Information Theory in Visual Analytics

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including recent work in collaboration with
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Oxford e-Research Centre
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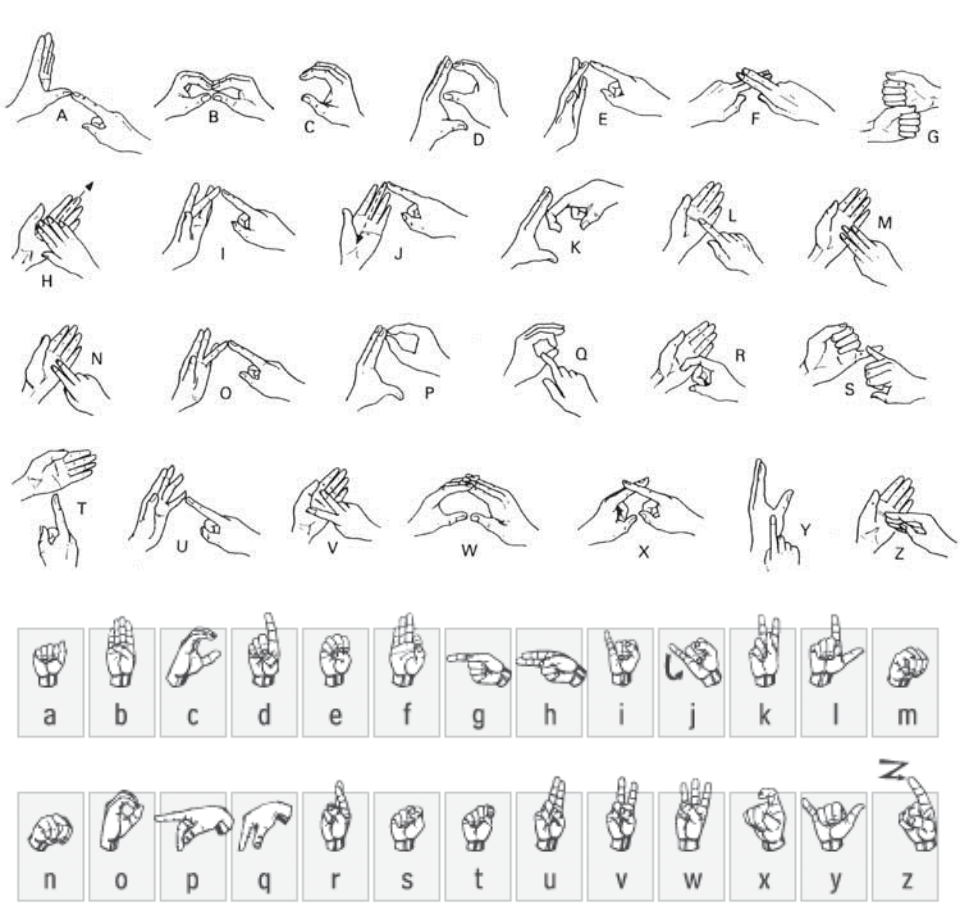
OXFORD e-Research CENTRE

UNIVERSITY OF OXFORD

http://www.bslhands4u.com/fingerspelling/4545036827
http://www.infoplease.com/ipa/A0200808.html



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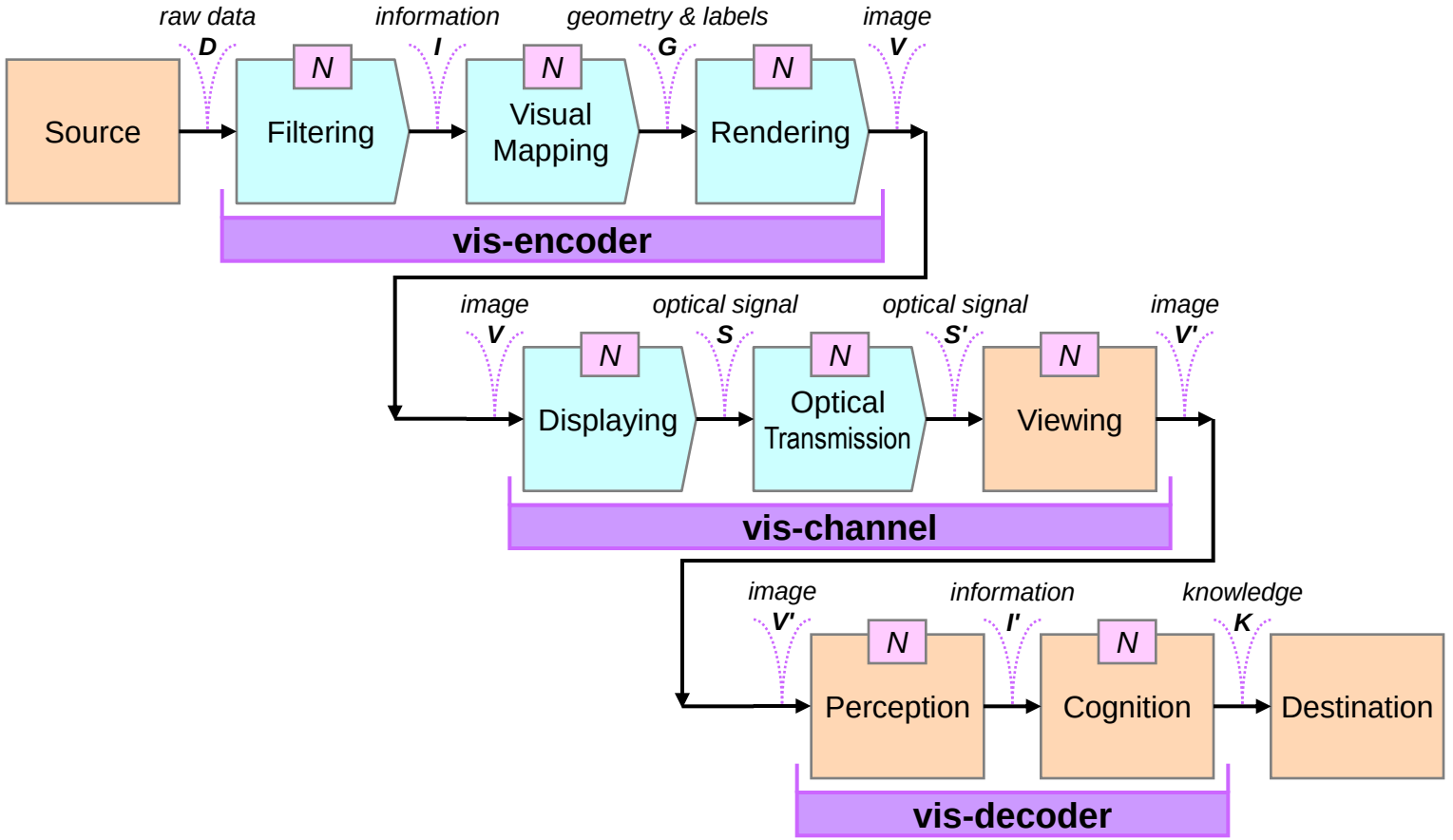
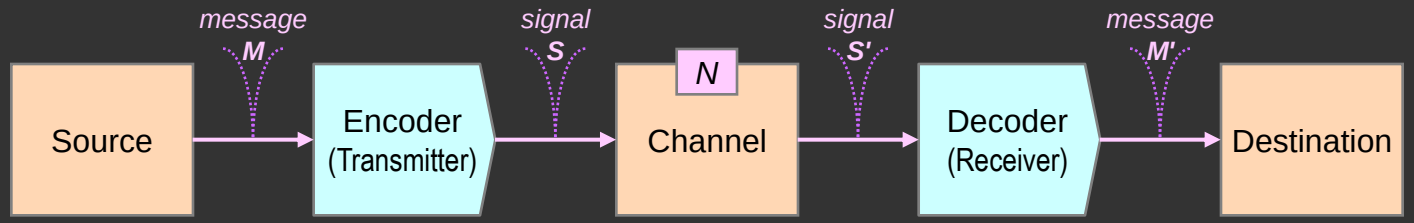
Three Visualization Subsystems





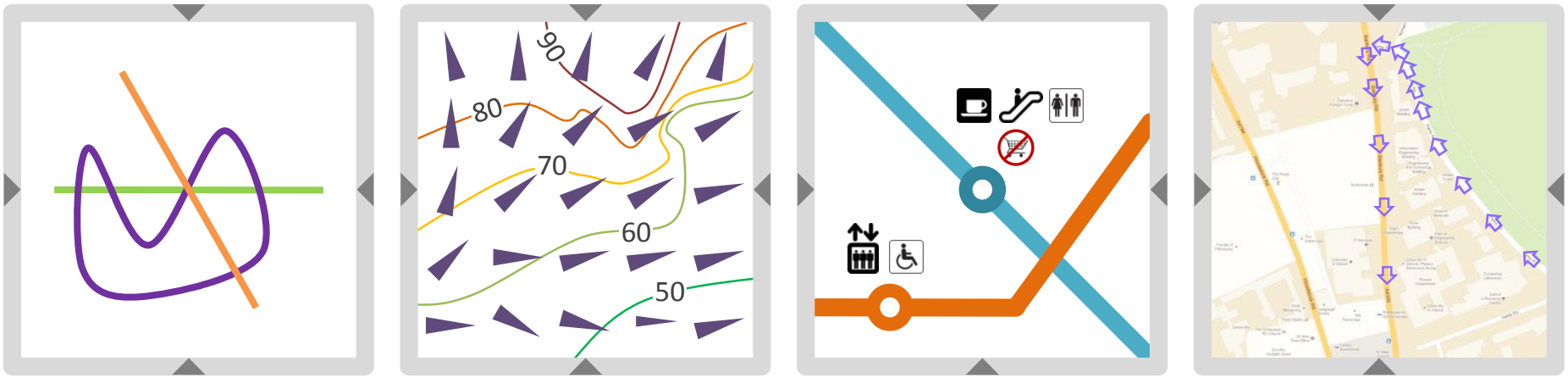
A General Communication System

Existing Uses of Information Theory

- Data processing
- View optimization
- Glyph design
- ...

