A Design Analysis of *Informed Omnivore*

PSYC 579: Special Topics in Perception:
Visual Display Design

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1 Introduction

The usability of a visual interface is largely dependent on the extent to which visual perceptual mechanisms are supported. This report investigates the design of a visual interface, identifying interface elements that are both optimally and poorly designed, with respect to perceptual mechanisms. Recommendations, grounded in an understanding of these mechanisms, are offered to improve the visual design of the interface.

What follows is a description of the interface: its visual and interactive features and the tasks they support. The investigation section discusses five perceptual mechanisms and their implications for the design of the interface. The report concludes with a summary of major recommendations.

2 Informed Omnivore

Informed Omnivore is an application for visualizing organic food production in Canada, based on 2006 national agricultural census data[1]. The application is a dashboard: interface elements are distributed between four linked panels, as shown in Figure 1.

[1] *Informed Omnivore* was developed by the author in Fall 2009 as a project for CPSC 533C: Information Visualization. Available at: `http://cs.ubc.ca/~brehmer/demo/omnivore/InformedOmnivore.html`

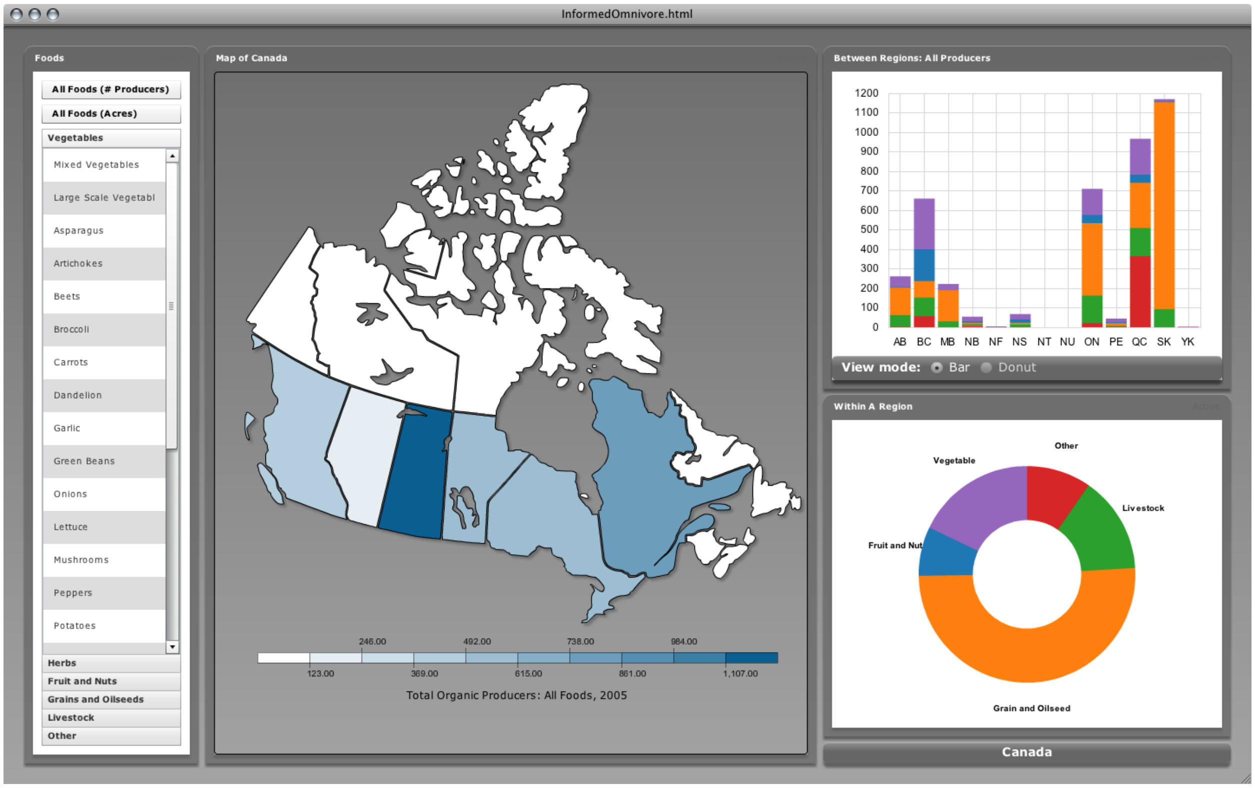

Figure 1: *Informed Omnivore*, an application for visualizing organic food production in Canada.

The *Food Type* Panel: (Figure 2) Here the user *selects* a food type, controlling what data is displayed in the other panels. The list of food types is composed of two buttons and an accordion list. The two buttons correspond to all food types aggregated together, first in terms of the number of producers and second in terms of acreage. The accordion list is divided into six tabs corresponding to top-level food categories: vegetables, herbs, fruits & nuts, grains & oilseeds, livestock, and other foods. Clicking on a tab *selects* the top-level food category and reveals the sublist of individual foods in that category. A vertical scrollbar is used to scroll long sublists. Clicking on an individual food item *selects* that food type. The buttons, accordion tabs, and sublist items support mouse-over and mouse-down states; accordion sublist items additionally have a *selected* state.

The *Map* Panel: (Figure 3) This panel displays an interactive map of Canada. Each provincial outline is denoted by a 1pt black border. Several pixels of empty space between provincial areas enhances boundary separation. The fill of each province corresponds to the absolute production level (in terms of number of producers or acreage) of the currently selected food type, mapped to a colour-lightness scale. Brighter regions correspond to lower production levels while dimmer, blue regions correspond to higher production levels. A map legend, outlined in black, supplemented with black tick marks, scale values, and a caption specifying the currently selected food type and scale unit is displayed below the map.

The provincial areas support several forms of interaction: mouse-enter, mouse-over (hover), mouse-out, and mouse-down (click). Mouse-enter occurs when the cursor enters a provincial region: a yellow glow radiates outward from the region's outline, then recedes inwards, lasting about one second. The largest size of the glow before receding inwards is roughly ten times the width of the region's outline, and is independent on the size of the region. Mouse-over changes the fill

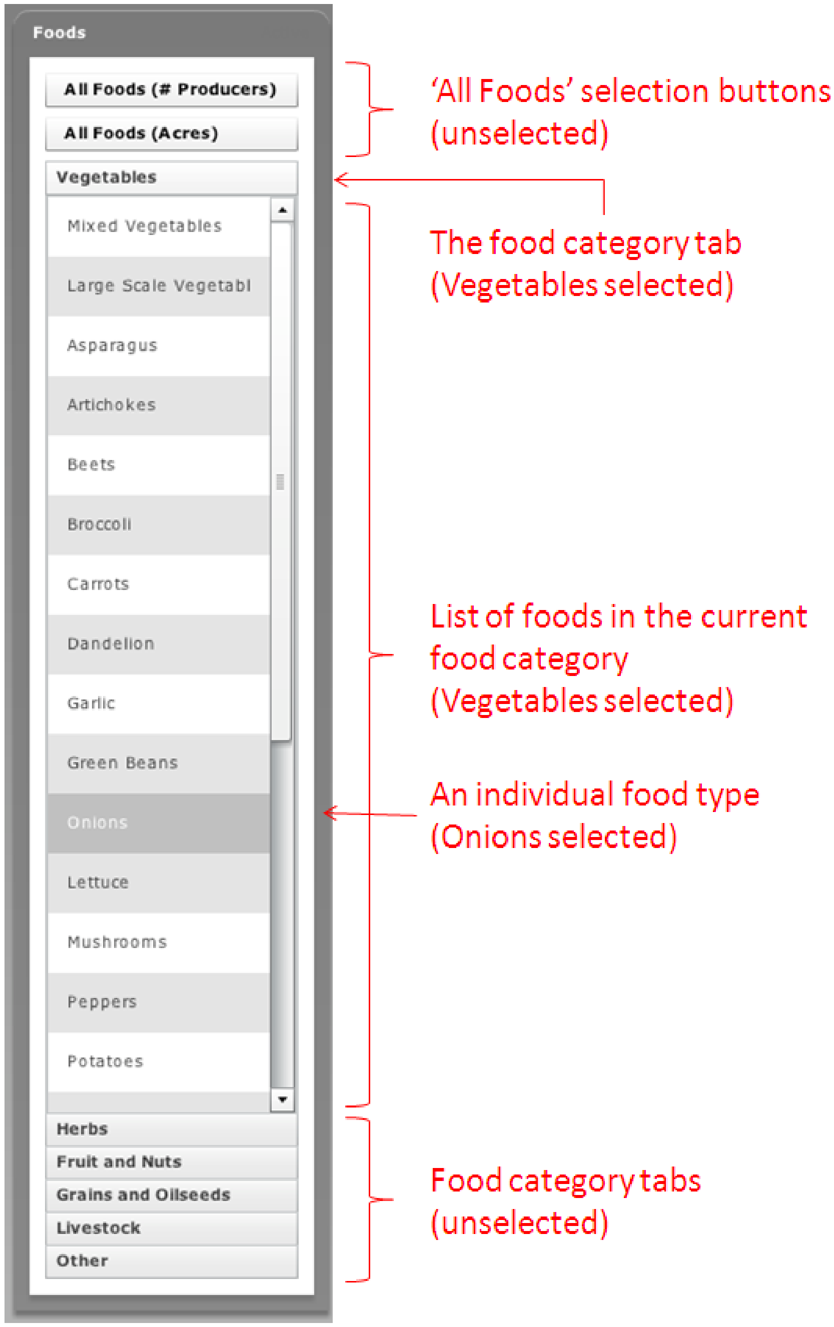

Figure 2: *Informed Omnivore*'s *Food Type* Panel.

