Log. Univers. 9 (2015), 331–343

1661-8297/15/030331-13, *published online* July 25, 2015
DOI 10.1007/s11787-015-0127-7

Logica Universalis

Sound Reasoning (Literally): Prospects and Challenges of Current Acoustic Logics

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Abstract. Building on the notational principles of C. S. Peirce's graphical logic, Pietarinen has tried to develop a propositional logic unfolding in the medium of sound. Apart from its intrinsic interest, this project serves as a concrete test of logic's range. However, I argue that Pietarinen's inaugural proposal, while promising, has an important shortcoming, since it cannot portray double-negation without thereby portraying a contradiction.

Mathematics Subject Classification. Primary 00A65; Secondary 03A99.

Keywords. Auditory representation, translations between logics, Peirce, diagrams, icons, double-negation, contradiction, inference rule, propositional logic.

1. Introduction

There is clearly a sense in which logic does not depend on the vagaries of our biological make-up. Whether or not one has, say, facial hair, is inessential to whether or not an inferential pattern like a *modus tollens* is valid. Still, because complex logical reasoning requires the use of some kind of notation, we can ask: are eyes, like facial hair, inessential to logic too? Or, to put the same question slightly differently: does the need for some kind of notation necessarily require the use of *symbolic* notation?

Pietarinen [15] has recently proposed that non-visual logics are feasible. Pietarinen's proposal pursues suggestive remarks made by the American polymath C. S. Peirce about a century ago. Peirce held that some sign-vehicles, namely diagrams, could be so arranged that they represent relations only, irrespective of the actual nature of their relata. In fact, Peirce believed that "every Deduction involves the observation of a diagram (whether optical, tactical or acoustic)" [13, p. 882]. Since logical inferences are usually assumed to be general in scope, trying to run a logic on something other than sight is a fine way to put that widespread assumption to the test. Hence, Pietarinen asks: "[W]hy could not there be non-pictorial and non-visual systems of signs that can do the same?" [15, p. 74].

In this paper, I want to investigate whether non-visual logics could accomplish tasks "comparable in their expressive power with that of propositional logic but which have next to nothing to do with visual images" [15, p. 74]. This endeavour is very speculative, but its potential spoils are considerable. We are, perhaps distinctively, symbol-using creatures [4], so most of our established reason-giving practices reflect this fact [1]. However, constructing a logic not reliant on sight might teach us a lot about cognition, both human and non-human, normal and abnormal.

Might communication with intelligent life from other planets require the use of inferences couched in sounds (cf. [19, p. 317])? Closer to home, might some children with cognitive disabilities come to this world expecting auditory, olfactory, or tactile modes of reasoning (cf. [11])? The ability to draw inferences may be an important marker of rationality, but ascribing a lack of such logical powers to an agent [5] will remain inconclusive as long as we have not essayed multiple kinds of logic.

So, even though the exploration into non-visual logics inaugurated by Pietarinen taxes the limits of the imagination, it points to an exciting research program. In a bid to attract discussants and trigger an incremental advance, I thus want to call attention to a flaw or drawback in Pietarinen's proposal. Before moving to my (friendly) criticism, I must explain the overall tenor of Pietarinen's inquiry.

2. Pietarinen's Abductive Approach

We have, at best, five senses. So, when Pietarinen argues for the possibility of a non-visual diagrammatic logic, he is essentially claiming such a possibility for touch, smell, taste, and hearing. These sensory channels, however, are not on a par. Taste and touch, for instance, seem like more challenging candidates. Pietarinen is convinced that his results could be duplicated for "smells, at least in principle" [15, p. 80], but it is unclear what underwrites his conviction. Nevertheless, like Pietarinen, I will limit myself to a system of inference conveyed by hearing (the expression "acoustic logic," which I retain, is absent from Pietarinen's published piece, but was suggested by him in a penultimate draft made available online).

