ORIGINAL ARTICLE

Living with alarms: the audio environment in an intensive care unit

Peter Sinclair

Abstract This article treats the use of sonification in Percy Military Training Hospital's intensive care unit, through an interview with Anaesthetist Professor Bruno Debien. It starts with a description of the environment completed by some technical information concerning the equipment. This is followed by a commented transcription of the interview with Bruno Debien and concludes with reflections on the nature of audio alarms and their relation to different modes of listening.

Keywords Sonification · Alarms · Music · Perception

1 Introduction

I was introduced to Dr. Debien by chance and happened during the course of our conversation to mention my research into artistic sonification. Surprised by his openness to my ideas, and probing a little further, I discovered that his own working environment is much dependent on sonification, and also that he has an interest in music.

In preparing the Locus Sonus symposium and subsequently this special issue of AI & Society, I formulated the title: Sonification: How? Why? What? Where? It struck me that these questions were clearly answered in Dr Bruno Debien's working environment. It occurred to me that it could be of interest to work those questions in reverse in order to explore the connections—both points of divergence and points of convergence—between medical and artistic uses of sonification.

I was particularly interested in how he as a 'user' perceived this sonification. It was my conjecture that with its connection to the human body, and the very concrete often vital role played by the sonification of data in the hospital setting, medical sonification, despite being of a different register to artistic sonification, would nonetheless provide a productive parallel in terms of the corresponding intensity of engagement, and the shared elevation of real-time data to a special status through sound.

My visit to Percy Hospital started with a guided tour of the Intensive Care Unit, during which Dr. Debien provided a descriptive commentary, focusing particularly on the signification of the sounds that we heard. Following the visit, we returned to his office where he answered my questions. I later asked him to clarify some of his answers via email. I have translated his responses from the original French.

2 Description of the environment

Hospital Percy is a military hospital situated in the south of Paris that provides care for both military and civilians. The intensive care unit is underground, (second floor basement) this is common for emergency wards since ground floors tend to be reserved for reception areas and vehicle access to a basement area is simple, whereas accessing higher floors adds complication and therefore risk. A consequence is that there is no natural light.

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Fig. 1 Dr. Bruno Debien standing next to a multi-parameter monitor, ICU, Percy Hospital

The unit is polyvalent meaning that it deals with both urgent medical conditions such as lung infections or heart failure and surgical pathologies, these latter either a consequence of complications during surgery or traumatic pathologies. When we arrived, the latest patients to have been admitted were a soldier from the Afghan war and a woman who had fallen drunk from a 4th floor—traumatic pathologies.

The way that the unit is laid out appears almost industrial; an elongated central area, occupied by mobile equipment ready to be put to use, is flanked with booths that open on one side to the central part of the ward. If it all seems rather sparse and inhuman, this is because both comfort and pleasantness of the environment take second place to the priority of functionality, more so than in an average hospital ward since while patients are in the unit they are mostly either unconscious or semi-conscious. As Dr. Debien explained, although this lack of comfort is undoubtedly necessary, it is not without its own problems, not least on the sonic front (Fig. 1).

3 The Soundscape[1]

The audio atmosphere at first struck me as similar to that to be found in any generic work place; the conversations of

medical personnel, a radio playing somewhere. For the first few minutes, I could not hear any evidence of sonification, just the sound of the gently breathing respiratory machines (ventilators) and the constant whirr and hum of pumps and other machinery. I was surprised that there were no significant continuous sounds present in the booths where beds where located. In my imagination, the systems monitoring vital functions would continuously 'play' the information they were tracking allowing the nurse or doctor to constantly assess the situation from the patient's bedside or indeed at a greater distance. I had probably gained this false impression from the way that cinema or television sound tracks portray scenes of ICUs: the suffering patient is routinely depicted surrounded by incessant cacophony emitted by medical equipment. The reality of the situation is very different: no beeps, tracing pulses or aggravating sine waves, no crackling alpha wave sonifications revealing variations in latent brain state.[2]

Just at the point when I am starting to wonder what we are going to listen to, a distant but loud middle-pitched sound breaks the apparent tranquillity: doot! doot! … doot! doot! … doot! doot!. The sound is double and the interval between the two sounds is short and seems to lend certain urgency to the signal, a little like a rapid double rap on a door might. It seems to have a one shot echo coming from a different position in the ward. It stops after a few seconds and is followed by a deeper sounding tone repeating three times with a longer interval: dong! dong! dong!

