



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



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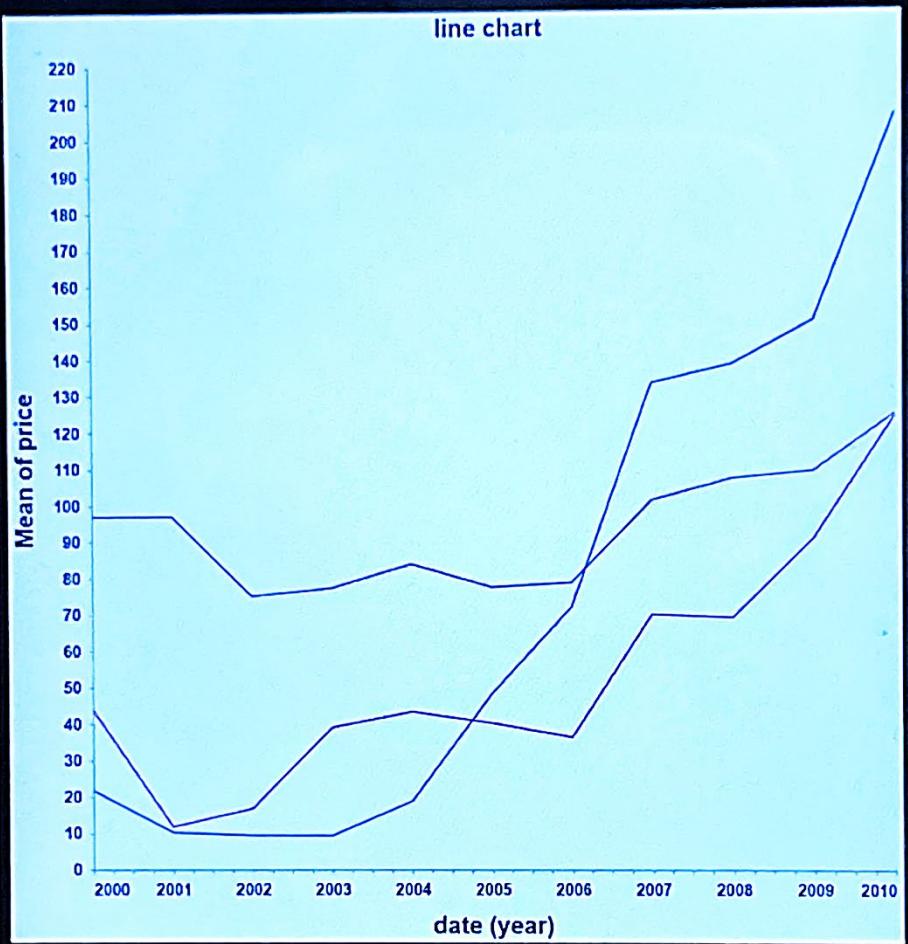




