Reasons to Question Seven Segment Displays

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ABSTRACT

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

This paper illustrates many examples of problematic uses of seven segment displays that could have been better managed or even avoided. More generally, the paper raises design questions and some solutions to be considered when designing numerical displays, and certainly before uncritically using seven segment displays. Although there are markets and applications where cost may be an overriding consideration, for safety critical and other dependable types of use (including general purpose devices that may sometimes be used for critical tasks) more legible alternatives than standard seven segment displays should be preferred.

Author Keywords

Seven segment display; number display; number error; dependable interaction; calculators; procurement.

ACM Classification Keywords

B.4.2. Input/Output Devices: Numeric displays

H.5.2. User Interfaces (D.2.2, H.1.2, I.3.6): Screen design

INTRODUCTION

By selectively showing or highlighting the seven individual segments making up the composite symbol 8, each of the ten decimal digits can be represented. Such seven segment displays (SSDs) are a convenient and a now very familiar way of presenting numbers to users. As well as numbers, seven segment displays can also display a few words and symbols, such as buSY, LoAd, PLAY, °F, and the ubiquitous Error, thus allowing a single display to show both numbers, some number units, and simple messages.

Many of the illustrations in this paper show examples of poor or inappropriate use of seven segment displays, with further criticisms and trade-offs discussed in the text of the paper.

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Figure 1. Digital calipers (used for measuring small items) shown held in the left hand, a situation that arises measuring awkward shapes or when the user is left handed. Here, the display might be read as 1•56 (cm?), misreading the space as a decimal point, when in fact it is displaying 9•51 mm. Note that the decimal point is very small and easy to misread.

Figure 1, above, shows a seven segment display being used where mis-reading is very likely, particularly because the user may be stressed by the awkward posture they are in to perform the measurement. Figure 1 illustrates the seven segment display's problems of poor digit spacing, small decimal point, and confusing 2 & 5 and b & 9, as well as a digit 1 that looks the same either way up. An "upside-down mode" could have been easily implemented using the same cheap display technology: the designers do not seem to have considered (or have discounted) the legibility problems that can arise with this device in normal use. Note that a better (more asymmetric) font, like Times, would be harder to misread as it is more obvious when it is wrong: compare the misleading display in Figure 1 with the more obviously upside-down 9•51 mm.

Seven segment displays may be appropriate for novelty applications (e.g., toys) and for decimal number displays where there is a fixed "up" direction (e.g., displays fixed to vertical walls). They are inappropriate for numbers with decimal points (if standard decimal points are used) and they are always inappropriate for hexadecimal numbers. They are particularly inappropriate if they are recessed (e.g., behind a protective screen; see Figure 10) or for use in poor lighting conditions, because just one obscured or badly-lit segment changes digits. *Given that alternatives are cheap, there are unlikely to be good reasons to use seven segment displays in any critical application.*

Seven segment displays remain popular because they are familiar and cheap and, we argue, because legibility is rarely

Figure 2. Graseby 500 infusion pump, illustrating typical number display design issues. (*i*) Numbers are shown using seven segment displays despite the available higher resolution dot matrix display. (*ii*) Units of displayed numbers are far too small to be read reliably. (*iii*) Number keys use a high resolution digit font that is different to the displayed digits. (*iv*) The digit keys 1 and 3 look like they have a decimal point; in fact, these digit buttons have two modes so they can also be used as arrow keys.

Figure 3. Screen shots of two iPhone applications. Seven segment digits are used to create a "retro" design feel despite the high resolution of the iPhone display — which has been used to render other high resolution text, including key legends.

considered a serious question. Almost all handheld calculators use seven segment displays. They are popular even for safety critical applications, such as for monitoring drug delivery to patients. Used by a nurse, who may be multitasking or stressed, an infusion pump (Figure 2) delivers drugs, and misreading a display could cause a fatality. An internet search for "new infusion pump" shows 80% use seven segment displays [5]. Undersea diving is another application. Divers may be hypoxic and working in poor lighting conditions and have problems reading displays, yet a similar search for "new digital divers watch" show 98% use seven segment displays. Ironically, sometimes seven segment displays are used to lend a trendy "technical" appearance to devices capable of higher resolution (Figure 3).

Seven segment displays are likely to be used during development, particularly for projects involving new hardware where simplicity and cost are important factors (it might be useful to be able to hijack a digit display to show an error code, like E4) — but prototyping must not be confused with good design practice for a final product. In fact, 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. Variations, 14 and 16 segment displays, generally show the same digit forms as seven segment displays, and since they increase complexity without changing readability (except for displaying some additional symbols), they seem to offer few advantages.

