DSCI 554 LECTURE 5

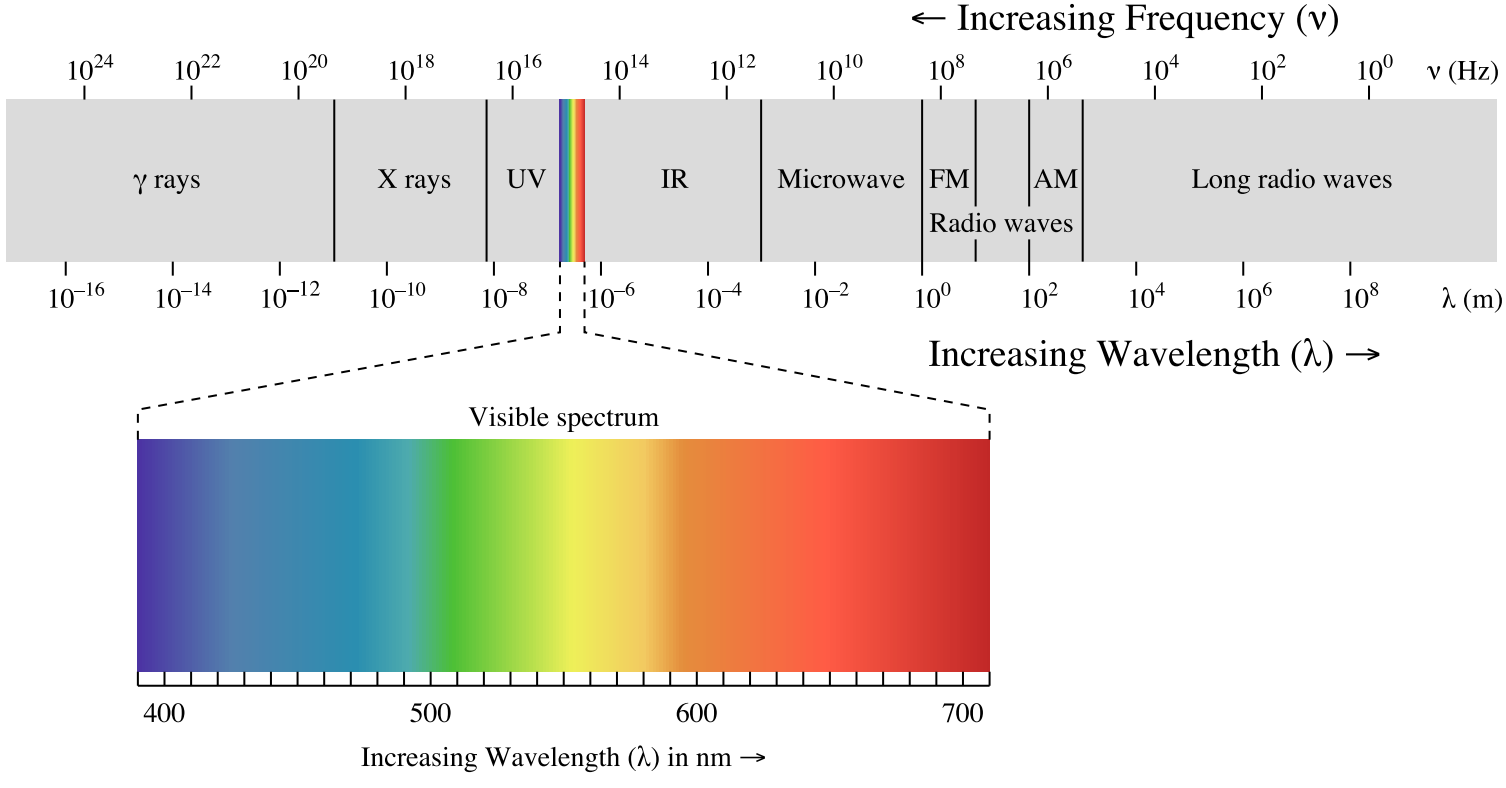
THE EYE AND THE VISUAL BRAIN, D3 SCALES AND AXES

Dr. Luciano Nocera

OUTLINE

- The eye and the visual brain
- D3 scales and axes

VISIBLE SPECTRUM



Visible spectrum wavelengths from 400-700nm (in nanometers)

MOST PEOPLE SEE RED

CLOSER THAN BLUE

BUT SOME SEE THE

OPPOSITE EFFECT

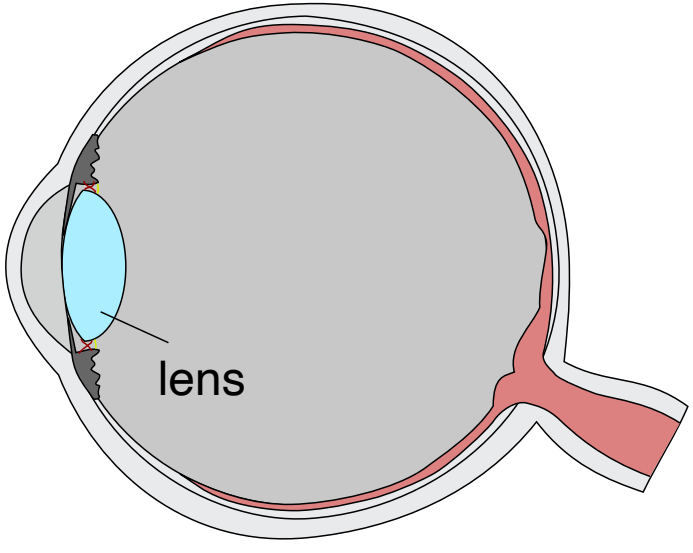
MOST PEOPLE SEE RED

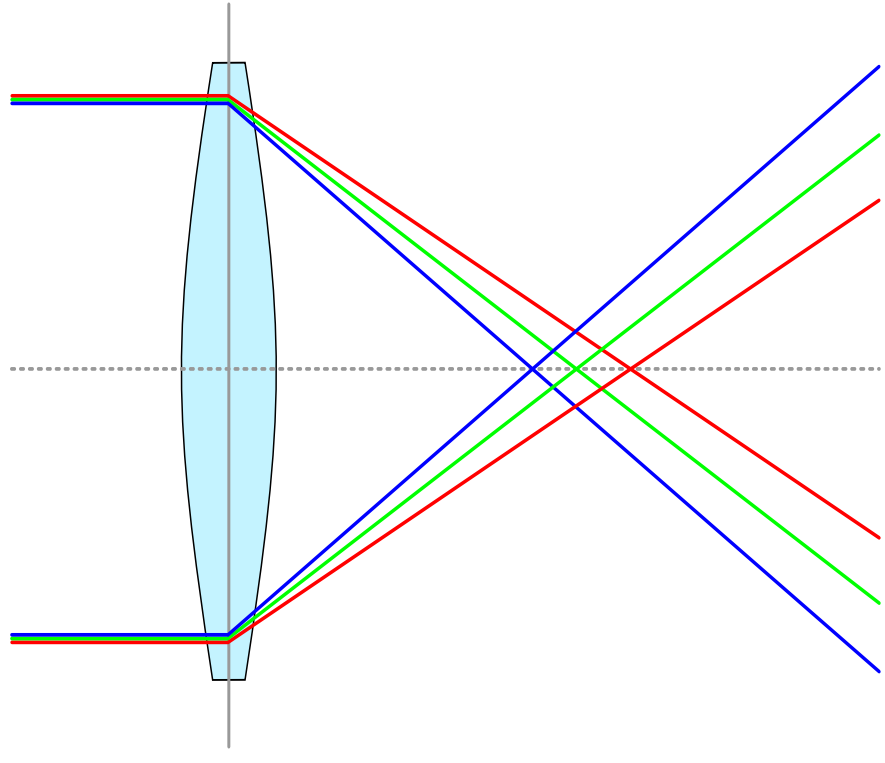
CLOSER THAN BLUE

BUT SOME SEE THE

OPPOSITE EFFECT

THE LENS





Eye: organ of the visual system that transforms light in signals that travel to the brain

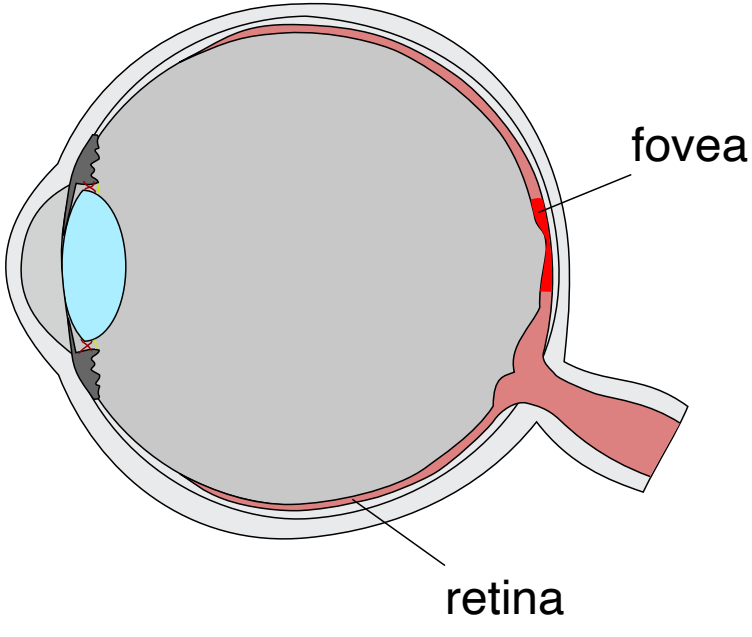
Chromatic aberration (Chromostereopsis), optical illusion caused by refraction and binocular vision

