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LAST BUT NOT LEAST

Harnessing vision for computation

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Abstract. Might it be possible to harness the visual system to carry out artificial computations, somewhat akin to how DNA has been harnessed to carry out computation? I provide the beginnings of a research programme attempting to do this. In particular, new techniques are described for building 'visual circuits' (or 'visual software') using wire, NOT, OR, and AND gates in a visual modality such that our visual system acts as 'visual hardware' computing the circuit, and generating a resultant perception which is the output.

Here I consider whether it may be possible to harness our natural visual powers for artificial computations, somewhat analogous to the way in which DNA molecules have been harnessed for computation (Adleman 1994). There are several reasons why the visual modality is a promising one for carrying out software of our bidding. First, the computations underlying our elicited perceptions are extraordinarily powerful, our visual system taking up about half our cortex (Felleman and Van Essen 1991). Second, our eyes and visual system are capable of inputting and processing large amounts of information in a short period of time. And, third, in spite of the trillions of calculations carried out at each glance, it *feels* effortless to perceive. Tapping into our natural visual capabilities to aid in logical thinking has been a recurring topic over the history of logic (Euler 1768; Venn 1881; Peirce 1885; Allwein and Barwise 1996), as well as more generally in mathematics (Cajori 1929), scientific visualization (eg Tufte 1983), and in reading (Changizi et al 2006).

What I suggest here, however, is something quite different. The broad strategy is to visually represent a computer program in such a way that, when one looks at the visual representation, one's visual system naturally responds by carrying out the computation and generating a perception that encodes the appropriate output to the computation. That is, there would be a special kind of image which amounts to 'visual software', software our 'visual hardware' computes, and computes in such a way that the output can be 'read off' the elicited perception. Ideally, we would be able to glance at a complex visual stimulus—the program with inputs—and our visual system would automatically and effortlessly generate a perception which would inform us of the output of the computation. Visual stimuli like this would not only amount to a novel and useful visual notation, but would actually trick our visual systems into doing our work for us!

Here I describe the beginnings of a promising such approach for digital circuits, which is a large and important class of computations.

Circuits need wire in order to transmit signals to different parts of the circuit, and an example case of 'visual wire' is shown on the left in figure 1a. It is bistable, and can be perceived either as tilted away (0) or tilted toward you (1). Stimuli of this sort serve as wire because your perception of its tilt at the top propagates all the way down it to the bottom. An input to a visual circuit is an unambiguous cue to the tilt at that part of the circuit. Here I utilize simple unambiguous boxes as inputs, as shown in figure 1a on the right. NOT gates are crucial for digital circuit computations, inverting