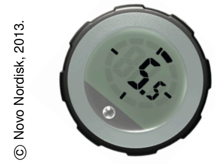

Figure 4*a* **Figure 4*b***

Figure 4*a*. A handheld thermometer pen, held in the left hand — about 10% of users are left handed. The display appears to show 29 (029), but in fact is displaying 62•0. The pen breaks ISMP guidance [8] (which applies to medical devices) because of the "naked" zero.
Figure 4*b*. The NovoPen Echo insulin pen has numbers on its end knob, so there is no natural "up" direction for reading it. (The NovoPen won a US Good Design Award, 2010.)

Figure 5. Digital multimeters are safety critical devices: mis-reading the display could lead to electrocution or other problems. Shown here is a Fluke 114 digital multimeter (a typical high-quality meter) upside-down. Is the (correctly functioning) display showing 70 or something else?

Background

It is widely assumed that seven segment displays are unproblematic. Although seven segment displays are widely used, then, the current research literature ignores them; see [6] for a review of the literature to the late 1980s. Wikipedia has brief but up-to-date information [20]. Interestingly there are no applicable ISO, IEEE or IEC standards. A great deal has been written about font design in general (of which number display is a special case) and the legibility for reading words: unfortunately these are large topics beyond the scope of this paper — but see [9, 15] for further details.

DESIGN QUESTIONS

We now raise design issues and present recommendations. In a safety-critical area, we would always like to reduce user confusion as much as possible (in Europe, this is a legally-enforced obligation), but in other application areas there are generally more subtle trade-offs. We have therefore phrased the issues raised in this paper as *design questions* — here is

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Figure 6. 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.

Figure 7. A clock showing 12:51 or 15:21? Displays like these are small enough to be put in the bodies of pens, so there is no natural up or down orientation, which is particularly problematic for left-handers.

an idea that will almost certainly make a user interface safer or better, but you may want to do an experiment to confirm whether the cost/benefit trade-offs are appropriate for your application, bearing in mind any critical hazards (and the risks of damages) for users. When doing usability experiments, we recommend A/B trials comparing with and without seven segment display conditions, particularly run in realistic viewing conditions from an appropriate range of angles.

Font choices: some fonts are better than others

The world-leading scientist and typographer Don Knuth expresses the opinion that seven segment digit fonts are better with swash serifs [10]. Thus, in Knuth's view, 7 is preferable to 7, which latter he calls "truncated." There are similar choices for the forms of 4, 6 and 9 (see Figure 8). 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, which make up the least confusable fonts? I consider the following digit choices, allowing 1 to be right- or left-aligned, as well as a variant J (1) with no "gap," a simplified form of 3 (2), and a quirky serif 4 (4):

0 o 0   1 1 J 1   2 J 2   3 3   4 4 4
5 5   6 b 6   7 7 7   8 8   9 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. Since the distance is 7, all 7 segments would need to be broken (or not seen correctly) to confuse these pairs of digits.

Conventional	Plain	Swash
4	4	4
6	6	6
7	7	7
9	9	9

Figure 8. Plain (sans serif) and swash (exaggerated serif) styles of seven segment digits side-by-side.

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Figure 9. The Air Inter Flight 148 crash on 20 January 1992 had multiple causes. The excessive rate of descent may have been partly caused by the pilots inadvertently setting the autopilot in vertical speed mode instead of flight path angle mode (a double use of the rightmost number in the picture above). The pilots entered 33 intending a 3.3° descent angle, which the autopilot treated as a descent rate of 3,300 feet per minute (both would have been displayed as –33). Airbus later modified the display so vertical speed is displayed as a four-digit number (top right) and flight path angle as a two digit number with a decimal point, thus attempting to reduce possible confusion [1]. Interestingly, the Report of the Commission of Inquiry has a diagram [14, Figure 8] of the autopilot using hi-res 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. Hence, in particular, we should be especially concerned where the distance is 1 — since just one fault will cause problems: we then say there is a *1-segment confusion*.

I compared all pairs of digits in every possible font. The following font has unique maximum average distance of 3•4 (throughout this paper we use • to emphasize the decimal point), with just two 1-segment confusions, o & b and 4 & 9.

o 1 2 3 4 5 b 7 8 9

It is pleasing that this font is purely sans serif, as one achieves legibility and typographic consistency simultaneously, rather than a trade-off between them.

This font was obtained in a human factors laboratory experiment minimising perceptual confusions [19], and has more recently been shown to *halve* error rates over the seriffed font [7] at all but the longest viewing distances (when everything is nearing the limits of legibility). This consistency between theoretical and empirical evaluation lends significant credibility to our subsequent discussion and recommendations. More so, the human factors experiment proves that users are very sensitive to the seemingly "minor" legibility issues we discuss throughout this paper.

The small o may cause confusion reading numbers like 1o — what value is that supposed to be? The ambiguity of 1o is another indication of potential problems arising with seven segment displays, especially when unusual symbols are combined with normal, full height, digits:

1o read as 10	the o is read as a zero;
1o read as 1•	the o is read as a decimal point;
1o read as 1•0	the o is read as a decimal fraction zero, and a decimal point inferred.

See Figure 9 for an unfortunate use of the small o.

