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Techniques for Rapid Visual Communication of Uncertainty in System Safety Analyses

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Overview

1. Discussion of Problem & Partial Solution
2. Biases Involving Uncertainty
3. Visualization Techniques
4. Scales of Measurement
5. Specific Visualization Techniques Investigated
6. Discussion / Conclusions

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Discussion of Problem & Partial Solution

- **Problem:** A decision maker's (e.g., regulator, manager, key policy maker) understanding of a system is often biased by impressive system visualizations focused on nominal system states or specific instances of system failure such that they discount uncertainty-related system risks

  - Decision makers tend to remember the impressive visualizations, but may forget risk-relevant probabilistic or other uncertainty details

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Discussion of Problem & Partial Solution

- **Example:** It appears that there are enormous differences of opinion as to the probability of a failure with loss of vehicle and of human life. The estimates range from roughly 1 in 100 to 1 in 100,000. The higher figures come from the working engineers, and the very low figures from management. What are the causes and consequences of this lack of agreement?

Richard P. Feynman (1986), *Report of the Presidential Commission on the Space Shuttle Challenger Accident*

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Discussion of Problem & Partial Solution

- **<u>Problem:</u> Visual representations of systems or subsystems presented to decision makers tend to be salient, efficient & memorable, but often do not include visual representation of *uncertainty* – esp. important in *System Safety Analyses***
  - Safety analysts must obtain deep knowledge of potential failures and subtleties of uncertainty impacting performance (known knowns, known unknowns, & respect for 'unknown unknowns')
  - How does the analyst transmit this wealth of uncertainty insight?

- **<u>Partial Solution:</u> Improve communication during a safety analysis review by using visual image manipulations including object focus, transparency, and color to quickly communicate uncertainties in a salient, efficient memorable manner.**

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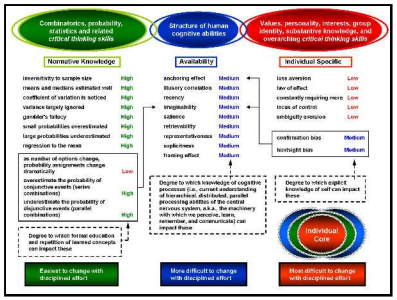
Biases Involving Uncertainty

- Roughly 80% of information used to understand our relationship to outside world is obtained visually
- Normative, Availability, & Individual Specific Bias Processes (27 bias processes in the NAVIS taxonomy)
- Culture: e.g., language habits in Western culture → People speak as if they are certain when they are only fairly certain; people perceive opinions to be worthless when they are only weakly supported
- Limitations of working memory (especially in brief, infrequent presentations to decision makers with many oversight responsibilities)
  - *"The magical number seven plus or minus two: Some limits on our capacity for processing information"* Miller (1956), Psychological Review, 63, 81-97.
  - Note: from those familiar with the research – stick to 5 or less distinctions that need to be held in working memory during a brief presentation & encoded in long term memory

NAVIS



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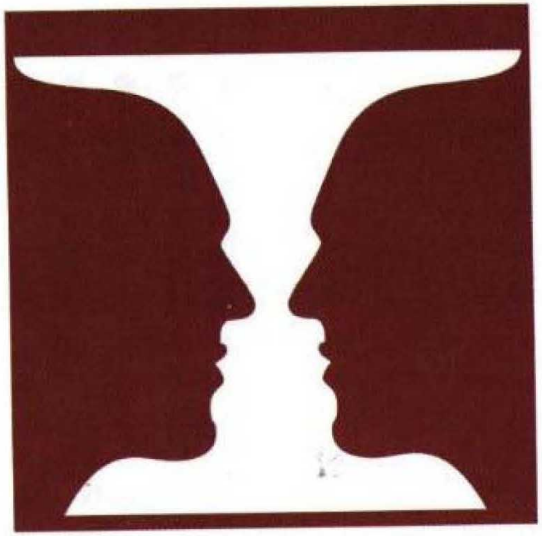
Visual Biases



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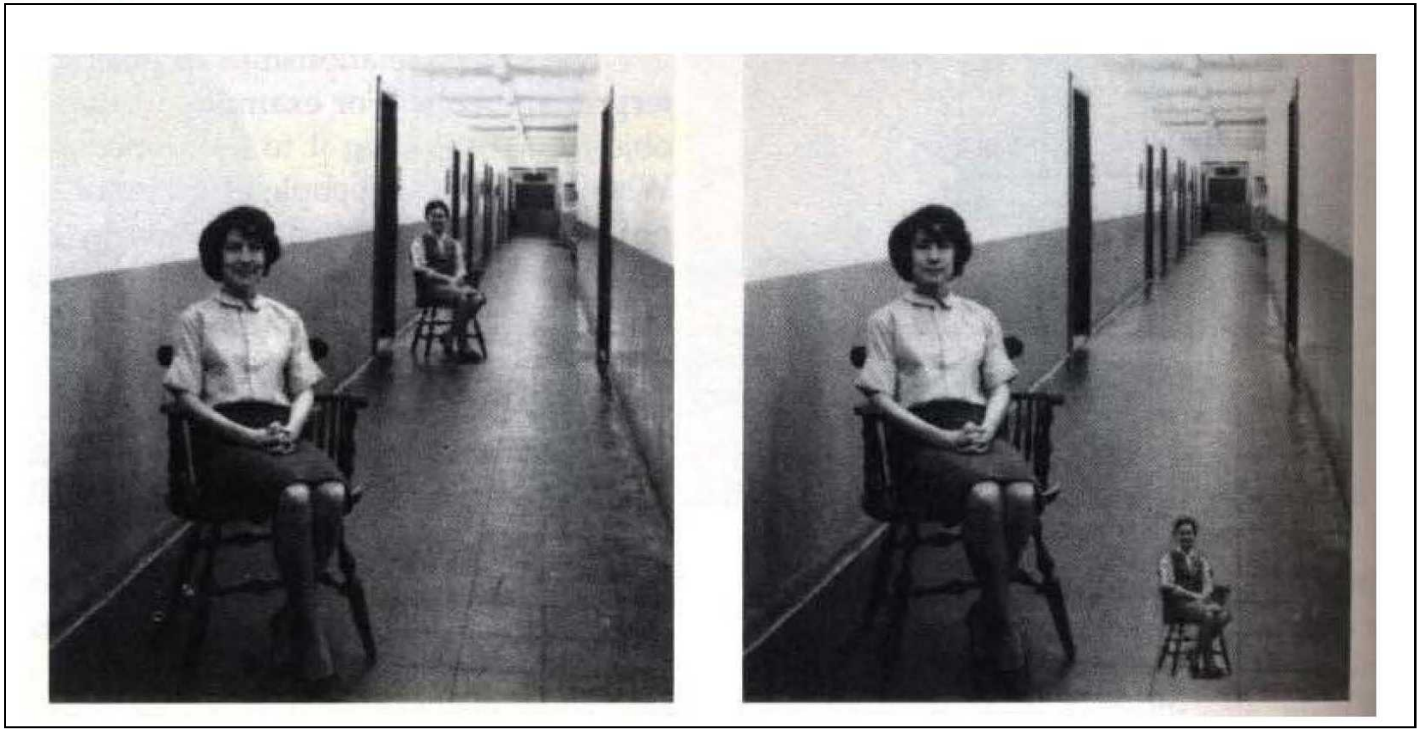

