EUROVIS Leipzig 2023

Don't Peek at My Chart: Privacy-preserving Visualization for Mobile Devices

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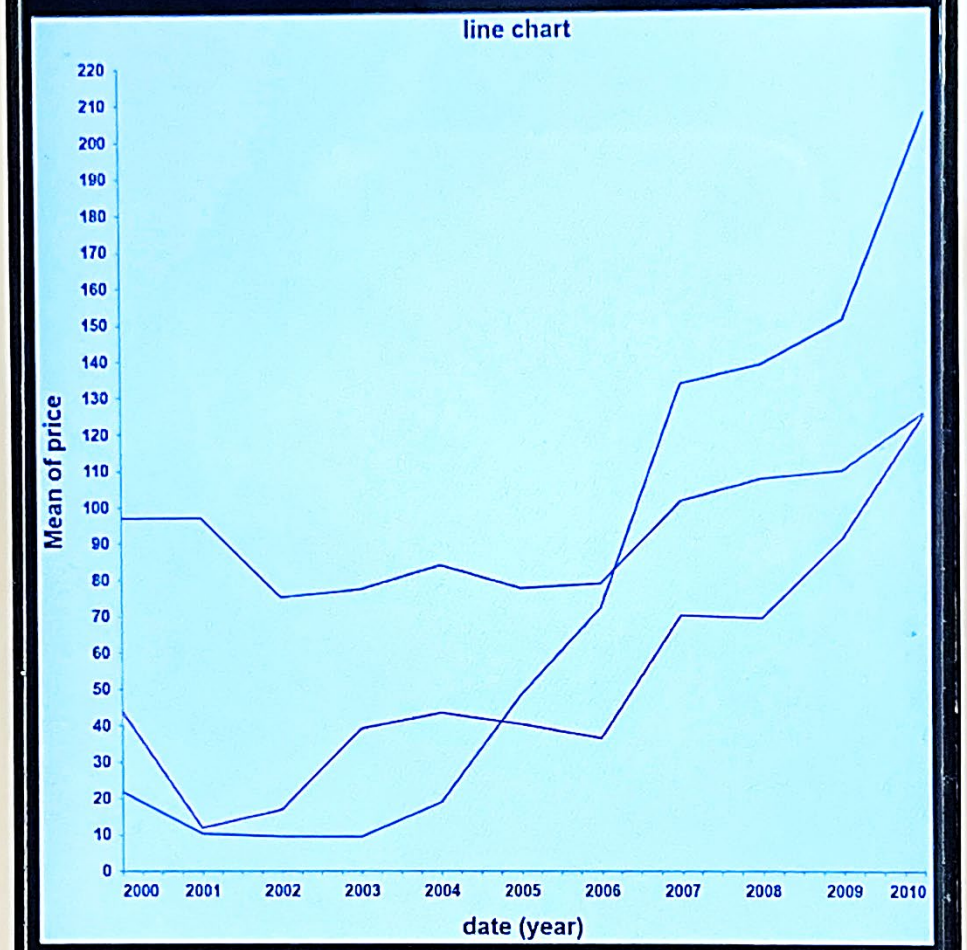
Take-away Message

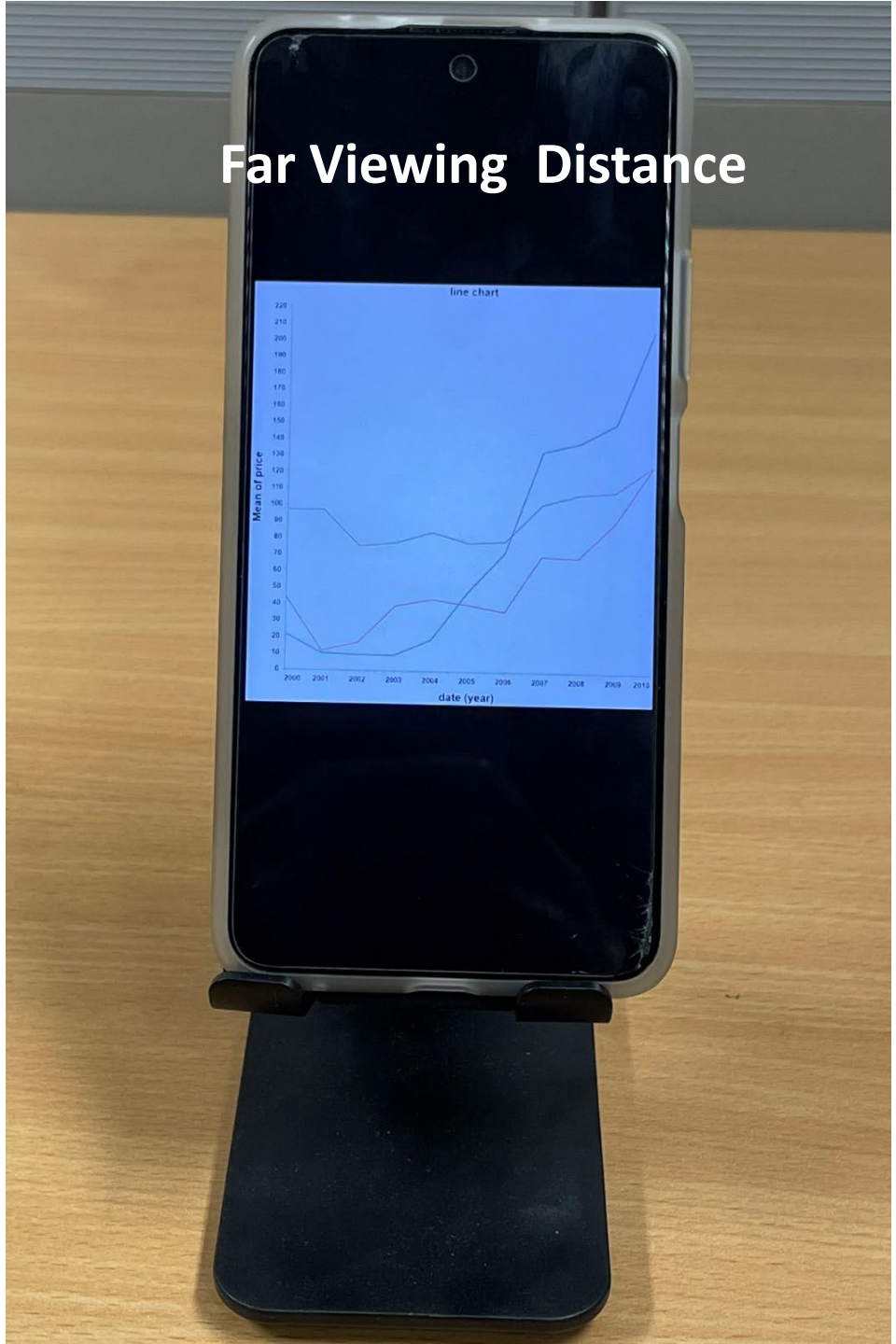
- Mobile data visualization is normally visible at both close and far viewing distances

- We propose a privacy-preserving mobile data visualization that is visible at a close distance but invisible at a far distance

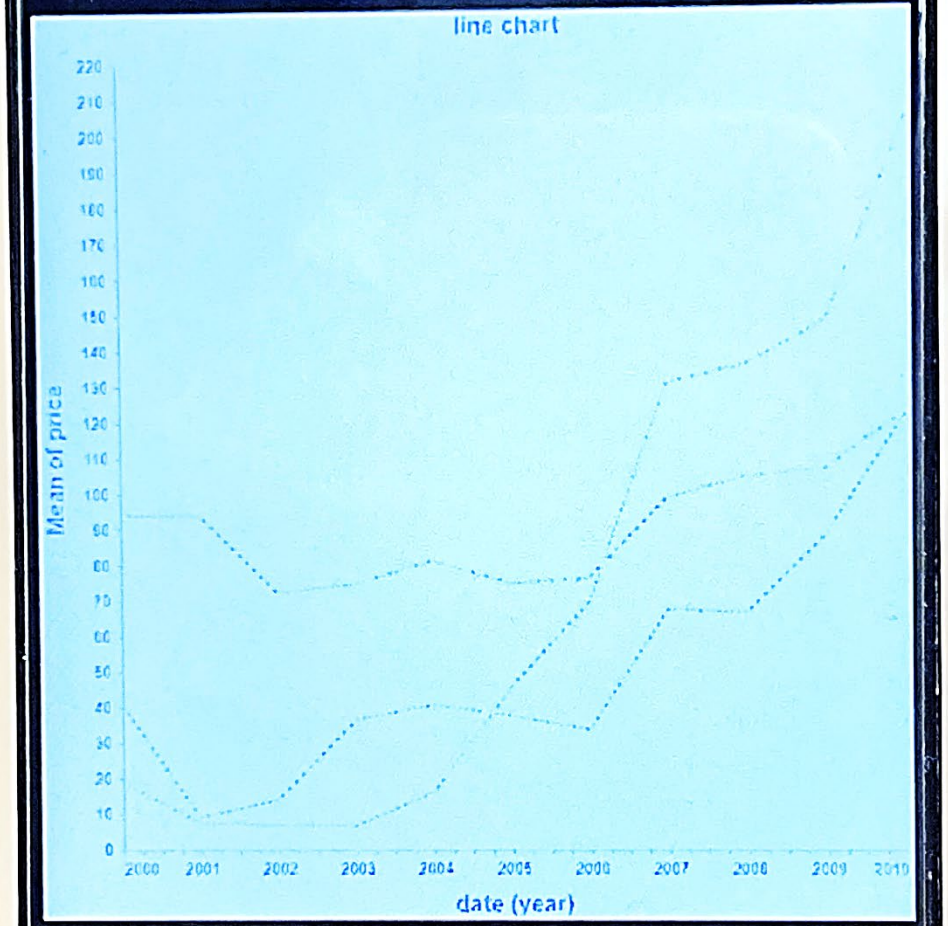
Close Viewing Distance



Far Viewing Distance



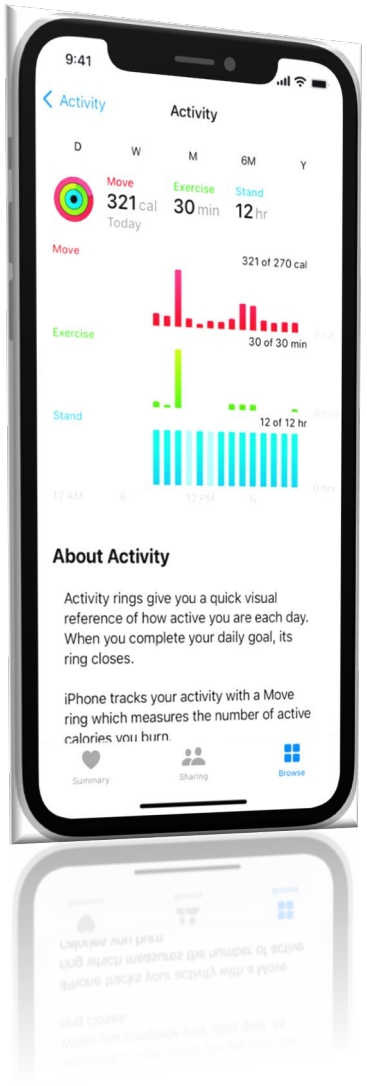
Close Viewing Distance

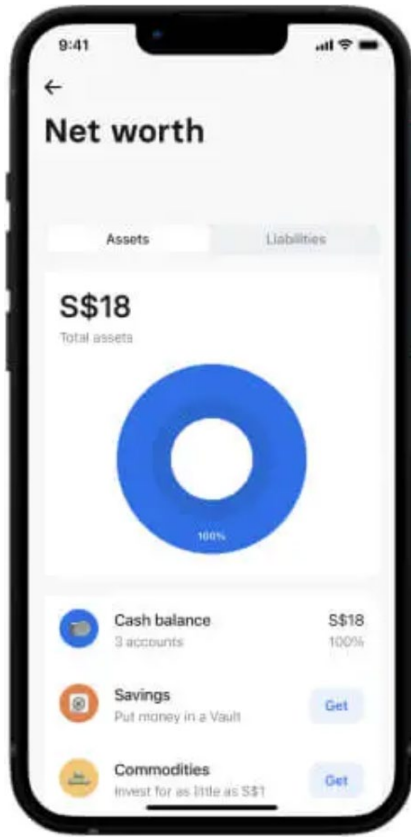


Far Viewing Distance

Background

Mobile Data Visualization





Shoulder-Surfing Attacks

*It happens **everywhere**!*

Challenges

- The easy-to-view nature of mobile data visualization is a double-edged sword; it's handy but also makes it easy for others to peek