Using the large 0 instead of the confusing o only reduces the average distance to 3•31 — and the sans serif 6, 7 and 9 still remain the best choice when compared against the whole font including the 0. Decimal points (another use of o) are discussed more fully below.

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

Q1. Do you need improved legibility? If so, the preferred font has a large 0, the 1 left-aligned and sans serif 6, 7 and 9.

The non-standard J form of 1 might be thought to help avoid spacing issues, but it is at the expense of increasing the 1-segment confusions and at the expense of user training.

Possibly 31 (and five other digit combinations) are more likely to be misread if the digit 1 is left-aligned, as it may appear to merge with the digit to its left; whereas there are only three such "tight" pairs if it is right-aligned. On the other hand, numbers starting 1 are very common (e.g., 10) and constitute about 30% of all decimal numbers, by Benford's Law [2]. The right-aligned 1 is probably popular because it tightens the spacing of small numbers 0 to 20 (however, whichever font is chosen, either 12 or 21 will have the larger spacing, etc). Figure 7 shows a plausible example of using *both* forms, and Figure 12 shows a much better general solution involving variable spacing.

Q2. Can variable spacing seven segment displays (as in Figure 12) be used to avoid 1 spacing problems?

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 avoid 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, which would have been a provocative result. As it happens, this was not the case. Interestingly, including 2 and 5 would increase the distances, but they *look* faulty!

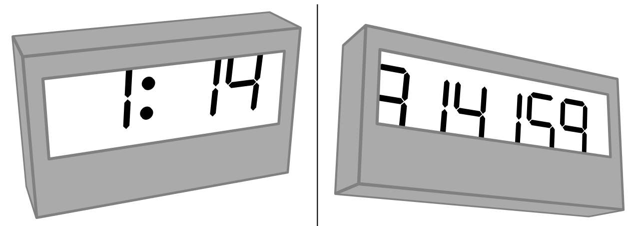


Figure 10*a* Figure 10*b*

Figure 10. Seven segment displays are often recessed behind protective panels, which may easily obscure the decimal point or entire segments, resulting in misreadings. The clock, Figure 10*a*, is not showing 1:14 but 7:19; and the display, Figure 10*b*, is not showing 3•14159 (π) but 81•4159 — the wide spacing of the 1 makes a missing decimal point seem plausible after "3." (The viewing angle need not be extreme: confusion increases even with partial obstruction.)

Hexadecimal digits

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

A A B b C c C D d E E F F

Of course, 6, previously 6, now needs a serif to avoid confusion with the hexadecimal B, b; a capital d would be the same as zero, 0; and a capital b would *be* 8, so neither of these hexadecimal forms can be used, although in purely textual contexts they may be acceptable, as in USB (USB).

Evaluating these choices against *all* of the previous choices (designing a completely new font, not just finding the best way to augment the best base-10 font), and 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). Even so, there is a significant risk of confusion: is b supposed to be b (B) or 6? It is very hard to tell, even when the digits are adjacent, as in 6b, where 6 "has" to be 6, so b "must" be B.

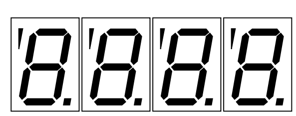
Q3. Is it important to distinguish decimal and hexadecimal digits? There are many ways of confusing digits, particularly 6, b (6 or b?), and 8 (8 or B?).

Q4. How familiar will users be with hexadecimal? The potential confusions of digits B, 6 and 8 *cannot* be avoided when seven segment displays are used without user training, and even then users may not notice critical errors in their readings.

If seven segment must be used for hexadecimal, show an example font to help users interpret displays correctly.

Packaging and decimal points

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



Though not shown in the schematic above, packages sometimes have interlocking dovetails: using them can simplify assembly, improve appearance, and possibly save using a PCB (printed circuit board) otherwise needed for rigidity.

Typically the decimal point has the same dimensions as the width of one of the segments, as shown above, though it is often much smaller (e.g., Figure 1). 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 245 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. 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 or 1.00 as 100, etc. ISMP (Institute of Safe Medication Practices) rules [8] *forbid* the representation of decimal numbers with leading or trailing zeroes because of such dangers.

Q5. How will large value numbers be displayed? Take care with more than three digits, as a decimal point or the gap before or after a 1 or 1 may 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 also used short crossed filaments to make an × 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 both digit size and colour.

Q6. Is it important to use decimal points? Most seven segment displays have very small decimal points that are easily misread.

Q7. If they are important, can you make decimal points more salient, perhaps by using flashing or by using displays with larger decimal points?

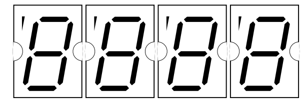
Q8. If it is essential to use decimal points, would showing a large decimal point like 2o45 be preferable?

Q9. Is it appropriate to dedicate some digit positions permanently to smaller decimal digits?