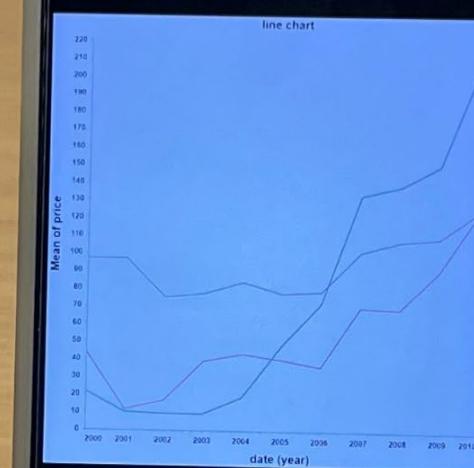
Take-away Message

- 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**

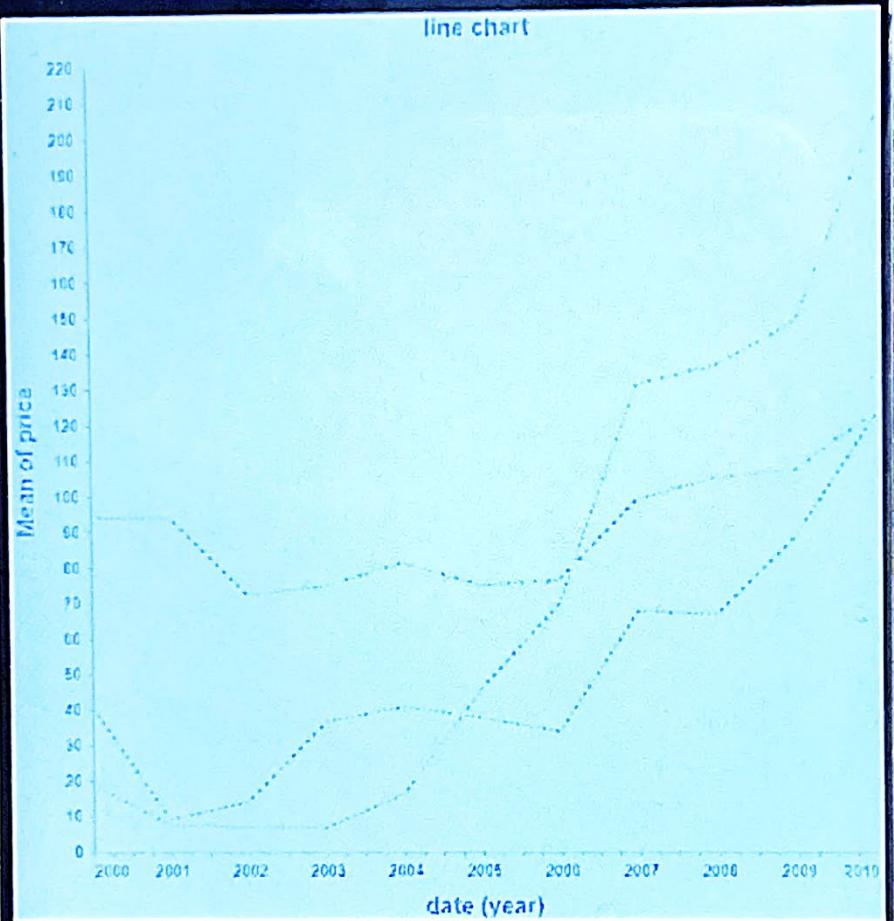
Close Viewing Distance



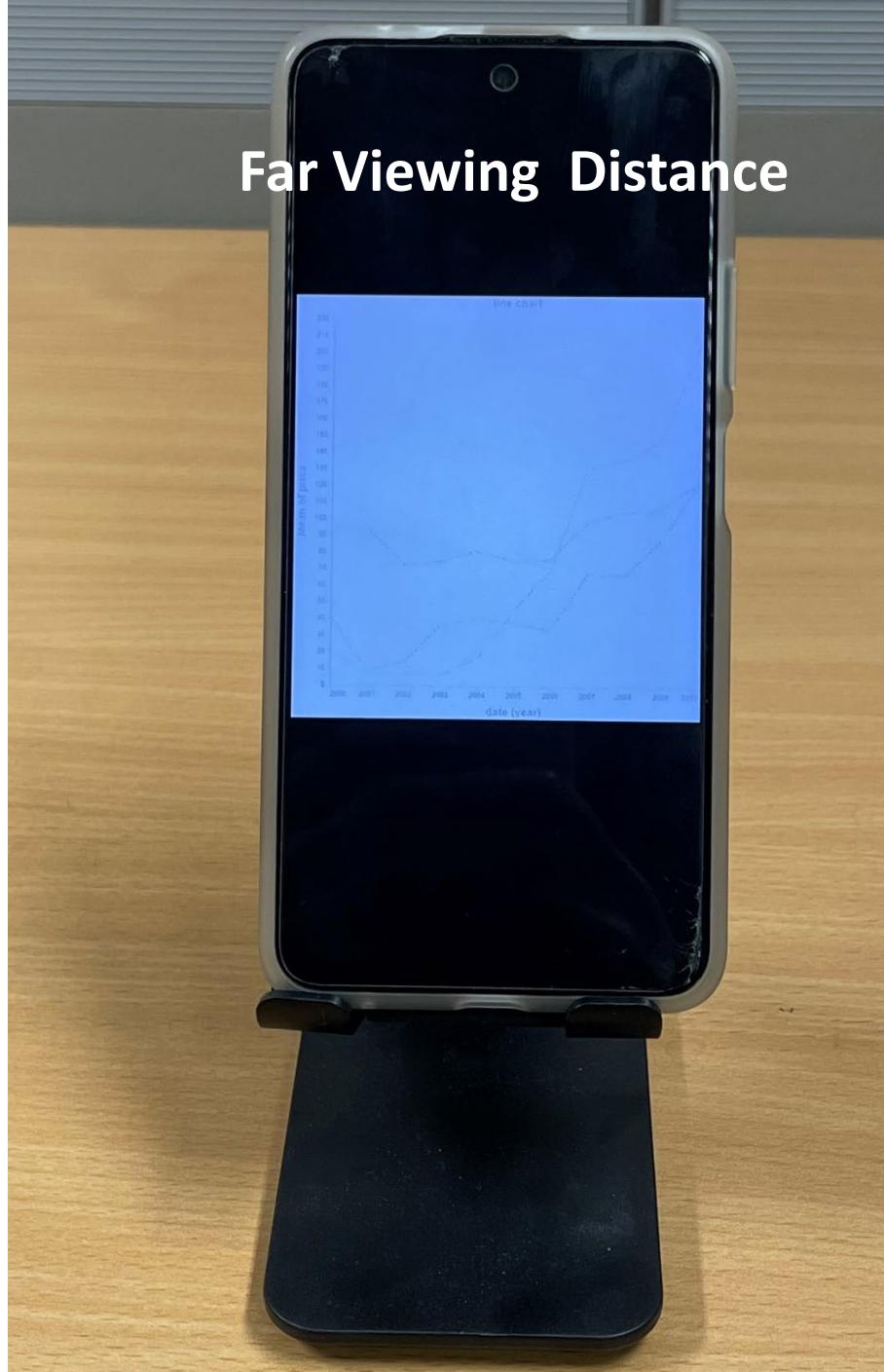
Far Viewing Distance



Close Viewing Distance



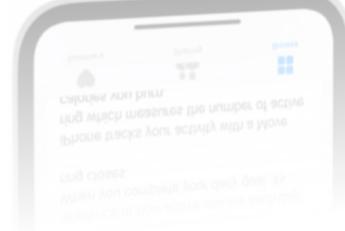
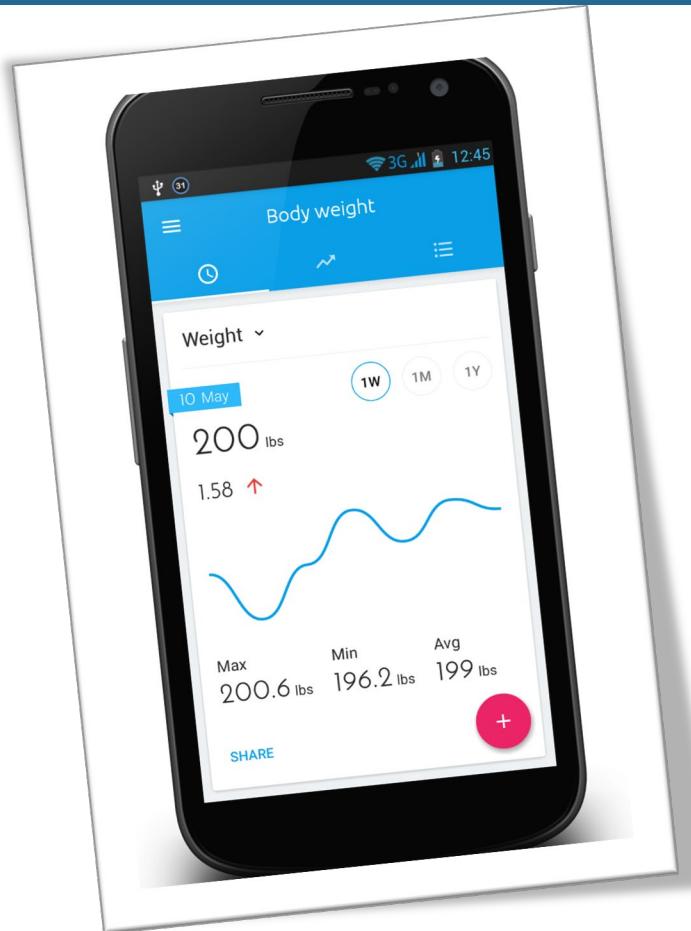
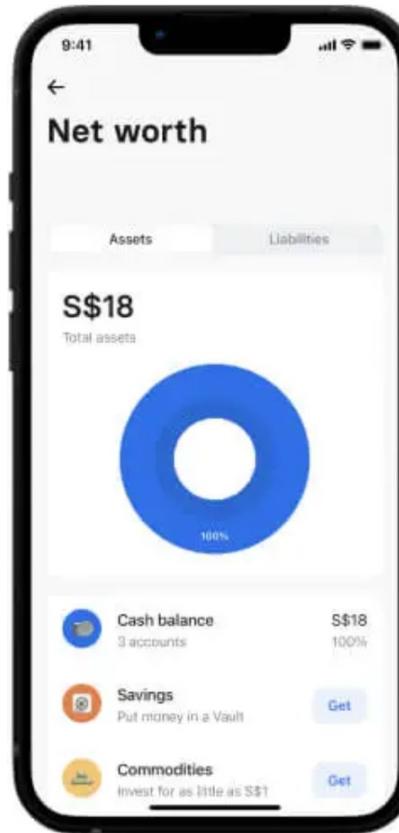
Far Viewing Distance



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ROVIE
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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



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

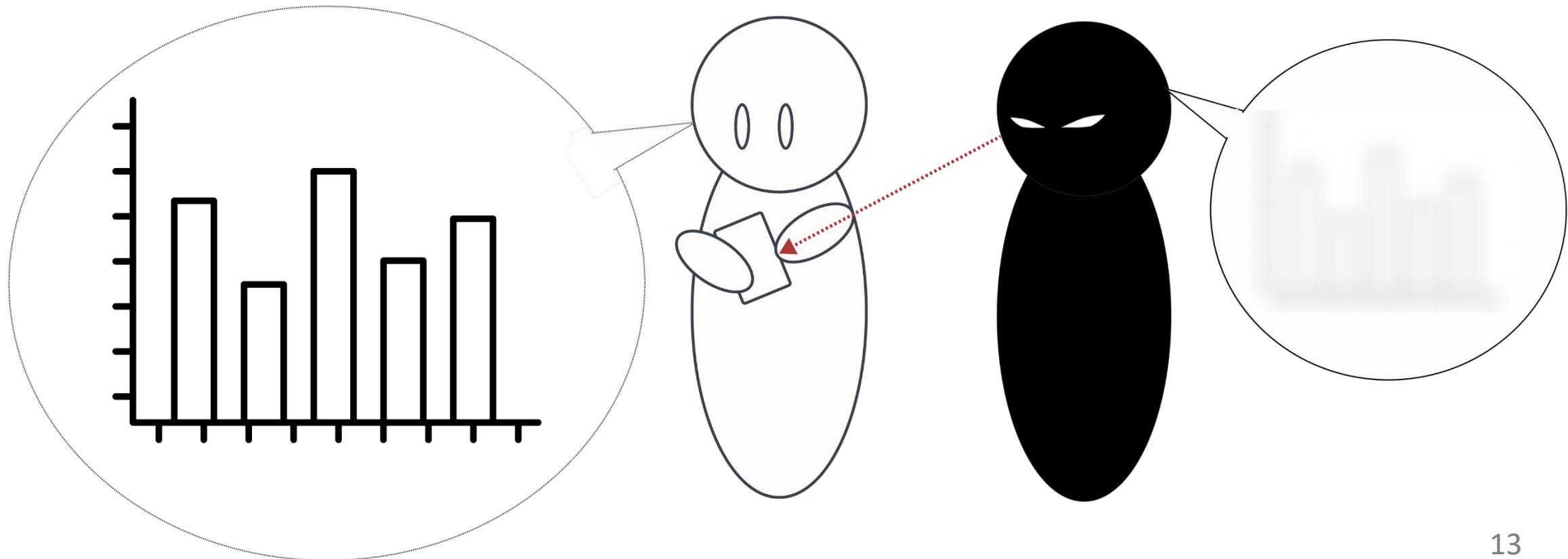
Approach



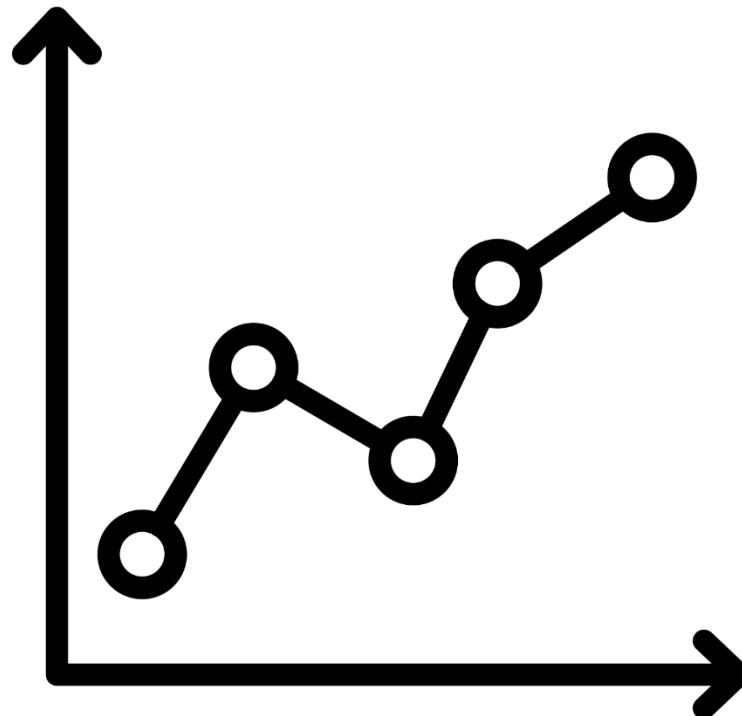
Our Approach

Users can see the visualization

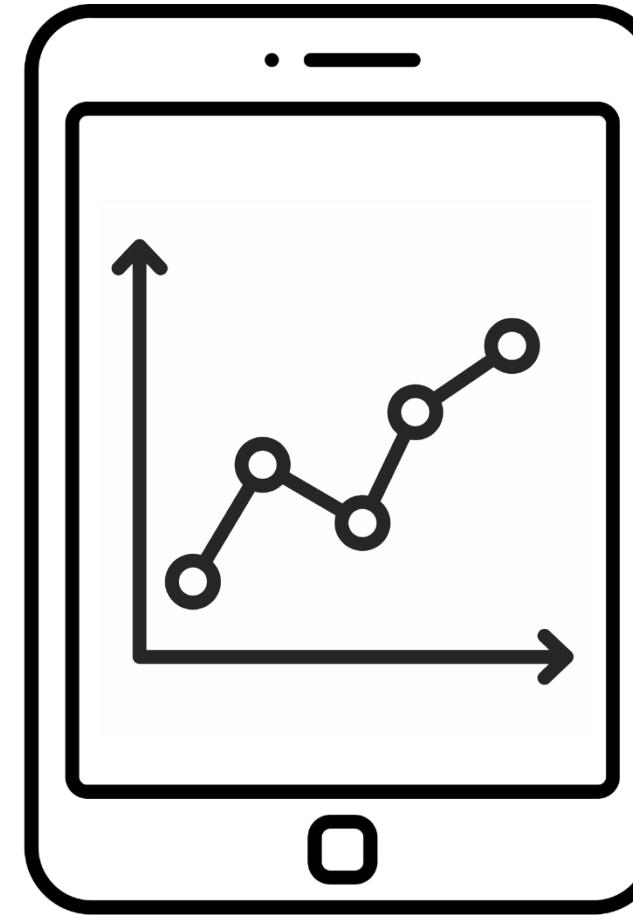
Peekers hardly see the visualization



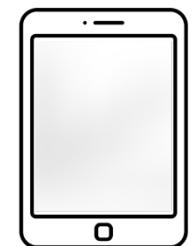
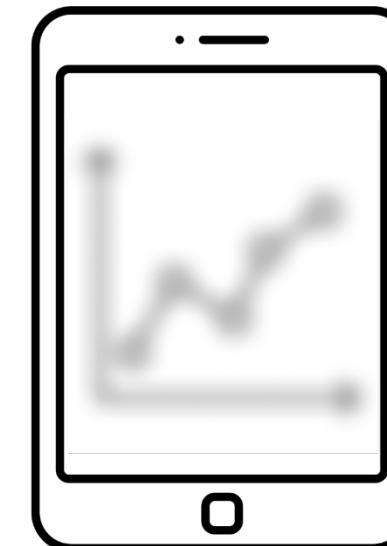
Our Approach



