Order of Magnitude Markers: An Empirical Study on Large Magnitude Number Detection

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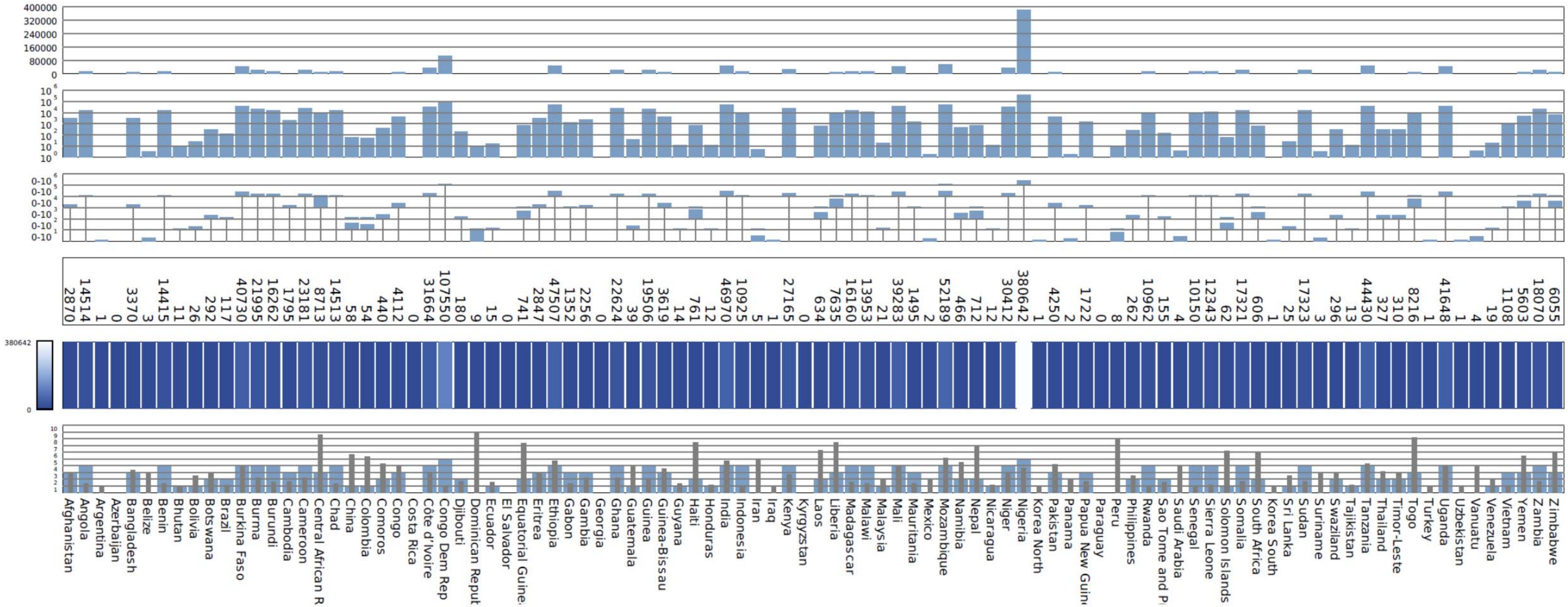
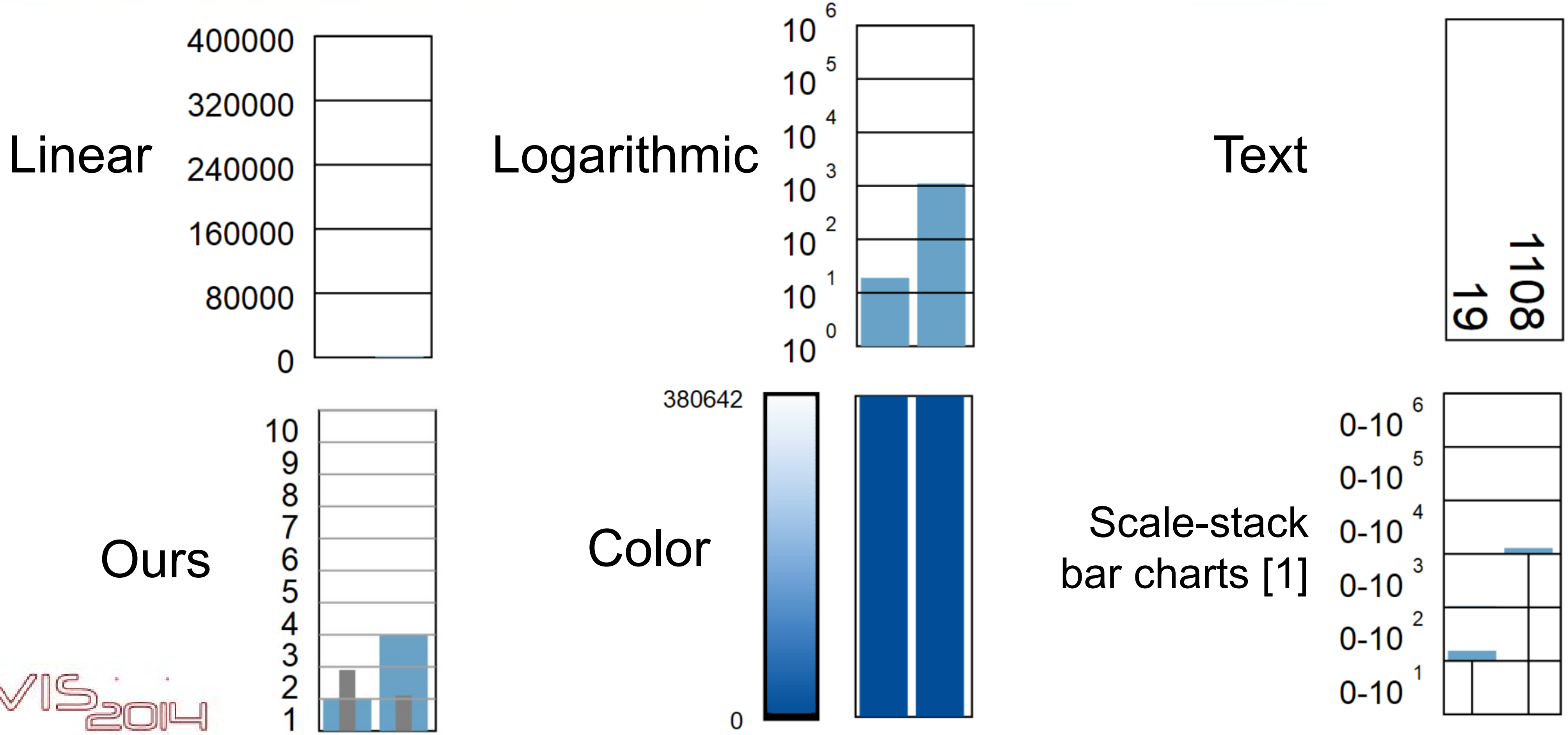
Problem – Compare Vietnam and Venezuela



Problem – Compare Vietnam and Venezuela



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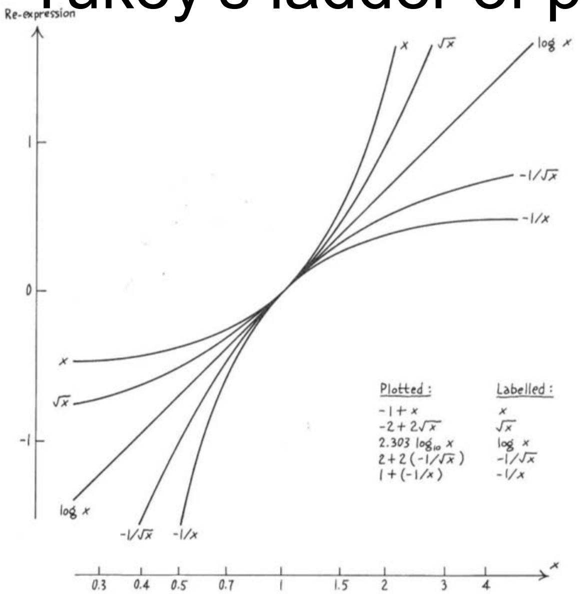
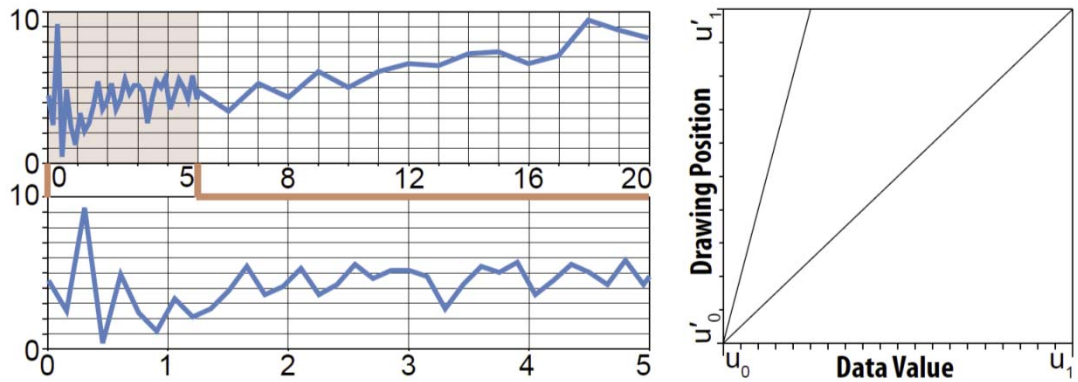
Research