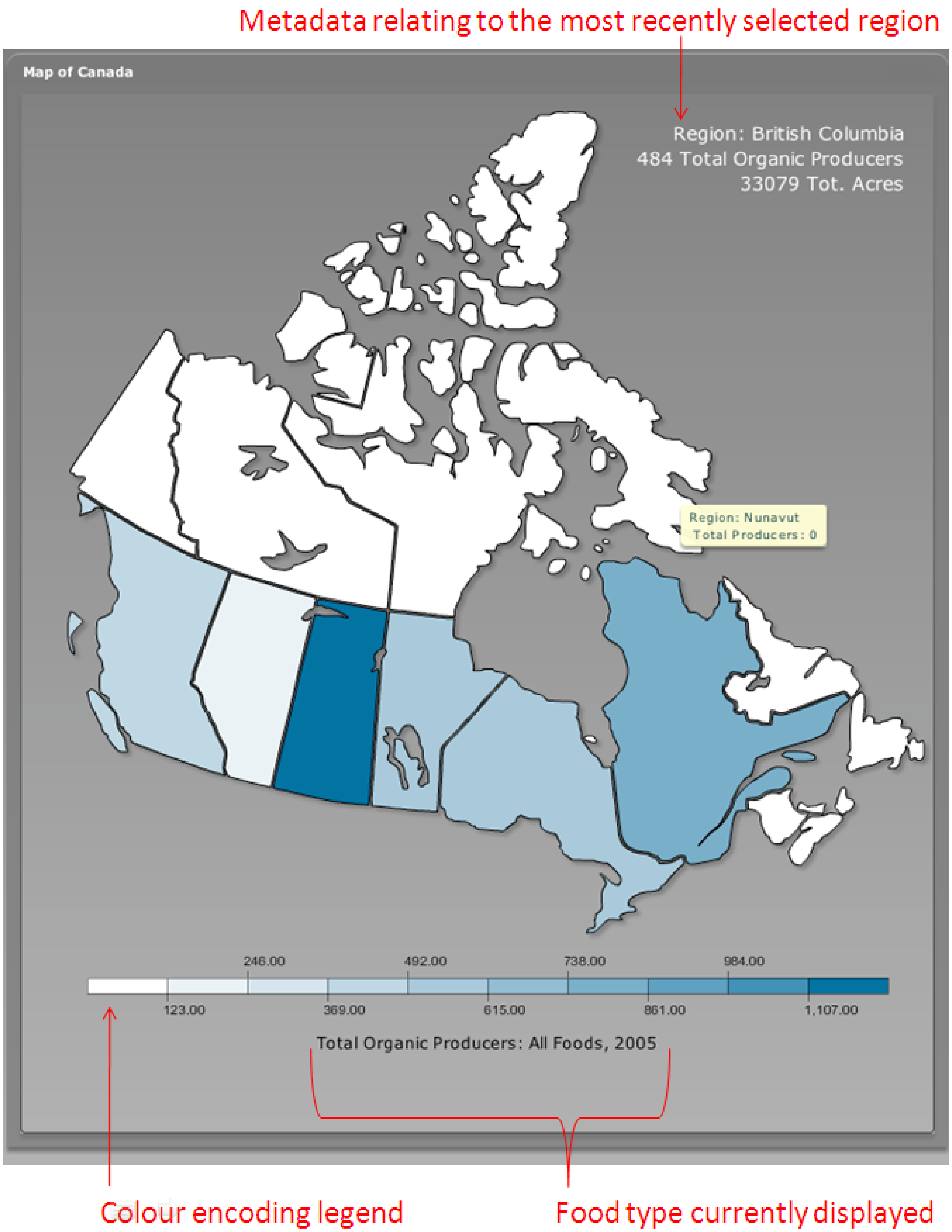

Figure 3: *Informed Omnivore*'s *Map* Panel. Hover-query text is displayed under the cursor.

colour of the region to that of a light-grey, and triggers the display of contextual text below the cursor icon (after a 2s dwell). Mouse-out is nearly identical to mouse-enter, however the colour of the glow is blue. Finally, clicking (mouse-down) is a mechanism for *selecting* a province. Once a provincial region is *selected*, several lines of white text related to the region's food production levels are shown, flush right, in the upper-right corner of this panel. The background of this panel also supports interaction. Mouse-over (hover) on the panel background adds a 1pt black outline to the interior border of the panel. Clicking on the background performs a reset operation: *de-selecting* any currently *selected* provincial region and removing the text from the upper-right corner.

The *Between Regions* Panel: (Figure 4) This panel displays interactive statistical graphs for performing food production level comparisons between regions.

Figure 4: *Informed Omnivore*'s *Between Regions* Panel. The vertical scale in the bar graphs is relative to absolute production levels for each food type. Clockwise from top left: (a) a stacked bar graph displaying the total number of organic food producers in each province, with each bar divided into top-level food categories (colours); (b) a bar graph displaying organic wheat production in each province; (c) a bar graph displaying the number of organic livestock producers in each province; (d) a donut graph displaying the same data as in c, albeit in proportional rather than absolute amounts (c). Note that the panel frame is omitted in (b,c,d).

Three types of statistical graphs are shown in this panel. When ‘All Foods (# of Producers)’ is *selected* in the *Food Type* panel, the *Between Region*’s panel displays a stacked bar graph. Each bar corresponds to a province, arranged alphabetically from left to right. The colours of the stacked bar graph correspond to the number of producers in each of the six top-level food categories. When other food types are *selected*, the user can compare absolute food production levels between regions using a bar graph, or alternatively view proportional production levels between regions using a donut graph. The user can toggle between these views using the radio buttons at the bottom of the panel. Bars and wedges in the bar and donut graphs are redundantly encoded by area size and by a colour-lightness scale[2]. Mouse-over interaction for areas in the graphs elicits a bright yellow border highlight and the appearance of hover text below the cursor after 2s dwell.

The *Within a Region* Panel: (Figure 5) This panel displays an interactive donut graph for performing food production level comparisons between food types within a region.

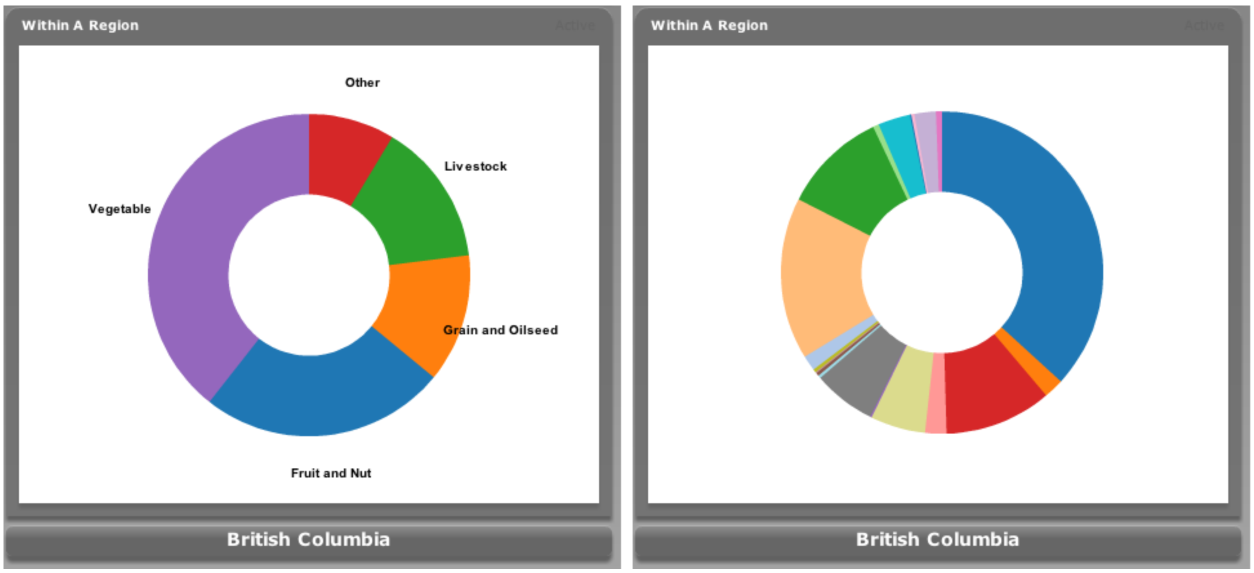

Figure 5: *Informed Omnivore*’s *Within a Region* Panel. *Left*: a donut graph displaying the proportional number of producers in each top-level food category in the currently *selected* map region (British Columbia). *Right*: a donut graph displaying the proportional number of producers for each type of livestock in the currently selected region.