- The privacy-preserving mobile data visualization must balance readability and privacy protection

The Goal of Mobile Vis Privacy Protection

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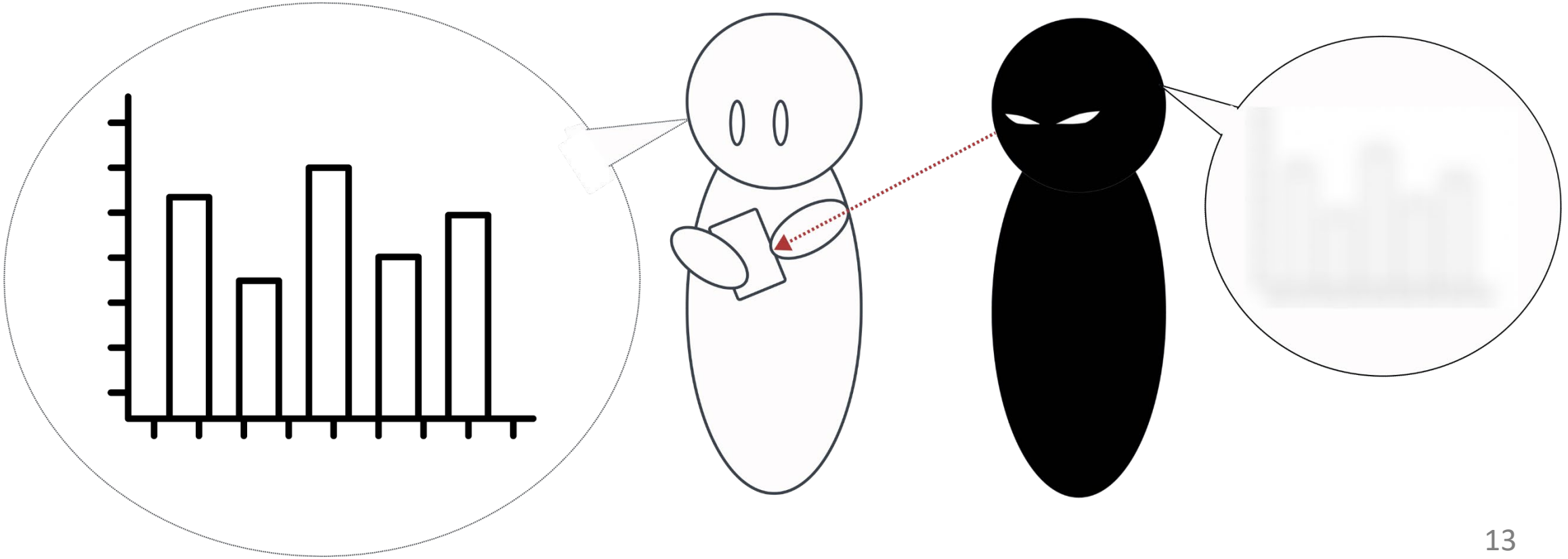
How can we maintain visualization visibility for users at proximity while effectively concealing it from peekers at a distance?

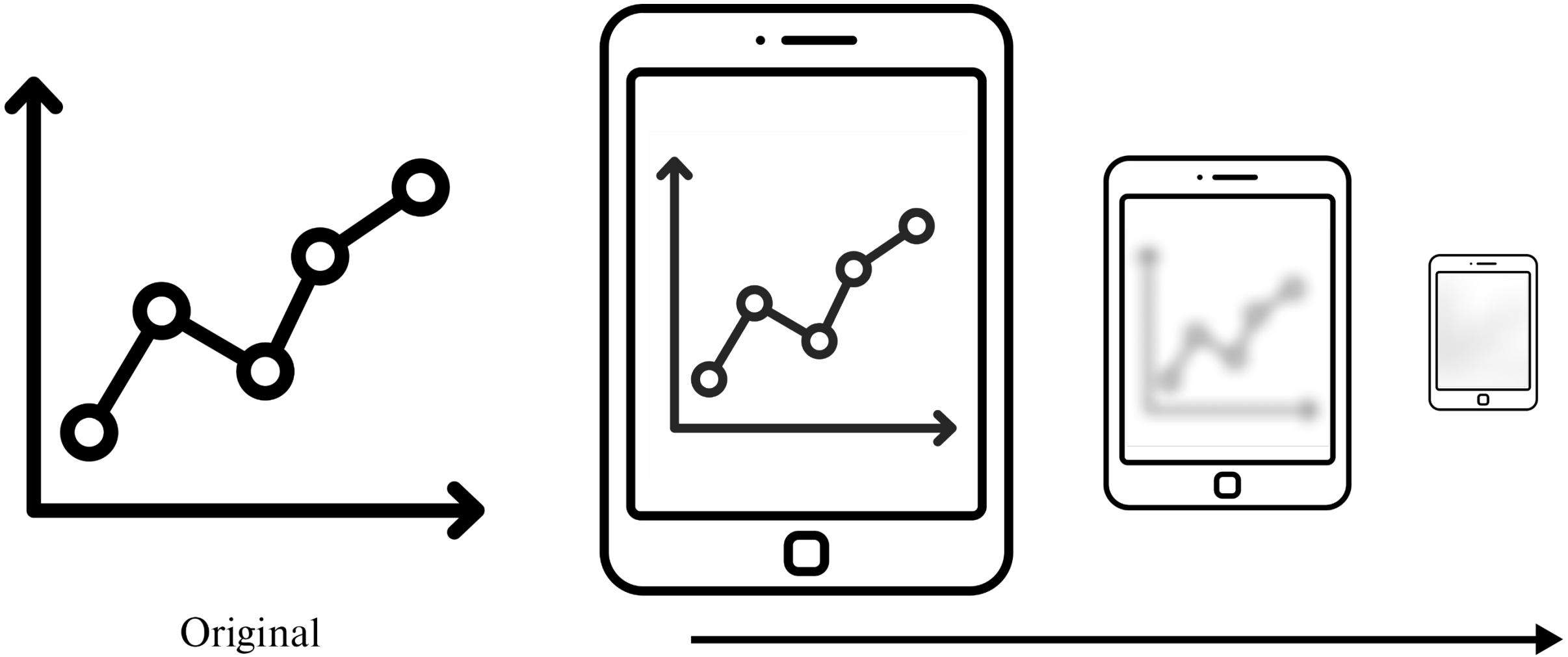
Approach

Our Approach

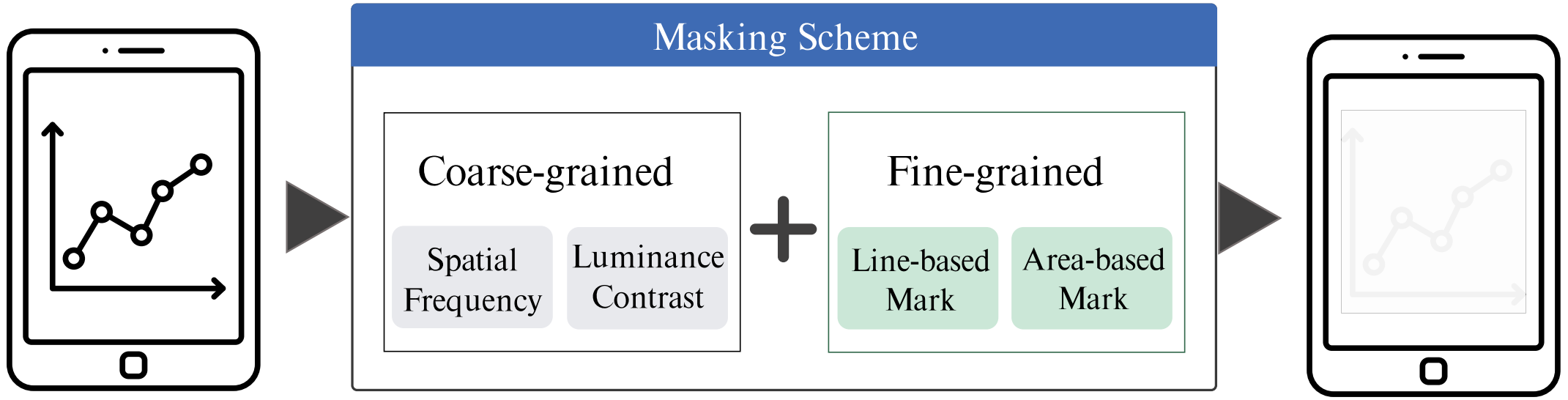
Users can see the visualization
Peekers hardly see the visualization



Our Approach



Approach Overview

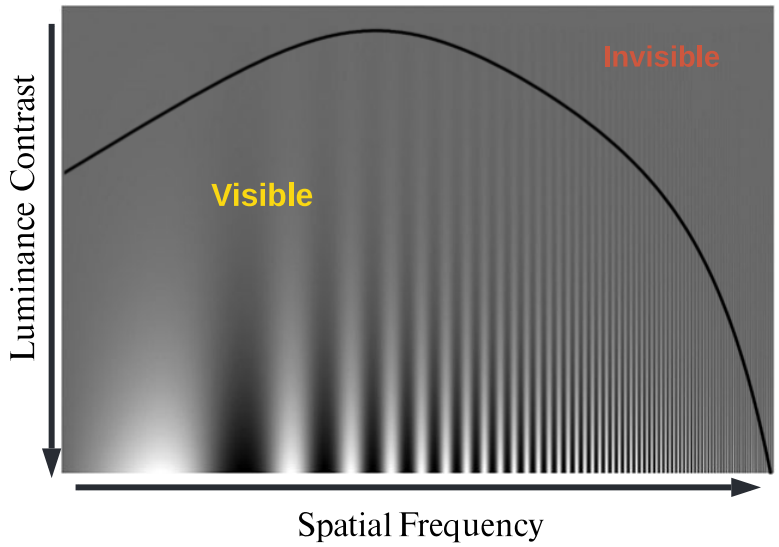


We propose a masking scheme to generate a privacy-preserving visualization.

