LIVE FIGURES: INTERACTIVE DIAGRAMS FOR STATISTICAL UNDERSTANDING ®

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Line diagrams may assist statistical understanding, but a colourful animated interactive version may be even better. Modern software, in particular Microsoft Excel, now makes it easy to build such live figures*. The author describes live figures and presents examples in the context of promoting understanding and use of confidence intervals. Interface design principles and expertise in statistical education should be combined to develop effective live figures. Animation, multiple representations, engagement through interactivity, and vivid 'take-home' images can all be valuable. Investigation of how best to design live figures and use them with journal papers and books should prove educationally valuable.*

FROM DEAD DIAGRAMS TO LIVE FIGURES

A simple black-on-white line diagram may assist statistical understanding, but a colourful animated interactive version may be even more valuable. Modern software, in particular the ubiquitous Microsoft Excel, now makes it easy to build such *live figures*. In the interests of improved statistical education and communication it is worth investigating practical ways that printed figures in journals and textbooks can be accompanied, or replaced, by live figures.

Numerous writers have presented strong advocacy for graphical representations for statistical communication, including notably Cleveland (1994) and Tufte (1983). There has, however, been discouragement of figures in journals and books on the grounds of space and expense. Also, in medical journals confidence intervals (CIs)—which are a focus of this paper—are routinely reported, but usually as values in tables rather than as error bars in figures. Altman, Machin, Bryant, and Gardner (2000), a major source of advice on CI use by medical researchers, mentioned figures only briefly and cautioned that they can be an inefficient use of space. Overall there is some equivocation about extensive use of figures, despite their strengths. However, the prospects may now be brighter: In psychology the new edition of the American Psychological Association (APA) *Publication Manual* (APA, 2001) has recognised technological advances and dropped any reference to production costs of figures. I hope the use of figures will increase, and wish to discuss the next step, the use of live figures, and will do this in the context of CIs.

UNDERSTANDING CONFIDENCE INTERVALS

There are three reasons to focus on CIs. First, the statistical practices of psychologists are in urgent need of reform (Cumming, Fidler, & Thomason, 2001; Thompson, 2001), especially to overcome the dominance of null hypothesis significance testing (NHST). Virtually all reformers advocate increased use of CIs and the new *Publication Manual* (APA, 2001) states that reporting CIs "can be an extremely effective way of reporting results" and "is therefore strongly recommended" (p. 22). Second, as Cumming et al also recount, psychologists may not understand CIs well and there is a lack of well-justified guidelines as to how CIs can best be presented and interpreted. Finally, my experience is that some aspects of CIs are difficult to understand and teach, but that visual approaches can be valuable.

The concept of live figures emerged during the development of two papers on CIs. Cumming and Finch (2001a) gave a tutorial on CI use for simple designs, and made links with other concepts including meta-analysis and statistical power. Cumming and Finch (2001b), using the title *Inference by eye*, analysed the relation between CI (and SE) error bars and inference. They suggested seven *rules of eye* (by analogy with rules of thumb) to guide reading of CI and SE bars and to make inferences. For example, with two independent groups the p value or statistical significance can be estimated from patterns of CI overlap. These and other target CI concepts seemed best explained with the help of a computer simulation. Simulations which run under Microsoft Excel were developed. Figures in the journal papers were part-screen images from the Excel workbooks: A dead diagram was extracted for publication from the live figure. The workbooks are available over the Internet, with the title ESCI ("ess-key"; Exploratory software for confidence intervals; information at: www.latrobe.edu.au/psy/esci).

MICROSOFT EXCEL FOR LIVE FIGURES

For a taste of how easy it is to build a rudimentary live figure, try this: In an Excel worksheet enter a few numbers and insert a simple chart of those numbers. Use View-Toolbars-Forms to display the Forms toolbar, click the scroll bar icon and insert a scroll bar in the worksheet. Right click the new scroll bar, select Format Control and point the Cell link to one of the numbers. Use the scroll bar to change the chart dynamically—yes, graphical interactivity is as simple as that! If you position cells that change (e.g., sum of the numbers) behind the chart, dragging the thumbnail in the scroll bar will change the chart smoothly and continuously.