When ‘All Foods (# of Producers)’ is *selected* in the *Food Type* panel and a province is *selected* in the *Map* Panel, this panel displays a donut graph corresponding to the aggregated proportional number of producers in each of the top-level food categories in the province. When no province is *selected*, the graph corresponds to national data. Adjacent to each area in the donut graph is a black text label corresponding to the top-level food category name[3].

Mouse-over interaction for areas in the donut graph elicits a bright yellow border highlight and the appearance of hover text below the cursor (name of food type and its absolute and proportional production level value).

When a sub-list food item is *selected* in the *Food Type* panel, the donut graph redraws to display the

[2]The same scale used in the *Map* panel.

[3]Only labels corresponding to top-level food categories are displayed. No labels are displayed when individual food types are selected, as in Figure 5-*right*.

proportional number of food producers within the item's top-level food category in the currently *selected* region. For instance, when Beef Cattle and Ontario are *selected*, the donut graph displays the proportional amount of each type of livestock producer in Ontario.

3 Investigation

In this section, *Informed Omnivore*'s interface is examined with regards to five perceptual mechanisms: lightness and brightness perception, colour perception, perceptual organization, visual attention, and scene perception.

The investigation follows the same format for each of these mechanisms. First, a review of academic knowledge relating to the perceptual mechanism is presented. These reviews combine psychological research with related applied research in visual display design. Then, optimally- and poorly-designed interface features are discussed with respect to the perceptual mechanism. Each section concludes with recommendations for modifications to existing interface elements as well as new interface elements.

3.1 Lightness & Brightness Perception

The human visual system can make reasonably accurate estimates of perceived surface reflectance, otherwise known as lightness, for regions in a scene. This is possible despite substantial changes in viewing conditions (i.e. different levels of atmospheric illumination) [12]. To some extent, it is thought that the visual system can re-arrange the following *atmospheric transfer function* [1] and solve for reflectance:

$$Luminance = Reflectance * Illumination \tag{1}$$

While observers can report estimates of perceived surface luminance, otherwise known as brightness, they are insensitive to absolute levels of illumination [12], however slow changes in illumination may be detectable.

The visual system's ability to estimate lightness is also apparent during the comparison of relative reflectance between adjacent regions in a scene [12]. Given an uncertain amount of illumination, the visual system makes an estimation of brightness by *anchoring* at the region of highest luminance, assuming it to be white. Other regions are compared relative to this region. In scenes where illumination varies, when shadows are cast on parts of the scene, the visual system maintains both an illumination map and a reflectance map for edges in the scene. Edges known to be caused by differences in illumination (cast shadows) can be ignored when making lightness estimations.

Local luminance ratios at edges contribute significantly to these estimates [12]. Luminance ratios at adjacent edges are multiplied successively across scene regions. As a result, the visual system is susceptible to contrast illusions, in which reflectance changes within a region go unnoticed [1, 24]. The *Craik-O'Brien Cornsweet effect*, shown in Figure 6-a, exemplifies such an illusion. In the *simultaneous contrast effect*, a region will appear lighter when surrounded by a dark background than an identical region surrounded by a lighter background, as shown in Figure 6-b. The availability of many different reflectance values in a local region can mitigate or eliminate the likelihood of these illusions. An *adaptive window* calculates a weighted distribution of lightness values in a region;

given a larger range of reflectance values in a local region, the visual system's estimate becomes more accurate [1]. The *adaptive window* can vary in shape and size, however the sampling is sparser as the window expands, resulting in less reliable estimates of lightness.

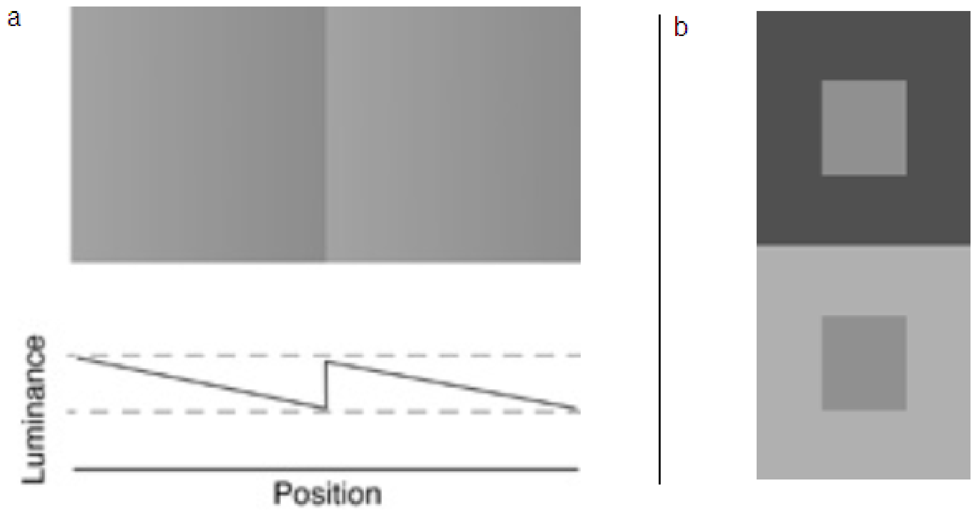

Figure 6: *a*: the *Craik-O'Brien Cornsweet effect*: luminance changes within a region, as shown in the profile at the bottom, are not perceived; the right square appears brighter due to the contrast at the edge between the squares. *b*: the simultaneous contrast effect, in which the square surrounded by a dark background (top) appears lighter than an identical square surrounded by a light dark background (bottom).

These contrast effects can be desired or undesired, dependent on the circumstance. It is often recommended to make use of contrast effects when other visual channels, such as colour or texture perception, are unavailable. When it is necessary to display fine detail, objects must stand out from their background. Enhancement of the contrast of edges, thus maximizing the luminance contrast, is advised [24].

Mid-level visual processing also contributes to lightness estimates [1]. Gestalt principles of perceptual grouping, discussed in section 3.3, are activated in response to contours and junctions in a reflectance map. These include good continuation, proximity, *prägnanz* (good form), and belongingness.

Lightness & Brightness Perception – Analysis

To maximize the readability of text, Ware recommends that the luminance contrast ratio between text and background be 3:1 [24]. In *Informed Omnivore*, text displayed in the *Food Type* panel, *Between Regions* panel, and the *Within a Region* panel satisfies this criteria; the majority of text is black on a white or light-grey background. Text contrast is poor in the *Map* panel, particularly the black text labels adjacent to the scale markers, which are difficult to read.

A common design technique for lists is to alternate the luminance of successive list items, as in the accordion sub-lists in the *Food Type* panel. The subtle difference in luminance between list items, being larger than a psychophysical *just-noticeable-difference*, helps to differentiate successive list elements. On the other hand, this contrast is not yet large enough to signify thematic group membership or interactive state (i.e. enabled, disabled, selected, etc.). If it was desirable to convey such information, increasing the luminance contrast between list items, or making use of another perceptual channel (i.e. colour, texture perception) would be advised.

There are several problems with regards to lightness perception in the *Map* panel, which are addressed below. Despite these problems, the thin black outlines and spacing between provincial regions in *Map* panel both serve to reduce contrast effects between adjacent regions. Were provincial regions displayed with no outlines or spacing, an observer would be more susceptible to simultaneous contrast effects between regions. These spaces increase contrast ratios at regional boundaries, which is where lightness values are estimated relative to neighbouring regions [12].

Simultaneous contrast effects pose the largest problem in the *Map* panel. Much of this problem can be attributed to the gradient background of the panel, from dark grey at the top to medium grey at the bottom. Therefore provincial regions at the top (Canada's territories) are above a darker background than regions near the bottom (Canada's maritime provinces). Value comparisons between any non-adjacent regions are susceptible to this contrast effect. The large size of some regions also contributes to this problem. To compare lightness values between regions, the observer's adaptive window must also be fairly large, and thus luminance samples across the panel are sparse. This results in inaccurate comparisons between non-adjacent regions [1].