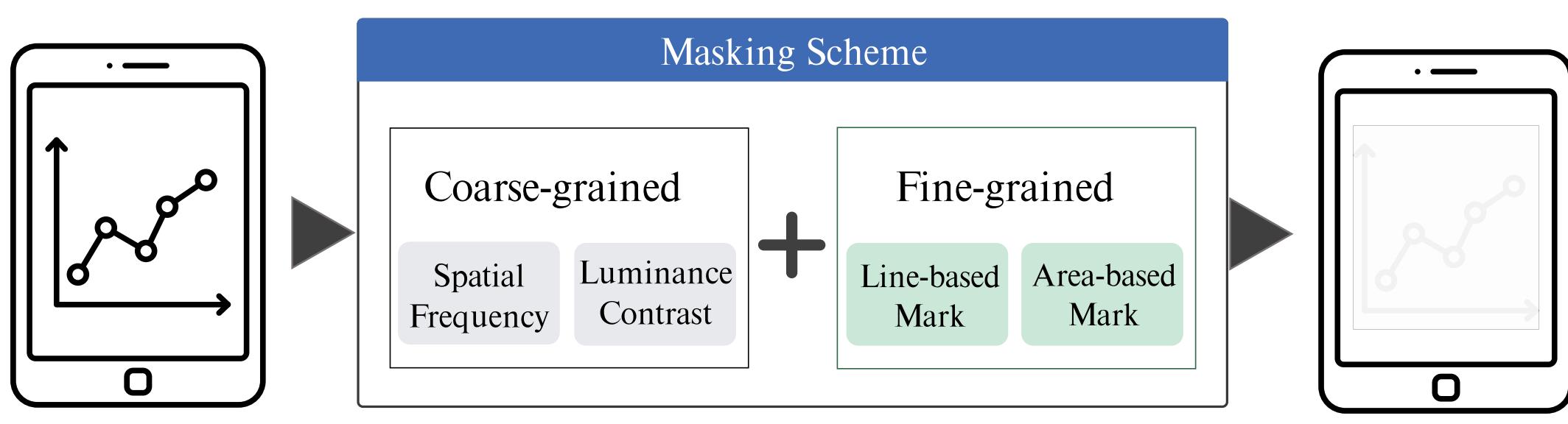
Original



Viewing Distance



Approach Overview



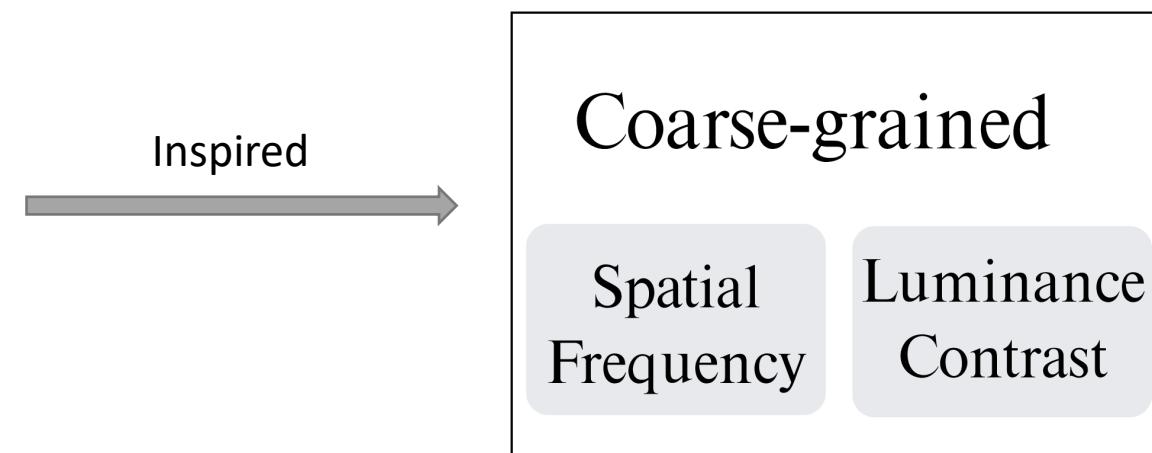
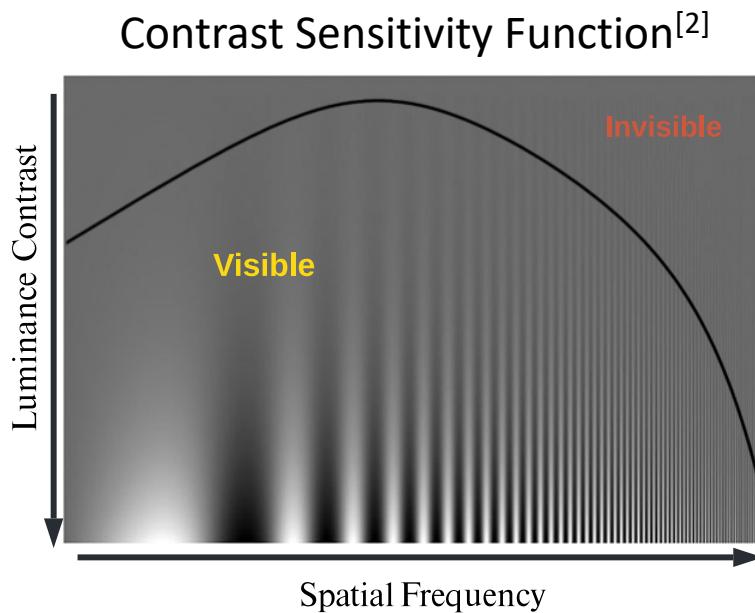
Original Visualizations

Privacy-preserving Vis.

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

Coarse-grained level

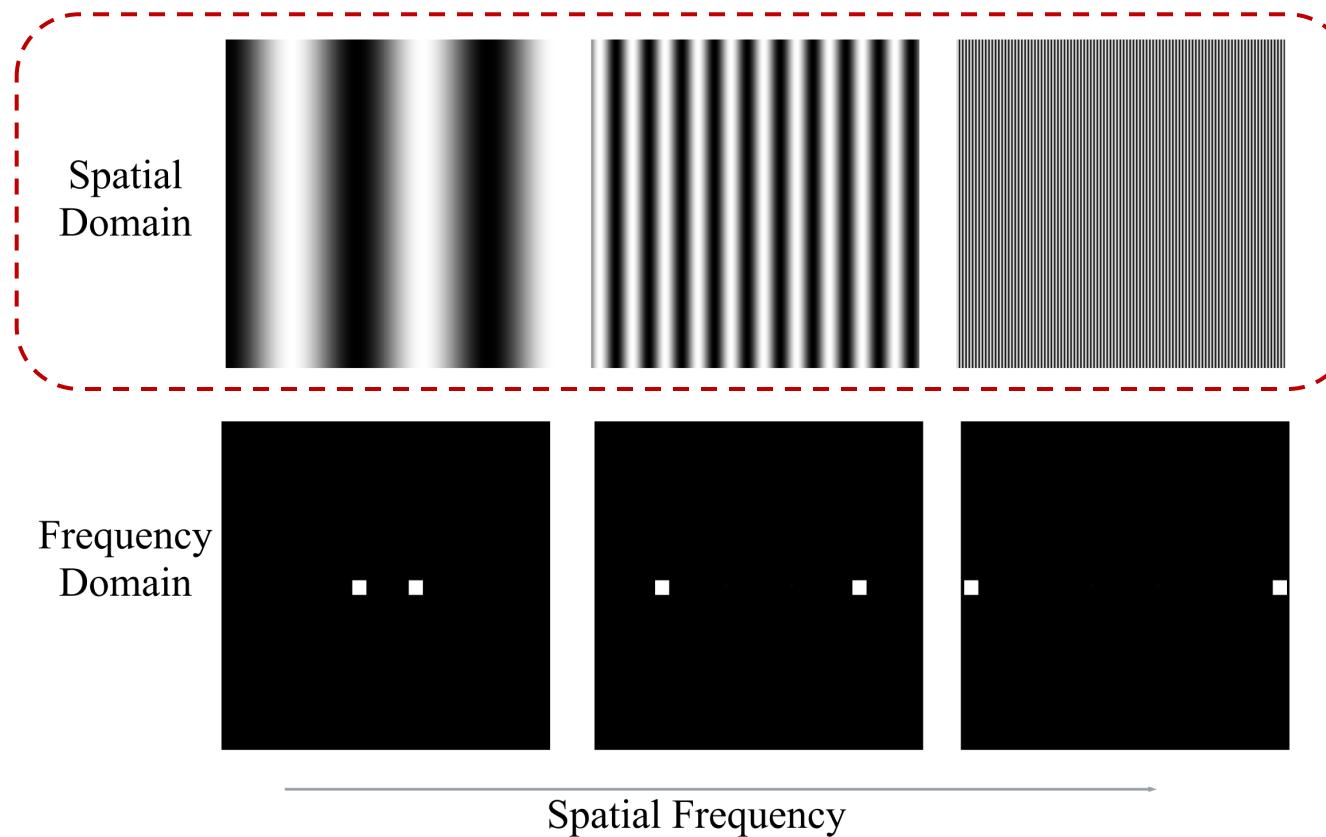
Our method is inspired by the **human vision system** characteristics



[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/>



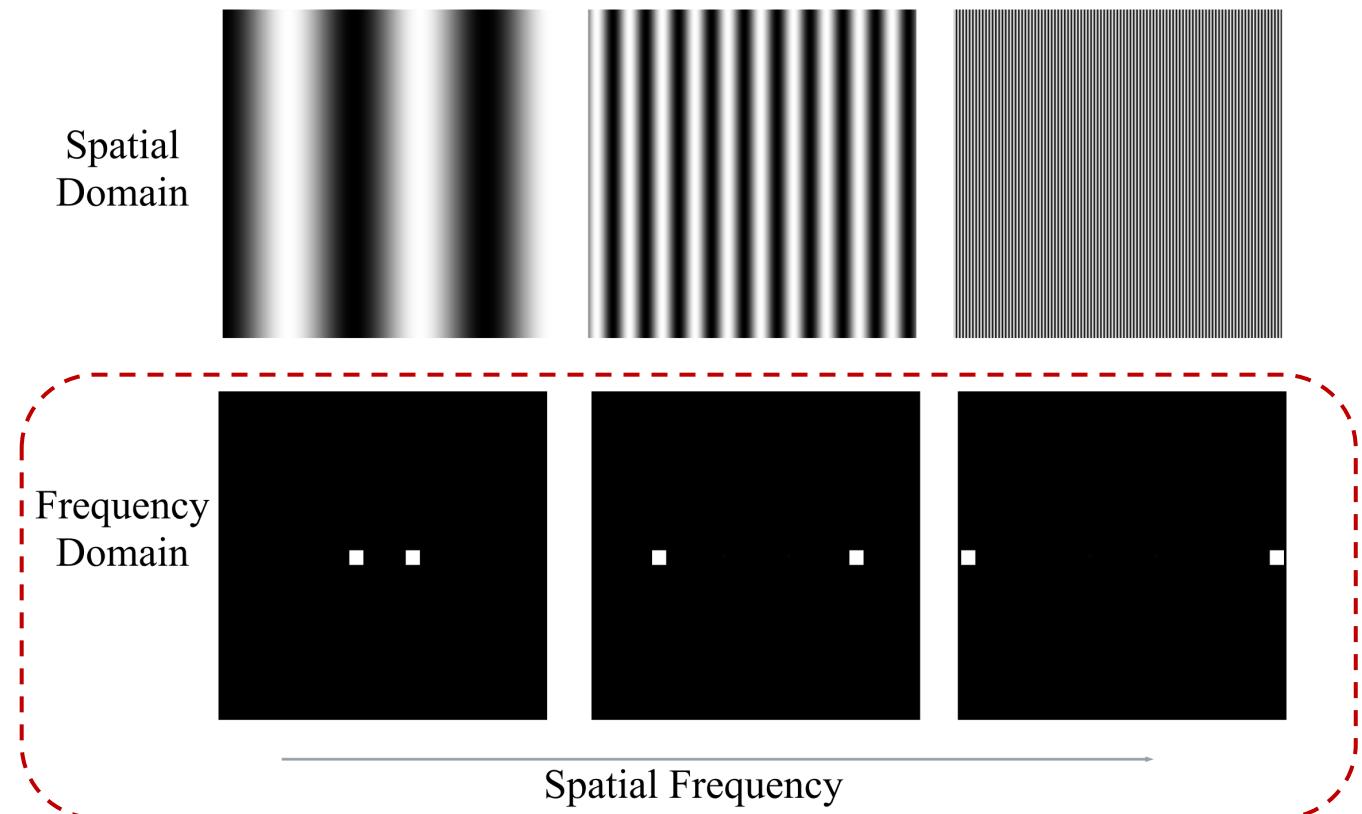
Coarse-grained level – Spatial Frequency