- Theoretical framework
  - *Measuring visualization capacity, and related quantities*
  - *Explaining phenomena in visualization processes*
  - *Defining laws (mathematically-validated guidelines)*
  - *Defining algorithm- or data-driven metrics*
  - *Confirming the significance of visual analytics*

Example: Visual Multiplexing

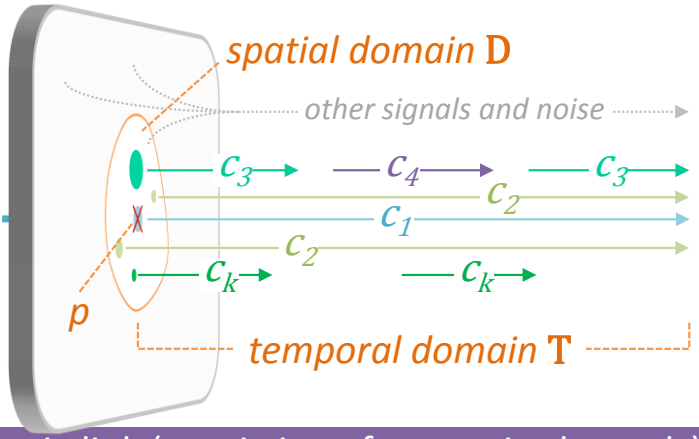


Location p can be associated with X in the source data or determined by a spatial mapping.

$X = \langle x_1, x_2, \cdots, x_k \rangle$ at p

MUX

X can be a data record or a set of partially encoded visual attributes.



Perceived information may include estimated values and relationships with data conveyed by other signals.

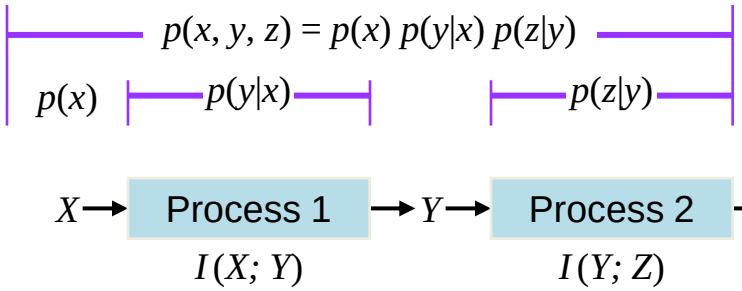
DEMUX

information about X at p

vis-encoder | vis-link (consisting of many vis-channels) | vis-decoder

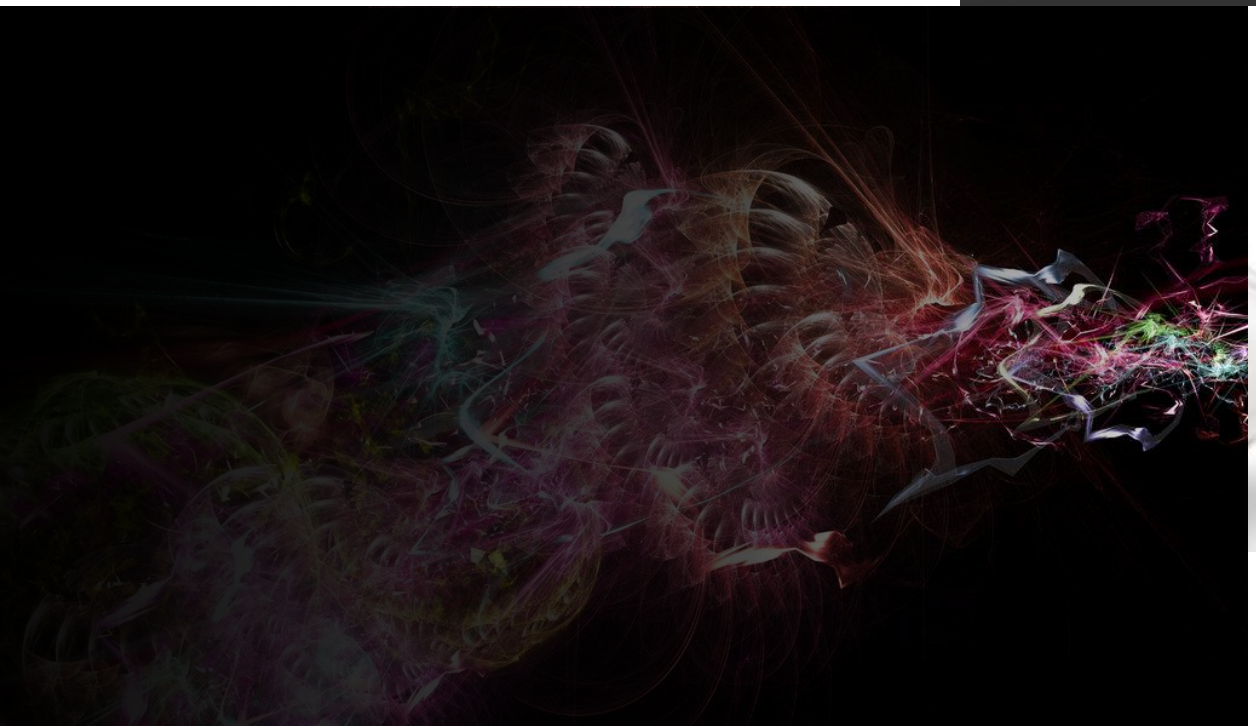
M. Chen *et al.*, "Visual multiplexing," *Computer Graphics Forum*, 2014

Data Processing Inequality

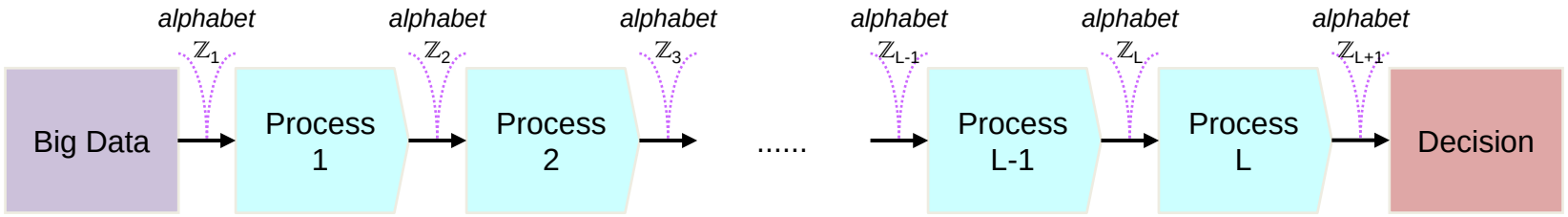


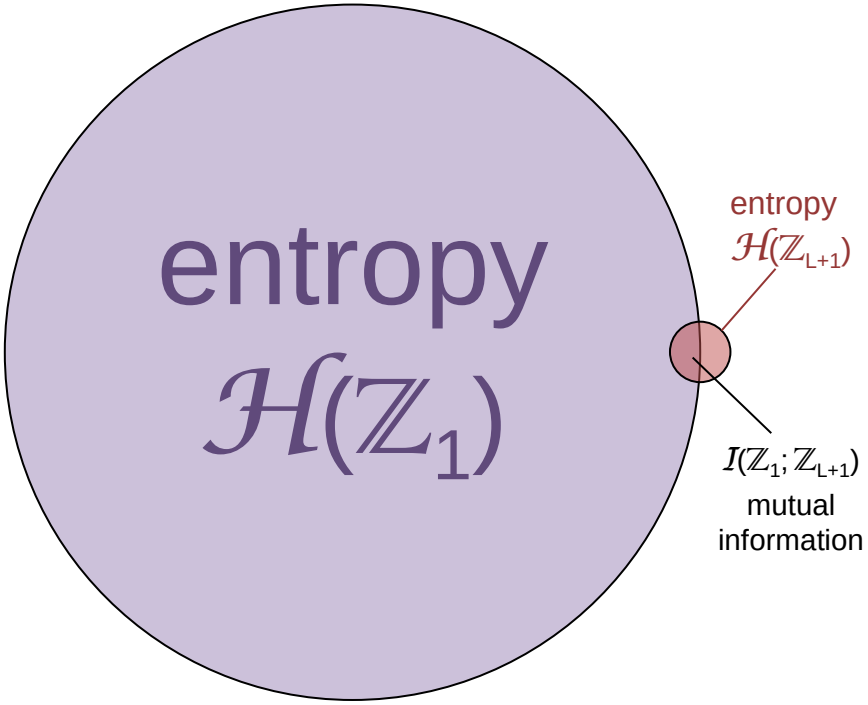
$$I(X;Y) \geq I(X;Z)$$

- "No clever manipulation of data can improve the inferences that can be made from the data" [Cover and Thomas, 2006]

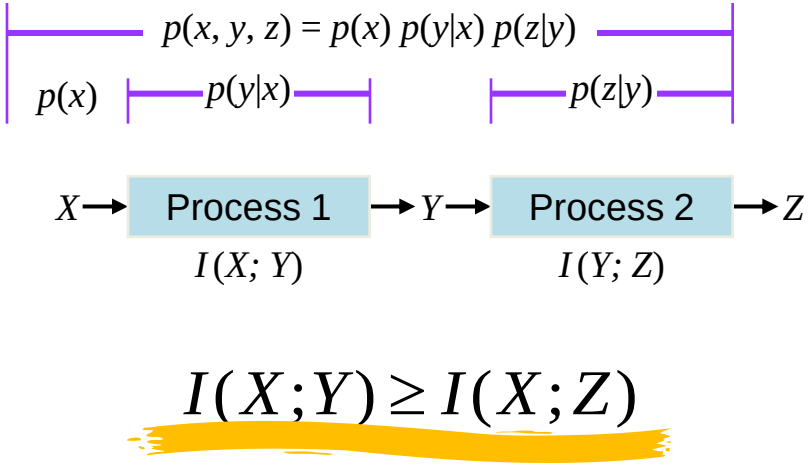


Data Processing Inequality: Big Data Input?