Stuart Anstis Eye Chart

High-res vision in central 1-2° of field of view

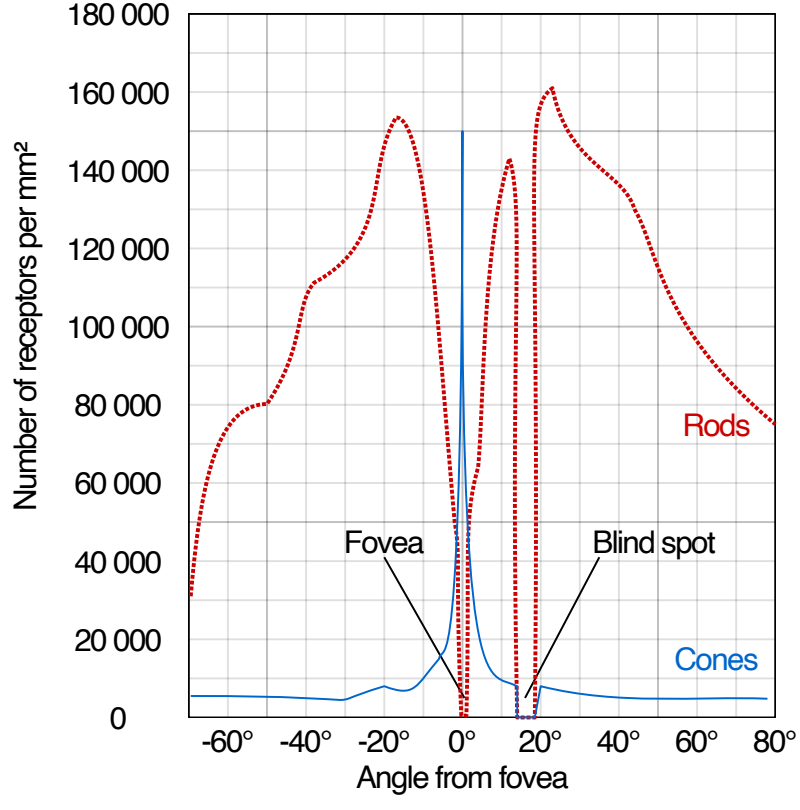
RETINA PHOTORECEPTORS: CONES AND RODS

FOVEA CORRESPONDS TO 1-2°

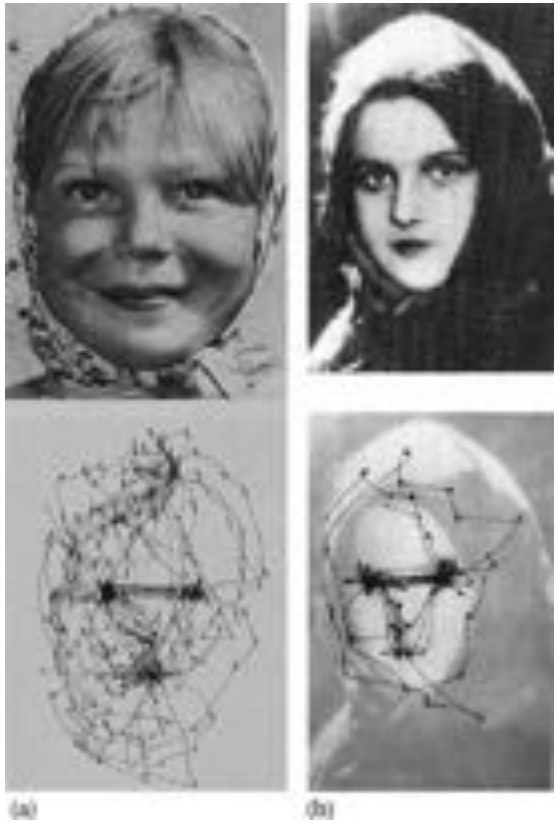


Retina: layer containing cells sensitive to light, from latin rete (net).

CENTRAL HIGH-RES VISION WITH CONES



Distribution of rods and cones along a line passing through the fovea and the blind spot of a human eye. -- Foundations of Vision, Brian A. Wandell.



Yarbus A L. Eye Movements and Vision. New York: Plenum Press; 1967

SACCADES

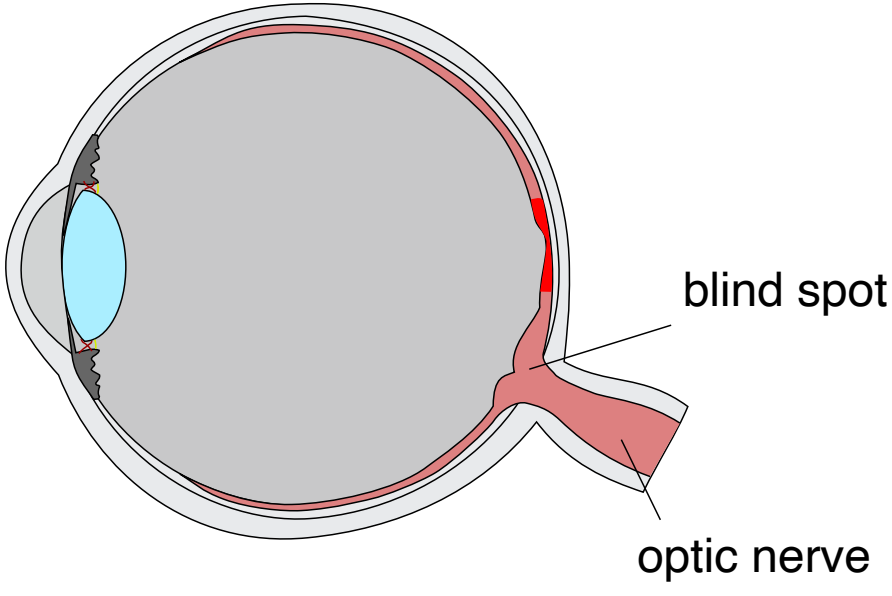
- Eye movements (about 3 each second)
- Accompanied by periods of blindness
- $> 200ms$ to initiate
- Fastest movements in body (up to $900^o s^{-1}$)