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



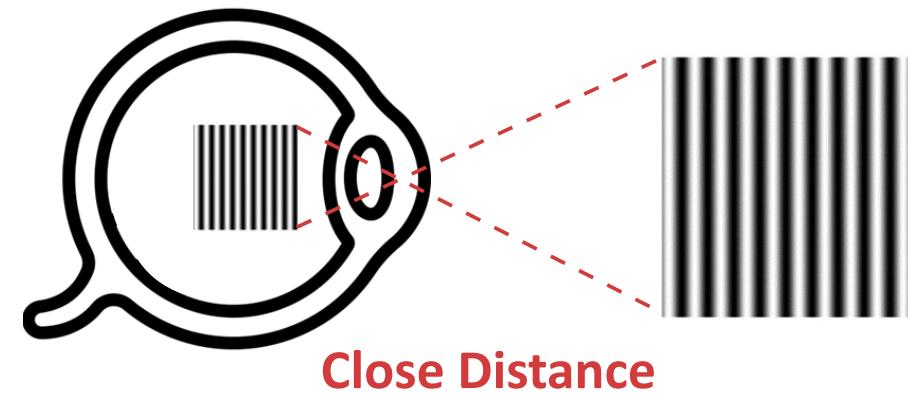
Coarse-grained level – Spatial Frequency



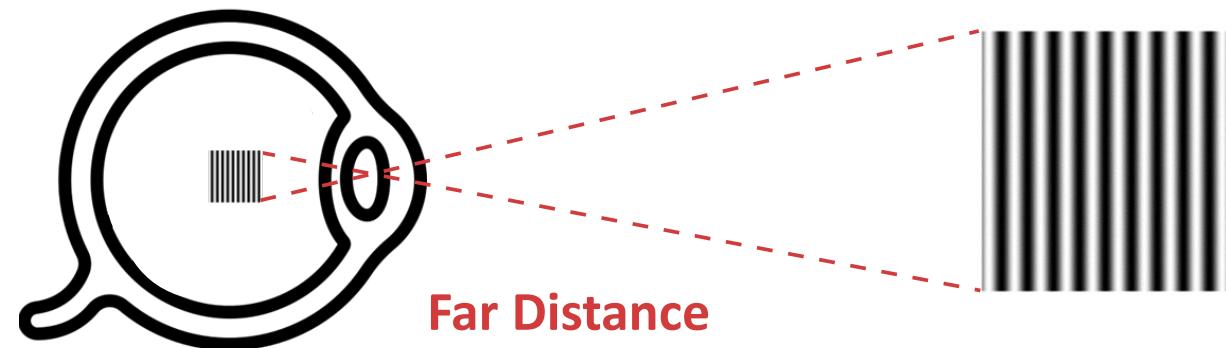
Spatial frequency relates to the frequency of color changes that humans perceive.

Coarse-grained level – Spatial Frequency

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



Close Distance

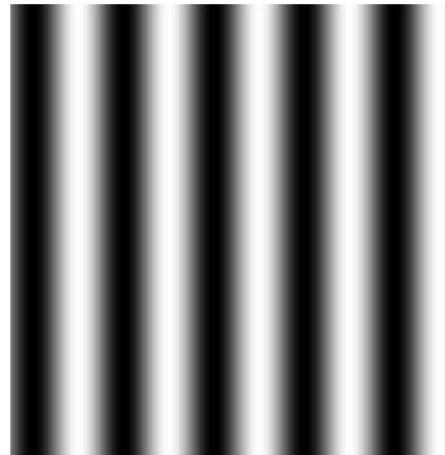


Far Distance

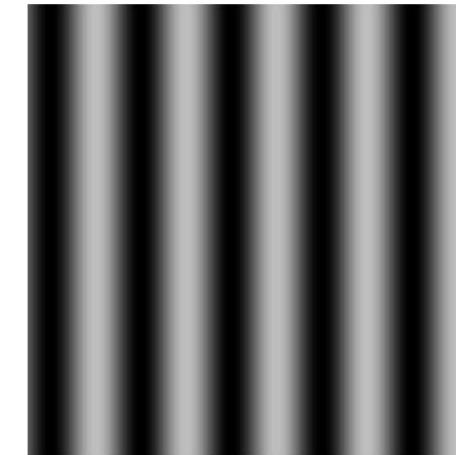


Coarse-grained level – Luminance Contrast

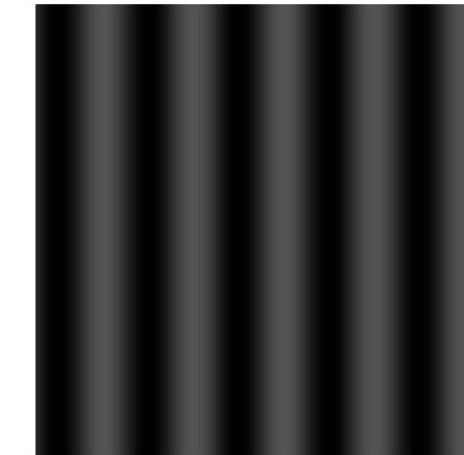
Contrast = 1



Contrast = 0.6



Contrast = 0.3

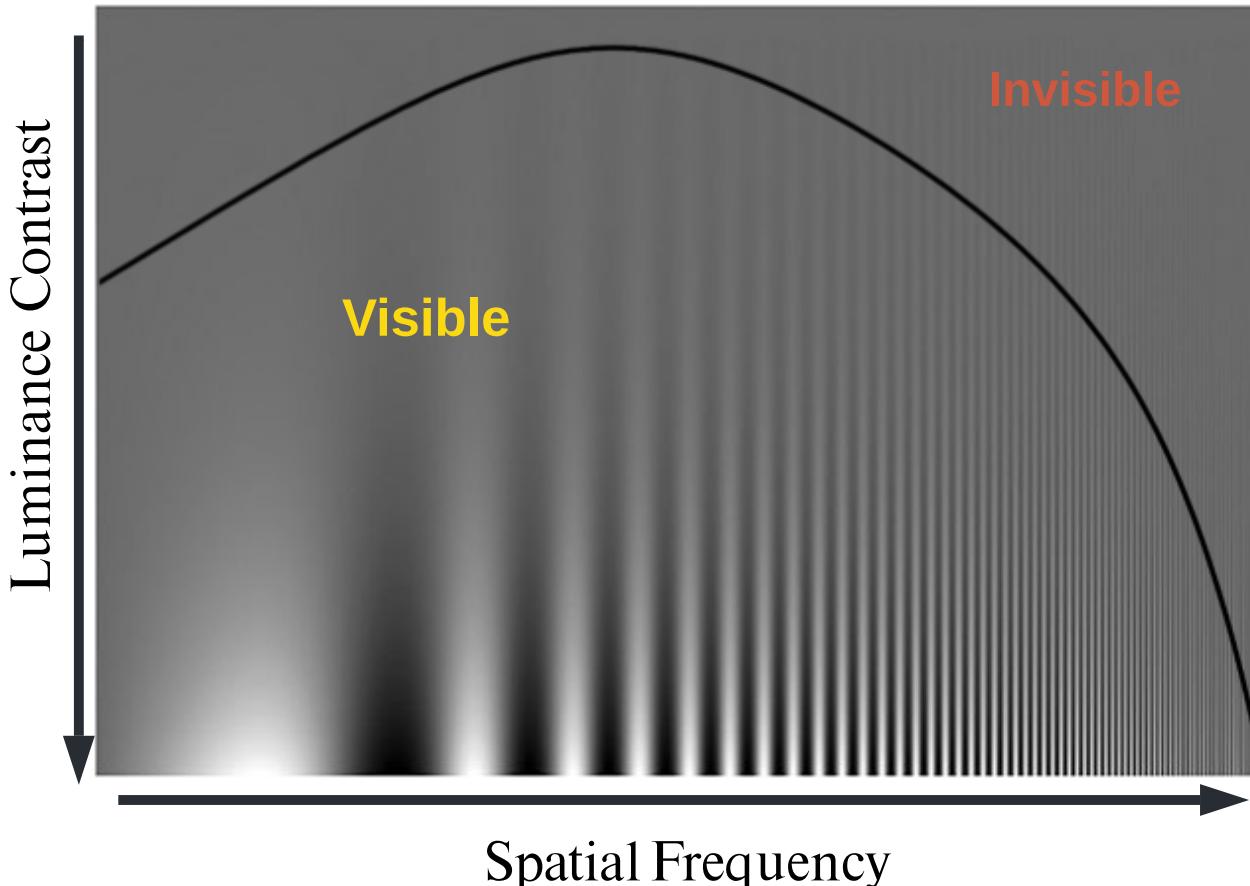


Contrast = 0



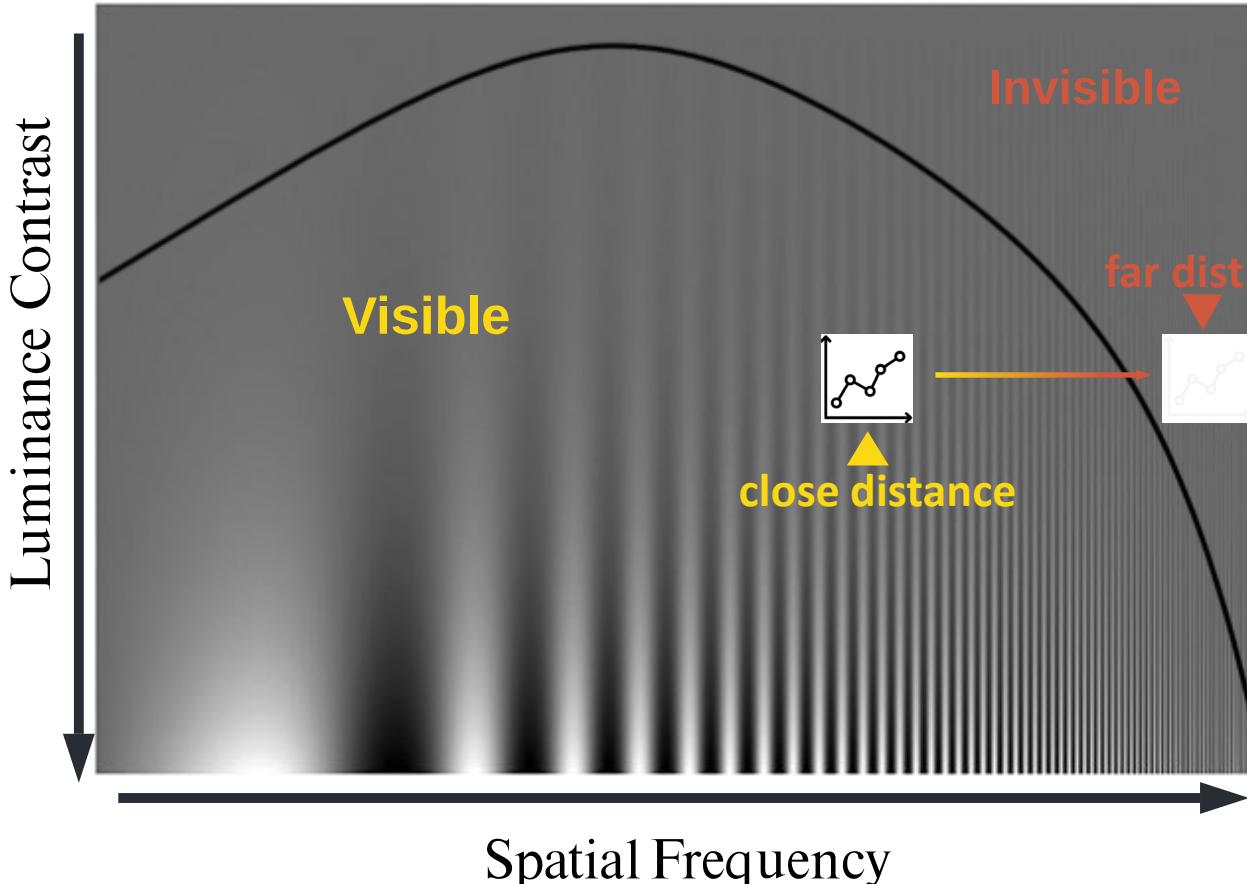
Luminance contrast refers to the difference in brightness between the two colors.