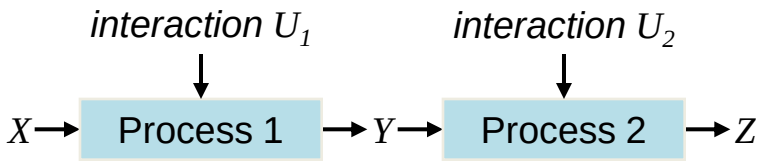


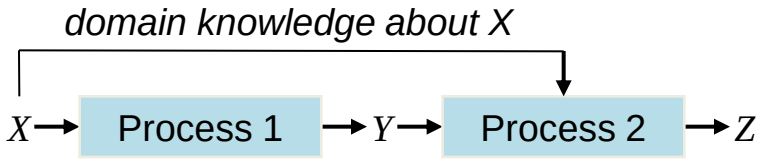


DPI is not Ubiquitous



$$I(X;Y) \geq I(X;Z)$$



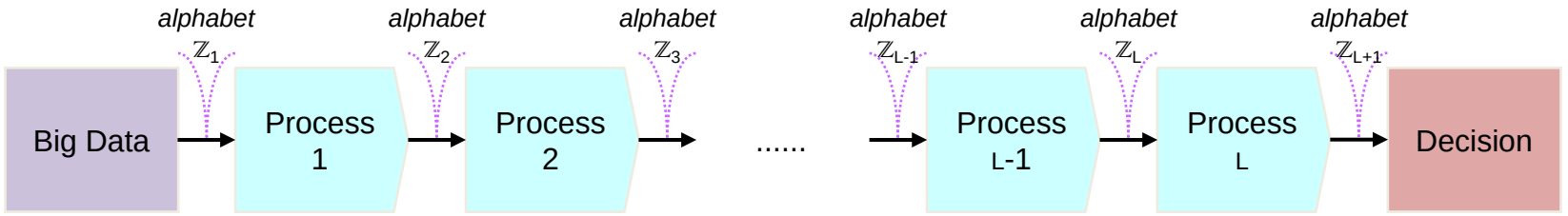


$$I(X;Y) \not\geq I(X;Z)$$

- Markov chain conditions
  - *Closed coupling: (X, Y), (Y,Z)*
  - *X and Z are conditionally independent*
- What if one of the conditions is broken?
- In visual analytics, both conditions are usually broken.

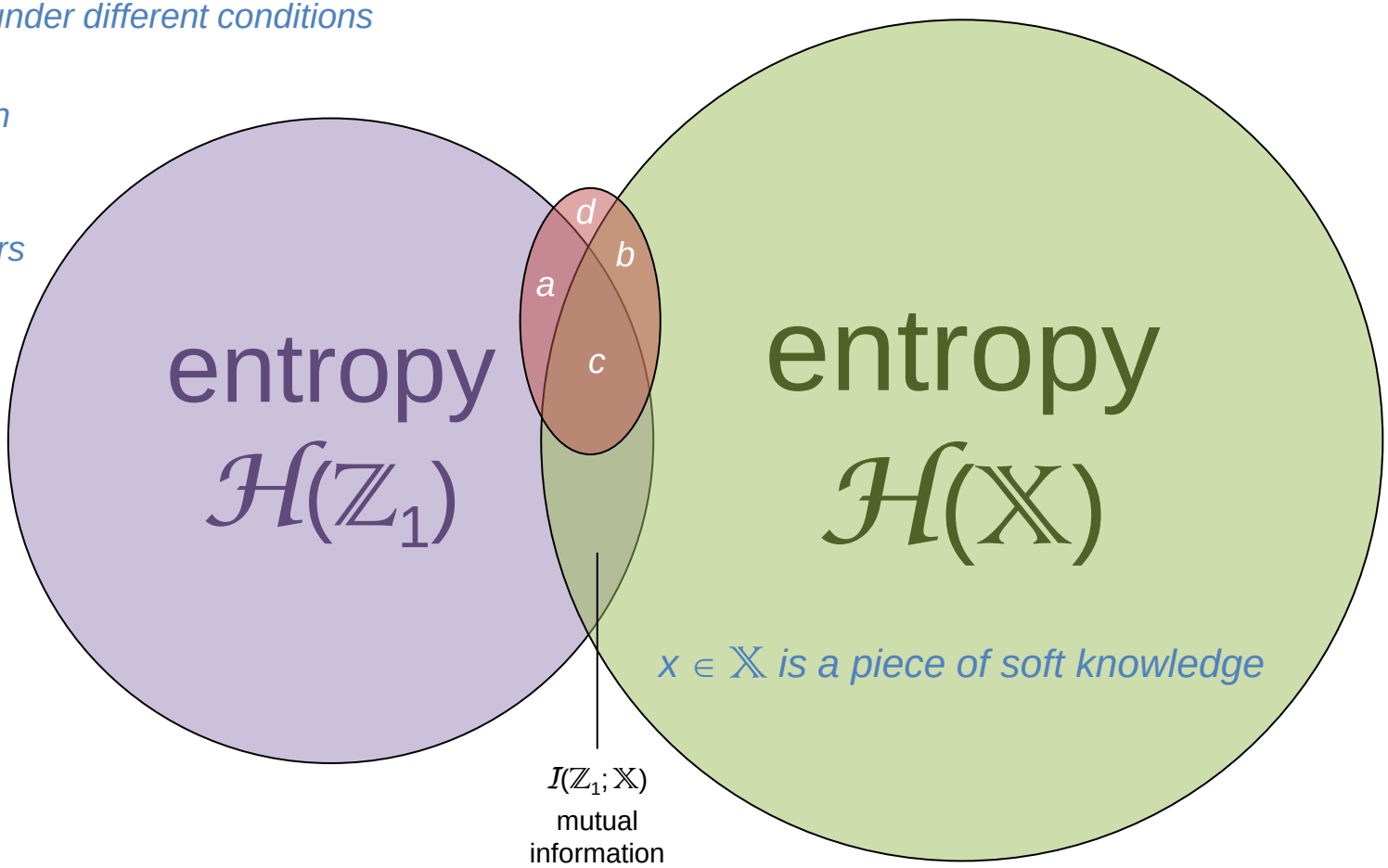
M. Chen and H. Jänicke, "An information-theoretic framework for visualization," *IEEE Transactions on Visualisation and Computer Graphics*, 2010

Soft Knowledge in Decision Space



All possible decisions under different conditions

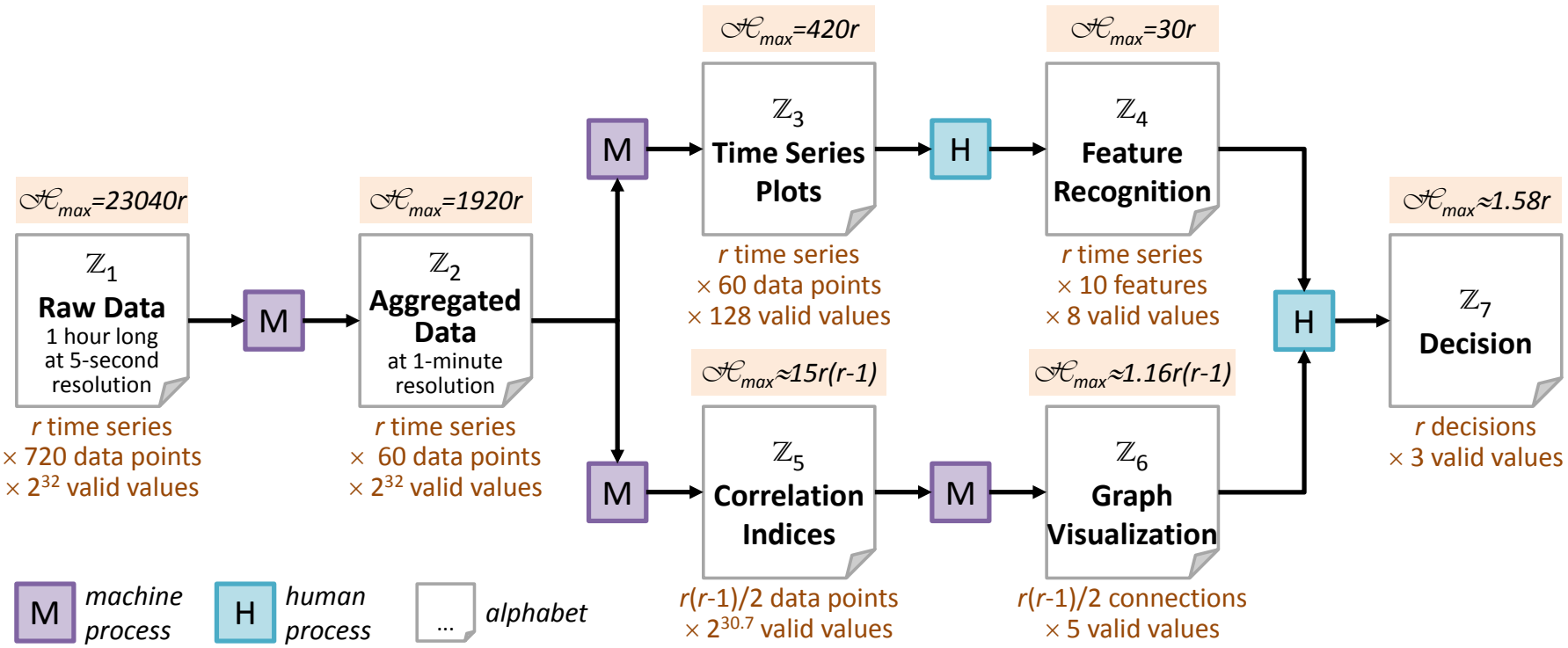
a) *totally data-driven*
b) *totally instinct-driven*
c) *data-informed*
d) *due to unknown or uncontrollable factors*