- Designed a new type of visual encoding
- Has 10x increase in numerical resolving power
- Compared against various encodings
- User study

Possible approaches

Tukey’s ladder of powers (re-expression) [2]

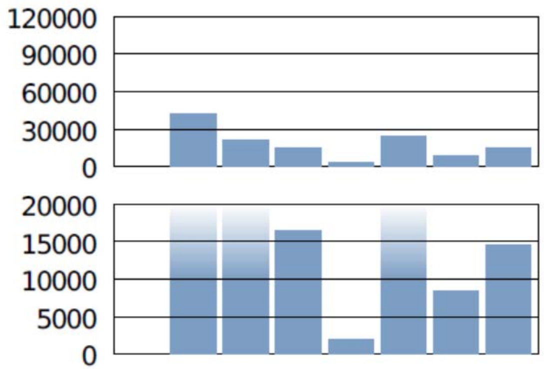


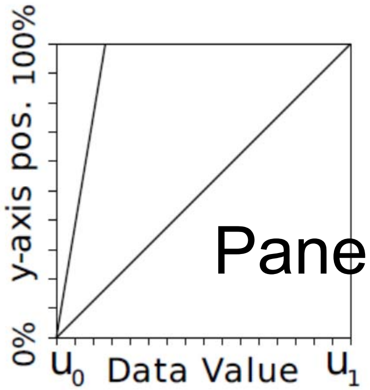


(a) A cut-out chart. (b) T for the x-axis.

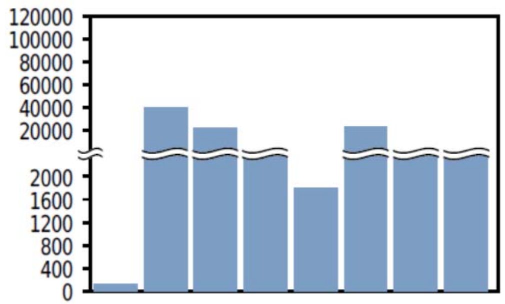
Isenberg et al. [3] Dual scale charts and transformations

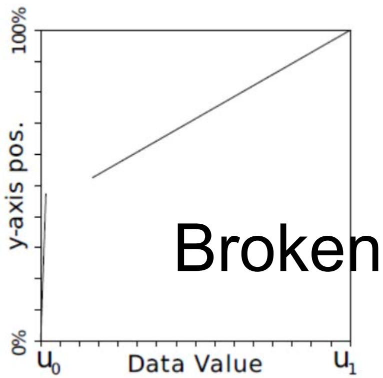
Possible approaches





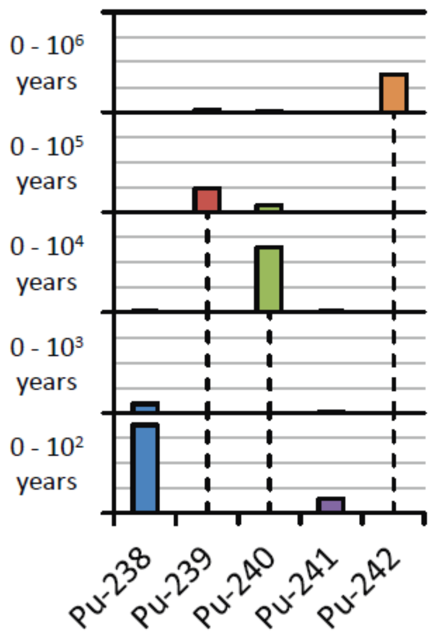
Panel charts





Broken axis charts

Scale-stack bar charts, Hlawatsch et al

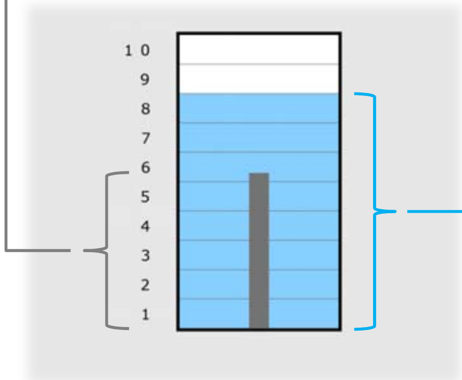


Our design aims

- Flexible encoding – working together within a chart (e.g. malaria data), or separately (e.g. across a map – tested in user study).
- View all data regardless of magnitude (broken axis and panel charts break this).
- Visualize positive and negative quantities.
- Greater resolving power compared to existing techniques.

Final design

- Normalized scientific notation $A \times 10^B$ where $1 \leq A \leq 10$ and $B \in \mathbf{Z}$.
- A Significand, B Exponent
- Big/small effect – exponent (largest effect on number) represented with the biggest visual component.