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

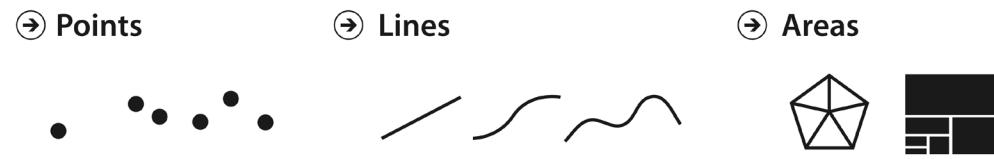
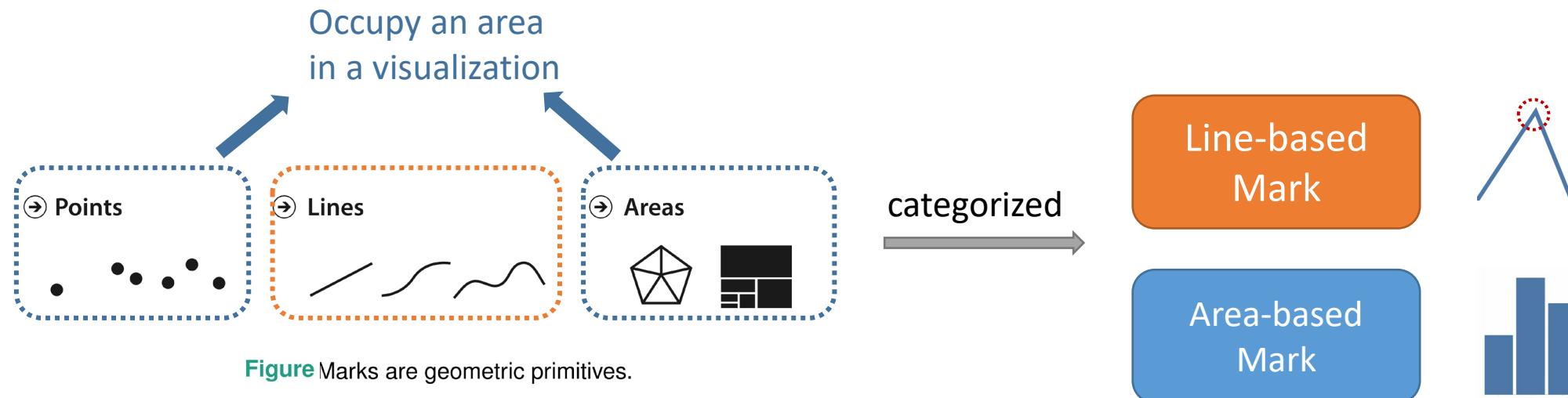


Figure Marks are geometric primitives.

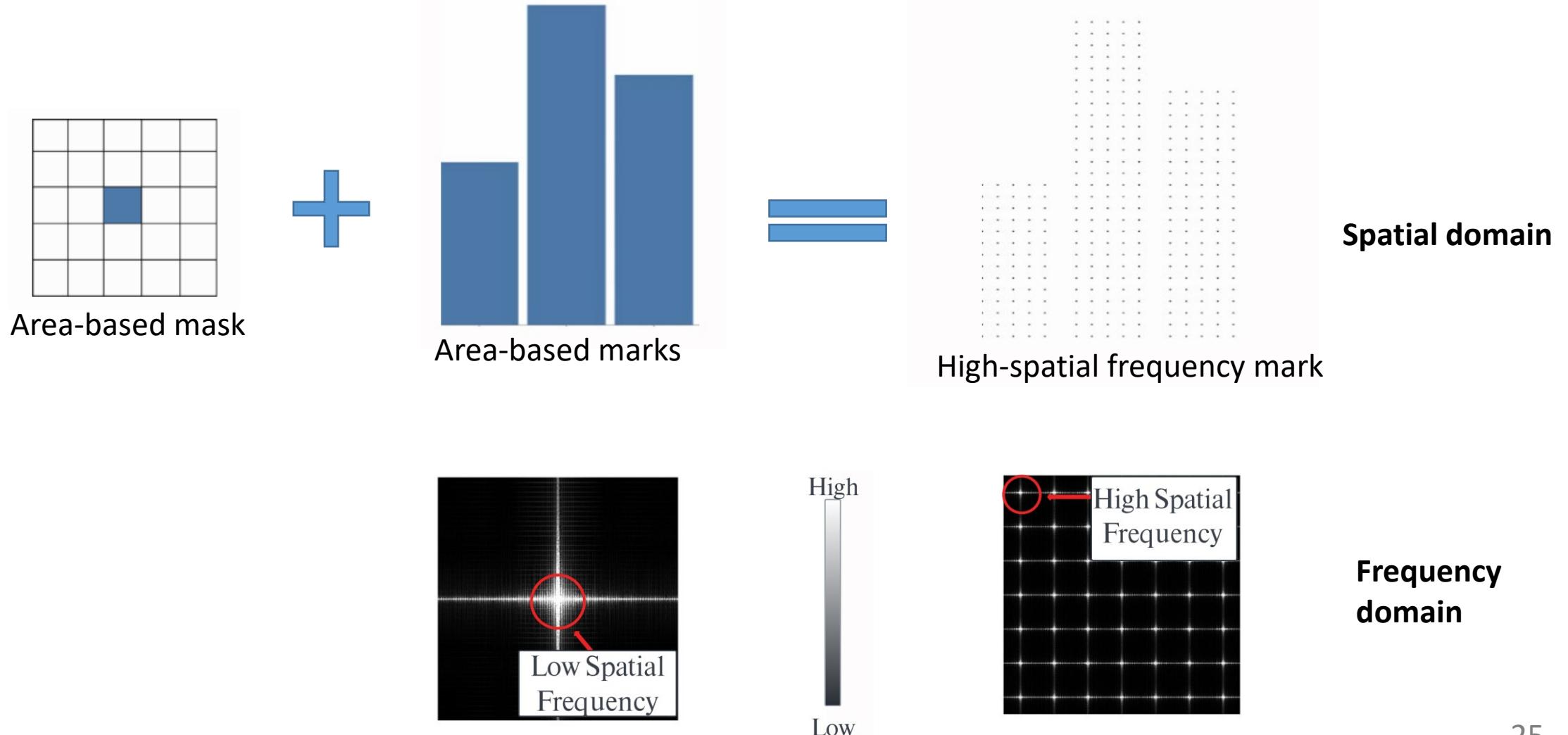
Source: Visualization Analysis & Design^[2]: Chapter 5 by Tamara Munzner

Fine-grained level

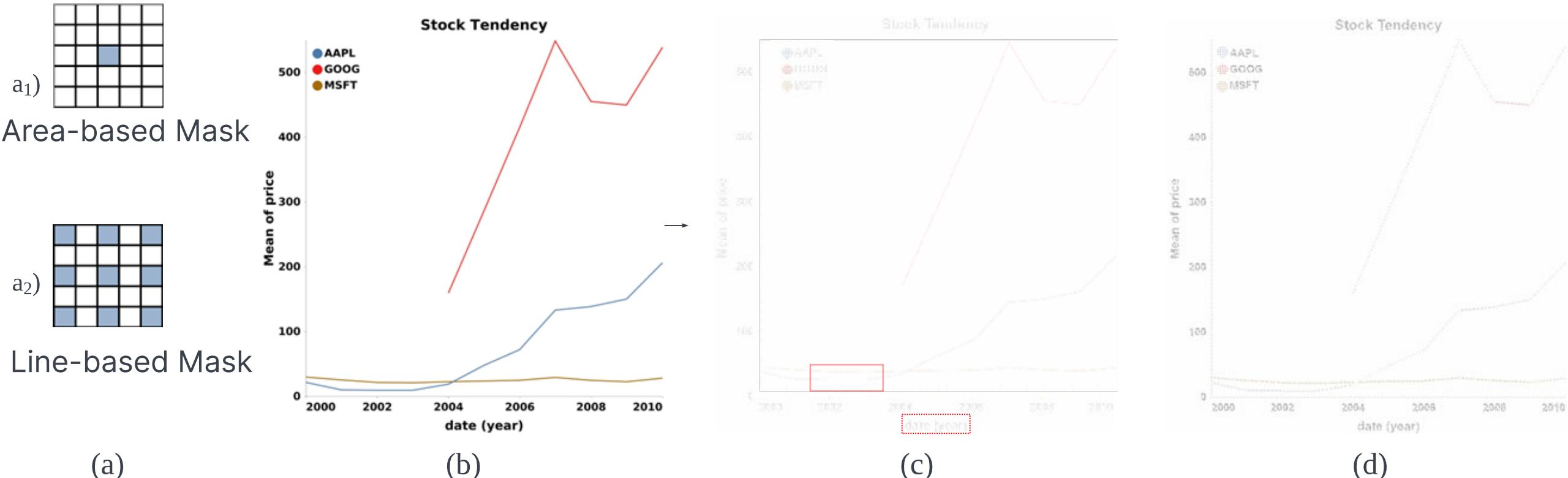


We utilized different schemes to process line-based marks and area-based marks!