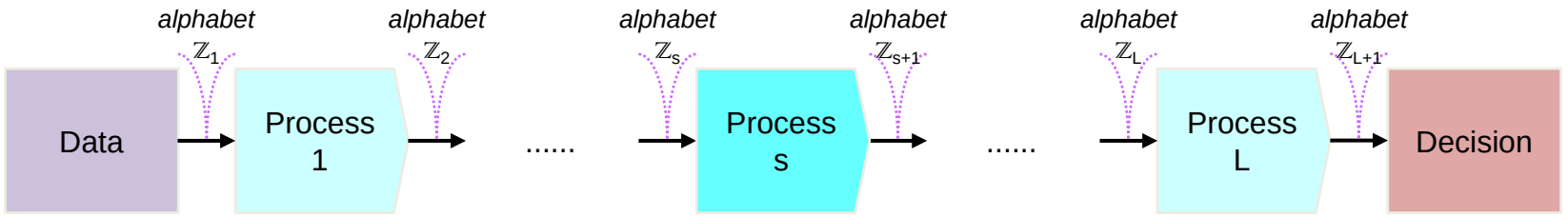
An Example Data Analysis and Visualization Process

- *r* time series
- 720 data point each series
- 2^{32} valid value each point

- *r* decisions
- 3 valid values each (e.g., buy, sell, hold)



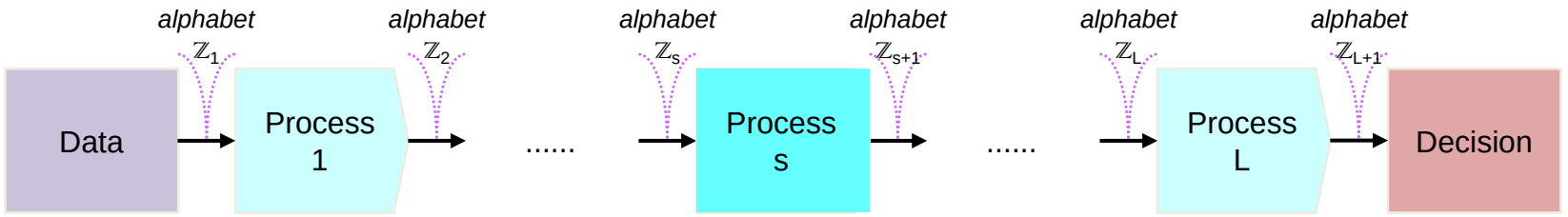
A Sequential Workflow and Two Basic Metrics



- The s^{th} Function (Process): $F_s : \mathbb{Z}_s \longrightarrow \mathbb{Z}_{s+1}$
- Alphabetic Compression Ratio (ACR): $\Psi_{ACR}(F_s) = \frac{\mathscr{H}(Z_{s+1})}{\mathscr{H}(Z_s)}$
- A Reverse "Guessing" Process: $G_s : \mathbb{Z}_{s+1} \longrightarrow \mathbb{Z}'_s$
- Potential Distortion Ratio (PDR): $\Psi_{PDR}(F_s) = \frac{\mathscr{D}_{KL}(Z'_s||Z_s)}{\mathscr{H}(Z_s)}$

M. Chen and A. Golan, "What may visualization processes optimize?," *under review*, 2015

Cost-Benefit Ratio



- Effectual Compression Ratio (ECR):

$$\Psi_{ECR}(F_s) = \frac{\mathscr{H}(Z_{s+1}) + \mathscr{D}_{KL}(Z'_s||Z_s)}{\mathscr{H}(Z_s)}$$

- Incremental Cost-Benefit Ratio (ICBR):

$$\Upsilon(F_s) = \frac{\mathscr{B}(F_s)}{\mathscr{C}(F_s)} = \frac{\mathscr{H}(Z_s) - \mathscr{H}(Z_{s+1}) - \mathscr{D}_{KL}(Z'_s||Z_s)}{\mathscr{C}(F_s)}$$

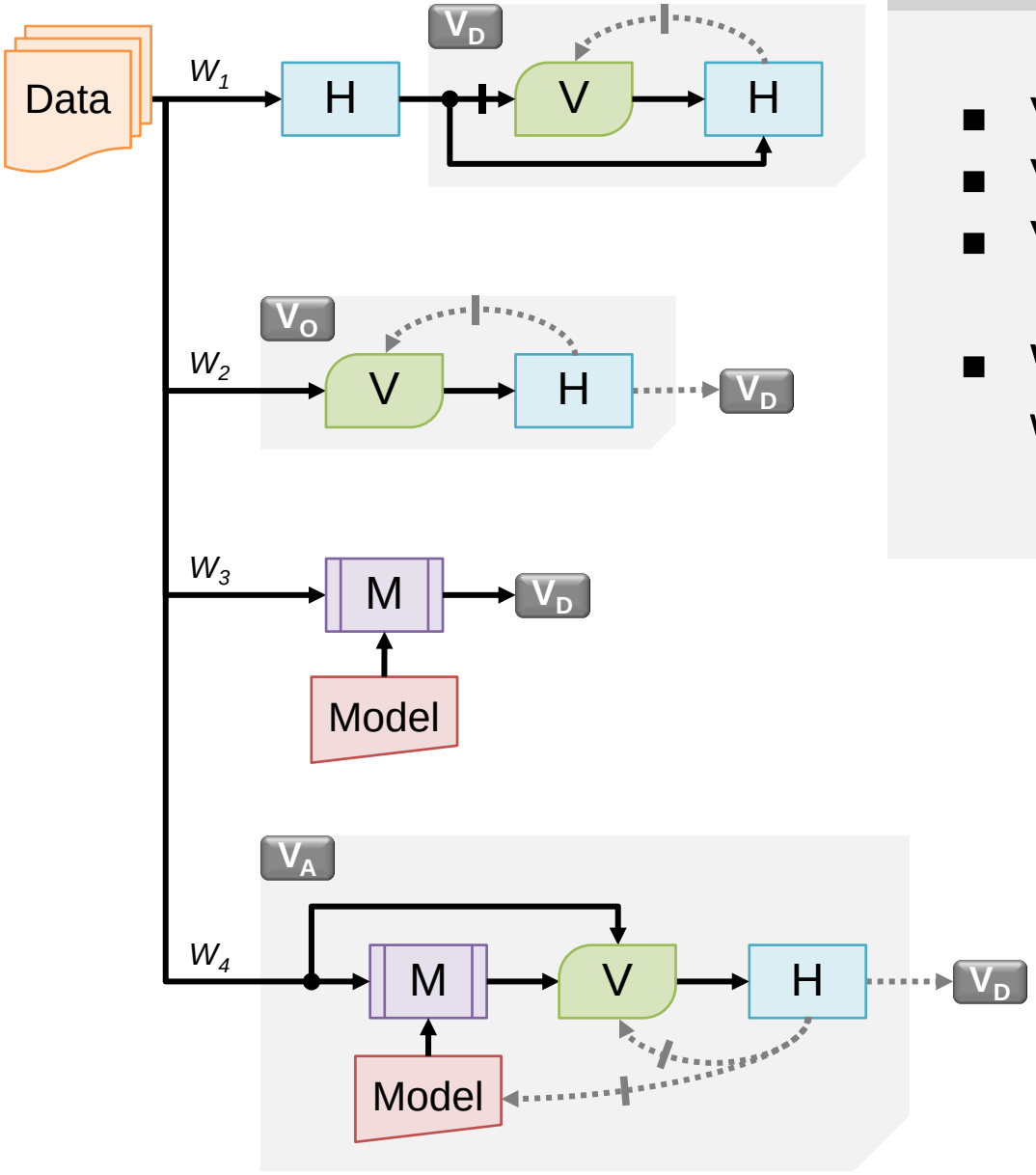
- *Cost can be measured in energy, time, money, etc.*

M. Chen and A. Golan, "What may visualization processes optimize?," *under review*, 2015

Four Levels of Visualization

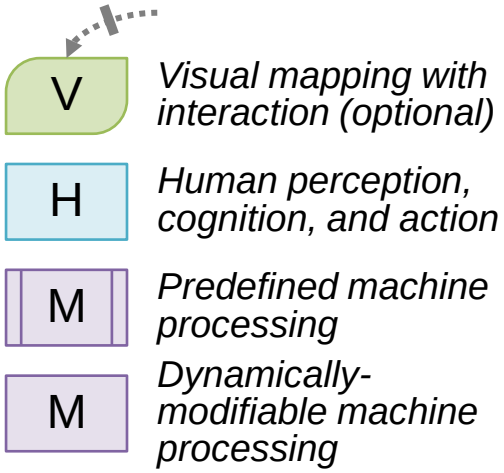
1. Disseminative Level (This is A!)
   - *A presentational aid for disseminating information or insight to others.*
   - *The creator does not expect to gain much new knowledge.*
2. Observational / Operational Level (What, when, where?)
   - *An operational aid that enables intuitive and/or speedily observation of captured data. Often part of routine operations.*
   - *Confirmatory observation, anomaly detection., etc.*
3. Analytical Level (Does A relate to B? Why)
   - *An investigative aid for examining and understanding complex relationships (e.g., correlation, causality, contradiction).*
   - *Evaluating hypotheses, models, methods, algorithms and systems.*
4. Model-developmental Level (How does A lead to B?)
   - *A developmental aid for improving existing models, methods, algorithms and systems, as well as the creation of new ones.*