Another problem regarding the gradient background is that the lightness scale under the map it is placed above an even lighter grey value than bottom of the map. Ware discusses how a lightness-scale legend with a different local background context than those of the map regions is unreliable for conveying quantitative information [24]. This is again due to simultaneous contrast effects, causing errors when an observer attempts to compare values between a scale legend and a map region. In experimental settings, Ware has documented value reading errors up to 20% in either scale direction. This problem is exacerbated when the local context of a sampling point in a map and the local context of the scale are different. Such is the case for *Informed Omnivore*, where map regions and scale are placed above a different background grey value.

Another poor design choice affecting the comparison of lightness values between map regions and the scale is the use of drop shadows; map regions cast drop shadows while the scale does not. As a result, the local background context, particularly under the scale, is of a markedly different luminance level than the local background context of map regions casting a drop shadow, producing yet another simultaneous contrast effect [24].

Lightness & Brightness Perception – Recommendations

The gradient background in the *Map* panel must be eliminated. Should a lightness scale be retained for encoding regional production levels, a solid dark background may not be the best solution. Since the current scale places low values at lighter values, large contrasts will draw attention to regions with low values, which may or may not be desired [29]. If the observer's task is to locate regions with high production values, regions with low values will be of little interest, despite being the most salient against a dark background[4]. Therefore, a white background is likely the best candidate for

[4] As a compromise, a choice of backgrounds could be provided for the user: a uniform dark background may be best for locating regions with low values, while a uniform white background may be best for locating regions with high values. A dark background also has the potential to produce illusory depth effects, in which lighter values appear closer to the viewer [2, 25]. As there is no depth information in *Informed Omnivore*'s data, such effects should be avoided.

the *Map* panel: regions with larger production levels, and thus lower lightness, will 'pop-out' due to high contrast with the background. A white background with black text labels also resolves the current text readability problem.

Shadows around regions in the *Map* panel should also be eliminated. This will reduce simultaneous contrast effects and result in matching local background contexts between map regions and the scale.

The scale should be enlarged, such that scale values are clearly read and matched with adjacent scale labels. It may also be preferable to align the scale vertically, rather than horizontally, such that high values are placed at the top of the scale[5]. Placing the vertical scale on both sides of the map is also likely to improve lightness value comparisons, as the distance between any given map region and a scale value is reduced. A smaller adaptive window would be used and lightness value sampling would be concentrated in a smaller area of the display [1].

The negative impact of simultaneous contrast effects on lightness value estimation would be reduced if the spatial resolution of regions in the map was increased, with large variation between adjacent regions. A division by counties, townships, or electoral ridings would produce a greater spatial resolution than the current provincial division. In the case of *Informed Omnivore*, variability between these smaller regions would be high due to concentration of population centres and arable land in Canada. Smaller regions and high inter-region variability would necessitate a smaller adaptive window, and thus lightness value samples would be concentrated in smaller areas, resulting in more accurate lightness estimations [1].

A final recommendation to consider involves the replacement of the colour-lightness scale with a colour-saturation scale. Using a fixed point of medium lightness, this scale would range from a medium grey (denoting low values) to a highly saturated colour (denoting high values)[6]. This scale would eliminate simultaneous contrast effects when estimating lightness values, as lightness values would no longer be estimated. Furthermore, all regions, regardless of their saturation value, would contrast with a white panel background.

3.2 Colour Perception

Colour perception involves cone receptors in the foveal region of the retina [24]. Rod vision is colour-blind; meaning that is is difficult to discriminate colours in the periphery or in low-light settings. Three types of cones correspond to different wavelengths of light: short (blue), medium (green), and long (red).

Colour perception is irrelevant to much of normal vision: determining object layout, how objects move, estimating shape and depth, and perceiving fine detail do not involve colour perception [24].

As with lightness and brightness perception, our perception of colour is vulnerable to contextual effects and illusions [20], such as edge fluting and simultaneous contrast effects, in which colours

[5]Currently, ordering of scale values proceeds from left to right. There is no culturally universal preference for ordering between right and left. Aligning the scale vertically from low values at the bottom to high values at the top is consistent with a cross-cultural bias for attributing higher with 'more' and lower with 'less' [23]

[6]This assumes a higher spatial resolution, as large regions of highly-saturated colour should be avoided, as discussed in section 3.2.

appear lighter or darker depending on their local context. These contrast effects can distort the reading of colour-coded maps [24].

It appears as though the neural basis for colour names is innate [24]. The number of distinct colour names in a language may vary, however the precedence of names for distinct colours is universal. Languages with two colour words will always correspond to black and white. Those with three will include a word corresponding to red. The fourth and fifth words correspond to either yellow or green, the sixth word corresponds to blue, followed by brown, then pink, purple, orange, and grey. The first six colours match the six colours of *opponent process theory*, composed of 3 intersecting colour axes: black-white, red-green, and blue-yellow.

Up to 1 million colours may be distinguished in paired comparison tasks [20]. Trained colour-experts may be able to discriminate and recall names for thousands of colours, however many of these names are idiosyncratic and imprecisely defined [24]. Tufte suggests that for practical purposes, a single display should contain no more than 20-30 colours [20].

While there is no agreed-upon quantitative ordering of colours between individuals or cultures, colour is often used to encode attributes of data in displays of information. For this reason, there exists a substantial body of literature relating to the design of colour encoding scales [18, 24]. Use of the six colours of opponent process theory are appropriate for categorical variables, as their is no natural ordering to them. Spectrum or rainbow encoding is a poor choice for continuous variables, for the very same reason. Instead, it is easier to extract ordering information from a lightness or saturation scale. When an equilibrium or zero-point is present in an continuous variable's range, double-ended scales place monotonically increasing lightness or saturation scales back-to-back with a shared endpoint (maximum lightness or minimum saturation), with unique hues at maximum and minimum scale values. Bivariate colour scales are appropriate for multivariate data, such that they encode one variable to one colour parameter, such as hue, and another variable to another parameter, such as saturation or lightness. Bivariate scales can also map a single variable redundantly to multiple colour parameters (hue, saturation, and lightness) for increased emphasis on distinct values and to assist observers with visual deficiencies [18].

Colour Perception – Analysis

Informed Omnivore uses colour effectively in that it uses colour minimally. It does use colour appropriately for encoding categorical values and for highlighting graph area contours in the *Between Regions* and *Within a Region* panels. The background colour of the application is a muted grey or white, and doesn't conflict with areas that make use colour [20].

When "All Foods (# of Producers)" is selected in the *Food Type* panel, the *Between Regions* panel displays a stacked bar graph containing isoluminant colours corresponding to production levels of top-level food categories in each region. These colours are also used in the *Within a Region* donut graph. Since there is no natural ordering of food types, an isoluminant colour scheme of unique hues is appropriate for encoding these categorical values [24]. While these colours do not correspond to the colour pairs in opponent process theory, they are among the 10 most common colours that most languages have names for[7] [24].

[7] White could not have been used due to it being the background colour in these panels. Yellow is used for highlighting area contours and likewise could not have been used. Brown could have been substituted for purple or orange.

The application uses bright yellow for highlighting area contours during mouse-over in the *Between Regions* and *Within a Region* panels, and for the mouse-enter glow in the *Map* panel. Pure bright yellow is undisputed between observers and is an ideal colour for directing attention [24]. It is particularly appropriate for defining edges, as it is light in value, yet intense and saturated [20].

There are several problems with *Informed Omnivore*'s use of colour. The categorical colour encoding used in the *Between Regions* and *Within a Region* panels may not correspond with cultural expectations. The Canada Food Guide[8] is pervasive in Canadian society. The guide makes use of colour in a graphical display of food groups: green is used for produce, yellow is used for grains, blue is used for dairy, and red is used for meat and protein alternatives. These colours are also among the six colours in opponent process theory. The colours used in the *Between Regions* and *Within a Region* panels do not match this convention. This Food Guide may bias observers of the display, leading to errors in understanding colour categories.

When a sublist food item is selected from the *Food Type* panel, the *Within a Region* panel displays proportional production levels of food types from the top-level food category in a donut graph. For example, the *Livestock* category contains 21 specific food types. In the corresponding *Within a Region* donut graph, 21 colours each occupy a wedge. Ware states that only 6–12 colours are likely to be seen as distinct [24]: the six colours in opponent process theory and their midpoints. As many of the wedges in any given donut chart tend to be very small, many of the colours representing specific food types are difficult to differentiate. The absence of text labels for each wedge exacerbates the issue.