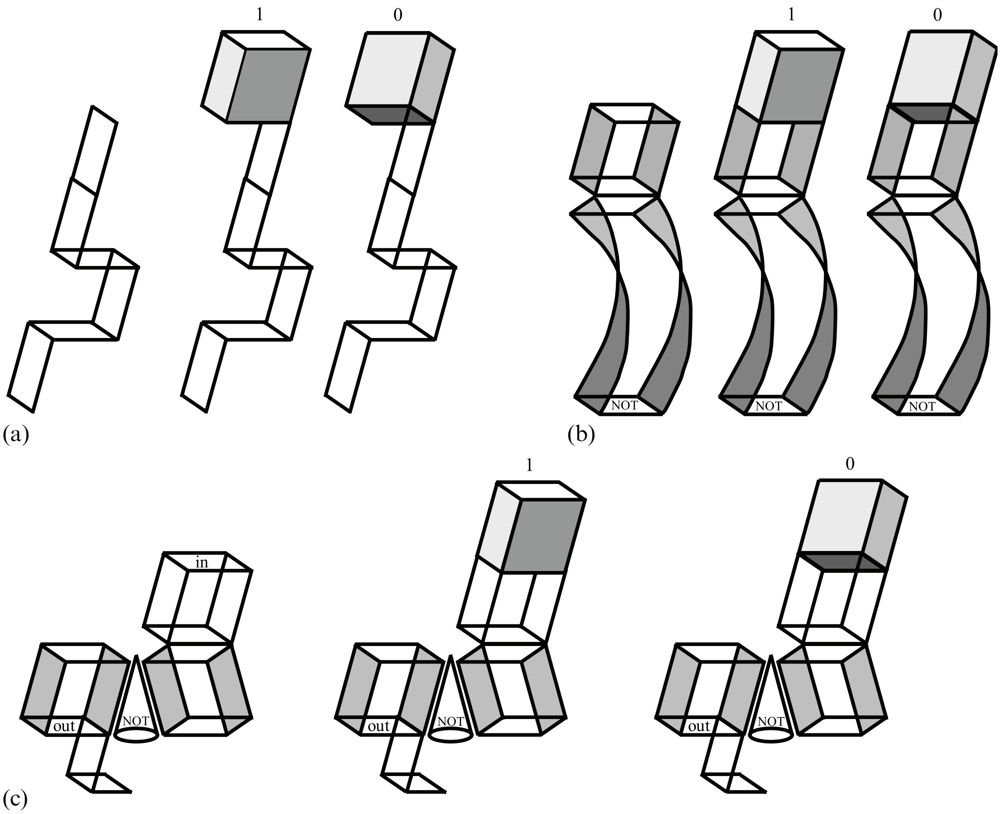

Figure 1. (a) Example visual wire, alone and with inputs. (b) and (c) Two kinds of NOT gate, each also with 1 and 0 inputs.

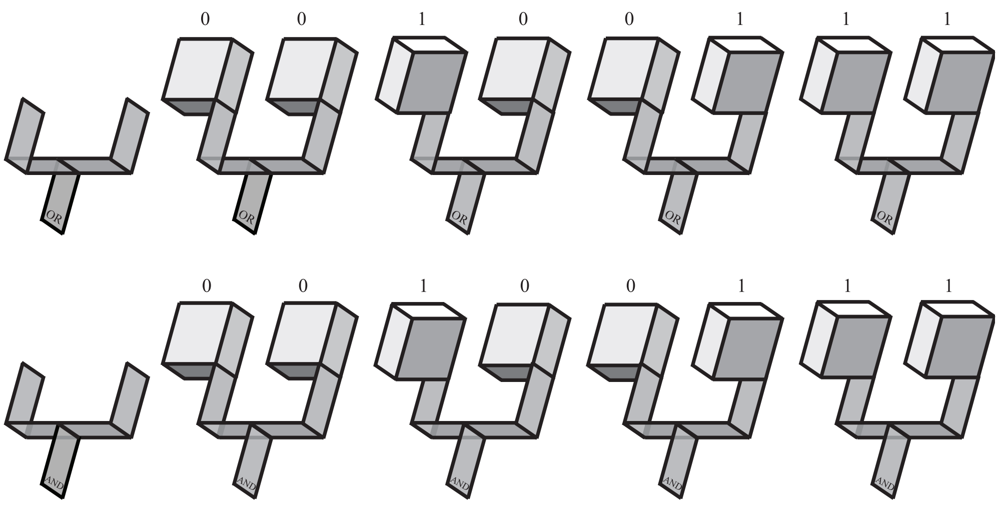

Figure 2. (a) OR gate. (b) AND gate. Note the distinct transparency cues: when there are no inputs, the cues favor a 1 interpretation (tilted toward you) for the output of the OR gate, and they favor a 0 interpretation (tilted away) for the output of the AND gate.

the signal from a 0 to a 1 or vice versa. Figure 1b shows one kind of visual NOT gate. It begins as a special kind of wire—roughly a wire-frame box—which undergoes a 'break' below it. The portion of wire below the break tends to be perceived as having the opposite tilt to that above the 'break'. The curvy portion below it is required here in order to bring the wire back into the down-and-leftward canonical orientation for wire in these circuits. Another variety of NOT gate is shown in figure 1c, this one utilizing a tendency for the perceived state of tilt to get transmitted from one side of a cone stimulus to the other (presumably via perception favoring symmetry). Figure 2a shows an example OR gate, which outputs a 1 if one or both of the inputs is a 1. This visual OR gate is designed with transparency cues so that the tilted-toward-you, or 1, interpretation is favored, and tends to be overridden only when both inputs are 0s. A similar idea works for an AND gate, but with a distinct kind of transparency cue. That is, the OR and AND gates are designed so that, without inputs, 1 and 0 output interpretations, respectively, are favored.

These circuit components are sufficiently powerful that any digital circuit can, in principle, be built from them. Figure 3a shows the traditional digital circuit notation for an XOR circuit (which outputs 1 if and only if exactly one of the inputs is a 1), and figure 3b shows the same circuit but implemented with visual components.