Levels 1, 2, 3



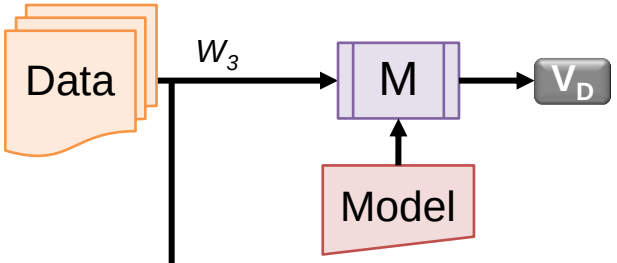
- V_D: Disseminative Visualization
- V_O: Observational Visualization
- V_A: Analytical Visualization

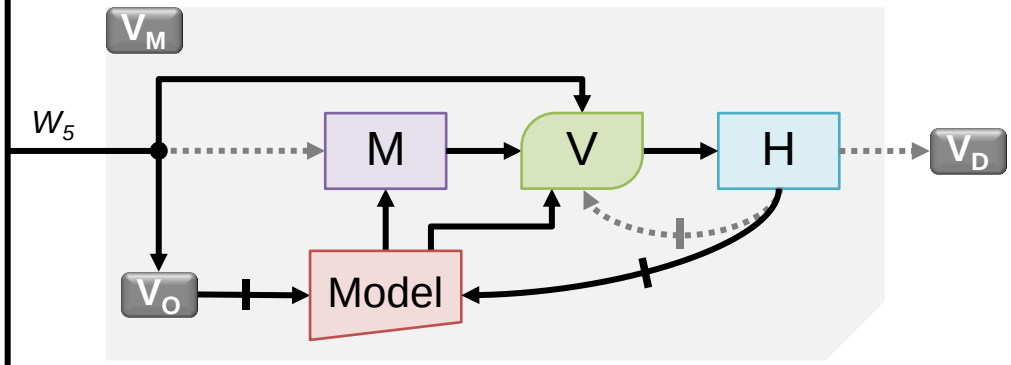
- When will workflow W_3 work and when will not?

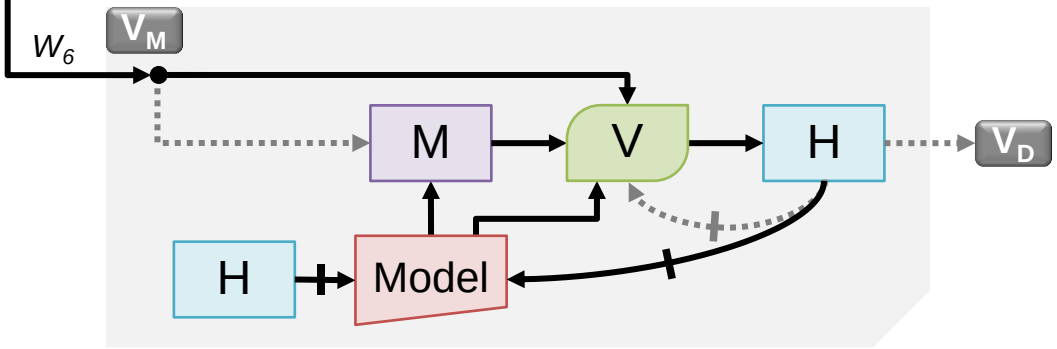


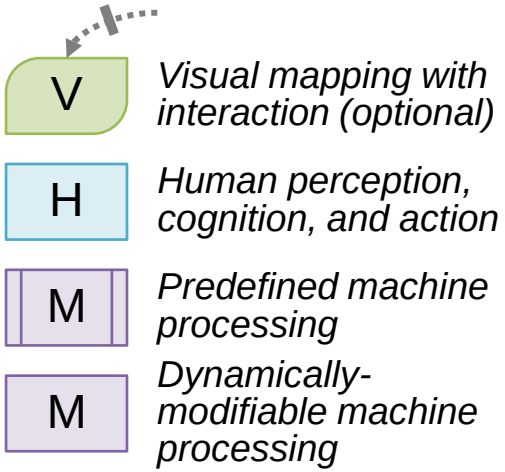
Level 4

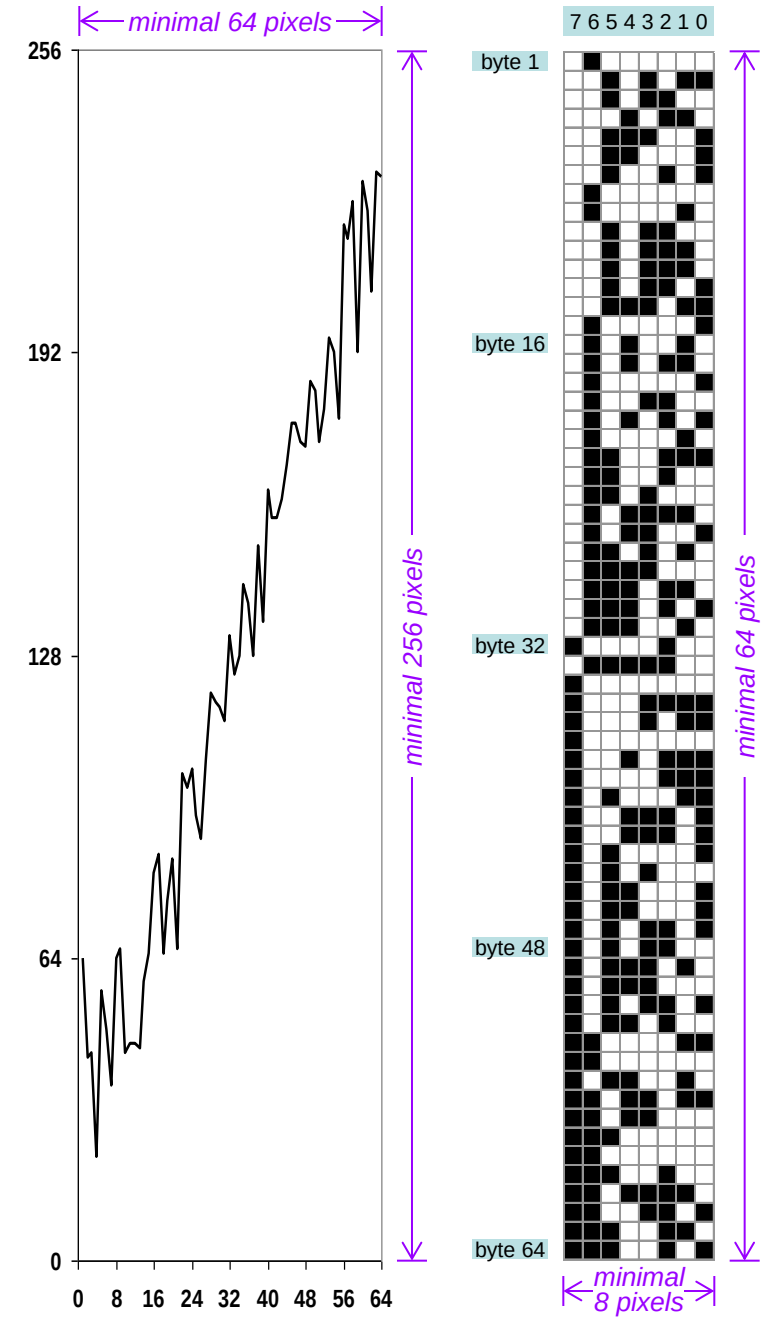
- When workflow W_3 does not work well, then ...
- V_M: Model-developmental Visualization











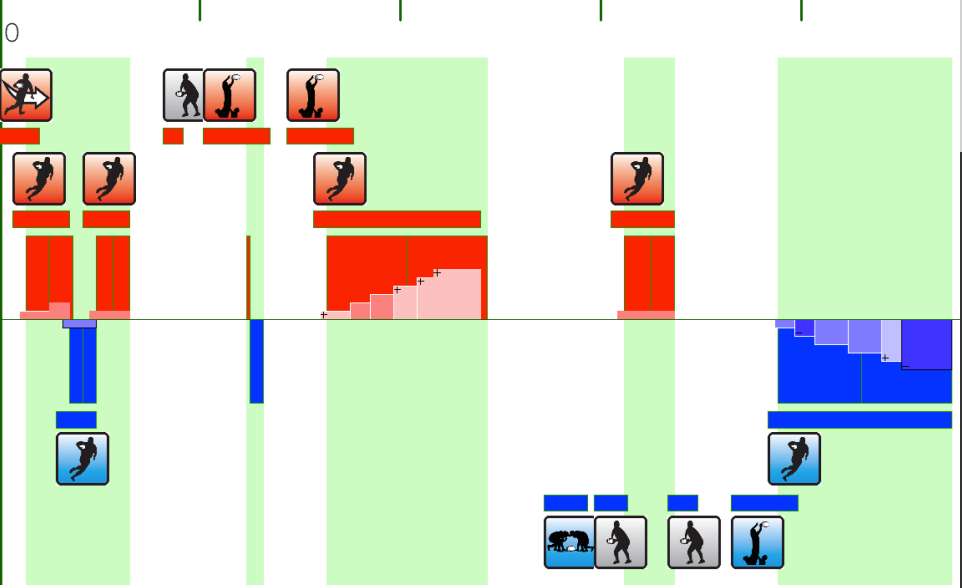
Example: Level 1

- Entropy of Data Alphabet

$$\boldsymbol{H}(Z) = -\sum_{t=0}^{64}\sum_{i=0}^{255}\frac{1}{256}\log_2\frac{1}{256} = 512$$