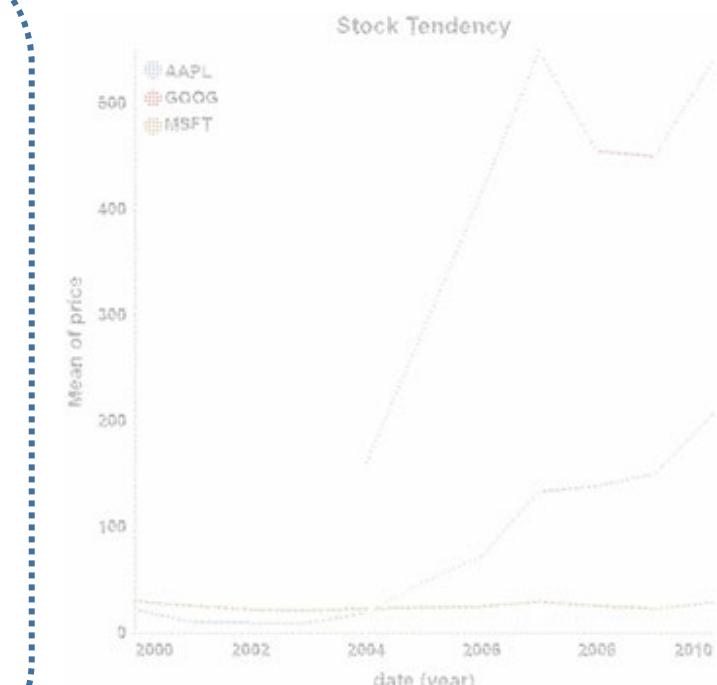
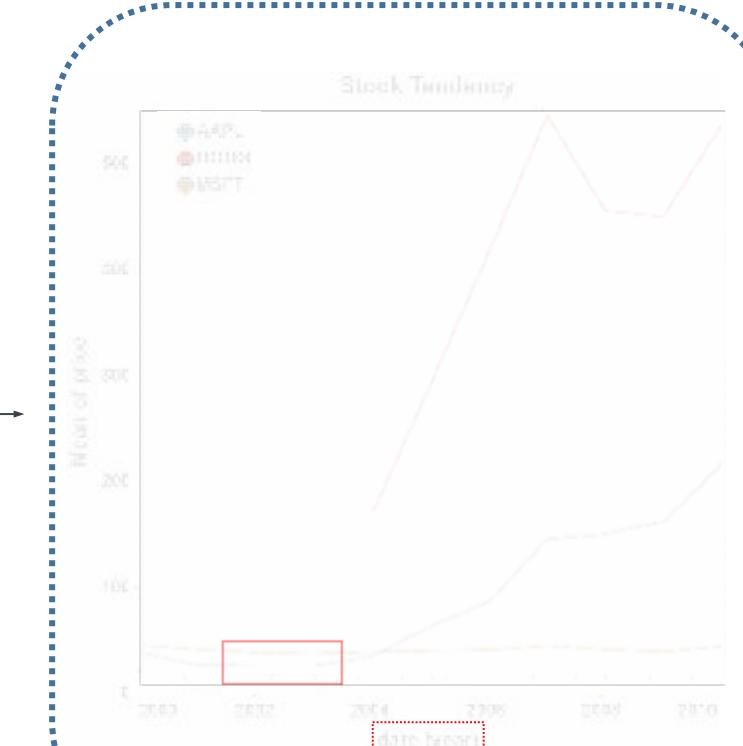
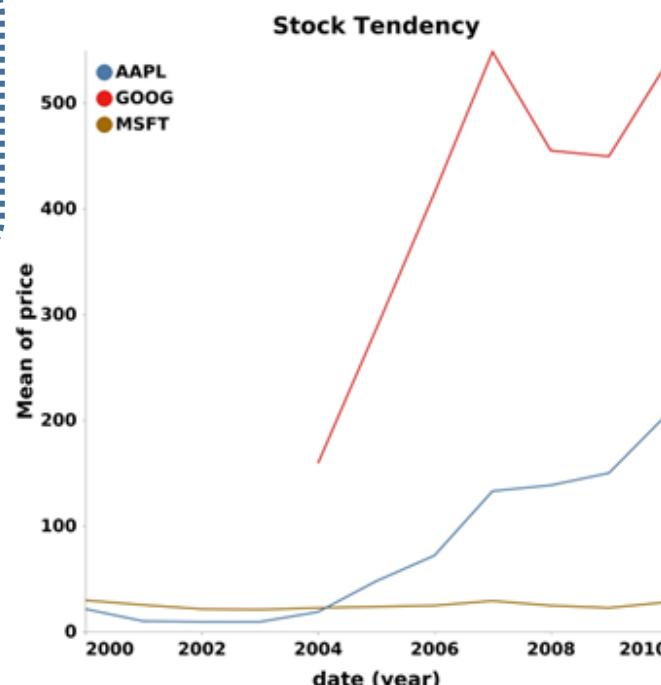
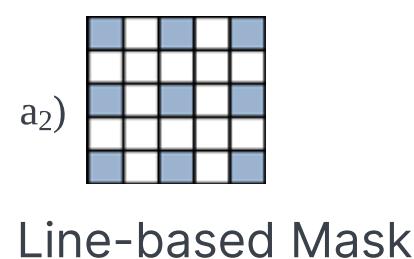
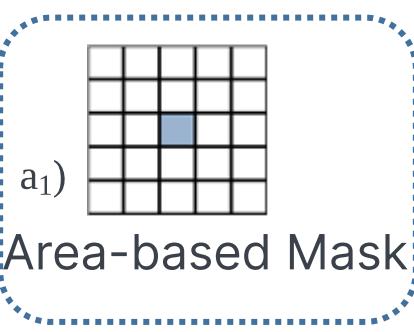
Masking Scheme for Area-based Marks



Masking Scheme for Line-based Marks



Masking Scheme for Line-based Marks



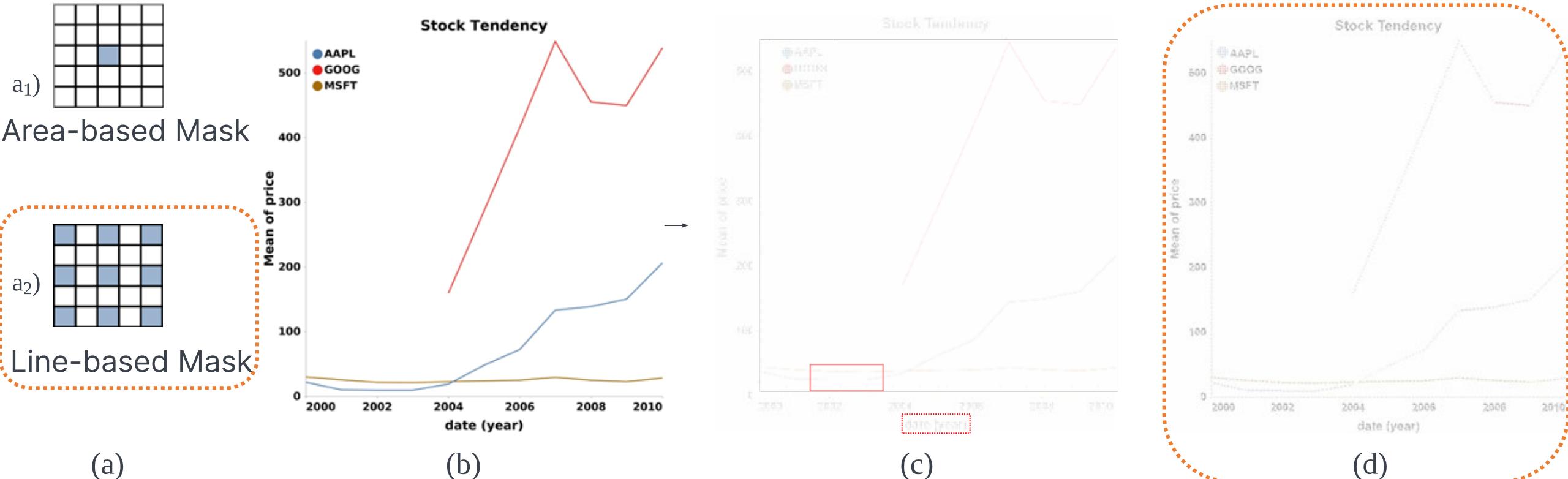
(a)

(b)

(c)

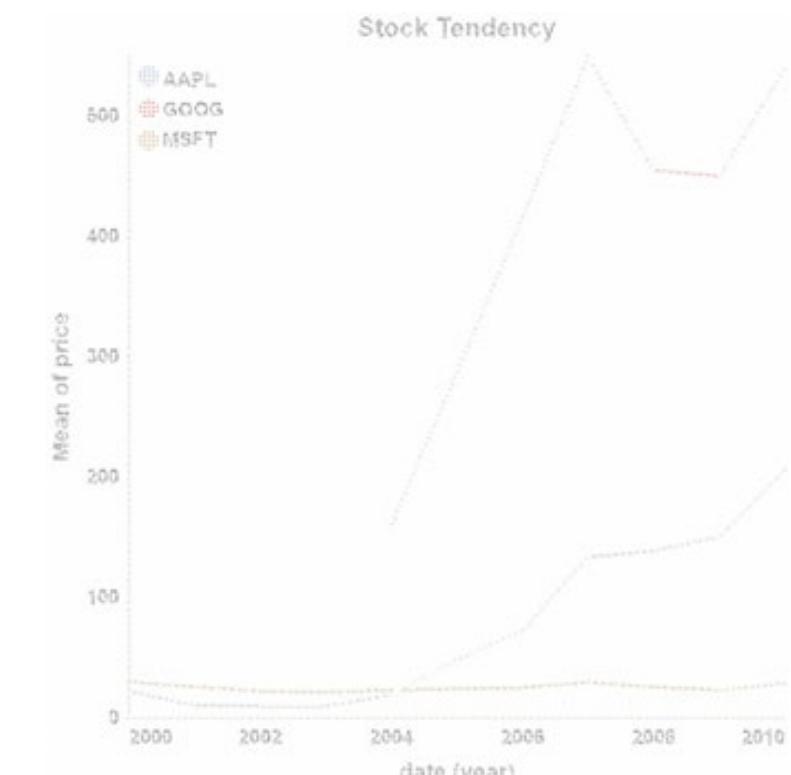
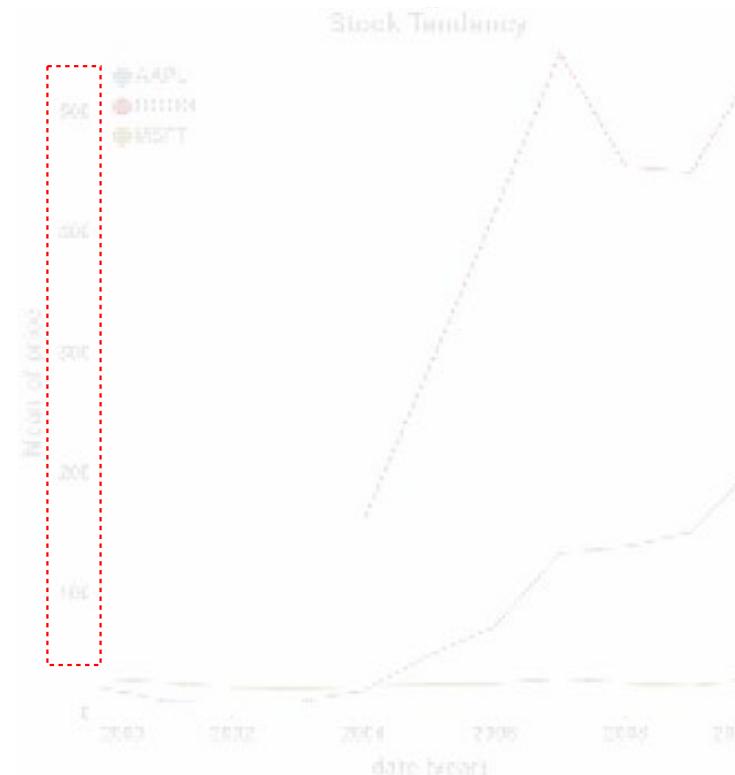
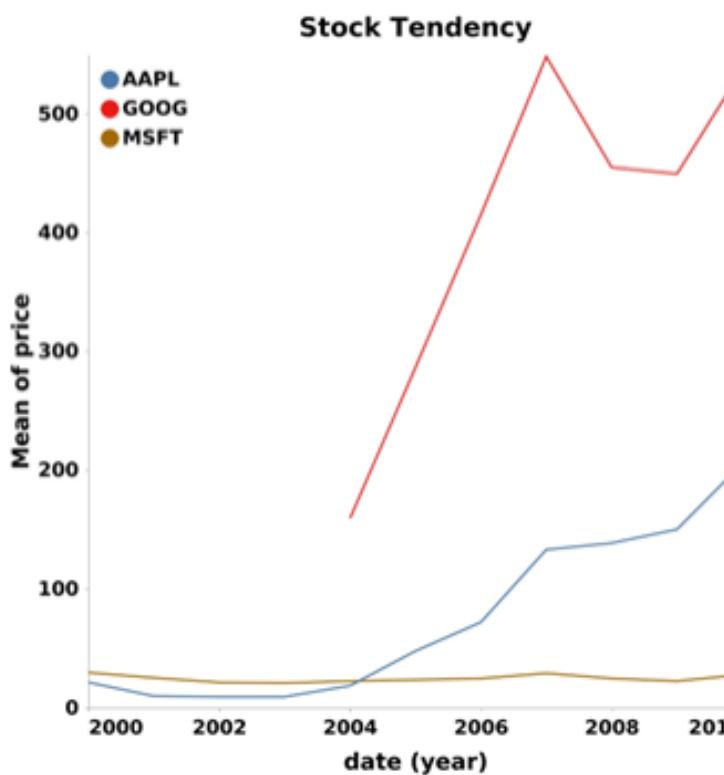
(d)