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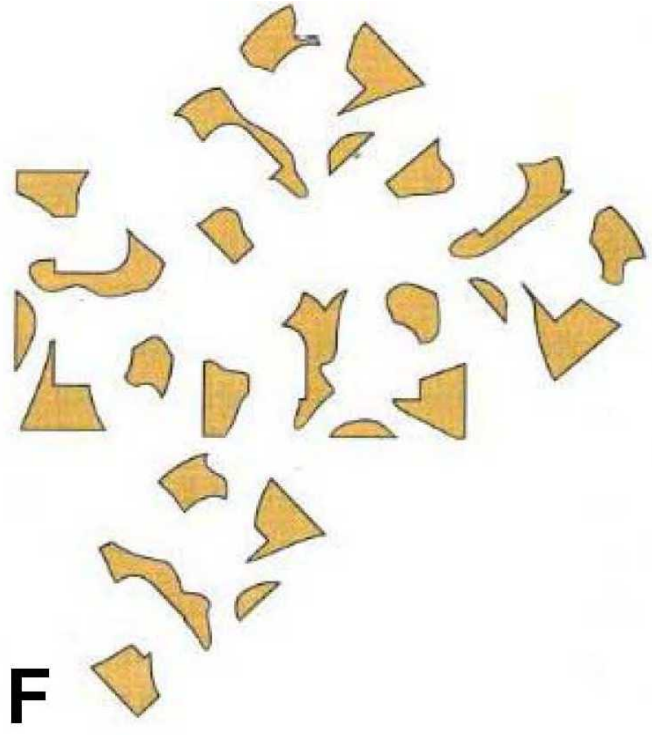
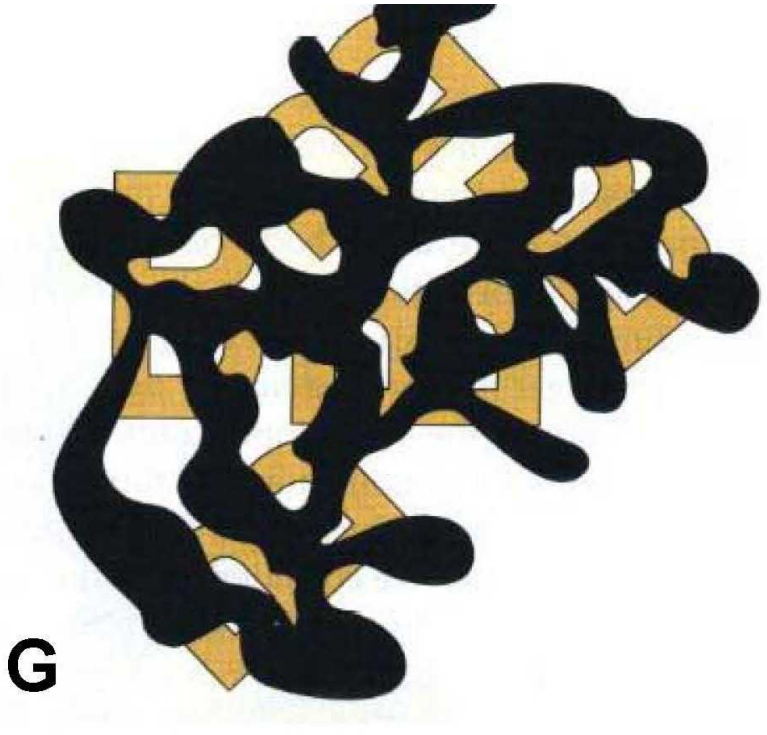
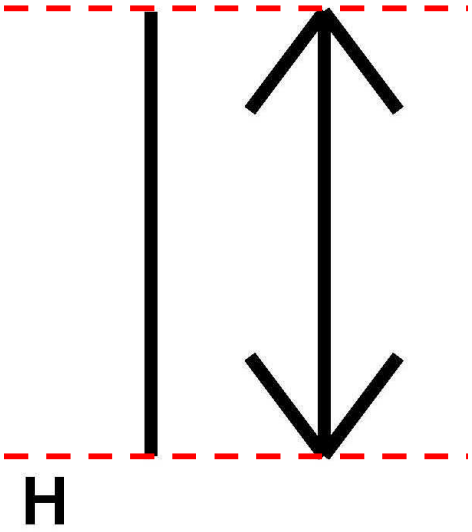






Visual Biases

Visualization Techniques

General Techniques

- Color
- Size
- Transparency
- Position
- Angle
- Texture
- Edge definition/crispness

Helpful References

Approaches to uncertainty visualization

Pang, Wittenbrink, & Lodha (1997)
[The Visual Computer, 13, 370-390]

An evaluation of blink inspection

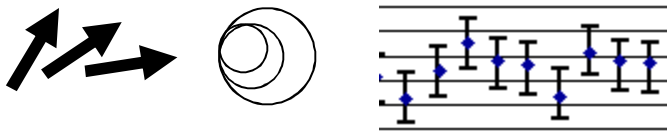
Luzzo & Drury (1980)
[Human Factors, 22, 201-210]

Uncertainty Visualization

- Color
- Blurring

  Blurred Icons versus probabilities, linguistic, & colored icon methods

  (Finger & Bisantz 2002, Bisantz et al. 2005)
- Texture
- Glyphs – geometrically plotted object that encodes data values



- Animation Effects
  - Speed of motion
  - Motion blur
  - Range or extent of motion
  - Blinking