LIVE FIGURES: TWO EXAMPLES

The left panel in Figure 1 is a simple figure, as may appear in print. The centre and right panels make a corresponding live figure, which allows entry of values for your own data, then adjustment of the CI%. This allows dynamic exploration of the relationship between CI width, and % confidence, and also the relations of the CI with exact *p* values. Figure 2 is an image from a live figure (*CIjumping*, which is part of ESCI) that has animation: Take a sequence of independent samples and see the means and CIs cascading down the screen. Reading this paper you need to imagine not only the animation but the use of colour and the pop up comment boxes that give definitions, explanations, hints and instructions.

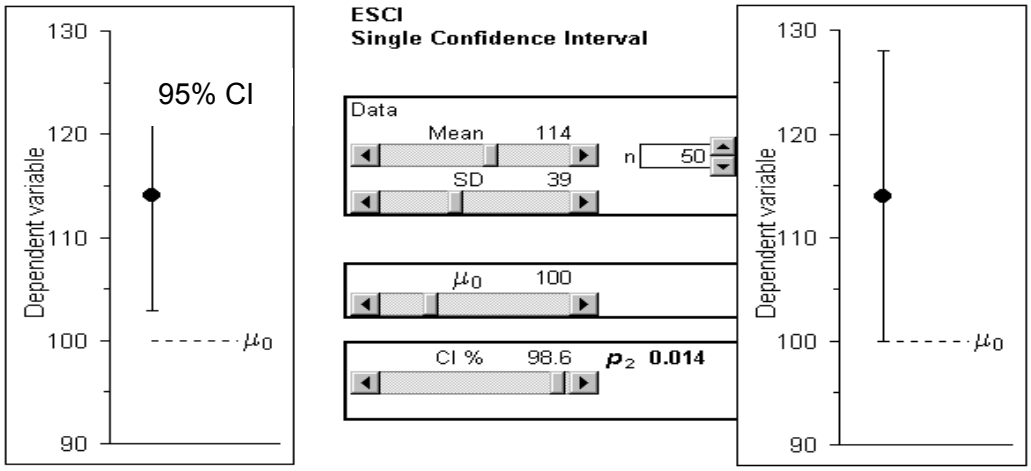

Figure 1. The left panel is a simple figure, as may appear in print, showing the 95% CI for a single group mean, and μ_0, a comparison value for the mean. Since the CI does not capture μ_0, the null hypothesis $\mu = \mu_0$ may be rejected, with $\alpha = .05$. Equivalently, $p < .05$, two-tailed. The right panel, including the control panel in the centre, is a corresponding live figure. Use the sliders to enter the mean and SD for your own data, and the spinner to enter the sample size. Select the μ_0 value of interest. (All these values are the same in the left and right panels.) Then in the live figure use the slider to adjust the CI% until the CI just touches μ_0, as shown in the right panel. The % for this CI is displayed and also the corresponding exact two-tail p value.