Masking Scheme for Line-based Marks



Masking Scheme for Line-based Marks

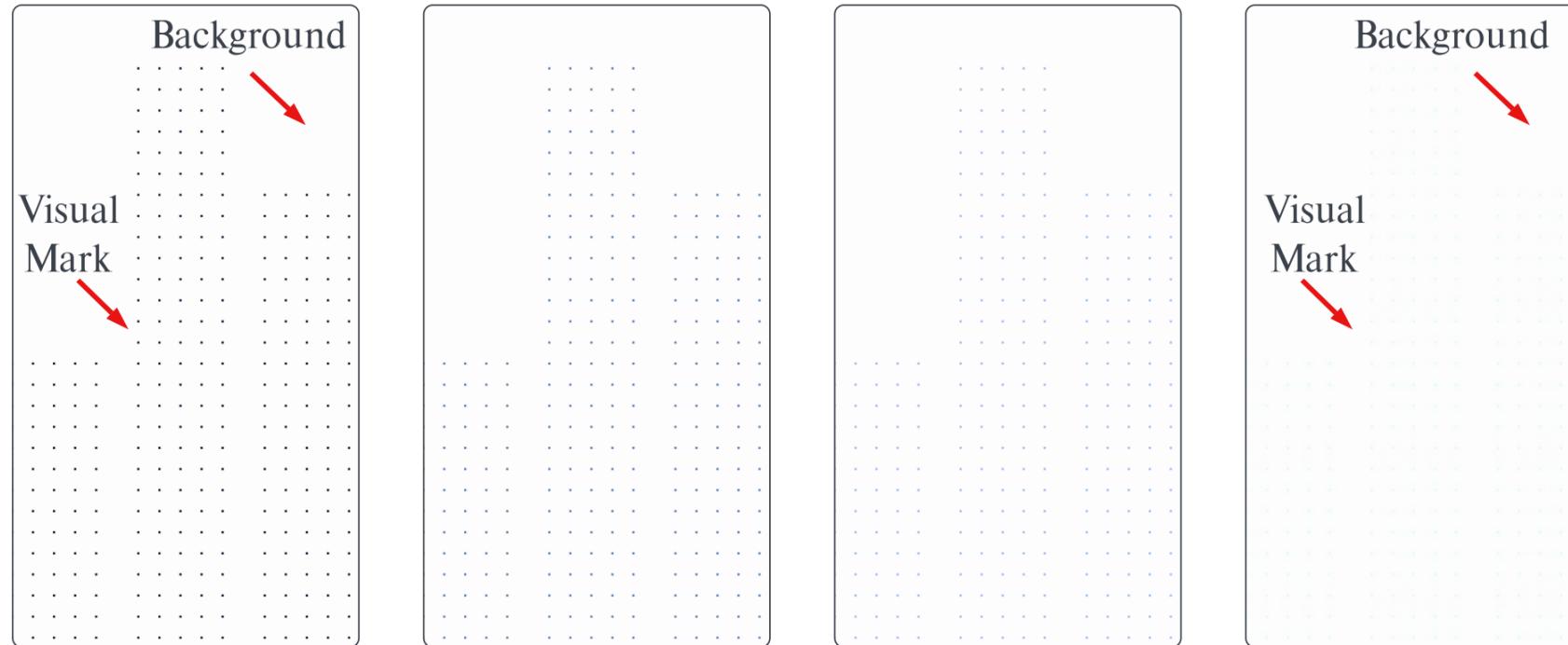
- We also apply the line-based mask on visualization axis and text because they are made of lines by nature





Masking Scheme for Area-based Marks

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



Luminance Contrast Decreases

Evaluation



Evaluation – Preliminary Study

- 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**

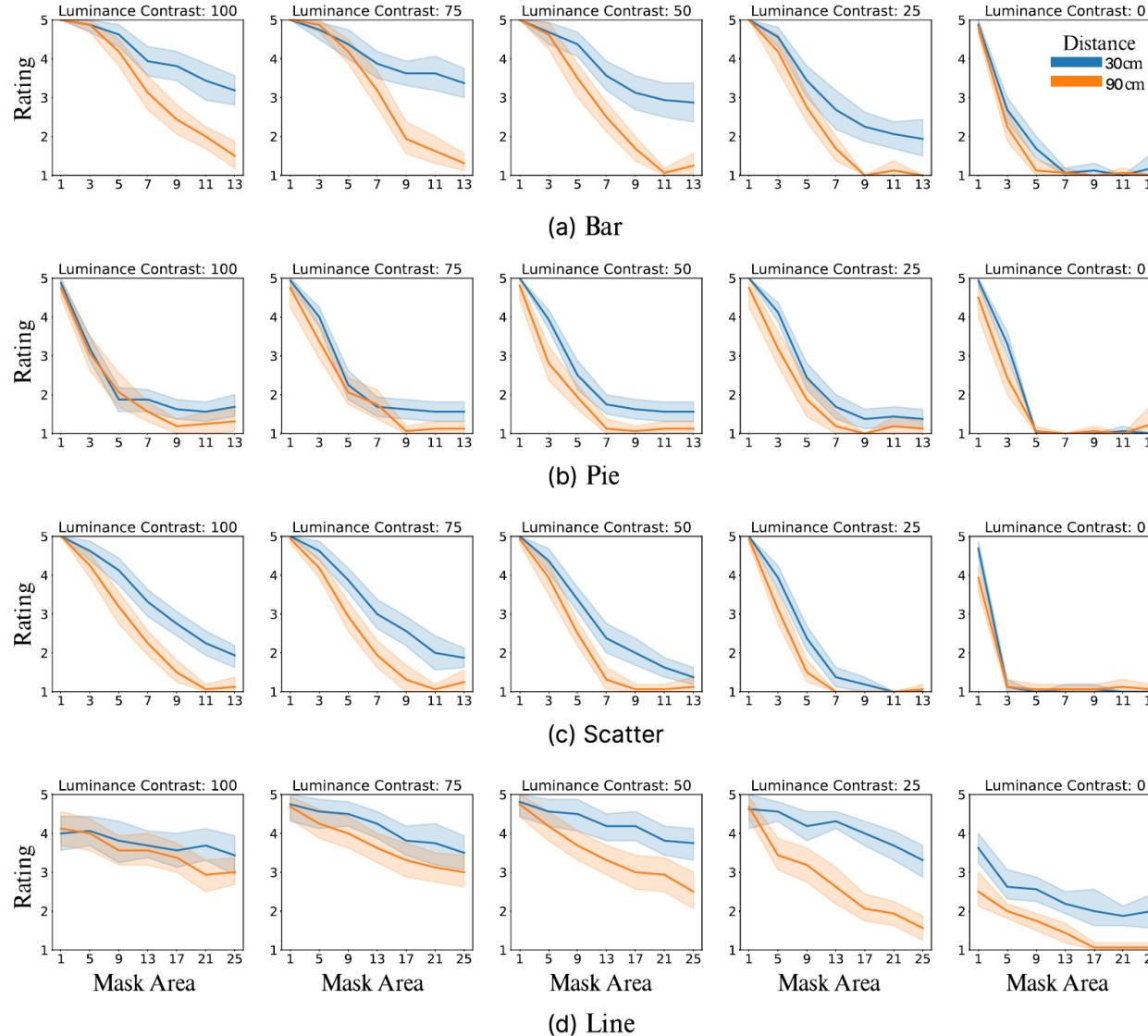


Evaluation – Preliminary Study

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.



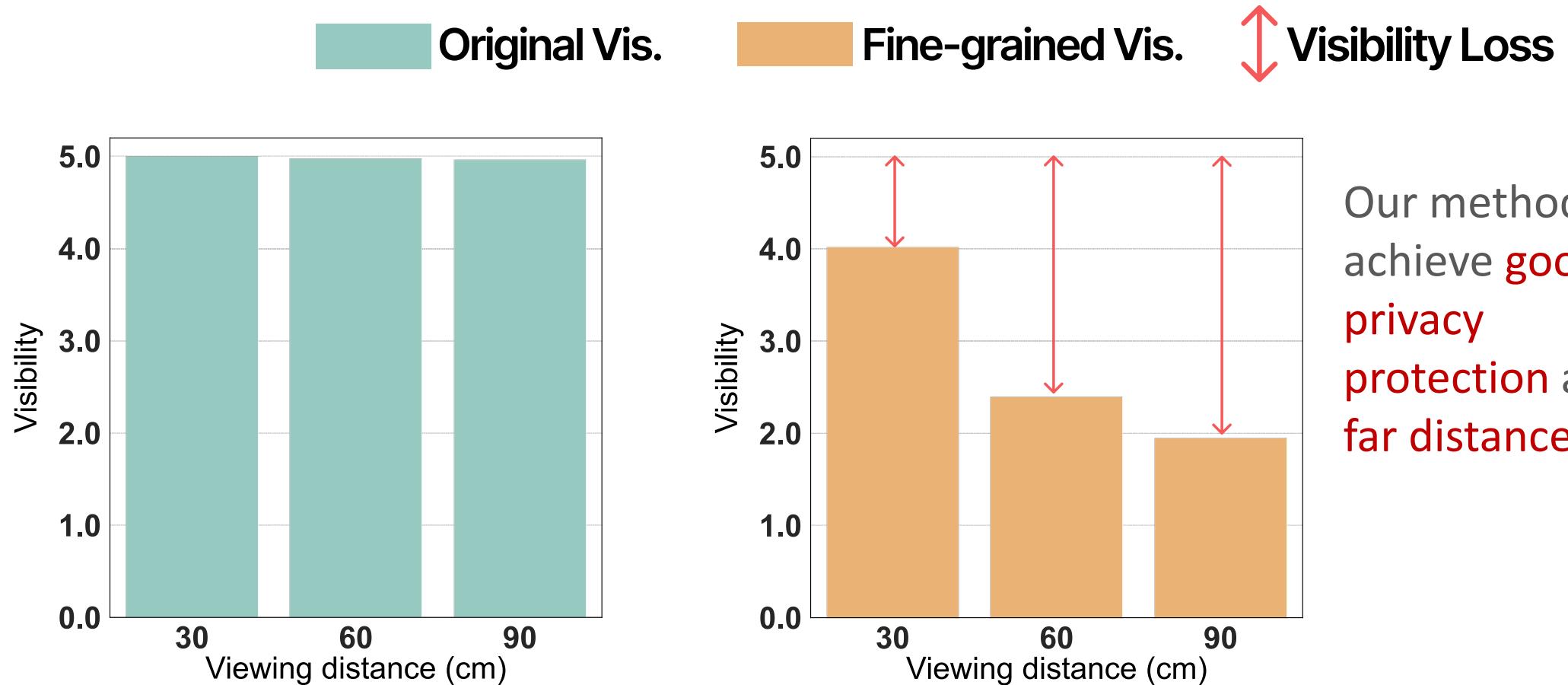


Evaluation – User Study

- 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.

