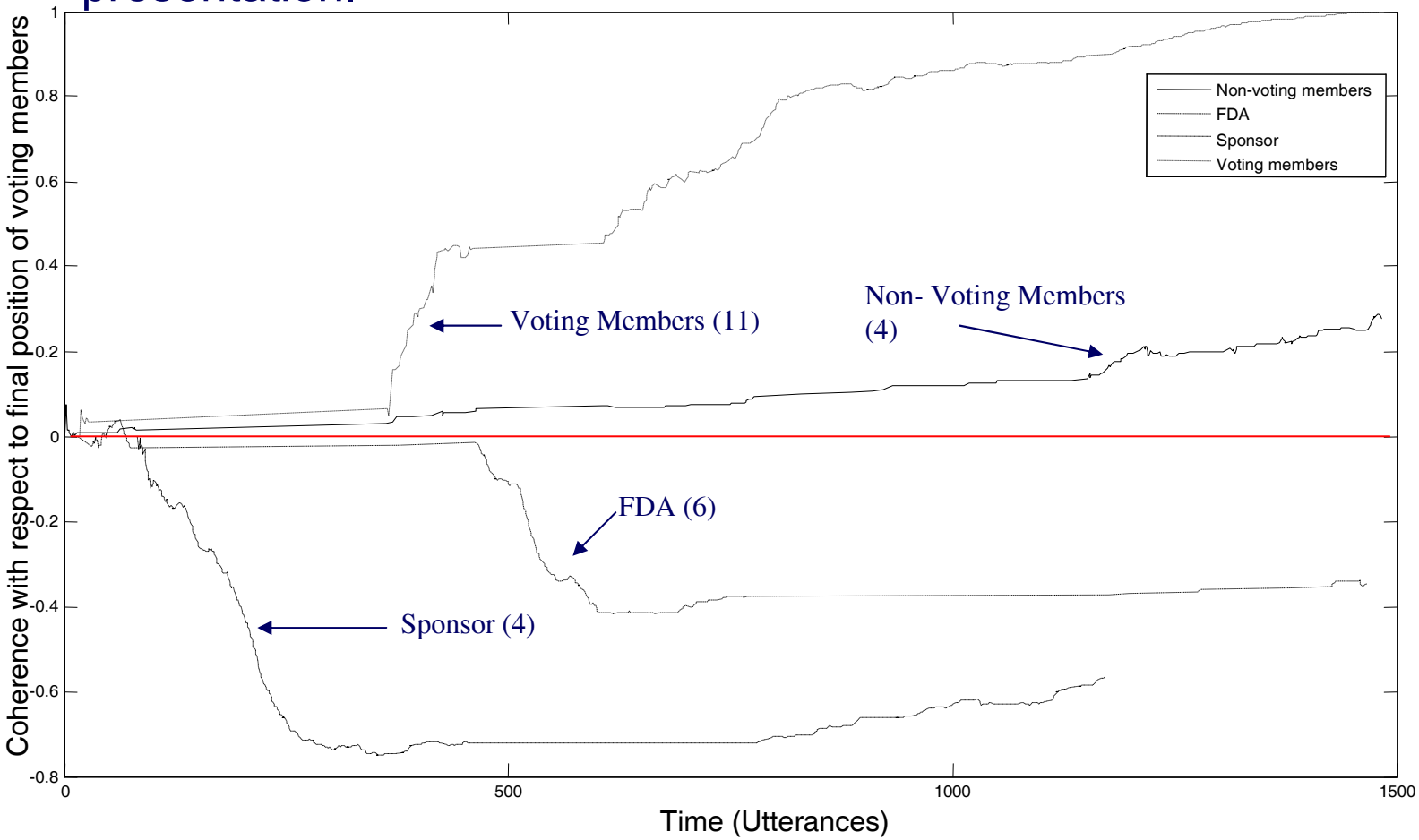
	FDA representatives and sponsors	Panel members
Cluster 1	2	14
Cluster 2	9	1