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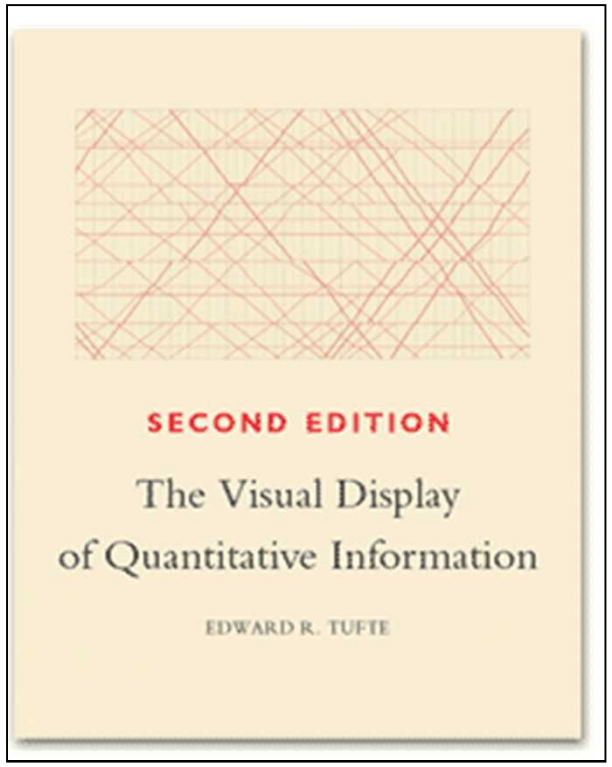
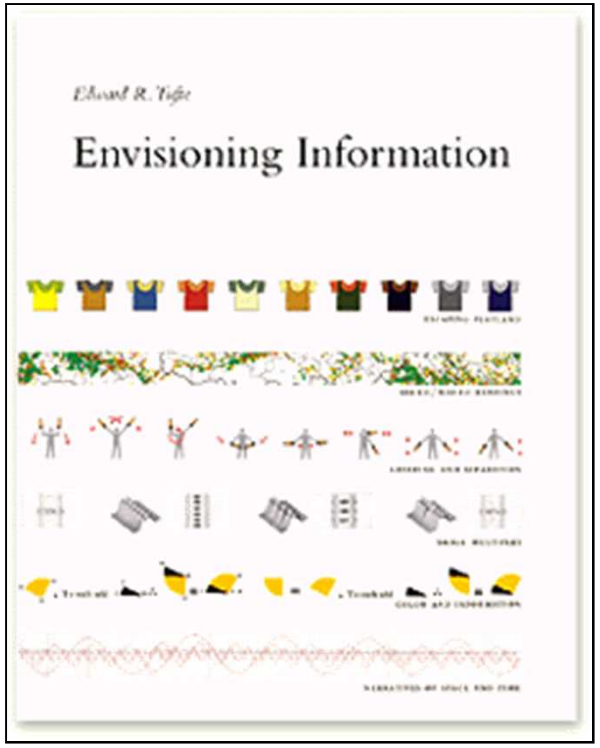
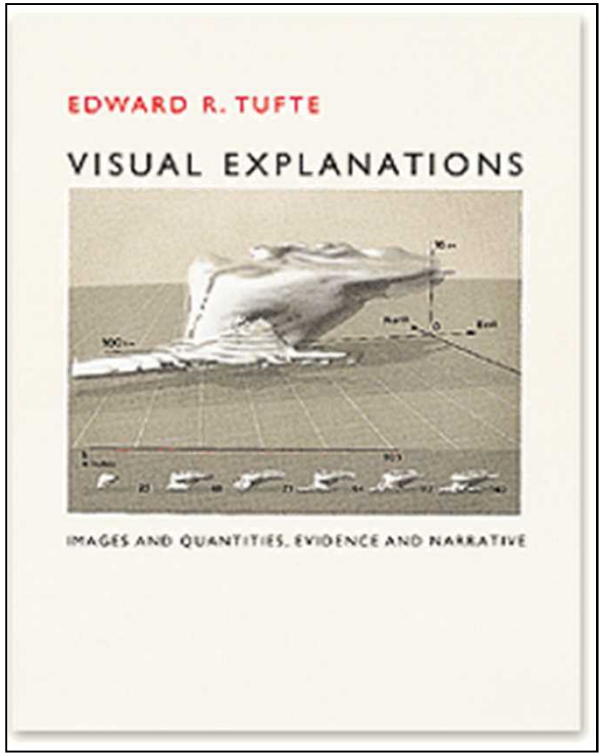
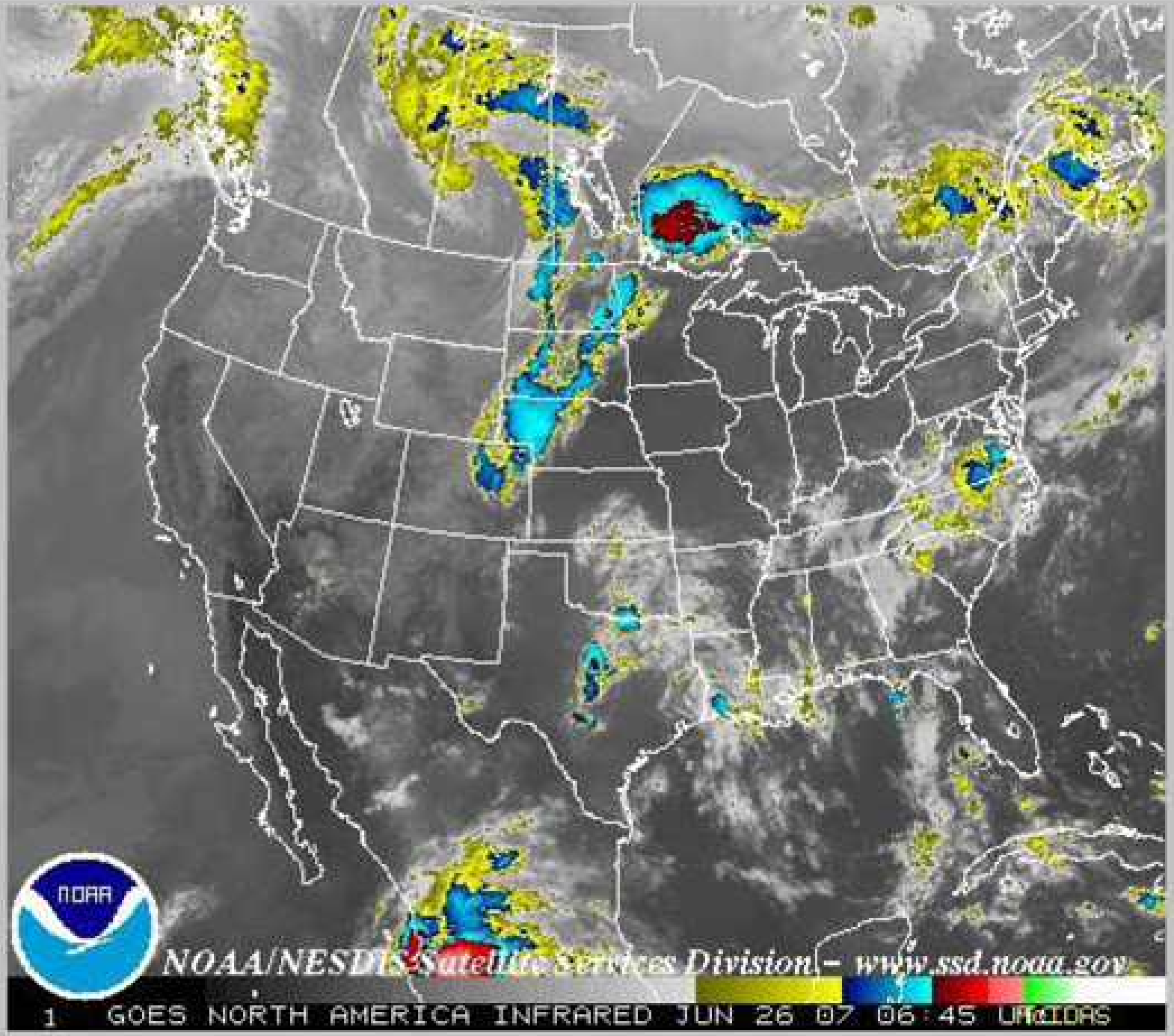
Excellent Information Visualization References by Edward Tufte








NOAA
NOAA/NESDIS Satellite Services Division - www.ssd.noaa.gov
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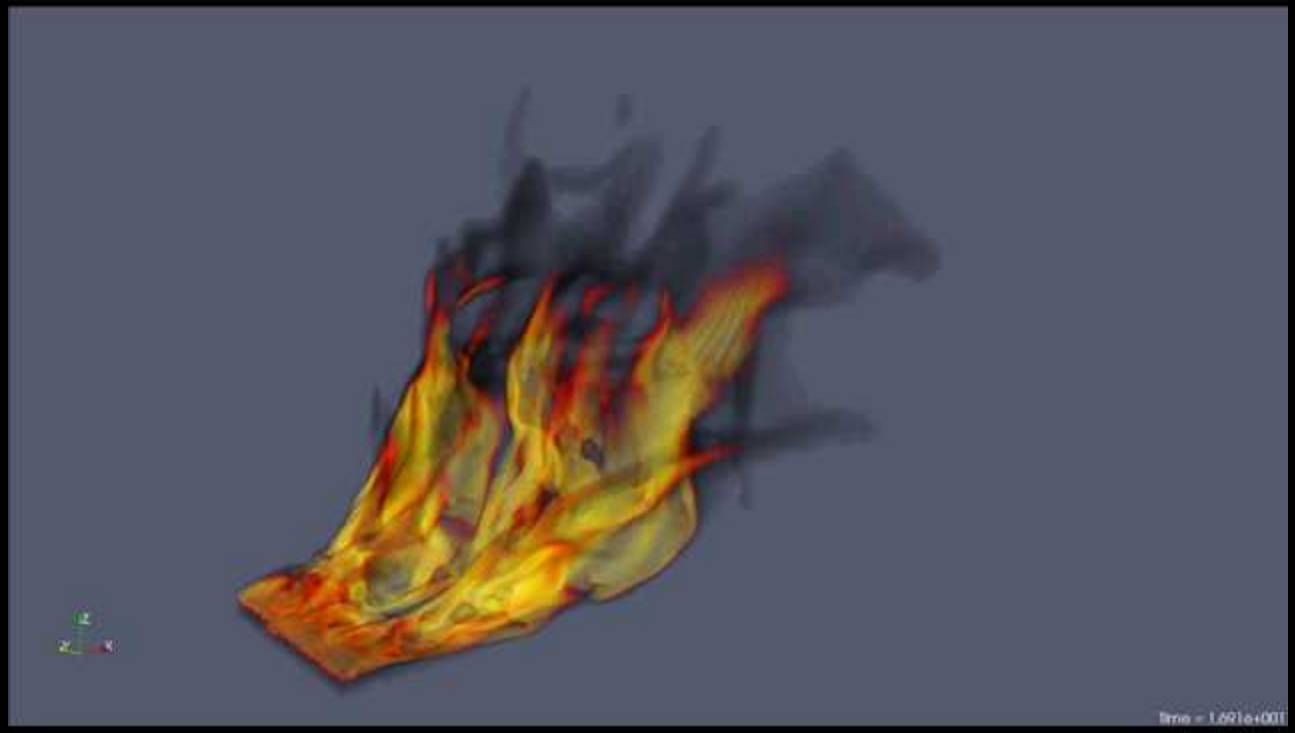