Dr Bruno Debien explains that we just heard an alarm of medium importance and that the second, lower frequency sound indicates that a member of the medical staff has arrived at the patient's side and is taking care of the problem.

4 The equipment

Each patient has a multi-parameter monitor that tracks several different vital signs simultaneously: electrocardiogram, blood pressure (from a bracelet, arterial catheter), temperature (skin sensor and catheter…), blood oxygen saturation, amount of CO_2 expired, intracranial pressure and cerebral perfusion pressure, electroencephalogram amongst other factors. The audio alarm system does not actually distinguish between the different types of sensor but rather signals a degree of gravity as soon as an abnormally has been detected. There are different alarm sounds indicating different levels of danger ranging from 'normal' to 'vital' which trigger when any given parameter either exceeds or falls below predetermined thresholds. These sounds vary in pitch and cadence, the higher they are the more urgent the alarm. It would seem

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[1] A soundscape is a sound or combination of sounds that forms or arises from an immersive environment. The word was first created by Canadian composer Schafer (1977).

[2] Dr. Debien assured me that this is typical of any ICU around the world.

that this is a universal factor in intensive care alarms despite the irony—pointed out by Dr. Debien—that the worse the situation, the 'higher' the sound becomes in pitch (In French, 'grave' means both low in pitch and serious in the medical sense of the word).

Each patient's monitor is networked to the central ICU monitoring station or 'central scope'. This was the source of the 'echo' of the alarm that I had heard earlier—the signal is first generated in the room where the pathology is detected before then being repeated on the 'central scope' located in the elongated central area.

When I expressed my surprise that there was not more information contained within the sounds themselves Dr. Debien explained that once alerted by the sound of the alarm, precise complementary information was given visually—the monitors are networked in such a way that when an alarm triggers, its provenance can be verified by glancing at the video display of any monitor by any bed. A signal appears indicating the whereabouts and nature of the problem, with the room number identified, the urgency level of the alarm indicated by colour, and a textual account of the nature of the pathology detected.

Ventilators and automated infusion pumps, used for intravenous line infusion (automated syringes) are equipped with alarms which are not connected to the central monitor. Ventilator alarms are non-specific, in that they give no information about the cause of the problem that triggers them while infusion pumps emit a series of alerts indicating that they are nearly empty, empty or dysfunctional.

5 Perception of the environment

The advantage of the sonification, of the alarms in intensive care is primarily that of gaining time. The audio alert can save precious minutes in getting over to a patient who might be in danger. There is clearly a trade-off between speed of reaction and the amount of information that is transmitted via sound. There is no immediate need for 'high definition' data; this can wait until you are beside the patient. In fact, according to Dr. Debien, machines are all very well but the most important thing is to look at the patient themselves; as a consequence, audio alerts are kept to a bare minimum in terms of their sophistication (either with regard to their acoustic texture or in terms of the resolution of the information which they communicate).

Dr Bruno Debien:
The audio message must be simple and clear. Simple because, in spite of the fact that the ear is able to differentiate between sounds efficiently and that we have a high level of learning ability, the aim is to reduce risk. So there can be no ambiguity in the audio messages.

However, this method of using a small number of successive levels of alarm does also create problems:

BD:
…The paradox, or rather, the problem one faces in an ICU is that the more one restrains the scope of an alarm the more artifacts one has to accept, false alarms. And the more one broadens the bandwidth of what is acceptable as a variation, the more you lose reaction time to a potentially dangerous incident…

It is of course important to maintain an uncluttered audio space so that essential sounds can be heard clearly and to limit stress due to unnecessarily high sound levels. As in many other domains, hearing is reserved for alerting the medical staff to danger. More precise information is then obtained visually, (and as mentioned above by turning attention directly to the patient in danger). This would seem to correspond to the primeval distribution of responsibilities amongst our senses. Another point that Dr. Debien made is that much of the time an alarm signal completes prior knowledge. He describes, for instance, the apparently magical way in which the nurses are able to 'guess' the whereabouts of an alarm in spite of the fact that the alarms of a same model of apparatus sound identical.