$(p = 9.97 \times 10^{-5};\ \chi^2 = 15.14;\ df = 1)$

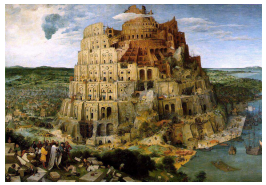
Coherence Analyses



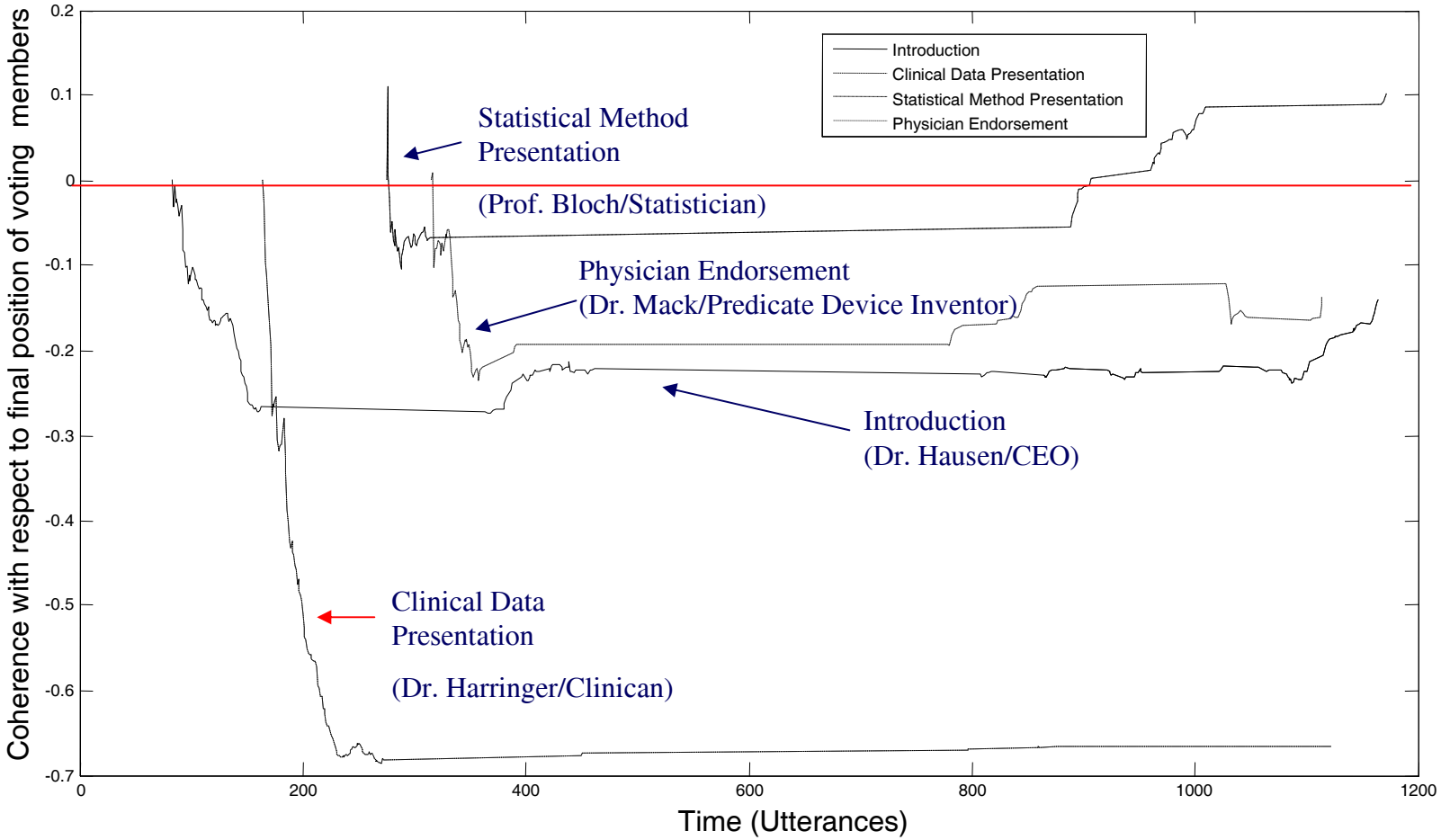
- Sponsor has very low coherence measured relative to the final centroid of the voting members; drop concurrent with data presentation.