Coarse-grained level

Our method is inspired by the human vision system characteristics

Contrast Sensitivity Function[2]



Inspired

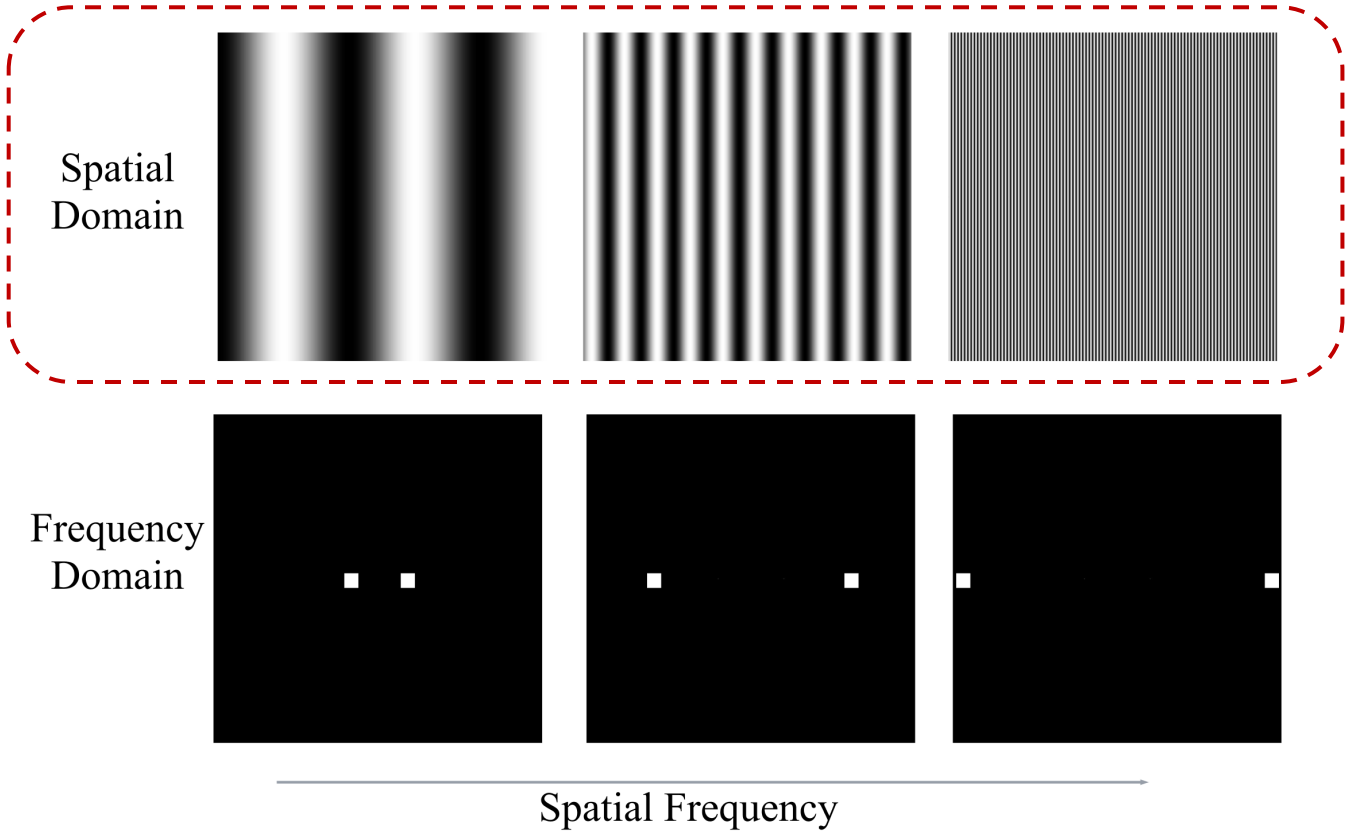
Coarse-grained

Spatial Frequency

Luminance Contrast

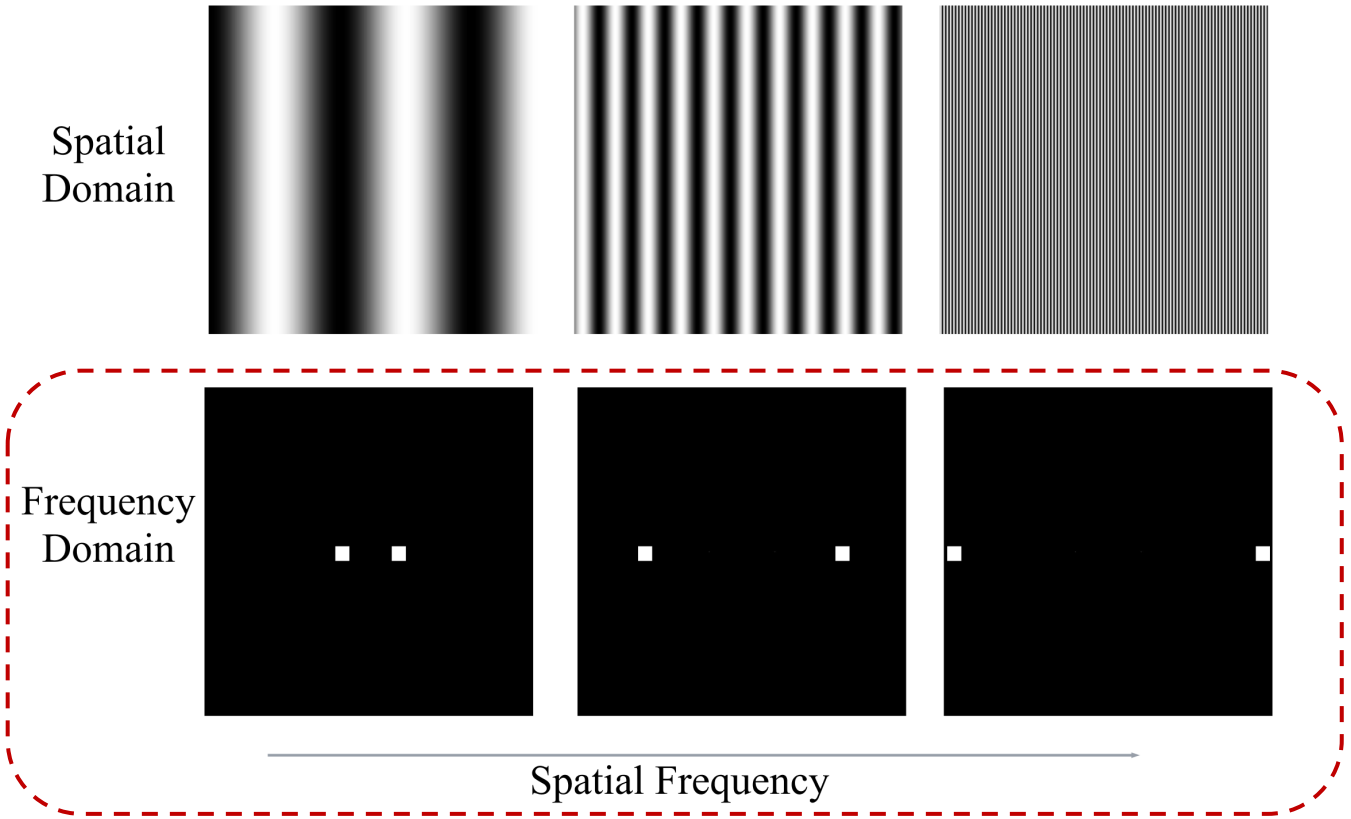
[2] National Research Council (US) Committee on Vision. Emergent Techniques for Assessment of Visual Performance. Washington (DC): National Academies Press (US); 1985. CONTRAST SENSITIVITY FUNCTION. Available from: https://www.ncbi.nlm.nih.gov/books/NBK219042/

Coarse-grained level – Spatial Frequency



Spatial frequency relates to the frequency of color changes that humans perceive.

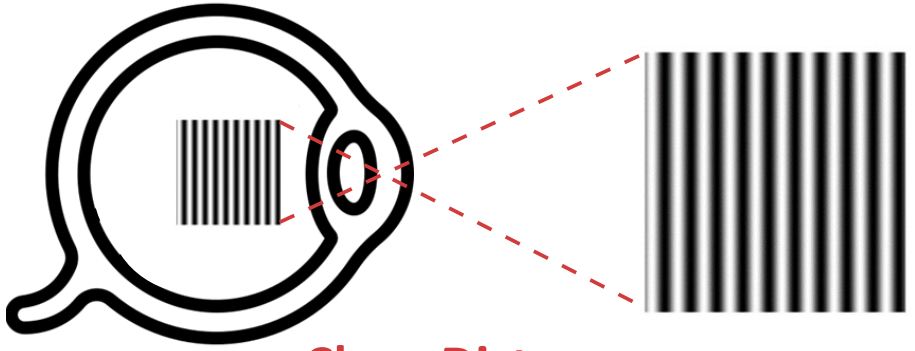
Coarse-grained level – Spatial Frequency



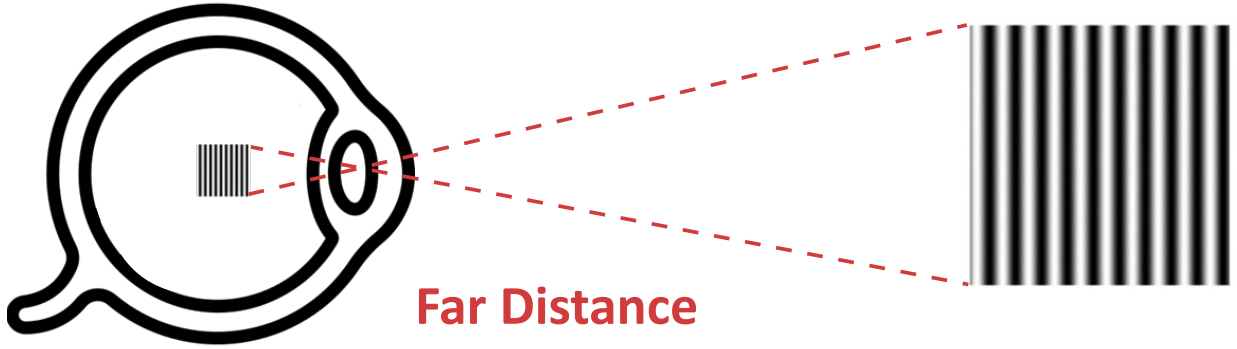
Spatial frequency relates to the frequency of color changes that humans perceive.

Coarse-grained level – Spatial Frequency

When viewing distance increases, the spatial frequency that humans perceive also increases.