Pietarinen finds it "surprising that no one has proceeded to suggest anything comparable to this idea, which we may call the 'logic of sounds'" [15, p. 74]. Yet, so long as we permit the translation of pre-existing logics into a non-visual medium, one could argue that what Pietarinen seeks is available right now. Indeed, if we relax expectations of novelty, we see that it is already possible to teach standard logic aloud. To make this point more extreme, we could even say that, since Morse code can convey a natural language and since natural languages can convey propositional logic, sound reasoning by sounds can be performed with the aid of a mere buzzer. I doubt this is what Pietarinen has in mind.

We should therefore distinguish two projects. A weaker project would be to probe whether it is possible to construct a non-visual logic that is allowed to

draw on or translate traditional symbolic logic. A stronger project would be to probe whether it is possible to construct a non-visual logic that is not allowed to draw on or translate traditional symbolic logic. Hence, if we consider the four non-visual senses individually, we get four variants of the weak project and strong project, respectively.

Once it is disambiguated in this manner, the issue allows for a more nuanced (and plausible) response. As such, in this paper, I will only be exploring a logical system that appeals to hearing. However, the construction of that system will be openly parasitic on many principles of propositional logic that were achieved visually.

Pietarinen [14] has a fully worked-out visual account of diagrammatic logic. While I share with Pietarinen the semiotic conviction that "representation really refers to a wide class of activities many of which cannot and should not be restricted to visual modes of perception" [15, pp. 76–77], I fear he may be setting the bar too high when he requires acoustic representations to "have *next to nothing* to do with visual images" [15, p. 74, emphasis added]. What Pietarinen is after, one might say, is a logic *indigenous* to hearing. This aspiration imposes very strong constraints. Mastering the canons of logic is hard enough without also having to surmount obstacles similar to those faced by Helen Keller. Those obstacles remain even if one accepts that the tightest auditory sign system would be "far from optimal for human performance, communication and comprehension" [15, p. 80, for a similar point, cf. 7].

The philosopher Strawson [18, pp. 65–86] once argued that sounds alone could never allow a subject to form relational concepts like "to the left of" or "farther than." Strawson's conclusion is not fatal in itself, but if Lakoff and Johnson [8] are right that spatial relations are crucial to shaping all other concepts, then those combined results cast doubt on the feasibility of devising a purely acoustic logic. A critic might thus argue that, if Pietarinen is going to run a canonical system of inferences solely on a temporal axis, he must first make sure that experiencing space is not in fact a necessary condition for knowledge.

Pietarinen [16, p. 278] has made it clear that he wishes to distance himself from the cognitive linguistics developed in the wake of Lakoff and Johnson. Taking his cue from Peirce, Pietarinen's abductive approach has been to proceed *as if* non-visual logics are possible. If they are not, as Lakoff and Johnson's work predicts, then that prediction should bear out, without any scholarly rebuttals. Pietarinen obviously thinks acoustic logics can succeed, so let us now see if they do.

3. Basic Building Blocks

Clearly, any non-visual logic would have to manifest some degree of articulation. So long as inferences constitute a (probable or necessary) movement from premise(s) to a conclusion, a systematic arrangement of the parts will have to come into play. Peirce, who was well-versed in Kant, realized that the only conceivable canvasses for such an arrangement would be either space or time

[12, vol. 1, para. 38]. Peirce thoroughly explored the use of a spatial canvass in his "Existential Graphs" (cf. [13]), but he also acknowledged that "a diagram can consist of parts separated in time" [15, p. 75]—although he "never went on to follow up on this line of thought in detail" [15, p. 75].

Pietarinen's exploration rests on the wide applicability of Peirce's diagrammatic notation. In contrast with the symbolic logics that are currently mainstream, Peirce strove to build a logical system that is, at root, iconically motivated. A sign is iconically motivated whenever the specific quality of its sign-vehicle matches the object it has or the logical role it plays. For example, if one puts small eggs in small cartons and large eggs in large cartons, consumers who take box size to be a sign of egg size will capitalize on an iconically motivated link. Inversing the pairing of large and small would still track the objects, but that would require participants to adopt (and observe) an added convention or code. Stipulated correspondences like these do not disappear from diagrammatic logics, but they are avoided in favour of qualitative likenesses, whenever possible. "Thus, Peirce's position shares a fundamental anti-psychologism with Frege and Husserl. But, unlike them, his is an *anti-psychologism without the linguistic turn*" [17, p. 4, emphasis in original].