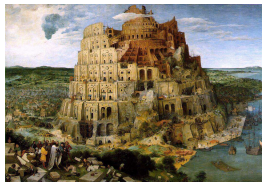
Coherence Analyses



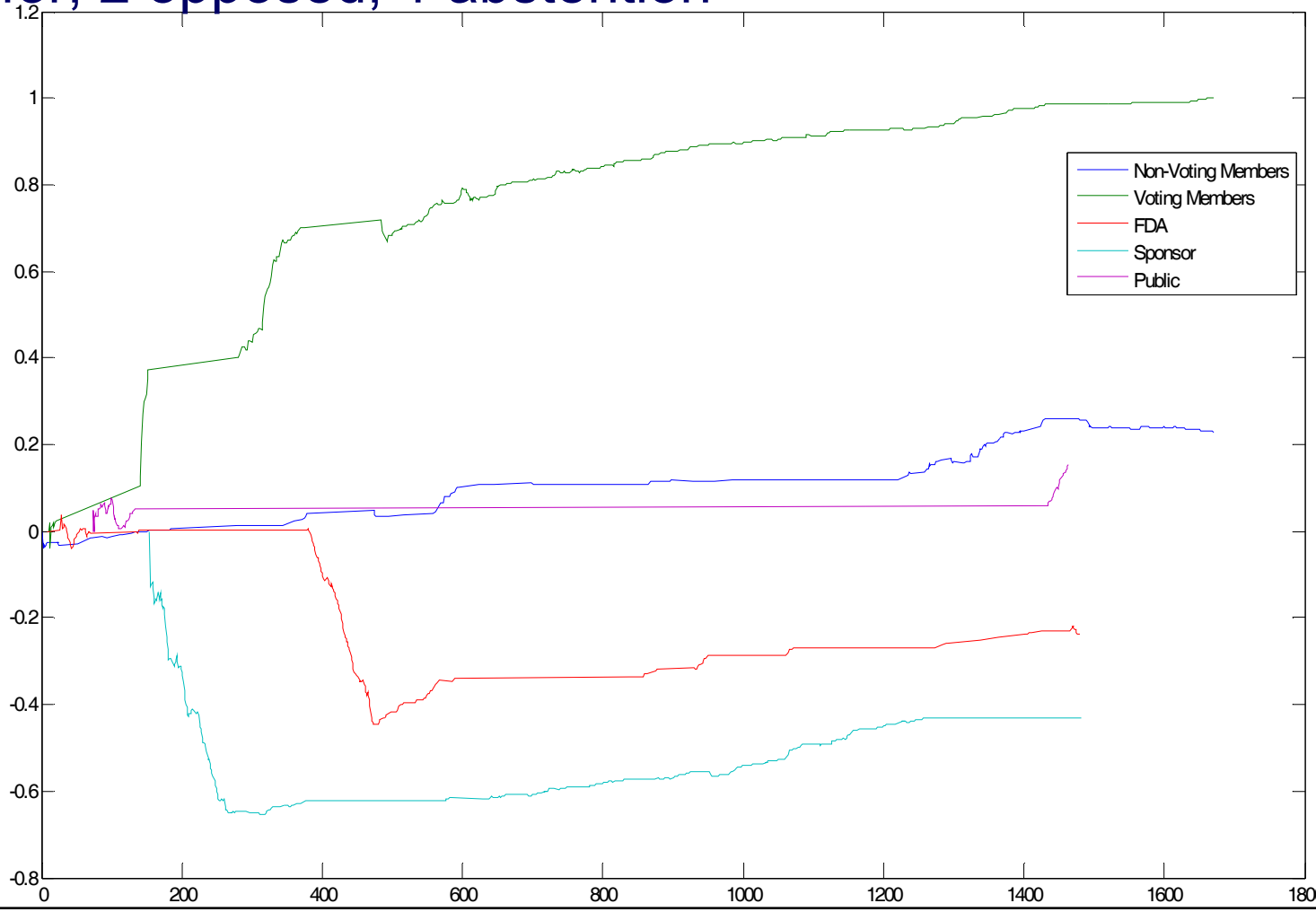
- Drop in sponsor's coherence relative to voting members is concurrent with their presentation of the data