Height of the thin grey bar indicates the significand on a 0 to 10 scale

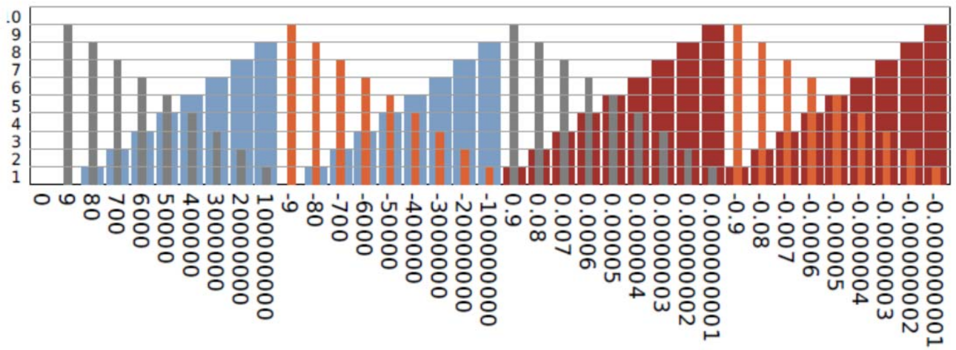
In this case 5.2

Number of blue lines stacked vertically indicates the exponent

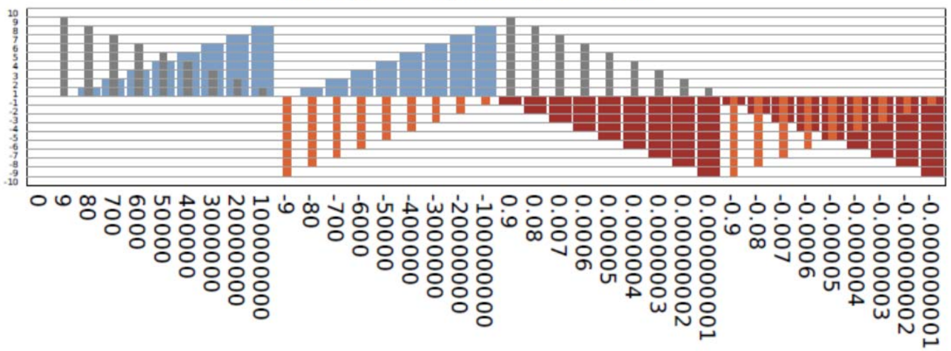
In this case 8

Value ≈ **5.2**E+8

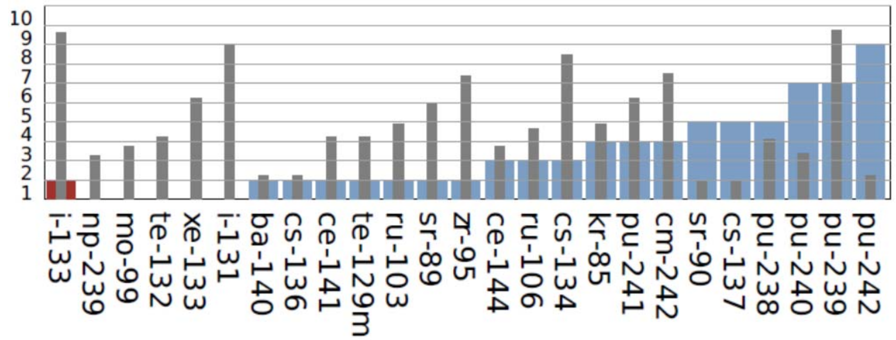
Final design



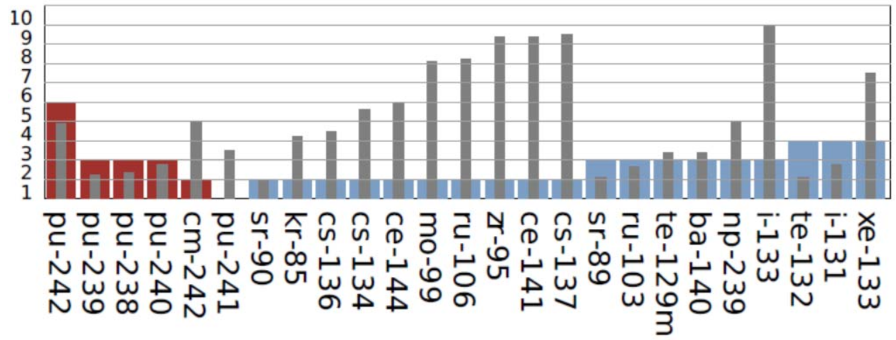
(a) Negative depicted above x-axis



(b) Negative depicted below x-axis



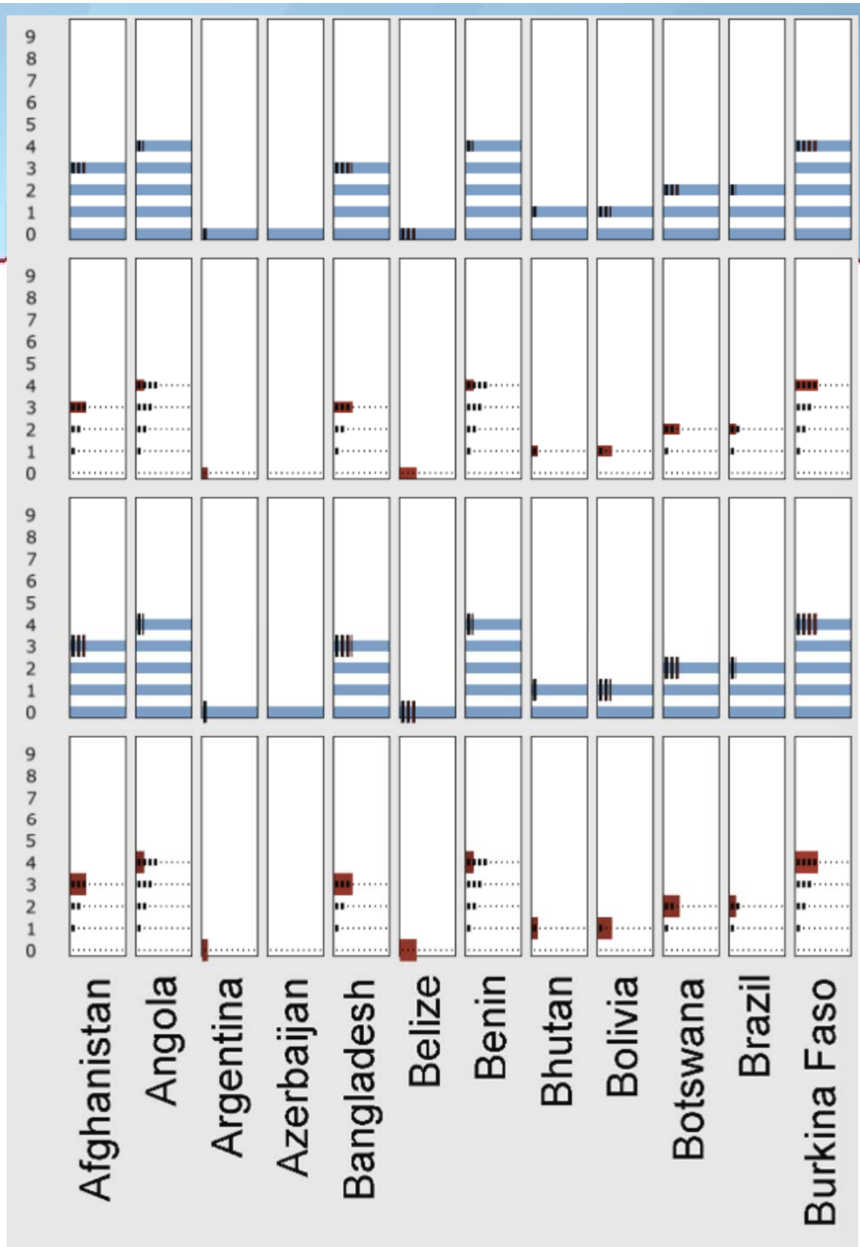
(a) Half-life of isotopes (days)



(b) Activity released of isotopes (PBq)

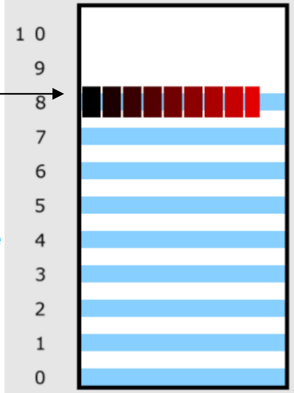
Other tested markers

- Design evolution.
- Other markers tested in user study.
- For the purposes of the user study, negative numbers were omitted to simplify things (logarithmic scale and ratio tests would be a problem).



User study: Task A, Magnitude Estimation

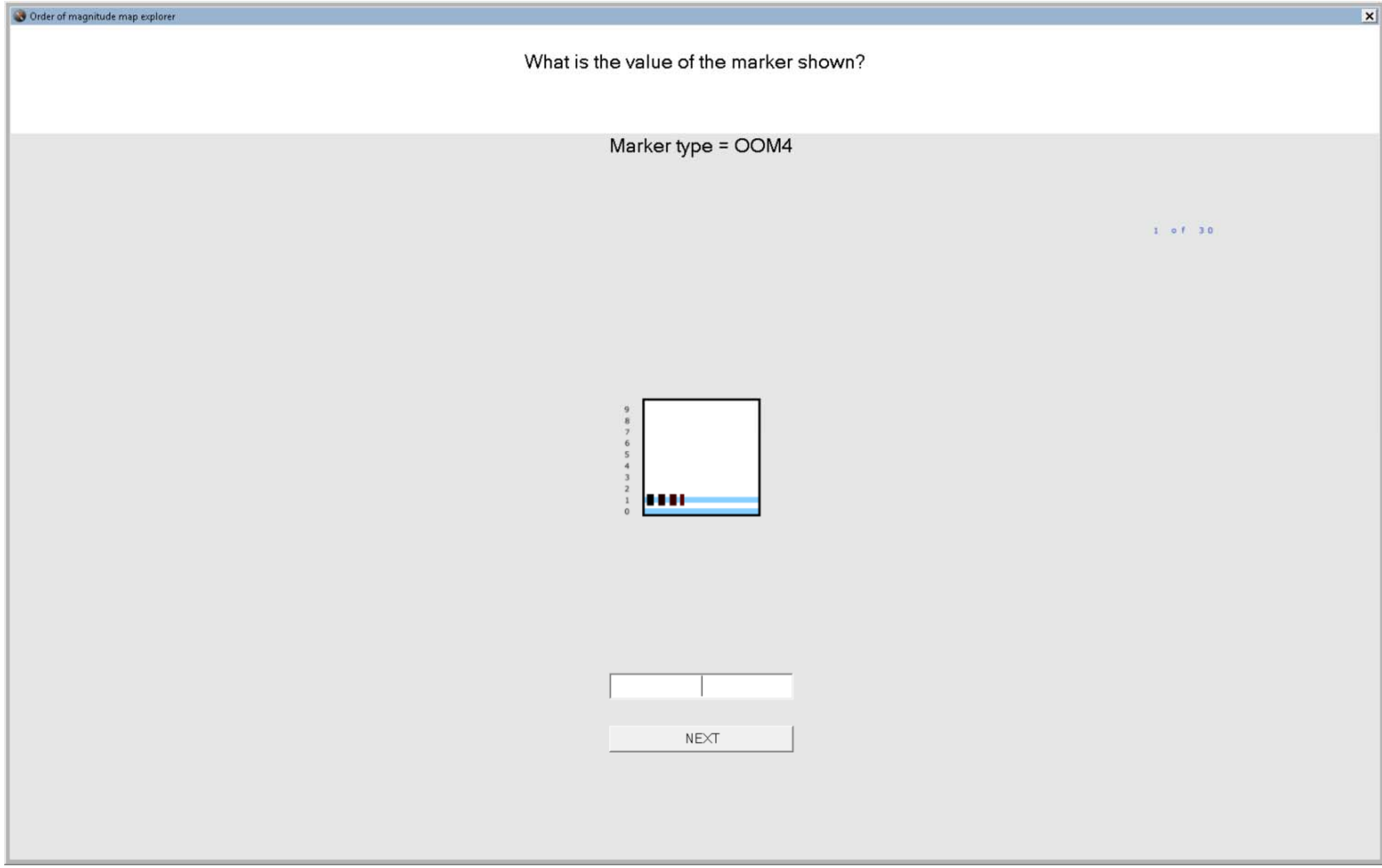
Number of black / red segments across (can be fractions) indicates the <u>significand</u>
In this case 8.8



Number of blue lines stacked vertically MINUS 1 indicates the <u>order of magnitude</u>

In this case 8

Value≈8.8E+8



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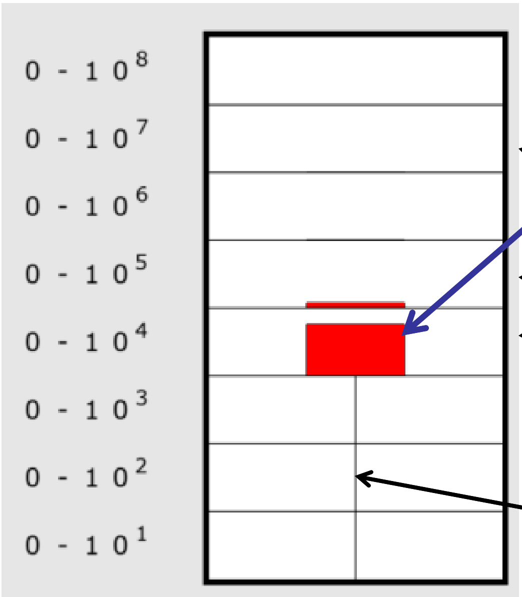
Magnitude estimate



Each space between the lines represents the number range indicated on a LINEAR scale, e.g. 0 to 10^4

The number value is illustrated by a coloured bar in every space that it is smaller than.