If decimal digits are in dedicated positions, it will be easy to use a special-purpose decimal point to increase legibility: contrast the usual 1.45 with 1•45 or 1.45.

A single round LED might be fixed so the decimal point is always in the same position, or there could be several LEDs, one between each digit. Unfortunately, there may be potentially confusing extra spacing between digits where the decimal point is off.

The standard seven segment package could be improved with a semi-circular dent in each side, for optional size and placement of a large decimal point indicator:



Here, I removed the decimal point from the package to encourage developers to use larger LEDs between packages instead. Alternatively, the large LED for the decimal point could be embedded inside the package, which would have the advantage of making the new design pin-compatible with existing seven segment packages.

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 must conform to hard industrial design requirements: thus often seven segment displays are recessed, which means from certain viewing angles some of the segments may be fully or partially obscured from view (Figure 10).

It must be ensured that for all possible reading angles and viewing conditions that complete digits (*and* the decimal point) are visible. For example, viewed from above, 4 and 9 look the same when the top segment is invisible to the user. Other confusions where just on side of a digit is fully or partially obscured are: 8 & 3, 5 & 6, 1 & 7, 9 & 4, etc (Figure 10). This is another reason why a good font should maximise distances between digits, although it should be noted that a user does not necessarily know what the base font is, and hence may be likely to make more errors than expected. Note that seven segment displays are particularly susceptible to poor viewing angles because entire segments can be obscured, leading to serious misreading; fonts with conventional digits are less likely to suffer from *unnoticed* obstruction (compare 49 with 49, etc).

Some seven segment technologies, notably LCDs (liquid crystal displays), are very sensitive to poor lighting and to the angle of view. However, with LCDs 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 some segments are unreadable. Poor visibility combined with reflections on the display screen may make some segments unreadable with the user unaware of this.

Q10. Is lighting an issue? Any number display should ideally have a non-reflective surface, and have illumination appropriate for its environment.

Q11. Do you need to ensure displays have adequate contrast and visibility from all or many angles (especially if the digit display is set back from the front panel)?

Q12. Does the user task compromise visibility? For example: firefighting (smoke), diving (hypoxia), operating machinery (vibration), emergency response (brief view), etc.

Blinking (which attracts attention) may create misleading after-images. A blinking or scrolling 83 may be read as a 1 (similar confusions include: -, minus, and 0; 8 and a gap — more if letters and hexadecimal digits are in use).

Figure 11. A handheld Russian radiation meter that misleadingly appears to be displaying two numbers, or perhaps a number and a mode, and it might even be misread as 0•16 if viewed from an oblique angle.

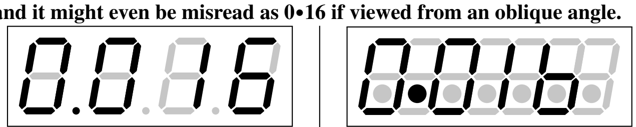


Figure 12*a* **Figure 12*b***

Figure 12. Comparing conventional LCD panels (Figure 12*a*, based on Figure 11) with a new approach (Figure 12*b*): large decimal points and "joined" seven segment displays, easily implemented in standard LCD technology, which achieve uniform digit spacing and improved legibility. (The unlit segments are hightlighted for illustration only.) Compare the better spacing in Figure 12*b* with Figures 1, 9 or 11.

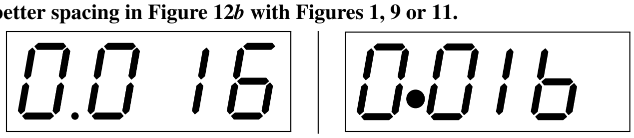


Figure 13. Old and new seven segment displays, without showing the off segments. Note use of preferred font, and that the 1 & 7 confusion is less likely.

Q13. Blinking and scrolling attract attention but degrade legibility; what is the trade-off for your design?

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.

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 standard 31-0 (now ISO/IEC 80 000) 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 unavoidable space around 1 or 1 may be confused with a grouping space. Figure 11 shows a radiation dosimeter that, because of standard seven segment spacing, appears to be displaying two numbers or a number and a code.

Some seven segment displays have a two-component decimal point, so it can be displayed as a dot or 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 (not dots) are decimal separators — and mobile devices may move between countries and user nationalities with different conventions. Figures 12 introduces a display that allows adjustable digit spacing, which can be used for digit grouping.

Q14. How should legibility of long numbers be ensured (or can you avoid long numbers)?

Input/display consistency

The following design questions do not apply just to seven segment displays, but occur frequently with seven segment displays perhaps because seven segment displays are a symptom of cost-saving efforts.

Many numeric displays display "nothing" as zero or as zero followed by a decimal point (e.g., immediately after they are switched on and the user has not had a chance to do anything):

0.