Sandia National Laboratories, Org. 1532 - Fire Science and Technology

Scales of Measurement

- **Nominal –** different classes or categories (e.g., power supplies, fuzes)
- **Ordinal –** enables ordering of entities (i.e., greater, less, or equal), but does not indicate the spacing between entities (e.g., output of a paired comparison approach)
- **Interval –** includes both ordering and spacing information; incorporates the concept of a unit distance (e.g., º Celsius, º Fahrenheit)
- **Ratio –** similar to interval, except that it has a natural measurement called zero, whereas the zero point for an interval scale is arbitrarily assigned (e.g., º Kelvin)

- **DoD** MIL-STD-882D, **NRC** RG 1.174, … (pick or create your uncertainty scale)

• Frequent	• Catastrophic	• 0.1	• Levels of dependency
• Probable	• Critical	• 0.01	• Correlation coefficients
• Occasional	• Marginal	• 0.001	• Confidence factors
• Remote	• Negligible	• 0.0001	• Reliability factors (k-factors)
• Improbable			

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Specific Visualization Techniques Investigated

1. **Identification of image objects to manipulate**
    1) Simplified functional block diagram
    2) Simplified hierarchical block diagram
    3) Near-photorealistic images
2. **Selection of image manipulation techniques**
    1) Color
    2) Transparency
    3) Blurring
3. **Selection of the number of levels of visual manipulation**

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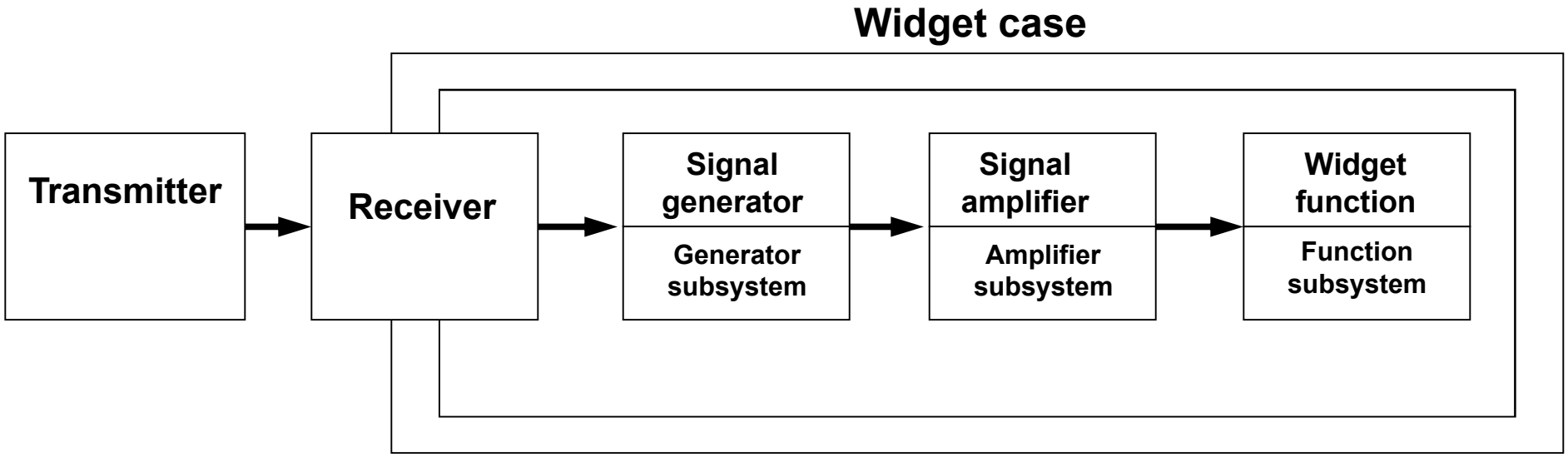
Simplified Functional Block Diagram
(notional weapon system)



(Notional weapon system)

Black, **white**, & **gray** colors were chosen for system entities (i.e., text, outlines, background, & surface shading – to facilitate visual discrimination between notional system and uncertainty display enhancements

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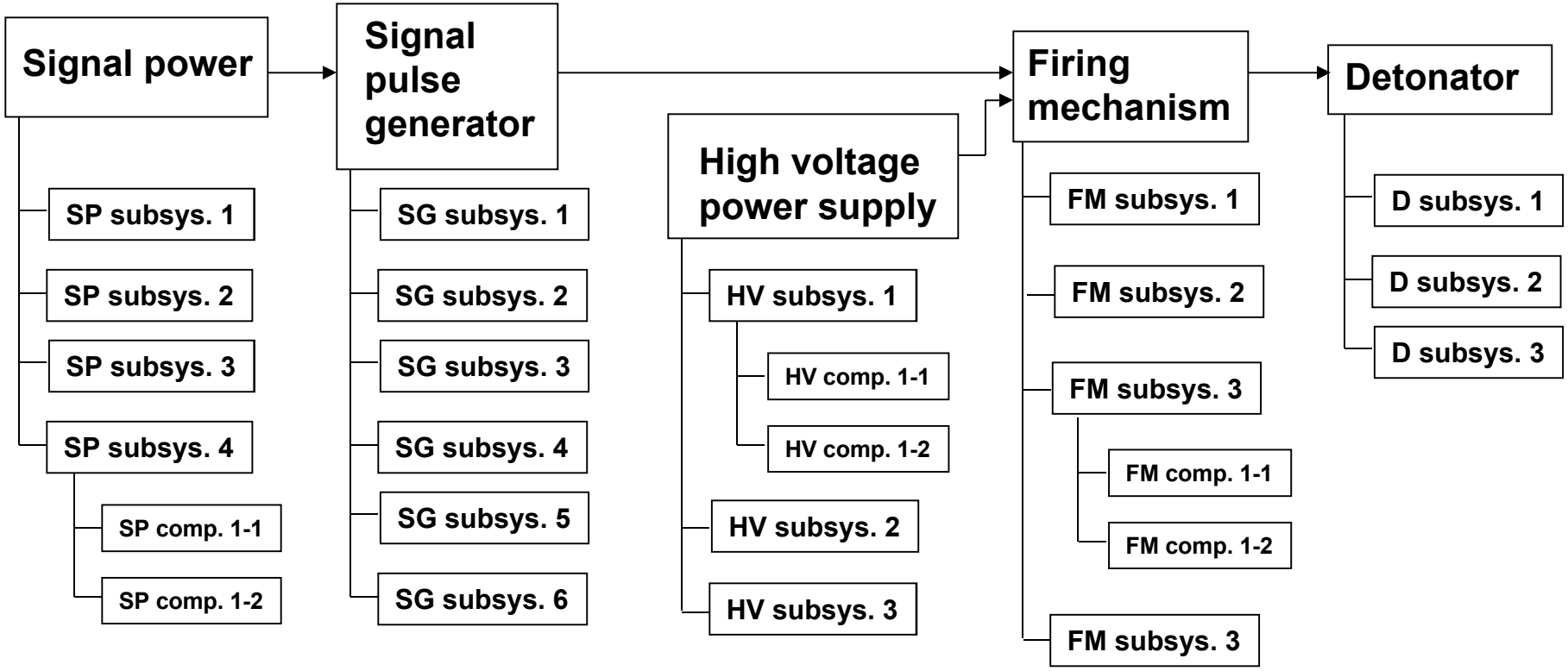
Simplified Hierarchical Block Diagram