A vertical line through a space indicates that the value is larger than that space and cannot be shown there.

Value≈7.6E+3

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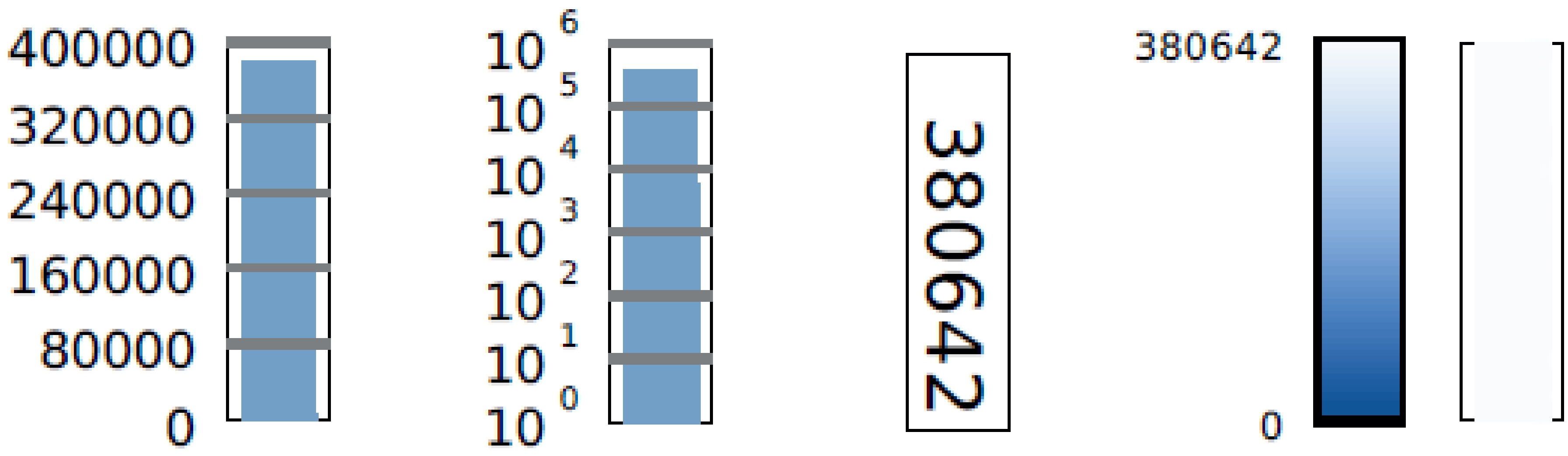
Remaining stimuli examples

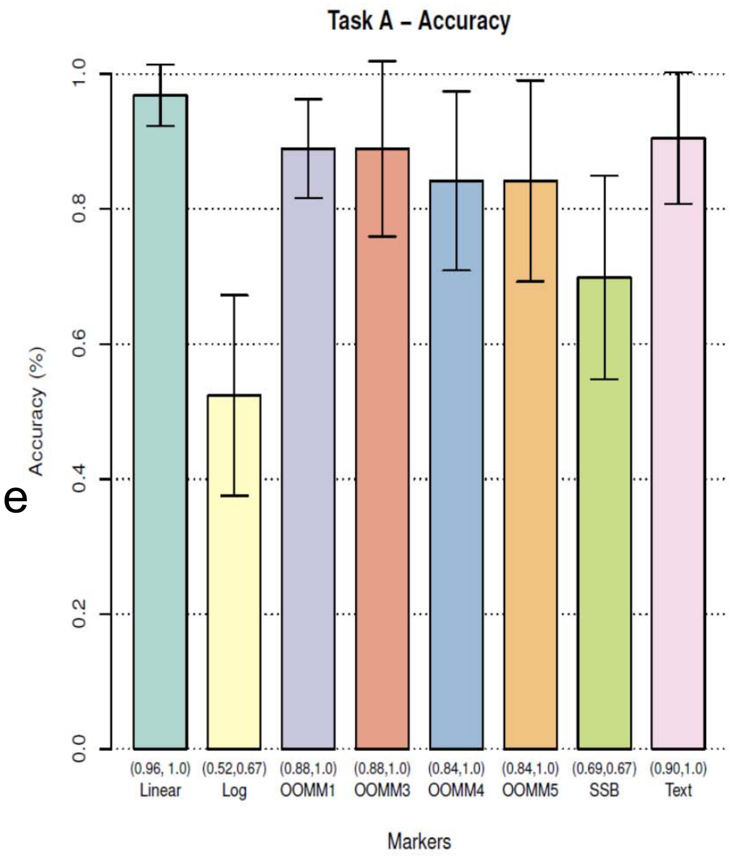


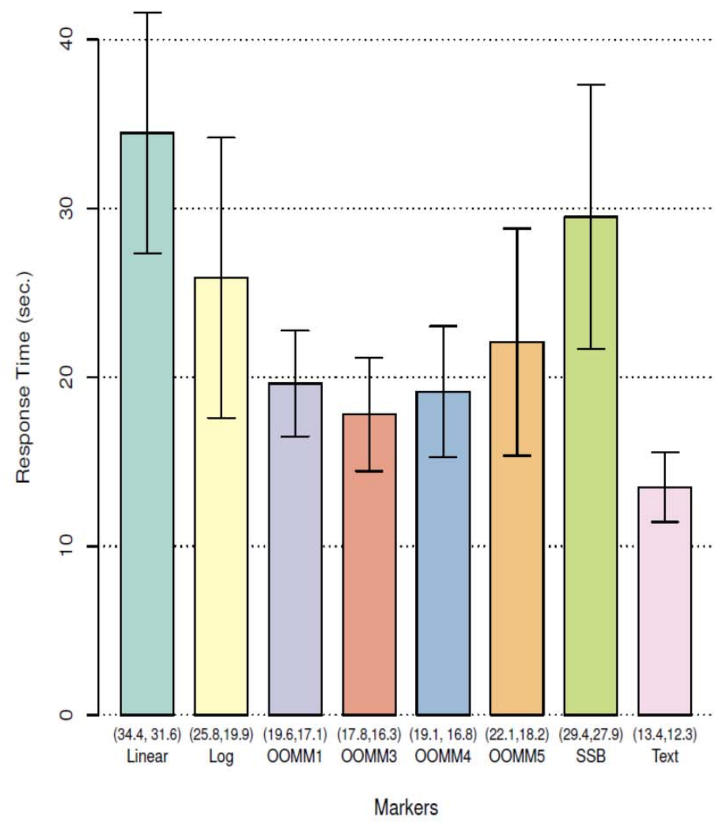
Stimuli design

- Significand and exponent generated randomly.
- Non-integers discarded to make fair comparisons with text marker. i.e., remove floating point numbers.
- 0 and 1 not used to make $\log(A \times 10^B) > 0$ and defined.
- Answers accepted as correct if within 10% of the target value.
- All stimuli are stored so a specific experiment can be reconstructed.

Results: Magnitude Estimation Task A

- OOMMs significantly more accurate than logarithm ($p \ll 0.002$)
- OOMM3 and 4 significantly more accurate than SSB ($p \ll 0.002$)
- See paper for response time analysis





User study: Target Identification Task B

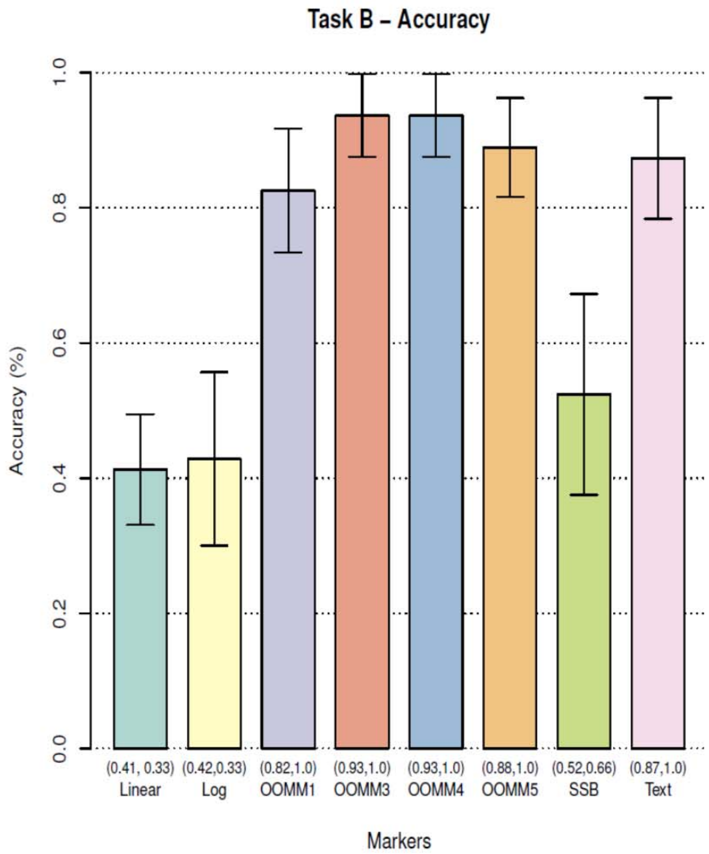
- Motivation: Can we compare values using the designs across the screen with many (potentially similar) distractors?