BD:
… They are helped by the fact that they plan tasks ahead. In the course of a day, the nurse knows they have given such and such a dose of antibiotic at 1300 h, and so it will end at 1400 h, and so at 1400 h when they taking a break, drinking an orange juice and there is an alarm that sounds off… I'm always amazed, I say to myself "how did she know that it was the Mr. X's syringe, or rather that the sound was coming from Mr. X's room?" In fact, she did not know, but she did know it's a pump alarm, and as she has her schedule in mind, she knows that it's the pump Mr. X's room. It's funny, because it is a mix of information and knowledge there is an anticipation of what will happen…

The ergonomics of audio and visual monitoring are important; they need to be minimal in order to avoid any form of fascination or fixation on a display that might distract attention from something else that needs to be noticed. So the line displays on the visual monitor are simple in aspect and update relatively infrequently. And alarms are somewhat brutal and unsophisticated—this is a subjective opinion: they have quite a sharp attack, they are loud, they use simple rhythmical devices to capture attention, they are not very complex in terms of harmonics, and they are placed well within the range of frequencies that we perceive most efficiently. It is interesting to note that this simplicity constitutes the polar opposite of the demands

that are configured in respect of medical imagery: there, the greater the resolution and the higher the definition the better, is the order of things. In intensive care, you do not want to be pondering on things too much and you do need to be aware of everything as fast as possible.

BD:

… The utility (of sonification) for us is that in the ICU we have very unstable patients, so the time factor, the reaction time to an acute problem, is extremely important. And by having alarms, or at least audio messages, we are able to respond as quickly as possible and in the way best adapted to patients' instabilities. So it saves time and allows us to treat patients faster and better, since we do not have a nurse in every room continuously 24 hour a day. In fact this situation cannot exist. In Swiss ICUs, there is a nurse-patient ratio of 1 to 1, one nurse per patient, but even when there is one nurse per patient, the nurse has to go to the bathroom from time to time, or to the pharmacy for the patient's medication, and even if she is present she may be looking away, so sound signals are essential…

I asked Dr. Debien to describe how he perceives the audio environment of the unit.

BD:

…It's an environment that is both helpful and hostile: It is useful, because as we have just seen, it allows us to monitor patients better, to react more rapidly. It is hostile, because it ends up being extremely noisy, because of the fact that we set the alarms to be quite sensitive therefore there are a lot of alarm messages and some "false" alarms. In actual fact, there is always something up when an alarm sounds otherwise it wouldn't trigger, but it is often not too serious, or at least the level of alarm triggered by the monitoring system is more urgent than the reality of the situation. So it is stressful, and one consequence of this is that you develop a kind of insensitivity: you get used to hearing alarms and so your perception varies over time and attention tends to diminish. The result can be that we react more slowly, because we think it will be another false alarm. So undeniably it's useful, but also hostile, or at least uncomfortable and stressful, so we try to work on it with the nurses. In particular, we changed some of the alarms criticality settings: we met, it was a working group, and we said «OK, we accept that this is a critical alarm», and elsewhere we attempt to change the alarm level so that it becomes less critical… We try to adapt the alarms provided by the manufacturer to the way that we work, in our unit.

From the patient's perspective: they are in a much "dehumanized" setting in ICU (despite all our efforts to improve their comfort). It's a trial: Firstly they are in intensive care. That means they are seriously ill or seriously injured, which is physically and mentally exhausting.

– And then when they wake up, when they are resuscitated they all say, "It's noisy, there is noise all the time I can't sleep." When they are doing relatively well, the patient may turn over and maybe move an electrode (at night, for example). If it triggers then he/she is automatically woken by the noise, and if he/she is not woken by the noise, he/she will be woken by the nurse who comes to resolve the problem that caused the alarm and then inhibit it… It's often expressed by the patients as a hardship—all these alarms ringing, and sometimes without good reason. There are also the syringe alarms—Intravenous line infusions fed automatically by a small machine—when the infusion is almost empty, there is an alarm—the "pre-infusion" alarm to tell the nurse to prepare the next syringe. Then, there is the "end of perfusion" alarm—a second alarm. Moreover, if the patient moves a little and bends the catheter (small intravenous tube), the pressure in the syringe will increase, so the machine will ring to alert the problem…