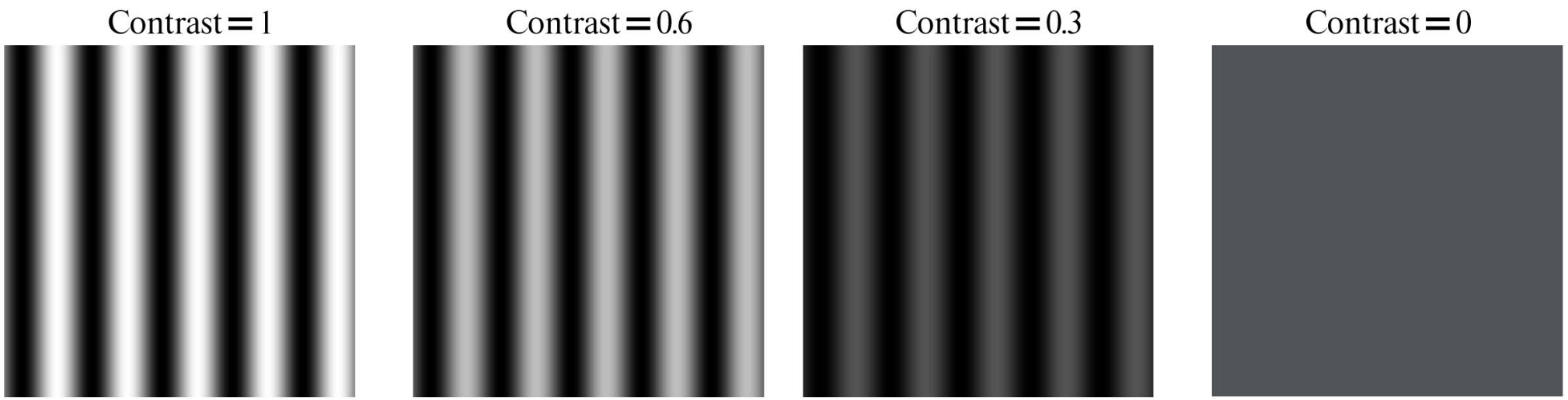


Close Distance



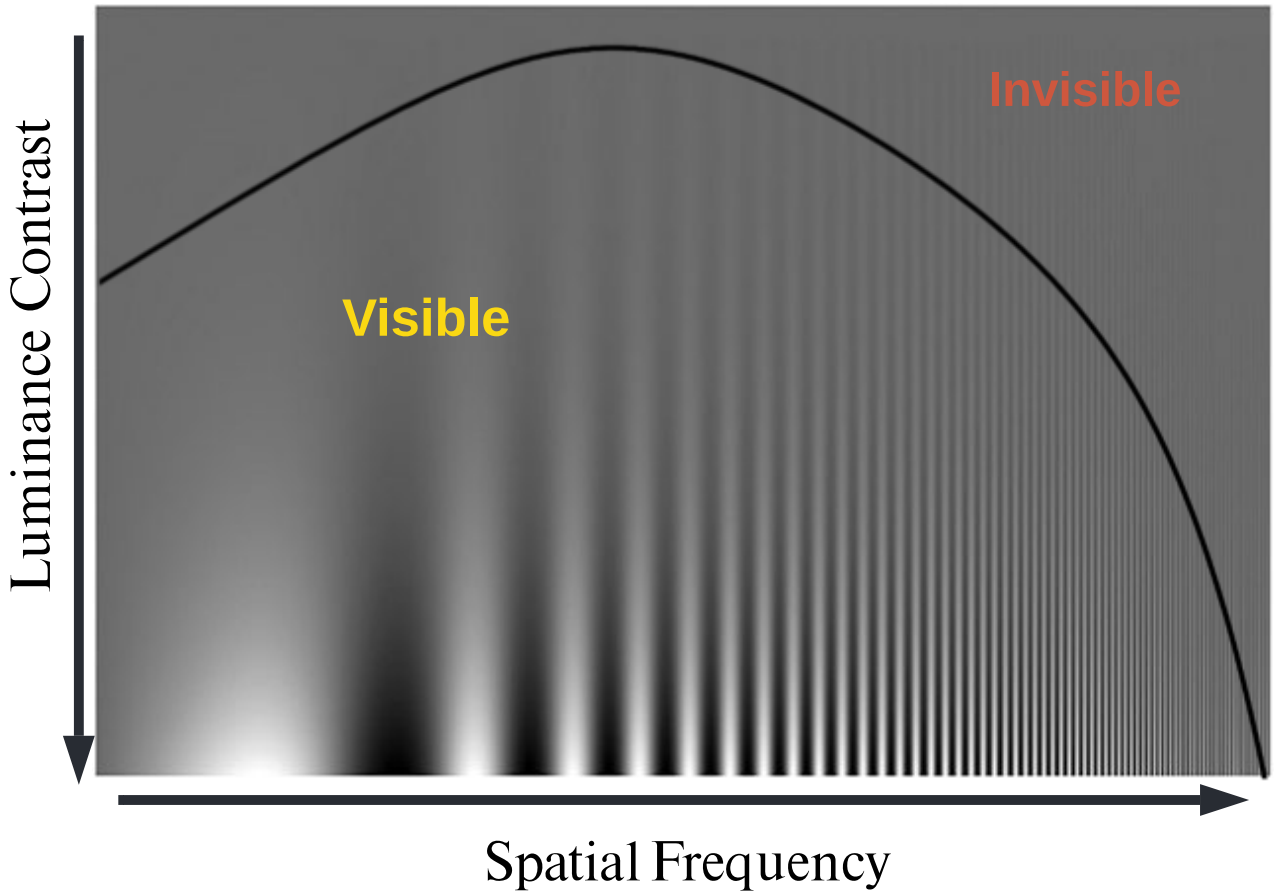
Far Distance

Coarse-grained level – Luminance Contrast



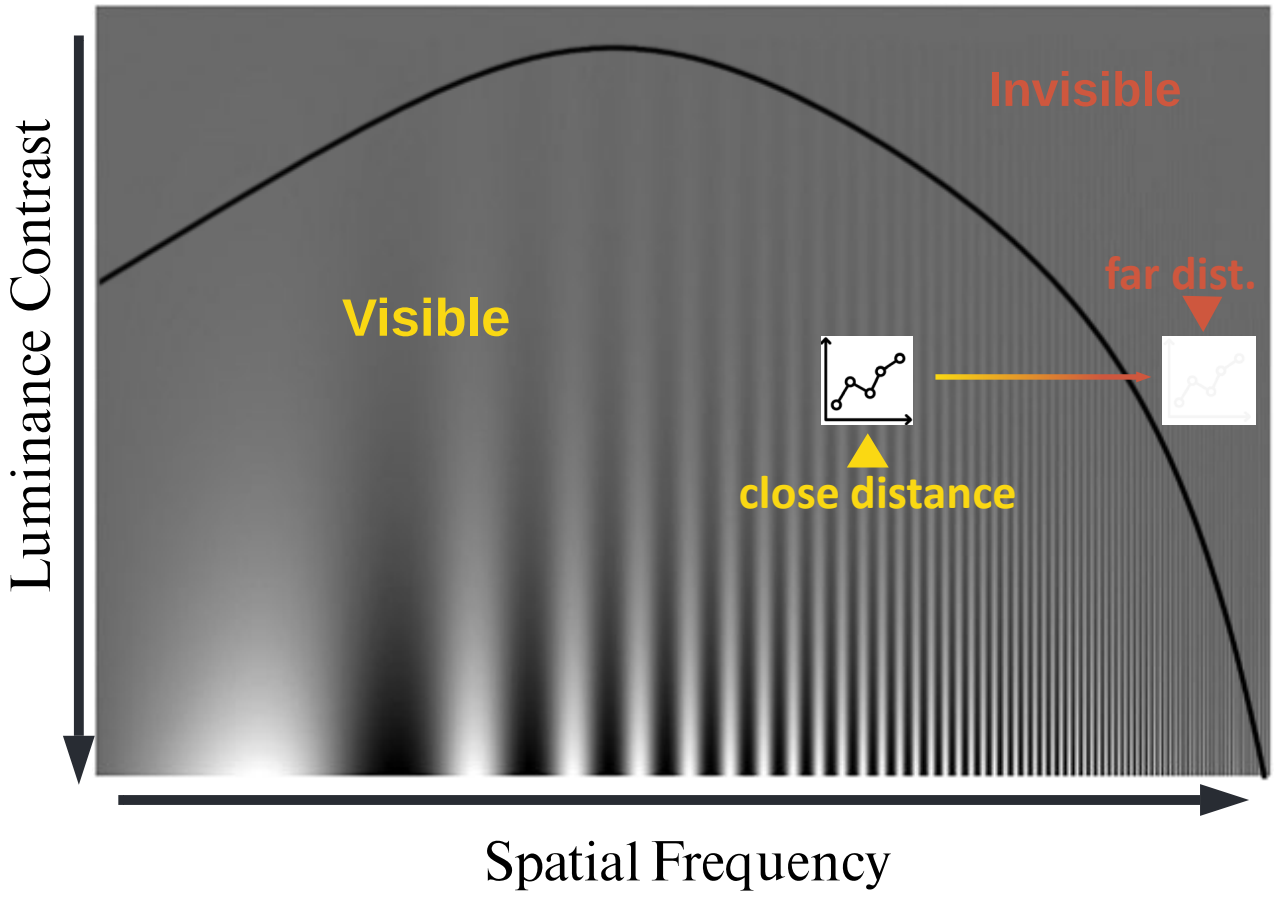
Luminance contrast refers to the difference in brightness between the two colors.

Coarse-grained level



The human vision system is affected by the coupling effect of both spatial frequency and luminance contrast.

Coarse-grained level



The human vision system is affected by the coupling effect of both spatial frequency and luminance contrast.

Fine-grained level

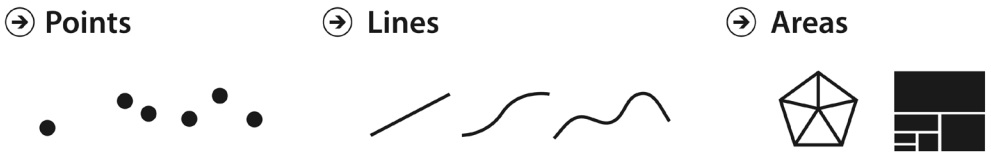


Figure Marks are geometric primitives.

Source: Visualization Analysis & Design[2]: Chapter 5 by Tamara Munzner

[3] Munzner, Tamara. Visualization analysis and design. CRC press, 2014.