Taking advantage of what Peirce achieved, Pietarinen's "strategy is confined to providing one suggestion" [15, p. 74]. Specifically, he wants to show that the basic building blocks of Peirce's diagrammatic logic—like assertion, negation, conjunction, and so on—can all have auditory counterparts.

Let us start with what is arguably the most basic feature of diagrammatic logics. According to Peirce, the very canvass on which one makes claims is itself a claim, namely that it is there. In the visual medium conveying Peirce's graphs, this layer of minimal commitment appears as the "sheet of assertion," which Peirce [13, p. 39] sometimes called a sheet of affirmation. As Pietarinen explains, "Peirce held denial and affirmation to be the proper contrasts that are manifested in diagrammatic syntax," and while Peirce deliberated on which ought to enjoy priority, he eventually concluded that affirmation, being simpler, "ought to be chosen as the primary mode in which propositions are expressed on the sheet, the denial requiring an additional operation" [14, p. 165].

The automatic assertion that occurs by the sheer presence of something is so primitive that it is easy to see why Pietarinen would regard it applicable to any sensory channel. What would a primitive canvass of sound like? Pietarinen suggests that "[t]he empty sheet of assertion is therefore an infinite-bandwidth white noise extending indefinitely in time" [15, p. 77]. If we let a shaded area stand for heard sound, we could illustrate this as shown in Fig 1.

According to Pietarinen, Fig. 1 plenum signifies tautology. Since I am after general lessons, I have left the units of measurement undefined. The spectrum of frequencies an agent can be aware of is presumably finite, whereas the open-ended axis of time on which acoustic inferences unfold constantly delivers more material to work with.

Because the underlying state is undifferentiated, it clearly will not suffice to convey non-trivial meanings. Thus, in the acoustic logic envisaged by

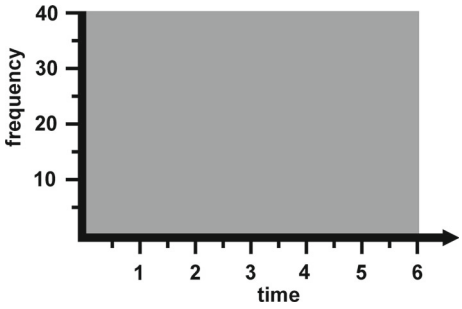

FIGURE 1. Tautology (or white noise)

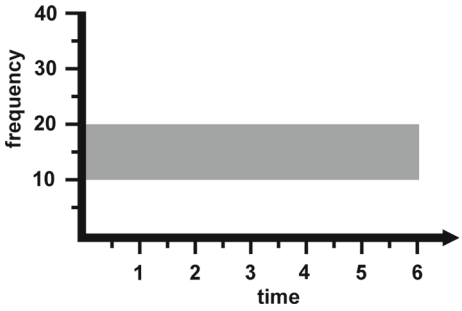

FIGURE 2. Atomic proposition (or tone)

Pietarinen, "tones" would serve as the atomic elements to be related (properly or improperly, as the case may be). Tones, for Peirce, are conveyors of meaning that are even more basic than tokens or types [2]. The moment we restrict the bandwidth to a specific frequency, we render it distinct in a way that allows it to carry information, since it is now this as opposed to that. A scheme of abbreviation or legend would track which auditory qualities stand for which proposition. Thus, if the proposition "John has a cat" were assigned the frequency ranging from 10 to 20, it would appear as shown in Fig. 2.

It is important to bear in mind that the visual images I am using in this article are not themselves sounds. It should be obvious that, in order to fit a journal format, I have depicted, not *played*, the various tones. I want to be upfront that this is not adequate. Discussions of two-dimensionality versus three-dimensionality (and so on) would thus be misplaced. Fancier computer graphics are nice, but in the end, the elements manipulated are tonal qualities that cannot be conveyed in a different medium without loss (which is why reading a sheet of music does not amount to experiencing a concert).