That is, the user has done nothing (other than switching the device on) yet the display seems to show that they have entered zero and a decimal point. A user cannot see the difference between not having done anything, entered zero, or entered zero then decimal point. (Potentially even more confusing is the behavior of a delete key.) That this a real problem is made clear by asking: if the display is as above, what happens when the user keys 2? Which of the following displays will be obtained:

2. *or* 0.2

The ambiguity potentially leads to a factor of 10 error in the number entered [18]. Many designs compound the confusion by implementing the delete key incorrectly: for example, the calculator in Figure 3 correctly does not show a decimal point if one has not been keyed but, incorrectly, the delete key will delete *two* keystrokes if pressed after a decimal point!

The ISMP *requires* that numbers must not be written with "naked" decimal points [8] at the start or end of numbers, because a number displayed like .5 may be misread as 5, which is 10 times larger. With 0., confusions arise: the decimal point is naked (so easy to misread); is the device merely on or displaying the number zero; has the user keyed zero and a decimal point, or just zero, or nothing?

Q15. Is a dedicated "on" indicator better than making the display have two confusible meanings. Consider using, e.g., ---- or on so the device is obviously on but not displaying a potentially misleading number.

Q16. Is it useful to distinguish nothing and zero? If so, do not display nothing as zero, and preferably not as 0. (i.e., as zero, decimal).

Q17. Naked decimal points are hard to see. Can you avoid them or make bigger ones?

Decimal points should be displayed for fractional values, but the design questions emphasise *naked* decimal points. A naked decimal point *has* to be displayed when the user has just keyed a decimal point, since displaying subsequent digits (e.g., as in 0.0, when the user has not yet keyed further digits beyond the decimal point) will introduce further confusion! Interestingly, this interactive problem with the ISMP rules appears to be little known [17], and it suggests that in high dependability domains one should consider the merits of

Figure 14*a*

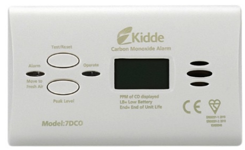


Figure 14*b*

Figure 14*a*. An old household carbon monoxide detector (approximately 15cm diameter). If a user mounts it overhead (which is not ideal for its intended purpose), there is no natural "up" direction to ensure it is read correctly.
Figure 14*b*. This current 2013 Kidde CO detector is rectangular; because of its obvious "right way up" affordance, users will mount it on walls correctly — where detection is more reliable as well (they are usually best mounted at normal breathing height).

other number entry methods, for instance, incremental number entry, which has a lower error rate [12].

Large seven segment displays

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

Large seven segment displays, vane displays, are readily made out of mechanical components. The relatively low cost and few moving parts make them economically attractive, for instance, for public display of train platform numbers or of the time. Public displays are relied on by many users, which must be taken into account in the legibility/cost trade-off. Of course, architectural displays are unlikely to suffer from upside-down readability issues.

Rapidly changing values

Arabic numerals, whether using seven segment digits or conventional "high resolution" digits, are not good for displaying changing values; in particular, a rapidly changing seven segment display looks like an 8, though perhaps flickering.

Q18. Rapidly changing values are prone to confusion with seven segment displays. Is there a better way for your application?

As well as tallying and analog displays (Figure 5 shows an example), possibilities for clearer representation of numeric values include FatFonts [11].

Rotation

Seven segment numbers may be easily misread when displays are or may be rotated. Examples include 1 6, which rotates to 9 1. Decimal points (particularly the standard small decimal points) exacerbate the problem: 0.1 (0•1) becomes 10, easily being misread by a factor of 100. Figures 1, 4, 6, 7, and 14 show typical examples.

The Sanofi-aventis OptiClik insulin pen has an LCD seven segment display in its body. The FDA (the US regulator) [4] warned that left-handed users (about 10% of users) would hold it upside-down when they turn its end knob with their dominant hand; they would then be very likely to misread insulin doses. The OptiClik was withdrawn in 2011.

Q19. About 10% of users are left handed and will hold devices differently; will this cause problems?

Personal sensors for health and safety monitoring are often attached to clothing, for instance to monitor noise levels, radiation or carbon monoxide; they can be attached to waist belts, collars or neck lanyards (as often used for staff name badges). Apart from the general low-readability of seven segment numbers (and decimal points) a key problem is that as the wearer turns the monitors to read the displayed numbers, the numeric display may be turned over and read upside-down. Ironically, health and safety monitoring is often required in environments with very poor visibility, such in diving and firefighting, as well as in environments where users are already multi-tasking and unlikely to have sufficient cognitive resources to carefully read (and double check) displays. See Figure 6.

Circular devices are pleasing because of their symmetry, and small circular devices are convenient to hold in the hand, but symmetry increases the likelihood a device will be read upside-down. Digital tire pressure meters are an example where the task requires the device to be held on the tire valve, and hence over time they will inevitably be used at all angles. Devices like carbon monoxide monitors may be installed in homes fixed to ceilings, where there is no natural "up" direction to read them correctly since they are overhead (Figure 14*a*). Different device affordances can make this problem less likely (Figure 14*b*).