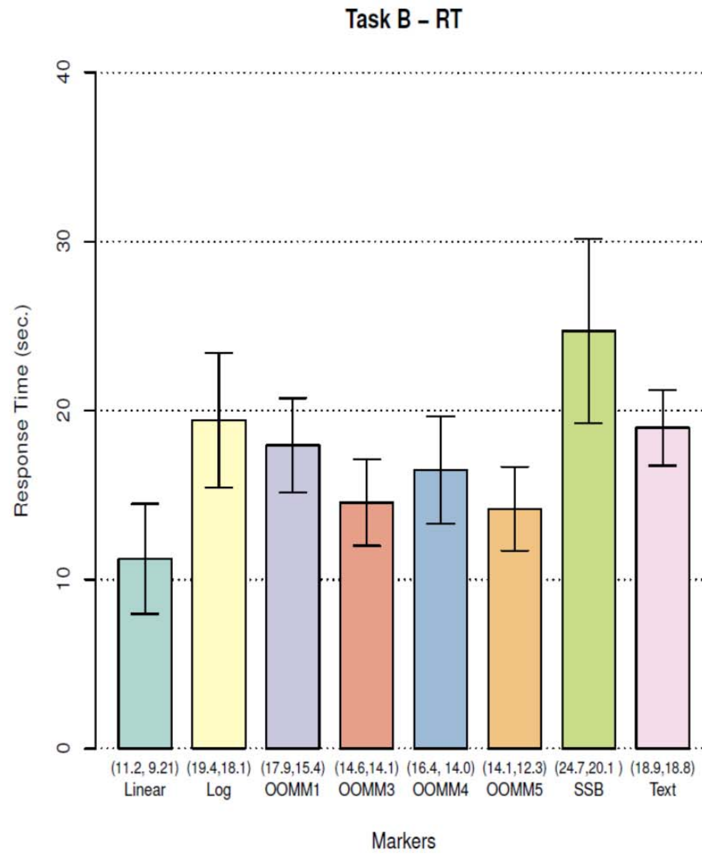
Stimuli design

- Same as A with additional requirement for target selection:
  - Largest number forced to be an outstanding outlier.
  - The second largest number and all the distractors are within two exponent levels.

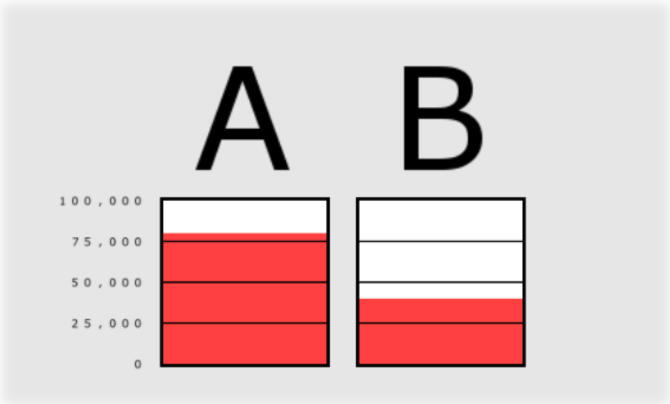
Results: Target Identification Task B

- OOMMs significantly more accurate than logarithm, linear and SSB ($p \ll 0.002$)



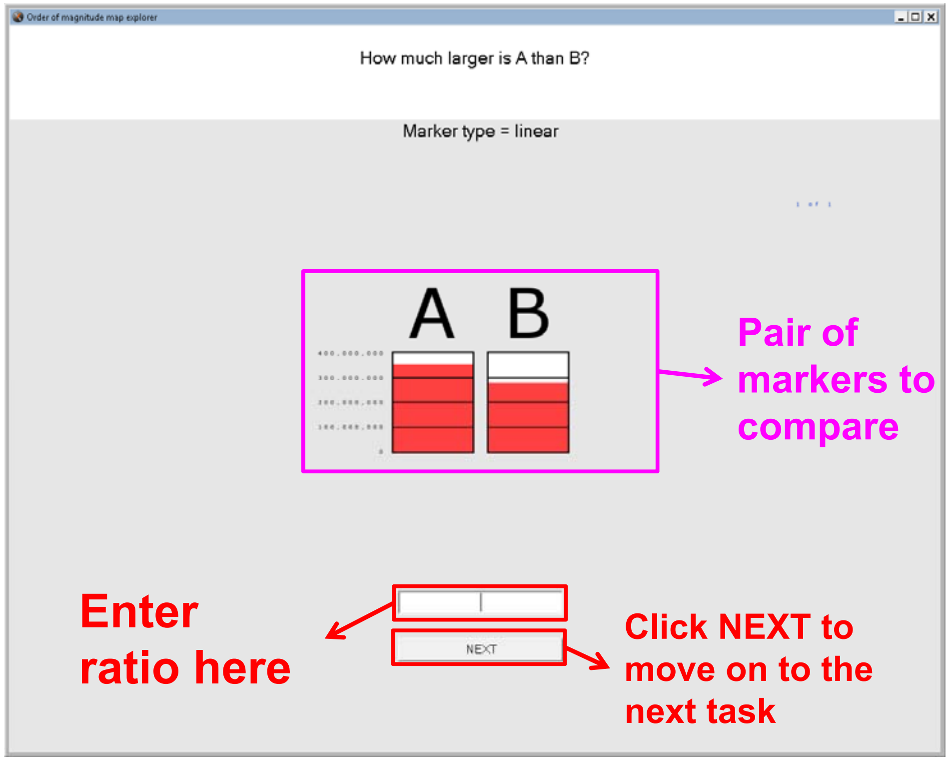


User study: Ratio Estimation Task C



Divide A by B = 80,000 / 40,000 = 2

A is 2 times larger than B



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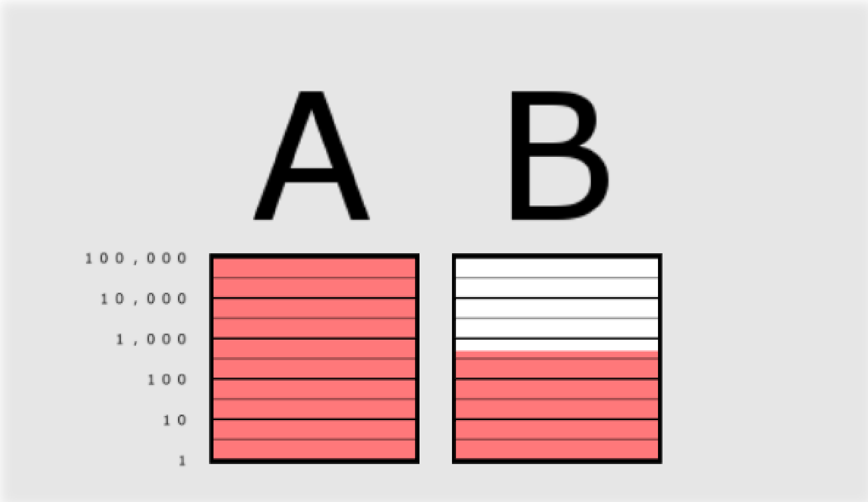
User study: Ratio Estimation Task C



Divide A by B = 100,000 / 500 = 200

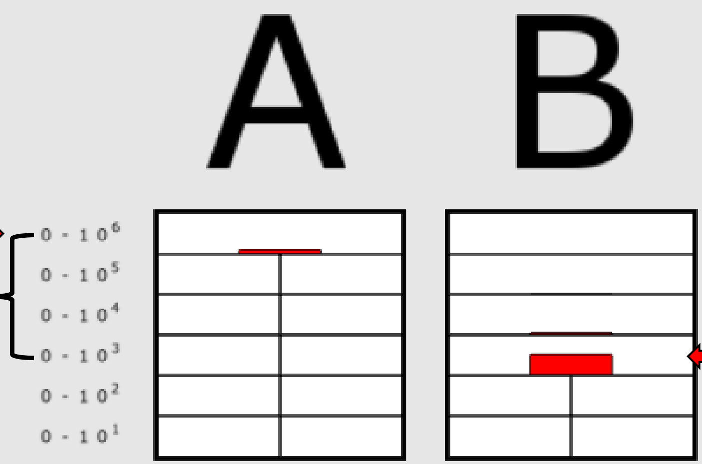
A is 200 times larger than B

User study: Ratio Estimation Task C

How to compare two **scale-stack bar** markers

Choose to view A in the space from **0 to 10^6** because it is easy to see there…
It is about **10%** of this space