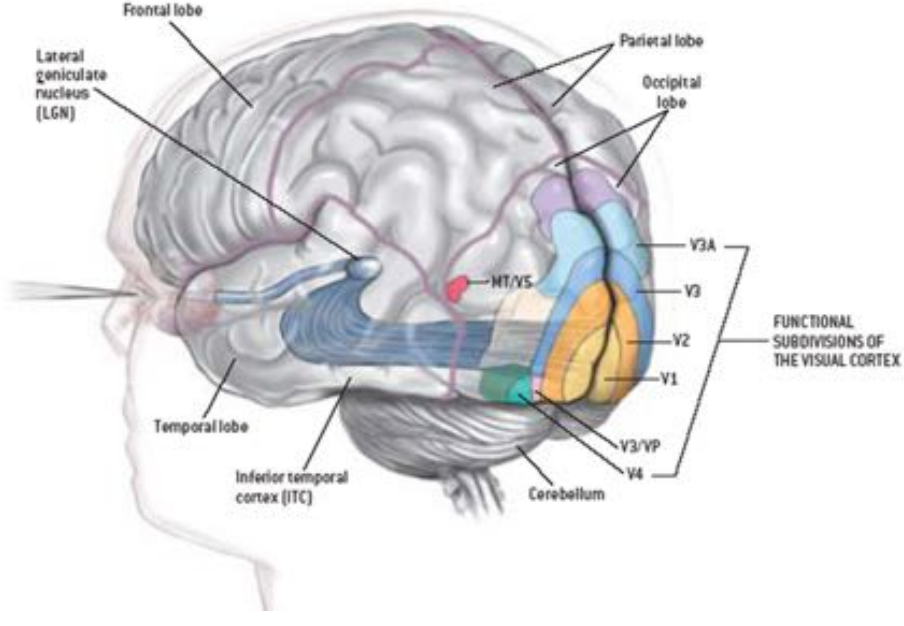
FIXATIONS

- A glimpse
- When visual information is acquired
- Task dependent

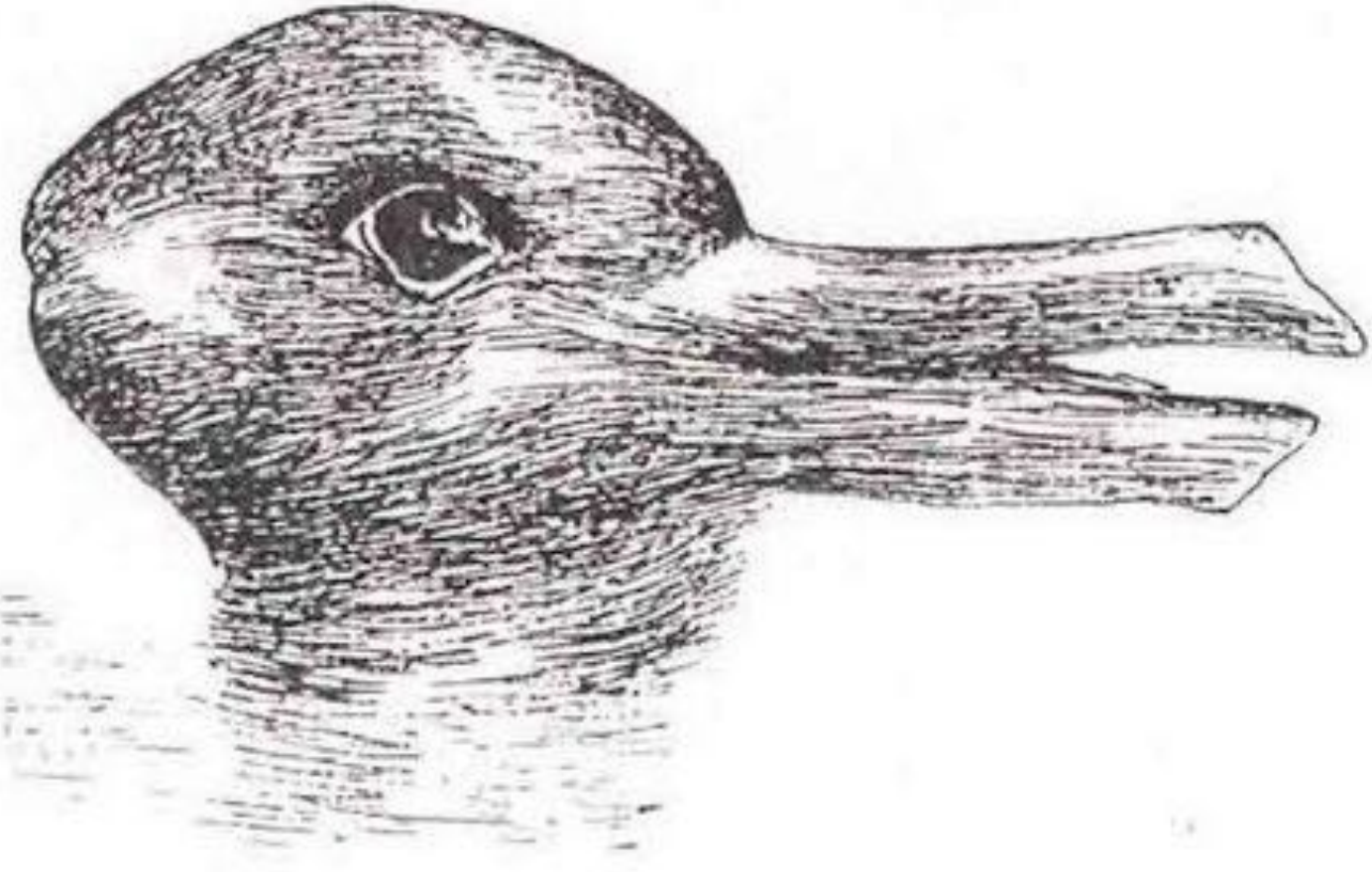
THE VISUAL SYSTEM

Eyes, nerves (optic nerve from eyes to brain) and visual cortex (areas V1-5)

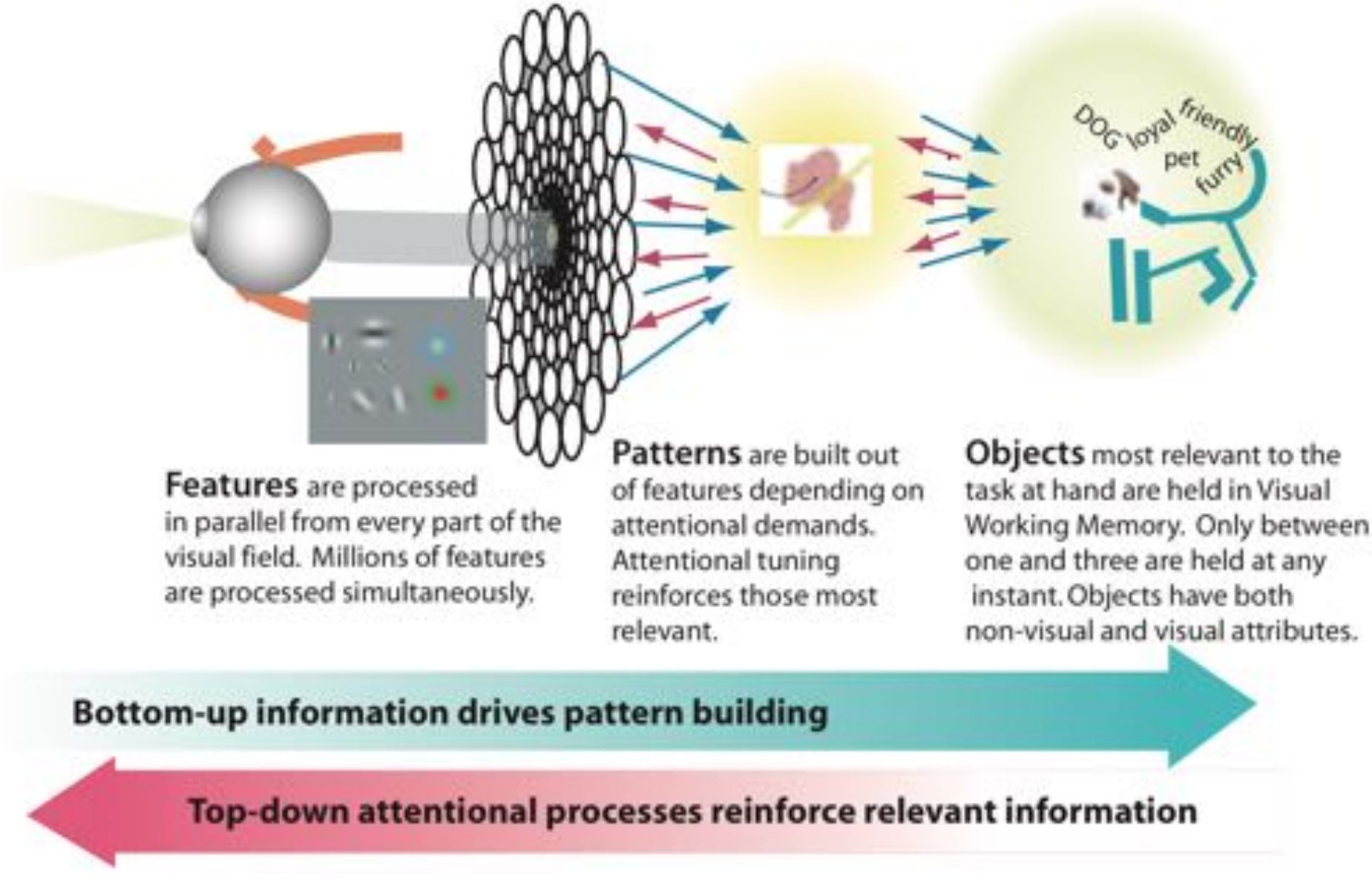




Expert Reviews in Molecular Medicine by Cambridge University Press 2004



Duck rabbit illusion. The figure is perceived as changing between two interpretations. As the brain interprets visual signals it provides continuity between fixations, adds information at the blind spot and performs object recognition.