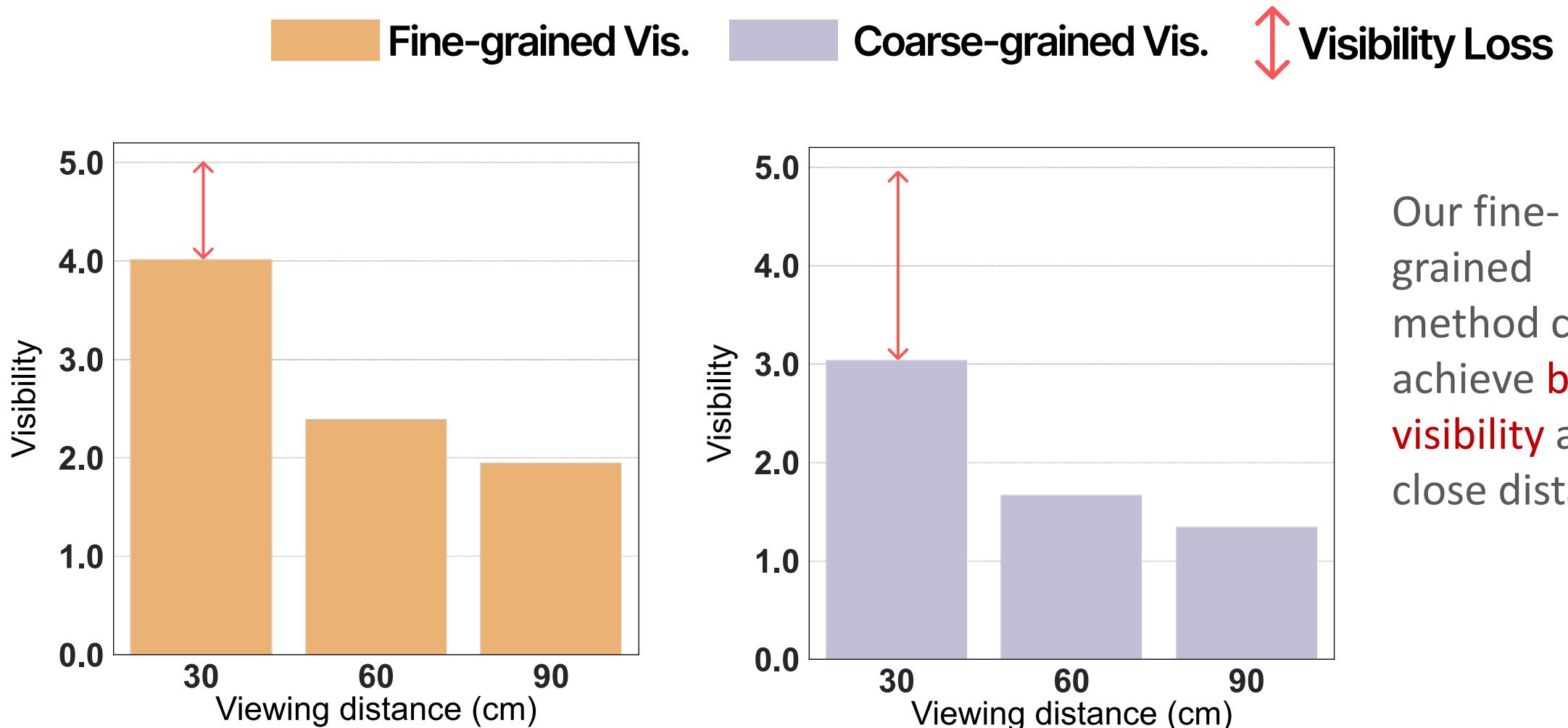
[5] Poco, Jorge, and Jeffrey Heer. "Reverse-engineering visualizations: Recovering visual encodings from chart images." *Computer graphics forum*. Vol. 36. No. 3. 2017.

Evaluation – User Study



Our method can achieve **good privacy protection** at a far distance

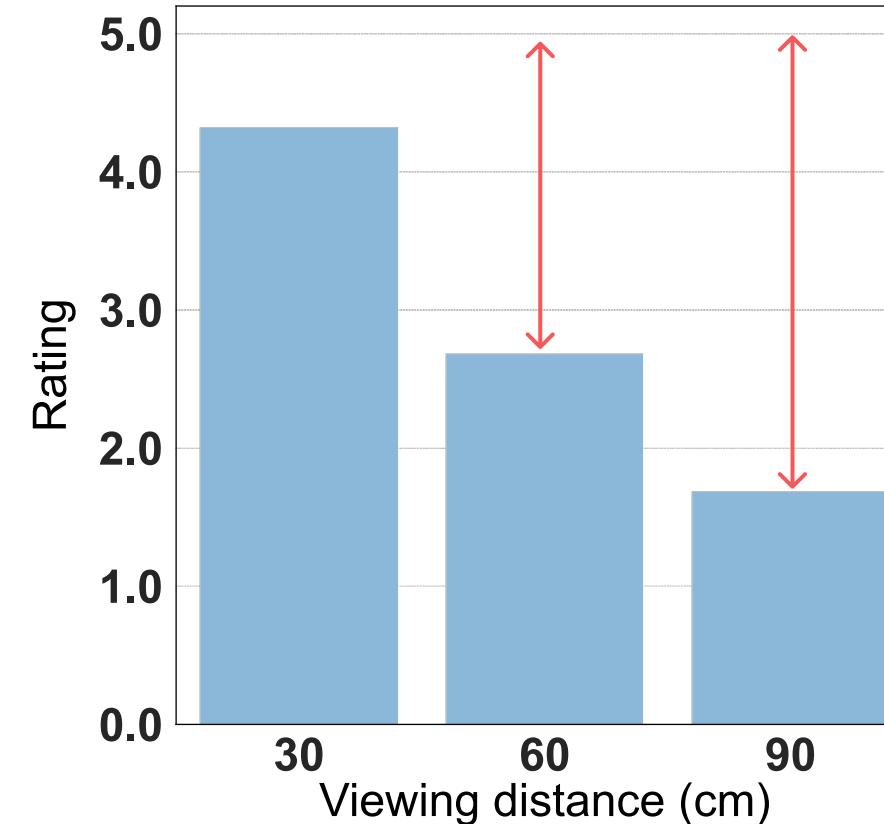
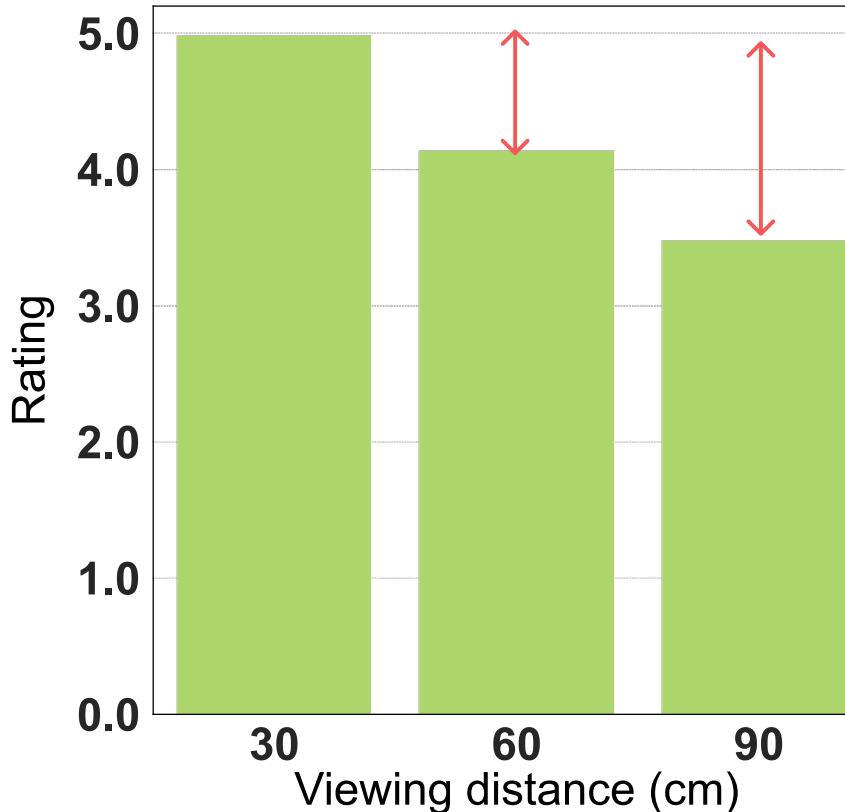
Evaluation – User Study



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

Evaluation – User Study

Original Text Fine-grained Text  Visibility Loss

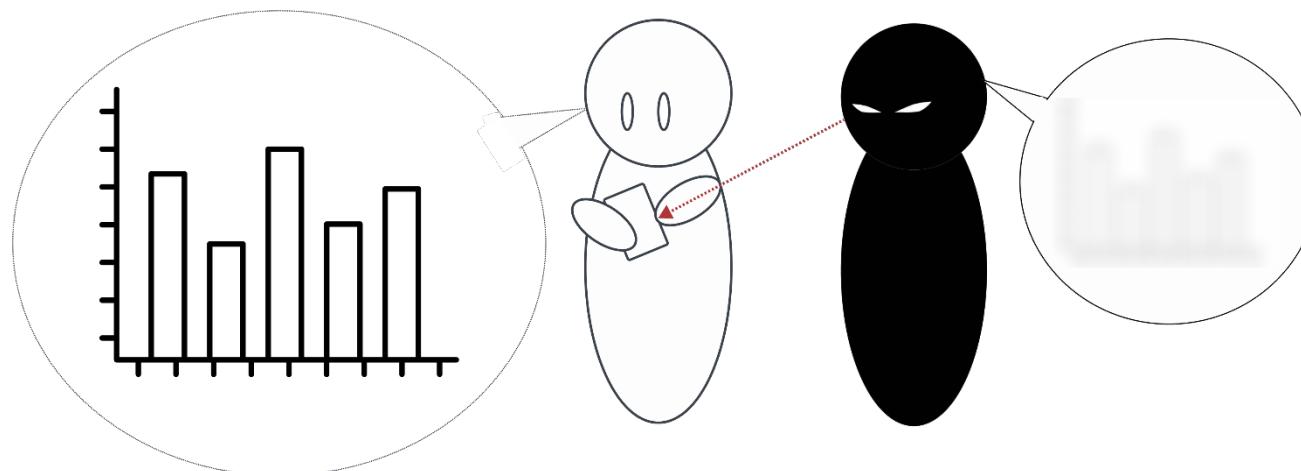


Our fine-grained method can achieve better privacy protection at a farther distance



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**



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