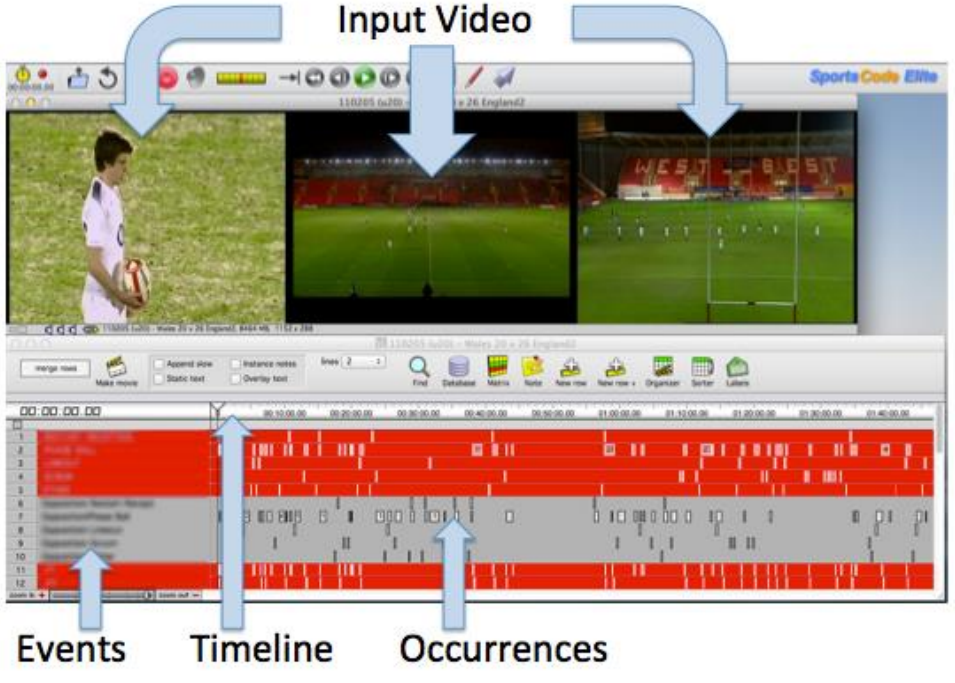
- Binary Pixel Plot
  - *4x4 pixels per bit* $\rightarrow 2^{13}$ *bits*
- Time Series Plot
  - *Minimal 256x64 pixels* (2^{14} *bits*)
- The more compact, the better?

Example: Level 2

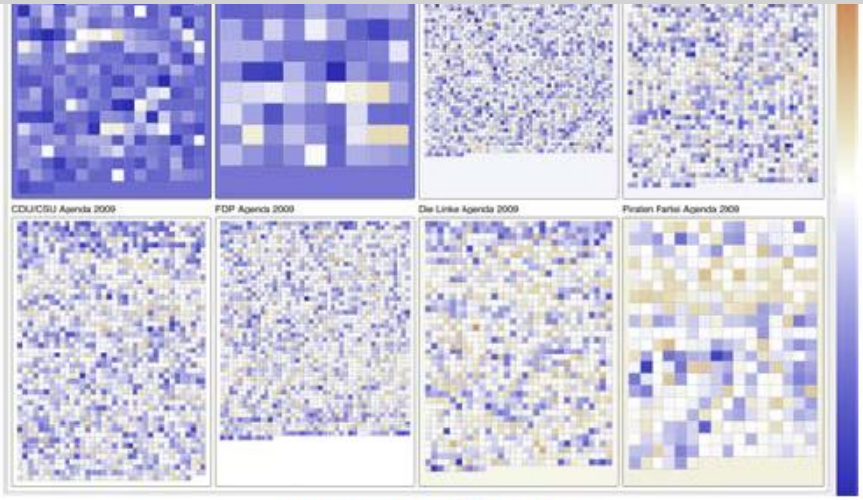


- Real-time or offline annotation results in a huge spreadsheet of events

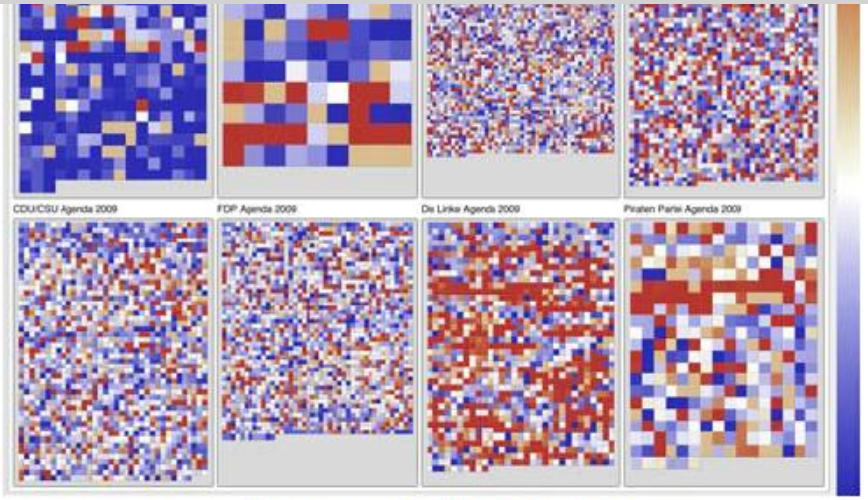
Legg *et al.*, “MatchPad: interactive glyph-Based visualization for real-time sports performance analysis,” *Computer Graphics Forum*, 2012