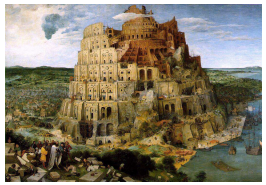
Jan. 13th 2005 Meeting – Gore TAG Septal Occluder



- Device was approved with conditions
  - 9 for, 2 opposed, 1 abstention

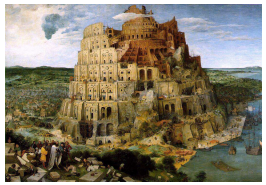


Preliminary Insights



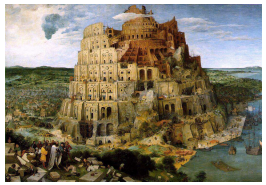
- PAS-Port is successfully marketed in Japan and Europe
  - Still undergoing clinical trials in the US as of Feb. 2008
- Panel had near-consensus not to approve device
  - Dissenter not an expert in a cardiac domain
  - Argued that device was likely safe and very efficacious
- Decision seemed to be based more on data uncertainty; less on clinical experience.
  - Little discussion about propriety of FDA's choice of *post hoc* confidence bounds.
  - Q3: Was the specialized knowledge of committee members put to its best/fullest use?

Figuring Out Which Design Knobs to Turn (Preliminary)



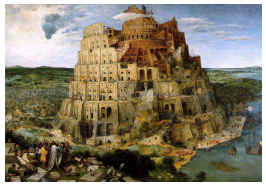
Testing for	Explanatory Variable	Dependent Variable
Construction of shared understanding	Membership in lexical clusters (**Committee Makeup**)	E.g., membership in voting groups
Effect of data uncertainty on voting pattern	Average & variance in semantic coherence (**Voting Process**)	E.g., variance in votes, number of votes, number of proposed conditions.
Effect of committee chair on voting patterns	Coherence with respect to **Committee Chair**	E.g., variance in votes
Stakeholder learning, and institutional adaptation	**Time** voting members have served on same committee	Inter-stakeholder semantic coherence, references, and order of speech.
Consensus on committee's recommendations within the profession	FDA recommendation at the committee meetings (**validation**)	Actual device safety and efficacy (as evaluated by outside experts in the medical community & meta-analyses)

