don't use 7-segment displays

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Seven segment number displays are ubiquitous and popular. They make economic sense: they are simple, and with only seven on/off segments, they require little wiring and electronics to support. They are cheap to buy and cheap to use; they make seemingly effective products.

We show how seven segment may be more or less dependable, and suggest some improvements to standard designs. However, we argue that for dependable domains (healthcare, avionics, etc) and for handheld devices that may be used in dependable domains, seven segment displays should not be used.

The paper includes many recommendations for developers and purchasers.

Seven segment display, number display, number error, dependable interaction, calculators, procurement

1. INTRODUCTION

By selectively showing or highlighting the seven segments making up the composite symbol 8, each of the ten decimal digits can be represented. Such seven segment displays are a convenient and a now very familiar way of presenting numbers to users. As well as numbers, they can also display a few words and symbols, such as bUSY, LoAd, PLAY, °C, °F and the ubiquitous Error.

In this paper, we raise design issues and present recommendations; for clarity we say "never" for design choices that are inappropriate for dependable or safety-critical applications. For novelty and other non-dependable applications, obviously examination of cost and design trade-offs may lead to other decisions, and such decisions should be backed by competent empirical evaluation.

Almost all handheld calculators use seven segment displays, as do many safety critical devices used in medicine, measurement, radiation metering and so on. Sometimes seven segment displays are used to lend a trendy, even familiar "technical" appearance to a device. Seven segment displays are popular primarily because they are cheap and very easy to build into devices. They seem good enough, and there is no consumer pressure to improve them. This paper argues that for some applications they are unsuitable, particularly when digits and symbols are mixed or when they are used for displaying hexadecimal or rapidly changing numbers.

Seven segment displays are likely to be used during development particularly for projects involving new hardware development — but this reasonable use of them must not be confused with good design practice for a final product. In fact, as this paper makes clear, for safety critical and dependable applications (even including general purpose applications that *may* be dependable, such as handheld calculators) seven segment displays have so many disadvantages compared to readily available alternatives that they should never be used.

See Green, *et al*. (1988) for a review of the literature to the late 1980s. Unfortunately, while seven segment displays continue to be used widely, the more research literature largely ignores them; Wikipedia has up-to-date information (Wikipedia, 2011). There are no applicable ISO, IEEE or IEC standards.

2. FONT CHOICES

Don Knuth expresses the opinion that seven segment digit fonts are better with swash serifs (Knuth, 2011). Thus, in Knuth's view, 7 is preferable to 7, which he calls "truncated." There are similar choices for the forms of 6 and 9. Knuth's opinion raises the question, given that there are choices for the forms of some digits, which fonts (complete digit collections) give the least opportunity for confusion in case one or more of the seven segments are faulty, too low contrast, or misread for any other reason?

For example, if the middle segment is broken, whether stuck on or stuck off, then zero and eight appear the same, both as 0 or both as 8. In fact, under the same circumstances, the swash serif 7 form of 7 is the same as the sans serif 9 form of 9.

Of all possible digit forms, then, which make up the least confusable fonts? I consider the following digit choices, allowing 1 to be right- or left-aligned, as well as introducing a variant 1 (1) with no "gap," a simplified form of 2 (2), and a quirky serif 4 (4) :

o0 1 1 1 2 2 3 4 4

5 6 6 7 7 8 9 9

I define the *distance* between two digits to be the least number of segments that must be changed (or misread) to change one digit into the other. The distance between 0 and 8 is therefore 1; the distance between 3 and the left-aligned 1 is 7. All 7 segments would need to be broken (or not seen correctly) to confuse these pairs of digits.

When distance is large (e.g., 1 to 3) the measure is less useful, as breaking fewer segments will anyway cause problems, mostly obvious problems, with other pairs of digits. Thus, in particular, we are especially concerned if the distance is 1 — since just one fault will cause problems — and we then say there is a *1-segment confusion*.

I compared all pairs of digits in each possible font. The following font has unique maximum average distance of 3•4, and two 1-segment confusions, o & 6 and 4 & 9.

o123456789

Exactly this font was obtained in a small human factors laboratory experiment minimising perceptual confusions (van Nes & Bouma, 1980), and has more recently been shown to **halve** lab error rates over the seriffed font (Gunderson, *et al.* 1991). This consistency between theoretical and empirical evaluation lends credibility to the further discussion in this paper.