A is 3 **orders of magnitude** larger than B because it is 3 rows up from B



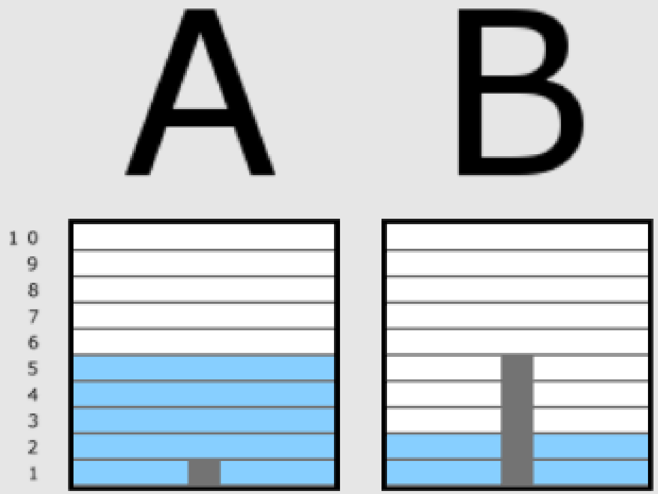
Choose to view B in the space from **0 to 10^3** because it is easy to see there…
It is about **50%** of this space

1000 times larger and **5 times smaller** = **1000** * **0.2** = 200

A is 200 times larger than B

User study: Ratio Estimation Task C

A has 3 more **blue bars** than B
=
A is 3 **orders of magnitude** larger than B



A has a **grey bar** 5 times smaller than B
=
A has a **significand** 5 times smaller than B

1000 times larger and 5 times smaller = 1000 * 0.2 = 200
A is 200 times larger than B

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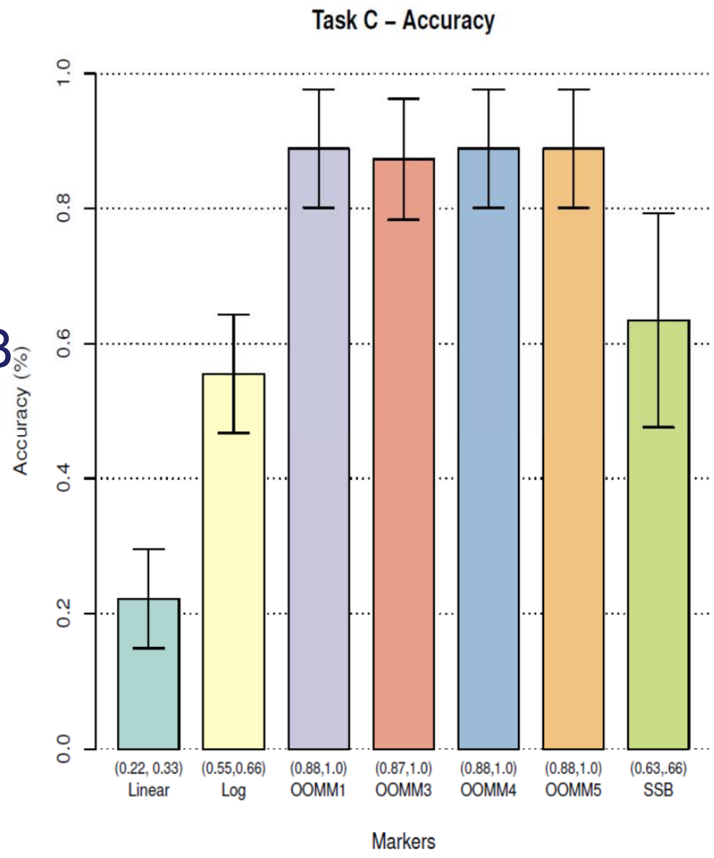
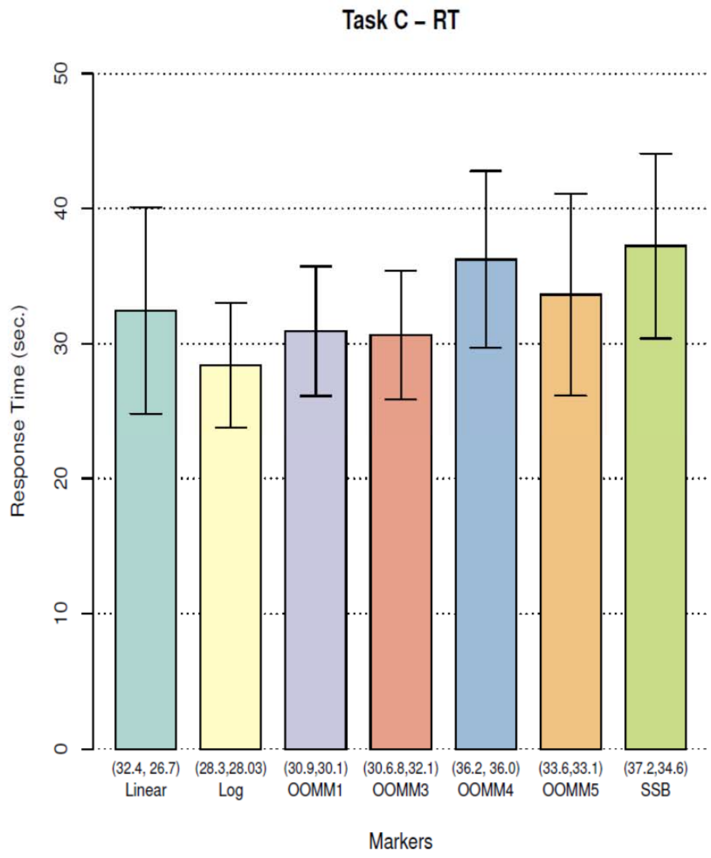
Results: Ratio Estimation Task C

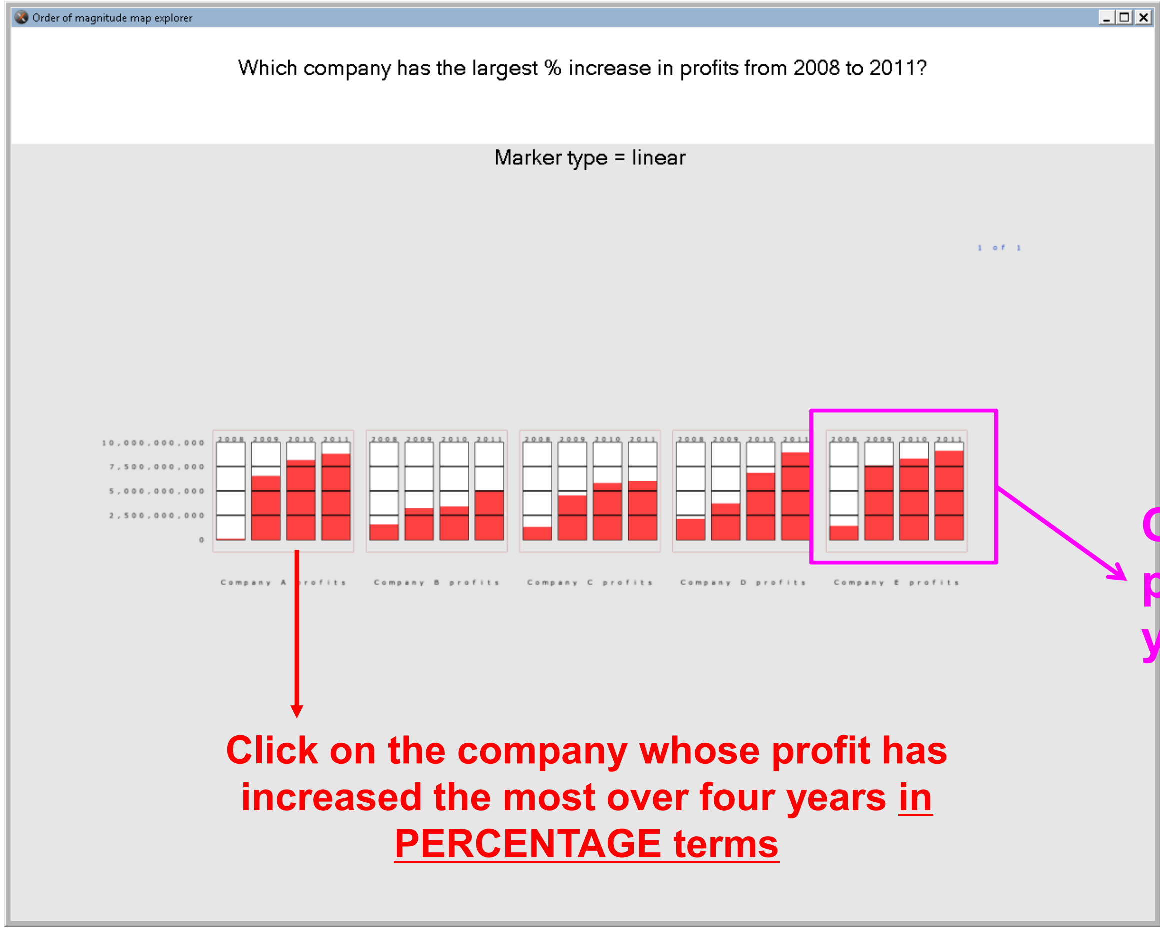
- OOMMs significantly more accurate than linear and logarithm ($p \ll 0.002$)
- OOMM5 significantly more accurate than SSB ($p \ll 0.002$)