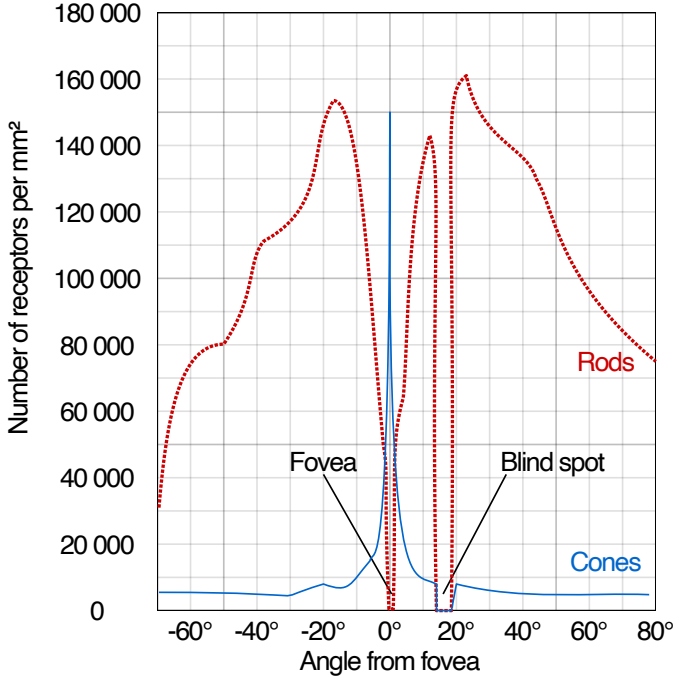
Colin Ware. Visual thinking: For design. Morgan Kaufmann, 2010.

INFORMATION PROCESSING IN THE VISUAL SYSTEM

Bottom-up or data-driven	Top-down or schema-driven
Perception results from transforming sensory input into higher level information	Signals from the eye are integrated and compared to examples in memory
Knowledge and attention influence perception	Object knowledge directs the eyes and the feature extraction processing

VISUAL QUERIES

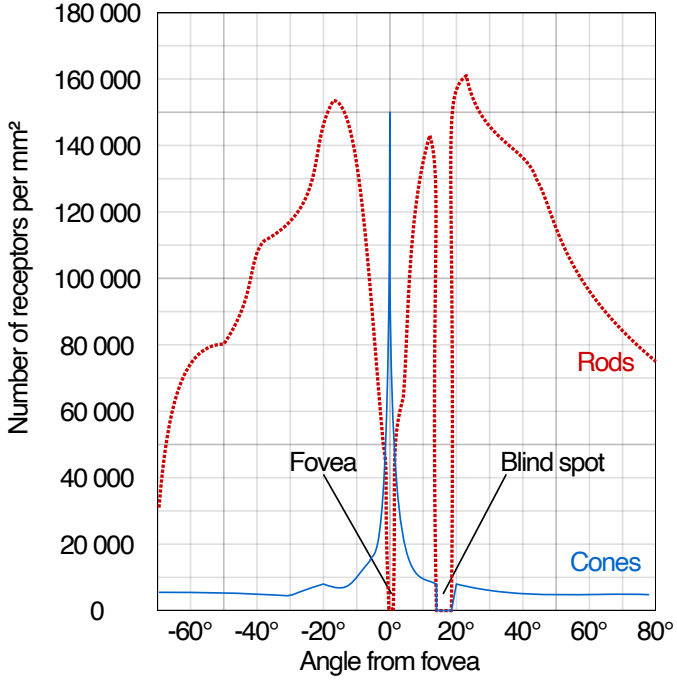
VISUAL QUERIES



WHICH PHOTORECEPTOR IS PRESENT IN THE FOVEA?

Answer: almost exclusively cones

VISUAL QUERIES



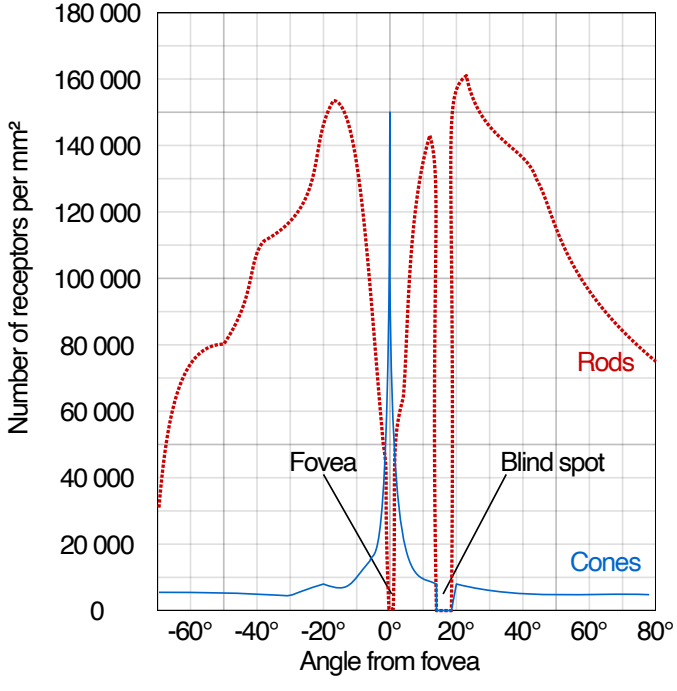
WHICH PHOTORECEPTOR IS PRESENT IN THE FOVEA?

Answer: almost exclusively cones

RELEVANT VISUAL QUERIES

- Find *"Fovea"* label
- Find Fovea region on x axis
- Find curve with larger y value (use grid lines)
- Follow corresponding curve and read label

VISUAL QUERIES



WHICH PHOTORECEPTOR IS PRESENT IN THE FOVEA?

Answer: almost exclusively cones

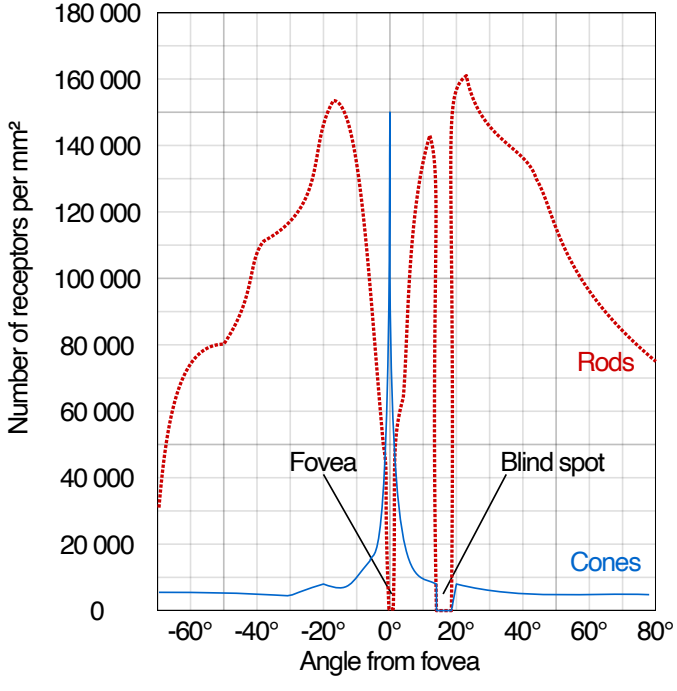
RELEVANT VISUAL QUERIES

- Find *"Fovea"* label
- Find Fovea region on x axis
- Find curve with larger y value (use grid lines)
- Follow corresponding curve and read label

EXAMPLE OF BOTTOM-UP PROCESSING

Perceiving the lines, e.g., perceived dots in dotted line are integrated into a line representation

VISUAL QUERIES



WHICH PHOTORECEPTOR IS PRESENT IN THE FOVEA?

Answer: almost exclusively cones

RELEVANT VISUAL QUERIES

- Find *"Fovea"* label
- Find Fovea region on x axis
- Find curve with larger y value (use grid lines)
- Follow corresponding curve and read label

EXAMPLE OF BOTTOM-UP PROCESSING

Perceiving the lines, e.g., perceived dots in dotted line are integrated into a line representation

EXAMPLE OF TOP-DOWN PROCESSING

Search for text, e.g., *"Fovea"*

VISUAL QUERIES AND DESIGN CONSIDERATIONS

Visual query: a pattern cognitively specified, that if found in the display will contribute to the solution of a problem
-- C. Ware

Visual thinking consists of a series of acts of attention, driving eye movements and tuning our pattern-finding circuits
-- C. Ware

VISUAL QUERIES AND DESIGN CONSIDERATIONS

Visual query: a pattern cognitively specified, that if found in the display will contribute to the solution of a problem
-- C. Ware

Visual thinking consists of a series of acts of attention, driving eye movements and tuning our pattern-finding circuits
-- C. Ware

Carefully craft visualizations to optimize visual queries
-- C. Ware

The attention test

The Monkey business illusion. Daniel J. Simons.