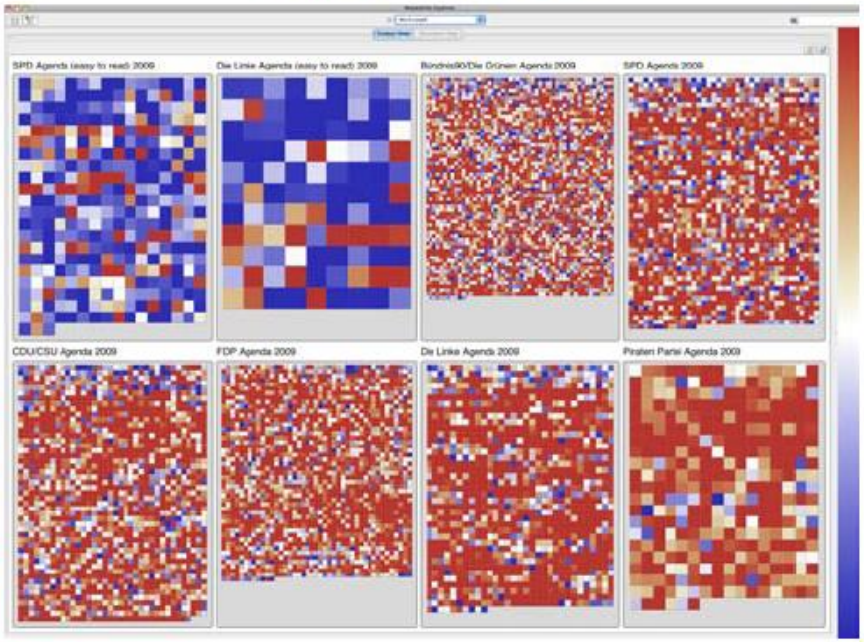
Example: Level 3



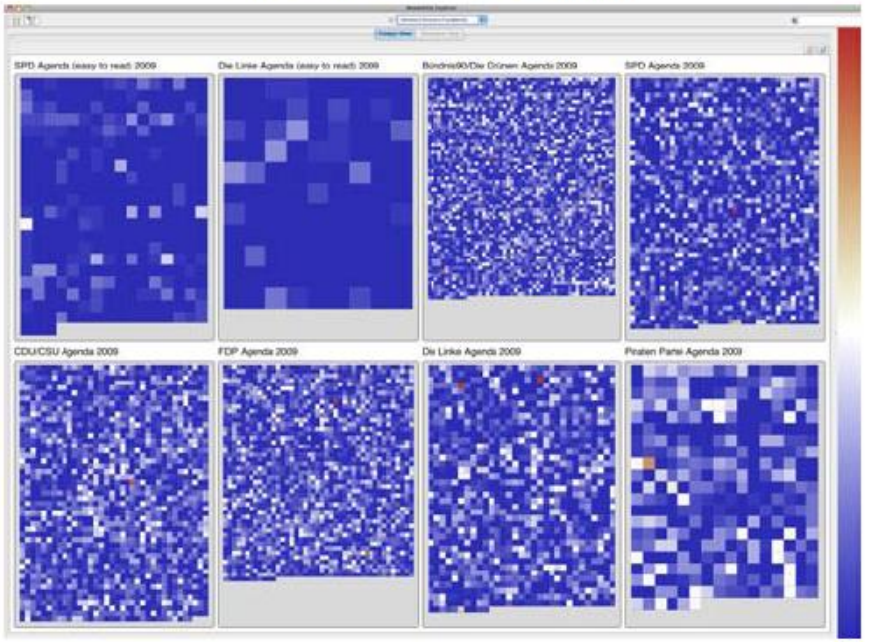
(a) Average Readability Score



(b) Feature: Vocabulary Difficulty



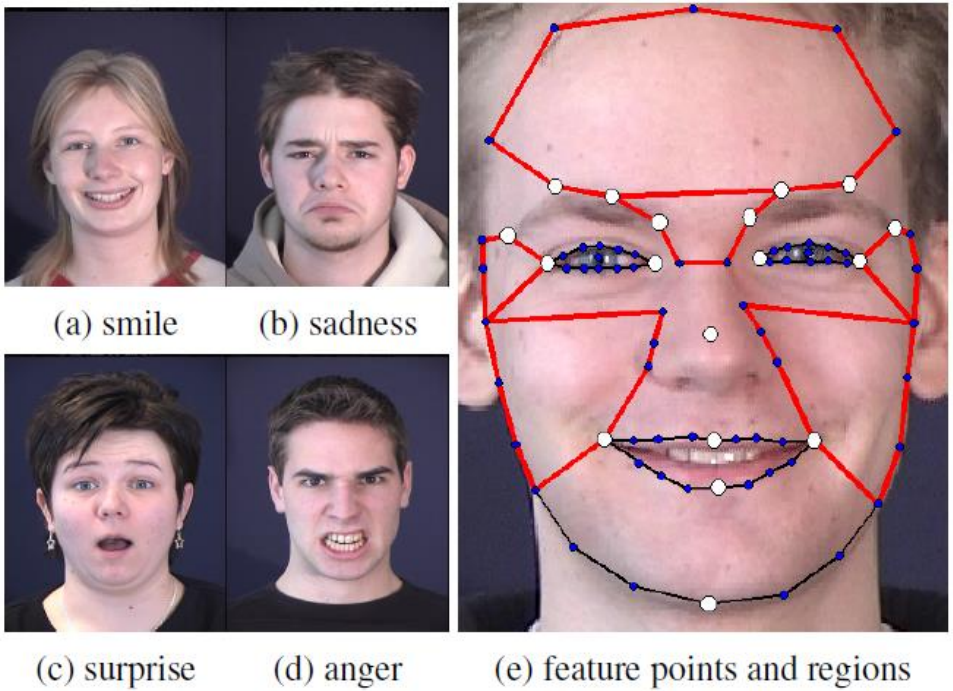
(c) Feature: Word Length

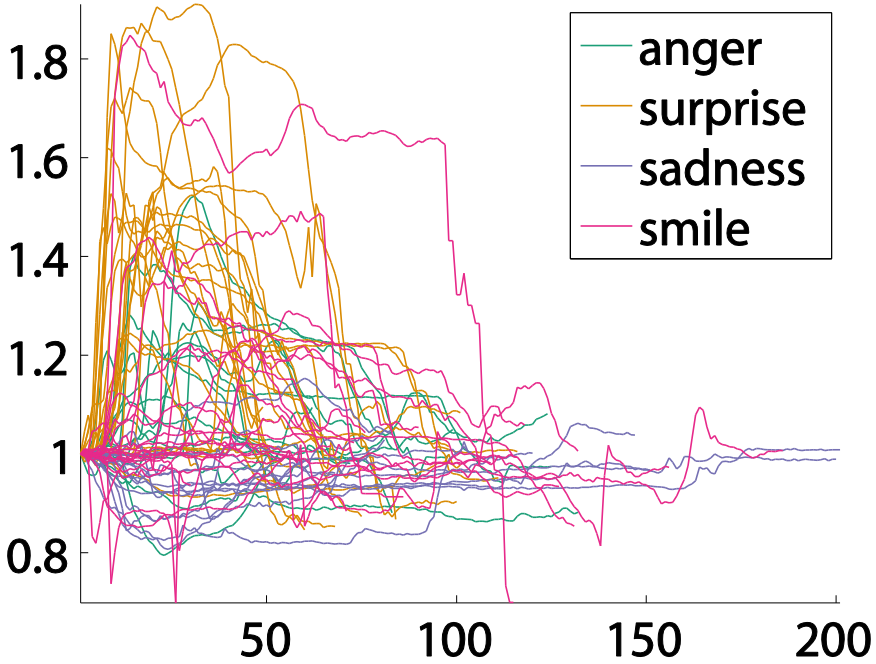


(d) Feature: Sentence Structure Complexity

D. Oelke, D. Spretke, A. Stoffel, D. Keim, “Visual readability analysis: How to make your writings easier to read,” *IEEE VAST*, 2010

Example: Level 4



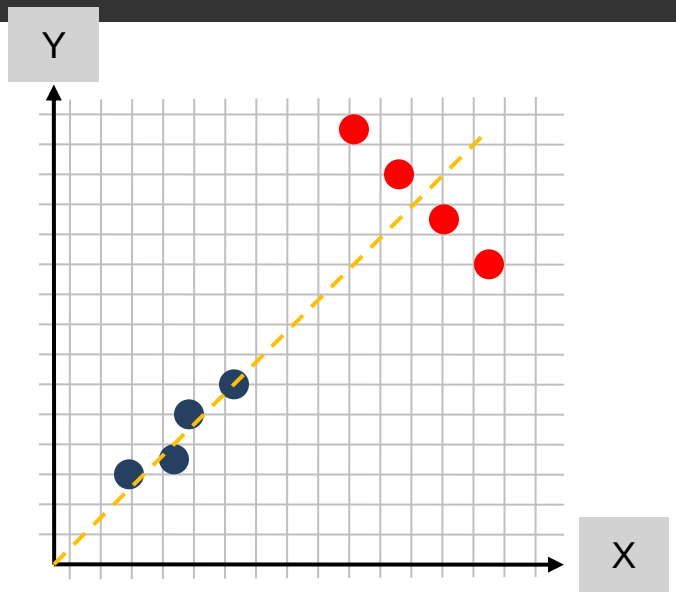


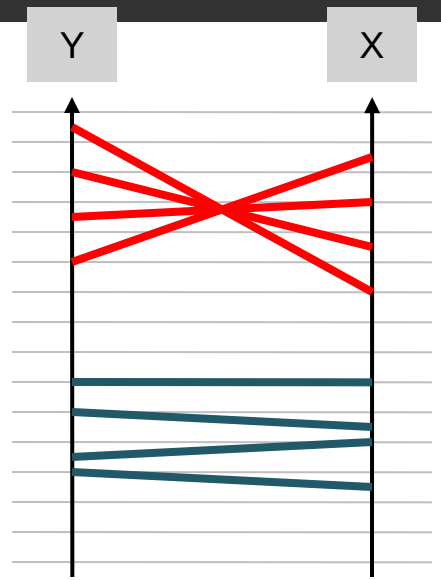
- Expression Recognition
  - *Humans are very good at*
  - *Machine vision is far behind*
  - *Limited understanding*
- Data
  - *Video*
  - *Feature changes*
  - *Time series*
- Challenges
  - *A lot of features*
  - *A lot of ways of measuring features*
  - *Non-uniform temporal behavior*

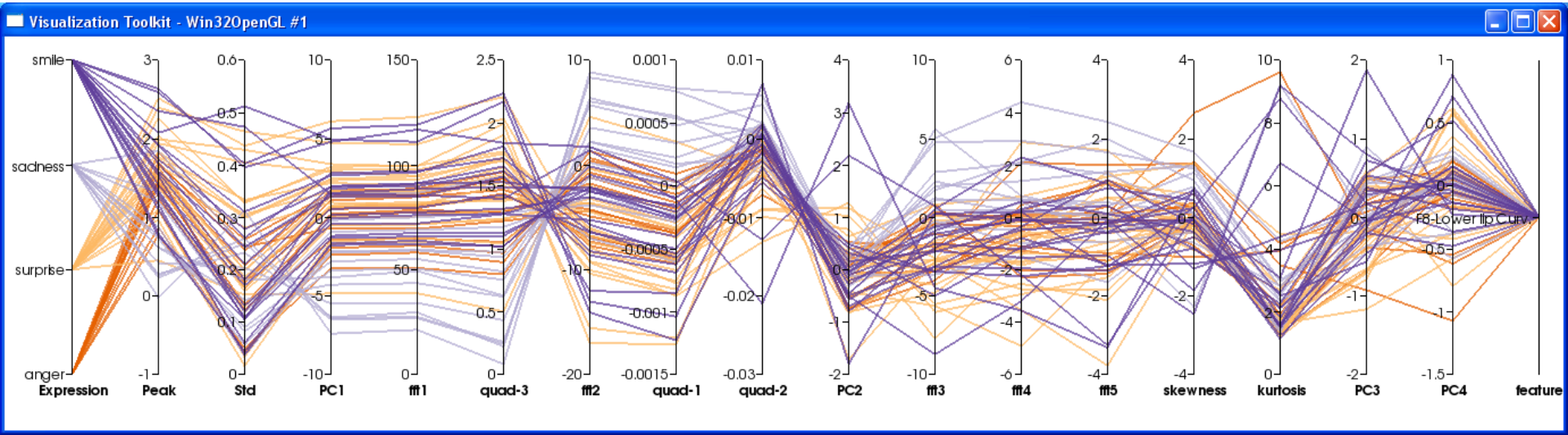
Tam *et al*., "Visualization of time-series data in parameter space for understanding facial dynamics," *Computer Graphics Forum*, 2011