He describes an additional disadvantage concerning the alarms, that of the incomprehension of visiting family members:

BD:

…Some patients are intubated (a tube into the trachea which connects to a ventilator that induces breathing) Coughing is physiological phenomenon, it is good for the body, it brings up the secretions from the lungs and eliminates germs and dust… Except that if a patient coughs while they are connected to a ventilator the coughing raises the pressure and the machine triggers an alarm. And families panic. So we have to speak to them, we warn them, we explain, "it's okay, it's understandable that you panic, but we're used to it, we have a trained ear, we know when an alarm is important, and when it is not…" When you know that it is a patient who is coughing, you do not come running at full speed, but for the family an alarm is an alarm, and it's scary…

6 Aesthetics

One of the more interesting aspects of our discussion concerned the aesthetics of the sounds present. I asked if it

was possible to compare musical listening to the type of listening practiced in his working environment:

BD:
…Instinctively, I would say no. That is, I cannot see it aesthetically, but rather in a functional way, as something informative, but at the same time, we sometimes 'sing' the alarms in the staff room. There is one particular ventilator, which sounds like this 'di di dit—di det'. Well, sometimes we sing it… In music, there is pleasure, and here there is none. We are not in the domain of pleasure, there is a lack of emotion here—there is neither positive emotion nor pleasure. Here sound is informative, it's intellectual, and sometimes there are negative aspects to it like 'something is seriously wrong'…

He had more to say about the ventilator later, when I wanted to know if some alarm sounds were perceived as more pleasant or unpleasant than others.

BD:
There are alarms that are judged as more unpleasant than others for an equal level of emergency. So yes.

Peter Sinclair:
Is it possible to explain why?

BD:
Our chosen multi-parameter monitoring system is universal throughout the unit so the sound from one room to another is invariable for the same level of alert. However, in the case of our ventilators, there are three different models: two models made by the same brand and one by another brand. In this case, for equal alarm levels, there are differences in the way the alarms are perceived (this is not my opinion, it's the general opinion of the collective using the apparatus) actually, the alarm I sang 'di di dit - di det'- everyone hates this particular alarm.

PS:
Do you know why that is the case?

BD:
I think it is a partly related to the fact that it identifies a particular ventilator, and it is not a ventilator that is considered agreeable or easy to use. We consider the audio message, not as responsible for, but as the label of the ventilator in question, so the sound itself is considered unpleasant. And then there are two different models of ventilator made by the same brand, one of which is older than the other. One has the impression that some progress has been made in relation to the sound of the alarm. It is less unpleasant to the ear. I cannot say more pleasant, because it

remains an informative warning of a level of danger for the patient, and so that is why we cannot evoke pleasure. But we have a less negative perception of it.

PS:
That's interesting, so there is really a notion that because the information transmitted is serious, or at least not linked to pleasure, the sound itself cannot be agreeable?

BD:
Yes, I think so.

PS:
So even if we put a sound, I do not know… let's say a chord played by an orchestra, a priori pleasing, if this sound became the sound of alarm, it would itself, by the same token, become unpleasant?

BD:
It would be an interesting experience. It is an a priori judgment that needs to be verified, why not test it? But yes I think so.

So for Dr. Debien (and possibly for all of us), the signification of a sound, in such a situation where the signification is vital, outweighs the perception of the sound as a sound per se to such an extent that he actually had difficulty in addressing the question I asked. Even though his definition of music is one that rather differs from my own—since I do not consider music as being intrinsically related to pleasure, at least not pleasure of the kind he describes—I can readily appreciate the argument that he was making.

His opinion that the choice of alarm sound could be relatively arbitrary was reiterated when I asked about the standardization of alarm sounds. He explained that alarms vary from one manufacturer to another and that while they do not need to be identical, it is necessary that certain functions follow the same simplified schemes—for example, the fact that alarms concerning vital functions vary from bass to treble, depending on the seriousness of the alert.