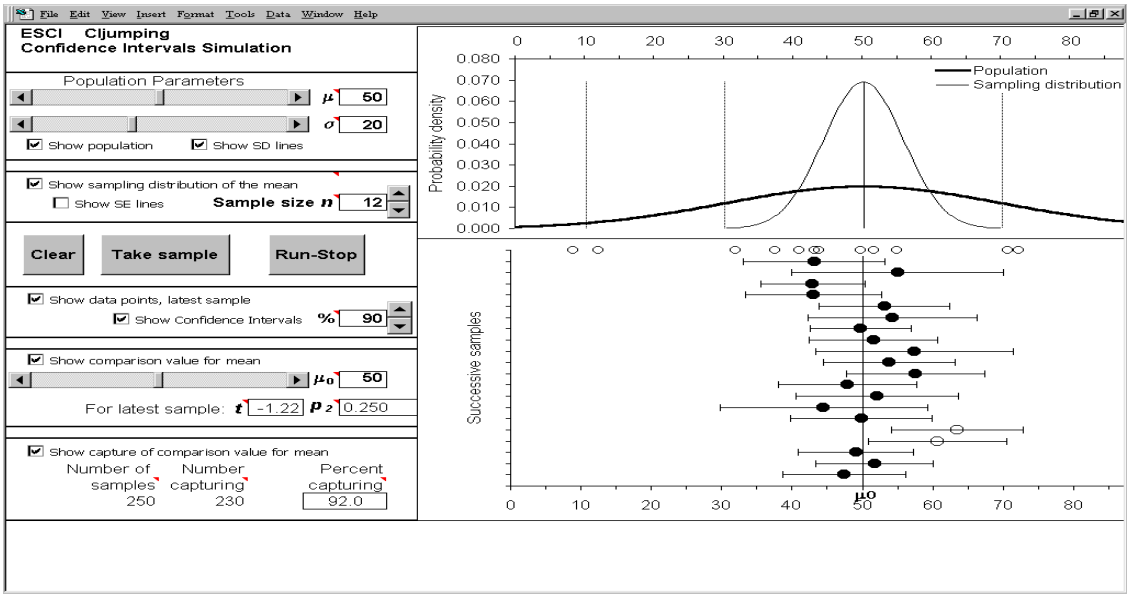

Figure 2. Textbooks often show a stack of means with CIs for a set of independent samples, as at lower right. In this live figure the population distribution (upper right), and other features, may be displayed or hidden by using controls at left. The horizontal row of open circles are the 12 data points of the latest sample, whose mean and CI are top on the stack. The CIs on means shown as a solid dot capture the μ_0 comparison value; CIs on open dot means (2 of the 20 means shown) do not. Click the Run-Stop button to take a further stream of samples, which appear cascading down the screen. At bottom left is a running total of how many CIs in the current sequence capture μ_0. This figure shows 90% CIs, and that 230 of 250 (92.0%) have captured.

DESIGN OF LIVE FIGURES

Follow principles of Human-Computer Interface design. Use symbols, graphics, colour and fonts consistently and as a user would expect; aim for a clean, spare layout. Respect statistical conventions. The goal is to maximise statistical communication and comprehension.

Experience with StatPlay (Thomason, Cumming, & Zangari, 1994), which is interactive multimedia for statistical learning, and work with live figures suggest additional design pointers:

- Use multiple representations: Consider accompanying a graphical representation by the corresponding symbol, value, formula, definition, and explanation, and an example.
- Make dynamic links between representations: When the user drags the slider, the graph and the displayed numerical value both change immediately and smoothly.
- Provide vivid take-home visual images and animations, to serve as hooks for the understanding of concepts. The cascading CIs of Figure 2 are an example.
- Provide examples but also encourage users to work with their own data.
- Design activities, examples, challenges and games to exploit the interactivity of live figures and to encourage exploration and multiple types of learning activity.
- Manage complexity by giving the user control: Open with a minimal display and allow the user to click to add chosen display elements. See the checkboxes of Figure 2, which specify the display elements that appear in the diagram to the right.

LIVE FIGURES FOR STATISTICAL UNDERSTANDING

Live figures have great scope to serve statistical and educational aims. I offer three examples. First, one modest goal of reform is to encourage use in hypothesis testing of exact *p* values rather than dichotomous decision making based on an α cutoff. Standard 95% CIs prompt an α approach: Simply note whether the μ_0 comparison value is captured or not. By contrast the live Figure 1 allows the CI% to be adjusted to *any* value, thus making the *p*-value approach natural. It should promote the building of conceptual links between CIs and a *p*-value approach.

Second, the live Figure 2 animates capture of the μ_0 comparison value by CIs, and also tallies the number and percentage of captures for an indefinitely long sequence of independent

samples—for any value of CI%. The user can thus observe random sampling variability in the short term—the latest 20 samples in the stack on the screen—and in the long term. Short term variability can be surprisingly capricious and 'lumpy' whereas in the long term the law of large numbers dictates very closely the percentage of CIs that capture. This disjunction between short- and long-run randomness can surprise even the statistically knowledgeable.

My third example is CIs for the standardised effect size, Cohen's δ or *d* (Cumming & Finch, 2001a). The rationale for this calculation is complex and requires use of noncentral *t* distributions and an iterative algorithm. The live figure *CIdelta* animates the steps. One design challenge was to make comprehensible the necessarily crowded screen: I used red numbers to indicate successive steps to be made by the user, and pop up comments to give explanations. Another was to illustrate the iterative procedure. *CIdelta* gives two options: The user can find the CI for δ by dragging a slider to move and change a displayed curve until a criterion is met, or can watch back and forth movements of the curve while the Excel *Goal Seek* tool finds the solution automatically.

The awkwardness of explaining here in words what can appear vivid, natural and comprehensible when encountered on screen just emphasises the appeal of live figures. As journals and books move online there is great scope for live figures to become widely used. I look forward to further investigation of their potential to contribute to statistical understanding.

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