Fine-grained level

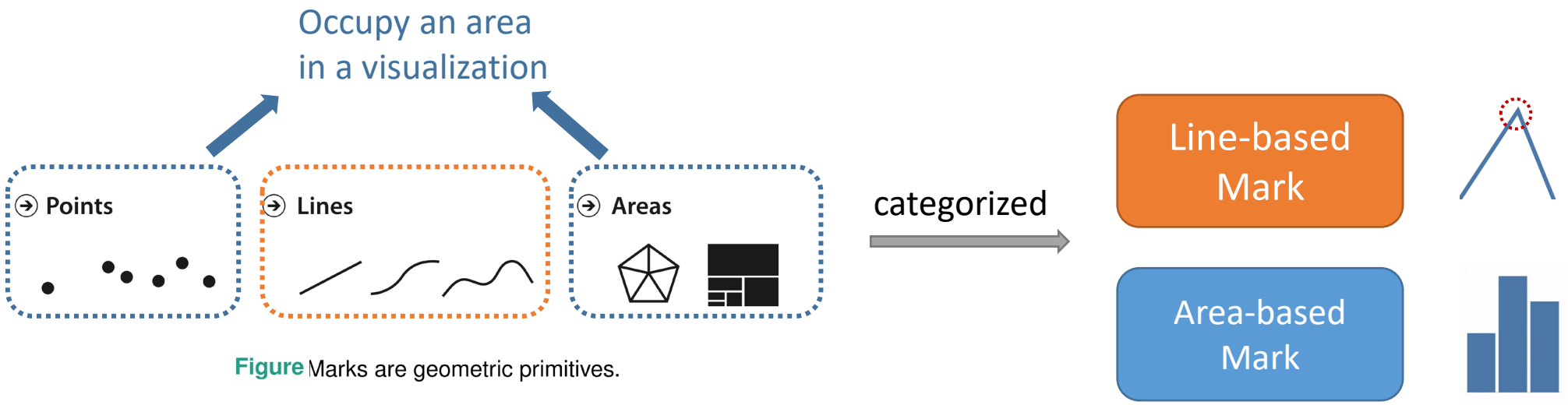


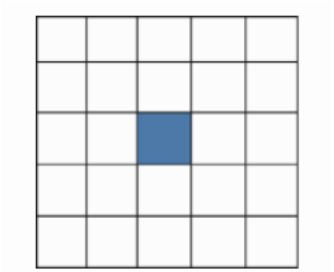
Figure Marks are geometric primitives.

Source: Visualization Analysis & Design[3]: Chapter 5 by Tamara Munzner

We utilized different schemes to process line-based marks and area-based marks!

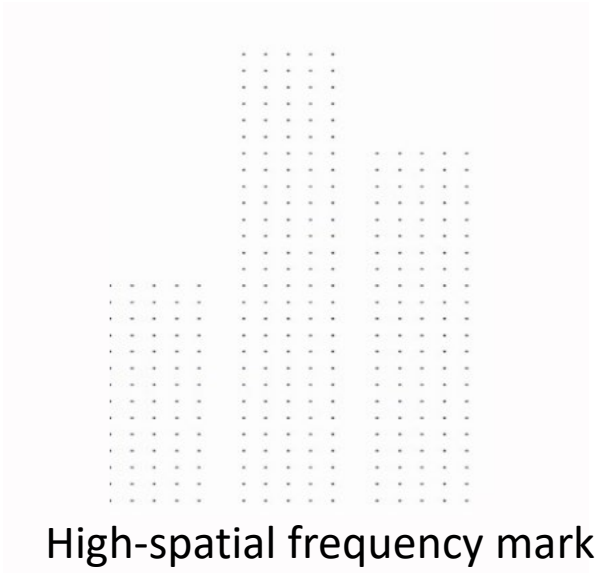
[3] Munzner, Tamara. Visualization analysis and design. CRC press, 2014.

Masking Scheme for Area-based Marks



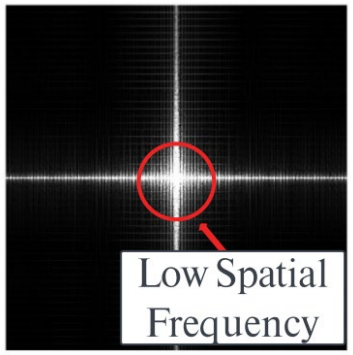
Area-based mask

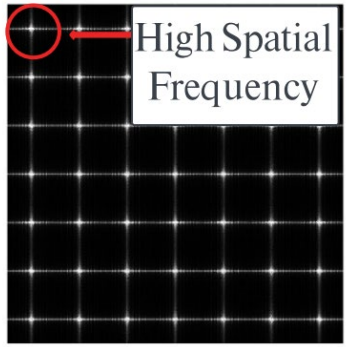
Area-based marks



High-spatial frequency mark

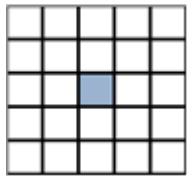
Spatial domain





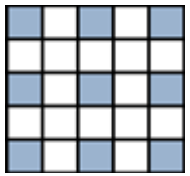
Frequency domain

Masking Scheme for Line-based Marks



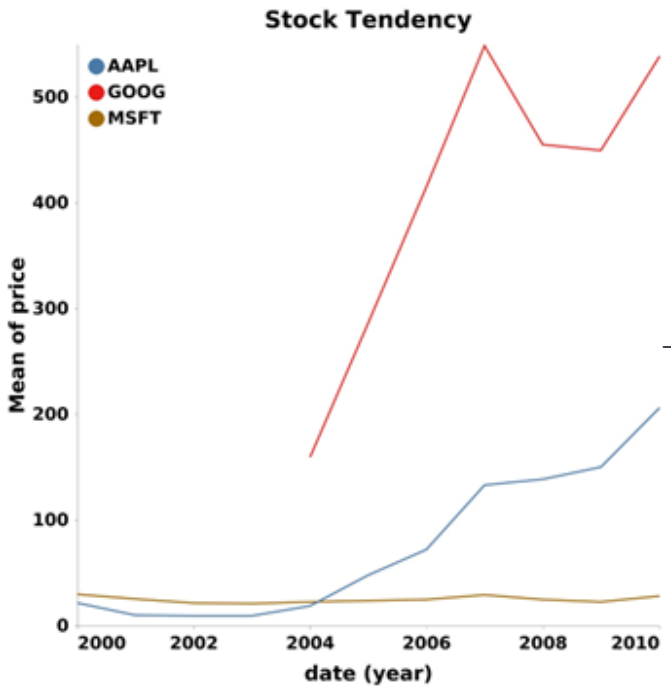
a_1)

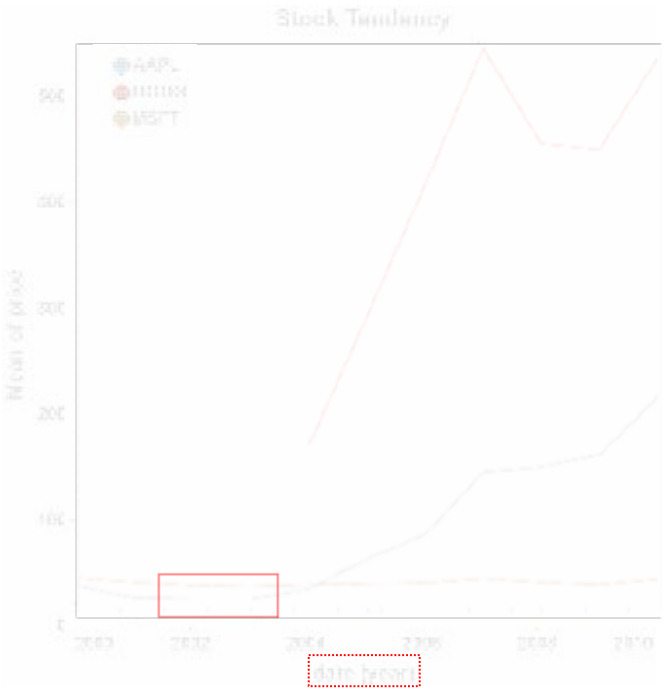
Area-based Mask

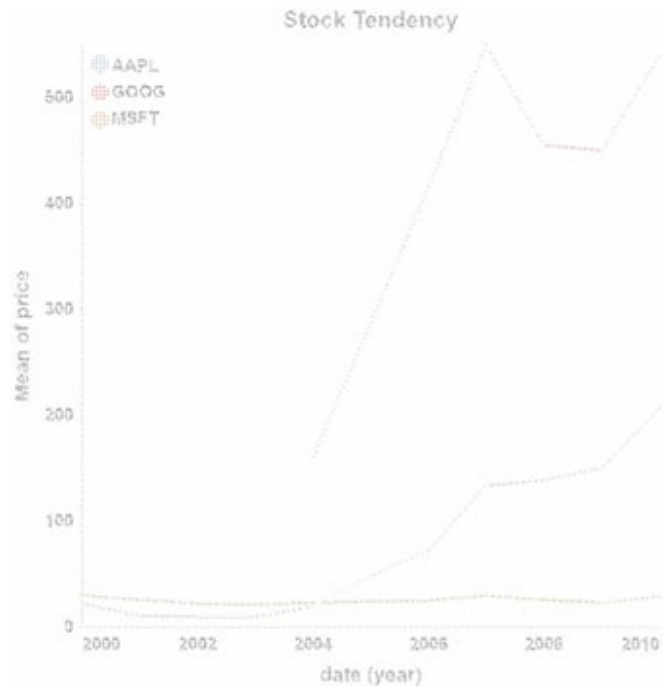


a_2)

Line-based Mask



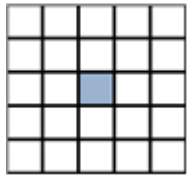




(a) (b) (c) (d)

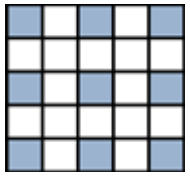
Masking Scheme for Line-based Marks

a_1)