Enriching the vocabulary further, a simultaneous appearance of tones would result in what Pietarinen calls a "chord." Thus, if the frequency between 30 and 40 stands for "The refrigerator is full," that tone could be joined to the tone of "John has a cat" so as to yield this chord:

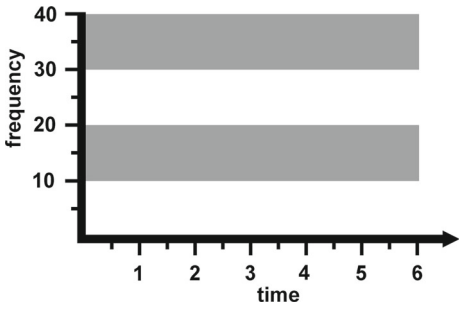

FIGURE 3. Compound proposition (or chord)

According to Peirce's diagrammatic approach, putting two or more items together in space and/or time is an iconic expression of logical conjunction (cf. [9, p. 219]). Since simply appearing in a field of awareness is the natural notational stand-in for affirmation, jointly appearing in such a field becomes a natural stand-in for conjunction. Thus, the previous propositions could also appear sequentially, as shown in Fig. 4.

One of the things that will need to be made clearer in future work is whether conjunction can be a succession in time (like Fig. 4) or whether it must be limited to a simultaneous co-presence of whatever is heard (like Fig. 3). I am not sure, but I think that Pietarinen endorses only the latter option. This may not be a wise move. Adopting simultaneous conjuncts might conceivably spare one some of the troubles I will sketch later, but only at the price of rendering illation impossible. After all, a conclusion is not just a proposition floating in isolation; rather, what bestows the status of conclusion on a given proposition is its rational association with other propositions (that thereby count as premises, in virtue of their own role). However, if the only way to glue a conclusion to such a body of premises is to hear all of these at the same time, then there is no way to distinguish which is which. In a way, that is not bad, since true premises will, in a valid argument, produce a conclusion with the same truth-value. Yet, when the proposition expressed by a conclusion is found also in the premises, this is begging the question—or, more charitably, an uninformative inference. For example, when one affirms a consequent as a premise alongside a conditional and an antecedent, then what might have otherwise been a *modus ponens* is reduced to a (far less interesting) repetition inference rule. I therefore think that, in the long run, glossing conjunction as a succession of claims in time is preferable to bundling claims in an instant (I will revisit this idea at the close of Sect. 4).

In any event, a succession of tones or chords appearing over time would amount to "this is the case and this is the case and this is the case. . . " However, in a valid argument, a conclusion does not just *follow* the premises, it must *follow from* those premises. Peirce recognized that "the illative relation is the primary and paramount semiotic relation" [12, vol. 2, note to para. 444]. Hence,

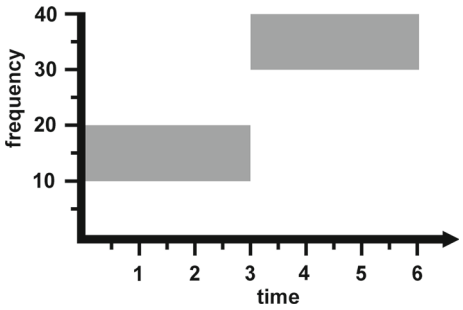

FIGURE 4. Conjunction

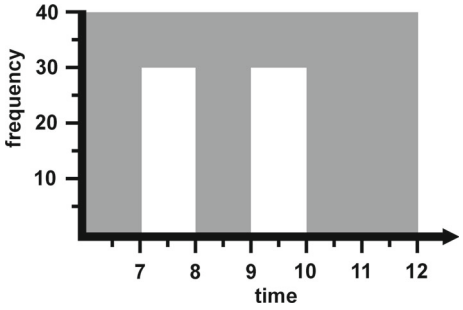

FIGURE 5. Simplification and repetition of premises provided in Figs. 3 and 4

until and unless we achieve sufficiently rich relations, the sounds will flatten to a level that is at best musical, not inferential.

