Faculty of Information Technology
University of Moratuwa

BSc(Hons) in Information Technology and Management

IN 2610 – Computer Graphics and Development

Level 2 Semester 2 Lecture Note 03

1. Elements of Design

Line

Explanation:
Lines are foundational elements that define boundaries, create textures, and convey motion or direction in a design. They can be straight, curved, dashed, thick, or thin.

Applications:

- Straight lines can divide content or lead the eye to a focal point.
- Curved lines are used in decorative or natural designs to create fluidity.
- Thick lines emphasize importance, while thin lines add subtlety.

Mathematical Perspective:

- A line in geometry is defined by a linear equation $y = mx + c$, where m is the slope, and c is the y-intercept.
- For curves, mathematical functions like parabolas ($y = ax^2 + bx + c$) or sine waves ($y = A\sin(Bx + C)$) model the flow or motion in design.
- In computer graphics, Bezier curves are often used to create smooth and scalable curved lines. A quadratic Bezier curve is given by:
$$B(t) = (1-t)^2 P_0 + 2(1-t)tP_1 + t^2 P_2, \quad t \in [0,1],$$
where P_0, P_1, and P_2 are control points.

Examples:

- Road signs use bold, straight lines for clarity.

- Curved lines in logos, like Coca-Cola, convey energy and movement.

Shape

Explanation:
Shapes are closed lines that create forms. They can be geometric (mathematically defined) or organic (free-form and natural).

Applications:

- **Geometric Shapes:** Squares, triangles, and circles create order and structure.
  - Squares represent stability and reliability.
  - Circles suggest infinity or unity (e.g., Olympic rings).
- **Organic Shapes:** Used in artistic or natural designs to make visuals more relatable or unique.

Mathematical Perspective:

1. **Geometric Shapes:**
   - A square's area is calculated as $A = s^2$, where s is the side length.
   - A circle's area is $A = \pi r^2$, and its circumference is $C = 2\pi r$.
   - Triangles follow properties like the Pythagorean theorem ($a^2 + b^2 = c^2$) in right-angled cases.
2. **Organic Shapes:**
   - Organic shapes in computer graphics are represented using splines or parametric equations.

Examples:

- Website buttons are often rectangular for clarity and usability.
- Logos often use circles for their inclusive and welcoming appearance.

Color

Explanation:
Colors influence emotion and perception. Designers use color theory to evoke specific feelings and maintain visual harmony.

Applications:

- **Primary Colors:** Red, blue, yellow (base for creating other colors).
- **Complementary Colors:** Colors opposite on the color wheel (e.g., blue and orange) create contrast.
- **Analogous Colors:** Adjacent colors on the wheel (e.g., green, yellow-green) create harmony.
- Warm colors (reds, yellows) are energizing; cool colors (blues, greens) are calming.

Mathematical Perspective:

- **RGB Model:** Colors in digital design are defined as (R, G, B) values, where R, G, and B range from 0 to 255. For example, pure red is $(255, 0, 0)$.
- **Color Distance:** The perceived difference between colors can be computed using Euclidean distance in RGB space:

$$d = \sqrt{(R_2 - R_1)^2 + (G_2 - G_1)^2 + (B_2 - B_1)^2}.$$

- **HSV Model:** Colors are represented by hue (angle), saturation, and value. Hue ranges from 0° to 360°.

Examples:

- Fast-food chains like McDonald's use red and yellow to stimulate appetite and energy.
- Healthcare brands often use blues and greens for trust and calmness.

Texture

Explanation:
Texture adds depth and realism to designs, whether visual (simulated texture) or tactile (physical texture). It can make a design feel more tangible.

Applications:

- Use rough textures to create a rugged, earthy feel.
- Smooth textures convey elegance or modernity.

Mathematical Perspective:

- Texture mapping in computer graphics uses coordinate transformations to map a 2D image onto a 3D surface.
- The function $T(u, v)$ defines texture color at coordinates (u, v), which is applied to the surface geometry.

Examples:

- Websites use gradients or patterns to mimic textures like fabric or wood.
- Print materials like business cards might use embossed textures for sophistication.

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2. Principles of Design

Contrast

Explanation:
Contrast refers to the difference between elements in a design, making one element stand out against another. It can be achieved through color, size, shape, or texture.

Applications:

- Dark text on a light background improves readability.
- Bold headlines create visual interest when paired with smaller text.