In fact, most digit fonts, not just seven segment fonts, are confusing upside-down: 0, 6, 8, 9 usually appear as correct digits when rotated, so 8069 becomes 6908, but seven segment displays additionally confuse 1, 2, 5 as well.

Q20. Numeric displays on handheld or small portable devices (which are often rotated in use), or in displays that can be viewed from the opposite side, are ambiguous. What design steps (forcing functions, affordances, etc) are appropriate to make orientation and legibility clearer?

Q21. Devices worn on the user's arm or belt, hanging from a neck loop or lanyard, etc, will turn over when lifted up or when picked up to be read (Figure 6). What design choices help reduce ambiguity or force the user to hold them the right way up?

Special care should be taken with any critical device that is rotatable or used in an enviroment or context where there is no natural "up" (ceiling sensors, diving equipment, etc) or can be read from several directions should augment displays with clear "up" direction indicators or other symbols (including text). Use alarm sounds if appropriate. Other possibilities to consider are displaying numbers using analog displays, as words, or using speech. Avoiding horizontal displays, when possible, will also help.

Games with seven segment calculators

There is a happy diversion in rotation ambiguity: used appropriately it may help children enjoy using calculators more. Thus 0.7734 (0•7734) is more interesting upside-down (maybe there is an advantage for those near-invisible decimal points after all!). 14 is a greeting; with an 8 digit seven segment calculator, 45199075 is about as good as it gets; and by 9 digits you can be self-referential: 378163771 .

Although seven segment displays on handheld calculators are fun and can even encourage learning arithmetic, this should not make us sentimental. Adults use calculators for many critical tasks, and dependability will typically be a more important design consideration.

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 faults (e.g., caused by dropping), 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 sequences of numbers they can predict (such as the time). Figure 15 illustrates an example of a test display that is briefly shown to the user on switch-on.

Seven segment displays have the deceptive advantage that only seven segments (per digit) need to be monitored to check whether a display is working correctly (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). "Deceptive," that is, in the sense that while the cost of automatic or semi-automatic checking may be cheaper, a higher resolution display would have higher redundancy. One pixel wrong even in a small 5×7 bitmapped display only reduces the quality of the digits; one segment wrong in a seven segment display changes the display to a completely different digit (or to something unreadable as a digit).

Q22. How will systems or users check displays are working correctly? Seven segment displays need checks, such as a flashing 8 or an animated "snake," so the user or system can confirm that all segments work 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 no technical fault is detected does not mean that a user will not misread the display.

Units

Seven segment displays may be used to show units such as °C, °F, cc. Poor units display will exacerbate the hazards of misreading — mSv/hr may be misread as μSv/hr, giving a reading a thousand times too low, which could lead to loss of life in an environment where users are monitoring radiation. The micro prefix should never be shown as u or μ (not least because μ written by hand may be misread as *m*), and U and IU (international units) should never be used [8], particularly not in seven segment displays where IU is too close to 10. See Figure 2.

Q23. Consider how to make the *whole* display, including units, legible, not just the numbers.

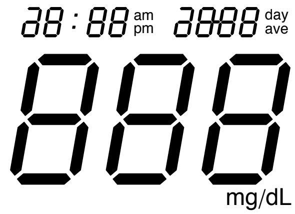


Figure 15. Part of the switch-on test display for the Roche Accu-Chek® Compact Plus [13] handheld blood glucometer (redrawn for this paper). The idea of the switch-on display is to confirm that all segments work; in fact two top left segments are never used (there is no physical need for them to show 12 or 24 hour times), so ironically the test display *appears* to be faulty because two segments are missing! Also notice the unusual high visibility decimal point (top right number), which is easy to implement in this sort of customised display.

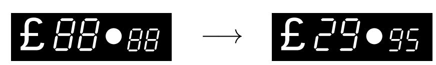
Display readability and consistency with the user's task

Familiarity skill, but seven segment displays are rarely encountered in everyday life, so untrained users are relatively unskilled at reading them compared to conventional digit forms. If number display fonts were closer to what users were more familiar with, readability should improve.

Fonts used by teachers on blackboards and in printing should be consistent with the handwriting rules that are taught [15]. In contrast, it is often the case that children are taught to write the simple letter g ("opentail") but more frequently encounter the form g ("looptail"). Potential confusion reigns, and children learn more slowly and make more errors. Similarly, seven segment displays are more likely to be misread because they are relatively unfamiliar and rarely written by hand. Figures 2 and 3 illustrate a confusing variety of fonts being mixed on single devices.

Q24. Can you have a consistent font for all numbers and displays, including button legends?

Few people *write* as legibly as seven segment fonts. Seven segment fonts can be used as simple guides for legible handwriting — just fill-in the appropriate segments with a pen:



Blank template **Inked-in by hand**

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

Q25. Can you use well-designed fonts for displaying numbers that can be written by hand the same way?

This way, we may also see the end of people writing 6 and then not knowing whether it is zero or six.