INATTENTIONAL BLINDNESS

- Failure to detect an unexpected stimulus that is fully visible
- Limited attention allows to focus on one thing at the time
- The brain prioritizes what to focus on

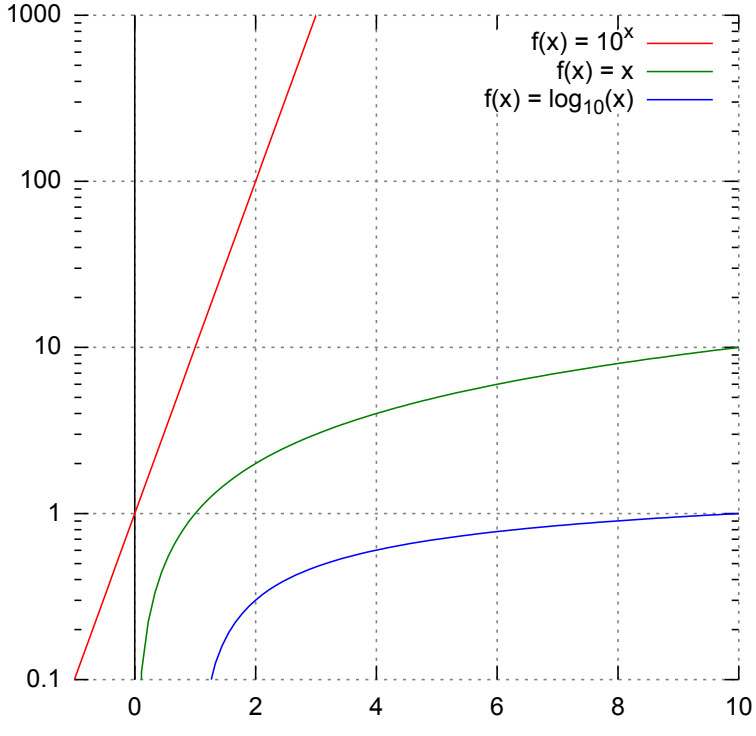
RELATED IMPLICATIONS FOR DESIGN

- For designers ... it is important to know what kinds of visual information the brain can process efficiently [Ware].
- Be aware of inattentional blindness. Never show simultaneous animations on different parts of the screen [Cairo].
- Do not use too many competing stimuli. Filling graphic with objects colored in pure accent tones disorients users [Cairo].

OUTLINE

- The eye and the visual brain
- D3 scales and axes

SCALE & AXES



Linear and log scales

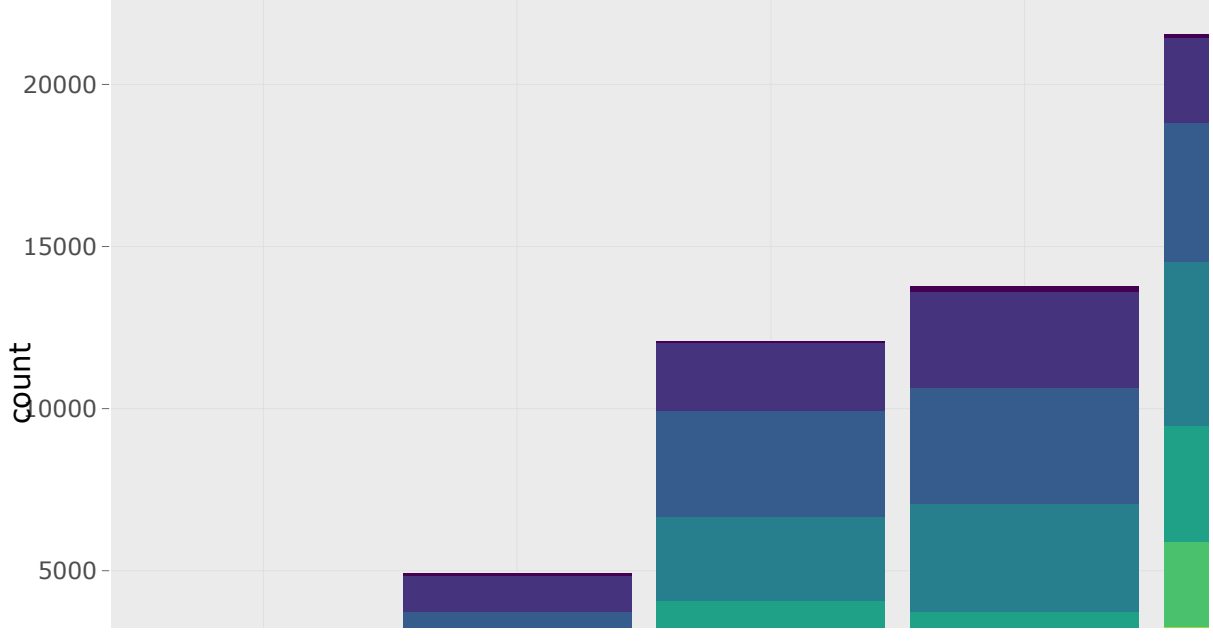
SCALES

Encodings used to map data to visual representations

AXES

Visual representations of the scale that let us read data values

ANNOTATIONS



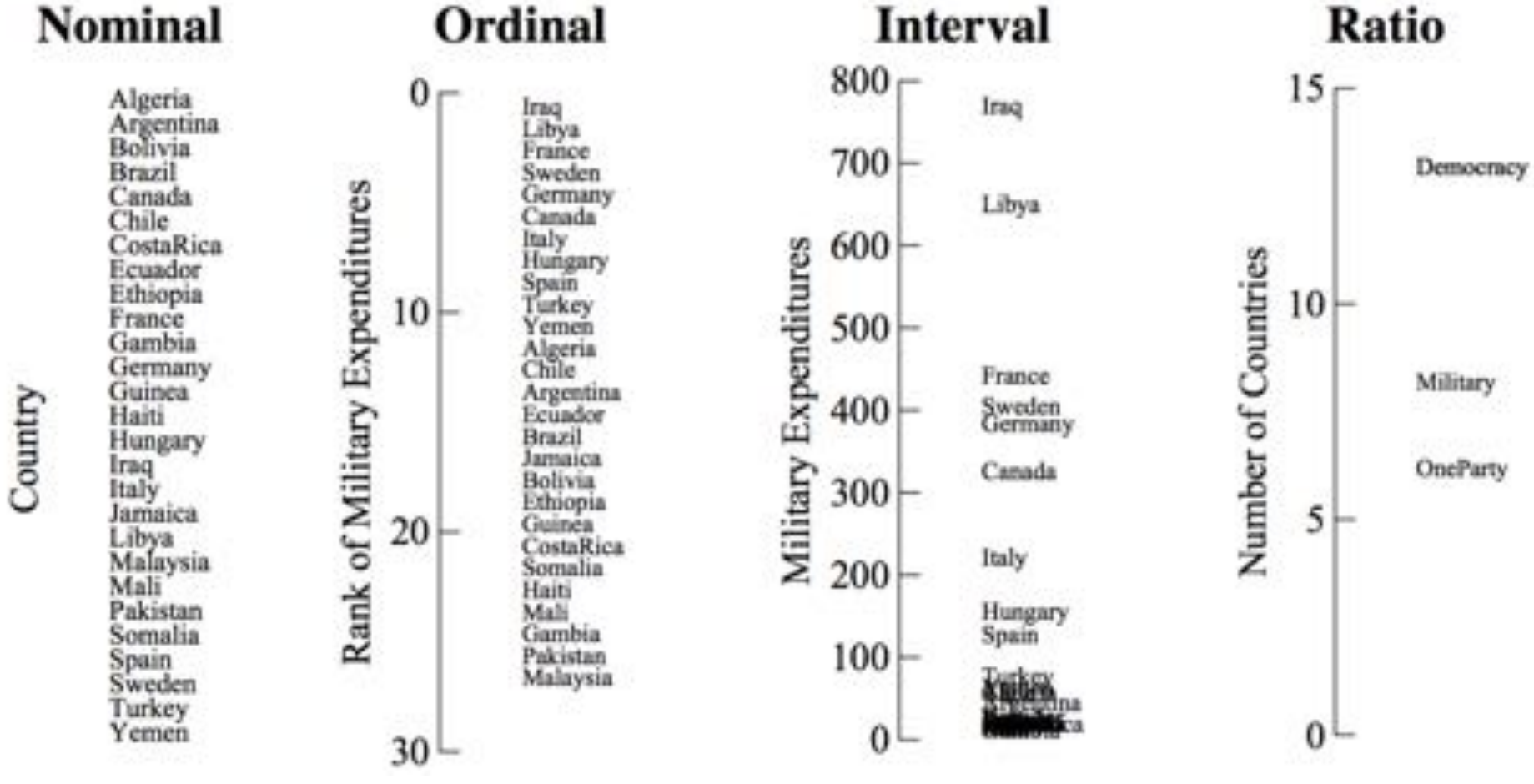
AXES

- axis
- axis labels
- axis values
- tick marks
- tick mark labels
- grid lines

LEGEND

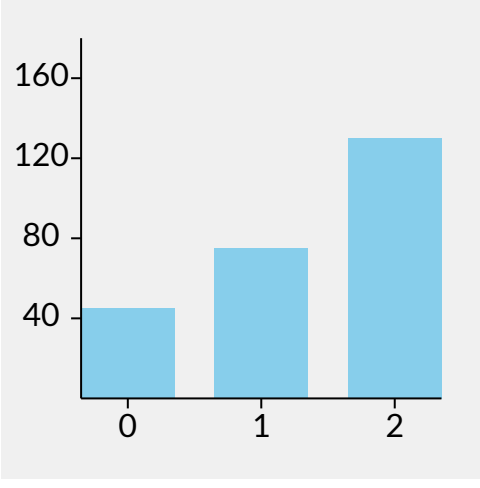
- title
- keys
- key labels

TYPES OF SCALES [STEVENS 1946]