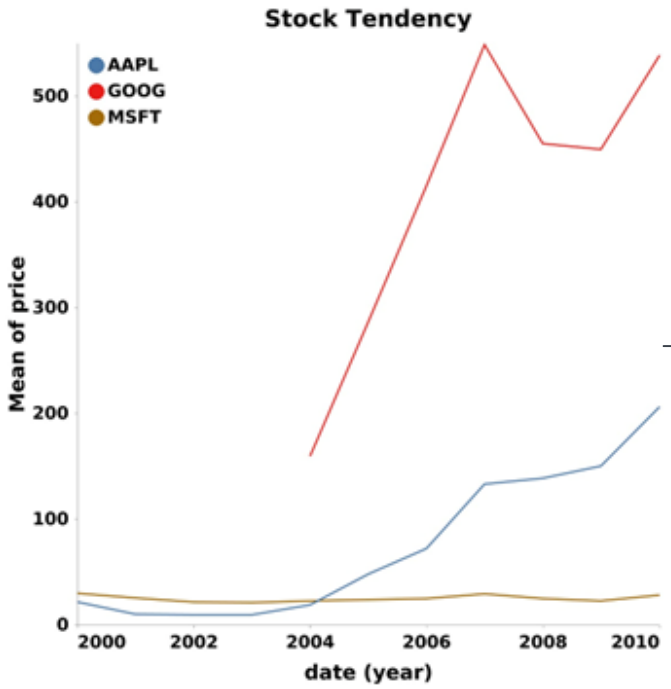


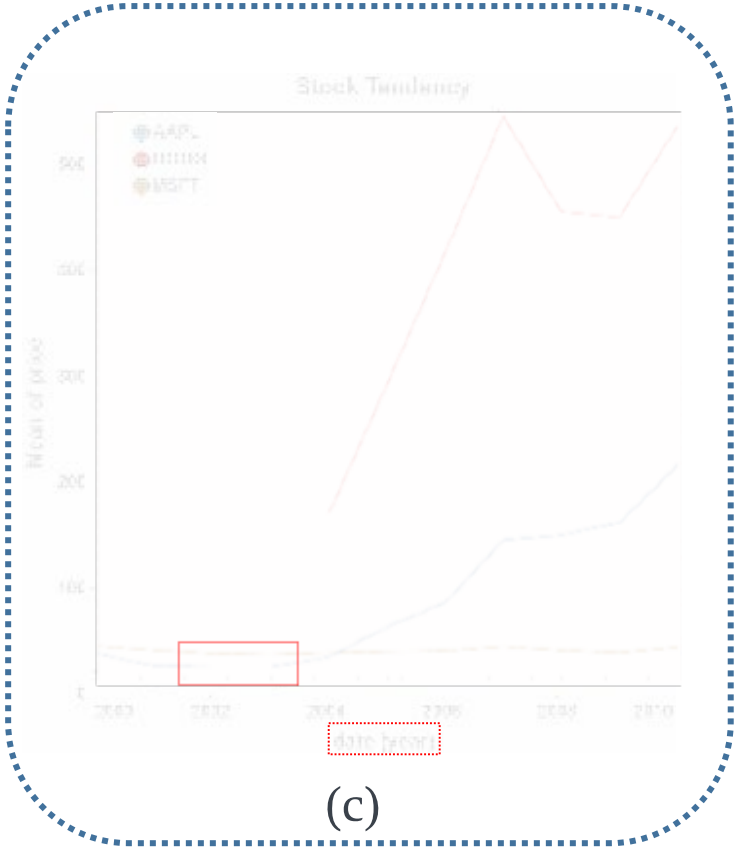
Area-based Mask

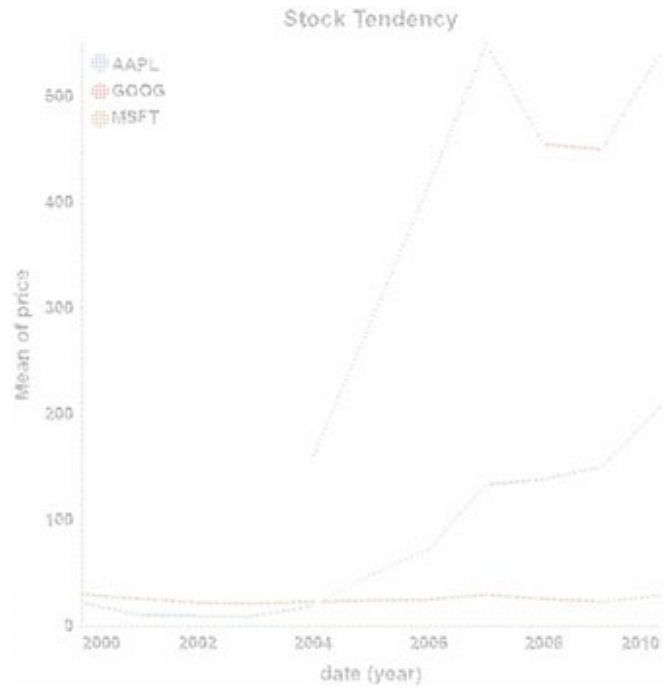
a_2)



Line-based Mask



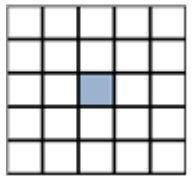




(a) (b) (c) (d)

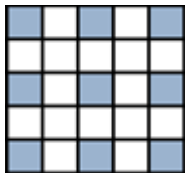
Masking Scheme for Line-based Marks

a_1)

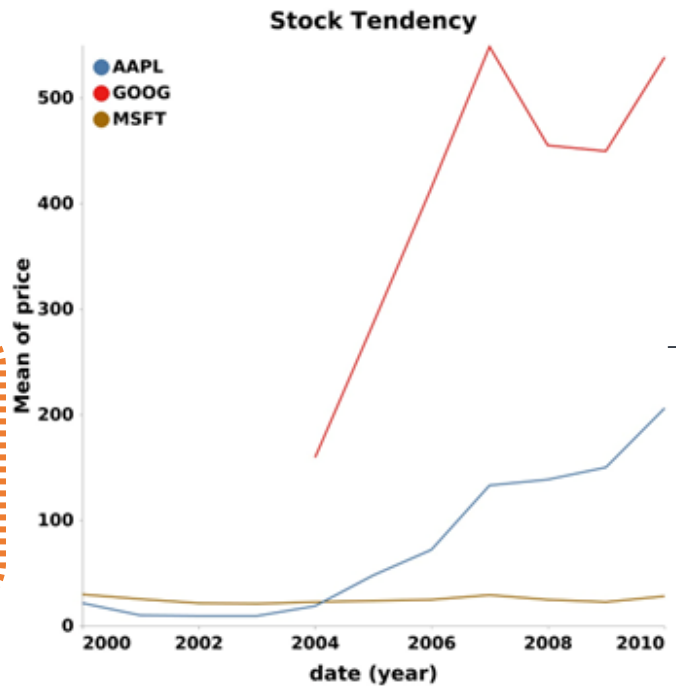


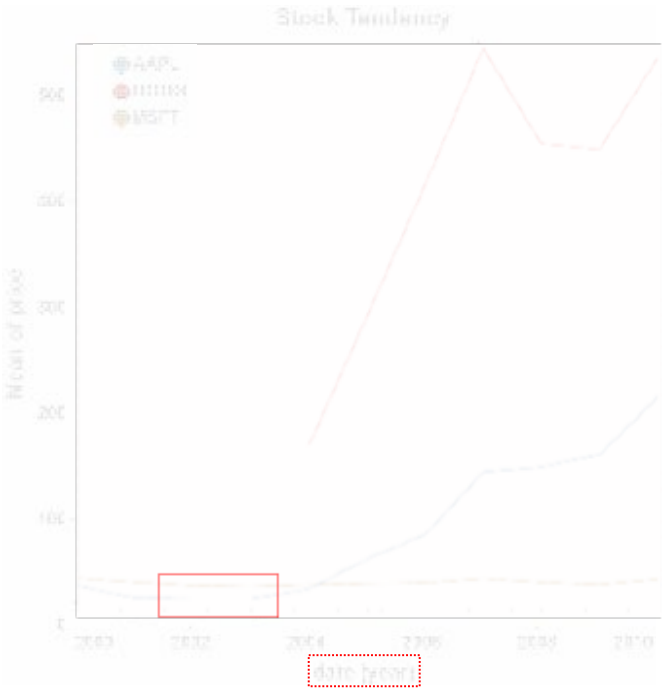
Area-based Mask

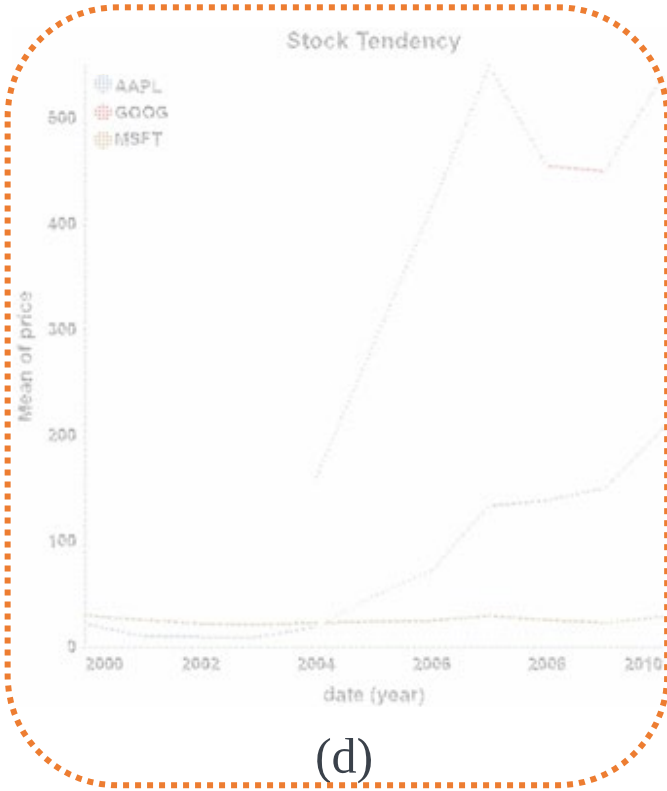
a_2)



Line-based Mask



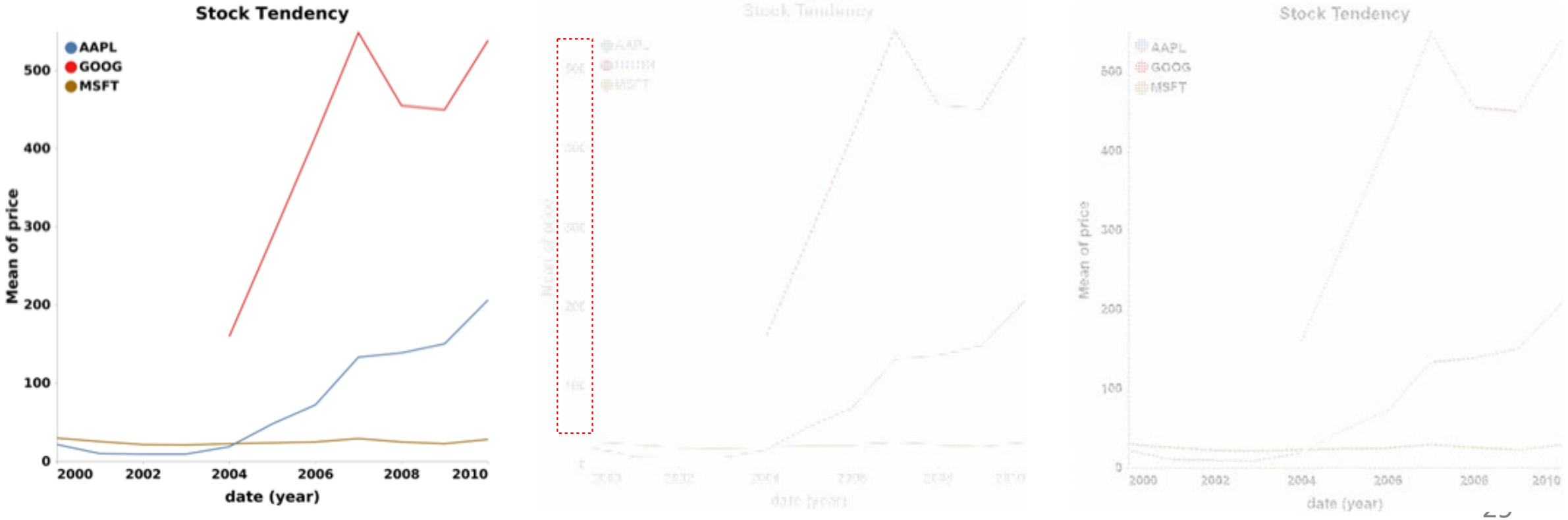




(a) (b) (c) (d)