User training

Seven segment displays are harder to read than conventional fonts, but with training users can become more proficient [3]. Unfortunately, according to [3], even users trained in reading seven segment displays have significantly reduced skills only one month later. Since users will be rarely aware when they misread a number, formal training must be used if users are to have low error rates reading seven segment numbers.

Q26. Do users need training to read displays reliably (e.g., to understand hexadecimal digits, to check the display is the right way up, etc)?

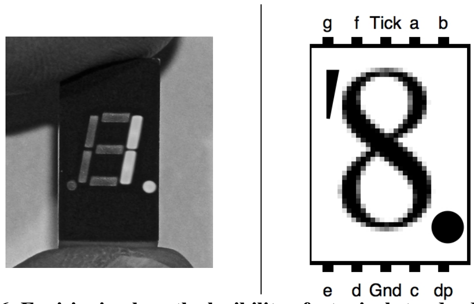


Figure 16. Envisioning how the legibility of a typical standard seven segment package (left) could be improved with a pin-compatible high resolution display (right; the pin letters a–g are the standard segment identifiers). Using BCD (instead of one pin per segment) or a pre-defined seven segment font would allow unambiguous display of hexadecimal digits. An extra pin could also be used to select a smaller font for fractional digits.

Q27. Can numbers be displayed with redundant information, such as standard values or with check digits [18], barcodes, etc, so that users (or the devices they use) are more likely to detect misreadings?

THE FUTURE

If BCD (binary coded decimal) drivers were built into the package (i.e., using 4 binary coded pins to cover 0–9 and A–F, rather than 7 pins one per segment), fewer pins would be needed and, more usefully, any display could be *transparently* upgraded to higher resolution with more readable number fonts — the external connections need not be changed. Indeed, it would not be too hard to make a single package with the conventional seven segment pins that are automatically converted to clearer high resolution digits *including* hexadecimal digits (for a given hexadecimal font). Figure 16 shows the sort of improvement possible, which also shows how dot matrix displays can be anti-aliased to enhance legibility. Even a standard 5×7 dot matrix would be an improvement over seven segments, because the digit shapes are curved and harder to completely obscure by straight escutcheon edges.

At higher resolutions, clearer numeral fonts (so-called text figures or old style, with ascender and descender variation) like the following become possible. Legibility can be further increased by a base line (providing an orientation), and enlarged spacing around the large decimal point. The fractional digits can be distinguished by being smaller and lighter.

12 346 • 678 90

Customers and procurement should prefer hi-res displays over seven segment displays; hi-res displays have many advantages, notably that they can display more legible numbers and, because their strokes can be curved, they do not suffer from the problems of obscured straight segments (Figure 10). Market pressure — if it reacts to this benefit — should drive hi-res displays to dominate. Their increased flexibility will also lead to more improvements in user interfaces generally.

While some applications (such as aircraft cockpits) are obviously safety critical (Figure 9) and all user interfaces in them should be regulated, handheld calculators are remarkable for being unreliable [16] as well as hard to read and yet widely used in safety critical environments, such as in hospitals.

Q28. Is it more cost-effective, bearing in mind the cost of error to the user, to use high resolution displays and fonts with curved strokes?

Q29. Wherever possible, replace calculators and other devices for ones with hi-res displays, in case they are used for tasks demanding dependability.

Fortunately such calculators are increasingly available, and often have additional features to improve dependability, such as multi-line displays.

If you are a user or an organisation:

Q30. Consider whether it is worth replacing seven segment display devices. If you cannot replace, what user training to be aware of readability is required?

It is ironic when hi-res displays are unnecessarily used to simulate seven segment displays (see Figure 3). Even the nixie tube (c. 1955) is an example of an older display technology that achieves much higher resolution than a modern seven segment display.

SUMMARY

Accurate reading of numbers is often critical for user tasks. Although seven segment displays are almost ubiquitous this, in itself, does not mean they are an optimal design choice for any particular application. The point of this paper has been to show that seven segment displays should not be an automatic choice, and dependable applications — including applications that *may* be used for critical tasks, such as handheld calculators and mobile phones (e.g., in emergencies) — almost certainly require higher legibility and greater user training than can be guaranteed.

We posed a number of design questions, numbered for easy reference. Every design question can also be thought of as a procurement question: does (should?) a customer want to buy a device designed like this? Condensing and rephrasing, then, the most important issues are:

- Seven segment displays are not normally suitable for any applications requiring dependable number display.
- Seven segment displays are poor for numbers with fractional parts, particularly as the decimal point is usually too small. Q6–9.
- Using seven segment displays for hexadecimal numbers is never recommended. Q3, 4.
- Seven segment displays are problematic if they may be viewed upside-down. They should not normally be used on devices with no natural “up” direction; they should not be used on ceilings, belts, etc. Q20–19.
- Seven segment displays should not be used for rapidly changing values or in scrolling displays. Q18.
- Where seven segment displays must be used, the font can be optimised for the application, and this will be more

effective when combined with regular user training. Q1, 2, 26.