The small o is likely to cause confusion reading numbers like 1o — is this 10 or 1•0? (Decimals are discussed in section 2.2.) Using the large 0 instead only reduces the average distance to 3•31 — and the sans serif 6, 7 and 9 still remain the best choice.

Using a right-aligned digit 1 would give a font with a worse average distance, as well as an extra 1-segment confusion, namely 1 & 7.

01 - ***Ensure displays have adequate contrast and visibility from all angles. "Off' segments should never look as if they are "on." (See figure 1.)***

02 - ***The preferred font has a large 0, the 1 left-aligned and sans serif 6, 7 and 9.***

Numbers starting 1 constitute about 30% of all decimal numbers — this is Benford's Law (1938) — so arguably 1 should be left-aligned to ensure it is less likely to be visually confused with following digits. (The right-aligned 1 is probably popular because it tightens the spacing of small numbers 0 to 20.) The 1 form of 1 would have avoided spacing issues, at the expense of increasing the 1-segment confusions and at the expense of user training. Note that there is little research on reading multi-digit numbers (and none to my knowledge exploring seven segment decimals or numbers with thousands grouping issues), but see sections 2.2 and 2.4, below.

It is not clear whether the "best" font criteria should have maximum average distance or least number of 1-segment confusions, or something else, and anyway digits are not equally probable. Indeed the font above does not have the minimum number of 1-segment confusions. The two cases of 1-segment confusions (0 & 8 and 4 & 9) seem to be unavoidable, at least in the sense that if the 4 to 9 distance is increased by adding the serif for 9, it creates a new 1-segment confusion, namely 8 & 9, which would reduce (worsen) the average distance measure of the font to 3•24. Alternatively changing the 4 to 4 would reduce the average distance too, also to 3•24, and of course doing so would introduce a serif (and a quirky serif at that!) in an otherwise serif-free font.

. . . The point of including the 4 was that *perhaps* we would have determined that a font including it was better than others. As it happens, this was not the case. Interestingly, including 2 and 5 would increase the distances, but they *look* faulty!

2.1. Hexadecimal digits

For the full hexadecimal font of 16 digits, the only new choice is between the two forms for C, namely:

AbcCdEF

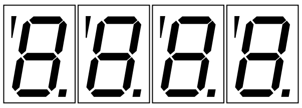
Of course, 6, previously 6, now needs a serif to avoid confusion with the hexadecimal B; a capital b would **be** 8 and so can't be used. On the same measure as before, the "best" font now uses the small c and the unusual 2 (2), but retains the left-aligned 1 and the sans serif 7, 9 forms (now stylistically contrasting with the serif 6). There are eleven 1-segment confusions (e.g., 6 & 5).

03 - ***Never use hexadecimal digits. There are many ways of confusing digits, particularly 6, b (6 or b?), and 8 (8 or B?).***

Figure 1: Infusion pump, an Upreal UPR-900, illustrating some features of seven segment displays. (i) Use of fixed decimal point and smaller decimal digit (middle row). (ii) Dual use to display Err4. (ii) Unlit segments are too visible, making digits unsafe to read — is the second row displaying 37•0, 38•0, 31•0, even 888•8, etc? (iv) Top row shows partial digit obstruction; U is the symbol for Unit (it is nearly showing 2U). For other numbers, 1 & 7, 4 & 9 may be confused. (v) A bespoke display panel was used; it would have been safer, easier to read, more versatile, and cheaper had a hi-res display been used (see section 4).

2.2. Packaging and decimal points

Seven segment displays are often packaged in rectangles, but the digit shape slants, which makes the digits more attractive and also creates a convenient space for a small decimal point at the bottom right and an inverted comma at the top left. The rectangular package simplifies assembly of multi-digit displays:



Though not shown in the schematic above, packages sometimes have interlocking dovetails: using them can further simplify assembly and save using a PCB. If BCD drivers were in the package, even fewer pins would be needed and digit display could be upgraded to higher resolution **transparently** — the external connections need not be changed.

The inverted comma in the top left of each digit is normally used for breaking large numbers into groups of three digits instead of the more conventional space (see section 2.4).