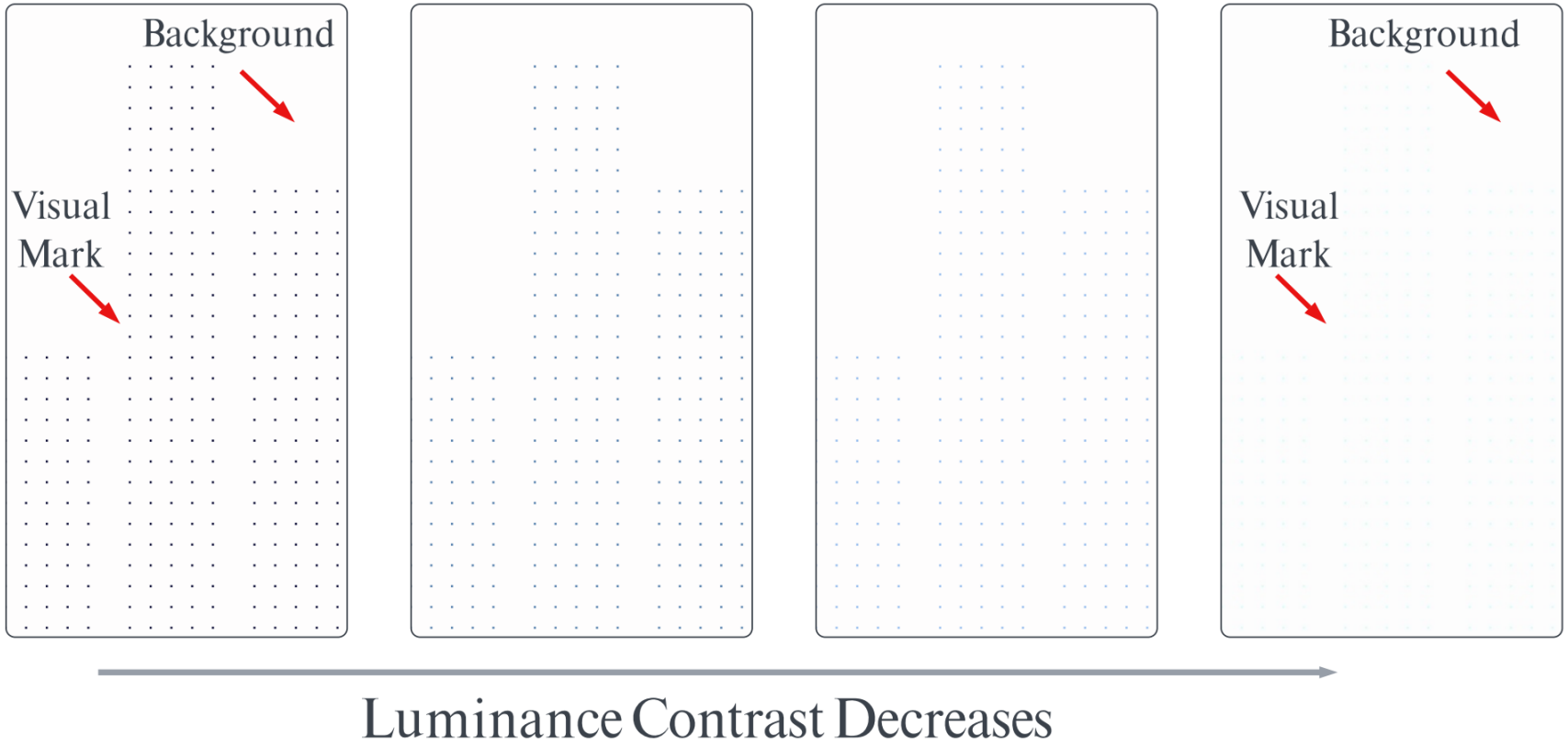
Masking Scheme for Line-based Marks

- We also apply the line-based mask on visualization axis and text because they are made of lines by nature



Masking Scheme for Area-based Marks

We change the luminance values of marks in the LAB color space



Evaluation

Evaluation – Preliminary Study

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- Human perception of visual indicators is affected by two elements: luminance contrast and spatial frequency

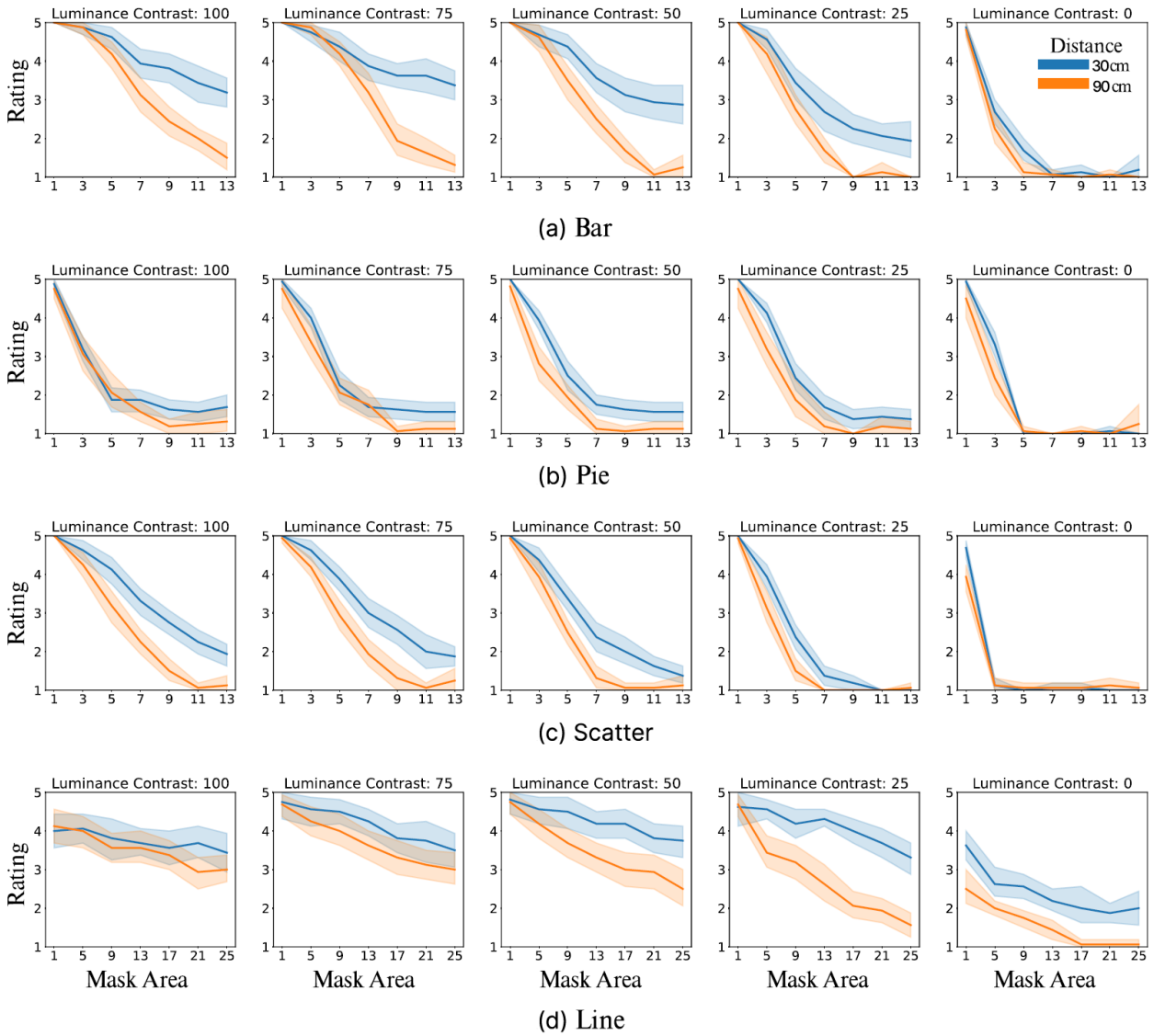
- To attain optimal privacy protection, we must identify the best combination of these two factors

Evaluation – Preliminary Study

We designed a 5-scale rating to evaluate participants' effort and time needed to see the visualization processed by our method.

1: I cannot recognize any visual marks from the visualization.
2: I can identify a few visual marks from the visualization.
3: I can identify a large portion of the marks from the visualization.
4: I need some time and effort to identify all visualization marks from the visualizations.
5: I can easily recognize all the visual marks at a glance.

Evaluation – Preliminary Study



- Four popular visualization types[3]:
  bar, pie, scatter, and line

[4] Battle, Leilani, et al. "Beagle: Automated extraction and interpretation of visualizations from the web." Proceedings of the 2018 CHI conference on human factors in computing systems. 2018.

Evaluation – User Study

- According to the preliminary study result, we selected the best combination of two factors and further conducted a user study.

- We recruited 18 participants to systematically assess the effectiveness of the method.

Evaluation – User Study

Baseline methods:

- **Original Visualization**: the original visualization is not processed by our approach.
- **Coarse-grained Visualization**: the visualization is processed by only the coarse-grained masking scheme in our method.

Our method:

- The visualization is processed by both the coarse-grained and fine-grained masking scheme.

Evaluation – User Study

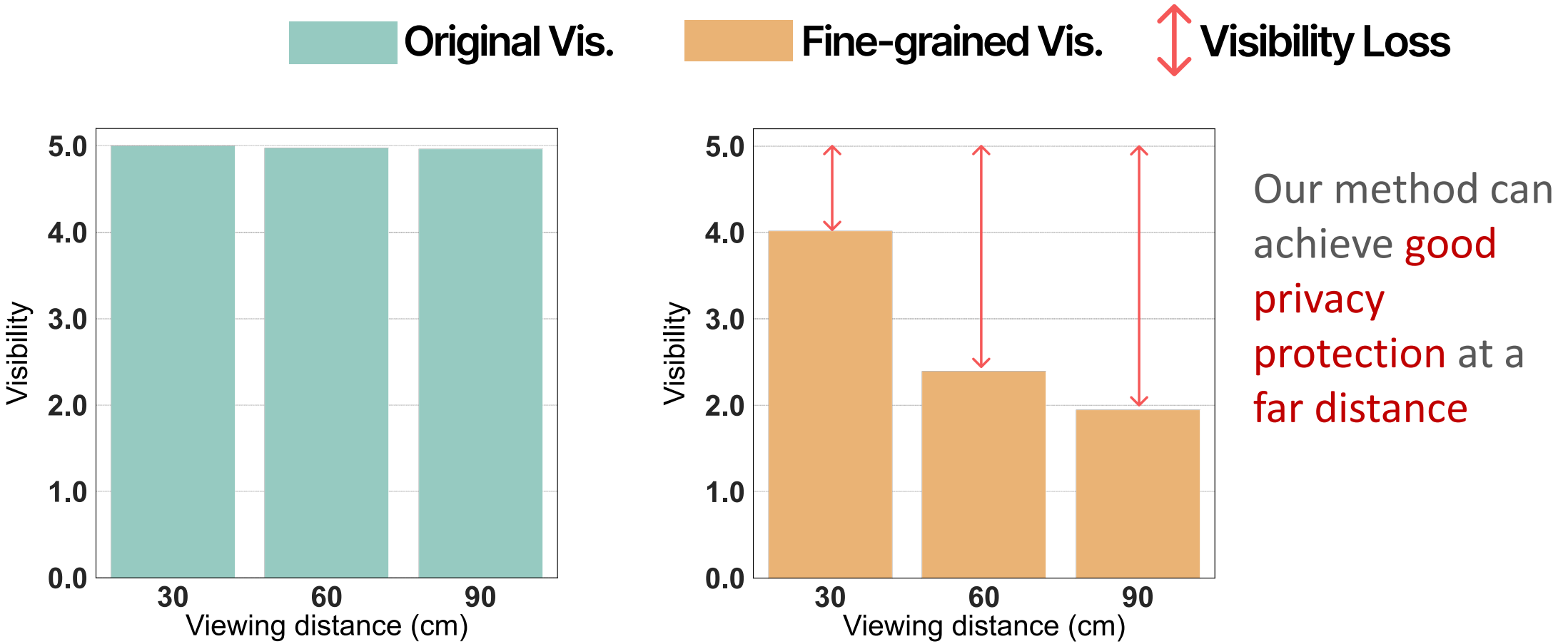
We conducted a within-subject study where the participants viewed the test visualization at three different distances: 30cm, 60 cm and 90 cm.