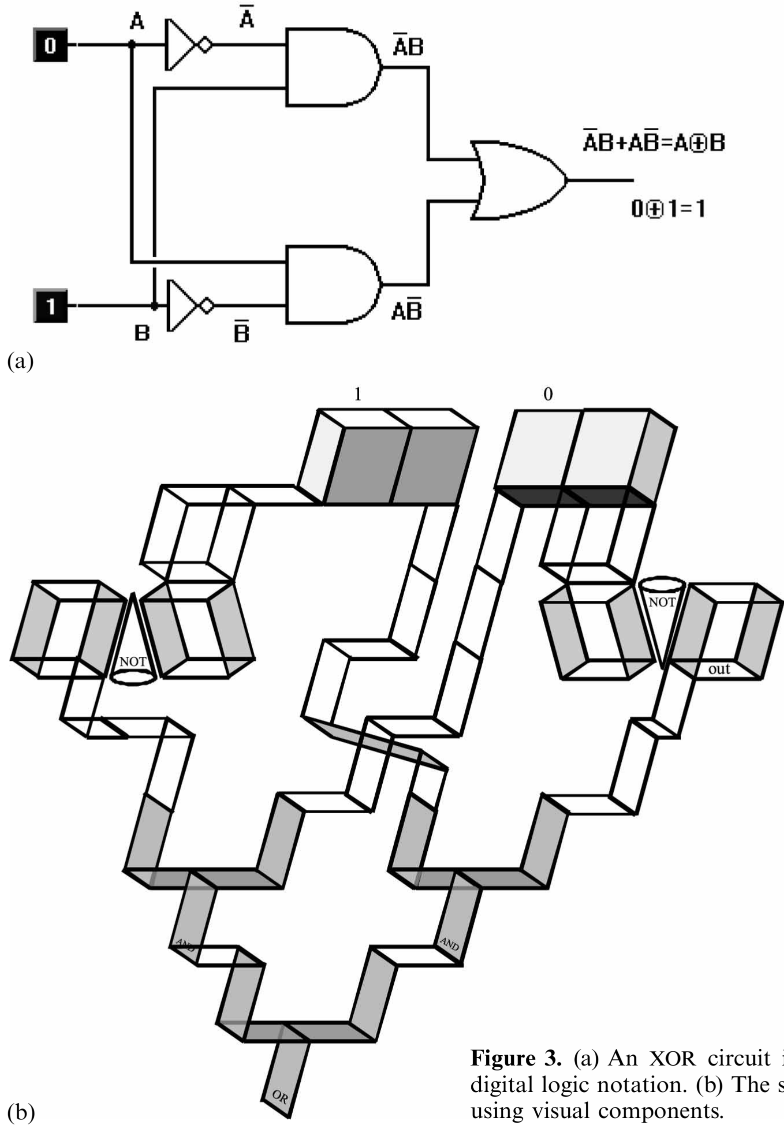

Figure 3. (a) An XOR circuit in standard digital logic notation. (b) The same circuit using visual components.

The output is at the bottom; ie your perception of the tilt at that point determines the output of the computation. To get our visual system to carry out this computation currently appears to require "perceptually walking through the circuit" from the inputs downward toward the output.

The visual stimuli I currently use for visual circuits are leaps and bounds beyond my first attempts at this. However, there are still serious technical difficulties to overcome. First, the visual logic gates do not always faithfully transmit the appropriate signal at the output. For example, although AND gates *tend* to elicit perceptions that are AND-like, it is a tendency only, not a sure-fire physical result as in real digital circuits. Second, even if one interpretation is unambiguously cued by the input, our perception is still somewhat volatile, capable of sudden Escher-like flips to the alternate state. The result is that it can be difficult to 'perceive one's way through' these visual circuits, although I have found considerable personal improvement with practice. And, third, building larger circuits will require smaller or more specialized visual circuit components in order to fit more functionally complex circuits on an image, and a major problem to overcome is how to do this while still ensuring that the visual system reacts to the circuit as intended (analogous to problems of VLSI design).

My hope in presenting these ideas to the *Perception* community is that there will be many who, using their vast knowledge of perception and illusion, will think of novel visual components which serve to mimic some digital (or analog) circuit component, thereby enriching the powers of visual circuits. Not only may our visual system one day give DNA computation a run for its money, but visual circuits have many potential advantages for teaching logic: people are notoriously poor logical reasoners (Cheng et al 1986), and, because of the equivalence of propositional logic and digital circuits, visual circuits may enable logic-poor individuals to 'see their way' through complex logical formulae.

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