User study: Trends Analysis Task D

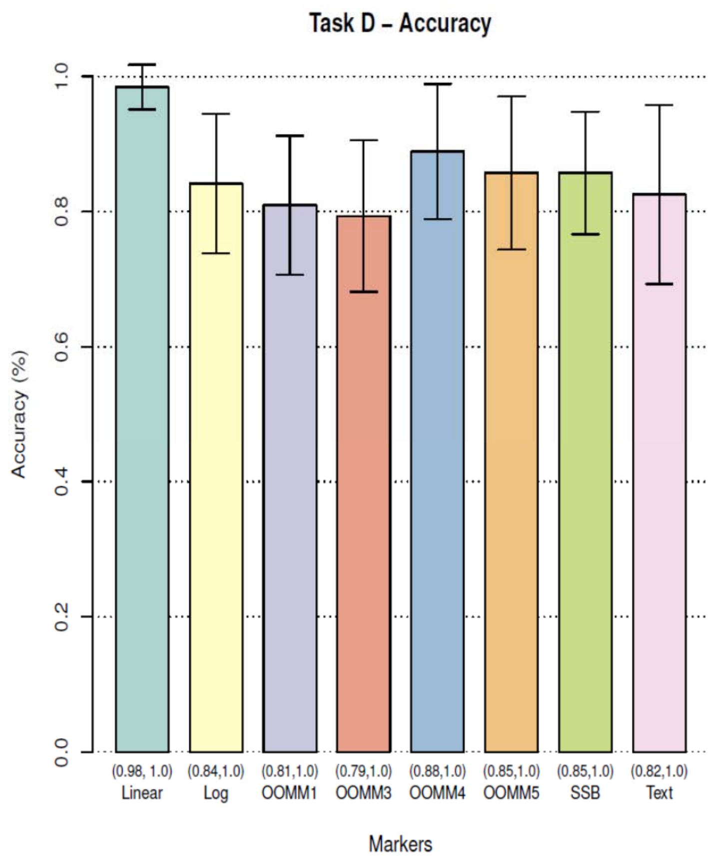
- Motivation: Analyse and quantify trends

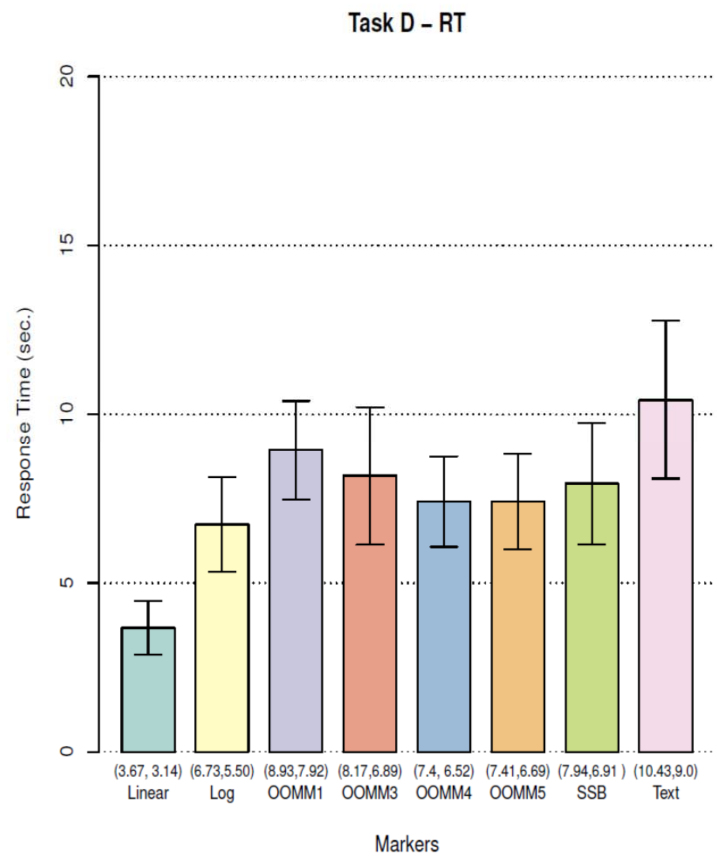


One company's profits for four years

Results: Trends Analysis Task D

- OOMM1 and 3 significantly less accurate than linear ($p \ll 0.002$)





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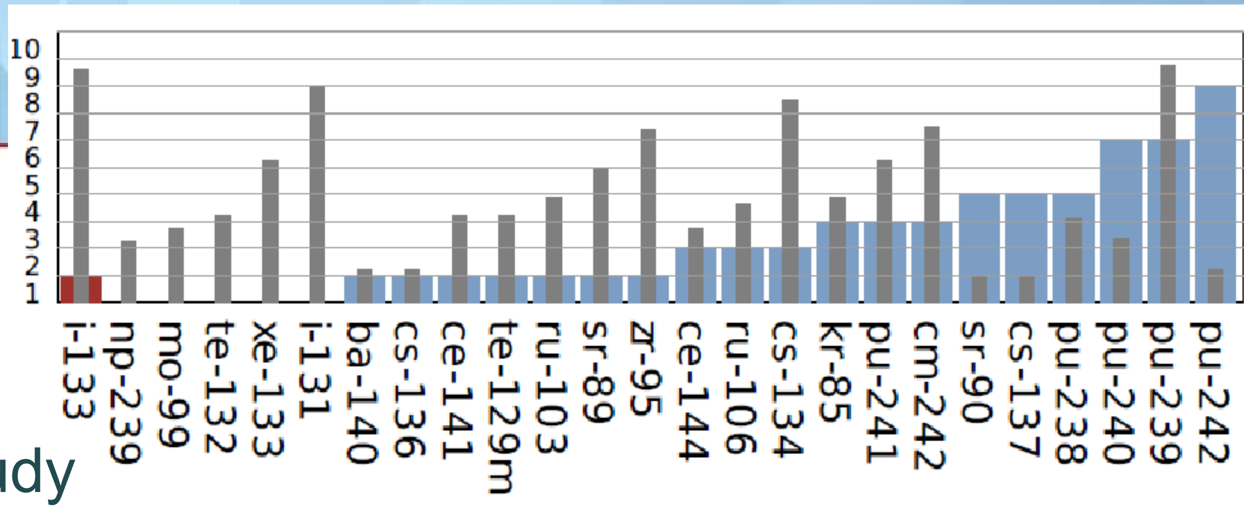
Conclusion



- Increased expressive power
- Good response time in user study
- Suggestive that usability outweighs novelty
- Confirms Hlawatsch et al - new designs that increase the space of representable numbers can increase task accuracy and speed

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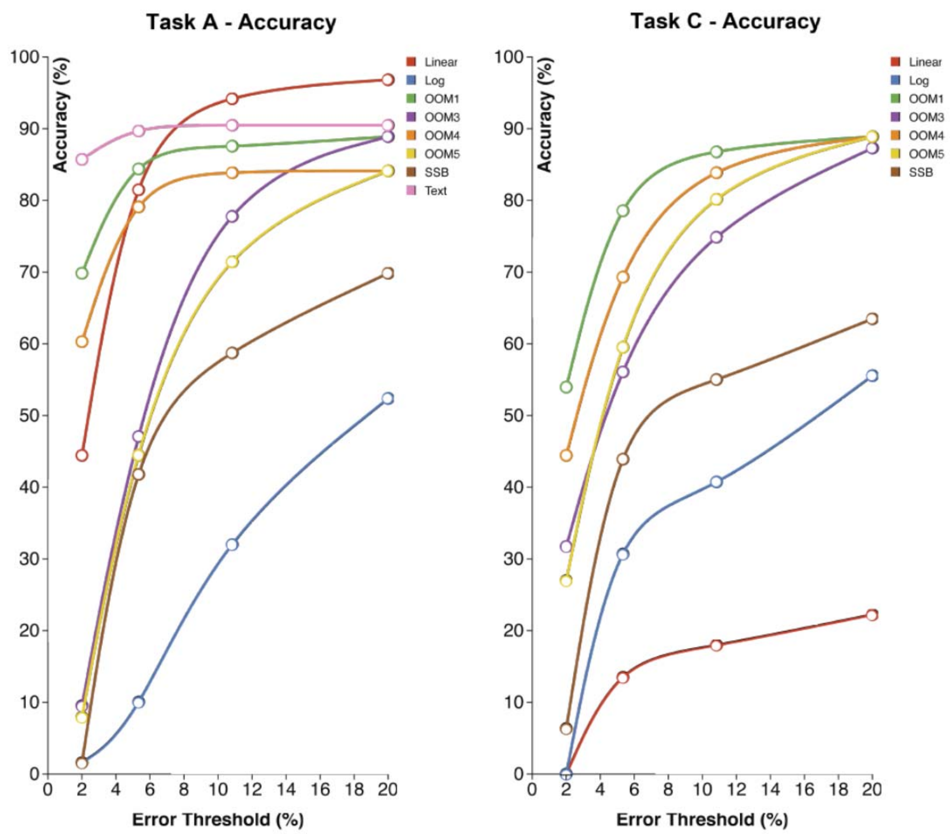
Work funded by: Leverhulme and RIVIC

Prepared answers

- Remaining slides are answers to anticipated questions or omitted slides.