When dealing with conjoined sounds, basic mereological principles would apply. If one hears a whole, one hears its parts. This may seem trivial, but it allows manipulations like copying and (prescissively) deleting [15, p. 79]. Thus, if one has heard the sounds expressing "The refrigerator is full and John has a cat," then in accordance with these simplification and repetition inference rules, one is henceforth logically entitled to emit the sound shown in Fig. 5.

Note that the sounds can revert to tautological white-noise at any time. Also, every sound must have some duration (I take this to be justified a priori), but the duration of a given tone or chord is inessential, since what matters is merely that the individuation of a qualitative character allow one to track which propositions are being affirmed. Minimally, "a diagram has got to be either auditory or visual, the parts being separated in the one case in time, in the other in space" [12, vol. 3, para. 418]. A diagram with no extension in space or time is no diagram at all.

Despite the added ability to sunder and reconfigure strings of heard sounds, a long auditory conjunction would still be insufficient to support the range of inferential relations we typically expect from logic. Pietarinen is aware that the diagrammatic ingredients for assertion and conjunction do not yet give

us access to relations of disjunction and implication. Now, we know from standard propositional logic that disjunction and implication can be eliminated by using conjunction and negation. The implication "if P then Q" can be rendered truth-preservingly as "not (P and not-Q)"—giving rise to a "scroll" in Peircean diagrammatic notation (cf. [9, p. 219]). Likewise, the disjunction "P or Q" can be rendered as "not (not-P and not-Q)"—it is this equivalence which underpins De Morgan's rules. So, if we can successfully add an icon to the mix that expresses negation, we will automatically get the equivalents of implication and disjunction.

In contrast with assertion and conjunction, negation is trickier. Since making something present to awareness is by that fact affirming its presence, we need to find a way to both state a content and deny its existence at the same time. These seem to be paradoxical demands. Pietarinen senses this tension when he writes that "in practice we would need an access to the information concerning the identity of the tones intended but not actually played out" [15, pp. 77–78]. As we will see in the next section, this turns out to be important.

Peirce's original solution was to exploit the fact that, if everything present on the sheet is affirmed, then anything cut off or separated from that sheet should in principle be absent or negated. In Peirce's visual diagrams, this is achieved by creating an enclosed region and scribing whatever is negated inside that region. This clever notational device allows us to see what, strictly speaking, should not be there. Hence, unlike the tilde of standard algebraic notation, Peirce does not assign a specific sign for negation in his visual diagrams [13, p. 91].

Like Peirce, Pietarinen does not introduce an additional tone to signify negation, since he thinks the same result can be achieved in sounds by using a "mute." Thus, if we stick to the convention of letting the frequency 10 to 20 stand for "John has a cat," negating that proposition would amount to the situation shown in Fig 6.

Notice that, because the frequencies from 0 to 10 and from 20 to 40 have not been assigned any specific claim, one cannot infer anything substantive from the negation shown in Fig. 6. Naturally, if the range of frequencies were exhaustively carved into, say, four claims (of 10 frequency units each), Fig. 6 would, in addition to being a negation, also be an affirmation of three claims. Such a situation, however, would require an assignment that is not present here. Hence, to read Fig. 6 this way is unwarranted, or at any rate a change of topic (note that we can always halt such an inference from being conclusive by allowing a sliver of sound to remain unassigned).

In light of what has just been said, a straightforward "P and not-P" contradiction would sound like Fig. 7. What we have in Fig. 7 is, in effect, "John has a cat and John does not have a cat."

We now have all the acoustic materials needed to assemble something that matches implication. If muting a sound is tantamount to negating whatever tonal quality it is assigned, then an implication would be "a mute of a chord consisting of a 'heard' tone (the antecedent) and the muted tone (the

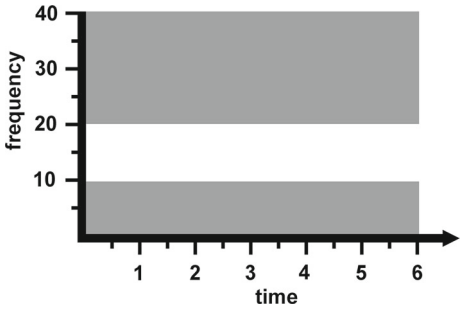

FIGURE 6. Negation (or mute)