The colour-lightness scale used in the map display is mapped relative to each food type, often resulting in the highest-producing region rendered as a large highly-saturated blue area. Tufte suggests avoiding pure, bright, saturated colours for large areas [20]. Ware also suggests that large regions should not be highly-saturated, however it is fine for smaller regions to be highly-saturated, facilitating foreground-background separation and target acquisition [24].

A significant proportion of the population is colour blind to some extent [24]. The most common colour vision deficiency is an inability to differentiate red from green, conditions known as protanopia or deuteranopia. This results in difficulties understanding visual displays like *Informed Omnivore*. Figure 7 illustrates how individuals with three types of colour deficiencies would view *Informed Omnivore*. These individuals would experience difficulties differentiating colours in the *Between Regions* and *Within a Region* panels.

Colour Perception – Recommendations

Where possible, colours used for categorical encoding in the *Between Regions* and *Within a Region* panels should match or approximate cultural conventions, while maintaining hue separability. Using the colour scheme from the Canada Food Guide is a logical choice, given its likelihood that it factors into top-down perceptual processing of colour in an display involving food groups.

When more than a dozen food types are to be represented, colour is no longer a viable categorical encoding dimension [24]. It may be necessary to dispose of the donut graph denoting proportional

[8] Health Canada's Food Guide is available at `http://www.hc-sc.gc.ca/fn-an/food-guide-aliment/index-eng.php`

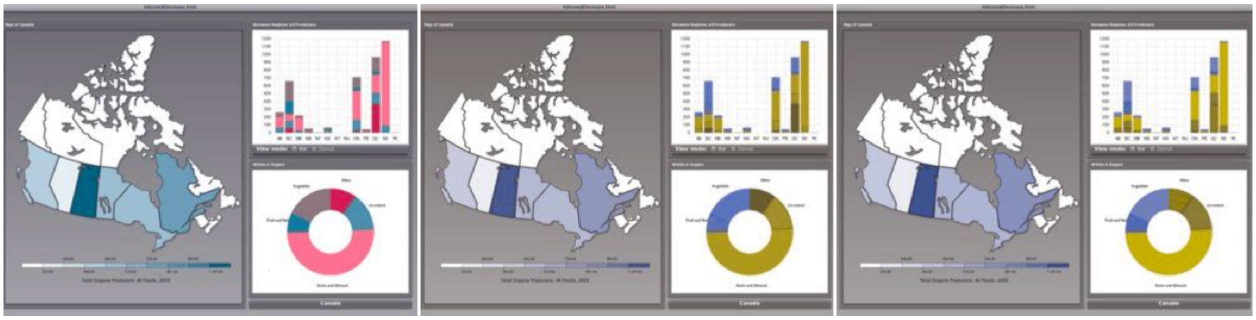

Figure 7: Colour blindness, particularly a red-green deficiency, affects how visual displays are perceived; *From left to right*: *Informed Omnivore* as seen by a tritanope, protanope, and deuteranope. Images generated at http://vischeck.com.

production levels in the *Within a Region* panel and replace it with a bar graph denoting absolute production levels, with food type labels along the x-axis[9].

If proportional production levels are still of interest, the donut graph could be retained if small wedges are collapsed into a single wedge denoting 'other' food types within the category, thus eliminating the necessity for additional colours. If one of collapsed food categories is of interest to the observer, the application should provide *details-on-demand* functionality, allowing the observer to expand a collapsed category [9]: a secondary pop-up display containing the collapsed data could be shown when requested.

The colour-lightness scale in the *Map* panel would be more appropriate for a map with higher spatial resolution. In Canada, this could correspond to counties, townships, or electoral ridings, rather than low-resolution provincial divisions[10]. Smaller regions, when observed at a national scale, may be small enough such that high-producing regions 'pop-out' [20]. Furthermore, the size and shape of small regions would not be distorted by large regions of saturated colour, as compared to large regions [18]. If the current spatial resolution is unavoidable due to the limited availability of data from contained regions, the colour encoding scheme should not permit highly-saturated regions, such that it ranges from white to a medium saturation level [20].

3.3 Perceptual Organization

Visual organization of a scene cannot be accomplished solely on changes in reflectance or luminance [13]. Instead, The human visual system uses a combination of innate perceptual mechanisms and contextual knowledge. The former can be described as perceptual grouping, the concatenation of low-level features into patterns, occurring before object recognition [26]. The latter involves long-term priming; observers are more likely to recognize patterns on subsequent appearances.

Perceptual grouping processes are described by Gestalt laws[11]. Given a reflectance map of edges

[9] According to Cleveland & McGill, observers make poor judgments of angle in comparison to judgments of length and position [4]. As a result, a donut graph is a poor choice for representing this data, especially given the potential for many food types to be represented in a single graph.

[10] Given the current encoding and spatial resolution, the observer is also susceptible to the perceptual bias known as the *modifiable aerial unit problem* [11], in which local detail in a geospatial display is lost in the encoding of a containing region's aggregated value. As a result, local trends and small areas of interest are not easily detected.

[11] Gestalt means 'pattern' in German. In practice, these are not truly laws, but rather principles or factors [13].

in a scene, these perceptual grouping principles contribute to the segmentation of regions, parsing and grouping them into figure and ground, into superordinate and subordinate units [13]. There are conceivably hundreds of such laws, however only a small subset refers to visual processing [3, 6, 13, 26]. The following list of Gestalt laws describes how low-level visual features are grouped:

proximity – items close to one another will be grouped together.

similarity – similar items (of colour, size, orientation) will be grouped together; there typically exits a trade-off point between proximity and similarity (i.e. items with small colour differences are more easily grouped by proximity than items with large colour differences, which are grouped by similarity [13]).

connectedness – connected items (i.e. by adjoining lines) are grouped together, overriding the prior two laws and many of the subsequent laws; smooth continuous adjoining lines are most effective [26].

symmetry – symmetrical structures are grouped together while asymmetrical patterns are not.

relative size, figure & ground – smaller components of a pattern are perceived as objects or figures, while the remainder is seen as ground; symmetry, convexity, parallelism, surroundedness, and closed contour all contribute to the separation of figure and ground. Items defined by a contour that appear 'thing-like' tend to be seen as a figure. In the case of holes, in which a surrounding region is seen as figural, there must be good evidence of a non-accidental continuity between the hole and the background around the figure; a hole with contours parallel to the figure's external contours are most effective, as non-parallel inner contours can result in the hole being seen as a layer above the figure [13].

good form – also known as *prägnanz*, and related to the simplicity and symmetry of a pattern; when everything else is equal, it is predicted that items will be grouped into the simplest forms.

continuity – lines are seen as continuous despite discontinuities; continuities tend to be simpler rather than complex.

closure – an extension of continuity, also known as *visual interpolation*, in which occluded items are filled in; i.e a circle partially occluded by a square is not perceived as a circle with a missing wedge beside a square, but rather as a circle behind a square. Familiarity, context, and *prägnanz* each contribute to visual interpolation. Both closure and continuity involve the matching of relatable edges at discontinuities. This law is responsible for the perception of illusory contours, the perception of illusory objects inferred by discontinuities in other objects. Tufte classifies this phenomenon as the *1 + 1 = 3* effect, which can either be desired or problematic for design [21]. The salience of the effect is typically proportional to the contrast in value between figure and ground objects.

isomorphic correspondence – based on learned experience, we are likely to recognize patterns once we have previously been exposed to them.

transparency – patterns are grouped into transparent layers if good continuity is retained between regions, and if the correct relationship of colour and luminance is present: the luminance of regions of overlap must be intermediate between those of overlapped regions. The superposition of textures, colours, and luminance values can effectively produce the effect of transparent layers. When designed well, a separable composite texture can signify overlapping regions. Otherwise, it is possible to produce a bistable texture, the perceptual interference of transparent layers [26].

common fate – also known as *synchrony*, in which items are grouped together if they change together, or if change onsets or offsets occur together. This dynamic law can be triggered by translocation (movement), changes in transparency, and changes in item orientation, size, or colour.

It is possible for some of the grouping principles to be at odds with one another, resulting in the problem of *multistability*, in which alternative perceptual groupings of a scene mutually inhibit one another, spontaneously alternating between each other [13].

Tufte has provided insight with regards to the layering and separation of elements in information graphics, much of which is grounded in perceptual grouping principles [21]. In the design of visual displays, layering helps with differentiating annotations from the annotated, one channel of information from another, or scale elements from physical elements. This enhances data dimensionality and density through the reduction of noise, thus improving the accuracy of reading data and reducing observer fatigue.