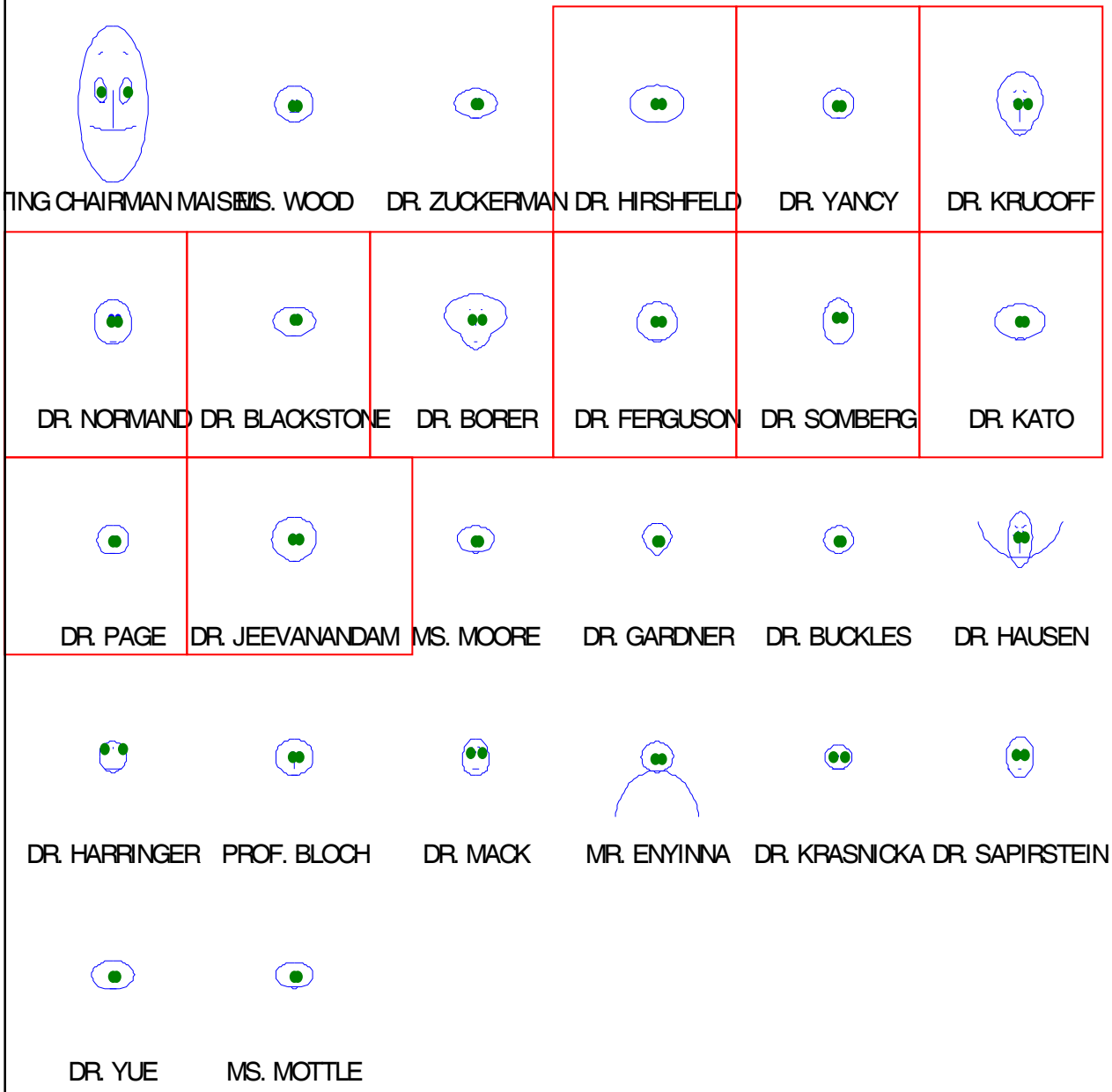
Next Steps



- Continue the analysis, focused on preliminary questions and other cases
  - Cross-sectional analysis: Analyze "famous" cases covered in literature in multiple committees
    - E.g. – Cardiac stents
  - Longitudinal analysis: Analyze one committee over 10-year period
- Implications for safety and efficacy – study meta-analyses and post-market analyses to determine the effectiveness of advisory committee recommendations
- Compare results to existing theoretical frameworks
- Experiment with other NLP methods & data visualization methods (e.g., LDA topic models (Blei et al. 2003))

PAS-Port Case: Concept Clusters





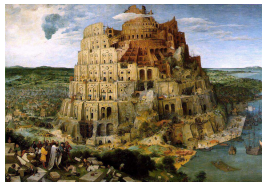
Concept Clustering – "bins" utterances using algorithm developed by Dhillon and Modha (1999)