Typically the decimal point has the same dimensions as the width of one of the segments, as shown above. This means that displaying a number with a decimal point may be hard to read: consider 2.45 (which has a decimal point drawn to scale — compare carefully with large diagram above) versus 2•45, which is the *same* number with a larger and more visible decimal point. In fact, knowing or expecting a decimal point in 2.45 does not help how to choose between •245, 2•45, 24•5 or 245•. On displays where the decimal point moves dynamically this poor readability may be a major source of problems (e.g., on some devices even if the user keyed a decimal point, if the number being entered becomes greater than 100, no decimal point is shown) ... to say nothing of misreading 1.000 as 1,000 and 1.00 as 100, etc. ISMP rules, also mentioned in section 3 below, **forbid** the representation of decimal numbers with trailing zeroes because of such dangers (ISMP, 2010).

4 — ***Take care with more than three digits, as a decimal point or the gap before or after a 1 or 1 can be mistaken for thousands separators.***

Some early seven segment displays (e.g., the RCA numitron, which used straight filament wires rather than LEDs) put the decimal point on the left rather than on the right. The numitron used crossed filaments making a small x as the decimal point, so it was much more salient than a dot.

Seven segment displays cannot show smaller digits, as recommended to improve legibility: for example, 2•45 is more legible because of the differences in digit size and colour.

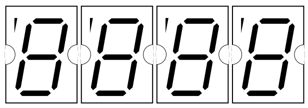
5 — ***Seven segment displays should never be used for numbers with decimal points.***

6 — ***If there is no choice (!), then steps must be taken to ensure decimal points are salient, perhaps by using flashing.***

If it is essential to use seven segment displays, then show a larger decimal point as follows: 2o45, preferably animating it so it is not confused with 0. This approach "uses up" a whole digit position for the decimal point, a trade-off that is worthwhile if dependability is a priority.

Another approach is to use a dedicated indicator between digits. A single LED might be fixed so the decimal point is always in the same position, or there could be several LEDs, one between each digit. The number 2.45 (to repeat the example) is now displayed much better as 2•45. Unfortunately, there may be potentially confusing extra spacing between digits where the decimal point is off.

These considerations suggest that the standard seven segment package could be improved with a semi-circular dent in each side, for optional size and placement of a decimal point indicator:



Here, I removed the decimal point from the package to encourage developers to use the larger LED instead.

2.3. Practical considerations of legibility

In real applications, there is a choice between a special purpose display or using off-the-shelf components to make up a display with enough digits for the application. The exterior of a device may have to be splash-proof, ruggedised or conform to hard industrial design requirements: thus, often the seven segment displays are recessed, which then means from certain viewing angles some of the segments may be fully or partially obscured from view. We noted above (rule 1) that it must be ensured that for all possible reading angles whole digits are visible.

For example, viewed from above, 4 and 9 look the same if the top segment is invisible to the user. Figure 1 shows a device viewed from a reasonable angle that nevertheless partially obscures segments. This is another reason why a good font should maximise distances between digits.

Some seven segment technologies, notably LCD displays, are themselves very sensitive to the angle of view. However, here the angle of view affects each segment equally, and a user would (hopefully!) be aware that the entire digit is unreadable, rather than being unaware that a few segments are unreadable. Unfortunately there are likely to be boundary cases: poor general visibility combined with reflections of lights on the display screen may make some segments unreadable with the user unaware of this.

7- ***Any number display should have a non-reflective surface.***

Blinking (which attracts attention) may create misleadingly valid complementary images. Thus a blinking or scrolling 83 may be read as a 1. After-images may cause further confusion: e.g., red LEDs with green "off" background segments may make any blinking digit appear as alternating with a green 8.

8- ***Do not blink or scroll seven segment displays.***

In some devices, the displays are multiplexed (e.g., at any one time, only one is actually on, but visual persistence makes it seem like all are on continuously) — while this saves electric power and wiring, it has the disadvantage of creating strobe effects that may compromise accurate reading.

2.4. Digit grouping

For legibility, long sequences of digits should be split into groups (compare 1234567 with 1 234 567 or $1'234'567$). The ISO 31-0 (now ISO/IEC 80000) standard specifies that groups of three digits should be separated by a small space, but seven segment displays make this almost impossible, as a space can only be created by sacrificing a digit position. Worse, the unvavoidable space around 1 may be confused with a grouping space. Many seven segment displays have a two-component decimal point, so it can be displayed as a dot or as a comma. Since its use does not reduce the number of digits available, it is tempting to use it as a group separator. This is not recommended: in some countries, commas are decimal separators — and mobile devices may move between countries with different conventions.