(notional weapon system)



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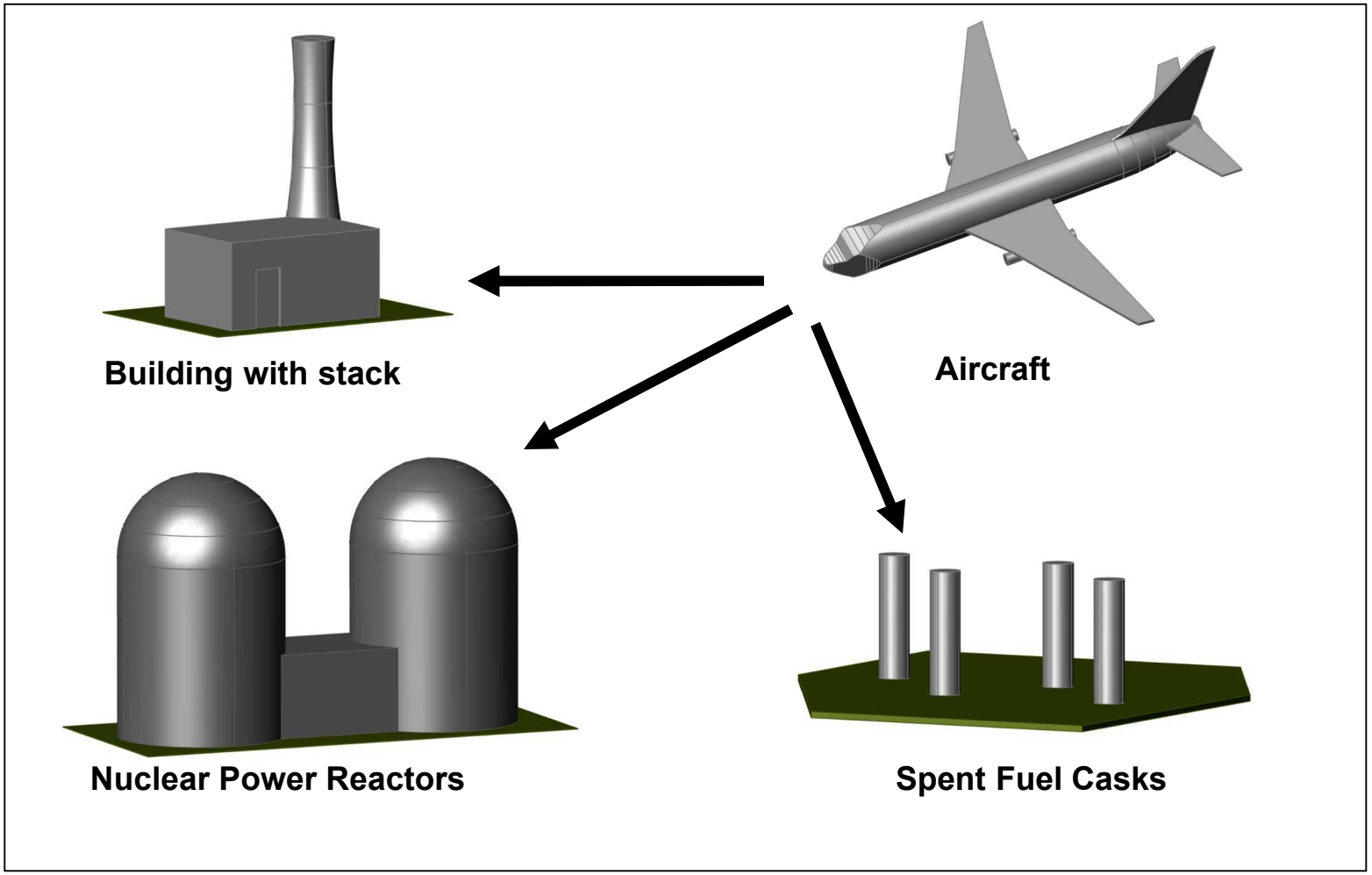
Near Photorealistic Images

(hypothetical vulnerability analysis)



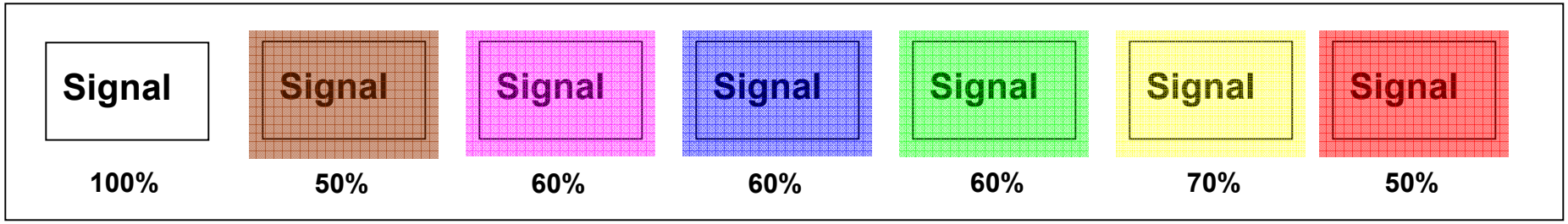
Selection of Image Manipulation Techniques & Number of Levels

Microsoft Office PowerPoint® 2003

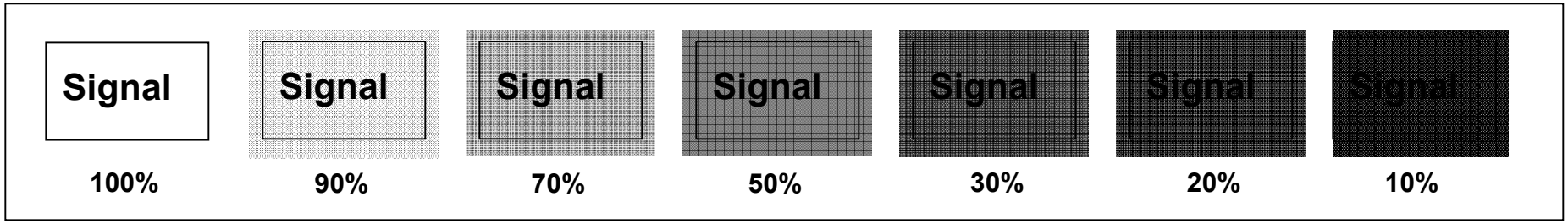
↳ **Format AutoShape**

↳ **Colors & Lines**

1) Color



2) Transparency



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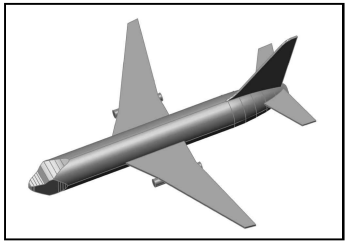
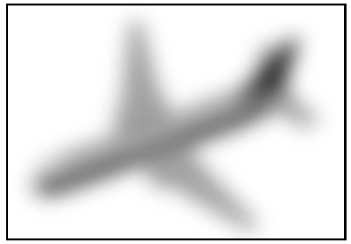
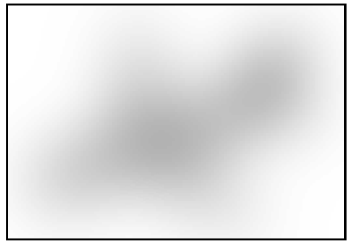
Selection of Image Manipulation Techniques & Number of Levels