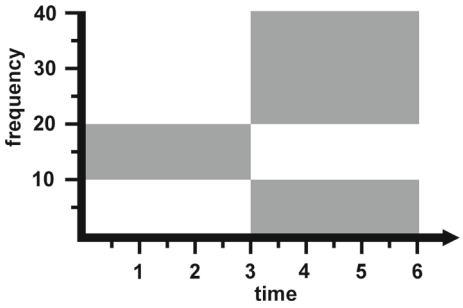

FIGURE 7. Contradiction

consequent)" [15, p. 78]. Likewise, a disjunction would be "a mute of a chord consisting of two muted tones" [15, p. 78]. In principle, once we have secured the acoustic means of expressing assertion, conjunction, and negation, all the truths expressible in propositional logic should be acoustically expressible. However, as we are about to see, there is a problem.

4. An Unexpected Feature

As mentioned earlier, an implication like "If John has a cat, then the refrigerator is full" can be transformed into the negated conjunction. Clearly, if one is able to render "not (P and not-Q)" acoustically, then one is also able to render "P and not-Q" acoustically. Yet, doing this in a step-wise fashion will help us to detect an unexpected feature in Pietarinen's proposal.

Abiding by the assignment of frequencies used in the previous section, let us express "John has a cat and the refrigerator isn't full" acoustically (visually in fact, but I must make do with the constraints of a printed or on-screen page).

To get the implication we are after, we must negate the entire conjunction of Fig. 8, presumably resulting in Fig. 9.

There is a sense in which we had to obtain the equivalent of an implication by doing this transformation in steps. Pietarinen writes that, "[f]or the system to be classical, a double mute is taken to be the originally heard sound again"

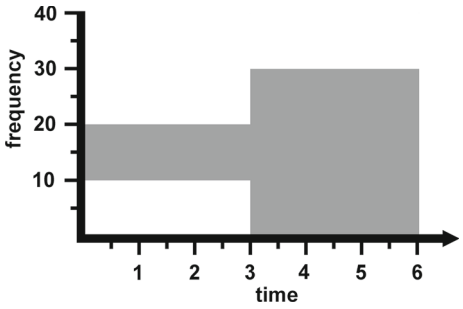

FIGURE 8. "John has a cat and the refrigerator isn't full"

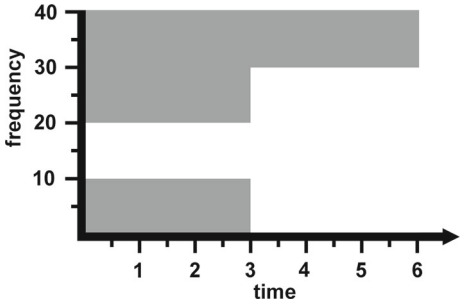

FIGURE 9. "John does not have a cat and the refrigerator is full"

[15, p. 78]. Mimicking the standard symbolic conventions, he thus suggests that "a heard bar is a bar not muted or muted an even number of times," whereas a "silent bar is a bar muted an odd number of times" [15, p. 78]. This may be, but I believe that, with the resources Pietarinen has given us, a double-negated proposition is not a well-formed formula (Fig. 9).

To see why, let us try to double-negate the chord shown in Fig. 3. Perhaps the most intuitive acoustic expression of twice-negated truth-value would be Fig. 10.

Superficially, one might think that because the compound proposition expressed in the time interval 4–6 reverts to the one expressed in 1–2, Fig. 10 captures Pietarinen's suggestion that "what is twice muted will bring back the original" [15, p. 78]. However, since the iconic account inspired by Peirce states that whatever is heard is thereby affirmed, we find on further scrutiny that what Fig. 10 really expresses is not a double-negation, but a *contradiction*.