Evaluation – User Study

- Visualization is composed of text, axes and visual marks[5].
- Therefore, there are two tasks for rating: visual mark visibility rating and text readability rating.
- We utilize the same rating criteria the same as the preliminary study.

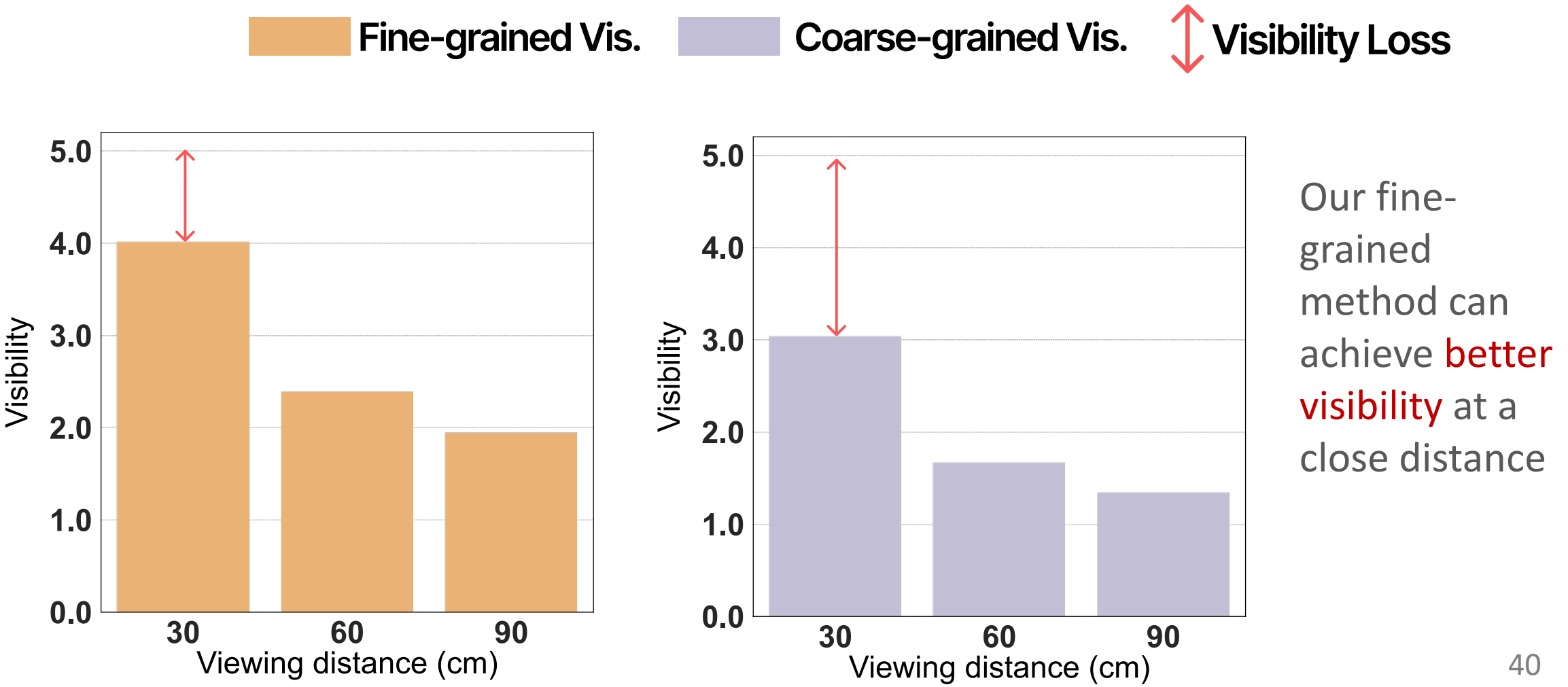
[5] Poco, Jorge, and Jeffrey Heer. "Reverse-engineering visualizations: Recovering visual encodings from chart images." Computer graphics forum. Vol. 36. No. 3. 2017.

Evaluation – User Study



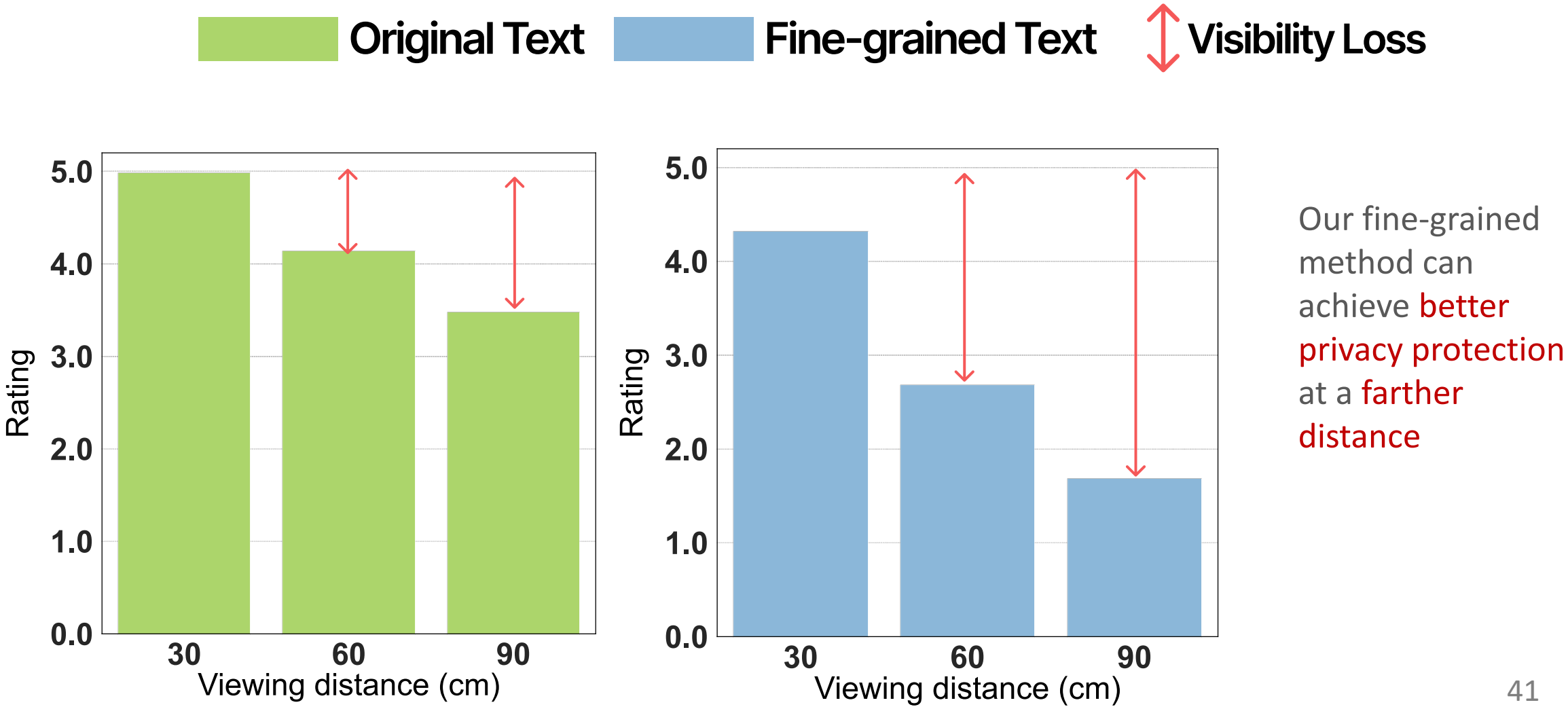
Our method can achieve good privacy protection at a far distance

Evaluation – User Study



Our fine-grained method can achieve better visibility at a close distance

Evaluation – User Study

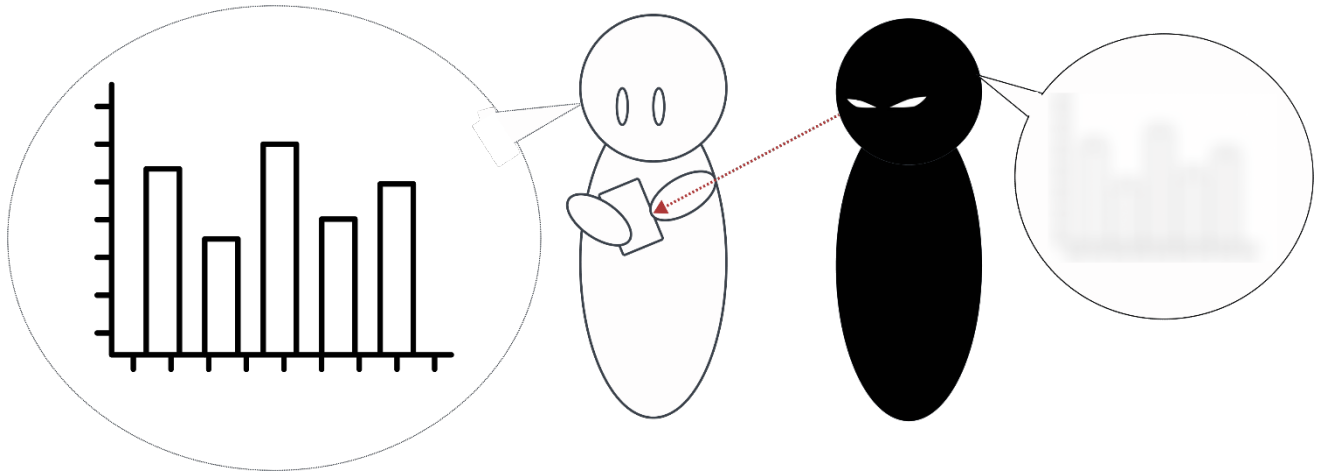


Our fine-grained method can achieve better privacy protection at a farther distance

Take-away Message & QA

- Our method enables humans to see visualization at a close distance but hardly see it at a far distance

- To this end, we utilize both the human vision system and visualization properties



Shzhang.2021@phdcs.smu.edu.sg