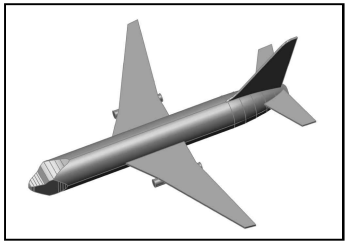
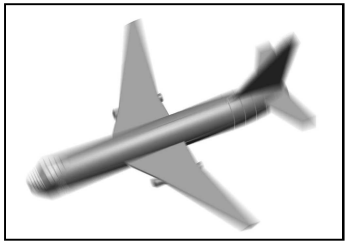
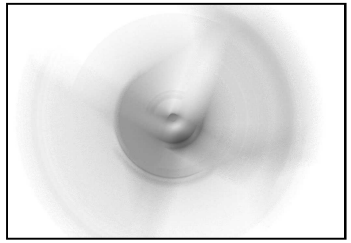
Adobe® ImageReady® CS, version 8.0

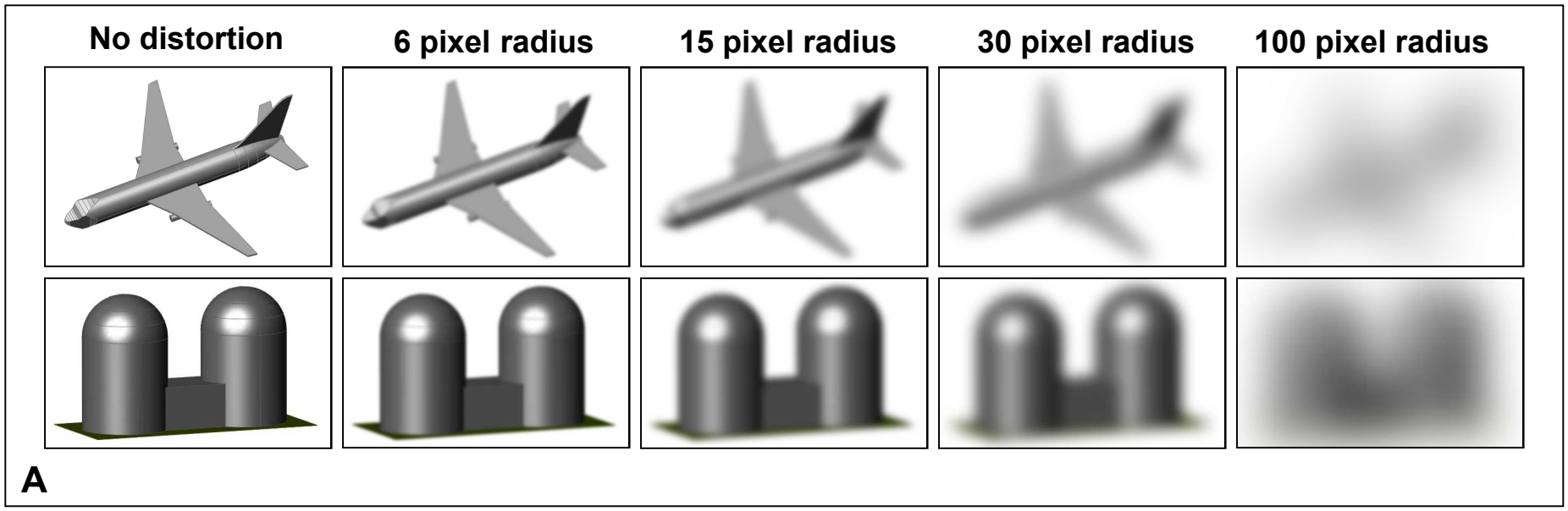
3) Blurring

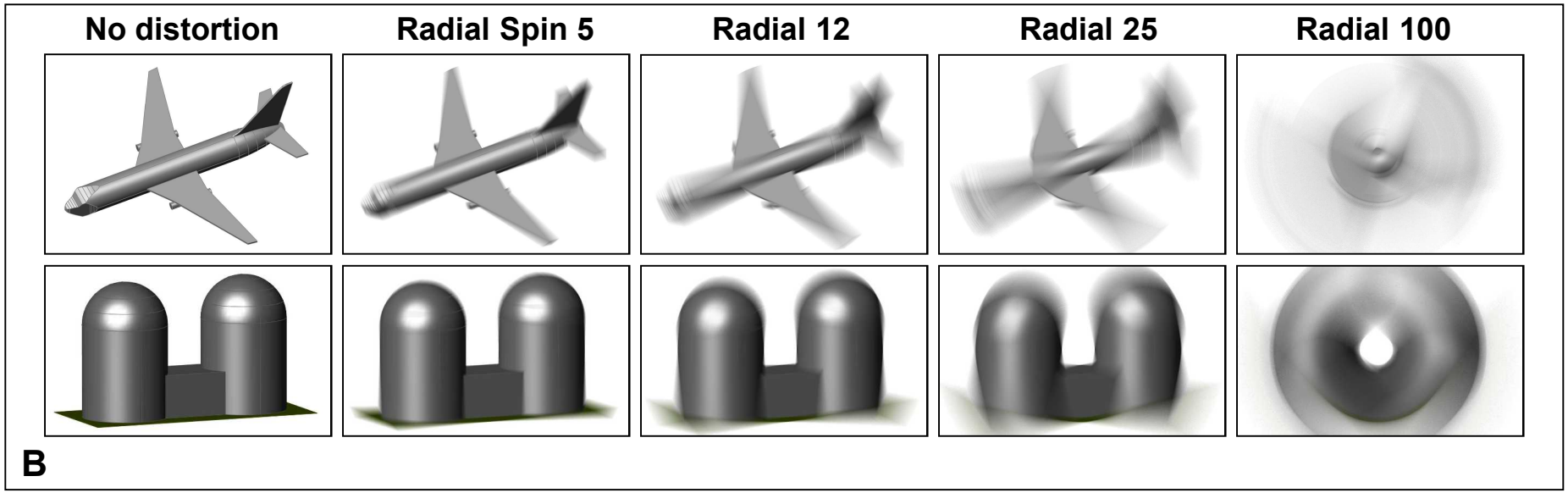