On the theory of scales of measurement, Stevens 1946

LET'S DRAW A CHART WITH AXES USING D3!




```
var dataset = [['0', 45], ['1', 75], ['2', 130]];

// define variables to use for chart sizing
var w = 200;
var h = 200;
var pad = 20;

var svg = d3.select('#svg00')
  .attr('width', w + 2 * pad)
  .attr('height', h + 2 * pad)
  .style('background-color', 'rgb(240, 240, 240)');

svg.selectAll('rect')
  .data(dataset)
  .enter()
  .append('rect')
  .attr('x', function (d, i) { return 2 * pad + i * (w / dataset.length); })
  .attr('y', function (d) { return h - d[1]; })
  .attr('width', w / dataset.length - pad)
  .attr('height', function (d) { return d[1]; })
  .style('fill', 'skyblue');

svg.selectAll('text')
  .data(dataset)
  .enter()
  .append('text')
  .text(function (d) { return d[0]; })
  .attr('x', function (d, i) {
    return 2 * pad + i * (w / dataset.length) + (w / dataset.length - pad) / 2; })
  .attr('y', function (d) { return h + 15; })
  .style('fill', 'black')
  .style('font-size', '16px')
  .style('text-anchor', 'middle')
  .style('alignment-baseline', 'middle');

svg.selectAll('line')
  .data(dataset)
  .enter()
  .append('line')
  .attr('x1', function (d, i) {
    return 2 * pad + i * (w / dataset.length) + (w / dataset.length - pad) / 2; })
  .attr('y1', function (d) { return h + 5; })
  .attr('x2', function (d, i) {
    return 2 * pad + i * (w / dataset.length) + (w / dataset.length - pad) / 2; })
  .attr('y2', function (d) { return h; })
  .style('stroke', 'black');

svg.append('line')
  .attr('x1', 2 * pad)
  .attr('y1', h)
  .attr('x2', w + pad)
  .attr('y2', h)
  .style('stroke', 'black');

svg.append('line')
  .attr('x1', 2 * pad)
  .attr('y1', h)
  .attr('x2', 2 * pad)
  .attr('y2', pad)
  .style('stroke', 'black');
```

Hard coded scales, insert/append of axes & labels (page 1)

```
svg.append('line')
  .attr('x1', 2 * pad)
  .attr('y1', h - 40)
  .attr('x2', 2 * pad - 5)
  .attr('y2', h - 40)
  .style('stroke', 'black');

svg.append('text')
  .text('40')
  .attr('x', pad)
  .attr('y', h - 40)
  .style('fill', 'black')
  .style('font-size', '16px')
  .style('text-anchor', 'middle')
  .style('alignment-baseline', 'middle');

svg.append('line')
  .attr('x1', 2 * pad)
  .attr('y1', h - 80)
  .attr('x2', 2 * pad - 5)
  .attr('y2', h - 80)
  .style('stroke', 'black');

svg.append('text')
  .text('80')
  .attr('x', pad)
  .attr('y', h - 80)
  .style('fill', 'black')
  .style('font-size', '16px')
  .style('text-anchor', 'middle')
  .style('alignment-baseline', 'middle');

svg.append('line')
  .attr('x1', 2 * pad)
  .attr('y1', h - 120)
  .attr('x2', 2 * pad - 5)
  .attr('y2', h - 120)
  .style('stroke', 'black');

svg.append('text')
  .text('120')
  .attr('x', pad)
  .attr('y', h - 120)
  .style('fill', 'black')
  .style('font-size', '16px')
  .style('text-anchor', 'middle')
  .style('alignment-baseline', 'middle');

svg.append('line')
  .attr('x1', 2 * pad)
  .attr('y1', h - 160)
  .attr('x2', 2 * pad - 5)
  .attr('y2', h - 160)
  .style('stroke', 'black');

svg.append('text')
  .text('160')
  .attr('x', pad)
  .attr('y', h - 160)
  .style('fill', 'black')
  .style('font-size', '16px')
  .style('text-anchor', 'middle')
  .style('alignment-baseline', 'middle');
```

(page 2)

D3 SCALES AND AXES TO THE RESCUE!

d3 / d3-scale

- Simplify mapping data to representation
- Facilitates complex data transformations

d3 / d3-axis

- Simplify drawing of axes

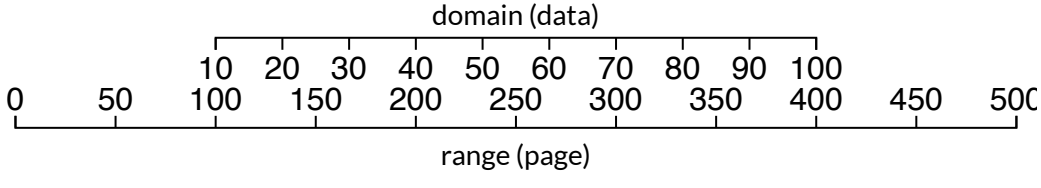
HOW D3 SCALES WORK

Input (Data) → Output (Representation)

Domain → Range

```
data = [10, 20, 30, 50, 80, 100];

min = d3.min(data);  //10
max = d3.max(data);  //100

domain = [10, 100];
```

```
range = [100, 400];
```



TYPES OF D3 SCALES

Continuous	Ordinal
◦ Quantitative data ◦ Continuous domain	◦ Qualitative data ◦ Discrete domain
◦ Linear ◦ Time ◦ Power ◦ Log ◦ Quantize (rounds to set of discrete values) ◦ Quantile (computes quantiles) ◦ Sequential ◦ Threshold (specifies arbitrary breaks)	◦ Ordinal ◦ Band ◦ Point

D3.SCALELINEAR()

$$y = a\,x + b$$

```
dataset = [100, 120, 150];

var x = d3.scaleLinear()  //function are objects in js
  .domain([d3.min(dataset), d3.max(dataset)])  //extent of the data
  .range([0, 100]);  //range is the extent of the svg in pixels

x(125);  //50
```

💡 You can run the code in the console!

D3.SCALETIME()

$$y = a\,t + b$$

```
//use Date() to specify time in milliseconds
var x = d3.scaleTime()
  .domain([new Date(2018, 8, 20), new Date(2018, 12, 12)])
  .range([0, 960]);

x(new Date(2018, 11, 30));  //evaluate for date
x(Date.now());  //evaluates scale for today's date
```

MDN Web docs: Date

💡 You can run the code in the console!

D3.SCALELOG()

$$y = a\,log(x) + b$$

```
var x = d3.scaleLog()
  .domain([1, 10000])
  .range([0, 1000])
  .base(10);

x(10);  //250
x(10000);  //1000
```

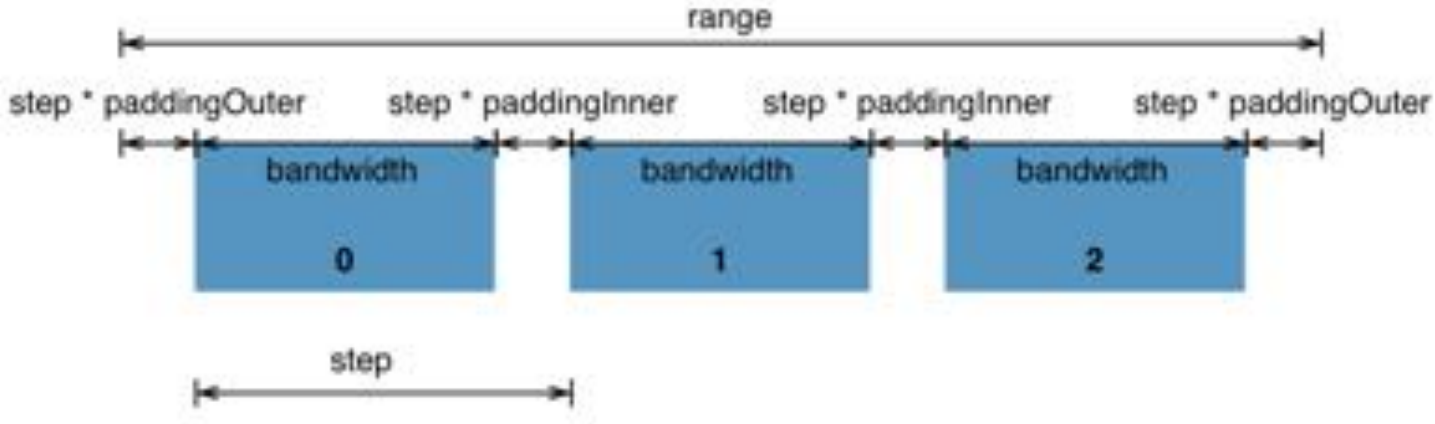
💡 You can run the code in the console!