BD:
…This is necessary for nurses to be able to assess the urgency of the situation… It is necessary to avoid any confusion concerning the interpretation level of danger. Variations from one brand of device to another do not matter. Nurses very quickly get used to a new signal, in one day they will have memorized the meaning of a given sound…

He did seem to think, however, that a universal code of sonification might be a useful development, provided that such a code was not too complicated:

BD:

…It could give more room for the interpretation of data through sound – as it stands the nurse does not know, when an alarm monitoring system is triggered, which vital function is responsible (breathing problem or blood pressure for instance), there is a big difference. It could help us to have more information but it shouldn't imply too long a learning time for nurses. They already have a lot of specific things to learn on arrival in our unit…

I wondered if there was some kind of 'occupational hazard' that related to being forced into this permanent alertness to the dynamic change in the audio environment:

BD:

Maybe in regards to the discrimination of sounds… for example: sirens, of the fire brigade, the police etc. This may be beyond the limit of your question, but I can tell the difference between police, private ambulances, fire engines etc. Well, I did work with the fire service, so I am used to these questions. Maybe we do acquire some discrimination in listening to noises…
I often say I don't like noise, I think I'm sensitive to noise and I tend to refuse it, also I don't like loud sounds, which I find annoying… So yes maybe I listen a lot, I analyze and I identify sounds.
It's impossible to avoid all environmental noises, but one can try to isolate oneself when it gets too loud, and also one can discriminate when listening, saying to oneself "Ok, that's one thing, that's another…" When I listen to music, I like to wear headphones that allow me to isolate myself from the environment, to cut out everything else. I don't know if it's related to my work, or if that's how I was before…

He did also mention a childhood fascination for alarms:

BD:

As a child I was fascinated by fire sirens and I learned to distinguish the codes they use to indicate different types of emergency… one ring for a fire, two for accidents, three for other types of intervention, (I do not really remember the details). I also liked the sirens that sounded at noon the first Wednesday of every month[3]…

In spite of the fact that Dr. Debien considers the domain of significant sounds (his terminology) as being apart from the musical domain, he was open to the idea that it is possible to use data to make music, he had looked at the documentation of my work and when I described

'Listening to The Mind Listening',[4] he was quite ready to accept the concept (in principal at least):

BD:

…I certainly wouldn't consider such a concept as reducing the music, but more as something unusual to experience. We listen to recordings of natural sounds (birds, flowing water…). It is even recommended (and I tried it with my last child Casimir) by "Nature et Découverte"[5] to help children to get off to sleep. So why not music whose source is "the musicalisation of the functioning body".

During our visit, he had pointed out a machine which, unfortunately I did not get to hear, a small mobile monitor called a pulse oximeter, which is used in transport, where one medic is responsible for continually surveying one patient. Compared with the alarm system, I find this monitor quite elegant in its conception—the same sound carries information about the two parameters that it monitors. The frequency of the occurrence of the sound represents the pace of the heartbeat and the pitch of this same sound represents the oxygen level in the blood. Unlike the other systems, I heard this monitor functions continuously and—incidentally—the pitch principal described above—the higher the pitch the greater the danger—is in this case inversed: the lower the pitch, the less oxygen in the blood, and the graver the danger. Dr Debien considered that it was not impossible to consider this monitor from a musical angle.

BD:

…For the sonified part of monitoring, as opposed to alarms, (when the message indicates the status of the patient, even when all is well… which I use when transporting patients), then one could imagine a more melodious sound message continuously adapted to the patient's condition…

On the other hand, he was quite clear about the fact that the vital nature of the alarms made it impossible to even compare the way in which he listened to them with the way in which one listens to music. This would suggest that it is not so much a question of the technical nature of the data, or even the situation, that modifies the listener's position so much as the gravity of the data being sonified. If it is possible to transform the 'causal listening' to a natural environment into 'reduced listening' through an effort of perception,[6] this process is

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[3] In France, early warning sirens are tested at noon on the first Wednesday of every month.

[4] See article by Stephen Barrass in this issue.

[5] Nature et Découverte is a French chain of stores selling environmentally friendly toys and gifts.