In time, reducing costs and increased volume should shift the emphasis to higher resolution options. This transition to better displays will be accelerated if market forces more often reject inappropriate uses of seven segment displays.

- Existing seven segment display devices (including calculators) may need to be replaced. Q28–30.

Other suggestions apply to all forms of numeric displays:

- Where appropriate, follow ISMP rules [8]. Q16–17.
- Do not normally use any number to mean "on" — display the word On or `----`, etc, instead, or use a separate indicator that cannot be confused with numbers. Q16, 15.
- Generally, users may need to be regularly trained to more reliably use and read number displays. Q26, 30.

While it would have been tempting to present definitive design rules or guidelines in this paper, actual design trade-offs depend on the application and the cost/benefit considerations of the market and user tasks — not just design and manufacturing cost/benefits, but particularly user cost/benefits. One user error in the lifetime of a product (plus perhaps suing the manufacturer) may cost more than the minor savings made possible by using a seven segment display. There is very little research to provide answers directly helpful to designers; to establish whether seven segment legibility in a particular case might be a significant hazard can only be established by very careful empirical evaluations, which themselves are costly and very difficult to do well.

Except perhaps for huge and rugged applications, there seems to be little useful future for seven segment displays.

Rather than doing questionable experiments, since seven segment displays introduce *predictable* problems that can be avoided, this paper's advice can be summarized:

JUST SAY NO

— don't use seven segment displays.

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REFERENCES

1. Aviation Safety Network, Accident description: Air Inter Flight 148, `aviation-safety.net/database/record.php?id=19920120-0`, 1992.
2. Benford, F. The law of anomalous numbers. *Proc. American Philosophical Society 78*, 4 (1938), 551–572.
3. Ellis, N. C., and Hill, S. E. A comparative study of seven segment numerics. *Human Factors 20*, 6 (1978), 655–660.
4. Federal Drug Administration. Possible dosing errors with the OptiClik insulin injection device. *FDA Patient Safety News #60* (February 2007).
5. Google, Search results for "new . . . ," first 200 images where displays are visible, `www.google.com`, Dec 2012.
6. Green, P., Goldstein, S., Zeltner, K., and Adams, S., Legibility of text on instrument panels: A literature review, The University of Michigan Transportation Research Institute, UMTRI-88-34 (NTIS No. PB 90 141342/AS), `deepblue.lib.umich.edu/handle/2027.42/790`, 1988.
7. Gunderson, J., Gruetzmacher, G., and Swanson, N. Legibility of seven segment numeric LED displays: Comparisons of two fonts at various distances. In *Proc. Human Factors Society 35th Annual Meeting* (1991), 491–495.
8. Institute of Safe Medication Practices, Error-prone abbreviations symbols dose designations, `www.ismp.org/Tools/errorproneabbreviations.pdf`, 2010.
9. Knuth, D. E. *Digital Typography*. Center for the Study of Language and Information, CSLI, 1999.
10. Knuth, D. E. *The Art of Computer Programming*, vol. 4A. Addison-Wesley, 2011.
11. Nacenta, M., Hinrichs, U., and Carpendale, S. Fatfonts: Combining the symbolic and visual aspects of numbers. In *AVI'12, Proc. Int. Working Conf. Advanced Visual Interfaces*, ACM (2012), 407–414.
12. Oladimeji, P., Thimbleby, H., and Cox, A. Number entry interfaces and their effects on errors and number perception. In *Proc. Interact 2011*, vol. IV, Springer-Verlag (2011), 178–185.
13. Roche Diagnostics, Accu-Chek Compact Plus® blood glucose meter owner's booklet, `www.accu-chek.com`, 2006.
14. RVS Group, Computer-related incidents with commercial aircraft: The Air Inter A320 accident near Strasbourg, `www.rvs.uni-bielefeld.de`, 2005.
15. Sassoon, R. *Computers and Typography*. Intellect Books, 1993.
16. Thimbleby, H. Calculators are needlessly bad. *International Journal of Human-Computer Studies 52*, 6 (2000), 1031–1069.
17. Thimbleby, H. Interactive numbers — A grand challenge. In *Proc. Int. Conf. Interfaces and Human Computer Interaction 2011*, K. Blashki, Ed. (2011), xxviii–xxxv.
18. Thimbleby, H., and Cairns, P. Reducing number entry errors: Solving a widespread, serious problem. *Journal Royal Society Interface 7*, 51 (2010), 1429–1439, DOI: `10.1098/rsif.2010.0112`.
19. Van Nes, F. L., and Bouma, H. On the legibility of segmented numerals. *Human Factors 22*, 4 (1980), 463–474, DOI: `10.1177/001872088002200407`.
20. Wikipedia, Seven-segment display character representations, `en.wikipedia.org`, 2011.