Perceptual Organization – Analysis

An observer can easily differentiate between figure and ground in the *Map* panel. Surroundedness and closed contour both contribute to this distinction [13, 26]. In addition, context and previous experience, especially for those familiar with Canada's geography, will recognize the geospatial outline of Canada's provinces as foreground objects. Holes in the figures, namely those contained in the outlines of prairie provinces, representing lakes, do not pose a problem for figure-ground segmentation, as the holes do not appear as new layers. While the holes (lakes) do not have contours parallel to those of provincial borders, there is a non-accidental continuation of background from outside the provincial outline to the lakes, reinforcing contextual information, resulting in the perception of holes [13].

The *Between Regions* panel's bar graph is an example of successful layering, an instance in which it is easy to discern between the physical data and the scale structure of the graph [21]. A muted grid is perceived as being behind the saturated colours, which represent data points.

Mouse-enter actions for provincial regions in the *Map* panel elicit a momentary glow around the provincial outline. This is particularly useful for regions with separated land masses, such as Canada's territories or Newfoundland & Labrador. For observers unfamiliar with Canada's geography, this animated glow allows them to perceptually group geographically segmented regions through the Gestalt principle of synchrony [13, 26].

An obvious problem with regards to perceptual organization in *Informed Omnivore* is the distance between related information. In other words, related information is not perceptually grouped by proximity. Examples of this occur both within and between panels: (1) In the *Map* panel, metadata relating to the currently *selected* region appears in the top right, regardless of which province is selected. (2) The contents of the *Within a Region* panel, a donut graph, also relate to the currently *selected* region in the *Map* panel; the distance from the donut graph to the currently *selected* region varies considerably[12]. (3) Similarly, information displayed in the *Between Regions* panel is

[12] The darkened boundaries and closed contours of each panel are in themselves a perceptual grouping cue, keeping information captive within a panel [21]. As a result, related information is not only separated by distance, but also

also separated from related information in the other panels.

Stacked bar charts, such as those in the *Between Regions* panel, can be perceptually grouped in several ways, resulting in possible *multistable* representations [13]. The bars could be grouped by proximity: the stacked components in each bar are vertically adjacent and parallel to one another and to the region label on the x-axis. It could be argued that perceptual grouping by proximity also occurs horizontally, in which adjacent columns and their components are grouped together[13]. While the columns do not share vertical edges, this grouping is likely weaker than the previously stated vertical grouping, as stacked components in each bar share horizontal edges. Multiple colours further complicate this problem, as areas may be grouped via the principle of similarity. Conceivably, the stacked components could also be grouped by similarity of size[14]. In summary, there are 4 possible groupings in this stacked bar chart, which runs the risk of overloading observer pattern processing.

Currently, there is no way to superimpose more than one food type onto regions in the *Map* panel. This functionality would allow for comparisons to be made between simultaneous food types, and would provide answers to questions regarding positive or negative correlation, such as "*which provinces produce large amounts of both wheat and corn?*". A possible technique for displaying overlap is via the use of transparent layers, as discussed above [26]. Unfortunately, transparent layers varying in luminance could not be applied to the existing *Map* panel display as the colour-lightness scale already makes use of the luminance channel.

Perceptual Organization – Recommendations

Graphical boundaries between panels should be muted or removed; currently, these salient borders impose upon the flow of related information between panels [21].

Related information should be proximal. For this reason, the *Within a Region* donut graph could be reduced in size to that of an icon or glyph and placed within each provincial outline in the *Map* panel. For smaller regions (i.e. Canada's maritime provinces), the donut glyph could be placed in the adjacent space next to the province, connected by a line, relying on the grouping principles of proximity and connectedness[15]. Similarly, region names or abbreviations should appear on the map adjacent to the glyphs. Thus, a redesigned provincial region will convey more related information: each will contain a *Within a Region* glyph, its name or abbreviation, and will be filled with a value corresponding to the colour encoding scale.

Moving the *Within a Region* donut graph into the *Map* panel as a glyph for each region frees a large amount of screen real estate: the *Between Regions* panel could conceivably be twice as large. This space could be used to address problems pertaining to the stacked bar chart. A possible solution

by graphically-imposed panel boundaries.

[13]This grouping is of little value, as the regions in this panel are arranged alphabetically, and not in their verisimilar arrangement from west to east; in other words, there is no isomorphic correspondence with the *Map* panel. A horizontal cognitive map of regions is possible for the provinces of Canada, being topologically arranged from west to east [5]. A verisimilar 1-D arrangement could not be achieved for many other countries, such as the United States, in which there is no such possible arrangement.

[14]Another grouping of little informational value; Cleveland & McGill have remarked how accurate comparisons of size require a shared baseline, which elements do not have in stacked bar charts [4].

[15]This arrangement would also permit a high-level overview and simultaneous comparison of *Within a Region* data between regions, which is not permitted in the current interface. The glyphs could additionally support *details-on-demand*, a enlarged annotated version of a glyph could appear when clicked, supported by regional information that currently appears at the top right of the *Map* panel.

is the use of small multiple displays. Small multiples, as defined by Tufte, are ordered slices of information, affording comparisons at a glance, wherein constancy of design places emphasis on differences in the data, rather than differences in presentation or scale information [22]. A range of options present themselves for *Informed Omnivore*'s *Between Regions* panel. Small multiple bar graphs could be indexed by top-level food type: a single graph for each of vegetables, fruits and nuts, grains and oilseeds, livestock, and other. As the user drills down into the *Food Type* menu, the user could select multiple individual food types to populate the small multiple graphs in the Between Regions panel. Each graph would contain data for each province, consistently labeled and arranged. Alternatively, the small multiple displays could be indexed by province; each display would contain data for each food type (either top-level food categories or user-selected food types), consistently labeled and arranged. An effective compromise could be to offer functionality for toggling between graphs indexed by region and graphs indexed by food type. This would permit grouping by proximity and comparison of related information to best suit the task at hand[16].

Recommendations for addressing the colour-lightness encoding in the *Map* panel have been discussed previously in sections 3.1 and 3.2. For multivariate data, bivariate colour scales encode one variable of data to one colour parameter, such as hue, and another variable to another parameter, such as saturation or lightness [18]. A justification for using a bivariate scale is that it could support perceptually separable layering: the grouping of areas by similarity (of hue and lightness or saturation), denoting positive or negative correlation between two food types. An example of a bivariate scale used to group regions of correlation by similarity is seen in Figure 8 [8]. The simultaneous comparison of multiple food type production levels is lacking from *Informed Omnivore*; currently, comparisons can only be conducted in a sequential fashion, a problem examined in section 3.5. A bivariate colour scale would support this functionality while adhering to principles of perceptual grouping.

3.4 Visual Attention

Where an observer directs attention in a scene is dependent on both top-down and bottom-up visual processes [28, 17]. The interaction of these processes is particularly relevant for visual search tasks. It is also worth noting how different tasks or modes of execution interact with these processes: a user performing a vigilance task will attend to a display differently than a user performing a diagnosis task [30].

Ware discusses the notion of a *useful field of view*, likening visual attention to an information-gathering searchlight [28]. The size of this spotlight may be 1-4 degrees of the viewer's field of view, however it may be larger if visual targets are in motion. Visual attention is constantly shifting, and little information is retained in iconic memory as the spotlight shifts between locations and objects in a scene.

Low-level and high-level top-down features of objects in a scene can be manipulated to direct the attention of an observer. The intent may be to facilitate search, or to coercively direct attention to or from a location in a scene [17]. In terms of search, visually pre-attentive features of objects

[16] While not currently represented in *Informed Omnivore*, temporal information, or food production levels over time, could also be well-suited for small multiple graphs [22]. An observer could compare food production levels between provinces and food types over time. This could be implemented as a 2D matrix of small multiple displays, wherein the vertical dimension is indexed either by region or food type, while the horizontal dimension is indexed by time (i.e. preceding agricultural census years); each graph would display food production levels (either by region or by food type, dependent on which indexes the horizontal dimension).