Contradictions have a crucial role to play in acoustic logics. Indeed, one way to prove an acoustic argument is to use the indirect method and derive a contradiction from a negated conclusion. Now, negating a conclusion is certainly possible. Yet, as we have just seen, contradictions have to be expressed sequentially. Non-overlapping frequencies can be heard simultaneously, but those tones cannot be both heard and silent at the same time (cf. [3]). Thus, because a logic of sounds must work on a temporal axis, I submit that, on

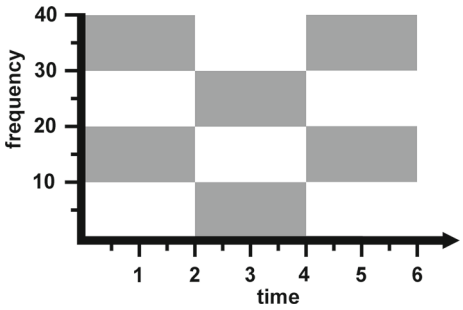

FIGURE 10. Attempt to double-negate a compound proposition (or chord)

the terms laid down by Pietarinen, every attempt to express double-negation must result in the expression of a contradiction.

One quick fix would be to assign a distinct tone for negation. This is, after all, what we do whenever we utter the sound "not." A more sophisticated corrective would be to tinker with the polarization of amplitudes. One could, say, use amplitude rotations of 90° or 180°, where the former would represent a negation and the latter represent a contradiction. There is no shortage of such engineering solutions (cf. [10]). Unfortunately, all of these require adopting conventions that are far more artificial than the iconic story that nicely motivated negation as an absence (Fig. 6).

Pietarinen might argue that this unexpected feature regarding double-negation will not follow so long as one restricts conjunction to a simultaneous co-presence of whatever is heard (as in Fig. 3). I have argued, though, that such a response would collapse the important conclusion/premise distinction. In addition, forbidding conjunction from being a succession in time (as in Fig. 4) means that one must jettison the idea that hearing two or more tones after one another is, in its own empiricist-like way, grounds to conjoin those tones. If hearing p and q over time is not an iconic expression of the logical conjunction "p and q" (as in Fig. 4), then by parity I fail to see why hearing p should be taken as the iconic expression of affirming "p" (Fig. 2).

If every argument must transpire in an instant in order for acoustic logics to avoid the drawback I have brought to the fore, then this would mean that semiosis—the "action of signs" that so captivated Peirce—is not an action but a static state (in inference, of all places). This, to my mind, would constitute an even bigger drawback.

5. Conclusion

Iconic logics abide by more stringent standards than symbolic logics. The desideratum of what might be called a "non-linguistic formal language" is

to avoid conventional imputation whenever possible. As Peirce wrote: "A diagram ought to be as iconic as possible; that is, it should represent relations by visible relations analogous to them" [12, vol. 4, para. 433]. Even if we switch to a non-visual medium, the whole point of appealing to iconic signs is that "logical constants must strive to show or communicate their own meaning" [15, p. 77]. Judged by this standard, affirmation (as presence), conjunction (as juxtaposition) and negation (as absence) fare quite well. I have argued, though, that double-negation runs into trouble. *In Pietarinen's current acoustic logic, whenever one says "not-not-P," one ends up saying "P and not-P."* This is problematic, since those are very different claims.

Counting odd and even numbers of negations can still be done (say, at a metalogical level), but all that the acoustic notation can do is register the final tally. This inability to express repeated tildes or repeated cuts is not fatal in itself. However, it certainly sets Pietarinen's inaugural proposal apart from all known visual avatars of propositional logic, be they mainstream or Peircean.

I have some ideas on how the problem of double-negation might be resolved using icons. My modest goal in this article, however, has been only to introduce the topic. I agree with Pietarinen that the best way to move forward is to work on the abductive assumption that acoustic logics are possible. Of course, as we move forward, we might simply decide to jettison double-negation (for a survey of systems that do just that, cf. [6, pp. 173–174]). Yet, despite being a pluralist, Pietarinen does want his first acoustic logic "to be classical" [15, p. 78]. Assuming that this is a prudent starting point, we might want to resolve the issue I have evinced before seeking "more expressive extensions beyond the simple sentential level" [15, p. 80].

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Received: January 26, 2015.
Accepted: July 12, 2015.