Mathematical Perspective:

- In digital imaging, contrast is adjusted by modifying pixel intensity values using a linear transformation:

$$I_{\text{new}} = a \cdot I_{\text{old}} + b,$$

  where a controls the contrast level, and b adjusts the brightness.

- High contrast can also be measured by the difference in luminance (L) between two areas:

$$C = \frac{L_1 - L_2}{L_1 + L_2},$$

  where L_1 and L_2 are the luminance values of two regions.

Examples:

- White text on a black background in headlines ensures high contrast for better visibility.
- Complementary colors like red and green create strong visual contrast.

Balance

Explanation:
Balance ensures that no single element overpowers the rest of the design. It can be symmetrical (evenly distributed) or asymmetrical (dynamic but balanced).

Applications:

- Symmetrical designs are often used in formal, professional layouts.
- Asymmetry adds energy and movement, commonly used in modern or artistic designs.

Mathematical Perspective:

- **Symmetry:** A design is symmetrical if it is invariant under a reflection transformation, defined as:

$$T(x, y) = (x', y'), \quad \text{where } x' = -x \text{ or } y' = -y.$$

- **Center of Mass:** For balanced layouts, the center of mass is calculated to ensure equal weight distribution:

$$\text{Center of Mass (CM)} = \frac{\sum(m_i \cdot x_i)}{\sum m_i}, \frac{\sum(m_i \cdot y_i)}{\sum m_i}.$$

Here, m_i is the weight (visual importance) of each element, and (x_i, y_i) are their positions.

Examples:

- A symmetrical logo, like Chanel's interlocking Cs, exudes elegance.
- Asymmetrical layouts, like magazine spreads, use visual weight to balance images and text.

Alignment

Explanation:
Alignment organizes elements relative to a line or a grid, creating a cohesive design.

Applications:

- Left-aligned text ensures readability in documents.
- Center alignment works well for formal invitations or announcements.

Mathematical Perspective:

- Alignment can be expressed using coordinate geometry, ensuring that elements share a common x - or y-coordinate. For instance:

$$x_1 = x_2 \quad (\text{vertical alignment}), \quad y_1 = y_2 \quad (\text{horizontal alignment}).$$

- Grids are defined using modular arithmetic, dividing the canvas into uniform sections.

Examples:

- Websites use grids to align text and images consistently.
- Center-aligned headings are common in posters for visual symmetry.

Repetition

Explanation:
Repetition reinforces visual themes by repeating elements like colors, shapes, or patterns throughout the design.

Applications:

- Consistent use of fonts and colors across a brand maintains identity.
- Repeated patterns create decorative backgrounds or borders.

Mathematical Perspective:

- Repetition involves periodic functions, such as sine or cosine waves for patterns:
$$y = A\sin(Bx + C),$$
where A controls amplitude, B controls frequency, and C adjusts phase.
- Tiling patterns follow translational symmetry, described by vectors:
$$T(x, y) = (x + a, y + b),$$
where a and b are translation distances.

Examples:

- A checkerboard pattern uses repeated squares for a uniform look.
- Websites repeat navigation elements like headers and footers across pages.

Proximity

Explanation:
Proximity groups related elements together, indicating a connection and improving visual organization.

Applications:

- Grouping contact details (email, phone) keeps information logical.
- Clustering related images conveys thematic unity.

Mathematical Perspective:

- Euclidean distance measures the closeness of elements:
$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}.$$
Elements with smaller d values appear visually grouped.

Examples:

- A business card groups name, title, and contact information for clarity.
- Navigation menus cluster related links together.

Space

Explanation:
Space refers to the area between and around elements in a design. It can be positive (occupied by elements) or negative (empty areas).

Applications:

- Negative space helps focus attention on the main subject and reduces clutter.
- Positive space defines the subject of the design.

Mathematical Perspective:

- The Golden Ratio (ϕ) is often used in spacing and composition. It is approximately 1.618, and relationships are defined as:

$$\frac{a+b}{a} = \frac{a}{b} = \phi.$$

- Grid systems use coordinate geometry to organize space efficiently.

Examples:

- Apple's minimalist product designs use negative space to highlight their products.
- The FedEx logo uses negative space to create an arrow, symbolizing speed.

3. Visual Hierarchy and Typography

Visual Hierarchy

Explanation:
Visual hierarchy refers to the arrangement of design elements in a way that guides the viewer's attention, emphasizing the most important aspects first. This is often achieved through size, color, placement, and contrast.