D3.SCALEORDINAL()

```
var x = d3.scaleOrdinal()
  .domain(['0', '1', '2'])  //discrete domain
  .range([0, 1, 2]);

x('0');  //0
x('1');  //1
```

You can run the code in the console!

D3.SCALEBAND()

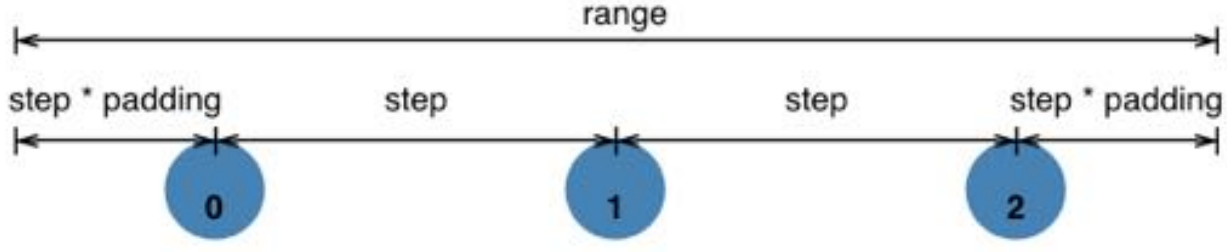



```
var x = d3.scaleBand()
  .domain(['0', '1', '2'])  //discrete domain
  .range([0, 600])
  .paddingInner(0.05);  //set inner padding in [0, 1], dafaults to 0.

x('0');  //0
x('1');  //303.4
x.bandwidth();  //193.2
```

You can run the code in the console!

D3.SCALEPOINT()

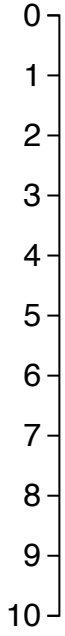
Same as scaleBand() with bandwidth = 0




```
var x = d3.scalePoint()
  .domain(['0', '1', '2'])  //discrete domain
  .range([0, 600]);

x('0');  //0
x('1');  //300
```

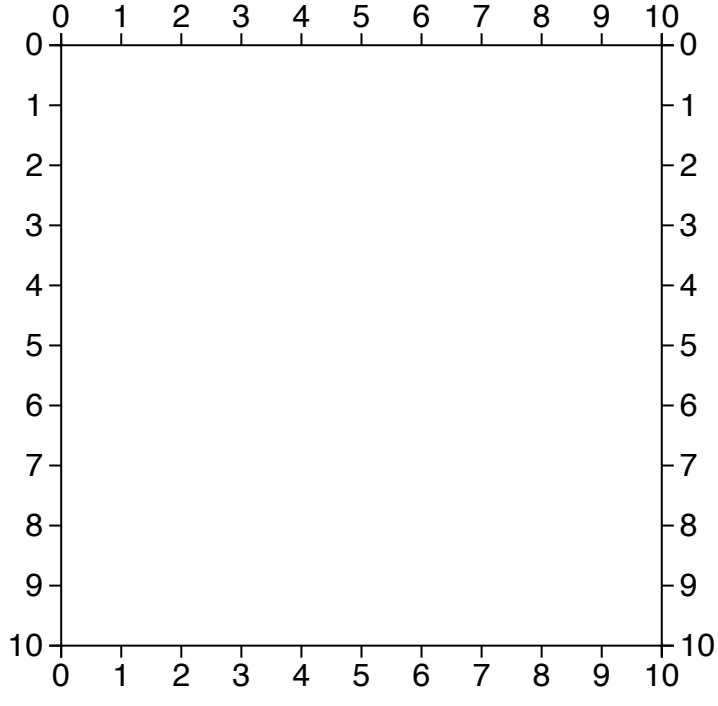
💡 You can run the code in the console!

BOILERPLATE CODE FOR DRAWING AXES



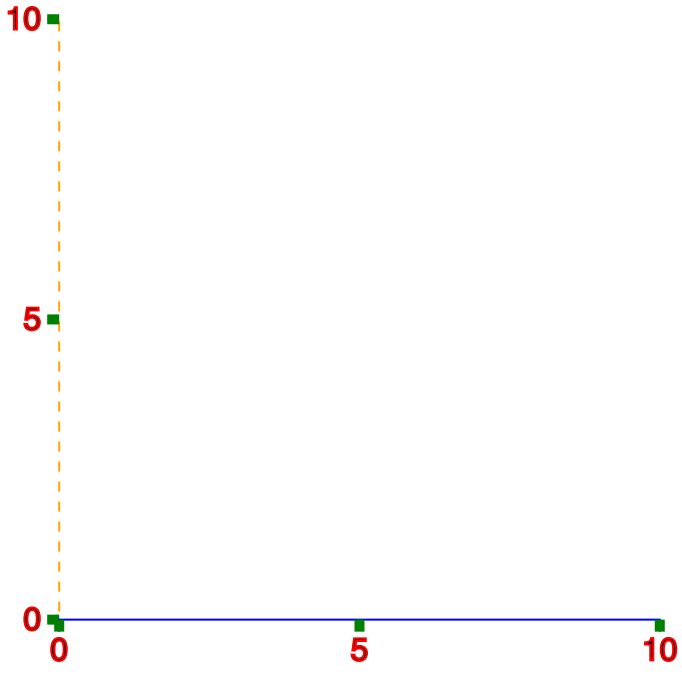

```
var svg = d3.select('#svg02')
  .attr("width", 400)
  .attr("height", 400);

// 1. CREATE SCALE FOR AXIS
var scale = d3.scaleLinear()
  .domain([0, 10])
  .range([0, 300]);

// 2. CREATE AXIS AND SET THE SCALE
var axis = d3.axisLeft(scale);

// 3. ADD AXIS IN A GROUP AND PLACE
svg.append("g")
  .attr("transform", "translate(50,50)")
  .call(axis);  //call axis to draw
```

4 TYPES OF D3 AXES




```
var svg = d3.select('#svg03')
  .attr("width", 400)
  .attr("height", 400);

var scale = d3.scaleLinear()
  .domain([0, 10])
  .range([0, 300]);

//vertical axis with ticks on the left
var axis_l = d3.axisLeft(scale);

//vertical axis with ticks on the right
var axis_r = d3.axisRight(scale);

//horizonal axis with ticks on the top
var axis_t = d3.axisTop(scale);

//vertical axis with ticks on the bottom
var axis_b = d3.axisBottom(scale);

svg.append("g")
  .attr("transform", "translate(50,50)")
  .call(axis_l);

svg.append("g")
  .attr("transform", "translate(350,50)")
  .call(axis_r);

svg.append("g")
  .attr("transform", "translate(50,50)")
  .call(axis_t);

svg.append("g")
  .attr("transform", "translate(50,350)")
  .call(axis_b);
```

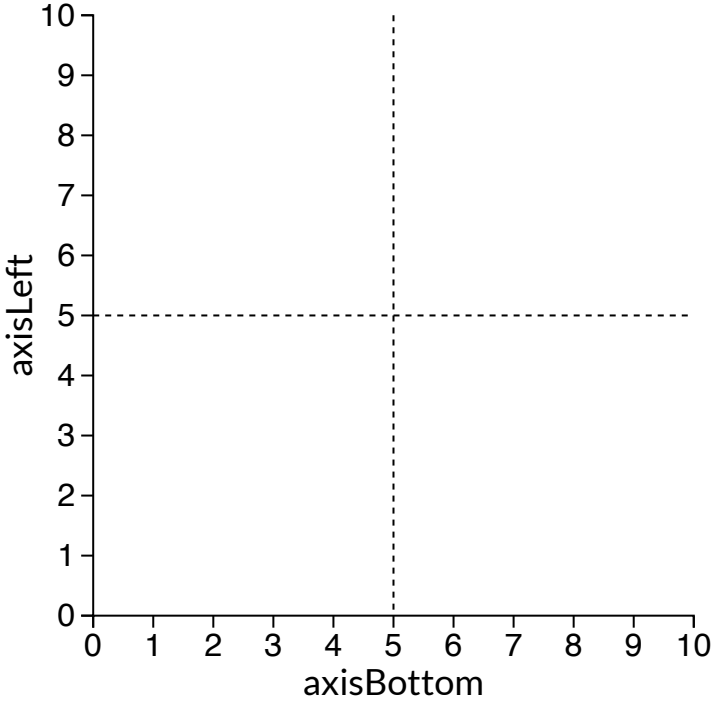
BOILERPLATE CODE FOR STYLING AXES




```
<style type="text/css">
  #svg04 path {
    stroke: blue;
  }
  #svg04 .dashed-axis path {  //axis is <path>
    stroke: orange;
    stroke-dasharray: 5,5;
  }
  #svg04 .tick line {  //ticks are <line>
    stroke: green;
    stroke-width: 5px;
    shape-rendering: crispEdges;
  }
  #svg04 .tick text {
    stroke: red;
    font-family: sans-serif;
    font-size: 16px;
  }
</style>

<script>
  var svg = d3.select('#svg04')
  .attr("width", 400)
  .attr("height", 400);
  var y = d3.scaleLinear().domain([0, 10]).range([300, 0]);
  var x = d3.scaleLinear().domain([0, 10]).range([0, 300]);
  var axis_l = d3.axisLeft(y).ticks(3);
  var axis_b = d3.axisBottom(x).ticks(3);
  svg.append("g")
    .attr("transform", "translate(50,50)")
    .attr('class', 'dashed-axis')
    .call(axis_l);
  svg.append("g")
    .attr("transform", "translate(50,350)")
    .call(axis_b);
</script>
```