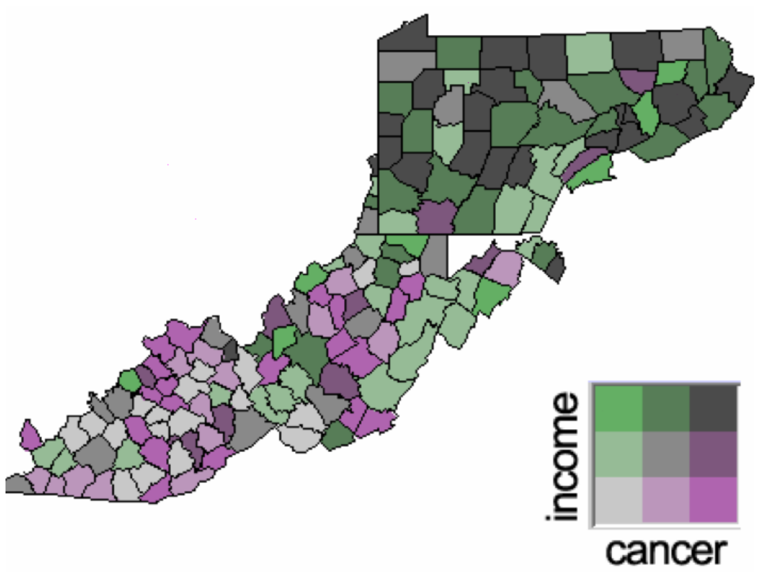

Figure 8: Bivariate colour maps support perceptual grouping along two dimensions of similarity (in this case, hue and lightness). Here, areas of high and low correlation between two variables (income and cancer incidence) are grouped together [8].

can cause them to 'pop out' from surrounding objects, allowing the observer to find or group them quickly [28]. However, many interactions between pre-attentive feature dimensions are possible; some feature dimensions are processed automatically, even if the observer is trying to ignore them [14]. Furthermore, some pairs of feature dimensions are more *integral* while others are more *separable*. Objects with an integral pairing of feature dimensions may be interpreted more holistically (e.g. objects that vary by hue and lightness) while a separable pairing may be interpreted more analytically (e.g. objects that vary by hue and shape). The latter allows the observer to selectively attend to a single feature dimension while ignoring the other dimension [28, 7, 14]. When pairs of integral features vary in a correlated fashion, (in other words, when a single variable is encoded by two feature dimensions), a *redundancy gain* is possible, in which the use of multiple feature dimensions improves classification time, when compared to elements encoded using a single feature dimension [14]. Conversely, when one integral feature dimension varies independently of the feature dimension used for classification and cannot be ignored, this inhibits classification, and is known as an *interference loss*. Magnitudes of interference losses and redundancy gains are not always symmetrical between pairs of integral feature dimensions [14]. As a result, it is important to select feature dimensions for encoding data that best suit the observer's tasks.

The separation of low-level features and top-down high-level visual properties of objects in a scene allows us to distinguish what constitutes as visual clutter, a barrier to dedicated attention and effective visual search [19]. Given top-down high-level knowledge about objects in a scene, the amount of clutter in a display depends on the nature of the task and the expertise of the observer. On the other hand, low-level visual properties, those affecting the visual saliency of individual objects in the scene, such as colour and luminance, can be easily measured. As such, a display can be described as sparse or cluttered with some certainty based on low-level features. The amount of clutter will undoubtedly affect the efficiency of visual search and the degree to which pre-attentive properties of objects 'pop-out' at the observer.

Visual Attention – Analysis

Several aspects of *Informed Omnivore*'s design are conducive to visual search. First, data points in the *Between Regions* bar and donut graphs are redundantly coded by size and luminance. These are separable dimensions, so the areas can be examined analytically. Analysis on either dimension will result in the same conclusion [28, 14].

The colour-lightness scale in the *Map* panel is scaled linearly. Often a single region produces the majority of a particular food type in the country (e.g. the majority of maple syrup is produced in Quebec). The region's fill value often has a 'pop-out' effect, since the lightness value is significantly different from that of adjacent regions [28]. Similarly, the hue is significantly different from the background colour of the panel itself. As a result, visual search for the largest producer of particular food type is usually very efficient.

Areas in the *Map*, *Between Regions*, and *Within a Region* panels are highlighted in the mouse-over state. This highly-salient highlight involves colouring the the region outline with a saturated yellow and increasing in the size of the outline. In the *Map* panel's mouse-enter state, this is further accentuated by an animated glow. This small change in area and outline size results in the perception of motion, which is easily attended to, even if occurring in the periphery [28][17].

There are several design features that present problems for visual attention. The *Food Type* panel and items in food sublists maintain a low salience throughout the use of application; as such, it is difficult to locate the currently *selected* list item and differentiate it from other list items. Furthermore, categorically different items do not differ from other categorical items on any low-level feature dimension; it is difficult to search the list or group the items pre-attentively in any way [28].

In addition to facilitating search and grouping, pre-attentive features of objects may also interact with how we perform rapid area judgments [28]. This could be be problematic for geospatial representations of data, such as the *Map* panel. An area that 'pops out' pre-attentively based on a significant lightness difference may lead the observer to perceive the region as being larger than it truly is.

Informed Omnivore could be considered to be a sparse display, according to Rosenholtz's feature-level definition of clutter [19]. The application makes use of at most three feature dimensions (hue, lightness, and area or x-y position). The *Within a Region* panel's donut graph uses colour as a categorical dimension and area to signify the amount of producers within a food category. The *Between Regions* panel's bar graph is similar, however area and lightness are redundantly coded. As a result, the observer is obliged make unreliable data comparisons in a sequential fashion.

Visual Attention – Recommendations

Previous recommendations have suggested an increase in both data dimensionality and granularity: increasing the spatial resolution and using a bivariate colour scale in the *Map* panel, placing *Within a Region* glyphs for each provincial region in the *Map* display, and using small multiple displays in the *Between Regions* panel. In other words, given the current sparsity of the application, more clutter could be afforded, according to Rosenholtz's feature-level definition of the term [19]. Increasing

[17] This is especially useful for passive observers of the display (those not holding the mouse), who do not have additional visuomotor cues given by moving the cursor from region to region.

data dimensionality and spatial resolution will allow for better comparisons between food types and provinces, and accommodate visual search through the use of separable feature dimensions.

If an increased spatial resolution in the *Map* panel is unfeasible, filling a region in the *Map* panel with a colour-lightness value may be unnecessary altogether. Currently, the *Map* panel is largely uninformative due to its low spatial resolution; furthermore, the current colour-lightness encoding scale could lead to poor area judgments, as discussed above [28]. Alternatively, food types could be displayed in the *Map* panel using glyphs or textures, allowing for superposed texture layers of multiple food types.

Visual search in the *Food Type* panel could be improved by displaying categorically distinct items using different pre-attentive feature values. One approach would be to colour-code the top-level food category accordion tab and background of each sublist[18]. Similarly, any currently *selected* food types in this panel should 'pop-out' pre-attentively. Use of a heavier font weight, a saturated colour background, an indentation, or a combination of these cues could facilitate rapid search to this item [28].

The currently *selected* region in the *Map* panel should also 'pop-out' pre-attentively. This could be done via a persistent glow around or inside the region outline, a thicker or brighter outline, or by adjusting depth of focus, such that currently *selected* regions remain in focus while other regions are blurred; alternatively, *unselected* regions could display data at a low spatial resolution, while *selected* regions could display data at a higher spatial resolution. This latter suggestion may not facilitate detailed comparisons between *selected* and *unselected* regions. Therefore, a user should be permitted to select multiple regions simultaneously.

3.5 Scene Perception

Scene perception is an observer's ongoing visual perception of an environment. The environment acts as external visual memory, wherein visual elements in the scene are queried when needed by the observer. This concept opposes the popular notion of a *visual buffer* in working memory, which suggests that entire scenes could be retained and compared when needed. Phenomena such as *inattentional blindness* and *change blindness* illustrate the absence of a visual buffer, in that observers fail to notice salient unattended stimuli or significant changes in a scene, even when changes are large and anticipated [15].

Rensink's *coherence theory* model explains how scenes are perceived via an interaction between a *triadic architecture* of visual systems: a *low-level vision system*, a *setting system*, and an *object system* [16, 15]. The latter is an attentional selection system which instantiates mid-level proto-objects from the low-level vision system. Both of these systems feed into and back from the setting system, which contains gist, layout, and schema information for a scene. Gist is a spatial representation that activates the meaning of the scene and facilitates attention to salient proto-objects in the low-level visual system [10].

The coherence theory model can account for how visual queries are executed in a scene. A scene is an external memory where proto-objects are accessed via selected attention when needed by the observer. This agrees with the observation that for most tasks, only one coherent object in a scene is attended to at any given time; saccades (eye movements) and attentional shifts are made between objects as needed.

[18] Using colours consistent with other panels, and/or according to convention, would be advised.

Saccades are rapid eye movements, lasting between 20ms and 100ms. During this time, an observer is less sensitive to visual input [27]. As a result, observers may be unaware of brief changes occurring in a scene during eye movement.