9- ***Avoid long numbers, or use the inverted comma as a digit separator. (Or use standard displays upside down!)***

2.5. Display consistency

Sassoon (1993) argues that fonts used in printing (and by teachers on blackboards, etc) should be consistent with the handwriting rules that are taught. In contrast, it is often the case that children are exposed to words with the letter g (looptail), but they are taught to write the simpler g (opentail). Potential confusion reigns and children learn more slowly and make more errors.

Similarly, if number displays were closer to what practitioners wrote, the consistency would drive convergence — good design in the display font might be an influence for the good details in handwriting. Thus, elegant, clear handwriting style numbers would seem to be preferable for displays.

However (questionably) legible seven segments might look on a display, few people *write* as legibly! Seven segment fonts can be used as guides for more legible handwriting — just fill-in the segments with a pen:

£88•88 → £29•95

With a dark background, as above, slightly inaccurate filling-in of the segments is not visible.

The design of fonts is a large topic beyond the scope of a short paper — but see Knuth (1999) and Sassoon (1993). Special considerations are needed for low resolution fonts, and note that there are differences between light-absorbing fonts (as on LCD displays) and light-emitting fonts (as on LED displays), as well as issues with colour perception.

10- ***Use well-designed fonts for displaying numbers that, preferably, can be written by hand the same way.***

That way, we may see the end of people writing 6 and then not knowing whether it's zero or six; better that they complain that it's worse handwriting than the display!

2.6. Large seven segment displays

The advantageous economics and low manufacturing complexity of severn segment displays become even more dominant with very big displays. Since high power illumination is expensive, the fewer components are needed, the better, at least in purely economic terms.

Large seven segment displays, called vane displays, can readily be made out of mechanical components. Again, the relatively low cost and few moving parts make them economic for large displays, for instance, for public display of the time or train platform numbers, which ironically are relied on by more people than smaller displays.

3. REDUCING AMBIGUITY

Many numeric displays display "nothing" as zero (for instance, immediately after they are switched on), or even as zero followed by a decimal point:

0.

This common behaviour breaks several rules. A dedicated "on" indicator would be preferable.

11- ***Never display 0. when On is meant.***

The Institute of Safe Medication Practices **requires** that numbers must not be written with "naked" decimal points (ISMP, 2010). Here, the decimal point *is* naked — there is no digit after it.

***Figure 2:** A pen with a clock showing 12:01 or 10:21?*

***Figure 3:** Mobile devices should be unambiguous when viewed from different directions. Here, seven segment radiation dosimeters hanging upside down from the wearer's belt can easily be read differently by a supervisor and by the wearer, who would lift them up to read them.*

Secondly, the user cannot see the difference between entering zero, or entering zero then decimal point. That this a problem is made clear by asking: if the display is as shown above, what happens when the user keys 2? Which of the following displays will be obtained:

2. or 0.2

This is unacceptable ambiguity, and potentially leads to an out-by-10 (factor of 10) error in the number entered (Thimbleby & Cairns, 2010).

Rule 12, below, is ambiguous (is nothing really nothing or zero?) but it is memorable and important:

12 - ***Never display nothing as zero, and certainly not as 0. (i.e., as zero, decimal).***

13 - ***Never display a naked decimal point unless the user has just keyed it.***

3.1. Rotation

Seven segment numbers may be easily misread when displays are rotated. Examples include 16, which rotates to 91. Decimal points exacerbate the problem: 0.1 (0•1) becomes 10, potentially misread as a factor of 100 out. Figures 2 to 4 show other examples.

14 - ***Never use seven segment displays on handheld devices, or in displays that can be viewed from the opposite side.***

15 - ***Never wear or hang seven segment devices (e.g., worn on the user's arm or belt) as they turn over when lifted up to be read.***

There is a small diversion in the rotation ambiguity: used appropriately it may help children enjoy using calculators

***Figure 4:** A handheld blood glucometer, here viewed upside down. The advert says "Bright, easy-to-read display." (Yes, it's easy to read 901, 60•2, and 52•5 . . . instead of what was intended.)*

more. Thus 0.7734 (0•7734) reads more interestingly upside down (maybe there is an advantage for those near-invisible decimal points after all!). The number factored by 2 × 5 × 71 provides an example that is too obvious to spell out. If you have an 8 digit seven segment calculator, 45199075 is about as good as it gets; and by 9 digits it becomes self-referential: 378163771.