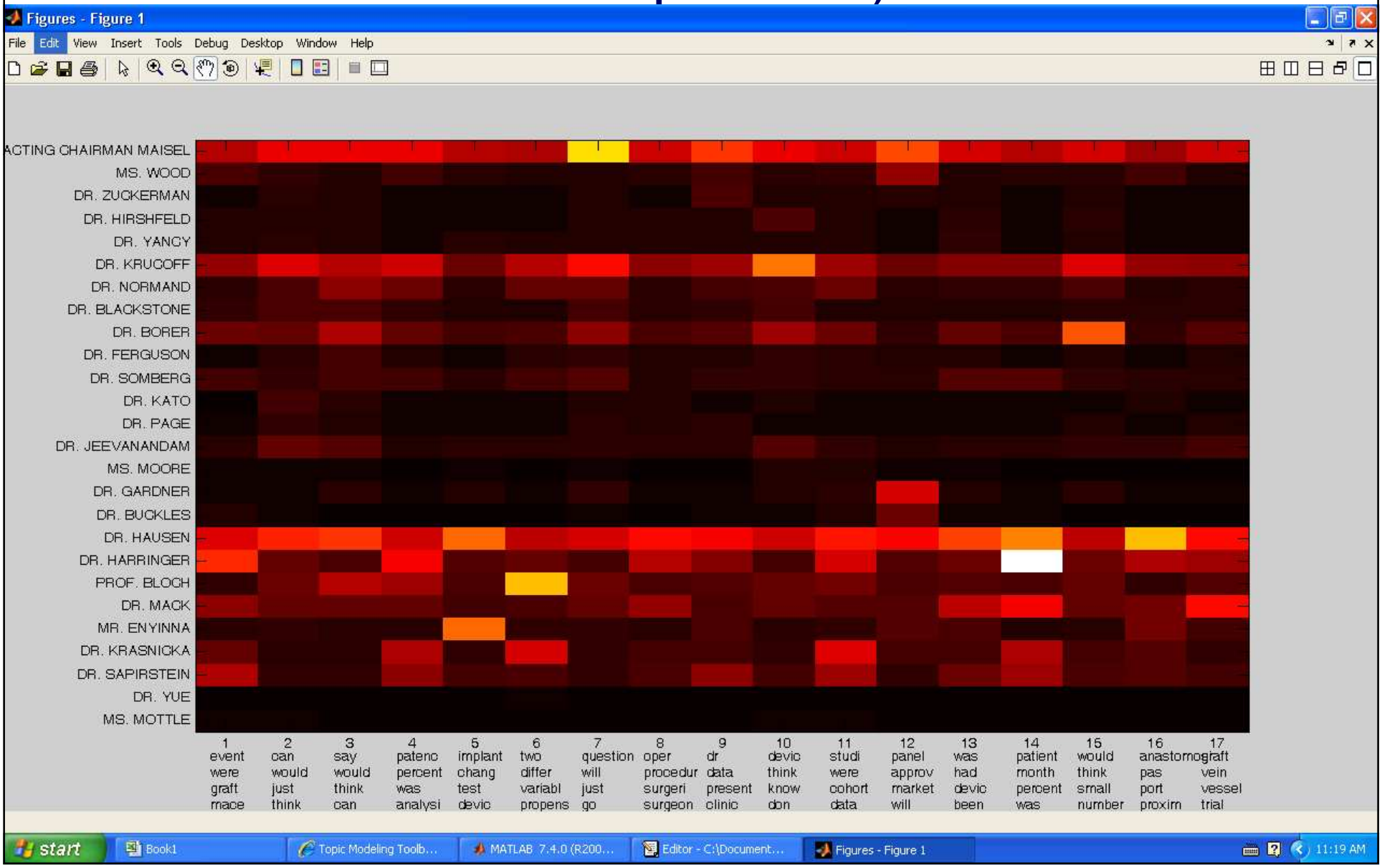
Visualization uses Chernoff Faces

Voting members are in red boxes

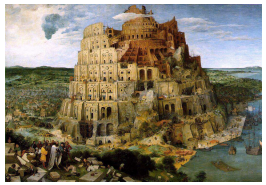
Recall that Dr. Somberg was the one abstention in this case, but that the voting members were largely aligned

PAS-Port Case (Running Sum of Proportions)



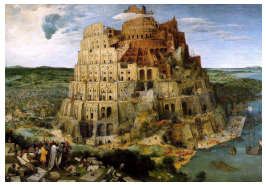


Summary



- Medical device approval is strongly influenced by institutional background
  - Strongly social and technical in nature; multi-stakeholder decisions, contained within a complex engineered system (health care)
- Expected Contributions:
  - **Methodological**: Algorithms and method for the analysis of expert committee meeting transcripts
  - **Theoretical**: New insights into group decision-making focusing on linguistic sources of influence.
  - **Practical**: Policy recommendations for how best to structure approval committees to enable medical device safety and efficacy while still promoting innovation

References (1)



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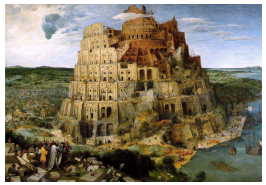

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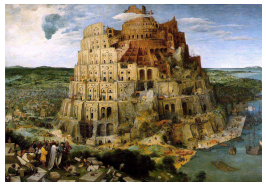

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