Parallel Coordinates

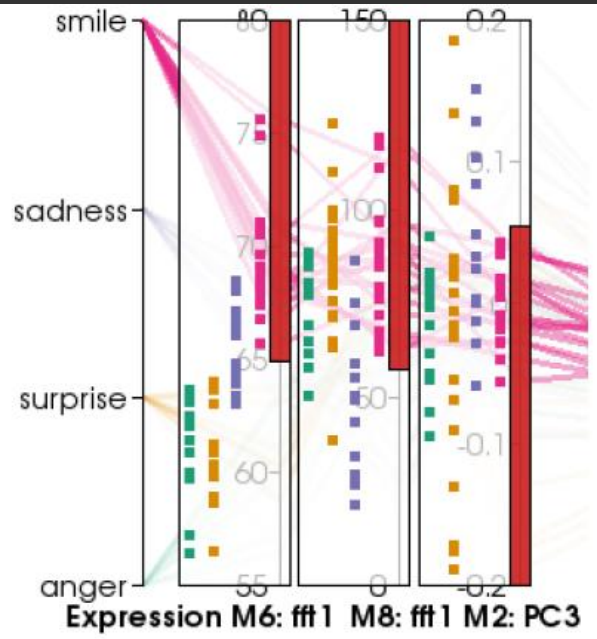
- Multi-dimensional data visualization



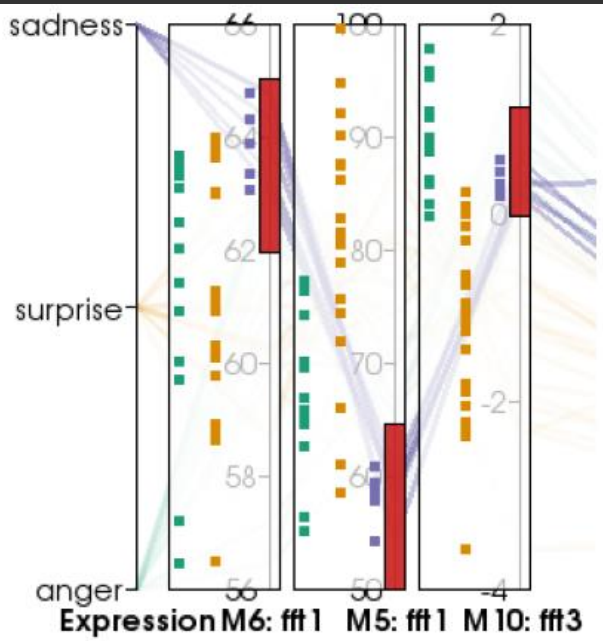




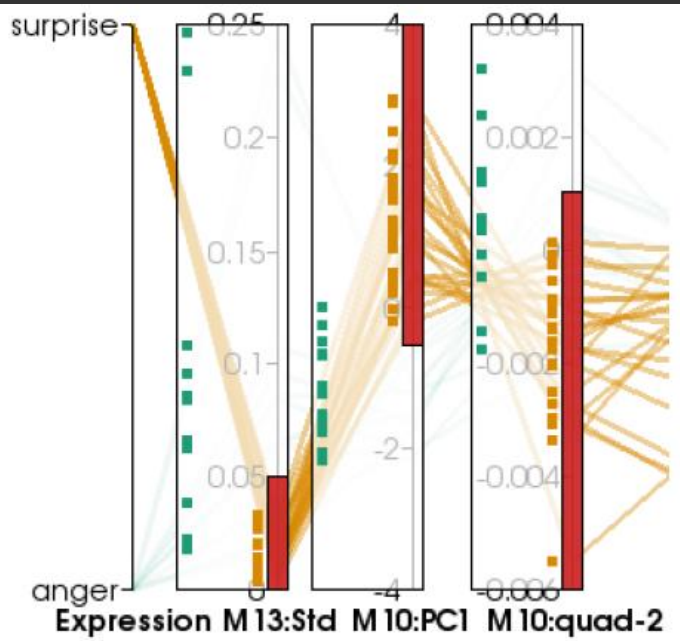
Interactive Visualization: Formulating Decisions



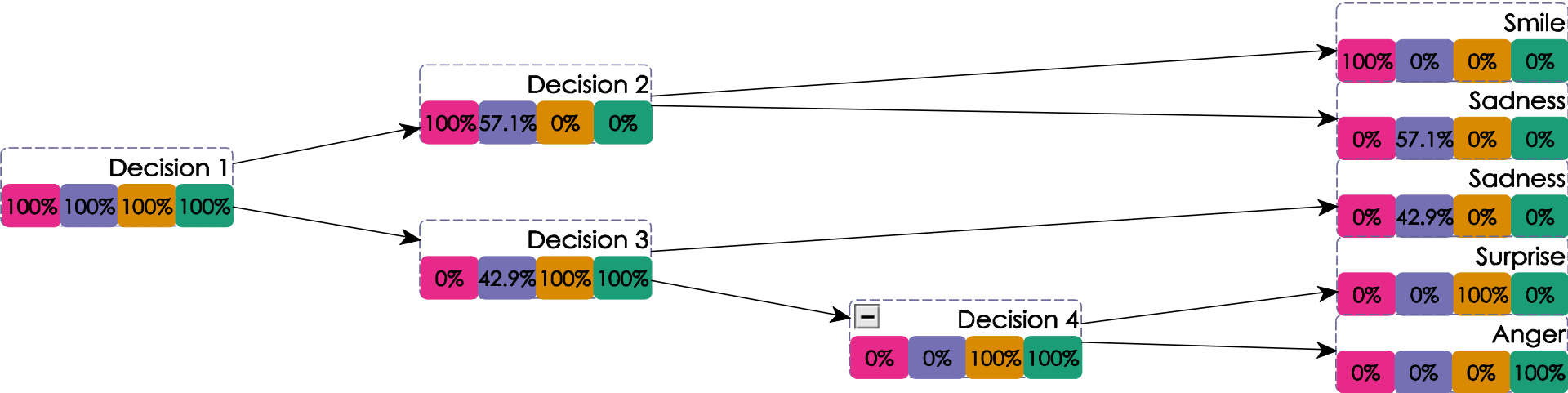
(a) Separate smile from all expressions



(b) Identifying sadness at Decision 3



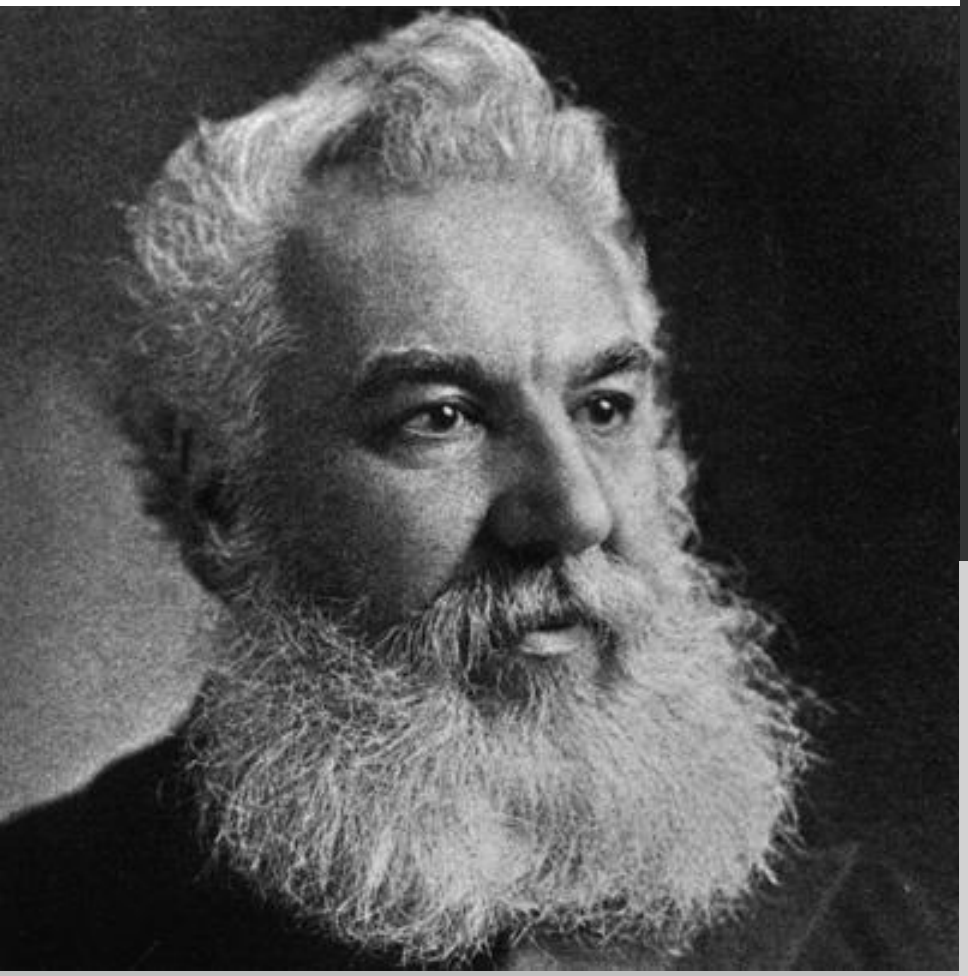
(c) Identifying surprise at Decision 4



Telephone

- In the 1870s, Bell travelled around to give demos ‘in concert halls, where full orchestras and choruses played “America” and “Auld Lnag Syne into his gadgetry.’
- Around 1880, Queen Victoria installed a pair of telephones at Winsor and Buckingham Palace

Primary source: J. Gleick, book, 2012



Alexander Graham Bell (1847-1922)

- Had Alexander Bell invented visualization, he would probably have said:

“Mr. Information,
come here.
I want to see you.”

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- Paul Rosin
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- Ralph Martin
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Past PhDs and ROs:

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- Abdula Haji Tablib (PhD, 1990-1994)
- Mike Bews (PhD, 1992-1996)
- Malcolm Price (MPhil, 1997-1998)
- Adrain Leu (PhD, 1996-1999)
- Simon Michael (PhD, 1996-1999)
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- Mark Kiddell (RA, 1999-2001)
- Ben Smith (TCA, 1999-2001)
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- Ann Smith (PhD, RA, 2001-2006)
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- Joanna Gooch (PhD, 2004-2007)
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- David Chisnall (PhD, RA, 2005-2008)
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- Heike Jänicke (RO, 2009-2010)
- Farhan Mohamed (PhD, 2008-)
- Ed Grundy (PhD, 2009-)
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- Karl Proctor (PhD, 2009-2011)
- Andrew Ryan (PhD, 2010-2011)
- Phil Legg (RO, 2010-2011)
- David Chung (PhD, RA, 2010-2011)
- Matthew Parry (MPhil, RA, 2010-2011)
- Richard M. Jiang (RO, 2010-2011)
- Brian Buffy (RO, 2011, 2013)
- Kai Berger (RO, 2012-2013)
- Karl Proctor (RO, 2012-2013)
- Jeyan Thiyagalingam (RO, 2013)
- Eamonn Maguire (PhD, RO, 2011-15)
- Alfie Abdul-Rahman (RO, 2012-2015)