Mathematical Explanation:

1. **Size and Scaling:**
   The size of elements follows a geometric progression to maintain proportional hierarchy. The size ratio can be calculated as:

$$\text{Size Ratio} = \frac{\text{Largest Size}}{\text{Smallest Size}}$$

For example, if the largest size (headline) is $48\,\text{pt}$ and the smallest size (body text) is $16\,\text{pt}$, the ratio is:

$$\text{Size Ratio} = \frac{48}{16} = 3:1.$$

2. **Positioning:**
   Elements placed at the top or center of a layout gain visual prominence due to natural reading patterns (e.g., Z-pattern or F-pattern).

Applications:

- Use size and color to emphasize primary content.
- Place key elements at the top or center of a layout for maximum visibility.

Examples:

- Headlines are $1.5\times$ to $3\times$ larger and bolder than body text to catch attention first.
- In a poster, the primary visual might occupy $\frac{1}{3}$ of the total layout space, following the rule of thirds.

Typography

Explanation:
Typography is the art of arranging text to make it readable, visually appealing, and impactful.

Key Mathematical Concepts:

1. **Font Size Ratios:**
   Font sizes are scaled using ratios like:

$$1 : 1.618 \quad (\text{Golden Ratio}) \quad \text{or} \quad 1 : 1.2.$$

For instance, if the base font size is $14\,\text{pt}$, subsequent sizes can be computed as:

$$\text{Golden Ratio Sequence: } 14,\ 14 \cdot 1.618 \approx 23,\ 23 \cdot 1.618 \approx 37\,\text{pt},\ \ldots$$

2. **Kerning:**
   Kerning adjusts the space between letters for readability. Mathematically, the optimal kerning distance d can depend on the font size F and the letter spacing coefficient k:

$$d = F \cdot k.$$

3. **Leading (Line Spacing):**
   Leading (line height) ensures readability by creating vertical space between lines. It is calculated as:

$$\text{Line Height} = \text{Font Size} \times \text{Factor},$$

where the factor typically ranges from 1.4 to 1.6. For a font size of $16\,\text{pt}$:

$$\text{Line Height} = 16 \times 1.5 = 24\,\text{pt}.$$

Examples:

- A poster headline may use a bold sans-serif font scaled to $2.5\times$ the body font size for impact.
- Body text uses serif fonts with a kerning coefficient $k \approx 0.1$ and a line height factor of 1.5 for readability.

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4. Creating Effective Layouts

<u>Layout Techniques</u>

Explanation:
Layouts organize content to achieve balance, clarity, and aesthetic appeal.

Key Mathematical Concepts:

1. **Grid Layouts:**
   Grid systems divide the canvas into rows and columns. The dimensions of each grid cell are calculated as:

$$\text{Grid Cell Area} = \frac{\text{Total Canvas Area}}{\text{Rows} \times \text{Columns}}.$$

For a canvas of $1200\,\text{px} \times 800\,\text{px}$ with 3 rows and 4 columns:

$$\text{Grid Cell Width} = \frac{1200}{4} = 300\,\text{px}, \quad \text{Grid Cell Height} = \frac{800}{3} \approx 266.67\,\text{px}.$$

2. **Rule of Thirds:**
   The canvas is divided into a 3×3 grid. Focal points are positioned at the intersections of grid lines. For a canvas of $1200\,\text{px} \times 800\,\text{px}$:

$$\text{Horizontal Division} = \frac{1200}{3} = 400\,\text{px}, \quad \text{Vertical Division} = \frac{800}{3} \approx 266.67\,\text{px}.$$

3. **Golden Ratio:**
   The golden ratio divides dimensions into two parts a and b, such that:

$$\frac{a}{b} = 1.618, \quad \text{and} \quad a + b = \text{Canvas Width}.$$

For a canvas width of $1200\,\text{px}$:

$$a = \frac{1200}{1 + 1.618} \approx 742\,\text{px}, \quad b = 1200 - 742 = 458\,\text{px}.$$

Applications:

- **Grid Layouts:** Ensure alignment and proportion in web pages or magazine designs.
- **Rule of Thirds:** Photographers position subjects at intersections for aesthetic appeal.
- **Golden Ratio:** Use harmonious proportions to design headers, images, and content sections.

Examples:

- Magazines and websites use grids to align text and images for structured readability.
- A photographer places a subject along the golden spiral for natural composition.