For details see Mike Bostock's Block: Axis Styling

BOILERPLATE CODE FOR AXES LABELS AND GRID LINES



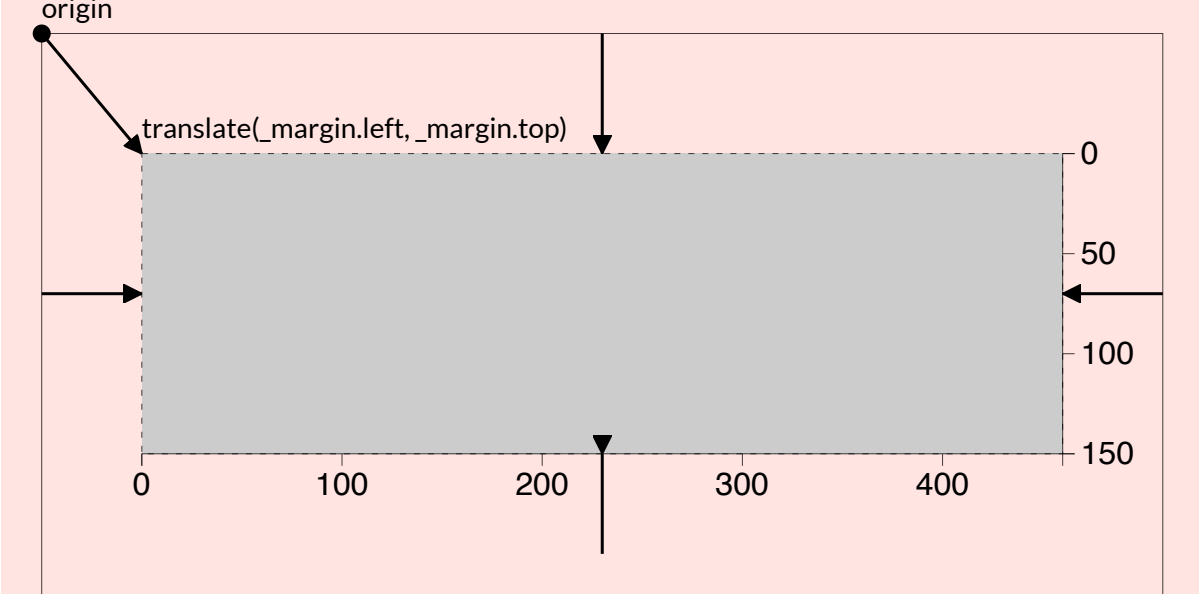

```
<style>
  .label {
    font-size: 18px;
    text-anchor: middle;
    alignment-baseline: middle;
  }

  .dashed-axis path {
    stroke-dasharray: 3, 3;
  }
</style>
<script>
  var svg = d3.select('#svg05').attr("width", 400).attr("height", 400);

  var y = d3.scaleLinear().domain([0, 10]).range([300, 0]);
  var x = d3.scaleLinear().domain([0, 10]).range([0, 300]);
  var axis_l = d3.axisLeft(y)
  var axis_b = d3.axisBottom(x)

  svg.append("g")
    .attr("transform", "translate(50,50)")
    .call(axis_l);

  svg.append("g")
    .attr("transform", "translate(50,350)")
    .call(axis_b);

  var axis_hg = d3.axisBottom(x)  //create and place grid lines
    .tickSize(0)
    .ticks(0);

  var axis_vg = d3.axisLeft(x)
    .tickSize(0)
    .ticks(0);

  svg.append("g")
    .attr("transform", "translate(50,200)")
    .attr('class', 'dashed-axis')
    .call(axis_hg);

  svg.append("g")
    .attr("transform", "translate(200,50)")
    .classed('dashed-axis', true)
    .call(axis_vg);

  svg.append("text")  //create and place labels
    .attr("x", 200)
    .attr("y", 385)
    .classed('label', true)
    .text("axisBottom");

  svg.append("text")
    .attr("x", -200)
    .attr("y", 15)
    .classed('label', true)
    .attr("transform", "rotate(-90)")
    .text("axisLeft");
</script>
```

MARGIN CONVENTION

```
var margin = {top: 20, right: 20, bottom: 20, left: 20};  //step1: set margin
var width = 600 - margin.left - margin.right,  //step2: set width and height
    height = 300 - margin.top - margin.bottom;

var svg = d3.select("body").append("svg")  //step3: set-up svg
  .attr("width", width + margin.left + margin.right)
  .attr("height", height + margin.top + margin.bottom)
  .append("g")
  .attr("transform", "translate(" + margin.left + "," + margin.top + ")");
```

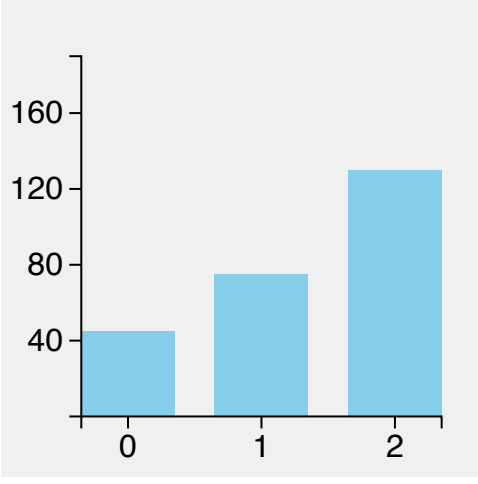
Facilitates plots:

- Moves origin to bottom-left
- Adds padding for labels
- Inverts the y axis

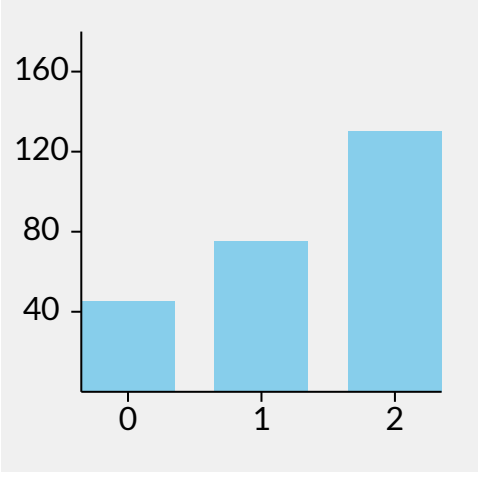


Mike Bostock's Block 3019563: Margin Convention

LET'S PUT IT TOGETHER!



Using D3 scales and axes



Manually added scales and axes

```
<svg id="p_39_1" style="background-color: #f0f0f0; margin-right: 40px"></svg>

<style>
  path { stroke: black; }
  .tick line { stroke: black; }
  .tick { stroke: black; }
  .tick text {
    stroke: none;
    fill: black;
    font-size: 16px;
  }
</style>

<script>
  var data = [['0', 45], ['1', 75], ['2', 130]];

  var margin = { top: 30, right: 20, bottom: 30, left: 40 };
  var width = 240 - margin.left - margin.right,
    height = 240 - margin.top - margin.bottom;

  var x = d3.scaleBand()
    .domain(data.map(d => d[0]))
    .range([0, width])
    .paddingInner(.3);

  var y = d3.scaleLinear()
    .domain([0, d3.max(data, d => d[1]) + margin.top + + margin.bottom])
    .range([height, 0]);

  var xAxis = d3.axisBottom()
    .scale(x);

  var yAxis = d3.axisLeft()
    .scale(y)
    .tickValues([40, 80, 120, 160]);

  var svg = d3.select("#p_39_1")
    .attr("width", width + margin.left + margin.right)
    .attr("height", height + margin.top + margin.bottom)
    .append("g")
    .attr("transform", "translate(" + margin.left + "," + margin.top + ")");

  svg.selectAll('rect')
    .data(data)
    .enter()
    .append('rect')
    .attr('x', (d) => x(d[0]) )
    .attr('y', (d) => y(d[1]) )
    .attr('width', x.bandwidth)
    .attr('height', (d) => height - y(d[1]) )
    .style('fill', 'skyblue');

  svg.append("g")
    .attr("transform", "translate(0," + height + ")")
    .call(xAxis);

  svg.append("g")
    .call(yAxis);
</script>
```

Complete code including CSS!