Gaussian Blur

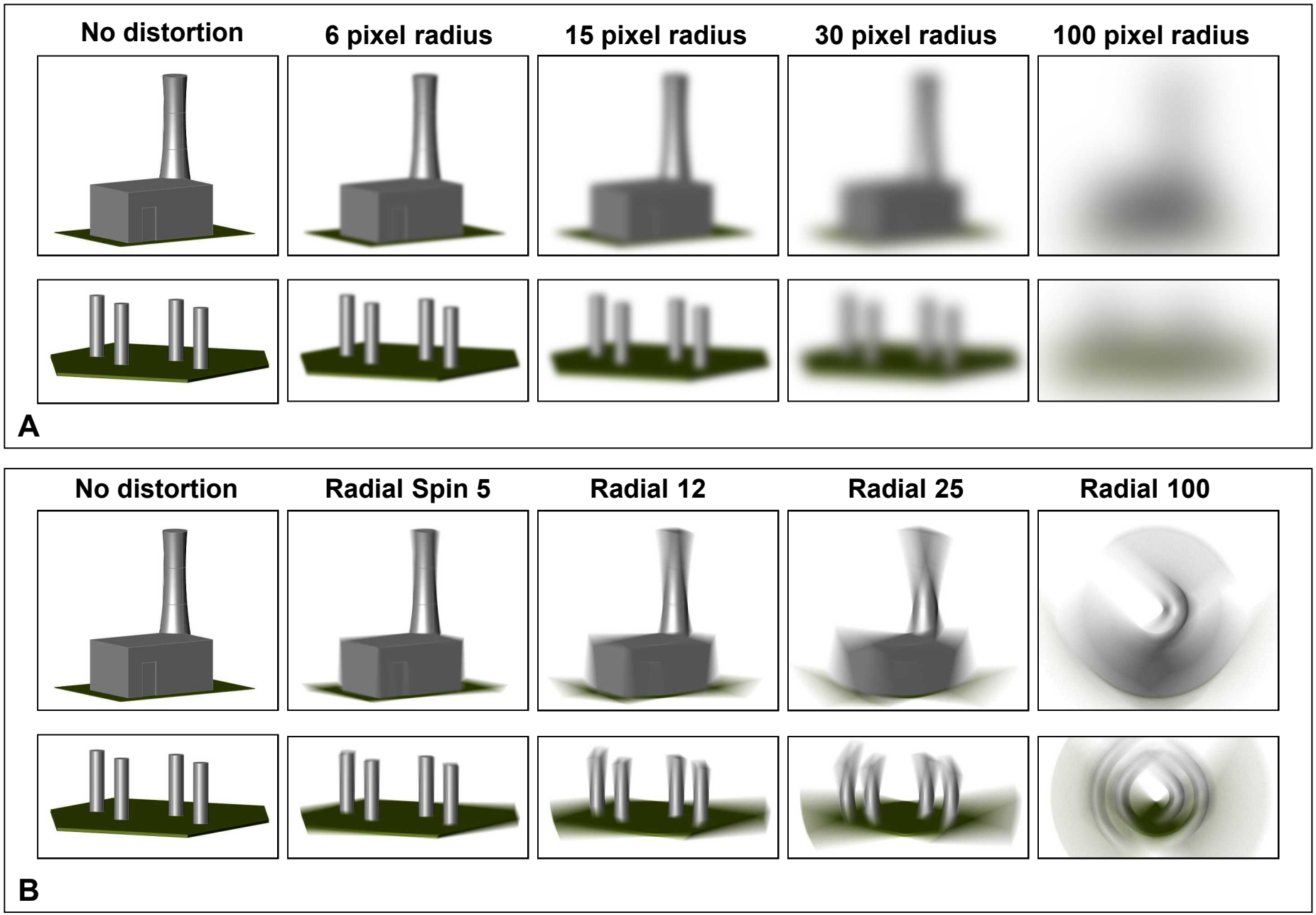
No distortion	6 pixel radius	15 pixel radius	30 pixel radius	100 pixel radius
				

Radial Blur

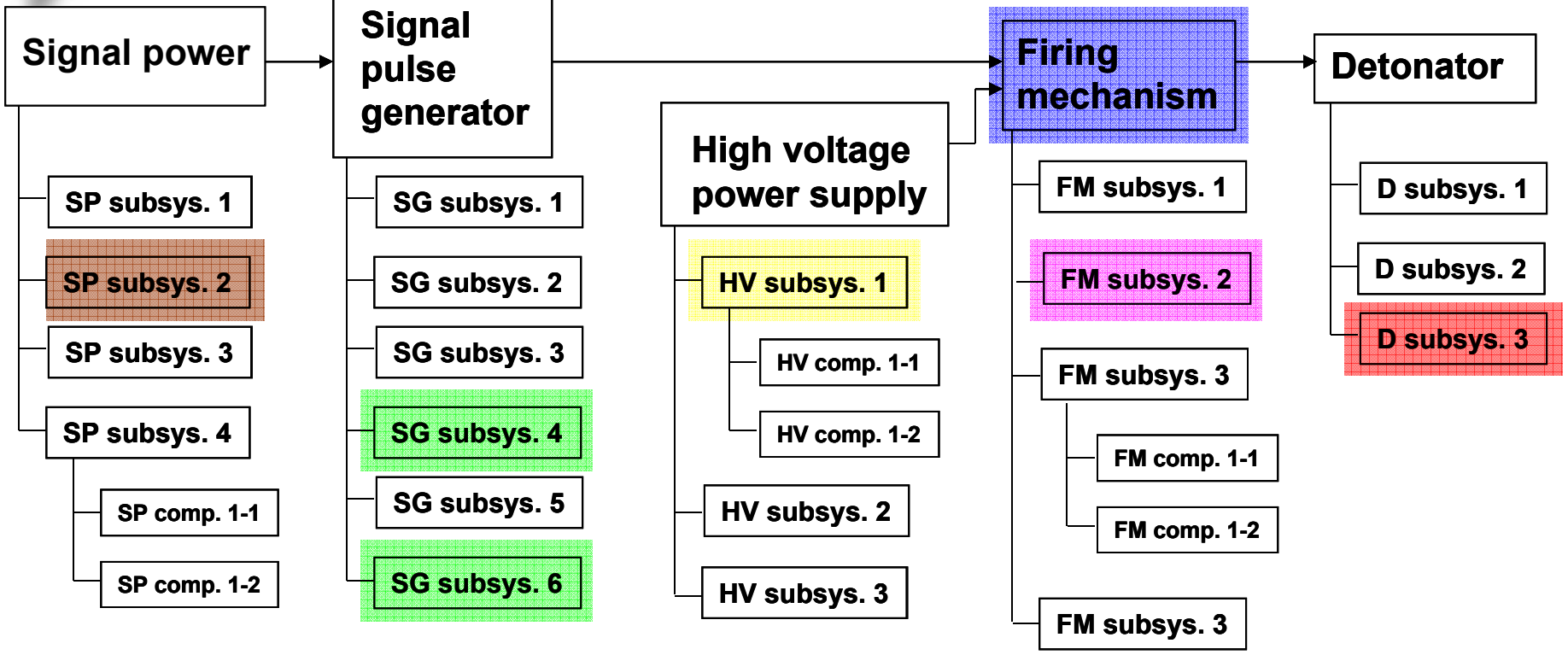
No distortion	Radial Spin 5	Radial 12	Radial 25	Radial 100
				