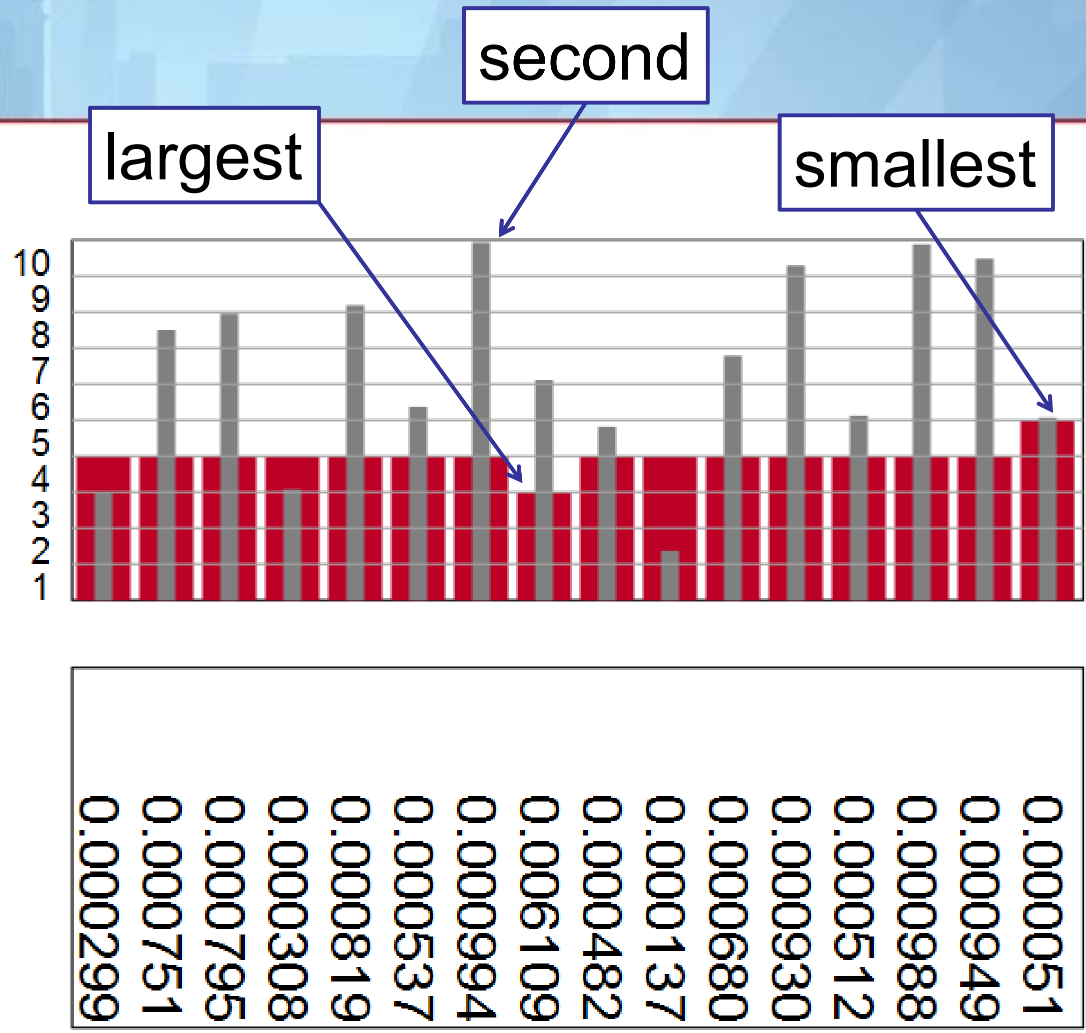
Analysis (A and C)

- A and C – magnitude estimation and ratio estimation – answers not exact.
- Use error threshold.
- Graphs show trend of accuracy against increasing error tolerance.



Text: small magnitude

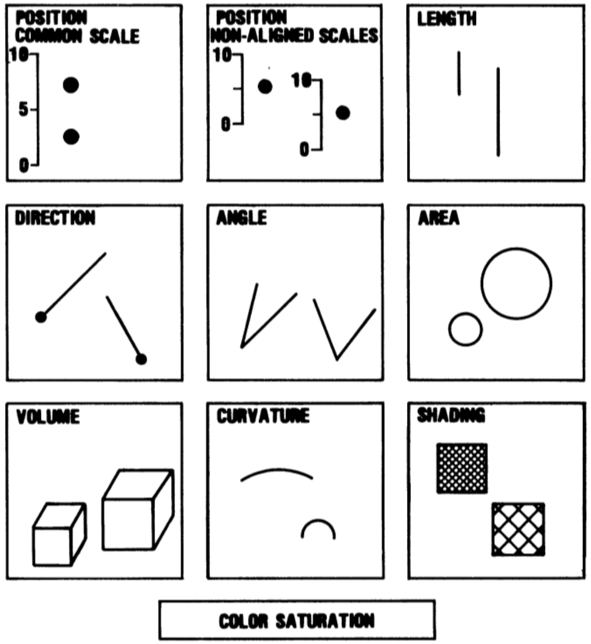
- Only integers were used in the user study.
- Identify the largest and second largest in this random data (apart from outstanding outlier).



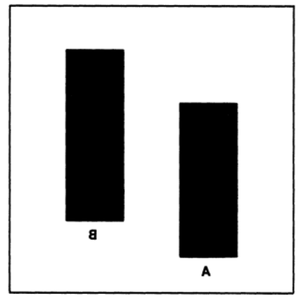
Resolving power

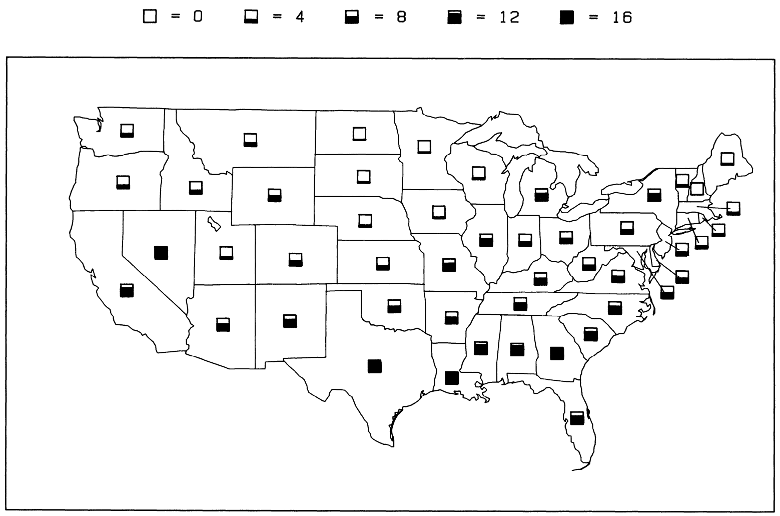
- Assume marker height of *150* pixels.
- Assume *b* bit colour display (usually 8 bit).
- Linear, logarithmic and scale-stack bars achieve *150* unique numerical representations.
- Text – 23 digits possible (in 150px): 99999999999999999999999
- Colour – 2^b unique numerical representations, although fewer are perceived.
- Ours – 1500 representations possible. (10× increase in resolving power)

Related literature

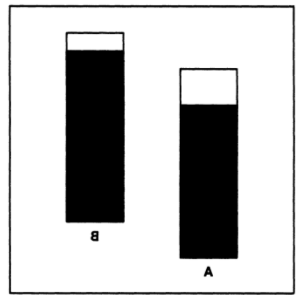


Cleveland and McGill [4], extracting quantitative information from graphs



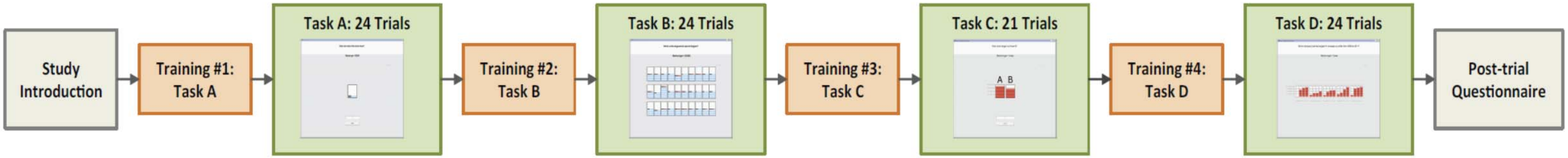


MURDER RATES PER 100,000 POPULATION, 1978



Final user study

- 21 participants, 2 females, 19 males.
- Basic knowledge required, graphs, logarithmic scale…, therefore
- Maths, Physics, Engineering and Computer Science graduates and undergraduates.



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Design history

- Designs that favoured pre-attentive processing.
  - Minimum of colours – 2-3.
  - Associating different colours to different shapes.
  - Low visual complexity (defined as detail, intricacy, number of geometric features, etc.)
- Software written to allow us to experiment with marker design.
- Big/small effect – exponent (largest effect on number) represented with the biggest visual component.