[6] I refer here to the three attitudes to listening as defined by Chion (1990), following Pierre Schaeffer, in his book L'Audio-Vision. Reduced listening is the act of listening to a sound for its intrinsic qualities as opposed to causal listening which attempts to identify the source or cause of the sound and semantic listening which identifies a code within the sound as for example in language or morse-code.

unimaginable in regard to alarm sounds on which patients' lives might depend, whatever the aesthetic qualities of those sounds. This is fortunate since if the opposite applied, reduced listening to their audio environment could potentially distract the medical staff. One might speculate that this particularity of audio perception might constitute a specific sub-category of causal listening devoted exclusively to alarms, where the perceptual response amounts to a kind of audio ducking. Through experimental research described in their paper 'Perception of Urgency and Alarm Design', Guillaume et al. (2002) compare the perception of artificial alarm sounds synthesized following the principles set by and Dennis (acoustic properties defined using psychophysics for which modulations induced different degrees of urgency) with real alarm sounds (Edworthy et al. 1991). The perception of sounds corresponding to nonexistent alarms was highly correlated with the theoretical degree of urgency, whereas 'real' alarm sounds correlated much less. A. Guillaume reaches the following conclusion: Auditory sequences can be categorized according to their perceived degree of urgency. However, judgment is based on two sets of cues: low level ones correspond to acoustical properties as studied by Edworthy et al. and high level ones involving mental representations which are highly dependent on acculturation.

7 A personal conclusion

I know that some people, possibly the more musically inclined amongst us, fail to understand why I raise the question of there being a difference between music and artistic sonification. After all, in this post John Cageian era,[7] where is the problem? We proved that anything can be music a long time ago; it just depends on how you listen to it. As a consequence of this interview with Dr Debien, I realized that the 'it just depends on how you listen to it' is exactly the question. If you put people in a situation where they are expecting to listen to music they will probably hear music whatever the sound or the provenance of that sound. However, if you play them sound which signifies something which it is hooked up to, if that something is of vital importance then it is the signification that will attract the attention rather than the audience's immersion in a 'reduced listening' that accords primary value to the textural and dynamic qualities of the sound itself. It will become a 'causal listening' or possibly a 'semantic listening' transporting the listener into a different perceptual domain, irrespective of the extent to which the acoustic

events resemble the conventions of pitch, placement, duration, and dynamic flow that we call music.

So of course sonification can be music. Possibly, if one is unaware that there is a source of data, it will probably be 'just' music or purely musical. It can also be a musical form that transports data that has extra-musical signification (or maybe 'intention' would be a better word in some cases); here, what we are experiencing may simultaneously be music and something else at the same time.

And it can also be something else altogether, regardless of how 'musical' the output is. It is worth noting that the use of alarm sounds in artworks can lead to some confusion. This is an extract from British sound artist John Wynne's biography:

> His first work with electronic alarms and reminders was for the LYD/Galleri in Copenhagen's Town Hall Square, using 25 speakers hidden under the paving stones: The Sound of Sirens was banned by the city council, which claimed that some members of the public were "frightened and confused" (Wynne 2003)

The notion of the existence of this other form was inspired by my discussions with Dr. Debien, but it is also an argument I have been addressing as a consequence of my own creative practice.[8] It seems to me that this is something different from John Cage's paradigm of silence and everything having the potential to become music.

In the case of sonification of real-time data, especially, the fact that there is a genuine connection to complex processes that are unfolding while you are listening can at times be as powerful or as evocative as the musical construction or the rewards of 'reduced listening'. This connection to mechanical and natural events and procedures delivers an 'other' dimension, a dimension that can, strangely, have the contradictory, and at times undesirable, effect of taking attention away from the musical aspects—if the audience become overly involved in the task of attempting to correlate sound with the data source for instance. In my practice of real-time sonification of complex environmental data, the tangibility of this other dimension—the real-time connection to aspects of the world itself—requires a delicate balance in what our listening delivers to us. This balance demands a listening that, on the one hand, informs and delights because we can discern the relationship of the sonification to unheard aspects of the situation—e.g. inaudible vibrations, patterns of light, and on the other hand, allows us also to inhabit a musical proposition which 'frames' this information. For me, this is both the challenge and the excitement in my

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[7] About John Cage: 'Cage is perhaps best known for his 1952 composition 4′33, the three movements of which are performed without a single note being played'. Source http://en.wikipedia.org/wiki/John_Cage.

[8] See artist's statement in this issue.

work. From this perspective, it is quite reasonable to question whether artistic sonification is necessarily music.

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