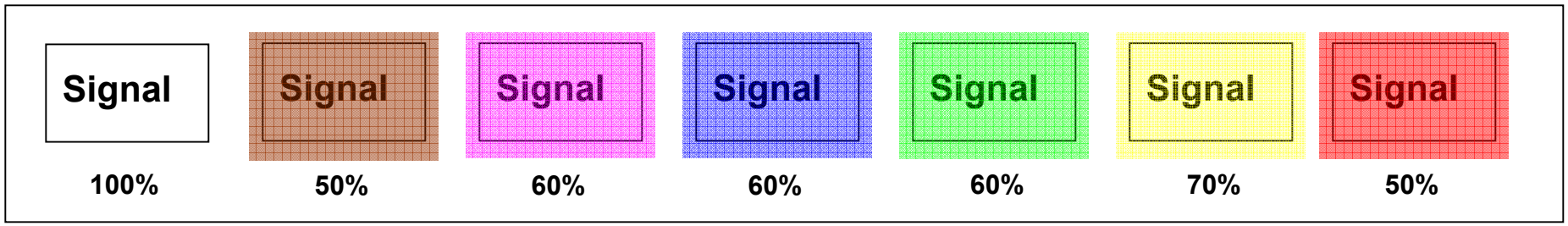

No distortion
6 pixel radius
15 pixel radius
30 pixel radius
100 pixel radius
A


No distortion
Radial Spin 5
Radial 12
Radial 25
Radial 100
B

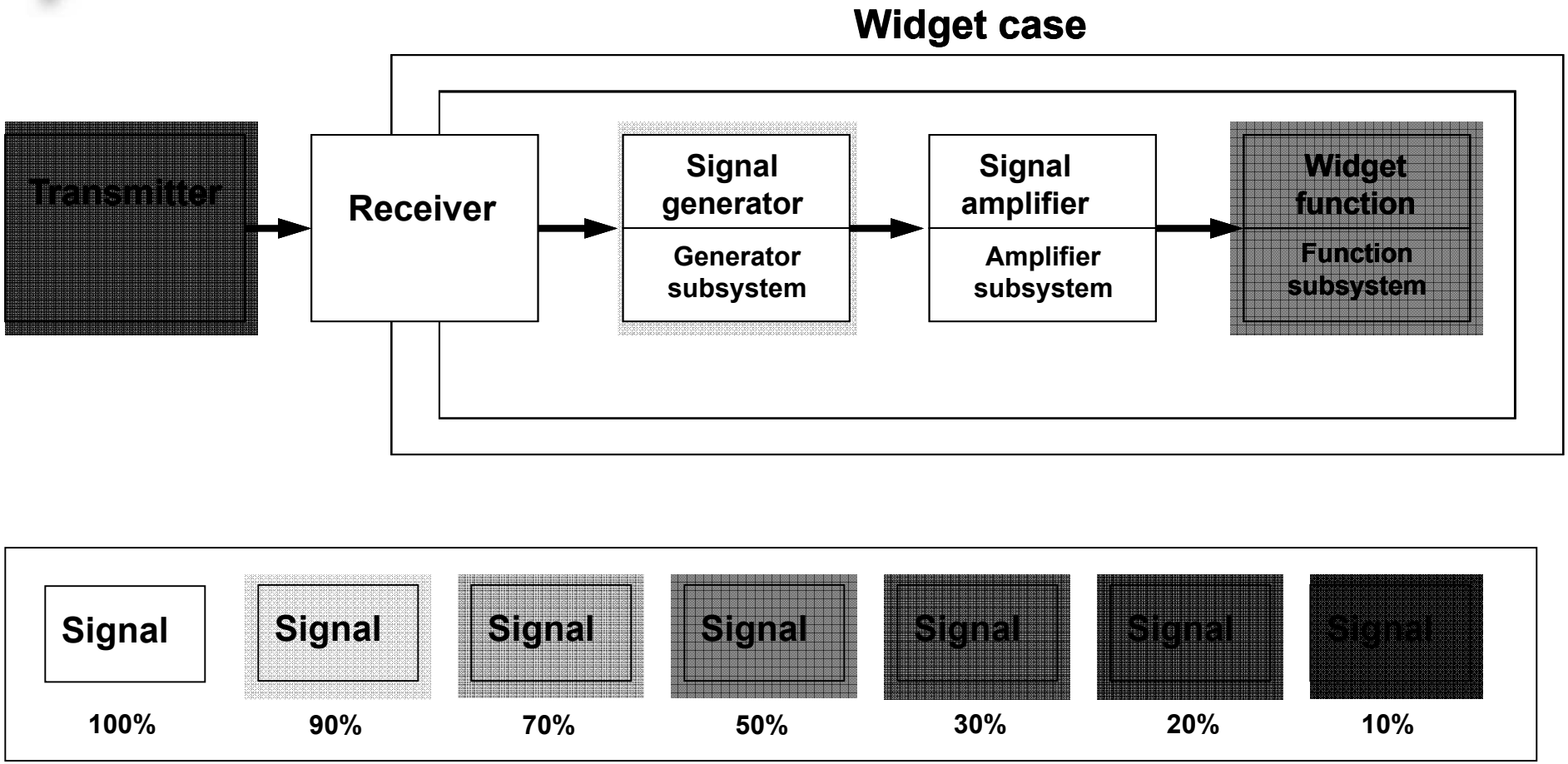

No distortion
6 pixel radius
15 pixel radius
30 pixel radius
100 pixel radius
A
No distortion
Radial Spin 5
Radial 12
Radial 25
Radial 100
B

Example of Color Manipulation
(with Blinking)





Example of Transparency Manipulation (with Blinking)



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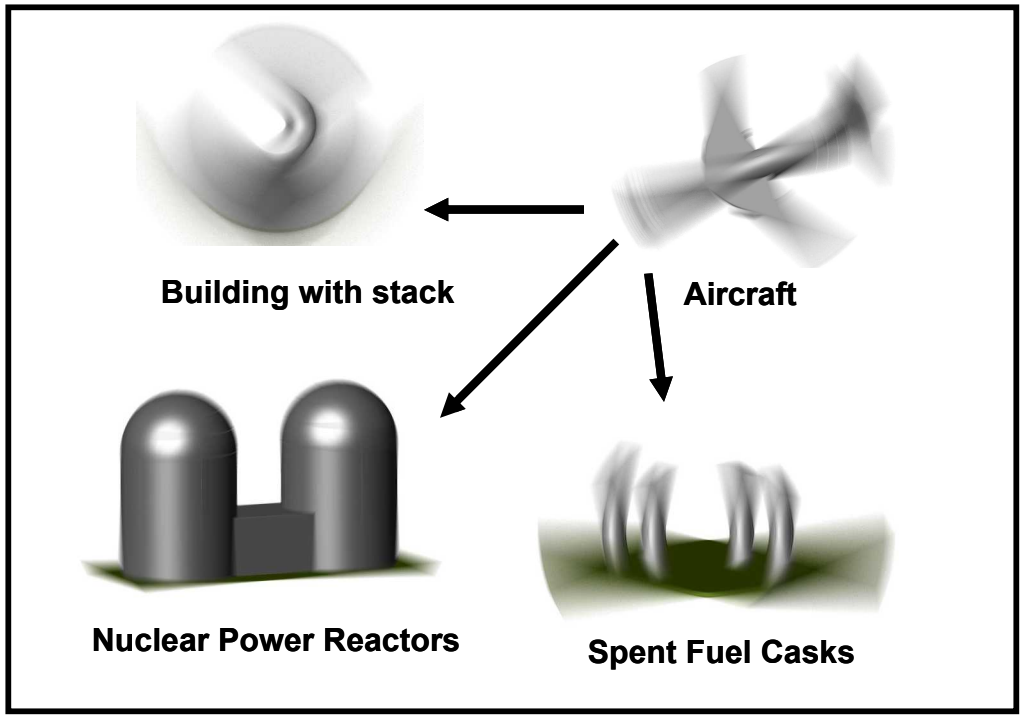
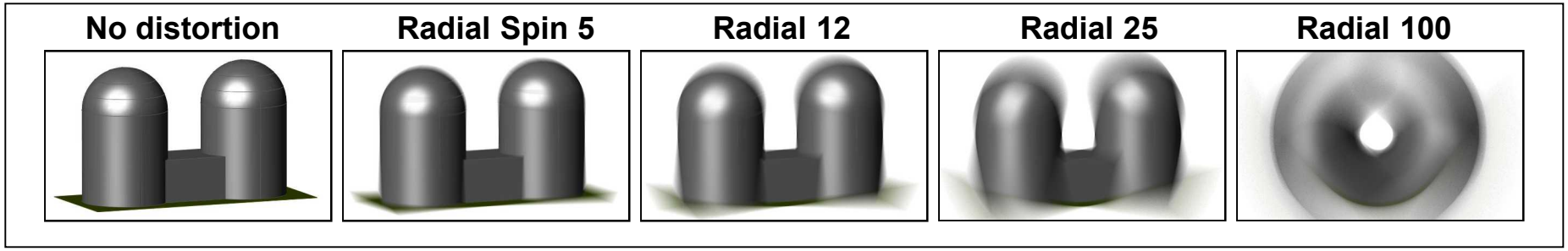
Example of Blur Manipulation
(with Blinking)





Discussion

- Selecting object images with **similar edge features** & **aspect ratios** (i.e., width / height) enables consistency of interpretation with **blurring method**
- Block diagram entities with **consistent forms** enables consistency of interpretation with **transparency method**
- **Color method** is less sensitive to similarity of object forms
- Use **5 or fewer** uncertainty levels
- **Blinking** between a nominal & uncertainty enhanced image is a highly effective communication approach

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Conclusions

Conclusion: Visual image manipulations including **object focus**, **transparency**, and **color** quickly communicate uncertainties in a salient, efficient memorable manner.

Note: The justification for this conclusion is based upon a review of visual display approaches, basic human factors insights, related experimental data, and the subjective judgment of the author.

Ideally, **systematic experiments** should be conducted to **verify** that the proposed visual manipulation techniques provide the proposed benefits in a context involving **decision makers** and system safety analysis **summaries/reviews**.