3.2. Detecting faulty displays

A user may sometimes be aware that a segment is broken and thus realise that the display is faulty. A concern is that reading a display may be compromised by unknown faults, or by poor lighting, reflections, low contrast, or by the user not paying sufficient attention. Unfortunately there are many cases (approximately 15; the exact number depends on the font) where faulty segments, stuck on or stuck off, will convert a digit into a different but correctly-formed digit: a user can only spot problems with "all on" and "all off" tests, or by displaying numbers they can predict (such as the time).

Note that if an automated monitoring system to check that a display is working correctly is provided for high dependability applications (see, e.g., US Patents 4,734,688; 4,951,037; 5,812,102, etc — the variety of patents suggests seven segment dependability is a vexing problem), seven segment displays have the deceptive cost advantage that only seven segments (per digit) need to be monitored to check that the display is working. "Deceptive," that is, in the sense that while the cost of checking may be cheaper, a higher resolution display would have higher redundancy. One bit wrong even in a small 5 × 7 bitmapped display just reduces the quality of the digits; one bit wrong in a seven segment display may change the display to a completely different digit.

16 - ***Seven segment displays need checks, such as a flashing 8 or an animated "snake," so the user and/or system can confirm that all segments work both on and off correctly.***

Many handheld devices on power-up briefly show all segments on; this is a compromise that avoids having an interactive feature to check the display — but it is obviously inappropriate for devices that should not be switched off and on regularly.

Unfortunately, the fact that there is no technical fault (or no fault *detected*) does not mean that a user will not misread the display.

3.3. Changing display values

Arabic numerals are not good for displaying changing values; in particular a changing seven segment display will always look like an 8, though perhaps flickering: changing seven segment displays are very prone to misreading.

17 - ***Avoid using seven segment displays for rapidly changing values.***

4. THE FUTURE

Multi-purpose high-resolution displays will soon dominate the market for displays, mainly because of volume efficiencies and consumer demand for features, like colour. Hi-res displays do not need bespoke manufacturing nor special programming; they can be connected directly to processors. Thus they are off-the-shelf, and they support very flexible user interface design. They can show all sorts of data, not just numbers, and therefore they save in the costs of other indicators that would have been required if numbers were displayed with seven segment displays.

18 - ***Use high resolution displays.***

Hi-res displays can show digits with anti-aliasing. Clear fonts like the following become possible (note the base line variations to increase legibility):

12 345•678 90

Except in low power and perhaps huge and/or rugged applications, there seems to be little useful future for seven segment displays.

Customers and procurement should prefer hi-res, legible displays over seven segment displays; hi-res displays have many advantages, notably that they can display more legible numbers. The market pressure — if it reacts to this benefit — will then further drive hi-res displays to dominate. Their increased flexibility will lead to faster improvements in user interfaces generally.

5. CONCLUSIONS

This paper has examined seven segment displays in depth, and provided a number of recommendations, numbered for easy reference. Condensing and rephrasing, the most important points were:

19 - ***Seven segment displays are not suitable for dependable number display.***

20 - ***Seven segment displays should never be used on handheld devices.***

21 - ***Decimal points require particular attention.***

22 - ***If seven segment displays must be used, the font should be optimised for the application.***

23 - ***The preferred font has a large 0, left-aligned 1, and no serifs for 679.***

24 - ***Do not use seven segment displays for hexadecimal numbers.***

25 - ***Follow ISMP rules for displaying numbers (ISMP, 2010).***

26 - ***Do not use any number to mean "on" — display On instead, or use a separate indicator.***

In the future, we see reducing costs and increased volume (and hence a growing skill base of developers) will shift the emphasis to hi-res flexible displays. This transition to better displays will be accelerated if market forces more often reject bad and inappropriate use of seven segment displays.

27 - ***Major purchasers (e.g., hospitals) of dependable equipment should not buy devices using seven segment displays.***

28 - ***If there is no available alternative to seven segment displays, purchasers should carefully buy devices flaunting as few of the rules above as possible.***

29 - ***In short, just say no.***

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