While visual working memory doesn't contain snapshots of scenes, it is thought that working memory maintains 'object files' of recently attended objects or patterns in a cognitive map, as well as a visual query pattern used for directing attention in a particular type of scene [27]. These object files are linked to high-level goals and strategies for interacting with an environment. These goals or strategies specify a need for visually-aided problem solving. Visually-aided problem solving can be broken down into several stages: (1) visual query construction, in which initial scene parameters (layout, gist, and verbal-propositional information) are primed for later use; (2) the pattern-finding loop, in which alternative proto-objects and patterns in a scene are evaluated[19]; (3) the eye movement control loop, in which low-level visual elements are constructed into coherent objects and patterns; and (4) the intra-saccadic scanning loop, constrained to single fixations and the limits of perceptual chunking in working memory (3-4 items at a time). The eye movement control loop can be substituted with interactive techniques in visual displays, which include brushing, zooming, and dynamic queries. However, these techniques each incur time and navigation costs, as compared to saccadic queries.

Scene Perception – Analysis

At a first glance, the gist and layout of *Informed Omnivore* coalesces with the arrangement of major components in the application: four panels, separated by dark backgrounds, containing bright interior regions. An advantage of large geospatial regions in the *Map* panel is that regions with extreme high and low values are spotted quickly as large feature-level proto-objects, 'blobs' of saturated blue and white. Subsequent visual queries can be directed towards the blue or white blobs. Once it is determined that the blobs represent regions in a map, this top-down conceptual information feeds back into the gist and layout of the scene, directing future visual queries based on prior experience with maps.

Informed Omnivore makes use of mouse-over hover queries for the display of contextual information about an area below the cursor. This interactive technique minimizes the distance of a saccade from the previous point of fixation (presumably at or near the cursor) to relevant information about the area being queried. As a result, visual query time is reduced.

There are several problems with regards to scene perception in the application. First, to compare production levels of different food types in the *Map* or *Between Regions* panels, all comparisons are performed sequentially. Upon making a selection in the *Food Type* panel, the other three panels reload with data pertaining to the newly-selected food type. The observer must attempt to maintain the previously selected food type's graphical representations in visual working memory. As mentioned in the above review, the notion of a visual buffer has been refuted [15]. This implies that valid comparisons between scenes (reloaded panels) in *Informed Omnivore* cannot be accomplished with any certainty of accuracy.

Another problem relating to sequential comparisons between food types are the subtle changes in scale between food types. It is not obvious to the observer that the colour-lightness scale in the *Map* panel is scaled relative to the maximum absolute production level of the *currently selected*

[19] The patterns involved in a visual query must be constrained such that the contents of several simple queries or a single complex query fit into the limits of visual working memory.

food type, not according to a global scale, to which the observer may assume is being used[20]. Therefore, current comparisons also involve a scale mapping. The scale labels change as the *Map* panel reloads, but it is likely that the change goes unnoticed: the colour-lightness gradient in the scale legend remains the same between reloads. Unless instructed that the scale varies relative to each food type, it is likely that an observer will be unaware of the change, which is an instance of inattentional blindness [15]. This problem is not limited to *Map* panel: the production level scale along the y-axis of bar and stacked bar graphs in the *Between Regions* panel is also relative to each food type. In summary, any comparisons made between food types in the application are unreliable due to visual queries interrupted by sequential interaction and non-obvious adjustments of scale information.

Clicking on the background of the *Map* panel de-selects the currently selected region. *De-selecting* a region involves several simultaneous changes occurring across two panels. In the *Map* panel, the luminance of the background is increased while the mouse button is down, and regional text information is instantaneously removed from the top right corner of this panel. Meanwhile, the contents of the *Within a Region* panel are instantaneously updated to display national information. Under this panel, the name of the currently selected region is also instantaneously updated. There are 4 simultaneous and instantaneous changes occurring during as a result of *de-selecting* a region. As an observer may be attending to one of these areas, they may be aware of a change occurring there. Given the brevity and low salience of these simultaneous changes, the limitations of peripheral vision, and the above-mentioned problem of change blindness [15], it is unlikely than an observer will notice all of these changes.

Finally, the accordion list of the *Food Type* panel does not provide any indication of the size of the sublist in any *non-selected* food category. An estimation of the size of the currently selected category sublist can only be made based on the vertical distance to the bottom of the list (for short sublists) or based on the size of the scroll bar widget (for long sublists). For a *non-selected* food category, an interaction (clicking on the category heading) followed by a visual query to the bottom of the list or to the scroll bar widget is the only way to determine the size of a sublist. To compare the size of sublists, non-saccadic sequential comparison queries must be performed, leading to the same problem as discussed above with regards to sequential comparisons in the *Map* and *Between Regions* panels. Therefore, these query tasks incur a high navigation cost and cannot be performed accurately due to their sequential nature [27].

Scene Perception – Recommendations

The problem of non-saccadic sequential comparisons in the *Map* and *Between Regions* panels may be resolved by the implementation of earlier recommendations: the use of small multiple displays in the *Between Regions* panel, and either the use of a bivariate colour scale, texture patterns, and/or glyphs in the *Map* panel. In both cases, a saccadic comparisons of production values could be made between food types mapped to a common scale. If relative food production levels are to be compared, these inequalities of scale will need to be made obvious to the observer. Alternatively, all food production levels could be discretized into several ordinal levels relative to each food type. In summary, these changes will facilitate saccadic visual queries; the observer will no longer rely on a ‘visual buffer’ for performing comparisons across scene changes [27, 15].

[20] In other words, physical and scale values are disconnected between sequential food type queries [4]: the range of possible physical values remains the same (white to blue), but the range of possible scale values change.

An alternative to the *Food Type* panel's accordion menu is a fish-eye menu, in which all menu elements are visible at all times, albeit subject to fish-eye distortion (individual list items could be reduced in size or aggregated to categorically-encoded icons or glyphs). Such a menu would facilitate saccadic visual queries, contribute to an perception of overall list size, and provide rough layout information, including hierarchical list structure and the relative size of sublists.

Placing *Within a Region* donut glyphs into each region in the *Map* panel will alleviate the above-mentioned concern relating to multiple simultaneous changes occurring between panels. Changes upon food type selection could be emphasized to a further extent by using coordinated animation, relying on the Gestalt grouping principle of synchrony. This includes animated changes in saturation, lightness, and hue among the map regions and changes in area size, hue, and orientation among the donut glyphs. When the display is refreshed, changes will be localized to regions in the *Map* panel, matching observer expectations and reducing the likelihood of change blindness [15].

4 General Conclusions

In the preceding sections, the visual design of *Informed Omnivore*, an interface for visualizing food production levels, was examined with respect to five perceptual mechanisms. This examination was grounded in psychological and applied research findings. Both positive and negative aspects of the interface's design were identified. For each perceptual mechanism, justified recommendations for redesigned or new interface elements were offered. The following list summarizes the major recommendations:

- Suppress simultaneous contrast effects by replacing the grey gradient background in the *Map* panel with a solid dark or white background; eliminate drop shadows in the *Map* panel.
- Reduce the size of the *adaptive window* for lightness value estimation by increasing the size & changing the orientation of the scale legend in the *Map* panel; increase the spatial resolution of regions in the *Map* panel.
- Use a bivariate colour scale to support simultaneous comparison between 2 food types.
- Avoid over-saturated colours in large regions by lowering the saturation level of the colour-lightness scale in the *Map* panel. Should a higher spatial resolution of regions be available, replace the lightness scale in the *Map* panel with a saturation scale such that regions with extreme values 'pop-out' pre-attentively.
- Ensure that colours used for the categorical encoding of top-level food types correspond with cultural conventions whenever possible (i.e. the Canada Food Guide).
- Replace categorically colour-coded donut graphs with bar graphs when more than 12 food types are present.
- Place donut graph glyphs within/adjacent to each province in the *Map* panel. This would eliminate the need for the *Within a Region* panel. Support details-on-demand by expanding these glyphs when clicked, augmenting the enlarged version with related information about the region. Synchronously animate changes in each region of the *Map* panel when a new food type is selected.

- Support saccadic comparison by replacing the contents of the *Between Regions* panel with small multiple displays bearing a common scale and indexed by region, food type, and/or agricultural census year.
- Support visual search for currently selected food types in the *Food Type* panel using pre-attentive features. Support visual search for the currently selected region in the *Map* panel in the same fashion. Replace the accordion menu in the *Food Type* panel with a menu that makes use of fish-eye distortion.

The implementation of some or many of these recommendations will increase the information bandwidth of the interface, facilitate visual queries, and minimize interaction costs, resulting in an interface that supports a wider range of tasks, thus answering a wider range of questions[21]. In summary, a perceptually-guided redesign of *Informed Omnivore* will result in dramatic improvements in user satisfaction and a greater understanding of food production in Canada.

[21] There are likely some unpredicted negative interactions of some of these recommendations. Furthermore, the feasibility of some of these recommendations is subject to the availability of data (i.e. at different temporal and spatial scales).

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